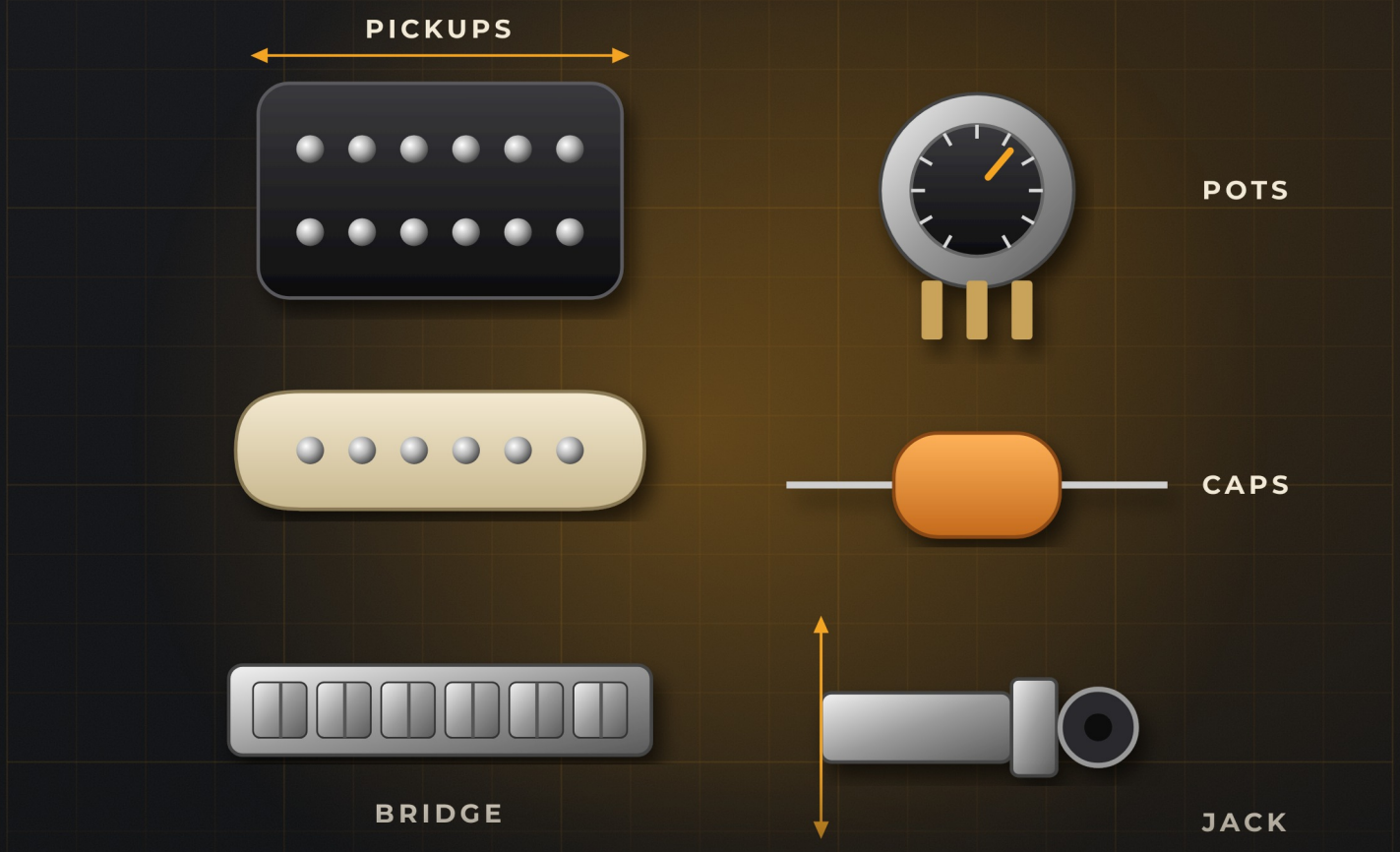
SECOND EDITION - ILLUSTRATED

EVERY PART, BY THE NUMBERS

INSIDE THE ELECTRIC GUITAR

Every Part, the Numbers Behind It, and How It Shapes Tone and Playability



BODY · NECK · FRETS · BRIDGES · PICKUPS · WIRING

ANDREW DOMINGUEZ

FROM THE BENCH AT TRINFINITY GUITARS

TRINFINITY Enterprises

Inside the Electric Guitar

Every Part, the Numbers Behind It, and How It Shapes Tone and Playability

Second Edition, Illustrated

Andrew Dominguez

Inside the Electric Guitar: Every Part, the Numbers Behind It, and How It Shapes Tone and Playability

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Specifications are quoted from each maker's published information as checked in October 2026. Makers change their products and specs, and individual parts vary. Check the current spec sheet before you buy, and take your guitar to a qualified technician for any work beyond your comfort level. Never open an amplifier unless you are trained to; amps can hold lethal voltages even when unplugged.

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Introduction

Every electric guitar is a pile of parts. A neck, a body, some frets, a nut, a bridge, six strings, a few tuners, one or more pickups, a couple of pots, a capacitor, a switch, a jack. Somebody chose every one of them, and every one of them comes with numbers attached. This book is about those parts and those numbers: what each part does, what values it comes in, how the values compare from maker to maker, and how it all adds up to the sound coming out of your amp and the feel under your hands.

More than 20 years ago, I started taking guitars apart to see how they worked and why some felt and sounded better than others. I do not play guitar myself, but I have an ear for tone and a background in technical systems. In the last few years I have built under the Trinfinity Guitars name. I wrote this book to give players and builders a plain, honest look at how every part of an electric guitar shapes its sound and feel.

I have worked on guitars for more than 20 years, and for about the last 4 of them I have built under my own brand, Trinfinity Guitars. I build, repair and modify guitars, and most of what lands on my bench comes with a question attached. "Will a 500k pot make my Strat brighter?" "Why does this Les Paul feel looser than my Tele?" "Is a stainless fret worth it?" Those are good questions, and most of them have real answers. The trouble is that the answers are scattered across spec sheets, catalog pages, forum threads, physics papers and marketing copy, and those sources don't always agree. I wrote this book to put the numbers side by side and to tell you which ones you can lean on.

Who this book is for

If you play an electric guitar and you've ever wondered why it sounds or feels the way it does, this book is for you. You don't need to know how to solder or how to read a schematic. You do need a little patience with numbers, because numbers are the point.

Beginners will find every hard term defined the first time it shows up in a chapter. Inductance, capacitance, radius, relief, taper: each gets a plain explanation before I use it. If a term shows up again in a later chapter, I'll define it again there, so you can read the chapters in any order.

Hobby builders and modders will find the tables most useful. When you're choosing a neck, a bridge or a set of pickups, it helps to see five makers' specs for the same kind of part in one place, with the source for each value. That's what most of the tables do.

Experienced players and techs will find the sources. Every number carries a citation, and every citation has a full reference and a web address at the end of its chapter. If you think I've got something wrong, you can check it yourself. I'd rather you did.

How to read a spec sheet

A maker's spec is a claim

When Seymour Duncan, Fender or Gibson prints a number on a product page, that number is the maker's claim about its product. Usually it's an honest claim. Sometimes it's a rounded one, sometimes it's a target rather than a measurement, and now and then it's just wrong. So throughout this book I write "Fender lists..." or "Gibson gives..." instead of stating the number as a plain fact about the part. That isn't me being fussy. It's a reminder of where the number came from.

You might ask, "Do makers really get their own numbers wrong?" Sometimes, yes. Here are a few I ran into while writing this book:

- Fender's American Ultra Stratocaster bridge page gives the string spacing as "2-1/16" (2.08")" [1]. But 2-1/16 inches is 2.0625 inches. One of those two numbers is a typo, and the page doesn't tell you which.
- Gibson lists the nut width of its Les Paul Standard 50s as 43.05 mm and the nut of its Custom Shop Les Paul Custom as 42.85 mm, and rounds both to "1.69in" [2, 3]. Two different widths end up with the same inch figure.
- Fender's own support page on fret sizes says the dimensions "can vary minutely from lot to lot" [4]. That's an honest admission that the number on the chart is a nominal size.

None of this is a scandal. It's just the way specs get written. When a page contradicts itself, I say so in the text and give both numbers.

Ranges stay ranges

A lot of parts are sold with a nominal value and a tolerance. *Tolerance* is how far a real part is allowed to stray from its label. Zollner, whose *Physics of the Electric Guitar* I lean on throughout this book, reports that recent potentiometers typically have a tolerance of about plus or minus 20%, so a pot labeled "250k" may measure anywhere from about 200k to 300k [5]. That's a bigger spread than the difference people argue about online. When a source gives a range, I keep it as a range. When a source says "about," I say "about."

Watch the units and the conditions

Guitar specs come in inches, fractions of an inch, millimeters, 64ths, and sometimes all of them on one page. I give both metric and imperial where a maker gives one, and I mark conversions that are my own arithmetic when the precision matters.

Conditions matter as much as units. A setup number means nothing unless you know where it was measured. Fender measures electric string height at the 17th fret [6]; several other sources measure at the 12th (Chapter 19 lists them). A pickup's resonant frequency means nothing unless you know what was plugged into it. Zollner gives about 9 kHz for a Stratocaster pickup with nothing attached, but with a normal cable and amp the peak lands between 2 and 5 kHz [7]. The pickup is the same; only what's plugged into it changed. String tension charts have the same catch: D'Addario's product pages print tension for each string but don't say what scale length they assumed [8]. (They very likely assume a 25.5-inch scale, an inference I explain in Chapter 4 and Chapter 11.)

Nominal is not the same as measured

Some numbers are names more than measurements. Gibson's spec pages give its scale as 24.75 inches [2], while StewMac says the Gibson scale "rarely ever measures out to be 24-3/4 inches" [9]. If a part has to fit, measure the guitar in front of you.

Measurements versus marketing

There are three kinds of source in this book, and I try to keep them apart.

The first kind is a measurement: somebody put a part on a test bench, or measured a guitar, and published how they did it. Zollner's work, papers in physics and acoustics journals, and conference papers on guitar acoustics all fall here. These carry the most weight, but even good measurements have limits. The lab studies

on guitar bodies and necks that I found tested one to six instruments each. That's a careful look at a few guitars, not a survey of all guitars, and I'll tell you the sample size when it matters.

The second kind is a maker's spec: a dimension, a value, a material. These are usually reliable for the physical facts (a bridge's post spacing, a pot's value) because the maker has to build parts that fit.

The third kind is a maker's or seller's claim about tone or performance. Callaham, which makes bridge parts, says an aluminum tailpiece "will NEVER come close" to its steel one in sustain [10]. Graph Tech says its String Saver saddles cut string breakage "by up to 90%" [11]. Maybe so. But neither page shows a test, a method or a baseline, so I report these as claims and say so. When I can't find a measurement either way, I tell you that too.

> **Tip:** When you read any gear page, sort each sentence into one of those three bins. Dimensions and values are usually solid. Sound words like "warm," "punchy" and "articulate" are opinions until someone shows you a measurement.

What "tone" and "playability" mean here

I use two words a lot in this book, so here's what I mean by them.

Tone means what reaches the amp: how loud the signal is, which frequencies are strong and weak, and how the note grows and dies away. When I say a change makes a guitar "brighter," I mean it lifts the treble or moves the pickup's resonant peak higher. When I say "darker," I mean the opposite. I try to tie every tone statement to something measurable, like a shift in frequency or a number of decibels (dB, the usual unit for comparing signal levels). If the best evidence says a change makes little or no audible difference, I say that plainly. That happens more often than the catalogs suggest.

Playability means how the guitar feels and behaves under your hands: how hard the strings are to press and bend, how far your fingers stretch, how high the strings sit, whether the notes buzz, whether the guitar plays in tune up the neck and stays in tune when you bend or use the arm. Playability is easier to measure than tone, and in my experience it's where part choices make the clearest difference to most players.

How the book is laid out

The book opens with Chapter 1, which walks the whole signal path from the string to the amp in one go. Read it first if you read nothing else. It shows how the parts connect, and every later chapter fills in one piece of that picture.

After that, the chapters fall into four parts.

Part 1, Body, Neck and Fretboard, covers the body (Chapter 2), the neck and its joint, profile and truss rod (Chapter 3), scale length and string tension (Chapter 4), the fretboard (Chapter 5), the frets (Chapter 6) and the nut (Chapter 7).

Part 2, The Hardware, covers bridges, saddles and tailpieces (Chapter 8), tremolo systems (Chapter 9), tuners and small hardware (Chapter 10), and strings (Chapter 11).

Part 3, The Electronics, starts with how a pickup works (Chapter 12) and then compares pickup types and models (Chapter 13). It goes on to pickup position, height and switching (Chapter 14), pots (Chapter 15),

capacitors and tone circuits (Chapter 16), switches, jacks, wire and shielding (Chapter 17), and cables, buffers and the amp input (Chapter 18).

Part 4, Putting It Together, collects the setup numbers that tie the parts to your hands (Chapter 19) and compares classic guitar designs side by side (Chapter 20).

Each component chapter ends with a section called "Tone and playability at a glance," a short table of what you'll hear and what you'll feel when you change that part. If you just want the bottom line, start there and work backward.

How sources and numbers are marked

Every fact that comes from somewhere else carries a number in square brackets, like [3]. That number points to the source list at the end of the same chapter, where you'll find the author or maker, the title and the web address. Each chapter has its own numbering, so [3] in Chapter 6 is not [3] in Chapter 12.

Some numbers in this book are mine, worked out from a source's formula or data. Those are always labeled. You'll see three labels:

- *Computed* or *my arithmetic* means I took a published formula and published values and did the math. For example, D'Addario publishes a string tension formula, so I can work out what the same strings pull on a shorter scale. The formula and its source are always named.
- *Converted* means I changed units myself, such as inches to millimeters. I mark these when the precision matters.
- *Modeled* means a curve or value from a circuit model. Several figures in the electronics chapters come from the standard pickup model described by Lemme, Zollner and ElectroSmash, run with values a maker publishes. A model is a simplified picture. It shows direction and rough size well, but it leaves things out (the pickup model leaves out eddy-current losses, for one), so real curves differ. I never present a modeled number as a measurement.

Figures are grayscale charts built from cited data or from that cited model. Every caption says which.

What this book leaves to my other books

This book is about parts and their numbers. Two related subjects get their own books, and I point to them instead of repeating them here.

My book *Chasing Tone: Guitar Myths Put to the Test* takes on the myths and the science of tone: whether body wood changes an electric guitar's sound, whether "vintage" capacitors are magic, whether expensive cables earn their price, and a lot more. Where a part in this book has a well-known tone myth attached, I give you the short version of the evidence and send you to *Chasing Tone* for the full story.

My book *Guitar Care and Maintenance* covers care, cleaning, restringing and the hands-on setup checks: how to turn a truss rod safely, how to set string height, how to intonate, how to set pickup height, and when a job belongs with a tech. Chapter 19 of this book gives the setup numbers makers publish and explains which parts drive each one, but the hands-on steps live in the maintenance book.

One last word before we start

You'll notice I take a stand where the evidence allows it and back off where it doesn't. That's on purpose. Guitar talk is full of confident statements built on one person's ears in one room. I'd rather tell you "nobody has measured this" than pretend. Where the data is solid, I'll say so just as plainly.

Grab a guitar, keep it nearby, and let's look at what it's made of.

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Chapter 1: How It All Ties Together

Before we take the guitar apart one piece at a time, I want to put it back together in your head as one machine. An electric guitar isn't a list of separate upgrades. It's a chain. The string makes the sound. The wood and hardware hold the string and steal a little of its energy. The pickup turns the string's motion into a voltage. Then the pickup, the pots, the capacitor, the cable and the amp's input work together as one electrical filter that decides which part of that voltage gets through. Your hands sit on top of all of it, and how the guitar is set up decides how hard they have to work.

This chapter walks that chain from start to finish in plain words. Every later chapter zooms in on one link. If you understand the chain, you'll know where to look when you want a guitar to sound or feel different, and you'll know which changes are likely to matter.

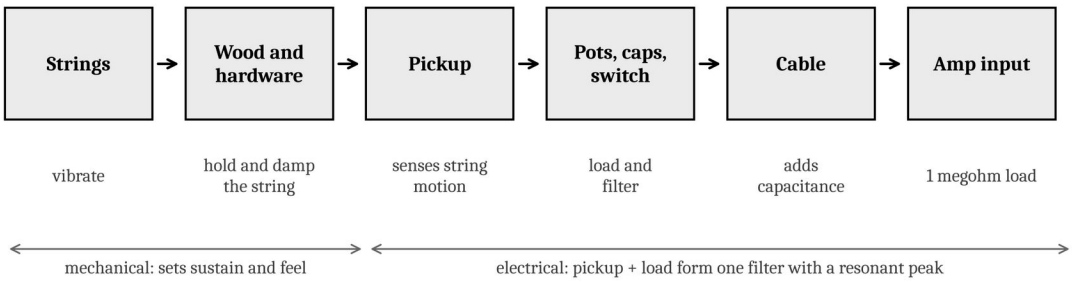


Figure 1.1: The signal path. The strings, wood and hardware set how the string vibrates and how the guitar feels; the pickup, controls, cable and amp input form one electrical filter.

The string: where the sound starts

A note is many notes

Pluck an open low E string and it doesn't just move back and forth at one speed. It vibrates as a whole, at the note you hear (about 82 Hz for low E), and at the same time in halves, thirds, quarters and so on. Each of those smaller vibrations adds a higher frequency on top. The lowest one is the *fundamental*. The higher ones are the *partials*, often called harmonics or overtones. The mix of fundamental and partials is a big part of what makes a guitar note sound like a guitar.

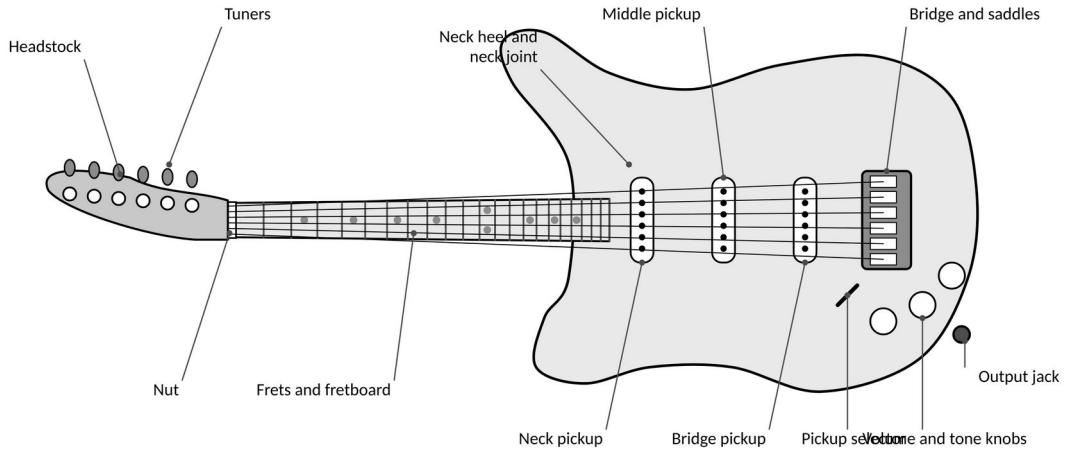


Figure 1.2: The main parts of a solid-body electric guitar.

Zollner points out that on a real string the partials don't land at exact whole-number multiples of the fundamental, because a real string is a little stiff. He prefers the word "partial" for that reason [1]. On a wound string the effect is small. In his example of a wound low E, the 20th partial sits about 2.5% sharp of a perfect multiple [1]. That's a detail, but it's a useful reminder that a string isn't an ideal textbook string (more on strings in Chapter 11).

Every note dies, and the treble dies first

A plucked note fades, and it doesn't fade evenly. High partials die away faster than the fundamental. Zollner measured a fresh wound low E from a 10-46 set: its fundamental took about 25 seconds to fall 30 dB, while its 12th partial, near 1 kHz, took about 7 seconds [2]. The rubbing between the winding and the core soaks up energy, and that loss hits the treble hardest [2].

Old strings make it worse. On a worn wound E string, Zollner found the decay time of a high partial (at 2,391 Hz) shrank to one seventh of a new string's, while the low partials decayed about the same [3]. Plain strings barely changed [3]. That's why a fresh set sounds brighter: the high partials last longer. It's also the cheapest tone change you can make, and it's real.

So the string already does two jobs before anything else touches the signal. It sets which partials are present, and it sets how fast each one dies.

Wood and hardware: holding the string, and stealing a little

Where the string loses energy

A string doesn't vibrate in empty space. It's anchored at the nut (or a fret under your finger) and at the saddle. Anything that moves at those ends takes a little energy from the string. On a solid body guitar, the neck end moves much more than the bridge end.

Paté, Le Carrou and Fabre measured this on a handmade Les Paul Junior-style guitar in 2014 [4]. Their measure of how easily each point moves (engineers call it *mobility* or *conductance*) reached up to about 58

times higher on the neck than at the bridge [4]. In plain words: the bridge on a solid body is very stiff, and the neck is where the string's energy can leak out.

Dead spots

Most of the time that leak is small. But a neck has its own *resonances*: frequencies where it likes to vibrate, the way a ruler hanging off a desk twangs at one particular pitch. When a note's frequency lines up with one of those neck resonances, the neck soaks up the string's energy and the note dies early. That's a *dead spot*.

Paté's team found a dead spot at the 12th fret on their G string that decayed more than 2 seconds sooner than the notes around it [4]. Fleischer, working on a Strat-type guitar, found a dead spot on the D string at the 4th fret and a "live spot" at the 11th [5]. In a later study of six guitars, Fleischer found that the neck, headstock included, moves far more than the body, and that the shape of the headstock changes how the neck twists [6]. A lopsided Strat-style headstock adds twisting, so the bass and treble strings at the same fret can behave differently [6].

Body wood and neck joints

What about the body? The best measurements I have say its effect is small and hard to pin down. Ray, Kaljun and Straže built two guitars with identical bodies, one ash and one walnut, using the same neck and electronics [7]. The fundamentals decayed about the same on both; a few higher partials on the low strings lasted longer on the ash body [7]. That's one body of each wood, with no listening test, so I wouldn't build a theory on it.

Mottola built one guitar as a neck-through, then sawed the neck off and bolted it on, then glued it [8]. The bolt-on version measured the longest sustain, but five listeners couldn't hear a sustain difference among the three, though they could pick the bolt-on as the loudest [8]. Again, one instrument.

The wood and the hardware matter mainly through how stiff and heavy the whole neck and body assembly is, which decides where dead spots fall and how much energy leaks away. The species of the body wood, on its own, is a much smaller effect than guitar talk suggests. Chapter 2 and Chapter 3 lay out the evidence in more detail, and my book *Chasing Tone* takes on that debate in full.

The pickup: a sensor with a narrow view

What it actually senses

A magnetic pickup doesn't hear the guitar. It senses the motion of a steel string in its magnetic field. The magnet magnetizes the string, the moving string disturbs the field, and the changing field through the coil makes a voltage. Horton and Moore modeled exactly this and found that up-and-down motion (toward and away from the pickup) produces a much stronger signal than side-to-side motion [9].

The pickup also doesn't sense the whole string. It senses a short stretch of it. Zollner puts the effective sensing width of a single coil, which he calls its *aperture*, at about 1 cm, set mostly by the magnet pole [10]. Move the string farther away and that window widens, which costs treble, and the level drops about 3 to 4 dB for every millimeter [10]. That's why pickup height matters (Chapter 14 and Chapter 19).

Position picks the partials

Where along the string that small window sits makes a big difference. Remember that a string vibrates in halves, thirds, quarters and so on. Each of those vibration patterns has still points, called *nodes*. If the pickup sits right on a node for one partial, it barely senses that partial.

Mohamad, Dixon and Harte measured a Squier Strat with a 648 mm scale. Its neck pickup sits about 159 mm from the bridge, roughly a quarter of the string length, so it weakens every 4th harmonic [11]. The bridge pickup sits at about 1/14 of the string length and weakens every 14th [11]. That's why the neck pickup sounds round and full and the bridge pickup sounds thin and bright: they're sampling different mixes of the same string. A humbucker samples the string at two points, and Zollner shows that with Gibson's 18 mm pole spacing that adds a cut near 3 kHz on the low E [12].

Notice that none of this is electrical yet. It's geometry, and Chapter 14 goes through pickup position and switching in detail.

The electrical filter: pickup, controls, cable and amp

Here's the idea I most want you to take from this chapter. Once the pickup makes its voltage, everything after it (the pots, the tone capacitor, the switch, the cable and the amp's input) joins the pickup to form one filter. You can't judge any of those parts on its own, because each one changes how the others behave.

> **Tip:** Units you'll see. Hz (hertz) counts vibrations per second, and kHz is thousands of them. Low E is about 82 Hz; the treble that makes a guitar sound bright sits around 2 to 5 kHz. The ohm (Ω) measures resistance: k means thousand and M means million, so a 250k pot is 250,000 ohms and a 1 MΩ amp input is a million. Capacitance comes in µF (millionths of a farad), nF (thousandths of a µF) and pF (thousandths of an nF), so a .022 µF tone cap is 22 nF.

Three electrical words

Three terms will come up again and again, so let's define them now.

Inductance is a coil's resistance to changes in current, measured in henries (H). It mostly comes from the number of turns of wire and the metal in and around the coil. Lemme gives pickup inductance as 1 to 10 H and calls it by far the most important number [13].

Capacitance is the ability of two conductors close together to store charge, measured in picofarads (pF). The coil has a little of its own. The cable has much more, because its center wire and shield run side by side for its whole length.

Resistance here means the electrical load hanging across the pickup: the volume and tone pots and the amp's input, all draining a little signal to ground.

The resonant peak

Put an inductance and a capacitance together and you get a *resonance*: one frequency band where the circuit responds more strongly than anywhere else. For a pickup, that means a band of upper midrange and treble comes out louder than the rest. Below it, the response is roughly flat. Above it, the treble falls away steeply, about 12 dB per octave and up to 18 dB per octave when eddy-current losses are strong [13]. (Eddy currents are small swirling currents induced in the pickup's metal parts that soak up energy.)

This chapter has one formula. The resonant frequency equals one divided by two pi times the square root of inductance times capacitance. In symbols, $f = 1 / (2\pi\sqrt{(LC)})$, the standard formula ElectroSmash prints for pickups [14]. You don't need to calculate anything. Just remember the direction: more inductance or more capacitance moves the peak lower, and the guitar sounds darker. Because of the square root, it takes four times the capacitance to halve the frequency.

Where does the peak land on a real guitar? Lemme and Zollner agree: with normal cables, between about 2 and 5 kHz [13, 15]. Zollner gives about 9 kHz for a Strat pickup with nothing attached, so the cable alone pulls the peak a long way down [15]. Zollner's typical cable is about 100 pF per meter, and normal lengths add up to 300 to 600 pF [16]. The amp's input tube adds roughly another 80 to 150 pF, and its wiring about 50 pF more [17].

The peak also has a height. Engineers describe its sharpness as *Q*, the quality factor. Lemme puts the peak between 1 and 4 times the flat level, which is 0 to 12 dB [13]. Zollner finds a Q of about 3 with the volume and tone pots and an amp connected [15]. The resistance across the pickup sets most of that height: the heavier the load (the lower its resistance), the flatter the peak.

That peak is a big part of a pickup's voice. Its position decides whether the guitar sounds bright or thick. Its height decides how much "bite" or sparkle there is.

What moves the peak: four modeled examples

To show how much each part moves the peak, I built the standard pickup model described by Lemme, Zollner and ElectroSmash and ran it with published values [13, 15, 14]. The model treats the pickup as its inductance and wire resistance in series, with its own winding capacitance across the output, and adds the cable capacitance and the resistance of the pots and amp across that. It leaves out eddy-current losses, so the modeled peaks are higher and sharper than a real pickup's. Treat every number below as modeled: right in direction and rough size, not a measurement.

The pickup's inductance. Fender lists 2.2 H and 5.8 kΩ for its Pure Vintage '59 Strat pickups [18] and 2.97 H and 6.56 kΩ for its Custom Shop Texas Special bridge [19]. TV Jones lists 1.83 H and 4.8 kΩ for its TV Classic bridge [20]. With two 500k pots at full, a 1 MΩ amp input and 450 pF of cable, my model puts the peaks near 4.9 kHz for the TV Classic, 4.5 kHz for the '59 and 3.8 kHz for the Texas Special. ElectroSmash's typical humbucker values (10 H, 15 kΩ, 200 pF) give a peak near 1.8 kHz, and a much flatter one, standing about 2.9 dB high against 7.8 dB for the '59 [14]. That 10 H figure is hot-pickup territory, though. Pete Biltoft of Vintage Vibe puts PAF-style humbuckers at about 2.8 to 4.6 H [34], and with those values (and an assumed 200 pF and about 8 kΩ) my model puts the peak near 2.8 to 3.6 kHz (Chapter 12 has the curves).

The pot values. With the '59 Strat pickup and the same cable, moving from 250k to 500k to 1M pots raises the modeled peak height from about 3.9 to 7.8 to 11.0 dB, while its frequency barely moves (4.2 to 4.5 kHz). Bigger pots mainly make the peak taller. Zollner also reminds us that pots carry about a 20% tolerance, so a "250k" can measure anywhere from 200k to 300k [21] (more in Chapter 15).

The cable. With the '59 pickup and two 250k pots, adding 300, 600 and 1,000 pF of cable (the subject of Chapter 18) moves the modeled peak from about 4.7 to 3.8 to 3.1 kHz. In this model, with no cable at all, there's no peak, just a flat response that rolls off.

The tone capacitor. With the tone knob at 10, the cap value barely changes anything in the model. Turn the tone knob all the way down and the cap becomes part of the resonance: in my model a 0.015 µF cap makes a new peak near 810 Hz, 0.022 µF near 650 Hz, and 0.047 µF near 390 Hz, while 0.1 µF leaves no real peak, and

the response is down about 3 dB by roughly 380 Hz. Zollner gives the common range for tone caps as about 20 to 50 nF (0.02 to 0.05 µF) [22], and Chapter 16 has the rest of the tone circuit.

So in one picture: the pickup's inductance sets roughly where the peak can live, the cable and amp capacitance push it lower, the pot values set how tall it stands, and the tone control, when you use it, replaces it with a lower, softer one. That's why a pickup that sounds bright in one guitar can sound dull in another. The pickup didn't change. The filter around it did.

> **Tip:** Before you buy new pickups to fix a dull guitar, try a shorter cable straight into the amp with the volume and tone knobs at 10. If the guitar wakes up, the problem was in the rest of the filter, not the pickup.

The amp input closes the loop

The amp is the last part of the filter. Zollner gives a typical guitar amp input as 1 MΩ [17]. That resistance sits across the pickup alongside the pots, so it's part of the load that sets the peak height. The amp's input capacitance adds to the cable's. Anything that sits between the guitar and the amp, like a buffered pedal, changes this picture by isolating the pickup from the cable (more on that in Chapter 18).

Playability: where the parts meet your hands

Tone gets most of the attention, but playability is where part choices make the clearest difference for most players. Here are the parts that decide it.

Scale length, gauge and tension

How hard a string is to press and bend depends on its tension. D'Addario publishes the formula: tension depends on the string's weight per inch, and on the square of both the scale length and the pitch [23]. So the same strings at the same pitch pull harder on a longer neck. Using that formula, I computed that a 24.75-inch scale carries about 5.8% less tension than a 25.5-inch scale with the same strings. That's the answer to a question I hear often: "Why does my Les Paul feel easier to bend on than my Strat?" It's mostly the scale (Chapter 4). Gauge matters more still (Chapter 11): D'Addario's published tensions for a 10-46 set add up to 102.5 lb, and for an 11-49 set 117.1 lb (my sums) [24, 25].

Action, frets and radius

Action is the height of the strings above the frets. Grimes, who studied the physics of string bending, found that action has the greatest influence on how hard you have to press to fret a note [26]. Get the action right and a lot of "this guitar is hard to play" goes away.

Fret size (Chapter 6) changes the feel too. With a tall fret, your fingertip pushes the string down onto the fret before it touches the wood, and Fender says jumbo wire can make bending easier because it takes less pressure [27]. Zollner adds the trade-off: with tall frets, how hard you press can pull the pitch a little sharp [28].

Radius (Chapter 5) is the side-to-side curve of the fretboard, given as the radius of a circle. Fender says a rounder board (smaller radius) is "generally perceived as more comfortable for playing chords," while a flatter one is "generally considered better for single-note playing and bending" [29]. A round board can choke bends at low action, which is why Fender's own setup figures call for more relief and higher action on a 7.25-inch board than on a 15-inch one [30].

The nut and the setup

The nut (Chapter 7) sets how high the strings sit over the first fret. If the slots are too high, the first few frets feel stiff and play sharp. StewMac's finished targets are small: about .020 inch of clearance at the low E and about .010 inch at the high E [31].

Then there's the setup itself: neck relief, action, nut height, intonation and pickup height. These are small numbers, and they tie all the other parts together. Evenness matters as much as any single value. Zollner shows that one fret standing just 0.1 mm too high spoils the note at the fret before it [32]. Chapter 19 collects the numbers makers publish, and my guitar maintenance book has the steps.

Hardware and tuning stability

The bridge, nut and tuners decide whether the guitar stays in tune, and Chapters 8, 9 and 10 go through that hardware piece by piece. Friction at the nut and string trees, the pivot of a tremolo, and the strings themselves all play a part. Some of it can't be fixed with hardware. Kemp showed that wound and plain strings change pitch by different amounts for the same movement of a tremolo arm, so a chord drifts out of tune with itself as you use the arm, even on a perfect bridge [33].

The complaint I hear most often at the bench is simple: "This guitar has never played right from the day I bought it." Before you blame the parts, check the setup. Chapter 19 collects the numbers that tie it all together.

Where the big differences are

I'd love to give you a neat ranked list of which changes matter most. I can't, because the effects are measured in different units by different people on different guitars. A pot swap is a change in dB at the resonant peak. A scale change is a change in pounds of tension. A dead spot is a change in seconds of decay. Ranking those against each other would be my opinion dressed up as data.

What I can do is put the sizes side by side, from the sources and models in this chapter, so you can see which ones are large and which are small within their own kind.

Table 1.1: Sizes of some changes, from this chapter's sources and models

Change	Size of the effect	Kind of evidence	Source
Fresh vs old wound string	High partial (2,391 Hz) decays in 1/7 the time on the old string	Measured, Zollner	[3]
Neck dead spot	Note decays more than 2 s sooner than its neighbors	Measured, one guitar	[4]
Ash vs walnut body	Fundamentals decay about the same; some low-string partials last longer on ash	Measured, one body each	[7]
Pickup 1 mm farther from the string	About 3-4 dB quieter, with some treble loss	Measured, Zollner	[10]
Single coil (2.2 H) vs PAF-style humbucker (2.8-4.6 H) vs hot humbucker (10 H)	Peak near 4.5 kHz vs 2.8-3.6 kHz vs 1.8 kHz	Modeled	[14, 18, 34]
250k vs 500k vs 1M pots	Peak height about 3.9 vs 7.8 vs 11.0 dB; frequency 4.2-4.5 kHz	Modeled	[18]
300 vs 1,000 pF of cable	Peak near 4.7 vs 3.1 kHz	Modeled	[18]
Tone knob at 10 vs fully down (0.022 µF)	Peak near 4.5 kHz vs a new, softer peak near 650 Hz	Modeled	[18]

Change	Size of the effect	Kind of evidence	Source
25.5 vs 24.75 in scale, same strings	About 5.8% less tension on the shorter scale	Computed	[23]
10-46 vs 11-49 set	102.5 vs 117.1 lb total tension	Maker figures, my sums	[24, 25]

Look down that table and a pattern shows up. The strings, the setup and the electrical filter have the most measurements behind them, and the most repeatable ones. The body wood row rests on one body of each wood, so I can't call that effect small, only unproven. That's why most of this book's pages go to the parts with the better-measured effects.

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Part 1: Body, Neck and Fretboard

Chapter 2: The Body

The body is the biggest piece of wood on an electric guitar, and it gets blamed or praised for more tone than any other part. It holds the bridge, the pickups and the controls. It rests on your leg or hangs from your strap, and it decides how heavy the guitar feels after a three-hour gig.

In this chapter I'll put the common body woods side by side with their published numbers, tell you what the lab work says about wood and solid-body tone, and walk through the main ways a body gets built: solid, weight-relieved, chambered, semi-hollow and hollow. Then we'll talk about weight, balance and comfort, which is where the body really earns its keep for most players.

What the body does

Picture the string as a wire stretched between two anchors: the nut at one end and the bridge saddle at the other. When you pluck it, the string pushes and pulls on both anchors. Any energy that leaks into the wood is energy the string no longer has, so the anchors matter.

Here's the part most players don't expect. On a solid-body guitar, the bridge end barely moves. Fleischer, an acoustics researcher at the Bundeswehr University in Munich, measured how easily different points on electric guitars could be set moving, and found the bridge of a solid body far less mobile than the neck [1]. In his later study of a Squier Bullet, the bridge's mobility normally stayed below 0.002 s/kg, while the neck at the nut reached about 0.026 s/kg near 170 Hz [2]. The few peaks he did find at the bridge, between 568 and 650 Hz, he traced to the vibrato bridge and its saddles, not to the body wood [2].

A team led by Paté built a Les Paul Junior replica (mahogany body and neck, rosewood fretboard, one P-90 at the bridge) and measured the same kind of thing on the G string. The neck end was up to about 1.02 x 10^-1 m/s/N, the bridge end up to about 1.76 x 10^-3 m/s/N [3]. The neck figure is about 58 times the bridge figure (computed from those two maximums), or a bit under two orders of magnitude. The neck is where a solid-body guitar's string loses most of its energy to the structure. The body mostly sits there being heavy and stiff, which is exactly what a good anchor should do.

You might ask, "So the body doesn't matter?" That's not what I'm saying. The body is part of the whole structure, and its mass and stiffness help decide how the neck moves. It just isn't the main path. Keep that in mind as we look at the woods.

Body woods by the numbers

The columns, defined

A few terms first. *Density* is mass per volume: how heavy a block of a given size will be. *Specific gravity* (SG) is the wood's density compared with water. The Wood Database gives two SG numbers for each species, a "basic" figure and one at 12% moisture content, a standard condition for seasoned wood [4]. *Janka hardness* is the force needed to press a steel ball halfway into the wood; it tells you how well a body resists dents. *Modulus of elasticity* (MOE) is stiffness, how hard the wood resists bending. *Modulus of rupture* (MOR) is bending strength, the load at which a test stick breaks.

All rows in Table 2.1 come from The Wood Database, one page per species. These are species averages at 12% moisture content. The board in your guitar can sit well above or below them.

Table 2.1: Common body woods compared (The Wood Database, 12% moisture content)

Wood (species)	Average dried weight	SG basic / 12%	Janka hardness	Stiffness (MOE)	Strength (MOR)	Source
Basswood (Tilia americana)	26.0 lb/ft³ (415 kg/m³)	0.32 / 0.42	410 lbf (1,820 N)	1,460,000 psi (10.07 GPa)	8,700 psi (60.0 MPa)	[6]
Okoume (Aucoumea klaineana)	27 lb/ft³ (430 kg/m³)	0.35 / 0.43	400 lbf (1,790 N)	1,228,000 psi (8.47 GPa)	10,870 psi (75 MPa)	[7]
Red alder (Alnus rubra)	28.0 lb/ft³ (450 kg/m³)	0.37 / 0.45	590 lbf (2,620 N)	1,380,000 psi (9.52 GPa)	9,800 psi (67.6 MPa)	[8]
Yellow poplar (Liriodendron tulipifera)	29 lb/ft³ (455 kg/m³)	0.40 / 0.46	540 lbf (2,400 N)	1,580,000 psi (10.90 GPa)	10,100 psi (69.7 MPa)	[9]
"Swamp ash" (trade name, not a species)	under 30 to 33.6 lb/ft³ (481-538 kg/m³)	not given	not given	not given	not given	[10]
Black ash (Fraxinus nigra)	34 lb/ft³ (545 kg/m³)	0.45 / 0.55	850 lbf (3,780 N)	1,600,000 psi (11.00 GPa)	12,600 psi (86.9 MPa)	[11]
African mahogany (Khaya spp.)	33.9 lb/ft³ (545 kg/m³)	0.46-0.54 (range)	850 lbf (3,800 N)	1,410,000 psi (9.72 GPa)	11,730 psi (80.9 MPa)	[12]
Limba, sold as "korina" (Terminalia superba)	35 lb/ft³ (555 kg/m³)	0.43 / 0.56	670 lbf (2,990 N)	1,520,000 psi (10.49 GPa)	12,510 psi (86.2 MPa)	[13]
Honduran mahogany (Swietenia macrophylla)	36.8 lb/ft³ (590 kg/m³)	0.52 / 0.59	900 lbf (4,020 N)	1,458,000 psi (10.06 GPa)	11,710 psi (80.8 MPa)	[14]
Soft maple (group)	30.2-38.0 lb/ft³ (485-610 kg/m³)	not given	700-950 lbf	not given	not given	[15]
Red maple (Acer rubrum), a soft maple	38 lb/ft³ (610 kg/m³)	0.49 / 0.61	950 lbf (4,230 N)	1,640,000 psi (11.31 GPa)	13,400 psi (92.4 MPa)	[16]
Black walnut (Juglans nigra)	38 lb/ft³ (610 kg/m³)	0.51 / 0.61	1,010 lbf (4,490 N)	1,680,000 psi (11.59 GPa)	14,600 psi (100.7 MPa)	[17]
White ash (Fraxinus americana)	42 lb/ft³ (675 kg/m³)	0.55 / 0.67	1,320 lbf (5,870 N)	1,740,000 psi (12.00 GPa)	15,000 psi (103.5 MPa)	[18]
Hard maple (Acer saccharum)	44.0 lb/ft³ (705 kg/m³)	0.56 / 0.71	1,450 lbf (6,450 N)	1,830,000 psi (12.62 GPa)	15,800 psi (109.0 MPa)	[4]

For the North American species, I checked these against the U.S. Forest Products Laboratory's *Wood Handbook* (2010 edition, chapter 5). Its 12% moisture rows give the same stiffness, strength and hardness figures for red alder, black ash, white ash, basswood, red maple, sugar (hard) maple, black walnut and yellow poplar [5]. Its specific gravity numbers land between the two Wood Database figures because it uses its own basis (oven-dry weight over volume at 12% moisture) [5]. So if you see "0.41" for alder in one place and "0.45" in another, nobody is wrong. They're measuring different things.

What the table tells you

Sort the table by weight and the body woods fall into three rough groups.

The light group is basswood, okoume, alder and poplar, all between about 415 and 455 kg/m³ [6, 7, 8, 9]. These are the woods of comfortable, easy-to-carry guitars. They're also the soft ones. Basswood and okoume sit around 400 lbf on the Janka scale, which is why a basswood body dents if you look at it wrong [6, 7].

The middle group is the light ashes, the mahoganies, limba and soft maple, roughly 480 to 610 kg/m^3 [10, 11, 12, 13, 14, 15].

The heavy group is white ash and hard maple, at 675 and 705 kg/m^3 [4, 18]. A hard maple body would be the heaviest on the list by a fair margin. That's why you mostly see maple as a thin top glued over a lighter back.

Stiffness tells a quieter story. Every wood on the list falls between about 8.5 and 12.6 GPa [4, 7]. Hard maple is roughly 1.5 times as stiff as okoume on paper (computed from the two Wood Database figures), but most of the common body woods cluster around 9.5 to 11.5 GPa [8, 9, 12, 14, 16].

One more caution. Real boards wander far from these averages. In a 2021 study I'll come back to below, the authors' ash averaged 807 kg/m^3 across their sample [19]. The Wood Database average for white ash is 675 [18]. Same name on the invoice, a very different board on the scale.

Hardness is a playability number

Janka hardness rarely gets talked about with bodies, but it's the column you'll feel over the years. A body takes knocks from belt buckles, mic stands and the edge of the stage. White ash, at 1,320 lbf, is a bit more than three times as hard as basswood at 410 lbf (computed from the Wood Database figures) [6, 18]. Alder sits at 590 lbf and poplar at 540 [8, 9]. The finish takes the first hit, of course, but once a ding goes through it, a soft body shows a deeper dent. If you play hard and gig a lot, that's a fair thing to weigh against the comfort of a light, soft wood.

Trade names you'll see on spec sheets

"Swamp ash" isn't a species. The Wood Database describes it as a trade name for lighter ash, usually from trees grown in wet ground, with a weight somewhere below 30 to about 33.6 lb/ft^3 [10]. Its black ash page notes that the lower-density black ash is the kind favored for electric guitar bodies [11]. So when a maker says "swamp ash," read it as "a lighter cut of ash." It doesn't name a tree.

"Korina" is the same story. It's a trade name for limba, *Terminalia superba* [13].

Honduran mahogany, the classic "genuine mahogany," is listed in CITES Appendix II [14]. CITES is the international treaty that controls trade in threatened species, and Appendix II means shipments need permits. That's likely one reason you'll see African mahogany (*Khaya*) and other substitutes on many spec sheets. Khaya isn't free of the rules either. NAMM reports that every Khaya species, along with every Pterocarpus (padauk) species, was added to Appendix II effective about 25 February 2023, covering logs, sawn wood, veneer, plywood and transformed wood [35].

Who uses what

Makers tend to stick with a short list. Fender's Vintera series spec sheet lists alder for most of its '50s and '60s style models, ash for the '70s Stratocaster and '70s Telecaster Thinline, and alder for the '70s Telecaster Deluxe and Custom [20]. The '60s Telecaster Bigsby came in alder for sunburst finishes and ash for white blonde [20]. Gibson lists mahogany backs with maple tops on its Les Paul Standard models [21, 22]. Ibanez lists basswood for the RG550 and African mahogany with a 4 mm flamed maple top for the RG8570 [23, 24].

Fender's own support page offers tone words for each wood: alder full and warm, ash snappier with a bright edge, poplar similar enough to alder that it's often used in its place, basswood the main wood on many Japanese-made guitars, mahogany with deep, warm mids, and maple bright and "particularly heavy," which is

why it often appears only as a laminated top [25]. Treat those as the maker's descriptions. Fender doesn't publish measurements behind them.

What the research says about wood and solid-body tone

This is the short version. I give the long one, with the myths and the arguments, in my book *Chasing Tone*.

The best direct test I've found is from Ray, Kaljun and Straže, published in *Materials* in 2021. They built two guitars with identical bodies, 430 x 186 x 42.8 mm, one in ash and one in walnut, and fitted the same neck and electronics to both [19]. The ash was much stiffer along the grain (17.22 GPa against 8.63 GPa) and damped its first body vibration a little less (a loss factor of 0.093 against 0.121) [19]. The body's own vibration modes sat at slightly different pitches: 118.0, 203.1 and 438.0 Hz for ash, 108.2, 200.6 and 419.2 Hz for walnut [19].

And the strings? The decay of the fundamental notes was not significantly different between the two guitars. Some upper harmonics of the low E and A strings did ring longer on the ash body; the G, B and high E strings showed only minor differences [19]. It's also worth knowing where the density numbers came from. The authors took them from a larger earlier sample of the same species: ash averaged 807 kg/m^3 with a coefficient of variation of 9.3%, and walnut 623 kg/m^3 with 7.5% [19]. A coefficient of variation is the typical spread around the average, given as a percentage of it. So even within that sample, boards commonly ran several percent heavier or lighter than the average.

Nobody ran a listening test. And this is one body of each wood, so we can't separate "ash versus walnut" from "this board versus that board."

Put that next to the mobility numbers from Fleischer and Paté. The bridge end of a solid body barely moves, and the neck does most of the robbing [2, 3]. That is why I tell players the body wood is a small effect in a solid body. It's not zero. It's just smaller than the price tags suggest, and much smaller than your pickups, your amp or your hands.

There is one physical point in favor of caring about the wood, and it's mostly about moisture. The *Wood Handbook* notes that damping in wood (how fast it turns vibration into heat) depends on temperature and moisture content, with a minimum near 6% moisture at room temperature [5]. It also notes that sound travels across the grain at roughly a fifth to a third of its speed along the grain [5]. Dry, stable wood behaves more consistently. That's a stability argument more than a tone argument, and it applies to necks even more than bodies.

Solid, chambered, semi-hollow and hollow

How much wood is in the body changes more than what kind of wood it is. Here's the range, from most wood to least.

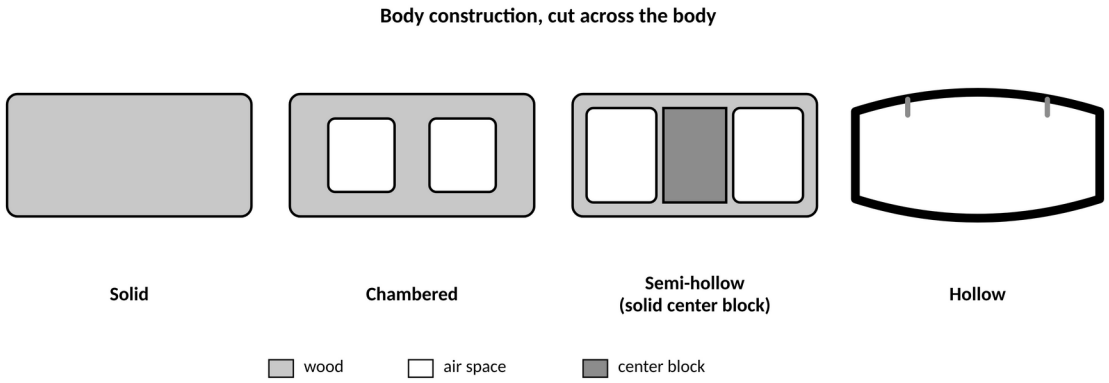


Figure 2.1: Body construction, cut across the body. Chambered bodies hide air pockets under a solid top; a semi-hollow has a solid center block; a hollow body has none.

Solid

A solid body is what it sounds like: a slab, sometimes in several glued pieces, with routes cut for pickups, controls and the bridge. Gibson's current Les Paul Standard 50s and 60s pages list their weight relief as "None," meaning a solid mahogany back under a maple top [21, 22]. Gibson's Custom Shop 1959 Les Paul Standard reissue lists "one-piece lightweight mahogany" with no relief, so Gibson chooses light boards instead of cutting holes [26]. The 1957 Goldtop reissue is the same: lightweight one-piece mahogany, a two-piece plain maple top, and no relief [27].

Weight-relieved

Weight relief means routing pockets inside the body, under the top, before the top goes on. You can't see them from outside. Gibson's spec pages give each model a weight-relief label. The Les Paul Modern and Les Paul Studio are listed as "Ultra-Modern" [28, 29].

What do the labels mean? Gibson doesn't explain them on those pages, so the descriptions I have come from retailers. Andertons describes four types. "Traditional" relief was nine round holes, the so-called Swiss cheese pattern, which it dates to the 1980s. "Chambered" uses large chambers around the central routing, and Andertons calls it slightly more prone to feedback. "Modern" used elliptical cavities with thin strips of wood between them and is now largely discontinued. "Ultra-Modern" is the current version, which Andertons says doesn't change resonance or feedback resistance [30]. The Music Zoo ties chambering to the 2008 Les Paul Standard and the "Modern" elliptical relief to the 2012 Les Paul Standard [31].

The two retailers don't agree on dates, and neither gives a weight saved. The label tells you a body has been hollowed out inside. How much weight that removes, and whether it changes feedback, hasn't been measured in anything I can cite.

Semi-hollow

A semi-hollow body has open air chambers in its wings and a solid block down the middle. The Gibson ES-335 is the classic. Gibson lists a laminated three-ply maple/poplar/maple body with a solid maple center block and spruce bracing [32]. The Custom Shop 1964 ES-335 reissue uses the same three-ply construction and a solid maple center block [33].

Why the block? It sits under the bridge, tailpiece and pickups, so the parts that anchor and sense the strings are mounted on solid wood, not on a thin, springy top. The hollow wings make the guitar lighter and give the top room to move.

Hollow

A fully hollow electric has no center block. The top and back are thin plates over an air cavity, like an acoustic. The more freely the top can move, the more easily loud sound from the amp can drive it, and that loop is what we call feedback.

Table 2.2: Body construction on current maker spec pages

Model	Body construction (maker)	Weight relief (maker label)	Source
Gibson Les Paul Standard 50s	mahogany back, maple top	None	[21]
Gibson Les Paul Standard 60s	mahogany back, AA figured maple top	None	[22]
Gibson Les Paul Modern	mahogany	Ultra-Modern	[28]
Gibson Les Paul Studio	mahogany	Ultra-Modern	[29]
Gibson Custom 1959 Les Paul Standard reissue	one-piece lightweight mahogany	None	[26]
Gibson ES-335	3-ply maple/poplar/maple, solid maple center block, spruce braces	not applicable (semi-hollow)	[32]

Weight, balance and comfort

This is where the body makes a difference you can feel every single time you pick up the guitar.

How heavy is a body?

I wanted to give you maker weights for common models. I couldn't. None of the Fender, Gibson or Ibanez spec pages cited in this book list a body weight or a total guitar weight [21, 23, 34]. The only figure in the retailer material is a "12 lb Les Paul," offered as an example of a heavy, unrelieved guitar, not as a spec [31].

So let's compute instead. The idea is simple: weight equals density times volume. Take a rectangular blank the size of the 2021 test bodies, 430 x 186 x 42.8 mm [19]. That's about 3.42 liters of wood (computed). Multiply by the Wood Database densities and you get Table 2.3.

Table 2.3: Computed weight of a 430 x 186 x 42.8 mm blank (weight = density x volume)

Wood	Density used	Blank weight (computed)	Density source
Basswood	415 kg/m^3	about 1.42 kg (3.1 lb)	[6]
Red alder	450 kg/m^3	about 1.54 kg (3.4 lb)	[8]
"Swamp ash"	481-538 kg/m^3	about 1.65-1.84 kg (3.6-4.1 lb)	[10]
African mahogany	545 kg/m^3	about 1.87 kg (4.1 lb)	[12]
Honduran mahogany	590 kg/m^3	about 2.02 kg (4.5 lb)	[14]
Black walnut	610 kg/m^3	about 2.09 kg (4.6 lb)	[17]
White ash	675 kg/m^3	about 2.31 kg (5.1 lb)	[18]
Hard maple	705 kg/m^3	about 2.41 kg (5.3 lb)	[4]
Ash, 2021 study's sample average	807 kg/m^3	about 2.76 kg (6.1 lb)	[19]

Please read that table for its spread, not its totals. A finished body has rounded edges, contours and routes, so it weighs less than a square blank. The real lesson is in the gap. The same size of wood weighs about 1.4 kg in basswood and about 2.4 kg in hard maple. And a blank at the study's ash average weighs nearly twice the basswood blank, while the Wood Database average for white ash would put it much closer to the middle. Picking boards by weight matters as much as picking the species.

So why does a Les Paul feel so much heavier than a Strat? The numbers in this chapter answer most of it. A Les Paul Standard is a mahogany back under a maple top [21]. Honduran mahogany averages 590 kg/m^3 and hard maple 705 [4, 14]. Fender's Vintera spec sheet lists alder for most of its '50s and '60s style Strats, and alder averages about 450 kg/m^3 [8, 20]. Both of the Les Paul's woods are denser than alder. Unless the maker chose light boards or routed out weight relief, the Les Paul is going to be the heavier guitar.

Balance and neck dive

Weight isn't the whole story. Balance is the other half. *Neck dive* is when you let go of the neck and the headstock drops toward the floor. It happens when the guitar's balance point sits on the headstock side of the strap buttons. A light body paired with a heavy headstock and heavy tuners makes it worse. Moving the strap button, for example out onto the upper horn, moves the support point and can fix it.

That's basic balance, and I haven't found published neck-dive measurements for any model. If you're choosing a light body (basswood, okoume, a chambered build), ask yourself what's hanging off the other end.

Contours and heels

Comfort is also about shape. Fender's American Ultra Stratocaster spec mentions "sculpted rear body contours" on its alder body [34]. Gibson's Les Paul Modern pairs Ultra-Modern weight relief with a "Modern Contoured Heel" [28]. A belly cut or forearm bevel doesn't change the sound in any measured way I know of, but your ribs and right arm will notice after an hour. Heel shapes affect how easily you reach the top frets, and I cover them in Chapter 3.

Reading a body spec sheet

When you shop, here's what the maker's page will usually tell you and what it won't. You'll get the species, sometimes with a top wood and its thickness: Ibanez lists a 4 mm flamed maple top on the RG8570, for example [24]. Gibson gives a weight-relief label [21, 28]. Fender names its contours when they're a selling point [34]. You won't get the weight of the body or the guitar, and you won't get the density of the board in front of you. Those two numbers matter more for comfort than anything on the page.

So if weight matters to you, put the guitar on a scale or ask the seller to. A trade name like "swamp ash" or a label like "lightweight mahogany" is a hint, not a number [10, 26].

Dead spots, briefly

A *dead spot* is a note that dies much faster than the notes around it. Paté and his team found two on their Les Paul Junior replica, at the 9th and 12th frets of the G string. The 12th-fret note decayed more than two seconds sooner than its neighbors [3]. The cause is a vibration of the guitar's structure lining up with a string's frequency, so the structure soaks up the string's energy [3]. Fleischer showed the same thing on a Strat-type guitar, with a dead spot on the D string at the 4th fret [1].

Because the neck moves so much more than the body, dead spots live mainly in the neck (Chapter 3 takes them up along with neck stiffness and headstock shape). The body's mass and stiffness play a supporting role by changing how the neck is held.

Tone and playability at a glance

Table 2.4: Body changes, rated

Change	What you'll hear	What you'll feel
Alder to ash (or other species swap)	Small at most; one two-guitar study found minor differences in some upper harmonics, none in fundamental decay	Depends on the board; ash can be much heavier
Light board to heavy board, same species	No measured tone difference found in these sources	More weight on your shoulder; the board-to-board spread can be large
Solid to weight-relieved (Ultra-Modern)	Retailer says no change in resonance or feedback; not measured	A lighter guitar
Solid to chambered	Retailer claims slightly more feedback; not measured	A lighter guitar
Solid to semi-hollow with center block	More air and top movement in the wings; feedback risk rises at high volume (general reasoning, not measured here)	Lighter, bigger body
Fully hollow	Most top movement and most feedback risk (general reasoning)	Large, light, deeper body
Adding body contours	Little or no audible change	More comfort against ribs and forearm
Light body with heavy headstock	Not measured; extra headstock mass could move a dead spot (Chapter 3)	Possible neck dive

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Chapter 3: The Neck

If the body is the part of the guitar you carry, the neck is the part you play. Your fretting hand spends its whole life wrapped around it. Its shape decides whether a guitar feels like an old friend or a baseball bat, and its stiffness and attachment decide where the guitar's weak notes fall.

In this chapter we'll look at how necks are attached to bodies, what they're made of, how thick they are (with real numbers from the makers), how the truss rod inside them works, and why the headstock at the end matters more than you might think. Fretboard wood, radius and width get their own chapter (Chapter 5), and frets get Chapter 6.

Why the neck matters more than the body

In Chapter 2 I showed you that the bridge end of a solid-body guitar hardly moves. The neck is different. In a lab test on a Les Paul Junior replica, Paté, Le Carrou and Fabre measured the neck end of the G string as up to about 58 times easier to set moving than the bridge end (computed from their peak figures; a bit under two orders of magnitude) [1]. Fleischer found the same pattern across six electric guitars: the neck, including the headstock, moved much more than the body [2].

That makes the neck the main place where a string loses energy into the wood. So when we talk about the "wood" side of an electric guitar's sound, the neck deserves most of the attention, and the way it's held to the body matters too.

How the neck attaches

There are three basic ways to join a neck to a body. Each has its fans and its folklore.

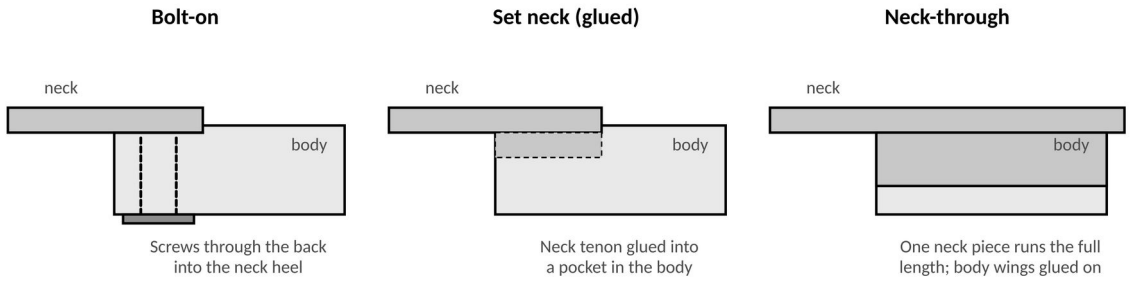


Figure 3.1: The three common ways a neck joins the body, seen from the side.

Bolt-on

A bolt-on neck sits in a pocket routed into the body and is held by wood screws driven up through a metal plate on the back. Call it bolt-on or screw-on; they're the same thing. It makes a neck easy to remove, replace or adjust.

Fender's current American Ultra Stratocaster lists "4-Bolt Standard" construction with a "4-Bolt Asymmetrical" neck plate and a tapered neck heel [3]. The service manual for that guitar lists neck screws in two lengths, 8 x 1-1/4 in and 8 x 1-1/2 in [4].

Fender also built a 3-bolt version. Its Vintera series spec sheet lists "3-Bolt with Micro Tilt" for the '70s Stratocaster, '70s Telecaster Thinline, '70s Telecaster Deluxe and '70s Telecaster Custom [5]. The parts list for Fender's '70s Stratocaster names a "Tilt Disk, Neck" along with the plate and screws [6]. The idea behind a tilt adjustment is to change the neck's pitch (the small angle between neck and body) without taking the neck off to add a shim. Neck pitch, in turn, sets how high the bridge saddles have to sit.

Other makers have their own bolt-on heels. Ibanez calls the joint on its RG8570 j.custom the "All Access Neck Joint" [7]. PRS says its S2 necks come from a quartersawn mahogany blank, with a scarfed headstock and a heel formed with a slip joint [8].

Set neck

A set neck is glued into the body. The joint usually uses a *tenon*, a tongue of wood on the end of the neck that fits snugly into a matching slot (the *mortise*) in the body. A longer tenon reaches farther into the body and gives more glue surface.

Gibson's Custom Shop pages are the clearest about this. The 1959 Les Paul Standard reissue lists a "long tenon, attached with hide glue" [9]. The 1957 Les Paul Goldtop reissue lists a trapezoid joint with a long tenon and a hide glue fit [10]. Gibson's standard-line pages don't list tenon type at all. The Les Paul Modern mentions a "Modern Contoured Heel," which is about reach, not glue [11].

Neck-through

A neck-through guitar has a neck that runs the full length of the instrument, with body wings glued to its sides. The pickups and bridge sit on the neck wood itself. There's no heel joint at all, which can make the upper frets easy to reach.

What the measurements say about joints and sustain

You've heard the ranking: neck-through sustains longest, set neck next, bolt-on last. R.M. Mottola tested it in a way I like a lot. He built one guitar as a neck-through, measured it, then sawed the neck off and bolted it back on with Fender-style hardware (with and without a spacer in the pocket), measured again, and finally glued it in and measured a third time [12]. Same wood, same guitar. He defined sustain as the time it took a note to fall by 21 dB.

Table 3.1: Sustain by neck joint on one test guitar (Mottola 2007)

Joint	High E sustain to -21 dB	Low E sustain to -21 dB	Source
Neck-through	2.82 s	12.13 s	[12]
Bolt-on, Fender-style hardware, no spacer	3.35 s	15.80 s	[12]
Bolt-on with spacer	3.58 s	17.08 s	[12]
Glued (set)	3.42 s	14.01 s	[12]

Look at that. The neck-through version had the *shortest* sustain on both strings, and the bolt-on with a spacer had the longest [12]. The folklore ranking came out upside down.

Still, five listeners could not tell the sustain apart by ear. They could pick out the bolt-on version as the loudest [12]. Mottola says he repeated the test on three instruments but shows one set of results, he didn't run statistics, and it appeared in *American Lutherie*, a builders' journal, not a peer-reviewed science journal [12]. He also doesn't say how many screws held the bolt-on version. So this doesn't prove bolt-ons sustain longer. It does show that the joint type alone doesn't put guitars in the order people expect.

Fleischer's six-guitar study adds a hint about why. The bolted Fender necks reached somewhat lower peak vibration levels than the glued Gibson necks. He suspected the bolted joints add damping, but he didn't measure it [2].

You might ask, "Then why does it matter what joint I choose?" For playability, it matters a lot. The heel shape decides how easily your hand gets to the top frets, and a bolt-on lets you change the neck angle or swap the neck entirely. I'll take sustain arguments to my book *Chasing Tone*.

Neck woods

Maple and mahogany, side by side

Most necks are maple or mahogany. Fender's necks are maple, some listed as maple with a walnut stripe [13, 14, 15]. Gibson's are mahogany [16, 17]. PRS uses quartersawn mahogany on its S2 necks [8]. Ibanez builds its Super Wizard necks from five pieces: maple and walnut on the RG550, maple and wenge on the RG8570 [7, 18].

Table 3.2: Hard maple and Honduran mahogany compared (The Wood Database)

Property	Hard maple	Honduran mahogany	Sources
Average dried weight	44.0 lb/ft³ (705 kg/m³)	36.8 lb/ft³ (590 kg/m³)	[19, 20]
Stiffness (MOE)	1,830,000 psi (12.62 GPa)	1,458,000 psi (10.06 GPa)	[19, 20]
Janka hardness	1,450 lbf (6,450 N)	900 lbf (4,020 N)	[19, 20]
Radial shrinkage, green to oven-dry	4.8%	2.9%	[19, 20]
Tangential shrinkage	9.9%	4.3%	[19, 20]
Volumetric shrinkage	14.7%	7.5%	[19, 20]
Tangential/radial ratio	2.1	1.5	[19, 20]

Read the table this way. Hard maple is about 25% stiffer than Honduran mahogany by these averages, and about 60% harder (both computed from the Wood Database figures) [19, 20]. A stiffer neck bends less under string tension and resists dents. Mahogany is lighter and moves much less with changes in moisture: its shrinkage from green to dry is roughly half of maple's, 43 to 60 percent depending on direction (computed) [19, 20]. The *tangential/radial ratio* compares shrinkage along the growth rings with shrinkage across them; the closer it is to 1, the less a board tends to cup or twist as it dries [19, 20].

A note on reading stiffness tables. The *Wood Handbook* says its stiffness figures come from bending tests that include some shear (sliding) deflection, and that you can approximate the true lengthwise stiffness by adding about 10% [21]. That applies to every species, so comparisons between woods still hold.

Quartersawn versus flatsawn

Quartersawn wood is cut so the growth rings run up and down through the thickness of the board. *Flatsawn* wood has the rings running across the board's face. Lots of players believe quartersawn necks are much stiffer.

Mottola looked at that claim. For long, beam-shaped parts like a neck, he concludes grain orientation makes no practical difference in stiffness, because the variation from one board to the next is bigger than the effect [22]. He cites one test that found no significant difference and another (Blilie, *American Lutherie* #128, 2016) that found quartersawn spruce typically stiffer [22]. Where quartersawn wood does help is across the grain, which matters for plates more than necks, and in stability: quartersawn boards shrink less in width [22]. For a neck, think "more stable," not "much stiffer."

Roasted maple

Roasted (or torrefied, or thermally modified) maple is maple that's been heated in a controlled way. Fender sells roasted maple necks and claims they're "resistant to humidity shifts" and give "more sustain" [23]. StewMac's listing for a Fender roasted Telecaster neck says such necks are far more resistant to temperature and humidity changes, lighter, and caramel in color [24]. Those are sales claims with no data attached.

What does real data say? I found one peer-reviewed study with numbers. Danihelová and colleagues heat-treated sycamore maple (*Acer pseudoplatanus*) in air at 135, 160 and 185 °C and published the results in *Polymers* in 2022 [25].

Table 3.3: Sycamore maple before and after thermal treatment (Danihelová et al. 2022)

Treatment	Density	Stiffness along the grain (dynamic MOE)	Loss coefficient (damping)	Source
Untreated	609 kg/m³	10.70 GPa	0.0175	[25]
135 °C	601 kg/m³ (-1.3%)	11.35 GPa (+6.0%)	0.0165 (-5.7%)	[25]
160 °C	603 kg/m³ (-1.0%)	11.43 GPa (+6.8%)	0.0168 (-4.0%)	[25]
185 °C	604 kg/m³ (-0.8%)	11.02 GPa (+3.0%)	0.0162 (-7.6%)	[25]

The wood got about 1% lighter, lost 2.5-4.6% of its mass, and damped vibration a few percent less [25]. Stiffness went up a little, but the authors report those stiffness changes as not statistically significant [25]. Moisture dropped from 8.0% before treatment to 5.8% after, though that wasn't a long-term humidity test [25]. They didn't measure hardness.

A doctoral thesis by Chenyang Cai at the University of Eastern Finland found that thermal modification lowered the moisture content wood settles at and reduced cupping in wet conditions, with hardness unaffected after humidity exposure [26]. I only have the university's summary, so I can't give you temperatures or species. A 2015 paper by Pfriem on thermally modified wood for musical instruments says mild treatment changes stiffness, damping and sound speed, but I only have its abstract, without numbers [27].

Roasting makes small, measurable changes in weight, stiffness and damping, and the sources point to better stability against humidity. That stability is the real benefit. The tone claims don't have data behind them in anything I can cite.

One caveat from my own bench, and it goes for any neck, roasted or not: a high-dollar neck does not mean high-quality wood or careful finish work. I won't name makers, but price alone tells you very little. Buyer beware.

Neck profiles and depth

What "profile" means

A neck's *profile* is the shape of its back in cross-section: the curve your palm and thumb feel. Makers name them with letters like C, D, U and V. A C is an even curve. A V comes to a soft point at the center. A U is round and full, with fuller shoulders. A D is flatter across the back. Names alone don't tell you much, because one maker's "C" can feel nothing like another's.

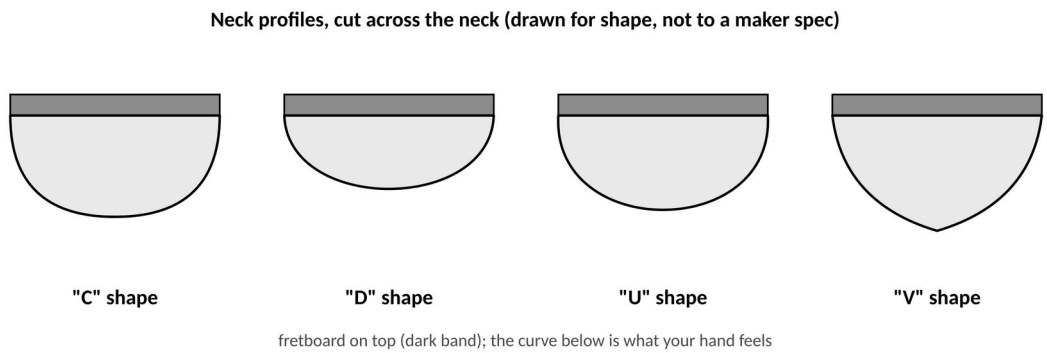


Figure 3.2: The letter names for neck profiles, drawn for shape only. One maker's "C" can feel very different from another's; the depth numbers in Table 3.4 tell you more.

Depth is the number that helps. It's the thickness of the neck from the fretboard surface to the back, measured at a given fret. Most necks get thicker toward the body, so makers usually give two depths: one near the nut and one near the 12th fret.

Where makers measure

This is a trap, so read it carefully. Fender lists depth "at the 1st fret" and "at the 12th fret" [28]. PRS measures at the 1/2 fret and 12 1/2 fret positions, between the frets [29]. Ibanez lists depth at the 1st and 12th frets [18]. And none of these makers say whether the depth includes the fret wire. A few hundredths of an inch can come from where the caliper sits.

Fender's American Ultra service manual notes that each neck is hand-sanded, so thickness may vary slightly from neck to neck [4]. A spec is a target, not a promise.

Table 3.4: Published neck depths, thinnest to thickest at the 1st fret

Profile (example model)	Depth near nut	Depth near 12th fret	Source
Ibanez Super Wizard (RG550)	17 mm (0.669 in, computed)	19 mm (0.748 in, computed)	[18]
PRS Chleo (at 1/2 and 12 1/2 fret)	23/32 in (18.26 mm)	52/64 in (20.64 mm)	[29]
PRS SE Wide Thin (at 1/2 and 12 1/2 fret)	13/16 in (20.62 mm)	57/64 in (22.60 mm)	[29]
Fender Modern "C" (Player Series Telecaster neck)	0.820 in (20.82 mm)	0.870 in (22.09 mm)	[13]
Fender "C" (Classic 60s Stratocaster neck)	0.820 in (20.82 mm)	0.900 in (22.86 mm)	[30]
Fender Deep "C" (American Professional Stratocaster neck)	0.820 in	0.920 in	[28]
Fender Mid '60s "C" (Road Worn 60s Stratocaster neck)	0.820 in (20.82 mm)	0.974 in (24.74 mm)	[31]
PRS Pattern Thin (at 1/2 and 12 1/2 fret)	53/64 in (21.03 mm)	57/64 in (22.60 mm)	[29]
Fender Soft "V" (Classic Player 50s Stratocaster neck)	0.850 in (21.59 mm)	0.890 in (22.6 mm)	[32]
Fender Thick Soft "V" (Road Worn 50s Stratocaster neck)	0.850 in (21.59 mm)	0.980 in (24.89 mm)	[14]
PRS Pattern (at 1/2 and 12 1/2 fret)	7/8 in (22.22 mm)	61/64 in (24.20 mm)	[29]

Profile (example model)	Depth near nut	Depth near 12th fret	Source
Gibson Authentic '68 Medium C (Custom 1968 Les Paul Custom reissue)	0.89 in	1.03 in	[33]
Fender 1951 "U" (American Vintage II 1951 Telecaster neck)	0.890 in (22.60 mm)	0.990 in (25.15 mm)	[15]

Fender's "C" family all start at 0.820 in at the 1st fret [13, 28, 30, 31]. What changes is how much they grow. The Modern C on the Player Telecaster neck adds only 0.050 in by the 12th fret, while the Mid '60s C on the Road Worn neck adds 0.154 in (both computed from Fender's figures) [13, 31]. So two necks that feel identical at the first position can feel very different at the 9th fret. If you play mostly open chords, the 1st-fret number is your number. If you live up the neck, watch the 12th.

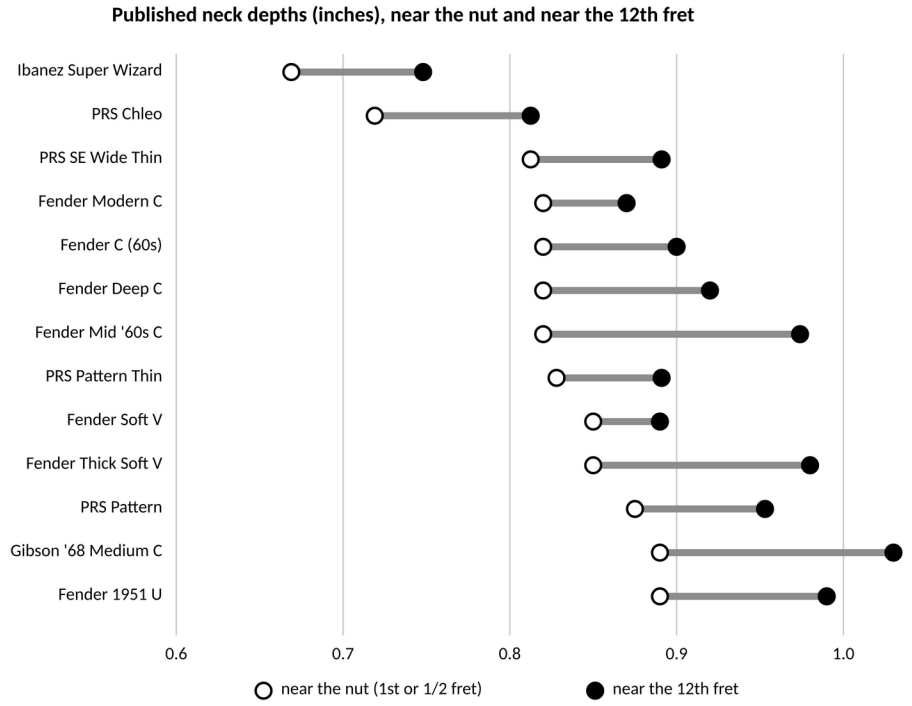


Figure 3.3: The published neck depths from Table 3.4. Each bar runs from the depth near the nut (open dot) to the depth near the 12th fret (solid dot). PRS measures at the 1/2 and 12 1/2 fret positions.

The Ibanez Super Wizard is the slimmest neck in the table, at 17 mm near the nut [18], with the PRS Chleo next at 18.26 mm [29]. That's about 4 mm thinner than a Fender Modern C (computed). The Fender 1951 "U" and the Gibson '68 Medium C sit at the other end, both 0.89 in at the 1st fret [15, 33].

Gibson is the frustrating one. Its standard-line pages name profiles ("50s Vintage," "SlimTaper," "Rounded," "Rounded C") but give no depths [16, 17, 34, 35]. The only depth figure I found on gibson.com is for the Custom Shop 1968 Les Paul Custom reissue [33].

PRS says its Pattern profile is an updated Wide Fat, and Pattern Thin is an updated Wide Thin; Pattern Vintage has the Pattern width but is slightly thicker and asymmetric [29]. Fender describes its newer Modern "D" as a medium thickness with shoulders that slope less steeply than the Modern C, but didn't publish depths in that article [36].

Does thickness change tone?

A thicker neck has more wood, so it's heavier and, all else equal, stiffer. That could shift where its resonances fall (more on that below). But I haven't found a study that measured tone against neck depth. Choose your profile by your hand. A neck that lets you play relaxed for an hour will do more for your sound than any extra millimeter of wood.

The truss rod

What it does

Six strings at pitch pull hard on the neck, trying to bend it forward. The *truss rod* is a steel rod in a channel inside the neck that pushes back. Adjusting it sets *relief*, the small forward bow in the neck that gives the strings room to vibrate without buzzing on the frets in the middle of the neck.

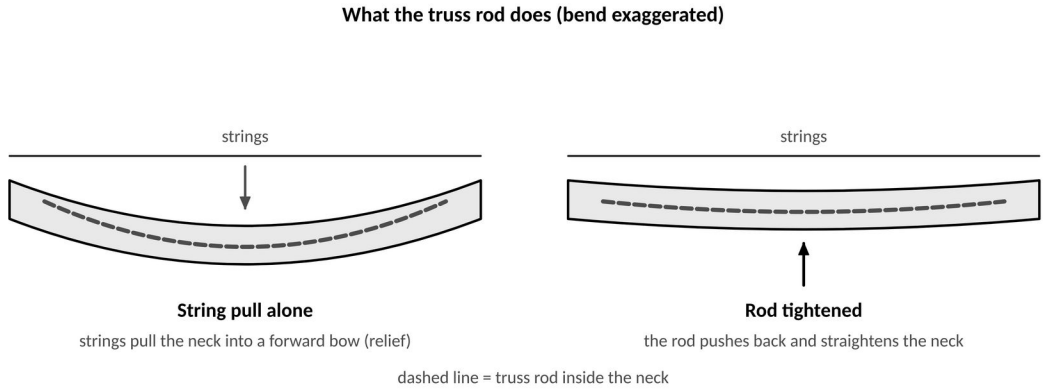


Figure 3.4: String tension bows the neck forward; tightening the truss rod pushes back against it. The bend is exaggerated.

The truss rod sets the bow, not the string height at the bridge. If your action is high everywhere, the rod is probably not the answer.

Single action

A single-action rod works in one direction only. Fender's Tech Talk says that's the kind most electric guitars use [37]. It can pull against forward bow (from string tension) but it can't push a neck that has bowed backward.

Where you adjust it matters a lot for convenience. Fender's Player Series Telecaster neck and its roasted maple Strat neck have a "Single Action, Head Adjust" rod with a 3/16 in hex [13, 23]. Vintage-style necks put the adjustment at the heel, which means removing the neck or moving the pickguard to reach it [14, 30, 31]. Fender's '70s style Vintera models use the "Bullet" rod, adjusted at the headstock [5].

Fender Bi-Flex

Fender's Bi-Flex rod is still a single rod, but it works in both directions [37]. Fender designed it in the early 1980s and says it's used on most American and American Deluxe series instruments, and today on the American Professional line [37, 38].

Here's how Fender describes it. Turn it clockwise and it straightens a neck that bows forward toward the strings. Back it off and it reaches a neutral point. Keep loosening and the rod pushes against a walnut dowel near the nut, bowing the neck forward to correct a neck with a back bow (a hump) [37, 38]. Fender added a

small retainer under the 7th-fret inlay after some test necks failed [37]. It also stresses that Bi-Flex is one rod, not a two-rod "dual-action" design [37]. The American Professional and American Ultra necks use Bi-Flex with a 1/8 in hex [3, 28].

Double-acting and two-way rods

PRS calls its rods double-acting. It says a double-acting rod "achieves twice the amount of adjustment as the single acting rod with the same amount of movement of the adjusting nut," and they're adjusted at the headstock under the cover [39]. Clockwise reduces relief; counter-clockwise increases it, and can straighten a neck with back bow [39]. PRS's Maryland-made guitars take a 5/16 in wrench; its SE models take a 7 mm wrench [40].

Gibson lists its standard models simply as "Adjustable," without naming the type [16]. The Custom Shop 1968 Les Paul Custom reissue says "2-way adjustable" [33]. Gibson's historic reissues list an "Authentic 1950s no-tube truss rod" without explaining how it acts [9, 41].

I'll use *two-way* as the umbrella term for any rod that can correct bow in both directions, whether it's one rod like Fender's Bi-Flex or a design like PRS's double-acting rod.

Table 3.5: Truss rod types on maker spec pages

Rod type	Corrects	Where you adjust	Example	Source
Single action, head adjust	forward bow	headstock, 3/16 in hex	Fender Player Series Telecaster neck	[13]
Vintage heel adjust	forward bow	neck heel	Fender Road Worn 50s Stratocaster neck	[14]
'70s Bullet	forward bow	headstock bullet	Fender Vintera '70s models	[5]
Bi-Flex (one two-way rod)	forward and back bow	1/8 in hex	Fender American Professional and American Ultra	[3, 28, 37, 38]
Double-acting	forward and back bow	headstock, 5/16 in wrench (SE: 7 mm)	PRS	[39, 40]
2-way adjustable	forward and back bow	headstock	Gibson Custom 1968 Les Paul Custom reissue	[33]
1950s no-tube	not stated by Gibson	headstock	Gibson Custom 1959 Les Paul and 1964 ES-335 reissues	[9, 41]

How much relief should you set? PRS publishes 0.005-0.010 in [39]. I cover setup numbers in Chapter 19, and the step-by-step adjustment lives in my guitar maintenance book.

> **Caution:** A truss rod nut that won't turn or keeps turning without resistance is a warning sign. Forcing it can strip the nut or break the rod, which is an expensive repair. Stop and have it looked at.

The headstock

Angled or flat

The headstock holds the tuners, and its angle decides how the strings leave the nut. On a Gibson-style neck the headstock tilts back. On a Fender-style neck it's flat, in line with the neck.

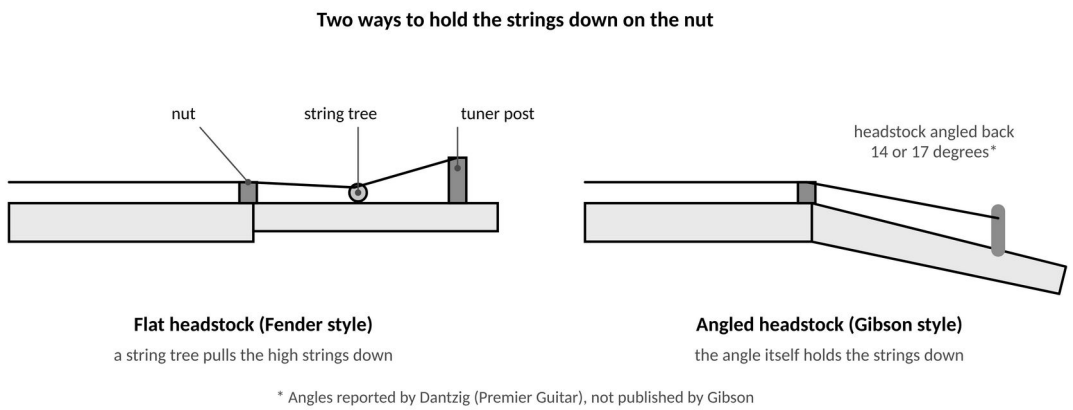


Figure 3.5: A flat headstock needs a string tree to hold the high strings down on the nut; an angled headstock does it with the angle.

Gibson doesn't publish a headstock angle on its spec pages. The numbers players quote come from secondary sources. Dantzig, a Hamer co-founder and luthier writing in *Premier Guitar*, says Gibson headstocks were 17 degrees before 1965 and 14 degrees from 1965 on [42]. Charlie Gelber of es-335.com says the same for ES models and notes 1965 is the only year both angles show up [43]. Two experienced voices agreeing is useful, but it isn't a factory spec, and I couldn't find the angle for current production.

Dantzig lays out the trade-offs plainly. A steeper angle presses the strings down harder on the nut, but it also adds friction there, which can hurt tuning stability on a vibrato guitar. It makes the headstock more fragile and costs more to build. He calls the sustain benefit debatable [42]. He chose 14 degrees for his own Hamer designs to avoid Gibson-style breakage, then went to 17 on a later model because dealers asked for it [42]. He also notes that Fender's flat maple headstock is essentially zero degrees, a choice made largely for cost [42].

A flat headstock gives the strings no downward angle over the nut on its own, so Fender-style guitars use string trees (Chapter 10) on the treble strings to hold them down in their slots.

For a sense of scale, Fender lists the American Professional Stratocaster neck's headstock at 0.540 in (13.71 mm) thick [28].

Why angled headstocks break

If you've worked a repair bench, you've seen a broken Gibson headstock. Why does it happen? Hayes, writing on the Haze Guitars repair shop blog, explains it this way: carving an angled headstock from the same piece of wood as the neck leaves *short grain* (wood fibers that run out across the thin section). That creates a fault line that is more prone to splitting [44]. A straight Fender-style neck has its grain running one way, along the neck [44].

One fix is a *scarf joint*: the headstock is cut as a separate piece and glued on at an angle so the grain follows the tilt. PRS uses a scarfed headstock on its S2 necks [8].

Caution: Never lean a guitar with an angled headstock against a wall or amp where it can slide and fall backward. A fall onto the headstock is the classic way to crack one, and a stand or case is cheap by comparison.

Dead spots and headstock shape

What a dead spot is

A dead spot is a fretted note that dies much faster than its neighbors. Paté and his team found two on their test guitar, at the 9th and 12th frets of the G string; the 12th-fret note's decay time was more than two seconds shorter than the frets on either side [1]. Their computer model predicted decay times within 0.6 seconds of the measured ones, so they understood what was going on [1].

The cause is a *resonance*: a frequency at which a structure vibrates easily. When a resonance of the neck lines up with one of the string's partials (the fundamental or an overtone), the structure soaks up the string's energy, and the note dies early [1]. Fleischer measured the same thing on a Strat-type guitar, with a dead spot at the 4th fret of the D string, a "live spot" at the 11th fret, and a neck resonance at 430 Hz [45].

Six guitars on the bench

Fleischer's 2001 study measured the neck resonances of six electric guitars [2].

Table 3.6: Neck resonances of six electric guitars (Fleischer 2001)

Guitar	Neck joint	Headstock	Frets	Neck resonances (Hz)	Source
Gibson Les Paul	glued	symmetric	22	58; 200/208; 445/455	[2]
Gibson Explorer	glued	strongly asymmetric	22	60; 142/148; 213/220; 343; 430	[2]
Fender Stratocaster SRV	bolted	asymmetric	21	64; 193/200; 245/258; 438-465	[2]
Fender Stratocaster (white)	bolted	asymmetric	21	58; 190/200; 235; 432	[2]
Squier Bullet	bolted	asymmetric	21	55; 158/170; 210/218; 423	[2]
Traveling Wilbury TW 500	bolted	symmetric	18	58; 185/200/228; 350/360; 425	[2]

Notice how similar the lowest resonance is on all six, between 55 and 64 Hz [2]. Fleischer found the pattern of resonances within about 10% of what an ideal beam gives when one end sits on a hinge-like (pinned) support and the other end is free [2]. In plain words, the neck swings and flexes like a long board hinged at the body.

The headstock shape is where it gets interesting. On guitars with a symmetric headstock (three tuners per side, like the Les Paul), the neck mostly bends straight up and down. On an asymmetric headstock (six in a row, like a Strat, or the Explorer's long, swept head), twisting gets mixed in [2]. The Explorer showed twisting resonances at about 142 and 343 Hz, which means the bass and treble strings at the same fret meet a neck that moves differently [2]. Fleischer's later report found strong differences between the bass and treble edges of a Strat headstock, and "extremely small" differences across a Les Paul's [46].

What does that mean for you? A dead spot can sit on one string at a fret and not on its neighbor, and an asymmetric headstock makes that more likely. It also suggests why adding weight at the headstock could shift a dead spot, since that changes the mass at the free end of the neck, though I haven't found a measurement of that. Dead spots depend on neck stiffness, mass, headstock shape and the joint, not on body wood alone [1, 2].

Reaching the upper frets

Where the neck meets the body, and how bulky the heel is, decides how far up the neck your hand can go comfortably.

The cleanest published example I have is the Gibson SG. A *Guitar.com* review of a 1963 SG Les Paul Standard notes its 22nd-fret body join [47]. With the neck leaving the body at the last fret, there's nothing in the way of your hand.

For the other classic models, I couldn't find a maker or reliable source that states which fret the neck joins at, so I won't guess. What makers do advertise is heel shaping: Fender's "tapered neck heel" and asymmetrical plate on the American Ultra [3], Gibson's "Modern Contoured Heel" on the Les Paul Modern [11], and Ibanez's "All Access Neck Joint" [7]. All of them aim at the same goal: less wood where your palm wants to go at the top of the neck.

Tone and playability at a glance

Table 3.7: Neck changes, rated

Change	What you'll hear	What you'll feel
Bolt-on vs set vs neck-through	One-guitar test found bolt-on sustained longest and neck-through shortest; listeners couldn't hear a sustain difference	Heel shape and upper-fret reach differ; a bolt-on can be removed, shimmed or swapped
Maple neck vs mahogany neck	No measured tone comparison found	Maple is stiffer and harder; mahogany is lighter and moves less with humidity
Quartersawn vs flatsawn	No measured tone difference; stiffness difference small for necks	Quartersawn is more stable in width
Roasted maple	Small changes in damping and stiffness; no measured tone data	Claimed better humidity stability; supported by thermal-modification research
Thinner vs thicker profile	No study found linking depth to tone	The biggest feel change on this list
Single-action vs two-way truss rod	No change	A two-way rod can also fix back bow; adjustment access varies
Angled vs flat headstock	Sustain benefit called debatable by a luthier source	Angled heads need no string trees but are more prone to breakage
Symmetric vs asymmetric headstock	Changes where dead spots fall and how they spread across strings	No difference in hand
Contoured heel or late body join	No change	Easier reach to the top frets

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Bracket numbers in this chapter point to this list. Web addresses were checked in October 2026; if one moves, search the site for the title.

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Chapter 4: Scale Length and String Tension

Scale length is the one number on a guitar that quietly sets up almost everything else. It decides where every fret goes. It decides how tight a set of strings pulls when you tune it to pitch, and how far your fingers stretch down in first position. You can swap pickups in an afternoon and change strings in ten minutes, but you can't change a neck's scale length without changing the neck.

In this chapter I'll show you where the common numbers come from, why the Gibson "24.75 inches" is more of a name than a measurement, how fret positions are worked out, and how much the tension of the same strings changes when they go on a longer or shorter neck. Then I'll go through what scale length does and doesn't do to tone, because that's where a lot of guitar talk gets ahead of the evidence.

What scale length means

Scale length is the length of string that's free to vibrate when you play it open, measured the way builders agree to measure it. StewMac defines it as the distance from the nut (at the point where the nut meets the fingerboard) to the center of the 12th fret, doubled [1]. If that distance is 12.5 inches, you have a 25-inch scale [1].

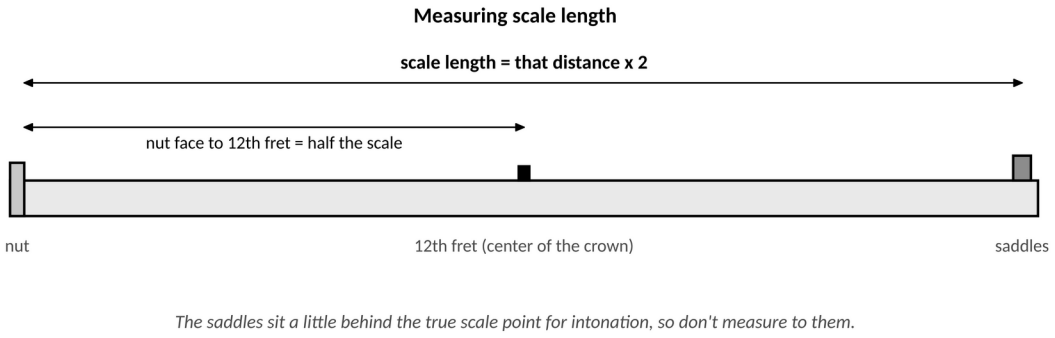


Figure 4.1: Scale length is twice the distance from the nut to the 12th fret.

You might ask, "Why not just measure from the nut to the saddle?" The saddles don't sit at the exact scale length. When you press a string down to a fret, you stretch it a little, and that stretch makes the note go sharp. Manfred Zollner, author of *Physics of the Electric Guitar*, the most detailed open text I know on the subject, works out that fretting the low E at the 12th fret raises its pitch by about 10 cents [2]. A cent is one hundredth of a semitone. To fix that, the saddle is moved back toward the tail of the guitar, which is called compensation. Zollner puts the low E compensation on electric guitars at up to about 6 mm [2]. So the saddle-to-nut distance is always a bit longer than the scale length, and it's different for every string. The nut-to-12th-fret method sidesteps all of that.

The scale length is a design number. Compensation is a setup adjustment. Keep them separate in your head (the intonation numbers are in Chapter 19, the saddle hardware in Chapter 8) and a lot of confusion goes away.

Common scale lengths by maker and model

These are the scale lengths the makers themselves list for current models. I've kept each maker's own units: Fender and Ibanez give both inches and millimeters, Gibson gives millimeters first, and PRS gives inches only.

Table 4.1: Scale lengths listed by makers for current models

Model	Scale (in)	Scale (mm)	Notes	Source
Fender American Professional II Stratocaster	25.5	648		[3]
Fender American Vintage II 1957 Stratocaster	25.5	648		[4]
PRS Silver Sky	25.5	not listed		[5]
Ibanez RG421DX and PWM20	25.5	648		[6, 7]
Gibson Custom Les Paul Custom Long Scale	25.5	647.7	a Les Paul at Fender length	[8]
PRS Custom 24 and SE Custom 24 (2025)	25	not listed		[9, 10]
PRS McCarty 594	24.594	not listed	model name comes from the scale	[11]
Gibson Les Paul Standard 50s, Les Paul Modern Figured, SG Standard, Custom Les Paul Custom	24.75	628.65	Gibson's stated figure; see below	[12, 13, 14, 15]
Fender Player II Mustang and Player II Jaguar	24	610		[16, 17]
Squier Mini Stratocaster	22.75	578	20 frets	[18]
Fender 75th Anniversary Player II Baritone Telecaster	27	686	tuned B to B	[19]
Squier Classic Vibe Baritone Custom Telecaster	27	686		[20]
.strandberg* Boden Standard NX 6	25.5 to 25.0	not listed	multiscale	[21]

StewMac, the luthier supply company, keeps its own reference list for people who make and repair necks [1]. It mostly agrees with the makers, with two differences worth knowing about.

Table 4.2: StewMac's reference scale list (selected entries)

Instrument	StewMac scale	Source
Fender (Strat, Tele)	25.500 in (21 vintage, 22 modern frets)	[1]
PRS	25.000 in (22 or 24 frets)	[1]
Fender Jaguar	24.000 in	[1]
Fender Duosonic and Mustang	22.500 in	[1]
Fender Bajo Sexto / Baritone Telecaster	30.1562 in	[1]
Gibson 24-3/4 in	"Varies"	[1]
Gibson Byrdland	23.500 in	[1]
Guild electric	24.750 in	[1]

Instrument	StewMac scale	Source
Fender bass / short-scale bass	34.000 in / 30.000 in	[1]

First, StewMac lists the Mustang at 22.5 inches, and Fender's current Mustang is 24 inches [16]. Both are right for their era. Fender's own history says the Musicmaster and Duo-Sonic came out in 1956 with a 22.5-inch scale, against 25.5 inches for the Telecaster and Stratocaster. From 1964 both were offered in short and medium (24-inch) scales, and the Mustang arrived in August 1964 as a 22-fret, 24-inch guitar. Fender adds that "a very few" 21-fret short-scale Mustangs were built [22]. If you're buying parts for an old one, measure it.

Second, StewMac's 30.1562-inch baritone figure is for the Bajo Sexto model. The current Fender and Squier baritone Telecasters are 27 inches [19, 20]. They're different guitars that share a family name.

The Gibson 24.75 question

Gibson's current spec pages list 628.65 mm (24.75 in) for the Les Paul Standard 50s, the Les Paul Modern Figured, the SG Standard and the Custom Shop Les Paul Custom [12, 13, 14, 15]. That's the official number, and it's the one I use for Gibson-style math in this book.

StewMac doesn't give a single number for Gibson at all. Its scale table says "Varies," and the article says the Gibson 24-3/4 scale "rarely ever measures out to be 24-3/4 inches," which StewMac blames on changes in Gibson's production equipment over about fifty years [1]. StewMac's slotted fingerboard for Gibson goes further. Its description says the scale everyone calls 24-3/4 inches "is actually 24.625" (625.47 mm), and that this is "the most common of three different scales" Gibson has described as 24-3/4 over the years [23]. The same product page's short summary gives a different figure, 24.562 inches [23]. So StewMac itself gives two values, and it ends by telling buyers to measure their guitar before ordering [23].

Neither Gibson nor StewMac publishes year-by-year factory figures, so I can't tell you which years used which scale. Treat 24.75 inches as Gibson's name for the scale. Expect a real Gibson to measure somewhere from 24.562 to 24.75 inches. Measure before you buy a replacement fingerboard, a neck, or anything that depends on fret placement.

How big is the gap? From 24.75 down to 24.562 inches is 0.188 inch over the whole scale, so the 12th fret moves about 0.094 inch (my arithmetic). That's small for a player and large for someone slotting a fingerboard.

There's a second wrinkle. Zollner measured fret positions on several guitars. Two Gibsons he checked drifted noticeably from the exact fret positions in the higher frets, but they were within tolerance of the old "rule of 18," while the Epiphone, Taylor and Martin guitars he measured were more precise [2]. Two guitars is not a survey, and he doesn't claim it is. It does tell you that "what scale is it?" and "where are the frets?" can be two separate questions on an older instrument.

Where the frets go

Every fret shortens the vibrating string by just enough to raise the pitch one semitone. In equal temperament (the tuning system where all twelve semitones in an octave are the same size), each semitone is a frequency ratio of about 1.05946, which is the twelfth root of 2 [2]. Twelve of those steps double the frequency, which is an octave. Since frequency goes up as length goes down, the 12th fret has to sit exactly halfway along the scale.

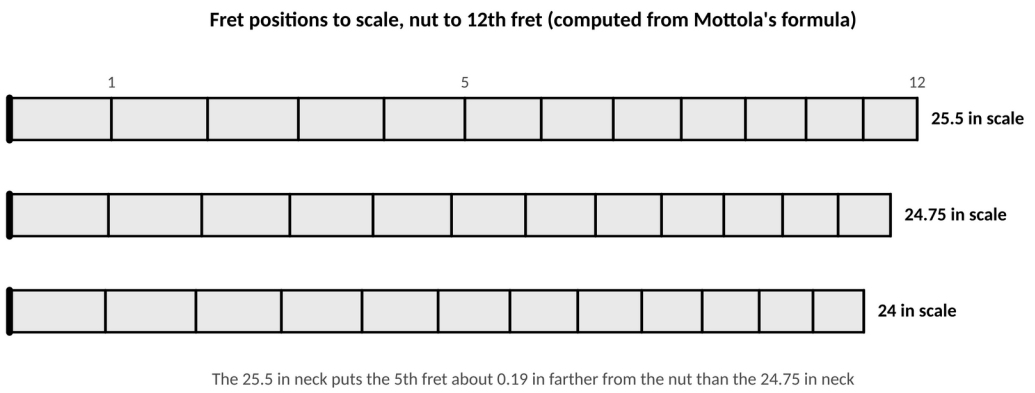


Figure 4.2: Fret positions to scale for three common scale lengths, nut to 12th fret, computed from Mottola's formula (Table 4.3).

Here's the working method in words. Take the distance from the nut to the bridge and divide it by 17.817. That's where the first fret goes. Then take the distance from the first fret to the bridge, divide that by 17.817, and you have the gap to the second fret. Keep going up the neck [24, 2]. On a 625 mm scale the first fret lands about 35.08 mm from the nut [2].

R.M. Mottola, a luthier who publishes lutherie formulas, also gives an exact version that works out each fret's position straight from the scale length and the fret number, so small rounding errors don't pile up as you go [24]. That's the one I'd use for anything you're cutting. Mottola notes that some references use 17.835 instead of 17.817. He calls it "mathematically unrelated" to the right answer, though it gives good results [24]. The older "rule of 18" uses 18 as the divisor. Mottola calls it old-fashioned and points out that with it, the 12th fret doesn't land at half the scale [24]. Zollner calls it the "(inaccurate) rule-of-18" [2]. Modern instruments don't use it [24].

Zollner puts the measuring tolerance for fret position at about plus or minus 0.05 mm [2]. That's a couple of thousandths of an inch.

Since each gap is a fixed fraction of what's left, the frets get closer together as you go up. The table below is computed from Mottola's formula, so these are math, not maker specs.

Table 4.3: Fret positions and spacing in inches (computed from Mottola's formula)

Scale	Nut to 1st	Nut to 5th	Nut to 12th	11th to 12th	21st to 22nd	Nut to 22nd	Nut to 24th	Source
22.5	1.263	5.644	11.250	0.669	0.375	16.186	16.875	computed [24]
22.75	1.277	5.707	11.375	0.676	0.380	16.366	17.062	computed [24]
24	1.347	6.020	12.000	0.714	0.400	17.265	18.000	computed [24]
24.594	1.380	6.169	12.297	0.731	0.410	17.693	18.446	computed [24]
24.75	1.389	6.208	12.375	0.736	0.413	17.805	18.562	computed [24]
25	1.403	6.271	12.500	0.743	0.417	17.985	18.750	computed [24]
25.5	1.431	6.397	12.750	0.758	0.425	18.344	19.125	computed [24]
27	1.515	6.773	13.500	0.803	0.451	19.423	20.250	computed [24]
30	1.684	7.525	15.000	0.892	0.501	21.582	22.500	computed [24]

Look at the "Nut to 5th" column. Going from 24.75 to 25.5 inches stretches the first five frets by about 0.19 inch (about 5 mm). Going from 25.5 down to 24 shrinks them by about 0.38 inch. Your fretting hand feels that in first position long before it feels anything at the 15th fret, where the gaps are small on every scale.

One more bit of math from the same formula: the 24th fret always sits exactly one quarter of the scale away from the bridge, because two octaves up means a quarter of the length. On a 25.5-inch neck the 24th fret is 0.781 inch past the 22nd (computed). That extra length affects where the neck pickup can go, which Chapter 6 takes up.

How scale length changes string tension

Tension is the pulling force on a string when it's tuned to pitch. It's what your fingers fight when you fret and bend. D'Addario puts the rule plainly: "The longer the scale length, the greater the tension." Their own example is the same set of 9-42 strings in standard tuning, which carries more tension on a Stratocaster at 25.5 inches than on a Les Paul at 24.75 [25].

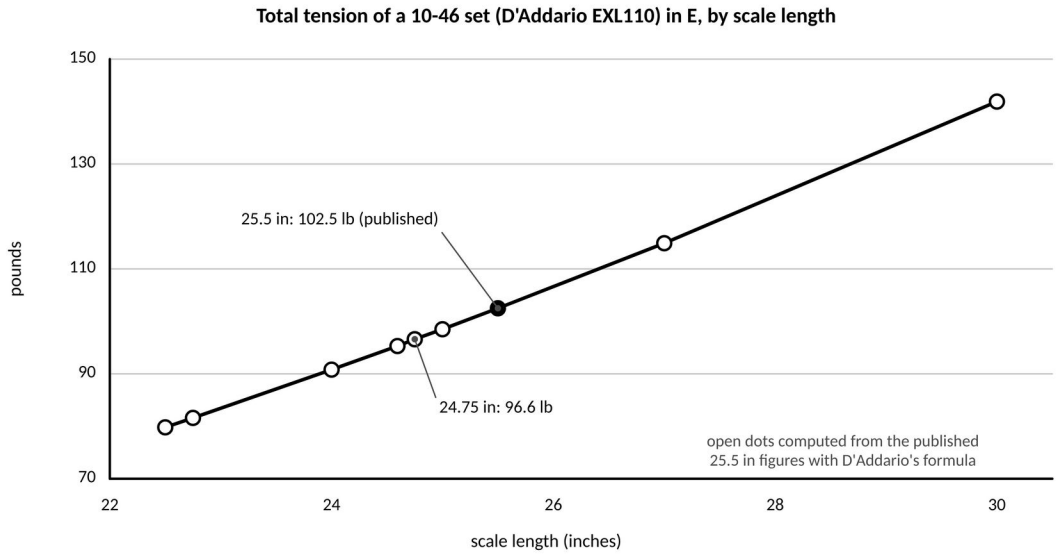


Figure 4.3: Total tension of a D'Addario EXL110 (10-46) set in standard E tuning against scale length (Table 4.4). The 25.5 in point is D'Addario's published figure; the rest are computed with D'Addario's formula.

D'Addario publishes the formula they use, and it's the one formula I'll give you in this chapter [25]:

Tension (lb) = unit weight x (2 x scale length x frequency) squared / 386.4

In words: take the string's unit weight (its weight per inch of length, in pounds per inch), multiply it by the square of twice the scale length in inches times the note's frequency in hertz, and divide by 386.4. That gives tension in pounds. Multiply by 4.45 for newtons [25].

You don't need to run that formula to use what it tells you. Scale length is squared in it, and so is pitch. So at the same pitch and gauge, a scale that's 3 percent longer gives about 6 percent more tension.

D'Addario prints a tension chart on each product page. For the EXL110 set (10-13-17-26-36-46), the page lists 16.2 lb on the high E, 15.4 on the B, 16.6 on the G, 18.4 on the D, 19.0 on the A and 16.9 on the low E [26]. The page doesn't say what scale length those numbers assume. When I run D'Addario's formula backward for the plain .010 string, it matches 25.5 inches exactly, and the .010's unit weight matches what a .010 steel wire

should weigh. So 25.5 inches is almost certainly the basis, but that's an inference, not something D'Addario states.

With those page values as the starting point, I can scale them to any length. Because tension follows the square of scale length, each value is multiplied by the new scale divided by 25.5, squared. Every number in the next table is computed that way. None of them are D'Addario's published figures except the 25.5-inch column.

Table 4.4: D'Addario EXL110 (10-46) tension in pounds, standard E tuning, at different scale lengths

String	22.5 in	22.75 in	24 in	24.594 in	24.75 in	25 in	25.5 in	27 in	30 in
.010 E	12.6	12.9	14.4	15.1	15.3	15.6	16.2	18.2	22.4
.013 B	12.0	12.3	13.6	14.3	14.5	14.8	15.4	17.3	21.3
.017 G	12.9	13.2	14.7	15.4	15.6	16.0	16.6	18.6	23.0
.026 D	14.3	14.6	16.3	17.1	17.3	17.7	18.4	20.6	25.5
.036 A	14.8	15.1	16.8	17.7	17.9	18.3	19.0	21.3	26.3
.046 E	13.2	13.5	15.0	15.7	15.9	16.2	16.9	18.9	23.4
Set total	79.8	81.6	90.8	95.3	96.6	98.5	102.5	114.9	141.9

Source for Table 4.4: the 25.5-inch column is D'Addario's published chart [26]; all other columns are computed from it with D'Addario's formula [25]. Nobody strings a 27- or 30-inch baritone with 10s in E; those columns are there only to show the effect of length by itself.

In short, with the same strings in the same tuning, a 24.75-inch neck has about 5.8 percent less tension than a 25.5-inch neck. A 24-inch neck has about 11.4 percent less. A 25-inch PRS-style neck sits in between, about 3.9 percent less than 25.5.

To put that in context, here are a few other D'Addario sets on the two most common scales. Again, the 25.5-inch figures are D'Addario's page values summed, and the 24.75-inch figures are computed.

Table 4.5: Total set tension in pounds, 25.5 in (published) vs 24.75 in (computed)

Set	Gauges	Total at 25.5 in	Total at 24.75 in	Source
EXL120	9-42	84.4	79.5	[27], computed [25]
EXL110	10-46	102.5	96.6	[26], computed [25]
EXL115	11-49	117.1	110.3	[28], computed [25]
EXL140	10-52	119.6	112.7	[29], computed [25]
EXL145	12-54	146.4	137.9	[30], computed [25]

That table answers a common question: "If I put 10s on my Les Paul, is it like putting 9s on my Strat?" No. 10-46 on a 24.75-inch neck is about 96.6 lb. 9-42 on a 25.5-inch neck is 84.4 lb. Going down a scale length takes off less tension than going down a gauge. The closer match is D'Addario's 9-46 set on the Strat, which totals 93.1 lb at 25.5 inches [31].

What you feel: bending, fretting and stretch

Put the same strings on a Les Paul and a Strat, tune them to the same notes, and the Les Paul's strings are under about 5.8 percent less tension. That's why it feels easier to bend on. Less tension means less push to move the string sideways and pull it up in pitch. StewMac describes the shorter scale as "slinkier," with easier bends, and the longer scale as having "a more rigid feel" [1].

I'll add one thing from string research, which I go into more in Chapter 11. J.A. Kemp, in a 2017 study of guitar strings, found that for plain steel strings, the stretch needed to reach a given pitch doesn't depend on the string's diameter [32]. What changes from string to string is the force needed to get that stretch, and force

tracks tension. So on the same guitar, a lighter plain string doesn't ask your finger to travel less for the same bend; it asks it to push less.

Scale length also changes the reach. StewMac notes that longer scales have wider fret spacing [1], and Fender says a shorter scale "places the frets closer together" [33]. Fender also reports that many players credit the Jaguar's 24-inch scale with "a faster, easier playing feel" [34]. Table 4.3 puts numbers on it: about 0.19 inch more stretch over the first five frets going from 24.75 to 25.5 inches. If you have small hands, that's a real difference in first-position chords. If you have big hands, the short scale can feel cramped up high.

There's a trade-off on action. Action is the height of the strings above the frets. StewMac says longer scales allow lower action before the strings buzz, and shorter scales can buzz at low action [1]. My reading is that this fits the tension story: a looser string swings wider for the same pick attack, so it needs a little more room. The action numbers themselves are in Chapter 19.

Tip: If you move from a 25.5-inch guitar to a 24.75-inch guitar and want the same feel under your fingers, go up in gauge before you go fiddling with setup. Table 4.5 shows how close the totals line up.

Short scale, baritone and multiscale

Short scale

Short-scale electrics are anything noticeably under the 24.75 to 25.5 range. Fender's current Mustang and Jaguar are 24 inches [16, 17]. The Squier Mini Stratocaster is 22.75 inches with 20 frets and a 1.6-inch (40.6 mm) nut [18]. The original 1956 Musicmaster and Duo-Sonic were 22.5 inches [22].

Look at the 22.5-inch column of Table 4.4. A 10-46 set on that neck totals about 79.8 lb (computed). That's less than a 9-42 set on a Strat. On a short scale, a player can use a heavier set and still get easy bends. The cost is that the strings feel floppier at the same gauge, and some players find low action harder to get clean.

Baritone

A baritone guitar uses a longer scale so it can be tuned lower without the strings going slack. Fender's 75th Anniversary Player II Baritone Telecaster is 27 inches (686 mm), ships with .013 to .062 strings, and is tuned B to B [19]. Squier's Classic Vibe Baritone Custom Telecaster is also 27 inches and ships with .014 to .068 strings [20].

Here's why both changes are needed. B is five semitones below E. Tension follows the square of pitch, so tuning the same strings down to B on the same neck drops tension by about 44 percent (computed from D'Addario's formula). Stretching the scale from 25.5 to 27 inches only puts back about 12 percent (also computed). The rest has to come from heavier strings, which is what Fender and Squier ship. The long scale helps, but the gauges do most of the work.

Multiscale

A multiscale (or fanned-fret) neck gives each string its own scale length. The frets fan out so the bass side is longer than the treble side. The .strandberg* Boden Standard NX is a good example. The 6-string runs from 25.5 inches on the bass side to 25.0 on the treble side, the 7-string from 26.25 to 25.5, and the 8-string from 28.0 to 26.5 [21]. Strandberg's page doesn't say which fret sits straight across the neck.

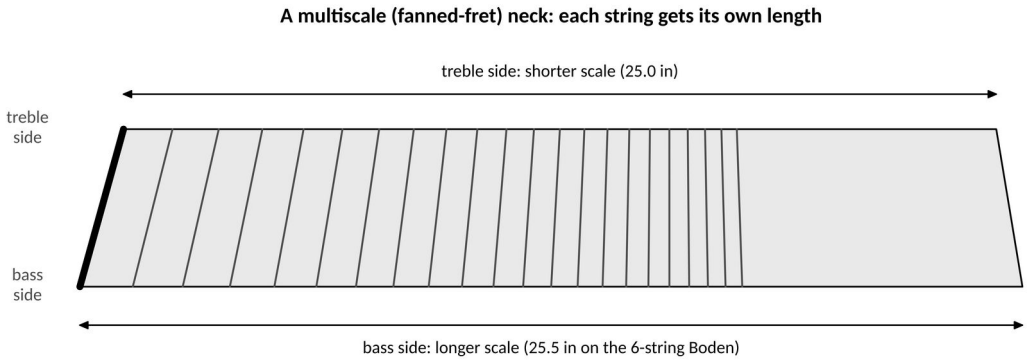


Figure 4.4: A fanned-fret neck gives the bass strings a longer scale than the treble strings. Lengths shown are Strandberg's for the 6-string Boden Standard NX.

Why do it? D'Addario's formula tells you. Longer length means more tension at the same pitch [25]. A fanned neck gives the low strings more length and tension, which matters most on extended-range guitars tuned low, without making the high strings stiffer. On the 6-string Boden, the treble strings get about 3.9 percent less tension than they would on a straight 25.5-inch neck (computed). Strandberg's page didn't state its own reasons, so that reasoning is mine, from the formula.

The playing difference is the slant. Your fretting hand has to get used to frets that aren't parallel, and your picking hand meets the strings at an angle near the bridge.

What scale length does to tone

StewMac says longer scales sound brighter and punchier and shorter scales sound warmer [1]. That's a common belief, and StewMac is a respected source for building. But the article gives it as description, not as a measurement. I treat it as opinion.

What the physics does support comes down to three things.

First, tension changes, and tension changes how hard the string swings for a given pick attack and how often it slaps the frets. That's a feel and attack difference more than a tone-circuit difference.

Second, inharmonicity. A real string is a little stiff, so its overtones (the higher frequencies that ring along with the note) sit slightly sharp of perfect multiples. That spread is called inharmonicity. Zollner shows that lower tension, as with down-tuning or a shorter scale with the same strings, raises it [35]. He also measured a .052 low E string and found the spread below the level where he says people clearly hear it [36]. So a shorter scale nudges inharmonicity up, but on normal electric strings the effect is small.

Third, pickup position. Zollner treats where a pickup sits along the string as a filter whose dips in the frequency response depend on the pickup's distance from the bridge [37]. A pickup sits a fixed distance from the bridge. On a longer scale, that same spot is a slightly smaller fraction of the string's length, so its filter lands in a slightly different place. That is real, and it's a pickup-placement effect (Chapter 14), not a "long scale wood magic" effect.

I couldn't find a controlled test that changed only scale length and measured the tone. Most real comparisons (Strat against Les Paul) change the pickups, the bridge, the body and the neck joint along with the scale, so

you can't pin the difference on any one part. If you want the long version of that argument, it lives in my book *Chasing Tone*.

Tone and playability at a glance

Table 4.6: What changing scale length does

Change	What you'll hear	What you'll feel
25.5 to 24.75 in, same strings	Little or no change you can pin on scale alone; "warmer" is a maker opinion	About 5.8% less tension; easier bends; first five frets about 0.19 in closer
25.5 to 24 in, same strings	Same; a looser string may buzz more at low action	About 11.4% less tension; noticeably closer frets
25.5 to 25 in (PRS-style)	Little or no audible change	About 3.9% less tension
Short scale (22.5-22.75 in)	Looser strings; can be hard to keep clean at low action	10-46 feels lighter than 9-42 on a Strat
Baritone (27 in)	You hear the lower tuning and heavier strings	Wider stretches; tension depends mostly on the gauge you choose
Multiscale	Little documented change; tighter low strings in low tunings	Slanted frets; more tension on the bass side only
Real Gibson vs stated 24.75 in	None you'd notice	Matters only for parts: measure before ordering

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Bracket numbers in this chapter point to this list. Web addresses were checked in October 2026; if one moves, search the site for the title.

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Chapter 5: The Fretboard

Run your fretting hand up the neck of any guitar and the part you touch most is the fretboard. It's the strip of material glued to the face of the neck (or, on a one-piece maple neck, the face of the neck itself) that holds the frets and gives your fingertips something to press toward. Players also call it the fingerboard; it's the same part.

Three choices define a fretboard: what it's made of, how much it curves from side to side, and how wide it is at the nut. In this chapter I'll give you the published numbers for each, compare the common options side by side, and sort out which of them you'll feel under your hand and which ones mostly live in catalog copy. Fret wire gets its own chapter (Chapter 6), and so does the nut (Chapter 7).

What the fretboard does

A fretboard has a simple job description. It carries the frets in slots cut across its face, it sets the curve your fingers follow, and it sets the width your hand has to wrap around. It also takes wear. Strings and fingertips rub it for years, and the frets are pressed into it and later pulled out of it when the guitar gets a refret.

On an electric guitar the string's vibration is sensed by the pickups, not by the board, so the board's effect on amplified tone is an indirect one at most. Whether board species changes an electric guitar's sound you can hear through an amp is a question I take up in my book *Chasing Tone*. Here I'll stick to what can be measured: weight, hardness, stiffness, curve and width.

Fretboard materials

Three numbers worth knowing

Before the table, let's define the three columns that matter.

Density is how much mass a material packs into a given volume. A denser board weighs more for the same size. The Wood Database lists density at 12% moisture content [1].

Janka hardness is a standard test: the force needed to press a steel ball halfway into the wood. The bigger the number, the better the wood resists dents and wear. It's given in pounds-force (lbf) and newtons (N).

Modulus of elasticity (MOE) is a measure of stiffness. It tells you how much a material resists bending under a load. A higher MOE means a stiffer piece of material, all else being equal.

All of the wood figures below come from The Wood Database by Eric Meier, one page per species [1, 2, 3, 4, 5, 6]. These are species averages. Any single board you hold can sit above or below them.

Table 5.1: Common fretboard materials compared

Material	Density	Janka hardness	Stiffness (MOE)	CITES status	Source
Gaboon ebony (Diospyros crassiflora)	60 lb/ft^3 (955 kg/m^3)	3,080 lbf (13,700 N)	2,449,000 psi (16.89 GPa)	Appendix II only for Madagascar Diospyros	[3]
Brazilian rosewood (Dalbergia nigra)	52 lb/ft^3 (835 kg/m^3)	2,790 lbf (12,410 N)	2,020,000 psi (13.93 GPa)	Appendix I	[2]

Material	Density	Janka hardness	Stiffness (MOE)	CITES status	Source
East Indian rosewood (Dalbergia latifolia)	53.4 lb/ft³ (855 kg/m³)	2,350 lbf (10,440 N)	1,783,000 psi (12.30 GPa)	Appendix II (finished instruments exempt since Nov. 2019)	[1, 7]
Indian laurel (Terminalia elliptica)	54 lb/ft³ (855 kg/m³)	2,340 lbf (10,390 N)	1,806,000 psi (12.46 GPa)	not listed	[5]
Pau ferro (Machaerium spp.)	54 lb/ft³ (865 kg/m³)	1,960 lbf (8,710 N)	1,574,000 psi (10.86 GPa)	not listed	[4]
Hard maple (Acer saccharum)	44.0 lb/ft³ (705 kg/m³)	1,450 lbf (6,450 N)	1,830,000 psi (12.62 GPa)	not listed	[6]
Richlite (composite)	75.84 lb/ft³ (specific gravity 1.213)	not published	not published	not applicable	[8]

Ebony is the hard one. Gaboon ebony's Janka figure of 3,080 lbf is about 31% higher than East Indian rosewood's 2,350 lbf, and a little more than twice hard maple's 1,450 lbf (both ratios computed from the Wood Database figures) [1, 3, 6]. It's also the stiffest wood on the list and the densest.

Maple is the soft one, but not the floppy one. Hard maple has the lowest Janka number and the lowest density of the woods listed, yet its stiffness (12.62 GPa) is a hair higher than East Indian rosewood's (12.30 GPa) [1, 6]. So if anyone tells you a maple board makes a neck stiffer than a rosewood board, the species averages say the difference is tiny.

Indian laurel is close to a twin of East Indian rosewood on paper. Same density at 855 kg/m³, Janka 2,340 lbf against 2,350 lbf, stiffness 12.46 GPa against 12.30 GPa [1, 5]. One limit: the Wood Database page for Indian laurel mentions fretboard use only in reader comments, not in the article itself [5]. Fender's Squier line uses it on the Mini Stratocaster and the Classic Vibe Baritone Custom Telecaster [9, 10].

Pau ferro is a little softer and noticeably less stiff than East Indian rosewood. Its Janka figure is 1,960 lbf and its MOE is 10.86 GPa [4].

Brazilian rosewood sits between East Indian rosewood and ebony on hardness, stiffness and bending strength, though it is a little less dense than either [1, 2, 3]. What sets it apart today is its legal status, covered in the CITES section below.

There's one more column in the Wood Database worth a look, the *modulus of rupture* (MOR), which is how much bending stress a sample takes before it breaks. Ranked from strongest to weakest: Gaboon ebony 22,930 psi (158.1 MPa), Brazilian rosewood 19,570 psi (135.0 MPa), pau ferro 17,750 psi (122.4 MPa), East Indian rosewood 16,680 psi (115.0 MPa), hard maple 15,800 psi (109.0 MPa) and Indian laurel 14,710 psi (101.4 MPa) [1, 2, 3, 4, 5, 6]. A fretboard is glued to a neck and never gets bent anywhere near its breaking point, so this number tells you more about the wood's general strength than about anything you'll feel.

What does all this mean for a player? Mostly durability. A board is a wear surface, and Janka hardness is a measure of how well a wood resists denting. I'd expect a harder board to hold up better to fingernails, string wear and the pulling and pressing of frets during a refret, though I haven't found a measurement of fretboard wear. As for stiffness, the board is only a thin layer on top of the neck (neck stiffness is in Chapter 3), and the woods here don't differ enough in MOE to make one an obvious choice for a stiffer neck.

Who uses what

This is how a sample of current production models list their boards. These are the makers' own spec pages.

Table 5.2: Fretboard materials on current models

Model	Fretboard material	Source
Gibson Les Paul Standard 50s	Indian rosewood	[11]
Gibson SG Standard	rosewood	[12]
Gibson Les Paul Modern Figured	ebony	[13]
Fender American Vintage II 1957 Stratocaster	maple	[14]
Fender American Ultra II Stratocaster	ebony or quartersawn maple	[15]
Squier Mini Stratocaster	Indian laurel	[9]
Squier Classic Vibe Baritone Custom Telecaster	Indian laurel	[10]
Ibanez RG421DX	jatoba	[16]

Maple boards and finish

A maple fretboard is the odd one out because it's usually the same wood as the neck under it. Fender's 1950s-style Stratocasters, such as the American Vintage II 1957, are listed simply as maple [14]. Fender's American Ultra II offers quartersawn maple as one of its two board choices [15]. Quartersawn means the board was cut so the growth rings run roughly up and down through its thickness rather than flat across it.

The thing everyone notices about a maple board is the finish on top of it, and that's the part I can't give you numbers for. I didn't find a maker source that publishes finish type or thickness for maple fretboards, or that compares how a finished board and a bare board feel or wear. So I'll leave it as a feel choice: some hands like the slicker surface, some prefer a bare wood surface.

Roasted maple

Roasted (also called torrefied or thermally modified) maple has been heated in a controlled process until it turns a caramel brown. StewMac's listing for a Fender roasted maple Stratocaster neck says the treatment makes the neck "far more resistant to temperature and humidity change," lighter in weight, and caramel in color [17]. That listing gives no process details and no moisture or hardness figures. So treat the stability benefit as the seller's and maker's claim. Chapter 3 looks at what lab work on heat-treated maple has actually measured, and the short version is that the changes are modest.

For reference, the neck on that listing is a 25-1/2 in scale with a 12 in radius, a 1-11/16 in nut and 22 jumbo frets listed at .055 in x .110 in [17].

Richlite and other composites

Richlite is a composite material, sold as an ebony replacement. Richlite's own fretboard blank, called Black Diamond, measures 20 in x 2.75 in x 0.3125 in, and the maker describes it as "inherently stable" and FSC certified [18]. The product page doesn't name any guitar makers that use it.

Richlite's published properties sheet gives a density of 75.84 lb/ft^3 and a specific gravity of 1.213 [8]. That works out to roughly 1,215 kg/m^3, which makes it about 27% denser than Gaboon ebony at 955 kg/m^3 (my calculation from the two sources) [3, 8]. So if you swap an ebony board for Richlite on the same neck, the neck gets a little heavier, not lighter.

The sheet also lists a flexural strength (the stress at which a bent sample breaks) of 22,000 psi in one direction across the face and 17,300 psi in the other [8]. The Wood Database gives Gaboon ebony a modulus of rupture, which is also a breaking strength in bending, of 22,930 psi [3]. Those two numbers are in the same

neighborhood, but the test methods aren't the same, so read that as a ballpark comparison only. The Richlite sheet publishes no hardness figure, and no stiffness figure that I could match to the wood columns [8].

CITES and the rosewood story

If you've shopped for guitars since 2017, you've probably heard that rosewood got "banned." It didn't, quite, and the rules have changed since. Here's the short history, because it explains some of the board choices you'll see on guitars built in those years.

CITES is the Convention on International Trade in Endangered Species, a treaty that controls cross-border trade in listed plants and animals. Species go into appendices. Appendix I is the strictest: commercial trade is mostly off the table. Appendix II allows trade, but with permits.

Table 5.3: Rosewood and CITES, key dates

Date	What happened	Source
11 June 1992	Brazilian rosewood (Dalbergia nigra) listed in Appendix I	[19, 20]
24 Sep-5 Oct 2016	CoP17 meeting in Johannesburg lists all Dalbergia species, plus three bubinga species, in Appendix II under annotation #15	[19, 20]
2 January 2017	CoP17 listing takes effect; finished items over 10 kg covered, non-commercial shipments up to 10 kg exempt	[19, 20]
August 2019	CoP18 meeting in Geneva adopts a revised annotation #15	[7]
3 October 2019	CITES Notification No. 2019/052 issued	[7]
26 November 2019	Finished musical instruments, parts and accessories of Dalbergia (except Brazilian rosewood) no longer need a CITES permit	[7]
21 April 2020	CITES Notification No. 2020/033 quotes the instrument exemption and records Decision 18.321, a study of the exemptions' effects	[21]
About 25 February 2023	CoP19 listings take effect: all Khaya (African mahogany) and Pterocarpus (padauk) species in Appendix II for logs, sawn wood, veneer, plywood and transformed wood; NAMM says finished instruments exported by its members need no permit	[41]

So, for most of 2017 through late 2019, makers shipping across borders had to deal with permits for rosewood. Since 26 November 2019, a finished guitar with an East Indian rosewood board can cross a border without one, according to NAMM's summary of the CITES notification [7]. The exemption wording, as quoted by the CITES Secretariat, covers "finished musical instruments, finished musical instrument parts and finished musical instrument accessories" [21].

Brazilian rosewood is different. It has been in Appendix I since 1992 and was never covered by the exemption [19, 20, 7]. If you own or want a guitar with a Brazilian board, the paperwork still matters.

Ebony has its own wrinkle. The Wood Database notes that only Diospyros species from Madagascar are in Appendix II, while Gaboon ebony is not CITES-listed but is rated endangered by the IUCN [3]. Pau ferro, Indian laurel and hard maple aren't listed at all [4, 5, 6].

Caution: CITES rules and national laws change. If you're shipping or traveling with a guitar that has a Brazilian rosewood board, check the current rules before you go.

Fretboard radius

What radius means

Look down the neck from the headstock end and you'll see that most fretboards aren't flat. They're slightly domed from side to side. *Radius* is the number that describes that dome. Picture the fretboard as a slice cut from the outside of a giant cylinder. The radius is that cylinder's radius. A small number, like 7.25 in, means a small cylinder and a rounder board. A big number, like 16 in, means a big cylinder and a flatter board.

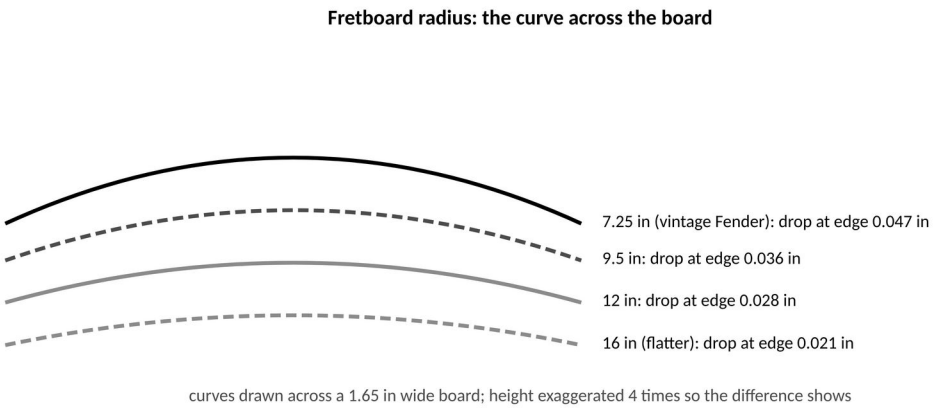


Figure 5.1: Four common fretboard radii across a 1.65 in wide board. The height is exaggerated four times; the "drop at edge" numbers are computed and are true size.

Smaller number, rounder board. Bigger number, flatter board.

Radius by model

Table 5.4: Fretboard radius on current and catalog models

Model or option	Radius	Source
Fender American Vintage II 1957 Stratocaster	7.25 in (184.1 mm)	[14]
PRS Silver Sky	7.25 in	[22]
Fender American Professional II Stratocaster	9.5 in (241 mm)	[23]
Fender Player II Mustang and Player II Jaguar	9.5 in	[24, 25]
Squier Mini Stratocaster	9.5 in	[9]
Fender Yngwie Malmsteen Stratocaster	9.5 in	[26]
PRS Custom 24, SE Custom 24, McCarty 594	10 in	[27, 28, 29]
Fender American Ultra II Stratocaster	10-14 in compound (254-355.6 mm)	[15]

Model or option	Radius	Source
Gibson Les Paul Standard 50s, SG Standard, Custom Les Paul Custom	12 in (304.8 mm)	[11, 12, 30]
Gibson Les Paul Modern Figured	10-16 in compound	[13]
Fender Special Edition Custom Telecaster FMT HH	15.75 in (400 mm)	[31]
Ibanez Wizard III neck (RG421DX, PWM20)	400 mm (15.75 in)	[16, 32]
Warmoth straight-radius options	9-16 in in 0.5 in steps; 7-1/4 in on vintage necks only	[33]
Warmoth compound options	10-16 in, 9.5-14 in, 12-16 in	[33]

Notice that the Fender Telecaster at 15.75 in and the Ibanez at 400 mm are the same radius written in two units [31, 16].

Lined up like that, the big makers spread out neatly from round to flat. Fender's vintage reissues sit at the round end with 7.25 in, and so does PRS's Silver Sky [14, 22]. Fender's modern models sit at 9.5 in, PRS's core models at 10 in, Gibson at 12 in, and Ibanez's Wizard III neck at the flat end with 400 mm [23, 27, 11, 16]. If you play guitars from several makers, that spread is a big part of why they feel different under your hand, even before you think about neck shape or frets.

Fender's own article on the subject gives a useful snapshot of its catalog at the time it was written. About two thirds of Fender electrics used 9.5 in. Just under a third used the vintage 7.25 in, which dates to the early 1950s and was on most Fender electrics until the 1980s. A dozen or so used 12 in, and about three dozen used a compound radius [31]. Fender's replacement neck guide adds that 9.5 in became its modern standard in the 1980s [34].

Round versus flat: what you feel

You might ask, "Why do so many players love a round vintage neck for chords, and so many shredders want a flat one?" It comes down to the shape of your hand. When you barre a chord, your index finger lies across all six strings. A rounder board curves the same way your finger and hand naturally curl, so it's easier to press every string cleanly. Fender says a smaller radius "is generally perceived as more comfortable for playing chords," while a larger one is "generally considered better for single-note playing and bending" [31].

Warmoth puts it in similar terms, and adds that it sees 10-12 in as the best balance for most players [33].

Bending choke

This is where the curve starts to matter for more than comfort. When you bend a string, you push it sideways across the board. On a round board, the frets are curved too, so the string is moving toward a part of the next fret up that sits higher than the spot it started from. If the string is low to begin with, it can hit that higher fret and stop ringing. Players call this choking or fretting out.

The fix on a round board is a little more clearance: more relief and higher action. *Relief* is the slight forward bow in the neck, measured as a gap between string and fret around the middle of the neck. *Action* is the height of the strings above the frets. Fender's published Stratocaster setup numbers show exactly this pattern, and Fender calls them minimum specifications [35].

Table 5.5: Fender's minimum Stratocaster setup figures by radius

Radius	Neck relief	String height at 17th fret, bass side	String height at 17th fret, treble side	Source
7.25 in	.012 in	5/64 in	4/64 in	[35]
9.5-12 in	.010 in	4/64 in	4/64 in	[35]
15-17 in	.008 in	4/64 in	3/64 in	[35]

So as the board flattens, Fender lets both the relief and the action come down. Warmoth says the same thing in words: small radii need somewhat high action to bend without fretting out, and large radii allow clean bends at low action [33]. The how-to of setting these numbers is in my guitar maintenance book. Chapter 19 of this book collects the setup numbers from every part of the guitar in one place.

Compound radius

A *compound radius* tries to give you both shapes on one neck. The board is rounder at the nut, where you play chords, and flatter toward the body, where you bend. Warmoth describes it as starting rounder at the nut for "maximum hand comfort in the chording area" and flattening toward the high frets to ease bends [33]. Fender lists compound examples of 9.5-14 in, 7.25-12 in and 12-16 in [31]. Gibson's Les Paul Modern Figured uses 10-16 in, and Fender's American Ultra II uses 10-14 in [13, 15].

One practical point from Fender: on a compound-radius neck, the action is usually set to match the radius around the 12th fret [31]. That's because the board doesn't have just one curve, so the saddles have to follow the curve at one chosen spot.

Is a compound board a must? No. A 9.5 in or 10 in straight radius already sits in the middle of the range, and plenty of players never choke a bend on one. A compound radius makes the most sense if you love a round neck for chords and also bend hard high on the neck.

Radius and the hardware

The radius isn't only about the board. The nut slots and the bridge saddles have to follow the same curve, or some strings end up higher than others. Warmoth lists a 10 in radius for the Floyd Rose locking nut it sells and says it suits boards from 9 in to 12 in, though Floyd Rose nuts come in more than one radius (Chapter 9 lists a 12 in R3), and that the LSR roller nut needs a 9-11 in radius or a 10-16 in compound board [36]. So if you're thinking about a neck with a very round or very flat board, check that the nut (Chapter 7) and bridge (Chapter 8) you want come in a matching curve.

Fretboard width at the nut

The numbers

The width of the fretboard at the nut sets how far apart the strings can be there, and how wide a grip your hand has to make. It sounds like a small number to fuss over. It isn't, once you hold two necks back to back.

Table 5.6: Nut width by model and option

Model or option	Nut width	Source
Squier Mini Stratocaster	1.6 in (40.6 mm)	[9]
Fender American Vintage II 1957 Strat, Player II Mustang, Player II Jaguar, Yngwie Malmsteen Strat, Squier CV Baritone Custom Tele	1.650 in (42 mm)	[14, 24, 25, 26, 10]

Model or option	Nut width	Source
PRS Silver Sky	1-21/32 in (1.656 in)	[22]
Fender American Professional II Strat, American Ultra II Strat, 75th Anniversary Player II Baritone Tele	1.685 in (42.8 mm)	[23, 15, 37]
PRS Custom 24, SE Custom 24, McCarty 594	1-11/16 in (1.6875 in)	[27, 28, 29]
Gibson Custom Les Paul Custom	42.85 mm, listed as 1.69 in	[30]
Gibson Les Paul Standard 50s, SG Standard	43.05 mm, listed as 1.69 in	[11, 12]
Gibson Les Paul Modern Figured	43.05 mm, listed as 1.7 in	[13]
Ibanez Wizard III neck (RG421DX, PWM20)	43 mm (58 mm at the 24th fret)	[16, 32]
Warmoth options	1-5/8 in (41 mm), 1.650 in (42 mm), 1-11/16 in (43 mm), 1-3/4 in (44 mm), 1-7/8 in (48 mm)	[38]

Most of the models in Table 5.6 land between 1.650 in and about 1.69 in. The spread looks tiny, but follow it through. The difference between Fender's 1.650 in and 1.685 in is 0.035 in, or about 0.89 mm, total [23, 14]. Spread across the five gaps between six strings, that's about 0.007 in per gap (my calculation). Some hands notice that. Many don't.

Watch the rounding on Gibson pages. Gibson lists both 42.85 mm and 43.05 mm as "1.69in," and one page rounds 43.05 mm to "1.7 in" [11, 13, 30]. Converted, 42.85 mm is 1.687 in and 43.05 mm is 1.695 in. If you're ordering a replacement nut or a neck, go by the millimeter figure or measure the guitar.

Wide or narrow?

Warmoth calls 1-11/16 in "the standard nut width" and the closest to modern Fender necks [38]. It says narrower widths are more comfortable for chords, and that 1-3/4 in adds string spacing for lead playing and bending and suits large hands [38].

That matches what the geometry would lead you to expect. A wider nut gives each fingertip a bit more room, so you're less likely to mute the string next door, and bends have a touch more space before the string runs off the edge. A narrower nut is easier to wrap your thumb around for chords. Neither is better. They suit different hands and different styles.

One small detail on string spacing, which Chapter 7 takes further: StewMac places the two outer E strings about 1/16 in in from each end of the first fret [39]. So on a narrow board, the strings themselves end up a little closer together, not just the edges.

Width at the nut is only half the story, because most boards get wider as they go up the neck. Ibanez is one of the few makers that publishes both ends: its Wizard III neck is 43 mm at the nut and 58 mm at the 24th fret [16, 32]. That's 15 mm (about 0.59 in) wider at the top (my calculation). Most of the other spec pages I used list only the nut width, so I can't compare the taper across brands.

At the small end, the Squier Mini Stratocaster pairs a 1.6 in (40.6 mm) nut with a 22.75 in (578 mm) scale and 20 frets [9].

Where scale length fits in

Width isn't the only thing that changes your reach. Scale length sets how far apart the frets are along the neck (Chapter 4). A short-scale guitar like a 24 in Mustang or Jaguar puts the frets closer together [40], and Fender pairs those models with a 1.650 in nut [24, 25]. If you have small hands, both numbers matter.

Choosing a fretboard

Let's put it together with the questions I hear most.

"Which wood should I pick?" Pick the one you like to look at and touch. The mechanical differences are real but modest, and I haven't found a measured difference in amplified tone. If you want the hardest-wearing surface, ebony tops the Janka list. If you want a pale board, maple is the one.

"Is a rosewood guitar hard to travel with?" Not since late 2019 for East Indian rosewood, according to NAMM's summary of the CITES change [7]. Brazilian rosewood is a different story.

"What radius should I get?" If you mostly play chords and open-position parts, a rounder board will feel natural. If you bend a lot and like low action, go flatter. If you do both, look at 9.5-10 in or a compound radius, or take Warmoth's view that 10-12 in suits most players [33].

"What about nut width?" Hold a 1.650 in neck and a 1.685 in or 1-11/16 in neck back to back if you can. Hands differ, and this is one spec that's worth trying rather than reading about.

Tone and playability at a glance

Table 5.7: Fretboard changes, rated

Change	What you'll hear	What you'll feel
Rosewood to ebony board	No measured difference in this chapter's sources; see my book *Chasing Tone*	A harder, denser surface; ebony is about 31% harder by Janka
Rosewood to maple board	Same as above: no measured difference in this chapter's sources	Softer wood (lowest Janka here) with a finish on top; feel depends on the finish
Rosewood to Richlite	No measured comparison found	A dense surface; a little more weight than ebony
Roasted maple neck	No measured tone data in these sources	Maker claims better stability against humidity
Rounder radius (7.25 in)	None directly	Comfortable chords; needs more relief and action to bend cleanly
Flatter radius (12-16 in)	None directly	Clean bends at lower action; chords can feel less natural
Compound radius	None directly	Round near the nut, flat up high
Wider nut (1-3/4 in)	None	More room between strings; bigger grip
Narrower nut (1.6-1.650 in)	None	Easier chord grip for small hands; strings closer together

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Chapter 6: Frets

Frets are the metal strips set across the fretboard. When you press a string down behind one, the fret becomes the end of the string's vibrating length, and that sets the note. Every fretted note you play stops on one of these little bars of wire, so their size, their material and how many of them there are all shape how the guitar feels under your fingers.

In this chapter I'll lay out the published sizes for the common fret wires, show you where the makers disagree on those sizes, compare the materials frets are made from, and look at why a 24-fret guitar has its neck pickup in a different spot than a 21-fret one. I'll also cover what frets do and don't do for tone.

Fret anatomy and how sizes are named

A piece of fret wire, seen from the end, looks like a mushroom. The rounded top you touch is the *crown*. The thin leg underneath, which is pressed into a slot in the fretboard, is the *tang*. The tang has little barbs on it that bite into the wood and hold the fret in place.

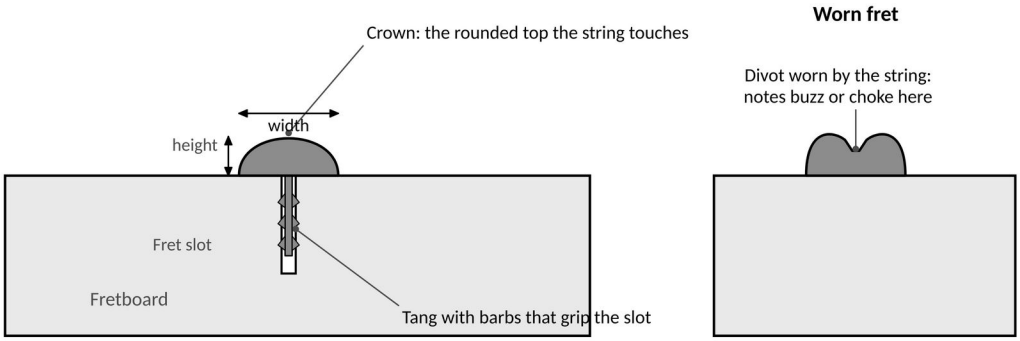


Figure 6.1: The parts of a fret: the crown you play on and the tang that holds it in the slot.

When people talk about fret size, they mean two crown dimensions:

- Crown width: how wide the top is, side to side along the neck.
- Crown height: how far the top stands above the fretboard.

Height is the number you feel most. It decides how far your fingertip has to push the string before it touches the fret, and whether your fingertip touches the wood at all.

Here's a detail that trips people up: makers don't all write those two numbers in the same order. Fender's support page and its buying guide give width first, then height, as in .084 in x .039 in for its vintage wire [1, 2]. But some Fender neck product pages print the same wire with the labels swapped, such as "0.094" (H) x 0.054" (W)" for Narrow Tall [3, 4]. A fret is never taller than it is wide in these sizes, so the first, larger number on those pages is clearly the width. Jescar goes the other way in its part numbers: the number encodes height first, then width. Jescar's 57110 is .057 in high and .110 in wide [5].

Dunlop's Accu-Fret chart is the source for the familiar four-digit numbers like 6105 and 6100 [6]. Its columns are labeled only A through E. By matching them against the sizes Fender publishes for the same wires, column

B lines up with crown width and column E with crown height. That's a cross-check, not a label printed by Dunlop, so I'll treat the Dunlop figures as good but not gospel.

One more thing about published heights: they're for new wire on the spool. StewMac notes that frets lose about .004 in to .010 in of height during installation and leveling [7]. So a fret listed at .055 in tall will usually measure a bit less on a finished guitar.

Size classes in millimeters

Manfred Zollner, in his book *Physics of the Electric Guitar*, groups frets into three classes by the visible crown [8].

Table 6.1: Zollner's fret size classes

Class	Crown width	Crown height	Source
Small / vintage	1-1.7 mm	0.6-0.8 mm	[8]
Medium	1-2.6 mm	0.7-1.1 mm	[8]
Large / jumbo	2.6-3 mm	0.9-1.5 mm	[8]

For a sense of scale, .110 in is about 2.8 mm and .055 in is about 1.4 mm (my conversions), so a typical "jumbo" wire sits right in Zollner's large class.

Fret wire sizes compared

This is the table most players want: one wire number, its size, and what it's called. The catch is that the sources don't fully agree. The same Dunlop number gets slightly different dimensions on Dunlop's chart, on two Fender pages and on Warmoth's options page. Fender itself says sizes "can vary minutely from lot to lot" [1]. So I've put every source's numbers side by side and you can see the range.

Table 6.2: Common fret wires, crown width x crown height (inches), by source

Wire	Dunlop chart [6]	Fender support [1]	Fender article [9]	Warmoth [10]	Closest Jescar size [5]	Common name
6230	.079 x .043	-	.078 x .043	.080 x .037	43080 (.080 x .043)	vintage small
6190	.084 x .039	.084 x .039	-	-	-	Fender vintage
6105	.093 x .059	.094 x .054	.090 x .055	.095 x .047	55090 (.090 x .055)	narrow tall
6150	.100 x .044	.103 x .046	.102 x .042	.104 x .047	47104 (.104 x .047)	medium jumbo
6130	.106 x .036	-	.106 x .036	.106 x .036	39106 (.106 x .039)	vintage wide and low
6110	.115 x .050	-	-	-	51108 (.108 x .051)	wide, medium-high
6100	.110 x .055	.110 x .055	.110 x .055	.118 x .058	57110 (.110 x .057)	jumbo
6000	.118 x .058	-	-	-	58118 (.118 x .058)	super jumbo
6310	.053 x .031	-	-	-	37053 (.053 x .037)	narrow

The "closest Jescar size" column is my own match by dimensions. Jescar doesn't publish a cross-reference to Dunlop numbers [5].

Look at how wide the spread is for the popular sizes:

- 6105 (narrow tall): .090 in to .095 in wide and .047 in to .059 in high, depending on who you ask [6, 1, 9, 10].
- 6150 (medium jumbo): .100 in to .104 in wide and .042 in to .047 in high [6, 1, 9, 10].
- 6100 (jumbo): Dunlop and both Fender pages agree on .110 in x .055 in [6, 1, 9]. Warmoth lists its 6100 "Super Jumbo" as .118 in x .058 in, which is the size Dunlop's chart gives for 6000 [6, 10]. Warmoth also says its Dunlop numbers are approximate [10].

The 6105 height range is the big one. From .047 in to .059 in is a difference of .012 in, about a quarter of the smaller figure (my calculation). On a fret, that is not a small difference. When you're choosing frets for a refret, ask your builder for the actual dimensions of the wire they'll use, not just the number.

What the big makers put on their guitars

Fender is the most open about which wire goes on which guitars, so here's its own list, from its support page and its replacement neck guide.

Table 6.3: Fender fret sizes and where Fender uses them

Fender name	Size (width x height)	Where Fender uses it	Source
Vintage (6190)	.084 x .039 in	vintage-style necks, American Original	[1, 2]
Vintage Tall	.083 x .045 in	American Vintage II 1957 Stratocaster neck	[2, 4]
Narrow Tall (6105)	.094 x .054 in	American Professional, Deluxe, SRV, many Custom Shop models	[1, 2]
Medium Jumbo (6150)	.103 x .046 in	Ultra, Player, Vintera	[1, 2]
Super Jumbo / Jumbo (6100)	.110 x .055 in	Yngwie Malmsteen Stratocaster	[1, 2]

Fender's article on fret sizes also lists 6230 at .078 in x .043 in as a size found on older Fenders, and 6130 at .106 in x .036 in [9]. Warmoth describes its 6130-class wire as "similar to many vintage Gibson necks" and its 6150-class wire as "similar to modern Fender" [10].

StewMac sells its own wire in three width families. Its medium wire runs .080 in to .095 in wide and its wide wire .100 in to .110 in, and its narrow wire is listed at .053 in to .080 in, though that page doesn't say which dimension the range describes [7, 11, 12]. StewMac calls its Medium/Medium #0148 the "most popular wire for refretting Martin, Fender, Guild, and Gibson," and its Wide/Highest #0150 is the one it says is "used on ESP, Jackson, Ibanez, Kramer and similar guitars" [7, 11]. StewMac defines "high" wire as a crown height of .045 in or more and says its wide wire fits a 0.023 in (0.58 mm) slot [7]. It doesn't publish a height for each profile, so I can't put those in the table.

Jescar's catalog at a glance

Jescar publishes a long list of crown sizes, which is handy for seeing the whole range in one place [5].

Table 6.4: Selected Jescar fret wire sizes (crown width x height, inches)

Jescar number	Width x height	Stainless version listed	Source
37053	.053 x .037	no	[5]
37080	.080 x .037	yes	[5]
43080	.080 x .043	yes	[5]
47095	.095 x .047	yes	[5]
47104	.104 x .047	yes	[5]

Jescar number	Width x height	Stainless version listed	Source
50085	.085 x .050	no	[5]
51100	.100 x .051	yes	[5]
51108	.108 x .051	yes	[5]
55090	.090 x .055	yes	[5]
57110	.110 x .057	yes	[5]
58118	.118 x .058	yes	[5]

Jescar lists tang widths from .0195 in to .0250 in, with most at .0200 in [5]. The tang has to match the slot in the fretboard, which matters more to the person doing the refret than to the player.

How fret size feels

Tall frets

With a tall fret, your fingertip pushes the string down onto the fret before it reaches the wood. Fender says jumbo 6100 wire can make for "easier playability" and easier bending because it takes less pressure [9]. Warmoth goes further and says its super jumbo wire gives an "almost scalloped feel similar to many Ibanez necks" [10]. (Scalloping comes up later in this chapter.)

The trade-off is pitch. Zollner points out that with taller frets "the strength and position of the fingering can have a small effect on the pitch" [8]. Press harder and you stretch the string down further toward the wood, which pulls it sharp. If you have a heavy hand, tall frets can make your chords drift a little sharp. A lighter touch fixes it, but it's something to know before you order the tallest wire you can find.

You might ask, "So should I just get tall frets?" Not necessarily. Fender itself says fret size "is purely a matter of preference" [9]. Tall wire suits players who bend a lot and like a light touch. It's less friendly to players who grip hard.

Low and wide frets

Low, wide wire like 6130 puts the string close to the wood. Fender says the lower frets (6130, 6150, 6230) suit players who like to feel the fretboard under their fingers [9]. The flip side, as I read Fender's description, is that your fingertip is in contact with the board as you bend, and that adds a little drag. Some players love that grounded feel. Others find it slows them down.

Wide versus narrow crowns

Width works more quietly. A narrow crown, like 6105 or the Fender vintage wire, gives a small contact point for the string. A wide crown, like 6100 or 6150, gives your fingertip a broader top to slide across. I haven't found anyone who measured the difference in feel between widths at the same height, so I'll leave it at that and let your hands decide.

Evenness beats size

If I could stress one point about frets, it's this: their size matters less than whether they're level with each other. Zollner shows that a single fret standing just 0.1 mm (about .004 in) too high spoils the note at the fret before it [13]. A guitar with perfectly leveled medium frets will play better than one with uneven jumbos every time. Leveling a full set of frets is a job for a tech. The second edition of my guitar maintenance book shows how to spot high or worn frets, how to fix a single high fret (Chapter 17), and when to hand the guitar over.

Where the frets are placed

Size and height get all the attention, but a fret also has to be in the right place along the neck. Modern fret positions come from an exact formula based on twelve equal steps per octave (Chapter 4 goes into it in more detail). R.M. Mottola explains that this formula doesn't pile up small errors from fret to fret. He calls the old "Rule of 18" shortcut old-fashioned, notes that it doesn't even put the 12th fret at half the scale, and says modern instruments don't use it [14]. Zollner gives a measurement tolerance for fret positions of about ±0.05 mm (about .002 in) [15]. He also reports that two Gibson guitars he measured strayed noticeably from the exact positions in the higher registers, though they stayed within tolerance of the older Rule of 18, while the Epiphone, Taylor and Martin guitars he checked were more precise [15]. That's two guitars, not a survey, so I wouldn't read it as a verdict on any brand. It's a reminder that "in tune up the neck" depends on the slots as well as the wire.

Fret materials

Nickel silver

Almost every electric guitar ships with nickel silver frets. Despite the name, the published recipes contain no silver at all. They're copper, nickel and zinc.

Zollner says fret alloys typically use about 12% nickel for classical guitars and 18% for electric guitars, and that nickel and zinc are what add hardness to the copper [16]. Alloys with more than 30% nickel, which look silver-white, aren't used for frets [16]. Dunlop's chart marks most of its guitar wire "18% N/S Hard," with a few sizes in "18% N/S Soft," a few in 12% nickel silver, and one size (6180) in brass [6].

How much copper and zinc? That depends on which alloy a maker buys, and Dunlop doesn't say. Luthier Paul Hostetter gives Jescar's nickel silver formula as 62% copper, 18% nickel and 20% zinc [17]. The standard alloy C77000, sold by Wieland as N17, is 55% copper, 18% nickel and about 27% zinc [18, 19]. Another 18% alloy, C75200, is about 65% copper, 18% nickel and the rest zinc [20]. All three hold the nickel near 18%. The copper and zinc trade places.

Stainless steel

Stainless steel is the main alternative. Strandberg's Boden Standard NX, for instance, lists 24 stainless steel frets [21]. Jescar offers stainless versions of ten of its sizes, marked with an "-S" suffix [5]. StewMac sells stainless in Medium/Medium, Medium/Higher and Wide/Highest [22].

None of the stainless pages I read named the steel grade.

EVO and gold-colored wire

Jescar's EVO wire is a gold-colored alloy sold as nickel-free and hypoallergenic, which matters if you have a nickel allergy. Hostetter calls it "Jescar's proprietary nickel-free hypoallergenic alloy" and notes it "contains no gold either" [17]. StewMac's own Gold fretwire is made "primarily of C425 copper alloy," is nickel-free, and StewMac describes it as harder than nickel silver and "similar in hardness and composition to Jescar EVO wire" [23].

Where does EVO sit on durability? The sources disagree a little. A retailer listing says EVO is "harder than nickel wire but softer than stainless steel" [24]. Hostetter calls EVO "the most durable fretwire I know of" [17].

Neither one gives a number. I'd read it this way: EVO is clearly tougher than nickel silver, and whether it outlasts stainless isn't settled by these sources.

Brass and bell brass

Brass shows up in Dunlop's chart as wire 6180 [6]. Zollner describes bell brass as roughly 77-80% copper with the rest tin, with hardness similar to nickel silver [16].

Hardness compared

Vickers hardness (HV) is a lab measure: a diamond point is pressed into the metal and the size of the dent is measured. A higher HV means a harder metal that resists dents and wear. Here are the only fret hardness figures I found, and where they come from.

Table 6.5: Fret materials, composition and hardness as published

Material	Composition as published	Hardness as published	Source
Nickel silver, 18%	Jescar NS: 62 Cu / 18 Ni / 20 Zn (per Hostetter); C77000: 55 Cu / 18 Ni / 27 Zn	Warmoth's wire: HV 170; C77000 alloy: about HV 90-250 depending on temper	[17, 18, 10]
Nickel silver, 12%	12% Ni	not published	[6, 16]
Brass / bell brass	bell brass about 77-80 Cu, rest Sn	similar to nickel silver (bell brass)	[6, 16]
EVO / gold (Jescar, StewMac Gold)	proprietary, nickel-free; StewMac's version is C425 copper alloy	between nickel silver and stainless (retailer, no number)	[17, 23, 24]
Stainless steel (Jescar)	grade not published	Warmoth: HV 300 ±20	[10]

Warmoth is the only maker or seller I've found that publishes fret hardness numbers. It lists its 18% nickel silver at HV 170 and its German-made Jescar stainless at HV 300, plus or minus 20 [10]. By those figures, the stainless is roughly 1.75 times as hard (my calculation). Wieland's datasheet for its CuNi18Zn27 nickel silver lists hardness figures from about HV 90 to about HV 250 across its tempers, so "nickel silver" isn't one fixed hardness [18].

Do fret materials change tone?

Warmoth states that it finds no discernible tone difference between its nickel silver and stainless frets [10]. StewMac says some players "hear a slightly brighter tone" from stainless [22]. Neither one offers a measurement. I haven't found a controlled test that settles it. If there's a difference, it's small, and it's a long way behind pickups, setup and amp in importance. I look at the listening side of it in my book *Chasing Tone*.

What material does to feel and upkeep

The material choice is really about wear and feel. Stainless is "slow to wear or develop grooves," in StewMac's words [22], and Warmoth says it lasts much longer between levelings but takes longer to level when the time comes [10]. Hostetter warns that stainless "eats normal tools fairly fast" [17]. Zollner notes steel frets are newer and that "No problems or issues have been reported" [16]. So stainless costs more in shop time up front and saves trips to the shop later.

How many frets: 21, 22 or 24

The counts

The original Stratocaster and Telecaster necks had 21 frets [25]. StewMac lists the Fender 25.5 in scale with 21 frets for vintage models and 22 for modern ones [26]. PRS builds 22- and 24-fret versions on its 25 in scale [26]. The Fender Yngwie Malmsteen Stratocaster keeps 21 frets, and the little Squier Mini Stratocaster has 20 [27, 28]. Fender's history of the Mustang adds another data point: the Mustang came out in August 1964 as a 22-fret guitar on a 24 in scale, and "a very few" 21-fret short-scale versions were built as well [29].

Adding frets isn't free, because they have to go somewhere. Warmoth explains that a 22-fret neck overhangs the end of the neck heel by about 1/4 in and usually needs no change to the body [25]. A 24-fret neck overhangs by about 1.062 in, and that extension "interfere[s] with standard neck pickup placement," so the neck pickup rout has to move toward the bridge [25].

Where the frets land

Using the standard fret position formula (Chapter 4 walks through it), the distances from the nut work out like this [14]. These are my calculations from Mottola's formula, not published specs.

Table 6.6: Distance from nut to the last frets (computed)

Scale length	Nut to 22nd fret	Nut to 24th fret	Extra length from 22 to 24 frets	Source
24.75 in	17.805 in	18.562 in	0.757 in	computed from [14]
25.5 in	18.344 in	19.125 in	0.781 in	computed from [14]

On a 25.5 in scale, those two extra frets push the end of the board about 0.78 in closer to the bridge. That's the space the neck pickup used to have.

The 24th fret and the neck pickup

There's a neat bit of math here, and a common mix-up to clear away.

First, two terms. A vibrating string doesn't just swing as one big arc. It also vibrates in halves, thirds, quarters and so on, all at once. Each of those patterns is a *harmonic*. Each harmonic has *nodes*, points along the string that stay still for that pattern. The 2nd harmonic (one octave above the open note) has its node at the middle of the string. That's the 12th fret, half the scale length from the bridge.

The 24th fret sits two octaves above the nut. By the fret formula, the string length from the 24th fret to the bridge is one quarter of the full scale [14]. That spot is a node of the 4th harmonic, the one two octaves up. It is not a node of the 2nd harmonic. You'll sometimes hear that a 24-fret neck puts the pickup "on the octave node." That's not right: the octave node is at the 12th fret, and the 24th-fret spot is a quarter of the scale from the bridge.

Why care? A pickup hears each harmonic according to how much the string is moving right above it. Zollner describes pickup position as working like a comb filter: it cuts certain frequencies, and where those cuts land depends on how far the pickup is from the bridge [30]. Move the neck pickup toward the bridge, as a 24-fret guitar has to, and those cuts move. In plain words, a neck pickup on a 24-fret guitar sits a little closer to the bridge and so hears the string a little differently than a neck pickup on a 21-fret guitar (Chapter 14 goes into pickup position in detail).

Will you hear the difference? Probably some, between the same pickup at the two spots. But I haven't found a measured comparison of 22- versus 24-fret neck pickup tone on real guitars, so I won't put a size on it.

Playability of extra frets

Two extra frets give you a full two octaves on each string, which some players need. They also mean the upper frets get very close together and sit close to the body, so reaching them depends a lot on how the neck joins the body and how deep the cutaway is (see Chapter 3).

The frets also get much closer together up there. Using the same formula, on a 25.5 in scale the gap from the nut to the 1st fret is 1.431 in, while the gap between the 21st and 22nd frets is only 0.425 in. On a 24.75 in scale those figures are 1.389 in and 0.413 in (my calculations from Mottola's formula) [14]. That's less than a third of the space, so fingertips that fit easily between the low frets get crowded at the top.

Scalloped fretboards

A scalloped fretboard has the wood scooped out between the frets. Fender's Yngwie Malmsteen Stratocaster is one production example. Fender describes its board as "scooped out between the frets" so the fingers touch only the strings, and says this helps speed, a lighter touch and bending [28]. That guitar pairs the scalloping with 21 super jumbo frets, a 9.5 in radius, a 1.650 in nut and a brass nut [28].

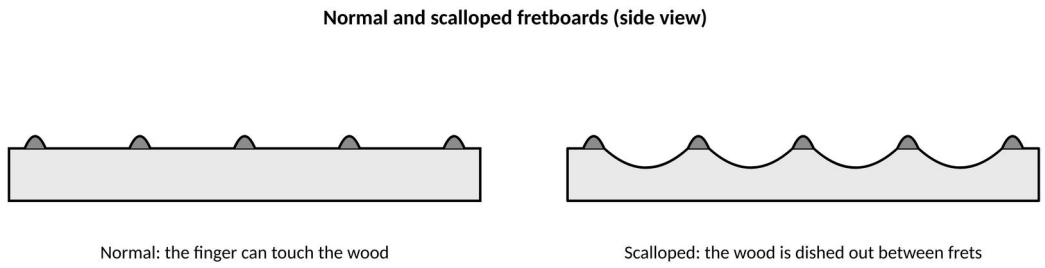


Figure 6.2: On a scalloped board the wood between the frets is dished out, so the fingertip touches only the string and the fret.

Scalloping does on purpose what very tall frets do partway. Your fingertip never touches wood, so there's no drag, but the pitch becomes very sensitive to how hard you press, for the same reason Zollner gives for tall frets [8]. That's why Warmoth describes super jumbo wire as giving an "almost scalloped" feel [10]. If you're curious about scalloping, a set of tall frets is a cheaper, reversible way to get a taste of it.

Choosing frets

If you're ordering a neck or a refret, here's how I'd think it through.

"Do I bend a lot?" Taller wire, such as the 6100 jumbo, takes less pressure and makes bends easier, according to Fender [9]. If you have a heavy grip, try them before you commit, since tall frets make pitch more sensitive to pressure [8].

"Do I like to feel the wood?" Then lower wire, like 6130, 6150 or 6230, is the place to look [9].

"Do I want to avoid another refret for a long time?" Stainless lasts much longer between levelings, by Warmoth's account, and EVO-type gold wire sits between nickel silver and stainless by the accounts in this chapter [10, 24].

"Am I allergic to nickel?" Then EVO or a gold-colored nickel-free wire is the one to ask about [17, 23].

And whatever you pick, ask for the actual crown width and height, not just a part number. Table 6.2 shows why.

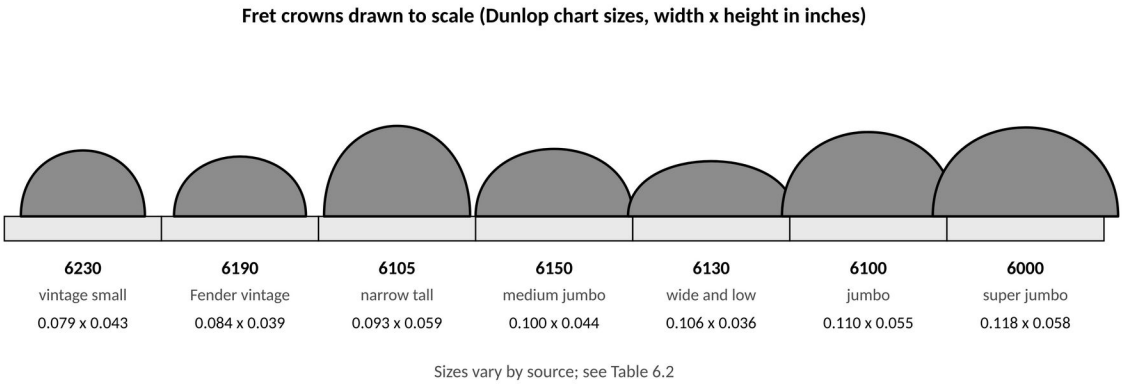


Figure 6.3: Common fret wires drawn to the same scale from the Dunlop chart sizes in Table 6.2.

Tone and playability at a glance

Table 6.7: Fret changes, rated

Change	What you'll hear	What you'll feel
Vintage (6190/6230) to jumbo (6100)	Little or no audible change	Less pressure to fret, easier bends; pitch more sensitive to a heavy grip
Medium jumbo (6150) to narrow tall (6105)	Little or no audible change	A little taller (heights vary by source), narrower top
Low wide (6130) frets	Little or no audible change	You feel the board; bends can drag a bit
Nickel silver to stainless	No discernible change per Warmoth; "slightly brighter" to some ears per StewMac	Much slower wear; harder to level when the time comes
Nickel silver to EVO / gold	No measured data	Nickel-free; wears slower than nickel silver
Uneven frets leveled	Notes stop buzzing or dying	The single biggest fret improvement you can make
21 or 22 to 24 frets	Neck pickup moves toward the bridge, which shifts its sound somewhat	Two more notes per string; a longer board
Scalloped board	Little or no audible change	No board contact; very touch-sensitive pitch

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Chapter 7: The Nut

The nut is the small notched bar at the headstock end of the fretboard. Every string passes through a slot in it on the way to its tuner. It's one of the cheapest parts on the guitar and one of the easiest to get wrong, and when it's wrong you feel it right away: notes in the first few frets go sharp, open strings buzz, or the guitar won't come back in tune after a bend.

In this chapter I'll cover what the nut actually does, what it's made of on current guitars, what the makers say about those materials (and what nobody has measured), the slot targets StewMac publishes, and the special nuts built for tremolo guitars. Cutting and fitting a nut is shop work. The second edition of my guitar maintenance book shows how to check nut height, how to lower a high slot carefully (Chapter 18), and when to take it to a tech. Here I'll give you the numbers and the reasons behind them.

What the nut does

The nut has three jobs.

It ends the vibrating length of every open string. When you play an open string, the string vibrates between the nut and the bridge saddle. When you fret a note, the fret takes over that job and the nut is out of the picture.

It spaces the strings across the neck, which sets how far apart they sit under your fingers in first position.

It sets how high the strings sit over the first few frets. That height decides how hard you have to press near the nut, and whether those notes play in tune.

That first job is worth thinking about for a second. The nut only touches the sound of open strings. Any effect a nut material has on tone is limited to those notes. Play a fretted note and the nut isn't part of the vibrating string at all.

Blank sizes

Nuts start life as blanks. StewMac's sizing sheet for its slotted bone nuts gives the dimensions of its Fender-style and Gibson-style blanks [1].

Table 7.1: StewMac slotted bone nut blanks

Style	Length	Height	Thickness	Low E to high E spacing	Source
Fender (#6001-VS to #6003-VS)	1-45/64 in (43.26 mm)	15/64 in (5.95 mm)	1/8 in (3.18 mm)	1-13/32 in (35.72 mm)	[1]
Gibson (#6012-VS, #6013-VS)	1-45/64 in (43.26 mm)	21/64 in (8.33 mm)	3/16 in (4.76 mm)	not given	[1]

Notice two things. The Gibson nut is thicker and taller than the Fender one. And at 1-45/64 in (about 1.703 in, my conversion), both blanks are a little longer than the common 1.650 in to 1.695 in factory nut widths in Chapter 5, so they get trimmed to fit the neck.

StewMac's rule of thumb for string spacing puts the two outer E strings about 1/16 in in from each end of the first fret [2].

The nut also has to match the width of the neck it sits on, and Chapter 5 lists the common widths. Warmoth offers necks with nuts from 1-5/8 in (41 mm) up to 1-7/8 in (48 mm), and calls 1-11/16 in "the standard nut width" [3]. A replacement nut is chosen to fit that width, which matters most for locking and roller nuts, since those come in fixed sizes.

Nut materials

What the factories use

Current models list these nut materials on their makers' spec pages.

Table 7.2: Factory nut materials on current models

Model	Nut material	Source
Fender American Professional II Stratocaster	bone	[4]
Fender American Vintage II 1957 Stratocaster	bone	[5]
PRS Silver Sky	bone	[6]
PRS McCarty 594	bone	[7]
Squier Classic Vibe Baritone Custom Telecaster	bone	[8]
Fender Player II Mustang and Player II Jaguar	synthetic bone	[9, 10]
Squier Mini Stratocaster	synthetic bone	[11]
Fender 75th Anniversary Player II Baritone Telecaster	synthetic bone	[12]
Fender American Ultra II Stratocaster	Graph Tech TUSQ	[13]
Gibson Les Paul Standard 50s, SG Standard, Les Paul Modern Figured	Graph Tech	[14, 15, 16]
Gibson Custom Les Paul Custom and Les Paul Custom Long Scale	Corian	[17, 18]
Fender Yngwie Malmsteen Stratocaster	brass	[19]
Ibanez PWM20	locking nut	[20]

So bone, synthetics and a few oddballs. There's a pattern in Fender's lineup: the American Professional II and American Vintage II list bone, the Player II models and the Squier Mini list synthetic bone, and the American Ultra II uses Graph Tech TUSQ [4, 5, 9, 10, 11, 13]. Gibson's production models list Graph Tech, while its Custom Shop Les Paul Customs use Corian [14, 15, 16, 17, 18]. So a nut that isn't bone isn't automatically a sign of a cheaper guitar. Let's go through what each one is and what's claimed for it.

Bone

Bone is the most common material in Table 7.2. A StewMac article by Erick Coleman prefers it, saying "a well made bone nut gives bright, resonant tone" [21]. It also says unbleached bone is denser and slightly brighter than bleached bone, and that a well-slotted bone nut on a tremolo guitar does better than one made of Micarta [21]. Those are the opinions of a very experienced repairman, but they aren't measurements.

TUSQ and Black TUSQ XL

TUSQ is Graph Tech's synthetic. Graph Tech describes it as a "high-performance synthetic" made from organic polymers under heat and pressure, and claims it has uniform density with no grain or soft spots, and produces

more mid and high harmonics than bone [22]. Graph Tech's page gives no measured numbers to back the harmonic claim.

Black TUSQ XL is the slippery version. Graph Tech calls it "permanently lubricated," claims "improved tuning stability," and says it introduced "the world's first self-lubricating nut in 1983" [23]. Warmoth describes TUSQ XL as "Teflon-impregnated" and repeats a claim that Teflon is "500% slipperier than graphite" [24]. Graph Tech's own page, as I read it, doesn't name Teflon or PTFE, so the composition comes from Warmoth, not the maker.

Brass, nickel silver and Corian

Warmoth sells several other nut materials and describes their sound. These are seller descriptions [24]:

- Brass: bright, with good sustain; recommended for bass and slide.
- Nickel silver: "very bright."
- Corian: "balanced, clear, even."

Corian is what Gibson Custom lists on its Les Paul Custom models [17, 18]. Brass is what Fender fits to the Yngwie Malmsteen Stratocaster [19].

Plastic

StewMac describes plastic nuts as suited to "high-speed, affordable repairs" on inexpensive guitars [25]. That's where they belong.

The claims, side by side

Table 7.3: Nut material claims and who makes them

Material	Claimed sound or benefit	Who claims it	Type of source	Source
Bone	"bright, resonant tone"; unbleached denser and slightly brighter	StewMac (Erick Coleman)	repair supplier's opinion	[21]
TUSQ	uniform density, no soft spots, more mid and high harmonics than bone	Graph Tech	maker claim	[22]
Black TUSQ XL	permanently lubricated, better tuning stability	Graph Tech	maker claim	[23]
Black TUSQ XL	"Teflon-impregnated," good for heavy tremolo use and bends	Warmoth	seller description	[24]
Brass	bright, good sustain; for bass and slide	Warmoth	seller description	[24]
Nickel silver	very bright	Warmoth	seller description	[24]
Corian	balanced, clear, even	Warmoth	seller description	[24]
Plastic	quick, low-cost repairs on inexpensive guitars	StewMac	repair supplier's opinion	[25]

What hasn't been measured

I looked for a measured comparison of nut materials on electric guitars, the kind where the same guitar is recorded with a bone nut, then TUSQ, then brass, under controlled conditions. I didn't find one. Every tone statement in Table 7.3 is a maker's or seller's description.

So what can we say? Two things. First, the nut only terminates open strings, so whatever a material does, it can only do it on open notes. Second, the things that clearly do matter, slot height, slot width and break angle, are about how the nut is cut, not what it's cut from. I'd take a well-cut plastic nut over a badly cut bone nut any day. I'd choose a nut material for how it wears, how slippery it is and how easy it is to cut cleanly, and treat the tone claims as a tiebreaker at most. My book *Chasing Tone* goes further into the listening side.

Slot height

Why it matters

Slot height is how deep each string sits in the nut, which sets how high it sits over the first fret. If your action is good at the 12th fret, why do the first few frets feel stiff? Usually it's the nut. If the slots are too high, you have to push the string a long way down to reach the first fret, which takes more effort and stretches the string, so notes in first position play sharp. If the slots are too low, the open string buzzes against the first fret [26, 27, 2].

The numbers

StewMac publishes targets in a few different articles, and they line up well.

Table 7.4: Nut slot height targets

Measure	Target	Source
Rough cut: slot bottom above the first fret's height	about .030 in (example: .040 in fret gives .070 in total)	[2]
Finished clearance over the first fret, low E	about .020 in (about 0.51 mm)	[2]
Finished clearance over the first fret, high E	about .010 in (about 0.25 mm)	[2]
Feeler-gauge method	fret height plus .005-.010 in, adding about .002 in moving toward the bass side	[26]
Capo check	gap over the first fret one to two times the gap over the second fret, with a capo at the first fret	[27]
String to first fret, measured (Zollner's examples)	0.3 mm (E4), 0.4-0.5 mm (E2)	[28]

The metric conversions of StewMac's figures are mine. Notice that Zollner's example gaps, 0.3 mm on the high E and 0.4-0.5 mm on the low E, are close to StewMac's finished targets: 0.3 mm is about .012 in and 0.4-0.5 mm is about .016-.020 in (my conversions) [28, 2]. A repair supplier and a physicist land in about the same place. That's reassuring.

The pattern in every source is the same: the bass strings get a bit more clearance than the treble strings.

> **Caution:** Nut slots can only be cut deeper, not shallower, without shimming or a new nut. If you're tempted to file your own, read the nut check in my guitar maintenance book first, and practice on spare nuts before

you touch the one on your guitar.

Slot width and depth

A slot also has to be the right width. StewMac says a slot up to .004 in wider than the string is fine [27]. Too narrow, and the string binds. StewMac's clue for a binding string is "a little ping sound" as you tune [27]. A binding string sticks in the slot, so tension doesn't even out on both sides of the nut, and the string can return slightly out of tune after a bend.

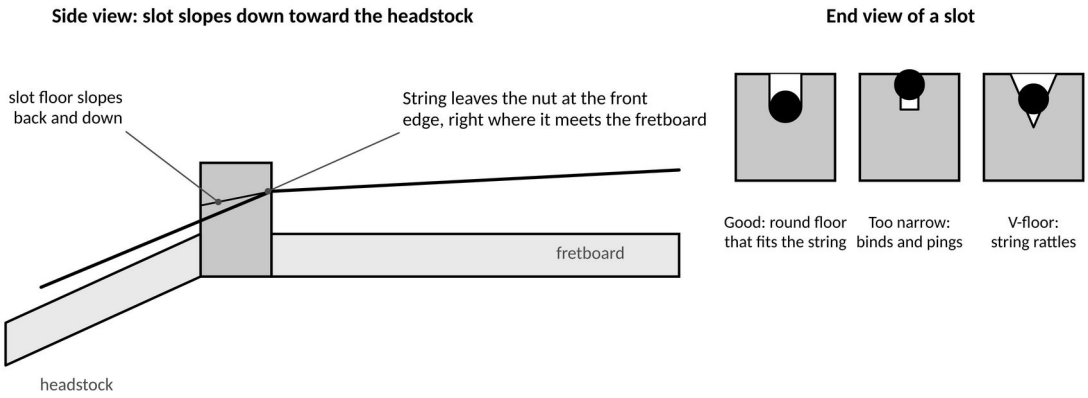


Figure 7.1: A good nut slot slopes down toward the headstock and has a rounded floor that fits the string.

How deep should the string sit inside the slot? Here StewMac's articles differ slightly. One says the top of the nut should sit about half the diameter of the thickest string above the slot bottoms [2], and another says about half the wound string's diameter should sit above the nut top [27]. The feeler-gauge article puts it at about one third of the string above the nut top [26]. These all describe a fairly shallow slot, where the string is partly exposed. A slot that buries the string is more likely to grab it.

Break angle

The *break angle* is the angle the string bends through as it passes over the nut and heads down to the tuner post. It's what holds the string down firmly in the slot. StewMac recommends cutting the back of each slot as a ramp that falls toward the headstock, as shallow as about 6 degrees and no steeper than 12-15 degrees, or matched to the headstock angle [2]. If the string has too shallow a break angle and isn't held down firmly at the front edge of the slot, StewMac says you'll hear a "muted drone-like sound," a bit like a sitar [27].

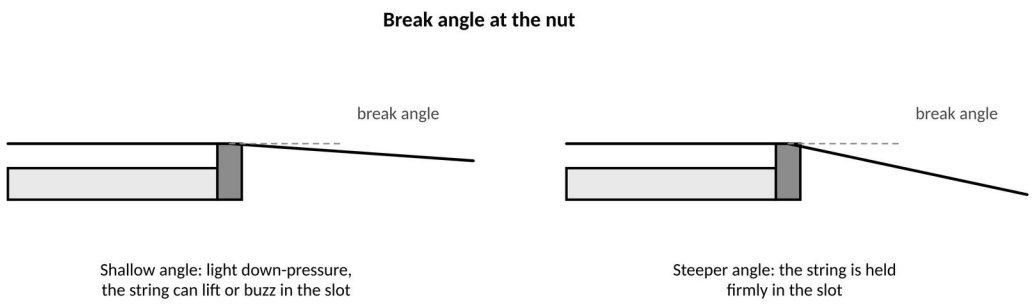


Figure 7.2: Break angle is the bend the string makes over the nut on its way to the tuner. More angle holds the string more firmly in the slot.

The headstock, the tuner posts and any string trees (more on those in Chapter 10) all help set that angle.

Roller nuts, locking nuts and other special nuts

Roller nuts

A roller nut replaces the slots with small rollers so the string can move through the nut as the tension changes. Warmoth sells the LSR roller nut and says its ball bearings "ease string movement and improve tuning stability" [24]. Warmoth says it needs a 1-11/16 in nut width and a radius of 9-11 in or a 10-16 in compound radius [24].

Locking nuts

A locking nut clamps the strings in place at the nut. Once the strings are clamped, nothing past the nut can slip, so the tuners are taken out of the tuning-stability problem. It's paired with a locking tremolo, which is the subject of Chapter 9. The Ibanez PWM20 is one current example [20].

Floyd Rose sells its locking nuts in a range of sizes: R2 and R3 for its 1000 Series and Special models, and R1 through R10 for its Original line [29, 30]. The mounting holes on its Original nut are .535 in (13.59 mm) apart, center to center [30]. The widths below come from Warmoth.

Table 7.5: Floyd Rose locking nut sizes (as listed by Warmoth)

Size	Nut width	Notes	Source
R2 / L2	1-5/8 in		[24]
R3 / L3	1-11/16 in	narrow string spacing	[24]
R4 / L4	1-11/16 in	wide string spacing	[24]
R5 / L5	1-3/4 in		[24]

Warmoth lists a 10 in radius for the Floyd Rose nut it sells and says it suits fretboards from 9 to 12 in [24]. Floyd Rose nuts come in more than one radius, though (Chapter 9 lists a 12 in R3), so check the size you're buying. That's worth checking before you fit one to a vintage 7.25 in board.

Compensated nuts

Warmoth also offers the Earvana compensated nut [24]. I have no published specs for it, so I'll leave it at a mention.

Zero frets and the ZerO Glide

A *zero fret* is a fret placed right where the nut would be, with a separate slotted guide behind it that only spaces the strings. The open string then stops on a fret, just like a fretted note. StewMac sells the ZerO Glide, a replacement nut that adds zero-fret behavior to a regular guitar, and the claims made for it are stronger, more resonant open strings and better tuning stability [31]. No data comes with those claims.

Should you upgrade your nut?

You might ask, "My guitar has a synthetic nut. Should I swap it for bone?" This is how I'd decide.

If the guitar plays in tune in first position, the open strings don't buzz, and it comes back to pitch after bends, the nut is doing its job. Swapping the material would change only the open strings, and the tone claims for each material aren't backed by any measurements I've found. I'd leave it alone.

If notes in the first few frets are sharp, or first position feels stiff, the slots are probably too high [26, 27, 2]. That's a cutting problem, not a material problem, and it can often be fixed on the nut you already have.

If the guitar pings while tuning or drifts after bends, look at slot width and smoothness first [27]. If you use a tremolo hard and a well-cut slot still isn't enough, that's when a self-lubricating material, a roller nut or a locking system makes sense [23, 24].

If the nut is cracked, chipped, or cut too low, it needs replacing. At that point, pick whatever material you like. Just make sure whoever cuts it hits the numbers in Table 7.4.

Tuning stability

Put the pieces together and you can see how the nut affects tuning. A string that sticks in its slot holds some tension on one side of the nut. Bend a note or use the tremolo, and the string slips through and doesn't slip all the way back, so it ends up a little out of tune. Every special nut in this chapter attacks that problem from a different angle [24, 27, 23]:

- A well-cut slot that's wide enough, smooth, and not too deep.
- A slippery material, such as Black TUSQ XL.
- Rollers that let the string move freely.
- A locking nut that stops the string from moving at all.

I'd fix the first one before buying any of the others. When a guitar won't stay in tune, the nut slots are the first place I'd look.

Tone and playability at a glance

Table 7.6: Nut changes, rated

Change	What you'll hear	What you'll feel
Plastic to bone	Open strings only; no measured comparison found	No change if both are cut well
Bone to TUSQ or Black TUSQ XL	Open strings only; maker claims, no measurements found	Smoother string travel with XL, per the maker
Bone to brass	Open strings only; seller calls brass bright	No direct change
Slots lowered from too high to correct	First-position notes stop going sharp	Easier fretting near the nut

Change	What you'll hear	What you'll feel
Slots cut too low	Open strings buzz	No improvement; the nut needs replacing or shimming
Binding slot widened	Fewer out-of-tune returns after bends	Smoother tuning, no "ping"
Shallow break angle corrected	Sitar-like drone on open strings goes away	No direct change
Roller or locking nut	Little or no audible change	Better tuning stability with tremolo use

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Part 2: The Hardware

Chapter 8: Bridges, Saddles and Tailpieces

The bridge is where the string's speaking length ends. Everything from the nut to the saddle vibrates. Everything behind the saddle is just anchoring. That sounds simple, but the bridge decides a lot about how the guitar plays: where each string sits sideways, how high it rides over the frets, how close you can get each string to perfect intonation, and how the guitar feels under the side of your picking hand.

This chapter covers fixed bridges, the ones that don't move when you play. Tremolo bridges get their own chapter (Chapter 9), though some spacing numbers from Strat tremolos show up here so you can compare. I'll give you the maker numbers and show you where the makers disagree with each other. One thing up front: there is a lot of tone talk about bridge materials and very little measured data behind it.

Now and then a guitar comes to a bench with tuning trouble blamed on the tuners when the real cause is a burr in the saddle or a poorly set saddle. It is not common, but it happens. The bridge is where string vibration passes into the body, so small flaws there show up everywhere.

What a bridge has to do

A bridge has a few jobs. It anchors the strings, or hands that job to a separate tailpiece. It holds the **saddles**, the small parts the strings actually rest on. Each saddle is the end point of a string's vibrating length. It sets the string spacing at the bridge end. And it lets you adjust height and intonation.

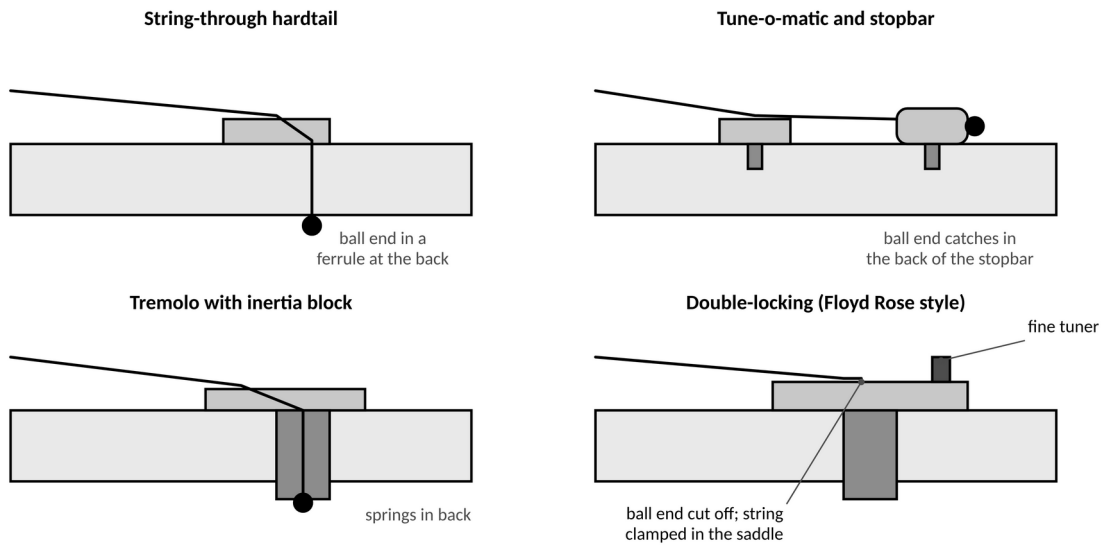


Figure 8.1: Common electric bridge types, seen from above.

Intonation means how well the guitar plays in tune as you go up the neck. You set it by moving a saddle forward or back until the note at the 12th fret matches the open string an octave higher. The amount a saddle sits behind the "theoretical" scale length is called **compensation**. Every string needs a slightly different amount, which is why a bridge with one saddle per string gives you the most control.

Break angle is the angle the string makes as it bends over the saddle on its way to the anchor point. Too little and the string can skip or rattle on the saddle. Plenty of sources talk about break angle, but I could not find a maker that publishes a number for it.

String spacing at the bridge is usually given as the distance from the center of the low E string to the center of the high E string, "E to E." Some makers give it per string instead, the gap between neighboring strings. Multiply a per-string figure by five and you get E to E for a six-string.

You might ask, "Why should I care about a couple of millimeters of spacing?" Spacing decides whether the outer strings line up with the pickup pole pieces, how close those strings run to the edge of the fretboard, and how much room your picking hand has between strings [1, 2]. Swap to a bridge with different spacing and all three change.

Hardtails and fixed plates

A **hardtail** is a fixed bridge on a guitar that could have had a tremolo, usually a Strat-style body. The strings pass through the body or anchor in the bridge plate, and the bridge is screwed down flat.

Hipshot is a good example because it publishes real dimensions. Its 6-string fixed bridge is a solid machined brass base plate with side walls and stainless steel saddles, and it loads string-through [3]. Hipshot offers two "floor heights," meaning how high the base plate sits off the top: 0.125" for guitars with a non-angled neck and 0.175" for guitars with an angled or raised neck [3]. That number matters more than it looks. If the neck angle and the bridge height don't match, you can run out of saddle travel before you reach a comfortable action, so check floor height against your neck angle before you order a fixed bridge.

Hipshot's bent-plate style hardtail comes in two string spacings, .430" (11 mm) or .446" (11.5 mm) per string, in stainless steel [4]. Five gaps of .430" gives about 2.15" E to E, and five of .446" gives about 2.23" (my arithmetic). Hipshot's drawing for its 7-string fixed bridge lists a 0.125" floor, a string height range of 0.30-0.46" from the bottom of the string to the guitar's face, and a weight of 5.04 oz with hardware [5]. A published height range like that is handy, since it tells you before you drill whether the bridge can reach your action.

The Telecaster bridge: three saddles or six

The classic Tele bridge is a steel plate with raised sides, often called an "ashtray," with three saddles. Each saddle carries two strings. The modern alternative uses six saddles. Both styles on the Fender and StewMac parts I looked at are string-through, meaning the strings feed from the back of the body up through the plate [6, 7, 8].

The 3-saddle "ashtray"

StewMac publishes the fullest numbers. Its Traditional 3-Saddle Bridge has a string spread of 2-1/8" (53.97 mm), three brass saddles that are unplated and ungrooved, and a stamped steel plate that measures 3-5/16" x 3" (84.14 x 76.20 mm) [8]. It mounts with four screws spaced 2-9/16" (65.09 mm) center to center and weighs 0.229 lb (0.10 kg) [8]. StewMac also warns that putting it on a guitar that had a modern American Standard Tele bridge "will require additional drilling" [8]. So "Tele bridge" is not one standard footprint.

Fender's own American Vintage 3-saddle bridge has four mounting screws and a plate stamped "Fender Pat. Pend." [6]. The product page contradicts itself on the saddles: the feature list calls them late-'50s stainless steel saddles, while the product title says chromed brass [6]. I can't settle that from the page, so I'm telling you both. If saddle material matters to you, ask the seller before you buy.

The playability catch with three saddles is intonation. Each saddle has to serve two strings, so the length you set is a compromise for the pair. Callaham, which makes Tele bridges, goes further and says uncompensated Fender saddles "cannot be adjusted for perfect intonation" [9]. Its answer is a **compensated** saddle: one that

is angled or shaped so the two strings land at different lengths. Callaham offers slant compensation or what it calls "enhanced vintage" compensation [9].

Callaham also gives plate figures. It makes its plate from .075"-thick cold-rolled material, and it describes Fender plates as .045 to .050" hot-rolled 1010 steel [9]. That's Callaham describing a competitor, so treat it as a maker claim. Callaham sells brass or stainless saddles and says brass is "warmer" while steel gives "more punch and sustain" [9]. No measurements come with that. I'll come back to saddle materials at the end of the chapter.

The 6-saddle bridge

Fender's 6-Saddle American Series Telecaster bridge lists a 2-3/16" string spacing (about 55.6 mm by my conversion), six saddles with offset intonation screws, and a string-through plate [7]. It fits American, American Deluxe and American Standard Teles built from 1986 to 2007 [7].

With six saddles, every string gets its own height screw and its own intonation adjustment. If you play in tune high up the neck, or use a gauge set the vintage saddles weren't built for, six saddles make the job easier.

Look at the spacing, though. StewMac's vintage-style 3-saddle is 2-1/8" and Fender's 1986-2007 6-saddle is 2-3/16" [7, 8]. That's about a 1.6 mm difference in E-to-E spread (my arithmetic), and the mounting holes differ too [8]. A swap between styles is a fitting job, not a bolt-on.

Table 8.1: Telecaster bridges compared

Bridge	Saddles	String spacing	Plate	Mounting	Source
Fender American Vintage 3-saddle	3 (page says both stainless and chromed brass)	not stated	stamped, string-through	4 screws	[6]
StewMac Traditional 3-saddle	3 brass, unplated	2-1/8" (53.97 mm)	stamped steel, 84.14 x 76.20 mm	4 holes, 65.09 mm apart	[8]
Fender American Series 6-saddle (1986-2007)	6, offset intonation screws	2-3/16"	string-through	not stated	[7]
Callaham 3-saddle (maker)	3 brass or stainless, compensated	not stated	.075" cold-rolled	not stated	[9]

The Tune-o-matic: ABR-1 and Nashville

The **Tune-o-matic**, or TOM, is the Gibson-style bridge with six adjustable saddles in a narrow body that sits on two posts. Height is set with thumbwheels on the posts. A separate tailpiece behind it anchors the strings. Wikipedia credits the design to the Ted McCarty era at Gibson, with first use on the Super 400 in 1953 and the Les Paul Custom in 1954 [10]. That's a secondary source, so I'm giving you the dates as Wikipedia states them.

There are two main families. The **ABR-1** is the original style. The **Nashville** came along in 1975, again per Wikipedia [10]. You can tell them apart at a glance by the intonation screws: on an ABR-1 the screw heads face the neck, and on a Nashville they face the tailpiece [10].

How they differ

The ABR-1 sold by StewMac under the Gibson Accessories name has a string spread of 2-1/32" (51.56 mm), a 12" saddle radius, a post spacing of 2-29/32" (73.66 mm), and 6-32 threaded posts 1-1/16" long [11]. StewMac's two figures differ by about 0.16 mm (2-29/32" is 73.82 mm). Its saddles come unnotched, and the bottom is closed [11]. Gibson's Historic non-wire ABR-1 shares the same spread, radius, post spacing and threads [12].

Radius here means the curve of the saddle tops across the six strings, given as the radius of a circle; it should roughly follow the fretboard radius (Chapter 5).

The Nashville from the same Gibson Accessories line has the same 2-1/32" spread and 12" radius, but a post spacing of 2-15/16" (74.61 mm) and M5 x .8 metric post threads [13]. The stud and thumbwheel are cast together, and the bottom is open [13].

The bigger practical difference is how the posts meet the wood. In a StewMac swap article, the ABR-1 posts thread straight into the wood (the author drilled 1/8" holes), while the Nashville posts thread into metal bushings pressed into the top [14]. The Nashville bushing holes in that guitar measured 17/64", about 6.75 mm [14]. The same article says the Nashville is slightly larger and gives "a wider range of saddle adjustment" [14]. More saddle travel helps when a heavy gauge or an unusual tuning pushes a saddle to the end of its slot. I found no figure for how much more travel, in millimeters.

Gotoh sells a hybrid: an ABR-1-style bridge with Nashville-style saddles. Its post spacing is 73.66 mm (2-29/32"), E-to-E spread 52 mm, 10.4 mm per string, with a "4 mm stud" [15]. Gotoh says it has "longer saddle adjustment like the Nashville style bridge" while keeping the ABR-1's threaded posts [15].

The makers disagree on one point. Gibson and StewMac say the ABR-1 post is 6-32 thread [11]. Gotoh says its post is a 4 mm stud [15]. A 6-32 screw is about 3.5 mm across the threads (my arithmetic). These may simply be different parts, the Gibson original and the Gotoh replacement, so measure your posts before you buy.

Callaham adds a few fitting numbers. Studs for Asian copies that use metric hardware need 2.915" (74.0 mm) spacing, and post centers "cannot exceed 2.930 in" [16]. Nashville conversion studs fit a .278" hole at least 1/2" deep [16]. Callaham lists the threads as #6-32 for vintage, M4 x 0.7 for metric, and 5/16"-24 for the tailpiece studs [16]. Callaham also makes some claims I'd treat as opinion: that the Nashville casting is "honeycombed zinc," that the original 1954 ABR-1 was zinc, and that the Nashville's extra width "causes problems with obtaining the correct back angle" [16]. No data comes with those.

The retainer wire

From 1962 to 1975, ABR-1 bridges had a saddle retainer wire, a thin spring wire across the saddles that keeps saddles and screws from falling out when the strings are off [10]. The 1954-1962 bridges had none [10], and Gibson's Historic "non-wire" ABR-1 recreates that earlier design [12]. Players often blame the wire for rattles. I couldn't find a source that tests that, so I'll only say it's a common complaint.

Table 8.2: Tune-o-matic bridges compared

Bridge	Post spacing	Post thread	How it mounts	String spread	Radius	Source
Gibson ABR-1	2-29/32" (73.66 mm)	6-32 x 1-1/16"	threads into wood	2-1/32" (51.56 mm)	12"	[11, 12]
Gibson Nashville	2-15/16" (74.61 mm)	M5 x 0.8	posts in pressed bushings	2-1/32" (51.56 mm)	12"	[13, 14]
Gotoh ABR-1 with Nashville saddles	73.66 mm	"4 mm stud"	ABR-style	52 mm (10.4 mm per string)	not stated	[15]
Metric import studs (Callaham)	2.915" (74.0 mm)	M4 x 0.7	not stated	not stated	not stated	[16]

The stopbar tailpiece

On a Les Paul-style guitar the TOM handles height and intonation, and a **stopbar** tailpiece behind it anchors the strings. The stopbar hangs on two large studs screwed into threaded inserts in the body.

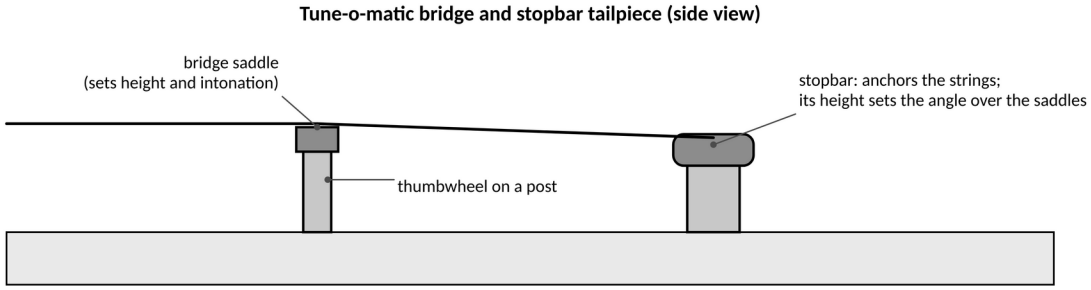


Figure 8.2: A Tune-o-matic bridge sets string height and intonation; the stopbar behind it anchors the strings.

Gibson's Historic Reissue stopbar is "lightweight nickel-plated aluminum," with 3.22" post spacing and 0.406" string spacing [17]. Amplified Parts sells a vintage-spec aluminum stopbar "to match the original 1950s version," with the same 3.22" (82 mm) stud spacing and a size of 4.02" long, 0.69" wide and 0.44" high [18]. Kluson offers its USA stopbar in aluminum, bell brass, steel or zinc, with steel 5/16-24 studs, a 13 mm stud cap, and 3.22" (82 mm) spacing [19].

So the 3.22" stud spacing is the shared number across these three sources. That's good news for swapping: a stopbar in a different material should drop onto the same studs.

What about material? Callaham sells a steel stopbar, agrees the 1950s originals were aluminum, and claims aluminum "will NEVER come close" to steel in sustain [16]. That's a strong claim with no data. Kluson, which sells all four materials, makes no tone claims at all [19]. Aluminum is far lighter than zinc for the same shape, so an aluminum stopbar should weigh less, but none of these makers published a weight. I'm not going to guess one.

Callaham also sells stud bushings in three heights; the tallest one imitates "top-wrapping" the strings over the bar, which gives the least break angle over the bridge [16]. Wikipedia says the break angle behind a TOM keeps the strings seated in the saddles and "contributes to sustain" [10]. The seating part is plain mechanics. The sustain part is a secondary source with no measurement, so I leave it at that.

Table 8.3: Stopbar tailpieces

Tailpiece	Material	Stud spacing	Stud thread	Source
Gibson Historic Reissue	nickel-plated aluminum	3.22"	not stated	[17]
Kluson USA	aluminum, bell brass, steel or zinc	3.22" (82 mm)	5/16-24	[19]
Amplified Parts vintage spec	aluminum	3.22" (82 mm)	not stated	[18]
Callaham	cold-rolled steel	not stated	5/16"-24	[16]

Wraparound bridges

A **wraparound** combines bridge and tailpiece in one part. The strings feed in from the front, wrap around the bar, and rest on top of it. Gibson has used this style: the Badass Wraparound is sold as a direct replacement for "Gibson wraparound bridges" [20], and a Gibson-branded Lightning Bar wraparound is sold as a replacement part [21]. I haven't been able to confirm which Gibson models used it, or when.

The Gibson "lightning bar" style has fixed, cast-in compensation, so each string's length is set by the shape of the bar [20]. You can move the whole bar with its two studs, but you can't adjust a single string. Gibson's Lightning Bar replacement comes with studs and 1/2" (13 mm) body inserts [21]. The retailer page I have gives no material or spacing for it.

The Leo Quan Badass Wraparound is sold as "a direct replacement for Gibson wraparound bridges," and it lets you intonate each string [20]. One retailer lists it as "high-density zinc alloy," with 5/16"-24 SAE studs for Gibson and other US-made guitars (a metric version is also sold) and a 2-1/16" string spacing [22].

So the choice is plain. The lightning bar is simple, light on parts, and right for its intended gauge and tuning. The Badass, or any wraparound with adjustable saddles, earns its place when the compensation built into the bar doesn't match your strings.

String-through or top-load

On a **string-through** bridge the strings pass through holes in the body and anchor in ferrules (metal cups) on the back. On a **top-load** bridge the strings anchor in the bridge itself. Many hardtails and Tele bridges are string-through [3, 6, 7, 8].

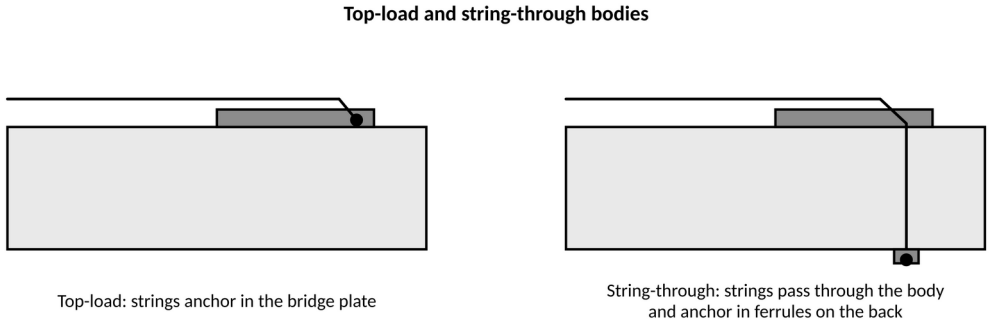


Figure 8.3: Top-load and string-through anchoring, cut through the body.

Hipshot says string-through gives "solid down pressure on bridge and saddles" [3]. That's a reasonable mechanical point, since the string comes up through the body and turns over the saddle. I found no controlled test comparing the tone of string-through and top-load on the same guitar. So I won't tell you one sounds better. The myth gets its own look in my book *Chasing Tone*.

Where string-through does matter is the build. It means six holes through the body and ferrules on the back, so you can't convert a top-load guitar without drilling. If you like the idea, decide before the body is finished. If the guitar is already built, I'd spend the effort on setup instead (Chapter 19).

String spacing across bridge types

The numbers get useful side by side. Table 8.4 lists the E-to-E spacing that makers publish for the bridges in this chapter, plus a few Strat tremolos for comparison (those are covered in Chapter 9).

One correction you'll see repeated elsewhere: Fender's modern Strat spacing is 2-1/16", about 52.4 mm, not 2-1/8" [1, 23, 24, 25]. The 2-1/8" (54 mm) figure is Kluson's "contemporary narrow" spacing [26], and it's also the StewMac 3-saddle Tele spread [8]. Vintage Strat spacing is 2-7/32", about 56.4 mm [2]. That vintage width spreads the E strings about 4 mm farther apart than Fender's modern figure (my arithmetic) [1, 2].

Even the metric value for 2-7/32" depends on whom you ask. StewMac says 56.33 mm [25], Kluson says 56.5 mm [26], and a straight conversion gives about 56.36 mm. Close enough for playing, but it's a nice reminder that maker numbers are rounded.

Table 8.4: String spacing at the bridge (E to E unless noted)

Bridge	Spacing	Source
Fender vintage Strat (6-screw)	2-7/32" (about 56.4 mm)	[2]
Fender modern Strat (2-point and narrow 6-screw)	2-1/16" (about 52.4 mm)	[1, 23, 25]
Kluson "contemporary narrow" Strat	2-1/8" (54 mm)	[26]
StewMac Traditional 3-saddle Tele	2-1/8" (53.97 mm)	[8]
Fender American Series 6-saddle Tele (1986-2007)	2-3/16" (about 55.6 mm)	[7]
Gibson ABR-1 and Nashville	2-1/32" (51.56 mm)	[11, 13]
Gotoh ABR-1 with Nashville saddles	52 mm (10.4 mm per string)	[15]
Leo Quan Badass Wraparound	2-1/16"	[22]
Hipshot bent-plate hardtail	.430" (11 mm) or .446" (11.5 mm) per string	[4]
Gibson Historic stopbar	0.406" per string	[17]

Tip: If you're swapping a bridge on a guitar with single-coil pickups, compare the new bridge's E-to-E spacing to your pickups' outer pole pieces before you buy. A wider bridge on narrow-spaced pickups can leave the E strings drifting off the poles.

Saddle and block materials: claims and data

The marketing is loudest on this subject, so I'm keeping the claims and the data apart.

What the parts are made of

The materials themselves are easy to list from maker pages. Fender lists bent steel saddles on several of its Strat bridges and polished steel block saddles on the American Ultra [1, 23, 24]. Callaham and Floyd Rose use hardened steel [27, 28]. StewMac's vintage Tele saddles are brass [8]. Hipshot and Callaham offer stainless [3, 9]. Blocks on Strat-style tremolos run from cold-rolled steel [1, 26] to zinc die-cast on some imports [29]. The Floyd Rose Original uses a nickel-plated brass block [27]. Graph Tech makes String Saver saddles from a composite material [30]. KTS makes titanium saddles [31].

What the makers claim

Here are the claims, labeled as claims.

- Callaham says brass Tele saddles are "warmer" and steel gives "more punch and sustain" [9].
- Callaham says "Zinc kills both sustain and clarity and your sound" [32]. No measurements appear on the page.
- Graph Tech says String Saver saddles reduce string breakage "by up to 90%" and add up to 25% more sustain [30]. The page gives no baseline, no method and no sample size, and the support it shows is testimonials [30].
- KTS says its titanium block saddles give a "tight sound with mid-range effect that is different from the crispy sound of pressed saddles" [31]. Schaller, which uses KTS saddles on one tremolo, claims longer sustain, clearer note separation, more stable tuning and zero corrosion [33]. Neither publishes a titanium grade, a weight, or test data [31, 33].

What is actually measured

Very little. Callaham reports a hardness figure for its saddle steel: 95-98 on the Rockwell B scale when new, work-hardening to "well over 115 Rockwell B" where the string crosses [28]. **Rockwell B** (HRB) is a standard hardness scale for softer metals; a higher number means harder. Callaham says the pre-CBS saddles it tested averaged 50 HRB [28]. That's a maker's own test with no published method, but it's at least a number. And what does hardness change? Wear and string notching. A harder saddle resists getting a groove worn into it. It doesn't show a tone change.

Graph Tech makes a mechanical argument worth repeating. Its blog says the material is "infused with Teflon" and argues that a metal saddle concentrates vibration stress at one spot on the string [34]. That's a plausible explanation for why strings break at the saddle.

Material choice clearly changes hardness, wear, corrosion and weight, and it may change how often you break strings. I found no independent measurement that shows a difference in amplified tone between saddle or block materials. I also found no controlled study comparing brass, steel and zinc blocks. If you want the physics of how bridge hardware can affect string vibration at all, my book *Chasing Tone* covers it.

Table 8.5: Saddle and block materials, what's claimed and what's measured

Material	Where you'll find it	Maker claim	Measured data found	Source
Bent steel	Fender Strat saddles	none on page	none	[1, 23]
Hardened steel	Callaham, Floyd Rose saddles	none beyond the hardness figures	Callaham hardness test: 95-98 HRB new, over 115 HRB at contact	[27, 28]
Brass	vintage Tele saddles	"warmer" (Callaham)	none	[8, 9]
Stainless steel	Hipshot, Callaham	"more punch and sustain" for steel (Callaham)	none	[3, 9]
Zinc die-cast	import Strat blocks, Badass	"kills sustain and clarity" (Callaham)	none	[22, 29, 32]
Graph Tech String Saver	aftermarket saddles	up to 90% less breakage, up to 25% more sustain	none published	[30]
Titanium (KTS)	aftermarket saddles	sustain, clarity, tuning, no corrosion	none published	[31, 33]

Tone and playability at a glance

Table 8.6: Bridge changes and what they do

Change	What you'll hear	What you'll feel
3-saddle to 6-saddle Tele bridge	little or no audible change from the bridge itself; better-tuned chords up the neck	per-string height and intonation; a different plate edge under your palm
Uncompensated to compensated Tele saddles	better intonation on each string pair	nothing different under the hand
ABR-1 to Nashville (or the reverse)	no measured tone difference found	more saddle travel on the Nashville; needs different studs or bushings
Aluminum to steel or zinc stopbar	makers claim a difference; no data found	a heavier part; same 3.22" studs
Lightning-bar to Badass wraparound	tuning improves if the fixed bar didn't suit your strings	per-string intonation
String-through to top-load	no controlled test found	no measured difference; conversion needs drilling
Different saddle material	no independent measurement of a tone change	harder saddles notch less; composite may break fewer strings (maker claim)
Wider or narrower spacing	outer strings may sit off or on the pole pieces	more or less room for the picking hand; E strings closer to or farther from the fretboard edge

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Chapter 9: Tremolo Systems

A tremolo bridge lets you bend the pitch of every string at once with a bar in your hand. Strictly speaking, that effect is vibrato, a change in pitch, and tremolo means a change in volume. Fender sells its bridges as tremolo assemblies anyway, and the name stuck. I'll use the word the makers use for each part, so you'll see "tremolo" for Fender, Floyd Rose and Gotoh, and "vibrato" for Bigsby.

A tremolo changes more than what you can do with your right hand. It changes how the guitar stays in tune, how bends feel, how the bridge sits under your palm, and how much setup the guitar needs. This chapter walks through the main designs with the numbers their makers publish, then gets into why tremolo guitars go out of tune and which parts of that you can fix. One piece of it, as you'll see, no hardware can fix.

How a tremolo works

Every spring tremolo is a balancing act. The strings pull the bridge toward the neck. Springs in a cavity on the back pull it the other way. The bridge rocks on a **pivot**, the line or points it rotates around. Push the arm down and the bridge tips forward, the strings slacken, and the pitch drops. Pull up, on a bridge that can move that way, and the pitch rises.

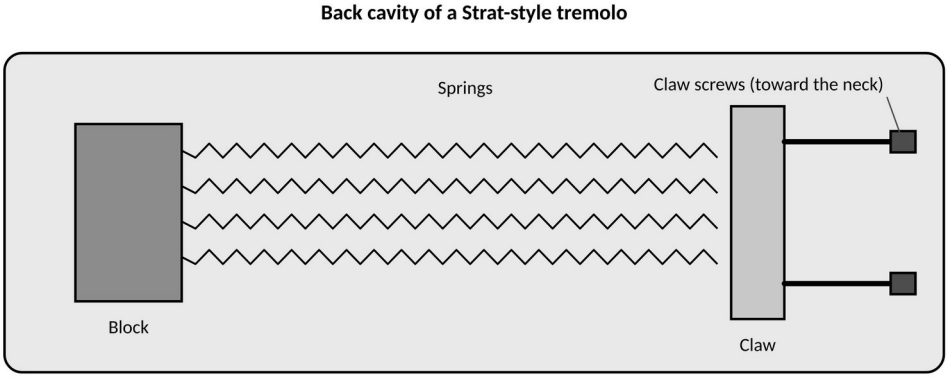


Figure 9.1: A Strat-style tremolo from the back: springs in the cavity balance the pull of the strings.

The springs hook to a **claw**, a metal bracket screwed into the body. Turning the two claw screws in or out changes how hard the springs pull. Under the bridge plate hangs the **block** (also called the sustain block or inertia block), a heavy piece of metal the strings pass through and the springs hook onto.

When the string pull and the spring pull are equal with the bridge lifted off the body, the bridge **floats**. When the springs win and the bridge rests flat on the body, it's **decked**. More on both in a moment.

Strat tremolos: 6-screw vintage and 2-point

The Fender Stratocaster tremolo comes in two families. The **vintage 6-screw** bridge pivots on a row of six screws through the front edge of the plate. The **2-point** bridge pivots on two posts, sometimes called studs.

The vintage 6-screw

Fender's American Vintage Series tremolo gives one figure for both mounting and string spacing: 2-7/32" (2.220") [1]. That's about 56.4 mm (my conversion). Fender also sells a Vintage/Narrow version on the same 6-screw base with 2-7/32" mounting-hole spacing but "modern 2-1/16" string spacing" [2]. That part has six bent, nickel-plated steel saddles stamped FENDER, a cold-rolled steel block and a 10-32 threaded arm, and it comes with a .050" hex wrench [2].

Callaham's technical page agrees on the vintage geometry: 2-7/32" center to center between the E strings and between the outer pivot screws [3]. Its blocks use 10-32 thread and a 3/16" arm diameter, and it notes that some non-domestic guitars use metric arms [3].

How do six screws work as a pivot? Fender's own setup instructions say to raise all six screws about 1/16" (1.6 mm), then tighten only the two outer screws down flush, so that the bridge "will now pivot on the outside screws" [4]. In other words, a well-set vintage bridge is really pivoting on its outer two screws. The middle four mostly keep it located.

The 2-point

Fender's Deluxe Series 2-Point tremolo has 2-1/16" (2.0625") string spacing and 2-7/32" (2.220") between its two pivot posts, with bent steel saddles and a steel block [5]. StewMac's listing of the Fender American Standard Strat tremolo gives the same two numbers in metric: string spread 2-1/16" (52.37 mm), post spacing 2-7/32" (56.33 mm), bent steel saddles, steel block [6]. Callaham describes the American Standard block as "soft cast steel" [3], while Fender and StewMac simply say "steel" [6]. That's a small disagreement, but it's worth knowing about.

The American Ultra bridge is also 2-point with 2-7/32" post spacing, but it uses six polished steel *block* saddles instead of bent ones, a steel block and a pop-in arm [7]. Fender lists its string spacing as "2-1/16" (2.08")" [7]. The decimal is wrong on that page, since 2-1/16" is 2.0625". It fits American Deluxe, Elite and Ultra models from 1986 on [7].

Why does pivot style matter? Fewer contact points means less friction at the pivot, and that is the main argument for 2-point bridges returning to pitch better. It's a sound mechanical argument. I didn't find a measurement that compares the two.

Fender's modern spacing is 2-1/16"

You'll often read that "modern" Strat spacing is 2-1/8". Fender doesn't publish that. Fender's modern figure is 2-1/16", about 52.4 mm [2, 5, 6, 7]. The 2-1/8" (54 mm) number is what Kluson sells as "contemporary narrow" spacing [8]. Kluson's version uses 10.8 mm between strings, a 6-screw spacing of 2-7/32" (56.5 mm), a machined solid steel block and stamped steel saddles [8]. So there are really three common spreads: vintage 2-7/32", Fender modern 2-1/16", and aftermarket narrow 2-1/8".

Import and US parts are not the same

Modders, watch for this one. Fender's Vintage-Style Standard Series tremolo, an import part, is a 6-screw bridge, but its *mounting* spacing is 2-1/16" (2.065"), the same as its string spacing [9]. The American vintage bridges use 2-7/32" between the outer screws [1, 2]. So a vintage-style import bridge and an American vintage bridge are not drop-in replacements for each other. The screw holes won't line up.

The import part also uses different threads. Its arm is M5 x 0.8 metric, and its saddle height screws are M4 x 0.5 [9]. The American parts use a 10-32 arm [2, 3]. The two arms won't swap. And the import's block is "Zinc Die-Cast," which Fender calls a "Big Block" [9], where the American Vintage/Narrow uses cold-rolled steel [2].

> **Tip:** Before you order a Strat tremolo, measure the distance between the outer two mounting screws on your guitar. If it's 2-7/32" (about 56 mm) you need a US-spaced bridge; if it's 2-1/16" (about 52 mm) you need an import-spaced one.

Table 9.1: Strat-style tremolos compared

Model	Pivot	Mount spacing	String spacing (E to E)	Saddles	Block	Arm	Source
Fender American Vintage	6-screw	2-7/32" (2.220")	2-7/32" (about 56.4 mm)	Fender-stamped	not stated	not stated	[1]
Fender Vintage/Narrow	6-screw	2-7/32"	2-1/16" (about 52.4 mm)	bent nickel-plated steel	cold-rolled steel	10-32	[2]
Fender American Standard	2-point	2-7/32" (56.33 mm)	2-1/16" (52.37 mm)	bent steel	steel	not stated	[6]
Fender Deluxe Series 2-point	2-point	2-7/32" (2.220")	2-1/16" (2.0625")	bent steel	steel	not stated	[5]
Fender American Ultra	2-point	2-7/32" (2.220")	2-1/16"	polished steel block	steel	pop-in	[7]
Fender Vintage-Style Standard Series (import)	6-screw	2-1/16" (2.065")	2-1/16" (2.065")	bent steel	zinc die-cast	M5 x 0.8	[9]
Kluson KNTS narrow	6-screw	2-7/32" (56.5 mm)	2-1/8" (54 mm)	stamped steel	solid steel	not stated	[8]
Callaham vintage	6-screw	2-7/32"	2-7/32"	hardened steel	cold-rolled steel	10-32	[3, 10]
Gotoh 510T-FE1	2-point, stud lock	56 mm	10.8 mm per string (54 mm)	steel	37 or 42 mm	"A7"	[11, 12, 40]

Floating, decked and in between

Fender's Strat setup article says a floating tremolo has a gap of 1/8" (3.2 mm) at the back of the bridge [4]. A floating bridge can go both ways: down with a push, up with a pull.

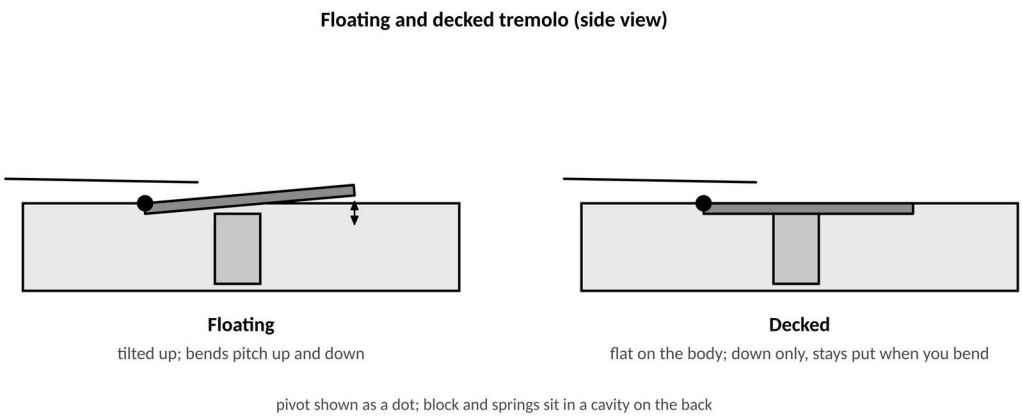


Figure 9.2: A floating tremolo tilts up off the body and moves both ways; a decked one rests on the body and only lowers pitch.

To deck the bridge, Fender says to balance the springs against the strings and then add about 1/2 turn to each claw screw, so the bridge stays down during bends [4]. Fender's locking tremolo page gives the same extra half turn for a decked bridge, and says a floating locking bridge should "sit parallel to the body" [13]. A decked bridge only goes down, but it gives you a solid feel when you bend.

You might ask, "Why does a floating bridge move when I bend one string?" Bending a string raises its tension. That extra pull tips a floating bridge forward a little, which slackens every other string. Floyd Rose's troubleshooting page says exactly this: bend one string on a floating tremolo and the others go slightly flat, and it calls that normal [14]. A decked bridge resists it because the extra spring tension holds the bridge against the body.

StewMac describes a middle path, a "semi-floater," where the back of the bridge is raised slightly [15]. It also gives a simple test: loosen the springs, bend the B string hard, and if the bridge pulls forward, the spring tension is too light for how you play [15].

Springs

How many springs should you run? Nobody publishes a rule, and the sources disagree about the starting point.

Fender's modern Tremolo Tension Springs come six to a set, in black-plated steel, with no guidance on how many to use [16]. Its American Vintage springs come in a pack of five, in nickel-plated steel, again with no guidance [17]. Callaham writes, "I recommend a minimum of 4 springs" [10]. A StewMac author prefers five on a Strat but calls it a personal choice that "will vary depending on playing style, string gauge and finding the feel you like" [15]. The same article says Floyd-style bridges usually run three, and some players run two [15].

Floyd Rose sells its Original springs as a "set of 3" [18]. It also sells Noiseless springs in sets of three, made of a polymer it calls "revolutionary new," in four versions: Black (standard), Red (Heavy Duty), Green (Heaviest Duty), and Steel [19]. Floyd recommends the higher-tension versions for heavy gauges, for running fewer springs, or for more resistance at the bridge [19]. It says the coating on its Noiseless springs damps spring noise "without affecting tremolo performance" [20]. That's a maker claim, and no measurement comes with it.

Fender's own pages don't tie spring count to string gauge [4, 16, 17]. The working method is simple. Pick a spring count that lets the bridge sit where you want it with the claw screws somewhere in the middle of their travel, then adjust with the claw.

Floyd Rose and locking systems

The Floyd Rose is a **double-locking** tremolo. The strings clamp at the bridge saddles and again at a locking nut. With both ends clamped, the strings can't slip at the nut or the tuners, which takes those two sources of tuning drift out of the picture. Because you can't use the tuners once the nut is locked, the bridge has **fine tuners**, small thumbscrews that adjust each string's tension a little.

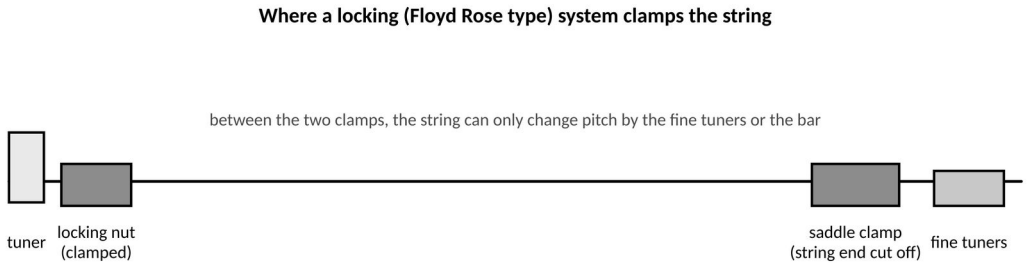


Figure 9.3: A locking system clamps the string at the nut and at the saddle, so tuning is set with fine tuners at the bridge.

The Original

Floyd Rose's spec table for the Original (FRTO) lists a hardened steel base plate, CNC-machined hardened steel saddles, a 37 mm nickel-plated brass sustain block, a stainless steel arm with a screw-on cap, hardened steel string retainer and screws, coiled steel springs, and a 12" radius [21]. StewMac's listing gives the same materials [22]. The locking nut is sold separately [21].

String and stud spacing are where sources split. StewMac says the 1000 Series Pro uses .420" per string, "the same as the Original" [23]. Five gaps of .420" make 2.100" E to E (my arithmetic). Allparts lists the Original at 2-1/8" (2.125") string spacing, 2-15/16" stud spacing and a 1-5/8" nut width [24]. Schaller, whose Vintage Tremolo is made to fit the same bolts, gives the "original Floyd Rose or Schaller" bolt spacing as 74.3 mm, which is 2.925" [25]. Allparts' 2-15/16" is about 74.6 mm. So call it about 74.3-74.6 mm between studs. The gap may just be rounding. StewMac also says the German Pro version is narrower [23].

Floyd Rose offers a range of upgrade parts. Its guide lists sustain blocks in brass (Fat Brass), tungsten, a double-thickness Fat Tungsten, and granite (Stone Tone), plus titanium hardware kits and USA saddle sets in hardened tool steel with 8", 10", 12", 14", 16" and 17" radii [20]. KTS sells titanium string-lock inserts for Floyd-style bridges, which it says prevent cracking from over-tightening or corrosion [26]. KTS makes no tone claim for those inserts and publishes no data [26]. I found no measurements behind Floyd's block options either. If you're curious whether a block swap changes the sound, my book *Chasing Tone* is the place for that argument.

Balancing a Floyd

Floyd Rose's own procedure starts with the fine tuners set "to the middle of their adjustment range" [27]. You then loosen the three nut clamps, adjust the claw screws until the base plate is parallel to the top, clamp the nut, and tune only with the fine tuners [27]. If you change string gauge or tuning, you redo the parallel step [27]. If the fine tuners run out of range, you repeat the whole procedure [27]. Action is set at the two pivot screws with a 3 mm Allen key [27]. The step-by-step version belongs in my guitar maintenance book; what matters here is that every change of gauge or tuning means rebalancing.

Floyd's troubleshooting page adds a few more points. If the base plate tilts forward, tighten the springs; if it tilts back, loosen them [14]. The **knife edges**, the sharpened edges of the plate that rock against the studs, should not be dull, rounded or chipped, which Floyd says is rare on Originals and more common on licensed bridges [14]. And it calls tightening the nut screws "critical for tuning stability" [14]. Fender's locking-tremolo page agrees on not over-tightening [13].

How much range do the fine tuners have, in cents or turns? I couldn't find a figure from Floyd Rose or anyone else.

Locking nut sizes

Floyd Rose sells its Original locking nut in sizes R1 through R10, in hardened steel, for top or rear mounting, with mounting holes .535" (13.59 mm) apart [28]. StewMac spells out two of the sizes [29].

Table 9.2: Two common Floyd Rose locking nut sizes

Size	Width	Radius	String spacing	Source
R2	1.625" (41.30 mm)	10"	0.2502" (6.35 mm)	[29]
R3	1.6875" (42.85 mm)	12"	0.2591" (6.60 mm)	[29]

Ibanez Edge family

Ibanez builds its own locking tremolos. On the S1070PBZ, Ibanez lists an Edge-Zero II with the ZPS3Fe system and 10.8 mm string spacing, and describes it as a "lower profile tremolo for playing comfort" with a "stud lock function for stable tuning" [30]. Ibanez credits its zero point system with "much greater tuning stability" [30]. That's a maker claim.

The Lo-Pro Edge on the RG8570 also uses 10.8 mm string spacing [31]. Ibanez's Japanese page explains that the unit is built low and the fine tuners are moved toward the back, so your picking hand is less likely to bump them and knock a string out of tune (my paraphrase) [31]. That's a comfort point if you palm-mute with your hand resting on the bridge.

Gotoh 510

The Gotoh 510T-FE1 is a 2-point tremolo with 10.8 mm string spacing, a block 37 mm or 42 mm tall, steel saddles, and what Gotoh calls a "Stud Lock" [11]. The stud lock holds the pivot studs firm [11, 32]. Gotoh's manual says a 1.5 mm hex key works the stud-lock screw and a 2.5 mm key sets stud height, and it warns to adjust stud height with the strings slack, because adjusting under tension can wear the plate [32].

Gotoh's dimension drawing confirms 10.8 x 5, which is 54 mm E to E [12]. Don't mix that up with the stud spacing: Thomann lists the bore hole distance as 56 mm [40].

Table 9.3: Locking and modern tremolos

Model	Base and saddles	Block	String spacing	Feature	Source
Floyd Rose Original	hardened steel, hardened steel	37 mm nickel-plated brass	.420" per string or 2-1/8" E to E (sources differ)	double locking, fine tuners, 12" radius	[21, 23, 24]
Ibanez Edge-Zero II	not stated	not stated	10.8 mm	ZPS3Fe, stud lock	[30]
Ibanez Lo-Pro Edge	not stated	not stated	10.8 mm	low profile, rear fine tuners	[31]
Gotoh 510T-FE1	steel saddles	37 or 42 mm	10.8 mm	stud lock	[11]

Model	Base and saddles	Block	String spacing	Feature	Source
Schaller Vintage Tremolo (KTS saddles)	hardened steel plate, titanium saddles	brass, 32/37/42 mm	10.8 mm (54 mm E to E)	74.3 mm bolt spacing; 327 g with 37 mm block	[25]

Bigsby vibratos

A Bigsby works differently from a Strat or Floyd. It's a vibrato tailpiece: the strings anchor on it behind a separate bridge, and the arm rotates the anchor point to slacken or tighten them. Bigsby's B5, for example, mounts with screws into the top of the guitar [33].

Bigsby matches each model to a kind of guitar. Its FAQ lists the B-3 for thin electrics, the B-5 for flat-top solid bodies, the B-6 for large acoustic or arch-top guitars, the B-7 for "thin electric guitars with more downward pressure," the B-11 for thin arched electrics, and the B-12, with a pressure bar, for large arch-tops [34]. Units come in long and short sizes [34]. The B5 uses four screws [33].

One disagreement: the B7 product page calls it a unit for "arch top electric guitars" [35], while the FAQ describes it for thin electrics with more down-pressure [34]. If you're fitting one, check the measurements against your guitar rather than trusting the label.

Bigsby publishes a weight for each unit, which is handy because a Bigsby adds real mass to the back of the guitar.

Table 9.4: Bigsby vibratos

Model	Intended guitar	Material and casting	Length x width	Weight	Source
B3	thin hollow and semi-hollow	aluminum, sand cast	7-5/8" (193.7 mm) x 3-5/8" (92.1 mm)	about 296 g (10.4 oz)	[36]
B5	flat-top solid body (SG, LP Jr, Tele, Rick 325)	aluminum; die cast RH, sand cast LH	4-3/4" (120.65 mm) x 3-3/4" (95.3 mm)	about 287 g (10.1 oz)	[33]
B7	arch-top electrics	aluminum; die cast RH, sand cast LH	8-3/4" (222.3 mm) x 3-5/8" (92.1 mm)	about 354 g (12.5 oz)	[35]
B16	Telecaster-style	aluminum, sand cast	8-3/8" (212.7 mm) x 4-1/4" (107.9 mm)	333 g (11.7 oz)	[37]

Why chords go out of tune under the arm

Most players don't know this part. Even a perfect conventional tremolo, one that returns to pitch every single time, can't keep a chord perfectly in tune while you're using it.

J. A. Kemp published a study in PLoS ONE in 2017 (the record is held in the University of St Andrews repository) on how wound and unwound strings respond to a tremolo arm [38]. His finding: for the same movement of the arm, wound and plain strings change pitch by different amounts. So when you dip a chord, the intervals between the strings shift, and the chord goes slightly out of tune with itself while the bar is moving. Kemp found that the ratio of a string's core mass to its winding mass is "a very powerful design parameter" for this effect [38]. He also found that the relative sensitivity of the plain steel strings on a Strat-type tremolo is "not possible to equalise" by changing string construction [38]. And under his linear assumption, changing gauge alone doesn't change the intervals for a given arm angle [38].

What does that mean at the bench? No spring, block, knife edge or nut will fix this. It's the strings. If a chord sounds sour while you hold the bar down and then comes back in tune when you let go, your tremolo is doing its job.

What makes a tremolo stay in tune

Most tremolo tuning trouble comes from something sticking or slipping, so the bridge or string doesn't return to where it started. These are the fixes the sources support.

- Nut and string-tree friction (the nut is Chapter 7, string trees Chapter 10). Fender recommends lubricating string trees with lip balm and saddles with light machine oil [4]. StewMac suggests cutting nut slots "a few thousandths larger" than each string and polishing the slot bottoms, and cleaning the underside of even new string trees [15].
- A locking nut removes slip at the nut entirely, and the fine tuners take over [13, 28].
- Pivot friction. On a 6-screw bridge, only the two outer screws should carry the pivot [4]. A 2-point bridge pivots on two posts [5]. Gotoh's stud lock holds those posts firm [11, 32].
- Sharp, hard knife edges. Floyd uses hardened steel [21] and tells you to check the edges for wear [14].
- Tight nut clamps on a locking system [14], without over-tightening [13].
- String physics you can't change [38].

One odd tip from Gotoh: its Magnum Lock tuner manual says that if you use a floating or "hip-up" tremolo with those tuners, you should put a cushion between the bridge plate and the body to stop the tremolo from sinking [39]. I mention it because it shows even tuner makers are thinking about the bridge.

> **Tip:** If your Strat goes flat after a dive and comes back with a tap on the bar, suspect friction at the nut or string trees before you blame the bridge.

Choosing a tremolo for how you play

So which one should you pick? I'd sort it this way, using only what the makers publish and what the physics says.

If you use the arm for light shimmer and want the guitar to feel like a hardtail when you bend, a Strat tremolo set decked, with Fender's extra half turn on the claw screws, does that well [4]. You'll give up up-bends, so ask yourself how often you really pull up on the bar now.

If you want the bar to go both ways, you need a floating setup, and you'll have to live with the fact that bending one string pulls the others flat [14]. If that bothers you more than losing up-bends, deck the bridge. Neither choice is wrong.

If you dive hard and often, a double-locking system is the tool built for the job. Floyd Rose's procedure makes clear what you sign up for: rebalancing whenever you change gauge or tuning, and tuning with the fine tuners once the nut is clamped [27]. If your picking hand rests on the bridge, the low-profile Ibanez designs with rear fine tuners are worth a look [30, 31].

If you want a vintage look on a guitar that wasn't routed for springs, a Bigsby matched to your body style is one answer [34]. Pick the model by your guitar's top, flat or arched, and check the published size against the space behind your bridge before you order [33, 35, 36, 37].

And whatever you choose, remember Kemp's point: on a conventional tremolo, chords bend slightly out of tune with themselves while the arm moves [38]. Swapping one conventional bridge for another won't change that.

Tone and playability at a glance

Table 9.5: Tremolo choices and what they do

Change	What you'll hear	What you'll feel
6-screw to 2-point	no measured tone difference found	fewer pivot contact points, so less friction (mechanism, not measured)
Floating to decked	little or no audible change at rest; no up-bends	firmer bends; bridge doesn't move when you bend one string
More or heavier springs	little or no audible change; Floyd sells coated springs it says damp spring noise	stiffer arm, more effort to dip
Steel block to zinc block	makers claim a difference; no controlled study found	little difference in hand
Non-locking to Floyd Rose	no measured tone difference found	built for tuning return under heavy use (no measurement found); tuning and gauge changes take longer
Floyd to Ibanez Lo-Pro Edge	no measured tone difference found	lower profile; fine tuners out of the way of your palm
Adding a Bigsby	added mass (about 287-354 g by model); no tone measurement found	a heavier guitar; mounts on the top
Conventional tremolo, chord under the arm	chord intervals shift slightly while the arm moves	set by the strings; a bridge swap won't fix it

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Chapter 10: Tuners, String Trees and Small Hardware

The headstock end of the guitar gets less attention than the bridge, but it's where a lot of tuning trouble starts. Tuners hold the string tension, string trees push the strings down onto the nut, and the posts set the angle the strings take over it. Then there's the small stuff that keeps the guitar on your shoulder: strap buttons and strap locks.

I haven't found a measurement showing any of these parts changes your sound through the amp. What they change is how easily the guitar comes into tune, how well it stays there, how the neck balances, and whether your guitar ends up on the floor. That's plenty to care about.

What a tuner does

A **tuning machine**, or tuner, is a small gearbox. You turn a button, which turns a worm gear, which turns a larger gear fixed to the **string post**, the round shaft the string wraps around. The worm drive does two jobs. It multiplies your turning into fine movement of the post, and it holds the string tension without slipping back.

The number that describes this is the **gear ratio**. This is the one formula for the chapter: the gear ratio is the number of turns of the button for one full turn of the post. In short, ratio equals button turns divided by post turns. A 15:1 tuner takes 15 turns of the button to turn the post once. A 21:1 takes 21 turns. A 12:1 takes 12.

Gotoh writes its ratios the other way round, as 1:15 or 1:18 [1, 2]. That means the same thing as 15:1 or 18:1. Don't let the order confuse you.

You might ask, "So is a higher ratio better?" A higher ratio gives you finer control, because each turn of the button moves the post less. That makes small tuning corrections easier. The trade-off is that you turn the button more when you change strings or retune a long way. Neither ratio holds tune better by itself. Holding tune comes from the gear fit and from what happens at the nut, the trees and the string wraps.

Gear ratios compared

Table 10.1 lists ratios from maker pages and major parts sellers. A few common claims need correcting.

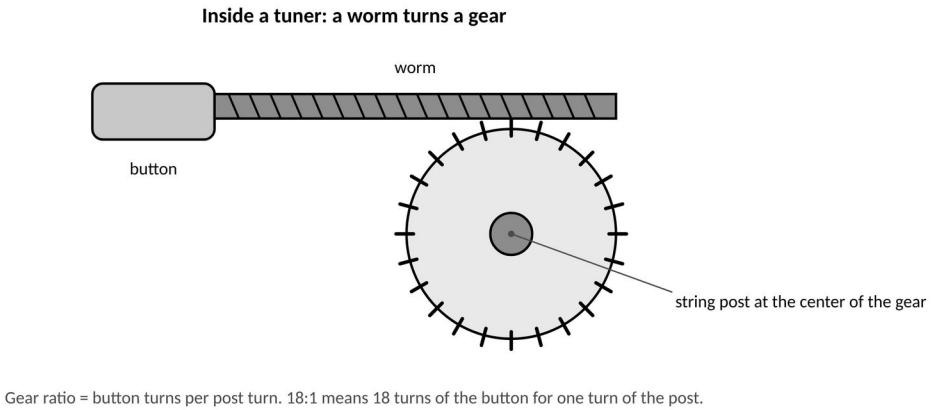


Figure 10.1: Inside a tuner, a worm on the button shaft turns a gear on the string post. The gear ratio is how many turns of the button make one turn of the post.

First, you'll see "vintage Kluson tuners are 12:1" in plenty of places. I couldn't confirm it. Kluson's period-correct 1956-64 single-line set is listed at 15:1 [3], Fender's Pure Vintage tuners are 15:1 [4], and Kluson's Deluxe page mentions only 15:1 [5]. The verified 12:1 example I found is the Sperzel Trim-Lok [6].

Second, "Gotoh 510 tuners are 21:1" is only true of two models. In Gotoh's 510 series, the SGL510Z and SGV510Z are 1:21 [2]. The SGS510 is 1:15, the SGS510Z is 1:18, the SGL510 and SGV510 are 1:18, and the SGi510 is 1:16 [2]. The letter Z is the clue.

Table 10.1: Tuner gear ratios

Model	Ratio	Locking	Source
Kluson 6-on-Plate Deluxe single line (1956-64 correct)	15:1	no	[3]
Kluson Deluxe (re-engineered)	"improved 15:1"	no	[5]
Kluson 6-in-line Supreme	18:1	no	[7, 8]
Kluson 3+3 Locking Deluxe	15:1	yes	[9]
Fender Pure Vintage	15:1	no	[4]
Fender Locking Strat/Tele	18:1	yes	[10]
Gotoh SD91	1:15	locking option	[1]
Gotoh SDS510	1:15	locking option	[11]
Gotoh SG360	1:14	not stated	[12]
Gotoh SG381	1:16	Magnum Lock option	[13]
Gotoh SG301	1:18	not stated	[12]
Gotoh SGS510 / SGS510Z	1:15 / 1:18	not stated	[2]
Gotoh SGL510 / SGL510Z	1:18 / 1:21	not stated	[2]
Gotoh SGV510 / SGV510Z	1:18 / 1:21	not stated	[2]
Gotoh SGi510	1:16	not stated	[2]
Grover Rotomatic 102	14:1	no	[14]
Grover Rotomatic 102-18	18:1	no	[15]
Grover Roto-Grip 502	18:1	thumb screw	[16]
Schaller M6 180 / M6 135	1:18	locking versions	[17, 18]
Hipshot Grip-Lock Open	18:1	pin and thumbwheel	[19]
Hipshot Classic Open	18:1	no	[20]
Hipshot enclosed (kit)	15:1	either	[21]
Hipshot Vintage kit	15:1	Grip-Lock	[22]
Hipshot Fender Directrofit	21:1	not stated	[23]

Model	Ratio	Locking	Source
Sperzel Trim-Lok 6-in-line	12:1	rear thumbscrew	[6, 24]

Post heights and break angle at the nut

On a flat, Fender-style headstock, the strings run almost parallel to the face of the headstock after they leave the nut. That gives them little **break angle**, the angle the string bends through as it crosses the nut. Too little and a string can lift or buzz in its slot (Chapter 7 covers the nut itself).

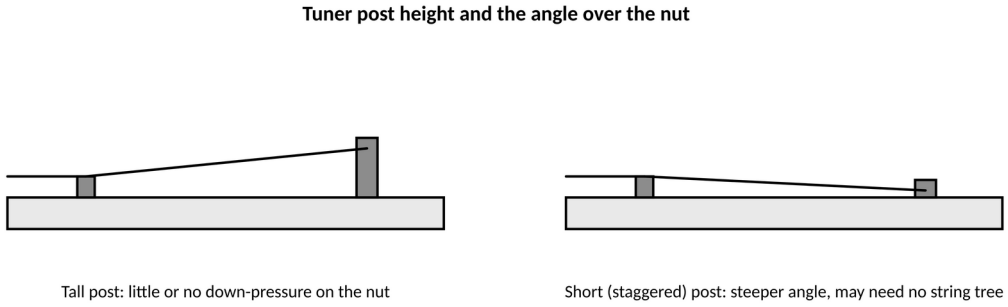


Figure 10.2: Shorter posts lower the point where the string winds on, which steepens the angle over the nut.

There are two ways to add angle without changing the headstock. One is a string tree, which I'll get to below. The other is a shorter tuner post. A shorter post pulls the string lower on the headstock, which steepens the angle over the nut. That's why many tuner sets use **staggered** posts, with the posts getting shorter as they get farther from the nut.

Fender says the staggered post heights on its locking tuners give a greater break angle over the nut [10]. Fender's set uses three long and three short posts [10]. StewMac says staggered-height locking tuners pull the strings across the nut at the right angle and can remove the need for string trees [25]. Kluson's Supreme series also uses a staggered post [8].

Here are the published heights. Schaller lists its M6 posts at 19.7, 21.7 and 23.7 mm for a solid headstock, 14.65 mm for a slotted headstock, and 19.5, 21.0 and 22.5 mm for the locking versions [17, 18]. Hipshot's Grip-Lock Open comes in .750", .787", .827" and .906" (19, 20, 21 and 23 mm) [19], and its Classic Open in 19, 20 and 21 mm [20]. Hipshot's kits are staggered: the enclosed kit has two each at 21, 20 and 19 mm [21], and the Vintage and Directrofit kits use 21, 20 and 19 mm staggered sets [22, 23]. Grover lists its Rotomatic posts at 23 mm to the string hole and 28.2 mm overall [14, 15, 16]. Kluson's period-correct single-line set has a 1" post [3].

Makers don't measure post height the same way, so compare within a brand rather than across brands.

Table 10.2: Tuner post heights and peghead holes

Model	Post height	Headstock hole	Source
Kluson 6-on-Plate Deluxe single line	1"	11/32" (8.8 mm per StewMac)	[3]
Kluson 6-in-line Supreme	staggered	11/32" (8.8 mm), press-fit	[7, 8]
Kluson 3+3 Locking Deluxe	not stated	11/32" (8.8 mm)	[9]
Fender Locking Strat/Tele	3 long, 3 short	not stated	[10]
Grover Rotomatic 102, 102-18, 502	23 mm to hole; 28.2 mm overall	25/64"	[14, 15, 16]

Model	Post height	Headstock hole	Source
Schaller M6 (solid headstock)	19.7 / 21.7 / 23.7 mm	not stated (10 mm step washer)	[17, 18]
Schaller M6 (slotted headstock)	14.65 mm	not stated	[17, 18]
Schaller M6 locking	19.5 / 21.0 / 22.5 mm	not stated	[17, 18]
Hipshot Grip-Lock Open	19 / 20 / 21 / 23 mm	13/32" (10 mm)	[19]
Hipshot Classic Open	19 / 20 / 21 mm	13/32" (10 mm)	[20]
Hipshot enclosed kit	2 each at 21, 20, 19 mm	10 mm	[21]
Hipshot Vintage kit	21 / 20 / 19 mm staggered	11/32" (8.5 mm)	[22]
Hipshot Fender Directrofit	21 / 20 / 19 mm staggered	fits American Standard 2-pin mount	[23]
Sperzel Trim-Lok	3 staggered heights	10 mm (13/32"); peghead 1/2"-9/16" thick	[6]

Peghead holes and swaps

When you change tuners, the hole in the headstock is the first thing to check. There are three common sizes in the sources.

- Vintage 11/32". StewMac calls it 8.8 mm [3, 8], Hipshot calls it 8.5 mm [22], and a straight conversion gives about 8.73 mm.
- Modern 10 mm, which makers also sell as 13/32" (strictly, 13/32" is about 10.3 mm) [6, 19].
- Grover's 25/64", about 9.9 mm by my conversion [14].

So a set of modern 10 mm tuners won't go into a vintage 11/32" hole without reaming it bigger. Going the other way, a vintage tuner in a 10 mm hole leaves a loose fit. Hipshot sells kits for both sizes, and its Directrofit kit is made to fit the 2-pin mounting of American Standard tuners [21, 22, 23]. Sperzel also lists a peghead thickness range of 1/2"-9/16" for its Trim-Lok [6]. Check that against your headstock, since a thick peghead can leave too little post sticking out.

> **Caution:** Reaming a peghead is a one-way job. If you're not sure the new tuners are right, test-fit one before you enlarge all six holes.

Reading a tuner spec sheet before you buy

A tuner swap mostly comes down to fit, so this is the order I'd check a spec sheet in, using the numbers from this chapter.

Start with the hole. Is your headstock drilled 11/32" for vintage tuners or 10 mm for modern ones [8, 19, 22]? That one number decides whether the swap is a screwdriver job or a reaming job. Then check the mounting. Some tuners use a press-fit bushing, as on the Kluson Supreme [8], and others mount differently, so compare the old and new hardware side by side. Hipshot's Directrofit exists for exactly this problem: it is made to drop into the 2-pin mount of American Standard tuners [23]. If the new tuners use a different anchoring screw or pin than the old ones, you'll have old holes showing and new ones to drill.

Next, check the peghead thickness range if the maker gives one, as Sperzel does with 1/2"-9/16" [6]. Then look at post height. If you want to drop the string trees, you need staggered or short posts [10, 25]. If your guitar has

trees now and the new tuners have taller posts than the old ones, you may find a string that used to sit fine in the nut now buzzing.

Only then look at the ratio. Table 10.1 shows major makers offering ratios from 14:1 to 18:1, plus a few at 21:1 and one at 12:1. A 21:1 gives finer steps, but it won't cure a sticking nut or a slipping wrap. A 12:1, like the Sperzel [6], moves faster with each turn and asks a slightly lighter touch on the last bit of tuning. And if neck dive bothers you, ask the maker for a weight. Schaller and Grover are the only makers I found that publish one [14, 17].

Weight and neck dive

Neck dive is when a guitar on a strap won't stay level and the headstock sinks toward the floor. The headstock is the far end of a long lever, so weight there has an outsized effect.

How much do tuners weigh? Few makers say. Schaller's per-tuner weights are the most complete figures I found: 36-38 g with metal buttons and 30-31 g with Perloid or ebony buttons [17]. A set of six therefore weighs about 180-228 g (my arithmetic). Grover lists its Rotomatics at 1.6 oz (about 45 g) per piece and 9.6 oz (about 272 g) per set [14, 15, 16]. StewMac lists 0.443 lb (0.20 kg) for the Sperzel Trim-Lok [6], but that looks like a shipping weight, and I can't confirm it's the weight of the set alone.

Does lighter hardware fix neck dive? Hipshot sells its Classic non-locking kit "for weight savings on guitars with neck dive" [21], and says its Classic Open tuners work "without adding extra weight" [20]. That's the only maker statement I found tying tuner weight to neck dive, and it gives no figures. I found no measured data on neck dive at all.

Locking tuners and string wraps

A **locking tuner** clamps the string inside the post, so you need few or no wraps around it. Why does that help? Every wrap is a bit of string that can stretch, settle or slip under tension. Fewer wraps means less to settle. That's the reason to use locking tuners, and it counts most on a tremolo guitar.

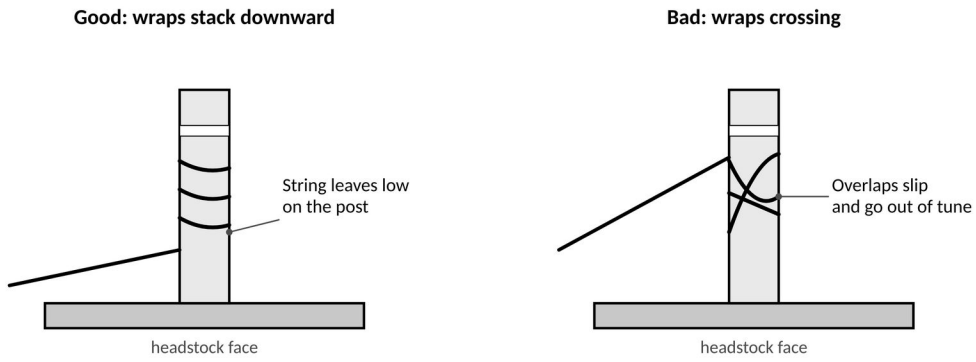


Figure 10.3: A few neat wraps on the post; locking tuners need little or none.

The locking methods differ.

- Gotoh's Magnum Lock is self-acting: string tension tightens the lock. Gotoh says to wind "less than one turn," because more than one turn can stop the lock from working [26]. The string holes are 1.2 mm and 1.8 mm, and by the manual's text the smaller holes are for strings 1-3 [26].

- Grover's Roto-Grip uses a thumb screw. You put the string through, wrap it once, then tighten the screw [16].
- Hipshot's Grip-Lock uses a pin and thumbwheel, and Hipshot says "no wraps needed" [19, 21].
- Sperzel's Trim-Lok locks with a thumbscrew on the back [6].

For standard tuners, Fender gives a target of at least 2-3 wraps on the high E string and fewer toward the low E [27]. Fender also gives hole positions for lining up locking tuners and a cut-to-length method for vintage split-shaft posts [27]. **Split-shaft** posts have a hole down the center and a slot, so the string end tucks into the post. Fender's Pure Vintage tuners are this type [4, 27]. The step-by-step versions of all of these belong in my guitar maintenance book.

> **Tip:** If you fit locking tuners on a Strat, try the guitar before you put the string trees back. With staggered posts you may not need them.

String trees and retainers

A **string tree**, also called a retainer or guide, is a small piece of hardware screwed into the face of a flat headstock that holds a string down behind the nut. Fender's explanation is clear: trees add downward tension where the strings pass over the nut, which steepens the angle across the nut and keeps the strings seated in their slots [28]. Fender says they can also add sustain on open strings [28]. The high strings need them because inline tuners put those posts far from the nut [28]. Headstocks angled back don't need trees, since the angle already gives the break [28].

Types

StewMac's catalog lists the main styles. Vintage disc trees are 3/8" across and hold two strings; butterfly trees also hold two [29, 30]. StewMac's vintage-style retainer uses a 3/32" pilot hole in hard maple [30]. There's a Three String Tree that also catches the G string, to add break angle and stop a buzzing G without drilling a new hole [29]. There are roller retainers, which StewMac says "help eliminate tuning problems and reduce string breakage," with a 5/64" pilot hole [31]. And there are Graph Tech TUSQ XL trees in 2x1 and 3x1 versions (PQL-7004-00 and PQL-7005-00, plus black PT-7004-00 and PT-7005-00) [32].

Fender sells its own in steel. The Pure Vintage kit is nickel-plated steel, with a '50s-era vintage mount and a '60s-era spacer to match guitars from those years [33]. Fender's American Standard guides come as a set of two in steel, in what Fender calls the "Modern" style [34]. Its Vintage-Style Strat guides are also a set of two in steel [35]. Fender says both "minimize tuning problems" [34, 35]. Spacer heights aren't given [33].

Friction

There's a catch. A string tree holds the string down, so the string has to slide under it every time you tune or use the tremolo. If it sticks, the string won't return to pitch.

Fender recommends a small amount of lip balm on the trees, applied with a toothpick [27]. StewMac says to clean the underside of even new trees with abrasive cord, and that Teflon-type trees (such as Tusq) or roller trees give a smoother surface [25]. Graph Tech claims its TUSQ XL trees are "permanently lubricated" and optimize string angles over the nut [32]. None of these makers publish friction measurements, so treat the roller and TUSQ claims as claims. What the sources agree on is the mechanism: less friction at the tree means better return to pitch.

Table 10.3: String trees and retainers

Tree	Type	Material	Strings	Claim or purpose	Source
Fender Pure Vintage kit	vintage, with '50s mount and '60s spacer	nickel-plated steel	not stated	vintage-correct	[33]
Fender American Standard guides (2)	modern	steel	not stated	"minimize tuning problems"	[34]
Fender Vintage-Style Strat guides (2)	vintage-style	steel	not stated	same wording	[35]
StewMac vintage retainer	3/8" disc	not stated	2	none	[29, 30]
Butterfly tree	butterfly	not stated	2	none	[29]
StewMac Three String Tree	3-string	not stated	3, adds the G	fixes G-string buzz	[29]
StewMac roller retainers	roller	not stated	not stated	"help eliminate tuning problems" (claim)	[31]
Graph Tech TUSQ XL 2x1 / 3x1	glide	TUSQ XL	2 or 3	lower friction (claim)	[32]

Strap buttons and strap locks

The last piece of small hardware is the one that keeps the guitar in the air. A strap button is just a shaped knob on a wood screw, and on most guitars there's one at the tail and one on the upper horn or the heel. A strap slides over it and is held by friction and the shape of the button. That works until a strap hole wears loose.

A **strap lock** replaces the plain strap button with one that latches to a matching piece on the strap, so the strap can't slide off.

Schaller's S-Locks use a slanted stainless steel locking bolt released by pulling up a ball [36]. A "Lock-Wheel" adds what Schaller calls a "3-Step security function" and stays attached so it can't be lost [36]. The strap button is one-piece hardened steel with a self-tapping wood thread and a 4 mm (5/32") screw, and it fits with a 3 mm (1/8") Allen key [36]. Schaller says the button is more than twice as thick as a standard one, comes with felt washers, suits straps up to 6 mm thick, and fits nearly all Gibson button holes without changes [36]. An old Schaller SecLock button works with the new lock, but Schaller doesn't recommend a new button in an old lock [36].

S-Locks come in three sizes set by the button's screw. The lock fits a 10 mm hole in the strap [37].

Table 10.4: Schaller S-Locks sizes

Size	Screw thread diameter	Screw length	Source
S	3.5 mm	18 mm	[37]
M	4.0 mm	22 mm	[37]
L	4.5 mm	27 mm	[37]

Schaller lists a button diameter of 12 mm and a Lock-Wheel grub screw of M2.5 x 5 stainless [37]. It gives no load rating [37].

Dunlop's Straplok Original is the other big name. Its product page gives only the model (SLS1101N) and the nickel finish [38]. The mechanism details are in a manual I couldn't check, so I won't describe them.

Why offer three sizes? So you can match the new button's screw to the hole already in your guitar. Schaller gives no load rating for any size [37], and I found no pull-out figures for strap button screws, so I can't tell you how much holding power a longer or thicker screw adds.

Tone and playability at a glance

Table 10.5: Small hardware changes and what they do

Change	What you'll hear	What you'll feel
Higher gear ratio (e.g. 15:1 to 18:1 or 21:1)	little or no audible change	finer tuning; more button turns per post turn
Standard to locking tuners	little or no audible change	fewer wraps, faster string changes, less slip on tremolo guitars
Staggered or shorter posts	possibly fewer buzzing strings at the nut	more break angle; may remove the need for string trees
Lighter tuners	little or no audible change	less weight at the headstock; Hipshot suggests it helps neck dive (no data)
Steel tree to roller or TUSQ tree	little or no audible change	smoother return to pitch claimed (no data)
Adding a Three String Tree	can stop a buzzing G string	more break angle on the G
Plain buttons to strap locks	no change	strap can't slip off the button

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Chapter 11: Strings

Strings are the part of the guitar that actually makes the sound. Everything else on the instrument either holds them, damps them, or listens to them. They're also the cheapest part you can change and the one you change most often, which makes them the easiest experiment in this whole book.

In this chapter I'll go through how a string is built, what the different wrap materials are and what makers claim for them, how gauge sets compare across D'Addario, Ernie Ball and Elixir, and how much tension each set carries. Then I'll get into what the measurements say: how much output really changes with the wrap, how fast strings go dead, and what two published studies found about bending. Along the way I'll keep the maker claims labeled as claims. String marketing is some of the most colorful writing in the guitar world, and only part of it has been tested.

I covered how scale length changes tension in Chapter 4, with the formula and a table of the same set on different necks. I won't repeat that here. In this chapter the tension numbers are for a 25.5-inch scale unless I say otherwise.

How a string is built

An electric guitar set has two kinds of strings. Plain strings are a single solid steel wire. Wound strings have a steel core with a second wire wrapped tightly around it, like thread on a spool.

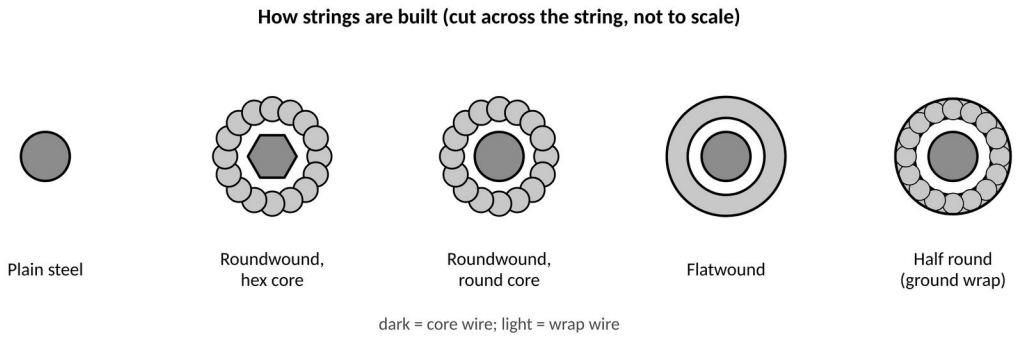


Figure 11.1: How strings are built, cut across the string. Not to scale.

Ernie Ball describes its Slinky plain strings as "specially tempered tin plated high carbon steel," and its wound strings as "nickel plated steel wire wrapped around tin plated hex shaped steel core wire" [1]. D'Addario's EXL110 uses a hexagonal high carbon steel core (D'Addario calls it Hex-Core) with a nickel-plated steel wrap [2]. That's the basic recipe for a standard round-wound electric set.

You might ask, "Why wrap a string at all? Why not just use a fat solid wire for the low E?" A thick solid wire is stiff. Stiffness pulls the string's overtones out of tune with each other (more on that near the end of this chapter). The wrap adds weight without adding much stiffness. Manfred Zollner, author of *Physics of the Electric Guitar*, puts it this way: the winding adds mass while the bending stiffness "is determined mainly by the core" [3]. The winding also doesn't carry the pull of the string. Zollner says the wrap doesn't carry tensile load [4], and J.A. Kemp's 2017 study found the winding carries less than 1 percent of the tension at pitch [5]. The core does that job.

Core and wrap proportions

Zollner gives the core as about one third to two thirds of the outer diameter [3], or about 30 to 60 percent in another chapter [4]. He lists typical ratios of core diameter to outer diameter as 0.33 to 0.42 for the low E, 0.33 to 0.50 for the A, 0.40 to 0.60 for the D and 0.48 to 0.60 for a wound G [3]. A small core makes a more flexible string but puts more stress on the core, so it's more likely to break. A large core makes the string stiffer and less in tune with itself [3]. String design is a balancing act between those two.

A wound string is about 10 percent less dense than a solid string of the same outside diameter, because of the air trapped in the winding [3]. Steel itself runs about 7,800 to 8,100 kg per cubic meter [3]. In normal tuning the steel carries stress up to about 2,000 newtons per square millimeter [3], which is a lot of load on a very thin wire.

Light sets have three plain treble strings, and heavier sets wind the G [3]. Zollner also points out that light electric strings carry roughly half the tension of acoustic strings, and that's what made string bending and finger vibrato practical on the electric [3].

Round core or hex core

Every set in Table 11.1 that names its core uses a hex core. The six flat sides give the wrap something to grip. A few makers still use round cores. DR Strings says a round core gives more contact between core and wrap and claims a fuller tone, more flexibility and more sustain [6]. Stringjoy, another string maker, says round core strings are "slightly more flexible" and credits hex cores with better tuning stability, a brighter tone and a tighter attack [7].

Those are maker claims. I found no lab measurement comparing the two. Zollner's only comment is that a non-round core needs just minor corrections in the string calculations [3]. If you like the feel of round core strings, use them. Just don't expect a chart to back up the tone story.

Ball ends and reinforcement

Strings almost always break where they're bent hard [8]. Zollner adds that once the nickel plating is damaged, sweat can set up a small electrochemical cell that corrodes the string at that spot [8]. Ernie Ball's RPS strings wrap a short length of brass wire around the ball end of the plain strings to reduce slipping and breakage [9]. Ernie Ball's Paradigm line claims up to 35 percent more tensile strength and up to 70 percent more fatigue strength [9]. I didn't find independent tests of either claim.

Wrap materials and what makers say

The wrap is where most of the marketing happens. Here's what the makers say about their own strings, in their words where I could quote them.

Table 11.1: Wrap types and maker claims

Type	Example	Wrap	Core	Maker's tone claim	Source
Nickel-plated steel, round	D'Addario EXL110	nickel-plated steel	hex, high carbon	"a bright, versatile tone"	[2]
Nickel-plated steel, round	Ernie Ball Regular Slinky	nickel-plated steel	tin-plated hex	"well balanced tone"	[1]
Pure nickel, round	D'Addario EPN110	pure nickel	hex	vintage, "the vibe of the '50s"	[10]
Pure nickel, round	Fender SuperSonic 150	pure nickel	hex	"rich, mellow warmth"	[11]

Type	Example	Wrap	Core	Maker's tone claim	Source
Pure nickel, round	Ernie Ball Classic Rock n Roll	pure nickel	tin-plated hex	"warm, rich"	[9]
Stainless steel, round	D'Addario EPS510 ProSteels	stainless	high carbon hex	"super bright, crunchy"	[12]
Stainless steel, round	Ernie Ball Stainless Steel Slinky	stainless	tin-plated hex	"brighter," longer life	[9]
Cobalt alloy, round	Ernie Ball Cobalt Slinky	cobalt alloy	tin-plated hex	more output than nickel	[13]
"Super Cobalt"	Ernie Ball M-Steel	Super Cobalt	maraging steel hex	fuller, more low end	[9]
Half round (ground)	D'Addario EHR310	stainless, ground smooth	high carbon hex	between round and flat	[14]
Flatwound	D'Addario ECG24 Chromes	stainless ribbon	high carbon hex	"warmest, mellowest"	[15]
Flatwound	Ernie Ball Cobalt Flatwound	cobalt ribbon	not stated	low finger noise	[16]
Coated	D'Addario XSE1046 XS Nickel	nickel-plated steel plus film	NY Steel hex	longest life of any D'Addario electric	[17]
Coated	Elixir OPTIWEB and NANOWEB	nickel-plated steel plus coating	not stated	same tone as uncoated, long life	[18, 19]

A couple of these claims are about magnetism, so they're testable. Ernie Ball says "The magnetic properties of Cobalt provide more output than nickel wound offerings" and also claims "more defined highs and increased low end response" [13]. D'Addario says ProSteels use a "highly magnetic alloy" that gives "a super bright, crunchy tone, and increased sustain" [12]. Neither company published a measurement on the pages I've cited.

What Zollner measured

That's where the lab work comes in. Zollner tested strings with different wraps on the same pickup and in listening tests. His results are worth knowing, because they cut through a lot of claims.

Bronze, the wrap used on acoustic strings, is close to useless magnetically. Zollner says its effect on a pickup is lower than steel or nickel by "several orders of magnitude" [4]. He compared a half-bronze .042 string to a steel-wound Fender 350 .042 with the same core wire. The bronze one was about 2 dB less sensitive, and he put it down to the wrap alone [4]. A decibel (dB) is the unit used to compare loudness or signal level; bigger numbers mean bigger differences.

Between nickel and steel the gap is much smaller. On Zollner's test bench, which shakes the string in a controlled way, a pure-nickel Fender 150 and a steel-wound Fender 350 showed no difference [20]. A nickel-plated steel string read about 1 dB higher, and about half of that came from a slightly thicker core, not the wrap [20, 21]. The thin nickel plating on most strings is too thin to matter magnetically [4]. Zollner's summary: "The solid strings and the core wires of the wound strings differ only little when it comes to magnetics" [20].

So why do nickel strings sound warmer to so many players? Zollner found a reason, and it isn't magnetism. In a listening comparison, the Fender 250 (nickel-plated steel wrap) and Fender 150 (pure nickel wrap) low E strings had a "just-about significant, noticeable" difference. When he raised the bridge so the string no longer hit the frets, the difference went away [4]. His explanation is that fret contact pushes energy into the treble. Nickel is softer than steel and soaks up more of that energy, so the nickel-wound string sounds a little less bright [4]. In other words, the wrap material does matter, but mainly through how it reacts to slapping the frets, and mostly at low action and hard picking.

Table 11.2: Measured output and decay differences

Comparison	Result	Source
Solid string at twice the diameter	about 4 times the voltage (about +12 dB)	[21]
Wound string compared with its bare core	about 7 times the cross-section, about 2 times the voltage	[21]
Half-bronze .042 vs steel-wound Fender 350 .042	bronze about 2 dB lower	[4]
Fender 250 vs Fender 150 and 350 (low E)	250 about 1 dB higher; about half of that from core size	[21, 20]
Fender 150 (pure nickel) vs 350 (steel), shaker bench	no difference	[20]
Fender 150 G vs D at equal pluck force (listening)	G about 4 dB louder	[21]
Pickup moved 1 mm closer to strings	about 2.1 to 2.7 dB louder	[21]
Old vs new low E, partial at 2,391 Hz	old string's decay time cut to about 1/7	[22]
Used vs fresh A string on a Les Paul	decay 50 to 80% shorter	[23]

Look at the pickup-distance line in that table. Moving the pickup 1 mm closer to the strings changes output by about 2 to 3 dB at gaps of 2 to 5 mm [21]. (Zollner's pickup-window work, quoted in Chapters 1 and 14, gives 3 to 4 dB per millimeter; either way it's a few dB.) That's more than any wrap difference Zollner measured between steel and nickel. If you want more output, pickup height (Chapter 14) beats a string swap. Zollner didn't test cobalt, and I haven't found anyone who tested Ernie Ball's cobalt output claim. I'm not calling it false. I'm saying I can't show you a number.

Gauges

Gauge is a string's diameter in thousandths of an inch. A .010 high E is ten thousandths of an inch thick. Sets are named by their lightest and heaviest strings, so "10-46" runs from .010 to .046.

D'Addario's item codes tell you the gauge and type: PL means plain steel, NW means nickel wound, and the digits are the gauge, so PL010 is a .010 plain string and NW046 is a .046 wound one [2].

Table 11.3: D'Addario XL set gauges (inches)

Set	Name	E	B	G	D	A	E	Source
EXL120	Super Light 9-42	.009	.011	.016	.024	.032	.042	[24]
EXL125	Super Light Top / Regular Bottom 9-46	.009	.011	.016	.026	.036	.046	[25]
EXL110	Regular Light 10-46	.010	.013	.017	.026	.036	.046	[2]
EXL140	Light Top / Heavy Bottom 10-52	.010	.013	.017	.030	.042	.052	[26]
EXL115	Medium / Blues-Jazz Rock 11-49	.011	.014	.018	.028	.038	.049	[27]
EXL116	Medium Top / Heavy Bottom 11-52	.011	.014	.018	.030	.042	.052	[28]

Set	Name	E	B	G	D	A	E	Source
EXL117	Medium Top / Extra Heavy Bottom 11-56	.011	.014	.019	.032	.044	.056	[29]
EXL145	Heavy, Plain 3rd 12-54	.012	.016	.020	.032	.042	.054	[30]
EXL148	Extra Heavy 12-60	.012	.016	.020	.034	.046	.060	[31]
EPN110	XL Pure Nickel 10-45	.010	.013	.017	.025	.035	.045	[10]

Ernie Ball's Slinky page lists a wide spread of sets. The page marks some G and D strings "w" (wound) or "p" (plain), which matters a lot for feel; I've copied those marks as printed [1]. A plain .022 G (Beefy Slinky) or .024 G (Not Even Slinky) is heavy for a plain string, so if that matters to you, check the pack.

Table 11.4: Ernie Ball Slinky Nickel Wound set gauges (inches)

Catalog	Name	E	B	G	D	A	E	Source
P02225	Extra Slinky 8-38	.008	.011	.014	.022w	.030	.038	[1]
P02229	Hyper Slinky 8-42	.008	.011	.014	.024w	.032	.042	[1]
P02223	Super Slinky 9-42	.009	.011	.016	.024w	.032	.042	[1]
P02222	Hybrid Slinky 9-46	.009	.011	.016	.026	.036	.046	[1]
P02221	Regular Slinky 10-46	.010	.013	.017	.026	.036	.046	[1]
P02227	Ultra Slinky 10-48	.010	.013	.017	.028	.038	.048	[1]
P02215	Skinny Top Heavy Bottom 10-52	.010	.013	.017	.030	.042	.052	[1]
P02220	Power Slinky 11-48	.011	.014	.018p	.028	.038	.048	[1]
P02226	Burly Slinky 11-52	.011	.014	.018p	.030	.042	.052	[1]
P02627	Beefy Slinky 11-54	.011	.015	.022p	.030	.042	.054	[1]
P02626	Not Even Slinky 12-56	.012	.016	.024p	.032	.044	.056	[1]
P02618	Magnum Slinky 12-56	.012	.016	.022w	.032	.044	.056	[1]
P02214	Mammoth Slinky 12-62	.012	.016	.024w	.034	.048	.062	[1]

The same page also lists other sets, such as Zippy 7-36 and Titan 11-56, and half-gauge sets like Primo 9.5-44 and Mega 10.5-48 [1].

Table 11.5: Elixir NANOWEB electric set gauges (inches)

Set	Name	E	B	G	D	A	E	Source
12002	Super Light 9-42	.009	.011	.016	.024	.032	.042	[19]
12027	Custom Light 9-46	.009	.011	.016	.026	.036	.046	[19]
12052	Light 10-46	.010	.013	.017	.026	.036	.046	[19]

Set	Name	E	B	G	D	A	E	Source
12077	Light-Heavy 10-52	.010	.013	.017	.032	.042	.052	[19]
12102	Medium 11-49	.011	.014	.018	.028	.038	.049	[19]
12152	Heavy 12-52	.012	.016	.024	.032	.042	.052	[19]
12302	Baritone 12-68	.012	.016	.022	.038	.052	.068	[19]

Notice that the common 10-46 set is the same on all three brands: 10, 13, 17, 26, 36, 46. The heavy-bottom sets aren't. Elixir's 10-52 uses a .032 D where D'Addario and Ernie Ball use a .030 [19, 26, 1]. Small differences like that change the feel of one string more than you'd guess from the set label.

What gauge changes

Zollner gives a clean rule: double a string's diameter and you quadruple its mass, so the tension has to quadruple to keep the same pitch, while the stress in the steel stays the same [3]. Thicker strings aren't more strained. They just pull harder on the neck and your fingers.

Ernie Ball says light gauges are easier to fret and bend, while heavy gauges need more finger pressure, give "hotter output," suit low tunings and "Exert more tension on the guitar neck" [9]. Elixir says a slim gauge "requires less pressure to fret notes and perform bends," and that heavier strings hold up better for drop tunings and slide [32].

The "hotter output" claim has real physics behind it. For solid strings, Zollner found "Redoubling the string diameter quadruples the output voltage (all other parameters remaining constant)" [21]. Wound strings are different. The wrap adds about seven times the cross-section of the bare core but only about doubles the output, because the magnetic path through the winding is much harder to travel than through solid steel [21]. In a listening test on a Strat with a Fender 150 set, the plain G came out about 4 dB louder than the wound D at equal pluck force, but Zollner reports it wasn't noticeable in normal playing, and he expects the strings of a set to be roughly equal in loudness [21]. A heavier set is a bit louder. Pickup height still moves output more per millimeter.

Tension

Tension is the pulling force on a tuned string. D'Addario's formula and the way scale length changes tension are in Chapter 4. The short rule from that chapter: tension rises with gauge, with the square of scale length, and with the square of pitch [33].

D'Addario prints a tension chart on each product page. The pages don't say what scale length they assume. When the formula is run backward on the plain strings, every one matches 25.5 inches exactly, so 25.5 is very likely the basis, but that's inferred, not stated [33, 2]. The totals in the next table are my sums; D'Addario doesn't print totals.

Table 11.6: D'Addario published tension (lb), standard E tuning unless noted

Set	E	B	G	D	A	E	Total lb (sum)	Total N (x4.45)	Source
EXL120 9-42	13.1	11.0	14.7	15.7	15.5	14.4	84.4	376	[24]
EXL125 9-46	13.1	11.0	14.7	18.4	19.0	16.9	93.1	414	[25]
EXL110 10-46	16.2	15.4	16.6	18.4	19.0	16.9	102.5	456	[2]

Set	E	B	G	D	A	E	Total lb (sum)	Total N (x4.45)	Source
EXL110BT 10-46 balanced	16.2	16.6	16.6	17.2	17.2	16.9	100.7	448	[34]
XSE1046 XS Nickel 10-46	16.2	15.4	16.6	18.3	19.0	16.8	102.3	455	[17]
EPN110 Pure Nickel 10-45	16.2	15.4	16.6	19.2	20.8	18.6	106.8	475	[10]
EPS510 ProSteels 10-46	16.2	15.4	16.6	17.0	17.8	15.8	98.8	440	[12]
EHR310 Half Rounds 10-46	16.2	15.4	16.6	20.7	19.3	16.5	104.7	466	[14]
EXL140 10-52	16.2	15.4	16.6	24.7	25.6	21.1	119.6	532	[26]
EXL115 11-49	19.6	17.8	18.6	21.1	21.0	19.0	117.1	521	[27]
EXL116 11-52	19.6	17.8	18.6	24.7	25.6	21.1	127.4	567	[28]
ECG24 Chromes flatwound 11-50	19.6	20.5	28.7	26.7	26.9	22.2	144.6	643	[15]
EXL145 12-54	23.4	23.3	22.9	27.6	25.6	23.6	146.4	651	[30]
EPN22 Pure Nickel 13-56	27.4	26.3	37.2	39.3	34.7	28.2	193.1	859	[35]
EXL117 11-56, tuned D standard	15.6	14.2	16.4	21.9	22.1	20.0	110.2	490	[29]
EXL148 12-60, tuned C standard	14.7	14.7	14.5	19.3	19.0	18.5	100.7	448	[31]

Elixir is the one maker here that states its basis outright: its tension charts assume a 25.5-inch scale and standard tuning, and it calls the numbers approximate [36].

Table 11.7: Elixir NANOWEB published tension (lb), 25.5 in, standard tuning

Set	E	B	G	D	A	E	Total (as printed)	Source
Super Light 9-42	13	11	15	16	16	15	85	[36]
Custom Light 9-46	13	11	15	18	20	17	94	[36]
Light 10-46	16	15	17	18	20	17	103	[36]
Light-Heavy 10-52	16	15	17	28	26	22	124	[36]
Medium 11-49	20	18	19	21	22	20	118	[36]
Heavy 12-52	23	23	28	28	26	22	151	[36]

Elixir's printed totals don't always equal the sum of the strings. The Super Light rows add to 86, the Medium rows to 120 and the Heavy rows to 150 [36]. That's rounding, and it's a good reminder that these are guides, not lab values.

Ernie Ball doesn't print tension on its Slinky page [1]. The Regular Slinky uses the same gauges as D'Addario's EXL110, so D'Addario's numbers are a fair rough guide. They aren't Ernie Ball numbers, though, because the weight of a wound string depends on the maker and the wrap.

Table 11.6 shows how much the wrap matters. EPN110 (pure nickel) and EPS510 (stainless) are nearly the same gauges, yet the pure nickel set totals 106.8 lb and the stainless set 98.8 lb. Different wrap metals weigh different amounts per inch, and tension follows weight.

Look at the EXL110BT too. "BT" means balanced tension. D'Addario shifts the B, D and A gauges (a .0135 B, a .025 D and a .034 A) so every string sits near 16 to 17 lb [34]. D'Addario says balanced sets usually stay "within 1 lb" across the strings [33]. Whether that feels better is personal. On paper it brings the B up to match the G at 16.6 lb each.

Fender's setup guide says that when you change string gauge, "you may need to adjust the specs somewhat to compensate," without giving numbers [37]. StewMac says to intonate again after fresh strings and again after a gauge change [38]. The setup numbers are in Chapter 19, and the steps are in my guitar maintenance book.

What the research says about bending

Two papers look at what your fingers do to a string. Both were published in the open journal PLoS ONE.

Grimes 2014

D.R. Grimes measured an Ernie Ball Regular Slinky set: plain .010, .013 and .017 strings of tin-plated high carbon steel, and .026, .036 and .046 wound strings [39]. He found that bending force rises roughly in a straight line with how far you bend the string. He measured the stiffness of the plain strings (their Young's modulus, a measure of how hard a material resists stretching) at about 177.6 to 188.4 GPa, and found the wound strings markedly lower, falling toward the bass [39]. His most practical finding is about fretting. In his words, "string fret-board action has the greatest influence on fretting force required to sound a notes" [39]. Higher frets also took more force [39].

So what does that mean for you? If a guitar feels hard to play, check the action before you blame the strings. Action is the height of the strings above the frets, and Grimes found it outweighs everything else for fretting effort.

Kemp 2017

J.A. Kemp studied the physics of plain and wound strings and applied it to the pitch changes a tremolo arm produces [5]. Several findings carry over to bending.

For plain steel strings, the fraction a string has to stretch to reach a given pitch doesn't depend on its diameter [5]. A whole-tone bend at the 12th fret took 12.5 mm of bend on the plain G strings he tested, 14.7 mm on a standard wound D, and 12.5 mm again on a custom D with a lower ratio of winding to core [5]. Swapping a .016 G for a .014 gave the same tremolo pitch changes to within about 6 cents (a cent is one hundredth of a semitone) [5]. Kemp's own summary: "The ratio of core to winding mass in the string, on the other hand, was found to be a very powerful design parameter" [5].

In plain words, the distance your finger travels for a bend is about the same on a light or a heavy plain string. What changes is how hard you push. A wound string needs more travel for the same bend, because the wrap adds weight without carrying any of the pull [5].

How much harder do you push? Neither paper gives a force per gauge that I can quote. Tension is the best stand-in. On D'Addario's charts the .011 high E carries 19.6 lb and the .010 carries 16.2 lb [27, 2]. That's about 21 percent more tension (computed). That's the extra push your fingers feel when you move up a gauge.

Kemp also measured how setup changes the tremolo. Raising a saddle about 0.5 to 0.6 mm raised tremolo sensitivity by 3.6 to 5.0 percent, and a locking nut raised the high E's pitch range by about 21 percent (from 113 to 137 cents) [5]. Tremolo setup itself is in Chapter 9.

Strings go dead: aging and decay

Every player knows old strings sound dull. Zollner put numbers on it. Decay time is how long a note, or one part of a note, takes to fade by a set amount.

On a low E, Zollner found the low second partial (164.8 Hz) faded at the same rate on old and new strings. Up at 2,391 Hz the old string's decay time dropped to one seventh [22]. A partial is one of the individual frequencies that make up a note. The plain high E showed no aging at all in his test. Wiping cleaned the plain strings but gave only very mild relief on wound ones [22].

In another test, a not-fresh A string on a Les Paul Classic had decay times 50 to 80 percent shorter than a fresh one [23]. Zollner lists the causes as surface corrosion, changes in cross-section, fret-worn grooves, and, most serious, grease, skin and dust packed in and between the windings. His warning is blunt: "After just a few minutes of typical guitar playing, grease and skin deposits already can lead to measurable effects" [23].

Even a new wound string loses treble to friction in its own winding [40]. On a fresh 10-46 set, the low E's fundamental (82.4 Hz) took about 25 seconds to drop 30 dB, while its 12th partial near 1 kHz took about 7 seconds [40]. Two new .026 D strings from different makers were significantly different [40]. So brand-to-brand differences in the wound strings are real, even if the labels look the same.

StewMac's line on this is "Old strings are the enemy of stable intonation" [38]. Dead strings don't just sound dull; they also make it harder to set intonation.

Flatwounds and half rounds

A flatwound string uses a flat ribbon for the wrap instead of round wire, so the outside is smooth. D'Addario's XL Chromes use a "stainless steel flattened ribbon wrap wire" on a hex core, and D'Addario calls them its "warmest, mellowest" electric strings [15]. Ernie Ball's Cobalt Flatwounds use a polished cobalt alloy ribbon and claim reduced finger noise, with a plain G "for easier bending" [16].

Zollner tested a fresh flatwound set (.022, .030, .040, .050 wound strings) on a US Strat and found stronger treble damping than on roundwounds. He puts it down to "larger internal friction losses within the string build," and notes many flatwounds are two-ply, a round inner wrap under the flat outer one [41]. So the mellow sound is measured, not just marketing.

Flatwounds also run tighter. D'Addario's ECG24 11-50 totals 144.6 lb, with a wound .022 G at 28.7 lb, against 117.1 lb for the round-wound EXL115 11-49 [15, 27]. A wound G that tight is a different animal for bending. If you want flatwound feel and still bend, look for a set with a plain G.

Half rounds sit between the two. D'Addario's EHR310 starts as a round-wound stainless string and is then ground smooth by a "centerless grinding process" [14]. D'Addario calls it "a nice medium between round and flat wound strings" [14]. Its tension is close to a normal 10-46 set at 104.7 lb [14].

Coated strings

Coated strings put a thin layer over the string to keep dirt and moisture out. Elixir says its NANOWEB coating is "ultra-thin" and keeps "gunk out of the gaps between the windings," with "Anti-Rust Plated" plain strings [19]. Its OPTIWEB version claims "the same crisp tone as an uncoated string" [18]. Elixir says its three coatings "differ in tone and feel" but give the same protection, and that OPTIWEB is for electric only [42]. Elixir doesn't give a coating thickness [19].

D'Addario's XS Nickel puts an "ultra-thin film coating" on the wound strings and a polymer treatment on the plain ones. It claims "the longest life of any D'Addario electric string" and "staying in tune 131% better than standard electric strings" [17]. It doesn't say how much longer the life is.

Those claims do line up with one measurement. Zollner found that the worst cause of dead wound strings is grease and skin packed between the windings [23]. That's exactly the spot these coatings are built to seal. So the idea makes sense. What I couldn't find is an independent test of coated tone or life.

Down-tuning

Tune down and tension drops with the square of pitch, the same rule as Chapter 4. One semitone down multiplies tension by about 0.891, and a whole step by about 0.794. The next table is computed from D'Addario's page values using that rule.

Table 11.8: Total set tension in pounds at lower tunings, 25.5 in (computed)

Set	E standard (published sum)	Eb standard (computed)	D standard (computed)	Source
EXL120 9-42	84.4	75.2	67.0	[24], computed [33]
EXL110 10-46	102.5	91.3	81.4	[2], computed [33]
EXL115 11-49	117.1	104.3	92.9	[27], computed [33]
EXL140 10-52	119.6	106.6	94.9	[26], computed [33]
EXL145 12-54	146.4	130.4	116.2	[30], computed [33]

A 10-46 set tuned to Eb (91.3 lb) is close to a 9-46 set at E (93.1 lb). An 11-49 set tuned to D standard (92.9 lb) lands about the same. That's why many players who tune down go up a gauge. Drop D on a 10-46 takes the low E from 16.9 lb to about 13.4 lb (computed).

D'Addario's own heavy sets show the same thinking. The EXL117 11-56 set, tuned to D standard, carries 110.2 lb on D'Addario's page, and the EXL148 12-60 set, tuned to C standard, carries 100.7 lb [29, 31]. That's right in the range of a normal 10-46 set at E.

Down-tuning changes more than feel. Kemp found that dropping the low E a whole tone widened its tremolo range from 348 to 419 cents [5]. Looser strings move more for the same arm travel. Zollner found that the same whole-step drop raised the out-of-tune spread of the low E's 20th partial from 2.5 to 3.9 percent [43]. Ernie Ball and Elixir both suggest heavier strings for low tunings [9, 32].

Inharmonicity, briefly

I've mentioned stiffness a few times. Here's the short version. A perfect string would vibrate at a fundamental frequency plus exact whole-number multiples of it. A real string is stiff, so its higher partials sit a little sharp. That spread is called inharmonicity. Zollner says that's why "harmonics" is not quite the right word and "partial" is better [43].

His example shows why strings are wound. A solid 1.2 mm string tuned to 82.4 Hz would have its 20th partial at 2,774 Hz instead of 1,648 Hz. A wound string of 1.3 mm outer diameter puts it at 1,688 Hz, about 2.5 percent sharp [43]. Fretting the octave raises that 20th-partial spread from about 2.5 to 9.5 percent [43]. Lower tension raises it too, which is why down-tuning and short scales push it up [43].

Does it matter? For normal electric strings, not much. Zollner measured a D'Addario .052 low E and found an inharmonicity level under the point where he says it's "clearly noticed." At far higher levels a string starts to sound like a wall-clock chime [44]. On a normal set it isn't something you'll pick out by ear.

Tone and playability at a glance

Table 11.9: What changing strings does

Change	What you'll hear	What you'll feel
Fresh strings vs old	Brighter wound strings, longer treble sustain; plain strings change little	Intonation holds better (StewMac)
Up one gauge (10s to 11s)	A little more output; no per-set measurement found	About 21% more tension on the high E; harder bends
Nickel-plated steel to pure nickel	Slightly softer treble, mostly when strings hit frets	Little difference
Nickel to stainless round wound	Makers claim brighter; Zollner measured little magnetic difference between steel and nickel	No measured difference found
Round core vs hex core	No measurement found	Makers claim round is more flexible
Roundwound to flatwound	Measured treble loss; warmer, darker	Smooth and quiet; tighter, especially with a wound G
Uncoated to coated	Makers claim little or no change; untested here	Smoother feel; claimed longer life
Tune down a whole step, same strings	Slightly more inharmonic low end, a small effect	About 21% less tension; more tremolo travel
Raise pickup 1 mm	2-3 dB more output, more than any wrap change	None

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Part 3: The Electronics

Chapter 12: How a Pickup Works

A pickup is a small generator. It has a magnet, a coil of very fine copper wire, and nothing that moves except your strings. When a steel string vibrates over it, a tiny voltage appears at the ends of the coil, and that voltage is the whole signal your amp will ever get from a passive guitar. Every other part of the electronics can only shape it or take something away.

This chapter is about how that works and which numbers describe it. I'll cover the coil (turns, wire, insulation), the three electrical values that matter (inductance, DC resistance and capacitance), the resonant peak that gives each pickup its voice, and the magnets. I'll also explain why the one number printed on almost every pickup box, DC resistance, tells you so little. Model-by-model spec tables live in Chapter 13. Pickup position, height and switching are in Chapter 14, pots are in Chapter 15, tone caps in Chapter 16 and cables in Chapter 18.

Induction in plain words

In short, a magnet makes a field around itself. Put a steel string in that field and the string becomes a weak magnet too, so it bends the field a little. When the string moves, the amount of magnetic field passing through the coil goes up and down in step with it. A changing field through a coil of wire pushes a voltage out of the coil. That effect is called *induction*, and it's described by Faraday's law.

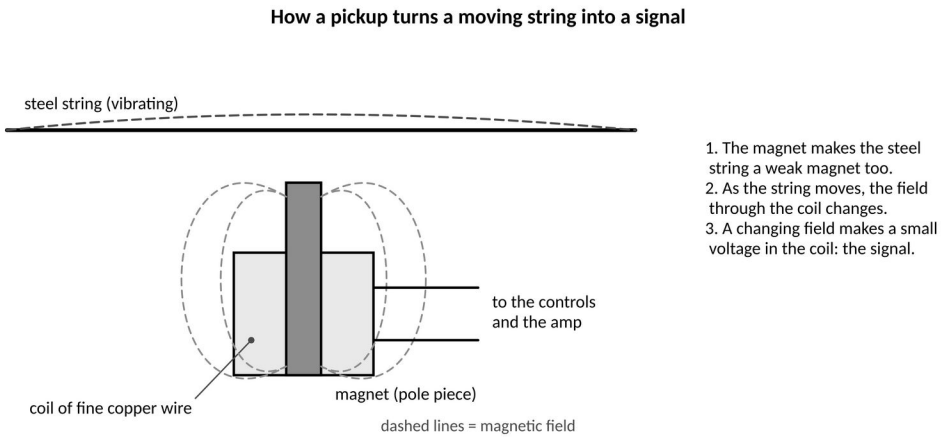


Figure 12.1: How a magnetic pickup works.

Horton and Moore built a physics model of a guitar pickup on exactly this idea and described it as a "straightforward application of Faraday's law" [1]. Their model and measurements agree on some useful details. Up-and-down string motion (toward and away from the pickup) makes a much stronger signal than side-to-side motion; they had to magnify the side-to-side curves 5 and 8 times just to plot them next to the vertical ones [1]. Because the field above a pickup isn't even, the output isn't a pure copy of the string's motion: the pickup adds some harmonics of its own [1]. Their model only drifted away from the measurements when the string got within about 5 mm of a magnet's top [1].

You might ask, "Does a pickup hear wood?" Not directly. It senses the motion of a steel string in a magnetic field. The wood can only matter through what it does to the string, which is a question I take up in my book *Chasing Tone*.

How big is the signal? Lemme puts the output of a passive pickup at roughly 100 mV to 1 V RMS [2]. That's small, and it comes from a source that is easy to load down, which is why the pots, cable and amp input matter so much later in this book.

The coil

Turns

The coil is one long strand of insulated copper wire wound around a bobbin thousands of times. Each pass around the bobbin is a *turn*. More turns give more voltage for the same string motion, but they also change everything else about the pickup, as you'll see.

Zollner gives the first Stratocaster pickups about 8,350 turns, the middle of a range of about 8,000 to 8,700 [3]. He puts single coils in general between 5,000 and 10,000 turns, and he gives Fender's Texas Special neck pickup about 8,200 [3]. His worked example for a 1960s Strat pickup uses 7,600 turns [4].

For the original humbucker, I found no turn count from Seth Lover himself. Zollner, summing up what gets claimed for the PAF, puts it wryly: "two coils with 4500 turns each ... or more .... or less" [5]. It's a good reminder that coils of that era varied.

Active pickups can use far fewer turns because a built-in preamp makes up the level. ElectroSmash's analysis of the EMG 81 reports about 5,500 to 6,000 turns of 0.06 mm wire per coil [6].

Wire gauge

Pickup wire is measured in AWG (American Wire Gauge), where a bigger number means thinner wire. Seymour Duncan names 42, 43 and 44 AWG as the most common gauges for humbuckers [7]. Zollner lists AWG 42 as typical for Fender single coils, with AWG 43 in some cases [3].

How thin is 42 AWG? Zollner gives a diameter of 2.5 mil, about 63.3 micrometers [4]. Its resistance is about 5.4 ohms per meter nominal, with a manufacturing range of 4.9 to 5.9 ohms per meter [4]. Diameter tolerance alone, plus or minus 5%, moves the resistance about plus or minus 10% [4].

In his 1960s Strat example, 7,600 turns at an average of 14 cm per turn add up to about 1,064 m of wire, and that length gives a DC resistance of about 5.7 kΩ [4]. That's more than half a mile of wire in one Strat pickup.

What does gauge do to the sound? A 2024 preprint by Batchelor and colleagues wound Strat-style test coils with Alnico V rods, from 5,000 to 12,000 turns, in 42 and 44 AWG, and measured them on their own with no guitar circuit attached [8]. At the same number of turns, the thicker 42 AWG coils had a higher resonant frequency and a taller peak than the thinner wire [8]. Using the curve fits in their paper, I computed that at 8,000 turns the unloaded peak would sit near 13.4 kHz for 42 AWG and near 10.9 kHz for 44 AWG. Those are unloaded numbers, far above what you hear once a cable is plugged in, but the direction is clear. Keep in mind this paper is a preprint and hasn't been through peer review [8].

Seymour Duncan's VP of Engineering, Kevin Beller, is quoted saying that going from 43 to 44 AWG on otherwise identical pickups raises DC resistance and changes the tone, "but not output" [9]. That doesn't clash with the Batchelor result, which looked at the resonance, not at overall level: thinner wire can move the peak without making the pickup louder.

Insulation

Each turn has to be insulated from the next, or the coil shorts out. Pickup wire is coated with a thin film rather than plastic sleeving. Zollner lists the main types [10]:

- Plain enamel: an oil-based varnish, the brownish or violet wire on many vintage pickups.
- Formvar (polyvinyl formal): glossy gold, and it can't be soldered through.
- Polyurethane: solderable, often red.
- Poly-nylon.

Makers name these on their spec sheets. Fender lists "Formvar-coated" wire on its Pure Vintage '59 Strat set [11] and enamel-coated wire on the Custom Shop Texas Special set [12]. Seymour Duncan lists "42AWG plain enamel mag wire" on its '59 Model [13].

Does the coating change the sound? A little, and mostly through geometry. Zollner explains that double-coat wire needs about 20% more room, so a full bobbin holds about 17% fewer turns, which lowers inductance and output [10]. The coating's effect on capacitance is small. In Zollner's example, doubling the coil's own capacitance from 50 to 100 pF, with a 450 pF cable attached, moves the resonance about 5%: the same shift you'd get from making the cable 11% longer, 3.75 m to 4.15 m [10]. In his words, "Compared to the all-dominating cable capacitance only marginal changes in capacitance are to be expected" [10].

One bit of history. Zollner reports that a 1960s Fender insulation called Polysol dissolved in hot wax and caused shorts, so Fender stopped wax potting until the 1980s [10].

Three electrical numbers

Once a coil is wound, it acts like three electrical parts rolled into one. Here they are in plain words.

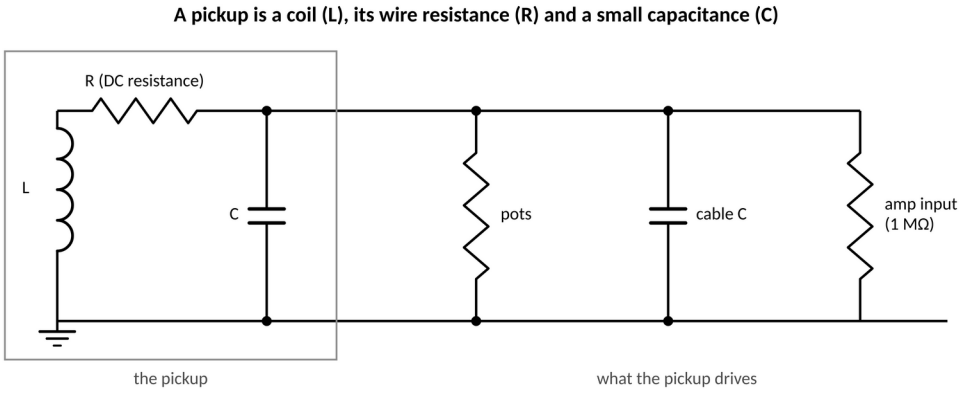


Figure 12.2: The usual simple model of a passive pickup and what it drives. The values for real pickups are in the tables in this chapter and Chapter 13.

Inductance is a coil's resistance to changes in current. It's measured in henries (H). For a pickup, inductance mostly depends on the number of turns, the shape of the coil, and the metal inside it. Lemme gives pickup inductance as 1 to 10 H and calls it the most important quantity [2]. Zollner agrees, calling inductance "the most important electrical parameter" [14].

DC resistance (DCR) is the plain resistance of the copper wire, what an ohmmeter reads across the leads. It depends only on the wire's length and thickness. Lemme calls it "the least interesting magnitude of all" [2].

Capacitance is the ability to store charge between two conductors that sit close together. In a coil, every turn sits right next to its neighbors, so the whole winding has a little capacitance of its own, measured in picofarads (pF). The sources disagree a bit on how much. Lemme gives 80 to 200 pF [2]; Zollner gives 10 to 150 pF for customary pickups [14].

How the numbers move together

Inductance grows faster than the turn count. Zollner reports that it scales roughly as the number of turns raised to the power 2.14 [14]. In practice that means 10% more turns gives about 23% more inductance, and at the same capacitance it pulls the resonance down by about 10% [14]. Voltage only goes up about 0.9 dB for that same 10% more wire [15]. So "hotter" winds get a little louder and noticeably darker.

The magnet and any steel parts raise inductance too. Zollner's Strat example has 7,600 turns and measures 1.7 H with no magnets, and about 2.2 H with them installed, so the magnets add about 30% [14]. Iron or nickel pole pieces, screws and plates raise it as well [14].

Two coils add up. Lemme explains that a humbucker, compared with one of its coils, has double the inductance and resistance and half the capacitance [2]. Zollner adds a wrinkle: if the two coils share their magnetic field fully, inductance can go up four times instead of two [14]. Coil splits and series and parallel wiring (Chapter 14) build on this.

Why DC resistance is a poor guide

DCR is printed on almost every pickup box because it's easy to measure. Makers use it to check that a coil was wound to spec. It was never meant to tell you how loud or how dark a pickup is.

Here's the clearest example I know. Zollner measured a DiMarzio SDS-1 at 9.1 kΩ and found it gave more voltage than a vintage Strat pickup at 5.8 kΩ, which makes sense. But a Gibson Tony Iommi signature humbucker at 17.8 kΩ, nearly twice the SDS-1's resistance, gave *less* voltage than the SDS-1 for the same string vibration [15]. His summary is blunt: "For identical DC resistances the transmission coefficient can vary as much as a factor of 4!" [15] A factor of 4 in voltage is a big difference, about 12 dB.

Why? Output depends on the turns, the strength of the magnetic field at the string and the shape of the coil. DCR depends on the length and thickness of the wire. Thinner wire, a wider bobbin, or a stacked design can all push DCR up without adding signal. Zollner points out the simplest proof of all: pull the magnet out and the DCR doesn't change, but the loudness "approaches zero fast" [4].

The makers say the same thing. DiMarzio's FAQ states that "DC resistance is not a direct indicator of tone or output" and says its own output figure is a better guide to relative loudness among its pickups [16]. DiMarzio's own data shows it: the Air Norton lists 12.58 kΩ and an output of 270, while the PAF 36th Anniversary Bridge lists 8.60 kΩ and an output of 285 [17, 18]. Seymour Duncan's blog opens with "Misinformation is rampant on the topic of DCR" and gives its own examples: a Cory Wong stacked bridge pickup reads 14.54 kΩ against 7.05 to 7.15 kΩ for the single coils in that set, yet, as Duncan puts it, that "doesn't mean" it's "twice as loud," and the Vintage Stack reads near 20 kΩ with output close to vintage levels [9]. Lollar notes that it builds pickups to turn counts, not to DCR, and that a wider coil or thinner wire reads higher for the same turns [19].

DCR also drifts with things that have nothing to do with sound:

- Temperature: copper's resistance rises about 0.39% per degree Celsius [4]. Lollar notes a warm pickup reads higher [19].

- What's connected: Zollner's example pickup of 13.00 kΩ reads 12.67 kΩ through a 500k volume pot and 12.36 kΩ through a 250k pot [15].
- Unit-to-unit spread: two Gibson 498T samples tested by German magazines differed by 9.6% [15], and Zollner reports Fender's ohmmeter check allowed plus or minus 20% [3].

So where is DCR useful? Within one maker's line, built the same way with the same wire, more DCR usually means more turns, more inductance, and a lower, darker peak. It's also a quick check for a broken coil. Lemme calls measuring only DCR "a fundamental error," and I agree [2].

The resonant peak

If you take one idea from this chapter, take this one.

A pickup's inductance and the capacitance around it (the coil's own plus the cable's) form what electrical engineers call a resonant circuit. *Resonance* is a frequency where a system responds more strongly than anywhere else, like a swing that goes highest when you push it at just the right rhythm. For a pickup, that means one band of treble comes out louder than the rest.

Picture the pickup's frequency response, from low notes on the left to high treble on the right. It's roughly flat through the bass and mids. Then it rises to a hump, the *resonant peak*. Past the peak it falls off steeply, about 12 dB for each octave higher, and as much as 18 dB per octave when eddy-current losses are strong [2]. (Eddy currents are small swirling currents induced in metal parts, such as magnets, covers and base plates, that soak up energy.)

Where does the peak land? The standard formula, which ElectroSmash prints for pickups [6], says: the resonant frequency equals one divided by the quantity two times pi times the square root of inductance times capacitance. In symbols, $f = 1 / (2\pi\sqrt{(LC)})$. You don't need to calculate anything. Just remember the direction: more inductance or more capacitance moves the peak lower, and the sound gets darker. Because of the square root, it takes four times the capacitance to cut the frequency in half.

Q: how tall the peak is

The peak has a height as well as a position. Engineers call its sharpness *Q* (for "quality factor"). A high Q is a tall, narrow spike. A low Q is a gentle hump, or no hump at all. Zollner calls Q "the second-most important transmission parameter right after the resonance frequency" [20].

Lemme puts peak height between 1 and 4 times the level of the flat part, which is 0 to 12 dB [2]. He says the height is set by the magnet material, the resistive load and any metal cover; a pickup with no cover has a higher peak [2]. Zollner shows Jazzmaster curves with Q values of 9.0, 2.5, 1.4, 0.9 and 0.5 [20]. Q of 9 gives a 19.1 dB boost, but that's the lightly damped case with no pots attached, too shrill to be practical; with volume and tone pots and an amp connected, he finds Q of about 3 [20]. By his rule of thumb that the boost in decibels is about 20 times the log of Q, I worked out that Q of 3 is about a 9.5 dB peak, though the rule gets less accurate at low Q [20].

What brings Q down? Resistance across the pickup. Every pot and the amp input sit across the pickup like a drain to ground, and the lower their combined value, the flatter the peak. Lemme describes a 1972 Strat pickup with a 470 pF load whose peak vanished completely once the resistive load dropped to 47 kΩ or less [2]. Losses inside the pickup work the same way. Lemme also measured a Hoyer pickup from around 1970 that showed no peak at all with 470 pF and 250 kΩ, because of strong eddy currents [2].

The pickup's own DCR matters less than you might expect. Zollner notes that raising coil resistance by 50% changes the height of the resonance only slightly [20]. The load across the pickup (mostly the pots, which get their own chapter, Chapter 15) and the eddy-current losses do most of the work.

Loaded and unloaded

This is where a lot of confusion comes from. A pickup sitting on a bench with nothing attached has only its own small winding capacitance, so its peak sits very high. Zollner gives about 9 kHz for an unloaded Stratocaster pickup [20]. Plug in a cable and the cable's capacitance (300 to 600 pF by Zollner's figures, 300 to 1,000 pF by Lemme's) dwarfs the coil's own [20, 2]. Both authors agree that with normal cables the peak lands between 2 and 5 kHz [2, 20].

The amp adds a bit more. Zollner gives a typical guitar amp input of 1 MΩ, and he notes that the input tube adds roughly 80 to 150 pF and its wiring about 50 pF more, on top of the cable [21].

So when you see a resonant frequency on a spec sheet, ask what was connected when it was measured. A number around 9 kHz is probably the pickup alone. The number you'll hear depends on your cable (more on that in Chapter 18), your pots and your amp.

Four pickups under the same load

To show how the numbers play out, I modeled four pickups under the same load. The model is the standard one described by Lemme, Zollner and ElectroSmash: the pickup is treated as its inductance and DC resistance in series, with its winding capacitance across the output, and the outside load adds a capacitance and a resistance across that [2, 20, 6]. I used the inductance and DCR each maker lists. Fender lists 2.2 H and 5.8 kΩ for its Pure Vintage '59 Strat pickups [11] and 2.97 H and 6.56 kΩ for the Custom Shop Texas Special bridge [12]. TV Jones lists 1.83 H and 4.8 kΩ for its TV Classic bridge, a Filter'Tron-style humbucker [22]. Most humbucker makers don't publish inductance, so for the fourth curve I used ElectroSmash's "typical" humbucker values: 10 H, 15 kΩ and 200 pF [6]. For the three single-coil-type pickups I assumed 100 pF of winding capacitance, ElectroSmash's typical single-coil value, because the makers don't list it [6].

The load is two 500k pots turned full up, a 1 MΩ amp input and 450 pF of cable. Those three resistances in parallel come to 200 kΩ (my arithmetic).

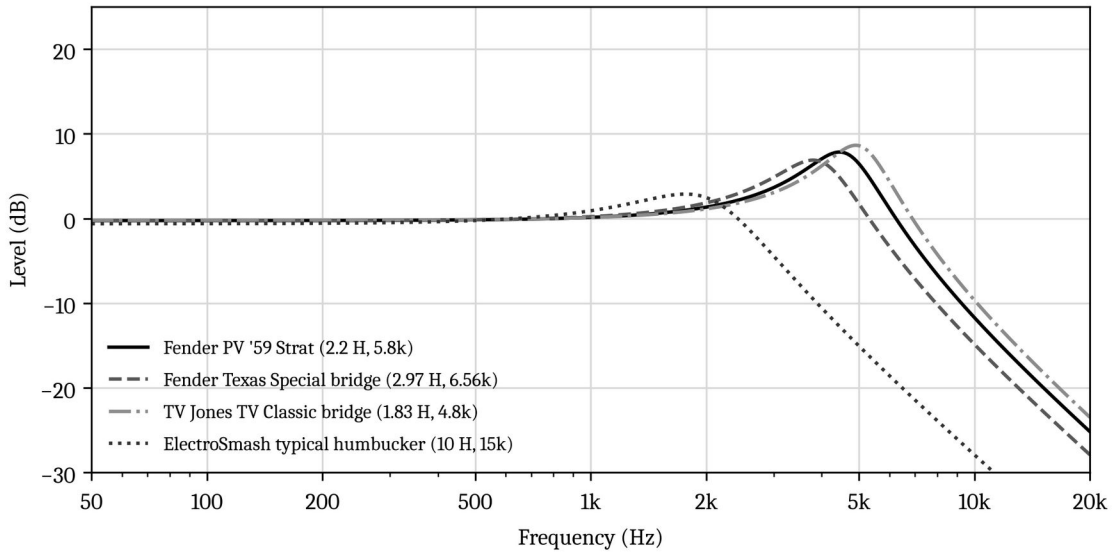


Figure 12.3: Modeled response of four pickups under the same load (two 500k pots at full, 1 MΩ amp input, 450 pF of cable). Values: Fender Pure Vintage '59 Strat (2.2 H, 5.8k), Fender Texas Special bridge (2.97 H, 6.56k), TV Jones TV Classic bridge (1.83 H, 4.8k), and ElectroSmash's typical humbucker (10 H, 15k, 200 pF). This simple model leaves out eddy-current losses, so real peaks are lower and broader.

Plugging those values into the formula above (winding capacitance plus the 450 pF of cable), I computed these resonant frequencies: about 5.0 kHz for the TV Classic bridge, 4.6 kHz for the Pure Vintage '59, 3.9 kHz for the Texas Special bridge and 2.0 kHz for the typical humbucker. The curves in Figure 12.3 come from the full model, which also includes the coil's resistance and the 200 kΩ load, and there the peaks land a little lower: about 4.9, 4.5, 3.8 and 1.8 kHz, standing roughly 8.6, 7.8, 6.9 and 2.9 dB above the low-frequency level, in that order. Damping pulls each modeled peak slightly below the simple formula's answer, and the most for the heavily damped humbucker. The low-inductance Filter'Tron-style pickup sits highest. The Texas Special, with about a third more inductance than the '59, sits lower. The humbucker, with several times the inductance, sits lowest, and its peak is much flatter because its higher DCR and heavier inductance leave it more damped by the same load.

Read this chart for direction and rough size, not as a picture of exact sound. The model leaves out eddy currents, covers, the amp's own input capacitance, and the comb-filter effects of pickup position (Chapter 14). Real peaks will be lower and broader than these curves. Still, it shows the pattern: among passive pickups, much of the difference between a bright one and a thick one comes down to where the peak sits and how tall it stands, and inductance sets most of that.

Magnets

The magnet does two jobs. It magnetizes the string so the string can disturb the field, and it sets how strong that field is, which sets how much voltage you get. It also pulls on the string, which matters for playability.

The alloys and their numbers

Pickup magnets come in three families. *Alnico* is a cast alloy of aluminum, nickel and cobalt with iron. *Ceramic* magnets are barium or strontium ferrite. *Rare-earth* magnets are neodymium-iron-boron (NdFeB) or samarium-cobalt.

Three data-sheet numbers describe a magnet material. *Remanence* (Br) is how strong the magnetism is that the material keeps after it's magnetized. *Coercivity* (Hc) is how hard it is to demagnetize. *Energy product* (BHmax) is a combined figure of merit for how much magnetic energy the material can deliver. Table 12.1 gives typical values from the magnet makers' own data sheets.

Table 12.1: Typical magnet material properties from maker data sheets

Material	Remanence Br	Coercivity Hc	Energy product BHmax	Conducts electricity?	Source
Alnico 2	7,200 G (0.72 T)	560 Oe (45 kA/m)	1.60 MGOe (12.7 kJ/m^3)	Yes	[23]
Alnico 3	7,000 G (0.70 T)	475 Oe (38 kA/m)	1.40 MGOe (11.1 kJ/m^3)	Yes	[23]
Alnico 4	5,500 G (0.55 T)	720 Oe (57 kA/m)	1.35 MGOe (10.7 kJ/m^3)	Yes	[23]
Alnico 5	12,500 G (1.25 T)	640 Oe (51 kA/m)	5.50 MGOe (43.8 kJ/m^3)	Yes	[23]
Alnico 8B	8,300 G (0.83 T)	1,650 Oe (131 kA/m)	5.50 MGOe (43.8 kJ/m^3)	Yes	[23]
Ceramic 5	3.80 kG (0.380 T)	2.40 kOe (191.0 kA/m)	3.40 MGOe (27.1 kJ/m^3)	No	[24, 25]
Ceramic 8	3.85 kG (0.385 T)	2.95 kOe (234.8 kA/m)	3.50 MGOe (27.9 kJ/m^3)	No	[24, 25]
NdFeB N42H	13,000 G (1.30 T)	12,300 Oe (979 kA/m)	42 MGOe (330 kJ/m^3)	Yes	[26]
NdFeB N52	14,500 G (1.45 T)	12,300 Oe (979 kA/m)	51 MGOe (406 kJ/m^3)	Yes	[27]

Metric values in parentheses for Alnico 3, 4, 5 and 8B were converted from Arnold's gauss and oersted figures; the others are as the data sheets print them. Ceramic and neodymium coercivity is the "HcB" figure.

Alnico 5 has a much higher remanence than Alnico 2, 3 or 4. Ceramic has low remanence but very high coercivity, so it's hard to demagnetize. Neodymium beats everything on every column, but Zollner notes rare-earth magnets show up in pickups only in tiny amounts [25]. Alnico grades also differ in what's in them: Arnold reports cobalt content from 0% in Alnico 3 up to 40% in Alnico 8 [23].

The last column matters more than it looks. Zollner points out that "Ceramic magnets are insulators unable to produce eddy currents" [25], while alnico conducts, and Alnico 5 conducts about 40% better than Alnico 2 [28]. A conductive magnet inside the coil adds eddy-current losses, which damp the peak a little.

Rods and bars

How the magnet is placed matters as much as what it's made of.

In a Strat or Tele pickup, the magnets are the pole pieces. Zollner describes six cylindrical Alnico 5 rods about 3/16 in (4.8 mm) across and 12 to 19 mm long, depending on the year [3]. The magnet sits right under the string and inside the coil. That's why removing the magnets from his Strat example dropped the inductance from 2.2 H to 1.7 H [14].

In a P-90, Gibson used two bar magnets under the coil, and six steel pole screws carry the field up to the strings [3]. Humbuckers follow the same plan with one bar under both coils. Since the magnet sits outside the coil, it affects inductance far less: Zollner reports that removing a humbucker's magnet changes its inductance only about 3% [5]. Ceramic magnets work best as short, wide shapes, so they're used as bars under the coil and almost never as rods inside it [25]. Once steel poles guide the field through the coil, the eddy losses in the steel come back [25].

What the alloy does to tone

This is where the claims get ahead of the evidence, so I'll stick close to the numbers.

A stronger field at the string gives a more sensitive pickup. Zollner puts it simply: "the stronger a magnet is, the more sensitive the pickup is" [29]. He measured fully magnetized cylinders at 2 mm and found about 35 mT for Alnico 2 and about 60 mT for Alnico 5 [29]. He also quotes the rule that "Alnico-V will produce a magnetic field twice as strong as that of Alnico-II or Alnico-III," as a rough guide for rod-magnet single coils [28]. Seymour Duncan reports that at equal DCR, output runs Alnico 2, then Alnico 5, then ceramic, from lowest to highest [9].

But the alloy name isn't the whole story. Zollner notes that magnets are often sold not fully magnetized [29], and Lollar says plainly that "AL-2, AL-3, AL-5 are not a measure of magnet strength" [19]. Both can be true. Alnico 5 material can hold more magnetism, but a maker can magnetize, or "age," any magnet to a lower level. Zollner found output differences of up to about 6 dB between magnets, with voltage rising in step with field strength [29].

What about the shape of the frequency response, the thing people mean by "warm" or "bright"? Zollner swapped Alnico 2 for Alnico 5 in a single coil and the frequency response changed by about 0.8 dB, which he judged inaudible [29]. Seven different humbucker bar magnets differed by less than 0.4 dB [29]. The changes that did show up came through inductance. Demagnetizing an Alnico 2 Tele pickup lowered its inductance 7% and raised its resonance 3.5%, and a magnetized Alnico 5 Strat pickup measured about 13% more inductance than when demagnetized [29]. Zollner adds that a stronger magnet usually gives slightly more brilliance, because it adds a little less inductance [28].

Ceramic follows the same logic. Seymour Duncan says ceramic magnets have "the effect of decreasing the inductance of the pickup and significantly raising the resonant frequency" [30], and Zollner explains why: ceramic barely adds to inductance because its permeability is close to 1 [25].

A magnet swap changes output more than tone color. If you hear a darker or brighter sound after a swap, check whether it's also louder or quieter, because level alone changes how we hear tone. I haven't found a level-matched blind test of magnet swaps. My book *Chasing Tone* has more on that myth.

Magnetic pull and warble

The magnet doesn't just sense the string. It pulls on it. Zollner explains that the magnet acts like a negative spring on the string (his term is "negative stiffness"), and "the fundamental will be detuned the most" [31]. In his measurement on a low E string the shift was only several hertz, but it was enough to split the string's up-and-down and side-to-side vibrations so they beat against each other at a few hertz [31]. That beating is the *warble* you hear when a Strat pickup is set too high. Lemme calls the effect "Stratitis": the magnets pull the strings and shift the harmonics, and the fix is to lower the pickup [2]. DiMarzio warns that a strong enough field "alters string vibration enough to make the guitar sound out of tune" [16].

Rod-magnet single coils are the usual suspects because the magnet sits right under the string. Bar-magnet designs put a steel pole between them. Either way, the fix is pickup height, and the makers' recommended numbers are in Chapter 14.

Tone and playability at a glance

Table 12.2: Pickup construction changes, rated

Change	What you'll hear	What you'll feel
More turns (same wire)	Somewhat louder; peak moves lower, so darker and more midrange (about 10% lower per 10% more turns)	Nothing directly
Thinner wire, same turns	Lower, smaller peak; little change in output	Nothing
Higher DCR alone (different design)	Can't tell from the number; output can vary by a factor of 4 at the same DCR	Nothing
Double-coat or thicker insulation	Fewer turns fit, so a bit less output and a slightly higher peak; the coating's own capacitance effect is tiny	Nothing
Alnico 2 to Alnico 5	More output if more strongly magnetized; frequency response change measured at about 0.8 dB	More string pull
Alnico to ceramic (bar)	Typically more output and a higher peak; no eddy losses in the magnet	Depends on field strength
Weaker or "aged" magnet	Less output; inductance shifts a few percent	Less pull, so the pickup can sit closer
Longer cable or more load capacitance	Peak moves lower: darker	Nothing
Higher-value pots (lighter load)	Taller peak: brighter, more "bite"	Nothing
Pickup set too close (rod magnets)	Warble, out-of-tune notes, less sustain	Notes that won't settle in tune

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Chapter 13: Pickup Types and Models Compared

Walk into any guitar shop and ask for "a warmer bridge pickup" and you'll get a stack of boxes, each with a short list of numbers on the back. Some list resistance. A few list inductance. One maker lists a number called "output" with no unit at all. In this chapter I'll line up the main pickup types side by side, give you the numbers the makers publish, and show you which of those numbers tell you something and which ones mostly fill space on the box.

The physics, how a magnet and a coil turn a moving string into a signal and why every passive pickup has a resonant peak, is in Chapter 12. I'll lean on that chapter here instead of repeating it. Where a pickup sits on the guitar, how high you set it, and how you switch and combine pickups all live in Chapter 14.

Players often ask for the hottest pickups they can buy, expecting instant great tone. I do not play, but my ear tells me when an overwound pickup turns muddy. A lot depends on how the manufacturer designed and wound the pickup. Matching the pickup to the guitar and amp gives a clearer voice than chasing output numbers.

A few terms before the tables

Four words show up in every table in this chapter, so let's pin them down.

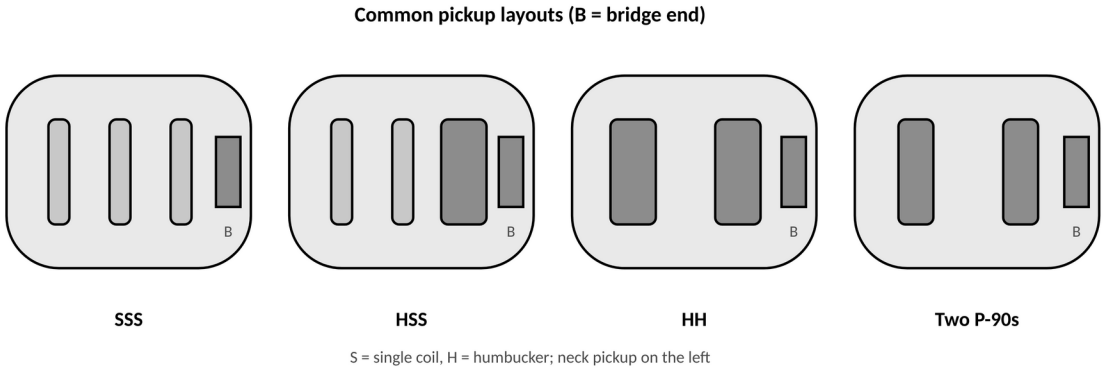


Figure 13.1: Common pickup layouts, neck pickup on the left.

DC resistance (DCR) is the resistance of the coil's copper wire, read with an ordinary ohmmeter. It's given in ohms, usually in thousands of ohms written as "k". It goes up with more turns of wire and with thinner wire.

Inductance is the coil's opposition to a changing current, measured in henries (H). It depends mostly on the number of turns, the coil's shape and the metal parts in and around it. Zollner calls it "the most important electrical parameter" of a pickup [1].

Resonant peak (or resonant frequency) is the point, in hertz (Hz) or kilohertz (kHz), where the pickup and everything connected to it give a small boost before the treble rolls off. Lower peak means a darker sound. Higher peak means a brighter one (Chapter 12 has the reason).

Hum rejection is how much less mains hum a pickup picks up compared to a plain single coil, given in decibels (dB). A decibel is a ratio of two levels on a log scale; bigger numbers mean more hum is removed.

One more thing before we start. Every spec in this chapter is the maker's own claim unless I say it was measured by someone else. When I write "Fender lists" or "Seymour Duncan lists," I mean exactly that.

Single coils

A single-coil pickup is one coil of fine wire wrapped around magnets. On a Stratocaster or Telecaster pickup, six round Alnico 5 rod magnets go straight through the coil, one under each string. Zollner gives their diameter as about 3/16 in (4.8 mm), with lengths of 12-19 mm over the years [2]. The wire is usually 42 AWG (American Wire Gauge, where bigger numbers mean thinner wire), sometimes 43, and single coils in general carry somewhere between 5,000 and 10,000 turns [2].

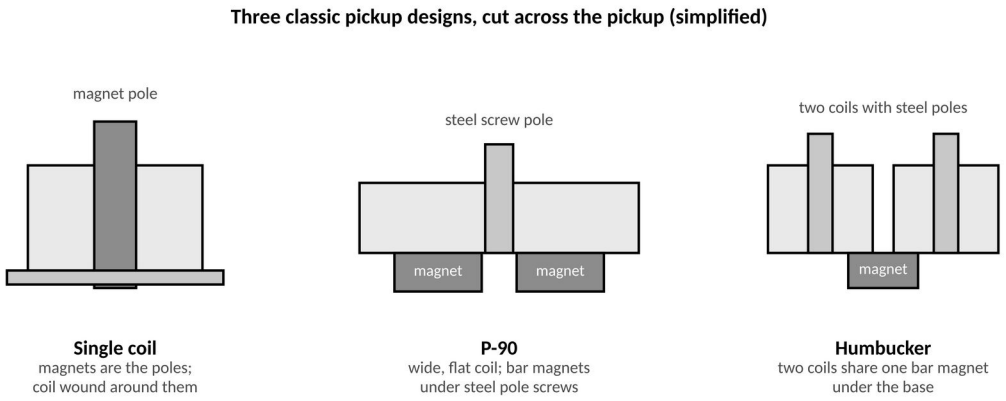


Figure 13.2: The three classic passive pickup designs, cut across the pickup and simplified. Details differ by maker and model.

The Stratocaster pickup

The first Stratocaster pickups had about 8,350 turns, the average of a range from 8,000 to 8,700 [2]. Fender checked them with an ohmmeter and allowed a tolerance of plus or minus 20% [2]. That's a wide window.

Fender staggered the pole heights starting around 1954 [2]. Staggering is about string balance. Zollner measured that wound strings give 4-10 dB less output than plain strings of the same pitch [3]. Fender's later beveled poles (on the Noiseless Strat) measured only 0.2 dB different from flat ones in Zollner's test [3]. That's well under what you'd hear.

Seymour Duncan's list of vintage-style values puts the Stratocaster pickup at 5.8K-6.3K [4]. Here is what current makers list.

Table 13.1: Stratocaster-style single coils, maker data

Model	DC resistance	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Fender Pure Vintage '59 Strat	5.8k (all three)	2.2 H	not listed	Alnico 5 rods	[5]
Fender Pure Vintage '65 Strat	5.9k (all three)	2.6 H	not listed	Alnico 5 rods	[6]
Fender Custom Shop Fat '50s (neck / middle / bridge)	6.26k / 6.34k / 6.43k (spec tab; overview says 6.0k / 6.3k / 6.2k)	2.49 / 2.5 / 2.63 H (spec tab; overview says 2.4 / 2.75 / 2.8 H)	not listed	Alnico 5 rods	[7]

Model	DC resistance	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Fender Custom Shop Texas Special (neck / middle / bridge)	5.94k / 6.27k / 6.56k	2.57 / 2.62 / 2.97 H	not listed	Alnico 5 rods	[8]
Seymour Duncan SSL-1 Vintage Staggered	6.5k	not listed	10 kHz	Alnico V rods	[9]
Seymour Duncan SSL-2 Vintage Flat	6.6k	not listed	9 kHz	printed as "Alnico V Bar"	[9]
Seymour Duncan SSL-5 Custom Staggered	12.9k full; 6.6k tapped	not listed	4.9 kHz full; 6 kHz tapped	Alnico V rods	[9]
Seymour Duncan SSL-4 Quarter-Pound Flat	13.3k; 6.9k tapped	not listed	4.8 kHz; 5.5 kHz tapped	0.25 in Alnico V rods	[9]
Seymour Duncan SSL-3 Hot	16.4k; 8.8k tapped	not listed	4.4 kHz; 5.3 kHz tapped	Alnico V rods	[9]

Look at the Fender rows and you'll see something useful. Within one maker's line, the hotter sets carry more inductance. The Texas Special bridge lists 2.97 H [8], while the Pure Vintage '59 lists 2.2 H for all three positions [5]. More turns means more inductance, and more inductance means a lower resonant peak, so the Texas Special bridge should sit lower and darker than the '59.

The Duncan SSL-5 shows the same thing inside a single pickup. Tapped, it reads 6.6k with a 6 kHz peak. Using the full coil, it reads 12.9k with a 4.9 kHz peak [9]. Nothing changed but the amount of wire, and the peak came down.

The Telecaster bridge pickup

For thirty years the Tele bridge pickup had a steel plate on its underside. Zollner describes that base plate as about 1.2 mm of copper-plated steel, used from 1951 to 1981 [2]. He measured what it does: about 0.6 dB more sensitivity, about 1 dB less resonance emphasis, and a resonance about 3% lower, from an inductance about 6% higher [2]. Lollar reports a similar effect from a steel baseplate on a Strat-type coil, which raises inductance from 2 H to "approximately 2.15 henries" [10]. So the plate does something, but it's a small something.

Early Tele bridge pickups are a good example of how loose old numbers can be. Zollner notes that one source gives 7.5k and another gives up to 11k [2]. Seymour Duncan's own list says 6.2K-6.6K for a Tele lead pickup and 7.6K for a Broadcaster lead [4].

The Telecaster neck pickup

The Tele neck pickup wears a metal cover. Seymour Duncan lists a vintage Tele rhythm (neck) pickup at 7.6K [4]. Fender's Pure Vintage '64 set lists a chrome cover on the neck and no cover on the bridge [11]. That cover matters more than you might think, and I'll come back to it under covers below.

Table 13.2: Telecaster pickups, maker data

Model	DC resistance	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Fender Pure Vintage '64 Tele neck	7.4k	2.1 H	not listed	Alnico 5	[11]

Model	DC resistance	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Fender Pure Vintage '64 Tele bridge	6.0k (spec tab; overview says 7.4k)	2.8 H (spec tab; overview says 2.1 H)	not listed	Alnico 5, copper shielding plate	[11]
Seymour Duncan APTL-1 (lead)	6.2k	not listed	8.5 kHz	Alnico II rods	[9]
Seymour Duncan STL-1 Vintage '54 (lead)	7.2k	not listed	9 kHz	Alnico V rods	[9]
Seymour Duncan STR-1 Vintage (rhythm)	7.3k	not listed	8 kHz	Alnico V rods	[9]

Fender's bridge listing is worth a second look. If the spec tab is right, the bridge has lower resistance (6.0k) but higher inductance (2.8 H) than the neck (7.4k, 2.1 H) [11]. That's not a typo in the physics. A different coil shape and the plate under the bridge pickup can raise inductance without adding wire. It's one more sign that resistance alone won't tell you how a pickup will sound.

Wider single coils

Fender didn't stop at the Strat coil. For the Jazzmaster in 1957, the coil was widened from 12 mm to 35 mm and made lower [2]. Zollner measured the Jazzmaster's hum at 7-8 dB more than a Strat's, but its signal was only about 5 dB stronger, so its signal-to-hum ratio was about 2 to 3 dB worse than a Strat's [12]. Wide and flat is not a hum fix.

The P-90

Gibson's P-90 dates from 1946 [2]. It's still a single coil, but it's built differently from a Fender pickup. Two bar magnets sit under a wide, flat coil, and six steel pole screws carry the magnetic field up to the strings [2, 13]. The poles adjust with a screwdriver, and the coil is wide.

Seymour Duncan's vintage list puts a Gibson P-90 at 8.6K [4]. Gibson lists its current P-90 Soapbar at an "Average DC Resistance" of 8K with Alnico 5 magnets, fully wax potted [14].

Table 13.3: P-90 pickups, maker data

Model	DC resistance (neck / bridge)	Resonant peak (Duncan 2015 chart)	Magnet	Source
Gibson P-90 Soapbar	8K (average)	not listed	Alnico 5	[14]
Lollar P-90 Soapbar	8.2K / 9.1K (average)	not listed	Alnico 5	[15]
Seymour Duncan SP90-1 Vintage	8.22k / 9.35k	4.3 / 3.8 kHz	Alnico V bar	[9]
Seymour Duncan SP90-2 Hot	11.86k / 14.9k	5.1 / 4.7 kHz	small ceramic	[9]
Seymour Duncan SP90-3 Custom	12k / 14.61k	4.5 / 3.5 kHz	large ceramic	[9]

The vintage SP90-1 has the lowest resonant peaks of any vintage-style model on Duncan's 2015 chart [9]. That fits what you'd expect from a wide coil with a lot of inductance, though Duncan doesn't say why. Notice too that the Hot P-90 has more resistance than the Custom on the bridge side (14.9k against 14.61k) but a higher peak (4.7 kHz against 3.5 kHz) [9]. The Hot uses a small ceramic magnet and the Custom a large one, so something besides resistance is moving the peak, though Duncan doesn't say what. On ceramic magnets in

general, Seymour Duncan says they have "the effect of decreasing the inductance of the pickup and significantly raising the resonant frequency" [16].

The humbucker

Where it came from

The humbucker was Seth Lover's design for Gibson. Gibson applied for the patent in 1955, guitars with humbuckers reached the market in 1957, and the patent was granted in 1959 [17]. For those two years in between, the pickups wore a sticker that said "Patent Applied For," which is where the name "PAF" comes from [17].

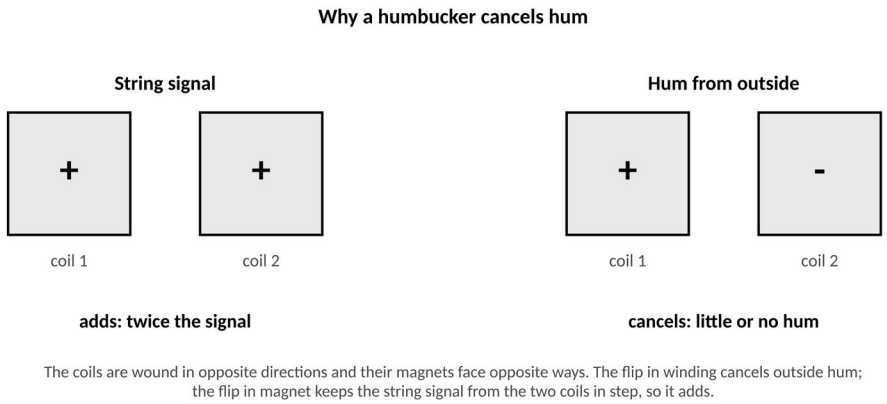


Figure 13.3: Two coils, wound and magnetized in opposite directions: the string signal adds, outside hum cancels.

One fun bit of history: later stickers carried patent number 2,737,842, but the humbucker's real number is 2,896,491. Lover said the wrong number was there to mislead competitors [17].

How many turns did a PAF coil have? The usual figure, as Zollner reports it, is about 4,500 per coil, "or more .... or less" [17]. You'll also see "about 5,000 per coil" in plenty of places. I couldn't find a solid source for that one.

How it cancels hum

A humbucker is two coils side by side. The two coils are wound so their hum signals are opposite, and the magnet's field runs the opposite way through each coil. Mains hum from your amp, lights and wall wiring hits both coils about equally, and because the coils are connected out of phase for hum, the two hum voltages cancel. The string signal, though, comes out in phase because the magnetic field is also reversed, so it adds [17]. Zollner puts the key idea simply: an outside interference field induces the same voltage in each coil [17].

Two details matter. First, the coils have to match for the cancelling to work well. If the coils are wound differently, Zollner notes, cancellation works only over some frequencies, usually the lower ones [17]. Gibson's Burstbuckers are sold with "historically unmatched coil windings" [18], so in theory they give up a little hum rejection for whatever their designers were after. Second, the magnet has less to do with the sound than you might guess. Removing the magnet changes a humbucker's inductance by only about 3% [17].

What two coils do to the numbers

Compared to one of its coils, a humbucker roughly doubles both inductance and resistance and halves the coil's capacitance [19]. That helps explain why a humbucker reads around 8k where a Strat pickup reads

around 6k, even though Lover's coils had fewer turns each than an early Strat coil [2, 17]. Gibson-type humbuckers space the two rows of poles 18-19 mm apart [20]. Sensing the string at two points that far apart also cuts some treble, especially around 3 kHz on the low E string [21]. That comb effect ties in with pickup position, so I deal with the two together in Chapter 14.

Humbucker specs compared

Seymour Duncan's vintage list gives a Gibson P.A.F. at 8.4K [4]. Current makers list these values.

Table 13.4: PAF-style and vintage-output humbuckers

Model	DC resistance (neck / bridge)	Resonant peak (Duncan 2015 chart) or DiMarzio output	Magnet	Source
Gibson Burstbucker Type 1 / 2 / 3	7.8K / 8.4K / 8.7K (average)	not listed	Alnico 2, unpotted	[18]
Gibson '57 Classic	8K (average)	not listed	Alnico 2, wax potted	[22]
Gibson 490R / 498T	8K / 14.2K (average)	not listed	Alnico 2 / Alnico 5	[23]
Seymour Duncan SH-1 '59	7.43k / 8.13k (2015 chart); 7.60k / 8.20k (current page)	6.8 / 6 kHz	Alnico V bar	[9, 24]
Seymour Duncan SH-55 Seth Lover	7.2k / 8.1k	8.14 / 5.9 kHz	Alnico II bar	[9]
Seymour Duncan APH-1 Alnico II Pro	7.6k / 7.85k	7.1 / 6.7 kHz	Alnico II bar	[9]
Seymour Duncan SHPG-1 Pearly Gates	7.3k / 8.21k	7.5 / 6.5 kHz	Alnico II bar	[9]
Seymour Duncan SH-2 Jazz	7.72k / 7.9k	8 / 7 kHz	Alnico V bar	[9]
Seymour Duncan Antiquity	7.70k / 8.60k	not on chart	aged Alnico 2 bar	[25]
DiMarzio PAF 36th Anniversary (DP103 / DP223)	7.31k / 8.60k	output 250 / 285	Alnico 5	[26]
Lollar Imperial, standard wind	7.6K / 8.4K (average)	not listed	not stated	[15]
Lollar Imperial, low wind	7.0K / 7.9K	not listed	not stated	[15]
Lollar Imperial, high wind	8.4K / 9.4K	not listed	not stated	[15]

Table 13.5: High-output humbuckers

Model	DC resistance	Resonant peak (Duncan 2015 chart) or DiMarzio output	Magnet	Source
Seymour Duncan SH-4 JB (bridge)	16.4k (2015 chart); 16.6k (current page)	5.5 kHz	Alnico V bar	[9, 16]
Seymour Duncan SH-5 Custom (bridge)	14.1k	6 kHz	ceramic bar	[9]
Seymour Duncan SH-11 Custom Custom (bridge)	14.4k	5.2 kHz	Alnico II bar	[9]
Seymour Duncan SH-14 Custom 5 (bridge)	14.4k	5.4 kHz	Alnico V bar	[9]

Model	DC resistance	Resonant peak (Duncan 2015 chart) or DiMarzio output	Magnet	Source
Seymour Duncan SH-6 Distortion (neck / bridge)	12.7k / 16.6k	6.5 / 5.5 kHz	ceramic bar	[9]
Seymour Duncan SH-8 Invader (neck / bridge)	7.2k / 16.8k	8 / 5 kHz	ceramic bar	[9]
Seymour Duncan SH-13 Dimebucker (bridge)	16.25k	5.1 kHz	ceramic bar	[9]
DiMarzio Air Norton DP193	12.58k	output 270	Alnico 5	[27]
DiMarzio Super Distortion DP100	13.68k	output 425	ceramic	[28]
DiMarzio Tone Zone DP155	17.31k	output 375	Alnico 5	[29]

Look at the Custom Custom and the Custom 5. Both list 14.4k, but one uses Alnico II and the other Alnico V, and their peaks differ by only 0.2 kHz [9]. Now look at the DiMarzio rows. The Air Norton reads 12.58k but has a lower DiMarzio output number (270) than the 8.60k PAF 36th bridge (285) [26, 27]. Higher resistance, lower output. Hold that thought for the spec-sheet section.

DiMarzio also publishes a four-band "tone guide" on each pickup page. The Super Distortion (introduced 1974) lists bass 8.0, low mid 6.5, high mid 6.5 and treble 4.5 [28]. The Tone Zone (1991) lists 9.5, 8.5, 8.0 and 4.0 [29]. These are DiMarzio's own scale and only compare DiMarzio pickups with each other.

The mini-humbucker

The mini-humbucker is a smaller humbucker with its two rows of poles closer together: about 13 mm in Zollner's figure [21], or 12.5 mm in his pickup database [13], versus 18-19 mm for a full-size Gibson [20]. Gibson's mini puts a bar magnet under the coils [13]. Closer poles push the humbucker's two-point treble cut higher up the spectrum [21], which should leave a mini with more treble than a full-size humbucker, all else being equal.

Seymour Duncan's list gives a Gibson Mini Humbucker at 6.8K [4]. Gibson lists its Original Mini-Humbucker (treble) at 6.2K average, with a bar Alnico 2 magnet, full wax potting and maple spacers [30].

The Filter'Tron

Gretsch's Filter'Tron, designed by Ray Butts, showed up around the same time as Gibson's humbucker [17]. It uses two rows of screws, one row per coil, which gives the two coils full mirror symmetry and, in Zollner's account, better hum suppression [17]. Its pole rows are 18 mm apart [20], about the same as a Gibson.

The big difference shows up in the numbers. TV Jones, which builds Filter'Tron-style pickups, lists its TV Classic at 4.0k and 1.4 H for the neck and 4.8k and 1.83 H for the bridge [31]. TV Jones says the design came from an analyzed 1959 "Pat. Applied For" Filter'Tron [31]. Compare that to a PAF-style humbucker at around 8k. Lower resistance and less inductance point to a higher resonant peak and a brighter sound than a PAF. TV Jones is also one of only two makers I've found that list inductance at all.

Table 13.6: Mini-humbuckers and Filter'Tron types

Model	DC resistance (neck / bridge)	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Gibson Original Mini-Humbucker (treble)	6.2K (average)	not listed	not listed	Alnico 2 bar	[30]
Seymour Duncan SM-1 Vintage mini	6.54k / 7.57k	not listed	7 / 6 kHz	Alnico V bar	[9]
TV Jones TV Classic	4.0k / 4.8k	1.4 / 1.83 H	not listed	not stated	[31]

Stacked and noiseless single coils

You might ask, "Can I get single-coil sound without the hum?" Makers have chased that since at least the early 1980s, going by the patent filings below. The usual answer is a stacked, or coaxial, pickup: two coils one on top of the other, inside a single-coil-size cover.

It works like this. The string's field mostly passes through the upper coil. Hum passes through both coils about equally. The coils are connected opposite each other, so hum cancels and most of the string signal survives [32]. Zollner lists patent filings for this idea by DiMarzio (August 6, 1982), Seymour Duncan (August 15, 1983), Kinman (March 15, 1996) and Fender (January 28, 1998) [32].

There's a price. In a split Strat-style winding, the upper coil gets about three times the lower coil's string voltage, so the net string signal roughly halves [32]. Connecting the coils against each other also lowers the inductance, which raises the resonant peak and lowers output. Makers fix this with about 50% more turns, which raises the resistance reading, and with plates that separate the two coils magnetically [32]. Zollner measured Fender's coaxial humbucker at about 24 dB of hum rejection [12].

That's why stacked pickups read high on an ohmmeter but don't play as loud as the number suggests. Seymour Duncan says the same. Its Custom Flat Strat stack reads 12.27k, 12.8k and 13.3k (neck, middle, bridge); its Cory Wong Clean Machine stacked bridge reads 14.54k against 7.05k and 7.15k for the single coils, and Duncan says that "doesn't mean" it's "twice as loud"; and its Vintage Stack reads near 20k with output close to vintage levels [33].

Table 13.7: Stacked, noiseless and rail pickups in single-coil size

Model	DC resistance	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Fender Gen 4 Noiseless Strat (neck, middle / bridge)	10.0k all (also listed as 10.3k)	3.2 / 3.6 H	not listed	Alnico 5	[34]
Seymour Duncan STK-S4 Stack Plus (neck / bridge)	9.62k / 10.36k	not listed	5.7 / 5.2 kHz	Alnico V rods	[9]
Seymour Duncan STK-S2 Hot Stack (neck / bridge)	13.2k / 20.6k	not listed	6.5 / 6 kHz	ceramic bar	[9]
Seymour Duncan Custom Flat Strat stack (neck / middle / bridge)	12.27k / 12.8k / 13.3k	not listed	not listed	not given	[33]
Seymour Duncan Vintage Stack	near 20k	not listed	not listed	not given	[33]

Model	DC resistance	Inductance	Resonant peak (Duncan 2015 chart)	Magnet	Source
Seymour Duncan SHR-1 Hot Rails (neck / bridge)	10.8k / 16.9k	not listed	4.8 / 3.5 kHz	ceramic bar	[9]

Fender's Gen 4 Noiseless set lists 3.2 H for the neck and middle and 3.6 H for the bridge [34]. Compare that to the Pure Vintage '59 at 2.2 H [5]. Even on Fender's own numbers, the noiseless set carries more inductance than a vintage Strat set, which points to a lower resonant peak, though Fender doesn't publish one.

Zollner's example of the Gibson P-100, a stacked P-90 replacement, shows why makers choose the connection with care. Its coils are wired in parallel and out of phase. Wired in series, Zollner says, the roughly 7 H inductance would have doubled and the resonance would have dropped by 30% [32].

Rails and blades

The other way to fit a humbucker in a single-coil slot is to put two coils side by side in the narrow space, usually with steel rails or blades in place of round poles. These pickups space their two sensing lines only 6-9 mm apart [35]. DiMarzio's DP184 measures 7.6 mm and the Joe Barden 7.5 mm [20]. Zollner describes a DiMarzio blade design with two iron blades 1.6 mm thick, 6 cm long and 7.5 mm apart [17].

Close spacing pushes the humbucker's treble cut way up. Zollner notes that shrinking the pole distance by a factor of 0.4 raises that cancellation by about 4-5 times in practice [35], and he measured the Joe Barden's highest response near 18 kHz, set by coupling between its coils [35]. In plain words, rails keep more top end than a full-size humbucker while still cancelling hum.

Seymour Duncan's Hot Rails is the classic high-output example: 10.8k neck and 16.9k bridge, with peaks of 4.8 kHz and 3.5 kHz on the 2015 chart [9]. That 3.5 kHz bridge peak ties the SP90-3 Custom bridge for the lowest figure I've listed from the chart. Rails don't automatically mean bright.

Covers

A metal cover sits right in the magnetic field. A changing field makes small swirling currents flow in any metal that conducts electricity. These are called *eddy currents*, and they turn some of the signal's energy into heat, mostly in the treble. Lemme notes that a pickup with no metal cover has a higher resonant peak than one with a cover [19]. German silver (a copper, nickel and zinc alloy) conducts less than brass, so it damps less, and plastic covers make no eddy currents at all [19].

How big is the effect? Zollner compared three Tele neck pickups and found they differed in treble by up to 12 dB, mainly from eddy currents in their covers [35]. Fender's cover was 0.5 mm German silver. A copy's 0.8 mm chrome-plated brass cover damped more [35]. Twelve dB is not subtle. If your Tele neck pickup sounds dull, the cover is a fair suspect.

> **Caution:** Taking the cover off a waxed humbucker or a Tele neck pickup means unsoldering and prying near very fine coil wire. A slip can break the wire and kill the pickup. If you're not comfortable with that, leave the cover on or have a tech do it.

Active pickups

An active pickup has a small preamp built in, powered by a battery. The preamp sets the level and voice and drives the cable from a low *output impedance*. Output impedance is how much a source resists the current it sends out; a low number means the cable and pots barely load it. Because of that, active pickups use 25k pots [36, 37], where DiMarzio recommends 500k pots for a passive pickup like the Super Distortion [28]. Pot values get their own chapter (Chapter 15).

EMG

EMG's current product pages say the 81 uses ceramic magnets with "close aperture coils," the 85 is "loaded with Alnico V magnets," and the SA uses "dual Alnico V loaded single coils" [36]. They don't list output or resonance.

For inside numbers, the best I found is ElectroSmash's teardown of an EMG 81 (no author or date given). It found coils of about 4.18k each, roughly 5,500-6,000 turns of 0.06 mm wire per coil, a ceramic magnet, and a preamp with a gain of about 5.5 times (14.8 dB), a low-cut at 241 Hz and an output impedance of 10k [38]. ElectroSmash also reproduces a spec table that gives a resonant frequency of 2.25 kHz and a current draw of 80 microamps [38]. Be careful with that 2.25 kHz figure. ElectroSmash's own circuit model gives about 3.1 kHz, so the page doesn't agree with itself [38].

On power, EMG's FAQ claims that one 9 volt battery gives, on average, 1,000 playing hours for a set of EMG pickups [39]. That's EMG's claim, not a measurement I've seen tested. EMG says the pickups need at least 9 volts, that 27 volts is the most you can supply, and suggests 18 volts for more headroom [39].

Fishman Fluence

Fishman's Fluence Modern humbucker is also active and offers several "voices" you can switch between. Fishman lists the peaks of each voice. For the Alnico version: 650 Hz for voice 1, 420 Hz and 8 kHz for voice 2, and 4.7 kHz for voice 3. For the ceramic version: 630 Hz, 1.8 kHz and 4.5 kHz [37]. Both list a 2k output impedance and 25k pots [37].

Fishman lists a current draw of 2.6 mA at 9 V (Alnico) and 2.7 mA (ceramic), and a battery life of "Up to 200 hours (for the set)" [37]. That's Fishman's claim, and "up to" means best case.

Table 13.8: Active pickups, maker data and one teardown

Model	Magnet	Pots	Power	Other figures	Source
EMG 81	ceramic, close aperture	25k	9 V minimum, 27 V maximum; about 1,000 hours per battery for a set (EMG claim)	teardown: coils about 4.18k each; preamp gain 14.8 dB; low-cut 241 Hz; 10k output impedance; reproduced spec 2.25 kHz, 80 µA	[36, 38, 39]
EMG 85	Alnico V	25k	9 V minimum (EMG FAQ)	none listed	[36, 39]
EMG SA	Alnico V	25k	9 V minimum (EMG FAQ)	none listed	[36, 39]
Fishman Fluence Modern, Alnico	Alnico V, bar with blades	25k	2.6 mA at 9 V; up to 200 hours per set (Fishman claim)	voice peaks 650 Hz; 420 Hz and 8 kHz; 4.7 kHz; 2k output impedance	[37]

Model	Magnet	Pots	Power	Other figures	Source
Fishman Fluence Modern, ceramic	Ceramic VIII, bar with blades	25k	2.7 mA at 9 V; up to 200 hours per set (Fishman claim)	voice peaks 630 Hz; 1.8 kHz; 4.5 kHz; 2k output impedance	[37]

Hum rejection compared

How much quieter is a humbucker, really? Zollner tested pickups in a hum field of 6.5 microtesla (a measure of magnetic field strength). Single coils produced 0.1-0.2 V of hum. Humbuckers produced at most 30 mV [12]. With the field in one direction, humbuckers improved signal-to-hum by about 19 dB to over 40 dB [12].

Turn the field to the worst-case direction and the picture changes. The Gibson 490R managed only about 16 dB, and Zollner sums it up: "the hum-rejection is rather modest" [12]. So a humbucker can still hum in the wrong spot in a room, just less than a single coil.

Table 13.9: Hum, measured

Pickup or comparison	Hum figure	Source
Single coil in a 6.5 µT field	0.1-0.2 V of hum	[12]
Humbucker in the same field	30 mV maximum	[12]
Humbucker signal-to-hum gain, favorable field direction	about 19 dB to over 40 dB	[12]
Gibson 490R, worst-case field direction	about 16 dB	[12]
Fender coaxial humbucker	about 24 dB	[12]
Jazzmaster vs Strat	7-8 dB more hum, about 5 dB more signal (net about 3 dB worse)	[12]

RWRP: the Strat's half-humbucker trick

On a Strat, positions 2 and 4 combine two single coils. If the middle pickup is wound the other way and has its magnets flipped, the pair cancels hum. That's what *RWRP* means: reverse wound, reverse polarity [40]. Seymour Duncan says an RWRP middle "cancels hum in switch positions 2 and 4" [40], and Fender's Custom Shop sets say the same about their reverse-wound middle pickups [7, 8]. Zollner dates this to 1970s Strats and notes that Strat pickups are wound clockwise and Teles counter-clockwise [41]. Positions 1, 3 and 5 still hum like any single coil (switching is in Chapter 14).

How to read a pickup spec sheet

Now let's put the numbers to work. The physics behind each one is back in Chapter 12; this section is about how I read a box.

DC resistance: a check, not a tone chart

DCR is the number every maker prints and the one players lean on most. It's also the weakest guide to sound. DiMarzio says so plainly in its FAQ: "DC resistance is not a direct indicator of tone or output" [42]. Seymour Duncan agrees: "Misinformation is rampant on the topic of DCR" [33]. Zollner gives the reason in one line. Take the magnet out of a pickup and the resistance stays the same while the output drops toward zero [43].

Some examples make the point. Zollner measured a DiMarzio SDS-1 at 9.1k giving more voltage than a vintage Strat pickup at 5.8k, but a Gibson Tony Iommi humbucker at 17.8k gave less voltage than the SDS-1 for the same string motion [44]. He goes further: for the same resistance, output can differ by as much as a factor of 4

[44]. Seymour Duncan says that moving from 43 to 44 AWG wire on an otherwise identical pickup raises DCR and changes tone "but not output" [33].

Table 13.10: Resistance versus output, examples

Pickup	DC resistance	What happened to output	Source
Vintage Strat	5.8k	less than the SDS-1	[44]
DiMarzio SDS-1	9.1k	more than both the Strat and the Iommi	[44]
Gibson Tony Iommi humbucker	17.8k	less than the SDS-1	[44]
DiMarzio PAF 36th bridge	8.60k	DiMarzio output 285	[26]
DiMarzio Air Norton	12.58k	DiMarzio output 270	[27]
Seymour Duncan Vintage Stack	near 20k	output close to vintage levels	[33]

So what is DCR good for? It's a quick check that a pickup is wound to spec and hasn't failed. That's how DiMarzio says it uses the number [42]. Lollar adds that its posted figures are batch averages and that it builds to turn counts, not to resistance [10].

Your own meter reading will also wander. Copper's resistance rises about 0.39% per degree Celsius [43], and Lollar notes that a warm pickup reads higher [10]. Reading a pickup while it's still wired to the volume pot lowers the number: Zollner shows a 13.00k pickup reading 12.67k with a 500k pot and 12.36k with a 250k pot [44]. A wider coil reads higher than a narrow one with the same turns, and thinner wire reads higher too [10]. And two Gibson 498T pickups tested by German magazines differed by 9.6% [44]. Don't panic if your meter is a few hundred ohms off the box.

Tip: Compare DCR only within one maker's line and one design, such as two Fender Strat sets or two Duncan SSL models. Across makers or across designs (a stack versus a plain single coil), the number tells you very little.

Inductance: the better number, when you can get it

If a maker lists inductance, that's the number to watch. More inductance, at the same capacitance, means a lower resonant peak and a darker sound [1]. Lollar says higher inductance generally means more output and more bass [10]. Of the makers I checked, only Fender and TV Jones list it on current product pages [5, 31]. Fender's numbers are handy for comparing sets: 2.2 H for the Pure Vintage '59, up to 2.97 H for the Texas Special bridge, and 3.6 H for the Gen 4 Noiseless bridge [5, 8, 34].

Resonant peak: read the fine print

Seymour Duncan's resonant peaks in this chapter come from its Tone Comparison Chart, which I've only seen as a printout dated May 29, 2015 [9]. The chart doesn't say what load the pickups were measured with. That matters. As Chapter 12 showed, a pickup's peak drops a lot once you add pots and a cable. Lemme and Zollner both put the loaded peak of a typical pickup at 2-5 kHz [19, 45], and Zollner gives 9 kHz for an unloaded Strat pickup [45]. Most of Duncan's chart figures sit between about 4 and 10 kHz [9]. My guess, and it's only a guess, is that they were measured with little or no load. Use them to compare Duncan pickups with each other. Don't expect your guitar to peak at those frequencies.

DiMarzio "output": DiMarzio only

DiMarzio product pages show "Output" as a bare number, such as 425 for the Super Distortion [28]. The unit appears only in DiMarzio's FAQ, which calls it "Output (mV)" and says it shows "a pickup's relative loudness compared to other DiMarzio pickups" [42]. DiMarzio doesn't publish a resonant frequency on any page I checked. So use the output number to rank DiMarzio pickups against each other, and nothing else. Seymour Duncan uses its own 10-100 output scale, measured with a mechanical strum arm and an oscilloscope, and says plainly it isn't an industry standard [33]. Don't compare one maker's output scale with another's.

Magnet type: a hint, not a verdict

The magnet line on a spec sheet tells you a little. Seymour Duncan says that at equal DCR its output order runs Alnico 2, then Alnico 5, then ceramic [33], and that ceramic magnets lower inductance and raise the resonant frequency [16]. Lollar warns that "AL-2, AL-3, AL-5 are not a measure of magnet strength" [10], because those labels name alloys and makers can magnetize them to different levels (the magnet data is in Chapter 12).

Putting it together

I'd read a box in this order. First, the type (single coil, P-90, humbucker, stack, rail, active), because that tells you about hum (Table 13.9) and construction before any number does. Second, inductance, if it's listed. Third, the resonant peak, if you know how it was measured. Last, DCR, and only against the same maker's other models of the same type.

Tone and playability at a glance

This summary sticks to what the measurements and maker data support.

Table 13.11: Pickup changes, rated

Change	What you'll hear	What you'll feel
Vintage single coil to hotter single coil, same maker and design	Lower resonant peak, so darker and more mids; somewhat more output (Zollner: 10% more turns gave about 0.9 dB more signal and a 10% lower resonance) [44]	Little or no change in feel
Single coil to full-size humbucker	Much less hum (about 19 to over 40 dB, but about 16 dB worst case) [12]; lower peak and some treble lost to two-point sensing [19, 21]	None from the pickup itself
Single coil to stacked noiseless	Hum cut (about 24 dB for Fender's coaxial design) [12]; higher inductance than vintage sets on Fender's figures [5, 34]	Little or no change
Full-size humbucker to mini-humbucker or rail	Treble cut moves up, so a brighter sound [21, 35]	Little or no change
PAF-style humbucker to Filter'Tron type	About half the DCR and lower inductance on TV Jones's figures, pointing to a brighter sound [31]	Little or no change
Remove a metal cover (or swap brass for German silver)	More treble; up to 12 dB treble difference measured across covered Tele necks [35]	None
Alnico 2 to Alnico 5 at the same DCR, same model family	Small change; Duncan's Custom Custom vs Custom 5 peaks differ by 0.2 kHz [9]	None found

Change	What you'll hear	What you'll feel
Passive to active	Preamp sets the voice; cable and pots barely load it (low output impedance) [37, 38]	A battery to change; 25k pots [36]
Tele bridge with steel plate vs without	About 0.6 dB more output and about 3% lower resonance [2]	None

Does a hotter pickup compress more? Players say so all the time. I haven't found anyone who measured compression for different winds, so I won't claim it. What the published measurements do show is that more turns raise inductance faster than they raise output [1, 44], so a hotter pickup of the same design gets a little louder and noticeably darker.

Sources

Bracket numbers in this chapter point to this list. Web addresses were checked in October 2026; if one moves, search the site for the title.

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Chapter 14: Pickup Position, Height and Switching

Two guitars can carry the exact same pickup and still sound nothing alike. Put that pickup near the bridge and it's bright and thin. Put it near the neck and it's round and warm. Raise it a millimeter and it gets louder. Raise it too far and the strings start to wobble out of tune. Flip a switch and the same coils can sound like a different pickup. None of this changes a single turn of wire inside the coil.

How a pickup turns string motion into a voltage and where its resonant peak comes from are in Chapter 12, and pickup types and spec sheets are compared in Chapter 13. This chapter is about the three things you control after the pickup is built: where it sits along the string, how close it sits to the string, and how it's switched and combined with its neighbors. Pots get their own chapter (Chapter 15), and so do switches, jacks and grounding as hardware (Chapter 17). Here I'll stay with what the switch does to the sound.

Position: where the pickup listens

A string is not the same everywhere

A plucked string doesn't move as one simple arc. It vibrates in its whole length (the fundamental) and in halves, thirds, quarters and so on (the harmonics) all at the same time. Each harmonic has spots along the string that don't move at all. These still spots are called *nodes*. The second harmonic has a node at the middle of the string. The fourth harmonic has nodes at each quarter point. A pickup that sits right on a node of a harmonic can't hear that harmonic, because the string isn't moving there for that frequency.

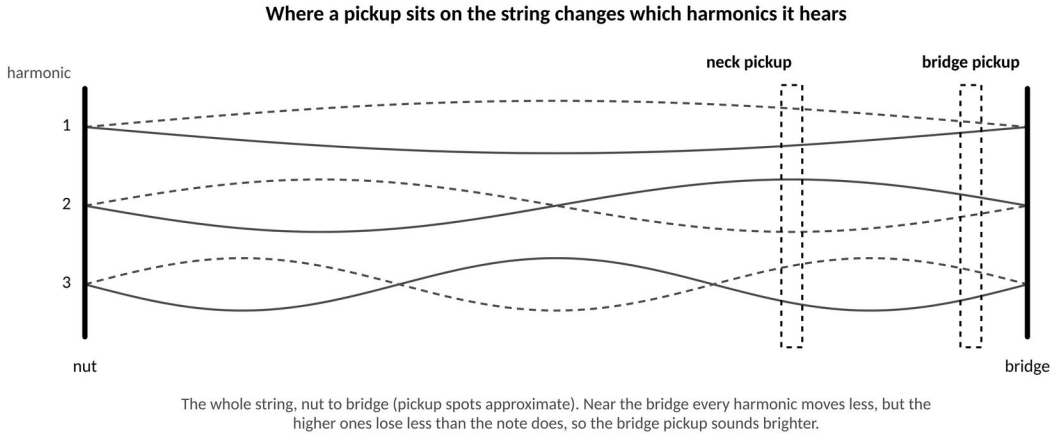


Figure 14.1: The first three harmonics on an open string. A pickup near the bridge sits close to where every harmonic moves least, but it loses less of the higher ones, which is why it sounds brighter.

Pickup position works on exactly that. A pickup listens to one short stretch of the string, and at that stretch some harmonics are strong, some are weak and some are missing. Move the pickup and you change which ones go missing.

Real distances on a Strat

Mohamad, Dixon and Harte, three researchers who presented at the DAFx digital audio effects conference in 2015, measured a Squier Stratocaster with a 648 mm scale [1]. They give the pickup positions as distances from

the bridge. That's the useful way to read them, because what matters is the pickup's distance divided by the string length [2].

Table 14.1: Pickup positions on a Squier Stratocaster, 648 mm scale

Pickup	Distance from bridge	Inches (my conversion)	Fraction of string length	Harmonics weakened (open string)	Source
Neck	158.75 mm	6.25 in	about 0.245 (about 1/4)	every 4th	[1]
Middle	101.6 mm	4.0 in	about 0.157 (about 1/6.4)	near every 6th-7th (my arithmetic, not in the paper)	[1]
Bridge (slanted)	38.1-50.8 mm	1.5-2.0 in	about 0.06-0.08 (about 1/14 on average)	every 14th	[1]

In their words, the neck pickup at about a quarter of the string "lowers the amplitude of every 4th harmonic, while the bridge pickup, at about 1/14 of the string length" does the same to every 14th [1]. The same team's 2017 DAFx paper used nearly the same numbers, about 160 mm for the neck, 100 mm for the middle and 38-48 mm for the slanted bridge, on a string length "around 650 mm" [2]. Their model weights each harmonic by a factor that depends on the pickup's distance divided by the string length. A harmonic with a node right at the pickup drops out [2].

Notice that the inch values come out round: 6 1/4, 4 and 1 1/2 to 2 inches. That's my conversion of their millimeter figures, not a Fender drawing.

Comb filtering in plain words

When a filter cuts a row of evenly spaced frequencies, the response looks like the teeth of a comb on a graph. Engineers call it a *comb filter*. Zollner, in his book *Physics of the Electric Guitar*, treats pickup position as exactly that kind of filter, and he points out that the place where you pluck is a second comb filter stacked on top of the first [3]. In a simple straight-line model, swapping the pluck point and the pickup point gives the same result [3]. So picking near the bridge brightens the sound for the same reason a bridge pickup sounds bright.

One part is easy to miss: the comb is different on every string. Zollner explains that the comb depends on how fast waves travel along that particular string, while the pickup's electrical resonant peak (Chapter 12) affects all six strings the same way [3]. On each string the notches land on the same harmonic numbers, but those harmonics sit at different pitches. On the low E a notch on the 4th harmonic is down in the midrange, and on the high E it's much higher.

Why the bridge pickup is brighter

Put the same pickup at the bridge instead of the neck and it gets brighter and thinner. The reason is in how the string moves. Near the bridge the string barely moves, so the signal is lower. But what motion there is carries a larger share of high harmonics compared to the fundamental. The first harmonic that gets notched out is way up the series (around the 14th on a Strat). Near the middle of the string the low harmonics swamp everything, and the notches fall on low-numbered harmonics such as the 4th. That sounds rounder and fuller.

Some sets carry a hotter bridge model, such as Fender's Texas Special (see Chapter 13). My reading is that a quieter spot on the string is one reason a maker would do that, though Fender doesn't say so.

Pickup width matters a little too. Zollner measured a single coil's effective listening window, which he calls the *aperture*, at about 1 cm wide, shaped roughly like a bell curve and set by the magnet pole rather than the coil [4]. The 2017 DAFx paper notes that a pickup's finite width acts like a gentle treble cut, though they didn't put a number on it [2]. A narrow window hears a sharper slice of the string.

The slanted bridge pickup

On the Squier in the DAFx paper the bridge pickup is slanted, so its distance from the bridge runs from 38.1 mm to 50.8 mm [1]. The geometry tells you what that does. The treble-side poles sit closer to the bridge, so the high strings get the brighter, thinner sound of a pickup near the end. The bass-side poles sit farther away, so the low strings get a little more body. That's a reading of the geometry. I haven't found a Fender source that states why Fender slanted it.

Humbuckers listen in two places

A humbucker has two rows of poles, so it samples the string at two points instead of one. Zollner shows that with Gibson-style pole spacing of 18 mm the low E string gets an extra cancellation near 3 kHz [5]. The higher strings get their extra dips at higher frequencies, and closer pole spacing pushes the dips higher still [5]. Zollner's blunt summary is that "the humbucker will absorb the 3-kHz-range that is important to obtain a brilliant sound" [5].

That's a big part of why a humbucker sounds thicker than a single coil even before you look at its higher inductance. Mini-humbuckers and rails (Chapter 13) have narrower spacing, which moves that dip up and out of the way. For reference, Zollner's example guitar places the bridge humbucker 45 mm and the neck humbucker 147 mm from the bridge [5]. In inches that's about 1.8 and 5.8 (my conversion).

Table 14.2: Sensing-point spacing and the extra humbucker dip

Pickup type	Pole spacing	Effect on the low E	Source
Single coil	one sensing point, about 1 cm window	no second dip	[4]
Gibson-type humbucker	18-19 mm	extra cancellation near 3 kHz	[4, 5]
Mini-humbucker	13 mm	dip moves higher	[5]
Single-coil-size humbucker (rails, blades)	7-9 mm	dip moves much higher	[5]

The 24-fret problem and the quarter point

Some fret math helps here. The distance from the nut to any fret is the scale length times one minus one over two raised to the fret number divided by twelve. Put the 24th fret into that and you get three quarters of the scale. So the 24th fret sits exactly one quarter of the scale length from the bridge (my arithmetic). On a 648 mm scale that's 162 mm from the bridge.

Now look back at Table 14.1. The Strat's neck pickup sits 158.75 mm from the bridge [1], only a few millimeters from that quarter point. On a 21-fret Strat-type neck that's fine, because the last fret is roughly 193 mm from the bridge (my arithmetic). On a 24-fret neck the fingerboard runs right over that spot, so the neck pickup has to move toward the bridge to make room. When it moves, it leaves the quarter point and its notch shifts off the 4th harmonic.

You'll hear claims that the quarter point (the 24th-fret spot) is a magic "sweet spot" for a neck pickup. I can't back that up. The published work says only what the quarter point does: it sits on a node of the 4th harmonic and weakens every 4th harmonic [1]. Whether that sounds better than a spot 10 mm closer to the bridge is a matter of taste, and nobody I've found has tested it with listeners.

Height: how close the pickup listens

What changes when you raise a pickup

Height is the most useful free adjustment on any electric guitar. Three things change when you move a pickup toward the strings.

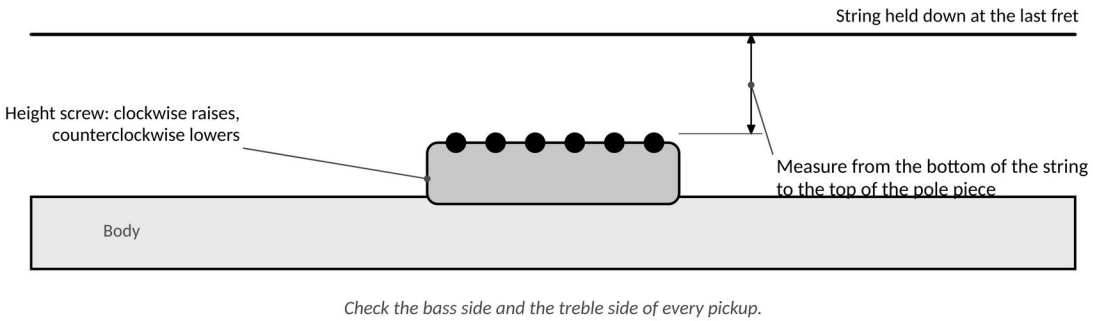


Figure 14.2: Pickup height is measured from the top of the pole piece to the bottom of the string, with the string held at the last fret.

It gets louder. Zollner measured output changing about 3 dB per millimeter, and 3-4 dB per millimeter on average [4]. A 3 dB change is easy to hear. So two turns of a height screw can matter more than switching to a "hotter" pickup.

The tone shifts. Zollner explains that more distance widens the pickup's aperture, and he puts it simply: "Both effects lead to an increasing treble loss with increasing distance" [4]. Lower pickups sound a bit softer and darker. Seymour Duncan's help center says the same in player terms: closer is louder and fuller, farther is softer, less full and cleaner [6]. Lindy Fralin, in a StewMac video, says closer is louder but the treble can turn harsh, while a lower setting is "a little sweeter" [7].

The pickup itself gets less clean. Novak and four colleagues tested a Seymour Duncan SSL-5 single coil, an SH-2N humbucker and an STHR-1B at 3, 5, 7 and 10 mm from the string, and presented the results at DAFx in 2018 [8]. Closer meant more output and more *nonlinear distortion*, which means the pickup adds harmonics that weren't in the string's motion. The humbuckers "exhibit much stronger distortion when placed closer to the string" at 3 mm [8]. In their small-signal test at 400 Hz the pickups were nearly linear [8]. My reading is that the distortion mainly shows up with big string swings, as in hard picking.

Magnetic pull

The fourth change is the one that hurts playability. A pickup magnet acts as a weak negative spring on the string (Chapter 12). Zollner measured this with an Alnico 5 magnet 18 mm long and 5 mm across, under a low E string on a 65 cm string length, 16 cm from the bridge [9]. As the magnet came closer, the fundamental and

second harmonic dropped in pitch, while the 4th and 5th harmonics didn't move [9]. When harmonics drift apart like that, a note can sound sour even though the open string was tuned.

Makers describe the symptoms in plain language:

- DiMarzio warns that a strong enough field "alters string vibration enough to make the guitar sound out of tune," and adds string buzz and lost sustain to the list [10].
- Seymour Duncan's Kevin Harvey lists strings pulled out of tune, buzzing or fretting out from a high neck pickup, and "unnatural overtones" or wolf tones, along with damped sustain [11].
- Erick Coleman at StewMac says the neck pickup is the most prone to this, and "People call them wolf tones, or people call it Stratitis" [12].
- Lindy Fralin notes that "The pole pieces of many pickups are strong enough to pull the strings out of tune" [7].

Lemme, whose pickup notes I lean on in Chapter 12, gives the cure: lower the pickup [13].

Which pickups pull hardest? I haven't found anyone who ranks them, but the construction suggests an answer (my reading): rod-magnet single coils, because the magnet itself sits right under the string, while humbuckers and P-90s put a steel pole between the bar magnet and the string. DiMarzio also sells low-pull models (it names the Virtual Vintage 2.1 and 2.2, VirtuAL 2, Virtual T and Fast Track) that it says can sit closer [10].

What the makers recommend

Every maker measures the same way, give or take. Hold the string down at the last fret, then measure from the top of the pole piece to the bottom of the string. DiMarzio spells this out, Seymour Duncan says the same, and so does StewMac [10, 14, 12]. Table 14.3 shows what each one recommends as a starting point.

Table 14.3: Recommended starting heights, string held at the last fret

Maker or source	Pickup	Bass side	Treble side	Source
DiMarzio	Full-size humbucker, bridge	5/64 in (2 mm)	at least 1/16 in (1.5 mm)	[10]
DiMarzio	Alnico 5 rod single coil, neck and middle	1/8 in (3.2 mm)	3/32 in (2.4 mm)	[10]
DiMarzio	Alnico 5 rod single coil, bridge	3/32 in (2.4 mm)	1/16 in (1.6 mm)	[10]
DiMarzio	Low-pull models, neck and middle	3/32 in	1/16 in	[10]
DiMarzio	Low-pull models, bridge	1/16 in (1.6 mm)	3/64 in (1.2 mm)	[10]
Seymour Duncan	Humbuckers	3/32 in (2.4 mm)	3/32 in (2.4 mm)	[14]
Seymour Duncan	Strat pickups	3/32 in (2.4 mm)	3/32 in (2.4 mm)	[15]
Seymour Duncan	Tele pickups	3/32 in (2.4 mm)	3/32 in (2.4 mm)	[16]
Seymour Duncan	JB Jr. Tele bridge	0.073 in (1.85 mm)	0.073 in (1.85 mm)	[11]
EMG	Active pickups	3 mm	3 mm	[17]
Lollar	Sixty-Four, Special S, P-90	about 1/8 in	about 1/8 in	[18]
Lollar	Humbuckers	as close as possible without string interference	same	[18]
Fender factory spec, as reported by StewMac	Strat	3/32 in	5/64 in	[12]

Millimeter values in parentheses are the maker's own. For reference, 3/32 in is about 2.4 mm, 5/64 in about 2.0 mm, 1/16 in about 1.6 mm and 1/8 in about 3.2 mm (my conversions).

Seymour Duncan uses one number, 3/32 inch on both sides, for nearly everything [14, 15, 16]. DiMarzio sets single coils lower on the bass side than the treble side, and bridge pickups closer than neck pickups. EMG's 3 mm is a little farther than most passive numbers [17]. Lollar starts its single coils and P-90s at about 1/8 inch, but runs humbuckers as close as they'll go [18]. That fits the construction, in my reading: a humbucker's bar magnet sits under the coil, so its poles should pull less than a rod magnet does.

The makers treat these as starting points, not rules. Coleman's own final settings on a Strat left smaller gaps than the factory spec, so the pickups sat closer to the strings: 1/16 in on both sides at the neck, 5/64 and 3/64 in at the middle, and 1/16 and 3/64 in at the bridge [12]. Fralin eyeballs a Strat neck pickup at about 1/16 in on the treble side and 1/8 in on the bass side [7].

Height as your balance control

Remember that a bigger number in these tables means a bigger gap, so the pickup sits lower. Look at DiMarzio's single-coil numbers again. The neck and middle pickups get bigger gaps than the bridge pickup [10]. That's how you balance positions. The neck pickup sits where the string swings widest, so it would be the loudest if all three were set the same. Lowering it brings it in line with the bridge pickup, which sits where the string barely moves. Since output changes 3-4 dB per millimeter [4], small moves do the job. Set each pickup for level against its neighbors first, then fine-tune by ear.

> **Tip:** Make small height changes, a quarter turn of the screw at a time, and play the same phrase each time at the same amp volume. Get the levels close before you judge tone, so you're comparing tone and not loudness.

Switching: choosing and combining pickups

The Strat: three positions, then five

Fender's own history of the Strat switch is clear. The Stratocaster had a three-way selector from 1954 to 1977 and a five-way from 1977 [19]. Players found the in-between sounds earlier by balancing the three-way switch between its notches, and Fender first acknowledged those settings in its 1968 catalog [19]. The five-way made them official.

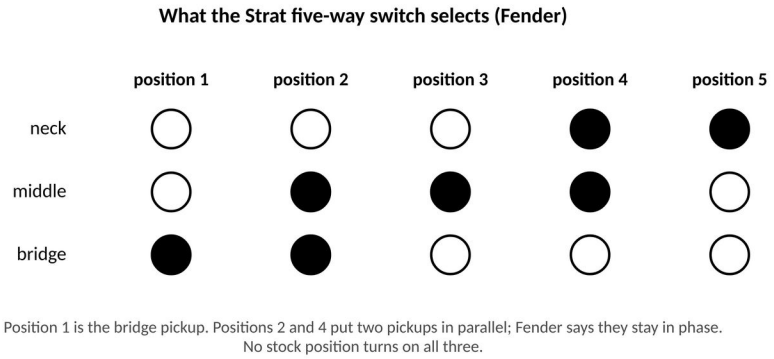


Figure 14.3: What each position of the Strat five-way switch selects (Table 14.4).

Table 14.4: Stock pickup selections

Switch	Positions	What each position selects	Source
Strat 3-way (1954-77)	3	neck, middle, bridge (in-betweens by balancing the switch)	[19]
Strat 5-way (1977 on)	5	1 bridge; 2 bridge + middle; 3 middle; 4 middle + neck; 5 neck	[19]
Tele 4-way (Fralin)	4	1 bridge; 2 bridge + neck in parallel; 3 neck; 4 bridge + neck in series	[20]
Two-pickup 3-way toggle	3	each pickup alone, or both in parallel	[21]

Fender's article makes two points worth repeating. First, "there is no means of having all three pickups on at once" on a stock Strat [19]. Second, the positions 2 and 4 sounds are often called "out of phase," but Fender's article says the pickups stay electrically in phase. The hollow sound comes from frequency cancellation when two pickups at different points on the string are added together [19]. That's the comb filtering from earlier in this chapter, working twice. Zollner describes the standard switch the same way: one pickup, or two pickups connected in parallel [21].

In positions 2 and 4 the middle pickup works with a neighbor. If the middle is wound and magnetized the opposite way (RWRP, covered in Chapter 13), Seymour Duncan says it "cancels hum in switch positions 2 and 4" [22]. Fender's switch article doesn't mention this.

The stock Fender five-way blade switch mounts with screws 1 5/8 in apart [23]. Electroswitch's selector guide lists the CRL E2 blade switch with 2 poles in 3 and 5 positions, and the Oak Grigsby 6MLR in 2 or 4 poles with up to 6 positions [24]. A *pole* is one separate circuit the switch can route. Two poles is enough to pick pickups and route one tone control. More poles let you do more per position.

The Telecaster and the four-way

Fralin says positions 1 to 3 of its four-way mod match a normal Tele: bridge, both in parallel, neck [20]. The fourth position adds bridge and neck in series, which is louder and thicker. There's a catch. Fralin notes that the neck pickup has to be converted, with its cover ground separated, or the mod won't work [20].

The Gibson-style toggle

Les Paul, SG and ES-335 type guitars use a three-way toggle switch. Switchcraft, which makes its toggles in Chicago, lists a family of them in its 12000 series [25]. The 12010X is the long-frame Les Paul style, the 12013X is the SG style, the 12012X is a right-angle locking type, and the 12120X is a short-frame part for thin bodies with pre-tinned lugs [25]. All are rated 3 A and 300 W maximum AC non-inductive load (Switchcraft gives watts here, not volts), with a nickel-plated copper frame and silver or gold-plated contacts [25]. A distributor listing for Switchcraft's right-angle three-way gives a 15/32-32 bushing 0.21 in long, the same 3 A rating, and says it replaces the Gibson L-type and fits 335-style guitars and the SG [26].

Frame length is a fit question, not a tone question. A deep Les Paul cavity takes the long frame. A thin body may only fit the short one.

With two pickups, the toggle gives each pickup alone or both together in parallel [21].

Ratings don't matter, contacts do

A guitar signal is tiny: a fraction of a volt and almost no current (Chapter 12). The 1.5 A and 3 A ratings on these switches are far beyond anything a passive guitar asks of them [24, 25]. What does matter is clean contacts and pole count. A dirty contact crackles. Too few poles limits the wiring you can do.

More positions: the Super Switch and the S-1

When you want coil splits or series wiring per position, you need more poles. StewMac's Oak Grigsby Super Switch has 4 poles and 5 positions, with 6 lugs per pole (24 in all) [27]. It needs a cavity 1 3/8 in (34.93 mm) deep and mounts on the same 1 5/8 in (41.28 mm) screw spacing as Fender's five-way [27, 23].

Fender's own approach is the S-1 switch, a push switch built into a volume or tone knob and introduced in the summer of 2003 [28]. Fender says it "gives you more tonal options by offering extra pickup-wiring configurations" [28]. What it does depends on the model:

Table 14.5: What the Fender S-1 switch does on a few models

Model	S-1 function	Source
American Elite Stratocaster	five alternate wirings, mostly series; position 4 becomes bridge + neck out of phase with a special tone cap	[28]
American Elite Telecaster	position 2 changes from parallel to series	[28]
Classic Player Baja Telecaster	positions 2 and 4 out of phase	[28]
James Burton Telecaster	positions 2 and 4 in series	[28]
Deluxe Roadhouse Stratocaster	bypasses the preamp, plus extra wirings	[28]

Series, parallel, split, tap and phase

Why it's all about inductance

Chapter 12 showed that a pickup's inductance (its opposition to changing current, measured in henries) mostly sets where its resonant peak falls. More inductance pulls the peak lower, which sounds darker and thicker. Less inductance pushes it higher, which sounds brighter and thinner. Every wiring trick in this section works mainly by changing the inductance the rest of the circuit sees.

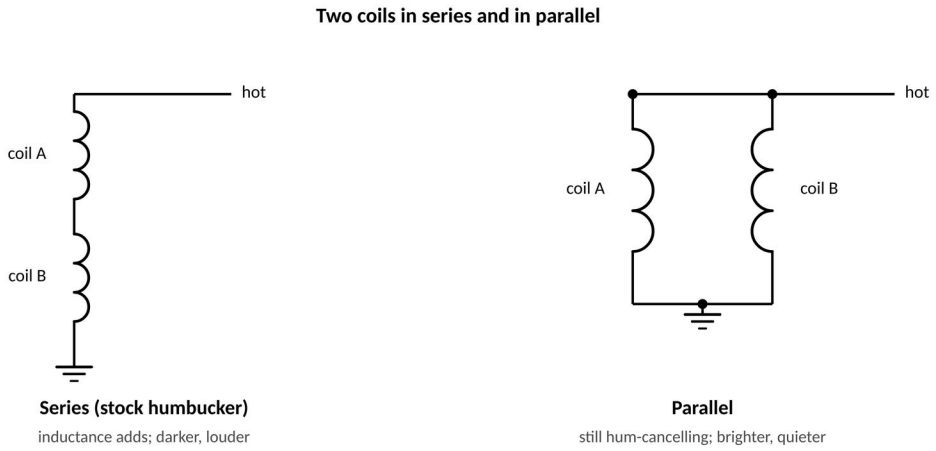


Figure 14.4: Two coils in series and in parallel.

Two coils can be connected two ways. In *series*, the signal runs through one coil and then the other, end to end, so their voltages and inductances add. In *parallel*, both coils connect across the same two wires side by side, so they share the load.

Lemme gives clean rules of thumb for a humbucker [13]:

- Series is the normal humbucker wiring.
- Parallel "cuts the inductance to a quarter of the initial value," and the resonance goes up about twice as high.
- One coil alone (a split) "halves the inductance," and the resonance goes up about 1.4 times (the square root of 2).

Both changes add treble. Lemme also says the difference between one coil and two is "overestimated by far," because most of what you hear is the resonance moving [13].

Now the caveat. Lemme's ratios assume two identical coils that don't affect each other. Zollner shows that real coils do. Two coils in series with separate magnetic fields double the inductance, but if their fields overlap, the voltage and inductance can go up four times [29]. He also notes that a humbucker's coils are magnetically coupled, and that in split mode the unused coil's poles still affect the active one [30]. Treat Lemme's numbers as a direction and rough size, not as a measurement of your pickup.

Table 14.6: Coil connections compared (ideal ratios plus measured examples)

Connection	Inductance compared with one coil	Resonant peak	Output	Hum	Source
Series humbucker (stock)	2 times (up to 4 times if fields overlap)	reference	highest	cancelled	[13, 29]
Parallel humbucker	0.5 times (1/4 of series)	about 2 times higher	lower	cancelled	[13]
Split (one coil)	1 times	about 1.4 times higher	lower	not cancelled	[13]
Tap, Vox CoAxe example	n/a	shifts about 20%	about 2.5 dB lower	n/a	[31]
Tap, Seymour Duncan SSL-5	n/a	6 kHz tapped vs 4.9 kHz full	lower (DCR 6.6k vs 12.9k)	single coil	[32]

Coil split

Seymour Duncan defines coil splitting as "the ability to disable one coil in a humbucker-type pickup" [33]. You need a four-conductor pickup (one with both ends of both coils brought out), and the split works by shorting one coil to ground or to hot [33]. On a Gibson-style split, Duncan says the stud side (the non-adjustable poles) stays on and the adjustable screw side is shorted, though that reverses if the leads are swapped [34].

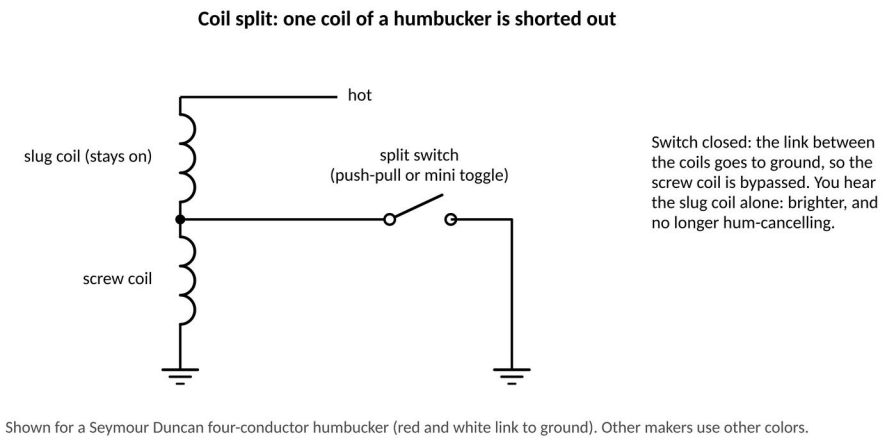


Figure 14.5: A coil split shorts one coil of a humbucker to ground.

The split gives you more treble and a lighter, single-coil-like sound. It also gives up hum cancelling. Zollner measured humbuckers improving the signal-to-hum ratio by about 19 dB to over 40 dB compared with a single coil in a field lined up with the pickup, and as little as about 16 dB in the worst orientation [35]. A split throws that away.

Does a split humbucker sound like a Strat pickup? Not quite. It still sits at a different spot on the string, with a different magnet, fewer turns per coil, and the other coil's poles nearby [30].

Parallel humbucker

Parallel wiring keeps both coils working, so it keeps the hum cancelling. Its inductance drops even further than a split in Lemme's ideal numbers, so the peak rises about twice as high [13]. Output drops. On paper, parallel is a middle ground: brighter than series, and still hum-cancelling.

Coil tap

A *coil tap* is different from a split. Seymour Duncan defines it as "a lead connected to an individual coil's winding," usually partway through, so you can use fewer turns of the same coil [36]. It's mostly found on single coils. Duncan's SSL-5 is a good example: tapped, it reads 6.6k with a 6 kHz peak; full, it reads 12.9k with a 4.9 kHz peak, on Duncan's 2015 chart [32]. Zollner's pickup database lists a Vox CoAxe tap at about 2.5 dB less output and about a 20% resonance shift [31]. That's the only measured tap figure I found.

Two pickups in series

You can also put two separate pickups in series, finish of one to the start of the other. Seymour Duncan describes connecting them finish to start, with pickups of the same winding and polarity, and notes that the Fender Duo-Sonic used series wiring in the late 1950s [37]. Inductance adds, so the peak drops and the output rises. That's what position 4 of the Tele four-way does [20].

Out of phase

Two pickups are *out of phase* when one of them is wired backward, so its signal subtracts from the other instead of adding. Zollner says that when one pickup in a combination is reversed, "the sound changes drastically" [38]. To put a humbucker out of phase with another pickup, reverse the whole pickup: swap its hot and ground leads. Seymour Duncan's help page also describes reversing the two wires on one of the bobbins, but it says that makes the pickup "electrically out of phase with itself" [39]. The two coils then work against each other, so you lose most of the signal and the hum cancelling. That isn't the same mod.

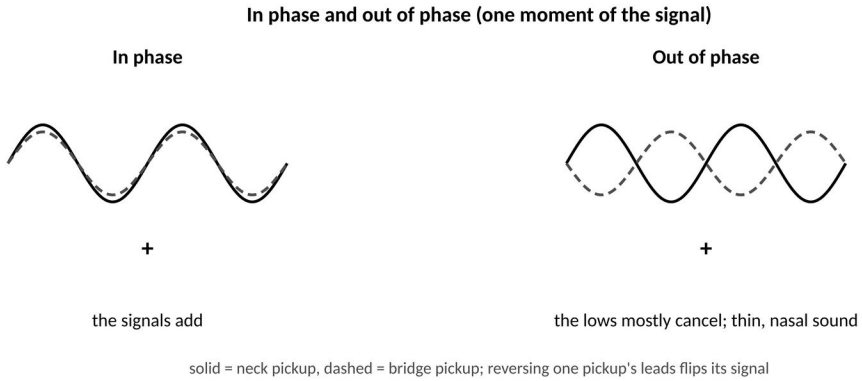


Figure 14.6: Two pickups in phase add; with one reversed, the parts of the signal they share cancel.

Why does it sound thin and nasal? This is my explanation, not a measured figure. Two pickups a few inches apart see the low harmonics moving almost identically, so when one is subtracted from the other, the lows mostly cancel. The higher harmonics differ more between the two spots, so more of them survive.

Four-conductor color codes

A four-conductor humbucker brings out both ends of each coil plus a bare shield wire. Every maker picks its own colors, which is why one wiring diagram doesn't fit every pickup. Table 14.7 shows what two major aftermarket makers say on their own pages.

Table 14.7: Standard series humbucker wiring, from each maker's own page

Maker	Hot (output)	Ground (with bare)	Series link (solder together, insulate)	Coil pairs	Source
Seymour Duncan	Black	Green	Red + White	Green/Red (screw coil), Black/White (slug coil)	[40]
DiMarzio	Red	Green	Black + White	Red/Black and White/Green	[10]

Seymour Duncan's Richard Irons puts it plainly: "We use green (and bare) for ground, then connect red and white to each other, and then black is our hot output" [40]. He adds that green and red are the two ends of the screw coil, the slug coil is the north coil, and the screw coil is the south [40]. To split a Duncan humbucker to its slug coil, a DPDT switch (double-pole, double-throw: two separate circuits, each with two choices), such as a mini toggle or a push-pull pot, grounds the red and white wires together, which removes the screw coil [40].

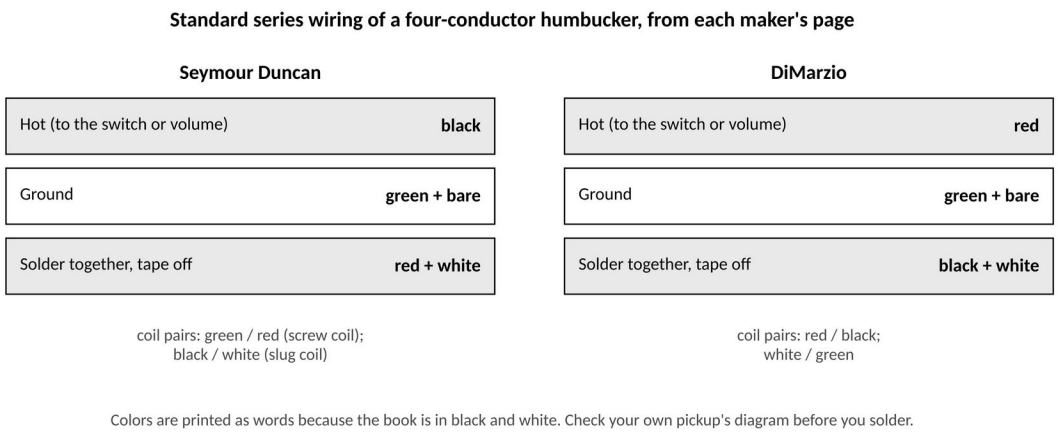


Figure 14.7: Standard series wiring of a four-conductor humbucker from Table 14.7.

DiMarzio's FAQ gives red as hot, green and bare to ground, and black and white soldered together and insulated [10]. To flip the phase, DiMarzio swaps green to hot and red with bare to ground [10]. Its resistance test pairs (black-red and white-green) tell you which wires belong to which coil [10].

For other brands (Gibson, Schaller, Fender humbuckers and more), StewMac publishes a multi-maker color chart with its Super Switch wiring notes [41]. I haven't reproduced it here. Use it alongside the pickup maker's own diagram, and go with the maker's diagram where the two differ.

When in doubt, use a meter. Each coil reads as a closed circuit across its own pair and open to the other pair.

Caution: Unplug the guitar from the amp before you open the control cavity. Pickup leads are thin and their insulation melts easily, and the coil wire inside is finer than a hair. Keep the soldering iron tip off the pickup cover and bobbin, work quickly on each joint, and never pull on a lead to free it.

Push-pull pots, briefly

The easiest way to add a split or a series switch without drilling a hole is a push-pull pot: a normal pot with a small DPDT switch on its shaft. Pull the knob up and the switch flips. Seymour Duncan recommends 500k push-pull volume pots (pot values and tapers are in Chapter 15) for coil splitting in its Les Paul wiring guide [42]. One CTS push-pull part, the CTS-PL-500KA-LK, lists 500k, a 15% audio taper, a 10% tolerance and a long bushing for Gibson-style guitars, with the switch rated 30 V DC at 0.1 A [43]. Bourns makes a 17 mm guitar pot with a latching DPDT push switch, the PDB185-GTR, in values from 10k to 1M [44]. As with the selector switches, the switch ratings are far above anything a guitar signal needs.

Tone and playability at a glance

Table 14.8: Position, height and switching changes, rated

Change	What you'll hear	What you'll feel
Pickup moved toward the bridge	Brighter, thinner, quieter; notches move to higher harmonics	Nothing directly
Pickup moved toward the neck	Rounder, fuller, louder; every 4th harmonic weakened at the quarter point	Nothing directly

Change	What you'll hear	What you'll feel
Neck pickup moved off the quarter point (24-fret guitars)	A small shift in which harmonics are cut; no tested "sweet spot"	Nothing
Humbucker instead of single coil in the same spot	Extra dip near 3 kHz on the low E, plus a lower peak from higher inductance	Less string pull (steel poles)
Pickup raised 1 mm	About 3-4 dB louder, slightly brighter, more added harmonics when picking hard	With rod magnets, more pull: warble, sour notes, less sustain
Pickup lowered 1 mm	About 3-4 dB quieter, a little softer and cleaner	Notes settle in tune; neck pickup stops buzzing
Strat positions 2 and 4	Hollow, thinner sound from two sensing points combined	Nothing
Series (two pickups or Tele position 4)	Louder, darker, thicker	Nothing
Parallel humbucker	Brighter, lower output, still quiet	Nothing
Coil split	Brighter and thinner, lower output, hum returns	Nothing
Coil tap	Somewhat brighter and quieter (about 2.5 dB in one measured case)	Nothing
Out of phase	Thin, nasal, less bass (not measured)	Nothing
Brand of selector switch	Little or no audible change if contacts are clean	Feel of the detents; crackle if dirty

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Chapter 15: Potentiometers

Turn the volume knob on a passive guitar and you're turning a potentiometer, or "pot" for short. Most electric guitars carry two to four of them. They cost a few dollars each and look like the dullest part in the control cavity. Don't be fooled. Every pot wired to a passive pickup is also part of that pickup's load, and the load decides how tall the pickup's resonant peak stands. Change the pot value and the guitar gets brighter or darker even with every knob on 10.

This chapter covers what a pot is, the common values (25k, 250k, 500k and 1M) and why each one exists, the tolerance that makes two "identical" pots different, and the taper, which decides how a knob feels as you turn it. Then I compare pots you can actually buy, cover the special types (no-load, TBX and switch pots), and finish with what you will and won't hear. Tone capacitors, treble bleed networks and 50s wiring get their own chapter, Chapter 16.

What a pot is

A potentiometer is a resistor with a third connection that moves. Inside the round metal can is a curved strip of resistive material called the *track*, with a solder lug at each end. A sliding contact, the *wiper*, rides along the track as you turn the shaft, and it connects to the middle lug. Between the two outer lugs you always measure the full rating, say 250 kΩ (250,000 ohms, usually written "250k"). Between the wiper and either outer lug you measure part of it, depending on where the shaft sits. Zollner gives about 270 degrees of rotation for a typical pot [1]. The CTS Series 450 and Bourns PDB241-GTR datasheets both list 300 degrees [2, 3].

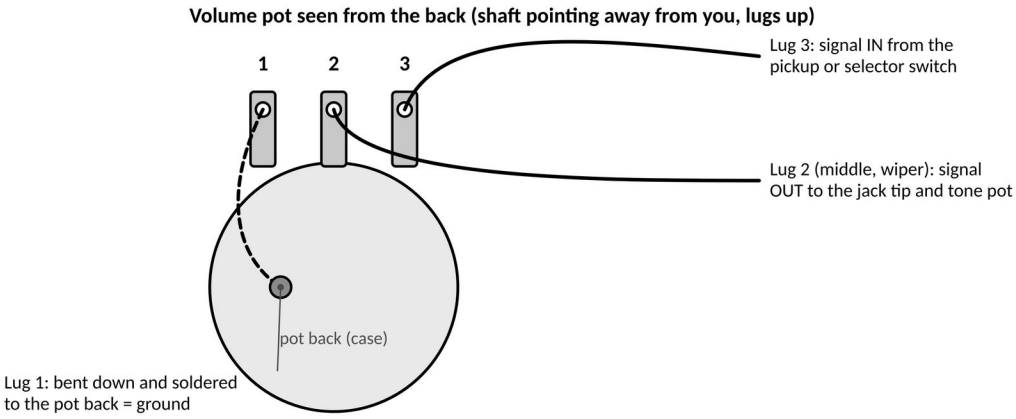


Figure 15.1: The usual volume pot connections, seen from the back with the lugs up. Some wiring uses the lugs differently.

A guitar uses that one part in two ways.

- As a volume control, all three lugs work. The pickup's hot lead goes to one outer lug, which Seymour Duncan's wiring guides call the input lug, and the middle (wiper) lug feeds the output [4]. The other outer lug goes to ground. On 10 the wiper sits at the hot end and passes everything. On 0 it sits at the ground end and passes nothing.

- As a tone control, the pot works as a plain variable resistor in series with the tone capacitor [5]. On 10 the full resistance sits in front of the cap, so the cap does almost nothing. Turn it down and the resistance drops, letting the cap pull treble toward ground.

You might ask, "Do I need a pot rated for a lot of power?" No. Zollner gives pot power ratings of 0.1 to 0.5 W, while a pickup delivers only microwatts [1]. The parts in this chapter list anywhere from 0.05 W to 0.5 W, and none of it matters in a passive guitar. Price doesn't need to scare you either: Zollner puts brand-name pots at about $2 to $4 [1].

One small spec does matter at the ends of the turn. A real pot never reaches exactly zero ohms at its end stop. Zollner calls this the residual resistance. He says good pots stay under 50 Ω, and above about 500 Ω the effect becomes audible and the pot should be thrown out [1]. Bourns lists a residual of 1% maximum for its 17 mm PDB181-GTR and 2 Ω maximum for the PDB185-GTR [6, 7].

The pot as a load on the pickup

Chapter 12 explained the resonant peak: the pickup's inductance and the capacitance around it make one band of treble stand out, usually somewhere between 2 and 5 kHz once a cable is plugged in [8]. *Inductance* is the coil's property that, together with capacitance, sets where that peak lands. Chapter 12 also showed that resistance across the pickup flattens the peak. This is where pots come in.

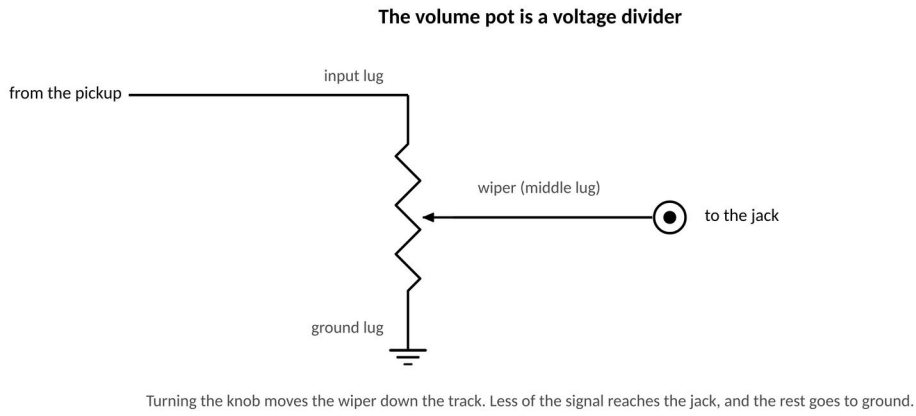


Figure 15.2: A volume pot is a voltage divider: the wiper picks off part of the signal and sends the rest to ground.

With the knob on 10, the volume pot's full resistance is connected from the pickup's hot lead to ground. The tone pot on 10, with its capacitor in series, does nearly the same thing, because at treble frequencies the cap's opposition to the signal is small next to the pot's resistance; Zollner found that shorting the cap out entirely changes the response by less than 0.01 dB with the tone up [5]. The amp's input sits across the pickup too. Zollner gives 1 MΩ as the usual guitar amp input [9], and Fender's manuals list 1 MΩ for input 1 on its '64 Custom Deluxe Reverb and '94 Twin Amp [10, 11]. All of these sit in parallel with one another [1].

Load is the word for whatever the pickup has to drive. Resistors in parallel always add up to less than the smallest one. Two 250k pots plus a 1 MΩ amp come to about 111 kΩ. Two 500k pots plus the amp come to 200 kΩ. Two 1M pots plus the amp come to about 333 kΩ. (That's my arithmetic.) The lower that total, the more energy it drains from the pickup at resonance, and the flatter the peak. Zollner and Lemme both describe the result the same way: the resistive load changes the height of the peak much more than its frequency [1, 8].

To show the size of the effect, I modeled one pickup with three pot values. The model is the standard one from Chapter 12, described by Lemme, Zollner and ElectroSmash: the pickup is its inductance and DC resistance in

series, with its winding capacitance across the output, and the cable capacitance and the resistive load added across that [8, 12, 13]. It leaves out eddy-current losses (the small currents induced in magnets and metal parts that soak up energy), so real peaks are lower and broader than these. I used Fender's listed 2.2 H and 5.8 kΩ for the Pure Vintage '59 Strat pickup [14] and ElectroSmash's typical 100 pF winding capacitance for a single coil [13].

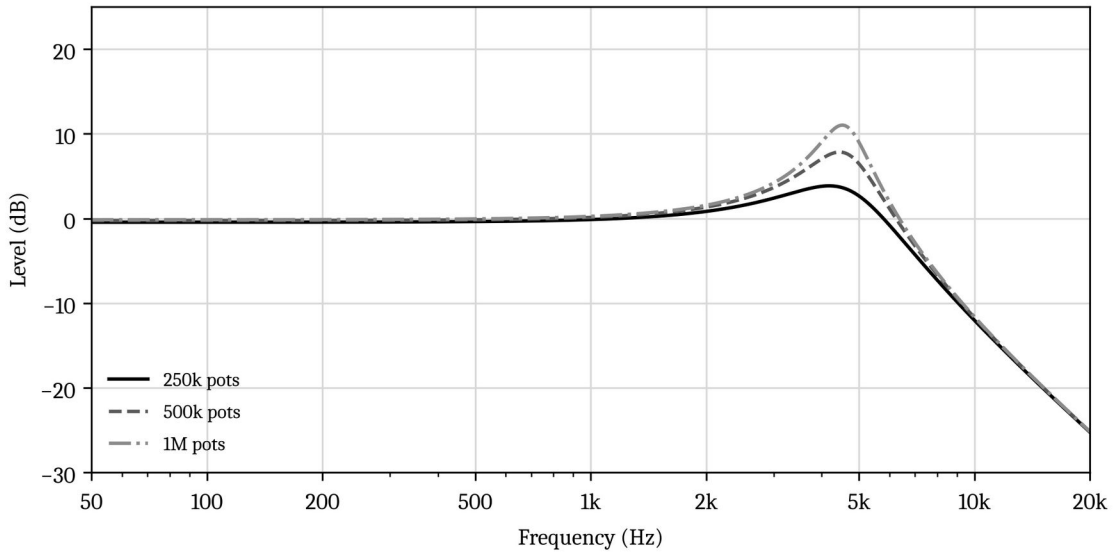


Figure 15.3: Modeled response of a Fender Pure Vintage '59 Strat pickup (2.2 H, 5.8k) with 250k, 500k and 1M pots (volume and tone both at full, 1 MΩ amp input, 450 pF cable). Bigger pots mostly raise the height of the peak; the peak frequency moves only a little.

In my model, the 250k pair gives a peak at about 4.2 kHz standing 3.9 dB above the low-frequency level. The 500k pair puts it at about 4.5 kHz and 7.8 dB. The 1M pair leaves it at about 4.5 kHz but lets it climb to 11.0 dB. So doubling the pot value from 250k to 500k roughly doubles the peak's height in decibels and nudges it up by about 300 Hz. Going on to 1M adds about 3 more dB and barely moves it.

How does that compare with a real guitar? Zollner reports a *Q*, or peak sharpness, of about 3 with volume and tone pots and an amp connected [15]. By his own rule of thumb, which Chapter 12 used, that works out to roughly a 9.5 dB peak. The direction in Figure 15.3 is solid. The exact decibel figures belong to a model without eddy losses, so read them as a guide to direction and rough size.

One caution for Gibson-style guitars with two volumes and two tones. Don't add up all four pots as if they all sit across one pickup. With the selector on a single pickup, only that pickup's volume and tone pots sit directly across its coil. The middle position is a more tangled circuit, and I won't pretend a simple "four 500k pots" figure describes it.

There's a quick way to hear a heavy load without opening the guitar. Fender lists input 2 at 136 kΩ on both of those amps, and the '64 Custom Deluxe Reverb manual gives that input 6 dB lower sensitivity [10, 11]. Zollner describes that low input as darker and lower in gain [9]. Plugging in there adds a load heavier than another 250k pot, which is a fair preview of what too low a pot value does.

The common values and where they came from

Why do Fender-style guitars use 250k and Gibson-style guitars use 500k? DiMarzio's FAQ gives the plain history: "Gibson used 500K controls and Fender used 250K," and that's where the rule of 250k for single coils and 500k for humbuckers comes from [16]. DiMarzio adds that higher pot values give "a little more power and treble response" [16]. EMG's FAQ agrees on the convention, saying passive pickups "traditionally use 250K/500K volume and tone pots" [17].

The makers' own parts follow that split today. Fender's Stratocaster pot kit holds three 250K CTS split-shaft audio-taper pots, and its Telecaster kit holds two 250K CTS solid-shaft audio-taper pots [18, 19]. Fender's Pure Vintage 250K solid-shaft pot is another single-pot option for the Tele and Fender basses [20]. On the Gibson side, Gibson sells a Historic Reissue 500k audio pot that it says is designed to replicate its late-1950s parts [21], and Seymour Duncan's Les Paul wiring guide is built around 500k pots [4].

Then there's 1M. Zollner names two Fender examples with a 1 MΩ volume pot: the Jazzmaster, and the Telecaster from 1967 on [1]. A 1M pot loads the pickup very lightly on 10, so the peak stays tall. The catch comes when you turn it down, which I cover near the end of this chapter. Zollner says 100k and 1M pots are used less often than 250k and 500k [1].

There's a twist here. DiMarzio, whose own FAQ explains the 500k-for-humbuckers rule, says its current favourite setup is "a 250K volume control and a 1 Megohm tone control," which it sells as EP1202 [16]. In load terms that pair sits between a 250k set and a 500k set: 250k, 1M and the 1 MΩ amp come to about 167 kΩ (my arithmetic). The FAQ text I'm relying on doesn't explain why DiMarzio prefers it, so I'll leave the reasoning at that.

Active pickups are a different case. EMG uses 25K audio-taper pots with 0.1 µF caps for its active pickups [17]. Those pots follow EMG's built-in preamp. The preamp drives them, so they don't sit across a bare coil the way a passive guitar's pots do, and the load rules above don't apply in the same way. ElectroSmash's analysis of the EMG 81 puts its preamp's output impedance at about 10 kΩ [13]. EMG says you can mix its actives with passive pickups in one guitar but doesn't recommend it; if you do, use 25K for the EMG and 250K or 500K for the passive pickup [17].

And if you're worried about trying a different value, DiMarzio's FAQ is reassuring: "You won't damage your pickups or your amp by mixing and matching different value controls" [16]. The worst outcome of a wrong guess is a sound you don't like and an hour with the soldering iron.

Table 15.1: Common pot values and where they're used

Value	Typical use	Load on a passive pickup	Source
25k audio	EMG active pickups, after the preamp	Not across the coil; driven by the preamp	[17]
250k audio	Fender Strat and Tele kits; passive single coils	Heavier: lower, flatter peak	[16, 18, 19]
250k no-load (tone)	Fender Delta Tone tone pot	Tone pot's load removed at 10	[22]
250k volume + 1M tone	DiMarzio's favourite, EP1202	Between a 250k set and a 500k set	[16]
500k audio	Gibson Historic Reissue; Les Paul wiring	Lighter: taller peak, brighter	[4, 21]
1M	Jazzmaster volume; Telecaster volume from 1967	Very light on 10; big treble loss when turned down	[1]

Tolerance: the number nobody prints on the knob

Pot values come with a *tolerance*, the amount the real resistance may differ from the number printed on it. Zollner says pots of recent production typically hold about plus or minus 20%, so a "250k" pot may measure anywhere from 200 to 300 kΩ, with outliers as far out as 150 to 350 kΩ [1]. CTS's 450G guitar-series datasheet offers two grades: code A for plus or minus 10% and code B for plus or minus 20% [23]. Bourns lists plus or minus 20% for its guitar pots [3, 6], and one Alpha 16 mm listing gives plus or minus 20% for the 500k and plus or minus 30% for the 1M [24].

Think about what that means. Two 250k pots from the same bag can be 100 kΩ apart and still be in spec. Two outliers can be 200 kΩ apart. That's not far off the 250 kΩ gap between a "250k" and a "500k" pot. So when one Strat sounds a little brighter than its twin, the pots are a real suspect.

Does the spread make an audible difference? Zollner looked at it on a Strat tone pot. A high "250k" pot measuring 350 kΩ sounds brighter, and a low one at 150 kΩ sounds duller, but he says the differences among 200, 250 and 300 kΩ are not "really dramatic" [1]. He also gives a fix for a pot that runs too high: a 0.9 MΩ resistor in parallel brings it back down [1]. A 350k pot with 0.9 MΩ across it comes to about 252k (my arithmetic).

> **Tip:** Measure pots before you install them. Set a multimeter to resistance and read across the two outer lugs. If you buy a few extra, you can match a pair or pick the high ones for a brighter guitar and the low ones for a darker one.

Tapers: how the knob feels

A pot's *taper* is the curve that links the knob's position to the resistance at the wiper. It doesn't change the sound with the knob on 10. It changes where on the dial things happen as you turn.

A *linear* pot changes resistance in step with the angle: half a turn, half the resistance [1]. CTS defines its linear taper as 50% of the resistance at mid-rotation [23]. An *audio* pot, also called a log pot, changes slowly at first and quickly near the top. Zollner gives a curve for it. In words: the resistance, as a fraction of the full value, equals a number k raised to the power of (the rotation minus 1), where rotation runs from 0 at one stop to 1 at the other [1]. In symbols, R/Rmax = k^(x-1). He gives k values from 50 to 300 [1]. With k = 100, half rotation gives one tenth of the full resistance, or 10% (my arithmetic).

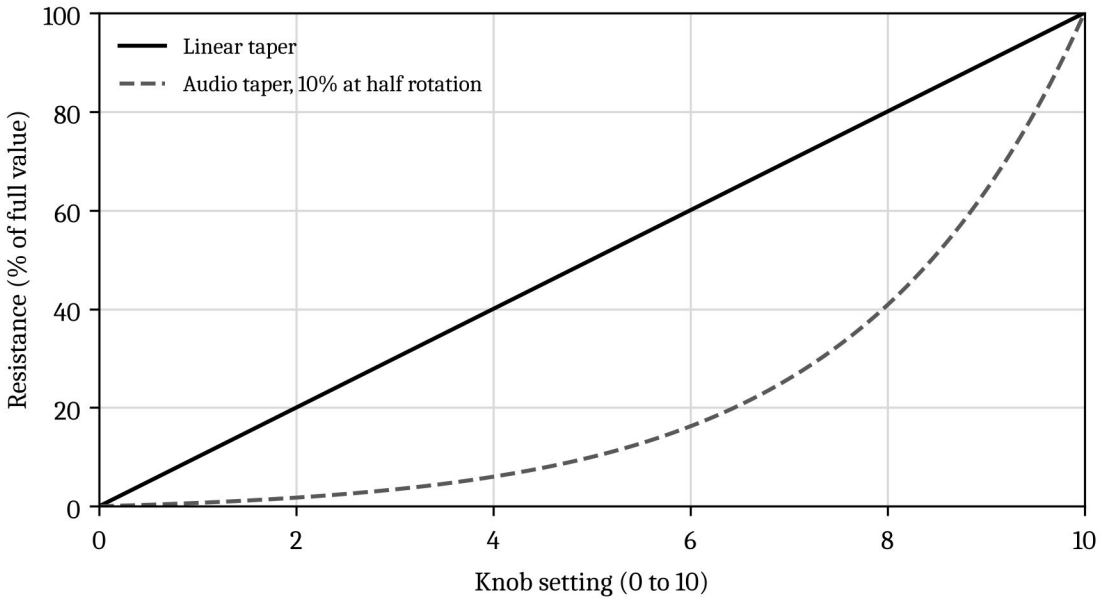


Figure 15.4: Resistance against knob setting for a linear taper and an audio taper that reaches about 10% at half rotation, drawn with the curve formula Zollner gives for log pots. Real pots follow their maker's curve more loosely.

Makers describe audio tapers by that halfway number. CTS defines "X% audio" as a taper whose resistance at 50% rotation is X% of the total, and its 450G guitar series offers a menu of them [23]. The general-purpose CTS Series 450 sheet lists fewer: linear, 10% audio and a 10% reverse audio [2]. A CTS 500k push-pull pot sold for Gibson-style guitars is listed as 15% audio [25].

Table 15.2: CTS 450G taper codes

CTS code	Taper	Resistance at half rotation	Source
1	Linear	50%	[23]
2	Audio	10%	[23]
3	Linear special "S" curve	not given	[23]
4	Audio	15%	[23]
5	Audio	5%	[23]
6	Audio	20%	[23]
7	Audio	25%	[23]
8	Audio	30%	[23]

Not every maker gives a number. Fender's kits just say "audio taper" [18, 19], and Gibson describes its Historic 500k as having a "dramatic audio taper" without a percentage [21]. Bourns names its guitar tapers by chart codes (A2, B0 and C2) and doesn't print the halfway value [3]. Be careful with letters on pots in general. On the CTS 450G sheet, A and B are tolerance codes, not tapers [23]. A letter that means one thing to one maker can mean something else to another, so check the datasheet before you trust a marking.

Why use audio taper for volume? The reasoning is arithmetic, not a listening test. Treat the volume pot as a simple divider and ignore the load for a moment. A linear pot at half rotation passes half the voltage, which is a drop of only about 6 dB. A 10% audio pot at half rotation passes a tenth, about 20 dB down (my arithmetic in both cases). Our ears judge loudness on a roughly logarithmic scale, so the audio pot spreads the change across the dial. With a linear volume pot, most of the turn does little and the real drop crowds into the last part near zero. The arithmetic shows why a linear pot is a poor fit for volume.

For tone controls, the evidence is thinner. Fender's Strat kit uses the same audio-taper 250k pot for volume and both tones [18], so Fender's own choice for tone is audio. I didn't find a maker or measurement source comparing linear and audio tone pots, so I won't rate one over the other.

Comparing real pots

Tables 15.3 and 15.4 put the maker specs side by side. The first covers pot families from component makers. The second covers the guitar makers' own replacement parts. As always, these are the makers' claims.

Table 15.3: Guitar pot families, maker data

Pot	Body	Bushing	Shaft	Values	Tolerance	Rotation	Rated life	Source
CTS 450G (guitar series)	23.8 mm (0.937 in)	3/8-32 UNEF brass	round, flat or split knurled; 0.250-1.125 in long	25k-500k	±10% (A) or ±20% (B)	not legible on sheet	not stated	[23]
CTS Series 450 (450T)	23.8 mm (0.937 in)	3/8-32 UNEF	metal or molded; 1/4 in or 3/8 in	100 Ω-10M (audio 1k-1M)	±10%, ±20% or ±30%	300°	10,000 cycles; 100,000 and 250,000 special	[2]
Bourns PDB241-GTR	24.0 mm (0.945 in)	3/8-32 UNF	plain or 18-tooth knurl	10k-1M	±20%	300° ±5°	15,000 cycles min; up to 100,000 option	[3, 26]
Bourns PDB181-GTR	17.0 mm (0.669 in)	3/8 in NEF	6 mm plain or knurled	10k-1M	±20%	300° ±5°	15,000 cycles	[6]
Bourns PDB185-GTR (push switch)	17 mm	not stated	not stated	10k-1M	±20%	not stated	not stated	[7]
Alpha 16 mm audio	16.5 mm wide	M7 x 0.75 metric	6 mm knurled, 15 mm long	500k, 1M	±20% (500k), ±30% (1M)	300° ±5°	15,000 cycles	[24]
CTS 500k push-pull	not stated	long bushing	split knurled brass	500k, 15% audio	±10%	not stated	10,000-cycle test listed	[25]

Table 15.4: Guitar makers' replacement pots

Part	Value and taper	Shaft	Notes	Source
Fender 0990830003 Strat kit	3 x 250K CTS, audio	3/8 in split shaft	Includes .022 µF and .100 µF caps	[18]
Fender 0990831002 Tele kit	2 x 250K CTS, audio	3/8 in solid shaft (set-screw knobs)	Includes .022 µF and .100 µF caps	[19]
Fender 0990831000 Pure Vintage	250K, taper not stated	3/8 in solid shaft	Fits Tele, Jazz Bass, P Bass; page conflicts on included cap	[20]
Fender 0990832000 no-load	250K, no-load	split shaft	Normal 1-9; out of circuit at 10; .022 µF cap	[22]
Fender 0992052000 TBX	250K/1Meg stacked, detented	not stated	.022 µF cap and a 1/4 W resistor	[27]
Gibson Historic Reissue 500k	500k audio ("dramatic audio taper")	short shaft, split with fine knurl, 3/8-32	Tolerance and maker not stated	[21, 28]
EMG active pots	25K audio	not stated	Used with 0.1 µF caps	[17]

CTS calls the 450G the "industry standard" guitar pot [29]. You'll also see 450T part numbers. I couldn't find one CTS page that compares the two, so this comparison is my own, built from two datasheets. The 450T belongs to CTS's general-purpose Series 450: same 24 mm can and 3/8-32 bushing, but a much wider value range, higher power ratings, 1/4 in shafts as an option and 300 degrees of rotation [2]. The 450G is the guitar build of that same size, with guitar values, guitar shafts and a wider menu of audio tapers [23]. For a guitar, the practical difference is shafts and tapers, not sound.

One spec on the 450G sheet confuses people: "shaft push-pull strength, 30 lb minimum" [23]. That's how hard you can pull on the shaft without damage. It has nothing to do with a push-pull switch.

What actually separates these parts for a player is fit and feel.

- Body size. Gibson's Historic pot uses a 3/8-32 thread [28], and Fender describes its kit pots as 3/8 in CTS parts [18]. That's the same bushing size as the 24 mm CTS and Bourns families [3, 23]. The 16 and 17 mm pots are the smaller format, with 6 mm shafts and either a metric M7 bushing (the Alpha) or a 3/8 in NEF bushing (the Bourns PDB181) [6, 24]. Swapping between formats can mean new knobs and redrilled holes.
- Shaft. Split knurled shafts take push-on knobs, like a Strat's. Solid shafts take set-screw knobs, like a Tele's [18, 19]. The knob has to match the shaft.
- Bushing length. The CTS push-pull part is sold with a long bushing for Gibson-style guitars [25], while Gibson's Historic pot is a short-shaft part [21]. Check the length against how thick the wood is where the pot mounts.
- Life. Bourns rates its 24 mm guitar pot for at least 15,000 rotations and announced in May 2025 an extended-life option of up to 100,000 [3, 26]. CTS lists 10,000 cycles as standard for the Series 450 [2]. That's a lot of knob twisting either way.

Will a Bourns sound different from a CTS of the same value? In the circuit model, a pot is just its resistance and its taper. Once you've measured two pots at the same value, nothing in these datasheets gives a reason to expect a different sound. The differences are fit, feel and how long they'll last.

Special pots

No-load pots

A normal tone pot still loads the pickup on 10, as we saw above. A *no-load* pot fixes that. Fender's 250K no-load split-shaft pot, part of its Delta Tone system on American series guitars, works "as a normal tone control from 1 to 9." At 10, Fender says, "the tone control is removed from the circuit" [22]. It ships with a .022 µF 250 V cap [22].

What does that do to the load? Take a Strat-type circuit with a 250k volume pot. With a normal 250k tone pot on 10, the pickup sees about 111 kΩ. With the no-load tone pot on 10, it sees only the volume pot and the amp: 250k and 1M in parallel, which is 200 kΩ (my arithmetic). That's the same total as two 500k pots and the amp, so the 500k curve in Figure 15.3 is a fair picture of a no-load tone pot on 10. On paper, a no-load pot gives you a 250k guitar from 1 to 9 and something close to a 500k guitar at 10.

TBX

Fender's TBX tone control is a stacked, detented pot that Fender lists as "250K/1Meg" [27]. The kit includes a .022 µF cap and a 1/4 W resistor, with no resistor value given [27]. Fender says positions 1 to 5 act as a standard tone control, and that past 5, "resistance decreases," which Fender's copy describes as more bass,

treble, presence and output [27]. A retailer listing for the part gives plus or minus 15% tolerance and a center detent [30].

Not everyone describes it the same way. In Premier Guitar, Dirk Wacker describes the 250k section working from 0 to 5 and a 1M linear section from 5 to 10, with a .022 µF cap and an 82k carbon-film resistor, and the center detent as the flat setting [31]. He says the TBX cuts bass or treble and never adds anything. Another Premier Guitar column by Hoepfinger gives .022 µF for guitar, .033 µF for bass, and 82k [32]. Those values come from magazine columns, not from Fender, and Fender's own page doesn't confirm them. My plain reading is that both descriptions agree on a stacked 250k/1M pot with a detent near the middle, and differ on what the top half does.

Push-pull and push-push pots

A switch pot is a normal pot with a small switch built onto the shaft. On a *push-pull* pot you pull the knob up to flip the switch and push it down to flip it back. On a *push-push* pot you press the knob once to switch and again to switch back. You can still turn the knob in either position, so you get an extra sound without drilling a hole for a mini toggle.

The common use is coil splitting (Chapter 14). Seymour Duncan's Les Paul wiring guide recommends 500k push-pull volume pots for it [4]. Seymour Duncan's Richard Irons explains that the split uses a DPDT switch, either a mini toggle or a push-pull, to ground the humbucker's red and white leads together and cut out the screw coil [33]. *DPDT* means double pole, double throw: two separate switches that flip together, each with two positions.

The parts I found compare like this. The CTS 500k push-pull pot has a DPDT switch rated 30 V DC at 0.1 A, a split knurled shaft and a long bushing [25]. Bourns's PDB185-GTR is a 17 mm pot with a DPDT latching push switch [7]. Fender's S-1 switch, introduced in summer 2003, is a push switch built into a volume or tone knob that Fender uses to add extra pickup combinations; on the American Elite Strat, most of them are series wirings [34]. Switch ratings like 30 V and 0.1 A are far above anything a guitar signal comes near, so they're not a concern. None of the makers I found states a life rating for the switch itself.

Stacked, concentric and blend pots

A stacked pot puts two pots on one shaft or two concentric shafts, so one knob position controls two things. The TBX above is the only stacked pot I've found published details on. Concentric dual pots (two knobs on one shaft) and blend pots (which fade between two pickups) exist, but I don't have maker data for them, so I'll leave their values alone.

Turning the volume down: where the treble goes

On 10, a volume pot is just a load. Turn it down and it does something else. Zollner explains that on a Strat, turning the volume down removes the resonance peak, so the sound gets duller [1]. The reason is in the wiring. As the wiper moves away from the hot end, part of the track's resistance ends up between the pickup and the cable. That resistance, feeding the cable's capacitance, forms a simple treble filter. At the same time the rest of the track damps the peak [1, 35].

Pot value makes this worse. A bigger pot puts more resistance in that path at the same knob position. Zollner says that on a Jazzmaster with a 1 MΩ volume pot, even a small turn-down "kills the treble radically" [1]. He also notes that when Fender gave the Telecaster a 1M volume pot in 1967, it added a 1 nF cap across the pot, which suggests Fender heard the same problem [1].

That cap is a *treble bleed*, a small part (sometimes with a resistor) that lets highs bypass the volume pot. The values, the versions with resistors, and 50s versus modern tone wiring are all in Chapter 16.

What you'll hear

So how big is each change?

Pot value is the one that matters most. Going from 250k to 500k on a passive pickup lightens the load, so the resonant peak stands taller. In my model that's the gap between about 4 dB and 8 dB of peak on a Strat pickup, with the peak itself moving only about 300 Hz. In listening terms, DiMarzio's phrase, "a little more power and treble response," is a fair summary [16]. Going on to 1M adds more of the same, and the cost shows up as soon as you touch the volume knob.

Tolerance is the hidden one. A pot marked 250k can land anywhere from 200k to 300k, and Zollner describes a 350k "250k" as brighter and a 150k one as duller, while calling the in-spec range not dramatic [1]. If two guitars with the "same" parts sound a bit different, measure the pots.

Taper doesn't change the sound with the knob on 10 at all. It changes the feel: where on the dial the volume drops and how smoothly. The brand of pot, at the same measured value and taper, isn't something I've found any reason to expect you'd hear.

A no-load tone pot on 10 sounds like a lighter load, close to the 500k case in Figure 15.3. A 25k pot in an EMG guitar sounds like nothing in particular, because it isn't loading a bare coil.

Tone and playability at a glance

Table 15.5: Pot changes, rated

Change	What you'll hear	What you'll feel
250k to 500k pots (passive)	Taller resonant peak: brighter, more bite; peak barely moves	Nothing on 10; more treble loss as you turn down
500k to 1M volume	Even taller peak on 10	Treble drops sharply on a small turn-down unless you add a treble bleed
250k tone to no-load tone	Lighter load at 10, close to the 500k case; same as 250k from 1 to 9	Little; the pot behaves as normal below 10
250k vol + 1M tone (DiMarzio EP1202)	Between a 250k and a 500k set	Nothing different on 10
Different pot within the same value (tolerance spread)	Small, sometimes audible; high pots brighter, low pots duller	Nothing
Linear to audio volume taper	No change on 10	Volume drops evenly across the dial instead of mostly near zero
Audio taper 10% to 20% or 30%	No change on 10	Volume holds up longer before it drops
CTS to Bourns at the same measured value	Little or no audible change	Fit, shaft and knob may differ
24 mm to 16-17 mm pot	Little or no audible change	Needs matching knobs and holes; different bushing thread
Standard to push-pull pot	None by itself	One extra switch under the same knob

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Bracket numbers in this chapter point to this list. Web addresses were checked in October 2026; if one moves, search the site for the title.

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Chapter 16: Capacitors and Tone Circuits

The tone knob is easy to ignore. Some players leave it on 10 forever because "it just makes it muddy," and others spend real money on fancy capacitors to fix a sound they rarely use. Both camps are missing what the knob can do.

This chapter covers the small parts that shape treble inside the guitar: the tone capacitor and its circuit, the treble bleed on the volume pot, and the two common ways of wiring a Les Paul style control set. I'll show you why the usual tone control formula gives silly answers, what the tone control really does to the pickup's resonant peak, which values the makers ship, and what the research says about capacitor types. Pots and their values are in Chapter 15, the pickup's resonant peak is in Chapter 12, and cables and the amp input are in Chapter 18.

What a capacitor is

A *capacitor* is two conductors (usually thin metal foils or metal coatings) separated by a thin layer of insulation. That insulating layer is called the *dielectric*. It might be plastic film, paper soaked in oil, or ceramic. A capacitor stores electric charge on its plates, and the amount it can store for a given voltage is its *capacitance*.

Why does that matter to a guitar? A capacitor blocks a steady current, but it lets a changing signal through. The faster the signal changes, the more easily it gets through. So a capacitor connected from the signal to ground acts like a drain that opens wider for treble than for bass. That's how a tone control works.

Capacitance is measured in farads, but a farad is enormous, so guitar parts use small fractions of it:

- microfarads (µF): millionths of a farad. Tone caps are usually written this way, like 0.022 µF.
- nanofarads (nF): thousandths of a microfarad. 0.022 µF is the same as 22 nF.
- picofarads (pF): thousandths of a nanofarad. 1 nF is 1,000 pF, which is also 0.001 µF.

Older parts and diagrams often drop the unit entirely. When you see ".022" on a capacitor or in a diagram, it almost always means 0.022 µF. When you see a treble bleed cap marked ".001", that's 1 nF.

A capacitor also has a *tolerance* (how far the real value can be from the printed one, like ±10%) and a voltage rating. It has a small energy loss, given as its *dissipation factor*, which depends mostly on the dielectric. Those last two specs are where most of the tone cap arguments come from, so I'll come back to them.

The tone control: a cap and a pot to ground

A standard passive tone control is simple. One end of the tone pot connects to the signal (usually at the volume pot). The pot's wiper connects to the capacitor. The other end of the capacitor goes to ground. So you have a variable resistor in series with a capacitor, and the pair hangs across the pickup's signal to ground.

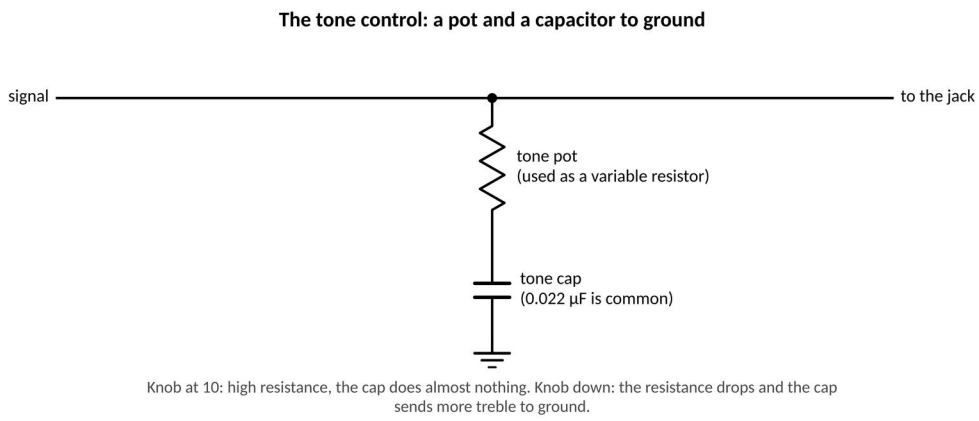


Figure 16.1: The tone control is a pot and a capacitor in series from the signal to ground.

Zollner, in his book *Physics of the Electric Guitar*, describes the tone pot as shunting a capacitor "typically in the order of 20 - 50 nF" across the pickup, which is 0.020 to 0.050 µF [1]. When the knob is on 10, there's a lot of resistance (the full 250k or 500k of the pot) between the signal and the cap. When the knob is on 0, the resistance is close to zero and the cap sits almost straight across the pickup.

With the knob on 10, the tone pot still matters, but not because of the cap. The pot itself is a resistor to ground, and it adds load to the pickup like the volume pot does. That's why pot values change brightness even with the tone wide open, and it's the load I went through in detail in Chapter 15.

The no-load pot

Fender makes a way around that load. Its 250K no-load tone pot, part of what Fender calls the Delta Tone system on its American series guitars, works as a normal tone control from 1 to 9. At 10, Fender says the tone control is removed from the circuit [2]. It ships with a .022 µF cap [2]. Turned all the way up, the guitar then sees only the volume pot and the amp as a load, so the pickup's peak stands a little taller. By my arithmetic, a 250k volume pot and a 1 MΩ amp input alone add up to a 200k load, the same total load as two 500k pots and the amp. So taking the 250k tone pot out of the circuit lightens the load about as much as moving from 250k pots to 500k pots (Chapter 15 has what that does) [1]. That's a real but modest brightening.

Why the usual formula gets it wrong

If you've read wiring guides, you've probably seen a tone control explained as a simple filter made of a resistor and a capacitor. Those guides use the textbook formula for the *corner frequency* of that kind of filter, the point where treble starts to roll off:

Corner frequency = 1 ÷ (2 × π × R × C). In words: one divided by the product of two, pi, the resistance in ohms and the capacitance in farads.

Let's try it. I plugged a guitar's full tone pot resistance into it (these are my calculations, not anyone's published figures) [1, 3]:

- A 250k tone pot with a 0.022 µF cap gives about 29 Hz.
- A 500k pot with the same cap gives about 14.5 Hz.
- EMG's 25k pot with its 0.1 µF cap gives about 64 Hz.

Those numbers don't mean what the guides say. In a resistor and capacitor wired in series to ground, that frequency only marks where the pair stops acting like a capacitor and starts acting like a plain resistor. Above about 29 Hz, a 250k pot with a 0.022 µF cap on 10 is simply a 250k load, which is all it is with the knob up. There's no treble cut, because nothing sits in series with the signal to form a filter with the cap. The only thing in series is the pickup, and the pickup is a coil with a lot of *inductance* (the property of a coil that resists changes in current), and the capacitor is wired across that coil. A coil and a capacitor together form a resonant circuit. Zollner treats the tone control that way, as part of the pickup's resonant system, and so should we [1, 4].

What the tone control really does

Chapter 12 explained the pickup's *resonant peak*: the pickup's inductance and the capacitance around it (the coil's own, plus the cable and amp input) create a band of treble, usually a few kilohertz, where the guitar responds more strongly than anywhere else. That peak is a big part of what makes a pickup sound bright, glassy or thick.

When you turn the tone down, the tone cap starts to join that circuit. Look at the left half of Figure 16.2.

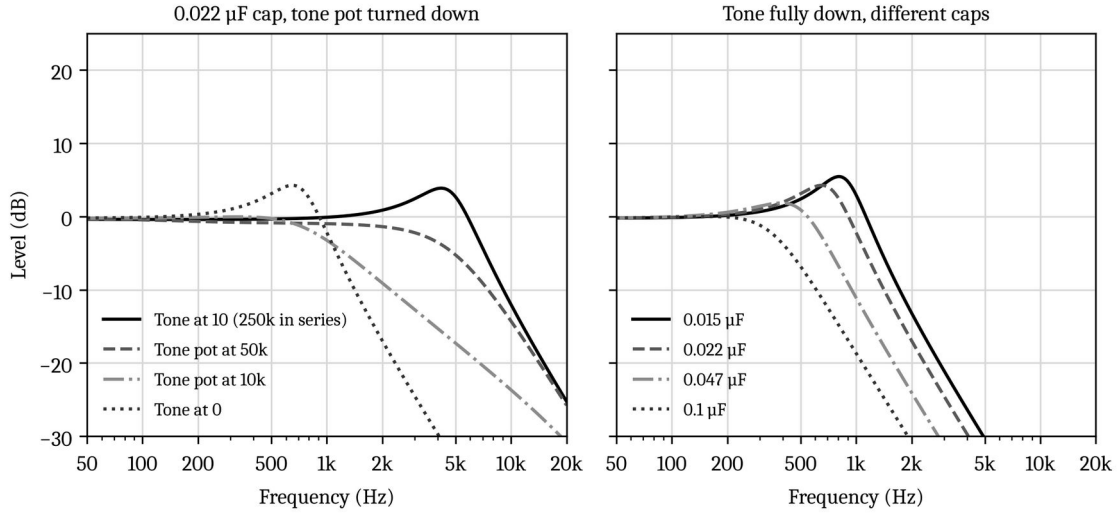


Figure 16.2: Modeled Strat pickup (2.2 H, 5.8k, 250k volume, 1 MΩ amp, 450 pF cable). Left: a 0.022 µF tone cap with the tone pot at full (250k), 50k, 10k and zero. Right: the tone fully down with four cap values. Turning the tone down creates a new, lower peak; a bigger cap puts it lower.

I built this figure with the standard pickup model described by Zollner, Lemme and ElectroSmash: the coil's resistance and inductance in series, with the winding capacitance, cable, pots and amp input across the output, plus the tone branch [5, 6, 7]. The pickup values are 2.2 H, the Strat inductance Zollner gives [5], and 5.8k, the resistance Fender lists for its Pure Vintage '59 Strat pickup (Chapter 15 gives that source). The model leaves out eddy current losses, so real peaks are lower and broader than these curves. Read it for the pattern, not exact decibels.

Tone on 10

With the tone pot at its full 250k, the cap barely changes the curve in my model. That matches Zollner's finding: with the tone pot up, he reports that even replacing the cap with a plain wire changes the response by

less than 0.01 dB [4]. At 10, the pot's resistance hides the cap almost completely. Whatever cap you've installed, at 10 you're mostly hearing the pot as a load.

Tone partway down

Partway down (the 10k curve in my model), the response shows a gentle downward slope across the treble rather than a sharp cut or a new peak. The original peak gets flattened and the highs ease off. This middle zone gives gentle shading rather than a dramatic change, and it's also where the knob's taper (Chapter 15) decides how the change feels under your fingers.

Tone fully down

At 0, something interesting happens. The tone cap now sits almost directly across the pickup. Electrically, it's like plugging in a very long cable: a big added capacitance. That doesn't just cut the treble. It makes a new resonance at a much lower frequency, in the midrange.

Zollner puts this new resonance below 1 kHz with the tone fully down, and he gives a Strat example (600 pF cable, 1 MΩ amp) resonating near 350 Hz [1]. In my model with a 0.022 µF cap, the new peak lands around 650 Hz and stands about 4.2 dB above the low-frequency level. Zollner doesn't state the cap for his example. By the bare resonance formula, 350 Hz on a 2.2 H pickup points to a cap near 0.1 µF, the vintage Strat value, so his figure and my 0.022 µF result describe different caps rather than disagreeing.

That's why a guitar with the tone rolled all the way off doesn't just sound dark. It sounds honky or vocal, a bit like a wah pedal parked partway. So why does the tone knob seem to do nothing until the last bit of travel? Part of it is the taper of the pot, and part of it is that the new low peak only really forms when the resistance gets small.

Cap value moves the low peak

The right half of Figure 16.2 holds the tone at 0 and swaps the cap. Bigger caps put the new peak lower and make it weaker. Smaller caps put it higher and make it more pronounced. Zollner's own comparison of 100, 50, 22, 10 and 3.3 nF shows the same thing: the smaller the cap, the higher and more pronounced the tone-down resonance [4].

In my model, 0.015 µF gives a peak at about 810 Hz standing about 5.4 dB tall, while 0.1 µF gives no real peak; the response is down about 3 dB by roughly 380 Hz. Table 16.2 below lists all four.

I also worked the bare resonance formula from Chapter 12 for each cap, using only the pickup's inductance and the tone cap and ignoring everything else. For a 2.2 H Strat pickup, ElectroSmash's 5 H EMG 81 model, and ElectroSmash's "typical humbucker" of 10 H, here's what it gives [5, 6]. The model numbers in Figure 16.2 come out lower than these because the model includes the coil's resistance, the cable and the pots.

Table 16.1: Tone fully down, computed resonance by cap value (my calculation, cable and losses ignored)

Tone cap	L = 2.2 H (Strat)	L = 5 H	L = 10 H	Source of L
0.015 µF (15 nF)	876 Hz	581 Hz	411 Hz	[5, 6]
0.022 µF (22 nF)	723 Hz	480 Hz	339 Hz	[5, 6]
0.033 µF (33 nF)	591 Hz	392 Hz	277 Hz	[5, 6]
0.047 µF (47 nF)	495 Hz	328 Hz	232 Hz	[5, 6]
0.1 µF (100 nF)	339 Hz	225 Hz	159 Hz	[5, 6]

Notice the pattern: a humbucker, with more inductance, lands lower with the same cap. So the same 0.022 µF that gives a Strat a midrange honk can take a high-inductance humbucker down into the low mids. That's one reason the traditional advice pairs smaller caps with humbuckers and bigger caps with single coils, which we'll get to in a moment.

Small caps, different job

Some builders use much smaller caps, switched in without a pot, to move the peak instead of killing it. Lemme recommends switchable caps of roughly 470 pF to 10 nF for usable resonance shifts [7], and Zollner mentions rotary switches that select caps of 1 to 10 nF [4]. A cap that small acts like extra cable: it slides the pickup's peak down a step at a time while keeping it tall. That's a very different sound from a rolled-off tone knob.

Choosing a cap value

So which value should you use? Here are the modeled and computed numbers side by side with where each value shows up.

Table 16.2: Common tone cap values, modeled peaks with tone fully down, and where they're used

Value	Modeled peak, Strat (Fig. 16.1)	Computed, 2.2 H only	Where it shows up	Source
0.015 µF	about 810 Hz, +5.4 dB	876 Hz	Seymour Duncan: finer high-end control on a Les Paul	[8]
0.022 µF	about 650 Hz, +4.2 dB	723 Hz	Fender "modern" kit cap; Strat from 1983; stock Les Paul (Seymour Duncan); Gibson Historic bumblebee; Fender no-load pot	[9, 10, 4, 8, 11, 2]
0.033 µF	not modeled	591 Hz	No maker use found	n/a
0.047 µF	about 390 Hz, +1.8 dB	495 Hz	Seymour Duncan: "beefier" Les Paul option; StewMac's Coleman on a bright Les Paul	[8, 12]
0.1 µF	no peak; -3 dB near 380 Hz	339 Hz	Fender "vintage-style" kit cap; original Strat; EMG actives (with 25k pots)	[9, 10, 4, 3]

Fender's history

Zollner gives the Stratocaster's factory tone cap history: 100 nF (0.1 µF) when it was first released, 50 nF (0.05 µF) from 1970, and 22 nF (0.022 µF) from 1983 [4]. He notes that old Fenders used 100 nF and that the common range today is 20 to 50 nF [4].

Fender's current parts reflect that. Its Stratocaster pot and capacitor kit and its Telecaster kit both include two metallized polyester film caps: a .022 µF Fender calls "modern" and a .100 µF Fender calls "vintage-style" [9, 10]. You choose which one to install.

What about the Telecaster? You'll often read that Teles shipped with a 0.047 µF tone cap. I could not confirm that on any Fender page. Fender's own Tele kit ships .022 and .100 µF [10], and Zollner's 50 nF from 1970 applies to the Strat [4]. Until I find a Fender source, I'm treating the Tele 0.047 µF as unconfirmed.

Gibson and the humbucker side

Seymour Duncan's Les Paul wiring hub says 0.022 µF is the stock Les Paul value. It calls 0.047 µF "beefier" and says 0.015 µF gives finer control over the high end [8]. Gibson sells Historic Reissue "Bumblebee" capacitors at 0.022 µF, paper-in-oil, and says they're the same caps used in many of Gibson Custom's Historic Collection guitars [11].

A dealer history from OK Guitars gives some period detail: early 1958 ES-335 and ES-355 models used Sprague paper-in-oil "bumblebee" caps, later 1958 to about 1961 used mylar bumblebees, and from 1961 Sprague "Black Beauty" mylar caps. ES-345 and stereo ES-355 models from 1959 to 1964 used ceramic discs [13]. Every one of those is listed at .022. You'll sometimes see ".02 µF" given as the 1950s Gibson value, but I couldn't confirm that, and this source gives .022 for every type [13].

A baseline from StewMac

Erick Coleman, a senior technical advisor at StewMac, gives a handy traditional baseline: about 0.020 µF for humbuckers and 0.050 µF for single coils [12]. That fits Table 16.1. A humbucker's higher inductance pulls its tone-down peak lower, so a smaller cap keeps it from turning to mud, while a single coil can take a bigger cap. Coleman also says he preferred 0.047 µF on a bright Les Paul, and his overall advice is to trust your own ears [12].

Active pickups

EMG says it uses 0.1 µF caps for all its volume and tone setups, guitar and bass, along with 25K pots [3]. In an active system the controls sit after a preamp, not straight across the coil, so the passive rules in this chapter don't carry over directly.

So which one?

Pick the value by where you want the tone-down sound to land, not by what's "correct." If you use the tone knob mostly near 10, the value barely matters, because the pot hides the cap. If you roll it off for a dark, vocal lead sound, a smaller cap gives a higher, more pronounced honk, and a bigger cap gives a darker, smoother roll-off. Going by Coleman's baseline and Seymour Duncan's Les Paul values, single coils sit toward the bigger end of the range and humbuckers around 0.015 to 0.022 µF [12, 8].

> **Tip:** A cap swap is cheap and quick to undo. Tack the new cap in with short leads before you trim and solder it for good, then play it through your own amp with the tone at 0, 3 and 6.

Does the type of capacitor matter?

This is one of the loudest arguments in guitar electronics. Paper-in-oil, polyester, polypropylene, ceramic, vintage bumblebees, modern Orange Drops: people will tell you each has its own voice. Here's what the measurements say.

Every capacitor loses a little energy inside its dielectric. That loss is the *dissipation factor*, written as a percentage. A lower number means a more nearly perfect capacitor. Zollner lists typical dissipation factors by dielectric type [4]:

Table 16.3: Tone cap dielectrics and their losses

Dielectric	Dissipation factor (tan δ)	Examples in guitars	Source
Polystyrene	0.1%	none found	[4]
Polypropylene	0.3% (class value); Orange Drop 715P: 0.1% max at 1 kHz	Orange Drop 715P and 716P	[4, 14]
Polycarbonate	1%	none found	[4]
Paper (paper-in-oil)	4-8%	Gibson Historic bumblebee; early 1958 bumblebees	[4, 11, 13]
Polyester (Mylar)	5-10%	Fender kit caps; later bumblebees; Black Beauty	[4, 9, 13]
Ceramic, class 1	under 1.5%	none found	[4]
Ceramic, class 2 (typical disc)	under 30%	ceramic discs in ES-345/stereo ES-355 and the Greasebucket (class not stated by those sources)	[4, 13, 15]

Looking at that table, you'd think a ceramic disc with up to 30% loss would sound terrible next to a polypropylene film cap. Zollner worked out whether these differences reach your ears, and they don't.

With the tone on 10, he found that swapping the cap for a short circuit changes the output by less than 0.01 dB [4]. With the tone fully down, the difference between a very low loss cap (0.1%) and a perfect, lossless one is under 0.1 dB [4]. He also checked distortion at 2 volts peak-to-peak: under 0.01% for film caps and about 0.1% for ceramic [4]. StewMac puts passive pickups typically under about 1 V [16], though a loud pickup's peaks can come close to Zollner's test level. Even there, the cap's distortion is a tiny fraction of a percent. Zollner's point is that the cap's internal loss is tiny next to everything else in the circuit, so it hardly matters whether that loss is large or small [4].

What does matter is the value. Zollner reports that a 20% tolerance, the difference between something like 40 nF and 60 nF, gives audible level differences on a Strat [4]. That makes sense from Table 16.1: a cap 20% off moves the tone-down peak. So the spec on a cap that actually changes your tone is the number on it and how close it really is to that number, not what it's made of.

I go into the listening side of this in my book *Chasing Tone*. The short version: if two caps measure the same value, I don't expect you to hear the difference.

What a fancy cap really buys you

Prices put this in perspective. Zollner gives about 18 to 20 cents for a standard polypropylene film cap, about 60 cents for a 1% tolerance one, and about $50 for a "replica" vintage cap [4]. Gibson lists its two-pack of Historic bumblebees at $89.99 [11]. If you're paying for a tighter tolerance, that's money with a real (small) effect. If you're paying for a dielectric, Zollner's numbers say you're paying for looks and history. That's fine for a restoration. Just know what you're buying.

Orange Drops by the numbers

The Sprague Orange Drop is one of the few tone-cap lines with a full maker datasheet I could find. Vishay's datasheet for the Type 715P lists a polypropylene film dielectric, values from .001 to .47 µF, a standard

tolerance of ±10% with ±5% and ±2% options, voltage ratings from 200 to 1,600 VDC, and a dissipation factor of 0.1% maximum at 1 kHz [14]. A current SBE-marked sheet for the 716P, hosted by a distributor, lists polypropylene film and foil construction, values from 220 pF to 1.0 µF, tolerances of ±3%, ±5% or ±10%, and a dissipation factor of no more than 0.028 to 0.047% at 20 kHz for the lower voltage, lower value parts [17]. The 715P is the round dipped shape and the 716P the flat pressed shape [17].

Table 16.4: Some tone caps compared

Cap	Dielectric	Dissipation factor	Tolerance	Source
Orange Drop 715P	polypropylene	0.1% max at 1 kHz (maker)	±10% standard; ±5%, ±2% options	[14]
Orange Drop 716P	polypropylene film and foil	0.028-0.047% max at 20 kHz (maker, lower values)	±3%, ±5%, ±10%	[17]
Fender kit caps (.022 and .100 µF)	metallized polyester	5-10% (class value, Zollner)	not stated	[9, 4]
Gibson Historic bumblebee (0.022 µF)	paper-in-oil	4-8% (class value, Zollner)	not stated	[11, 4]
Typical ceramic disc	class 2 ceramic	under 30% (class value, Zollner)	not stated	[4]

Read that table for the tolerance column. An Orange Drop ordered at ±5% will land closer to its printed value than a part with no stated tolerance, and per Zollner, that's the spec that can show up in your tone-down sound [4]. Those voltage ratings in the hundreds of volts are far beyond anything a passive guitar produces, so they don't matter here.

Treble bleed: keeping the highs when you turn down

Now to the volume knob. Most players notice that a guitar gets duller as they roll the volume back. That isn't your imagination, and it isn't the tone cap.

Here's why it happens. When you turn the volume down, the pot puts resistance between the pickup and the cable. The cable has capacitance to ground. A resistance feeding into a capacitance to ground is a treble cut. At the same time, the lower part of the pot loads the pickup more heavily and damps its resonant peak [1, 18]. Zollner describes turning a Strat's volume down as removing the resonant peak, which makes the sound duller [1]. With a 1 MΩ volume pot, like a Jazzmaster's, he says even a small turn-down cuts the treble drastically [1].

A *treble bleed* is a small network soldered between the volume pot's input lug and its output (wiper) lug. The cap in it passes high frequencies around the pot's resistance, so some treble skips past the volume control when you turn down. Adding a resistor limits how much gets through, which keeps the volume taper and tone more even [1, 19].

This isn't a new idea. Zollner notes that when Fender gave the Telecaster a 1 MΩ volume pot in 1967, it apparently noticed the strong tone change, and it fitted a 1 nF bridging cap [1].

Three common layouts

There are three basic ways to build a treble bleed. Premier Guitar's Dirk Wacker, writing in a magazine column, lays them out [19]:

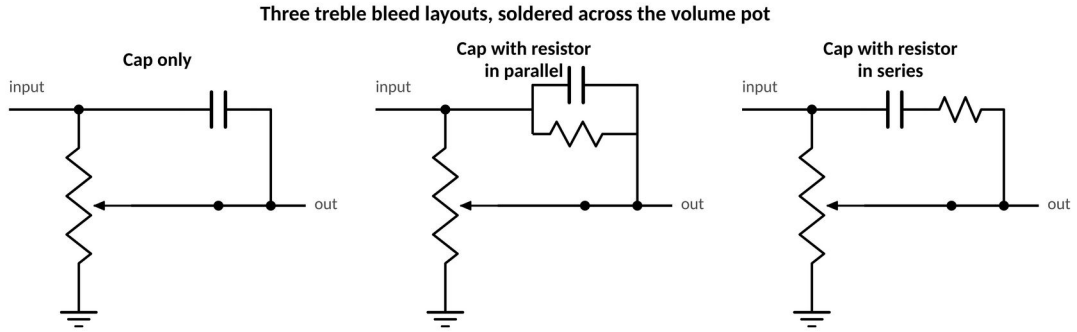


Figure 16.3: The three treble bleed layouts, each soldered between the volume pot's input lug and its wiper.

- Cap only: Wacker gives 1,000 pF (1 nF) for the 1960s Fender Tele with 1M pots, with a workable range of 220 to 1,500 pF. He says this can get thin or tinny near the bottom of the knob [19]. Fender's own article makes a similar point, that a cap alone can cut too many lows when you turn down [18].
- Cap with a resistor in parallel: Wacker calls 1,000 pF with 150k a popular choice, with ranges of 220 to 1,500 pF and 100k to 330k [19].
- Cap with a resistor in series: Wacker gives the Kinman network as 1,200 pF with 130k, and the Fender Tone Saver as 1,000 pF with 130k [19].

His rule of thumb: the resistor sets how bright it is (lower resistance lets more highs through), and the cap sets which frequencies are affected (a smaller cap acts on higher frequencies) [19]. He also points out that each volume pot needs its own network, so a Les Paul with two volume pots needs two [19].

Table 16.5: Treble bleed values compared

Network	Cap	Resistor	Layout	Source
Fender 1967 Tele (1M volume)	1 nF	none	cap only	[1]
Zollner comparison	150 pF	none	cap only	[1]
Zollner comparison (Strat)	1 nF	100k	parallel	[1]
Zollner (Jazzmaster)	1 nF	150k	parallel	[1]
StewMac Golden Age kit	1 nF (.001 µF)	150k, 1%	parallel	[20]
Seymour Duncan blog	".002" (2 nF presumed)	100k	parallel	[21]
Kinman (as reported by Premier Guitar)	1.2 nF	130k	series	[19]
Fender Tone Saver (as reported by Premier Guitar)	1 nF	130k	series	[19]
Fender American Professional single coils	one cap	two resistors	series and parallel	[18]

A few notes on those rows. StewMac's Golden Age kit puts a 150k, 1% resistor in parallel with a .001 µF cap, soldered across the volume pot's input and output lugs. It comes with a ceramic cap (#1467, $15.29) or an Orange Drop (#1468, $20.49), and StewMac claims it gives "more uniform tone from 1 to 10" [20]. Seymour Duncan's blog suggests a ".002" cap and a 100k resistor in parallel [21]. The page doesn't print the unit, so I'm

reading it as 0.002 µF, which is 2 nF. That's twice the cap and a lower resistor than StewMac's kit, so on paper it lets more treble through.

The Kinman and Tone Saver values come from Premier Guitar, a magazine, not from Kinman or Fender. Fender's Tone Saver page describes a resistor and capacitor network in one enclosure, of "Mylar and tin foil construction," with two solder points to the volume pot's center and outer lugs, sold in 250K and 500K versions for $69.99, but it doesn't list values [22].

Fender's article on treble bleeds says its American Professional single-coil models (Strat, Tele, Jaguar and Jazzmaster) use one cap and two resistors, one in series and one in parallel, a design credited to Fender engineer Jonathan Parrish. Its Shawbucker circuits use a cap and one resistor. No values are given [18].

Should you add one?

It depends on how you play. If you ride the volume knob to clean up a dirty amp, a treble bleed keeps those cleaner sounds from going dull. If you never touch the volume, it does nothing for you, since a bleed only acts when the knob is below 10. And if you like the darker sound of a rolled-back volume (some players use it as a second tone control), a bleed takes that away. Start mild. A 1 nF cap with 150k in parallel is the most common starting point in these sources, and it's easy to change.

> **Caution:** A treble bleed sits between two lugs that are already carrying solder. Use a heat sink or work quickly so you don't cook the pot, and keep the leads short and clear of the pot's case so they can't short to ground.

50s wiring vs modern wiring

On a guitar with separate volume and tone pots for each pickup (a Les Paul, SG or ES-335), there are two common ways to hook the tone pot to the volume pot. The difference is only where the tone cap connects. Fralin's Tyler Delsack makes the point directly: "50's wiring" refers only to how the tone cap is wired into the guitar [23].

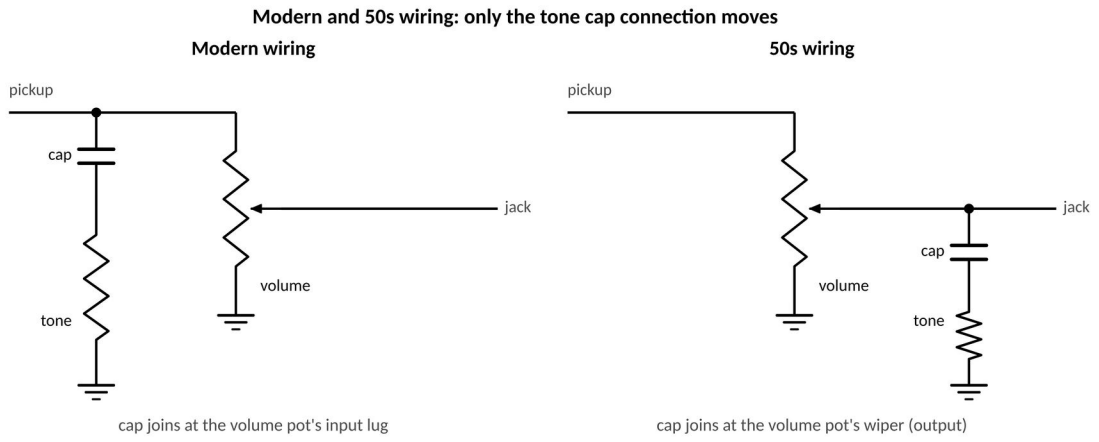


Figure 16.4: Modern and 50s wiring differ only in where the tone cap joins the volume pot (Table 16.6).

In modern wiring, the tone circuit connects to the volume pot's input lug, the one that comes straight from the pickup [8]. The tone control works on the pickup before the volume pot.

In 50s wiring, the tone pot's outer lug connects through the 0.022 µF cap to the volume pot's middle lug, the wiper (output) [8]. The tone control now works after the volume pot.

What do you hear? According to Seymour Duncan, 50s wiring keeps more high end as you turn the volume down, but turning the tone down also drops some volume and the pickups interact more [8]. Modern wiring holds volume better as you roll off the tone, at the cost of some highs when the volume comes down [8]. Fralin says the same: modern wiring sends some treble to ground as you lower the volume, and 50s wiring can sound too bright at high gain [23].

Table 16.6: 50s and modern wiring compared

	Modern wiring	50s wiring	Source
Tone cap connects to	volume pot input lug (pickup side)	volume pot wiper (output)	[8]
Volume turned down	loses some highs	keeps more high end	[8, 23]
Tone turned down	holds volume better	drops some volume	[8]
Pickup interaction	less	more	[8]
Possible downside	duller at lower volume	can sound too bright at high gain	[23]

You might ask, "Isn't 50s wiring just a built-in treble bleed?" Not quite, but it's aimed at the same complaint. Either one helps if your Les Paul goes dull when you roll back. 50s wiring costs nothing but a resolder; a treble bleed lets you tune the effect.

Special tone circuits

Fender's Greasebucket

Fender introduced the Greasebucket circuit in 2005 on its Highway One series and on various Custom Shop Strats. The details here come from a Premier Guitar column by Dirk Wacker, who cites Fender. Per that column, the circuit uses a 0.1 µF and a 0.022 µF ceramic disc cap, plus a 4.7 kΩ resistor in series with the 0.022 µF cap [15]. The resistor keeps the tone pot's resistance from ever reaching zero. Wacker describes the result as acting like a band-pass: it cuts highs without adding bass [15].

The resistor is the key part. The tone-down midrange peak only forms when the resistance in series with the cap gets very small, so a resistor that keeps it from reaching zero tames that peak. That's my reading of why the circuit sounds the way Wacker describes, not a measurement.

Gibson's Vari-Tone

The Vari-Tone on Gibson's ES-345, stereo ES-355 and Lucille models uses a rotary switch to pick from several caps. Zollner describes it as switched capacitors combined with an inductor, and his text mentions an 8 H coil [1]. The dealer history above says the Vari-Tone caps are ceramic [13]. I'll stop there: it's a switched control with a coil of its own, not a plain pot and cap.

Tone and playability at a glance

Table 16.7: Tone circuit changes, rated

Change	What you'll hear	What you'll feel
Swap cap dielectric, same value (paper, polyester, polypropylene, ceramic)	Little or no audible change; Zollner measures under 0.1 dB	Nothing

Change	What you'll hear	What you'll feel
Bigger tone cap (0.022 to 0.047 µF)	Tone at 10: little or no change. Tone at 0: darker, lower and weaker midrange peak	The knob's low end sounds darker and smoother
Smaller tone cap (0.022 to 0.015 µF)	Tone at 10: little or no change. Tone at 0: higher, more pronounced honk	The bottom of the knob sounds more vocal
Tighter-tolerance cap (±5% or better)	Tone-down sound closer to the printed value; matched guitars sound more alike	Nothing
No-load tone pot	Slightly brighter at 10, like a lighter pot load	No feel data found; normal tone control from 1 to 9
Treble bleed on volume	Clearer, brighter sound when the volume is turned down; nothing at 10	Volume knob stays useful for clean-up; the taper can feel more even
50s wiring (Les Paul type)	More highs kept as you turn down; tone knob drops some volume	Volume and tone interact more
Greasebucket-style series resistor	Cuts highs without adding bass (Wacker); less tone-down honk (my reading)	Tone pot never reaches zero resistance

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Bracket numbers in this chapter point to this list. Web addresses were checked in October 2026; if one moves, search the site for the title.

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Chapter 17: Switches, Jacks, Wire, Shielding and Grounding

This chapter covers the small parts that sit between the pickups and the cable: the selector switch, the output jack, the hookup wire, the shielding in the cavities and the ground connections that tie it all together. None of them is glamorous. Most of them have little or no direct effect on tone when they work. When they fail, though, they cause crackles, cut-outs and buzz.

That's the theme of this chapter. These parts mostly decide whether the guitar is quiet and reliable, not what it sounds like. I'll give you the maker specs so you know what you're buying, then tell you straight which numbers matter. What each switch position selects (bridge, middle, series, split and so on) is Chapter 14's job; here I stick to the hardware itself. Pots are in Chapter 15, tone caps in Chapter 16, and the cable and amp input in Chapter 18.

Selector switches

What a switch spec means

A switch is a set of metal contacts that open and close as you move a lever. Two words come up in every switch spec. A *pole* is one independent circuit the switch can route. A *position* is one stop of the lever. A two-pole, five-position switch can steer two separate signals through five settings at once. More poles mean more wiring options per position, which is why the fancy wiring schemes in Chapter 14 often need a bigger switch.

Switch makers also print current and voltage ratings. Those ratings are for power circuits. A passive guitar signal is a small voltage at tiny currents (Chapter 18 gives the numbers), so a rating of 0.5 A or 3 A tells you nothing about tone. What matters for a guitar is that the contacts stay clean and press firmly so the signal doesn't crackle or drop out.

Blade switches

The Strat-style lever switch is a *blade switch*: the contacts sit on flat wafers stacked in a slim metal frame, and the lever slides a wiper across them. Electroswitch makes the two names you'll see most. Its CRL E2 series has 2 poles in 3- or 5-position versions, rated 1.5 A at 28 VDC and 0.5 A at 115 VAC, made in the USA [1]. Its Oak Grigsby 6MLR series comes in 2 or 4 poles and up to 6 positions, with solder or PC-board terminals, rated 1.5 A at 28 VDC [1]. There's also a miniature SMLR series with up to 4 positions [1].

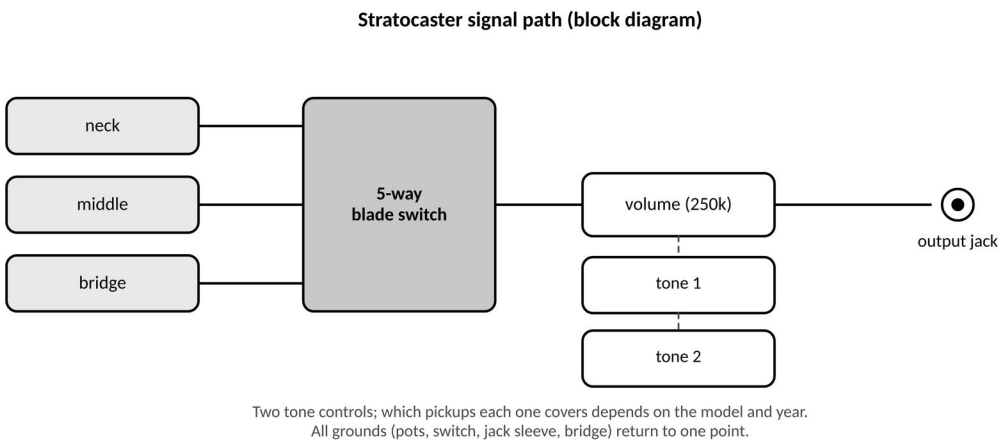


Figure 17.1: The Stratocaster signal path as a block diagram. Follow your guitar's own wiring diagram for the lug-by-lug connections.

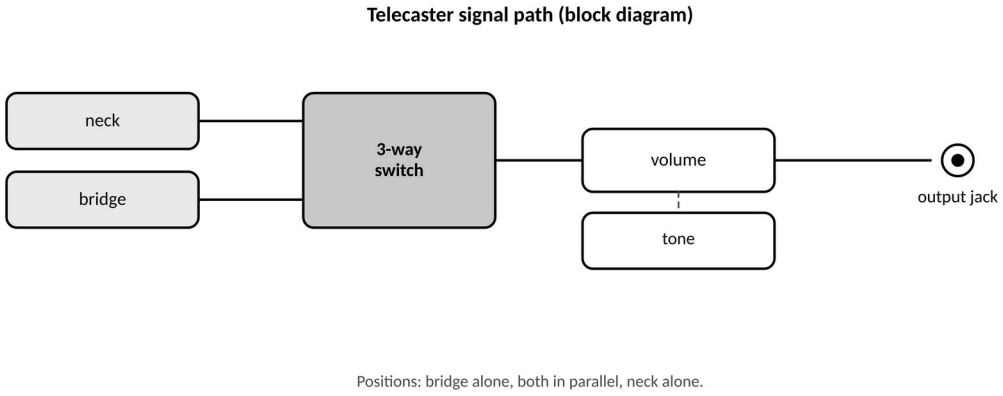


Figure 17.2: The Telecaster signal path as a block diagram.

The Oak Grigsby Super Switch is the 4-pole, 5-position member of that family. StewMac lists it with 6 lugs per pole (24 lugs in all), a cavity depth of 1-3/8 in (34.93 mm), mounting screw spacing of 1-5/8 in (41.28 mm), and a pickguard slot of 1/16 x 1-1/16 in [2]. Fender's own 5-position Strat switch uses the same 1-5/8 in screw spacing [3], so the Super Switch's screw holes line up with a standard Strat guard. The catch is depth. Check that your cavity has room for the taller body before you order one.

You might ask, "Why would I want 4 poles if I only have three pickups?" On a stock Strat, one pole selects the pickups and the other routes the tone controls. With four, each lever position can also split a humbucker, put two coils in series, or choose a different tone path [1, 2]. If you're keeping stock wiring, a 2-pole switch does the job.

Fender's S-1 system takes another route. It's a push switch built into a volume or tone knob, introduced in summer 2003 [4]. On the American Elite Strat it adds five alternate wirings, mostly series combinations, and on the American Elite Tele it turns position 2 from parallel to series [4]. Fender's article doesn't give its pole count.

Toggle switches

Gibson-style guitars use a three-way toggle: a bat-handle lever on a threaded bushing, with the contacts in a frame inside the cavity. Switchcraft's 12000 series is the familiar American version. The bulletin lists the 12010X long-frame Les Paul style, the 12013X SG style, the 12012X right-angle 3-position locking type, and the 12120X short-frame thin-body Les Paul style with pre-tinned lugs, plus variants with silver or gold-plated contacts [5]. All are rated 3 A and 300 W maximum AC non-inductive load (Switchcraft gives watts here, not volts), with nickel-plated copper frames, and they're made in Chicago [5]. A distributor listing for a Switchcraft right-angle 3-way gives a 15/32-32 bushing thread, 0.21 in bushing length, 250 VDC dielectric rating and leakage resistance of at least 1,000 MΩ [6].

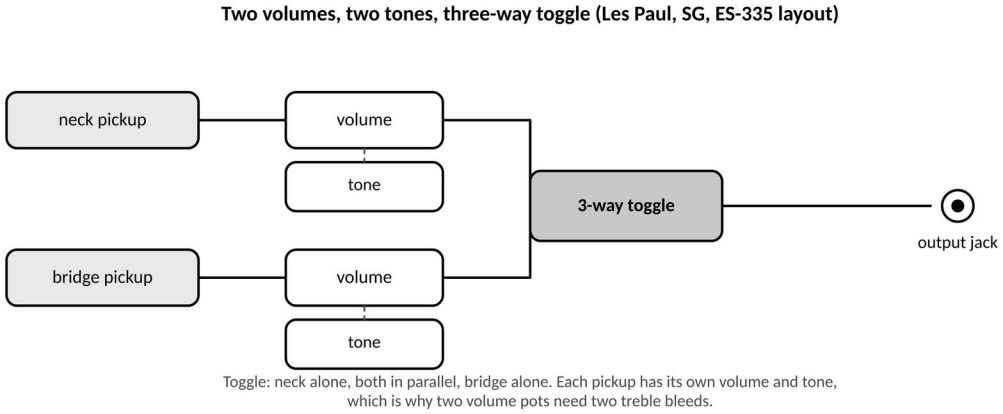


Figure 17.3: The two-volume, two-tone layout with a three-way toggle, as a block diagram.

Here frame length is the spec that bites. A long-frame toggle needs the deep cavity of a Les Paul. A thin body or an SG needs a short frame or a right-angle type [5]. Order by your guitar's depth, not by the photo.

Table 17.1: Selector switch hardware from maker and dealer listings

Switch	Type	Poles	Positions	Rating	Fit note	Source
CRL E2	Blade	2	3 or 5	1.5 A at 28 VDC; 0.5 A at 115 VAC	Strat-type	[1]
Oak Grigsby 6MLR	Blade	2 or 4	up to 6	1.5 A at 28 VDC	Solder or PC terminals	[1]
Oak Grigsby Super Switch	Blade	4	5	6MLR family	1-5/8 in screw spacing; 1-3/8 in cavity depth	[2]
Fender 5-position Strat	Blade	not stated	5	not stated	1-5/8 in screw spacing	[3]
Switchcraft 12010X	Toggle	3-way	3	3 A, 300 W AC load	Long frame, Les Paul	[5]
Switchcraft 12013X	Toggle	3-way	3	3 A, 300 W AC load	SG style	[5]
Switchcraft 12120X	Toggle	3-way	3	3 A, 300 W AC load	Short frame, thin body	[5]
Switchcraft right-angle 3-way	Toggle	3-way	3	3 A; 250 VDC dielectric	15/32-32 bushing	[6]
Fender S-1	Push switch in a knob	not stated	on/off	not stated	Built into a pot	[4]

What switches do to tone

A clean switch adds nothing you can hear. Good contacts have very low resistance (Switchcraft rates its #11 jack contact at 0.03 Ω [7]), and a pickup coil has thousands of ohms of its own. The tone changes you get from a switch come from what it connects, which is the subject of Chapter 14. A dirty or worn switch is another story. It crackles when you move it, cuts out in one position, or works only if you hold the lever just so. That's a playability problem and a reliability problem, and the fix is cleaning or replacement, not a "better sounding" switch.

The output jack

The output jack is the part you touch most often without thinking about it. Every time you plug in, you push a plug past a spring contact, and that contact has to grip the plug's tip for years.

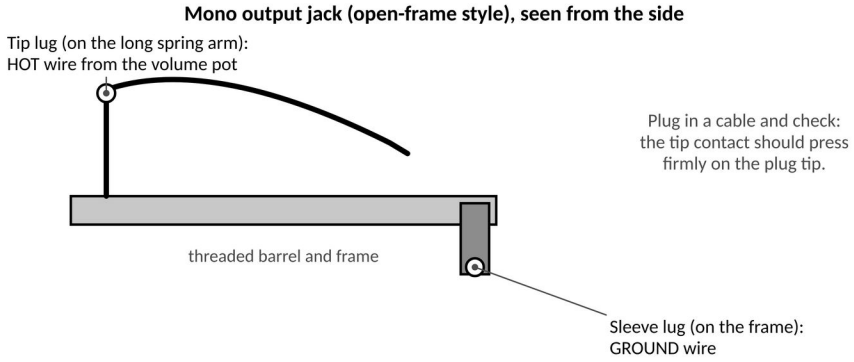


Figure 17.4: A mono output jack: the hot wire goes to the tip lug, the ground wire to the sleeve lug.

The Switchcraft #11 is the standard open-frame mono jack. Switchcraft lists it as a 1/4 in, 2-conductor, open-circuit jack in nickel-plated copper alloy, with a contact resistance of 0.03 Ω, a rating of 25 V and 1 A, a dielectric withstand of 500 V, insulation resistance of 10,000 MΩ, an operating range of -55 to +85 C, a panel thickness of 0.156 in, an operating force of 7 lb, and a life of 10,000 cycles [7]. Two of those numbers matter to a player. The operating force is the grip you feel when you plug in. The 10,000-cycle life is a rating for plugging in and pulling out. A jack on a working guitar also takes sideways yanks when someone steps on the cable, and the rating doesn't speak to that. If a plug wiggles or drops out, the jack's spring contact is the first thing to check.

Active pickups need one more contact. EMG says its active pickups need a stereo jack: the extra contact connects the battery only when a plug is in, so the battery isn't drained while the guitar sits unplugged [8]. EMG's passive models work with a normal mono jack [8]. Switchcraft's 12B is a stereo, 3-conductor open-frame jack sold for this job, rated 1 A and 25 V with the same 0.156 in panel thickness [9]. That distributor page is inconsistent about the switching details, so check the lugs with a meter before you wire one.

> **Tip:** If an active guitar's battery keeps dying, unplug the cable when you put the guitar down. With a stereo jack, a plugged-in cable keeps the preamp powered.

Table 17.2: Output jacks

Jack	Type	Contacts	Rating	Other specs	Source
Switchcraft #11	Mono, open frame	2	25 V, 1 A	0.03 Ω contact; 7 lb force; 10,000 cycles; 0.156 in panel	[7]
Switchcraft 12B	Stereo, open frame	3	25 V, 1 A	0.156 in panel; used to switch onboard electronics	[9]

Wire

Hookup wire

Inside the guitar, the parts are joined by *hookup wire*. Two vintage styles show up again and again. Fender-style guitars traditionally use cloth push-back wire. StewMac's Gavitt version is 22 AWG tinned stranded copper with an outside diameter of 0.070 in (1.78 mm), wrapped in a white Celanese layer under waxed braided cotton [10]. *AWG* stands for American Wire Gauge; a bigger number means a thinner wire. You don't strip push-back wire. You push the cloth back to bare the conductor, and it slides forward again to cover the joint. StewMac sells it in six colors plus orange, and it lists no voltage rating [10]. CE Distribution lists the same 22 AWG and 0.07 in diameter [11].

Gibson-style guitars use shielded braided wire. A retailer listing for Gavitt's shielded push-back describes 22 AWG wire with 7/30 stranding (seven strands of 30 AWG), a cloth-like inner insulation, and a braided outer conductor that serves as both ground and shield [12]. The braid shields the lead itself, so the hot conductor inside is wrapped in ground for its whole length.

Does wire capacitance matter?

Every pair of wires has some *capacitance*, the ability of two conductors close together to store a little charge. In a guitar, capacitance across the pickup acts like a bit of extra cable. Zollner puts unshielded two-wire leads at about 50 pF per meter, so a 20 cm lead adds about 10 pF [13]. Shielded coax runs 50-200 pF per meter [13]. Next to a guitar cable of several hundred picofarads (Chapter 18), the short leads in a normal guitar are small change.

There's one exception worth knowing. Zollner measured a 50 cm Gibson P-90 coax lead at about 700 pF, because moisture had soaked into its insulation. After 5 hours at 75 C it dropped to about 160 pF [13]. Water's dielectric constant is about 80, against 2-4 for the usual insulation [13], so damp old shielded wire can add as much capacitance as a cable and pull the resonant peak down audibly [13].

Shielding

Two kinds of noise

Most of the confusion starts here. A guitar picks up noise two ways. *Electric-field* noise couples in through capacitance, the same way your body can act as an antenna. It sounds like buzz that changes when you touch the strings or move your hand near the controls. *Magnetic-field* hum comes from transformers, power lines and other gear, and it induces a voltage straight into the pickup coil, which is built to sense changing magnetic fields.

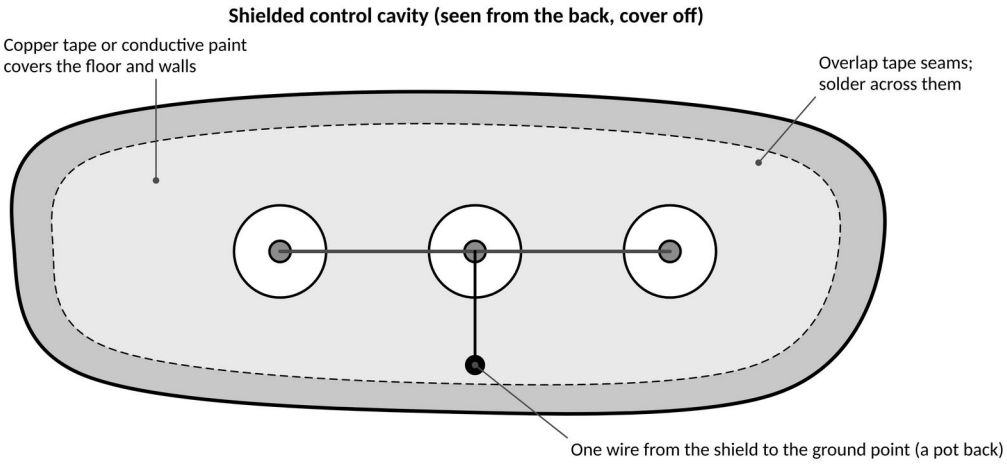


Figure 17.5: A shielded control cavity, with one ground wire from the shield to the back of a pot.

Shielding (copper foil or conductive paint, connected to ground) blocks electric-field noise. It does not stop magnetic hum. Zollner is plain about it: magnetic shielding is possible in principle but inefficient and impractical in a guitar [14]. StewMac's shielding article says the pickup coil is an antenna that picks up 60-cycle hum [15], and that's true. Foil just can't fix that part. Only a humbucking design, more distance from the source, or turning the guitar can [14].

Copper foil

StewMac's method uses copper foil tape (a 2 in roll, or a 5 x 7 in sheet for the control cavity) [15]. Overlap the pieces so they all touch, and lap the foil over the top edge of the cavity so the pickguard or control cover's shield presses against it. Then check continuity across every piece with a multimeter [15]. StewMac notes the jack cavity is often left bare, with shielded 2-conductor wire run to the jack instead [15].

Conductive paint

StewMac's conductive shielding paint is water-based, and the instructions list graphite and carbon black among its ingredients [16]. The product page calls it dark gray [17]. The instructions call for at least 2 coats on clean, dry wood, with 24 hours between coats [16]. A half pint (236.6 ml) is sold as enough for several guitars [17]. The instructions give no target resistance [16]. Paint is easier in deep or odd-shaped routes; foil is easier to solder to. Either one only works when it's connected to ground.

> **Tip:** After paint or foil goes in, measure from one corner of the cavity to the far corner and to the ground lug. If any patch reads open, it isn't shielding anything.

Metal near the pickups

Shielding can cost you treble if you put a lot of metal close to the pickups. Metal near a coil carries small swirling currents called *eddy currents* that soak up energy and flatten the resonant peak (Chapter 12). Zollner found that an aluminum Strat pickguard shield cuts the brilliance range by about 2 dB, enough to hear in an A/B test, and thicker foil or sheet damps more [18]. Plastic guards have no eddy currents [18]. Brass versus other Tele bridge plates made very little difference, and a slit in a plate stops the eddy currents [18]. So keep foil in the control cavity and under the guard where it does its job, and don't wrap the pickups in it.

Grounding

What ground does

Ground is the shared return path for the signal. Fralin describes it as the connection that ties every piece of metal on the guitar together and back to the amp [19]. Pots, switch frames, the jack sleeve, the shielding and the bridge all join it. The strings are grounded through the bridge so that your body doesn't act as an antenna [19]. That's why a guitar often gets quieter when you touch the strings.

Ground loops and star grounding

A *ground loop* happens when a part is grounded through two different paths. The two paths form a loop of wire, and Fralin explains that a loop works like a one-turn coil that can pick up interference [19]. The cure is to ground each part only once. On a Les Paul that can be a single "horseshoe" run of wire from pot to pot [19].

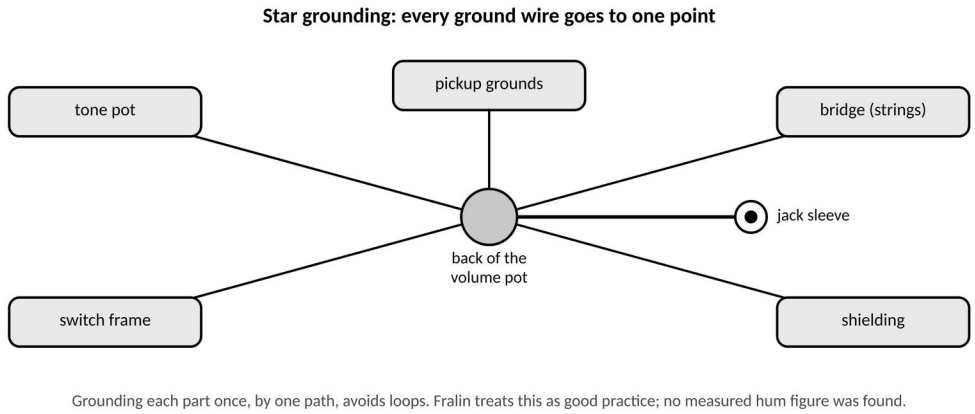


Figure 17.6: Star grounding: every ground runs to one point, and one wire goes from there to the jack sleeve.

Star grounding takes this further: every ground wire runs to one point. On a Strat that's usually the back of the volume pot, with one wire from there to the jack sleeve [19]. Fralin also gives the other side. Some engineers consider star grounding unimportant, and Lindy Fralin prefers it mainly because it makes loops harder to create [19]. Shielding paint or foil has to connect to ground, but it shouldn't form a second path alongside a ground wire [19].

Treat star grounding as good practice, not a measured requirement. I found no measurement of how much hum a loop inside a guitar adds. Keep your grounds tidy and single-path, and you've covered the likely problem whichever side is right.

Hum: sources and numbers

How much hum are we talking about? Zollner gives some real numbers [14]. A wire carrying 10 A makes a field of about 1 µT (microtesla) at 2 m. In his examples an old CRT monitor half a meter away produced hum peaks of about 12 mV, and an amp transformer's stray field about 0.9 mV [14].

In a test field of 6.5 µT at 500 Hz, single-coil pickups put out 0.1-0.2 V of hum, while humbuckers put out at most 30 mV [14]. That's the reason humbuckers exist. Their two coils are wired so the string signal adds while hum, which induces about the same voltage in each coil, cancels [20].

The cancellation isn't perfect, and it depends on the direction of the field. In a field that hits both coils evenly, the favorable case, humbuckers gain from about 19 dB to more than 40 dB in signal-to-noise ratio [14]. In the worst-case direction the Gibson 490R manages only about 16 dB, and Zollner calls the rejection rather modest there [14]. A Fender coaxial (stacked) humbucker gets about 24 dB [14]. A *decibel* (dB) is a ratio unit for comparing levels; the bigger the number, the bigger the difference.

Single coils aren't all equal either. Strat and Jazzmaster hum differ by 7-8 dB, but their signals differ by only about 5 dB, so the Jazzmaster's signal-to-hum ratio comes out about 2 to 3 dB worse [14].

On a Strat with a reverse-wound, reverse-polarity (RWRP) middle pickup, the two-pickup positions 2 and 4 cancel hum the same way a humbucker does [21]. Positions 1, 3 and 5 still hum like any single coil.

Table 17.3: Hum figures from Zollner's measurements

Situation	Figure	Source
Single coil in a 6.5 µT, 500 Hz field	0.1-0.2 V of hum	[14]
Humbucker in the same field	up to 30 mV	[14]
Humbucker S/N gain, favorable field direction	about 19 to over 40 dB	[14]
Gibson 490R, worst-case direction	about 16 dB	[14]
Fender coaxial humbucker	about 24 dB	[14]
Strat vs Jazzmaster	hum 7-8 dB higher on the Jazzmaster; signal-to-hum about 2-3 dB worse	[14]
Strat with RWRP middle, positions 2 and 4	hum cancels (Seymour Duncan)	[21]

So what fixes what? If the noise changes when you touch the strings or controls, look at shielding and grounding. If it changes when you turn your body or move away from the amp, it's magnetic, and the fixes are humbucking pickups, distance and angle.

Active electronics

Active pickups have a small preamp, a circuit that boosts the signal, built into the pickup or the guitar, and it runs on a battery. That changes several of the parts in this chapter. EMG uses 25k audio-taper pots and 0.1 µF caps on its actives, and it needs the stereo jack described above [8]. EMG says mixing actives with passive pickups is possible but not recommended, and if you do it, use 25k pots for the EMG and 250k or 500k for the passive pickup [8].

Voltage and headroom

EMG's actives run on 9 V. EMG says two 9 V batteries in series (18 V) barely raise the output but give more *headroom*, the room a circuit has before it clips, with crisper transients, especially for slap bass [8]. EMG gives 27 V as the highest supply its pickups accept [22]. ElectroSmash's analysis of the EMG 81 lists a preamp gain of 5.5 times (14.8 dB) and a current draw of about 80 µA, and notes it runs on one or two 9 V batteries [23].

Battery life claims

These are maker claims, and they aren't stated the same way. EMG says a typical EMG-equipped guitar or bass gets up to 1,000 hours from a battery [8], and elsewhere that one 9 V battery averages 1,000 playing hours for a set [22]. EMG adds that a battery left plugged in day and night lasts about a month, and that with typical gigging and rehearsing you'd change it once or twice a year [8]. Fishman lists its Fluence Modern humbuckers

at 2.6 mA (Alnico) and 2.7 mA (Ceramic) at 9 V, with battery life of up to 200 hours for the set [24]. Those are the makers' own figures.

Safety first

> **Caution:** A soldering iron tip runs hot enough to burn skin and melt plastic in an instant. Use a stand, keep cords where you won't snag them, and work with fresh air moving past you. The guitar's own signal can't shock you; it's far too small. But the strings are connected to your amp's ground, so a faulty amp or bad wall wiring can make them live. Use a properly grounded outlet and never defeat the ground pin. The amp itself is a different matter. Tube amps hold lethal voltage inside, even after they're switched off and unplugged. Never open an amp. Take it to a qualified amp tech.

Tone and playability at a glance

Table 17.4: Switches, jacks, wire and shielding, rated

Change	What you'll hear	What you'll feel
New CRL or Oak Grigsby switch for a worn one	Crackles and dropouts go away; no change in tone	Positions that work every time
2-pole to 4-pole Super Switch	No change until you wire new combinations (Chapter 14)	Same lever; check cavity depth
Long-frame vs short-frame toggle	Little or no audible change	Fit only: depth of the cavity decides
New Switchcraft #11 jack	Cut-outs and crackle stop; no change in tone	A plug that seats firmly
Mono to stereo jack (actives)	Needed for EMG actives to power up	Unplug to save the battery
Cloth push-back vs modern hookup wire	Little or no audible change in normal lengths	Easier to work at the bench
Damp, old shielded leads replaced	Can restore some treble if the leads were soaked	None
Foil or paint shielding, grounded	Less buzz that changes with touch; magnetic hum unchanged	None
Aluminum pickguard shield	About 2 dB less brilliance (Zollner)	None
Star grounding	Removes loop noise if a loop existed; otherwise little or no change	None
Single coils to humbuckers	Much less hum (16 dB to over 40 dB S/N gain) plus a different voice	None
Active pickups, 9 V to 18 V	More headroom per EMG; output barely changes	A second battery to carry

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Chapter 18: Cables, Buffers and the Amp Input

Most players think of the guitar cable as a pipe. Signal goes in one end and comes out the other. With a passive guitar, that isn't how it works. The cable is part of the tone circuit, as much as the pots and the tone cap. It sits right across the pickup, and its capacitance helps decide where the pickup's resonant peak lands and how tall it stands.

This chapter follows the signal out of the jack. I'll give you real capacitance numbers from cable makers, show what they do to the resonant peak, explain what a buffer changes, and finish at the amp's input jack, where the last part of the load lives. The resonant peak itself is explained in Chapter 12, and the pots that load the pickup from inside the guitar are in Chapter 15.

Why a cable has a sound

A guitar cable is two conductors: a center wire and a shield wrapped around it, with insulation between them. Any two conductors held close together have *capacitance*, the ability to store a little electric charge. It's measured in picofarads (pF). One picofarad is tiny, but cables have a lot of them, because every meter adds more.

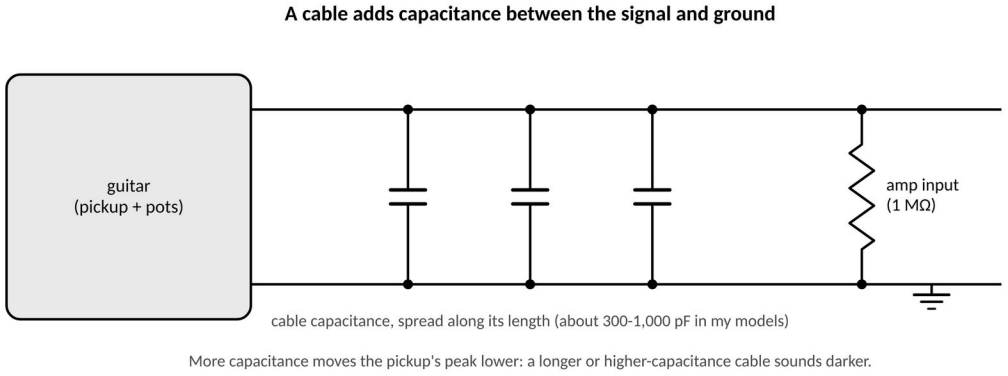


Figure 18.1: A guitar cable is a capacitance between the signal and ground, spread along its length.

A passive pickup is a coil with a lot of *inductance*, the property of a coil that resists changes in current, measured in henries (H). Put an inductance and a capacitance together and you get a *resonance*: a frequency where the pair responds more strongly than anywhere else. In a guitar, that's the pickup's resonant peak, a hump in the treble response with a steep roll-off above it. Lemme puts the roll-off above resonance at 12 dB per octave, and up to 18 dB per octave once eddy-current losses are counted [1].

Zollner sums up the cooperation: cable capacitance and pickup inductance together make a resonance that lands somewhere between 2 and 5 kHz [2]. That's the treble range where a guitar's brightness lives, so moving the peak changes the sound.

What about the cable's resistance and inductance? Zollner says a cable's series resistance (a few ohms) and inductance (about 1 µH) are negligible, and its insulation is over 100 MΩ [2]. For a passive guitar, capacitance is the cable spec that matters.

How much capacitance is in a cable?

Zollner says guitar cable capacitance is usually around 100 pF per meter, give or take 30% [2]. Normal cable lengths add up to about 300-600 pF, and very long ones reach about 1.5 nF (1,500 pF) [2]. Special low-capacitance cables go down to about 70 pF per meter, and he lists the Klotz LaGrange at 67 pF per meter [2].

Here's what the makers print. Mogami lists its W2524 at 130 pF/m (39.7 pF/ft) and its W2319 at 155 pF/m (47.3 pF/ft) at 1 kHz [3]. Canare lists the GS-6 at 160 pF/m [4]. Belden lists the 9778 at 45 pF/ft [5]. Belden's own data sheet calls the 9778 a microphone cable, so it's here as a comparison, not a recommendation.

Table 18.1: Cable capacitance from maker sheets, with computed totals

Cable	pF/m	pF/ft	10 ft (3.05 m)	18 ft (5.49 m)	20 ft (6.10 m)	f0 at 20 ft (calc.)	Source
Klotz LaGrange	67	20.4*	204 pF	367 pF	408 pF	4.8 kHz	[2]
Zollner "typical"	100 (70-130)	30.5* (21-40)	305 pF	549 pF	610 pF	4.0 kHz	[2]
Mogami W2524	130	39.7	397 pF	715 pF	794 pF	3.6 kHz	[3]
Belden 9778	147.6*	45	450 pF	810 pF	900 pF	3.4 kHz	[5]
Mogami W2319	155	47.3	473 pF	851 pF	946 pF	3.3 kHz	[3]
Canare GS-6	160	48.8*	488 pF	878 pF	976 pF	3.3 kHz	[4]

Values marked * are my conversions (1 ft = 0.3048 m). All length totals are computed by multiplying the per-foot figure by the length. The last column is computed from the resonance formula below, using 2.2 H and 100 pF of winding capacitance, with pots, amp input and losses left out, so it shows the direction and size of the shift rather than a real guitar's peak.

Look at the spread. Twenty feet of the lowest-capacitance cable here adds about 408 pF. Twenty feet of the highest adds about 976 pF, well over twice as much. Notice too that every cable here with a maker data sheet is above Zollner's 100 pF/m "typical" figure.

Old and odd cables are worse. Zollner measured a 40-year-old 4 m cable at 1,050 pF and old coiled cords at about 2.1 nF (2,100 pF) [2]. Microphone cables run about 250 pF per meter [2]. If you've ever plugged into a vintage coil cord and wondered where the treble went, that's where.

Other cable specs

The makers print more than capacitance, and some of it matters for how a cable lives on stage. Mogami lists the W2524 at 20 AWG with a 6.0 mm outside diameter and a flex life of 15,000 cycles, and the thinner W2319 at 23 AWG, 5.0 mm, and 11,000 cycles [3]. Both are rated for microphonics of 0.3 mV at most [3]. *Microphonics* is the noise a cable makes when it's flexed or stepped on. The W2319 adds a conductive PVC (carbon) sub-shield under its served shield [3]. Canare's GS-6 is 18 AWG, 5.8 mm, with a double carbon layer plus a braided copper shield [4]. Belden's 9778 is 20 AWG and 0.235 in across [5].

Table 18.2: Cable construction from maker sheets

Cable	Conductor	Outside diameter	Shield	Other	Source
Mogami W2524	20 AWG	6.0 mm	Not stated	Flex life 15,000 cycles; microphonics 0.3 mV max	[3]

Cable	Conductor	Outside diameter	Shield	Other	Source
Mogami W2319	23 AWG	5.0 mm	Carbon sub-shield plus served shield	Flex life 11,000 cycles; microphonics 0.3 mV max	[3]
Canare GS-6	18 AWG	5.8 mm	Double carbon plus braided OFC	Conductor 1.8 Ω per 100 m	[4]
Belden 9778	20 AWG	0.235 in	Conductive textile plus 75% spiral	Listed as microphone cable	[5]

Capacitance inside the guitar counts too

The cable isn't the only capacitance on the pickup. The leads inside the guitar add some as well. Zollner puts unshielded two-wire pickup leads at about 50 pF per meter and shielded coax at 50-200 pF per meter [6]. In a normal guitar those runs are short, so they add far less than a cable (Zollner's example: 20 cm of unshielded lead is about 10 pF) [6]. The exception is old shielded wire that has soaked up moisture: Zollner measured one 50 cm P-90 lead at about 700 pF, as much as a typical cable [6]. Chapter 17 has the details. The point for this chapter is that the pickup doesn't care where the capacitance comes from. Leads, cable and amp input all add up into one number.

Choosing a cable

So how should you pick one? Start with length. Buy the length you need, not the longest one on the wall, because every extra foot is more capacitance. Then look for a printed capacitance figure. Mogami, Canare and Belden publish theirs [3, 4, 5], and that lets you compare cables on the one spec that changes the sound of a passive guitar. After that, the things that matter are mechanical: a conductor and jacket that survive being coiled every night, low handling noise, and plugs that grip. Those decide whether a cable lasts, not how it sounds.

What the capacitance does to the peak

The formula

Here's the one formula for this chapter. The resonant frequency of a pickup and its capacitance is one divided by two pi times the square root of the inductance times the total capacitance: $f0 = 1 / (2\pi\sqrt{(L \times C)})$. The total capacitance is the pickup's own winding capacitance plus the cable plus the amp input. Zollner's sections don't print the formula, but his reported values match it within rounding, and ElectroSmash states it outright [7, 8].

The important part is the square root. Resonance moves with one over the square root of capacitance, so it takes four times the capacitance to halve the frequency [1, 2]. Doubling the cable length doesn't halve the peak frequency. When the cable is most of the capacitance, it drops it by about 30% (calculated from the square-root rule).

Table 18.3: Resonant frequency vs added capacitance (calculated)

Added capacitance	L = 2.2 H (Strat)	L = 5 H	L = 10 H
0 pF	10.7 kHz	7.1 kHz	5.0 kHz
300 pF	5.4 kHz	3.6 kHz	2.5 kHz
600 pF	4.1 kHz	2.7 kHz	1.9 kHz
900 pF	3.4 kHz	2.3 kHz	1.6 kHz
1,200 pF	3.0 kHz	2.0 kHz	1.4 kHz

Added capacitance	L = 2.2 H (Strat)	L = 5 H	L = 10 H
1,500 pF	2.7 kHz	1.8 kHz	1.3 kHz

These are calculated with the formula above, including 100 pF of winding capacitance, and ignoring the amp's input capacitance and all losses. The 2.2 H figure is Zollner's Strat inductance [7]. The 5 H figure is ElectroSmash's coil model for the EMG 81, and 10 H is its typical humbucker [8]. The 100 pF winding value is ElectroSmash's typical single coil [8].

Treat the top row with care. My calculation puts an unloaded Strat near 10.7 kHz, but Zollner gives about 9 kHz for an unloaded Strat [9]. The gap means the real winding capacitance is higher than 100 pF, or the inductance is different. I'd trust his measured figure over my arithmetic.

For a real measured example, Zollner gives the screw coil of a Gibson PU490 humbucker (one coil on its own, no metal parts) at about 21-23 kHz unloaded, 7.7 kHz with 330 pF, 5.5 kHz with 700 pF and 4.6 kHz with 1,030 pF [7]. Same pattern: each extra few hundred picofarads pulls the peak down, and the steps get smaller as the capacitance grows.

Lower and taller

Capacitance doesn't only move the peak. Zollner describes a longer cable as lowering the resonance and making the peak stronger [2]. You might ask, "Why would more cable make the peak taller?" The short answer is that the pots and the amp input load the pickup with resistance, and that resistance damps the peak. For the same resistance, the damping gets weaker as the capacitance goes up, so a bigger capacitance leaves a taller peak.

That's what my model shows. Figure 18.2 is the same Strat pickup with four amounts of cable.

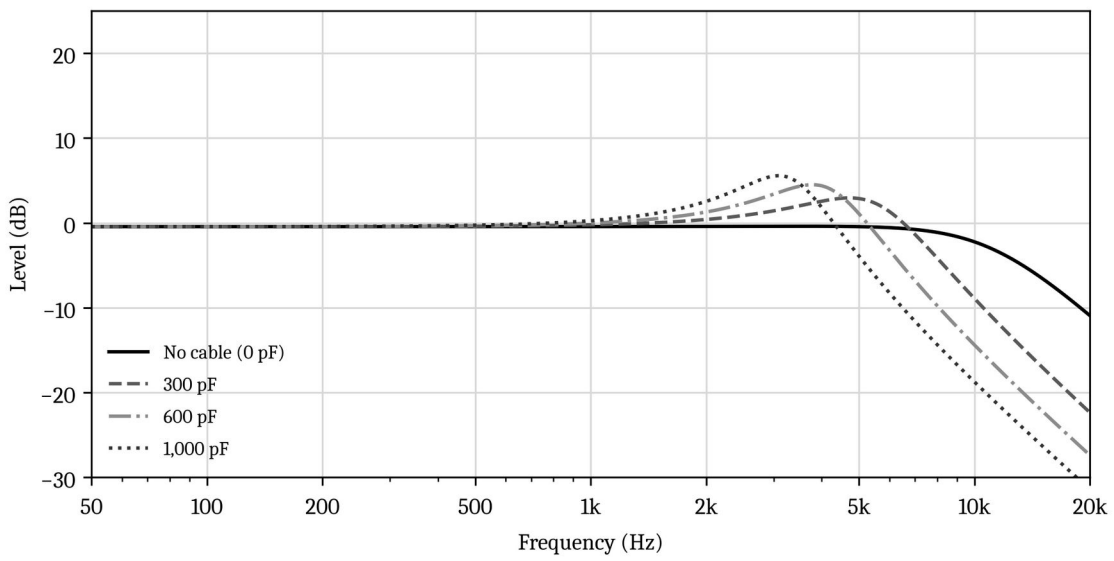


Figure 18.2: Modeled Strat pickup (2.2 H, 5.8k, two 250k pots at full, 1 MΩ amp input) with no cable and with 300, 600 and 1,000 pF of cable capacitance. More capacitance moves the peak lower and makes it taller.

In the model, with no cable, there's no peak at all: the response stays flat and then rolls off. With 300 pF the modeled peak sits at about 4.7 kHz and rises about 2.9 dB. With 600 pF it's about 3.8 kHz and 4.5 dB. With 1,000 pF it's about 3.1 kHz and 5.6 dB. A *decibel* (dB) is a ratio unit for comparing levels. The model leaves out

eddy-current losses, so real peaks are lower and broader than these. The frequencies are also lower than Table 18.3's, because the model includes the pots and amp load and the table doesn't.

How tall is a real peak? Zollner says that with the volume and tone pots and the amp connected, the peak's *Q* (a measure of how tall and narrow it is) comes out at about 3 [9]. With only a 600 pF load and nothing else, he gets a Q of 9, a 19.1 dB peak that he calls shrill and impractical [9]. So the pots and amp input aren't just loading the pickup down. They're what keeps a passive guitar from sounding piercing.

Is a short cable always better?

No. A short, low-capacitance cable puts the peak higher, which sounds brighter and more open. A longer or higher-capacitance cable puts it lower and a little stronger, which sounds warmer, with more midrange push. Neither is "correct." Lemme puts typical loaded resonances at 2,000-5,000 Hz with cable capacitance of 300-1,000 pF [1].

What I'd tell you is to know your number. If your guitar sounds great into a 10 ft cable and dull through 20 ft of a different brand, you now know why, and you can pick a cable on purpose.

Buffers

A *buffer* is a small active circuit with a high input impedance and a low output impedance. *Impedance* is resistance that can change with frequency, measured in ohms. A buffer takes almost no load from what's in front of it and can drive a long cable behind it without the cable changing the sound.

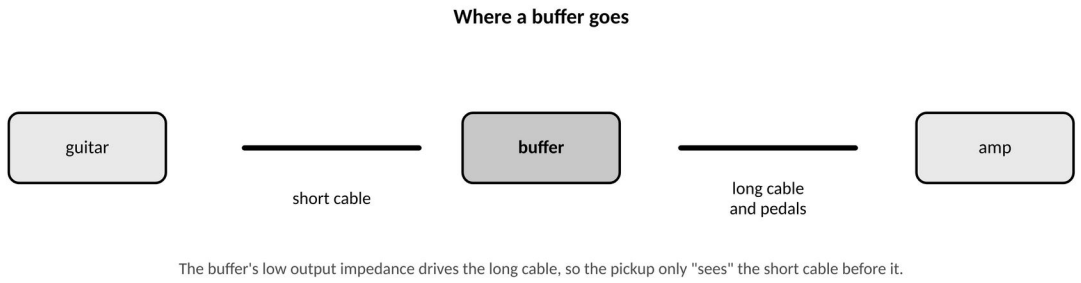


Figure 18.3: A buffer early in the chain drives the long cable, so the pickup only sees the short cable before it.

Put a buffer right after the guitar and the pickup only sees the short cable to the buffer. Lemme describes the result of a buffer near the pickup as a brighter sound with a higher resonance and a taller peak [1].

BOSS makes the case for buffers in an article by Jim Bybee. It says treble loss from cable capacitance becomes audible and measurable at about 18 ft, that full pedalboard rigs often exceed 40 ft of total cable, and that a buffer can drive about 100 ft after it with little or no loss [10]. The article also argues that true bypass does nothing to fix the underlying loss [10]. That makes sense: a true-bypass pedal that's switched off is just two more jacks and a bit more wire in the path. BOSS sells buffered pedals, so read that as a maker with a stake in the answer. The physics behind it agrees with Zollner and Lemme, though.

If your total cable from guitar to amp is short, you may not need a buffer at all. If it's long, the first buffered device in your chain sets the end of the guitar's tone circuit. Everything after it is driven by a low-impedance output, and cable length stops mattering much. I take up cable and buffer claims in more detail in my book *Chasing Tone*.

Tip: Count your total cable length, including every patch cable between true-bypass pedals. Then compare it to the 18 ft figure.

The amp input

What the amp adds

The amp's input jack is the last part of the load on a passive pickup. Zollner gives the typical guitar-amp input as 1 MΩ, with a 34k resistor in series on the high-sensitivity input (two 68k resistors in parallel) [11]. That series part is called a *grid stopper*, a resistor in front of the first tube that keeps it stable.

The tube itself adds capacitance. Zollner puts a tube's input capacitance at about 80-150 pF, which he attributes to the Miller effect (the tube's own gain makes its internal capacitance look larger), plus about 50 pF of wiring [11]. That capacitance adds to the cable's. At Zollner's 100 pF per meter, that's roughly 1.3-2 m of extra cable hiding inside the amp (computed).

Input 1 and input 2

Many amps have two input jacks. Fender's manuals give the numbers. The '64 Custom Deluxe Reverb lists 1 MΩ on input 1 of both channels and 136 kΩ on input 2, with input 2 at lower sensitivity (-6 dB) [12]. The '94 Twin Amp lists input 1 at 1 MΩ and input 2 at 136 kΩ [13]. A third-party copy of the Blues Junior IV manual lists a single input at 1 MΩ [14]. Zollner describes the same pattern in general: a "Hi" input near 1 MΩ and a "Lo" input near 136 kΩ with a 50% divider, giving a darker sound with less gain [11].

Table 18.4: Amp input impedance from Fender owner's manuals

Amp	Input 1	Input 2	Source
Fender '64 Custom Deluxe Reverb	1 MΩ	136 kΩ (-6 dB)	[12]
Fender '94 Twin Amp	1 MΩ	136 kΩ	[13]
Fender Blues Junior IV	1 MΩ (single input)	none	[14]

Why does input 2 sound darker? A 1 MΩ input barely loads the pickup. A 136 kΩ input loads it heavily, and that flattens the resonant peak. With two 250k pots at full, the total load on the pickup works out (computed, resistors in parallel) to about 111k on input 1 and about 65k on input 2. Lemme measured a 1972 Strat with 470 pF of capacitance losing its peak entirely at a load of 47 kΩ or less [1]. Input 2 doesn't go quite that far, but it heads in that direction, and it also drops the level by 6 dB [12].

StewMac gives a rule of thumb for any connection: the input impedance should be at least ten times the output impedance of the source driving it [15].

Active pickups and low-impedance outputs

Active pickups carry their own buffer. That's one reason they behave so differently from passive ones in this chapter.

ElectroSmash's analysis of the EMG 81 lists a preamp output impedance of 10 kΩ [8]. Fishman lists its Fluence Modern humbuckers at 2 kΩ output impedance [16]. Compare that with an amp input of 1 MΩ. The amp is

100 times the EMG's output impedance and 500 times the Fishman's, far past StewMac's ten-times rule [15]. A passive pickup has no buffer, so, as you've seen, the cable becomes part of its resonant circuit.

The result is that the cable's capacitance no longer sets the active pickup's resonant peak. The coil's resonance is fixed inside the pickup, by the coil and the preamp, before the signal ever reaches the jack [1]. Cable length matters much less with actives, which is the same job a buffer pedal does for a passive guitar.

Active pickups also change the pots. EMG uses 25k volume and tone pots on its actives [17]. They come after the preamp, so they don't hang across the coil the way passive pots do. And actives run hotter. StewMac says passive high-impedance pickups typically stay under about 1 V of output, some low-impedance designs exceed 2 V, and actives typically run on 9 V [15]. The batteries and the stereo jack that go with that are in Chapter 17.

Tone and playability at a glance

Table 18.5: Cables, buffers and amp inputs, rated

Change	What you'll hear (passive guitar)	What you'll feel
10 ft to 20 ft of the same cable	Peak moves lower and a little taller; slightly warmer, less sparkle	More slack on stage
High-capacitance cable to low-capacitance (same length)	Brighter, more open top end	Usually little difference
Old coil cord (about 2.1 nF)	Clearly darker; peak pulled well down	Stays coiled and out of the way
Buffer right after the guitar	Tone of a short cable, even with a long rig	One more device to power
True-bypass pedals with long patch runs	Adds cable capacitance; darker as the total grows	None
Amp input 1 (1 MΩ) to input 2 (136 kΩ)	Darker, about 6 dB quieter, less gain	Needs more amp volume for the same loudness
Passive to active pickups	Cable length matters much less	Battery to change; stereo jack
Cable resistance or "low-loss" conductor claims	Little or no audible change (resistance is negligible)	None

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Part 4: Putting It Together

Chapter 19: Setup Numbers: Where the Parts Meet Your Hands

Every chapter so far has been about one part. This one is about the place where all of them meet: the setup. A *setup* is the set of small adjustments that decide how a guitar plays. There are five of them, and each comes down to a small number. How much the neck bows. How high the strings sit. How deep the nut slots are cut. Where each saddle sits front to back. How close the pickups are to the strings.

None of these numbers lives on its own. The radius of the fretboard changes how much relief and action a guitar needs. The scale length and the string gauge set how hard the strings pull on the neck. The fret height changes where the nut slots should land. The bridge decides how far you can move a saddle and how the strings sit over a radius. The magnets in the pickups decide how close they can go. So this chapter collects the numbers makers publish, explains why each one exists, and points back to the parts from earlier chapters that drive it.

What it doesn't do is walk you through the adjustments. The step-by-step work of turning a truss rod, setting saddle height, intonating and setting pickup height is in my guitar maintenance book. Here we're after the numbers and the reasons.

One of the best parts of the work is handing a guitar back after setting the neck relief, string height and intonation. Players often say it feels like a different guitar, even with no parts changed. A careful setup turns a pile of parts into a playable instrument.

How to read setup numbers

They're starting points

Every number in this chapter is a starting point. Fender calls its own setup figures "minimum specifications" meant as a guide [1]. PRS says to adjust string height to taste [2]. That's not the makers dodging the question. Your pick attack, your string gauge and how hard you fret all change what "right" means for you.

Measure the way the source measured

The second rule is to compare like with like. Makers measure the same thing at different places. Fender measures electric string height at the 17th fret; MusicNomad, Gibson and PRS measure at the 12th [1, 3, 4, 2]. Fender measures relief at the 8th fret with the string held at the last fret; MusicNomad measures at the 6th fret with the string held at the 12th [1, 5]. A 17th-fret action number will read a little higher than a 12th-fret number on the same guitar. So when you check your guitar against a table, check where the table measured.

StewMac adds one more condition: measure in playing position, tuned to pitch, because gravity and string tension both change the readings [6]. A neck lying flat on a bench with slack strings isn't the neck you play.

The order matters

The five adjustments affect each other. Change the relief and the action changes with it. Change the action and the intonation shifts. Raise the strings and they move away from the pickups. That's why Fender, PRS, StewMac and MusicNomad all start with the neck [1, 7, 6, 5]. This chapter follows the usual order: relief, action, nut, intonation, pickup height.

Neck relief

What it is

Relief is the slight forward bow of the neck under string tension. A neck with relief is a hair concave between the first fret and the body, like a very shallow valley. That small dip gives the strings room to swing in the middle of the neck without hitting the frets. MusicNomad ties too little relief to buzz on the lower frets, and a flat or back-bowed neck (one bowed away from the strings) to buzz in the middle of the neck [8].

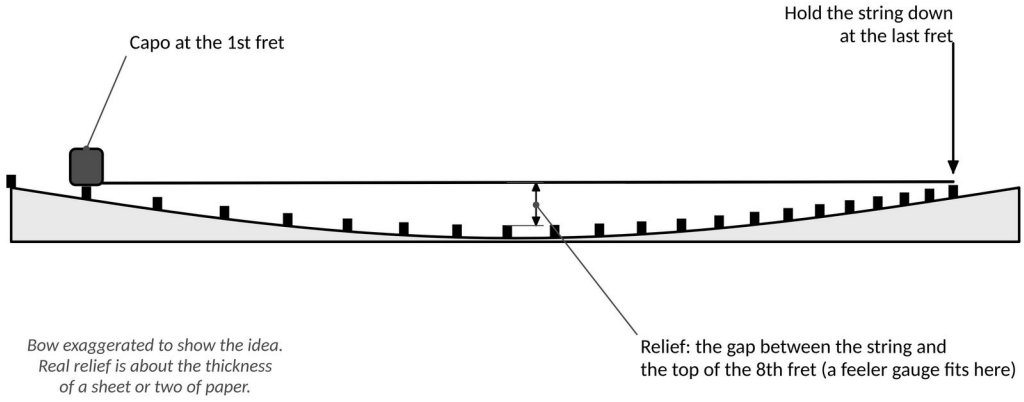


Figure 19.1: Checking relief: capo at the first fret, string held down at the far end, gap measured near the middle.

The *truss rod* is the steel rod inside the neck that sets the relief by pushing back against the strings. Rod types get their own detailed look in Chapter 3.

The numbers

Table 19.1: Published neck relief for electric guitars

Maker or source	Guitar	Relief	Where it's measured	Source
MusicNomad	Electric	.006" (0.15 mm)	6th fret, capo at 1, fretted at 12	[5]
Fender	Electric, 7.25" radius	.012" (0.3 mm)	8th fret, capo at 1, fretted at last fret	[1, 9]
Fender	Electric, 9.5" to 12" radius	.010" (0.25 mm)	8th fret, capo at 1, fretted at last fret	[1, 9]
Fender	Electric, 15" to 17" radius	.008" (0.2 mm)	8th fret, capo at 1, fretted at last fret	[1, 9]
PRS	All PRS guitars	.005" to .010"	8th fret, capo at 1, fretted at last fret	[10, 7]

These are small numbers, a few thousandths of an inch. StewMac's basic setup method starts from a nearly straight neck and adds a little relief for players who dig in hard [6].

Why the number changes from guitar to guitar

Look at the Fender rows. The flatter the fretboard, the less relief Fender asks for. That's radius at work. *Radius* is the side-to-side curve of the fretboard (Chapter 5), given as the radius of a circle, so a 7.25-inch board is much rounder than a 15-inch one. When you bend a string on a round board, it moves toward a part of the

next fret that sits higher, and it can hit that fret and choke. A little more relief and a little more height give it room [1, 11].

String tension is the second driver. The strings are what bend the neck forward, so more pull means more bow for the same truss rod setting. D'Addario's formula shows that tension rises with the square of the scale length and with the string's weight per inch [12]. Using D'Addario's published tension charts, a 10-46 set adds up to 102.5 lb and an 11-49 set to 117.1 lb (my sums), about 14% more pull on the neck [13, 14]. That's why Fender says a change of string gauge or material can be enough to need a neck adjustment, and why seasonal humidity swings often call for one too [15]. A longer scale with the same strings adds pull in the same way (the tension tables are in Chapters 4 and 11).

The third driver is the truss rod itself. A single-action rod can only straighten a neck that bows forward. Fender's own description says a single-action rod "works in one direction only" and that it's what most electric guitars use [16]. Fender's Bi-Flex rod is one rod that works in both directions, and PRS uses a double-acting rod that can correct a back-bowed neck as well as a forward bow [16, 10]. If a neck sits back-bowed with the rod fully slack, a single-action rod can't help you.

The fourth driver is how level the frets are. Relief only works if every fret is the same height. Zollner shows that one fret standing just 0.1 mm (about .004 inch) too high spoils the note at the fret before it [17]. That's a fret job (Chapter 6), not a truss rod job.

> **Caution:** A truss rod is easy to adjust and expensive to break. Never force a stuck rod nut. If it binds, creaks, or does nothing after small turns, stop and take the guitar to a tech. The safe procedure is in my guitar maintenance book.

Action

What it is and why it matters most

Action is the height of the strings above the frets. If I could only check one number on a guitar that "plays badly," this would be it. Grimes, who studied the physics of string bending, found that action has the greatest influence on how hard you have to press to fret a note [18]. Lower action means less force and less stretch, so notes go less sharp as you press them down.

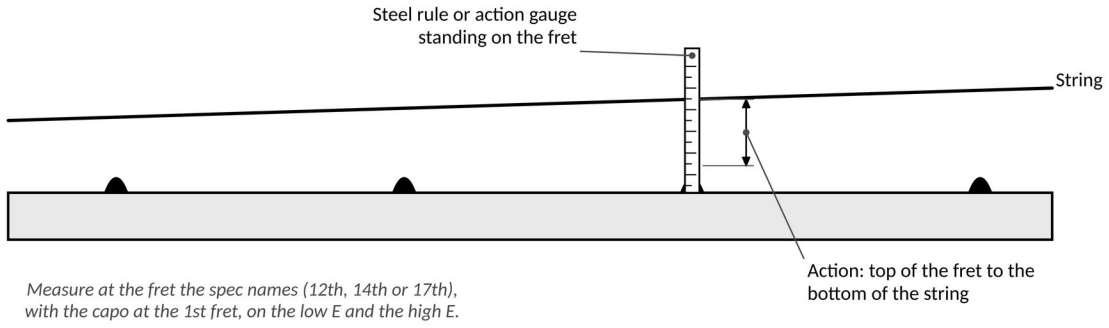


Figure 19.2: Action is the gap from the top of the fret to the bottom of the string.

Too low, though, and the strings hit the frets. Zollner describes what happens: a hard pluck makes the string strike the frets, and contacts in the first 50 milliseconds or so blend into the attack, while later ones are heard as separate buzzes [19]. He adds that a little fret contact can be part of a player's expression [19]. So "no buzz at all" isn't always the goal. "No buzz you don't want" is.

The numbers

Table 19.2: Published string height for electric guitars

Maker or source	Guitar	Bass side (low E)	Treble side (high E)	Measured at	Source
MusicNomad	Electric 6-string	.060" (1.5 mm)	.050" (1.25 mm)	12th fret, capo at 1	[3]
Fender	Electric, 7.25" radius	5/64" (about 2.0 mm)	4/64" (about 1.6 mm)	17th fret	[1, 9]
Fender	Electric, 9.5" to 12" radius	4/64" (about 1.6 mm)	4/64" (about 1.6 mm)	17th fret	[1, 9]
Fender	Electric, 15" to 17" radius	4/64" (about 1.6 mm)	3/64" (about 1.2 mm)	17th fret	[1, 9]
Gibson (Les Paul, via Sweetwater)	Electric	5/64" (about 2.0 mm)	3/64" (about 1.2 mm)	12th fret	[4]
PRS	U.S. electric (most bridges)	1.5-1.9 mm	1.4-1.8 mm	12th fret	[2]

Fender lists its figures in 64ths of an inch only; the millimeter values in parentheses are conversions. Every source gives the bass side the same height as the treble side or more.

What drives it

Radius. Fender's table shows it plainly: a 7.25-inch board gets a higher bass side than a 15-inch board [1]. Warmoth says the same thing in words. Small radii need somewhat higher action to bend without fretting out, and large radii allow clean bends at low action [20]. On a compound-radius board, which is rounder at the nut and flatter up the neck, Fender says the action is usually set to match the radius around the 12th fret [11].

The bridge and saddle radius. The saddles have to follow the fretboard's curve, or some strings end up higher than others. That's easy on a Strat or Tele bridge, where each saddle has its own height screws. It's fixed on other bridges. The Gibson ABR-1 sold through StewMac has a 12-inch saddle radius [21], which matches the 12-inch boards Gibson lists on its Les Paul and SG models (Chapter 5). Floyd Rose lists a 12-inch radius for its Original tremolo [22], and Floyd sells replacement saddle sets in 8, 10, 12, 14, 16 and 17-inch radii for other boards [23]. If your board and your bridge don't share a curve, the middle strings will sit too high or too low no matter what you do with the outer ones.

How the bridge adjusts. A Strat or Tele saddle usually has two height screws, so you set each string on its own. A Tune-o-matic bridge rises and falls as a whole on two posts with thumbwheels [21]. A Floyd Rose sets overall height at its two pivot posts; Floyd Rose's instructions use a 3 mm Allen key there [24]. A fixed Hipshot bridge offers a fixed range: Hipshot lists floor heights of 0.125 inch for guitars with a straight (non-angled) neck and 0.175 inch for angled or raised necks [25]. Bridge height and neck angle have to agree. If a bridge bottoms out before the action is low enough, no amount of saddle work will fix it, and Chapter 3 and Chapter 8 are where to look.

Fret height. Action is measured from the top of the fret, so taller frets don't change the number. They change the feel. With tall frets your fingertip pushes the string onto the fret before it reaches the wood. Zollner points out that with tall frets, how hard you press can nudge the pitch sharp [26]. Fender says lower frets suit players who like to feel the fretboard under their fingers [27].

Scale length. StewMac says longer scales allow somewhat lower action before buzz, and shorter scales can buzz at low action [28]. That fits basic string physics, since a longer scale at the same pitch carries more tension, but StewMac gives no number and I haven't found a measurement of it. Take it as a direction.

Tremolo setup. On a tremolo guitar, saddle height changes how the arm behaves. Kemp found that raising a saddle about 0.5 to 0.6 mm made the tremolo 3.6 to 5.0 percent more sensitive [29]. Small, but it's another reason to set action before you fine-tune a floating bridge.

> **Tip:** Lower the action in small steps and play every string up the neck between steps. It's much easier to find "just low enough" coming down slowly than to overshoot and climb back up.

Nut slot height

What it is

The nut sets how high each string sits over the first fret. Slot height is easy to overlook, and it can be the reason a guitar with good 12th-fret action still feels stiff in first position. If the slots are too high, you push the string a long way down to reach the first fret, which takes more effort and stretches the string sharp. If they're too low, the open string buzzes on the first fret [30, 31, 32].

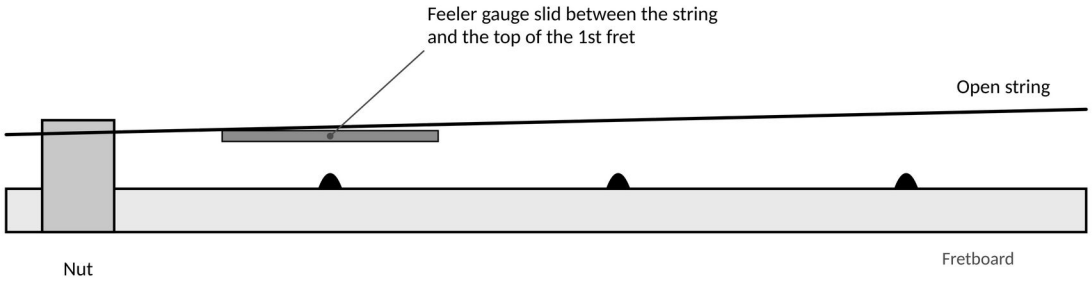


Figure 19.3: Checking nut height with a feeler gauge over the first fret.

The numbers

Table 19.3: Published nut slot height targets

Maker or source	Strings	Target	Source
MusicNomad	Low E and A	.020" (0.50 mm) gap over 1st fret	[33]
MusicNomad	D and G	.018" (0.45 mm) gap over 1st fret	[33]
MusicNomad	B and high E	.016" (0.40 mm) gap over 1st fret	[33]
StewMac (Fender-style assembly guide)	Wound strings (low E, A, D)	.013" to .020"	[34]
StewMac (Fender-style assembly guide)	Plain strings (G, B, high E)	.007" to .012"	[34]
StewMac (nut making)	Low E / high E, finished	about .020" / about .010" clearance	[30]

Maker or source	Strings	Target	Source
StewMac (feeler-gauge method)	Slot bottom	fret height plus .005"-.010", adding about .002" toward the bass	[31]
StewMac (capo check)	All	gap over 1st fret one to two times the gap over 2nd fret, capo at 1	[32]
Zollner (examples)	E4 / E2	0.3 mm / 0.4-0.5 mm string to first fret	[35]

The sources don't agree to the thousandth, but they agree on the pattern (Chapter 7 has the full nut story): bass strings get more clearance than treble strings, and the whole thing is measured in a few thousandths of an inch. Zollner's example gaps sit right alongside StewMac's targets, which tells me those targets are realistic [35, 30].

What drives it

Fret height. Look at StewMac's feeler-gauge method: it starts from the height of the first fret and adds a few thousandths [31]. A guitar refretted with taller wire needs the slots to sit higher, or the new frets will leave the nut slots too low by comparison, and the open strings can buzz. If you change fret size, plan on a new nut or at least a check.

String gauge. The bass strings get more clearance than the trebles in every row of the table, and the heavier the bass strings, the more that matters.

Relief and action. The nut is checked last of the three because it's measured against the first fret, and MusicNomad sets string height before nut height for exactly that reason [3]. Get the neck and saddles right first, then judge the nut.

Nut type. A locking nut (Chapters 7 and 9) clamps the strings, so there are no slots to file. Its radius has to match the board instead: StewMac lists the Floyd Rose R2 locking nut at a 10-inch radius and the R3 at 12 inches [36].

> **Caution:** Nut slots can only be cut deeper. A few strokes too many and the fix is a shim, a filled slot, or a new nut. Leave the filing to a tech unless you've practiced on spare nuts.

Intonation

What it is

Intonation is whether the notes you fret play in tune with the open string. You set it by moving each saddle forward or back. Why can't every saddle sit exactly at the scale length? Because pressing a string down to a fret stretches it a little, and stretch raises the pitch. Zollner works out that fretting the low E at the 12th fret raises it about 10 cents (a cent is one hundredth of a semitone), and he puts the low E's *compensation*, the extra length behind the theoretical scale, at up to about 6 mm on electric guitars [35]. Every string needs a different amount, which is why the saddles on a well-set guitar end up staggered.

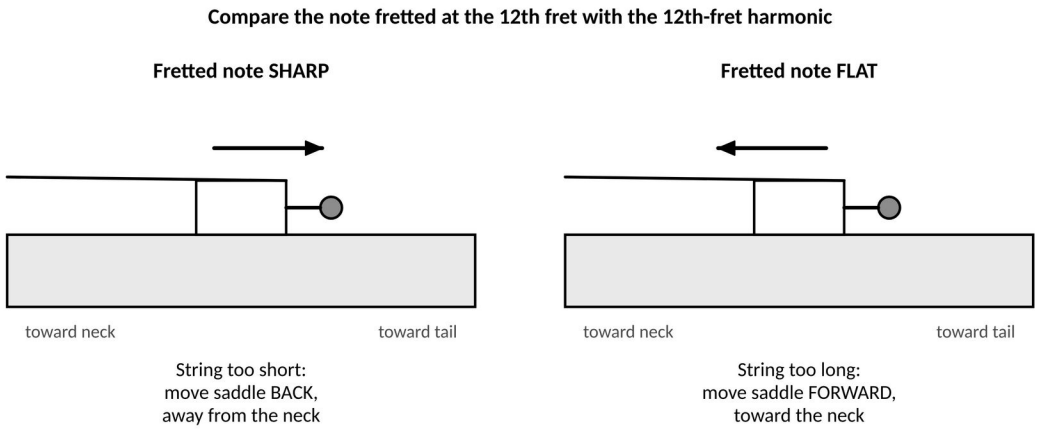


Figure 19.4: Which way to move an electric saddle for intonation.

The numbers, such as they are

Intonation doesn't have one published number like relief or action. The target is simply that the note fretted at the 12th fret matches the 12th-fret harmonic (or the open string an octave up). What makers do publish is when to check it. Fender says to check intonation after every string change [37]. StewMac says to intonate after fresh strings and again after any change of gauge, and adds that "Old strings are the enemy of stable intonation" [38]. Set the action first, too: a string that sits high has to stretch farther to reach the fret, which pulls the fretted note sharp.

So the useful table here isn't a list of numbers. It's a list of what each bridge lets you do.

Table 19.4: Intonation adjustment by bridge type

Bridge	Adjustment	What limits it	Source
Strat-style (6 saddles)	Each string on its own	Saddle screw travel	[1]
Tele 3-saddle	One saddle per pair of strings	Each pair is a compromise; compensated saddles reduce the error	[39]
Tele 6-saddle	Each string on its own, offset intonation screws	Saddle travel	[40]
Gibson ABR-1	Each string on its own	Less saddle travel than a Nashville	[41]
Gibson Nashville	Each string on its own	Wider saddle travel than an ABR-1	[41]
Lightning-bar wraparound	None per string; compensation cast into the bar	Fixed shape; a Badass-style wraparound adds per-string adjustment	[42]
Floyd Rose Original	Each string on its own	Bridge must sit parallel; redo after gauge or tuning changes	[24]

Callaham, which makes Tele bridges, says uncompensated three-saddle bridges "cannot be adjusted for perfect intonation" [39]. That's a maker selling the fix, but the geometry backs it up: two strings that need different lengths can't both be perfect on one straight saddle. StewMac's comparison of Tune-o-matic styles says the Nashville gives "a wider range of saddle adjustment" than the ABR-1 [41], which matters if you run heavy strings or tune down.

What drives it

String gauge and construction. Each gauge stretches a different amount when fretted, so every gauge change means a fresh intonation check [38]. Kemp's measurements show that wound and plain strings respond differently to stretch, and that the ratio of core to winding is "a very powerful design parameter" for how a string behaves [29].

Action and nut height. Both stretch the string as you fret, so both pull notes sharp when they're too high. That's why intonation comes after relief, action and the nut check [30].

Frets. Tall frets let a heavy hand press notes sharp [26]. Fret placement matters too. Zollner measured two Gibson guitars whose higher frets strayed noticeably from the exact positions, while other guitars he checked were more precise [35]. Two guitars isn't a survey, but it's a reminder that no saddle can fix a misplaced fret.

Tremolo float. On a floating bridge (Chapter 9 compares floating and decked setups), the strings and springs balance each other. Change the gauge or the tuning and that balance shifts, the bridge tilts, and the saddles move with it. That's why Floyd Rose says to redo the "parallel" step (bridge level with the body) whenever you change gauge or tuning, and to start with the fine tuners in the middle of their range [24]. Fender says a floating Strat tremolo sits with about a 1/8-inch (3.2 mm) gap at the back, and a decked one gets about a half turn more on each spring claw screw so it stays down during bends [1]. Fender's locking tremolo page says a floating locking bridge should "sit parallel to the body" [43]. Set the float first, then intonate.

Bending on a floating bridge. Floyd Rose notes that bending one string on a floating tremolo makes the others go slightly flat, and calls that normal [44]. That isn't an intonation fault, and moving saddles won't fix it. Decking the bridge or adding spring tension is the hardware answer, and StewMac's test for spring tension (bend the B string hard and see whether the bridge pulls forward) is a good check [45].

Pickup magnets. A pickup set too close can pull the string out of tune. I cover that next, but it's worth knowing that a guitar that "won't intonate" sometimes just has a neck pickup set too high.

Pickup height

What it is and why it matters

Pickup height is the gap between the top of the pickup's pole pieces and the bottom of the strings, usually measured with the strings held down at the last fret. It's the one setup number that's mostly about tone, though it has a playability side too.

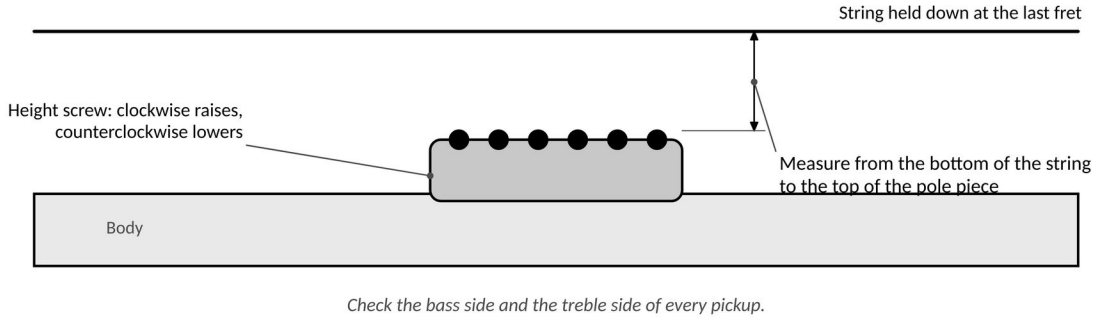


Figure 19.5: Pickup height is measured with the string held down at the last fret.

Closer means louder. Zollner puts the drop at about 3 to 4 dB for every millimeter of extra distance, and he notes that more distance also widens the stretch of string the pickup senses, which costs treble [46]. His string measurements give a similar slope, about 2.1 to 2.7 dB per millimeter at 2 to 5 mm [47]. Seymour Duncan says the same in plain words: closer is louder and fuller, farther is softer and cleaner [48].

Closer also means less clean. Novak and colleagues tested three Seymour Duncan pickups at 3, 5, 7 and 10 mm and found that output and distortion both rose as the pickup came closer; the humbuckers showed "much stronger distortion" at 3 mm [49].

Too close and the magnet starts to fight the string. Zollner explains that the magnet acts like a negative spring on the string and that "the fundamental will be detuned the most" [50]. The string's up-and-down and side-to-side motions split apart and beat against each other, which you hear as a warble. DiMarzio warns that a strong enough field "alters string vibration enough to make the guitar sound out of tune" [51]. Seymour Duncan's blog adds damped sustain, buzz on neck pickups, and "unnatural overtones," sometimes called wolf tones [52]. StewMac's Erick Coleman calls the result "Stratitis" and says the neck pickup is the most prone to it [53].

The numbers

Table 19.5: Published pickup heights (string held at the last fret, bottom of string to top of pole piece unless noted)

Maker or source	Pickup	Bass side	Treble side	Source
Fender	Standard single-coil	5/64" (2 mm)	4/64" (1.6 mm)	[9, 1]
Fender	Vintage-style single-coil	6/64" (2.4 mm)	5/64" (2 mm)	[9, 1]
Fender	Texas Special / Noiseless	8/64" (3.2 mm)	6/64" (2.4 mm)	[9, 1]
Fender	Humbucker	4/64" (1.6 mm)	4/64" (1.6 mm)	[9, 1]
StewMac (Coleman), reporting a Fender "factory spec"	Strat	3/32" (= 6/64")	5/64"	[53]
DiMarzio	Full-size humbucker, bridge	5/64" (2 mm)	at least 1/16" (1.5 mm)	[51]
DiMarzio	Alnico 5 rod single coil, neck and middle (to top of magnet)	1/8" (3.2 mm)	3/32" (2.4 mm)	[51]
DiMarzio	Alnico 5 rod single coil, bridge (to top of magnet)	3/32" (2.4 mm)	1/16" (1.6 mm)	[51]
DiMarzio	Low-pull models, neck and middle	3/32"	1/16"	[51]
DiMarzio	Low-pull models, bridge	1/16" (1.6 mm)	3/64" (1.2 mm)	[51]
Seymour Duncan	Humbuckers, Strat and Tele pickups	3/32" (2.4 mm)	3/32" (2.4 mm)	[54, 55, 56]
Seymour Duncan	JB Jr. Tele bridge	0.073" (1.85 mm)	0.073" (1.85 mm)	[52]
EMG	Active pickups	3 mm	3 mm	[57]
Lollar	Sixty-Four, Special S, P-90	about 1/8"	about 1/8"	[58]
MusicNomad	Stratocaster, all pickups (to pickup screw)	3/32" (2.4 mm)	1/16" (1.6 mm)	[59]

These numbers spread more than any other table in this chapter, and the reason is the magnets. Makers set different starting points for different magnet designs. DiMarzio gives its low-pull models a lower setting than its standard Alnico 5 rod pickups [51], and Fender sets its Texas Special and Noiseless pickups well farther from the strings than its standard single coil [9]. Lollar starts its humbuckers as close as possible without interference, and its single coils and P-90s at about 1/8 inch [58]. EMG's active pickups sit at 3 mm [57].

One Fender row needs a word of warning. StewMac's Erick Coleman gives a "Fender factory spec" for a Strat of 3/32 inch on the bass side and 5/64 inch on the treble side [53]. Fender's own support pages list 5/64 and 4/64 inch for a standard single coil and 6/64 and 5/64 inch for a vintage-style single coil [9, 1]. Since 3/32 inch is the same as 6/64 inch, StewMac's figure matches Fender's vintage-style row, not its standard row. StewMac doesn't say which pickups it had in mind, so I show both and let you pick the row that fits your pickups.

What drives it

The magnet. Strong rod magnets right under the string pull hardest (magnetic pull is in Chapter 12), so rod-magnet single coils usually sit lower than bar-magnet designs. That's the pattern in DiMarzio's and Fender's rows.

Position. Look at DiMarzio's single-coil rows: the bridge pickup sits closer than the neck and middle. The string swings much less near the bridge than in the middle of its length, so a bridge pickup sees less motion and needs to sit closer to keep up in level, while the neck pickup, under the widest swing, is the one most likely to pull the string. Coleman's own final settings on a Strat show the same idea: he ran the neck at 1/16 inch on both sides, the middle at 5/64 and 3/64, and the bridge at 1/16 and 3/64 [53]. Lindy Fralin, in another StewMac video, eyeballs a Strat neck pickup at about 1/16 inch on the treble side and 1/8 inch on the bass side [60]. Height is also the balance control between positions: you set each pickup so they sound about equally loud when you switch.

String gauge. MusicNomad notes that heavier strings pull harder on the magnets, so they may need the pickups a little lower [59].

Action. Pickup height is measured to the string, so every change in saddle height changes it. That's why pickups come last in the order.

> **Tip:** If notes warble up near the 12th fret after you raise a pickup, it's too close. Lower it a little and check intonation again.

How the numbers tie back to the parts

This table pulls the chapter together: each setup number, and the parts from earlier chapters that decide where it lands.

Table 19.6: Which parts drive each setup number

Setup number	Parts that drive it	Chapters
Neck relief	Truss rod type, string gauge and tension, scale length, fretboard radius, fret level	3, 4, 5, 6, 11
Action	Fretboard radius, saddle radius, bridge type and height range, neck angle, fret height, scale length	3, 4, 5, 6, 8

Setup number	Parts that drive it	Chapters
Nut slot height	Fret height, string gauge, nut type (standard, locking)	6, 7, 11
Intonation	String gauge and construction, action, nut height, fret height and placement, bridge type, tremolo float	6, 7, 8, 9, 11
Pickup height	Magnet type and strength, pickup position, string gauge, action	11, 12, 13, 14

Tone and playability at a glance

Table 19.7: Setup changes, rated

Change	What you'll hear	What you'll feel
More relief	Little or no audible change, unless it cures a buzz	Strings higher in the middle of the neck; less buzz on the low frets
Less relief or a back-bowed neck	Buzz in the middle of the neck if overdone	Lower feel; more buzz
Lower action	Little or no change until the strings start to hit the frets, then buzz	Less force to fret (Grimes); notes go less sharp
Higher action	Cleaner hard picking, fewer fret contacts	More effort; fretted notes pull sharp
Nut slots cut to target	Open strings unchanged unless they buzzed before	First-position chords easier and more in tune
Intonation set	Chords in tune up the neck	Nothing different under the hand
Pickup 1 mm closer	About 2-4 dB louder; a little brighter; more pickup distortion	Too close: warble and notes that won't settle in tune
Floating vs decked tremolo	No measured tone difference found	Floating goes up and down; decked feels solid during bends
Heavier strings, same setup	Depends on the strings (Chapter 11)	More pull: recheck relief, intonation and pickup height

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Chapter 20: Classic Recipes Compared

Every chapter so far has pulled one part off the guitar and looked at it alone. Nobody buys a guitar that way. You buy a recipe: a scale length, a neck, a bridge, a set of pickups and a handful of pots and caps that a maker put together on purpose and kept building for decades. This chapter lines up seven of those recipes side by side. Every number in it is one I already sourced in an earlier chapter, and I give each one its source again here so you don't have to go hunting.

Then I flip the question around. Instead of asking what a part does, I ask what you want, and which change gets you there with the most certainty for the least money. That table is ranked by evidence, not by how often a change gets recommended online. The chapter ends with a short guide to using this book when you shop or build.

How to read the spec tables

Specs change from model to model and year to year, so a "Stratocaster spec" doesn't really exist. Each value below names the model whose spec page it came from. When two Fender models disagree, I show both, because the gap between them is often the most useful thing in the table.

A cell marked "not published" means I didn't find that value on any maker page or other source behind Chapters 2 to 18. The maker may well list it somewhere I didn't read. "Varies by model" means I found more than one answer for the same family.

Maker numbers are the maker's claims, as everywhere else in this book. Where I computed something, such as string tension at a different scale length, the table says so.

One gap matters enough to flag up front. I found detailed electrical specs for replacement pickups, but not for the pickups fitted to most of these specific models. So the pickup data lives in its own table (Table 20.9), built from reference parts in each style, and I say plainly that those aren't necessarily the stock pickups.

The seven recipes

The Stratocaster

The Strat recipe is a 25.5 in scale, a bolt-on maple neck, three single-coil pickups, 250k pots and a tremolo. Fender has built it in so many versions that the spread inside the family is as interesting as the comparison with other guitars.

Table 20.1: Stratocaster specs by model

Spec	Value	Model the value belongs to	Source
Scale	25.5 in (648 mm)	American Professional II Stratocaster	[1]
Radius	9.5 in (241 mm)	American Professional II Stratocaster	[1]
Radius	7.25 in (184.1 mm)	American Vintage II 1957 Stratocaster	[2]
Nut width	1.685 in (42.8 mm)	American Professional II Stratocaster	[1]

Spec	Value	Model the value belongs to	Source
Nut width	1.650 in (42 mm)	American Vintage II 1957 Stratocaster	[2]
Nut material	bone	American Professional II and American Vintage II 1957	[1, 2]
Frets	22 Narrow Tall (6105), .094 x .054 in	American Pro II Strat neck	[3, 4]
Frets	21 Vintage Tall, .083 x .045 in	American Vintage II 1957 Strat neck	[5, 6]
Neck profile	Deep "C", 0.820 in at 1st fret, 0.920 in at 12th	American Professional (first series) Strat neck	[7]
Truss rod	Bi-Flex, two-way, 1/8 in hex	American Professional line	[7, 8]
Neck joint	4-bolt, asymmetrical plate, tapered heel	American Ultra Stratocaster	[9]
Neck joint	3-bolt with Micro Tilt	Vintera '70s Stratocaster	[10]
Body wood	alder ('50s and '60s styles); ash ('70s)	Vintera series	[10]
Bridge	6-screw tremolo, 2-7/32 in (about 56.4 mm) E to E	American Vintage Series tremolo assembly	[11]
Bridge	2-point tremolo, 2-1/16 in (about 52.4 mm) E to E	Deluxe Series 2-point tremolo assembly	[12]
Tuners	15:1	Fender Pure Vintage; Kluson 1956-64 single-line set	[13, 14]
Tuners	18:1, locking, staggered posts	Fender Locking Strat/Tele tuners	[15]
Pickups	three single coils (see Table 20.9)	stock units for these models not published	[16]
Pots	three 250K CTS, audio taper	Fender Stratocaster pot and capacitor kit	[17]
Tone cap	0.1 µF at launch, 0.05 µF from 1970, 0.022 µF from 1983	Stratocaster factory history (Zollner)	[18]
Tone cap	.022 µF "modern" or .100 µF "vintage-style," polyester	Fender Stratocaster kit	[17]
Treble bleed	one cap, two resistors; values not published	American Professional single-coil models	[19]
Switch	3-way 1954-77; 5-way from 1977	Stratocaster (Fender history)	[16]

Look at the two radius rows and the two fret rows together. The American Vintage II 1957 pairs a round 7.25 in board with small Vintage Tall frets, while the American Professional II pairs a flatter 9.5 in board with taller, wider Narrow Tall wire [2, 1, 4, 6]. Both are Strats. They'll feel like different guitars under a bend, and Fender's own setup chart shows why: Fender's minimum relief is .012 in for a 7.25 in board against .010 in for 9.5-12 in, and its minimum bass-side action at the 17th fret is 5/64 in against 4/64 in [20]. *Radius* is the curve across the fretboard, *relief* is the slight forward bow in the neck, and *action* is the string height above the frets. A rounder board needs a little more of both to bend cleanly.

The bridge rows hide a fit trap. Vintage 6-screw bridges spread the E strings 2-7/32 in; Fender's modern figure is 2-1/16 in [11, 12]. Swap one for the other and the E-to-E spread changes by about 4 mm (my arithmetic in Chapter 8), so the outer strings shift against the pickup poles.

The Telecaster

The Tele shares the Strat's 25.5 in scale [21] and its bolt-on neck, but trades the tremolo for a fixed bridge and the three pickups for two.

Table 20.2: Telecaster specs by model

Spec	Value	Model the value belongs to	Source
Scale	25.5 in	Telecaster (Fender history)	[21]
Radius	9.5 in	Player Series Telecaster neck	[22]
Radius	7.25 in (named in the listing)	American Vintage II 1951 Telecaster neck	[23]
Nut width	not published for a standard Telecaster	n/a	n/a
Frets	22 Medium Jumbo (6150), .103 x .046 in	Player Series Telecaster neck	[22, 4]
Frets	21	original Telecaster necks	[24]
Neck profile	Modern "C," 0.820 in at 1st, 0.870 in at 12th	Player Series Telecaster neck	[22]
Neck profile	1951 "U," 0.890 in at 1st, 0.990 in at 12th	American Vintage II 1951 Telecaster neck	[23]
Truss rod	single action, head adjust, 3/16 in hex	Player Series Telecaster neck	[22]
Neck joint	3-bolt with Micro Tilt	Vintera '70s Telecaster Thinline, Deluxe and Custom	[10]
Body wood	ash ('70s Thinline); alder ('70s Deluxe and Custom)	Vintera series	[10]
Bridge	3 saddles, string-through, 4 mounting screws	American Vintage 3-saddle bridge	[25]
Bridge	6 saddles, 2-3/16 in spacing, string-through	American Series 6-saddle bridge (1986-2007)	[26]
Bridge pickup plate	copper-plated steel, about 1.2 mm, 1951-1981	Telecaster history (Zollner)	[27]
Tuners	15:1 or 18:1 locking	Fender Pure Vintage; Fender Locking Strat/Tele	[13, 15]
Pickups	bridge and neck single coils (see Table 20.9)	stock units for these models not published	[28]
Pots	two 250K CTS, audio taper	Fender Telecaster pot and capacitor kit	[29]
Pots	1M volume with a 1 nF bridging cap from 1967	Telecaster history (Zollner)	[30]
Tone cap	.022 µF or .100 µF; the often-quoted 0.047 µF is not confirmed	Fender Telecaster kit	[29]
Switch	3-way: bridge, both in parallel, neck	a standard Tele as Fralin describes it	[28]

The steel plate under the bridge pickup is the Tele's quiet signature. Zollner measured it adding about 0.6 dB of sensitivity and lowering the resonance about 3% [27]. That's real, and it's small. The 1M volume pot from 1967 is a bigger deal for the knob's behavior than for the sound on 10: a 1M pot loads the pickup lightly, but treble falls away fast on a small turn-down, and Zollner reads Fender's added 1 nF cap as a sign Fender heard the same problem [30].

The Les Paul

The Les Paul recipe is a shorter 24.75 in scale, a glued-in mahogany neck, a mahogany body under a maple top, a Tune-o-matic bridge with a stopbar tailpiece, and two pickups into 500k pots.

Table 20.3: Les Paul specs by model

Spec	Value	Model the value belongs to	Source
Scale	24.75 in (628.65 mm) as stated by Gibson	Les Paul Standard 50s	[31]
Radius	12 in (304.8 mm)	Les Paul Standard 50s	[31]
Nut width	43.05 mm, listed as 1.69 in	Les Paul Standard 50s	[31]
Nut material	Graph Tech	Les Paul Standard 50s	[31]
Fretboard	Indian rosewood	Les Paul Standard 50s	[31]
Frets	22; wire size not published	Les Paul in Fleischer's six-guitar study	[32]
Body	mahogany back, maple top, weight relief "None"	Les Paul Standard 50s	[33]
Neck wood	mahogany	Les Paul Standard 50s	[33]
Neck joint	glued; long tenon with hide glue	Custom Shop 1959 Les Paul Standard reissue	[34]
Truss rod	"Adjustable" (type not named); "1950s no-tube" on the reissue	Les Paul Standard 50s; 1959 reissue	[33, 34]
Neck profile	named, no depth published	Les Paul Standard 50s	[33]
Bridge	ABR-1: 2-29/32 in post spacing, 6-32 posts into wood, 12 in radius	Gibson Accessories ABR-1 part	[35]
Bridge	Nashville: 2-15/16 in post spacing, M5 posts in bushings	Gibson Accessories Nashville part	[36]
Tailpiece	aluminum stopbar, 3.22 in stud spacing	Gibson Historic Reissue stopbar	[37]
Tuners	not published	n/a	n/a
Pickups	two humbuckers (see Table 20.9)	Seymour Duncan's Les Paul wiring guide	[38]
Pots	500k audio taper	Gibson Historic Reissue pot; Seymour Duncan's Les Paul guide	[39, 38]
Tone cap	0.022 µF stock; Historic bumblebee is 0.022 µF paper-in-oil	Seymour Duncan's Les Paul guide; Gibson Historic part	[38, 40]
Switch	3-way toggle, Switchcraft 12010X long frame	"Les Paul style" in Switchcraft's catalog	[41]

Two things explain why a Les Paul feels easier to bend on than a Strat: the strings are looser and the board is flatter. On the same 10-46 set, the Les Paul's stated 24.75 in scale gives about 96.6 lb of total tension against 102.5 lb at 25.5 in, about 5.8% less (computed in Chapter 4 from D'Addario's published figures) [42, 43]. Add a 12 in radius against 9.5 in or 7.25 in on the Strats, and a bend has less tension to fight and less curve to choke on [31, 1, 2].

The SG

The SG shares the Les Paul Standard's published neck numbers but lives in a thinner body with the neck leaving the body much later.

Table 20.4: SG specs by model

Spec	Value	Model the value belongs to	Source
Scale	24.75 in (628.65 mm) as stated by Gibson	SG Standard	[44]
Radius	12 in (304.8 mm)	SG Standard	[44]
Nut width	43.05 mm, listed as 1.69 in	SG Standard	[44]
Nut material	Graph Tech	SG Standard	[44]
Fretboard	rosewood	SG Standard	[44]
Body join	at the 22nd fret	1963 SG Les Paul Standard (review)	[45]
Body and neck wood	mahogany	SG Standard	[44]
Neck joint	glued in, long tenon, set neck	SG Standard	[44]
Frets	22, medium jumbo	SG Standard	[44]
Bridge, tailpiece	aluminum Nashville Tune-O-Matic, aluminum stop bar	SG Standard	[44]
Tuners	Grover Rotomatic	SG Standard	[44]
Vibrato option	Bigsby B5 lists the SG; about 287 g	Bigsby B5	[46]
Pickups	490R neck, 490T bridge	SG Standard	[44]
Controls	2 volume, 2 tone; pot and cap values not published	SG Standard	[44]
Switch	3-way toggle, Switchcraft 12013X	"SG style" in Switchcraft's catalog	[41]

The SG's published difference from a Les Paul is mostly about reach. With the body join at the 22nd fret on the 1963 example, there's nothing in the way of your hand at the top of the neck [45]. On paper, the scale, radius and nut width match the Les Paul Standard 50s exactly [44, 31]. The switch frame doesn't: a thin body needs a different toggle than a deep Les Paul cavity [41].

The ES-335

The ES-335 is the semi-hollow member of the group: hollow wings with a solid block down the middle.

Table 20.5: ES-335 specs by model

Spec	Value	Model the value belongs to	Source
Body	3-ply maple/poplar/maple, solid maple center block, spruce braces	ES-335 Vintage Burst	[47]
Body	same 3-ply build with solid maple center block	Custom Shop 1964 ES-335 reissue	[48]
Neck wood	mahogany	ES-335 Vintage Burst	[47]
Truss rod	"1950s no-tube"	Custom Shop 1964 ES-335 reissue	[48]
Headstock angle	17° before 1965, 14° from 1965 (secondary sources, not a factory spec)	ES models by era	[49, 50]
Scale	24.75 in (628.65 mm)	ES-335 Vintage Burst	[47]
Radius	12 in (304.8 mm)	ES-335 Vintage Burst	[47]
Nut width	43.05 mm, listed as 1.7 in	ES-335 Vintage Burst	[47]
Frets	22, medium jumbo	ES-335 Vintage Burst	[47]
Bridge, tailpiece	ABR-1 Tune-O-Matic, aluminum stop bar	ES-335 Vintage Burst	[47]

Spec	Value	Model the value belongs to	Source
Tuners	Vintage Deluxe with keystone buttons	ES-335 Vintage Burst	[47]
Vibrato option	Bigsby B3 for thin hollow and semi-hollow bodies; about 296 g	Bigsby B3	[51]
Pickups	Calibrated T-Type, neck and bridge	ES-335 Vintage Burst	[47]
Controls	2 volume, 2 tone; 500K pots, Orange Drop caps (value not given)	ES-335 Vintage Burst	[47]
Tone cap	.022: paper-in-oil early 1958, mylar late 1958 to about 1961, "Black Beauty" mylar from 1961	ES-335 history (dealer source)	[52]
Switch	3-way toggle	Gibson-type guitars (Switchcraft)	[41]

The 335's defining spec is the body, and that's where measured effects are thinnest. In Chapter 2 I explained why more air and moving top in the wings should raise feedback risk at high volume, but I flagged there that it's general reasoning, not a measurement. The tone cap history is a nice detail: every type in the dealer's list is .022, so the dielectric changed over the years while the value stayed put [52].

The PRS Custom 24

PRS sits between the Fender and Gibson camps on almost every published number.

Table 20.6: PRS Custom 24 specs

Spec	Value	Model the value belongs to	Source
Scale	25 in	Custom 24 and SE Custom 24 (2025)	[53, 54]
Radius	10 in	Custom 24 and SE Custom 24 (2025)	[53, 54]
Nut width	1-11/16 in (1.6875 in)	Custom 24 and SE Custom 24 (2025)	[53, 54]
Frets	24 on a 25 in scale; wire size not published	PRS (StewMac's scale list)	[55]
Neck profile	varies by model: Pattern is 7/8 in at the 1/2 fret; Pattern Thin is 53/64 in	PRS profile chart	[56]
Truss rod	double-acting; 5/16 in wrench (SE: 7 mm)	PRS Maryland and SE models	[57, 58]
Relief spec	0.005-0.010 in	PRS	[57]
Body	mahogany back, carved figured maple top; mahogany neck	Custom 24	[53]
Neck joint	set	Custom 24	[53]
Bridge	PRS Patented Tremolo, Gen III	Custom 24	[53]
Tuners	PRS Phase III Locking	Custom 24	[53]
Pickups	85/15 treble and bass	Custom 24	[53]

Spec	Value	Model the value belongs to	Source
Controls	volume and tone with a 5-way blade switch; pot and cap values not published	Custom 24	[53]

The 25 in scale puts a 10-46 set at about 98.5 lb, between the Les Paul's 96.6 and the Strat's 102.5 (computed in Chapter 4) [42, 43]. The 10 in radius sits between Fender's 9.5 and Gibson's 12 [53, 1, 31]. If you want a guitar that doesn't lean hard either way on feel, the numbers say this is it.

The superstrat: Ibanez RG

A *superstrat* is a Strat-shaped guitar pushed toward speed and heavy tremolo use. Ibanez's RG line is the clearest published example I found, but no single RG gives me a full spec sheet, so this table borrows from several RG models and one S model. Read the model column.

Table 20.7: Ibanez superstrat specs by model

Spec	Value	Model the value belongs to	Source
Scale	25.5 in (648 mm)	RG421DX	[59]
Radius	400 mm (15.75 in)	Wizard III neck (RG421DX, PWM20)	[59, 60]
Nut width	43 mm (58 mm at the 24th fret)	Wizard III neck (RG421DX, PWM20)	[59, 60]
Fretboard	jatoba	RG421DX	[59]
Frets	StewMac says its Wide/Highest #0150 wire is used on Ibanez	StewMac statement, no model named	[61]
Neck	5-piece maple/walnut Super Wizard, 17 mm at 1st fret, 19 mm at 12th	RG550	[62]
Neck	5-piece maple/wenge Super Wizard	RG8570	[63]
Neck joint	bolt-on, "All Access Neck Joint"	RG8570	[63]
Body	basswood	RG550	[62]
Body	African mahogany, 4 mm flamed maple top	RG8570	[63]
Bridge	Lo-Pro Edge, 10.8 mm string spacing, rear fine tuners	RG8570	[64]
Bridge	Edge-Zero II, ZPS3Fe, stud lock, 10.8 mm spacing	S1070PBZ	[65]
Nut	locking	PWM20	[60]
Tuners, pickups, pots, tone cap, switch	not published	n/a	n/a

The RG550's 17 mm neck depth at the 1st fret is about 4 mm thinner than Fender's 0.820 in (20.8 mm) C shapes (computed in Chapter 3) [62, 7]. Add the 400 mm radius Ibanez lists for its Wizard III neck on the RG421DX, flatter than any other recipe in this chapter [59], and you have the recipe's whole point on two lines of a spec sheet: low action without choking bends, and the slimmest neck in Chapter 3's profile table.

Side by side

Table 20.8 squeezes the seven recipes into one grid using the model rows above. It's a summary, so when a family has two values I give the range and you can look back at its own table for which model is which.

Table 20.8: Seven recipes side by side

Spec	Stratocaster	Telecaster	Les Paul	SG	ES-335	PRS Custom 24	Ibanez RG
Scale	25.5 in	25.5 in	24.75 in (stated)	24.75 in (stated)	24.75 in (stated)	25 in	25.5 in
10-46 set tension (computed)	102.5 lb	102.5 lb	96.6 lb	96.6 lb	96.6 lb	98.5 lb	102.5 lb
Radius	7.25-9.5 in	7.25-9.5 in	12 in	12 in	12 in	10 in	15.75 in (400 mm)
Nut width	1.650-1.685 in	not published	1.69 in (43.05 mm)	1.69 in (43.05 mm)	43.05 mm	1.6875 in	43 mm
Frets	21-22, varies by model	21-22, varies by model	22	22	22	24	not published
Neck joint	bolt-on (3 or 4 bolts)	bolt-on	glued, long tenon (1959 reissue)	glued, long tenon	not published	set	bolt-on (RG8570)
Bridge	6-screw or 2-point tremolo	3 or 6 saddles, fixed	Tune-o-matic and stopbar	Tune-o-matic and stopbar	Tune-o-matic and stopbar	PRS tremolo	locking tremolo
Pickups	3 single coils	2 single coils	2 humbuckers	2 humbuckers (490R/490T)	2 humbuckers (T-Type)	2 humbuckers (85/15)	not published
Pots	250K	250K (1M volume from 1967)	500k	not published	500K	not published	not published
Tone cap	0.022-0.1 µF by era	.022 or .100 µF kit	0.022 µF	not published	.022 by era	not published	not published
Switch	5-way blade	3-way	3-way toggle	3-way toggle	3-way toggle	5-way blade	not published

Values and sources as in Tables 20.1-20.7. Tension is the D'Addario EXL110 set, computed in Chapter 4 from D'Addario's published figures [42, 43]. The Tele's 3-way follows Fralin's description of a standard Tele [28].

The pickups behind the recipes

The pickups decide more about the sound of these recipes than anything else in the tables, so here are the reference parts in each style that do have published specs. *Inductance* is a coil's resistance to changes in current, measured in henries (H); it matters more than DC resistance (DCR) for where a pickup's treble peaks. The *resonant peak* is the frequency where the pickup and everything loading it (pots, cable, amp input) together give a bump in output before the treble rolls off. The last column comes from my model in Chapter 12, which ignores eddy-current losses, so real peaks sit lower and broader. *Capacitance*, the ability to store electric charge, is what the cable adds across the pickup, and more of it pulls the peak lower.

Table 20.9: Reference pickups by style, maker data and modeled peaks

Style	Pickup	DCR	Inductance	Modeled peak (Chapter 12: two 500k pots, 450 pF cable, 1 MΩ amp)	Source
Strat single coil	Fender Pure Vintage '59 Strat	5.8k	2.2 H	about 4.5 kHz, +7.8 dB	[66]
Strat single coil, hotter	Fender Custom Shop Texas Special bridge	6.56k	2.97 H	about 3.8 kHz, +6.9 dB	[67]
Strat-size noiseless	Fender Gen 4 Noiseless (bridge)	10.0k (also listed as 10.3k)	3.6 H	not modeled	[68]

Style	Pickup	DCR	Inductance	Modeled peak (Chapter 12: two 500k pots, 450 pF cable, 1 MΩ amp)	Source
Tele single coil	Fender Pure Vintage '64 Tele neck / bridge	7.4k / 6.0k (spec tab)	2.1 / 2.8 H	not modeled	[69]
Vintage-output humbucker	Gibson Burstbucker Type 1 / 2 / 3	7.8K / 8.4K / 8.7K	not published	not modeled	[70]
Vintage-output humbucker	Gibson '57 Classic	8K	not published	not modeled	[71]
Vintage-output humbucker	Seymour Duncan SH-1 '59 neck / bridge	7.43k / 8.13k (2015 chart)	not published	Duncan chart: 6.8 / 6 kHz (load not stated)	[72]
High-output humbucker	Seymour Duncan SH-4 JB	16.4k (2015 chart); 16.6k (current page)	not published	Duncan chart: 5.5 kHz (load not stated)	[72, 73]
High-output humbucker	DiMarzio Tone Zone DP155	17.31k	not published	not modeled	[74]
Medium-output humbucker	DiMarzio Air Norton DP193	12.58k	not published	not modeled	[75]
Filter'Tron type	TV Jones TV Classic bridge	4.8k	1.83 H	about 4.9 kHz, +8.6 dB	[76]
Typical humbucker (model value)	ElectroSmash typical	15k	10 H	about 1.8 kHz, +2.9 dB	[77]
Active humbucker	EMG 81	not published	not published	preamp sets the voice; 25k pots	[78]

Read the last column with care. My model puts ElectroSmash's typical 10 H humbucker, which is a hot pickup, near 1.8 kHz. A PAF-style humbucker at about 2.8 to 4.6 H, the range Vintage Vibe's Pete Biltoft gives [110], lands near 2.8 to 3.6 kHz. A vintage Strat pickup sits at 4.5 kHz under the same load [77, 66]. That modeled gap of roughly 1 to 3 kHz, depending on the humbucker, is bigger than any measured wood or hardware difference I found, and I'd argue it's a large part of why a Les Paul and a Strat sound like different instruments. The same chapter shows why DCR alone misleads: Zollner found output can differ by a factor of 4 between pickups with the same resistance [79].

What actually separates the recipes

Strip the tables down and four things set these guitars apart that someone has measured or that the model can show.

The first is the electrical pairing. Fender pairs low-inductance single coils with 250k pots. Gibson pairs higher-inductance humbuckers with 500k pots [17, 38, 39]. In my Chapter 15 model, the same Strat pickup peaks at about 4.2 kHz and +3.9 dB with 250k pots, and about 4.5 kHz and +7.8 dB with 500k [66]. A bigger pot mostly makes the peak taller; it barely moves it. In model terms, the Gibson choice of 500k lifts a peak that sits much lower to begin with, and the Fender choice of 250k tames a peak that's already high. Swap a Strat to 500k pots and, in the model, it gets a taller and more cutting peak.

The second is hum. A single coil has no hum cancelling. Zollner measured a humbucker's signal-to-hum advantage at about 19 dB to over 40 dB in a favorable field direction, and about 16 dB for a Gibson 490R in the worst direction [80]. A Strat narrows that gap only in positions 2 and 4, and only with a reverse-wound, reverse-polarity middle pickup [81].

The third is tension and curve, which you feel more than hear. From the Les Paul to the Strat, the same strings carry about 6% more tension (computed), and the board runs from 12 in down to 7.25 in [42, 43, 31, 2]. Chapter 4 found no controlled measurement of scale length alone against tone, so I treat scale as a feel spec first.

The fourth is the neck as a vibrating part. Fleischer measured neck resonances on six guitars and found the Les Paul's at 58, 200/208 and 445/455 Hz and a Strat's at 58, 190/200, 235 and 432 Hz [32]. Those resonances set where dead spots fall. The ranges overlap a lot, which tells you the Les Paul and the Strat don't live in different worlds structurally, even though their dead spots can land on different notes.

And here's what doesn't separate them in any measured way I found. Mottola's single published result on neck joints (one test instrument, no statistics) ran opposite to the folklore: the bolt-on sustained longest, up to about 40% longer than the neck-through, yet five listeners couldn't hear a sustain difference [82]. Ray and colleagues built ash and walnut bodies with identical necks and electronics. The fundamentals decayed about the same, though some low-string partials lasted longer on ash [83]. I haven't found independent measurements behind saddle and tailpiece material claims. Those debates get the full treatment in my book *Chasing Tone*.

If you want X, change Y

Now turn the question around. For each goal I list the changes roughly from the biggest, best-supported effect down to changes with no measurement behind them, which sit at the bottom. Electrical changes come first because they're the ones Chapters 12 to 18 could measure or model. Wood and hardware-material swaps come last because that's where the evidence runs out.

I use four evidence labels. *Measured* means a named source measured it. *Modeled* means it comes from the standard pickup model (Chapters 12, 15, 16 and 18) or a plain calculation, not a listening test. *Maker claim only* means the only support is the maker's or seller's word. *No measured evidence found* means exactly that: I looked and didn't find a measurement.

Table 20.10: Tone goals, ranked by evidence

Goal	Change	What it does	How big, and the evidence	Chapter
Brighter	250k to 500k pots (passive)	Lighter load, taller resonant peak	Modeled: 4.2 kHz +3.9 dB to 4.5 kHz +7.8 dB on a Strat pickup [66, 84]	15
Brighter	Shorter or lower-capacitance cable, or a buffer	Less capacitance, so the peak moves up	Modeled (Strat pickup, two 250k pots): 1,000 pF puts the peak at about 3.1 kHz, 300 pF at about 4.7 kHz [66, 84]; Zollner gives about 100 pF per meter, give or take 30%, as typical for cable [85]	18
Brighter	Fresh strings	Wound strings' treble rings longer	Measured: an old low E's 2,391 Hz partial decayed in about 1/7 the time [86]	11

Goal	Change	What it does	How big, and the evidence	Chapter
Brighter	Remove a metal pickup cover	Less eddy-current loss in the treble	Measured: three covered Tele neck pickups differed in treble by up to 12 dB, mainly from eddy currents in their covers; no with-and-without test [87]	13
Brighter	Split or parallel a humbucker	Lower inductance, higher peak	Modeled ideal: split peak about 1.4 times higher, parallel about 2 times [88]	14
Brighter, when turned down	Treble bleed or 50s wiring	Keeps highs as you roll back the volume; nothing on 10	No measured evidence found for the size; Zollner explains the mechanism, and Seymour Duncan and Fralin describe the effect [30, 38, 89]	16
Brighter	Nut, saddle or stopbar material	Claimed brighter or "more punch"	Maker claim only (sources in Chapters 7 and 8)	7, 8
Darker	Bigger tone cap, used with the knob down	Lower, weaker tone-down peak	Modeled: 0.022 µF gives about 650 Hz +4.2 dB, 0.047 µF about 390 Hz +1.8 dB; little change on 10 [66, 84]	16
Darker	Amp input 2 instead of input 1	Heavier load, less level	Maker spec: 136 kΩ and -6 dB against 1 MΩ [90]	18
Darker	Hotter pickup of the same design	More turns lower the peak	Measured: 10% more turns, about 10% lower resonance and 0.9 dB more signal [79]	12, 13
Darker	Flatwound strings	More treble damping in the string	Measured: stronger treble damping than roundwounds [91]	11
Darker	Cap dielectric swap, same value	Paper, polyester, polypropylene	Measured: under 0.1 dB; little or no audible change [18]	16
More output	Raise the pickup	String closer to the magnet	Measured: about 2-4 dB per mm across two Zollner tests [92, 93]	14
More output	Series wiring (Tele 4-way, stock humbucker)	Coils add instead of averaging	Modeled ideal [88]; Fralin calls it louder and thicker, a maker claim [28]	14
More output	Pickup swap chosen by DCR	Can go either way	Measured: a factor of 4 in output at the same DCR [79]	12, 13

Goal	Change	What it does	How big, and the evidence	Chapter
More output	Alnico 2 to Alnico 5	Stronger magnet if magnetized harder	Measured: output follows field strength, up to about 6 dB between magnets; the frequency response changed only about 0.8 dB [94]	12
More output	Cobalt or "high output" strings	Claimed stronger magnetic response	Maker claim only [95]	11
Less hum	Humbucker in place of a single coil	Two coils cancel hum	Measured: about 16 dB (worst case) to over 40 dB [80]	13, 17
Less hum	Stacked or coaxial single-coil-size pickup	Hum-cancelling in a single-coil slot	Measured: about 24 dB for Fender's coaxial design [80]	13
Less hum	RWRP middle pickup on a Strat	Cancels in positions 2 and 4 only	Maker claim only; no dB figure [81]	13, 14
Less hum	Shielding the cavities	Cuts touch-sensitive buzz, not magnetic hum	No measured evidence found for the buzz reduction (StewMac guidance) [96]; Measured: an aluminum pickguard shield cost about 2 dB of brilliance [97]	17

Table 20.11: Playability and sustain goals, ranked by evidence

Goal	Change	What it does	How big, and the evidence	Chapter
Easier bends	Lower action (within the limits of your frets)	Less force to fret and bend	Measured: Grimes found action has the greatest influence on fretting force [98]	11, 19
Easier bends	Lighter strings	Less tension	Maker spec: D'Addario's charts sum to 84.4 lb for 9-42 against 102.5 lb for 10-46 (my sums, Chapter 11) [99, 42]	11
Easier bends	Shorter scale, same strings	Less tension	Computed: 25.5 to 24.75 in is about 5.8% less; to 25 in about 3.9% less [43]	4
Easier bends	Flatter or compound radius	Bends clear the next fret at lower action	Maker spec: Fender's setup minimums drop from .012 in relief on 7.25 in to .010 in on 9.5-12 in; no measured bend test found [20]	5
Easier bends	Taller frets	Less pressure to fret	Maker claim only (Fender); no measured evidence found [100]	6

Goal	Change	What it does	How big, and the evidence	Chapter
Better tuning stability	Fix a binding nut slot	String returns after bends	No measured evidence found; StewMac's guidance is that a "ping" while tuning means binding [101]	7
Better tuning stability	Lower a pickup set too close (rod magnets)	Removes magnetic pull on the string	Measured: magnet pull detuned a low E's fundamental by several hertz [102]	12, 14
Better tuning stability	Locking nut and locking tremolo	Clamps both ends of the string	No measured evidence found (mechanism only)	7, 9
Better tuning stability	Self-lubricating nut material	Less friction in the slot	Maker claim only [103]	7
Better tuning stability	2-point instead of 6-screw tremolo	Fewer pivot contact points	No measured evidence found (mechanism only)	9
Faster feel	Thinner neck, flatter radius, narrower nut	Less neck in the hand	Dimensions published (17 mm RG550 against 0.820 in Fender C); no measured evidence found for speed [62, 7]	3, 5
More sustain	Fresh strings	Treble partials ring longer	Measured: a used A string on a Les Paul had decay times 50 to 80% shorter [104]	11
More sustain	Pickup lower (rod magnets)	Less magnetic drag on the string	Measured as pitch effects only [102]; no measured evidence found for the sustain change itself	14
More sustain	Change the neck joint	Bolt-on, set or neck-through	Measured on one guitar: bolt-on longest; listeners heard no difference [82]	3
More sustain	Change body wood	Different stiffness and damping	Measured (one body each): fundamentals decayed alike; some low-string partials lasted longer on ash [83]	2
More sustain	Steel stopbar, special saddles, roasted neck	Claimed more sustain	Maker claim only [105, 106, 107]	3, 8

The cheapest changes sit near the top. Pickup height costs nothing and moves output by a few dB per millimeter [92, 93]. Fresh strings cost a few dollars and are the best-measured sustain change I found [86, 104]. A pot swap costs little more and changes the peak height in my model by about 4 dB.

Also notice where "more sustain" ended up. It's the goal with the weakest support for the changes people usually make. The one change with a real sustain measurement behind it (fresh strings), and the one with a measured mechanism (pickup height), aren't the ones that get sold as sustain upgrades. Neck joint and body wood tests found measurable but unproven differences: up to about 40% more sustain for one bolt-on that listeners couldn't hear, and some low-string partials lasting longer on ash [82, 83]. The structural effect that is

well measured, the dead spot, comes from neck and body resonances lining up with a note, and Paté's team traced it to how easily the structure moves at the neck end of the string [108]. That's not something a part swap reliably fixes. For the long version of the sustain and tonewood arguments, see my book *Chasing Tone*.

How to use this book when you shop or build

None of this needs a lab. Here's how I'd put the book to work, in order.

1. Start with the feel numbers on the spec page: scale, radius, nut width, neck depth and fret size. Find the same numbers for a guitar you already love, measuring it if you have to. Chapters 3 to 6 tell you what each one changes, and Tables 20.1 to 20.7 show how much they vary even inside one family.
2. Note what the spec page leaves out. Body weight, neck depth on many Gibsons, and pot and cap values are often missing. Ask the seller, or open the control cavity on a used guitar. A blank spec isn't bad news, but it's a question you should answer before you pay.
3. Read pickup specs for inductance first. If the maker only gives DCR, treat it as a rough hint about the wire, not a measure of output (Chapters 12 and 13).
4. Check the load the pickup will see: pot values (Chapter 15), tone cap and wiring (Chapter 16), and the cable and amp input (Chapter 18). In my Chapter 15 model, a 250k-to-500k change alone moves the peak height by about 4 dB.
5. Do the free and cheap things before buying parts. Fresh strings, pickup height, a proper setup and a clean nut slot sit at the top of Tables 20.10 and 20.11 for a reason. The setup numbers are in Chapter 19, and the steps are in my guitar maintenance book.
6. Measure before you order. Gibson's real scale can differ from its stated 24.75 in, so measure before buying a fretboard (Chapter 4). Check tuner holes for 11/32 in (8.8 mm) vintage or 10 mm modern before ordering tuners [14, 109]. Check bridge post spacing (ABR-1 and Nashville differ) [35, 36], toggle frame length against cavity depth [41], and pot shaft and bushing type (Chapter 15).
7. Read every claim for its source. When a table in this book says "maker claim only" or "no measured evidence found," that's not a verdict that the claim is false. It means you're paying for a promise, and you should decide whether you want to.
8. Change one thing at a time and write down what you changed. If you swap pickups, pots and strings together, you'll never know which one you're hearing.

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Glossary

50s wiring. A way of wiring a tone cap to the volume pot's output (wiper) lug instead of its input lug.

Action. The height of the strings above the frets.

Active pickup. A pickup with a battery-powered preamp built in, with a low output impedance.

Alnico. A cast magnet alloy of aluminum, nickel and cobalt with iron, sold in numbered grades.

Aperture. The short stretch of string a pickup actually senses, about 1 cm for a single coil.

Audio taper. A taper, also called log taper, where resistance changes slowly at first and quickly near the top; "10% audio" means 10% of the resistance at half rotation.

AWG. American Wire Gauge; a bigger number means thinner wire.

Back bow. A neck that curves backward, away from the strings, which usually causes buzz.

Balanced tension. A string set chosen so each string carries about the same tension.

Baritone guitar. A guitar with a longer scale, often about 27 inches, built to be tuned lower than standard.

Bending choke. When a bent string hits a higher fret and stops ringing; also called fretting out.

Binding. A string sticking in a nut slot that's too narrow or rough.

Blade switch. A lever switch with contacts on flat wafers in a slim frame, used on Strat-style guitars.

Bolt-on neck. A neck held to the body with screws through a metal plate, as on a Strat or Tele.

Break angle. The angle a string bends through as it passes over the nut toward the tuner.

Buffer. A small active circuit with high input impedance and low output impedance that keeps cable from loading the pickup.

Capacitance. The ability of two conductors close together to store charge, measured in picofarads (pF).

Capacitor. A part made of two conductors separated by an insulator that stores charge and passes changing signals more easily as frequency rises.

Cent. One hundredth of a semitone, used to measure small pitch differences.

CITES. The Convention on International Trade in Endangered Species, a treaty that controls cross-border trade in listed species such as rosewoods.

Claw. The bracket in the back cavity that the tremolo springs hook to; its screws set spring tension.

Coercivity. How hard a magnet material is to demagnetize.

Coil split. Shorting out one coil of a humbucker so only the other one works.

Coil tap. An extra lead brought out partway through a coil's winding so fewer turns can be used.

Comb filter. A filter that cuts a series of evenly spaced frequencies, like the teeth of a comb.

Compensation. Moving a saddle back from the exact scale length so fretted notes play in tune.

Compound radius. A fretboard curve that starts rounder at the nut and gets flatter toward the body.

Computed value. A number worked out from a published formula and published data, rather than read from a source.

Corner frequency. The frequency where a simple resistor-capacitor filter starts to cut; a poor description of a guitar tone control.

Crown. The rounded top of a fret that the string touches.

DC resistance (DCR). The plain resistance of a pickup's copper wire as read by an ohmmeter; it depends on wire length and thickness.

Dead spot. A note that dies away early because a neck resonance at that frequency soaks up the string's energy.

Decay time. How long a note, or one partial, takes to fade by a set amount.

Decibel (dB). A unit for comparing loudness or signal level on a ratio scale.

Decked. A tremolo set so the bridge rests flat on the body and moves only downward.

Density. Mass per unit volume; how heavy a block of a given size will be.

Depth. The thickness of the neck from the fretboard face to the back, measured at a given fret.

Dielectric. The insulating layer between a capacitor's plates, such as plastic film, oiled paper or ceramic.

Dissipation factor. A measure of the energy a capacitor loses inside its dielectric, given as a percentage; lower means closer to ideal.

Double-locking. A tremolo system that clamps the strings at both the bridge and the nut.

DPDT. Double pole, double throw: a switch with two separate sections that flip together, each with two positions.

Eddy currents. Small circulating currents induced in metal parts near a coil that soak up energy and flatten the resonant peak.

Equal temperament. The tuning system in which all twelve semitones of an octave are the same size, a ratio of about 1.05946.

Feedback. A loop where sound from the amp moves the guitar, which the pickups sense and send back to the amp.

Filter'Tron. Gretsch's humbucker design with two rows of screws, wound lower than a PAF-type.

Fine tuner. A small thumbscrew on a locking bridge that adjusts one string's tension after the nut is clamped.

Flatwound. A string wrapped with flat ribbon instead of round wire, for a smooth surface.

Floating. A tremolo set so the bridge sits lifted off the body, balanced between strings and springs, so it can move up or down.

Fret. A metal bar across the fretboard that ends the vibrating length of a pressed string.

Fretboard. The strip of wood or composite on the face of the neck that holds the frets; also called the fingerboard.

Fundamental. The lowest frequency a vibrating string produces, heard as the note's pitch.

Gauge. A string's diameter in thousandths of an inch.

Gear ratio. The number of turns of a tuner's button for one full turn of its post.

Grid stopper. A resistor in series with the first tube's input in an amp.

Ground loop. A loop formed when a part is grounded through two paths, which can act like a one-turn coil and pick up noise.

Half round. A round-wound string ground partly flat on the outside.

Hardtail. A fixed, non-tremolo bridge on a guitar body style that often carries a tremolo.

Harmonic. One of the simpler patterns a string vibrates in at the same time as the whole, such as halves or quarters of its length.

Headroom. How much a circuit can handle before it clips or distorts.

Hex core. A string core with six flat sides that helps the wrap grip.

Hum rejection. How much less mains hum a pickup picks up than a plain single coil, in decibels.

Humbucker. A two-coil pickup wired so hum cancels while the string signal adds.

Impedance. Resistance that can change with frequency, measured in ohms.

Inductance. A coil's resistance to changes in current, measured in henries (H); the main number setting a pickup's resonant peak.

Induction. The voltage that appears in a coil of wire when the magnetic field passing through it changes.

Inharmonicity. The slight sharpening of a string's overtones caused by the string's stiffness.

Intonation. How closely a guitar plays in tune up the neck, adjusted by moving each saddle forward or back.

Janka hardness. The force needed to press a steel ball halfway into wood; a measure of dent resistance.

Knife edge. The sharpened edge of a 2-point or locking tremolo plate that rocks against the pivot studs.

Leveling. Filing the tops of the frets so they all sit at the same height.

Linear taper. A taper where resistance changes in step with rotation, 50% at the halfway point.

Load. Everything a pickup has to drive, mainly the pots, cable and amp input; a lower resistive load flattens the resonant peak.

Locking nut. A nut that clamps the strings in place, used with locking tremolos.

Locking tuner. A tuner that clamps the string inside the post so few or no wraps are needed.

Microfarad, nanofarad, picofarad. Units of capacitance: 1 µF = 1,000 nF, and 1 nF = 1,000 pF.

Microphonics. Noise a cable makes when it is flexed, bumped or stepped on.

Miller effect. The way a tube's gain multiplies its internal capacitance, raising the capacitance the guitar sees at the amp input.

Mobility. How easily a point on the guitar is set moving by a force; high mobility means the string loses energy there more easily.

Modeled value. A number or curve from a simplified circuit model, used to show direction and rough size.

Modulus of elasticity (MOE). A measure of stiffness: how strongly a material resists bending.

Modulus of rupture (MOR). Bending strength: the stress at which a test piece breaks.

Multiscale. A neck with fanned frets that gives each string its own scale length.

Neck dive. When a strapped guitar's headstock drops because its balance point is beyond the strap buttons.

Neck pitch. The small angle between the neck and the body, which sets how high the bridge has to sit.

Neck-through. A construction in which the neck runs the full length of the guitar and the body wings are glued to its sides.

Nickel silver. The usual fret alloy, made of copper, nickel and zinc, with no silver in it.

No-load pot. A tone pot that disconnects itself from the circuit at 10.

Node. A point on a vibrating string that stays still for a given partial.

Nominal value. The value a part is sold as, which a real part may not measure exactly.

Nonlinear distortion. Harmonics a device adds that weren't in the original signal.

Nut. The slotted bar at the headstock end of the fretboard that spaces the strings and ends the open strings' vibrating length.

Nut slot height. How high each string sits over the first fret, set by the depth of its slot in the nut.

Out of phase. Two pickups or coils wired so one signal subtracts from the other.

Output impedance. How much a signal source resists the current it sends out; low values are barely affected by cables and pots.

P-90. Gibson's single-coil pickup with a wide coil, two bar magnets underneath and adjustable pole screws.

Parallel wiring. Connecting coils or pickups side by side across the same two wires so they share the load.

Partial. One of the higher frequencies a string vibrates at along with its fundamental; often called a harmonic or overtone.

Pickup height. The gap between a pickup's pole pieces and the bottom of the strings.

Pivot. The line or points a tremolo bridge rocks around when you move the arm.

Plain string. A single solid steel wire with no wrap.

Playability. In this book, how a guitar feels and behaves under the hands, including effort, buzz and tuning.

Pole (switch). One separate circuit a switch can route at the same time as the others.

Potentiometer (pot). A resistor with a movable contact, used for volume and tone controls.

Profile. The cross-section shape of the back of a neck, named with letters like C, D, U and V.

Push-back wire. Cloth-covered hookup wire whose covering slides back to bare the conductor, so it needs no stripping.

Push-pull pot. A potentiometer with a small switch worked by pulling up or pushing down on its knob.

Q (quality factor). A measure of how tall and narrow a resonant peak is.

Quartersawn. Wood cut so the growth rings run roughly through the thickness of the board rather than flat across it.

Radius. The side-to-side curve of a fretboard, given as the radius of a circle.

Recipe. The full set of design choices (scale, neck, bridge, pickups, controls) that defines a guitar model.

Relief. The slight forward bow in a neck that keeps strings from buzzing in the middle frets.

Remanence. The magnetism a material keeps after it has been magnetized.

Residual resistance. The small resistance a pot still shows at its end stop.

Resonance. A frequency at which a structure vibrates easily and can absorb energy from a string.

Resonant peak. The band of frequencies where the pickup and everything connected to it respond most strongly.

Rockwell B (HRB). A standard hardness scale for softer metals; a higher number means a harder material.

Roller nut. A nut that uses small rollers in place of slots to let strings move freely.

Rule of 18. An old fret-spacing method that divides by 18; it doesn't place the 12th fret at half the scale.

RWRP. Reverse wound, reverse polarity; a pickup wound and magnetized opposite its neighbor so the pair cancels hum.

Saddle. The small part on a bridge that a string rests on, which sets the end of the string's vibrating length.

Scale length. Twice the distance from the nut to the center of the 12th fret; the nominal vibrating length of an open string.

Scalloped fretboard. A fretboard with wood scooped out between the frets so the fingertip touches only the string.

Scarf joint. A glued, angled joint that attaches a separate headstock piece to a neck.

Semi-hollow. A body with hollow wings and a solid center block under the bridge and pickups.

Series wiring. Connecting coils or pickups end to end so their voltages and inductances add.

Set neck. A neck glued into the body, as on a Les Paul.

Setup. The group of adjustments (relief, action, nut height, intonation, pickup height) that decide how a guitar plays.

Shielding. Grounded copper foil or conductive paint in a cavity that blocks electric-field noise, but not magnetic hum.

Short grain. Wood fibers that run out across a thin section, leaving a weak line that splits easily.

Slot height. How high a string sits in its nut slot, measured as clearance over the first fret.

Specific gravity. A material's density compared with the density of water.

Split-shaft post. A vintage-style tuner post with a center hole and slot that the string end tucks into.

Stacked pickup. A hum-cancelling pickup with two coils on top of each other in a single-coil-size housing; also called coaxial.

Staggered posts. A tuner set whose posts get shorter farther from the nut to add break angle.

Star grounding. Running every ground wire to a single point.

Stopbar. A bar-shaped tailpiece mounted on two studs that anchors the strings behind a Tune-o-matic.

Strap lock. A strap button and latch pair that keeps the strap from slipping off.

Stratitis. Warble and pitch wobble caused by a pickup's magnet pulling on the strings when it sits too close.

String post. The round shaft on a tuner that the string wraps around or locks into.

String tension. The pulling force on a string tuned to pitch, usually given in pounds or newtons.

String tree. A small guide on a flat headstock that holds strings down behind the nut.

String-through. A bridge design in which the strings pass through the body and anchor in ferrules on the back.

Superstrat. A Strat-shaped guitar built for speed and heavy tremolo use, usually with a thin neck, flat radius and locking tremolo.

Sustain. How long a note keeps sounding; in Mottola's test, the time for a note to fall by 21 dB.

Sustain block. The heavy block under a tremolo bridge that the strings pass through and the springs pull on.

Tang. The barbed leg of a fret that is pressed into the fretboard slot.

Taper. The curve that links a pot's knob position to its resistance.

Tenon. A tongue on the end of a set neck that fits into a matching slot (mortise) in the body.

Tolerance. How far a real part is allowed to differ from the value printed on it.

Tone. In this book, what reaches the amp: level, frequency balance, and how a note grows and decays.

Tone control. A pot in series with a capacitor, connected from the signal to ground, that adds the capacitor to the pickup's circuit as the knob turns down.

Treble bleed. A small capacitor, often with a resistor, across a volume pot's input and output lugs that keeps treble as the volume is turned down.

True bypass. A pedal switching scheme that passes the signal straight through by wire when the effect is off.

Truss rod. A steel rod inside the neck that counters string pull and sets relief.

Tune-o-matic. Gibson-style bridge with six adjustable saddles on two height-adjustable posts, used with a separate tailpiece.

Tuning machine. The geared tuner that holds a string's tension and lets you change its pitch.

TUSQ. Graph Tech's synthetic nut and saddle material.

Two-way truss rod. A truss rod that can correct both forward bow and back bow.

Unit weight. A string's weight per inch of length, used in D'Addario's tension formula.

Vickers hardness (HV). A lab measure of metal hardness based on the size of a dent made by a diamond point; higher is harder.

Weight relief. Pockets routed inside a body under the top to reduce weight.

Wiper. The sliding contact inside a pot that connects to the middle lug and moves along the track as the shaft turns.

Wound string. A steel core with a second wire wrapped around it to add mass.

Wraparound. A one-piece bridge and tailpiece that the strings wrap around and rest on.

Young's modulus. A measure of how strongly a material resists being stretched.

Zero fret. A fret placed where the nut would be, so open strings stop on a fret.

About This Book

This book walks through every part of the electric guitar: the body, neck, fretboard, frets, nut, bridge, tremolo, tuners, and strings, then the pickups, pots, capacitors, switches, wiring, and cables. Each chapter explains what the part does, the numbers behind it, and how it shapes tone and playability. Maker specs are labeled as maker claims, and where the evidence is thin, I say so.

The last part brings it all together with setup numbers and classic wiring and parts recipes compared side by side. This edition has more than 60 drawings and diagrams, from neck profiles and fret spacing to pickup construction, switch positions, and wiring layouts, so you can see each part as you read about it. A glossary is at the back.