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Voices of the electric guitar

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Intro

The solid body electric guitar is the result of many guitars and innovations that came before it, followed by the guitar's need for volume to compete with louder instruments, particularly when soloing. In the 1930s, jazz and its various forms incorporated the guitar, but at the time there was no way for an acoustic guitar to compete with the volume of a trumpet or saxophone, let alone with an orchestra of trumpets and saxophones, such as in big band jazz. As a result, amplification of the guitar was born and the electric guitar has been evolving since, from a hollow bodied ES-150 arch-top with a pick-up used by Charlie Christian to the Les Paul played by Slash today. The electric guitar began to compete with other instruments both in volume and in popularity. It has found its way into many genres of music, including rock & roll styles from Chuck Berry to the Offspring, from jazz to fusion, from R&B to reggae and many others, some of which have evolved alongside with it. Competition to create the best sounding and most versatile instruments has led to the birth of many designs and different voices. Many guitar makes are found predominantly in specific genres, usually due to a genre-specific tone, while others are known to be adept at many genres.

There are many materials and specialized components used to build a guitar, all of which have their own effect on a guitar's tone. The modern guitar luthier has the knowledge and skills to craft together these raw materials and components to create a guitar and thus is an excellent resource for understanding the instrument. The scope of this paper is to discuss the traits, principles, materials and components of a solid body guitar and how they affect the sonic qualities of the instrument.

The basic parts of a guitar consist of the body, neck and head (Koch 10). The body is essentially the base of the guitar. It houses the electronics and on its surface, the bridge, tailpiece, toggle switches, tone and volume knobs as well as any other peripherals such as a tremolo bar. Traditionally, the neck is fastened to the body and stretches out to the head. The strings are anchored in at the bridge, span the length of the neck and are anchored again at the head to the tuning shafts. In doing so, the strings are taut across the neck and can be pressed down to the fretboard, producing a different pitch at each spot across the neck.

Acoustics; Resonation, Timbre, Materials & Sustain

At the extremes, one could use rubber for the body and the sound would be absorbed, giving a muffled, dead sound. Or a luthier could use metal or stone (such as a cinder block) and get a very bright sound. However, it would sound artificial, weigh too much and be extremely uncomfortable to play (Koch 15). A compromise between hard and soft woods is usually the way to get the most satisfactory sound. The inherent properties of each type of wood (i.e. grain pattern, density) contribute to the resonation and timbre of a guitar’s sound.

Each type of wood used brings out certain frequencies more strongly. The hardness of the wood will reflect the strings' vibrations through the bridge. A harder wood will produce a brighter sound while a softer wood will produce a darker sound. Soft woods (conifers) have poor tone due to the looser structure of the wood. Manmade woods (such as plywood) often have a cross-grain structure. With a cross-grain structure, each piece of wood is overlapped at a right angle to the next, as a result, each piece's grain is at a right angle from the adjacent piece's grain, weakening the transmission of vibration, and producing a poorer tone (Koch 14). Every hardwood has a different structure and hence a different sound. These are the differences an expert looks at when analyzing and selecting wood.

Neck and Fretboard Woods

The following woods are often used for necks, though many are used for fingerboards as well. A few of them are also used for bodies ("Warmoth Custom Guitar & Bass Parts"). Some of the properties to consider in selecting a wood for this purpose are cost, tone, density and grain. Table 1 on the next page summarizes the differences and similarities of commonly used woods.

Sustain is the length of time a string sounds after being plucked. Traditionally, the longer the sustain, the better. The length of sustain depends less on the weight and density of the wood used for the body and neck than on the stiffness of the entire system. A stiffer system means that less energy will be withdrawn from a vibrating string. Accordingly, a guitar with a stiff, firmly fixed neck and a body made of a lighter wood, such as alder, can offer more sustain than a guitar with a heavy, dense body and a soft neck (Koch 85).

The joint between the neck and the body is about the halfway mark of a string's scale length. This makes it extremely important to have a good joint to achieve maximum stiffness and sustain. While it is easier to achieve this with a straight-through neck, it is possible to obtain with a bolt-on or glued-in neck provided the joint is sound.

Many factors can take away from the sustain of a string on a guitar. For example, a cardboard shim underneath a saddle can dampen a string’s vibration and reduce its sustain, as can a bad tuner shaft or loose saddle. The bridge should be well fixed to the body. A solid brass bridge allows for more sustain then a thin, metal plate with saddles attached. There is a limit to how stiff a system should be. If the system is too stiff, it will not be stimulated by the strings, and elements of the sound will suffer (Koch 85).

Species	Latin Name	Color	Tone	Grain	Uses		
					Neck	Fretboard	Body
Afromosia	Pericopsis elata	Brown with yellow hues	Bright	Medium Fine	X		
Birdseye Maple	Acer saccharum	Light tan	Very Bright	Dense	X	X	
Bocote	Cordia elaeagnoiders	Light & dark brown stripes	Slightly Warm	Smooth &Dense	X		
Bubinga	Guibourtia demeusei	Red	Slightly bright	Fine	X	X	X
Canary	Centrolobium ochroxlon	Yellow with red streaks	Moderately Bright	Fine	X	X	
Cocobolo	Dalbergia retusa	Reddish Brown	Slightly warm	Smooth		X	
Ebony	Dispyrus melanoxylon	Black	Bright	Smooth & hard		X	
Flame Maple	Acer saccharum	Light tan	Very bright	Dense	X	X	
Goncalo Alves	Astronium fraxini folium	Tan	Clean & warm	Dense & smooth	X		
Indian Rosewood	Dalbergia latifolia	Brown to dark purple	Warm	Smooth	X	X	X
Kingwood	Dalbergia cearensis	Brown	Moderately warm	Smooth		X	
Koa	Acacia koa	Brown and tan stripes	Moderately warm	Dense	X		X
Korina	Terminalia superba	Light yellow green	Moderately warm	Dense	X		
Macassar Ebony	Dispyrus macassar	Brown stripes	Very bright	Dense	X	X	
Mahogany	Khaya ivorenis	Brown	Very warm	Open pore	X		X
Pau Ferro	Machaerium villosum	Tan to dark coffee	Very bright	Tight pore	X	X	
Purpleheart	Peltogyne pubesens	Purple	Even	Hard & dense	X	X	X
Satine	Brosimum paraense	Dark red	Bright	Tight	X	X	
Walnut	Juglans nigra	Brown	Balanced	Mid density	X		X
Wenge	Millettia laurentii	Black & brown	Balanced	Open and stiff	X	X	X
Ziricote	Cordia dodecandra	Gray to brown & black	Even	Dense	X	X	

Head

The type of headstock, or head, on a guitar affects the way in which the strings are loaded. The angle at which the string "breaks" from the nut to the tuners influences the tone and tuning stability of the guitar. Too shallow of an angle will cause the string to rattle in the nut slot, harming its tone (Burrluck 65). On guitars that have a standard back-angled headstock, without a locking nut, the string should be wrapped around the tuner post two to four times, depending on the gauge of string and height of the string-post above the tuner bushing (Hobbes). A heavier gauge string on a shorter post needs fewer turns than a lighter gauge string on a longer post. Some peg-heads have the tuners all on one side, such as a Telecaster, while others have tuners on both sides, such as a Les Paul.

A headless guitar offers some advantages. It reduces the weight of the instrument. It is also easier to build and allows the strings to run in a straight line. Because of the absence of windings on tuners, the instrument has more stable tuning. Since it has a zero-fret, no lengthy nut filling is needed. Additionally, the instrument itself is more compact. However, it does require strings with two ball ends (Koch 88).

Body

The bodies of electric guitars are usually built using hardwood deciduous trees. Of the many types of hardwood, typically only a few are actually used for building guitars (Koch 14), although as noted in Table 1, some more exotic woods are used. The body is traditionally made of ash, mahogany, alder, basswood or the classic mahogany body with a maple top. Birchwood was once used for cheap guitars but provides bad tone. Mahogany has a medium-hard to hard timbre and offers dense and warm tonality, combining great lows and mids. Ash offers great lows and highs while having slightly less mids. Alder produces a thick midrange with solid lows and enough high-end articulation to cut through. Basswood has a softer timbre and produces an even balanced frequency response. The combo of maple on mahogany gives a dense, well-defined midrange with balanced lows and high response. A standard Les Paul is consists of a mahogany body with a maple top and a rosewood fretboard on a mahogany neck. The tone of a traditional Telecaster comes from combining either a maple or rosewood fretboard with a maple neck and a body made of ash or alder (Hobbes).

Body shape style and size

As mentioned above, the first electric guitars were hollow body arch-tops with electro-magnetic pick-ups in the 1930s. A hollow body (also known as a semi-solid) is similar to an electric but weighs less than a solid-body guitar. A hollow-body has its own sound. It adds a bit of an unplugged tone. Some can cause feedback or muddiness. Modern examples range in construction from having a carved out body with a glued on top to a routing of a little wood from an otherwise solid-body (such as a Tele Thinline) (Hunter 36).

There are many types of bodies used in making electric guitars. Fender released the first solid-body electric guitar in 1950, the Broadcaster, which in 1951 was redesigned and became known as the Telecaster. In 1954, Fender released the Stratocaster, a more ergonomic body that has influenced many guitar designs ever since. In 1952, Gibson released the Les Paul in response to the Telecaster. They would later release the SG, a lighter weight instrument ("The Gibson SG: 50 Essential Facts").

The semi-acoustic is similar to an electric acoustic but with a slimmer body depth. They have a thin top plate and back plate with sides that are bent from thin strips of wood, and inside, range from having small reinforcing blocks to full-length or full-width solid sections, which change the tone, in particular, the overtones. Generally, a semi-acoustic adds resonance, imparting a degree of sweetness and mellowness while keeping the low end well defined. A few examples include the 1955 Gretsch Chet Atkins and the 1957 Gibson Byrdland. The added wood inside the body helps to reduce feedback (Hunter 34).

Nuts & Bolts of an Axe

Guitar Electronics

Potentiometers are three-poled resistors that adjust the volume of an electric guitar**.** Pick-ups are transducers that convert the energy of a vibrating string into a signal. There are two basic types of pick-ups. Piezo pick-ups, which use a crystal to amplify the signal of steel, nylon or gut strings, are used to amplify acoustic instruments. Electro-magnetic pick-ups are used on electric guitars and basses. There are many types and manufacturers, but they all rely on the same principle: the movement of metal strings creates fluctuations in the magnetic field produced by a permanent magnet or magnets. These fluctuations in the magnetic field are proportional to the string's vibrations, turning the string's energy into an electrical signal (Lemme).

The magnet (or magnetized bar magnets) is wrapped in a thin enameled copper wire through which an electric current travels. The string's vibrations undergo transduction in the magnetic field of the pick-ups, which is captured as an alternating current in the copper wire wrapped around the magnets. From here the signal can be sent out the 1/4" output of the guitar, amplified and put it through a speaker (Koch 29).

A guitar's output can vary. If a pick-up has stronger magnets, has more coil wrapped around the magnets, or has two adjacent magnets per string, such as on a humbucker, you can increase its output. Bringing the pick-ups closer to the string will also increase the output. The output range for most pick-ups lies within 100 mV to 1 VRMS. A high output pick-up makes it easier to overdrive an amplifier. The frequency response of most pick-ups is nonlinear. Their variation is what gives each pick-up make and type a different sound. There are not as many peaks and notches in the frequency response, however, as we find when comparing loudspeakers; most people will notice that a song they are familiar with sounds very different from one set of loudspeakers to the next. The same phenomenon occurs with different pick-ups; given all other variables kept constant, switching out pick-ups will change the tone of the guitar (Lemme).

Single coil pick-ups usually have a bright and clear tone. They generally consist of four to six magnets with seven to ten thousand windings of .06 mm copper wire around it. Interference is a common problem with single coil pick-ups. Main sockets, light bulbs and fluorescent lights can interfere with the signal and create a hum (Koch 29).

Humbuckers are unaffected by the interference. They use two identical coils wired out of phase with each other, each with a different pole of the magnet facing the strings. This makes the signal twice as strong and hence louder. It also produces a darker, lower sound, due to the two out of phase signals cancelling some of the higher frequencies (Koch 29).

The position of the pick-up affects the sound. Pick-ups closer to the neck sound darker while pick-ups closer to the bridge sound brighter. The front pick-up is fitted in an area where the strings vibrate more, and the bridge pick-up will catch the string where its vibrations are not as wide. Usually the rear pick-up’s output is higher to compensate for differences in volume levels. Luthier Steve Crisp, owner of The Guitar Shop in Santa Cruz, pointed out that very often a guitar from a big retailer will need adjusting on one or both pick-ups to get the volume balanced.

By adjusting the height of the pick-up**,** you can balance an instrument's sound. Strings that are close to the pick-up will give a hotter output, making the guitar louder and bassier. If the strings are too close, the magnetic pick-ups can interfere with the vibration of the strings, in particular wound strings. This will result in loss of clarity. So, the goal is to find the compromise between maximum output and minimum interference. Single-coils should not be fitted more than 3 mm – 5 mm (1/8" - 1/4") from the strings (Crisp). Since active pick-ups do not have a strong magnetic field, they can be closer to the strings. Humbuckers with magnets beneath the coils should be 1.5 mm – 3 mm (1/16" - 1/8") from the strings and should be parallel to the strings so that both coils are equidistance from the strings. The pick-ups should not be mounted any further away from the strings than necessary as it only reduces the signal in relation to other electrical noises (such as hum). Ideally, all strings should have the same loudness. To compensate for volume differences in the lower to higher strings, we can have the pick-up lower at the low strings. By adjusting the height tone can be changed; the closer the pick-up is to the string, the more low end it captures. Individual strings' volume can be raised or lowered with adjustable pole pieces. Multiple pick-ups should be balanced with one another. The bridge pick-up is typically not as hot as a pick-up at the front. To compensate for this, you can lower the front pick-up or raise the bridge pick-up (Koch 211).

Bridge

The bridge is the point of contact for the strings on the body. The bridge and tailpiece on a solid body guitar have a lot of influence on sound from the instrument. Ideally, a bridge system should allow one to make three types of adjustments: the string length, string height, and spacing between strings. Simple bridges consist of an angled chrome plate, which the strings pass through. The small rollers on which the strings rest can be adjusted to a position further back or forward by means of a screw tensioned by a spring. Two tiny allen screw adjust the height and spacing of the strings (Hunter 30).

There are also bridges that mount on two posts and have fixed, already compensated saddles. The better systems have a tailpiece that anchors the string and adjustable intonation at the saddle, such as Gibson's Tune-o-matic. The stop-tailpiece and Tune-o-matic combination offer solid tone and precise intonation adjustment. Additionally, you can raise or lower the string height with a Tune-o-matic (Koch 24).

A vibrato bridge**,** also known as a tremolo, is a mechanical device that allows the stretching or loosening of the strings by use of pressing an arm, which raises or lowers the pitch of a tone.[1] The most common kind is the Strat-style tremolo, essentially a bridge which can be tilted and has three or more steel springs mounted inside of a cavity on the backside of the body to hold it in place (Koch 25). Pulling or pressing on the arm of the tremolo results in the bridge being tilted on its pivot. Upon releasing the arm, the springs pull the bridge back to its resting position. A major problem with these is that they have to reliably go back to the correct position to keep in tune, which led to the development of many types. The bigger problem is that it loosens the strings, unwinding them from the tuning shafts, which is why some tremolo systems are clamped down at the nut and at the tremolo unit after tuning. Fine-tuning screws on the

[1] There is much debate on what is actually the correct term; tremolo actually means a fluctuation in volume, whereas vibrato is the term for a pitch fluctuating.

tremolo system allows fine-tuning of pitch to compensate for the clamping (Burrluck 79). This system was invented by Floyd Rose and has been widely mimicked by other companies (Burrluck 87). Another option is to use locking tuners in conjunction with a synthetic, slippery material for the nut, which reduces friction. There are a few tremolo styles, such as the Bigsby tremolo, that do not require a body cavity, but rather rest on the top of the guitar and work with a rocking bridge. The arm of the device is spring loaded and attached to a bar to which the strings are installed, which, when depressed, lowers the pitch of the string (Koch 27).

Nut

The nut is the resting spot on the neck for the strings. It dictates the spacing of the strings and their height above the fret. The nut keeps the strings in their relative position and away from the fretboard. Each type of nut has its own sound. Plastic nuts are used on inexpensive instruments. Bone is a good material to use. It is a very hard material with a vintage look. Care must be taken to cut the slots cleanly so that the strings will not bind. It has a detailed sound that is bright and clear. Graphite is an excellent material. Graph Tech TUSQ is precision engineered under high pressure and heat. It is specifically designed to deliver an optimum sonic transfer rate. It is very rich and evenly balanced in tone and harmonic content. It is slightly brighter in sound than Graph Tech TUSQ XL, which has Teflon included in the materials. Teflon is five times as slippery as graphite, making it great for electric guitars using tremolo or with tuning stability issues. It, too, has a well-balanced tone, but it possesses a bit more warmth than standard TUSQ. The LSR roller nut has ball bearings that the strings rest upon to minimize friction. Used with locking tuning heads, tuning issues can be significantly reduced. To install one of these, a cut must be made at the nut slot towards the first fret to 7/32". Brass is a hard material that polishes well. It has great sustain for bass guitars and slide guitar playing. Brass produces a very bright tone. The nickel used at Warmoth is of the same composition as their fretwire (18% hard nickel/silver). It is very bright with great articulation and sustain. Corian is a very hard synthetic material. It has a balanced and clear sound ("Warmoth Custom Guitar & Bass Parts").

Tuners

Tuners consist of a shaft, a knob and a worm gear. Tuners have a gear ratio, which indicates how many turns the knob must make to make the shaft turn one full rotation. The most common gear ratios are between 1:12 and 1:20. The higher the ratio, the finer you can tune the instrument. Their quality is crucial in maintaining stable tuning. Enclosed-gear tuners are often preferred to open ones because they can keep out dust and grime, but on bass guitars, which are a lot bigger, they are usually open. Some have a screw on the knob that allows you to adjust the tension. Tightening this screw makes the tuner feel firmer (Koch 20).

Locking tuners lock the string onto the string post by clamping it into its hole or slot. This is usually achieved with tension-adjusted internal pegs. They eliminate winding the string around a shaft, thus reducing slippage problems and increasing tuning stability (Burrluck 67).

Frets

The length of the neck is divided up into frets. Each adjacent fret is at the specific spot where the next chromatic note lies on the string (assuming it is tuned). Fretwire separates each adjacent fret. When a string is pressed down, or fretted, the fretwire is what the string rests on. There are several sizes of fretwire. Warmoth's standard silver-nickel fretwire is made of nickel and brass; it contains no silver at all. Stainless steel fretwire is smoother and harder than nickel-silver fretwire. Gold color fretwire, made of a copper alloy, is almost as hard as the stainless steel and is smooth when polished for fast playing and a freer string bending. If a player is tough on their frets, they may want to consider stainless steel. Warmoth has not found a significant difference in tonality between stainless steel and nickel/silver fretwire. Fret size plays into a guitar's action. Having lower frets means the player’s fingers are close to the fingerboard, so there is little room to squeeze the strings out of tune or to bend them. Conversely, taller frets allow for more bending but are more prone to being squeezed out of tune. Wider frets wear more slowly and narrower frets wear more quickly ("Warmoth Custom Guitar & Bass Parts").

Neck types

Bolted-on necks were designed to make repairs or replacements easier. They have their own characteristic tonality. They are bright and edgy with a cutting tone. They have a woody resonance, decent sustain and good tuning stability. A set neck is glued in, giving the instrument more sustain and changing the tonal qualities, giving more sonic depth and a darkness to the overall sound. Paired with hum-buckers, a set neck lends a round, warm tonality. They are much harder and costlier to repair or replace then a bolt-on neck. Though it had been around much longer, in the late 70's, the "through-neck" hit the market.[2] As the name implies, the neck goes all the way through the body and is essentially the core of the guitar’s body. They are believed to have better tuning stability and better sustain. They are much more difficult to repair

[2] Rickenbacker was building through-necks in 1956.

or replace than a set-neck as a replacement requires extracting the neck from the core of the guitar, taking more time, effort and, as a result, cash for the repair (Hunter 32).

Radius is the angle of the curve on the fretboard. The smaller the number, the more curve there is on the neck, making it easier for the fretting hand. A larger radius is flatter and allows for more string bending. Vintage Fenders once used 7.25"; they now use 9.5", leaning towards a flatter fretboard. Most Gibsons use 10" to 11". Jackson necks use a 16" radius. Warmoth uses a compound radius, which stars with a 10" radius at the first fret and gradually increases to 16" at the heel of the neck (Ratcliffe).

Truss rods

A truss rod reinforces a guitar's neck. There are several different types but they fall into two categories: adjustable truss rods and non-adjustable truss rods. They are used to counteract against the forces of weather, humidity and the tension of the strings. As the wood of a neck seasons, it wants to change its shape. At the same time, the strings constantly pull the neck, which, over time, can create a "hollow," a low spot in the fretboard, making it harder to play. By tightening the nut on an adjustable truss rod, the rod can be straightened to raise the fretboard of the neck, making the instrument easier to play because it is physically closer to the strings so that they do not have to be pressed down as far. Over tightening can cause a "bow," which is a high spot in the center of the fretboard. Bowing can also occur from using a lighter gauge of string than the instrument was designed for due to less tension from the lighter strings. Additionally, bowing can occur from expansion of the fretboard wood. This usually happens due to moisture. As the fretboard expands lengthwise, it forces the neck into an arc. A light bow leaves more room for the vibration of the strings but any more than that is not wanted. The suggested amount of relief on a guitar is .25-.3 mm (.01"-.013") at the 6th fret and about .5 mm (.02") for bass guitars (Markarsky).

Truss rods also add to the mass of the neck, giving it more tone and greater sustain. Additionally, truss rods should always be sleeved so as not to rattle (Burrluck 70). Non-adjustable truss rods serve to make a neck stiffer and are often made of an ebony or carbon fiber rod. This rod is anchored at a plate on either end.

Compression rods are the most common type of truss rod used in electric guitars. A 5 mm diameter steel rod is embedded into a curved channel in the neck. At one end, the rod is anchored down, and at the other end it is threaded. The rod is covered by a curved, wooden filler, giving the truss rod no room to move. Tightening the nut will straighten the truss rod and with it the neck (Koch 81).

Strings

Strings on a shorter scale guitar physically vibrate less and as a result, the sound produced by the guitar is actually lower in volume. Also the strings can rest closer to the fretboard, which allows lower action. With a longer scale length, the strings vibrate more and the instrument is louder, but the strings cannot sit as close to the fretboard as on a short scaled guitar (Koch 66).

When using electro-magnetic pick-ups, the guitar or bass must use strings made of a magnetic material (Koch 29). The thicker the string (wider the gauge), the more mass it has, making more impact on the magnetic field of the pick-ups and consequently the louder it sounds. In order to keep the same relative volume for the different gauge strings in a set (i.e. .12 - .56 or

.10 - .54) we use steel wire for the small strings and a steel wire core covered in nickel wire for the lower strings (Koch 28).

Gauge is the thickness of a string's thickness and is measured in thousandths of an inch, or millimeters. Mass is a measurement of a strings size and weight as a whole. The industry name for plain steel strings is "mandolin wire," and the lightest commercially available strings begin .008" and range up to .024". Wound strings start at .016" and range up to .060". It should be noted that pianos use the same type of wire but of a heavier gauge. This heavier gauge string is called piano wire (Leonard 52).

Maintenance

Many luthiers recommend that instruments receive a tune-up once or twice a year for intonation and neck adjustments, which also usually includes any bridge, saddle and nut adjustments. Every once in a while, a well loved instrument will also need a fret level, which is a re-leveling of the frets as they will wear down with time. Uneven fret wear can cause buzzes at the point of string-fret contact when fretting lower than that spot. Sometimes the only way around it is an entire re-fret which is only worthwhile on loved and/or expensive instruments.

Tools of the Trade

Tools of the trade range from hand planes and saws in a hobbyist's garage to table saws and planers in a luthier's shop. A cordless power drill is needed at the least. Due to the added stability, a drill press can be even better if there is room for it. Additionally, the right bit set is needed. A Forstner bit is for drilling large diameter holes. It can also be used to remove wood prior to routing. It creates a hole with a flat bottom and a small point in the middle from the drill bit. A Brad point bit is also used on wood. Like the Forstner bit, the brad point produces a hole with a flat bottom, but it makes a smaller hole. A twist drill bit can be used for wood and metal and produces a cone shaped hole (Koch 94).

A plunge router is very versatile. Routers are used to produce a cavity in a guitar's body. The collet holds the router bit in place by 'gripping' the shank of the bit. Most manufacturers offer collets of different sizes. The different size collets hold bits with different shank lengths. Having 12 mm (1/2"), 8 mm (3/8") and 6 mm (1/4") collets allows the use of almost any router bit. Shank adaptors (also known as reducing collets or bushing adaptors) allow one to use a 1/2" collet with bits that have smaller shanks by using a 1/2" to 1/4" or 1/2" to 3/8" shank adaptor, but can cause increased cutter vibration (Koch 94). The depth of a cut that a plunge router can make depends on its maximum plunge depth and the lengths of the cutter and cutter shank. The three types of router bits are HHS (High Speed Steel), TCT (Tungsten Carbide Tipped) and solid carbide. HHS wears quickly when used on hardwoods and is therefore recommended for soft wood only. TCT has carbide blades, making them cut cleaner and last longer (Koch 96).

Planes are used to shape and smooth the surface of wood. Planes can be made of wood or steel and must allow for fine adjustment of the blade projection by using adjustment screws. They need a flat bottom and should be solid. The three types used for building electric guitars are the spokeshave, the block plane and a normal plane. A spokeshave is used for shaping the neck. It consists of two handles, one on either side of the narrow blade. A spokeshave with a curved base is used to smooth the sides of the body. On a block plane, the angle between the wood surface and the blade is less than 15 degrees, making them suitable for end grain surfaces and most fine-planing jobs (Koch 98).

Scrapers are a sharp-edged blade for smoothing surfaces. They are much faster than sandpaper. A sanding tool can be used afterwards, but there needs to be a way to deal with the dust. Some type of sawing tool will be needed as well. A jigsaw or a band saw will do the trick for cutting out a guitar body from a blank. The jigsaw will require relief cuts to be made. The thinner the saw blade, the finer the radius that can be sawed. Relief cuts will help if the blade is too thick.

Intonation

The guitar is designed for equal temperament, and the strings must be tuned to the tempered intervals rather than the pure ones. It would require about three dozen frets per octave to achieve pure chords in all forms. In order to play in tune, a guitar's fret spacing must be correct. The stretching of a guitar string, which happens when we fret a note, increases the total length and tension of the string, which causes the note to play sharp. Each string is different in regards to the sharpening tendency when fretted ("Earvana Compensated Tuning for Guitars"). Three rules come into play here:

1. The Pitch Rule - Sharpening from fretting is inversely proportional to pitch.
2. The Tension Rule - Pitch is directly proportional to tension.
3. The String Mass Rule - String tension is proportional to string mass.

The pitch rule tells us that a guitar has a tendency to go sharp as the pitch of an open string goes down. However, because of the tension and string mass rules, the G and D strings react differently. You would expect the D string, being lower in pitch, to go sharper than the G string as the pitch sustains. The metal winding on the D string adds mass and therefore has more tension than the G string and will sharpen less ("Earvana Compensated Tuning for Guitars").

Locking nuts secure the string within the nut. There are several licensed locking nuts on the market, all using the same design principal but offering different dimensions and radii. They are often used in conjunction with a locking bridge ("Warmoth Custom Guitar & Bass Parts"). The Earvana nut is designed to compensate the notes on a guitar which go flat or sharp as a result pitch, tension and string mass rules. By moving the string break off point forward (towards the first fret), we shorten the length to the fret and reduce the sharpness caused by the string stretching ("Earvana Compensated Tuning for Guitars").

To intonate a guitar (without a locking nut) tune the strings to pitch and sound the harmonic at the 12th fret of the first string. Then play the note on the 12th fret of the same string to compare pitches. If the fretted note is sharper than the harmonic, the string length needs to be increased. This can be done by moving the saddle away from the neck. If the fretted note is flatter than the harmonic, the string length needs to be decreased, which is achieved by moving the saddle forward, or towards the neck.

Scale length

Scale length is the distance between the two points at which the string rests: the inside edges of the nut and the saddle. The scale length of a Les Paul is 24.75" and the scale length of a Stratocaster which is 25.5". The shorter scale length produces a softer sound because the strings are not as highly tensioned. The shorter scale length also means the frets will be shorter, which makes it easier for someone with small hands to play. It also gives a slightly more brilliant sound. When the neck is shorter, there is slightly less strain on it. The action can be set lower, or closer, to the fretboard since there is less tension on the strings (Koch 66).

Longer scale lengths mean longer distances between the frets, which is better for bigger hands. It emphasizes the lower frequencies more than a short-length scale. It leads to a longer neck, which puts more tension on the neck. It has more tension in the strings. Since the strings vibrate more, the instrument is louder, but the action cannot be set as low as that of a short-scale guitar (Koch 67).

The NOVAX fingerboard is a fanned fret, multiple scale system that tries to reconcile the advantages of both the short- and long-scale lengths. It uses concurring frets along with a nut and bridge that are not parallel to each other. So, the guitar can have a 25.5" scale length on the lower three strings and a 24.75" on the higher strings (Koch 67).

Significant Visionaries/Companies

Two of the biggest and most influential guitar companies are Fender and Gibson, both of which had important visionaries. Leo Fender designed the Telecaster and Stratocaster for Fender. He is also responsible for the Fender empire, having started it from little more than a radio repair shop he was running in the early 1950's. Les Paul worked closely with Gibson and was very involved in the design of the guitar named after him, the Les Paul, which was released very shortly after Fender released the Telecaster. The result is two different guitar companies with entirely different philosophies and preferences on guitar building and tone in general.

Some of the biggest differences in the two companies include scale length, neck angle and wood selection. Fender uses a 25.5" for most guitar models and a 25" for their Jaguar while Gibson uses a 24.75" scale length (Hobbes). Further, Gibson uses an angled neck in which the neck has a slight angle towards the player while Fender has a straight neck. Additionally, the neck on a Gibson is a set-neck while a Fender neck is a bolt-on. The woods they use are very different, too. Although they both use rosewood on some of their fretboards, Fender uses a lot more maple and Gibson uses more ebony and rosewood. The bodies of many Fender guitars are often ash or alder while Gibson uses a lot of mahogany with a maple top. The Stratocaster and Telecaster boast single coil pick-ups while the Les Paul is stocked with humbuckers. The Fender neck is very often made of maple, and the Gibson neck is generally mahogany. These basic differences result in two entirely different sounding and feeling guitars and have been the jumping-off point for many other guitar designs since the two dominant companies emerged. The Fender guitars have a lot of high end from the combo of a maple neck with single coil pick-ups and get their 'twang' from the bolt-on neck. The Les Paul gets a lot more midrange and low end out of the mahogany body while the maple top brings some highs. Also, armed with humbuckers, some of the higher frequencies are cancelled out. Finally, the scale length between the two also leads to lower tones produced by the strings on Fender's scale length, and brighter tones produced by Gibson's scale length. With all the options available now, a guitar’s tone, feel and capability can be tailored anywhere in between these classic models (Hobbes).

Conclusion

Pushed by innovation and need for volume, the electric guitar has a unique history which led to its development. While there are a few top companies, there are certainly many different manufactures, not only of guitars, but also of individual components. The raw materials and specialized components used to build a guitar are what give each guitar its unique voice. The possibilities lead to an endless amount of different guitars. Switching out pick-ups yields a different sound. Selecting the right neck gives the right feel and tone. Changing the wood for the body changes the sound and weight of the guitar. Adding a tremolo, changing string gauge or scale lengths all change what a guitar’s tone and capabilities are. Combined, these variables give a guitar its character. No matter what kind of guitar is at hand, they all must be taken care of and maintained. Making sure that the intonation is good, the neck is straight, the electronics and strings are clean and that the bridge, tuners and nut securely have the strings in place are essential steps to finding a guitar’s voice.

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