

MARTIN KOCH

Building Electric Guitars



**How to make
solid-body, hollow-body
and semi-acoustic
electric guitars and bass guitars**

eBook Edition

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Translated from German by Franz Luttenberger
Published by Martin Koch, Gleisdorf, Austria

Martin Koch

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Send me your suggestions, ideas, requests or complaints. Any letter or e-mail will be very much appreciated.

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Before we begin: thank you for reading this book. I did my best to make it a really helpful one. But I would also strongly recommend that you read other books as well. Every author chooses a different approach or a different style, and one has to keep trying to learn from more than just one source to constantly widen one's horizon. You won't become poor from buying every book available on the building of electric guitars, for the simple reason that there are not that many books around. You may well find a number of books on how to build acoustic guitars, but when it comes to building electrics, you can count the number of publications worldwide on one hand! There might be one or two more, but the only ones I got to know so far are *Melvyn Hiscock's "Make Your Own Electric Guitar"* and *Roger Simminoff's "Constructing A Solidbody Guitar"*. So please do read and enjoy those books as well (as I hope you will mine).

Doing it yourself can be looked at in two different ways, one of them being mocked by my Austrian fellow-countryman, the actor/comedian *Lukas Resetarits*, who has one of his characters, who likes "doing it yourself", say the following:

"So I bought myself this power drill for 3000 shillings, thinking one can always do with one of these. Mind you, since I bought it, I've only drilled ten holes with it - that's 300 bucks a hole!"

Looking at things from such a purely economical perspective may in many cases be appropriate and the right thing to do. If, however, by "doing it yourself" you are hoping to save money, you had better forget about it: in times like these, where guitars are built in low-wage countries, it is easy to get hold of an electric guitar of sufficient quality for relatively little money in every music-shop - without taking any risks or investing a lot of time. Remember also that the first guitar you build will never be a world-class instrument. Even the most professional guitarbuilder will, at some point, have had to start with the basics and will have gradually built up his/her competence. As a proverb puts it so appropriately: "No master has as yet fallen from the sky."

Some things cannot be paid for with money, and if you regard your spare-time activities as hobbies and a welcome break from your everyday job, the economical perspective loses its importance. How could anyone put a figure on the satisfaction that a positive learning experience or the joy of having successfully produced something can bring? I am not interested in the economical side of things; to me, building guitars is a meaningful spare-time activity and all about gaining experience - which can probably be said of any other hobby, too. It is all about trying to consume less and creating something of your own. If you feel like building an electric guitar, you should just do it.

This book is aimed at people who enjoy working with wood in their spare time, who are interested in building instruments and either play the guitar themselves or would like to surprise a son, a daughter or a grandchild or someone else. For all of these groups of people the question of finding a suitable workplace will in most cases not arise and will already have been solved. I mention this because I consider the availability of a workshop where you can do whatever you like as one of the prerequisites for the successful completion of a project such as this. In this respect, someone living in the countryside will, of course, be one up on someone who lives in an urban area and who may already count themselves lucky to be allowed to use a basement room. As for tools, huge investments should not be required. If the wood needed has been adequately prepared in a joiner's workshop, no other tools apart from what I would call "hobby tools" will be needed. If, however, your guitar is to seriously compete with professional instruments, good tools will be indispensable.

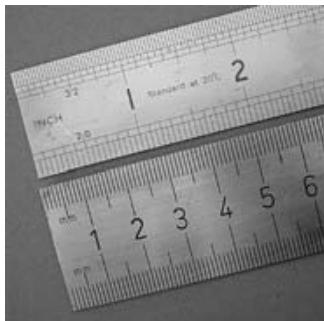
Reading alone won't be enough. Trying to describe the individual steps of work involved in detail, I have followed the motto "A picture is worth a 1000 words" by including pictures, illustrations and drawings to better illustrate the verbal descriptions. You will, however, always need to bear in mind that there is of course a huge difference between reading something and actively doing it. Just as you are not going to satisfy your hunger by merely listening to a description of food, you will have to gather your own experiences in the world of guitarbuilding. The ability to put an idea which exists in someone's head into practice is what makes a great craftsman - this also applies when it comes to building guitars. On the long road between the initial idea and the actual result, a lot of compromises will have to be made at the beginning, due to not-yet-learnt skills, lack of both experience and patience or peculiarities of materials used. Although you will find that there are many pictures in this book, please do none the less read the instructions carefully: not each and every individual step of work has been captured in picture!

Only those who do nothing will not make any mistakes. While building a guitar there will be moments of great joy as well as of huge frustration. If the latter is the case, sleep on it: something one presumes to have gone terribly wrong quite often doesn't look all that bad after a good night's sleep or after a couple of days. What you will certainly find then is enough energy to start all over again, in case things should have gone so badly wrong that there is no other alternative. Never try to achieve anything by force. Remember that sometimes it may be better to pause and not do any work, or to stop working rather too soon than too late. Mistakes made should not be regarded as setbacks but rather as opportunities to gain experience and, above all, to

Guitarbuilding on the WWW

On the World Wide Web most of the established guitarbuilders as well as quite a few individuals who build guitars are represented with more or less informative pages. Talking about "guitarbuilding individuals" on the *WWW*, I would like to invite you to come and visit my guitar-building pages on the *World Wide Web* at www.BuildYourGuitar.com

I shall be trying to update my web site regularly - but what can you expect to find there? Well, first of all obviously guitarbuilding-related links; apart from that, my webpages give me the opportunity to occasionally share a few things I have recently learnt with those who visit the pages. They are also to be a source of useful addresses such as of suppliers of materials you may need. Apart from that you can find pages with useful guitarbuilding tips, a quiz and a fret calculator. Finally, you can order my guitar-building instruction materials there.



Units of measurement

Measurements in inches may not be something you are familiar with unless you live in an English-speaking country such as the USA; as a guitarbuilder, however, you should be. Despite the fact that electric guitars are now built all around the world, it is well worth remembering that they had their origins in the U.S., and therefore a working knowledge of the measurement system most commonly used in the U.S. is a must. The metric system, although not being totally unheard of, is much less commonly used in the U.S. In Great Britain and Australia both systems of measurement are in use on a more or less equal basis.

Metric: $\frac{1}{1000}$ meter is 1 millimeter, abbreviated as 1mm. The numbers on the bottom rule shown above indicate the centimeters (10mm is 1 centimeter, abbreviated as 1cm).

Imperial: 1" is short for 1 inch and is exactly 25.4mm (or 2.54cm).

To make matters even worse, inches often appear in fractions, such as one fourth, one eighth, one sixteenth, one thirty-second, or one sixty-fourth. Measurements such as $\frac{29}{32}$ " look rather strange to the "metric eye". Almost all measurements in this book are given both in millimeters and in inches (usually in brackets). Where the exact value is not so important, I have simply given an approximate, rounded figure.

learn. Only those who do nothing will not make any mistakes. All steps of work which you have never tried your hand at before should always be practiced on a piece of scrap material first.

There are many different methods of designing and building an instrument. In this book, I am going to describe my personal approach and experiences. If work is carried out with great care and precision, everybody will in the end have a good-quality and nice-looking instrument to call their own. I would even go so far as to claim that a home-made electric guitar can well compete with expensive, industrially-manufactured makes; after all you can afford to select the best wood available and to buy high-quality hardware as well as to tailor the instrument to fit your personal requirements. And, what's more, you can afford to invest a lot of time. I should also like to mention the special relationship with "your" guitar that you are going to enjoy, a feeling which you will hardly ever experience with a bought instrument. Maybe, at a later stage, you will develop a desire to build an acoustic guitar. I consider the building of an electric guitar - which is not as difficult as building an acoustic one - as a first step in that direction.

In this manual you are not going to be presented with finished recipes for building different models of guitars. What you will, however, get is a number of suggestions and ideas for designing and building an electric guitar. Wherever possible, I have tried to suggest several different approaches. It will be up to you to choose the one that suits you and your personal circumstances best.

How I started. I am myself not a trained joiner or instrument-builder. I do, however, enjoy working with wood. One day I felt a desire to build my own electric guitar. At that time I was a regular reader of the German music magazine *Fachblatt*. In some of the editions of that magazine I found interviews with British bass builders, and what they had to say about wood and all the rest of it captured my imagination. So the first instrument I built had to be a bass: a fretless and headless bass with a long and very thick and straight-through-the-body neck without truss rod.

Building on the experience of this "project" I gradually extended my knowledge of things by reading books and continuing to learn from experience. If you are a beginner, I can only recommend that you design and build a very simple and basic guitar to start with. Later, once you have gained some experience, you can always increase the degree of difficulty with any further project.

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Preparation



General introduction

This book describes the building of solid-body, hollow-body and semi-acoustic electric guitars. The term “electric guitar” also includes the electric bass, which, despite its slightly longer neck, is pretty similar to build. I use the term hollow-body guitar for a solid-body guitar with hollowed-out body and glued-on top.

The term semi-acoustic guitar is used specifically for guitars like the one shown on page 90. The body consists of a thin top and back plate and the sides are bent from thin strips of wood. A solid block of wood runs down the center of the body. Building a semi-acoustic guitar has more in common with building an acoustic guitar than building an electric.

Parts of an electric guitar

An electric guitar has steel strings which produce vibrations that are then, via a magnetic pick-up, transformed into an electric current (thus the letter “E” which is sometimes used short for “electric” in front of the word guitar). An electric guitar needs an amplifier and a speaker to produce a sufficient level of sound to be audible.

The conventional electric guitar consists, roughly speaking, of three parts: (a) the peghead, where the tuners are fastened, (b) the neck, where the strings are played, and (c) the body, where the strings are fastened and the electronic parts are fitted.

The nut is the contact-point between the strings and the neck; it is situated next to the peghead and represents the zero-fret on the guitar. There are also guitars which have got an actual zero-fret and where the nut merely serves the purpose of holding and guiding the strings. At another point of the guitar, the strings make contact with the body at the saddles of the bridge. The ends of the strings with the smaller balls are fitted from the back through holes in the body or anchored at a special string-holding device (tailpiece) or at the bridge. The other ends of the strings are wound around the tuner shafts and the strings are tuned by turning the tuners.

The higher a string is fretted, the shorter its wavelength becomes. Each fret increases the pitch of a string by a semitone.

The vibrating length of each string is the distance between the nut and the saddle and is also called scale length.

The pickups are fastened to the body just under the strings. The control cavity is a recess in the body covered by a plate or the pickguard and contains controls, switches, condensators, etc. The pickguard is most commonly made of plastic. It protects the body surface against damage that can be caused by playing the guitar. At the output jack the cord linking guitar and amplifier is plugged in.

String frequencies

Guitar

An electric guitar has six strings which, just like an acoustic guitar, are tuned to the following tones (starting with the bottom string):

e, B, G, D, A, E

Here are the frequencies of the open strings:

E: 82.41 Hz
A: 110.00 Hz
D: 146.82 Hz
G: 196.00 Hz
B: 246.94 Hz
e: 329.63 Hz

Hz is short for Hertz, the unit of frequency which tells the number of vibrations per second. It is named after the German physicist *Heinrich Rudolf Hertz* (1857-1894).

The frequency of a tuning fork is that of standard concert pitch (A), i.e. 440 Hz.

12-string Guitar

A 12-string guitar has two strings per tone placed close to each other. The frequencies of the twelve strings are as follows:

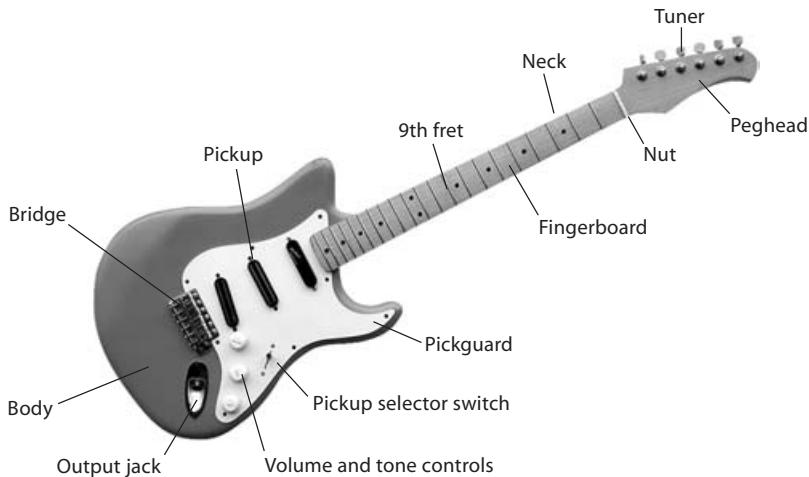
E: 82.41 Hz
e: 164.82 Hz
A: 110.00 Hz
a: 220.00 Hz
D: 146.82 Hz
d: 293.64 Hz
G, g: 196.00 Hz
B, b: 246.94 Hz
E, e: 329.63 Hz

Bass guitar

An electric bass guitar normally has four strings which are tuned to the same tones as - but one octave lower than - the four bottom strings of a guitar, i.e. to E, A, D and G. This means that the strings of a bass guitar are tuned to the following frequencies:

E: 41.20 Hz
A: 55.00 Hz
D: 73.41 Hz
G: 98.00 Hz

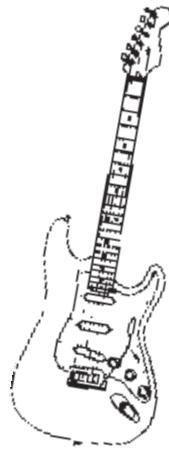
A four-string bass is more than sufficient for accompanying purposes. For solo-playing, however, the availability of a wider range of tones might be desirable. This is why there are such things as five-string and six-string basses. Normally, a five-string bass has an additional lower B-string (30.9 Hz) or an additional treble C-string (130.8 Hz). A six-string bass has both these strings.





Fender Telecaster

The *Telecaster*, or *Tele* for short, was the first industrially-manufactured and commercially successful electric guitar; it was built by the American company *Fender*. The shape of this nice-looking, simply-constructed and purpose-built guitar has hardly changed at all since the 1950ies, and it is still as popular as ever.



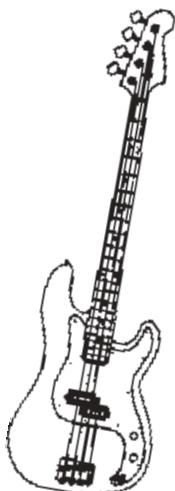
Fender Stratocaster

The *Stratocaster*, or *Strat* for short, was *Fender's* second big success; tremolo, three pickups and an ergonomically-shaped body turned it into "the" electric guitar.



Gibson Les Paul

The *Les Paul* is a classic *Gibson* model named after its endorser. It was designed by *Ted McCarthey*. Its body and neck are made of mahogany, and because the neck is glued to the body, it is difficult to remove. The body usually has a maple top.



Fender Precision Bass and Jazz Bass

The most commonly-used *Fender* bass models are the *Precision Bass* and the *Jazz Bass*. The *Precision Bass* was the first bass with frets, which, as the name implies, made it possible to play the instrument with much more "precision".

Guitar classics

Attempts to increase the sound-volume of acoustic instruments by mechanical means were made quite early this century; later pickups and amplifiers were used to achieve the same effect. Since such attempts were numerous, nobody can seriously lay claim to having invented the electric guitar. What is certain, however, is the fact that the idea was developed in the 1930ies and '40ies and that the first electromagnetic pickup was fitted on a *Rickenbacker* guitar that looked more like a frying pan with handle than a guitar as we know it today. But one name will forever be associated with electric guitars: *Leo Fender*. *Fender* guitars mostly have a body made of either maple, ash, alder or basswood and a bolt-on neck made of maple.

The names of these guitars are mere product names and of no further significance, just as in the world of cars, where manufacturers give different names to different models. Most of these names given to guitars have become household names and are nowadays widely used in everyday language. But be aware that almost all guitar names are registered trademarks owned by the respective manufacturers.

There are countless variations of these types of guitar, the shape of the peghead often being the main distinguishing feature. On the whole, the majority of all types of guitar - including the modern ones - can be classified under one of their above-mentioned predecessors.

There are also guitars without peghead. These guitars often have carbon-fiber necks, which have the advantage of offering greater stability than wooden necks. Such headless guitars need special strings with two ball-ends that are fastened at the tuners at the end of the body. A "normal" electric guitar, however, is made entirely of wood, and the special magic and sound qualities of this material will no doubt ensure the continued popularity and survival of guitars made of this product of nature.

Trees

Many things in our everyday life are perceived only in their finished or prefabricated form, and knowledge about the original state of things tends to get lost more and more.

Take shopping: we buy milk in pasteurised form and packed in cartons, or meat, all ready for taking away and immediate consumption. And when looking at a board of wood, do we actually think of its origin, the living tree? How about a little walk in one of the many forests that still exist to take a look at the origin of all wood, the living trees?

Trees consist of an aboveground part called trunk, which splits up into smaller branches, and of the roots, which are hidden underground. The underground extension of a tree's roots is normally about the same as that of its crown of leaves. Around the trunk's core, the pith, a layer of wood is added each year. On the outside of the trunk the bark shields the bast and the cambium, two very thin tissues, from many kinds of possible harm. Each year between spring and autumn a new layer of wood is formed and the trunk becomes stouter. Growth is strongest in spring and early summer and slackens in autumn; in the winter months the tree rests and growth comes to a standstill. This rhythm of growth is reflected in the trunk's typical cross-section appearance: broad layers of wood that have grown fast and are light in color alternate with narrow, darker layers, reflecting the time of year when they were formed.

By counting the number of these so-called annual rings, or growth rings, the age of a felled tree can be determined very easily. Because trees grow faster in their youth, the rings formed near the center of a trunk are broader than those farther out. The slower and steadier the process of growth has been, the more solid and fine-grained the wood will be. Tropical timbers are the exception to this rule: due to

Wood

Wood for solid-body guitars

Electric guitars are normally built with wood from deciduous trees, so-called hardwoods. However, of all the different types of hardwood only very few are actually used for guitarbuilding purposes.

For making the body these are traditionally maple, ash, mahogany, alder, basswood and nut. This limitation to such a small number may at first sight seem surprising, but bearing in mind the large quantities of wood that big guitar-manufacturing companies need, it is understandable that using the wood of less common trees cannot be a serious option.

A much greater number of different types of wood, including such exotic ones as bubinga or wenge, are used for building electric basses.

The above-mentioned hardwoods have become the standard ones used because experience has shown that they are the ones most likely to produce the sound which we have come to expect from an electric guitar. Birchwood, for instance, was also once used for making cheap guitars, but was found to produce a rather poor sound. Maple and mahogany have a lot in common, both being medium-hard to hard timbers. Basswood, on the other hand, is relatively soft. While the typical *Les Paul* sound is created by a mahogany and maple body and a mahogany neck, the typical *Stratocaster* sound is the result of a maple neck and a body made of either maple, ash or alder. Different scale lengths and, of course, pickups can further add to differences in sound. Due to its shorter scale length of 24.75" (as opposed to a *Stratocaster*'s 25") a *Les Paul*, for instance, will sound softer than a *Stratocaster* because its strings are not as highly tensioned.

The wood of conifers such as spruce is not ideal for building electric guitars for reasons of sound and insufficient solidity. Equally, plywood or similar man-made types of board cannot be recommended, either, because of their cross-grain structure (the grain of each ply of wood runs at right angles to the next one) by which the transmission of vibrations is weakened, resulting in a poor sound.

One of the many factors determining the tone color of an electric guitar is the type of wood used for building it. Hardwood and softwood, for instance, are totally different in their resonance characteristics. But even different types of hardwood can, owing to the specific structure of each wood, be different in sound. These structural differences are what experts look at when identifying and analysing wood. Each type of wood brings

out certain frequencies more strongly. Via the bridge the hardness of the wood is passed on and reflected in the strings' vibrations: a guitar made of softwood will sound slightly "darker", one made of hardwood slightly "brighter". If you wanted to go to extremes, you could, for instance, make a guitar with a rubber body which would then sound extremely muffled and lifeless. If, on the other hand, you were to make the body from metal or stone, the guitar would produce a very bright, yet artificial and cold sound. A reasonable "compromise" between hardwood and softwood will most probably produce the most satisfactory results. Weight is another aspect to consider when deciding which wood to use: some types of wood are heavier than others, and it is common practice to substitute heavier types of wood with lighter varieties of the same species: much lighter swamp ash is, for instance, commonly used in place of ordinary ash.

For reasons of stability it is best to use wood cut from the middle of a log which is as near as possible quartersawn - this reduces the risk of the guitar neck or body warping. If, however, the body surface is to have a more attractive-looking grain pattern than just parallel lines, you need well-seasoned, rather flatsawn timber. Alternatively, you could also glue on a thin piece of nice-looking veneer.

Most necks of electric guitars are made of either maple or mahogany. Slowly-grown hard rock maple is ideal for this purpose. The closer-ringed the wood is, the harder it is. A hard, stiff neck will favour a quick attack while a softer neck will make the guitar sound warmer. For making the neck, wood of the highest quality available should be used; ideally, it should be straight-grained and without knots or defects. Maple necks are usually made from flatsawn and mahogany necks from quarter-sawn wood. Rosewood and other exotic timbers are also, but less commonly, used for making necks of electric guitars.

the lack of extreme seasonal variations in temperature they do not show such clearly visible annual rings.

The tree's roots draw water and nutrients from the soil. These are then carried upwards in the outer layers of the trunk and the branches to the leaves, from the surface of which the water evaporates. The leaves of a tree breathe through tiny pores, constantly absorbing carbon dioxide from the air and breaking it up into oxygen and carbon with the help of sunlight. Man benefits from this oxygen, which is released into the air, while inside the tree, the carbon is carried downwards to contribute to the expansion in girth of the tree. The sap flowing upwards is primarily needed for forming the crown of leaves. All of these processes are, of course, far more complex than I can describe here, but if I mention them in this place, or be it very briefly, it is to draw attention to the enormous importance trees have for all of us. Living forests are a gigantic climate machine, producing oxygen and cleaning the air.

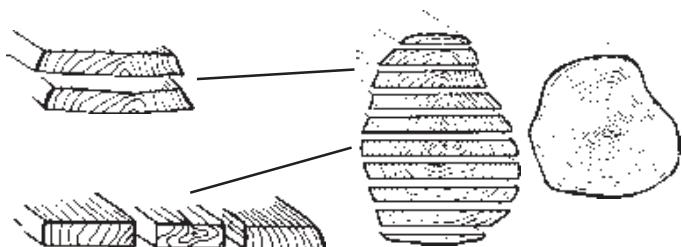
Abnormalities

Sometimes abnormalities occur in the growth of a tree, which can lead to beautiful and much-sought-after grain patterns forming on the wood surface. The best-known example of such vagaries of nature is maple, which is available as bird's eye maple, curly maple or flamed maple.

This is how a log is normally sawn up in a sawmill.

When being dried, a flatsawn board which is straight when damp will warp as shown below.

The two outer parts of the middle board, after having had the middle piece removed, will remain straight during drying (quartersawn wood).



Some types of wood and their characteristics

Spruce: soft, not particularly suited for building electric guitars

Alder: soft, easy to work; pretty, reddish wood

Ash: hard, solid, tough, extremely elastic; the light type of ash (e.g. swamp ash) is ideal for making the guitar body; open-grained, coarse structure

Maple: hard to medium-hard, straight-grained, but also wavy-grained (flamed maple), solid, tough, elastic, for all electric-guitar-building purposes

Birch: medium-hard, close-grained, tough, elastic

Basswood: soft, straight-grained, tough

Cherry: hard to medium-hard, solid, dense

Nut: medium-hard to hard, close-grained, tough, solid, low elasticity

Mahogany: medium-hard, straight-grained, wood for all electric-guitar-building purposes, very easy to work, open-grained; unfortunately, - unless mankind changes its ways - threatened by extinction, as are rosewood and other exotic timbers

Wood for the fingerboard

Plum: medium-hard to hard, dense, slightly brittle, well-suited for fingerboards because of its dark, reddish colour

Pear: hard

Maple: medium-hard to hard

Nut: medium-hard to hard

Rosewood: hard

Pau Ferro: similar to rosewood

Ebony: dense, heavy, extremely hard

The decision which wood to use is a very important one. An electric pickup can never add anything to or improve a lifeless-and dull-sounding guitar; all it can do is process and modify the frequency range that is already there - and a body with good resonant properties is obviously a better basis to start from. So contrary to what one might assume the type of wood used for building an electric guitar does matter and its acoustic qualities do have an effect on the overall sound.

For environmental reasons I personally prefer locally-grown wood. The excessive use of tropical timbers, together with the slash-and-burn farming methods used in order to gain land, lead to the decimation of the world's rainforests that are so vital for the Earth's climate. Commercial exploitation of tropical timbers also causes a lot of unnecessary pollution through transport. Only when sustainable forest management replaces the present worldwide practice of uncontrolled exploitation can tropical timbers be used with a clear conscience. Sustainable forest management is not only about replacing felled trees through reforestation, but also about maintaining biodiversity.

It is also important to mention that trees suitable for building guitars are not all that easy to find even in rainforests, and once such a tree has been found and felled it has to be transported out of the forest, an undertaking for which wide strips of forests have to be cleared. In an article in its July/August issue of 1993, *Acoustic Guitar* reported that the area on the Atlantic coast of the Amazon region in which Brazilian rosewood grows had been reduced from 470,000 to just 23,000 square miles.

Even if the quantities of wood used for building guitars are rather small compared to those used in the furniture industry, it has to be stressed that timber from locally-grown trees is perfectly suitable for making high-quality guitars, as has been proven many, many times. Although tradition and customer demands may suggest the opposite, using such exotic woods as mahogany, Brazilian rosewood, Indian rosewood, ebony, bubinga, pau ferro, wenge or others is really not necessary.

Sound characteristics

Generalizing descriptions of the sound of different types of wood ought to be taken with caution: firstly, because each piece of wood is different, and secondly, because what matters most is the combined effect of all the different components of an electric guitar. The choice of a particular type of wood can, however, support certain tendencies.

Buying wood

For buying wood there are several options. The safest one is to buy ready-cut and already-planed wood from a tonewood

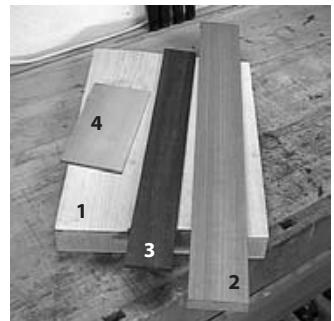
supplier, the advantages being that such wood will be of good quality, you will neither need a workshop for preparing the wood nor will there be much waste created, and the wood will also be dry and ready for immediate use. Remember all of these advantages when you are told the price of such wood. Joinery firms might also be able to supply you with wood. You can even buy ready-made bodies and necks which only need finishing.

Wanting to do it all yourself is an understandable ambition - but when even professional guitarmakers work with necks and bodies made with computer-controlled routers, what much of a difference is there? A good electric guitar is arguably less about the art of joinery than about the quality of its individual components, how well they are mounted and adjusted and the quality of its electronic parts.

Guitar kits. Unless you already have a fully-equipped workshop, in which case you obviously can prepare everything yourself, a guitar kit is well worth buying as it will provide you with all the parts needed for building a guitar. If you take into account how much time you'll save and also how little in the way of machinery and tools will be needed a guitar kit is indeed a very good and value-for-money way to start with guitarbuilding.

Replacement necks and bodies. An alternative to guitar kits, which leave almost no freedom in design, could be to buy a ready-made replacement neck and body and separate hardware; or you make your own body and mount a ready-made neck onto it. There are also ready-made necks with oversized peghead available that allow cutting out your own peghead shape.

However, if you wish to, as I do, prepare the wood yourself, what you will certainly need - apart from being well-equipped with machinery - are a transport vehicle and patience, as in the majority of cases the wood you buy will not be ready for immediate use. The following scenario is much more likely: at most sawmills the hardwoods you need will be available cut up into large planks; one of the workers will dig several out from a pile with a forklift, leaving you standing in front of large, several meters (yards) long, 50-60mm (2" to 2 $\frac{3}{8}$ ")-thick wooden planks among which you will have to choose. Remember also that you cannot just buy one half of a plank or so, but that you will always have to take the whole thing. Ask if you can have the plank sawed up into shorter pieces to facilitate transport, but if you do so, make sure that the individual pieces are not made too short, for you can never know how far checks and cracks at the ends extend into the wood. When you touch the wood and it feels dry, don't be fooled by this first impression: being rough from sawing, the wood only appears to be dry, but is not, as you will probably soon find out at home after planing when the surface will suddenly be



Wood for a solid-body guitar

All you need is:

(1) a body blank (e.g. alder, maple, ash, basswood, or poplar), 45mm (1 $\frac{3}{4}$ ") thick; the size depends on the desired length and width of the body (350mm x 500mm / 13 $\frac{3}{4}$ " x 20" will be sufficient for the majority of guitars); the blank can be glued up from two or more narrower pieces.

(2) a neck blank (e.g. maple, or mahogany), 25mm (1") thick; the length depends on the desired scale length and the width on the desired width of the peghead (690mm / 27" long and 100mm / 4" wide for a guitar; 860mm / 34" long and 115mm / 4.5" wide for a bass); if you glue "ears" to the peghead, the neck blank can be less wide (i.e. as narrow as the fingerboard end); mahogany blanks should be quartersawn.

If you don't make a one-piece-neck, you additionally need:

(3) a fingerboard (e.g. rosewood, ebony, or pau ferro), 6mm ($\frac{1}{4}$ ") thick; the neck blank must be 19mm ($\frac{3}{4}$ ") thick in this case.

If you make an angled-back peghead, you additionally need:

(4) a peghead veneer (any beautiful hardwood), 2mm - 3mm ($\frac{3}{32}$ " - $\frac{1}{8}$ ") thick.

Relative humidity

The amount of water air can hold depends on the air temperature: the higher it is, the more water it can hold. Given an atmospheric pressure of 1 bar (14 psi), one cubic meter (35.7 cubic feet) of air can hold 4.8g (0.17 ounces) of water at 0 degrees Celsius (32 degrees Fahrenheit), while it can hold 30.3g (1.07 ounces) of water, i.e. about six times as much, at 30 degrees Celsius (86 degrees Fahrenheit).

Relative humidity is the ratio between the actual amount of water contained in the air and the maximum amount it can hold at a given temperature. A relative humidity of 50 per cent in a room or out of doors therefore means that the air holds only half of the amount of water it could hold. As the air temperature rises, the percentage of relative humidity drops: the same amount of water contained in the air as before, which earlier constituted 50 per cent of the maximum possible, now represents a smaller share, say 40 per cent, of the total as the air temperature is higher and the air could now hold more water than before. As the air temperature drops, the percentage expressing relative humidity increases because the amount of moisture in the air is now closer to the maximum possible and the air is more saturated (70 per cent saturation, for instance).

Relative humidity is measured with a hygrometer. Why not use your next shower to set it? When the mirror in your bathroom is beginning to steam up relative humidity is 100 per cent, and you can set your hygrometer accordingly.

moist or wet - and this despite the sawmill employee's assurances that the wood has been kiln-dried. So what has happened? The wood may indeed have been dried; but because it was stored out of doors (or in an open-sided out-of-doors place) after seasoning it has taken up some moisture again. Or it may well never have been dried in the first place. Although a wood moisture meter should, in my opinion, be an absolute must for everybody trading in timber, I have never actually seen one in any of the sawmills I visited for buying wood.

Drying wood

Since there is a direct link between the moisture content of wood and that of the surrounding air, an equilibrium between the two will at some point be reached at which the wood will cease to absorb or lose moisture. This is a very slow and sluggish process that can nevertheless be easily followed by checking the weight of a wood sample.

Due to the direction the transport channels inside the wood run, the loss of moisture is highest at the end grain. For this reason these areas should always be sealed with hot wax or paint. This is an important precautionary measure to take to prevent the development of cracks that can be quite deep and can reduce the amount of usable wood or even make all of it unusable.

Because green wood reacts very strongly to changes that only one side of it is exposed to, it should always be stacked in piles with small spacers between the individual layers to allow air to flow freely around each piece of wood. When you leave a straight board somewhere without putting anything under it, the top side will lose or absorb moisture more quickly than the bottom side and the board will bend. Since the same thing happens when wood is treated on one side only, finishes, for example, should be applied on both sides. And because wood moisture is rarely evenly spread and the center of a piece of wood will always be wetter or drier than its surfaces, any kind of surface treatment such as planing has to be carried out on both sides - if you plane off too much on one side, the two surfaces will become unevenly wet and the wood will be likely to warp.

The main problem with moist wood is the formation of mould. This white, woolly coating develops very quickly unless wood is immediately seasoned and the moisture content reduced to below 18 per cent. Seasoning timber is basically all about finding the right balance between too fast and too slow drying: one can lead to cracks developing and the other to the formation of mould. The seasoning process needs to be closely monitored; it can be slowed, if necessary, by covering the wood with plastic foil. If the boards to be dried are from the same log, they should be placed above each other in the same order in which they were cut from the log. The first board of a pile should be about 30cm (1

foot) above ground and flat wooden spacers should be placed at no more than 40cm (16") distance from each other. To prevent undesired changes of shape occurring, it is also important to place the spacers exactly above each other. 30mm x 40mm roof slats are well-suited for this purpose. The sealed ends of the boards have to be flush and the top board should be protected against drying out too quickly by covering it with a scrap board.

As a result of the loss of water and the associated shrinkage wood warps. Flatsawn timber is particularly affected by this. Wood will, in general, always warp so as to give the impression that the annual rings are trying to become straight. Changes of shape occur because the outer areas of a board dry first and shrink in the process. Only quartersawn wood (i.e. wood with straight, "vertical" annual rings) is not affected by warping; it does none the less shrink. Wood shrinks by different amounts in different directions: radially, perpendicular to the annual rings, shrinkage is less than in tangential direction, parallel to the annual rings. By stacking wood in piles until it is evenly dry its tendencies to change shape and warp are counteracted by the weight of the boards that make up the pile. Putting some additional weight on top of the pile can, however, only be recommended as the top boards will inevitably warp when the wood becomes lighter if there is nothing on top of the pile to replace the lost counter-pressure of the moist, heavier boards. A board containing the core of a log will always crack. For this reason it is advisable to saw out this core bit from the middle board of a log before seasoning it.

All wood moisture content figures can only be averages. Similarly, the equilibrium moisture content will vary according to the climate and the time of year.

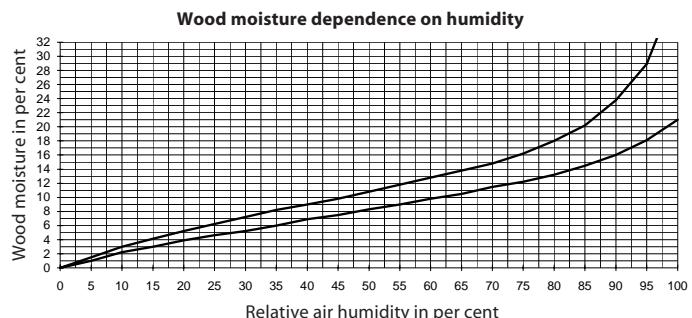
In my Central European climate, where average humidity is about 70 per cent, wood stored out of doors will, on average, always have a moisture content of well over 10 per cent. For making furniture and instruments this is still too high a percentage, since the wood will be worked and used in heated indoor rooms where humidity is lower. Wood will therefore continue to dry indoors and often warp or get cracks until it reaches a point

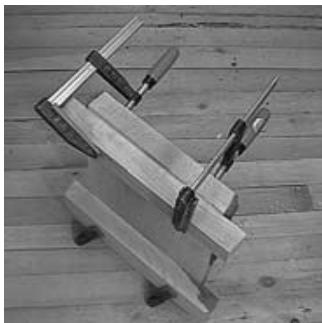
Wood moisture content

The weight of a piece of wood always includes the weight of the water contained in it. The relative wood moisture content is the ratio between the weight of the water contained in wood and the fully-seasoned wood. The approximate wood moisture content can be determined with electronic measuring instruments measuring the electrical conductivity of wood, which is directly linked to the wood moisture content.

Another method is to first weigh a relatively small sample of wood and to dry it in an oven afterwards until it ceases to lose weight, which is when it is fully-seasoned. From the remaining weight of this fully-seasoned sample piece the wood moisture content can be determined.

With the help of the diagram on the right you can estimate what moisture content a piece of wood will have after being stored a sufficiently long time at a particular constant humidity. The resulting wood moisture will lie between the two curves for almost all types of wood.





One-piece body

This piece of alder, which was wide enough for a one-piece body, was sanded down to 45mm (1 $\frac{3}{4}$ ") with a big thickness sander. After this I kept it straight for several months by clamping it with 2 pieces of wood and 4 clamps. This, however, only works if the blank was sufficiently dry before sanding or planing. Otherwise it would almost certainly have warped.

where its humidity equals that of the surrounding air. It is therefore essential that wood which has finished drying out of doors is made to adapt over a sufficiently long time to the climate of the environment in which it will be used later.

Checking the weight of wood over a longer period of time is a simple way of determining when it's dry enough. When wood has been stored for a sufficiently long time at constant humidity, the moisture content will eventually become constant, too. The easiest way of finding out when this point has been reached is to regularly weigh a not-too-small piece of wood from the stack. Kitchen or bathroom scales (for larger samples) will do for this purpose.

The water contained in moist wood makes up a high proportion of its total weight; as the wood becomes drier, this proportion becomes ever smaller and eventually constant when the wood moisture content is in equilibrium with the air moisture content. The sample should be weighed once a month at the beginning of the drying process, and once a week in the later stages. Each time you weigh a piece of wood, note its weight and the date straight onto it. When the weight of the sample piece remains constant over three weeks you can be sure that the wood has finished losing moisture and has reached a moisture equilibrium with the air surrounding it. This form of wood-seasoning often takes very long and can even take years, depending on the thickness and the type of wood.

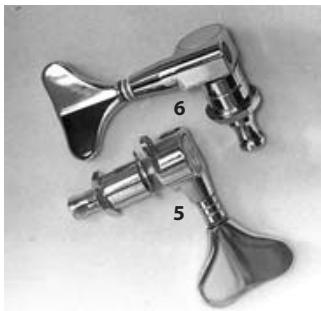


Hardware

Tuners

The tuners consist of a shaft, a worm gear and a knob. Gear ratios indicate how many turns of the knob are required to make the shaft complete one turn. The most common gear ratios are between 1:12 and 1:20. A gear ratio of 1:14, for instance, means that 14 turns of the knob are required to make the shaft complete one full turn. As the name implies, tuners allow the tuning of a guitar, and their quality is crucial for a guitar's ability to maintain a stable tuning; it would therefore be a false economy trying to save money on them. Go for good quality instead. The smoother and more precise the operation of the tuners is, the easier it will be to tune the guitar. Enclosed-gear tuners with sealed lubrication are better than ones with open gears. The amount of play can often be adjusted with a screw on the knob. *Schaller* (1), *Gotoh* (2), *Grover* (3), *Kluson* and *Sperzel* (4) are some manufacturers of quality tuners, and especially the ones produced by the German manufacturer *Schaller* have a very

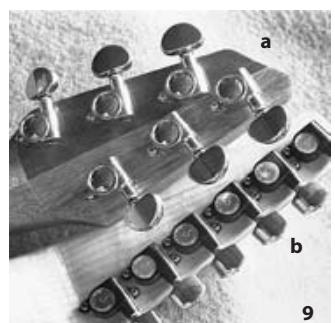




good reputation. Those made by the Japanese company *Gotoh* are less expensive but equally good in quality. Most tuners come in chrome- or gold-finished form or in a colored style. If you want to save a bit of money, buy machine-polished tuners instead of hand-polished ones.

Bass tuners are bigger and stronger than guitar tuners. The picture shows a *Schaller* (5) and a *Gotoh* (6) bass tuner. There are even bigger models which have a visible gear wheel (7).

HipShot bass tuners (8) are light in weight and smaller and thus help to keep the weight of the bass peghead low (especially with 5- or 6-string bass guitars). Further advantages: peghead can be made smaller, gear ratio 27:1, greater shaft diameter ($\frac{3}{8}$ " = 9.5mm), can be fitted on left- or right-hand side.



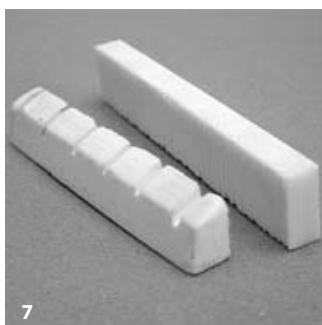
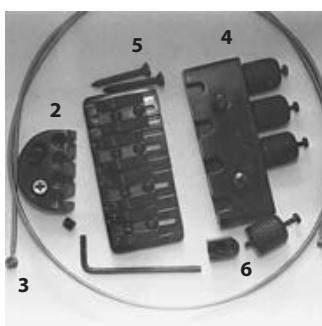
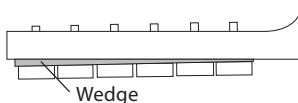
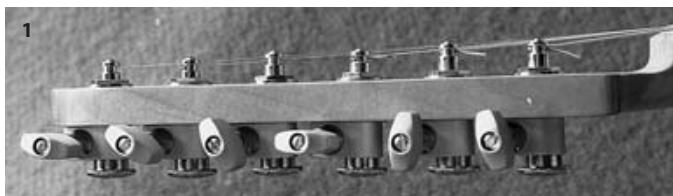
There are "L" (left) and "R" (right) tuners (3L/3R or 2L/2R), according to the side of the peghead on which they have to be fitted (9a). It is also possible to fit all tuners on one side (6-in-line or 4-in-line). If you choose to do so, you obviously have to buy either "L" or "R" tuners only (9b); but if the head is not to become too large, the tuners will in this case have to be rather small-sized. The tuners are normally mounted from above with bushings. Their outside diameter determines the size of the holes needed for fitting them (pegholes). This diameter is normally between 9mm and 10mm ($\frac{3}{8}$ " - $\frac{13}{32}$ ") on electric guitars and between 12mm and 17mm ($\frac{1}{2}$ ", $\frac{9}{16}$ ", $\frac{11}{16}$ ") on basses. Most of the tuners can be fastened additionally with a small oval or round-head wood screw to stop the unit turning.



On locking tuners, which are mostly used in conjunction with tremolos, the strings are clamped in the tuner shaft with a knob situated at the bottom (10) or at the top of the tuner (11).

Locking tuners are of general advantage: the guitar can be strung more quickly because the strings obviously don't have to be wound up; and due to the absence of windings which could settle the tuning is stable immediately. Fastening knobs situated on the top of tuning machines fitted on the right-hand side of the peghead have a counterclockwise thread.





Staggered tuning machines (1) with shafts of differing lengths are only needed if the peghead is not angled back. Because such tuners help to maintain sufficient string pressure against the nut, peghead string retainers are not required.

The same effect can be achieved with normal tuning machines by using a wedge like shown in the drawing below. Such wedges or stager stripes are commercially available. Alternatively it is also possible to taper the thickness of the entire peghead.

Locking tuners and staggered tuners are now available from almost all manufacturers. *Gotoh* has recently developed a model where the shaft height is infinitely variable.

Headless tuners are mounted on the body. The picture shows the full set of the German manufacturer *ABM*. The head part (2) is screwed to the top end (head end) of the neck. Special ball-end strings (3) are anchored here and in the tuning unit (4), which is fitted at the end of the body. An alternative with this *ABM* unit is to use normal bass strings with one ball-end and clamp the other end with allen screws at the head part. The bridge (5) is screwed onto the body between the head part and the tuning unit (as shown in the picture, but turned at an angle of 180°). The guitar is tuned with small 3mm-diameter screws that pull back a small string-holder in which the ends of the strings with the larger balls are anchored, thus tightening the strings (6).

Nuts

Sound differences

When an open string and a fretted string are played, there may be a certain difference in sound because of the different materials used for the nut (bone) and the frets (metal). Using a brass nut can help to reduce this difference. But I should also mention that such a sound difference due to a different nut material is only of a theoretical nature; in practice, most of us won't hear any difference. So I wouldn't worry about it - almost every guitar has a bone or synthetic nut anyway.

The nut (7) is the point where the strings rest on the neck. It serves to guide the strings and helps to keep them clear of the fingerboard. Plastic nuts are only used on cheap instruments. Good, hard materials to use for making the nut are bone, which is either solid bone or compressed bonemeal, or a synthetic substitute of bone.

Nuts made of graphite or some other high-tech material and roller nuts with small rollers on which the strings rest help to keep friction to a minimum.

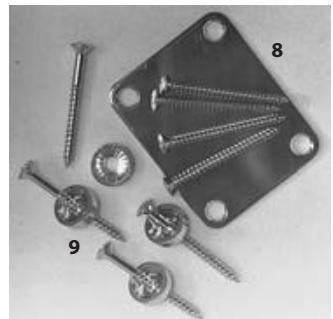
Nuts can be bought as blanks or in pre-slotted form. When buying pre-slotted nuts the desired neck width, fingerboard radius and string spread have to be taken into consideration. Nut blanks have to be trimmed and slotted to the dimensions

needed. There are also metal nuts with height-adjustable string rests available which will save you some work because they do not require any slot filing.

It is also possible to use a zero-fret in place of a nut. In this case the nut is placed directly behind the zero-fret and only serves to guide the strings.

Bolt-on neck hardware

Neck attachment plates for bolt-on necks are normally 3mm ($1/8$ ")-thick, 40mm x 50mm (about 1.5 " x 2 ")-large, chrome, black or gold metal plates (8). Alternatively, when a flat neck attachment plate is impractical you could also use special round, 4mm (about $5/32$ ")-thick, 15mm-diameter neck attachment ferrules, for which 15-16mm ($5/8$ ") counterbore holes are needed (9). Plates as well as ferrules are used with 45mm ($1\frac{3}{4}$ ")-long Phillips oval-head screws with 4mm ($5/32$ ") wood thread.



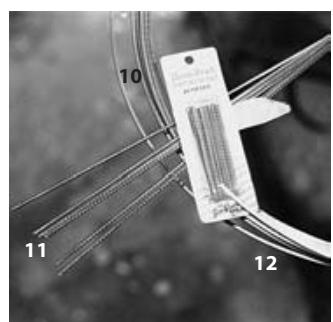
Pickguards

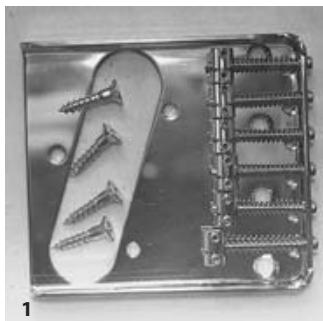
On the pickguard some or all of the electronic parts can be mounted. There are plastic sheets available for custom-cutting your own pickguards, but you can, of course, also buy finished shapes. Most of these have already-cut-out pickup cavities, but there are also some available for custom-cutting cavities. The standard screws used for mounting pickguards are 3mm x 13mm oval-head screws. Pickguards come in white, black and in a few other colors. They can consist of several differently-colored laminated layers. Apart from plastic they can also be made of veneer or some light metal such as aluminium. The electronic parts (or parts of them) can also be mounted on additional metal cover plates.



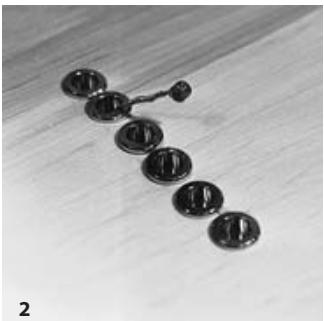
Fretwire

Fretwire is available in many different dimensions, e.g. in packs of 24 short-length pieces (10), in 2-foot lengths of straight wire (11) and in rolls (12). On most electric guitars medium-sized fretwire or an even higher and wider type - so-called jumbo fretwire - is used. The short-length pieces are difficult to bend evenly and should be avoided if you want to use a radiused fingerboard.

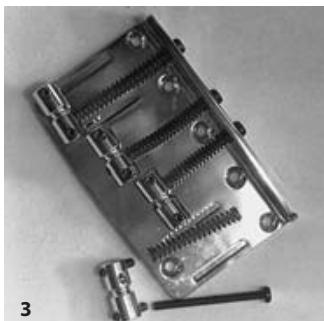




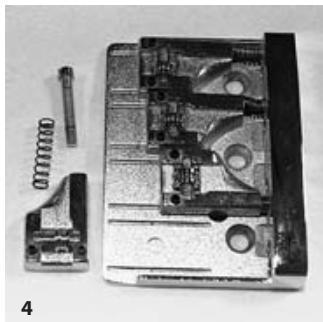
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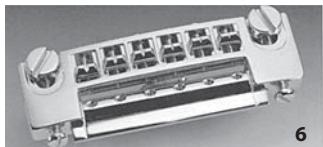
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6



7

Bridges

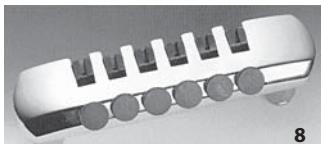
The bridge is the point where the strings rest on the body. Very good bridge systems allow making three-dimensional adjustments: the string-length and the height of each individual string can be varied as well as the string spacing. The height of the bridge can be additionally increased by inserting small shims under it. On a *Telecaster* (1) the bridge is mounted with four wood screws and also serves as a frame for the rear pick-up. The strings are fitted through six holes from the back of the body (2) and the string spacing is fixed at $25/32"$.

Simple bridges (3) consist of an angled chrome plate, through the rear part of which the strings are passed. With a screw tensioned by a spring the small rollers on which the strings rest can be set to a position further back or forward. The string height can be adjusted with two tiny allen screws, and the string spacing is $2.25"$.

More modern bridges (4) are made of cast material and also allow string spread adjustment: with the help of small rollers on a thread string spacings can be set to anything between $2"$ and $2\frac{3}{16}"$ on guitars and between $2\frac{3}{32}"$ and $2.5"$ on four-string basses.

Bridges mounted on two posts can be used on domed tops. Bridges such as the one shown in picture 5 have a fixed, already-compensated saddle, similar to an acoustic guitar. The strings are loaded from the front and passed back over the saddle. The bridge radius is $12"$ and the height of the bridge can be adjusted with the posts. Minor string length adjustments can be made with the help of two small allen screws. The better systems, however, are those with adjustable intonation (6).

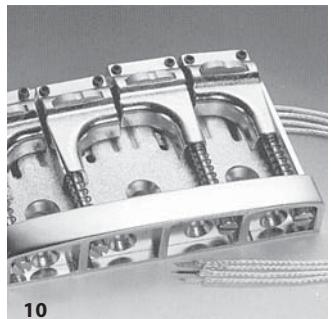
Strictly speaking a distinction has to be made between the bridge and the tailpiece; when these parts are separated (7) the strings are anchored in the tailpiece, which is mounted further back by pressing two bushings into the body and anchoring the tailpiece at two posts. The bridge shown in the picture is three-dimensionally-adjustable, with string spacing adjustable



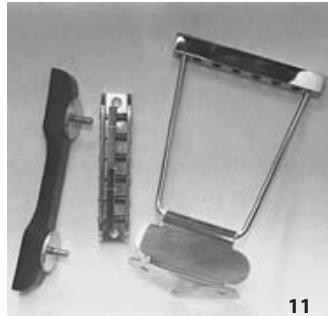
8



9



10



11

between $1\frac{29}{32}$ " and $2\frac{1}{4}$ ". Other tailpiece models are equipped with fine tuners (8).

There are expensive, heavy brass bridges available, too (9), which, with a bit of skill and the right workplace, can also be made at home.

Another type of bridge is fitted with piezo ceramic saddles (10). These make it possible to pick up each string separately and feed each one into a guitar synthesizer individually or to mix the acoustic piezo sound with the sound of the electric guitar.

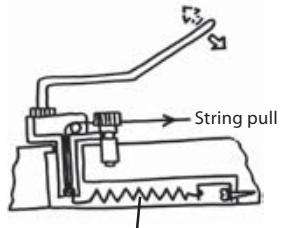
Archtop guitar bridges (11) are placed and kept on the body solely by the downward pressure of the strings. The tailpiece is fastened at the side of the body, together with the strap pin.

Most bridges are available in chrome, gold or black chrome. String spacings vary from manufacturer to manufacturer and the figures given above apply to the models shown only.

Tremolos

A tremolo is a mechanical device allowing the stretching or loosening of strings by means of pressing an arm, thus raising or lowering the pitch of a tone.

The most common type of tremolo is the *Strat*-style tremolo. It is basically a bridge which can be tilted and is held in its resting position by three or more steel springs mounted in a cavity on the back of the body. By pressing or pulling the tremolo arm, the bridge can, to a certain extent, be tilted over its pivot. After the arm is released, the force of the spring pulls the bridge back into its resting position. The biggest problem with all tremolo systems is that they always have to reliably return to this resting position at which the guitar is accurately tuned. This being a problem ever more complicated and sophisticated mechanical marvels were developed over the years. Some systems pivot on six screws, others, with less friction, on only two. These latter systems have two knife edges which bear against two beveled posts that are screwed into the body. To keep friction as low as possible the knife edges should be slightly lubricated. In order to make the tuning more stable, the tremolo unit can be mounted in such a



Spring tension counteracts the pull of the strings. The tension can be adjusted so that the tremolo "floats" or rests on the body in its neutral position.



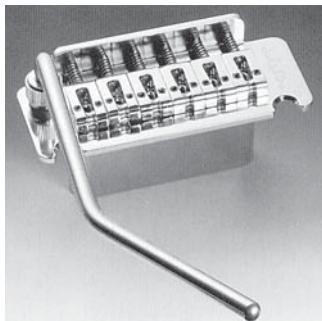
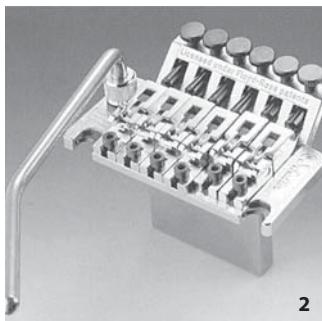


Photo: Stewart-MacDonald's Guitar Shop Supply



way that it rests on the body when it is in its resting ("neutral") position.

However, the main problem is that as the tremolo arm is pressed down the strings are loosened and unwind from the tuner shafts and do not wind up again in exactly the same way after the arm is released.

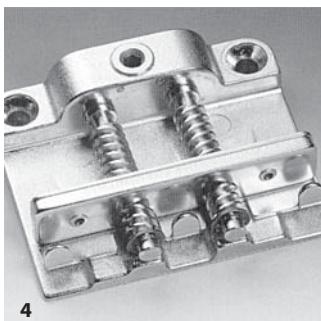
This is why on some tremolo systems the strings are clamped at the nut (1) and at the tremolo unit (2) after tuning. With the help of fine-tuning screws on the tremolo system the strings are then fine-tuned to the exact pitch as they will have gone out of tune after having been clamped. This system - which is rather expensive, but very effective - was invented and patented by an American named *Floyd Rose*. Fairly commonly a bit of wood is routed off behind the tremolo system so that it can be tilted further back.

Instead of using a clamp on the nut it is, as already mentioned above, also possible to use so-called locking tuners (3), where each string is clamped in the tuner shaft hole and thus kept from unwinding.

To keep the friction at the nut to a minimum, it is possible to use a roller saddle, where each string rests on a small roller. Nuts made of self-lubricating synthetic materials also serve this same purpose of minimizing unwanted friction.

By the combined effect of the number of springs used, the positions at which they are hinged and the adjustment of spring tensions a balance between string pull and spring tension can be found. The baseplate of the tremolo unit is suspended approximately parallel to the body surface and makes contact only at the mounting posts. This set-up allows the operation of the tremolo in both directions. Another possibility, which, however, only allows loosening the strings, is to mount the tremolo so that in its neutral position its baseplate rests on the body.

There are special systems which allow the adjustment of spring tension with one single allen screw (4).



On systems where the tremolo is mounted so that it “floats” players used to resting their hand on the bridge in doing so often unintentionally operate the tremolo. To prevent this from happening, a mechanical lock (sometimes called “Black box”) was invented which only unlocks the tremolo when a certain amount of pressure is exerted on the arm. Such systems are hinged between the tremolo block and the springs.

On all *Strat*-style tremolo systems the strings are fitted from the back and passed through the tremolo block.

Apart from the *Strat*-style tremolos there are a few others which do not require a body cavity. The *Bigsby* tremolo is the best-known of these: here the strings are anchored in a low-friction, horizontally-mounted shaft. By moving a lever the shaft is turned and the strings are tensioned or loosened. Other tremolo models such as *Mustang* or *Vibrola* are less commonly used.

Other hardware parts needed

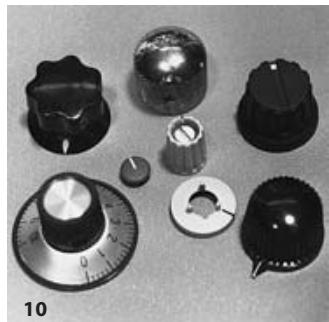
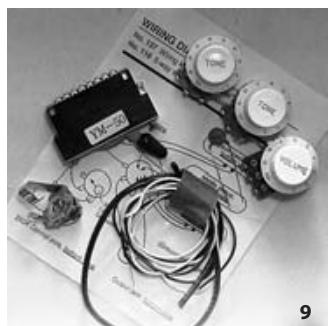
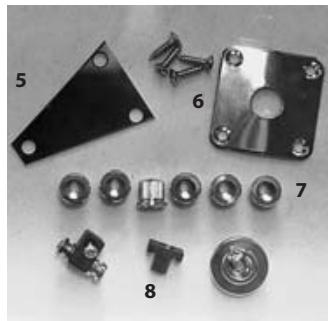
Depending on the type of guitar you are going to build other smaller parts may be needed. A peghead-end adjustable truss rod requires a cover plate for the adjustment nut (5). For mounting the output jack on the side of the body, a slightly-arched metal jack plate (6) is needed. String mounting grommets (7) are available for strings that are fitted through the body from the back, and string retainers which can be screwed on (8) are needed for guitars which do not have an angled-back peghead.

You also need parts for the electronics. Picture 9 shows an example of a passive electronics system: a pickup selector switch, pots with knobs, a jack, a capacitor and some wire. Pickups and electronics will be discussed later.

Potentiometer knobs have to be chosen according to the shaft diameter. 6mm ($15/64"$ or $1/4"$)-shaft-diameter knobs are the ones most commonly used. The knob in the middle of picture 10 fits on a 4mm-diameter shaft, while all other knobs shown fit on 6mm shafts. Smaller shaft diameters, such as 4mm, are not very common in guitarbuilding.

Knobs can be fastened in three different ways: either you press them on a fine- or coarse-knurled pot shaft, or you clamp them with one or two small, laterally-mounted screws, or you use a collet, which is the most reliable fastening method. Knobs fastened with a collet have a removable top and a hex nut or a screw under it that can be tightened to fasten the knob on the pot shaft. A scale on the knob can be very useful. And why not use knobs from old radios or other out-of-use appliances? They can look very good on your guitar, too.

I strongly recommend that you have all of these parts, smaller and larger ones, ready in front of you before you start designing or even building the guitar.



Environmentally-friendly strings

Another aspect that should also be considered when buying strings is their packaging: the majority of string manufacturers use plastic to package their products; they thus contribute to creating a lot of totally unnecessary waste. Don't buy products of such resource-wasting manufacturers.

Strings

When buying strings, the scale length of the guitar has to be taken into consideration. Nowadays, however, this is no longer a real problem as most sets of strings are made to fit the longest scale length and just have to be cut off if necessary. String gauges are normally given in inches - it is common to talk of .011, .010 or .009 string sets, the number describing the diameter of the thinnest string of the set.

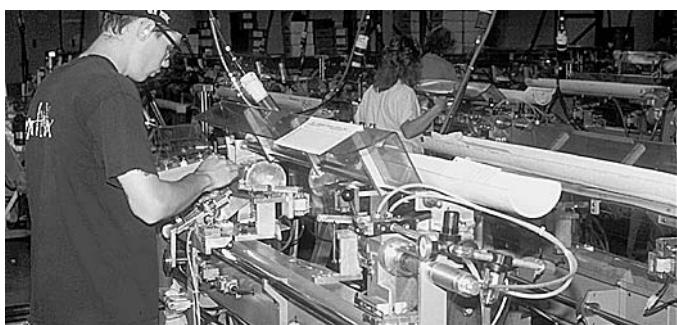
Only strings made of magnetizable material can be used on electric guitars. Thicker strings make the guitar sound louder because one of the many factors determining the output of a pickup is the amount of mass that is moved in a magnetic field.

While the thinner strings are made of steel wire, the thicker strings have a steel core which is mostly surrounded by nickel wire. Since all the strings are of equal length and should have equal or near-equal tension, the mass of some of the strings has to be increased somehow to make them produce a lower-pitched tone. This is achieved by winding either flat or round wire around the steel core, giving either "flatwound" or "roundwound" strings. Using flat wire helps to prevent the strings from making unwanted noises while playing, whereas roundwound strings are more "supple", vibrate more freely and thus produce more harmonics than flatwound strings. Roundwound strings, however, also tend to accumulate dirt more easily in their fine grooves.

When strings are very old or even rusty they no longer produce a clean sound and should be replaced. Even though it is a fact that all strings sound best when they are new, it also has to be said that is not such a good idea to change strings all the time for that reason. Throwing away strings that no longer sound as brilliant as new ones do is basically a huge waste of material. By regularly wiping the strings with a cloth, the bad effects of hand sweat can be relieved.

String manufacture

The picture on the right taken in the *Martin* acoustic guitar manufacturing plant in Nazareth, PA, shows a machine used for winding strings. The more precisely the wire is wound around the steel core, the better the harmonics of the string can develop. Only evenly-wound strings will vibrate evenly and cleanly.



Guitar electronics

Pickups

Because the sound produced by the strings of a solid-body electric guitar is very low, pickups are mounted; all pickups rely on the same principle: the movement of the strings - which have to be made of some kind of material that is conducive to magnetization (like nickel) - has an effect on a magnetic field created by one or several permanent magnets. Inside thin enameled copper wire, which is wound around these magnets or around material magnetized by bar magnets, an electric current proportional to the strings' vibrations is generated. Via a cord this alternating current is then directed into an amplifier and made audible through a speaker.

A **single-coil** (shown at right) is a pickup that usually produces a bright, clear sound. There are however, some types with a much darker sound, like for instance the P-90 (shown on page 44). A single-coil has four or six permanent magnets wound with 7,000 to 10,000 windings of 0.06mm-thin copper wire. Such pickups are very popular on account of their sound, but they unfortunately also have one disadvantage: in a world where we are constantly surrounded by a great number of electromagnetic fields an interference signal is generated in the pickup as soon as it gets anywhere near a mains socket, a light bulb or a fluorescent light, and an interfering hum equal in pitch to the mains frequency is superimposed on the guitar signal.

The **humbucker** - because of the way it is built - is unaffected by interference. It has two identical coils wired out-of-phase in a series connection, each with a different pole of the magnet facing the strings. Any interfering hum passed on via the air is now picked up by both coils, with the result of one coil cancelling the hum of the other. In order to prevent the same mutual cancellation of the current magnetically induced by the vibrating strings, the magnets in the two coils are placed in opposite directions, so that the top end of one coil is magnetically south and the top end of the other coil magnetically north. This has the additional advantage of the two currents adding up instead of cancelling each other out and the pickup producing a signal twice as strong as that of a single-coil pickup. A humbucker sounds "darker", bassier, more "middly" than a single-coil pickup because due to the distance between the magnetic poles of the two coils the strings induce two differing signals, leading to the cancellation of certain higher frequencies.

Alternating current (a.c.)

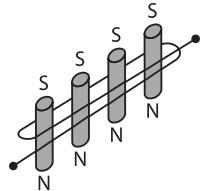
Alternating current is called so because it is a type of current that flows alternately backwards and forwards all the time. The best-known example of alternating current is the current we get from the socket: depending on the country, it changes its polarity (direction of flow) 50 to 60 times per second (Hz). A pickup generates an alternating current which changes with the rhythm of the vibrating strings. When you amplify this alternating current by directing it into a speaker, the speaker's membrane vibrates at the same rhythm, thus making it possible for the human ear to hear the sound waves produced by the membrane.



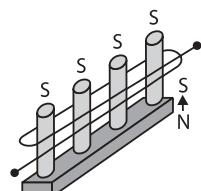
Humbucker

- two single coils
- windings connected out-of-phase: ends of windings connected, beginnings of windings become leads
- magnets in the two coils oppositely polarized

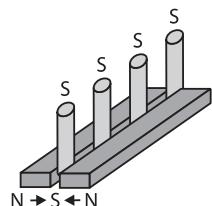
Types of single-coil



Coil of copper wire around bar magnets

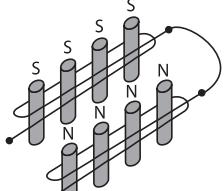


Soft iron cores magnetized by a flat, vertically-magnetized magnet

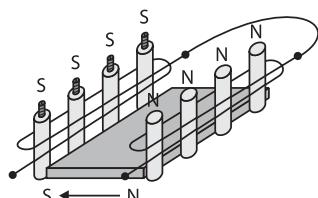


Soft iron cores magnetized by two flat magnets polarized across their width

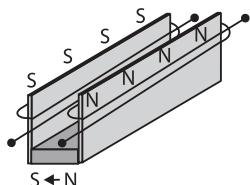
Types of humbucker



Copper wire coils around bar magnets



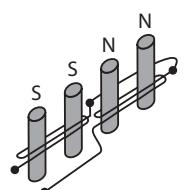
Copper wire coils around soft iron cores with screws magnetized by a flat magnet polarized across its width



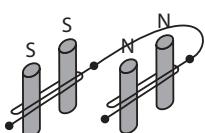
Soft iron metal blades magnetized by a flat magnet polarized across its width

Split single-coil with humbucking effect

- two coils, each around half of the magnets
- windings connected out-of-phase: ends of windings connected, beginnings of windings become leads
- magnets in the two coils oppositely polarized



Single-bobbin humbucking pickup



Split pickup humbucking pickup

How pickups work

When a current flows through a wire, a magnetic field is created around it. Electric motors make use of this phenomenon. Conversely, an electric current is generated in a wire which is moved in a magnetic field. This is the principle on which electric generators such as bike dynamos rely. Pickups also make use of this principle, the difference being that it is not the wire which moves in a magnetic field, but the magnetic field which is moved, with the wire windings remaining in a fixed position. The continuous alteration of the pickup's magnetic field by the strings' vibrations generates an alternating current in the wire windings which is proportional to the vibrations of the strings. Regardless of whether the wire moves in a magnetic field or the magnetic field moves around a wire, the result is always the same: a current is induced in the wire.

There are many different types and manufacturers of pickups. On most models differences in volume levels between different strings can be compensated by varying the distance between the poles and the strings by means of screws; or fixed, staggered polepieces of different lengths are used to make up for different string diameters. Other models have magnetized metal blades in place of individual polepieces, allowing for the string spacing to be chosen freely. But keep in mind that the maximum allowed string spacing is a bit smaller than the blade length to allow sensing all of the movement of the two outer strings. Bass pickups can have two polepieces per string in order to better sense the wider movements of the thicker strings.

Single-coil format humbuckers (1) have coils placed so close next to each other that both of them fit into a single-coil casing.

Stacked humbuckers are of a single-coil format and have two coils placed on top of each other; the bottom coil is without magnets and only serves to cancel the hum. Like in an ordinary humbucker, where the coils are placed next to each other, there is an out-of-phase in-series connection between the bottom and the top coil; they can, however, also be connected in parallel. Both coils have to be adjusted to each other accurately and have to generate the same amount of hum.

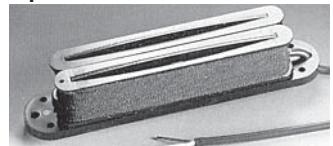
Split pickups can be placed in-line, next to each other; if, however, their size requires it, they have to be placed so that they overlap (2). With split pickups each coil is "in charge of" one half of the strings and both coils are connected out-of-phase. Such pickups produce a single-coil sound while still maintaining their humbucking function.

A lipstick pickup (3) is a particularly simply-built type of single-coil pickup. Its windings are wound directly around a flat magnet (4) and the whole thing is housed in a chrome-plated casing which resembles that of a lipstick. The coil's direct current (d.c.) resistance is 4.7K ohms. The sound of lipstick pickups is very popular with blues musicians.

Active pickups already have a tiny pre-amp circuit integrated in the pickup casing and require battery power. With such pickups a hi-fi sound is guaranteed, the sound is independent of the guitar cord and the high output voltage assures an excellent signal-to-noise ratio.



1



2

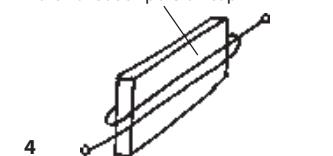


2



Photo: Stewart-MacDonald's Guitar Shop Supply

North or south pole on top



4

Resistance

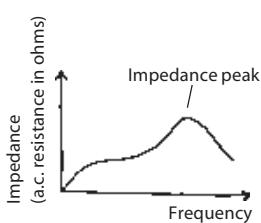
Resistance is the property of a building component to impede the flow of electric current and to, as the name implies, present it with a certain amount of resistance. It is measured in ohms: 1,000 ohms equals one K ohm (K = Kilo), and 1,000K ohms equals 1M ohm (M = Mega). Instead of writing "ohm" you can also use the Greek symbol W (1kW is therefore another form of writing 1K ohm).

Apart from the unavoidable wire resistance of, say, a coil, it is also possible to build small building components with two lugs, so-called resistors, into any circuit to limit the flow of an electric current. Ordinary resistors which can withstand 0.25 watts are sufficient for all requirements in connection with building electric guitars.

In circuit diagrams the ohm symbol is often left out, so that for instance 22K is used for 22K ohm. As it is easy to miss out on the decimal points, it is advisable to write 4M7 or 2K2 rather than 4.7M ohm or 2.2K ohm.

The d.c. resistance of a pickup can be measured with an ohmmeter. On most *Fender-style* single-coil pickups the coil's d.c. resistance is between 6 and 7.5K ohms, and on humbuckers the resistance of both coils connected in series is between 8 and 14K ohms. Generally, more windings give more output; but the more windings there are on a pickup and the thinner the wire used is, the higher its d.c. resistance and the less clear its sound will become. A pickup's d.c. resistance is easy to measure, but can only give a rough idea of its sound. Coils with low-ohm values of between 3 to 6K ohms give a brighter sound than high-resistance coils of 10K ohms or more. Pickups with resistance values of 16K ohms or higher give an extremely bassy and lifeless sound.

Impedance (a.c. resistance) is the resistance a pickup's coil presents to an alternating current. It is frequency-dependent and cannot be measured as easily as d.c. resistance. The coil's a.c. resistance varies according to the frequency of the pickup's output signal because the pickup coil represents a resonant circuit made up of the elements windings capacitance, inductance and wire resistance. At a certain frequency the impedance of this circuit will reach a maximum (1). The position and shape of this impedance peak in the pickup's frequency spectrum is what determines the sound. The position of this peak is also strongly dependent on the load capacitance (the capacitance of everything connected to the pickup). Often the resonance peak is around 2-3KHz. The resonant frequency of humbuckers whose coils are connected in parallel is half as high as that of normally-connected (i.e. in series) humbucker coils.



(1) The diagram shows the typical dependence of a pickup's impedance (a.c. resistance) on frequency

High output power of a pickup is desired as it increases the ratio of output signal to unwanted noise (e.g. hum). Amplification of a guitar signal not only increases the signal itself but also the noise, and the smaller the noise is compared to the amplifier input signal, the better. A pickup's output power is determined by two factors: the stronger the magnets are and the more wire is wound around them, the higher the output of a pickup will be. However, permanent magnets that are too strong shouldn't be used because of the unwanted magnetic effect they have on the vibrations of the strings: the strings can't vibrate freely if they are attracted by the polepieces. Also, the use of an excessively high number of windings is bad for the sound of a pickup because it pushes d.c. resistance up to unacceptably high levels.

The place where a string is sensed is crucial for determining the sound of the pickup. A string vibrates up and down over its entire length, but also within itself. These overtones, or harmonics, are what determines the sound of a string. Apart from the fundamental tone there are always additional higher-pitched tones vibrating which usually decrease in volume the higher-pitched

they are; the highest of these are virtually inaudible. What the vibration curve of a string looks like is also strongly dependent on the place where the string is plucked: a string plucked near the bridge sounds different to one plucked somewhere halfway down its length as more harmonics are produced at the bridge. Ideally, these harmonics are always simple multiples of the fundamental frequency. If they are not, this can be due to poor string quality or the strings being old and having accumulated dirt. Such strings do not sound clean because their harmonics are either too high or too low.

When a string is sensed near the bridge, its up-and-down motion, and consequently also the pickup's output, is smaller. For this reason, and in order to maintain the volume balance with the neck pickup, bridge pickups normally have more windings.

Differences in sound between single-coils and humbuckers not only arise from their different impedances but also from the way the strings are sensed. A single-coil transforms the strings' vibrations into an electric charge proportional to those vibrations: as the strings vibrate away from the pickup, output power is decreased, and vice versa. Movements parallel to the pickup are not registered. The resulting output is a bright sound, a rough reflection of the vibration curve inclusive of all its harmonics.

On a humbucker, the distance between the poles causes the deletion of the one harmonic whose maximum is above one and whose minimum is simultaneously above the other pole - opposite charges are cancelled. Because this particular harmonic is then no longer present in the tonal spectrum made audible by the speaker and because other harmonics are also weakened, a humbucker does not sound as bright.

When two single-coils from different humbuckers or two single-coils are connected to form a humbucker, the coils are at a great distance from each other and a totally different range of harmonics is deleted. By making use of such and similar different combinations the sound of an electric guitar can be varied in different ways.

Two humbucker coils connected in parallel (instead of, as usually, in series) give less output, but in the human ear this loss of volume is to a certain extent compensated for by the trebles gained.

Pickup positions

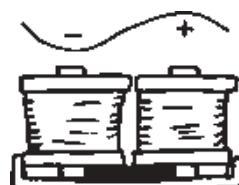
Pickups and especially bridge pickups are often placed at positions with strong harmonics. On a *Telecaster*, for example, the bass side is placed at the position of the 43rd fret. Positions of strong harmonics can be found by experimenting. You can assemble the guitar before routing the pickup cavities and play it acoustically only. If you find a point of strong harmonics, note the exact distance from your fingertip to the front of the nut. Then measure the same distance from the saddle and mark it on the body. If possible mount the pickup on center with this mark and it will sense the same harmonic you found earlier.

Neck pickups are sometimes placed at the position where the 24th fret would be situated.

Pickup positions of a Jazz Bass (Scale 34")

Year	NeckPU	BridgePU
1962	710mm	802mm
1973	710mm	810mm

All positions are measured from the front side of the nut, or zero-fret, to the middle axis of the pickup.



Helmut Lemme, author of several German books on guitars and guitar electronics, knows what he is talking about. The following article is reprinted with his kind permission.

The Secrets of Electric Guitar Pickups

By Helmut E. W. Lemme

An electric bass or guitar's sound depends greatly on its pickups. There are weighty discussions between musicians about the advantages and disadvantages of different models, and for someone who has no knowledge of electronics the subject may seem very complicated. Electrically, though, pickups are fairly easy to understand - so this article will examine the connection between electrical characteristics and sound.

I am sorry to say that most pickup manufacturers spread misleading information on their products in order to make more money and disturb their competitors. So some correction is necessary. I am not affiliated with any manufacturer.

There are two basic pickup types, magnetic pickups and piezoelectric pickups. The latter work with all types of strings (steel, nylon, or gut). Magnetic pickups work only with steel strings, and consist of magnets and coils. Singlecoil pickups are sensitive to magnetic fields generated by transformers, fluorescent lamps, and other sources of interference, and are prone to pick up hum and noise from these sources. Dual coil or "humbucking" pickups use two specially configured coils to minimize this interference. Because these coils are electrically out of phase, common-mode signals (i.e. signals, such as hum, that radiate into both coils with equal amplitude) cancel each other.

The arrangement of the magnets is different for different pickups. Some types have rod or bar magnets

inserted directly in the coils, while others have magnets below the coils, and cores of soft iron in the coils. In many cases these cores are screws, so level differences between strings can be evened out by screwing the core further in or out. Some pickups have a metal cover for shielding and protection of the coils, others have a plastic cover that does not shield against electromagnetic interference, and still others have only isolating tape for protecting the wire.

The magnetic field lines flow through the coil(s) and a short section of the strings. With the strings at rest, the magnetic flux through the coil(s) is constant. Pluck a string and the flux changes, which induces an electric voltage in the coil. A vibrating string induces an alternating voltage at the frequency of vibration, whose voltage is proportional to the velocity of the strings motion (not its amplitude). Furthermore, the voltage depends on the string's thickness and magnetic permeability, the magnetic field, and the distance between the magnetic pole and the string.

There are so many pickups on the market that it is difficult to get a comprehensive overview. In addition to the pickups that come with an instrument, replacement pickups - many of them built by companies that do not build guitars - are also available. Every pickup produces its own sound; one may have a piercing metallic quality, and another a warm and mellow sound. Correctly spoken: A pickup does not "have" a sound, it only has a "transfer characteristic". It transfers the sound material that it gets from the strings and alters it, every model in its own way. For instance: Mount the same Gibson humbucker on a Les Paul and on a Super 400 CES: you will hear completely different sounds. And the best pickup is useless when you have a poor guitar body with poor strings. The groundrule is always: garbage in - garbage out!

Replacement pickups allow the guitarist to change sounds without buying another instrument (within the limitations of body and strings, of course). Different pickups also have different output voltages. High output models can make it easier to overdrive amplifiers to produce a dirty sound, while low output models rather produce a clean sound. The output voltage of most pickups varies between 100 mV and 1 V RMS.

Unlike other transducers that have moving parts (microphones, speakers, record player pickups etc.), magnetic guitar pickups have no moving parts - the magnetic field lines change, but they have no mass. So, evaluating pickups is much easier than with other transducers. Although the frequency responses of nearly all available magnetic pickups are nonlinear (which creates the different sounds), they don't have quite as many adjacent peaks and notches in frequency response as something like a loudspeaker. In fact, the frequency response can be smooth and simple enough to be easily described with a mathematical formula.

The Pickup as Circuit

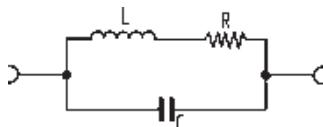


Fig. 1. Electrical equivalent circuit of a magnetic pickup

From an electrical standpoint, a magnetic guitar pickup is equivalent to the circuit in Fig. 1.

A real coil can electrically be described as an ideal inductance L in series with an Ohmic resistance R, parallel to both the winding capacity C. By far the most important quantity is the inductance, it de

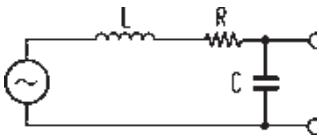


Fig. 2. A pickup as an audio voltage source plus second-order lowpass

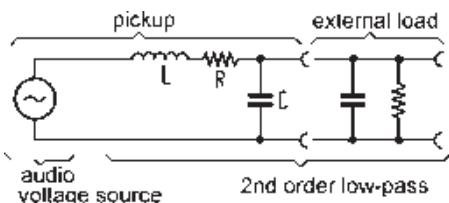


Fig. 3. A pickup plus real external load (pots, cable, and amp input resistance)

pends on the number of windings, the magnetic material in the coil, and the geometry of the coil. The resistance and the capacitance don't have much influence and can be neglected. When the strings are moving an AC voltage is induced in the coil. So the pickup acts like an AC source with some attached electric components (Fig. 2).

The external load consists of resistance (the volume and tone potentiometer in the guitar, and any resistance to ground at the amplifier input) and capacitance (due to the capacitance between the hot lead and shield in the guitar cable). The cable capacitance is significant and must not be neglected. This arrangement of passive components forms a so-called second-order low-pass filter (Fig. 3). Thus, like any other similar filter, it has a cut-off frequency f_g ; this is where the response is down 3 dB (which means half power). Above f_g , the response rolls off at a 12 dB per octave rate, and far below f_g , the damping is zero. There is no low frequency rolloff; however, a little bit below f_g there is an electrical resonance between the inductance of the pickup coil and the capacitance of the guitar cable. This frequency, called f_{max} , exhibits an amplitude peak. The passive low-

pass filter works as a voltage amplifier here (but doesn't amplify power because the output current becomes correspondingly low, as with a transformer). Fig. 4 shows the typical contour of a pickup's frequency response.

If one knows the resonant frequency and height of the resonant peak, one knows about 90 percent of a pickup's transfer characteristics; these two parameters are the key to the "secret" of a pickup's sound (some other effects cannot be described with this model, but their influence is less important).

What all this means is that overtones in the range around the resonant frequency are amplified, overtones above the resonant frequency are progressively reduced, and the fundamental vibration and the overtones far below the resonant frequency are reproduced without alteration.

How Resonance Affects Sound

The resonant frequency of most available pickups in combination with normal guitar cables lies between 2,000 and 5,000 Hz. This is the range where the human ear has its highest sensitivity. A quick

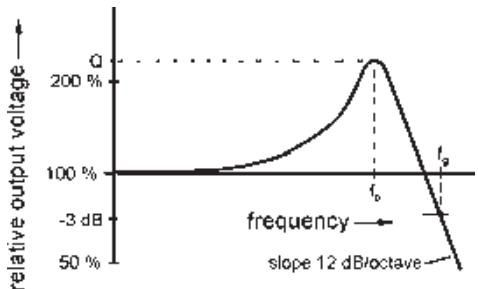


Fig. 4. Fundamental frequency response of a magnetic pickup. Position and height of the peak vary from type to type

subjective correlation of frequency to sound is that at 2,000 Hz the sound is warm and mellow, at 3,000 Hz brilliant or present, at 4,000 Hz piercing, and at 5,000 Hz or more brittle and thin. The sound also depends on the height of the peak, of course. A high peak produces a powerful, characteristic sound; a low peak produces a weaker sound, especially with solid body guitars that have no acoustic body resonances. The peak heights of most available pickups range between 1 and 4 (0 to 12 dB), it is dependent on the magnetic material in the coil, on the external resistive load, on the metal case (without case it is higher, many guitarists prefer this).

The resonant frequency depends on both the inductance L (with most available pickups, between 1 and 10 Henries) and the capacity C. C is the sum of the winding capacitance of the coil (usually about 80 - 200 pF) and the cable capacitance (about 500 - 1,000 pF). Since different guitar cables have different amounts of capacitance, it is clear that using different guitar cables with an unbuffered pickup will change the resonant frequency, hence, the overall sound.

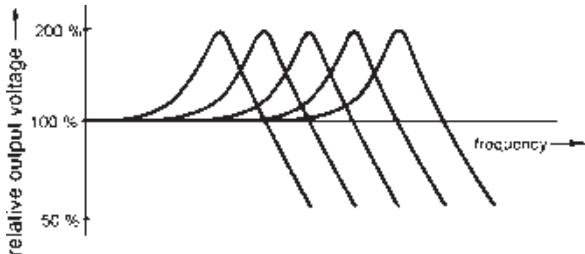


Fig. 5. Changing the frequency response with different external capacitors parallel to a pickup coil

Altering Pickup Characteristics

Basically, there are three different ways to change a guitar's sound as it relates to pickups:

1. Install new pickups. This method is most common, but also the most expensive.

2. Change the coil configuration of the built in pickups. This is possible with nearly all humbucking pickups. Normally, both coils are switched in series. Switching them in parallel cuts the inductance to a quarter of the initial value, so the resonant frequency (all other factors being equal) will be twice as high. Using only one of the coils halves the inductance, so the resonant frequency will increase by the factor of the square root of 2 (approximately 1.4). In both cases, the sound

will have more treble than before. Many humbucking pickups have four output wires - two for each coil - so different coil combinations can be tried without having to open the pickup. Some single coil pickups have a coil tap to provide a similar flexibility.

3. Change the external load. This method is inexpensive but can be very effective. With only a little expense for electronic components, the sound can be shaped within wide limits. Standard tone controls lower the resonant frequency by connecting a capacitor in parallel with the pickup (usually through a variable resistor to give some control over how much the capacitor affects the pickup). Therefore, one way to change the sound is to

replace the standard tone control potentiometer with a rotary switch that connects different capacitors across the pickup (a recommended range is 470 pF to 10 nF). This will give you much more sound variation than a standard tone control (**Fig. 5**). Also, adding an internal buffer amplifier can isolate the pickup from some of the loading effects of cable capacitance, thus giving a brighter sound with higher resonance frequency and higher peak.

The table correlates some well-known pickups and their electrical characteristics. However, note that pickups are not precision devices, and that old pickups in particular (e.g. Fender and Gibson pickups of the fifties) vary so much that almost each one sounds different from the next. Thus, the values of the resonant frequency in the table are rounded to the nearest 100 Hz. Also note that peaks become very flat and large below 1,000 Hz. As the height of the resonance peak depends on the external load resistance (volume pot, tone pot and amplifier input resistance), lowering this load (e.g. by switching resistors in parallel to the pickup) lowers the height. For raising the height of the peak, the load resistance must be increased. In many cases this is only possible by installing a FET or other high-impedance preamp in the guitar.

Resonant Frequencies of some well-known pickups with different additional capacitors

Pickup type	Winding		Additional capacity						
	Inductance (Henry)	Capacitance (pF)	470pF	680pF	1nF	1.5nF	2.2nF	3.3nF	4.7nF
Fender Stratocaster (1972)	2.2	110	4.4	3.8	3.2	2.7	2.2	1.8	1.5
Gibson Humbucker	3.8	130	3.3	2.9	2.4	2.0	1.7	1.4	1.2
Gibson P90	6.6	95	2.6	2.2	1.9	1.5	1.3	1.1	0.9
DiMarzio Dual Sound (coils in series)	6.4	80	2.7	2.3	1.9	1.6	1.3	1.1	0.9
DiMarzio Dual Sound (coils in parallel)	1.6	200	4.9	4.2	3.6	3.1	2.6	2.2	1.8
Seymour Duncan 59	5.0	120	2.9	2.6	2.2	1.8	1.5	1.2	1.0
Fender Jazz Bass	3.6	150	3.4	2.9	2.5	2.1	1.7	1.4	1.2
Fender Precision Bass	6.0	15	2.9	2.5	2.1	1.7	1.4	1.1	0.9
Gibson Bass EB 0/1/2/3	65.0	160	0.8	0.7	0.6	0.5	0.4	0.3	0.2

Continuously variable resonance

With different capacitors on a rotary switch, the resonance frequency can only be varied in discrete steps. It can be made continuously variable with an active circuit called "state variable filter". The first instrument manufacturer to apply this was *Alembic* since the seventies, later it was copied by others. For a skilled electronic expert it is easy to build. A technical layman can buy a complete circuit board. It needs a 9 V battery for supply and some space inside the body that must be routed.

Measuring Frequency Response

To precisely measure a pickup's frequency response, it would be necessary to measure the vibration of the string and compare it with the output voltage at every frequency. Practically, this is very difficult to do. An alternative to moving the string is to subject the pickup to an outside magnetic field, generated by a transmitting coil. This induces a voltage by changing the magnetic flux through the coils. As the induced voltage in the pickup is proportional to the variation of the magnetic field with time, the driving current through the coil must be inversely proportional to the frequency.

A sine wave voltage feeds an integrator circuit to produce an output voltage that is inversely proportional to frequency. This signal then goes into a power amplifier and then to the transmitting coil that actually couples the signal into the pickup. The coil can consist of a pickup bobbin wound with about 50 turns of enameled copper wire (approximately 0.5 mm, or 0.002 inches, in diameter). The exact number is not critical. The coil must be driven with constant current independent on its impedance. It is mounted above the pickup so that

it radiates its magnetic field into the pickup coil(s) as fully as possible. With single coil pickups, the axes must be in line with each other; with humbucking pickups, the axis of the transmitting coil must be perpendicular to the axes of the pickup's coil.

To plot the response, vary the sine wave frequency from about 100 Hz to 10 kHz and measure the pickup's output voltage with a broad-band multimeter or oscilloscope. The absolute value is not important; what matters is the position of the resonance peak and its height above the overall amplitude at lower frequencies. The effect of different load capacitors (cables) and resistors (pots) is easy to examine with this setup. One of the main advantages of this measuring method is that no modifications on the guitar are necessary, and the pickups need not be removed from the guitar.

The measured result is really precise only with single coil pickups. Humbucking pickups have certain notches at high frequencies because the vibrations of the strings are picked up at two points simultaneously. High overtones where the peak of the waveform occurs over one pole and the trough (valley) of the wave occurs over the other can produce cancellations. These notches are at different frequencies for each string and cannot be described with a single curve. For instance, with standard size humbucking pickups, for the deep E string the notch is at about 3,000 Hz, for the A string at 4,000 Hz. For the high strings the notch is far above the cutoff frequency f_g and can hardly be heard.

The effect of the sound difference between one coil and two coils with a humbucker is by far overestimated. The main reason for getting more treble with one coil is the raising of the resonant frequency because of halving the inductance. Sensing the strings at only one

point instead of two also has an effect, but this is much smaller. It can only be compared when the resonant frequency is held constant while switching.

Furthermore, this measuring method does not take into consideration the effect of different output voltages of different pickups. In the "crunch" range of a tube amp a loud pickup produces a different tone than a low pickup, even when their transfer characteristics are equal. Nevertheless, testing a pickup in this manner gives useful information on its characteristics. With this knowledge, you can find which type of sounds appeal to you the most, and possibly bend and shape the frequency response with external capacitors and resistors to "tune" pickups to your liking (and for the best match to the body and strings).

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The described rotary switches with different capacitors, high impedance guitar preamps, state variable filters and the measuring instrument for analyzing pickup frequency responses are handmade by

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http://www.gitarrenelektronik.de*





Making your own pickups

Winding your own pickups is certainly possible; there are no secrets behind this art, as the opened *Schaller* bass pickup or the disassembled *DiMarzio* humbucker show. The latter has a magnet polarized across its width that is on both sides in contact with six tiny 5mm ($3/16$ ")-diameter, 16mm ($5/8$ ")-long allen screws, which serve as adjustable magnetic poles. The flat magnet shown is too narrow and has therefore had a small piece of soft iron attached. The two bobbins are fastened to the brass base from the underside by means of the four tiny screws shown. See next page for details of the dimensions of this humbucker with five leads: two on either side for connecting the coils and the fifth for the connection to the metal grounding plate.

If you intend to make your own pickup, compare the cost of the wire and the magnets with that of a finished pickup first. My personal experiences with winding my own pickups are quite positive.

Magnets

Getting hold of suitable magnets can prove difficult, and I regret that I cannot offer much help there, either. True, there are a lot of magnet manufacturers, but they normally accept large-quantity orders only. One idea would be to use magnets and bobbins of pickups that no longer work, if you can get them.

Flat magnets polarized across their width, however, are very difficult to obtain in small numbers. On my hunt for magnets, I came across the pickup manufacturer *Kent Armstrong*. He also sells magnets and was kind enough to send me two pairs of them (which I used for the *P-90* pickups shown later) for free. Another source for such flat magnets may be *Allparts* (see supplier addresses).

If you find it too difficult to obtain suitable magnets, you can always improvise. Instead of placing a magnet polarized across its width between the two coils of a humbucker, you can also mount one flat, vertically-polarized magnet under each of the two coils, or you can use six short bar magnets as shown on the facing page. If you place the magnets so that the south pole of one and the north pole of the other faces the top, you don't need the more-difficult-to-obtain magnet polarized across its width. Thicker flat magnets increase the height of the pickup but are easier to get hold of. Small bar magnets that are inserted directly into the coil are relatively easy to find. There are, however, also unpolarized magnets available. In fact, many pickup manufacturers do not polarize the magnets until these have been fitted. To do this, they use extremely powerful magnets or special magnetizers with large capacitors which are capable of giving off a short-lasting, high-voltage electric impulse.



Pickup bobbins

Anyone can wind a normal single-coil pickup with magnets directly in the coil (1). The small Alnico-5 bar magnets needed for this, e.g. 20mm, 3/4", 15mm, or 5/8" long, and 5mm or 3/16" in diameter, which are normally used for switching reed relays, should be relatively easy to obtain from an electronics store. Magnets of these dimensions are exactly the right size and only have to be stuck into two thin plates to form a single-coil bobbin. Any kind of stiff material such as 1/16" or 3/32"-thick vulcanized fiberboard, 2mm (3/32")-thick plywood or some synthetic material can be used for the top and the bottom plate, synthetics having the disadvantage of not being very well suited for soldering purposes. I use 2mm-thick plywood because it is very easy to obtain. Make sure to leave enough space on the bottom part to allow a safe and reliable cable connection, ideally with a small clamp or a simple knot as a protection against pulling out the wires. The drawing on the next page shows the shapes of the top and bottom plate of a typical single-coil bobbin. Drill holes at both ends of the bottom plate; these will later be needed for mounting the pickup. A few holes are also needed for the pickup cable. Then drill six holes into both plates with a suitable bit, making sure to get the spacing between the poles right, and insert the magnets. Fix them with super glue. Wrap one layer of insulating tape around all the magnets and deburr all edges carefully as the wire breaks very easily when it gets caught there.

Jason Lollar (see supplier addresses) offers ready-made laser-cut bobbin top and bottom flanges made from vulcanized fiberboard. These are available for about US\$ 3,- per bobbin. Picture 3 shows two pairs: the top one will, after sticking in 3/16" x 5/8" Alnico rod magnets, give a *Tele*-style neck pickup, and the bottom one will, after sticking in 3/16" x 3/4" Alnico rod magnets, give a *Tele*-style bridge pickup. Each bobbin comes with two small eyelets, which serve as soldering points for the pickup leads. The original *Tele*-bridge pickup has a thin, ferrous plate glued to its underside. The plate is connected to ground and acts as a shield; it also helps to improve high-frequency response.

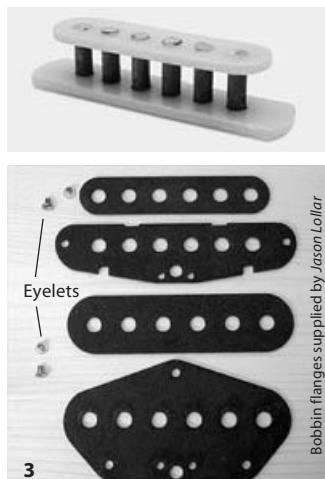
Wire

What you need is very thin enameled copper wire, about 0.06mm in diameter (AWG 42). With a bit of luck you will get such wire in an electronics store or from firms that repair and rewire motors. I bought my wire straight from a wire-manufacturing company, and they charged me approximately 700 Austrian shillings (about US\$ 55) per kilogram (approx. 2 pounds) of 0.06mm-diameter wire. Using thicker wire would not leave enough space on the coil for the number of windings needed, and the use of thinner wire would result in d.c. resistance becoming excessively

Magnetic materials

ALNICO is an artificially-produced, permanently magnetic material consisting of a mixture of aluminum, nickel and cobalt. Depending on composition and strength, these magnetic materials are named differently: Alnico-5 is the most famous one of these mixtures.

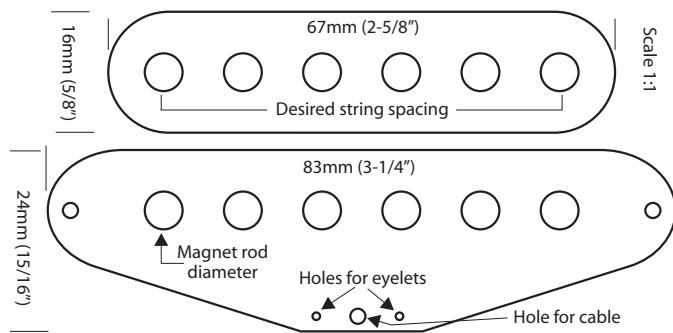
Ceramic magnets, however, are much more powerful. With all other factors remaining the same, a ceramic magnet will produce more output. They are also more resistant to demagnetization. Its a myth that the magnetic material has an influence on the sound. You can produce any pickup sound with any magnet.



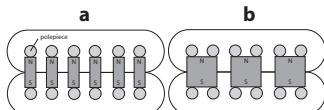
Orientation of magnets

When you stick bar magnets into the bobbin plates make sure that they are all equally oriented. All magnets in a coil should have either their north pole or their south pole at the top of the coil (except for single-bobbin split pickups where one half has to be oppositely polarized to get a humbucking effect). How to determine magnetic polarity is explained later.

Strat-style singlecoil bobbin flanges

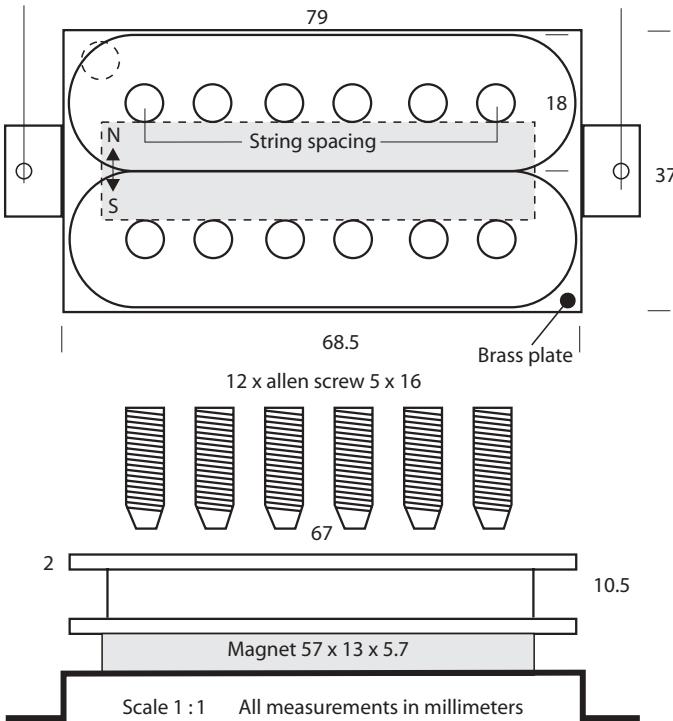


Dimensions of a typical Humbucker



Alternatives to a flat magnet

You can substitute the difficult-to-get single flat magnet with six 1/2"-long bar or flat magnets as shown in (a), or you could use some square magnets (b).



Wire gauges

Most original pickups are wound with 42 AWG (American Wire Gauge) wire. Especially for winding smaller coils 43 AWG or even thinner wire is sometimes used, although less commonly, as the total d.c. resistance of thinner wire is extremely high.

AWG	Diameter	D.c. resistance	Recommended tension
40	0.078 mm	1.08 ohms/feet (3.5 ohms/meter)	1.9 ounces (53 grams)
41	0.071 mm	1.32 ohms/feet (4.3 ohms/meter)	1.5 ounces (42 grams)
42	0.063 mm	1.66 ohms/feet (5.4 ohms/meter)	1.2 ounces (33 grams)
43	0.056 mm	2.14 ohms/feet (7.0 ohms/meter)	0.9 ounces (26 grams)
44	0.050 mm	2.59 ohms/feet (8.5 ohms/meter)	0.7 ounces (21 grams)
45	0.044 mm	3.35 ohms/feet (11.0 ohms/meter)	0.6 ounces (17 grams)
46	0.039 mm	4.21 ohms/feet (13.8 ohms/meter)	0.5 ounces (13 grams)

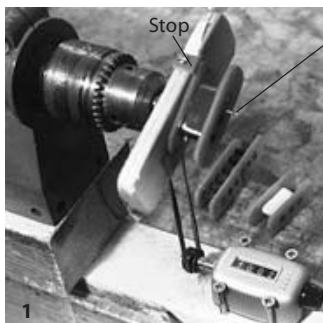
high, thus making the pickup sound less clear. When winding your own pickup success literally hangs by a thread. I wound my first few pickups with 0.036mm wire - not because I needed a challenge, but because a shop-assistant had erroneously sold it to me as 0.06mm (AWG 42) wire, and I continued to use it until the day I checked the gauge. Since I managed to successfully wind a few pickups without making a considerably thinner wire break, I now dare say that with a bit of care it is "almost impossible" to make the "right-gauge" and comparatively thick wire that I use now snap.

When making my first home-made pickup, I wound each of the six magnets individually because I could not imagine that winding around an uneven bobbin could possibly work well. Meanwhile I have tried both methods and would recommend winding around all the magnets or, on split pickups, around one half of the magnets and then around the other half. This method works very well, saves time and also saves you from potential mistakes as you don't need to solder the individual windings together. Winding a single-coil guitar pickup the way I first did would take you about six times longer than with the method I would recommend now.

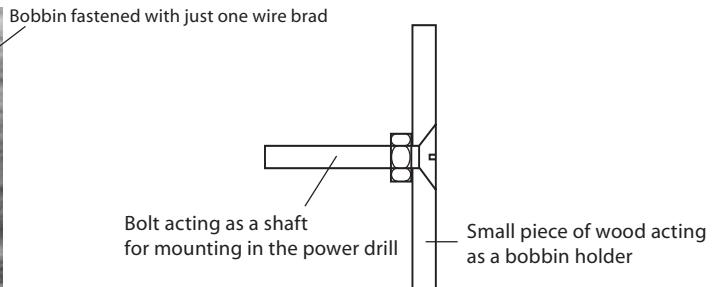
Pickup covers

Your self-wound pickup will look like a piece of professional work with a commercially-available cover on top of it. Such covers and the screws and springs needed for mounting them are available as spare parts. Make the bobbin so that it matches the cover and fits in tight. But of course you can also make your own pickup cover out of some pieces of pretty wood.

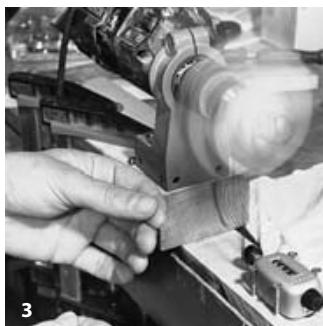




1



2



3



4

Winding pickups

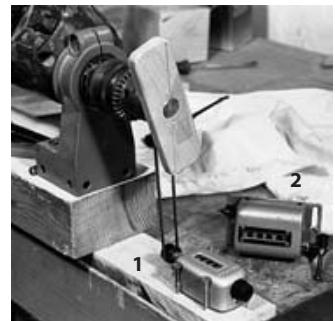
For turning the bobbin I use a piece of wood onto which a shaft such as a 6mm ($1/4"$) countersunk bolt with nut is mounted. You can fasten the bobbin either with double-stick tape, small nails or screws (1). A lot of pickups have only one tiny mounting hole in the top cover. This single hole is nevertheless sufficient if a stop for the bobbin is made on the bobbin holder.

The rotating power needed can be provided by a small electric motor or a power drill - ideally in combination with a foot pedal to allow control of the rotating speed. Set the lowest possible speed to start with, set the drill so that it rotates away from the body and fasten it on a holder mounted on the table (1), placing the spool of wire standing on the floor, as in picture (2). Then start making a few windings by hand and tape the end of the wire down on the bobbin with adhesive tape. Alternatively, you could also solder the end of the wire to the right lug straight away. Then switch on the drill with one hand and complete a few windings. When you feel confident, press the locking knob on the drill and continue winding, guiding the wire first with one hand (3) and then with both hands, without pulling it, though (4). The wire will unwind from the spool automatically (probably because it was also initially wound onto the spool from above). For this to work well and not to cause the wire to break, the top edge of the spool obviously has to be very smooth. This simple wire-unwinding-method has always worked well when I used it. As already mentioned, make sure to pull the wire - which is almost as thin as a human hair - as little as possible (the friction between your thumb and index finger is sufficient) and to keep moving it slowly and evenly from one side to the other. If you should wind wire over the edges, stop the drill immediately and remove those windings. For a single-coil it is not really necessary to place the windings neatly parallel to each other around the bobbin; this is, in fact, virtually impossible without appropriate equipment. The very first pickups were all wound by hand more or less sloppily, and nowadays everyone is full of praise for them. When I wind a pickup, I just try to keep the coil evenly thick and to not let it become thicker in the middle and thinner near the edges where one naturally tends to be overcautious.

Be careful, the wire can easily break. If this happens early on, the best thing to do is to change the rotating direction of the drill, unwind the wire, throw it away and start all over again. If you have already progressed a bit further in the winding process, you can either do the same and start from scratch, or you can solder the broken wire. If you choose to do the latter, twist about 10 to 20mm ($1\frac{1}{2}$ " to $\frac{3}{4}$ ") of the wire ends together so that they remain joined and heat this area with the tip of a soldering iron until the joint begins to shine silvery (when solder is applied). When heated, the coating will evaporate and the copper wire will come to the surface. Alternatively, you could also first sandpaper the ends of both wires and then twist them together. This is certainly a case of precision work, and although there is unfortunately no possibility to test the joint made, it should be fine if the solder has been heated sufficiently and sticks on the wires. Before you continue winding with the drill, start again by making a few windings by hand. Anyway, I'm convinced that with a bit of care and practice you will manage to wind up all the wire in one go and without making it break so that all of these mending instructions may well be superfluous.

After some time you will become more confident and will probably want to increase the speed of the drill. When you do so, be patient and do not go over the top. The maximum speed I use is 10 revolutions per second. At this speed the one-but-last digit of the counter changes every second, and winding 6000 turns takes only about 10 minutes. You should be able to work with maximum concentration over such a relatively short time-span. Winding faster, makes it difficult to keep things under control. I also recommend that you use a bright background to relieve the straining effect of having to keep your eyes fixed on the thin wire for quite some time. Depending on how you hold your head, the wire can be seen better or less well. When you approach the end, switch off the winding jig early enough as it will continue to rotate for a short while. The last few windings can be made by hand and should always be placed on the base plate.

For more in-depth information on pickup-winding I can recommend a book written by the American *Jason Lollar*. He gives exact measurements of standard pickup bobbins, explains how to make them and describes how to build a comfortable pickup winder that winds unattended (see the section on literature).



Counting the windings

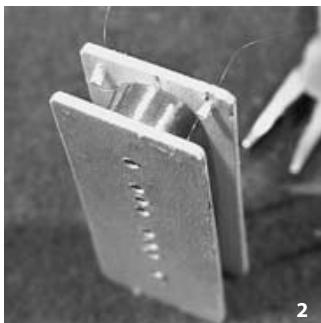
Counting the windings to reach an exact number of turns is not really important when making a single-coil pickup; just keep winding until the bobbin is fully covered with wire. Mathematical calculations will not get you very far, and only the end-product, the finished pickup, will reveal the tonal qualities. Remember, however, that the more windings there are the higher the d.c. resistance will become, and with it the sound less clear.

In some cases the exact number of windings does matter, though: when making a humbucker, for instance, both coils have to be identical, and some way of counting the turns has to be found. One possibility would be to couple the bobbin with the counter of an old tape recorder or a bike speedometer. If the counter has only three digits, each new start at "000" has to be noted. I use a four-digit counter (1) that is linked to the bobbin with a rubber band. If the bobbin and the counter shaft diameter are the same, the number shown on the counter equals the number of windings on the coil.

Other counters have a lever which has to be operated with each winding that is added (2).



1



2



3



4

How many turns?

The number of turns depend on the wire you use and the sound you want to achieve. Here's a rough guideline when using AWG 42 wire: use about 8,000 turns for a single coil and about 5,000 turns per coil when making a humbucker.

To equalize the output single-coil bridge pickups can have more turns (e.g. 7,800) than neck pickups (e.g. 8,200). Humbuckers used at neck position could have 4,500 turns per coil and if used at bridge position 5,000 turns.

When the desired number of turns has been reached and winding is finished, the hour of truth has come. Break the wire and carefully remove the finished coil from the winding jig (1). If you have not yet put the two ends of the wire into the contact eyelets (2) and soldered them into place (3), do so now. If necessary, remove the insulation with a bit of sandpaper; the insulation is gone when the wire color changes. Alternatively, you can also do this the way I do, which is to continue soldering until the insulation melts. After this, set the function switch of an ohmmeter to the 100K-ohm position to start with and bring its probes in contact with the ends of the wire. If the ohmmeter shows a figure, the coil is fine. If, on the other hand, it shows an "infinite" ohms reading, or "OL" on a digital multimeter, there is a problem and only one hope left, which is to reheat both ends of the wire. If there is still no connection after this, the wire connection is broken somewhere in between and all you can do is destroy your piece of work, remove the wire and start from scratch. If the coil is fine, mark the ends of the windings (S=start, E=end) and solder two contact wires into place (4), making sure to fasten them in such a way that they are exposed to as little pull as possible.



Magnets supplied by Kent Armstrong

Finished pickups

A split bass pickup (**left**): the magnets are thicker and longer than usual. For each string there are two bar magnets.

After about 10,000 windings, this P-90 reproduction (**right**) shows a resistance of 10 ohms, which is a fairly tolerable value, also when compared to the roughly 8.3K ohms of the original P-90. Its original flat magnets are polarized across their width.



Potting pickups

Microphonics will be a problem when pickups are wound too loosely and the loose wire subsequently behaves like a microphone, generating an additional alternating current inside the magnetic field and thus making the pickup susceptible to feedback or causing it to pass on fretting noises or clapping on the body. To fix the windings in place, immerse the finished coil in hot, liquid wax of a maximum temperature of 65 degrees Celsius (150°F). At this temperature, the pickup is absolutely safe and nothing can go wrong. A deep fryer would be ideal for this purpose, but it is probably not worth ruining one for the sake of just very occasionally immersing the odd pickup in it. I put a metal container into a hot water bath to heat the wax (5).

Always use a mixture of paraffin and beeswax for potting pickups. Pure paraffin wax is too brittle and pure beeswax has a melting point that is too low. By adding about one part of beeswax to four parts of paraffin wax, you get a perfect mixture. Always check the temperature, for instance with a meat thermometer. As the wax can be much hotter close to the container walls and at the bottom, try to steer clear of these. By putting small pieces of wood at the bottom of the container, you can make sure that the pickup is safe from making contact with it. Leave the pickup in the wax-bath for 10 to 20 minutes, but at least until there are no more air bubbles rising. Wear eye protection when placing the pickup into the wax-bath, just to make sure.

Pickups can also be encapsulated with epoxy resin. This kind of treatment, however, has the disadvantage of making the pickup inaccessible afterwards. Apart from that epoxy resin does not penetrate the windings as well as wax but just sticks to the outside of the coil. Wax is also easy to remove by re-heating the pickup. Immersing the pickup in wax is an environmentally-friendly method used by a lot of manufacturers.

A bit of physics

While the pickup was in the wax-bath, I connected it to an ohmmeter and found that its resistance had risen: the cold pickup had shown a resistance of 10K ohms, the hot pickup showed 12.57K ohms.

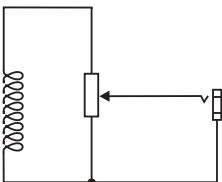
What can we learn from that? Electrical resistance increases and decreases with temperature.

Because wax is extremely flammable, I recommend that you always pot your pickups in a safe place outdoors and that you keep a lid at hand for quickly covering the pot in case of fire. Always use a thermometer to ensure a temperature of 65 degrees Celsius (150°F) is never exceeded. Since paraffin gases can easily catch fire, you must never even attempt to heat the wax in a microwave oven.

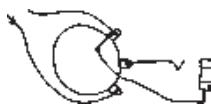
Passive circuits



1



2



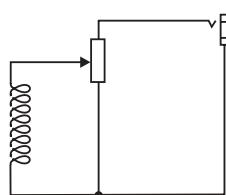
3

So far I have only dealt with the pickup on its own. As soon as you connect a pickup's leads to something, a circuit is formed and the pickup changes its characteristics. The simplest form of circuit is a pickup directly linked to the output jack (1) and an amplifier on which the level of volume and the tone can be adjusted. In this form of circuit only the cord resistance, the amplifier input resistance and, above all, the cord capacitance determine the sound of the pickup.

A volume control (2,3) is another example of a simple circuit that is quite sufficient for the purists among guitar-players, in the eyes of whom an abundance of switches, pickups and circuit combinations only makes operating the guitar more complicated and diverts from the actual playing of the instrument. The volume control on the guitar enables the player to adjust the volume without having to head for the amplifier all the time. Apart from that the volume control also serves as a signal adaptor for amplifier inputs that are too sensitive. When the wiper blade is fully turned to the end to which the "hot" pickup wire is soldered the electric current does not have to flow through the resistance path and is therefore not weakened. As a result, the full volume is produced. The further the wiper is turned to the opposite end, which is the end connected to the ground wire, the longer the path of resistance that the signal has to pass becomes and the weaker the flow of current gets, leading to the signal gradually decreasing in volume and finally becoming inaudible when short-circuited to ground.

The volume pot is another factor that has an influence on the sound of the pickup. Normally, single-coil pickups have 220 or 250K-ohm pots, and humbuckers 470 or 500K-ohm pots, but this is also a matter of taste. Volume pots are not free from unpleasant side-effects, though: the further the wiper is turned towards the ground contact the more trebles are cut. This typical feature of electric guitars - turning down the volume pot makes the sound become more and more muffled - is due to the fact that the pickup inductance and the cord capacitance form a resonant circuit from which the resonant peaks, which are responsible for making the sound bright, are increasingly weakened by the resistance part of the pot that is switched in between.

This problem of treble loss becomes even worse when the pot is connected "the wrong way round" (4). As the volume is turned down, the coil is more and more loaded until it is eventually short-circuited against ground. The resonance peak is weakened.



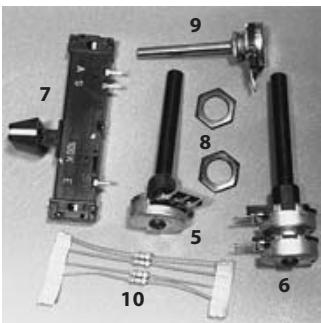
4



Output jacks

The standard jack used on electric guitars is a 6.35mm (1/4") female audio jack. Because this type of jack is also used as an input jack on the amplifier, both ends of a standard guitar cord are identical so that it does not matter which end is plugged into the guitar and which into the amplifier.

Mono jacks have two contacts (1), one of which is connected to the casing and the other to the contact lug. When a phone plug is plugged into the jack its specially-shaped tip clicks into place at this lug while the rear part makes contact with the casing (2). On open jacks these connections are clearly visible. On insulated, synthetic jacks the contact situated closer to the mounting nut is the ground contact. Some jacks also have additional on-off switch contacts (4) that are activated when the cord is plugged in. Stereo jacks and plugs have an additional third connection (3).



Types of potentiometer

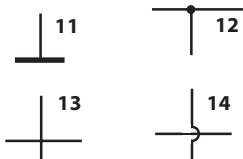
- (5) Normal potentiometer
- (6) Stereo pot: two wipers on two resistance paths are simultaneously moved by one shaft
- (7) Slider pot: the wiper is moved in a straight line on a resistance path; although conceivable, this type is hardly ever used on electric guitars
- (8) Mounting nuts
- (9) Pot with thinner shaft

Potentiometers

The level of volume can be adjusted with manually-adjustable three-pole resistors called potentiometers, or pots for short. These are building components with three lugs - both ends of a path of resistance and a wiper - protruding from their case. When the wiper is moved on the conductive path by turning the shaft the resistance between the wiper and one of the two outer poles is changed. On linear pots the resistance changes evenly: when the wiper is in the middle position, for instance, the resistance value is half of the maximum possible.

Audio taper pots, or logarithmic pots, are a special type of pot where the resistance changes unevenly as the wiper is turned from one end to the other, with most of the resistance change occurring at one end of the turn. This type of pot is often used for volume and tone controls because they create an impression in the human ear of hearing a gradual change around the full turn. But it is of course also possible to use linear pots for volume controls - after all, tastes are different. Linear pots are commonly marked with the letter A, audio taper pots with the letter B. So a pot marked 250KA is a linear and one marked 250KB an audio taper pot.

The representation of a resistor or pot in a wiring diagram is regionally different. Where I live, the "Deutsche Industrie Norm (DIN)" is valid and the symbol for a resistor is a small rectangle; a pot is represented by an arrow across a rectangle. The American style is more graphic but also more difficult to draw. I use a hybrid in this book.

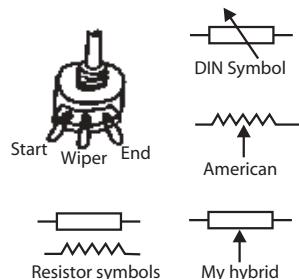


Rules for circuit diagrams

The ground wire is the common point of reference for all electric charges in an electronic circuit. To make circuit diagrams easier to read, wires connected to ground are often only shown as symbols (11) and are not connected in the diagrams. This is especially useful for more complicated circuit diagrams where the number of lines that would otherwise have to be connected to ground would make the diagram difficult to read. In the actual wiring, however, all ground points have to be linked with each other and with the rear contact of the jack.

A wire junction is represented in a circuit diagram by a fat dot (12).

Two wires crossing each other without any connection are often represented by two crossing lines without dot (13), or in American



Capacitors

Capacitors constitute obstacles for direct currents which only allow alternating currents to pass. In a capacitor two physically separated plates are positioned so close to each other that alternating charge flows - such as alternating currents - can influence each other. The resistance of a capacitor is low at high frequencies and high at low frequencies - or to put it differently: it presents less resistance for higher frequencies. Capacitors are building components that can be used as a kind of frequency-dependent resistor. The higher their value is, the lower the frequencies that can pass will be. Low-value capacitors can be mica or ceramic disc capacitors. Capacitance is measured in picofarad (pF), nanofarad (nF) or microfarad (μF or mf). 1nf equals $1,000\text{pf}$, and $1,000\text{nf}$ equals 1mf (i.e. $0.001\text{mf} = \mu\text{F} = 1\text{nf} = 1000\text{pf}$). Unfortunately, capacitance values are all too often not clearly and unmistakably printed onto capacitors. On most of them you will only find numbers, and any indication of the dimensions will be completely missing. The value of such capacitors has to be "guessed" primarily by going by their size; this should not prove too difficult when applying a bit of common sense. The number "1000" printed on a small-sized capacitor will, in all likelihood, mean $1,000\text{pF}$ ($= 1\text{nF}$). " $1E3$ " could stand for "ten to the power of three," which would also be $1,000\text{pF}$. And finally ".001" could be used short for $0.001\mu\text{F}$, which would also be 1nF . Fortunately, some multimeters allow measuring capacitance.

Another possibility is a three-figure code printed onto the capacitor, with the first two digits denoting the value in picofarads (pf) and the third the number of zeros: "503" is then $50 + \text{three zeros} = 50,000\text{pf} = 50\text{nf} = .050\text{mf}$



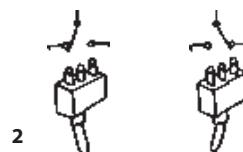
Circuit symbol and
actual components

Toggle switches

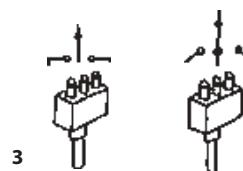
Switches are connections that can be broken by mechanical means. They can also be used to change the path of signal flows. Switches are named after the number of their poles and possible switch positions (throws). The simplest type of switch is the ON-OFF switch (SPST = single-pole single-throw) with two contacts which are connected by throwing a lever or pushing a knob. Figure (1) shows the symbol for such a switch.



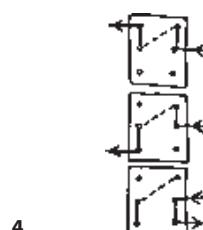
An ON-ON switch (SPDT = single-pole double-throw) needs three contacts (2), and there are two positions for the lever or the knob: when it is in its left position the contact in the middle is connected with the contact on the right, and vice versa. Thus a signal can be rerouted.



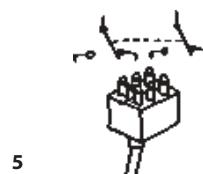
An ON-OFF-ON switch has a third, "neutral" middle position for the switch (3) where no connection with either of the outer two contacts is established. This makes it possible to switch two capacitors in parallel with the pickup or none.



An ON-ON-ON switch is a special type of switch which works as shown in illustration 4 or in a mirror-image form, depending on the model. Such switches make it possible to select either the left or the right signal-path, or both simultaneously when the switch is in its middle position.



Multiple-pole switches can open or close several contacts simultaneously. Thus a double-pole double-throw (DPDT) switch (5) works like two SPDT switches placed side by side and activated simultaneously, and a three-pole switch represents three SPDT switches activated simultaneously.



If you are not sure whether a switch is working properly or not, or for exploring how it works, use an ohmmeter to find out.

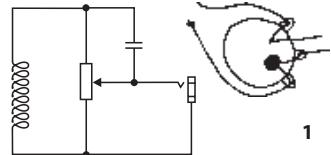
Treble loss caused by a volume pot can be reduced by using a capacitor (1). The right value should be found by experimenting with capacitors of different values. A typical "treble bleed" capacitor value is .001mf (microfarad). Because a current will always choose the way of least resistance, the higher frequencies of a signal will flow through the capacitor the more readily the greater the pot resistance is. This is an elegant way of compensating for the loss of trebles caused by the pot. On humbuckers and 500K-ohm pots connecting a .001mf and a 150K-ohm resistor in parallel has proven a good method (2) as such a parallel connection leaves the pickup loaded with approximately 300K ohms and keeps the sound evenly balanced throughout the entire adjustment range. With single-coils and 250K volume pots a .0025mf capacitor and a 220K resistor will keep the tone more consistent when the volume is turned down.

Capacitors are traditionally used to control the tone. (3) The smaller the pot resistance before the capacitor becomes, the more high frequencies of the guitar signal are short-circuited to ground and do not reach the output jack, which causes the tone to become less trebly. Experience, however, has shown that most players keep the tone control pots fully turned up in order not to cut too many treble frequencies and let the sound become too muffled. To ensure a relatively even adjustment a logarithmic pot has to be used. Common tone pot capacitance values are 0.047mf or 0.05mf (47nf and 50nf respectively) for single-coil pickups and 0.02mf (20nf) for humbuckers, but it is certainly worth experimenting with different values.

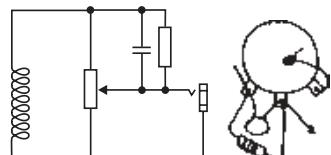
If your tone control is a pot with built-in switch (a one-pole switch will do), you can switch between two different-value capacitors (4).

To get even more tone control options you can connect different capacitors in parallel with the pickup by means of a simple rotary switch (5). This shifts the pickup's resonant frequency and other pickups are imitated. Experimenting with capacitors of different values between 0.0005mf (0.5nf or 500pf) and 0.010mf (10nf) - which one exactly is pickup-dependent - will allow you to find out differences in tone colors. A higher-value capacitor switched in parallel will cut more treble and make the tone bassier than a smaller-value one. If there are any crackling sounds when the rotary switch is turned, connect a 10M-ohm resistor in parallel with each individual capacitor. You can buy ready-made rotary switches with built-in capacitors (6) for most common pickups and guitars from the German guitar electronics expert *Helmuth Lemme* (see supplier addresses).

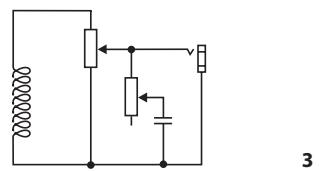
A further option worth experimenting with is to connect a fixed-value resistor in series (6-8K ohms) or in parallel (100-150K ohms) with the capacitor. This resistor should cut resonant peaks that are too high and make the sound warmer.



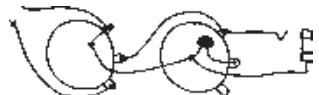
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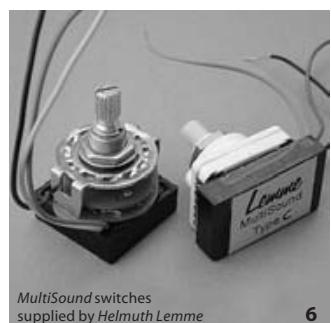
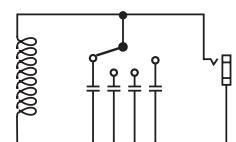
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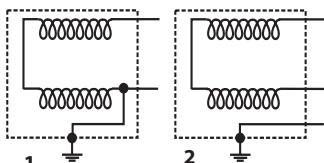


5

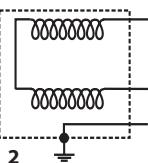


MultiSound switches
supplied by *Helmuth Lemme*

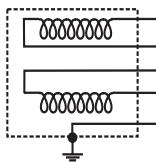
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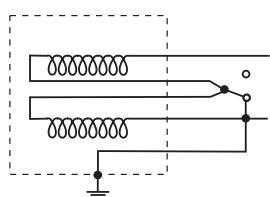
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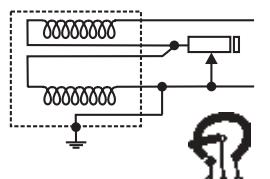
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5

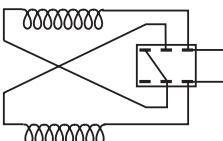
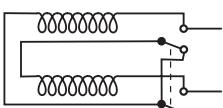
A humbucker consists of two identical coils that are normally connected in series, with the ends of the windings connected and the beginnings of the windings coming out from the coil as separate leads (or vice versa). One of these leads is often connected with a metal grounding plate (1), thus providing a shield for the pickup. In this case it is essential that this lead is also connected to ground. Although normally two leads are sufficient, you can get more tone options when the shield wire is turned into a third lead and is made accessible from outside (2). The maximum amount of wiring freedom on humbuckers is obtained with five leads (3) (the four coil wires (two beginnings, two ends) plus the ground wire).

Turning a humbucker into a “real” single-coil pickup (coil tap) is possible by short-circuiting one of its coils by means of a switch (4). This will give the typical single-coil sound, but of course the hum-cancelling effect will be lost.

Instead of using a switch it is also possible to connect a modified pot in parallel with a coil (5). To do this, carefully open the pot and interrupt the path of resistance at one end by making a few cuts with a knife. This will leave the humbucker unchanged at this end of the pot. By turning the pot the wiper will re-establish contact with the other end and the coil will gradually be more and more short-circuited against ground.

Connecting the two coils of a humbucker in parallel will give further tone color options while leaving the humbucking effect intact. This is possible by means of a DPDT (double-pole double-throw) switch (6). Such a parallel connection will result in a brighter sound, yet give less output.

6



Manufacturers and wire colors used for pickup connections (cw = clockwise, ccw = counterclockwise)

Single-coil

Manufacturer	Start	End	Polarity/Winding
Tom Anderson	black-	white+	N cw
Kent Armstrong	black-	white+	S cw
Seymor Duncan	black-	white+	S cw
Gibson P-90	black-	white+	N cw
Fender Strat	black-	white+	S cw
Fender Tele	black-	white+	S ccw
Gotoh	black-	white+	S cw
Lindy Fralin	black-	white+	variable
Lawrence	grey -	white+	N cw
Schaller	black-	white+	variable



Humbucking combination of two single-coils

When two separate single-coils with an opposite magnetic polarity field in each coil are used simultaneously both pickups can be connected in parallel or in series, like a humbucker. Why this option is not made use of on Jazz Bass pickups like the ones shown on the left is a bit of a mystery to me. On this cheap types the magnetic polarities is the same in both pickups and very difficult to change because the magnets are stuck right between the windings.

Conversely, on pickups which have their flat magnets lying under the coil the polarity of the magnetic field can easily be altered by changing the orientation of the flat magnets.

Determining the coil leads

If you have no wiring instructions and no idea of how a humbucker is connected inside, you have two options for finding out: you can either try to take the pickup apart - which I would advise against as the pickup can easily be damaged in the process -, or you can use an ohmmeter to measure resistance and then draw logical conclusions from it. To do this, switch a multimeter to the ohms-section, set the function switch to 20K ohms and bring the probes in contact with any two wires. If they are not connected, they belong to different coils. Continue holding one of these wires to one of the probes and test the others systematically through until a resistance value is shown, which means that you have found the two leads of one coil. Note their colors before you proceed in the same manner with the other leads. When you have found and noted the colors of the leads of the second coil, there will be one lead left which should be connected with the metal bottom plate. Quite often this wire is identical with the braided shield wire of the pickup cable and therefore instantly recognizable.

Determining coil polarity

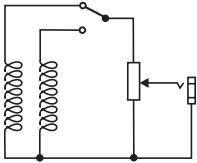
To determine the coil polarity connect the coil to a voltmeter, touch one of the magnetic poles with a screwdriver and take it off quickly after a second or so. If no voltage is shown for this coil, try the other. For a short moment an either positive or negative voltage will be induced in the pickup. If it is negative, reverse the probe connections. Now note the color of the wire that is connected to the + socket of the voltmeter and find out the positive contact of the other coil in the same manner. To get the normal humbucking effect both positive leads are used as pickup leads and the other two are connected. One of the positive leads is defined as a ground lead and connected with the shielding wire. Although this method does not make it possible to tell whether the two positive leads are the beginnings or the ends of the windings, it does none the less enable in-phase wiring if other pickups are measured in the same way. Such "tests" are absolutely safe - nothing can be destroyed by carrying them out.

Determining magnetic polarity

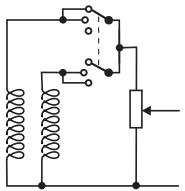
With a compass it is easy to determine the magnetic polarity of a pickup's polepieces. Simply hold it to the polepieces and watch which end of the compass needle is attracted. If the south-end is showing to the pickup, the polepieces have the north poles on the top of the coil (If the south pole is at the top of the pickup, the north-end of the compass needle is attracted). You will only need the compass once if you mark the magnetic polarity on a "reference" magnet with the above-mentioned method. If this magnet is then repelled by a polepiece, the polepiece has the same polarity as the side of the reference magnet that is held to it.

Humbucker

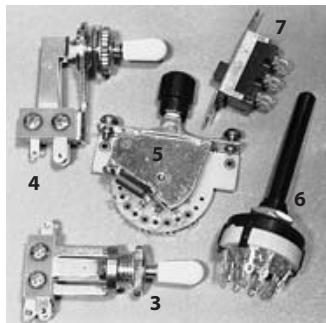
Manufacturer	Adjustable Poles		Fixed Poles	
	Start	End	Start	End
Tom Anderson	black-	white	green	red+
Kent Armstrong	red+	blue	green-	white
Seymor Duncan	green-	red	black+	white
Gibson	black-	green	red+	white
Lindy Fralin	black-	red	white+	red
Lawrence	green	black-	white	red+
Schaller	white	green-	brown	yellow
Joe Barden	green-	red	black+	white
Benedetto	green-	white	red+	black
DiMarzio	green-	white	red+	black



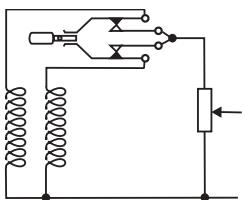
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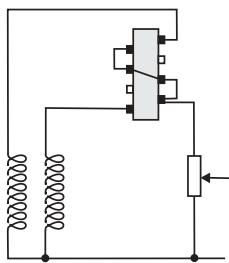
2



8



9



A pickup selector switch is needed when a guitar is fitted with more than one pickup. An SPDT switch (1) would do for this purpose, although this would not allow combining both pickups. This would, however, become possible with a double-pole three-position toggle switch (2), which would give the following options: the front pickup alone in position one, the front and the rear pickup together in position two, and the rear pickup alone in position three. To prevent huge volume level differences arising from the use of extremely low- or high-ohm pickups both pickups should be of a similar resistance. When using two single-coil pickups with opposite magnetic polarity in both coils a humbucking effect can be obtained by throwing the switch into position 2, which connects the two coils in series.

Special pickup selector switches allow selecting pickups 1 and 2 alone as well as both combined. One of these models (3, 4, 8) is very simple: by moving the toggle to one side the leaf contacts on the other are separated while in the middle position both sets of contacts are connected. There are also L-shaped types (4) available for fitting into bodies thinner than 45mm (1 $\frac{3}{4}$ "'). Apart from toggle switches there are also slider switches (7).

Three-way lever-action switches (5) are a bit more complicated. But when wired as shown in illustration 9 they will give the options pickup 1 alone, 1 and 2 combined, and pickup 2 alone (in that order).

It is also possible to use a double-pole rotary switch (6) with three switch positions for each pole, but most guitarists prefer toggle switches. There are rotary switches with an individual level for each pole. Each level consists of a printed circuit board on which the lugs of each pole are arranged in a circle. The way these switches work and the assignment of the poles is easy to understand. Other rotary switches have 12 lugs in a circular arrangement working differently depending on the number of poles. Depending on the model, 1 x 12, 2 x 6, 3 x 4 or 4 x 3 contacts are possible. There is a common pole for each level in the middle. On some models the number of switch positions (throws) can be altered by changing the position of a small pin and thus turning a 2 x 6 switch, for instance, into a 2 x 3 switch.

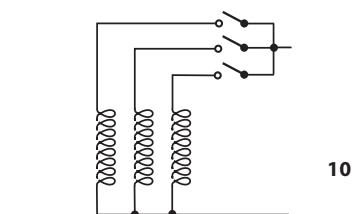
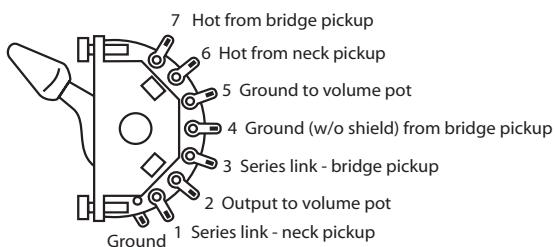
With three or more pickups the number of possible combinations increases, but the wiring gets more and more complicated, too. Using three individual ON-OFF (SPST) switches is a simple way of getting any desired pickup combination (10). However, on most guitars with three pickups a special five-position leveraction switch is used that looks similar to switch 11 and gives the following options for pickup selection: 1, 1 and 2, 2, 2 and 3, and 3. Such five-position switches were developed in response to the demand for a more stable switch position than the improvised in-between positions many players used with the

conventional three-position switch to get pickups 1 and 2 or 2 and 3 together.

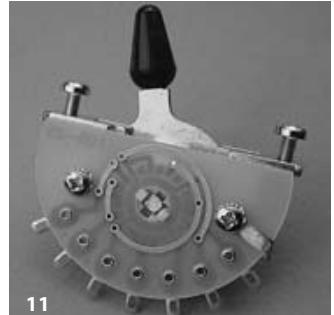
More pickup combinations are made possible by using multiple-pole rotary switches. But as guitarists often prefer the five-way lever-action switch special versions of this type of switch which give more than the usual number of combinations have been developed.

The **Megaswitch** (11), a high-quality lever-action switch, can be used in place of an ordinary five-way switch. Apart from the standard Stratocaster and Telecaster functions (S- or T-models with 8 lugs) there is also a P-model which simulates the pickup combinations of a *Paul Reed Smith* guitar; its two humbucking pickups are connected to give the following positions and combinations: 1: bridge humbucker, 2: inner coils of both humbuckers connected in parallel, 3: outer coils of both humbuckers in parallel, 4: outer coils of both humbuckers in series, 5: neck humbucker.

The first *Megaswitch* was developed to get five good sound combinations from three pickups. It can be used in the following combinations: single-coil/single-coil/single-coil, humbucker/single-coil/single-coil, humbucker/single-coil/humbucker and humbucker/humbucker. This *Schaller* switch comes with detailed wiring instructions, so I'm not going to enlarge on them here and now.



10



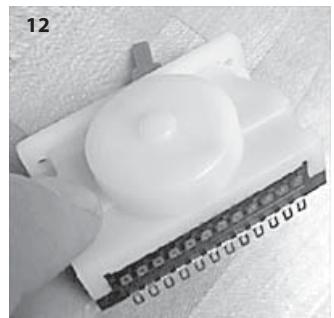
11

Megaswitch P-model for two humbuckers
(Outside coils must have opposite polarity)

Positions:

- 1 Bridge humbucker
- 2 Inner coils in parallel
- 3 Outer coils in parallel
- 4 Outer coils in series
- 5 Neck humbucker

With *Yamaha's* four-pole five-position lever-action switch (12) a particularly high number of different combinations is made possible. Its wiring, however, is accordingly complex. This switch is available from *Stewart-MacDonald*. Because the wiring instructions that come with it are very detailed, I will not repeat them in this book. I would strongly recommend that you really only use such a switch if you consider the number of conventional pickup combinations not sufficient.



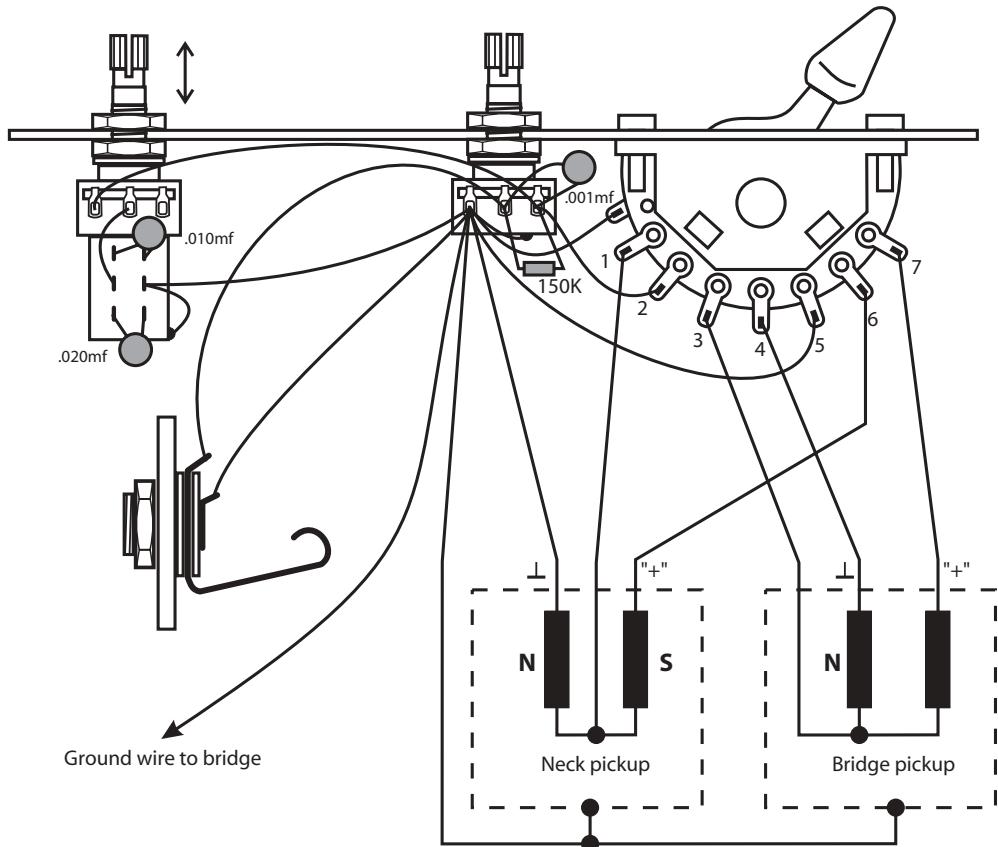
12

Pickup selector
Schaller Megaswitch P-Model

- 1 Bridge humbucker
- 2 Inner coils in parallel
- 3 Outer coils in parallel
- 4 Outer coils in series
- 5 Neck humbucker

Tone
500K ohms log Push/Pull- pot
with DPDT switch

Volume
500K ohms log



**PRS-like circuit with
Megaswitch P-model**

This circuit is mounted on a metal control plate. I used it for the guitar I built most recently (see page 86). The .001mf capacitor and the 150K-ohm resistor soldered to the volume pot should equalize the change of volume over a complete turn of the pot.

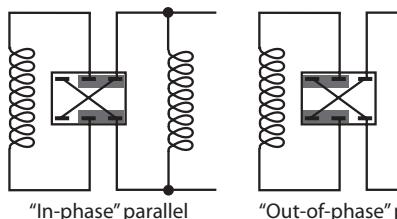
The outside coils of the pickups must have opposite magnetic polarity

Out-of-phase wiring of pickups is a further possibility of getting yet more tone color options. The effect will only occur when at least two pickups are on and will be most obvious when the pickups are at approximately the same volume. When two or more pickups are simultaneously switched on all pickups react in the same way when a string vibrates over their magnetic poles, inducing, for instance, a positive voltage as the string moves towards the pickups and a negative voltage when the string moves away from them. When one or several pickups are connected "out of phase" a thin nasal sound useful for certain styles of music is produced. This can be achieved by simply reversing the leads of one of the pickups. Phase-switching is possible with an ON-ON DPDT switch (1) or a potentiometer with built-in DPDT switch. The latter has the advantage of not requiring the drilling of an additional hole for fitting the switch. If you have two or more humbuckers, you can connect one of them to a switch as shown in figure 2 to reverse its leads and to achieve the "out-of-phase" effect (the humbucker must have a separate ground wire). Two single-coils can be connected to the phase-switch in the same way as the two coils of a humbucker.

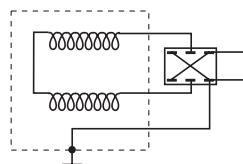


Potentiometer with built-in switch

Such pots help to keep the number of controls on an electric guitar down. Pulling the shaft of the pot activates a DPDT (double-pole double-throw) switch, pushing it back switches back (push/pull pot). There are also push/push versions of this type of switch (push/push pots), with the first push used for switching on and the second for switching back.



1



2

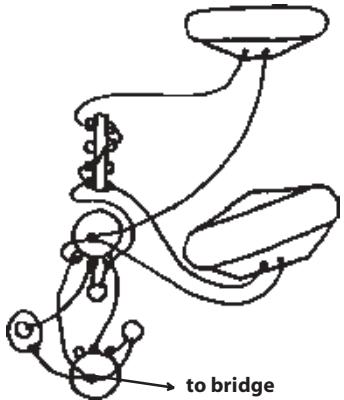
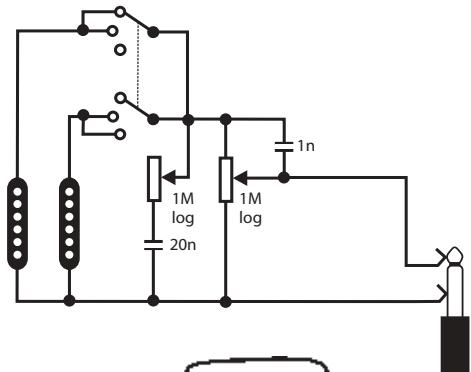
Phase relationship between two coils

The chart assumes the typical parallel connection - the connection you get with a selector switch.

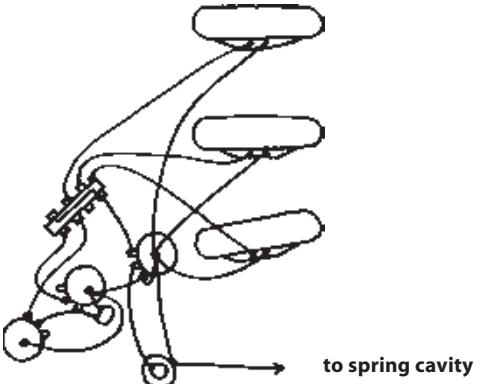
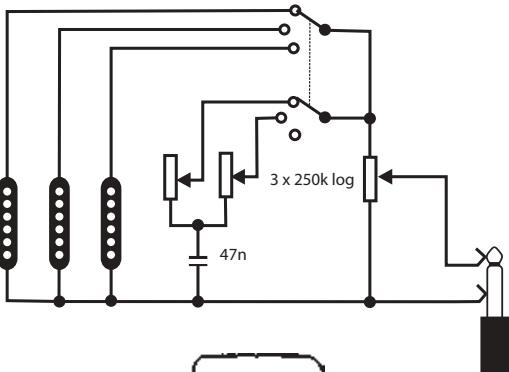
CW = clockwise / CCW = counterclockwise / N = north pole / S = south pole
IN = "in-phase" / OUT = "out-of-phase" / HC = Hum-canceling

	CW-S	CW-N	CCW-S	CCW-N
CW-S	IN	OUT	OUT	IN-HC
CW-N	OUT	IN	IN-HC	OUT
CCW-S	OUT	IN-HC	IN	OUT
CCW-N	IN-HC	OUT	OUT	IN

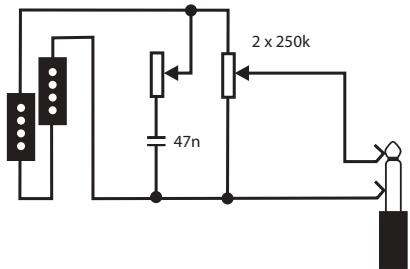
Classic circuits



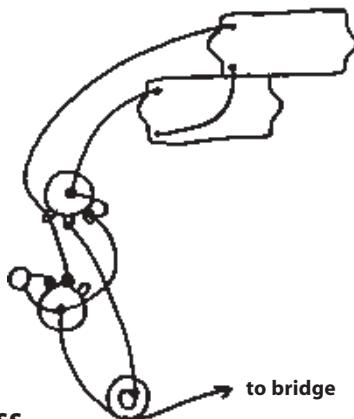
Telecaster

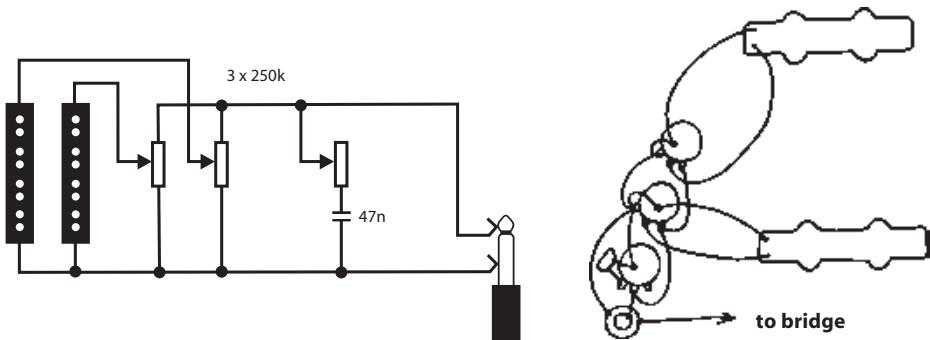


Stratocaster

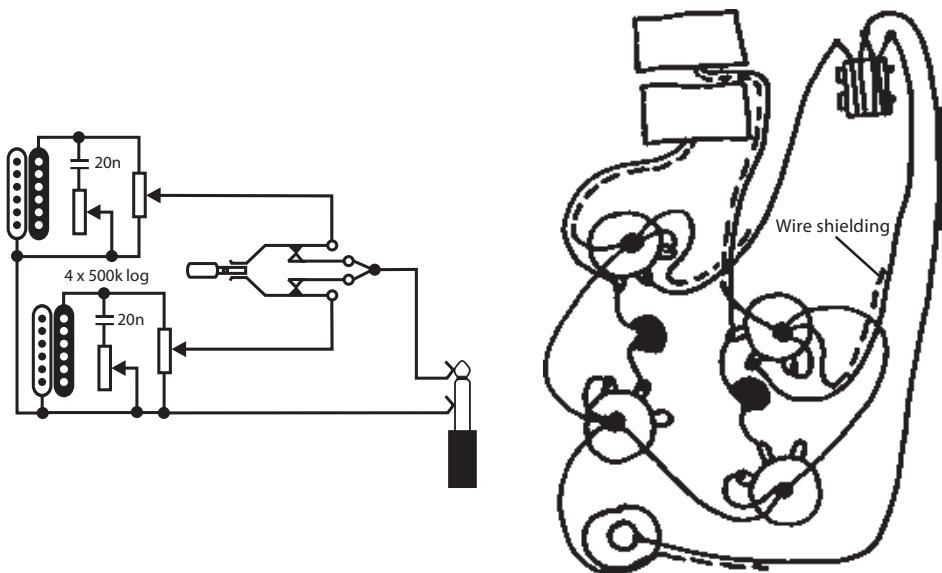


Precision Bass



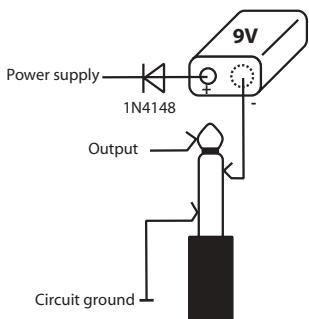


Jazz Bass



Les Paul

Active electronics



Using active electronics instead of passive circuits offers advantages: the sound of the guitar becomes independent of the guitar cord and the sound can be controlled much more effectively (these advantages become less important if a wireless transmitter and external sound equipment are used). Apart from that all drawbacks such as the production of a muffled sound when the controls are turned down are eliminated and infinitely variable mixing of several pickup signals and much more becomes possible with active electronics.

In the majority of cases an active amplifier powered by a 9-volt battery is built into the guitar, which has one drawback, however: batteries will only last so long and need replacing after some time, and often they run out of power when needed most.

Having spare batteries with you when playing is therefore strongly recommended. An even better solution would be to provide for a possibility to manually select either the active or passive system so that the guitar can also be played when the batteries have run out.

Another way out of the problem would be to supply the circuit with external power over a special stereo cord. The need for such a special cord with stereo phone jack is, however, a potential drawback.

It is also conceivable to use a rechargeable battery, provided the guitar is fitted with the contacts needed for charging the battery.

Special plastic compartments with cover lid can be used for building a 9-volt battery into a guitar. These are available from electronics stores or guitarmakers' suppliers and make replacing a battery very easy. Most 9-volt batteries have special connectors with "snap-on" terminals on one end.

All such systems have to have a switch to allow switching the power supply on and off. If you forget to switch it off, the battery will soon become discharged. A stereo jack could also be used for switching off the power supply as the cord is normally unplugged from the guitar after playing. The negative pole of the battery has to be connected to the middle lug of the stereo jack and the ground of the circuit to the ground lug of the jack. If a normal guitar cord with an ordinary mono phone plug is plugged into such a stereo jack (1), the negative battery pole is grounded by the rear part of the phone plug and the current can flow. When the guitar is not used the electrical circuit has to be interrupted by unplugging the cord.

With a small semiconductor component, a diode, the entire circuit can be protected against erroneously connecting the battery poles with the wrong contacts. Diodes allow the passage of current in one direction only and use up only 0.6 volts of the total battery voltage, thus leaving 8.4 volts for the circuit. Almost

Diodes

A diode is a building component with two contacts which allows the passage of current in one direction only. As such it is capable of protecting a circuit in case the battery poles are wrongly connected. If the lower-voltage charge is connected to the end of the diode with the mark - mostly a line - the diode is correctly connected and allows the passage of a current. If the connections are reversed, the diode acts as a reliable block.



Circuit diagram symbol



Building component

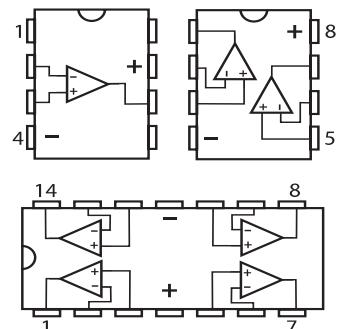
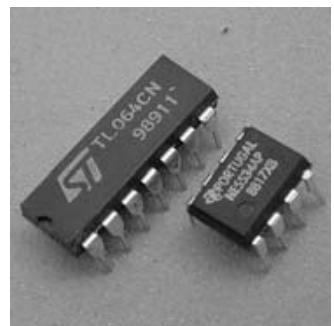
all diodes are suitable for this purpose. 1N4001 and 1N4148 are two very common types of diode.

These days all active circuits are built with operational amplifiers. Most building components with one internal operational amplifier have eight contacts. Contact 1 is often marked with a dot, and the layout of most types of operational amplifier such as NE530, TL061, TL071, TL081, LF351, LF411, μA771 and others is standardized. Building components with two operational amplifiers also have eight contacts: TL062, TL072, TL082, LF353, LF412, μA772, NE5532, NE5535, AD712 are some examples of this type of building component. When there are four internal operational amplifiers, such as on types OP11, TL064, TL074, TL084, LF347, μA774 and others, the casing has 14 contacts.

Analog Devices, Texas Instruments and National Semiconductor are a few names of manufacturers of operational amplifiers. All of them offer different types with a great number of different properties. Low-noise and/or power-saving types can be used on guitars. The active circuits I am going to describe are low in current consumption if the models TL061, TL062 and TL064 of *Texas Instruments* are used. On the other hand, there are also low-noise types (such as TL071, TL072 and TL064) which consume more current. All operational amplifiers come with detailed information sheets that provide all the essential data.

Obviously, if you wish to get more in-depth knowledge about active electronics some training in the field will be required. My introduction here is of a very general nature and I am trying to keep things simple - after all, there is so much that can go wrong, and often it is the details that cause the problems. So I would advise against trying to develop active electronics without having the necessary technical knowledge and measuring equipment such as a tone generator or an oscilloscope. If you do not have any experience in the field and find it difficult to read a circuit diagram, please ask somebody working in the electronic field to build the circuit needed on a small printed circuit board. The majority of guitar manufacturers do not develop the electronics themselves, either, but pass this job on to others. Passive circuits, on the other hand, are easier to understand and build.

Pickups with integrated active electronics are the easiest ones to fit on a guitar; they only need a power source and are these days available from several manufacturers. They have the electronic circuit integrated into the pickup's casing in the shape of tiny SMD building components (surface-mounted-devices). The pickup's characteristics are therefore preset and cannot be altered from outside. They can be connected with tone and volume pots in the usual manner, but these must not have more than 25K ohms, which is a tenth of the normal resistance value.

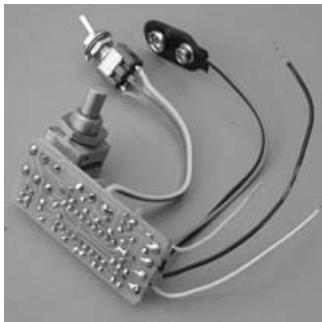


Amplifier arrangement in standard 8-pin and 14-pin packages

All operational amplifiers mentioned in the text have the standard layout shown above. Other types may differ so be careful.

Operational amplifiers

An operational amplifier, or op amp for short, is an integrated circuit (IC) which can be used for boosting voltages. They are basically tiny chips with a great number of semiconductors such as transistors, diodes, etc. that form a complex miniature electronic circuit. Their main advantage is their extremely high input and extremely low output resistance. They can be used for many different purposes as their electrical properties can be varied by external components such as resistors and capacitors.

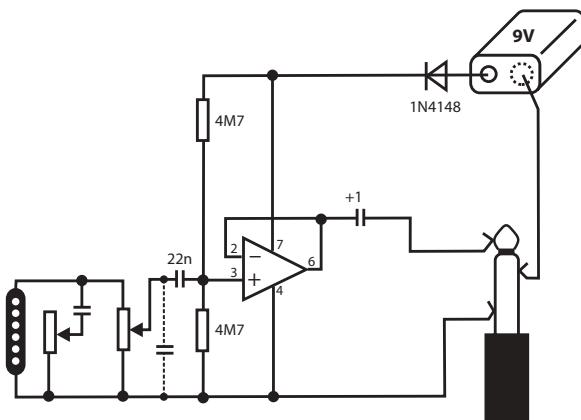


Lemme Soundfilter

The small printed circuit shown above is a state-variable filter manufactured by *Helmuth Lemme* (see supplier addresses). The Q-pot is replaced by a mini toggle switch which is more than adequate in practice. From left to right there are frequency pot, Q switch, 9 volts battery clip, input wire, ground wire and output wire which will be connected to the volume pot.

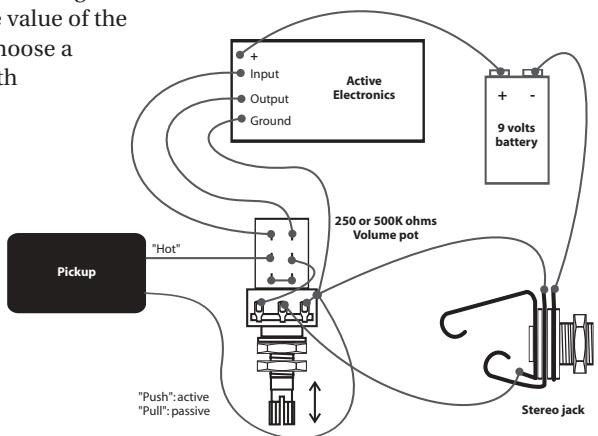
A lot of manufacturers offer ready-made active circuits, which do not require any specific knowledge of electronics. These are often built onto a potentiometer or on a printed circuit board. Using the enclosed wiring instructions the wiring of such ready-made components is mostly fairly straightforward. Equalizers often allow the selection of different corner frequencies via a miniature DIP switch.

A voltage follower is the most basic type of active electronics; it totally eliminates the influence of the guitar cord on the pickup's tonal characteristics. One way of fitting it on a guitar is to build the circuit straight into the guitar, between the usual passive wiring and the output jack. Another possibility is to build it into an external casing that is fixed at the guitar strap and switched between the output jack and the guitar cord. This has the advantage that by simply moving the casing the system can be used on another guitar. The absence of any cord capacitance makes the pickup's resonant frequency become very high and the tone unpleasantly bright and piercing. By connecting a small capacitor (dotted line in the illustration) in parallel with the input the resonant frequency can be brought back to a normal level. Find the best capacitor value by trial and error. The capacitance of commercially-available standard guitar cords - 500pF to 1000pF (1nF) - can serve as a guideline.



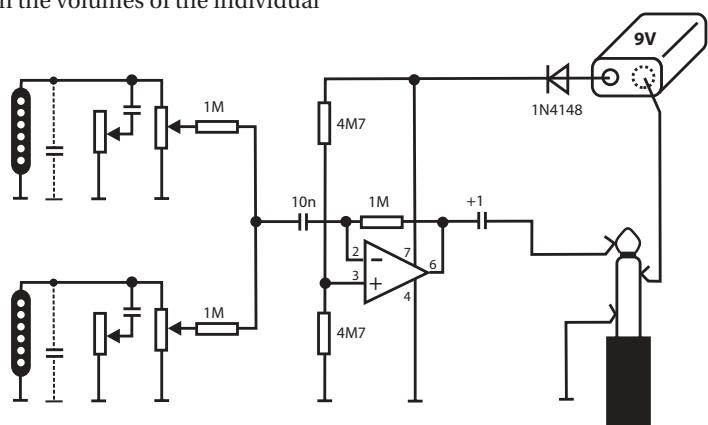
Being able to switch between the active and the passive mode by means of a DPDT switch can be a very useful thing and will be particularly appreciated when the battery has run out. The best solution would be to use a volume pot with built-in switch. The drawing on the left shows an active electronic circuit fitted after a conventional tone and/or volume control. Also, by switching to the passive mode the power supply is cut off and battery power is saved.

The wiring diagram below shows a variant with the volume pot fitted after the active electronic circuit. By pulling the volume pot the guitar still works even if the battery has run out. 25K ohms or 50K ohms volume pots are often used together with active electronics, in practise however the value of the volume pot doesn't matter and you can choose a pot value that you would normally use with passive electronics.

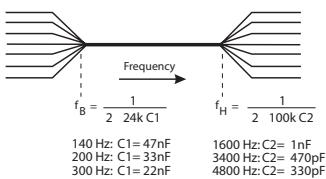


A totally independent mixing of pickup signals is only possible with an active system because here the volume controls do not interfere with each other and any combination of the signals of both pickups can be selected. The capacitors (dotted lines in the illustration below) are again used to lower the resonant frequencies of the pickups.

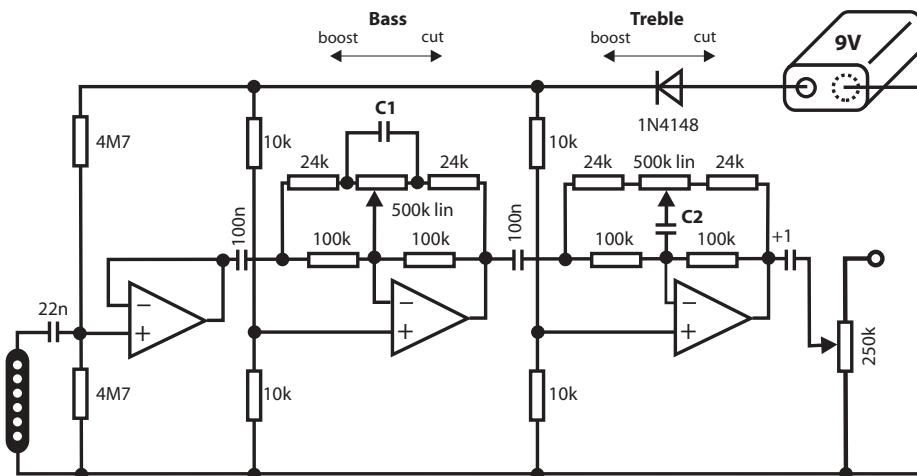
This type of circuit also allows mixing output voltages of piezo elements with a pickup signal. Via 1M-ohm decoupling resistors any number of inputs can be connected to the amplifier input (before the 10nF capacitor). Often each string of a guitar has its own piezo element so that six signals have to be mixed together, with a small trim pot for each piezo element making it possible to find a good balance between the volumes of the individual strings.



An active bass and treble control enables a very effective tone control without the usual treble loss of passive circuits. Bass boost and cut starts at the corner frequency f_B and is 6dB/octave. This means that the trebles are boosted or cut by 6dB per octave starting at f_H . With two formulas the capacitor values can be worked out for any corner frequency. The maximum boost or cut possible is approximately 12dB (quadrupling).



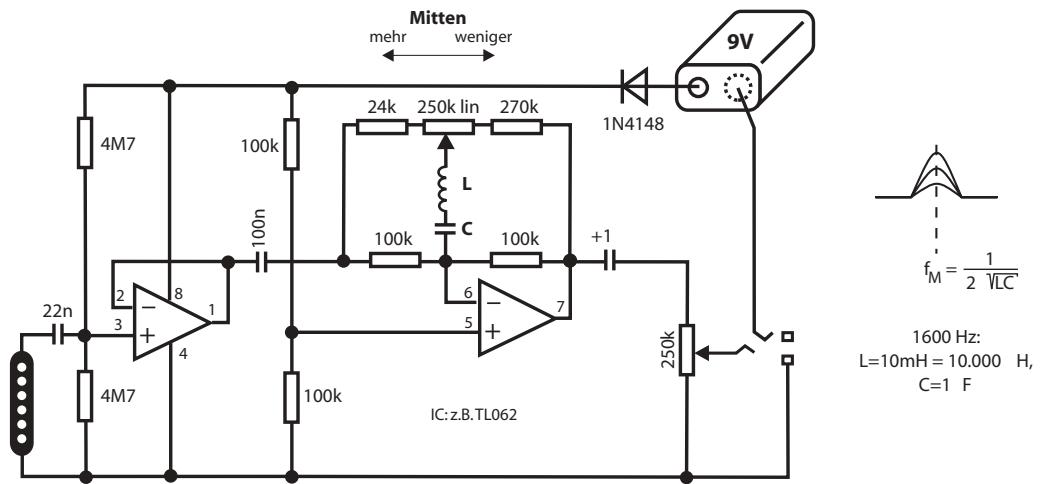
Using a dual pot with concentric shaft has the advantage of requiring only one hole to be drilled into the body. Concentric shafts are hollow - the shaft of the second pot is inside the hollow shaft of the first pot - and their special operating knobs are arranged in two rows, one above the other.



Boosting the mid-range frequencies can be achieved on the above-mentioned treble control by switching a small inductive element in series with the capacitor. Such small coils are available in electronics stores in the shape of miniature fixed-value building components in various values. Inductance is measured in Henries (H). When using a 10mH (milli-henry) coil and a 1 μ F capacitor in the circuit the frequency band around 1600Hz is infinitely variable between 0 and approximately 12dB (quadrupling). Mid-range boosting gives the sound more “power”.

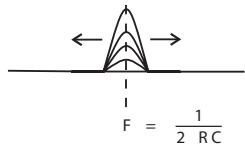
If the circuit is to also allow a cut of the same size, you only have to replace the pot with a 500K-ohm linear pot and the 270K-ohm-resistor with a 24K-ohm resistor.

Coils can cause problems in electronics. Because they are very susceptible to hum, circuits should be well shielded. Apart from that the relatively large tolerance of such building components (between 5 and 10 per cent) makes exact calculations difficult.

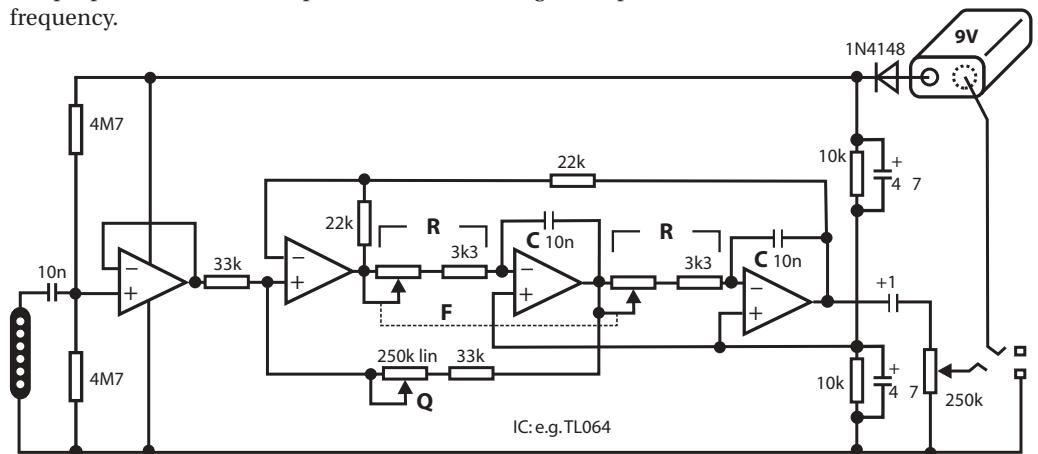


State-variable filters offer the maximum amount of freedom in shaping the tone of a pickup as they allow selecting and influencing of a specific frequency band with the frequency (control F) as well as the boost (control Q) infinitely variable between 0 and 12dB (quadrupling). Thus any tonal characteristic can be imitated and the properties of the passive pickup become less important.

Quadrupling operational amplifier components are used for this purpose. A linear stereo pot is used for selecting the impact frequency.



Guitar: F = 1200 Hz - 4800 Hz: P = 2 x 10k lin
Bass: F = 560 Hz - 4800 Hz: P = 2 x 25k lin



Shielding

Providing for additional shielding of single-coil pickups is highly recommended, and humbuckers can also only benefit from it. A single-coil pickup will always produce a certain amount of hum - if it was fully shielded, it would not give any output at all. So for reasons of sound it may not even be desirable to shield a guitar all too well. Shielding always increases capacitance, and the closer the shielding is to the pickup the stronger its influence on the tone will be. Capacitance always lowers a coil's resonance peak and makes the sound less trebly and more lifeless. Taking off the metal cover of an old pickup improves the sound and is therefore very popular.

Using shielded wires only makes sense with wire lengths of at least 15cm (6"), as a few inches or centimeters of bare wire ends will always be needed for making solder connections. A shielded wire consists of conducting wire surrounded by braided wire. Cheap shielded wire often has a very poor braided shield which is very patchy and therefore remains ineffective. Quality wire has a tightly-woven braided shield. To be effective the braid has to be connected to ground. The braided wire can also be used as a pickup lead.

Apart from using braided wire, lining the pickup and control cavities with thin copper foil also helps to minimize hum. Cut the thin copper foils to the sizes required and glue them to the wood with spray glue. To be effective they have to be grounded. Using conductive shielding paint is another option provided it is connected to ground.

All pot casings should also be shielded by connecting them to ground. Some manufacturers even have the pots entirely encased in grounded metal containers.



Grounding the strings is an absolute necessity with single-coil pickups if you want to keep humming noises to a minimum. This can be achieved by means of a wire which connects the metal of the bridge to ground. On tremolos the ground wire is soldered to the metal plate that holds the spring. When the guitar is played the strings are almost constantly touched by the player so that the electronic circuits of the guitar are grounded and shielded via the bridge, the strings and the body of the player.

In the past there have even been casualties because amplifier casings became part of the electrical circuit. Theoretically, this can, of course, always happen. But normally electrical installations have a mains trip system that interrupts the circuit if such a situation should occur. If, however, there is no such switch or the amplifier is not properly grounded, the current flowing through the cord can become fatal if it reaches the strings. To be on the safe side connect the strings to ground via a high-ohm resistor and a capacitor switched in parallel. With such a precautionary

measure any current that, if things went wrong, would flow through the player's body is weakened and the voltage is brought down to unharful, no-longer-fatal levels (around 40 volts, depending on the individual body resistance) while still providing sufficient grounding of the strings. The capacitor used should have a value of 0.001mf (1nF) and be able to withstand not less than 500 volts. Use a 220K-ohm resistor. Both building components should be protected against short-circuiting by surrounding them with insulating tape or - which is even better - a piece of heat shrink tube. Although this doesn't provide 100 per cent protection as the metal jack plate will still remain ungrounded, the light electric shock you will receive as a result should be a strong-enough warning to make you immediately unplug the amplifier from the mains. On occasions such as big concerts experts are specially employed to check the grounding and other safety measures before anybody goes on stage.



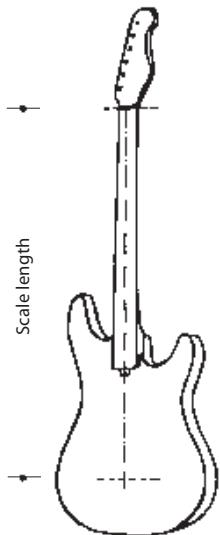
And finally, a few hints for wiring. Wiring diagrams may look very simple and clear, but when it comes to soldering you can easily end up with a chaotic tangle of wires. To prevent this, work systematically: always tick off finished connections on the diagram; try to minimize any hum potential by keeping wires as short as possible; use colored wires to facilitate keeping track of individual wires and checking faults - use "warm" colors such as red, orange or yellow for signal-carrying ("hot") wires and "cold" colors such as black or blue for ground wires.

Crackling sounds in the speaker are mostly due to poor-quality soldered connections. To repair them, reheat those dull-looking, lump-shaped connections and add a bit of tin. When turning a pot produces a crackling sound, replace it or spray it with contact spray. If a logarithmic pot works the wrong way round, interchange its outer connections. And finally: if a guitar remains silent, make sure you first check whether the guitar cord is working properly before you start disassembling the guitar's electronics.

Designing the Guitar

Designing a well-proportioned guitar is not easy, but I would none the less encourage you to try to design your own model and not just copy an already-existing design. Of course you can always take already-existing models as a guideline (others do so as well!), but you should always try to remain individual. If you are interested in original designs, you may find two books mentioned on page 75 useful. Some guitarmakers' suppliers offer blueprints of certain guitar models.

My personal favorite as far as shape is concerned is the *Fender Telecaster*. Especially the shape of its peghead is, in my opinion, an ingenious choice, and it is therefore not without reason that it is registered as a trademark, as are other shapes of other models, too. This is also why other companies had to develop slightly differing shapes to avoid having to pay licence fees for selling their guitars. Not always do these designs, however, match or get near the beauty of the original; in fact, some guitars look rather inelegant and ugly, which just goes to show that designing a guitar does require a good sense of proportions.



Standard scale lengths

Electric guitars

24.75" (628.65mm) ... Gibson
25.00" (635.00mm) ... PRS
25.50" (647.70mm) ... Fender

Electric bass

34.0" (863.60mm) ... Long scale
32.5" (825.50mm) ... Medium scale
30.0" (762.00mm) ... Short scale

Scale length

The choice of the scale length is a fundamental step in the designing process and as such has repercussions for the final sound of the guitar. The scale length is the distance between the two points on which a string rests, i.e. the front edge of the nut and its saddle on the bridge. This length determines the total length of the guitar: a guitar can never be shorter than its scale length. A headless guitar may be the answer if you are looking to build a very compact model. These guitars have the tuners fitted on the body so that no peghead is needed. As a result, the total length of a headless guitar is only marginally greater than its scale length.

Scale lengths are normally given in inches and not in metric units. The original *Stratocaster*, for instance, has a scale length of 25.5 inches. Although the differences between the standard scale lengths used by different manufacturers are not very big - $\frac{3}{4}$ " between *Fender* and *Gibson*, for instance - these do none the less result in differences in sound and playability of the guitar.

In theory you can, of course, choose any scale length you like. But if you intend to use finished standard parts such as ready-made pickguards, bridges or pickups, you will have to stick to the dimensions of the "original" more or less closely. After you have decided on the scale length you can start calculating the distances between the frets. If you choose one of the standard scale lengths, you can find the distances in the table on the facing page; otherwise you will have to work them out

yourself with a calculator or a computer. The standard tuning for guitars today is the tempered tuning, where each octave is split up into twelve mathematically perfectly equal intervals. This is a compromise solution, and people with sensitive ears will be able to hear the friction between different intervals. If you wanted a guitar to produce pure intervals in all keys, you would need twelve individual, removable fingerboards - one for each key.

A shorter scale length ...

... means that the distances between the frets are shorter, and therefore fingering chords is easier for players with small hands or short fingers.

On bass guitars this difference can be particularly noticeable. Unfortunately, a long scale length emphasizes especially the lower-pitched tones of a bass; therefore a long scale length should be preferred.

... gives a somewhat more brilliant, trebly sound.

... means reduced string tension.

... means a shorter neck sticking out from the body and, as a result, slightly less strain on the neck.

... results in the strings vibrating less. The sound produced by the guitar is therefore lower in volume, and the strings can be placed relatively low above the fingerboard (i.e. the action can be set lower).

A longer scale length ...

... means slightly longer distances between the frets, which favors players with longer fingers.

... makes the overall sound somewhat bassier. The longer the scale length of a bass is, the bassier it will sound. There are even basses with scale lengths of 36" (915mm), which were built to get more "power", but because these can create neck stability problems, their necks have been made thicker than normal. When it comes to long scale lengths, however, the traditional double bass is still in a league of its own: 1200mm (47,24") is its impressive scale length, and its extremely strong neck does not stick out of the body too far. Additionally, the double bass has a high bridge that helps to transform a lot of the string pull into pressure exerted on the top of the guitar.

... means a longer neck sticking out from the body and more strain on the neck.

... increases string pull.

... makes the instrument louder as the strings can vibrate more; the action can therefore not be set as low as on a guitar with a shorter scale length.

NOVAX fingerboard

The NOVAX fanned-fret, or multiple scale, system is one way of reconciling the advantages of a short and a long scale length. This system, which was patented by the American *Ralph Novak*, has concurring frets, and the nut and the bridge are not parallel to each other. Thus a guitar could, for instance, have a bass-side scale length of 25.5" and a treble-side scale length of 24.5". On a bass guitar this will result in both basses and trebles being emphasized. A five-string bass could have the following scale lengths:
B: 37" E: 36.25", A: 35.5",
D: 34.75", G: 34".

Baritone guitar

This special type of guitar is tuned lower than normal. It consists of a standard-sized body with a longer neck and, consequently, an increased scale length. A typical scale length of baritone guitars would be 27.67" (702.82mm).

When a standard scale-length guitar is tuned lower than normal, the strings become slack and lifeless, which seriously affects the tone of the guitar. The longer scale length of a baritone guitar avoids this drawback. The instrument can effectively be tuned to a low B without sacrificing tone.

Baritone guitars require special (longer) strings.

	A	B	C	D	E	F	G	H	I
1		Fret distances for some standard scale lengths in inches							
2									
3	Scale length:	24.75	25	25.5	27.67	30	32.5	34	inches
4									
5	Fret	Distances from front edge of nut or zero fret in inches :							
6	0	0	0	0	0	0	0	0	0
7	1	1.389	1.403	1.431	1.553	1.684	1.824	1.908	
8	2	2.700	2.728	2.782	3.019	3.273	3.546	3.709	
9	3	3.938	3.978	4.057	4.402	4.773	5.171	5.410	
10	4	5.106	5.158	5.261	5.708	6.189	6.705	7.014	
11	5	6.208	6.271	6.397	6.941	7.525	8.153	8.529	
12	6	7.249	7.322	7.469	8.104	8.787	9.519	9.958	
13	7	8.231	8.315	8.481	9.203	9.977	10.809	11.308	
14	8	9.159	9.251	9.436	10.239	11.101	12.026	12.581	
15	9	10.034	10.135	10.338	11.217	12.162	13.175	13.784	
16	10	10.860	10.969	11.189	12.141	13.163	14.260	14.918	
17	11	11.639	11.757	11.992	13.012	14.108	15.284	15.989	
18	12	12.375	12.500	12.750	13.835	15.000	16.250	17.000	
19	13	13.070	13.202	13.466	14.612	15.842	17.162	17.954	
20	14	13.725	13.864	14.141	15.345	16.637	18.023	18.855	
21	15	14.344	14.489	14.779	16.036	17.387	18.836	19.705	
22	16	14.928	15.079	15.380	16.689	18.095	19.602	20.507	
23	17	15.479	15.636	15.948	17.306	18.763	20.326	21.265	
24	18	16.000	16.161	16.484	17.887	19.393	21.010	21.979	
25	19	16.491	16.657	16.990	18.436	19.989	21.655	22.654	
26	20	16.954	17.126	17.468	18.955	20.551	22.263	23.291	
27	21	17.392	17.568	17.919	19.444	21.081	22.838	23.892	
28	22	17.805	17.985	18.344	19.905	21.582	23.380	24.459	
29	23	18.195	18.378	18.746	20.341	22.054	23.892	24.995	
30	24	18.563	18.750	19.125	20.753	22.500	24.375	25.500	
31	25	18.910	19.101	19.483	21.141	22.921	24.831	25.977	

Fret distances for some standard scale lengths

	A	B	C	D	E	F	G	H	I
1									
2									
3	Scale length:	628.65	635.00	647.70	702.82	762.00	825.50	863.60	mm
4		24.75	25.00	25.50	27.67	30.00	32.50	34.00	inches
5									
6	Fret	Distances from front edge of nut or zero fret in millimeters :							
7	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
8	1	35.28	35.64	36.35	39.45	42.77	46.33	48.47	
9	2	68.59	69.28	70.67	76.68	83.14	90.06	94.22	
10	3	100.02	101.03	103.05	111.82	121.24	131.34	137.40	
11	4	129.69	131.00	133.62	144.99	157.20	170.30	178.16	
12	5	157.70	159.29	162.47	176.30	191.15	207.08	216.63	
13	6	184.13	185.99	189.71	205.85	223.19	241.79	252.94	
14	7	209.08	211.19	215.41	233.75	253.43	274.55	287.22	
15	8	232.63	234.98	239.68	260.07	281.97	305.47	319.57	
16	9	254.85	257.43	262.58	284.92	308.91	334.66	350.10	
17	10	275.83	278.62	284.19	308.38	334.34	362.21	378.92	
18	11	295.64	298.62	304.59	330.52	358.35	388.21	406.13	
19	12	314.33	317.50	323.85	351.41	381.00	412.75	431.80	
20	13	331.97	335.32	342.03	371.14	402.39	435.92	456.04	
21	14	348.62	352.14	359.18	389.75	422.57	457.78	478.91	
22	15	364.34	368.02	375.38	407.32	441.62	478.42	500.50	
23	16	379.17	383.00	390.66	423.91	459.60	497.90	520.88	
24	17	393.17	397.15	405.09	439.56	476.57	516.29	540.12	
25	18	406.39	410.50	418.71	454.34	492.59	533.64	558.27	
26	19	418.87	423.10	431.56	468.28	507.72	550.03	575.41	
27	20	430.64	434.99	443.69	481.45	521.99	565.49	591.59	
28	21	441.75	446.22	455.14	493.87	535.46	580.08	606.85	
29	22	452.24	456.81	465.95	505.60	548.17	593.85	621.26	
30	23	462.14	466.81	476.15	516.67	560.17	606.86	634.86	
31	24	471.49	476.25	485.78	527.12	571.50	619.13	647.70	
32	25	480.31	485.16	494.87	536.98	582.19	630.71	659.82	

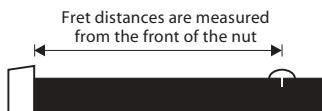
Calculating fret distances

The fret constant 17.817

When pressing a string against a fret the string's vibrating length is shortened to a precisely determined value. With each fret the frequency of the string's vibration increases by a semitone. Since an octave is divided into 12 semitones the pitch of a string pressed down on the 12th fret is twice as high as that of the open string.

To calculate the length by which a string has to be shortened to increase its pitch by a semitone the string length has to be divided by the twelfth root of two. With the fret constant thus determined it becomes possible to calculate by how much each string has to be shortened. Measuring the distances between the frets from a point on the fingerboard is obviously more practical than measuring them from the body-end of the string.

By dividing the total scale length by 17.817 you will get the length by which a string has to be shortened to increase its pitch by a semitone, i.e. the distance between the nut and the first fret. This constant is used like other constants such as the circle constant pi (=3.1415) and others. It guarantees a well-tempered fret distribution, and the three digits behind the comma (of this constant) are totally sufficient as we shall also see later when marking the fret positions.



Calculating fret distances

If you divide any scale length by the constant 17.817, you will get the distance from the front edge of the nut to the first fret. Here is one example: a scale length of 25.5" (650mm) divided by 17.817 gives 1.4312173" (36.482011mm), which can be rounded down to 1.431" (36.48mm). Three digits behind the comma are sufficient when using Imperial measurements (two when using metric units), as it is virtually impossible to place a fret much more accurately than to $\frac{1}{1000}$ of an inch. The first fret is therefore placed at a distance of 1.431"

(36.48mm) from the nut. To calculate the position of the second fret, the remaining scale length (25.5" minus 1.431" = 24.069") is again divided by 17.817. This gives the distance from the first fret at which the second fret has to be placed - in the above example this would be 1.351" (34.43mm). All fret distances should ideally be measured from the front side of the nut or a potential zero-fret, as otherwise several minor errors in the actual fretting could eventually add up to quite considerable differences. It is consequently advisable to determine all fret positions by measuring from the nut: the first fret is placed at a distance of 1.431" from the nut, the second at 1.431" + 1.351" (=2.782") from the nut, and so on. For calculating the position of the third fret, the remaining scale length - i.e. the distance from the second fret to the bridge - is again divided by 17.817, and so on for all other frets. For the 12th fret the calculations have to

give exactly half of the total scale length (at least if you ignore anything beyond the 3rd (or 2nd) digit behind the comma as there are always unavoidable rounding errors if you use a calculator or a spreadsheet program).

A	B
1	SCALE LENGTH
2	25.5
3	Dist. to fret 0
4	0
5	Dist. to fret 1
	=(\$B\$1-B2)/17.817+B2
6	Dist. to fret 2
	=(\$B\$1-B3)/17.817+B3
7	Dist. to fret 3
	=(\$B\$1-B4)/17.817+B4
8	...
9	...

Using a spreadsheet program

Doing all these calculations with a calculator can be a bit tedious, but it can easily be automated with a spreadsheet program such as *Microsoft EXCEL*:

Enter the scale length in field B1 assign the value "0" to B2, and enter the formula " $=($B$1-B2) / 17.817 + B2$ " for calculating the distance between the nut and the first fret into field B3. To calculate all other fret distances simply copy the formula of field B2 into the other fields below it. Finally number all frets in column A and then print out the sheet, checking that no errors have occurred and that, for instance, the distance calculated for the 12th fret is exactly half of the total scale length (ignore unavoidable rounding errors past the second or third digit behind the comma).

On-line fret calculator

If you have access to the World Wide Web you are invited to use my on-line fret calculator at:

www.BuildYourGuitar.com/resources

Laying out the guitar

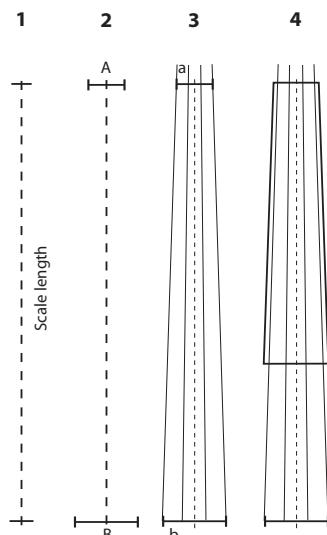
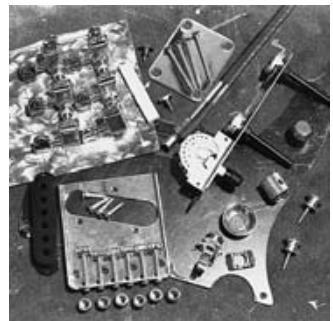
Once you know the distances between the frets you can start designing the guitar. Make sure that you really have all hardware parts ready in front of you. This is the only way to ensure that you use the right dimensions and exclude any errors which might occur as a result of relying on catalog or brochure information about sizes and dimensions - these are not necessarily correct. This also means that decisions for or against certain hardware parts have to be taken at this stage already.

A simple sketch (1-4) should always be made whenever you plan to build a guitar. Note that the shape of the fingerboard *always* is determined by three measurements: the scale length and the string spread at the nut (A) and at the bridge (B). Again, when you start have all parts needed ready in front of you. And another piece of advice would be to not just trust catalog drawings but to always measure everything accurately yourself. This is the only way to prevent nasty surprises. You will need a large sheet of paper; if you do not have one, make one by taping together several smaller sheets. A guitar for left-handed players can be designed like one for right-handed players: all you have to do is to draw the right-handed model on transparent paper and then work with the mirror-image on the reverse side.

Instead of making a drawing you can also calculate the taper of the fingerboard like shown on the next page. Calculating the fretboard layout is a quick and accurate method which can only be recommended.

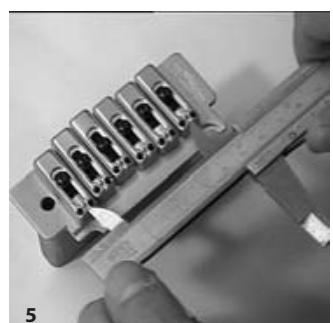
The dimensions of the neck can and should be individually chosen - they are a very important factor for the playability of a guitar. Start by drawing a line in the middle of a sheet of paper and mark the scale length and both the front edge of the nut at the top and the point at which the strings rest on the saddles at the bottom with a short line as shown in illustration 1.

The next thing to decide on is the string spread. If you do not have any specific string spread in mind, take 35mm ($1\frac{3}{8}$ ") at the nut (A) for guitars and 32mm ($1\frac{1}{4}$ ") for four-string basses. These distances are the distances between the center lines of the two outer strings. At the bridge the string spread (B) is often predetermined by the model you are going to use, but some bridges also allow variations. If you measure the string spread at the bridge (5), you will find that it is quite commonly $2\frac{1}{8}$ " (54mm) or $2\frac{3}{32}$ " (53.2mm) on guitars and $2\frac{1}{4}$ " (57.2mm) on basses. Mark the string spread and the two outer strings at the nut (A) and at the bridge (B), as shown in illustration 2. Then draw the other strings at equal distances between them (3). The distances between the individual strings (a, b) can be worked out easily by dividing the nut width A and the bridge width B by 5 ($a = A/5$, $b = B/5$) for guitars, and by 3 ($a = A/3$, $b = A/3$) for four-string basses.



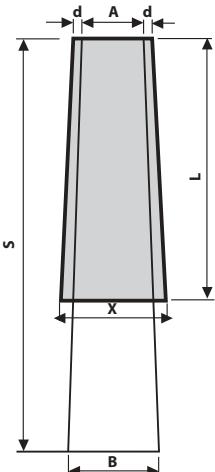
Some standard nut widths

$1\frac{5}{8}$ " (41.3mm) ... Strat, Tele, Les Paul
 $1\frac{1}{2}$ " (38.1mm) ... Jazz Bass



Calculating the layout

Three measurements determine the width of the fretboard: The nut width (A), the distance (d) from the outer strings to the fingerboard edge (which should be equal along the entire fretboard length) and the string spacing at the saddle (B). Calculate the width of the fretboard (X) at any length (L) with this formula:



$$X = A + d + d + \frac{L(B - A)}{s}$$

d ... distance of outer strings
to fingerboard edge

A ... nut width

B ... bridge stringspread

L ... distance from nut

S ... scale length

If the position of the pickup(s) is predetermined by the pickguard, make sure that the strings are precisely above the pole-pieces. If you use pickups with blade polepieces, the string spacing can be chosen more freely. When using standard parts in conjunction with standard scale lengths the string spacing will automatically be right. If the bridge is adjustable, the string spread can easily be varied so that the strings pass over the poles in the right place.

To prevent the outer strings from gliding over the fingerboard edge during playing a minimum distance to the edges has to be kept: about 3.5mm (1/8") on either side is sufficient. The neck of a guitar with a string spread of 35mm (13/8") at the nut will therefore be 42mm (15/8") wide at the nut (35mm + 3.5mm + 3.5mm / 13/8" + 1/8" + 1/8"), which is a standard nut width.

A bass neck with 32mm (11/4") string spread at the nut will be 39mm (11/2") wide at the nut (32mm + 7mm / 11/4" + 1/4"), which is very common, too.

Although guitars can have up to 36 frets, most of them have only 21 or 22. If your guitar is to have 22 frets, mark the distance from the nut to the 23rd fret: this is roughly where the fingerboard ends. Now draw its outline parallel to the outer strings (4, previous page). If you use a *Stratocaster* pickguard, the distance between the end of the neck and the bridge is predetermined. The neck has to end approximately at the 22nd fret, but the fingerboard can extend over the end of the neck if necessary.

Design options

The shape of the peghead can be chosen according to your own likes, but it is advisable to place all the tuners in such positions that the strings can pass in a straight line and are not bent at all, or if, only slightly. The nut will be grateful to you for heeding this advice and you will also have less trouble tuning the guitar.

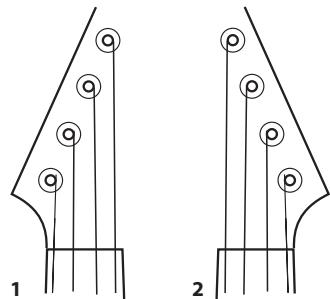
Positioning the tuners with this in mind is relatively easy when all tuners are fitted on one side of the peghead. If the tuners are fitted on both sides of the peghead, a staggered layout is required.

Measure the diameter of a tuner shaft and extend the lines for the strings beyond the nut and onto the peghead. When designing a bass it is advisable to draw the actual string gauge.

When all tuners are fitted on one side ("4-in-line" or "6-in-line" sets), all tuners look the same. Make sure you leave enough room between the nut and the first tuner and draw the first peghole so that the line representing the string is tangential to this hole (1). Proceed in the same manner with the other holes. To prevent the peghead from getting too long you should use miniature tuners if you decide to use a "6-in-line" set on a guitar. For these there is a standard distance of 24mm (15/16") between the centers of the



tuner shafts (45mm / 1³/₄" on basses and when using normal enclosed-gear tuners). Always check the validity of these figures by checking the tuners you have bought (and now have ready in front of you). The tuners should be placed at such distances from each other that their knobs do not touch, that your fingers feel comfortable when you turn them and that it is actually possible to mount them - not only in theory, but also in practice. With 6-in-line or 4-in-line tuners the peghead can be "reversed" so that the tuner knobs face downwards and the bass E string is anchored at the tuner which is at the top end of the peghead (2). This type of layout may be more hand-friendly when it comes to tuning the guitar, and on top of this it also looks quite cool.



If the tuners are to be fitted on the top and bottom side of the peghead, you need "left" and "right" tuners, often marked in catalogs with the letters "L" and "R" (3L, 3R; 2L, 2R). Such tuners are normally of a standard size and fitted at a minimum distance of 40mm (1⁹/₁₆") from each other on guitars (45mm (1³/₄") on basses).

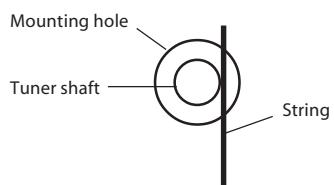
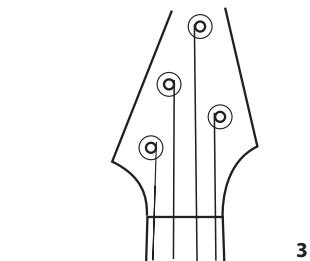


When tuners are fitted on both sides of the peghead a straight string line can only be achieved by mounting the tuner pairs successively closer to each other towards the end of the peghead. Unfortunately, the tuners traditionally used do not allow a symmetrical layout of the two top tuners as the distance between the two middle strings is too small. The solution is to use a staggered tuner layout (3), which inevitably makes the peghead asymmetrical.

This advantage of the strings being able to pass in a straight line is, however, offset by the fact that this makes it more difficult to use a truss rod adjustment wrench to get at a truss rod nut mounted on the peghead side of the neck, as the middle strings block access to the nut for almost any wrench - allen keys excepted. Another potential drawback is a merely optical one: the rather small peghead might not really look good on the guitar.

The next step is to draw the peghole diameter around each tuner shaft: this is the diameter of the mounting nut or bushing, both of which are mounted from the face of the peghead. Guitar tuners normally require 10mm (13/32")-diameter holes, bass tuners 12mm (13/32") 14mm (9/16") or 18mm (23/32")-diameter holes. But again, before doing anything else double-check and measure your tuners.

After the position of the tuners has been determined you can move on to drawing the shape of the peghead, the part of a guitar that is often considered the trademark of a guitar-builder. Design the peghead according to your own likes, but be careful if you intend to build a bass that the peghead does not get too large

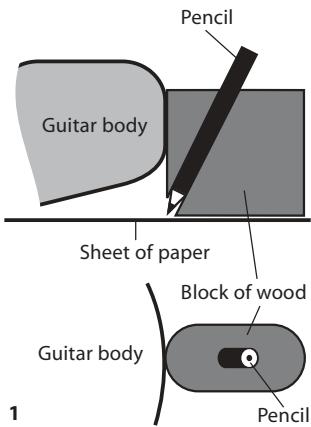


and heavy. Especially on six-string basses the two additional tuners can increase the weight of the peghead considerably. Using *Hipshot* bass tuners on six-string basses helps to keep the weight of the peghead low.

When you draw the shape of the peghead make sure a part of the knob shafts remains visible. It doesn't look good when knobs are too close to the peghead. The width of the peghead determines the width of the blank needed for making the neck, and with a good design (*Fender Telecaster*) you can save material.

You can now move on to planning the neck pocket (that will allow mounting the neck on the body), taking the neck design as a basis. Decide from which fret the neck is to stick out from the body. If you choose the 16th fret, you will have to rout off a shape identical with the (previously drawn) neck shape between the 16th fret and the end of the neck. This will be a slightly trapezoidal shape and symmetrical to a center line lengthwise through the body. The front edge can be curved, as on a *Stratocaster* (7" radius), or straight.

When using a finished *Stratocaster* pickguard the distance between the end of the neck and the bridge is predetermined and the neck pocket must not be routed beyond the 22nd fret (roughly). If you intend to have more frets, just make the fingerboard - which is glued on - longer. This also applies when using a *Telecaster* bridge in conjunction with a *Telecaster* pickguard.



The body has to be at least as long as to leave enough space for fitting the entire bridge. One possibility of getting a body outline would be to copy the outline of an already-existing guitar - if you have one at hand, that is, of course. For correctly transferring the sometimes odd shapes of guitar bodies onto paper you can use a simple jig (1): an oblique hole in a block of wood takes a pencil and makes it possible to follow the exact body outline.

Another possibility would be to enlarge an illustration or a picture or to copy it by drawing it freehand, using the scale length or some other known length as a fixed value to get the dimensions right. There are plenty of books containing high-quality pictures of guitars. To enlarge a picture put a grid over it, trace the outline and then transfer it onto a larger grid. Or you can use a personal computer and a scanner to digitize and enlarge the body shape from a photo by using software like e.g. *CorelDraw*. Apart from that you only need a large-sized printer or plotter; and if these are not available, you can always take a floppy disk to an appropriate service company. Alternatively software like *CorelDraw* allows to tile a picture to several pages so that you can use your printer.

Pictures can also be infinitely scaled up with modern photocopying machines. If necessary, repeat the photocopying a few times until one of the known details is the right size. You could even

use a slide projector to project an enlarged picture on a sheet of paper, but if you choose this method make sure that the dimensions of the original do not get distorted by the projector lens or the camera perspective.

And finally, there is always the option of making your own very personal design, which is precisely what I would recommend. After all you want a "personal" guitar and not just a copy of different outline features of a commercially-available model. "Borrowing" certain elements is, of course, permitted, as long as you do not copy already-existing designs too slavishly. If you use a standard pickguard, you will have to take its dimensions into account anyway when designing your guitar. Make sure you leave enough space between the pickguard and the edge of the body to allow rounding off the body. The body shape of a solid-body electric guitar can be chosen absolutely freely, as opposed to acoustic or semi-acoustic guitars where air resonances play a crucial role. Anything goes in principle; the only restrictions that have to be considered are the factors weight and playability. Very odd-looking guitars, such as guitars with a simple rectangular board as a body and other off-the-wall shapes have been built in the past. Feel free to add to their number if you feel like it.

The cutaways at the neck end of the body are a feature typical of electric guitars. They serve to allow reaching the higher frets on the neck more easily.

The upper body horn is important for reasons of balance. If the ratio between the weight of the body and the peghead is badly balanced, a guitar can feel very uncomfortable and can be very unstable on your shoulders. The weight of the tuners, which is further increased by the neck's leverage, has to be taken into account as well. For guitars with a long neck and a heavy peghead I would strongly recommend that you make a long top body horn as this ensures an ideal weight distribution, making the guitar hang on the player's body without him or her having to use force. Unfortunately, this balance can only be tested after the instrument has been finished; but under normal circumstances this should not really be a problem if the body is not too light and the peghead not too large and heavy.

Dimensions of a Stratocaster body

To give you some rough ideas for designing (the body is in a upright position):

Width: 325mm (12 $\frac{3}{4}$ "")

Upper part: 285mm (11 $\frac{1}{4}$ "")

Smallest width: 230mm (9")

Length: 400mm (15 $\frac{3}{4}$ "")

Length of left part: 460mm (18 $\frac{1}{8}$ "")

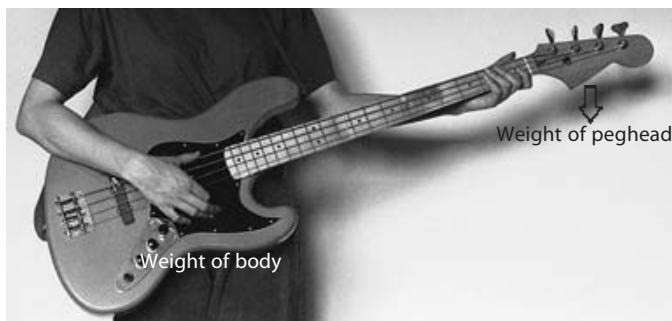
Exact dimensions of classic guitars

Unfortunately, I do not know of more than two books which contain reasonably well-readable drawings of guitar necks and bodies:

A.R.Duchossoir:
The Fender Stratocaster,
and, by the same author:
The Fender Telecaster

The book *The Fender Bass* written by Klaus Blasquiz unfortunately only contains unreadable blueprints

Some blueprints of Fender and Gibson guitars can also be obtained via mail order from guitarmakers' suppliers.



Apart from their aesthetic function the cutaways on the sides of the body also serve to keep the guitar from gliding off the thighs of a seated player. Rounding off the body to enable more comfortable resting of the arm and shaping the top of the back of the body in line with the player's body can further contribute to making the instrument more comfortable to play.

Some bodies are partly symmetrical. To get a symmetrical shape draw one half of the body outline, cut it out and then draw the other half using this template. To give you a rough idea of the body dimensions - and these are really only very rough figures - you could make the body about 320mm (12.5") wide at its widest part and approximately 400mm (15.75") long between the lower edge of the body and the upper edge of the neck pocket. Most basses have fairly similar or only marginally larger bodies. *Jazz Basses* have, due to their shape, the widest bodies of all.

After having drawn the shape of the body on paper you can transfer it onto plywood, cut it out and then use it as a template.

The minimum body depth depends on the electronics fitted on the guitar and the thickness of the material required under the neck pocket. The deeper the body is, the heavier the guitar will become. A lot depends, of course, on the type of wood used. A concert of two hours with 4kg (9 pounds) on your shoulder is no fun and can be quite straining on the back muscles. *Fender* guitars and, in fact, most guitars have a body depth of approximately 45mm (1 $\frac{3}{4}$ "), which is a good depth to start with. Making the body less than 40mm (1 $\frac{9}{16}$ ") deep gives the guitar a less attractive appearance, and if you want to use a *Strat*-style tremolo, the body has to be at least 45mm (1 $\frac{3}{4}$ ") thick. *Les Paul* guitars are heavy and roughly 57mm (2 $\frac{1}{4}$ ") deep in the middle of the domed maple top and approximately 50mm (2") deep at the edges.

Now that the basic dimensions of your guitar have been fixed you can start thinking about the further details.

An angled-back peghead (1) offers the advantage of making the strings exert just the right amount of pressure on the nut. Most guitars have a head angle of between 4 and 17 degrees.

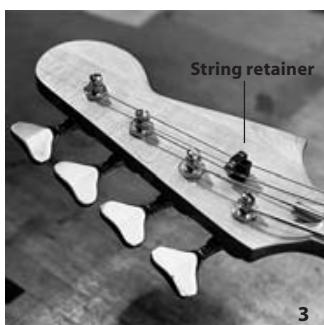
Fender-style pegheads with no angle (2) require string retainers (3) to produce the necessary pressure on the nut, which increases friction when tuning the guitar. String retainers are in particular needed for those strings that are fastened at tuners close to the top of the peghead. For strings anchored at tuners closer to the nut the necessary angle can also be achieved by winding them around the tuner shafts in such a way that each winding is put under the preceding winding.



1



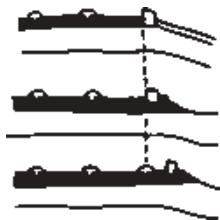
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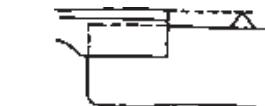


3

Zero-frets can be found on a number of very expensive basses and headless guitars, but they have never quite made a real breakthrough - though undeservedly so, as most guitar-builders would agree, considering the fact that they provide for an ideal string height over the first fret, which leads to fewer intonation problems. Another advantage sometimes mentioned, but probably neglectable, is the absence of differences in sound between open and fretted strings due to the use of different materials for the frets and the nut. Using a zero-fret is in many ways similar to putting a capo on the first fret and does work well. The strings rest on the zero-fret, and the nut, which is placed about 5mm ($\frac{3}{16}$ ") behind the zero-fret, only serves to guide the strings. Worn zero-frets can be replaced just as nuts can.

Headless guitars intended for use with double-ball-end strings require a space of approximately 12mm ($\frac{1}{2}$ ") between the zero-fret and the head end of the neck. Since on guitars of this type the strings are anchored very close to the zero-fret, you have to make sure that the ends of double-ball-end strings, which are always thicker than the rest of the string, are behind the zero-fret and not on it. Keep in mind that, if you make the distance between zero fret and head piece longer than the space mentioned above, double-ball-end strings because of their fixed length may force an extra tuning unit too close to the fingerboard end, leaving not enough room for placing an extra bridge exactly at the scalelength mark. I recommend that you test the whole setup by mounting head piece, tuning unit, bridge and double-ball-end strings on a piece of scrap.

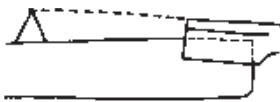




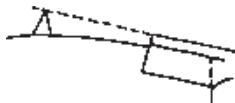
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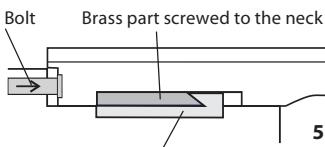


4

A bolted-on neck requires a pocket in the body where the neck can be fastened with screws from the back of the body. Because it is obviously easier to build two separate parts, this is the simplest type of neck-body joint to make. On top of this, a bolt-on neck can easily be replaced if necessary.

When using a tremolo or a low bridge the neck is fitted parallel to the body surface (i.e. at an angle of 0 degrees). The neck is inserted into the body just as far as necessary to make the fingerboard surface exactly the same height as the saddles on the bridge (1). When the saddles on the bridge are set to their lowest point a tensioned string should be resting on the fingerboard. Don't worry about the height of the frets at this stage - the neck will inevitably bend and thus increase the distance between the strings and the fingerboard. The action can later be set to the right level by increasing the height of the saddles. When you have set the action to its lowest point measure the height between the lower edge of the bridge and the point where the strings make contact with the saddle. Low bridges will normally be between 8mm and 12mm ($5/16"$ and $15/32"$) high. The value measured (which could, for instance, be 9mm / $3/8"$) is the distance that the fingerboard surface has to be above the body surface. In the area where the neck is bolted onto the body a standard neck is always 1" (25mm) thick, no matter whether it is made from one piece or whether it has a glued-on fingerboard. In the above example, the neck pocket would therefore have to be 16mm (25 - 9mm) or $5/8"$ (1" - $3/8"$) deep.

If the bridge is higher than that, you can obviously make the slot less deep and place the neck even higher (2), but at some point this will not give enough stability. If this is the case, the neck has to be angled back to achieve a good action (3). An angled-back neck is also required if the body surface is domed (4). Alternatively, you could slightly sink the bridge into the body.



Brass part screwed into the neck pocket

The CNF (covered neck fixing) system (5), which was patented by the German company *Schack Guitars* does not require any mounting screws. It consists of a brass part that is screwed to the neck and another screwed into the neck pocket, so that you can simply hook in the neck. No mounting elements are visible from outside and the neck-body joint can be shaped very hand-friendly. After the neck has been hooked into the body it is fixed with a bolt which is accessible via the neck pickup cavity. The neck is held in place by the pull of the strings alone.



What was said about bolted-on necks also holds true of glued-in necks, although these always require a heel at the end of the neck to provide a larger gluing area. The glued-in part of the neck should always be surrounded by three gluing surfaces in the neck pocket (or mortise in this case). If the neck end has a tenon (6), the glued joints will be hidden after the neck has been glued in.

Furthermore, a tenon gives a smooth, stepless transition from the neck into the body.

On guitars with two body horns and the pickup fitted right at the end of the fingerboard, with a lot of frets sticking out of the body (figure 5, top), there is little space left for mounting the neck. If this is the case, the end of the neck has to be made thicker and a part of it has to be inserted farther into the body under the pickup (figure 5, bottom) in order to get a larger area for gluing or fastening it by means of screws. You can see a picture of such necks in the section "A visit to PRS Guitars".

If, however, you do not make an upper (left) body horn, you will have enough space for bolting on the neck (6).

On straight-through-neck guitars (7) the fingerboard surface would be in too low a position and the action therefore far too high and not adjustable to a lower position if no counter-measures were taken to correct this. There are several ways of doing this: you can either glue on a very thick fingerboard or lower the position of the bridge by sinking it into the body; or you can use a neck blank that is thicker than the body and rout off or sand down the bit behind the fingerboard end that protrudes over the body surface (a). How much precisely has to be removed depends on the bridge used. I recommend this method because the guitar is easier to build as with the method described below.

A further possibility would be to glue in the middle part not strictly parallel to the body but slightly angled back and to then rout, plane or sand it level with the body (b). This is probably the best solution for very high bridges. Note that you must make a full-scale drawing for determining the necessary angle.



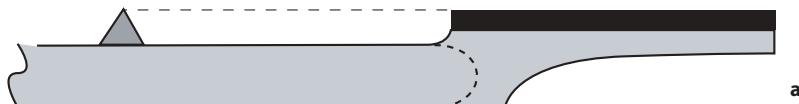
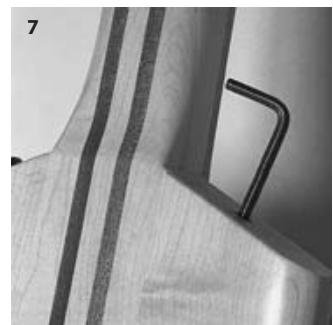
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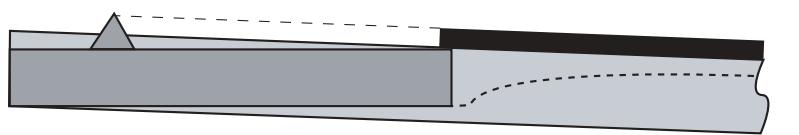
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6



a



b

Truss rods

Truss rods or other neck reinforcement measures are absolutely necessary on electric guitars with their long necks sticking out from the body. To reduce the likelihood of the neck twisting, it can also be made from several pieces.

Non-adjustable truss rods

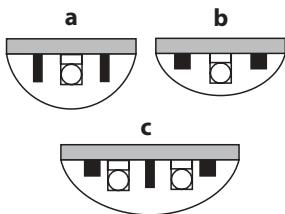
One way of making the neck stiffer is by installing an ebony or carbon fiber rod beneath the fingerboard. This rod is slightly tensioned and firmly anchored at a plate on either end. It has to be only slightly longer than the distance between the two anchor plates and is glued in under pressure.

Owing to their great stiffness and low weight carbon fiber strips are very popular these days. They are cut from blocks made up of extremely thin layers of carbon fiber and epoxy resin. Carbon fiber can be planed or sanded. Always wear gloves and safety glasses when you machine this hard, brittle, celery-like material. It will dull your cutting tools and it should not be machined with power tools. For shortening the material better use a hack-saw. The material can be sanded but the dust is dangerous and you should always wear a dust mask.

If you want to use power tools to cut carbon fiber, use abrasive blades or wheels. The carbon fiber manufacturers cut these materials with lasers or water-jet cutters.

Because of their low weight even two or more 3mm x 10mm ($5/16" \times 3/8"$) carbon fiber strips can be glued into the neck using Superglue, epoxies, or wood glues. Figures a and b show typical neck designs that use an adjustable truss rod and two reinforcing rods for rigidy and stability. Figure c shows an approach for five and six-string basses where two truss rods are used. The two truss rods help to control warping and twisting of the neck on this type of guitar.

Another way of making the neck stiffer is by installing a 10mm x 10mm ($3/8" \times 3/8"$) square steel tube under the fingerboard. Solid metal inlays would be far too heavy.



Adjustable truss rods

Adjustable truss rods give more options for adjustments: if the neck bends too much under the pull of the strings, it can be straightened with the truss rod.

If you make your neck thick like a base ball bat you can do without one but with modern, thin necks its a necessity. You need the ability to adjust the neck relief when you change string gauges for instance. Let's say you had medium strings on your guitar and put on lighter ones: the string pull becomes less and the neck which was adjusted for the pull of medium strings will now bend back. Its good to have the possibility of adjusting a slight relief again which you can do by loosening the truss rod.

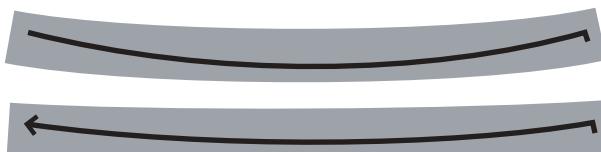
If you change from light to medium strings on the other hand the neck will bend more because of the increased string tension. You'll be happy if you have a truss rod which will straighten the neck if you tighten the truss rod nut.

Compression rods are the most common type of truss rod installed in electric guitars: a 5mm ($3/16$ ")-diameter steel rod is embedded into a slightly curved channel (1) in the neck. One of the ends of the rod is firmly anchored, the other end is threaded. The truss rod is covered with a wooden fillet which is also curved on its bottom side, the curve matching that of the rod so that the latter has no room for movement. The neck can then be adjusted by means of an adjustment nut with washer: tightening the nut straightens the truss rod and with it also the neck (2). This type of truss rod only works in one direction and can only straighten the neck or bend it backwards. The more deeply it is embedded into the neck, the more effective it will be.

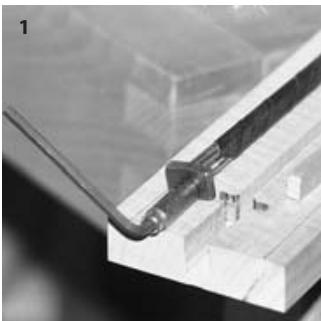
It is also possible to install a straight truss rod inside the neck, as long as it is embedded as deeply as possible and not much wood is left under it so that the neck is effectively bent backwards when compressed. Such straight truss rods are, however, less effective than curved ones because they require a lot of force.



1



2



1

Using twin rods (1) is another very effective method of neck adjustment: the neck is bent strongly and in a very even curve by only slightly turning the nut. As the name implies, twin-rod systems consist of two metal rods; these are about 5mm ($3/16"$) in diameter and are joined at one end and placed above each other in a channel inside the neck. At the other end the top rod is anchored in an anchoring block while the bottom rod is threaded and has an adjustment nut, which, when tightened, bends the rod downwards. Twin rods are fitted into a flat-bottom channel and can also be removed from the neck after installation. They can only bend the neck backwards, and are, because they need a deeper channel, less suited for access from the peghead. The top rod can also have a rectangular cross-section to better fill out the space inside the channel.



2

Another possibility is to glue a 12mm x 10mm ($15/32" \times 13/32"$) aluminium U-channel with internal 5mm ($3/16"$) steel rod into a flat-bottomed channel (2). This is basically a twin-rod system, the only difference being that the top rod is replaced by an aluminium U-channel, which gives greater stiffness. When mounting such a system care has to be taken to ensure the opening of the U-channel faces the back of the neck so that the neck will bend backwards when the nut is tightened. This system is also effective in one direction only.



Using a two-way adjustable compression truss rod makes the neck adjustable in both directions: at either end of a steel rod a nut is firmly anchored in the neck; the nuts are oppositely-threaded (one of them turns clockwise, the other counterclockwise). The neck is adjusted by turning the entire truss rod. Depending on the turning direction, the nuts are either pulled towards each other or pushed apart so that the neck will bend either forwards or backwards. Such truss rods are best installed slightly curved (see above). If you make such a rod yourself, make sure that the front nut is twisted on the thread before the adjusting head is firmly connected (e.g. welded on) to the rod.



Two-way twin rods have both ends of both rods firmly bolted into blocks. The rods have a clockwise thread at one end and a counterclockwise thread at the other. By turning the bottom rod the neck can be adjusted equally well in both directions and be made to bend forwards or backwards, depending on the direction the rod is turned. For installing this system both rods have to be simultaneously turned into the threaded blocks. To ensure the bottom rod can be turned the front block has to be mounted and an adjusting head has to be firmly connected (e.g. welded on) to the rod at one of its ends. This type of truss rod requires a flat-bottomed channel and can, if necessary, be pulled out and removed easily after installation.



What are two-way truss rods for?
If the string gauge you've chosen is not able to bend the neck either because the strings are very light or the neck is quite thick or stiff it comes in handy to be able to adjust the truss rod the other way around so that it bends the neck a bit forward for a sufficient relief.

The patented ABM **two-way twin rod** (3) has a threaded insert with a counterclockwise 8mm thread on its inside. The insert is welded to the end of the top, 6mm x 3mm, flat rod. The adjustment nut has a counterclockwise 8mm thread, too, but on its outside, and a clockwise 5mm thread on its inside. The bottom rod has a clockwise 5mm thread. The other ends of the rod are welded together. The truss rod is operated with a 5mm allen key. Turning the nut in a clockwise direction causes the bottom rod to be pulled towards the nut while the oppositely-threaded top rod is pushed away. This forces the rod to bend downwards, just like any other rod. When the nut is turned anticlockwise the rod will bend the other way, i.e. upwards. This is another system that is fitted into a flat-bottomed, 6mm-wide and 10mm-deep channel.



3



Access to the adjustment nut is on most truss rod systems possible either from the peghead end or the body end of the neck. Peghead-end nut adjustment cavities should be kept as small as possible in order to not weaken this part over and above what is necessary. Avoid hex nuts, if possible, as they require a lot of space (which is not easy to find at the peghead side) to allow getting at them with an adjustment wrench. Allen nuts on the other hand make ideal adjustment nuts as they require no room around them and the allen key can be inserted right into the nut (similarly with cross slot nuts).

When access to the nut is on the body end of the neck a small cavity can be made in the body so that the neck does not have to be removed to allow adjusting the nut. If the guitar is to have a front pickup, at least 20mm ($\frac{3}{4}$ ") of space should be left for a recess to allow getting at the adjustment nut and adjusting the truss rod with an allen key or a wrench without having to take off the neck. If necessary, the allen key can be shortened with a metal saw to enable access to the nut. Another option would be to install one fret less on the neck and to make an adjustment cavity in its place. Cover the cavity with a small metal plate. This makes it possible to place the pickup right next to the fingerboard.

Some effects on sound

The position of the pickups has a strong influence on the sound. Since there is only a limited amount of space left between the bridge and the end of the fingerboard, guitars with more than three pickups are very rare. A pickup fitted closer to the neck sounds bassier, whereas one mounted at the bridge sounds brighter. The front pickup is fitted in an area where the strings vibrate more, while the pickup further back picks up the less wide vibrations of the strings. Normally, the rear pickup's output is somewhat higher to compensate for differences in volume levels.

Due to the fixed distances between their polepieces conventional pickups do not allow much variation with regard to positioning - as already mentioned, the strings have to be precisely above the polepieces. Pickups with blade polepieces leave more options for positioning, but the blade always has to be wider than the distance between the two outer strings.

Sustain

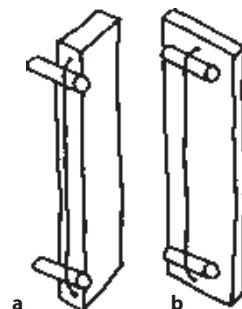
Sustain is the length of time over which a string sounds after being plucked - the longer it does so, the better. Getting a lot of sustain is one of the declared goals of guitar-building. Stopping a vibrating string, on the other hand, is no problem. The length of sustain depends less on the density and weight of the body or the material used for making the neck than on the stiffness of the entire system. Here's an example: a string mounted on the narrow side of a piece of wood (a) will vibrate longer than one mounted on its broad side (b). Although the mass is the same in both cases, the first way of mounting gives a much stiffer system as less energy is withdrawn from the string. When mounted on the broad side the resistance to bending is much lower and the board "swallows" the energy of the vibrating strings far more quickly. This explains why a guitar with a stiff and firmly fixed neck and a body made from a lighter type of wood such as alder, swamp ash or even poplar can give more sustain than a guitar with a heavy, dense body and a "soft" neck.

Because the neck-body joint is approximately in the middle of a string, it is extremely important to have a good, firm joint to get maximum stiffness and a long sustain. This is easier to achieve on guitars with stiff, straight-through neck, but is also possible on guitars with bolt-on or glued-in neck as long as the joint is well made.

Consider every detail that might withdraw energy from the strings' vibrations: inserting a cardboard shim under one of the saddles can be sufficient to dampen the strings' vibrations and to give a strongly reduced sustain. A loose saddle or tuner shaft vibrating with the strings can have the same bad effect. A well-fixed solid brass bridge will give more sustain than a thin metal plate with saddles.

Making the system too stiff, however, is not advisable, either, as it would then not be sufficiently stimulated by the strings and a loss of some of the elements of the sound would be unavoidable. Although an electric guitar made of stone would most certainly have an "endlessly long" sustain, we would no doubt be less impressed with its lifeless, sterile sound, let alone the weight of such a guitar which nobody could put over their shoulder.

Mahogany necks can be made stiffer by using a quartersawn neck blank. Conversely, a very stiff maple neck can be made less stiff by using flatsawn timber, resulting in a mellower, warmer attack.





Design examples

The Botar

This example of innovative guitar design was created by the German guitar maker *Thomas Dramm*. His electric guitar can be successfully played with a bow.

The idea to play the electric guitar with a bow is not new but players have always used standard electric guitars which have their limitations: you can not play single notes with the bow on a normal guitar and the bowed notes are faint compared to the plucked sounds. The latter is due to the construction of conventional electric guitar pickups.

Only few parts of the conventional electric guitar could be left unchanged; the neck and the fingerboard, the body, the bridge, the pickups and the electronics had to be redesigned. The fingerboard is much more curved than on a standard guitar and the radius of the bridge has to be accordingly curved. The curved fingerboard and

bridge allows playing every single string separately. The body is specially shaped to give room for the bow when the outer strings are played and the pickups and electronics have to work with strings that are played with a bow.

The guitar has a swamp ash body and a glued-in hard rock maple neck with ebony fingerboard.

The scale length of the *Botar* is 25.5 inches. The fingerboard sports 22 frets of which the first fret is a zero fret which in conjunction with the ebony string guide replaces the otherwise commonly used nut. All strings run straight to their respective tuning machines. The pickups are handwound and their covers are made from the same wood as the body. Together with the likewise special active electronics this gives a good balance between the volumes of the bowed and the plucked sounds.

Solid-body guitar

Scale length: 24.75" (628.65mm)

Neck: mahogany

Fingerboard: rosewood, 12" radius

Body: alder, one piece

The entire guitar is oiled with

Danish Oil and waxed.

Wilkinson tremolo

Electronics: 2 humbuckers wired in a *PRS*-circuit.

I also offer a blueprint of this guitar (see additional materials).



My first-ever electric guitar (1990)

Scale length: 34" (863.6mm)
Total length: 1040mm (40.9")
Neck: straight-through, maple/
mahogany
Fingerboard: stained maple
Body wings: maple
Body depth: only 35mm
The entire instrument is finished
with satin nitrocellulose lacquer.

This fret- and headless bass with its extremely thick straight-through neck made up of three strips of maple and two thin strips of mahogany has no truss rod. The maple fingerboard was stained in a darker color. The body wings are made from maple.

Because the strings are clamped at the head end, it is possible to use normal strings. However, I would now use special headless bass strings, which I had not yet heard of at the time of making this bass guitar. The bridge and the tuners are made of brass. The strings are tensioned with 6mm-diameter allen screws. Using thinner, 3mm- diameter bolts with finer thread would, however, also be sufficient and would allow twice-as-fine tuning. Since the fingerboard surface is only 6mm higher than the body surface, the entire tuning unit had to be lowered into the body.

As for the electronics, this bass has a *DiMarzio* bass humbucker, one tone control and one volume control.



My latest electric bass (2000)

Scale length: 34" (863.60mm)
Neck: maple, one piece, straight-
through, headless.
Fingerboard: ebony, 16" radius,
fretted up to the 12th fret, rest is
fretless.
Body wings: cherry
Finished with Danish Oil.
ABM tuning unit.
Electronics: 1 *MusicMan*-style
pickup wired to an active filter
circuit.



Headless bass

Scale length: 34" (863.6mm)
Total length: only 960mm (37.8")!
Neck: bolt-on, maple finished with clear nitrocellulose lacquer
Fingerboard: ebony, untreated
Body: ash, finished in black

This bass has a special and rather expensive tuning unit manufactured by the German company ABM. When you compare prices, bear in mind that this unit includes the bridge as well as the tuners. It is possible to use special strings with two ball ends.

The split *Precision Bass* pickup is connected to an active filter circuit. The controls allow the adjustment of frequency, impact volume and volume level.

A headless guitar is undoubtedly the easiest type of guitar to build, saving you work as, for instance, no peghead is needed on the neck. Further advantages of a headless instrument: the strings run in a totally straight line; due to the absence of windings on tuner shafts the instrument is perfectly stable in its tuning; because of its zero-fret no lengthy nut-filing is required; the instrument is a compact whole, and the risk of making the peghead too heavy simply does not exist. With all these advantages, why aren't all guitars built like this? Well, guitarists are a fairly conservative lot after all (aren't they?), and maybe headless guitars are just not as "sexy" as conventional ones.



Hollow-body guitar

Scale length: 24.75" (628.65mm)
Neck: bolt-on, ash, clear nitrocellulose lacquer
Fingerboard: plum wood
Body: 6mm-thick spruce top on alder body. The alder body is, its lengthwise middle strip excepted, hollow.

The two halves of the split, hand-wound pickup are linked in series and act as a humbucker due to the opposite magnetic poles of the coils. The neck is angled back slightly.





**Solid-body guitar
with Stratocaster pickguard**
Scale length: 25.5" (647,7mm)
One-piece neck: maple, vintage
amber stain, clear nitrocellulose
lacquer, peghead with staggered
tuners
Body: alder (two pieces), one can of
primer, one of blue color
Electronics: standard *Stratocaster*
wiring, one single-coil and two
single-coil-format humbuckers;
fingerboard is longer than the neck.

**Solid-body bass
with Jazz Bass pickguard**
Scale length: 34" (863,6mm)
One-piece neck: maple, vintage
amber stain, clear lacquer
Body: birchwood (three pieces);
color: green (two spray cans); *Jazz
Bass* electronics.

*Due to the shape and position of the
pickguard the end of the neck of the
two Fender-style guitars has to be
around the 22nd fret.*

**Solid-body guitar
with P-90 pickups**
Scale length: 24.75" (628,65mm)
Angled-back neck: mahogany,
angled-back peghead
Fingerboard: rosewood, untreated
Body: alder (two pieces), clear
nitrocellulose lacquer
Electronics: two self-wound *P-90*
pickups with opposite magnetic
poles. This gives a humbucker when
the switch is in the middle position.



Semi-acoustic vs. hollow-body

The term semi-acoustic guitar is used specifically for guitars like the one shown on the left. The body consists of a thin top and back plate and the sides are bent from thin strips of wood. A solid block of wood runs down the center of the body. Building a semi-acoustic guitar has more in common with building an acoustic guitar than building an electric.

I use the term hollow-body guitar for a solid-body guitar with hollowed-out body and glued-on top.



Semi-acoustic guitar

Scale length: 24.75" (628.65mm)

Neck: glued-in, angled head, maple, clear lacquer

Fingerboard: rosewood, untreated

Body: 5mm-thick maple plywood, clear lacquer

Greatest body width: 410mm (16.1")

Body length: 490mm (19.3")

Body depth: 45mm to 55mm (1 $\frac{3}{4}$ " to 2 $\frac{5}{32}$ ")

This Washburn semi-acoustic guitar is the only electric guitar I ever bought. Each of its two humbuckers has one volume and one tone control. A toggle switch allows selection of the following pickup combinations: 1, 1+2, 2. The head is angled back. The depth of the body is approximately 55mm (2 $\frac{5}{32}$ ") at its deepest part in the middle and 45mm (1 $\frac{3}{4}$ ") at the edges. The sustain block is glued to the top and the bottom and becomes thinner towards the edges.



Hollow-body bass

Scale length: 34" (863.6 mm)

Neck: mahogany, oiled

Fingerboard: ebony, untreated

Body: mahogany top on ash, lower part of the body hollowed out, oiled, top French-polished

Electronics: self-wound *Precision Bass*-style pickup

Making templates

After having designed and drawn the guitar you should make a "flat" guitar from 6- to 10mm-thick plywood on a scale of 1:1. Using these templates and a router bit with end-mounted ball bearing in a table-mounted router the body and neck contours are routed later. Use hard beech plywood for this purpose; if soft plywood is used, the ball bearing of the router could lead to undesired changes of shape. A body and a neck template are required. I even use a separate peghead template as this makes it easier to plane the fingerboard template edges straight. For an angled-back peghead you always need a separate peghead template.

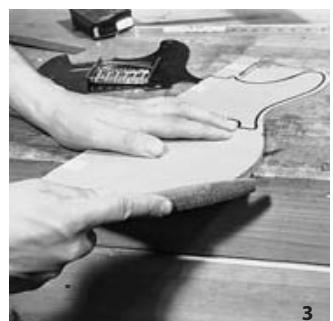
For making a symmetrical body fasten two pieces of the template material with adhesive tape on top of each other and then cut them out together (1). After rough-cutting the body shape, I use a rasp and sandpaper to smooth the contours. If you then open the two halves that were kind of folded together, you will have a perfectly symmetrical body template from which only the cutaways are missing. If you use a pickguard, its shape has to be taken into account when determining the body shape. Where the body is not symmetrical (2) - and this is fairly often the case - templates obviously cannot be cut out in this manner (i.e. folded up).

It is advisable to take a lot of time for filing and smoothing the template contours (3) as any uneven spots and dents will later be transferred onto the wood and will then be far more difficult to correct than on the thin template. If your work is in danger of becoming sloppy and rushed, it may be a good idea to grant yourself and your templates a little overnight rest and to finish the sanding the next day.

Using a jointer I plane the sides of the neck template from a long, square piece of plywood. To taper it plane the piece over a short length only to start with and then gradually work your way up the entire length.

If you then screw the neck template to the body template and also attach the peghead provisionally, you can get a first impression of what your guitar will eventually look like and you will be able to assess its proportions (4). Like it or not, except for the guitar being very flat you see a "life-size" version of your future guitar!

It is not a bad idea to first make "master" templates out of 3mm ($1/8"$)-thick plywood as shaping such thin material is much easier. Then make your "work" templates by simply copying them from the master template by means of a table-mounted router and a router bit with end-mounted ball bearing. Keep the master template in a safe place afterwards.



Workshop

Electric guitars have been built in all kinds of rooms, from living rooms to fully-equipped workshops. I even know somebody who built an electric bass on chairs and the floor of his living room. Ideally, though, you should have a room of your own, with plenty of light, where you can leave things without having to worry about them and where producing dust and noise won't get you into trouble. The room should also be dry, with a relative humidity of 50 to 70 per cent. Because wood - and in particular a musical instrument - reacts to changes in humidity, any such changes should be minimal. Buying a hygrometer will therefore be an absolute must. It doesn't have to be an expensive hair hygrometer; a cheap one will do as well. What matters is that you keep an eye on humidity and do not totally ignore it.

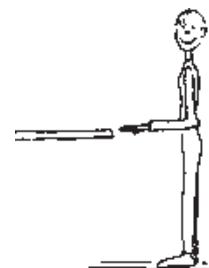
If your workshop is inside a heated house, for instance in a basement room, humidity will most certainly not be a problem. Things are different, though, when using an external workplace without proper insulation of the walls against ground moisture. In such rooms humidity is often as high as or even higher than the humidity outside.

Depending on the weather, humidity can then vary between 50 per cent on dry, windy days and 80 per cent and higher on close or rainy days. In very moist rooms humidity can even be between 90 and 100 per cent. If a room is heated during winter, humidity will be lower.

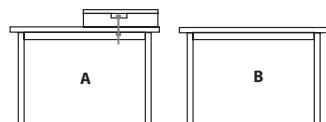
Electric air dehumidification is unfortunately an expensive option, (a) due to the cost of buying the appliance (1) and (b) because of the energy costs. In some cases they will, however, be needed if your guitar is to be of good quality. Alternatively, if your workshop is too moist, you could also move the wood between the workshop and a drier place in the house, taking the wood to the workshop only when you work on it and then taking it back to the drier place for storage.

A workbench would be an ideal work surface, but basically any stable table can be used. Small workbenches that can be folded up and allow clamping a great number of differently-shaped objects also make good work surfaces.

Another important thing to consider is the height of the work surface. Most of the work surfaces I have come across are far too low. Since most of the jobs are carried out standing, your back will soon start aching if you have to constantly bend down to work; as a result, not only you but also the quality of your work will suffer. The ideal height for the work surface required for guitar building is hip level. For example, a person 6 feet (1.83m) tall should have a work surface just over 3 feet (96cm) high. Before you start working, adjust the height of your workbench to suit your height, using bricks or wooden blocks if necessary. A lower work surface is, of course, better for jobs that require a lot



of physical power and force. In order to have both options, instead of raising the workbench, a platform could be clamped to the table (A), which could be removed when performing tasks that require more downward force, such as planing (B). A footstool on the floor on which you can put one foot while working is “back friendly”, allowing you to stand upright.

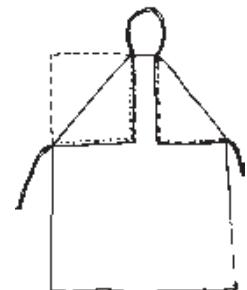


Tools

Workshops of “hobby carpenters” will be equipped with different tools ranging from hand plane and saw to tablesaw, bandsaw, jointer and planer. The better equipped with tools you are, the better for you. If you don't own certain machines or tools, you might, however, know somebody who doesn't mind you using their tools, or you may have to ask a joinery firm to cut, plane or even glue up the wood for you.

An electric guitar can for the most part be built with ordinary woodworking tools, but some experience and skill at doing jobs such as planing surfaces will be indispensable. Planing by hand is the healthier approach as no health-damaging noise or dust is produced and wearing noise and dust protection is made unnecessary. I find it remarkable what former generations have achieved with simple hand tools. We are nowadays capable of producing things much more quickly, efficiently and at a lower cost, but we have become incapable of patience.

Power tools make guitarbuilding easier and also allow you to work with more precision; even beginners can get good results in no time at all. On the other hand, they also produce a lot of noise and dust. I wrote this book at a time when I was upgrading my workshop; so don't be surprised if you see a great variety of tools in this book.



Apron

I normally wear an apron during work. It can be put on and taken off quickly and I find it comfortable to wear. If you are impressed with my ultra-modern working apron, why not sew one yourself or have one made for you? All you need is a strong cloth, about $\frac{3}{4}$ by 1 meter (2.5 by 3.25 feet) in size, and three strings. The design and choice of color of such an original guitar-builder's apron is entirely yours!

Basic equipment

This is the equipment that I started with; and if you have been suddenly overcome by the desire to build your own electric guitar you will probably have a similar arsenal of tools, or maybe an even smaller one. Although it is possible to build an electric guitar with these tools, the majority of guitarbuilders use better equipment. Having good-quality tools will in the long term always pay off. Each tool is an extension of our physical capabilities and most jobs could simply not be done without them.

Power drill

You will probably already have a power drill; if not, it is worth buying one, not least because they are quite cheap anyway. You should also have a good and stable drill stand with vise. Cordless drills (powered with rechargeable batteries) are also useful as they are small, quiet and easy to handle and can be recharged within 10 minutes to an hour, depending on the battery charger. Obviously, a hand drill will also be quite sufficient if you buy ready-made hardware.

A drill press - as opposed to a power drill on a stand - will be a real blessing and not that more expensive than some of the more expensive power drills. With a drill press everything is firmly in place and the noise level is pleasantly low, too.



Drill bits

1 Forstner bit for drilling large-diameter holes and removing wood prior to routing. It produces a hole with a flat bottom. A small depression in the middle is left by its point.

2 Brad point bit for use in wood. It has a useful centering point and produces a hole with a flat bottom.

3 Twist drill bit for use in metal and wood. The bottom of the hole is cone-shaped.

Power tools

There are a great number of portable power tools available for almost any kind of application. Portable machines such as belt sander, power planer or circular saw can be very useful and make work easier, but they are not absolutely indispensable for building an electric guitar. Whenever possible buy semi-professional or even professional tools; the machines aimed at the amateur woodworker are in general less powerful and, although sufficient for your needs, will not bring such long-lasting delight. Your finances permitting, it is obviously always advantageous to buy high-quality tools and machines rather than low-quality ones.

Plunge router

A plunge router is an absolute must. I would even say that it is the most important and most versatile tool needed for building an electric guitar. There are countless books and videos on what you can do with a router - in fact, there is hardly anything that can't be done or made with it. Although a small one will do, a more expensive and more powerful model will obviously be more versatile. Power drills with routing attachment cannot replace routers as they are not capable of producing the high speed required.

Almost all router manufacturers offer collets of different sizes (6), and I would recommend that you buy an assortment of all collets offered by the manufacturer of your router in addition to the one(s) which come(s) as a standard. This has the advantage of allowing the use of virtually all router bits.

I would strongly recommend buying a medium- to large-sized router with a 12mm ($1/2"$) collet. Although a router of this size is often twice or even three times more expensive, it is also far more versatile. Buying a more expensive, professional router might well cause an intense, short-lasting pain, but compared to the life-long "suffering" with an undersized machine this is clearly the better choice for the long term. And if one day you decide to give up your hobby altogether and you sell the machine, potential buyers will be happy to pay good money for a high-quality machine.

Buying $1/2"$, 12mm, $3/8"$, 8mm, $1/4"$ and 6mm collets will allow using almost any router bit. If you would like to save money, buy shank adapters (also called reducing collets, reducer sleeves or bushing adapters): one $1/2"$ collet will then be sufficient and bits with smaller shanks can be fastened by using e.g. a $1/2"$ to $1/4"$ or a $1/2"$ to 8mm shank adapter. For larger router bits these adapters are not as well suited as the shanks are prone to slipping out of the adapter, but for the small cutters that you will need for building your electric guitar these adapters will do the job, as



My plunge routers

I have a small router (**4**) with 600 watts power, a maximum 24,000 rpm (revolutions per minute), an electronic speed and torque control and a 6mm and $\frac{1}{4}$ " collet. I found it was sufficient for me until I discovered how much better it was to work with a stronger and more powerful model.

My second router (**5**) has an 1800 watts motor, a constant 22,000 rpm and can accept a $\frac{1}{2}$ " bit shank. Because it doesn't have an electronic soft start control, there is a jerk when the machine is switched on, but this is not really a problem. Now I use the smaller model for precision work where the heavier router would be too difficult to handle. At the front (**6**) you can see collets, shank adapters (reducer sleeves) and a 10mm thread adapter.

long as you make sure that the collet is *very well* tightened. Another drawback is the increased cutter vibration. Shank adapters are more of a makeshift and I would recommend that you to use a right-sized collet straight away.

Some routers additionally allow the use of cutters with threaded shanks which are simply screwed onto the machine. Reducing sockets to fit other thread sizes are also available.

Collets should never be tightened with brutal force and never without a correctly-sized bit in it. They are wearing parts and should be replaced as soon as they are slightly damaged.

The depth of cut that can be made with a router depends on its maximum plunge depth, the length of the cutter and the length of the cutter shank. Two-thirds of the length of a normal-length cutter shank should always be in the collet. Cutters with longer shanks can not only be fastened better but also allow making deeper cuts than correctly-fastened cutters with shorter shank. If you do not make deep cuts, use bits with normal-length shank as the longer the cutter, the more it vibrates.

The depth of cut can be adjusted without using a scale. The scales of some routers are quite unreliable anyway. Place the router on the piece you are working on, lower the bit until it just touches the surface of the piece and lock the router. Then put something which is the same height as the desired depth of cut under the depth stop and fix the stop. Feeler gauges are suitable for low-depth cuts and drill shanks (as shown in the picture on the right) for deeper cuts. When using a template errors in setting the depth of cut often occur because the thickness of the template is not taken into account.

Always wear eye and ear protection when using a router. Never change the cutter bit while the router is still plugged in.



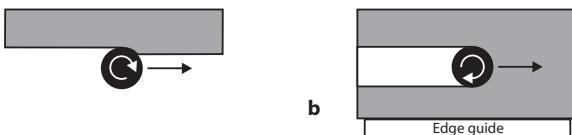


Table-mounted router

Most routing jobs can be done better and more safely if the router is mounted upside down on a table. I built a very basic router table from a board and a router mounted beneath it. When working with it I simply secure the board on the workbench with two clamps. The router that I use for this is a very old model of the German manufacturer Scheer (shown on the left in the picture above) which was a real bargain as I bought it secondhand. A lot of carpenters prefer smaller, more modern and easier-to-handle models and additionally have a shaper so that such old-style routers are often no longer needed and just use up space. I also find them quite unwieldy as routers, but for use as simple table-mounted routers they are ideal. The Scheer-model has 1800 watts power, a constant 12,000 rpm and a 10mm thread for holding the router bits. I also managed to get a collet-adaptor and a 12mm and $1\frac{1}{2}$ " collet. Cutters with end-mounted ball bearing which are sufficiently long for the body of an electric guitar all come with such a thick shank.

Make sure to move the router in the correct direction (i.e. in the opposite direction of the revolving cutterhead). When routing around the outside of a piece of work the router has to be moved in a counterclockwise direction (a). Cavities on the inside, such as pickup cavities, are made by routing in a clockwise direction. Routing against the direction of rotation has the advantage of making it a lot easier to guide the router smoothly.

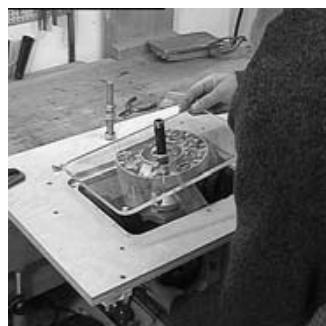
The same is true if you use an edge guide. When routing in the right direction (against the direction of rotation) the edge guide is pulled towards the work (b), thus keeping the routing line straight. Routing in the opposite direction would make it very difficult to keep the guide close to the piece of work.



Router bits

There are three types of router bits: HSS (High Speed Steel) TCT (Tungsten Carbide Tipped) and solid carbide ones. The HSS steel cutters wear much more quickly when used on hardwoods. They can therefore only be recommended for routing softwoods. The TCT router bits have welded-on carbide blades. Such cutters are more expensive, but they also last longer and allow cleaner cutting.

When buying router bits the size of the collet of your router has to be taken into account. Cutters with thicker shank are more stable. Also be aware of the maximum shank diameter permissible on your router. Avoid using a much longer cutter bit than is necessary for doing a particular job as the longer the bit is, the less smoothly it will turn.



How to quickly turn a router into a table-mounted router

By fastening a rectangular base plate to the router base as shown on the left you can quickly convert your router into a table-mounted router. The table opening has a rabbet around its circumference and the rectangular base plate is fastened with two screws placed at diametrical corners. The inserted router base is adjusted flush with the table with shims glued on the rabbet. The table on the left is a simple plywood board fastened to the table edge with two clamps. It was stiffened on its underside to keep it flat.



Flush-trimming cutter bits, which can have the ball bearing mounted on the shank (2-6) or at the end (7), are extremely useful for building electric guitars. The diameter of the ball bearing and the bit are identical, and the bearing can be guided along the edge of a 1:1 template fixed on the workpiece. By stacking on the right ball bearing you can turn an ordinary bit into a ball-bearing cutter bit. The smallest ball bearing size I managed to find has an inside diameter of 6mm and an outside diameter of 10mm; I used it on a 10mm router bit with 6 mm shank (2). Always use some kind of protection to stop the bearing from sliding up the shank during use as this could ruin your work. The ball bearing could be kept from sliding up by fastening a metal ring with a tiny allen screw (3, 5, 6) or by stacking two or more ball bearings above each other, in which case the collet keeps them in place (2, 4). If you can't get hold of a small-diameter bearing, it may be necessary to use the bit shank as a stop (1). Be aware that in this case the fast-turning shank becomes very hot and can damage the template during routing.

Rounding-over bits with ball bearing are very useful for rounding off body edges. They are available in different radii or as oval shapes of different sizes (8). Always make sure not to exceed the maximum cutter bit diameter or the maximum speed that is permissible on your router.

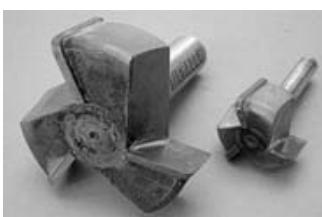
Special surface-trim cutter bits like the ones shown below make smoothing wood surfaces easier. They have three cutting edges, which gives smoother surfaces.

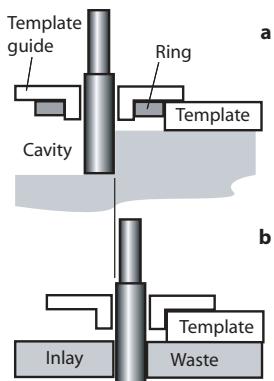
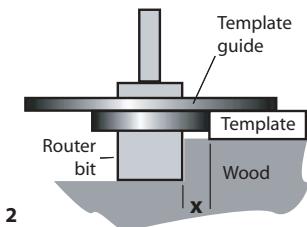
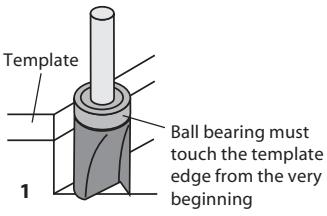


Spiral bits

The parallel cutting edges of normal router bits are not permanently in contact with the wood, which results in vibrations and tool marks left on the surface.

Bits with spiral edges, on the other hand, are always in contact with the wood and cut continuously. There is no vibration from the impact of entering and leaving the wood. Furthermore the shearing action of their cut produces shavings and leaves a much cleaner surface. Last but not least this type of bit is quieter. The more cutting edges a spiral cutter has - the one on the right has two, the one on the left four - the better. There are bits with up-cutting or down-cutting spiral. Chips are always removed in the direction of the spiral. The bit on the right in the picture above has cutting edges on its point and an up-cutting spiral and can be used for drilling holes. The bit on the left also has an up-cutting spiral but no cutting edges on its point.





Flush-trimming cutter bits with shank-mounted ball bearing always have to be lowered deep enough for the ball bearing to be on the same level as the template (1). This is why the cutting depth cannot be below a certain minimum. If the cutter is too long, the template has to be made thicker. Such cutters are available in different cutting-edge lengths - the shortest one I know of has a $1/2"$ (12.7 mm)-long cutting edge.

Template guides are an alternative to ball-bearing cutter bits. They are fastened on the router base, centered on the cutter bit. One drawback of this method is that using a 1:1 template is no longer possible. This is, however, offset by the fact that the cutting depth can be chosen freely. The template has to be placed at a distance x from the actual routing line (2). The offset x equals half the difference between the diameter of the guiding ring and that of the cutter bit.

Precise fitting of inlays is possible with an additional ring fastened on the template guide. The difference between the outside diameter and the inside diameter of the ring divided by two has to be the same as the diameter of the router bit. You only need one template with an offset of x (see above) plus router bit diameter. The cavity is routed with the ring stacked on (a), and the piece to be routed without the ring (b). The ring should be fastened with a tiny allen screw.

The picture shows a template guide (3) with additional ring (4) and a cutter bit of proper size (5). The allen key (6) is for tightening the tiny allen screw.

Planes

Planing can be done either by hand, with a router or a planer. Planing by hand will only produce satisfactory results if you have a lot of practice and experience in adjusting and sharpening the blade. Although a beginner will, of course, not have much of the experience needed, hand planing is certainly a skill well worth learning - not only because nothing compares to the surface quality of a hand-planed piece of wood, but also because this makes you less dependent on machines. In contrast to machine-planing, where the rotating knife blades are not continuously in contact with the wood, only hand-planing produces those wonderful, wafer-thin wood shavings.

A plane, no matter if it is made of wood or steel, has to allow a fine adjustment of the blade projection by means of adjustment screws. It also has to be solid and must have a flat sole. The companies *Record* or *Stanley* manufacture quality, medium-priced metal planes which are a delight to work with. Three different planes belong to the basic equipment needed for

making an electric guitar: a block plane (8), a normal plane (9), and a spokeshave (7). On block planes the angle between the blade and the wood surface is less than 15 degrees. This makes it possible to even plane end grain surfaces particularly smoothly although they are basically suitable for all fine-planing jobs. My personal favourite among planes is the spokeshave. It is primarily used for shaping the neck. This type of plane has one handle on either side and a narrow blade. When working with it, it is held at both handles and pulled towards the body. A spokeshave with a curved sole can be used for smoothing the body sides.



Scrapers

Scrapers allow better and faster smoothing of surfaces than would be possible with sandpaper. If you have never used a scraper before, why not try your hand at one now - after all there is no better woodworking tool than this one, which is basically a sharp-edged metal blade that is held at an angle to the wood surface and thus planes off wood. Scrapers come in different shapes and sizes, the thinner ones often being more versatile. Very thin scrapers made of extra-hard steel are also very useful. *Sandvik* is one manufacturer of high-quality scrapers.

Any hard steel can be turned into a scraper. Blunt metal bandsaw blades of large workshop machines constitute an ideal material for making narrow scrapers - just grind off their teeth.

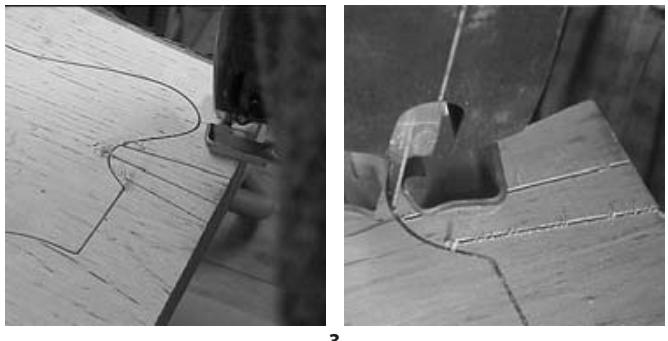
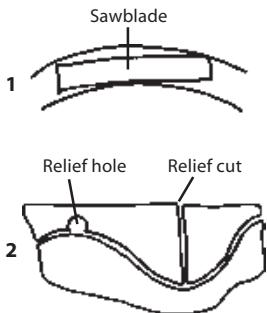
If the steel blade is blunt and you get wood dust rather than small shavings, the blade needs sharpening. To do this, use a fine file to file the edges straight and square to the scraper surface. After that work each edge with a sharpening stone, carefully removing all filing marks. By using a piece of wood it is easier to hold the scraper at a right angle (10). Putting the scraper onto the workbench on a block of wood and sharpening it on the sharpening stone is to be recommended more strongly, though.

The above-mentioned steps only need to be taken when the edges have become blunt. For in-between sharpening of worn scraper edges the following two steps are sufficient.

Step one: Bend the outward-pointing burr of the scraper back with a burnisher, a tool made of hardened round steel. You can also use the smooth surface of a round file handle. Put the blade on the surface of the table so that it projects slightly over the table edge slightly. Then move the burnisher along the edge at a slight angle, pressing it down all the time as shown in picture 11.

Step two: Bend the burr at the edge of the scraper back towards the outside as shown in picture 12. It should form a mini hook now. Burnishing tools such as the *Timberland Tools* one shown below help to keep the correct angles and make sharpening a scraper a breeze. Other useful burnishing tools are available from *Lee Valley & Veritas*.



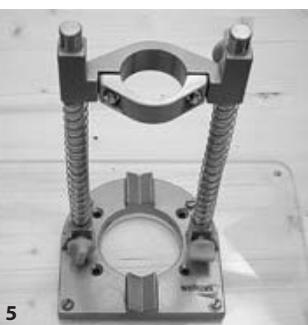


3

Sawing tools

Curved lines can be cut with either a European bow saw, a jigsaw or a bandsaw. If you prefer a hand saw, a lot of patience and practice will again be required, and you should make sure that the teeth are correctly set. However, I have not yet met anyone who would cut out the body of a guitar by hand. Although a jigsaw will also do the job, a bandsaw is much more commonly used. It doesn't even have to be a big one - for building electric guitars a benchtop model will do.

The smallest radius that can be sawed is determined by the width of the sawblade (1). If relief cuts or holes are made, a wider blade can be used as well (2). When using a jigsaw - where the blade is only guided at one point - making such relief cuts or holes at all points where the curve changes direction is absolutely necessary (3).



Sanding tools

For sanding wood surfaces you can use a countless number of products and machines. Sanding machines such as a random orbit sander (4) save a lot of time and hard work. Always have sandpaper of different grits (for example 80, 100 and 120) ready at hand. Whenever you do any sanding remember to protect yourself against dust. Some way of removing and collecting dust would be ideal. This could be done with a bag fastened on the machine, or better still, by connecting a vacuum cleaner hose directly to the machine.

Home-made spindle sander. In my corner of the world a lot of additional holders for power drills are commercially available (I use one of these for holding the power drill horizontal while winding pickups). All drills over here have a standardized "neck" that is 43 mm in diameter and fits into one of the holders.

With a drill stand (5), which is widely available (at least in Germany and Austria), I converted my power drill into a simple

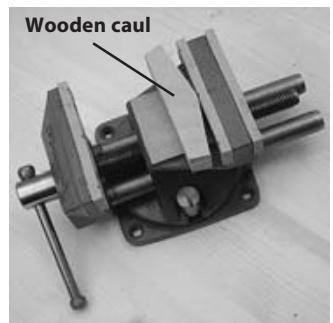
spindle sander. The table is the same as on page 96, but this time, by inserting my power drill and putting in a sanding drum, I got a spindle sander (6). Alternatively, you can use the sanding drum upside down in a drill press.

Japanese Tools

Japanese chisels (a) have an extremely fine blade that is hammered onto a softer metal core while the metal is in a red-hot state. This way of making leads to blows being softened and allows for the metal of the blade to be very hard and brittle. Japanese chisels are extremely sharp, but also very sensitive. This is why they should only be used for fine, intricate work. Only use Japanese waterstones for sharpening such chisels.

Japanese saws (b) have a particularly fine blade that allows making very fine cuts. During use the teeth point towards the user and the saw has to be pulled. If such a thin saw had to be used like a Western one, it would immediately bend; but because it is pulled it remains straight. Since discovering it I have used only this type of saw for precision-cutting.

There are two types of Japanese saws: one with stiffened back and teeth suited for making both cross-grain and along-the-grain cuts (b, right), and another with slightly wider-set teeth on one edge for making cuts along the grain and finer-set teeth on the other edge for cuts across the grain (b, left). This second type allows making deeper cuts. The sawblades of the saws shown in the picture above can be replaced if necessary.



Record RM2075 vise

This compact and inexpensive vise is better than nothing. The jaw capacity can be doubled from 89mm ($3\frac{1}{2}$ ") to 178mm (7") by removing the front jaw from the body and inserting it in the back, the latter being mounted on a 360 degrees swivelling base. By using a specially shaped wooden caul which just rests on the surface as shown above, it is possible to safely fix non-parallel work like for instance a guitar neck.





Sharpening

Properly sharpened tools are absolutely essential for successful woodworking. Sharpening can be done manually or with a machine, the goal being to restore the sharpness of a blunt cutting edge. This applies to planes, chisels and drill bits as well as scissors or knives.

When sharpening a tool, its blade has to be held at a certain angle to the surface of the sharpening tool; the more precisely this angle is maintained, the better. In this way one side is beveled and the other remains flat. Coarse sharpening can be done with a 220 sharpening stone, a belt sander or a grinder. Using a wet grinding stone and operating the machine at a low to moderate speed is least wearing on the tools involved. Note that when doing the sharpening by machine the tool that is sharpened must never get too hot as this would cause it to lose its hardness. Overheating can be prevented by regularly cooling the tool in cold water. Continue sharpening until an even, sharp edge has formed. Sharpening by machine only serves to remove the worst defects. It is also possible to use an apparatus where the sharpening stone is moved manually by turning a handle.

To get a really sharp edge this rough-sharpening by hand must be followed by honing on good-quality sharpening stones. For honing it is extremely important to keep a precise angle. There are special holders called honing guides designed to help you move the tool that is to be sharpened at a constant angle to the surface of the sharpening stone. My honing guide consists of two parts set on a threaded bolt that grip the sides of the blade when the bolt is tightened (1).

Continue sharpening with increasingly finer stones. When you have finished flip the blade over (i.e. put it on its flat side) and remove the little burr which has formed during sharpening by moving the even surface of the blade in a circular motion (2). The last thing to do is to wipe the cutting edge against a piece of leather, with the beveled side of the blade facing upwards. Always use water to moisten Japanese stones and oil for Arkansas stones. Diamond and ceramic stones can be used with either water or oil. If you are into cleanliness, don't use oil. Water stones should best be stored in a water-covered container with lid. Dry stones ought to be moistened for at least ten minutes before use.

Sharpening stones are available in many different grits. For our purpose a 1000/6000 combination would be sufficient. To get an even sharper blade you could use an 8000 sharpening stone after that. Japanese sharpening stones such as *King Stones* are a good choice: although they are softer, they sharpen better than other stones. Sharpening stones wear off after some time and require flattening of their uneven surfaces. This is best done by rubbing the uneven sharpening stone against a very expensive diamond



sharpening stone. There is, however, another, cheaper method of doing this: putting a sheet of moist silicon-carbide sandpaper onto a sheet of glass; the sandpaper will stick to the glass and you can make the surface of the sharpening stone smooth and flat by moving it in circles over the sandpaper. Do so until the sharpening stone is beginning to stick to the sandpaper, which is when the stone's surface is flat again. Use 150- to 180-grit sandpaper for rather coarse and 300- to 600-grit sandpaper for an 8000 sharpening stone. Sandpaper wears off quickly and has to be replaced regularly. To sprinkle silicon-carbide powder onto a sheet of glass instead is not a good idea as the glass surface will wear out and become uneven.

Sharpening produces a thin layer of grease on the stone's surface, which gradually reduces the surface coarseness of the stone. This is why this layer needs to be washed off regularly if the original roughness is to be maintained. Instead of using sharpening stones it is also possible to use silicon-carbide sandpaper: just moisten it, put it on a sheet of glass and throw it away after use.

Alternatives for sharpening

When using a sharpening stone or a belt sander for rough-sharpening a blade the tool's bevel remains flat (**a**). It also remains flat if it is held against the side of a grinding wheel. There is a drawback, though: sharpening with finer stones takes longer as the whole bevel area has to be worked. Honing a micro-bevel (**b**) is an excellent way of shortening the time required for sharpening. Hold the tool slightly steeper for this purpose.

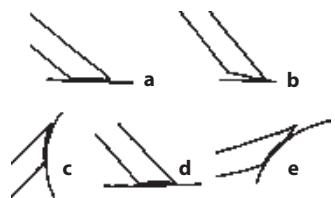
When the blade of the tool is held against a grinding wheel (**c**) a hollow bevel will automatically be formed, the curve of which will depend on the diameter of the sharpening stone. There is, however, one drawback: as the blade gets weakened during sharpening - in particular when the diameter of the stone is rather small -, it can quite easily break under heavy-duty use. On the other hand there is the advantage of a smaller area that has to be sharpened by hand afterwards. If this is done with the front and the rear edge placed onto the whetstone, the blade will be in a relatively stable position so that even the use of a honing guide will become unnecessary (**d**). If the chisel is to be used for fine, light-duty work only, this is definitely a very fast method of sharpening that can only be recommended.

An alternative would be to round off parts of the tool bevel (**e**). This not only allows heavy-duty work to be carried out but is also a faster method as the bevel area that needs to be honed is relatively small.



Tormek Super Grind 2004

The Tormek Super Grind 2004 is a very good but also expensive motorized wet stone grinder. Its honing leather wheel will probably do away with any further need for sharpening on stones.





Safety

Power tools handled carelessly are a source of great danger. Please always read the instructions for use carefully and heed the words of warning about potential dangers. Understandably, the joy or excitement about a new machine may initially be too great to have time for worrying about such "irrelevant matters" as safety. Our eyes, ears, fingers and hands are, however, far too precious to be ignored - and they deserve every precautionary measure conceivable. After all, what is the use of building yourself a guitar if you won't be able to play it in the end?

Even if you consider yourself familiar with a particular tool, re-read the instructions for use as this might reveal things which you may have been unaware of until now.

To exclude the possibility of switching on a tool by mistake, always unplug power tools when mounting or removing parts. I have all my power tools plugged into a multiple plug with ON-OFF switch, which is quite handy as it frees me from plugging in and unplugging cords when working with different machines.

Apart from power tools sharp hand tools also require attention: always work in a direction away from your body.

Not using eye or ear protection, guard, push stick and so on, is certainly not a sign of professionalism but rather of thoughtlessness and often also stupidity. Professionals especially tend to become numb to certain dangers over the years. Once an accident has happened it is too late, and being handicapped for life can be the sad result.

Safety also includes preparing everything well, having the working area well cleared and, above all, creating the circumstances which allow you to work calmly and without need for any rushing. As far as working area tidiness is concerned, I am myself guilty of regularly allowing a "battlefield-like situation" to develop, taking, as I do, different tools, using them and then putting them "somewhere" instead of in their proper place. This gradually builds up to a huge mess of tools, scrap pieces and accessories. Thinking about it, I have come to the conclusion that I probably make the mistake of jumping from one step to the next instead of moving on slowly.

Each tool ought to have a fixed place, a place that is easily accessible from where you work, without requiring a lot of manoeuvring to be done. Any obstacles such as packaging or a closed toolbox blocking access to a tool's proper place are open invitations to just leaving a tool wherever it is most convenient to put. Similarly, it would be a mistake not to use a drill stand just because one cannot be bothered to set it up - the results of freehand drilling will be accordingly.

Clear up after each individual step of work. I am convinced that such self-discipline will have a positive effect on the end product. Scratches and other kinds of damage done to the guitar are not really necessary and can be prevented by using protective pads, clamping cauls, etc., and by keeping everything as clean as possible. A few thoughts about where to best put things in the room you work in will not go unrewarded.

Building



Making the body



Making a solid body

Preparing the body blank

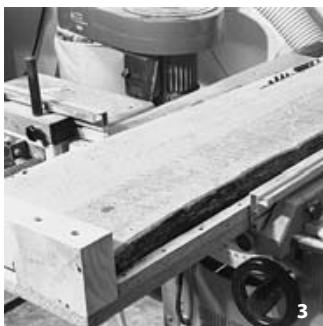
For making the body of an electric guitar from one piece of wood a thickness planer or a drum sander are the obvious tools to use. Planers intended for professional use are wide enough and therefore suitable for this purpose, while common "hobby" thickness planers that can accommodate a maximum stock width of 260mm or 300mm (10" or 12") cannot be used for planing one-piece guitar bodies. Getting hold of high-quality and sufficiently wide pieces of wood is another potential problem. In most cases the body will therefore have to be made by gluing two halves together.

If you buy finished, ready-cut wood from a tonewood supplier you can obviously skip the steps of work described on the following pages. For some of these steps of work you would need quite expensive machines anyway. If, however, you have decided to do it all yourself and you have seasoned but otherwise untreated wood in front of you (as in picture 1, which shows a parcel I got from the Austrian tonewood supplier *Kölbl*), you will have to cut and plane the wood to the required dimensions yourself. Two pieces can obviously also be cut from one long plank. The plank shown in pictures 2 to 5 is about 60mm (2³/₈) thick and one meter (about 1 yard) long.

Start by planing one of the surfaces flat (2). Move the plank over the jointer, using a push stick for pushing it. The shape of the push stick does not really matter; it can be rounded off and given a more hand-friendly shape than the one in the picture. When planing hardwood not more than 3mm (1/8") should be planed off in one pass and several passes may be required until the surface is flat. If the plank is too wide for the jointer, reduce its width with a tablesaw (see below).

Cut a straight edge on the tablesaw (3). Since in this state the plank cannot be guided along the rip fence of the tablesaw, I placed it on a rectangular jig. The guard was removed only for taking the picture.

Now plane the newly-sawn edge flat and square to the main surface (4). Before you start make sure that the fence is set exactly at right angles to the jointer table (correct it if necessary). These two surfaces have to be exactly square to each other before work on the two other surfaces is started.

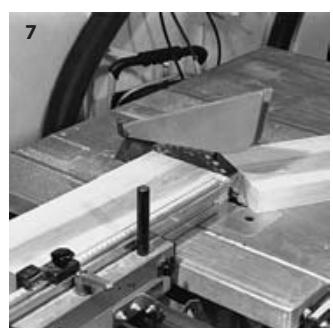
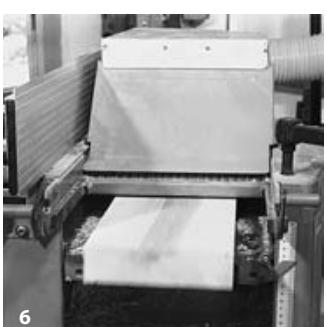


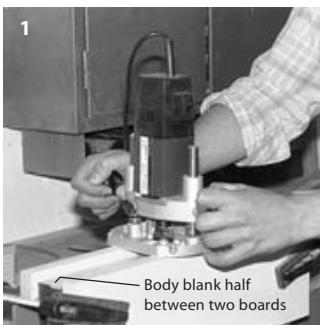
Then saw the piece of wood to its final width of about 200mm (77/8"), as shown in picture 5, where the slanting outside edge of the plank makes the piece look wider than it actually is. This sawn edge remains rough and will later be used for positioning the clamps when gluing the body together.

Finally plane the wood down to a thickness of (usually) 45mm (13/4") (6). Again the amount taken off in one pass should not exceed 3mm (1/8"). Thickness planers tend to plane off slightly more over the last few inches of a board or plank because the piece of wood loses touch with the guide rollers as it comes out of the planer, which in turn causes the rear end of the wood to be lifted slightly. If you have several pieces to plane, you can limit this problem to the last piece by feeding the individual pieces into the machine one after the other. Machine-planed pieces of wood should therefore always be left 50mm (2") longer so that areas with planing defects can be sawn off later. If you have one long piece of wood, cut it through in the middle (7). The two halves can then be jointed and glued together.

Before gluing two pieces together hold them against each other and up to the light to find out if there are any gaps. If there are large gaps, the surfaces to be joined have to be planed until they are flat and hardly any or no light at all shines through. When planing make sure that the jointer knives are sharp as only sharp knives will give good results. Fasten the fence at right angles to the jointer table. Set the guard so that the unused part of the rotating knives is hidden, and set the depth of cut to no more than 0.4mm (1/64"). Then slowly push the first body half (bottom side facing the fence) over the jointer (8). Make sure it is in permanent contact with the fence and press the board down at the outfeed table only. If the edge of the board has a convex curve, start planing just before the middle on the first pass and only plane down the whole length of the board on the second pass. Repeat this procedure until the edge is perfectly straight. Now move the second body half, with its upper side facing the fence, over the jointer. Planing one board with its upper side and the other with its bottom side facing the fence has the advantage of still giving matching edges even if the fence should not have been set exactly at right angles to the table.

When there are no gaps along the edges of the two pieces they are ready for gluing. Take your time; it is possible to join two pieces so that the glue line is almost invisible.





With appropriate jigs routers can also be used for jointing or planing. The following examples will illustrate how versatile routers are and how they can make buying a jointer or thickness planer unnecessary. Quite commonly the width of work that can be accommodated by most thickness planers used by hobby woodworkers is below what is required for preparing guitar bodies anyway.

Jointing with a router (1)

When I started building guitars I used a router for jointing the body halves as I did not own a jointer then. The method I used works quite well with thicker body pieces and consists of a jig with which a router is guided over the edges to be jointed. The body halves have to be accurately thickness-planed or thickness-sanded.

Put a thin, narrow piece of wood on a flat surface and place one body half on it so that the edge that you are going to work on faces downwards. Then put a thin board (plywood or hardboard) and one board with a perfectly straight edge (I used two 19mm ($\frac{3}{4}$ "-)thick plywood boards) to the left and right of it, clamp it all together with two clamps and mount it in the workbench upside down, with the edge that is to be worked facing upwards.

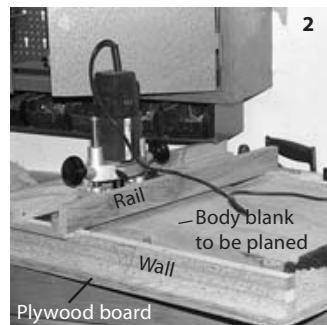
Then take a square and check whether the edges of the two outer boards, which will later serve as a table for the router, are the same height. If they aren't, repeat the

procedure described above. The thin boards serve to keep the distance between the router bit and the boards on the sides. Now the router can be placed on the edges of the two outer boards. Mount a cutter as great in diameter as possible (a special surface-trim cutter is highly recommended). Lower the cutter onto the wood surface and move it over the whole of the side. The result of this should be a flat area, which after careful (optional) treatment with a scraper is ready for gluing. Proceed similarly with the side of the second piece of wood that is to be glued to the first one.

For jointing thin boards, such as those used for a body top, and if the length of the cutter permits, both boards can be fastened together in a flat, lying position and then be routed together (bookmatching). The router is then guided along a fence which is mounted exactly parallel to the edge of the boards. This is, however, only possible if the boards have been accurately thickness-planed or sanded and if the router is pressed firmly on it to prevent it from tilting and doing damage to the wood surface. Try to rout off rather little at the beginning and keep moving the fence by a very small amount at a time until wood is routed off over the whole length of the boards. Because it leaves a very smooth surface a spiral-fluted cutter bit is the best choice for this task.

Thickness-planing jig (2)

The jig consists of a plywood board with two walls on either side and one rail. On this rail the router can be moved across the board, while movements along the board are possible by pushing the rail on the walls. A well-working jig should allow for the router to be guided over the whole surface. I used 19mm ($\frac{3}{4}$ "-)thick plywood for building it. Since the individual pieces needed should be available at most larger DIY stores, most of which even offer the service of



cutting the wood to the required dimensions, getting hold of the material needed should not really be a problem.

Fasten the board that will be planed with wedges to keep it from moving from one side to the other. If it has warps, insert wedges under it as well. Mount the largest cutter bit that you have on the router - the greater its diameter is, the faster you will be and the nicer the surface will look. If you have a bit of money to spare, you can also buy special surface-trim cutters; but note that there is a limit to the maximum cutter diameter a router can hold. Place the router on the jig and lower it not more than 2mm ($\frac{3}{32}$ ") into the wood. Then start routing, always moving in one straight line from the beginning to the end. Proceed like this until, line by line, the whole surface has been routed.

As a smooth, pretty surface will only be obtained if the bit can reach the entire surface, it is important that the jig is not made too small. Also take into account (a) the space that will be taken by the router on both ends of the rail, and (b) the space needed by the rail itself as it is moved to the ends. The rail has to be sufficiently stiffened to keep it from bending under the weight of the router. After one side of the board has been routed turn it over, fasten it again with wedges and rout the other side until it is flat, too.

Gluing up the body blank

For gluing the two halves of the body together any ordinary commercial wood glue will do - it doesn't have to be water resistant. White PVA (polyvinyl acetate) glue is easiest to obtain. Only buy it in quantities that you can use up within a year or so as its shelf life is limited. Basically two types of glue can be distinguished: those that take longer to set (advantage: you have more time for placing the clamps), and others that set quickly. The common PVA glue must be clamped as soon as possible or at least within 5 minutes after applying the glue. Always read the manufacturer's instructions that come with the product.

Glued joints will only be strong and durable if the glue is applied in a thin layer; thick layers of glue will break. The quality of a glued joint depends on how clean and smooth the two surfaces onto which the glue is applied are. A well-made glued joint will never break at the joint, just as a welded joint will never break at the point where the two pieces are welded together. Dowels are not required. The best and smoothest surfaces for gluing will be achieved by professional manual planing.

Pieces of wood can only be glued together along the direction of their grain; glued joints of end-grain surfaces will not be strong. Pieces that are to be glued together should only be planed immediately before gluing as this will give clean and smooth surfaces.

Before applying any glue cover the table or workbench with some pages from a newspaper. Also have all clamps that are needed ready. It might also be a good idea to dry-clamp the pieces together without glue and to check whether the individual pieces are in contact in all places or whether there are any unforeseen problems arising from tightening the clamps. If everything is fine, untighten the clamps, apply glue to both surfaces and spread it thinly and evenly with your little finger. Use the little finger instead of your index finger so that you can grab something in between without messing it up with glue. If you apply too much glue and/or spread it unevenly, much more pressure will be needed to press the two pieces together. In theory, two perfectly flat surfaces would require no pressure whatsoever as the pressure is only needed to maintain contact between the two pieces until the glue sets and takes over this "job". In practice, however, clamps are always required. Keep in mind that they exert a local pressure, as when pressing down a sponge with your index finger. To spread the pressure evenly over a larger area a strong piece of wood should always be placed between the clamps and the pieces that are glued together. Applying too much pressure should be avoided as this can lead to most of the glue being squeezed out.

Hide glue

Hide glue is made from animal hides and consists of small flakes which are soaked in cold water for an hour and then heated and applied with a brush. Always mix glue and water by weight and not by volume. Mix about one part of hide glue with two parts of water. The consistency of hide glue can always be adjusted by adding water. Do not prepare too much of it at a time and keep it in the fridge. Don't worry - hide glue is absolutely non-toxic. It gives a very strong joint and sets very quickly, but you should leave it to dry and not do any further work on the glued-together parts for the next 24 hours. Hide glue joints have been around for centuries and some of the joints made with this type of glue are still as strong as ever.

Hide glue must never be brought to the boil. For this reason it is advisable to heat the mixture in a water-bath or in a baby-bottle warmer to a maximum temperature of 65°C (150°F).

Parts are best glued up at normal room temperature; if it is too cold, hide glue will immediately start to gel. By using a hair drier or a moderately-set heat gun you can keep the glue and the parts hot enough until clamping pressure is applied.

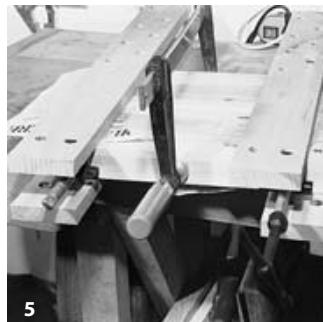
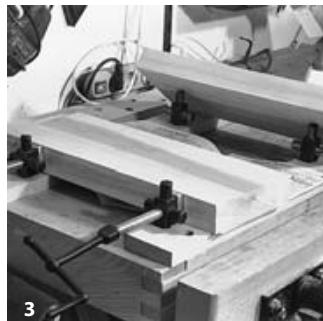
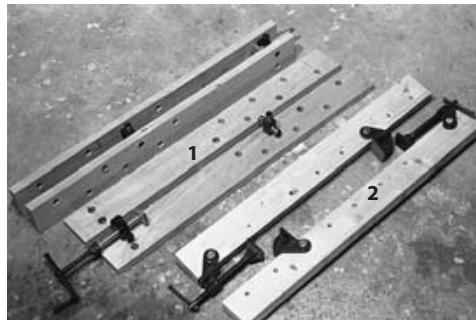
One great advantage of using hide glue is that joints made with this type of glue can easily be disassembled again by reheating. If an undone joint is to be reglued, the remaining pieces of glue don't have to be removed as the newly-applied hot glue will combine with it. And, finally, hide glue is not as slippery as for instance PVA glue so that fewer additional clamps are needed to keep the pieces in place.

Panel clamps

My personal favorite is a special panel clamp (1). If you manage to find one of these traditional, European-style clamps in a shop, don't hesitate to buy it. The set I have consists of a cast-iron cross with four 18mm-diameter tenons and another cross with an additional worm-gear spindle. Depending on which side the asymmetric cross is stuck in, it allows gluing together either 20mm ($\frac{3}{4}$ ") or 40mm-50mm ($1\frac{5}{8}$ "-2")-thick pieces of wood. Additionally, you might want to buy a special wrench. And last but not least each clamp needs two hard-wood boards with several holes drilled into them (1). This type of clamp has been around for about a century in German woodshops but was "re-invented" in the "New World" and patented by Lee Valley & Veritas. The Veritas Panel Clamp can be found in their catalog. There are also a few other similar working clamps around; some of these can be found for instance in Woodcraft's catalog.

The panel clamp is set to the required width by positioning the crosses. Then place the two body halves between the clamps (3), putting a bit of newsprint in between to soak up any excess glue that might be squeezed out. Next put on the top boards (4) and tighten the clamps.

This type of clamp has the huge advantage of ensuring that the pieces that are glued together remain absolutely flush. The more you tighten the clamp, the greater the tension on the top and bottom board will become, thus ensuring that the two parts of the body are absolutely flush with each other. If you want, place a third panel clamp or an ordinary clamp in the middle (5). If the panel clamp boards are thick enough to allow putting in the crosses from both sides, several bodies can be glued together at once, which is not only faster but also requires less space. Only one board is needed for each additional body.



Bar clamps (2) and pipe clamps

Apart from the well-known common clamps there are also bar clamps or pipe clamps which are infinitely variable in length. With a *Cramping Head Set* from the British company Record you can make your own bar clamps from 25mm (1")-thick square timber (2).

For making pipe clamps you can buy a special set which fits on a $\frac{3}{4}$ " standard pipe threaded at one end.

Put the two halves on two narrow pieces of wood, press them together and wait for a moment until the glue keeps them in position. Then place two small clamps onto the ends of the glue line and tighten them a little; these clamps only serve to keep the pieces from moving. After that place several stronger clamps from the sides and tighten them (6). Small beads of glue appearing all along the joint are a sign of the good quality of a joint. After about 30 minutes, when the glue is harder, these bits of excess glue can be removed with a spatula and a wet cloth or paper.

Depending on the type of glue used and the temperature of the air the glue will take longer or shorter to cure. The clamps can normally be removed after just 30 minutes, but the joint must not yet be exposed to any strain after that time. To be on the safe side wait for three to four hours. I normally leave glued joints to fully cure overnight.

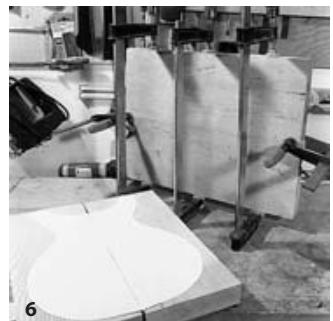
If your pieces of wood are quite narrow, you can also make the body by gluing three or even more pieces together (7).

Cutting out the body

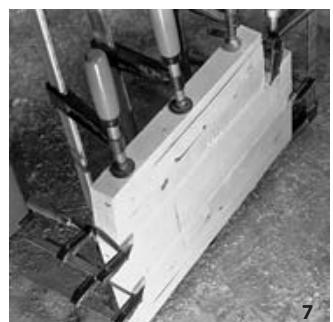
Using the body template transfer the body shape onto the glued-up body blank, taking the joint as a center line on a two-piece body (8).

Cutting out the body shape with a bandsaw (9) is the method used by the majority of guitarbuilders. For this purpose you need a well-adjusted bandsaw and a sawblade suitable for cutting curves. Only narrow sawblades (about 6mm / 1/4" wide) are suitable for cutting the tight curves of the body of an electric guitar, although even a 6mm (1/4")-wide sawblade may not be narrow enough to follow the very tight curves of the cutaways. In this case making relief cuts from the outside (as described on the next page) will help. Wider sawblades can only be used for making straight or lightly-curved cuts.

A well-adjusted bandsaw always cuts square to the wood surface and gives a very clean cut, provided you cut slowly and carefully. For reasons of safety and better control over the sawblade always set the top sawblade guide down to a position 10mm (about 0.5") above the work. When cutting out the body the sawblade should be quite close to the drawn line; this line must, however, always remain visible. A calm hand and a lot of patience are needed for this. Cutting out the body shape should be done with great care; you should give it at least 20 minutes of your time. Work out the best way of cutting so that you won't need to buy a new bandsaw because you think yours is not wide enough.



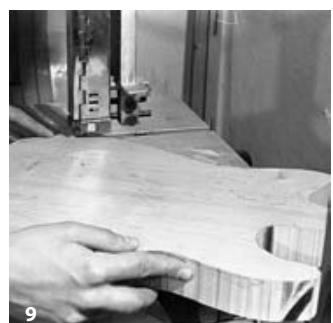
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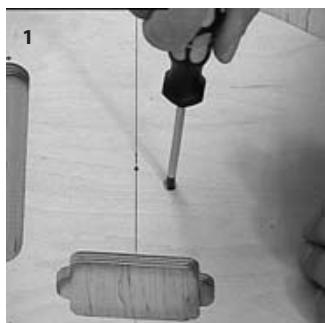
Cutting out the body with a jigsaw

When I started building guitars, I used a jigsaw instead of a bandsaw. If your jigsaw has an orbital blade action mode you had better switch it off. You will also have to put a longer sawblade into the tool.

In order to follow tight curves with a jigsaw it is important that you make several relief cuts towards the body shape line (see page 98). These cuts, which are needed to allow changing the direction of sawing should be stopped a jigsawblade-thickness before the body line. Cut v-e-e-e-ry slowly and calmly along the outside of the drawn line, making sure that the line remains visible at all times. Never force the sawblade into a curve as this can easily lead to a strong lateral deformation of the shape of the blade and can result in an oblique cut as the blade is no longer cutting perpendicular to the

body surface. You should therefore check the right-angle between the body surface and the body side at regular intervals. Bear in mind that sawing 45mm ($1\frac{3}{4}$ ")-thick hardwood is a great strain on a jigsaw and that no high sawing speed should therefore be expected. The body shown is made of alder, which is relatively soft and was easy to cut with the jigsaw. It is also better to move or turn the workpiece than to turn the saw. Patience and caution will pay off and reduce the time needed for cleaning up the body edges later.

It is also possible to use a more expensive, high-quality jigsaw with an attachment for additionally guiding the sawblade on the base to make it more stable. Workmen often have to cut holes into 40mm ($1\frac{5}{8}$ ")-thick hardwood boards, for instance when working in a kitchen.



Smoothing the body side

Routing the body shape is common practice in guitarbuilding. Often overarm pin routers are used for this purpose in place of table-mounted routers or shapers. Mount the body on a board and fix the body template on its underside. A guide pin protruding over the table serves to guide the template. The pin is of exactly the same diameter as the router bit and exactly under it.

I use a table-mounted router and a 50mm (2")-long flush-trimming bit with end-mounted ball bearing for routing the body shape (3). Such router bits come only with 12mm or $1\frac{1}{2}$ " shank and a larger, more expensive router is therefore needed.

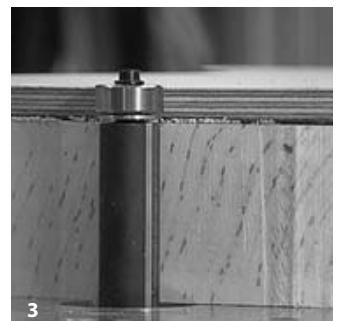
Fasten the body template so that the holes of the mounting screws can later be hidden under the bridge (1) or are removed by routing the pickup cavity or neck pocket. Two screws will do the job perfectly well, unless you use a split template, in which case four screws will be required.

It is important that you remove any wood that protrudes more than 2mm ($\frac{3}{32}$ ") over the template. Do so with a rasp and very carefully, especially at the tips of the body horns (2); the router bit can tear out big chunks of wood if there is too much material. Work the body horn tips almost flush with the template.

Set the bit so that the cutting edge is high enough for cutting the whole height of the body while still allowing the ball bearing to be guided safely along the template edge (3).

This is quite dangerous work: the router bit can easily get caught in the wood and pull the fingers dangerously close towards it. For this reason I urgently recommend the use of a protective shield. Such a protection consisting of a threaded rod (fastened at the table with two nuts) and a small clear plastic plate that can be adjusted for height and fastened with two further nuts will do the job (4).

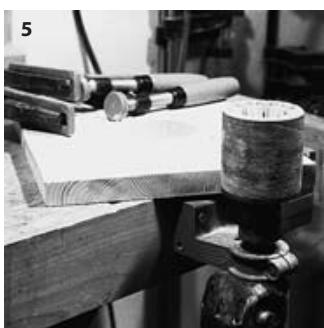
Not more than 2mm ($\frac{3}{32}$ ") of wood should need to be routed off as otherwise the risk of tearing out chunks of wood would be too great. This danger exists in particular when routing against the wood fibers, which is unfortunately inevitable as the the body is of a curved shape and you will have to rout with the wood grain in some places and against the grain in others. The routing direction has to remain the same all the time: always move the wood counterclockwise. Getting rough spots and having small chunks torn out is therefore almost inevitable. Most body side areas, however, will be extremely smooth and not require much further attention. Because of its vibration-free shearing action a spiral-fluted router bit would be ideal. Instead of the ball bearing you could use an index pin above the router bit.



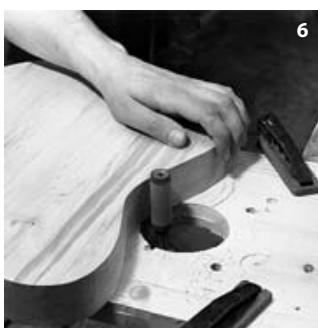
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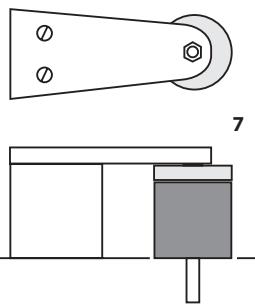
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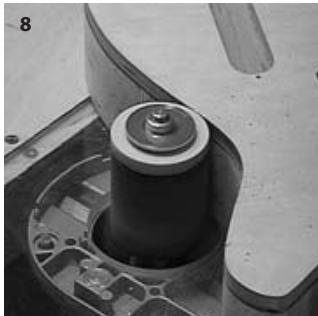
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Spindle-sanding of the body side

The best tool for smoothing the sides would be an oscillating spindle sander as it has an additional up/down movement; build your own "poor man's" spindle sander (6) with a vertically-mounted electric drill, a sanding drum and a board (5). Areas that are more difficult to get to, such as the cutaways, can be sanded using small-diameter sanding drums.

Wheel-guided sanding drums

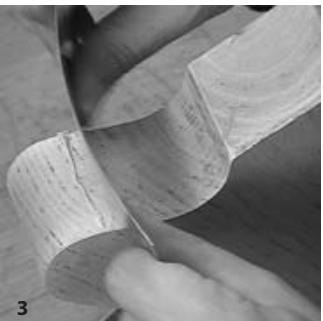
Sanding drums with end-mounted guide wheel are very useful as you can leave the routing template on the body. Such guided drums can be home-made (7) or are available from Woodcraft (RoboSander) (8). Because I found the diameter of the RoboSander-wheel too large, I replaced it with a slightly smaller wooden wheel. You can also use sanding drums in a drill press.



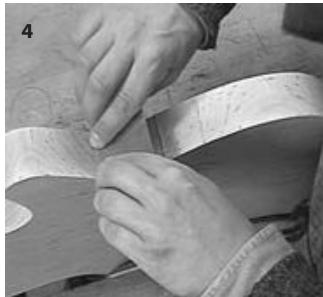
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Domed-body top

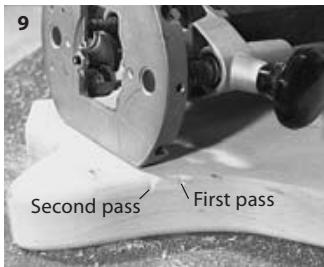
To make a domed surface you can use a special violin-makers' plane with convex sole (8) or a rasp (7). Finish with sandpaper of successively finer grits.

Sanding the body

Fine-sanding and smoothing of the surfaces is very time-consuming. A random-orbit sander can be an invaluable tool for this. Mount a hard sanding pad for flat (1) and a soft one for domed or curved surfaces (2). For difficult-to-get-at areas such as the cutaways a scraper is extremely useful (3,4). Start with 80-grit sanding discs and than move on to 120. Final sanding should be done by hand with 180-grit paper and only in the direction of the grain.

Sanding can of course also be done entirely by hand, without power tools, but this demands a good deal of patience. Use either 80- or 100-grit sandpaper for sanding the body (5) - which one to choose depends on the initial smoothness. If you start with 80-grit paper, sand at an angle across the whole surface. Then switch to 100-grit paper and sand in the opposite direction. This way it is easy to see when the traces of the rougher paper have been removed. Finish off with 120-grit sandpaper, sanding in the direction of the grain (6) and removing any traces of the rougher paper used before. For hand-sanding convex parts wrap sandpaper around a short bar. As a lot of work still needs to be done on the body, there is little point in using finer sandpaper than 150- or 180-grit at this stage.

When you sand properly you will inevitably be exposed to wood dust for quite a long time. Use a dust bag or vacuum hose with power tools and a protective mask when sanding by hand.



Rounding off the edges

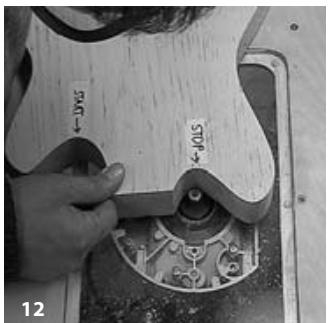
Rounding off the edges is best done with a rounding-over bit with end-mounted ball bearing. These come in different radii. The edge radius of a standard-size body which will be fitted with a standard pickguard is to be fitted must not be too large and must on no account exceed 6mm ($1\frac{1}{4}$ "') as otherwise the rounded edge will extend under the pickguard and the edge of the pickguard will not lie flat on the body. If no pickguard is fitted, any radius is possible. There are even router bits which are elliptically rounded (twice as wide as high, for instance).

Setting the right cutting depth on the router to get an evenly-rounded edge is not easy. I do it by sighting along the baseplate of the router - the curve of the bit should flow nicely and evenly into the router base. Then I set the depth stop and check the result on a piece of well-fastened scrap wood; if necessary, adjust it differently until you get just the right curve.

I always round off such edges in two passes: on the first one I do not lower the router bit fully, and on the second pass I rout off what is left after the first. This gives a clean curve and the bit isn't overstrained and doesn't leave burns on hardwood surfaces.

Picture 9 shows both stages of routing in a small area. Two passes are also advisable when using a table-mounted router (10).

If the neck is bolted on with an attachment plate or attachment ferrules, the edge radius has to end before the neck attachment area (on the back of the body). The area under the neck pocket on the back of the body has to remain flat as otherwise the radiused edge would extend under the plate or ferrules (11). To make sure I stop and start in the right places I mark these points on the back of the body (12). The remaining edge sections are rounded off by hand, the edge radius turning into a sharp edge at the points marked with arrows in picture 11.

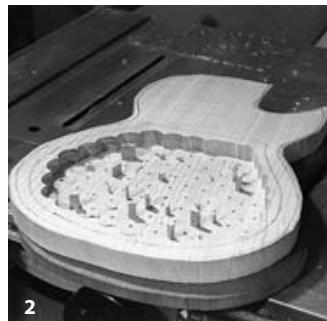


Making the body more comfortable. The areas on which the hand rests are contoured with a small plane (13), and the back of the body is rounded with a spokeshave, rasp, scraper and sandpaper (14). When after careful inspection from different angles and against the light no more scratches or uneven areas are found on the body, the neck can be mounted.

Hollowing-out with the plunge router

The body can also be hollowed out from above with a router. For this a sufficiently large additional base-plate will have to be fastened to the base of the router to make it possible to rout all across the width of the body. If you use a clear plastic plate, you will be able to follow what's going on under it.

Another option would be to fasten two long battens like skis on the two bars of the edge guide of the router. There ought to be some form of dust collection on your router.



Making a hollow body

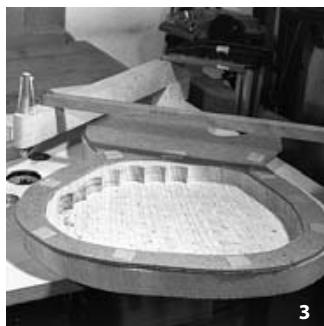
Hollowing out the body

A body made from two pieces - a top and a bottom - allows hollowing out parts of it. This adds an additional acoustic element to the sound of an electric guitar but also increases the likelihood of feedback at higher volume levels.

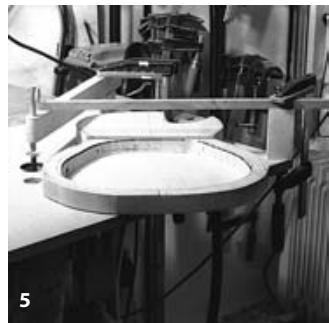
Make a template for the outline of the hollowed-out parts. If you leave wood in the middle, the pickup and the bridge can be mounted as usual if you make this middle part wide enough in the bridge area. The bottom part of the body in picture 1 is 40mm ($1\frac{5}{8}$ ") and the glued-on spruce top 6mm ($\frac{1}{4}$ ") thick. The hollowed-out areas are 34mm ($1\frac{5}{16}$ ") deep and not very wide so that they can be cut out with a router. Remove as much as possible with a Forstner bit before cleaning everything up by guiding a router bit with shank-mounted ball bearing along the template. This leaves fewer shavings and is less of a strain for the router bit. Set the depth of cut to the point of the drill bit so that the marks left by the point can be routed off later. There should be at least 6mm ($\frac{1}{4}$ ") of wood left under the hollowed-out parts; the shavings are best removed by sucking them off.

If the body is to be hollowed out all across its width, the top will have to be thicker to allow bolting on the bridge. I made the bottom of the body (2) 30mm ($1\frac{3}{16}$) and the top 15mm ($1\frac{19}{32}$) thick. In this case the hollow-out has to be 24mm ($1\frac{5}{16}$) deep.

If you have one, use an overarm pin router and mount the template on the back of the body. I made a kind of upside-down (reversed) overarm pin router (3), consisting of a table-mounted router and an arm with a pin of exactly the same diameter as the router bit. The additionally stiffened arm is adjusted so that the pin is situated exactly above the router bit. My bit is 19mm ($\frac{3}{4}$) in diameter and the pin is a short piece cut off a 19mm ($\frac{3}{4}$) dowel bar. It is tensioned by means of a rubber band as shown in picture 3. The template, which in picture 3 is still lying on the

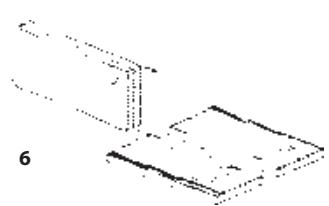


body, is fastened on the back of the body. Then place the body (with attached template) between the pin and the router bit on the table. By guiding the index pin along the template a precise line can be followed (4); the shavings will fall through the hole in the router table. By going about the job systematically and regularly checking whether any areas have been left out the hollow-out will become quite clean (5). This is a very safe approach too, as the router bit is completely covered and can never cut any deeper than to the depth set. With a conventional overarm pin router the body is easily lifted by shavings so that more than originally intended is removed.

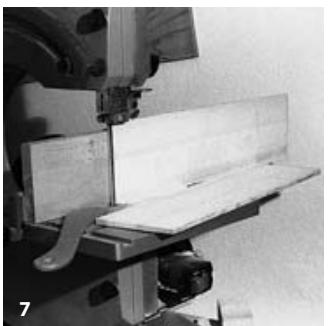


Making the top

A lot of guitar tops are “bookmatched”: A board is bandsawn lengthwise through its middle (a technique known as resawing) and then the two halves are opened up like two pages of a book and glued together as shown above (6). The result is a surface with an almost perfectly symmetrical grain pattern. To be able to make such a precise parallel cut at such a great height of cut the fence has to be set extremely accurately. This is why I use an additional board screwed to the fence. Better than a long fence is a very short guide fence just in the area of the blade as this allows small corrections of the blade drift. The blade I am using in picture 7 is rather narrow; use a wider blade than that if at all possible.

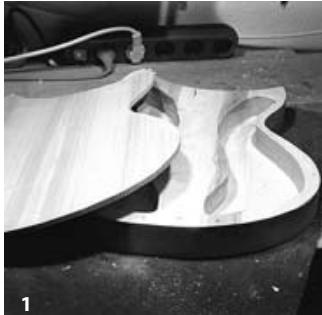


Be careful when resawing wood. If anything should go wrong because, for instance, the bandsaw tension is badly set, or the piece is pushed too strongly, the sawblade might bend and suddenly come out in the middle although the cut may look fine at the top and bottom. So keep your fingers clear of these areas. As a matter of principle you should always use a push stick for pushing the wood anyway. If the bandsaw has been correctly set, making such a difficult cut should, however, not be too much of a problem.

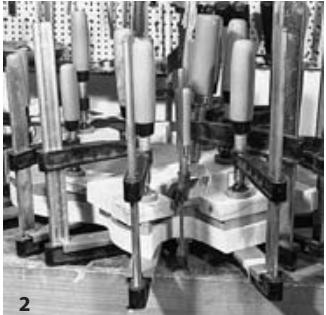


After both halves have been jointed they are glued together as shown in picture 8. The weight of a clamp or a hammer is sufficient to keep the pieces flat, and only little pressure (exerted by wedges) is needed for pressing the two pieces together.





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3



4

Photo: Stewart-MacDonald's Guitar Shop Supply



Fancy guitar tops

If you can afford the wood, it is also possible to glue pretty-looking tops of curly, quilted, flamed or bird's eye maple onto a solid-body or semi-hollow body.

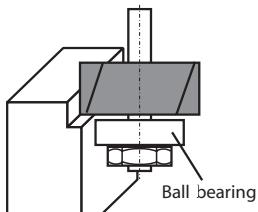
Gluing on the top

After the glued top has been sanded flat cut out the body shape by sawing just outside the drawn line (1). Use all the clamps and weights you have for gluing on the top (2). The pressure of the clamps can be spread more evenly by using cauls.

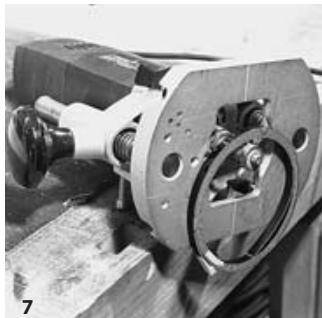
After the top has been glued on the body template is screwed on and the body is routed flush as described on the solid-body model (3). Again the holes for screwing on the template could be placed in the neck pocket and pickup cavity area. I was lucky enough to have wood wide enough to allow making the ash bottom and mahogany top from one piece. Use a router bit with end-mounted ball bearing for routing a thin glued-on top flush with the already-routed body (4).

Binding

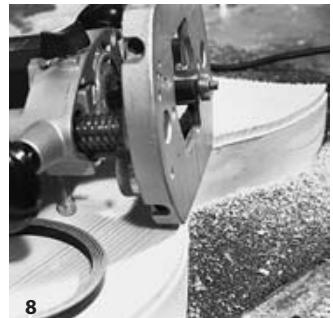
Often bodies look better with a binding. The rabbet needed for this purpose can easily be made (at least if the guitar top is flat) with a rabbetting router bit (6). Since it is much easier to scrape the binding flush with the body than vice versa, the rabbet should be made about $1/10$ mm (0.004") less wide than the binding is thick. For the same reason the rabbet depth is also set to $1/10$ mm (0.004") less than the height of the binding. In



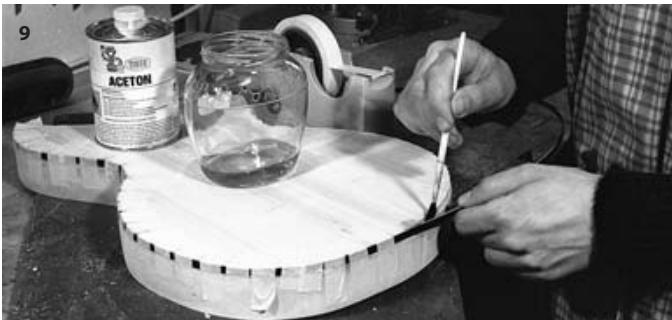
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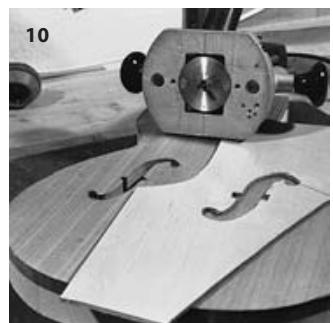
Binding cement

When ordinary celluloid binding is cut into small pieces and left soaked in a glass of acetone overnight a creamy mixture - so-called binding cement - is formed which can be used for correcting mistakes and replacing missing bits of binding. It takes about a day before it is dry and any further work can be done on it. Be careful, though, when repairing guitars: acetone attacks nitrocellulose lacquer!

picture 7 you can see the rolled binding being used to check whether the router is correctly set. Rolling together the binding also makes it easy to sand away any bits of it that may be too high. The binding should protrude over the body only very slightly. Before starting work on the body practice on a piece of scrap wood. When everything is fine cut the rabbet(s) on the body (8).

When you buy a binding from a guitarmakers' supplier it is normally made of celluloid and is therefore an acetate. Consequently, the best solvent to use for gluing on the binding is acetone. Brush it generously on to the binding and into the rabbet (9) over a length of about the width of your hand. Press the binding against the rabbet and secure it with adhesive tape. Then apply acetone over the next section and again tape on the binding. Repeat until the whole body is bound. After about six hours the tape can be removed and the binding can be scraped flush with the body using a scraper.

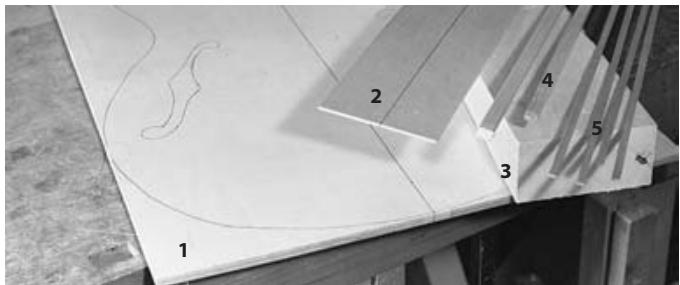
Soundholes and f-holes are best routed with the help of a template. I normally use a 5mm router bit and a 10mm template guide (10). In my case the template has to be made $10\frac{1}{2}$ minus $5\frac{1}{2}$ = 2.5mm larger all around. Fasten it with double-sided tape. If any shavings should fall into the body, they can easily be removed with a vacuum cleaner. Soundholes can also be lined with a binding (11).



10



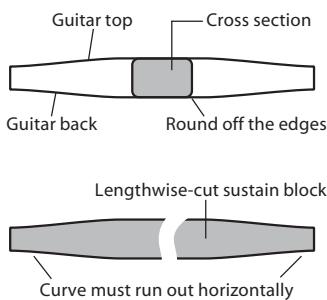
11



Making a semi-acoustic body

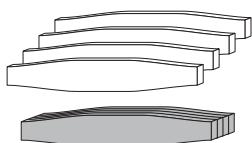
Shape of the sustain block

Make a full-scale drawing of the lengthwise-cut body shape on thick paper and cut it out as a template. Form the sustain block accordingly and round off its edges.



Gluing up the sustain block

An alternative to making a sustain block by shaping one solid piece is to glue it up from several already lengthwise-shaped slices (see figure below). Rough-saw the slices and then shape them on a table-mounted router with the help of a template. Use dowels for aligning the pieces during gluing.



By making a semi-acoustic-body guitar you get quite close to building an acoustic guitar. I use 2mm (0.08")-thick Finnish birch or airplane plywood, which is resin-bond and water resistant, for making this type of body. Unlike ordinary plywood, this has no voids, is sanded on both sides and is made up of thin layers that make it very strong. It would also be possible to use solid wood (e.g. maple), but most of the commercially-available models are made of plywood. To make a semi-acoustic body you need two thin plates of wood large enough to cut the body from them (1) and one narrow piece which has to be wider than twice the height of the body's sides and a bit longer than half the body's circumference (2). The sustain block (3), which extends through the whole length of the body, should be made from rather light types of wood such as mahogany, basswood, spruce or alder. It has to be as high as the middle of the body and about 100mm (4") wide. The block in the photograph is about 51mm (2") high. Together with the top and bottom (each 2mm / 0.08" thick) the height of the body will be 55mm (2.08") in the middle and 45mm (13/4") at the edges as the side strips will be 41mm (15/8") high. Make the sustain block wide enough to allow bolting on or gluing in the neck. You also need four 6mm x 10mm (1/4" x 3/8") wooden strips for the lining (4) and four thin strips (5) for binding the body. These strips have to be half as long as the body's circumference.



Any cutaways have to be considered when laying out and making the sustain block, which is best done with a bandsaw. Since the block will be glued to the top and the bottom, its shape will have to be made to match their curve (6). To make the top and the bottom of the body evenly curved a light lateral curve should be sanded which should become increasingly flatter towards the ends. At both ends the sustain block has to be as high as the sides (in my case it is 41mm thick). It is obviously easier to make a body without domed top, especially when building your first-ever semi-acoustic guitar. If you decide not to make a domed top, just make the block the same height as the sides.

Bending the sides

Bending the sides might at first glance appear tricky; but there is no reason why with a bit of practice and careful work the first attempt should not be successful. However, always practice on a piece of scrap wood before you start on "the real thing".

Wood can be bent to a certain extent when exposed to steam, and it will later retain any shape it has been forced into. Even several-centimeter-thick wood can be bent provided it is exposed to steam for a sufficiently long time. An example of this plastic quality of wood is the well-known coffeehouse chair of the Viennese company *Thonet*.

The sides of a guitar are only 2mm (0.08") thick and will therefore bend much more easily than thicker wood. The simplest bending device that could be used would be a tube heated by a gas flame. A tube with an oval- or drop-shaped cross-section offers a variety of radii for bending, but a round one that corresponds in diameter to the tightest curve of the sides will do as well. Apart from that it is also possible to use a tube with a greater diameter (7cm to 8cm / 2³/₄" to 3") for greater and a thinner tube for smaller radii. An electrically-heated bending iron, however, is a more comfortable tool.

Before bending the sides the wood has to be put in hot water for a few minutes. A bathtub or the saucer of a window planter will do nicely for this purpose. Do not put more than one piece of wood in at a time and put some weight on it to make sure it remains under water. How long the piece has to remain there depends on the type of wood used and on one's own experience: five minutes are quite normal, more than twenty minutes should not be required.

Fasten the tube horizontally in a vise and heat it by positioning a blowtorch so that its flame burns into the pipe (7). The tube is at the right temperature for bending when a drop of water "dances" on it. If it evaporates immediately, the tube is too hot, and if nothing is heard, the tube is too cold. The gas flame will have to be regulated or even switched off temporarily as the tube



Photo: Stewart-Macdonald's Guitar Shop Supply

Bending iron

Instead of using a heated tube you can also use more comfortable, electrically-heated and adjustable bending irons. These are available from suppliers of guitarbuilding tools.





Fox Universal Side Bender

Bending is made very easy with an apparatus developed by the American *Charles Fox*. Its blueprint is available from *Luthiers Mercantile International (LMI)*. Their catalog, which can only be recommended, also includes a detailed description of how to use this side bender.

It consists of a form and two steel slats heated by three 150-200-watt light bulbs. The wet guitar side is placed between the steel slats, and the tight curve at the waist is pressed down on the form while its underside is supported by a metal bar. The steel slats are pulled tight towards the form and the heat is left on for about ten minutes. After cooling down the bent side is removed and occasionally touched up on a bending iron.

A new version of this bender uses slats made of spring steel, thus eliminating the need for the support bar.

Silicone heating blankets

Another approach for bending sides is to use a silicone heating blanket on a form. The blanket has to be as wide and as long as the sides of the guitar and it should work with a low voltage. One source for such silicone blankets is *Watlow* (www.watlow.com), which has branches all over the world.

must not get too hot to not burn the wood too much. Deep burns on the outside of the wood are almost impossible to remove - so be careful when placing the outside on the bending tube.

Start bending at one end, slowly pushing the wet piece of wood over the tube while pressing lightly all the time. The heat will lead to the formation of vapour. At some point the wood will start to bend and you can shape it - do so carefully and "with feeling". Putting on cotton gloves makes the heat more bearable for the hands. By varying the pressure and the speed at which the thin wood is pushed over the tube the radius of the curve can be varied. When the desired curve has been reached continue bending for a little while; after bending is finished the wood will spring back slightly. Be careful throughout the bending process as the thin wood can easily break.

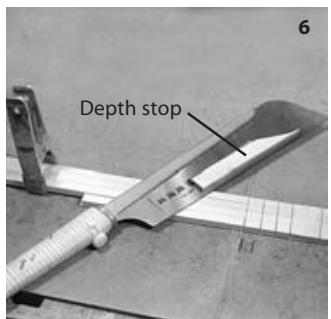
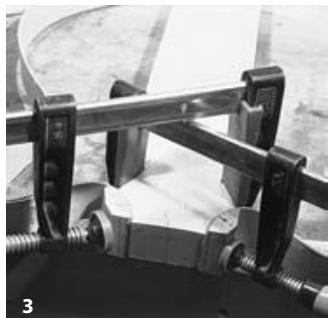
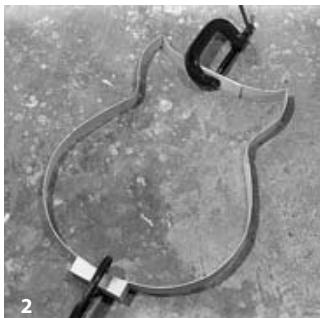
Take the bent piece from the tube and hold it for a short while until it has cooled and the curve is stable. Now is the time to find out whether the wood has really been bent: on the hot tube a curve is easily produced simply by pressure; if the wood loses its curve after it has been released, it has not been bent enough yet. The wood bends properly when its fibers are saturated with water vapour - the moment when this is the case can be felt, but patience is required.

To get the right curve constantly check your progress against a drawn outline and correct the curve if necessary. The latter can be done by hand by bending the piece the other way or by placing it with its outside on the tube and by rocking it until you get the right curve.

When you have finished bending the first side of the body leave the second piece to soak in water and then proceed as with the first piece; try to bend it as symmetrical to the first side as possible. If the body is asymmetric in shape bending the second side will be easier as you as you don't have to make both sides perfectly identical. After both sides have been bent put the two pieces away and leave them to dry overnight.

The morning after you will inevitably find that the curves will have changed slightly. The original shape can, however, easily be restored by bending the two sides over the tube for a short time. This final bending should take place before the lining is glued on as the curve of the sides will keep changing with changes in air humidity.

A lot of guitarmakers use forms into which they put the sides after bending. Thus symmetry between the two halves is much easier to achieve, but the sides will still have to be bent just as precisely. Making forms is worthwhile if all or most of the guitars you build are of the same shape. If this isn't the case, it should nevertheless not prove too difficult to bend the sides precisely even without the help of such equipment; but a bit of practice is obviously always helpful.



With symmetrical bodies I usually bend only one piece of wood from which I then cut two pieces with a tablesaw (1). This is faster and guarantees that the two sides are perfectly symmetrical. Be very cautious and wear goggles as the blade guard has to be removed for sawing. You could also use a bandsaw for this purpose.

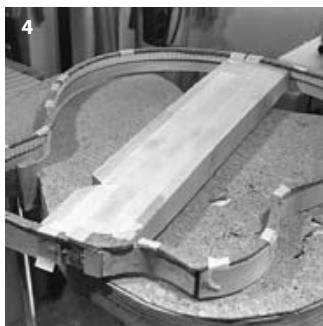
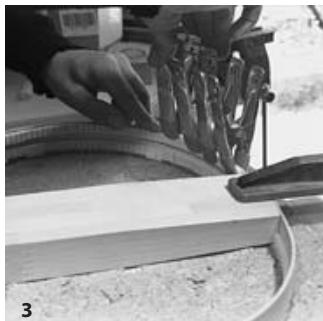
The sides above (2) were bent with the *Fox Universal Bender* (shown on the next page). I just bent one side (a little more than twice as wide as needed) and cut it lengthwise into two parts on the tablesaw. Then I sawed off the top parts, flipped them over and joined them again.

Gluing the sides to the block

The sides are glued to the sustain block. In the cutaway this is best done by cutting out a small square-cornered piece from the sustain block and using a specially-shaped caulk to allow stable positioning of the clamp (3). I would advise you to make the sustain block wider than in picture 3 to have more space for the neck pocket. If the body is to have a pointed horn, a caulk that fits on the body horn (4) will ensure a good glued joint. If the sides are fastened at the lower end of the body with two screws and a shaped caulk (5), you will not need to place a clamp along the body. The screwholes can later be hidden by covering them with veneer. This piece of veneer also serves to embellish the joint between the two sides.

Making the lining

By using reinforcement strips (lining) the gluing area at the edges of the body top and bottom can be increased. Take a few 6mm x 10mm ($1/4" \times 3/8"$) wooden battens and make a few cuts in them so that they become flexible: the cuts should be made close to each other and should be quite deep; always make sure, however, that the battens are not sawn through entirely. Such cuts are best made with a hand saw with taped-on depth stop (6), a tablesaw with very thin sawblade or - and this would



be the fastest way - with a bandsaw (1). Draw a line on the table of the saw to help you get equal distances (about 6mm / $1/4$ ") between the cuts. A depth stop ensures a small web (0.4mm / $1/64$ ") is left behind the cut. Finished strips, so called kerfed lining, can also be bought. As for which wood to use I would recommend mahogany, alder or spruce. The number of strips needed depends on the body circumference: twice its length will be needed.

Gluing on the lining

Spread the glue with your fingers evenly all across the back of the lining and glue it on with the help of spring clamps (2). Normally, the glue is spread on the web side of the kerfed lining, but some guitarmakers glue on the strips with the kerfs facing the sides, which gives them more stability. Check the position of the lining in relation to the edge with one finger (3); it may be slightly higher but must never be lower than the side edge. About 25 spring clamps are sufficient for gluing on the lining on one half of the body. Since ordinary clothespins do not give enough tension for this purpose, you will additionally need elastic bands to get the right amount of tension. Proceed similarly now with all the remaining strips until the whole body is done. The spring clamps and any excess glue that may have been squeezed out can be removed after about 30 minutes.

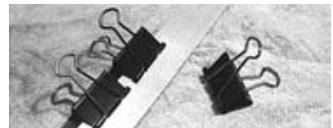
Since the guitar is to have a domed top and bottom the body will be slightly higher in the middle than at the edges and will therefore be unstable when lying on the table. To put it into a stable position I cut strips in the right thickness from cork and fasten them around the edges (4). It should be possible to find the cork with the right thickness for your needs (I use 6mm-thick cork strips). It is essential that the body is in a stable position when the top and the bottom are glued on.

Using sandpaper over a shaped block the lining is then sanded flush with the sides and the ends of the sustain block (5).

Gluing on the top and back

Gluing on the top and the back is made easier by using a work-board in the shape of the body. The best and least expensive method of gluing on a domed top and bottom is to use a rubber strip - the inner tube of an old car tyre would be ideal for this purpose. Cut it with scissors into a 5cm (2")-wide strip; by cutting round and round until the tube is used up you will get a strip several times longer than the circumference of the tube. Normally, a strip thus cut from a car tyre tube will be long enough, but if an even longer strip should be needed, you can also tie together two strips. If you cannot get a car tyre tube, you can also use the inner tube of truck tyres (check the *Yellow Pages* for truck repair shops). These are much stronger, so you will need to cut a slightly less wide strip from it. Before you start gluing on the top and bottom of the body I strongly recommend that you practice every single step of work beforehand. Only when no more problems are foreseeable must glue be applied on the lining and the surface of the sustain block. The glue should be put on evenly thick and in the middle of the lining; do not spread it with your fingers.

Then place the back - which, as you will remember, has been cut out 3mm to 5mm larger than the desired body size - onto the side lining and fix it on both ends of the body with two clamps and cauls. Hammering in two small nails in the area where the neck or the bridge will be fastened later or in the pickup cavity area helps to keep everything in place. Make sure that the center line really ends up in the center. Next put the rubber strip around the waist, tie it together at the bottom, pull it firmly upwards and put it across the lower part of the body. The first "layer" should be placed right next to the clamp, and not as shown in picture 6. Then pull the strip firmly downwards, pass it back under the workboard, pull it upwards again next to the first layer and place it so that it crosses the first layer. After that continue in the same manner (pulling the strip downwards, etc.) until all of the lower part of the body is wrapped up.



Paper clips

Paper clips can be bought at any stationer's. They come in different sizes and are normally used for holding together sheets of paper. But they also come in quite handy in guitarbuilding, serving the same purpose as the more expensive spring clamps; even large guitar manufacturers such as *Yamaha* use them. By buying such clips in bulk you should be able to get a better price although they are quite cheap anyway.

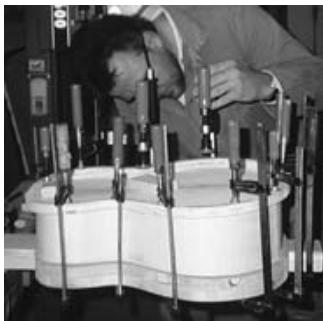


Please do it better and place the first winding right next to the clamp!



Proceed similarly with the upper part of the body until its edge too is firmly pressed down by several layers of rubber strip (1). When pulling the strip up- and downwards it should be well stretched. The strip can be twisted on the bottom side, but on the top it has to lie really flat on the body. After a few final layers have been wrapped around the waist the rubber strip is tied up and the body left to dry overnight. The bottom should not protrude too far over the sides as it might otherwise break under the pressure.

When the glued joint is dry, remove the cork edge supports from the linings and attach them to the edge of the already glued-on back. After that the top is glued on in the same way as the back.



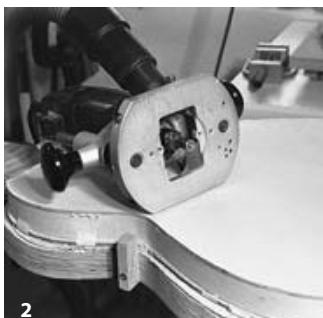
Using clamps

If you use clamps for gluing on the back make a narrow guitar-shaped clamping caul like shown above.

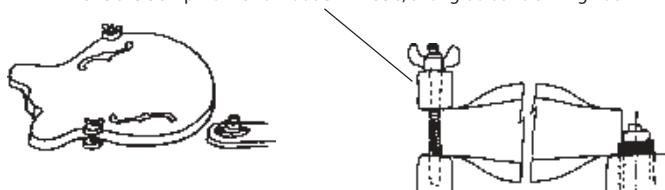
Cutting the projections of the top and back flush is best done with a flush-trimming bit with end-mounted ball bearing (2). Depending on how much needs to be routed off several passes may be required to prevent the splintering-off of pieces of wood. Since the router bit cannot be guided parallel to the sides - the router is always at an angle because of the domed body - the top and the back won't be routed completely flush with the sides. This does not matter, however, as we will take care of that when we rout the rabbet for the lining.

Routing the binding rabbet

Routing the rabbet for the lining is not as easy on a domed-top as on a flat-top guitar, as the router bit cannot be guided parallel to the sides of the body. A stable set-up is obtained by placing two self-made spool clamps on the edge of the body and by using a shim around the bit on the router table as shown in the figure below. This should make it possible to rout the rabbet evenly. I also needed 6mm-thick shims for this job. Note, however, that this method only works with bodies that are the same height all around their edge, as semi-acoustic guitars are. If the height of the side of your electric guitar varies around the edge, the router is best guided independent of the body and moved up and down on a vertical slide bar.



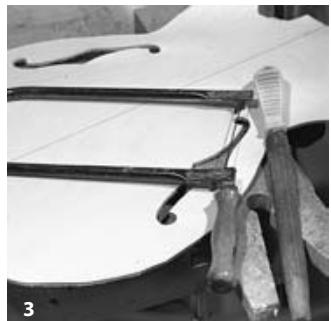
Make the clamp from two wooden wheels, a long bolt and a wing nut



Glue the binding to the body as described above. Remember that a wooden binding has to be bent first. Use wood glue for gluing on a wooden binding.

Making f-holes

F-holes can be cut out with a coping saw before the top is glued on (3), but as already described in the section on hollow-body guitars they can also be cut out with a small router bit, using a template and a template guide (4). Tweezers and a vacuum cleaner will be useful for cleaning up the inside of the body.

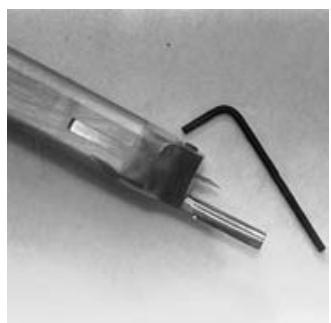


Making the neck pocket

The neck pocket that will take the neck can be routed like that of a solid-body guitar. This will be explained in more detail in the section on fitting the neck. The neck is traditionally glued in, but it is equally well possible to bolt it on. Due to the height of bridges normally used on domed-top guitars the neck inevitably needs to be angled back. As the body is domed, a curved shim has to be used to hold the neck pocket template at an angle and in a stable position. For bolting on the neck you need neck attachment ferrules. Pots and switches are best fitted through the pickup openings. Threadening pots in by using a string fastened at a tiny hole in the pot shaft may sometimes be necessary.

Cutting the rabbet by hand

Traditionally, hand tools are used for cutting rabbets. With a purfling cutter (the one shown in picture on the left was designed by *Irving Sloane*) you can mark and cut a rabbet even on a domed-top body. The distance between the knife-blade and the guide pin can be infinitely varied by means of two allen screws. As the guide pin of the tool is guided along the side of the body, the domed top doesn't cause any problems. With each pass the knife cuts deeper. This is repeated on the sides of the body before the rabbet is chiseled out. Use a sharp chisel for that. It goes without saying that a lot of patience and skill is required for this kind of work, but there are also instrument builders who do not need any power tool for this job.



Making the neck

Flatsawn or quartersawn hardwood which is knot-free and has a straight grain pattern is ideal for making the neck as such wood carries the lowest risk of warping. Maple and mahogany are the most commonly used types of wood for making the neck, but in principle there is no reason why you should not be able to use other hardwood timbers such as birch, alder, ash, oak, or others.

The neck can be of two different types: the frets can be installed directly into the neck, or a separate fingerboard can be glued on. There are differences in making these two types of neck which I will explain in the following. I recommend that for your first guitar you make a neck with glued-on fingerboard; although it is a little bit more work-intensive, it is at the end of the day the easier and safer approach.

Preparing the neck blank

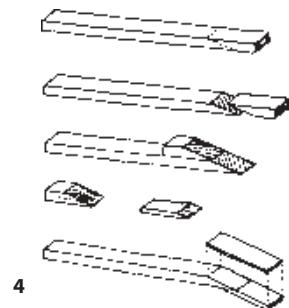
For making a one-piece neck a 25mm (1")-thick blank is required; for a neck with glued-on fingerboard you need a 19mm ($\frac{3}{4}$ ")-thick blank. The width of the neck blank depends on the width of the peghead, and its length on the length of the neck plus the length of the peghead. If the board is not wide enough, you can glue on pieces later to make it wider on the peghead. In this case the neck blank can be as narrow as the fingerboard end.

Plane the blank down to the right dimensions, leaving it a bit longer than needed. One edge of the board has to be planed flat and square to the surface (1). Picture 2 shows a piece of flatsawn birchwood which will be used for making a one-piece neck, provided no hidden knots or defects appear during planing.

If a piece of wood is not free from such knots or defects, I recommend that you glue together two or more strips, making sure that the curves of the annual rings of two strips placed next to each other show in opposite directions. Picture 3 shows two pieces of mahogany, both from a more than 30-year-old window ledge which had been lying in the loft for years and was therefore



particularly dry when I used it for making a neck. This example just goes to show how well wood can be recycled. Another possibility would be to combine two different types of timber to make a so-called "sandwiched" neck - by gluing in two strips of one type of wood between three strips of maple for instance. This "sandwiching" method is very stable and unlikely to warp. If you make a guitar without angled-back head, this is about it as far as preparations are concerned. If, however, your guitar is to have an angled-back head a few more preparations are required.



4

Options for making a angled-back head

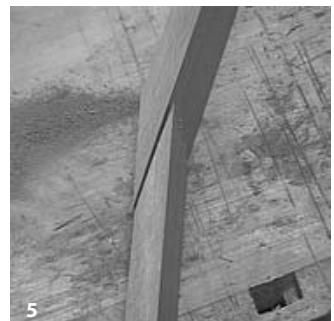
I quite like guitars with angled-back heads as these increase the downward pressure of the strings on the nut so that no string retainers are needed, which are an additional source of friction during tuning. The angle can be anything between 4 and 15 degrees.

Cutting the peghead from the neck blank is a good example of how little material can be used most efficiently (4,5). If you choose this approach, I recommend a peghead angle of 15 degrees. Because the neck blank and the peghead part have the grain running along their length greater stability is gained. The fibers run through the whole length of the peghead, contrary to the peghead shown in figure 6. It is obviously also possible to make the peghead from a separate piece of timber.

Industrially-manufactured guitar necks with angled-back pegheads are often cut from one thick piece of wood so that a lot of wood is unnecessarily wasted (6) if you just cut one neck from it. A further drawback of this method is the reduced stability and greater likelihood of the peghead breaking as a result of the short-grained structure of the peghead. Use a peghead angle below 10 degrees with this method.

Less material is wasted when you make a neck with angled-back peghead by cutting several strips of wood from a blank of hardwood and by gluing them together, as shown in figure 7.

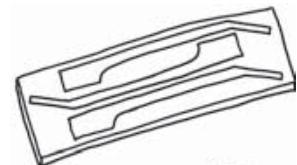
Most electric guitars, however, do not have an angled-back peghead at all. Instead, they have a neck made from one straight blank and a peghead face that is lower than the fingerboard surface (8). Such *Fender*-style types of peghead need string retainers (as long as you don't use a locking nut) in order to achieve a sufficient amount of string pressure on the nut. Even though to an industrial manufacturer gluing on an angled peghead is additional work which only increases manufacturing costs, an angled-back peghead is none the less the better solution.



5



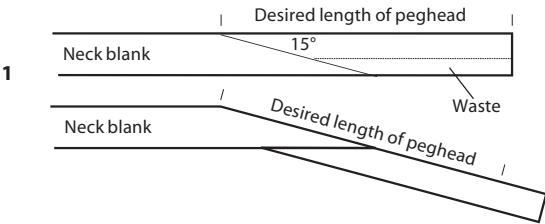
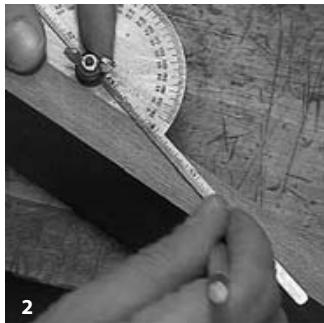
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7



8



Making a glued-on peghead



Before the peghead part is sawn off the wood has to be planed very carefully and all surfaces have to be parallel or square to each other. Then roughly mark the desired length of the peghead on one end on the face of the blank with a line across its width. From there draw a diagonal line back towards the end at an angle of 15 degrees, as in figure 1 (top). Do this on both sides of the board (2) and then connect the ends of these two lines with another line across the width on the back of the board. After planing down the peghead part and gluing it on the entire peghead face will be the right length (plus a little bit of reserve). If you choose other peghead angles than 15 degrees, make a drawing to determine how far from the end the peghead part has to be sawn off.

Fasten the board with two clamps and in an upright position on the edge of the workbench so that it protrudes over the latter. Sawing off the peghead part should be done at elbow height (3). A crosscut saw or a tall enough backsaw are suitable for this, but I would use a Japanese saw (now that I have one). Put the saw on the diagonal line and make a first cut; saw carefully along the line, without exerting pressure. The saw should soon be guided by the wood. Continue by pulling and pushing the saw evenly, making sure to cut perfectly vertically. If the saw should begin to deviate from the drawn line, try to correct this tendency.



The gluing surface can be planed smooth by fastening the peghead part on the neck so that the two pieces form a slanting surface (4). Even though after sawing the two halves will rarely be a perfectly slanting surface, they have to be fastened parallel to and on top of each other. The edges may not be a perfectly straight line, either, and there may be some protruding parts. Two strips of thin double-stick tape will do. To improve the adhesive quality of the tape clamp both parts for a short time. To make planing easier clamp everything onto a plank, as shown in picture 6. A well-sharpened block plane is ideal for planing the slanting area flat. Set the plane very finely for this purpose and move it over the surface diagonally and with several parallel pushes. To prevent planing off too much on one side the planing direction has to be altered by 90 degrees with every pass. Press the plane firmly and above all evenly onto the wood. It is also

important to maintain a line parallel to the nut line. If the latter should have been planed off, draw it on again slightly further back.

Check the progress you make at regular intervals by measuring along the length and width as well as diagonally with a straight edge. This is best done against some source of light such as a window or a lamp. Mark the areas where no light shines through; these are the spots that are too high and that require further planing. Finally, any marks left from planing are removed with a scraper and the surfaces are flattened with a sanding board (5, a small, flat board with sandpaper that has been glued on with spray glue). After this remove the peghead part from the neck blank with a flat tool.

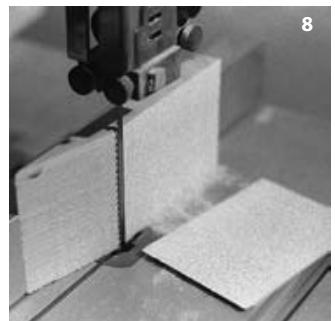
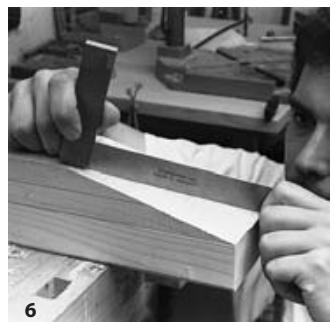
As already mentioned before, the flatness of the surface should be checked very closely. Lay a straight edge on at different angles and in different places (6). The peghead part is ready for gluing on if there is no light that shines through between the straight edge and the wood. Take your time and prepare the surfaces as best you can.

Next the peghead part has to be planed down to a thickness of 13mm ($\frac{1}{2}$ "") so that it is not too thick for mounting the tuners. Make the peghead part thinner by planing it down (7) or by sawing off a piece with a bandsaw (8) and planing and sanding the surface afterwards. Together with a 2mm-3mm ($\frac{3}{32}$ " - $\frac{1}{8}$ "")-thick peghead veneer which will later be glued on this will make the peghead 15mm-16mm ($\frac{19}{32}$ " - $\frac{5}{8}$ "") thick. It should never be thicker than 17mm ($\frac{21}{32}$ "") altogether as this would make it impossible to mount the tuners.

Mark the required height all around the peghead part before clamping it. Set the plane rather coarsely and then move it over the wood diagonally (7), as when planing the slanting surface. To prevent planing off more on one side than on the other turn the workpiece by 180 degrees after a few passes. When the drawn line is only just visible fine-set the plane and remove the rest until the line has completely disappeared. Finally, smooth the surface with sandpaper.

The peghead part can also be made thinner by cutting off a "slice" with a bandsaw (8). If you choose this approach, use a push stick. Smooth up the bandsawing marks with a beltsander or a sanding board.

A few preparations are necessary if the peghead is to be glued on successfully. Unless you do something to counteract the clamping pressure, the two parts will not remain in position. Five clamps will solve the problem. Before you apply any glue check that everything is fine and that the two parts are pressed against each other well. Fasten the neck blank on a workboard, using two clamps. Make sure that the workboard and the neck blank are





Sawing off the peghead part with a tablesaw

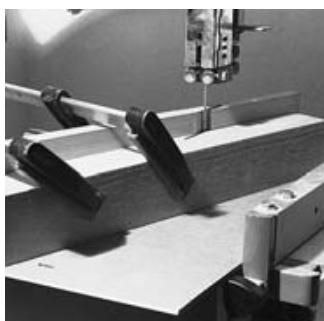
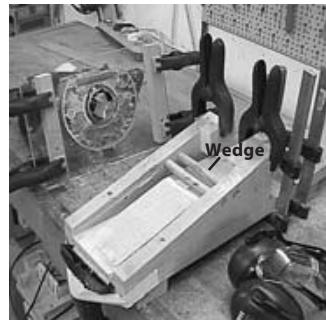
The peghead part can be sawn off with a tablesaw if the blade diameter is large enough (If you glue "ears" onto the peghead later, the neck blank is at this stage narrow enough even for smaller blades).

A simple jig consisting of a plywood base with a screwed-on or glued-on fence is needed to allow making this cut. For a 15-degree peghead angle the fence angle has to be 90-15=75 degrees. The neck blank is held in position by two clamps and the whole jig is guided along the tablesaw fence. The small peghead part that is sawn off should additionally be fastened with double-stick tape. Being 75mm (3") high, the neck blank should not be sawn off in one pass but in two passes. Fastening the peghead part with double-stick tape ensures a clean cut which requires hardly any or no more planing at all. When sawing through the neck blank the fence will have to take a little cut as well.

Smoothing with the router

Routing the surface smooth with a router saves time and produces excellent results, even if you are a beginner. A jig will be needed, though, to allow guiding the router over the surface at the desired head angle. Screw two pieces of wood with perfectly identical slant (angle identical with the head angle, i.e. in our case 15 degrees) to a baseboard that has to be wider than the neck blank. Arrange the peghead part and the neck blank as described above. You won't need any adhesive tape if you clamp the two parts with a small, flat wedge between the base and a horizontal wooden bar (8) fastened about 5mm ($\frac{3}{16}$ ") above the two parts of the neck. A thin strip of wood placed on either side of the base ensures that there is enough distance from the sides of the jig. Fasten the router on a sufficiently large baseplate and set two edge guides so that the router can reach the whole area that needs to be routed but cannot rout into the jig. Mount a cutter bit as large in diameter as possible and do not take off more than 1mm on each pass. Orientation is made easier with a clear plastic base.

Wearing eye protection and kneeling on the floor I sight the router as I smooth the surface. If the surface should not be perfectly smooth after the first pass, set the bit lower by another millimeter and continue to rout until the surface is smooth. Finally, all marks left by the router are removed with a scraper.



Sawing off the peghead part with a bandsaw

I now use a bandsaw for sawing off the peghead part. The principle is exactly the same as with a tablesaw, but bandsaws also allow sawing through wider neck blanks.



1



2

square to each other (1). Put some newspaper under the gluing area. Use a third clamp to hold a stop block on the lower end of the neck; this stop block is supposed to keep the neck blank from slipping away.

Lay the peghead part onto the neck blank so that the beveled neck blank area and the peghead form one long slant (2).

Another clamp placed there serves as a second stop block. A fifth clamp on the head part keeps it from slipping upwards. Check that the head part is perfectly square to the workboard. The angle can be adjusted by moving the position of the clamp. The two parts are pressed together with two more clamps and two clamping cauls cut so as to fit the gluing area.

When you have made sure that all parts are held in place safely and there are no gaps between them you can start applying glue to the surfaces. Remove the two clamps and the clamp used for holding down the head part and spread glue thinly and evenly over the beveled head part area. Then gently move the head part up and down the neck blank slant. The friction thus produced will spread the glue and squeeze out any air contained in it. After that place the clamps again and check once more that the workboard and the two parts glued together are square to each other. Tighten both clamps and remove them after an hour. If any glue should have been squeezed out, scrape it off after ten minutes.

Use C-clamps

If you buy two C-clamps with 4" opening and normal throat depth and two with a greater throat depth of at least 3" (or more, which would be even better) the peghead part can be glued on more safely. With four C-clamps it is possible to put one clamp on each of the four corners of the gluing area. Fasten the clamps one after the other and tighten them, moving clockwise from clamp to clamp. It is important that the stop blocks are fastened very, very well as otherwise the clamping pressure will cause these blocks to wander away. I would even suggest that you screw on the two stop blocks with at least two screws instead of clamping them down.

Yellow glue

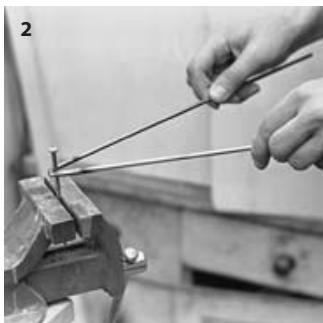
Before switching to hide glue for all guitarbuilding purposes I successfully used "normal" white PVA glue for gluing on peghead parts. American guitarbuilding books recommend the use of yellow glue for this task because it has greater strength and durability. I have never tried yellow glue simply because it's not available in my part of the world. Yellow glue (also called aliphatic resin or AR glue) is a higher grade of white glue with some color added. I don't know if white European PVA glue is superior to white American PVA glue.



Making Trussrods

Making a one-way twin-rod system

Making your own one-way twin-rod system is not particularly difficult. Take a 5mm ($3/16$ ")-diameter steel rod of twice the length of the truss rod channel plus about 50mm (2") as a reserve, mark it in the middle and, using a triangular file, make a 2mm ($1/16$ ")-deep groove at this mark. Then heat this point over a propane torch (1), turning the rod over the flame until the heated area is red-hot. From now on you have to be very quick because the rod must not cool down. Before starting to heat the rod you should fasten a piece of the rod or a nail vertically in a vise. Now bend the rod around the piece in the vise, with the filed groove on the inside as shown in picture 2. Press the ends of the rod together and use a hammer to flatten the area where the rod has been bent (3). If you are no stranger to welding you could get the same result by welding together the ends of two separate rods over a length of about 13mm ($1/2$ "). After that file the weld flat so that the rod will fit into the truss rod channel nicely.



Shortening the rod is best done by placing it inside the channel and marking a point on it 10mm up from the cross channel towards the end of the neck. Mark and cut off the second end exactly in the middle of the cross channel. Finally, smooth and deburr the end areas and all edges.



The thread is cut onto the longer of the two bars (4). It should be made about 25mm (1")-long, using a 5mm die for a 5mm rod and a 10-32 die for a $3/16$ " rod. Fasten the rod in a vise, put a wedge between the two bars to get the shorter end out of the way, place the die on the longer end and turn it clockwise, exerting only little pressure. It takes a short while until the die really starts to cut. Each time two or three turns have been made turn the die back counterclockwise by about one turn and add a drop of oil. When turning back the die you will hear a noise - that of the iron filings breaking.



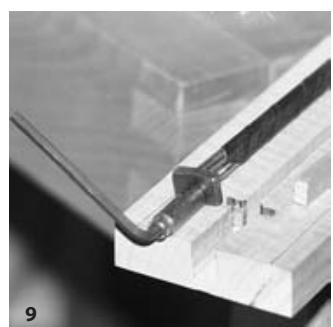
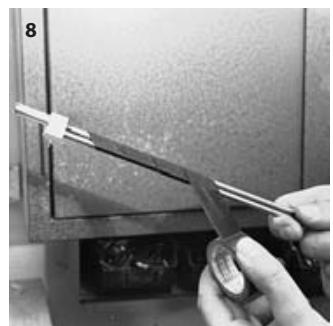
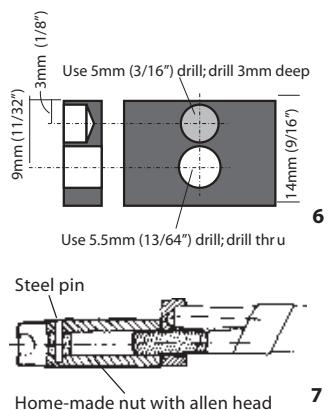
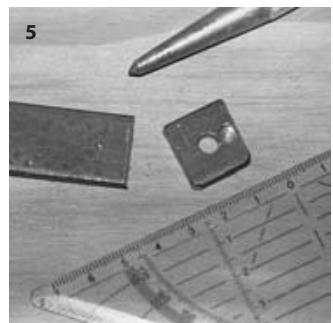
The bearing cap for the twin rod is 14mm ($9/16$ ")-long; cut it from a 20mm ($3/4$ ")-wide and 5mm ($3/16$ ")-thick flat metal bar (5). Mark the center of the top hole 3mm ($1/8$ ") and the center of the second hole 9mm ($11/32$ ") from the top edge (6). Center-punch the hole centers accurately and drill the lower hole all the way through the cap, using a 5.5mm ($13/64$ ") twist drill, and the top one, only 3mm ($1/8$ ") deep, with a 5mm ($3/16$ ") bit (6). To do this use the drill press and its vise.

The adjustment nut should be made of brass, which, because it is softer than iron, cannot damage the iron thread of the rod.

When the neck is finished, access to the truss rod is no longer possible. I was not able to get hold of a 20mm ($\frac{3}{4}$ "')-long 5mm thread brass nut with allen head and I am not sure whether you will, so you might have to make one yourself (7,9). For this you could, for example, take a 10mm-diameter brass rod, cut a 25mm-long piece off it and drill a hole into its center, using a 4.2mm drill bit for a 5mm thread (if you use a $\frac{3}{16}$ " rod use the appropriate drill bit and thread cutter). If you have access to a lathe, this will be an easy job and quickly done. Alternatively, you will have to center-punch the piece and clamp it exactly vertically in the vise of a drill press. The vise should have a V-groove in the middle of its jaws. Next cut a 5mm thread into the hole just drilled. Use a 5mm allen bolt which is threaded all the way up to the head as an allen head and shorten the thread to a length of 5mm with a hack saw. If the thread should not go right up to the head of the screw - the thread often ends 1mm to 2mm under the head - you will have to enlarge the beginning of the brass nut thread with a 5mm drill bit. Apply a bit of super glue on the thread and turn the screw into the brass part. Next mark and drill a 2mm-diameter hole on the side of the brass part, 3mm from the edge. This hole should go exactly through the screw but not all the way through the brass part. Put some glue around the hole, hammer in a steel pin - sawn off a 2mm-diameter steel nail, for instance - and there you have it, your very own brass adjustment nut with allen head. It would, of course, also be possible to use a nut with a slot for a screwdriver. It would also be conceivable to use a long hex nut as long as you make sure that you can still get at it with a wrench.

Before you install the truss rod put the bearing cap on it and wrap gummed metal tape or strong fabric tape tightly around the whole length of the rod (8). Place the layers next to each other and try to avoid too much overlapping as the rod must not become too thick. Press the rod to the bottom of the channel with a screwdriver; a snug fit is desirable, but don't make it sit in there too tight. A truss rod fitted too loosely can cause unwanted noises later. If the rod should have been made too thick to fit into the channel, make the channel wider with a router. Do so very carefully, making sure that the cutter is exactly in the middle of the channel. Put a strip of adhesive tape on the edge guide of the router and cut along one side of the channel.

Picture 9 shows a one-way twin-rod before installation. The cross channel for the truss rod bearing cup and the adjustment nut cavity at the end of the neck can also be seen. Make sure that the longer of the two iron rods - the one which has the thread - is installed at the bottom of the channel, facing the back of the neck. A wooden fillet will be glued over the truss rod. The channel itself is 13mm ($\frac{1}{2}$ ") deep. The access opening to such a type of truss rod should always be on the body side of the neck.





Making a compression truss rod

Making a compression truss rod is fairly straightforward. Take a 5mm ($\frac{3}{16}$ ")-diameter steel rod and a propane torch, and bend and hammer one end (see section above on how to make a twin rod) to form an about 10mm ($\frac{3}{8}$ ")-long hook which acts as an anchor. Thread the other end for the adjustment nut with a 5mm (10-32) die (3). The thread should be about 19mm ($\frac{3}{4}$ ") long. Compression rods produced in larger quantities are threaded at both ends because in serial production it is easier to turn the rod around and to repeat the threading. Ready-made truss rods available from guitarmakers' suppliers have a small anchor plate or a nut in place of the hook end. If you want, you can make such a truss rod yourself by fixing the anchor nut in place with a few punches (4) and additionally by welding. The anchor must be firmly fixed and impossible to turn as otherwise the truss rod is without effect. I personally prefer hook-end truss rods as they are foolproof and nothing can come loose.

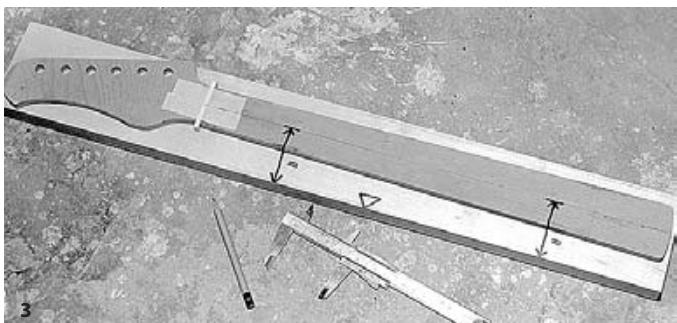


Making the trussrod channel

On one-piece necks the truss rod is installed from the back of the neck, as opposed to necks with glued-on fingerboards, where the truss rod is installed directly under the fingerboard and from the front. With both types the truss rod adjustment nut can either be on the peghead end or on the body end of the neck.

Mark the neck center line on the neck blank and transfer the shape of the peghead onto the peghead using a template. Mark the nut width and draw a line through its middle. This line has to be parallel to the edge of the neck blank that will later be used for guiding the router. Then mark the neck width at the body end so that it is symmetrical to the center line. Connect these two points with those at the nut and you will get two lines showing the shape of the neck. These lines will most probably not be exactly in the center of the neck blank; this is only the case if the peghead is symmetrical in shape. On necks with 6-in-line tuners (all

tuners fitted on one side) the neck center line will be either left or right of an imagined neck blank center line (3). Both the entire peghead and neck template have to fit on the neck blank. If you make a one-piece neck, also mark the center line and all other auxiliary lines on the back of the neck.



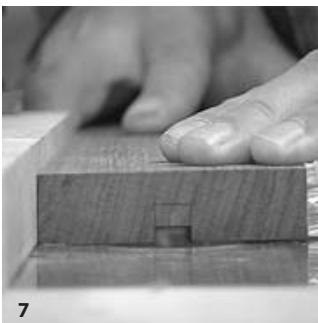
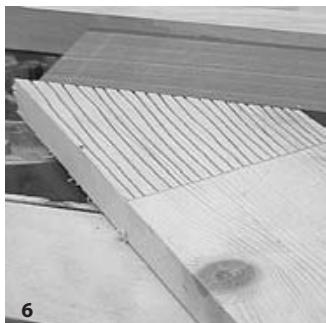
Cutting a straight truss rod channel

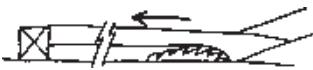
Making a straight truss rod channel is easy with a router. Mount the edge guide on the router and fit a 6mm ($\frac{1}{4}$ ") cutter bit. If your edge guide is rather short, it is advisable to make it longer by attaching a piece of wood to make it easier to move the router more safely and evenly, especially at the ends. To be able to fasten the neck blank safely I screw a block of wood onto the area outside the neck outline (4). Choose the correct feed direction, which is towards the body in picture 4.

A 6mm ($\frac{1}{4}$ ") cutter bit is just the right size for cutting the truss rod channel as a small bit of space has to be left for a layer of adhesive tape or a plastic sleeve around the 5mm ($\frac{3}{16}$ ")-diameter truss rod. Cutter bits which are smaller in diameter normally have thicker shanks, making it impossible to rout a channel deep enough for holding the truss rod unless they have an extra-long cutting edge.

Set the edge guide so that the cutter bit will move exactly along the truss rod channel center line. Try this first without switching on the router and with the cutter lowered to just above the wood surface. Then cut out the channel in several passes, routing against the direction of the cutter rotation. If you rout in the opposite direction, you could deviate from the drawn line. Stop routing just before the nut position. Do not lower the cutter more than 3mm ($\frac{1}{8}$ ") into the wood on the first pass. How deep the channel has to be made depends on the truss rod used. The anchor piece requires a cavity square to the truss rod channel and should be fitted flush with the neck surface.

Using a table-mounted router (5) is an alternative for cutting a straight truss rod channel. It is important to use a feather board that constantly pushes the neck blank against the fence of the router table (6). A featherboard is easy to make: just saw a lot of long kerfs, one close to the other. Rout in several passes (7). A 10x10mm U-channel truss rod (8) will be fitted into the channel shown (7).

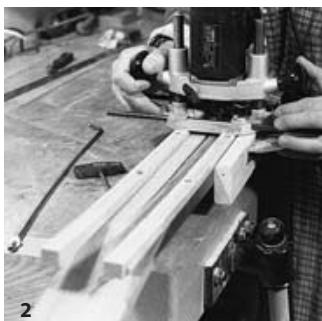




1

A tablesaw can also be used for cutting a straight truss rod channel. The desired width of the channel is obtained with a dado head or two or more cuts made next to each other with a normal sawblade.

When making an angled-back head with head-end truss rod adjustment, cut down the whole length of the neck and fill one of the ends of the channel with wood later. If the channel must not extend beyond the nut, because the adjustment nut will be at the body end of the neck, the curve of the sawblade has to be taken into account (1): make a "blind" cut and closely check how far the neck blank may be pushed into the saw. This is best done by removing the sawblade and marking its curve on the side of the neck blank. With this method you will know exactly where you have to stop cutting the truss rod channel on a neck with head-end adjustment nut. Clamp a stop onto the sawtable. The curved end of the cut channel can be squared up using a chisel.

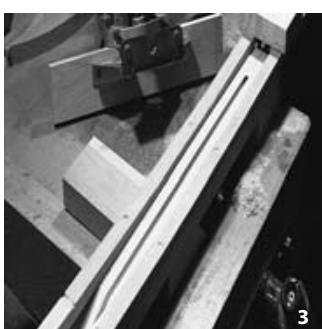


2

Making a curved truss rod channel

For making curved truss rod channels make two curved rails and fasten them with double-stick tape on both sides of the neck blank parallel to each other. If the truss rod is fitted from above, a concave rail curve is required (2). Mount the edge guide on your router (make it longer with an additional board) and adjust the router bit to the neck center line. Then start routing the truss rod channel, removing no more than 4mm ($5/32"$) in one pass. Always adjust the cutting depth by placing the router in the middle of the rails. The curve I use is about 6mm ($1/4"$) lower in the middle than at its ends (3). The channel should be 8mm ($5/16"$) deep at its ends to leave about 3mm ($1/8"$) for the wooden fillet. In the middle the channel is therefore $8+6=14\text{mm}$ ($5/16" + 1/4" = 9/16"$) deep. This means that only 5mm ($3/16"$) of wood will be left under the truss rod. When you finally shape the neck it will become even less. The truss rod may also be totally flat towards the end of the neck and will still retain its function.

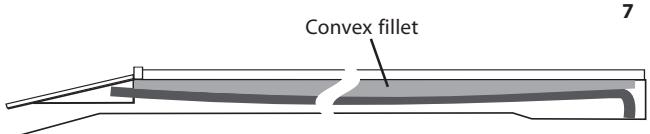
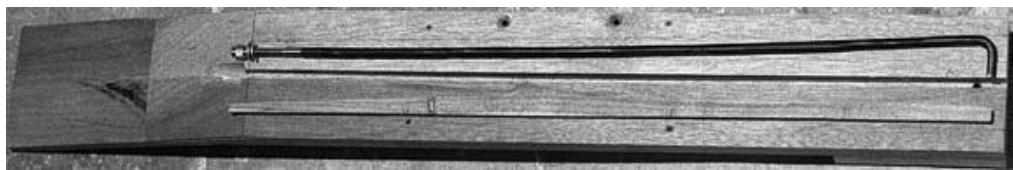
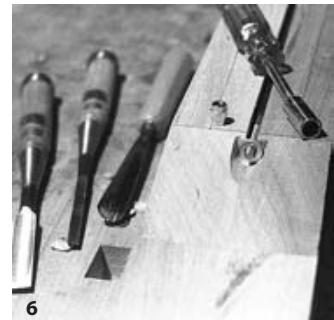
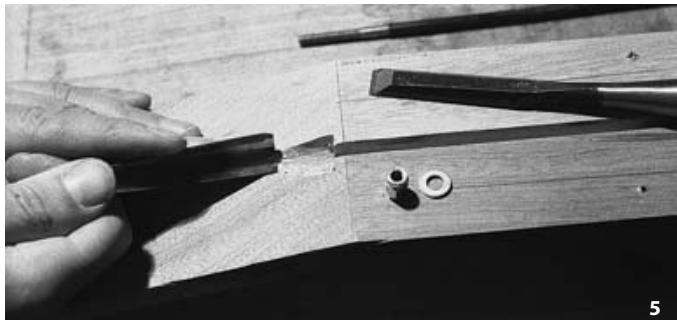
Compression rods with one bent end need a hole at the end of the truss rod channel where the rod can be anchored (4).



3



4



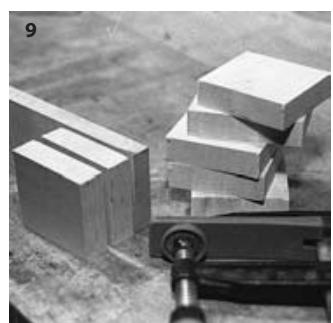
Making the access cavity

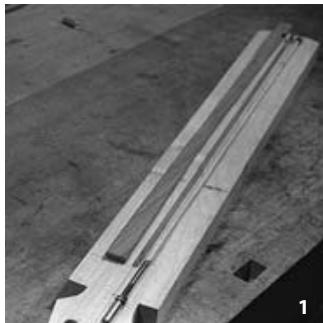
On guitars with angled-back head and head-end adjustable truss rod enough space has to be left to allow getting at the adjustment nut. In the case of allen nuts the width of the channel will do, but for hex nuts a sufficient amount has to be removed around the truss rod nut; use a chisel and a 12mm ($1/2"$) carving gauge to remove just as much wood as is necessary to allow access to the nut for an adjustment wrench (5). The washer used on this 5mm nut and shown in the picture is 8mm in diameter, and the wrench needs a 12mm opening (6).

Picture 7 shows a neck ready for truss rod installation. The bottom side of the fillet has to be shaped in accordance with the curve of the truss rod as shown in the illustration below.

Gluing up a heel

On glued-in necks a heel is often built up to make the neck end thicker to increase the gluing surface (8). High heels can be made up of one block, but equally well of several pieces sawn off a second neck blank and glued on top of each other (9). A beautifully shaped heel can contribute to making the guitar look nicer.

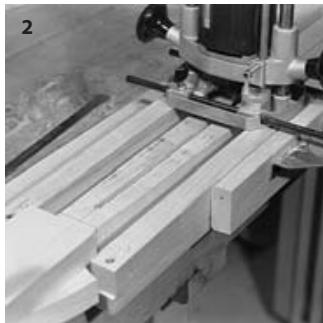




Fitting the truss rod

Fitting a truss rod into a one-piece neck

On one-piece necks (without separately-made fingerboard) the truss rod has to be installed from the back (1). For this purpose the rails used for routing have to be made convex. Instead of taping the rails onto the neck blank the blank can also be placed into a jig (2,3) fitted with a block for stopping the router. Several passes will be required to cut the channel to the desired depth.



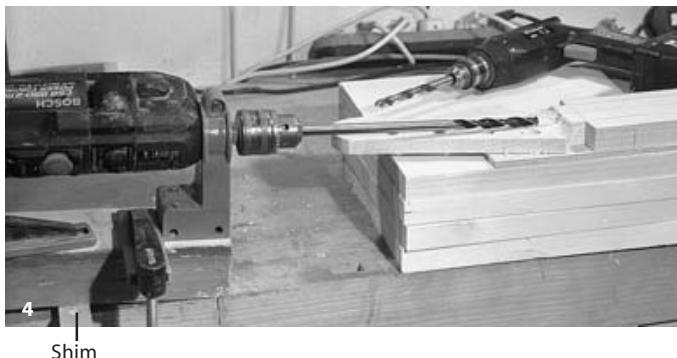
Concave cover strip

Guitars which are to have a back-mounted truss rod and a head-end adjustment nut require the drilling of a hole that connects the peghead with the truss rod channel. How to make a *Fender*-style peghead, which is necessary for this purpose, will be explained on page 149. Making a reliable jig for this quite difficult drilling job can be a lot of work. I tried to keep things simple and had good results, too. Draw the depth of the channel and the necessary drilling angle onto the edge of the neck blank. Fasten the power drill in a holder, inserting a shim (4) under it so that it ends up lying at an angle of about 3 degrees. Bring the neck blank up to the required height by putting some boards under it (4). The drill bits used have to be at least 30cm (1 feet) long.



Skunk stripe

The cover strip fitted over a truss rod installed from the back is often made from contrasting wood. That's why it was given its graphic name after the skin pattern of an animal called skunk.



Shim

Start with a bit that is equal in diameter to the adjustment nut. How deep you have to drill depends upon the length of the nut plus washer. The adjustment nut may also protrude slightly. To make the bit really bite into the wood I pre-drill a little bit by hand before turning to the electric drill. Push the neck blank into the drill by moving it along a fence. Then mount a 6mm ($\frac{1}{4}$ ") bit and drill right through to the truss rod channel on the back. A mark made on the bit before drilling indicates when the right depth has been reached.

Cover the channel in which the back-mounted, and therefore convex-curved, truss rod lies with a strip of hardwood timber (1). For optical reasons it is advisable to use a strip of dark-colored wood for this purpose. Cut out the strip slightly wider and thicker than needed and then carefully plane or rout it down so that it can be pressed into the channel and fits there tight. Use a file to cut one of its ends flush with the curved end of the channel. Getting the size of the cover strip right is essential, in particular when using it to cover a back-side channel. So if you discover your strip doesn't fit precisely, you had better make a new one which is exactly the right size; a cover strip that is too wide can break the neck blank when the strip is glued in, while one that is too small, and perhaps also glued in badly, may be pressed out later by the force of the truss rod. This is less of a problem when the cover strip is fitted from the front as in that case the strain is spread all over the glued-on fingerboard.

Fitting a two-way twin truss rod

A two-way twin rod does not require a wooden fillet under the fingerboard as the straight channel, which is made 11mm ($\frac{7}{16}$ ") deep and 6mm ($\frac{7}{32}$ ") wide, is covered by the fingerboard. Due to the large gluing area and the thickness of the fingerboard there is no danger of it being pressed away from the truss rod. The truss rod shown in picture 5 comes from *Stewart-MacDonald* and is called "Hot Rod" (a similar truss rod is also available from *LMI*).

In picture 5 you can see me fitting a "Hot Rod" from the back, for which I needed a fillet (a so-called "skunk stripe"). Because it is fitted from the back, the truss rod channel is made 16mm ($\frac{5}{8}$ ") deep, so 3mm ($\frac{1}{8}$ ") of wood will be left under the fingerboard. As suggested in the fitting instructions that came with this truss rod, I embedded the thread blocks in silicone.

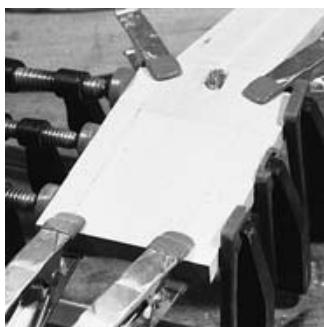


Two-way compression rod

For the installation of a two-way compression rod a straight channel and two short cross channels for the anchor nuts are needed. The headless neck shown in picture 4 is intended for a headless bass. The hole for the adjustment nut was drilled with several bits, starting with a small-diameter one, followed by one 0.5mm greater in diameter, and so on. Alternatively, you could also choose the easier approach of temporarily placing the fillet strip into the channel and to drill only once, using the right size of bit straight away.

Cut out two anchor nut cavities from the fillet. Make sure that the truss rod can be turned after it has been installed.





Fitting the truss rod cover strip

When the cover strip (fillet) is the right width, saw it off to truss rod channel length and round off one end in accordance with the diameter of the router bit. Apply some glue and gently press the strip into the channel; use several clamps over the whole length of the strip (If you use a one-way twin rod, make sure it is placed in the channel the right way round). The truss rod must remain movable. It is advisable to put on the truss rod nut first and, in the case of hex nuts, to also stack on the adjustment wrench. When fitting a twin-rod system no clamps must be used; instead, knock the strip in gently (1). Remove any excess glue after about 20 minutes. After the glue has set plane down the protruding wood to just above neck surface (2). Move the plane carefully and without tilting it to one side or the other to avoid damaging the neck. Finally, take a scraper and scrape the remaining wood flush with the neck.

Making the peghead

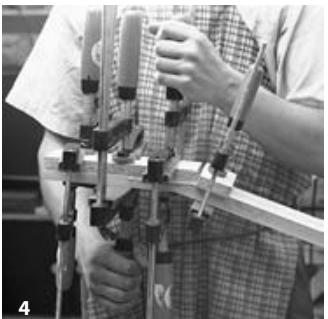
Gluing on the peghead veneer

Gluing on peghead ears
By gluing "ears" onto the peghead you can save material as this allows using a neck blank that isn't much wider than the end of the fingerboard. Use a sufficient number of clamps.

The peghead veneer for angled-back heads should be between 2mm and 3mm ($3/32" - 1\frac{1}{8}"$) thick, but depending on how much had to be removed to make the head flat the veneer can also be thicker or thinner than that. Try to choose veneer which looks pretty and whose color matches that of the rest of the guitar. The veneer could, for example, be of the same type of hardwood as is used for the body or the neck, or it could, in fact, be any type of hardwood with pretty grain pattern. You can either use a small board planed down to the appropriate thickness or several layers of thin sheets of veneer (3). Bevel the nut-end edge of the peghead veneer so that it butts up right against the nut. If the peghead has an angle of 15 degrees, the edge of the veneer has to have an angle of 75 degrees. Some finished bone nuts have an additional slant of 7 degrees so that the edge would have to be



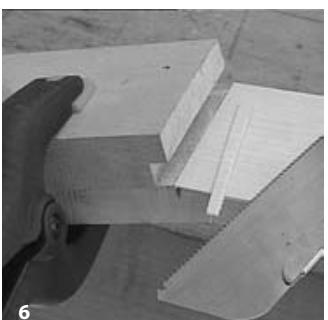
3



4



5



6



7

slanted at an angle of below 68 degrees to make it butt up against the nut. Also remember to cut out an opening for allowing access to the adjustment nut. Copy its outline on a piece of paper and transfer it onto the veneer. Only one layer of thin veneer must be glued onto necks without separate fingerboard (one-piece necks) and with angled-back head as otherwise the veneer would be in the way of the strings.

For gluing on the peghead veneer fasten a stop block at the line where the head angle starts. Apply glue thinly and evenly all over the head surface, lay the veneer on it and rub it on. When the glue is beginning to grab push the veneer against the stop block. Use six clamps and a clamping caul to press the veneer onto the head (4). Tighten the clamps evenly and a little at a time. If the veneer should start to move away from the stop block, untighten the clamps immediately and correct the position of the veneer.

Instead of using heavy, ordinary clamps for gluing on the peghead veneer you can use light-weight spring clamps made of plastic. The 2mm maple peghead veneer shown in picture 5 is glued on with the help of a 10mm ($\frac{3}{8}$ ")-thick plexiglass caul.

As an alternative you can cut the veneer afterwards. To keep the veneer from sliding away during gluing use a longer piece that protrudes into the nut area. After the glue is dry you can use a block as a guide (as shown in picture 6) for sawing the veneer to the correct angle and length.

Sawing out the peghead shape

Before sawing out the head extend the neck center line to the end of it. Line the peghead template up on centers with the neck center line and fasten the neck so that the head is horizontal and accessible from all sides. Then transfer the shape of the peghead template onto the head and mark the centers of the pegholes with a sharp needle.

The peghead shape is cut out with either a jigsaw (7), a bandsaw or a coping saw. Cut just outside the drawn line. For bandsawing you can draw the outline of the head onto the back

Alternatives to a peghead inlay

If you do not want a peghead inlay, it's about time to think of alternatives for a peghead logo. There are a lot of possibilities and your imagination is challenged. Trademarks are, of course, owned by the respective companies. Apart from that I find it rather strange to write *Fender* or *Gibson* or something else well known on your guitar.

Just a few possibilities:

- Write your signature on the peghead with a felt pen or a thin paint marker
- Put on rub-off symbols or letters
- Design your logo on a computer, print it out on transparency film, cut it out and glue it on.

It is very important that you test in advance if the material used for the logo is compatible with the finishing method chosen (a logo written with a paint marker might, for instance, dissolve when you apply lacquer).

Some more possibilities:

- Chip carving
- Screw on a small brass name plate. These are available very cheap.
- Use of a branding iron.

of the head, or you could use a block of wood onto which the angled head can be placed horizontally.

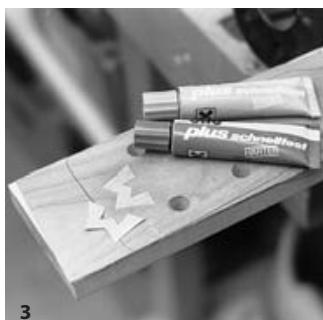
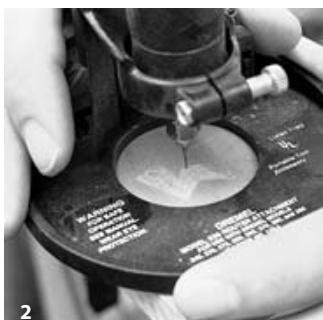
Fitting a peghead inlay

Inlays are traditionally made from mother of pearl or abalone. A modern and easy-to-work-with alternative is *AbaLam*. The patented *AbaLam laminated shell* is made from genuine abalone shell in thin epoxy-bonded layers, which saves resources. All these inlay materials come in thin, flat sheets. Always wear a respirator mask when cutting shell materials as their dust is toxic. There are also pre-cut and shaped inlays available.

Inlays can also be made from veneer or different types of metal. Even compact discs no longer needed can be recycled for inlay material use. Use a very fine jeweler's saw to cut out inlays.

Using tiny bits of double-stick tape, fasten the inlay symbol in the desired place and then scratch its outline into the wood with a fine knife (1); make several passes to make the outline deeper. After that carefully lift off the inlay with a flat knife. If the wood is very dark, you might want to paint a thin layer of whitener from your water color paintbox on the inlay area before. Working in a well-lit area and with the help of a headband magnifier makes inlay work considerably easier.

Using a very fine router bit the inlay area is routed deeper (2). A standard tool for such inlay work is the *Dremel* mini router. The router should be set so that it cuts just marginally less deep than the thickness of the inlay piece. By moving the cutter carefully along the outline small chips will be produced that will fall out of the way. This makes it possible to rout very precisely along the line. Tight corners have to be cut with a knife later. Check at regular intervals whether the inlay fits and use a knife for making any recuts that might be necessary. When the inlay fits exactly into the cut-out area it can be glued on with 5-minute epoxy (3) or super glue; use a clamp and a small caul for gluing. When the glue has set sand the inlay flush with the surface. The inlay shown in picture 4 is a thin piece of brass polished to a shine with steel wool and cut out with scissors.



Making the fingerboard

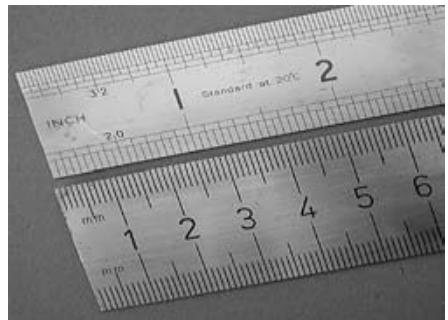
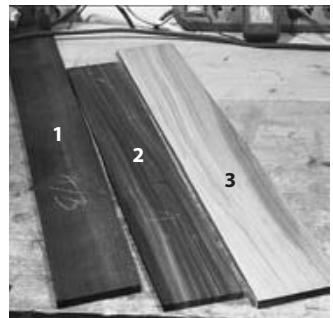
Dense, hard wood is an ideal material for the fingerboard. You can use ebony (1), rosewood (2), pau ferro, maple, plumwood (3) and pearwood. The easiest way of planing the fingerboard down to its eventual thickness is with a thickness planer. If you need to plane the board thinner than the machine can accommodate, raise the fingerboard by placing a flat, 19mm ($\frac{3}{4}$ "")-thick board under it in the thickness planer and fasten it so that it cannot be pulled out of the machine. The fingerboard could, however, just as well be planed by hand (4) as long as you plane evenly thick and keep turning the fingerboard regularly. Fingerboards are usually 6mm ($\frac{1}{4}$ ") thick. First plane one surface of the fingerboard flat, then the opposite, until the two are parallel. Before you start working with the handplane fasten the fingerboard with double-stick tape.

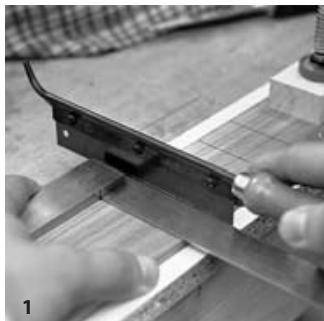
Marking the fret positions

To mark the fret positions place the fingerboard on a flat, narrow surface at the edge of the table. Using a clamp on either end, fasten a long rule at a short distance from and parallel to the edge of the fingerboard so that its zero-mark is slightly inside of the fingerboard end. Have a list of all the fret distances from the zero-fret (front nut edge) ready in front of you. If you measure in inches try to get a ruler with $\frac{1}{100}$ " marks or use one that is divided into $\frac{1}{64}$ " and estimate the fret positions as accurate as you can. Don't use a tape measure for this task - always use a quality steel ruler for marking fret distances.

Using a very fine knife, make little grooves into the edge of the fingerboard at all fret positions, starting at the zero-mark of the rule (5). It is obviously impossible to work to an accuracy of one hundredth of a millimeter or one thousandth of an inch, so the figures will have to be rounded up (5-9) or down (1-4) to tenths of a millimeter or hundredths of an inch. Try to be as accurate as possible when laying out the fret distances.

When the zero-fret and all other frets (plus one additional one for the fingerboard end) have been marked, double-check the distances by reading off each position from the rule and then comparing these readings with the figures in the table. If the two differ by more than 0.3mm or $\frac{1}{64}$ ", the mark is invalid and has to be recut.

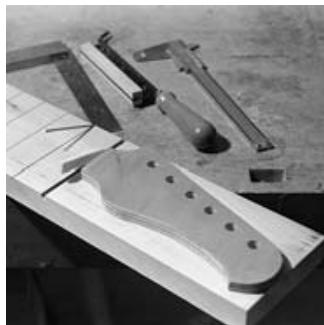




1



2



Fret slots in a one-piece neck

On one-piece necks without separate fingerboard the fret slots are cut directly into the neck blank. The nut, too, is seated in a slot cut into the neck. The front edge of the nut slot has to be exactly identical with the zero-fret line. Make a few more cuts to make the nut slot wider towards the peghead side of the line until the nut fits in.

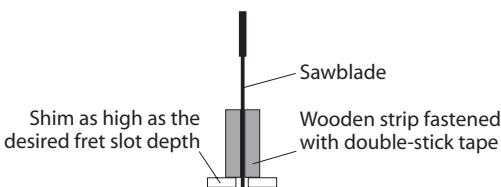
Making the fret slots

The fret slots can be cut by hand with a backsaw or a Japanese saw. Use a sawblade that produces a cut corresponding in width to the width of the fret tang. Very often an 0.6mm (0.024") sawkerf will be just right. The German-made *Blitz* saw (available from guitarmakers' suppliers) shown in pictures 1 and 2 can be fitted with blades of different widths; the wide choice available (widths graded by 0.1mm) should make it easy to get the width of the fret slots right. Before measuring the width of the fretwire tang with a caliper remove any burrs with a file in order to get an accurate measurement.

Place the saw on the mark and cut a small groove. Then place a square on the edge of the fingerboard and push it towards the sawblade. Using the square as a fence the fret slots can now be cut perfectly square. When you approach the end of the fingerboard turn the fingerboard so that you have a long-enough fence for the square to ride against. If a zero-fret is to be fitted, saw off the fingerboard about 5mm ($\frac{3}{16}$ ") from it towards the peghead. If you don't use a zero-fret, saw through the fingerboard exactly at the zero-fret slot. At the body end the fingerboard is sown through at the additionally marked fret.

All fret slots should be a little bit deeper than the tang of the fretwire. To ensure this is the case fasten a depth stop on either side of the sawblade (2). Place the sawblade between two strips of wood or metal that are raised on either side by shims of a thickness that you want the fret slot depth to be (see illustration below). By firmly pressing the two strips, which have double-stick tape on them, against the blade you get an accurate depth stop.

The fret slots should ideally be of exactly the same width as the fretwire (without barb) or only marginally (by 0.1mm) less wide. Fret slots that are too narrow can cause the neck to be bent backwards by the wedge effect of all the frets combined while fret slots that are too wide make the neck too flexible.



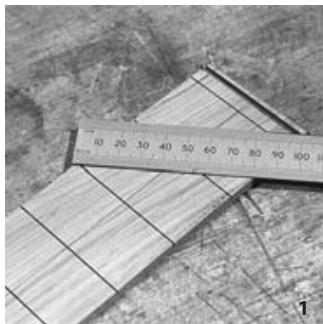
Cutting fret slots with a machine is a time-saving alternative. Commercial guitar manufacturers use computer-controlled routers which can cut the fret slots to an accuracy of 0.01mm. You can, however, also cut them in your own workshop using a tablesaw with a very thin blade. Sawblades intended for cutting metal are available from tool suppliers in various widths. The one shown in picture 3 is 0.6mm (0.024") thin. If the center hole does not fit onto your tablesaw arbor, you will have to get it enlarged. Since they do not have set teeth, they should not be used for making deeper cuts than those required for the fret slots, or else the extremely thin sawblade could quickly be overstrained. My blade, which is shown in picture 3, had a 22mm-diameter hole. In order to fit on my 30mm tablesaw arbor it was enlarged on a lathe using a cone-shaped grinding stone. Tablesaw blades for cutting 0.024"-wide fret slots are also available from guitarmakers' suppliers. These are specially intended for wood. I must say that I never experienced any problems with my 0.6mm-wide HSS sawblade although it was made for cutting metal. It is advisable to use stiffeners on both sides of the blade that are only marginally smaller in diameter than the blade itself, but I didn't notice any drawbacks without them.



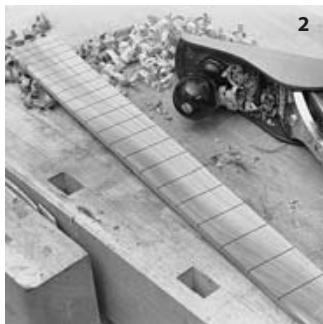
A further improvement would be to use a template as this would do away with the time-consuming and error-prone job of marking fret positions. Templates for a number of common scale lengths can either be bought from guitarmakers' suppliers or made on a big milling machine; they are normally made of clear plastic or of metal and have small notches at the fret positions along one of their edges. Fasten the template with either two short strips of double-stick tape or one long strip of adhesive tape on the back of the neck (4). An index pin is mounted in a long narrow board which is fastened at the miter gauge or the crosscut sled of the tablesaw; the pin fits accurately into the template notches (arrow). I have one index pin for fingerboards, fastened about 8mm ($\frac{5}{16}$ ") above the tablesaw surface, and when I turn the board upside down there is a second pin for one-piece necks about 27mm ($\frac{11}{16}$ ") above the surface. By moving the fingerboard (plus the template that is fastened to it) and locating the index pin in the next notch after each cut the fret slots in the neck will be absolutely accurate, i.e. in the right places and at the right distance from each other, provided the template was made accurately enough (5). In this way all the fret slots can be cut in a matter of minutes.

Such templates can also be used with a jig and a backsaw as shown in the section on *Steve Jarman*.





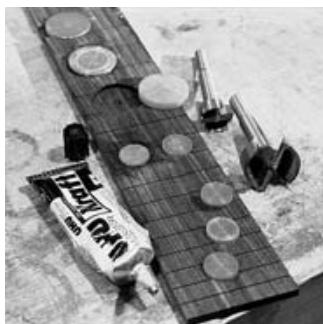
Plane the fingerboard down to the width chosen when designing the guitar. With a rule laid across the fingerboard as shown in picture 1 the center line can be found very quickly. Note how I placed the rule: the zero-mark is exactly at one edge of the fingerboard and the 80mm mark exactly at the other. The center point is halfway between zero and 80mm, i.e. at 40mm.



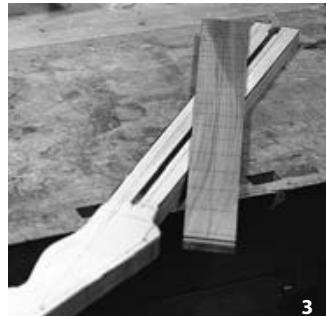
As already mentioned in the chapter on design, the fingerboard shape is determined by the nut width and the width of the fingerboard at the last fret. Transfer this shape onto the fingerboard with a pencil. Picture 2 shows a fingerboard which was fastened in the workbench upright between cork clamping cauls and then had its edges planed. To plane a tapered edge start at one end and then set the plane back a bit and plane further; repeat this until you can plane down the whole length of the edge and the side is parallel to the line marking the fingerboard edge. Alternatively, you could also use this method for planing the edges with a jointer.

The wider slot behind the slot for the zero-fret in picture 1 will accept the nut. This fingerboard will be glued onto a neck with *Fender*-style peghead. On guitars with angled-back head the nut is placed between the fingerboard and the peghead veneer and held in place by these and a drop of glue.

Gluing on the fingerboard



The fingerboard can now be glued onto the neck. It is up to you whether you rough-cut the neck shape now (3) or only after you have glued on the fingerboard (4). Several strong clamps and a long clamping caul are needed to spread the pressure evenly across the fingerboard surface. Cut a slot into the caul in the position of the first and the 15th fret. To ensure that the fingerboard does not slip about during gluing fasten it with small wire brads. Since these have to be removed later, they must obviously not be knocked in all the way and therefore require a bit of space in the clamping caul - which is provided for by the slots in the caul.



Fingerboard inlays

Any inlay work on the fingerboard surface should be done now, before the fingerboard is glued on. The picture above shows large plastic dots made on a lathe. If you make a radiused fingerboard, thin inlays should only be fitted after the fingerboard surface has been rough-radiused. For details of materials that can be used for this purpose please refer to the section on peghead inlay work.



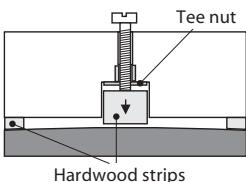
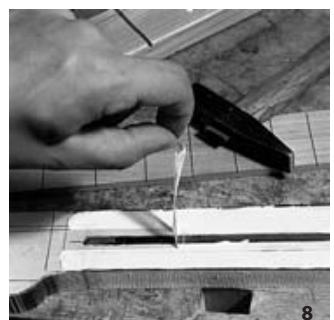
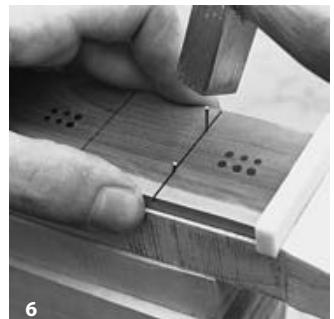
Drill two holes of the same diameter as the wire brads into the slot of the first fret and another two into the slot for the 15th fret. By drilling these holes the fingerboard is kept from splintering when driving in the nails (6). Have five strong clamps as well as all other bits and pieces needed ready at hand before you apply the glue; spread the glue thinly and evenly on the back of the fingerboard or within the fingerboard outline on the face of the neck (7).

If you use a truss rod which does not need to be covered with a wooden fillet, it is advisable to protect it against the glue by masking it with a narrow strip of adhesive tape. The tape can then be removed after the glue has been applied so that the glue will not stop the rod working properly (8). The pressure of the tightened clamps will force the glue towards the areas left and right of the channel.

When making a guitar with angled-back head always place the nut between the peghead veneer and the fingerboard to ensure that the fingerboard is glued on in the right place.

Place the fingerboard carefully on the neck and push it firmly towards the fitted nut so that it butts up against it. Put the wire brads into the holes drilled earlier and knock them into the neck with a hammer (6). Make sure that the fingerboard has not moved in any way. If it has, correct it immediately.

Then clamp the fingerboard down; use the clamping caul for this and tighten the clamps evenly (9). Remove any excess glue after 20 minutes and leave the neck to rest overnight. Pull out the wire brads the next day; use pliers for this. After the frets have been fitted the holes will be invisible.



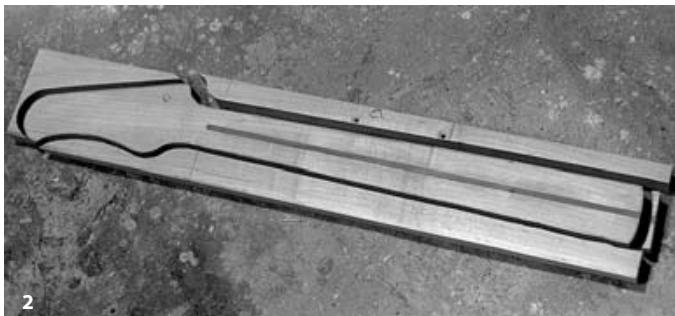
Clamping caul for radiused fingerboards

For gluing on radiused fingerboards you can build the caul shown below. It is used, as usual, together with clamps (as shown on the right) and presses down both fingerboard edges. An extra hardwood strip placed in a slot in the middle and activated by several bolts additionally presses down the fingerboard along its center line.





1



2



3



4



5

Routing the neck shape

Rough-cut the neck shape with a jigsaw (1) or on the bandsaw (2), cutting about 2mm ($\frac{3}{32}$ ") outside the glued-on fingerboard or neck contour line. Then fasten the peghead template, and on a one-piece neck also the neck template, with double-stick tape and use a flush-trimming cutter with end-mounted ball bearing to rout the neck to shape (3) (See section on making the body for details of how to use the flush-trimming cutter). A short cutter bit will do for routing the neck, but you can of course also just set the one used for routing the body a bit lower.

When making a neck with glued-on fingerboard I use the fingerboard as a guide for the ball bearing. If the fingerboard should have a slight projection at the neck end, sand this end flat before gluing on the fingerboard.

Flush-trimming cutter bits with shank-mounted ball bearing can be used for routing necks with angled heads (4). When routing such necks be particularly careful and stop just before the point where the head and the neck meet (5). The safest approach is to make the peghead template not too thick and to fasten it so that it butts up against the fingerboard. This provides a continuous template edge for the ball bearing. The cutter bit used could just as well only be half as long as the one shown in picture 4. The guard, which was removed for this picture, should always be used whenever you do any work on the router table.

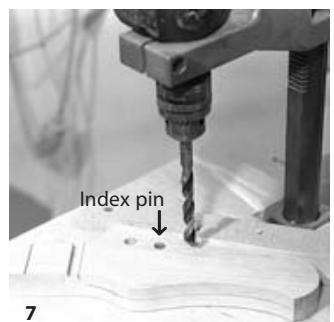
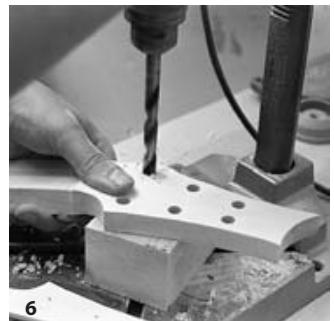
Bound head

The binding rabbet around the head can be cut with a flush-trimming cutter provided its ball bearing is removed and a smaller one mounted instead. After applying some glue use strips of adhesive tape to press the wooden binding into the channel. At the corners, miter the binding with a small chisel. The ends towards the fingerboard will be hidden by the nut.



Drilling the tuner holes

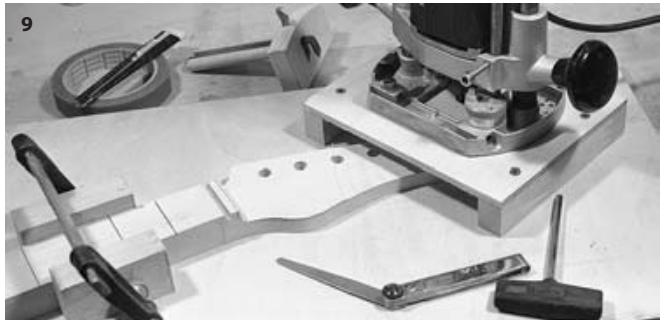
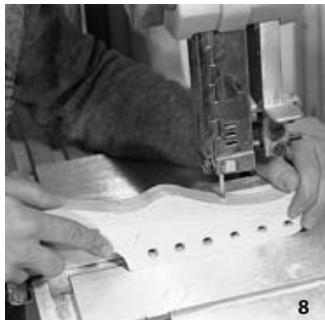
Mark the centers of the tuner shaft holes before drilling. Measure the diameter of the tuners, mount the drill in a stand and then drill the holes vertically so that they are ideally the right diameter straight away and no filing is required later. When drilling, press the head firmly against the workboard to prevent the wood from splintering, which can easily happen when the bit comes out at the bottom of the head. Brad point drill bits are ideal due to their handy point. When drilling holes into an angled-back head a block of wood has to be put under the head (6). Drilling the tuner shaft holes for 6-in-line tuners at equal distances from each other is made easier with a jig consisting of a fence and an index pin in the workboard (7). The short pin sticking out from the workboard is placed at exactly the desired tuner-shaft-distance from the drill bit. After a hole has been drilled, this hole is “anchored” at the pin and the next hole is drilled. This will ensure equal distances between the tuner shaft holes.



Shaping a *Fender*-style peghead

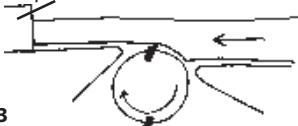
Fender-style heads, which are lower than the fingerboard, can also be cut out on a bandsaw (8). Lock the guard of the bandsaw blade in a position slightly further from the table than the head is deep. Lay up the neck with its back facing the fence. As you approach the nut, tilt the neck downwards to get a cut parallel to the nut. Just before the nut the sawblade is made to rise out of the wood in an evenly-curved line. The radius of this curve should correspond to the radius of one of your sanding drums.

For routing the face of the peghead flat you can use the jig shown in picture 9. Such a jig also allows making the head thinner without need for a bandsaw. By inserting a piece of very thin metal, such as a feeler gauge, between the depth stop of the router you will be able to lower the surface-trimming cutter bit very precisely. The area which the cutter bit can reach has to be limited with a stop.





Stop block on the outfeed table



The curve towards the nut can also be made with a cove bit. In picture 1 you can see me using a small-radius cove bit; I used it only because I didn't have a bigger one. A greater radius is preferable, though, not only because it looks better, but also because it gives better stability. The picture is only to illustrate the basic idea. Make sure to set the stop blocks very accurately.

You can also use the table saw for thinning the peghead and for rough-shaping the curved transition (2). With this method the radius is determined by the table saw blade. Use a stop block and make several cuts beside each other. This is a quick method especially if you use a dado blade.

If your jointer allows lowering the infeed table by 10mm ($\frac{3}{8}$ ") or more, which should be possible on larger machines, I would use it for planing a *Fender*-style (lowered) peghead (3) as this will give a smooth surface immediately. The transition curve towards the nut is determined by the radius of the jointer's cutterhead in this case. Plane in several passes, removing about 1.5mm ($\frac{1}{16}$ ") on each pass. I would recommend that you use a long support block (fastened with double-stick tape) over the peghead area on the back of the neck blank as this will avoid vibrations. A stop must be fastened on the outfeed table. If the cutterheads are to leave a smooth surface, the grain in the peghead has to run towards the nut. Bear this in mind when deciding which end of the neck blank is to be the peghead end.

Sanding is the far more common method of smoothing the curved area between the neck and the head. This is done in the same way on both one-piece necks, such as the one shown in picture 4, and necks with glued-on fingerboard. Care is needed, though, for you do not really want to sand off too much and end up with a depression, in which case the head would have to be made thinner than originally intended. To be on the safe side it is therefore advisable to leave the head slightly thicker before you start sanding. The sanding drum can also be mounted vertically in a drill press. With this approach an already tapered neck is clamped to a workboard so that the neck center line is parallel to the workboard edge. The workboard and the attached neck can now be placed upright on the drill press table and guided towards the sanding drum along a fence.

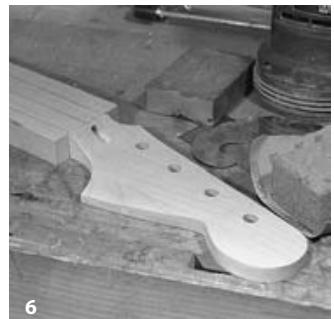
Finish off by smoothing and sanding the head to shape (5,6). Be patient, watch out for uneven curves, and make corrections if necessary.

Fitting fingerboard dots

Fingerboard markers in the shape of dots look good and help the guitar player to find the frets more easily. Dots are normally fitted between frets on the side of the fingerboard which faces the player and also on the fingerboard itself. Often you will find four dots spread symmetrically over 12 frets: the 3rd, 5th, 7th and 9th fret are marked with one dot each, while the 12th fret has two dots. The next 12 frets are marked as a mirror-image of the first 12 frets, and fingerboards with 24 frets have this last fret also marked with two dots. Because they are more difficult to see for the player, the dots on the fingerboard are not absolutely necessary, as opposed to those on the side of the fingerboard. Both functions of the dots (ornamental and practical use) would be met by fitting marks of rectangular, round or some other shape on the side of the fingerboard. Materials and shapes can be chosen according to one's own likes.

Dots are easy to fit. Draw two diagonal lines to determine the center between two frets and, after marking this center, drill holes of about 2mm to 3mm ($3/32"$ - $1/8"$) depth, preferably with a brad point drill bit as these produce flat-bottom holes (7). Then glue the dots into the holes and finish by sanding all dots flush with the fingerboard, using extremely fine-grit sandpaper. An alternative to buying plastic dots from guitarmakers' suppliers would be to cut thin pieces off a black plastic shaft of a potentiometer. Often, however, such shafts and other plastic rods contain tiny holes because of entrapped air, in which case not all dots may be suitable. For a dark fingerboard you need bright-colored dots made of either some synthetic material or mother-of-pearl or abalone (8).

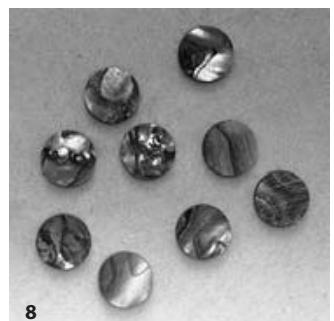
Wooden fingerboard dots (9) are also possible. On the neck shown on the left I used dark hardwood dowels as fingerboard markers. The picture also shows my expensive Japanese saw; here I am using it to cut the dowels flush with the fingerboard. There are also saws made specifically for this purpose with set teeth on one side only that leave no scratches on the surface. It's about time I bought one of these special saws, too.



6



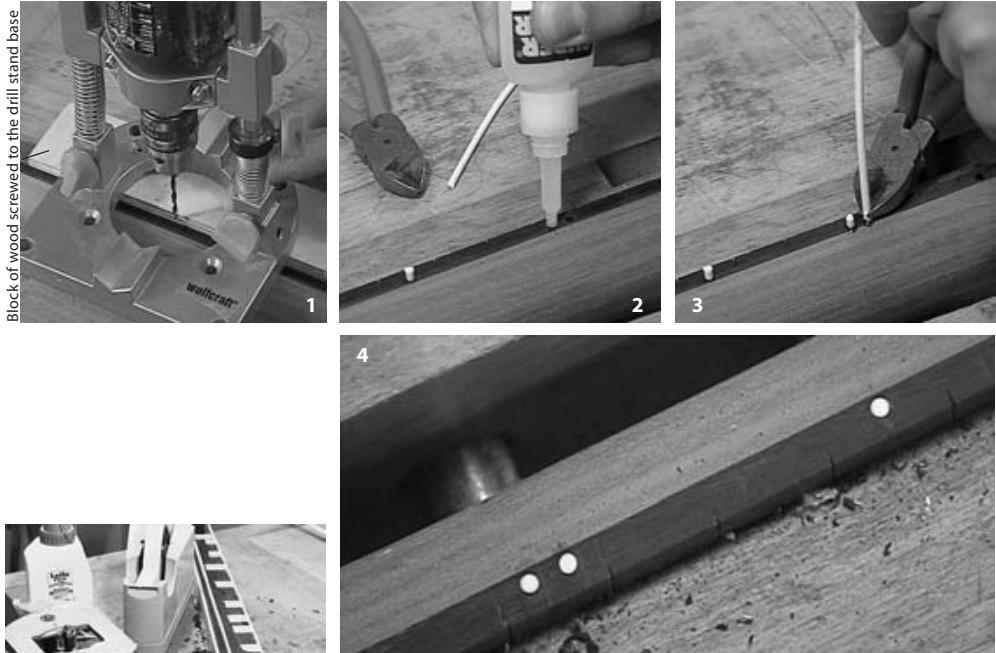
7



8



9



Fitting side dot markers

Side dot markers on the fingerboard are an invaluable help for the player. These dots are often made from some sort of synthetic material and are either black or white to contrast with the color of the fingerboard. Plastic rods, $1/16"$, $3/32"$, 1.5mm or 2mm in diameter, which can be used for making such dots, are commercially available from guitarmakers' suppliers (also via mail order). It is also possible to use copper wire that is thick enough for the purpose, but you can only cut it flush with a file. Mark and drill one hole each between the 2nd and 3rd, the 4th and 5th, the 6th and 7th and the 8th and 9th fret, and two holes for fitting two dots between the 11th and the 12th fret.

For drilling the holes (1) I used a drill stand with an attached block of wood to guarantee equal distances from the fingerboard edge (the neck is fastened in the workbench vise). After drilling fit each dot by putting a spot of super glue into the hole, sticking in the plastic rod (2), cutting it off (3) and then sanding and scraping it flush (4). Note that the dots are not centered on the fingerboard edge because this edge will become narrower after radiusing the fingerboard.

Fingerboard binding

Cut a suitable rabbet and then glue on the binding. Do this before you make the radius on the fingerboard as routing the rabbet is easier on a flat surface. In the picture on the left I am using thin strips of wood as binding material. A flush-trimming cutter bit can be used for cutting the rabbet, provided that a fairly small ball bearing is mounted. The depth of the rabbet can be worked out by subtracting the diameter of the ball bearing from the cutter bit diameter and dividing the result by two.

Radius the fingerboard and make the fret slots deeper before gluing on the binding.

For details on how to glue on plastic bindings and what glue to use please read the appropriate section in the chapter on how to make a semi-acoustic body.

If you wish to make the fingerboard radius before gluing on the fingerboard, you will need a special clamping caulk (shown on page 149). I prefer gluing on the flat fingerboard before making the radius but that's a matter of taste.

Radiusing the fingerboard

With a radiused fingerboard (5) a guitar is easier to play. Common radii are 7", 7.25", 9.5", 10", 12", 14", 16" or 20". With bigger radii, such as 12" or 16", you get a flatter fingerboard curve which makes it easier to pull strings without causing them to touch the frets, while smaller radii are better suited to the shape of the human hand and thus make fingering chords easier.

A cylindrical and a conical fingerboard surface are fundamentally different, and it is important to understand this difference. Take a tube, for example: when you place a straight edge on it so that it is parallel to the cylinder axis the straight edge will lie flat on the tube. But if you move it only slightly out of this parallel position, it will be left resting in the center only and you will be able to move it up and down at both ends. The two outer strings on a guitar are in a similar "non-parallel position". By filing a fingerboard or the frets along the line of the strings a kind of cone, a so-called compound radius, is produced. It is, however, also possible to make a fingerboard that has different radii at the nut and at the end of the fingerboard. This is, for example, the case with all instruments of the violin family.

The difference between a cylindrically-shaped and a conically-shaped fingerboard surface is illustrated, or be it slightly exaggerated, in the illustrations on the left which show the view from the nut towards the end of the fingerboard.

You can see that on the cylindrical fingerboard (a) the fingerboard edge is getting increasingly thinner towards the wider end of the fingerboard. In reality, the difference is less than 1mm, i.e. very small indeed. This also explains why it is possible to file a compound radius into the frets.

If the fingerboard has a compound radius (b), the edges of the fingerboard remain (more or less) equally thick from the nut to the end of the fingerboard. But the main purpose of a compound radius should be that the strings run parallel to the fingerboard surface.

Very often, though, the fingerboard surface is made cylindrical, and long concave sanding blocks can be used for leveling it. If, nevertheless, a small compound radius is desired, it can be made when dressing the frets by filing them accordingly.



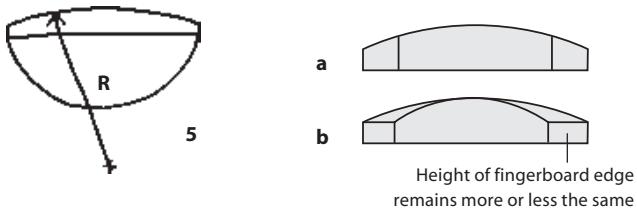
Using a belt sander

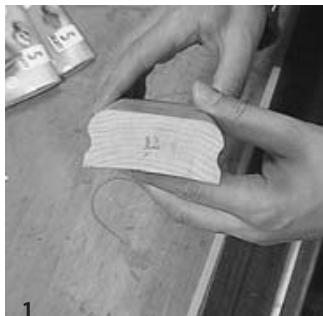
The best way of making an accurate fingerboard radius is by using a jig mounted over a large belt sander, as shown in the picture above: the fingerboard, or the neck with glued-on fingerboard, is fastened between two arms and can be moved over and lowered onto the belt surface bit by bit until the radius is right.

The jig shown above is used by the acoustic-guitar manufacturer *Martin*, and the distance between the fingerboard surface and the pivot is exactly 12". By lowering the whole assembly onto the belt sander and rocking the fastened fingerboard a precise fingerboard radius is produced. (Other manufacturers use similar self-developed jigs which rely on the same principle).

Making such rather complicated jigs obviously only pays off if you build guitars in large quantities. If, however, you happen to own a long belt sander, you should seriously consider constructing such a jig for making the fingerboard radius.

With such a clever jig it is also very easy to make a compound-radius fingerboard by simply using arms of different lengths so that, for instance, the front arm produces a 10" radius and the back arm a 16" radius.



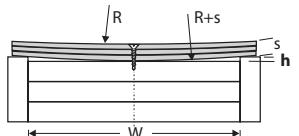


Making a radius-sanding block

Long radius-sanding blocks for finish-sanding fingerboard surfaces are a great help. Necks with cylindrical fingerboard are moved over these blocks, which are fastened on the workbench in a lying position. As I am unfortunately not aware of any source of such (long) radius-sanding blocks, you will have to make them yourself.

The one I am going to describe in the following gets its radius from three pieces of bent 3mm ($\frac{1}{8}$ "-) thick plywood. With plywood thicker than that you won't get an even curve. Even better, because stiffer would be using five pieces of 2mm (0.08")-thick plywood.

The base block can be built from five boards. The necessary protrusion (h) of the two side boards can be calculated for any radius with the formula given. Spread glue between the plywood sheets and screw them down along the center line.



$$h = (R + s) - \sqrt{(R + s)^2 - 0.25 W^2}$$

$$s = 9 \text{ mm}, R = 12" = 304.8 \text{ mm}, W = 150 \text{ mm}$$

$$\mathbf{h = 9.09 \text{ mm}}$$

$$s = 0.375", R = 12", W = 6"$$

$$\mathbf{h = 0.369"}$$

A cylindrical fingerboard will be produced if you consistently sand strictly parallel to the center line (b). For this purpose only may a radius-sanding block be used over the whole length of the fingerboard. Wooden or synthetic sanding blocks for the most common fingerboard radii are available via mail order from guitarmakers' suppliers (1).

Using a pencil, or white chalk for dark-colored woods, draw a center line on the fingerboard. After that radius the fingerboard surface by sanding in long, even lines, using 80-grit self-adhesive sandpaper on a radius-sanding block (2). Check the progress you are making at regular intervals - use a radius template, which you can make yourself, for this purpose. To prevent too much wood being sanded off on one side it is also advisable to change the direction in which you are working a few times by regularly turning the fingerboard by 180 degrees. How quickly you make progress will depend on the material used for the fingerboard - with ebony, for example (3), this can be quite a bit of hard work and take time. When there are sanding marks all over the fingerboard surface except for a narrow strip in the center, the radius is nearly finished and you can switch to finer 120-grit sandpaper. If the fingerboard is to have (thin) inlays, fit them now, before you start sanding with 120-grit paper.

On cylindrical fingerboards the flatness of the surface always has to be checked parallel to the center line (b). Place a straight edge parallel to the center line and check the gap against the light (4);



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spots where light shines through are depressions in the fingerboard. Mark the spots on the fingerboard that are too high: starting at one end, place the straight edge repeatedly parallel to the center line across the width of the fingerboard and mark all the spots where no light shines through with pencil lines. This will give you a good indication of where material has to be removed. When all lines can be drawn all along the fingerboard it is finished and ready for finish-sanding (5). Use progressively finer grits of sandpaper for sanding, starting with 180-grit and continuing with finer grits until you are happy with the result. An ebony fingerboard can also be polished using a buffing wheel and a polishing compound.

A **compound radius** can be made with a plane. By always planing along the (imagined) line of the strings a radius that becomes increasingly flatter towards the end of the fingerboard will be created (like the fingerboard of a violin). Always work in the direction of an imagined point at which the sides of the fingerboard would concur (6,a). Fine-sanding with a flat sanding block also has to be done radially. A compound radius is certainly far more difficult to make than a cylindrical radius.

The technique of dressing the frets with a long, narrow sanding block also works for leveling compound-radius fingerboards. For details please read the section on how to set up the guitar.



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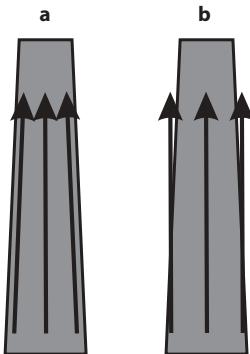
Can you make a radius-sanding block with a cove cut?
Yes, in theory you can; in practice, however, you can't make radius-sanding blocks by making cove cuts on the tablesaw. For a cove cut a block of wood is moved several times across the sawblade at an angle; the blade is set slightly higher for each pass until the channel is the right height and width. The channel thus cut will, however, not be circular but elliptical. This is fine as long as all sanding blocks you use have been made in this same way. One thing that might, however, be a problem is the size of the sawblade required: for making a 12" radius the blade radius has to be greater than 12" (305mm), which would equal a saw blade diameter of 25" (635mm) at the least. Large tablesaws suitable for cutting firewood could probably do the job, but they won't produce a fine-enough cut and are also far too dangerous.



Making your own neck support caul

A neck support caul is quite easy to make with a cove cut made on a tablesaw. For details on how to make a cove cut see above and/or consult any good book on joinery.

Using clamps and a plastic tube as a clamping caul a layer of cork is glued into the channel. Under pressure, the tube, which should be about 100mm (4") in diameter, will adopt the shape of the channel.



Making a fingerboard radius using a router

A cylindrical fingerboard radius can also be made with a plunge router. To be able to do this you need as big a cutter as possible - the one shown in picture 1 is 50mm (about 2") in diameter! To make it possible to move the router over the fingerboard surface in a circular arc a jig consisting of a baseplate with circular-arc rails is required (2). Fasten the router onto this jig and place this assembly on two rolls placed parallel to each other (3). Using double-stick tape fasten the fingerboard at the right height and exactly parallel and centered on the rolls. The two rolls have to be long enough to leave enough space at either end for the baseplate and to allow access to the whole of the fingerboard. Make the radius of the rails 6mm ($\frac{1}{4}$ ") larger (x) than the desired fingerboard radius so that when the cutter is set 6mm ($\frac{1}{4}$ ") lower than the lower edge of the curved rails you will get the right fingerboard radius. Once the cutter height has been set it must not be changed again; if necessary, raise the fingerboard. The necessary fingerboard height (H) is easy to calculate with the given formulas. Move the router over the fingerboard in sideways movements until the whole of the fingerboard has been routed. Finish by removing any marks left by the router with a sanding block.

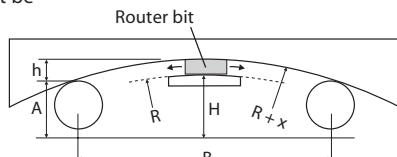
This is quite a basic jig which could certainly be improved to allow for finer adjustments. Making such a relatively complicated jig is really only worth the effort if you have a lot of fingerboards to radius - and even then the "belt-sander-method" used by *Martin Guitars* (see page 149) is quicker, provided you have a belt sander of that size. If you are an amateur guitarbuilder, I recommend that you stick with sanding blocks.

This jig is a typical example of how not being confident about certain steps in guitarmaking can

sometimes result in making quite complicated, and often not really necessary, jigs.

Picture 4 shows an early version of my radius routing jig which I used for making the fingerboard radius of a one-piece neck. At one end the neck is bolted to the baseplate from below, and at the other it is fastened with a clamp on the peghead. For angled-back heads a recess in the baseplate is required. The distance between the two tubes (B) was chosen so that the highest point of the curved rails was exactly 6mm ($\frac{1}{4}$ ") above neck surface. Since neck blanks are normally 1" thick, I did not provide for a possibility to lower or raise the neck.

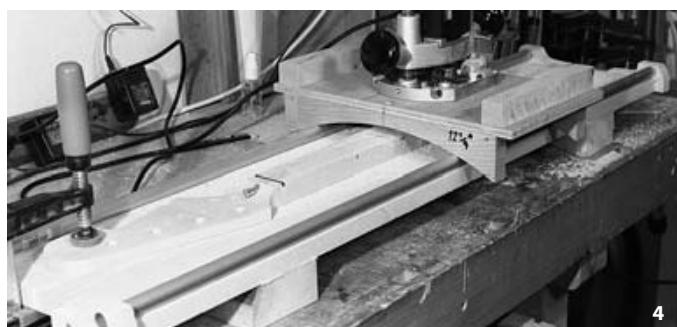
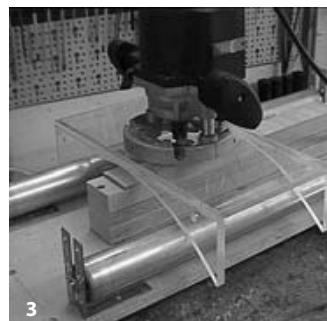
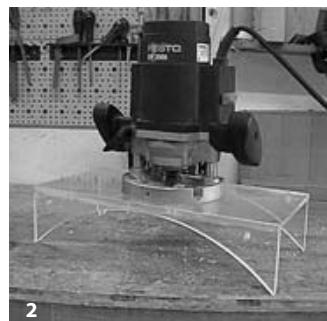
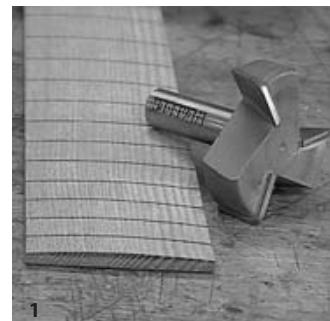
Such a radiusing jig can also be combined with a neck-jig that simulates the string pull (a neck can deform quite strange under string tension). Please find details on the neck-jig in *Stewart-Macdonald's* catalog.



$$h = R - \sqrt{R^2 - 0,25 B^2}$$

$$H = A + h - x$$

$$B = \sqrt{(R - \frac{h}{2}) 8 h}$$



Now restore the fret slot depth. By making the fingerboard radius the fret slots will have become less deep or will have disappeared near the edges. Recut the slots now and make them deeper wherever necessary (5).



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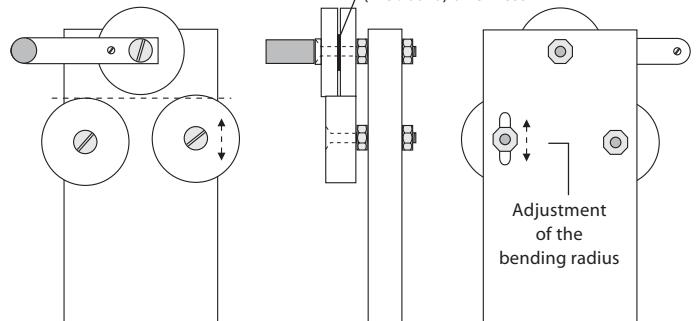
Installing the frets

Before installing the frets remove any grease and other residue from the fretwire with a naphta-drenched cloth (6). Don't be surprised if the cloth gets all black.

Now chamfer the edges of the fret slots with a small three-corner file. This will make it easier to install the frets later and will also make it possible to remove frets without any wood splintering off.

Bending fretwire

The radius of the fretwire used should always be slightly smaller than the fingerboard radius. Fretwire supplied in sticks has to be bent before installation. Fretwire supplied in rolls may already have the right radius, but might just as easily not. In any case it is advisable to take the trouble of building a jig for bending fretwire. Such a jig will produce very good results in no time at all. I've got one made of wood (7), with a wheel that can be raised or lowered to set the required radius. Adjusting the proper radius is kind of trial and error, but once set you can radius fretwire on and on by simply pushing the wire into the rotating wheels. When doing so, make sure the fret wire tang faces upwards. If both lower wheels are the same height, the fretwire will remain, or become, straight. By fastening a washer between the two narrow wheels that make the top wheel a slot in which the fret tang can be guided is created. Each of the three wheels is fastened with a bolt and two nuts. Tighten the two nuts on the board so that the wheels can turn without moving sideways. What diameter you choose for the wheels is not important. You can either use an adjustable circle cutter or a hole saw for making them. With both tools you will automatically get the center-hole for the bolt.



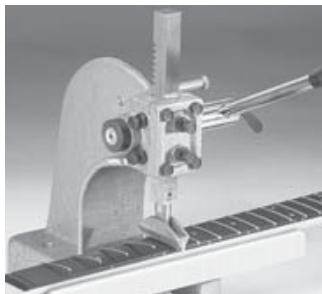
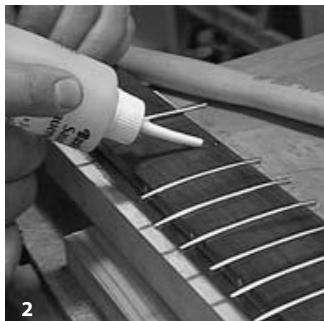
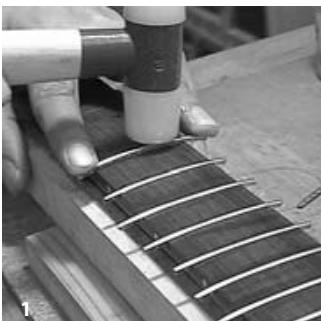


Photo: Stewart-MacDonald's Guitar Shop Supply



Pressing in the frets

The method most commonly used nowadays by guitar manufacturing companies is to press the frets into the slots with special arbor presses and cauls whose bottom side is shaped to fit the fretboard radius.

Stewart-MacDonald's fretting arbor set can be used in a drill stand and comes with 6"-, 7.25"-, 9.5"- and 12"-radius fretting cauls (picture below). This useful tool allows easy and fret-friendly fret installation: gently hammer the bent fretwire into the slot on one side, place the neck in a concave neck support caul under the fret press, and press in the fret, taking care to install the frets perfectly square to the fingerboard. This set guarantees high-quality installation of frets.

Fretting

The traditional method of installing the frets is to gently bang them in with a hammer. This method, which is still as good as any, requires a hammer made up of some material softer than the fretwire to prevent any possible damage being done to the wire. A normal plastic hammer from a DIY store would be perfectly suitable for this purpose, but alternatively you could also use a brass head hammer or, better still, a special "dead-blow" hammer with an oil/shot-filled head which allows for smooth but firm fret installation. With all hammers you have to take care not to make dents into the fingerboard surface.

As already mentioned, the fretwire should ideally be bent slightly more (have a slightly tighter curve) than the radius on the fingerboard. Start knocking in the frets at either end and then work towards the center (1). At both ends the frets should protrude slightly. Provided that the fret slots are the right size, the barb on the tang of the fretwire should ensure that the frets stay in their slots in the fingerboard. If the ends protrude and you press them upwards, the frets must not move; if they do, they need to be glued down. Some guitarbuilders put a bit of glue on the tang before knocking the frets in, the idea being that the glue will fill any existing hollow spaces in the slot and thus make the fret stay in place better. You could also just dip the ends of the frets in a bit of glue or super glue, or you could tilt the neck, put a bit of super glue into the fret slots and let it flow from one end to the other. On maple fingerboards you could put a drop of water into the fret slots before installing the frets. This makes the wood swell and holds the frets in the slots even more safely. If you use glue, remember to protect the areas around the fret slots by masking them with adhesive tape or by applying a coat of wax.

There are nearly as many approaches as there are guitarmakers around. I personally put thin hide glue into the fret slots (2) and wipe off any excess immediately with a damp cloth. Any hide glue film still remaining after fret installation can be removed with a damp cloth, too. I put the small dosage bottle into a hot water bath in between.



The frets should be installed as tight as possible in the slots to ensure a good sound transmission onto the fingerboard. Glue fills hollow spaces and thus improves the transmission of sound.

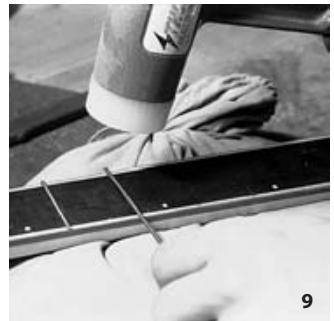
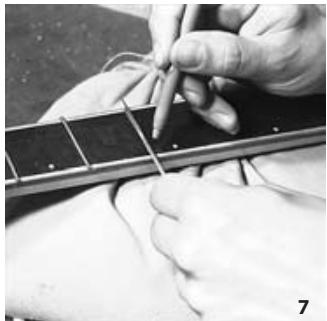
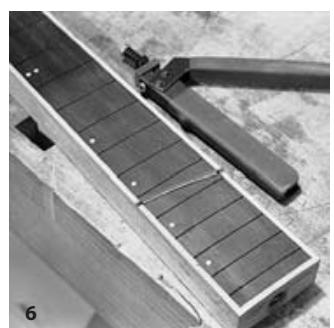
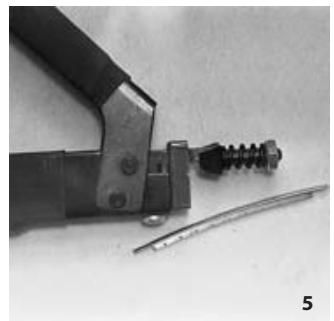
When the frets have been fitted their ends are cut off with a special fret nipper (3). If you have pliers with two bevels, as I have, the front one will have to be removed to ensure the pliers cut right at the tip (4). For removing material I used a disc sander. When cutting the fretwire press the pliers downwards with the free hand to prevent the fretwire from being pulled up in the process.

For fretwire to fit over neck bindings a part of the tang has to be removed on either end of the fret (6). This can be done by hand and fret by fret using a file, or, if you feel like making a small investment, with a special fret tang nipper (5) that will do the job in a matter of seconds. Cut off one end and mark the other (7). The nipper undercuts the fretwire cleanly (8) and makes the fret ready for installation (9).

Undercutting the fretwire might even be appropriate on unbound fingerboards. The projecting fret ends can then be hammered in even further so that they will be bedded down into the fingerboard even more safely. This also helps to minimize any risk of the frets loosening while cutting their ends flush with the edge of the fingerboard.

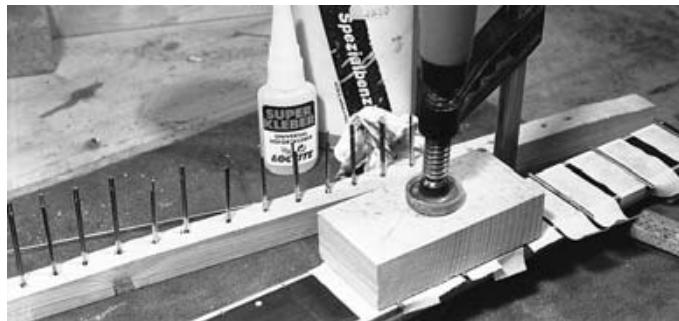
Installing the frets from the sides

The frets can also be installed from the sides. In order for you to be able to do this in your own workshop the fret has to be held down with a block while you bang it in from one side with a hammer. This obviously has to be done very carefully. If the fret is not held down firmly enough, the fretwire will not be properly seated, and if you hammer too hard, it will bend.



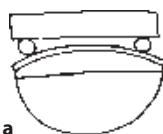
Using epoxy

Some guitarbuilders also use epoxy for fixing the frets in place. For this method the fret slots have to be made wide enough to allow pressing the frets into the slots with one finger. If necessary, the frets can then be removed again easily and without the fingerboard splintering. Use 24-hour epoxy with an open time of about 20 minutes. The two components of the epoxy glue have to be mixed together very carefully: put them on a sheet of glass in two parallel and equally-long lines and keep mixing them until an evenly grey color emerges. Rub some wax all over the fingerboard and mask the areas to the left and right of the fret slots with adhesive tape. Then use a small spatula to put a small amount of glue into each slot, making sure not to put in too much as this would make it difficult or even impossible to press in the frets later. After that remove the strips of adhesive tape and press in the frets, which have obviously already been prepared and cut to the right dimensions earlier. When you have pressed in the frets place one iron rod at either edge of the fingerboard and put one wooden clamping caulk on top of them (a). Tighten the clamps only lightly so that the fret crowns lie flat on the fingerboard. If the frets are slightly overbent, they will be pressed flat onto the fingerboard. If, however, they are strongly overbent, they will be higher in the middle. Remove any excess glue the next day with a chisel.



Removing frets

Mask the fingerboard to the left and right of the fret, heat the fret with a powerful soldering iron, adding some solder to better spread the heat. Then remove the fret with special pliers whose jaw faces lie flat on the fingerboard so that they can "bite" under the fretcrown without damaging the fingerboard. Be careful when removing frets to not cause any wood to splinter off. If this should happen none the less, glue down the splinters.



Using super glue

The frets can also be glued in with cyanoacrylate glue (super glue). For masking the areas between the fret slots you can use teflon tape because super glue does not stick to teflon. Then press in two frets at a time, using a clamp and a wooden clamping caulk (its underside must be concave for a radiused fingerboard). If you use super glue, the fret slots should be cut slightly less wide than for epoxying them in place.

If for some reason a fret should be loose, apply a bit of thin super glue under it and clamp the fret down for five minutes. Before you apply the glue cut the frets to the right length and have them ready at hand in the right order.

You can also use 5-minute epoxy in place of super glue.



The fret ends are cut flush with the edges of the fingerboard with a fine file. I use a fret file with glued-on handle for this job. Keep filing the ends until the file makes contact with the side of the fingerboard and until there is no gap left for any light to shine through.

Bevel the ends of the frets by holding the file at a slight angle towards the fingerboard. This is necessary to ensure that any jagged fret ends do not foul the player's fingers. The angle should not be below 70 degrees, as the smaller the angle is, the less space there will be for the strings. Stop filing when the file touches the edge of the fingerboard (1).

Shaping the neck

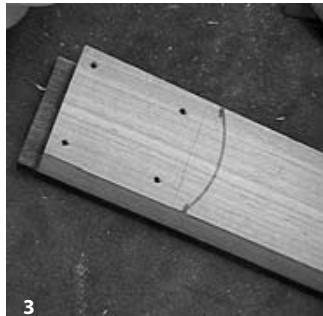
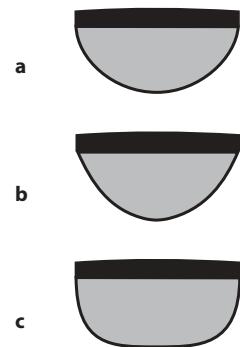
The shape of the neck is a matter of personal taste. The neck should be comfortable to hold for the player and not be too "fat". Perceptions of what is "comfortable" may vary from player to player. There are basically three different neck shapes : (a) oval-shaped, (b) V-shaped, and (c) U-shaped ones. And why not make an asymmetrical neck, in particular if this is considered more "comfortable"? The shape of the neck could even change along its length, from the first fret to the last. Everything that improves playability should be welcome. A thin neck is, however, more likely to bend, whereas a thicker one will give more stability and a longer sustain. If you have no idea of what neck shape to choose, I recommend that you try an oval-shaped one. With a spokeshave you can always make changes to it later, if necessary even after finishing.

After you have made up your mind about the shape of the neck, I recommend that you cut out a negative of its shape in three positions and that you use these templates to check the curves of the neck.

Mark the point on the neck from where it is to stick out of the body (2). Draw a curved line about half an inch away from this mark as shown in picture 3. Now draw a center line on the back of the neck (4). Then shape it from that point so that it gradually turns into a flat area where it will join the body.

The best tool to use for shaping the neck is a spokeshave. To enable you to work in a comfortable position the neck should be fastened sufficiently high in relation to your body and so that it is higher at its body end (as shown in picture 5). If your neck has a *Fender*-style peghead, fasten it face down on a jig. A neck with angled-back peghead is brought into a comfortable working position by clamping its head to the edge of the workbench (5).

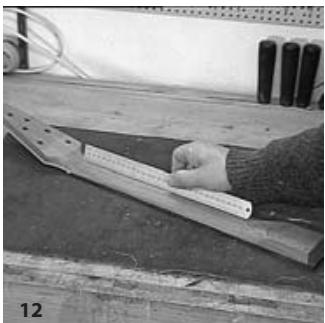
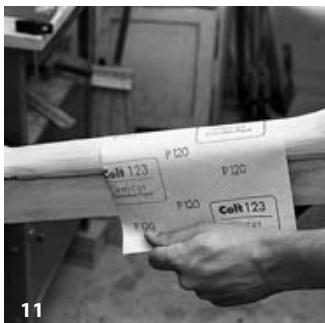
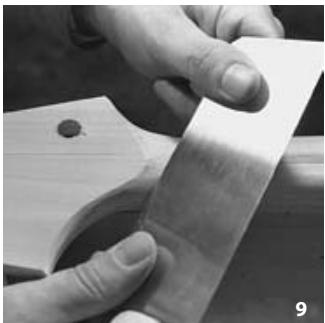
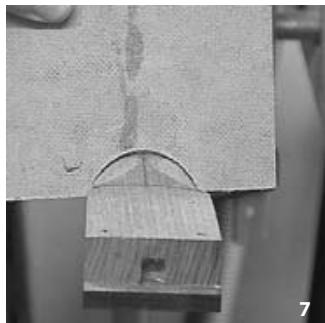
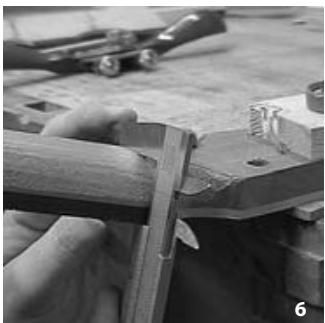
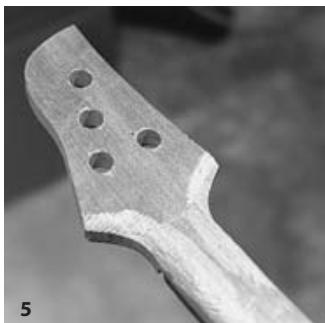
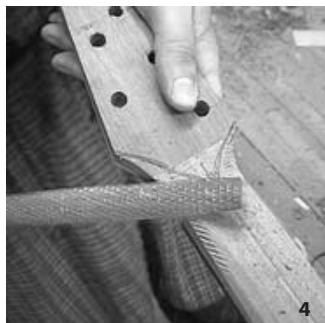
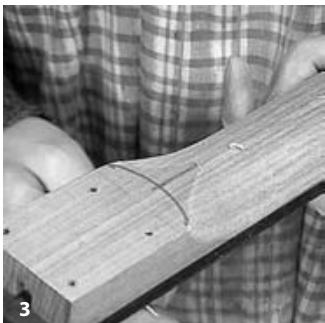
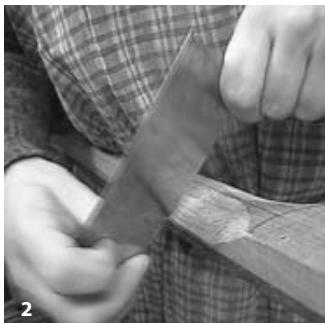
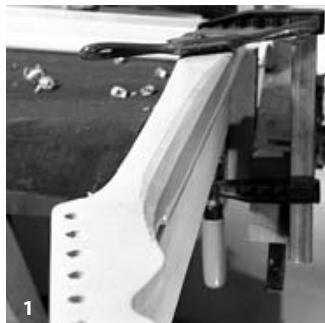
Using a spokeshave a chamfer is now planed between the area where the neck leaves the body and the beginning of the peghead (7). Start by planing the edges at 45 degrees. Change the side you're working on regularly to ensure even progress is made on both sides.



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Then plane further chamfers as required to get the desired neck shape (1). Do not make the neck thinner at this stage or take anything off the sides of the fingerboard.

The transition into the flat area where the neck is made to join the body (2,3) and the transition into the peghead are rough-shaped with a wood rasp and a scraper (4,5).

Later, the neck can be made thinner. Do this very carefully, making sure that the neck becomes evenly thinner towards the nut and is exactly as thick as wanted at the first fret. Leave at least 3mm ($\frac{1}{8}$ ") of wood over a straight truss rod at the nut. If the truss rod was fitted curved, leave 3mm ($\frac{1}{8}$ ") of wood over its highest point. Always check and measure how much wood has already been taken off (6). I once had a rendezvous with a truss rod at this stage, which I wasn't very pleased about, and I guess you wouldn't be, either.

Use the templates from time to time - as shown in picture 7 - to check your progress (i.e. if the desired neck profile has been reached).

After the neck has been rough-carved with the spokeshave continue with a scraper (8) and clean up the transition between the neck and the peghead as well (9). Always work in the direction of the grain. As a cat wants to be stroked in the direction of its hair, wood also "wants" to be treated this way.

Unclamp the neck at regular intervals and inspect it by turning it in different directions to find out any irregularities (10). It is very important to inspect the neck at different angles against the light. Also feel the neck with your fingers to find out any areas which still require work.

Finish off with 80-grit and 120-grit sandpaper, sanding the neck in a shoe-polisher-movement (11) until the wood is evenly rounded over the whole length of the neck. From now on sanding should only be done in the direction of the grain. Check if the back of the neck is straight by laying up a straight edge (12). Take your time and continue sanding until you can see no more irregular areas or scratches on close inspection of the neck (13). The neck is now finished for the time being and can be put to one side (14). If any irregularities should be found afterwards, they can always be corrected later.



Machine-sanding the neck

Most guitarbuilders do all the neck-shaping with a belt sander. When using a belt sander the curved parts in the area of the neck-body-joint and towards the peghead are sanded with the freely-accessible end of the sander. For this kind of work it is essential that you provide for reliable dust collection. A belt sander is a simple power tool and building one yourself therefore quite conceivable.

However, I personally prefer shaping my necks with a spokeshave. This is a very quiet tool and does not produce any dust.

Fitting the neck

Routing the neck pocket

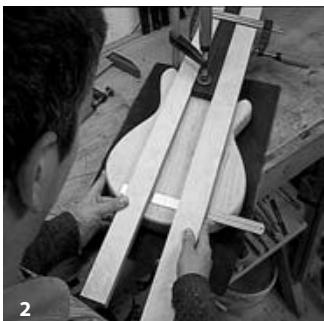
The correct neck alignment is extremely important: the outer strings have to run parallel to the fingerboard edges from the nut to the bridge and the neck center line should line up correctly with the body center line. If the neck is not mounted dead straight, parts of an outer string might end up off the fingerboard. The pocket that will accept the neck is best cut with a flush-trimming cutter bit with shank-mounted ball bearing. For this purpose you need an accurate 1:1 template of the neck shape. Such templates are commercially available for standard *Fender*-style necks. I personally prefer using a jig made up of two long, 19mm ($\frac{3}{4}$ "-) thick and about 50mm (2")-wide boards plus another short piece of wood to using just one template for defining the shape of the neck pocket. The straight edges required on the boards are easy to plane.

Place the neck in exactly the position it will eventually be in and fasten it on the body provisionally using a clamp and a clamping caul (1). Then put the two straight, narrow boards to the left and right of the neck and clamp them to the neck at the 1st and 14th fret, as shown in picture 2 (the second clamp is missing in this picture). A rule taped down across the body in the bridge area - a zero-mark in the middle of the rule would come in very handy - helps to center the neck. To determine the position of the bridge transfer the scale length onto the body with a long rule, starting from the front edge (body side) of the nut. If you don't have such a long rule, you can either measure up half the scale length from the 12th fret or the difference of the scale length minus the distance from the nut to the last fret from the last fret. If the guitar is to have a pickguard, fasten it temporarily for aligning the neck. The neck can now be aligned very accurately by lining it up on center with the body (2). When the correct neck alignment has been found fix the position of the boards by fastening each of them with two clamps at the lower body end. At the upper end of the neck the distance between the two boards is fixed by placing a short scrap board under the neck and across it (3). Fasten the board with two clamps. The two clamps placed on the boards right at the beginning can now be removed in order to allow removing the neck.

Now insert a third piece of wood at the lower end of the neck. It doesn't matter if this piece doesn't fit in tight because the ball bearing of the cutter bit is large enough to not follow into any gaps in the corners. If the end of the neck is rounded off, the front end of the piece of wood has to be cut and filed accordingly to ensure it fits in. Since the piece of wood and the two boards



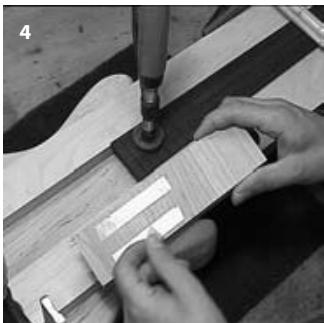
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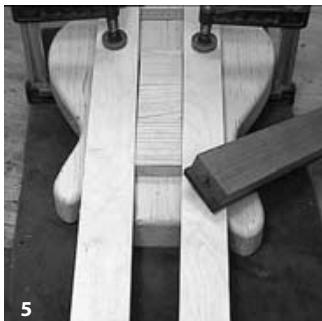
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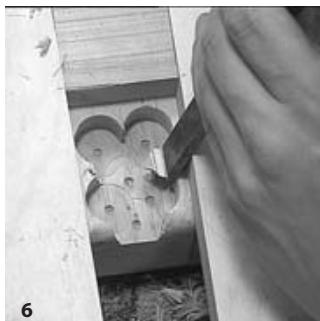
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are all 19mm ($\frac{3}{4}$ "") thick, it would also fit under a fingerboard that is longer than the neck. Fix the piece of wood with thin double-stick tape (4). Thick tape such as that used for fastening mirrors would be far too strong for this purpose and would make it very difficult to remove the template afterwards. Apart from that the marks left by such tape would also be very difficult to get rid of.

Remove the neck now and you have an exact 1:1 template for your ball-bearing cutter bit (5). How thick the template has to be made depends on the length of your cutter bit - the ball bearing must obviously touch the edge of the template. Flush-trimming cutter bits with shank-mounted ball bearing are commonly 1" long. There are also $\frac{3}{4}$ "- and $\frac{1}{2}$ "-long bits, but these are less common and more difficult to get hold of. *Wealden Tools* offer a wide range of cutters (see addresses of material suppliers at the back of this book). I use a 1"-long cutter bit, which is why the template has to be quite thick.

The depth of the neck pocket depends on the bridge used, as I have already mentioned in the section on "Design". When the bridge is set to its lowest position the strings should touch the fingerboard. The pocket depth is therefore "thickness of neck plus fingerboard (25mm or 1") minus lowest possible saddle height". Pre-drill the pocket and remove as much as possible with a chisel (6). Then cut it out cleanly in several passes (7). Set the stop to the point of the bit less 1mm (0.04"). This will make it possible to safely remove the holes left by the point of the bit. The tighter the neck fits into the body and the flatter the contact surfaces are, the better the sound transmission will be. If, by mistake, the pocket has been made too deep, correct it by gluing in a piece of hardwood.

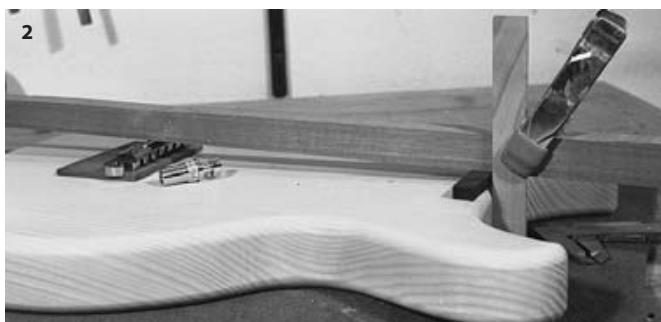
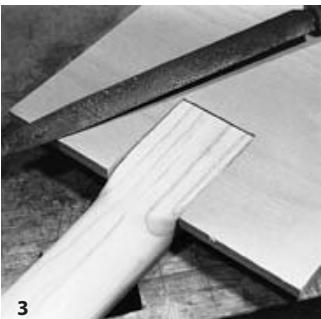


Set the drilling depth to the point of the bit

If you use a brad point bit or a Forstner bit, always take its point into account. Lower the drill bit onto the wood until its point almost touches the surface. Now set the drilling depth just a little shallower, to be on the safe side. The depressions left by the point of the bit are finally routed off.

Take the thickness of the template into account!

A mistake commonly made when making the neck pocket is to not take the thickness of the template into account. Put the template on the body and then the router on top of both. Lower the bit until it touches the body surface and then lock it. The cutting depth can now be set by putting a shim of appropriate thickness under the depth stop.



Mounting an angled-back neck

There are two ways of mounting an angled-back neck: you can either make an angle on the neck pocket, or you can make it on the bottom side of the neck tenon. An angled-back neck should be fitted to the body so that a straight edge placed on the guitar touches the frets as well as the bridge (see picture 1). The action can be set later by raising the saddles or the entire bridge.

To work out the neck angle place the bridge roughly in the position it will eventually be in and set the saddles as low as possible. If the bridge is mounted so that it doesn't touch the body - because it is, for instance, supported by posts - insert a shim of appropriate height under it. Then put a piece of wood left over from cutting out the fingerboard on the top edge of the body and lay a T-bevel (made up of two battens held together by a clamp) on top of it and the saddles (2).

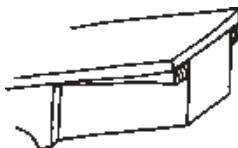
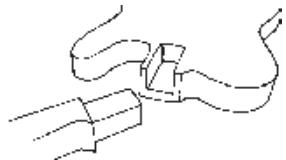
If you make the angle on the neck pocket in the body, the template has to be placed at the appropriate angle. You can use the same "three-boards"-technique that was used for aligning the neck and cutting out the neck pocket, but you can obviously also make one sufficiently large and tight-fitting template from one piece (3). The angle can be made greater or smaller by placing a wooden shim across the rear end of the template and

fastening it with two clamps (4). To save your cutter bits it is advisable to remove most of the wood with a Forstner drill bit before using a router. Set the depth to the point of the drill bit so that any holes left by it can later be removed with the router. For routing set the depth stop to about 2mm ($\frac{3}{32}$ ") above the depth needed and cut out the pocket. Then set the exact depth required and cut out the pocket in a final pass (5). Because of the template being quite thin a rather short ball bearing cutter bit has to be used for this ($1\frac{1}{2}$ " long for instance).

Cutter bits leave round corners which will have to be squared with a chisel if the neck end has sharp edges (6). If the end of the neck is rounded, it may be necessary to mount a flush-trimming cutter bit of smaller diameter and to tidy up the corners with it.

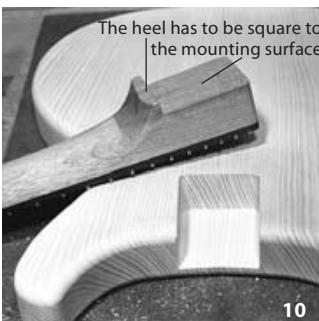
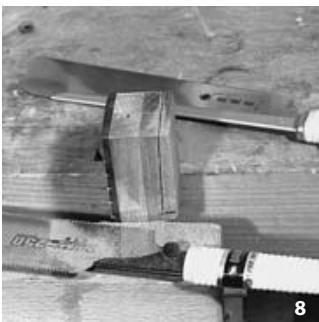
Gluing in the neck

By making a neck tenon all glue lines are hidden well. Cut the neck tenon before gluing on the fingerboard. For gluing in the neck apply glue on both the neck tenon and the bottom side of the fingerboard and then press the neck into the pocket in the body. Use a clamp for pressing in the neck.



Fingerboard wider than the neck

By making the fingerboard wider than the neck you can hide things that may have gone wrong with making the neck pocket. If the neck is to be angled and the body surface is flat, two small wedges will have to be glued in (one on either side).



Making the angle on the neck tenon

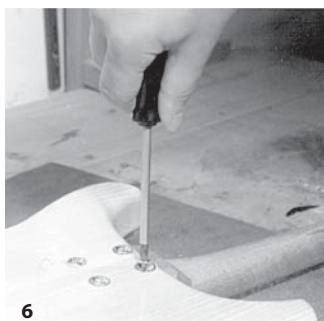
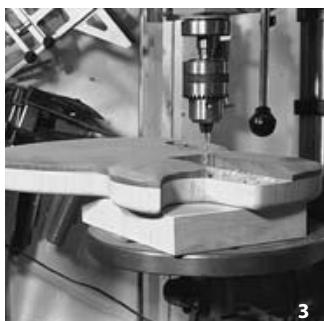
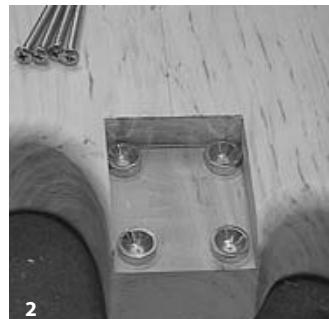
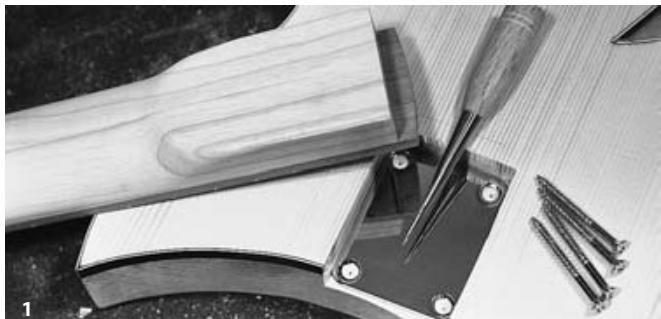
A neck angle can also be achieved by transferring the angle onto the neck tenon (7). This is a bit more tricky, though. If the neck is to have a heel, it must be square to the mounting surface on the neck. Fasten the neck upright and cut its mounting surface at the appropriate angle (8). Make sure to fasten the neck so that you can cut vertically. Leave the front edge for the time being as it is, to enable placing the routing template there (9). The neck shown below (10) is intended for bolting on, but it could equally well be glued in. Since the neck tenon is cut at an angle, the front of the neck also has to be angled to ensure the neck can be pressed fully into the slot. I use a disc sander for this job and set the table at an angle.

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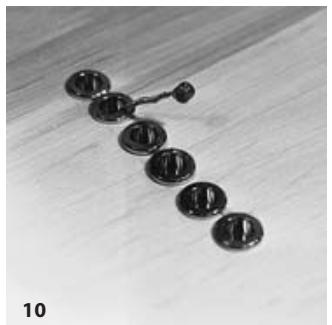
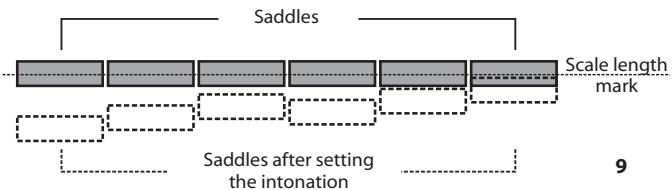
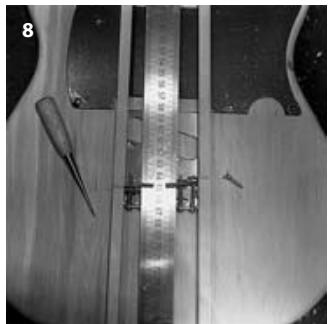


Bolting on the neck

For bolting on a neck several 4mm ($5/32"$) holes have to be drilled into the body. This is best done by placing the neck attachment plate (1) or ferrules (2) into the neck pocket, center-marking the holes and then drilling them with a drill press (3).

Next clamp the neck in the pocket and mark each hole center on the neck by sticking the brad point drill bit just used for drilling the holes into these and lightly knocking on it with a hammer; this will leave a clearly visible mark (4).

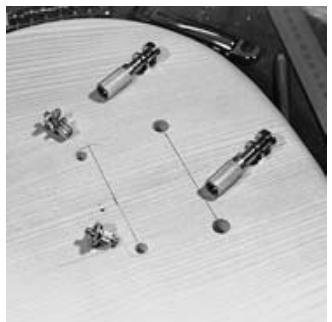
As with all hardwoods the neck mounting holes have to be pre-drilled (5), or else the screws could easily be destroyed when being tightened. Since the pre-drilled holes should be slightly smaller in diameter than the screws (ideally about 80-90 per cent of their diameter), pre-drilling to a diameter of 3.5mm ($1/8"$) would be just right for standard-sized neck attachment screws. Using a drill press, pre-drill these holes to a depth of 15mm ($19/32"$). Make sure to set the depth stop very carefully to avoid disappointments such as drilling through the neck. Finally, fit the neck into the pocket and bolt it on (6).



Positioning the bridge

The exact position of the bridge should be determined after the neck has been fitted (7). Place a 1-meter (3-feet)-long rule along the neck so that it butts up against the front edge of the nut and mark the scale length on the body center line (8). If you don't have such a long rule you can either measure half the scale length up from the 12th fret or measure the difference of scale length minus the distance from the nut to the last fret up from the last fret. Then place the bridge on the body so that it is centered on the neck; the center is easy to find with one straight, narrow strip of wood placed on either side of the fingerboard. Set all the saddles on the bridge as far towards the fingerboard as possible and then move the entire bridge back or forward until the saddles are at the scale mark. Later, when you set the intonation, all the saddles are set back a little to make the vibrating length of the strings longer than the scale (9). This is necessary to compensate for the increase in pitch caused by pressing down the strings. Picture 7 shows a guitar with a rule on top of it and two strips of adhesive tape marking one end of the *Telecaster's* 25.5" (647.7mm) scale. Note that the bridge still needs to be moved back until the left saddle, which has been set as far to the front as possible, is exactly at the scale mark. When this position has been found hold down the bridge and mark the bridge mounting holes.

If the strings have to be passed through the body, mark and drill those holes as well. I'm convinced you will manage a more evenly-spaced layout and a straighter line than I have (10).



Bridges mounted on two posts
Bridges mounted on two posts are positioned slightly out of right angles to the fingerboard center line to get the best intonation adjustment options possible. If the guitar is to have a separate tailpiece, fit it about 50mm (2") behind the bridge. How deep you will have to drill and what hole diameter will be required depends on the height-adjustment bolt bushings of both the bridge and the tailpiece.

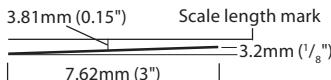
Determining the position of a bridge with separate tailpiece

The exact position of the bridge can only be determined accurately after the action has been set correctly and strings of the same gauge as the ones that will eventually be used have been fitted.

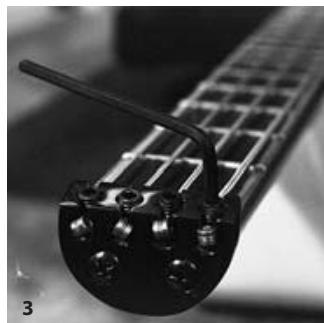
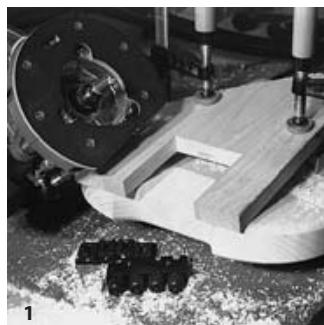
When using a bridge with separate tailpiece it is not just possible but actually advisable to initially only fit the tailpiece and the tuners and to string the guitar. At this stage a rough-cut nut will do. By moving the bridge under the strings you can now find the correct intonation. Remember: whenever you change the action or put on a different string gauge, the bridge has to be repositioned; and every time the bridge position is changed the strings have to be retuned. Please refer to the set-up section for details. If due to the height adjustment posts the bridge is suspended, it has to be moved together with a suitable shim placed under it.

Bridges that can't be adjusted

If you have a bridge that doesn't allow string length adjustments, try a slanted saddle position as on an acoustic guitar. Move the saddle 3.81mm (0.15") back and then turn it slightly so that over a length of 7.62mm (3") the bass side is 3.2mm ($\frac{1}{8}$ ") further back than the treble side (as shown below):



Another approach would be to string up the guitar first and fasten the strings temporarily with an archtop guitar tailpiece fixed at the strap pin hole. Now try to find the best position for the bridge by moving it until the intonation is right. Remember to re-tune after each movement of the bridge. This adjustment is, however, only valid for the one string gauge and also only for new strings.



Fitting a headless unit

Headless guitar tuning units are often fitted to the body at a small downward angle. For this you need an angled surface which can be made with a template fastened accordingly (1). Then test-fit the unit (2), fastening the head part at the end of the neck with two screws (3). The allen key demonstrates that ordinary strings without second ball-end can also be used.

Fitting a tremolo

For installing a *Strat*-style tremolo you first have to cut out a 78mm x 16mm (3" x 5/8") elongated hole from the body. For measuring I always use the tremolo unit that will eventually be installed on the guitar. Unscrew the tremolo block from the bridge, place the bridge on the body as you would do with a normal bridge, trace its outline and mark the center line of the tremolo block to the left and right and also the position of the tremolo block. Then rough-drill a 78mm (3")-long hole with a 14mm (9/16") bit mounted in a drill press or in a stand-mounted power drill as in picture 4. I clamped two guide boards and a backing board to the body. After that make a routing template from four rectangular pieces of wood (5) by fastening them around the rough-drilled hole with double-stick tape. The two middle pieces are both 16mm (5/8") wide. Now clean up the elongated hole as deep as possible with a 19mm (3/4")-long flush-trimming cutter with shank-mounted ball bearing. After removing the template deepen the elongated hole, using the already-cut hole walls as a guide for the ball bearing to ride against. Remove anything that is still left after that with a chisel (6). Alternatively, you can also carefully pre-drill and then clean up the whole elongated hole in one pass with a 12mm (1/2")-diameter, 50mm (2")-long flush-trimming cutter with end-mounted ball bearing in a table-mounted router.

Now mount the bridge plus tremolo unit on the body and mark a 57mm x 100mm (2 $\frac{1}{4}$ " x 4") rectangle on the back of the body, on center with the string fastening holes (7). Cut out this cavity, which will be the spring cavity, to a depth of 16mm (5/8"). Note that this cavity is slightly offset from the elongated hole.

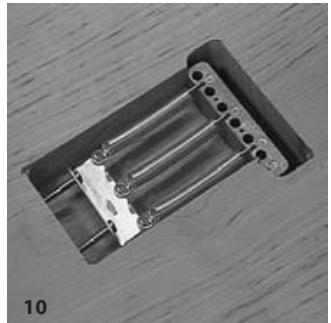
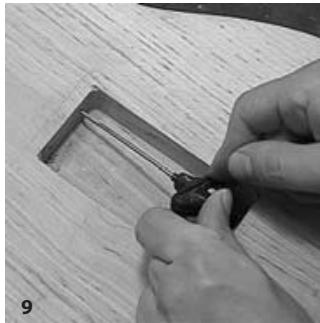
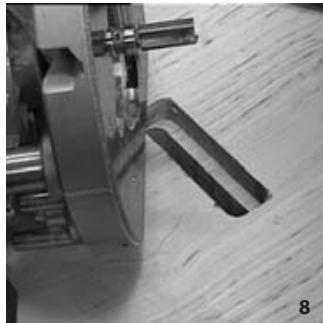
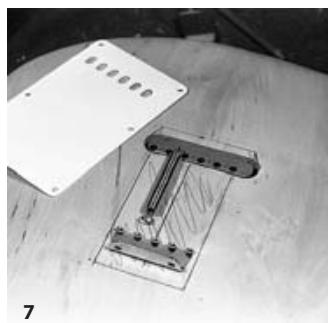
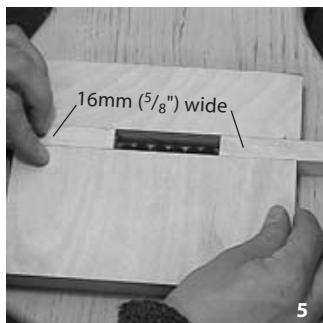
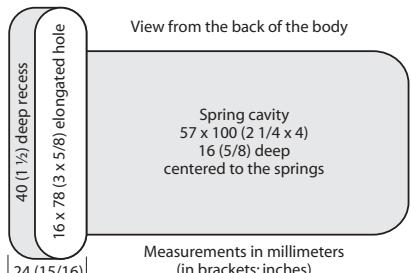
The elongated hole will have to be made slightly wider at the back of the body to make it possible to tilt the tremolo. Again tape on four pieces of wood to form a template (the two middle pieces must now be 24mm (15/16" wide) and cut as deep a cavity as possible with a router, widening the elongated hole to about 24mm (15/16"). Then remove the template (8) and continue routing until the recess is 40mm (1 $\frac{1}{2}$ ") deep and only 5mm (1/4") of the body are left over a 16mm (5/8") wide area. Standard *Strat*-style tremolo units can only be fitted to bodies that are at least 45mm (1 $\frac{3}{4}$) thick.

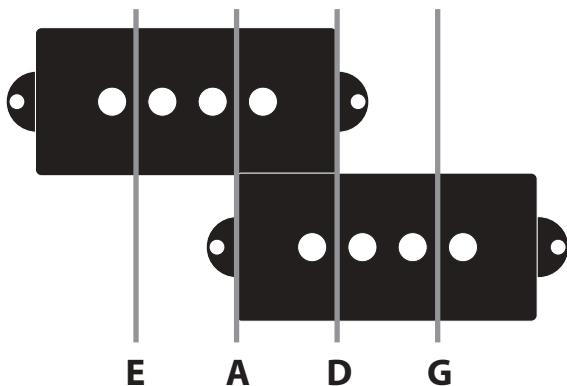
Fasten the spring mounting claw at the front of the spring cavity by means of screws placed at a small angle of about 6 degrees. A long and thin drill bit is required for pre-drilling these screwholes. Alternatively, you can also use a 3mm (1/8") auger gimlet (9). To allow spring tension adjustment don't drive the screws in all the way (10). Remember also to drill a hole into the control cavity for the string-grounding wire.

Fit a cover plate over the spring cavity. The strings can be fitted by passing them through the six holes of the cover; the cover itself doesn't have to be removed for fitting the strings.

Routing for a *Strat*-style tremolo

View from the back of the body





Split pickups

Split pickups are arranged so that each string can run centered over its respective polepiece. On some split pickups, like for instance *Precision Bass* pickups, each string has to be on center with two pole-pieces. How far the two pickup halves have to be moved together depends on the string spacing.

Universal pickup cavity templates

Since the shape and the measurements of so-called standard pickups can vary slightly from manufacturer to manufacturer, I see little point in showing any "universal" pickup cavity templates in this book. Please measure your individual pickup accurately and make a template. Remember to leave some space around it (about 1mm or 0.04"). You can, and always should, use the finished template for test-fitting the pickup before you do any routing.

Pickguard and pickup

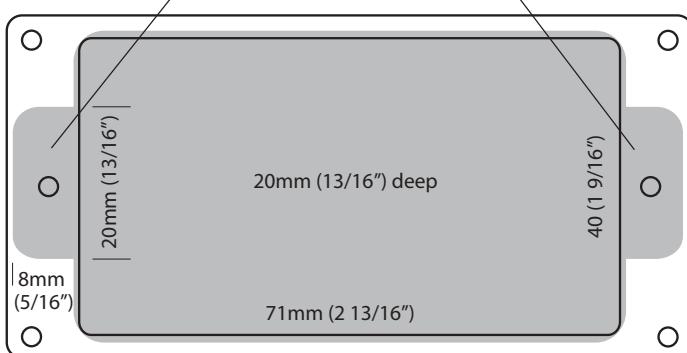
If you fit a pickguard on the body of your guitar, you can be far more generous as far as the size of the pickup cavity is concerned.

The *Fender American Strat*, for instance, has got just one single, rectangular and fairly wide, cavity that can hold all three pickups. This has one obvious advantage: it makes it possible to fit any pickup combination later by simply removing the pickguard and without having to cut any new cavities. Another advantage of a larger cavity is the slightly reduced weight of the guitar.

Because of the pickups being virtually suspended in the air the sound transmission is sometimes said to be less good with larger cavities than with pickups that are closely surrounded by wood. Whether or not this has an effect on the sound is not for me to decide.

Scale 1:1

"Ears" can be routed deeper if necessary

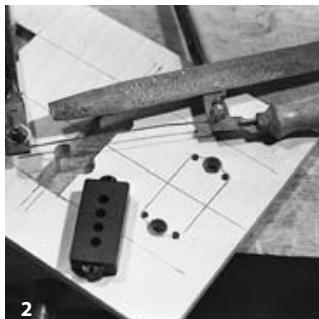


Cavity needed for humbucking pickup (grey area)

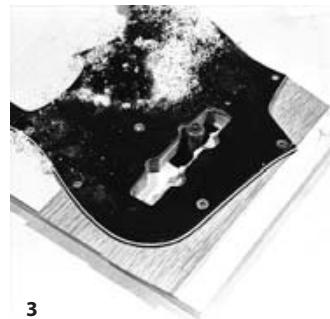
If you use a humbucker mounting ring, as shown in the drawing on the left, you can be far more generous with regard to the size of the pickup cavity. Obvious limitations are that the ring must cover the whole cavity and that there is still enough wood left in the corners for screwing down the mounting ring.



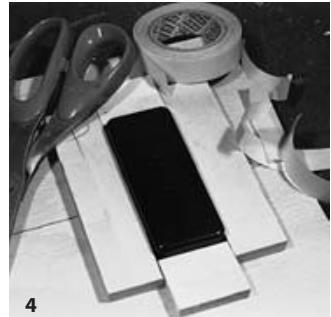
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Making the body cavities

Routing the pickup cavities

Make the pickup cavities 19mm ($\frac{3}{4}$ ") deep. With some modern single-coil pickup shapes you can use a 19mm ($\frac{3}{4}$ ") cutter bit for this by simply guiding the router base along a fence fastened parallel to the pickup cavity (1).

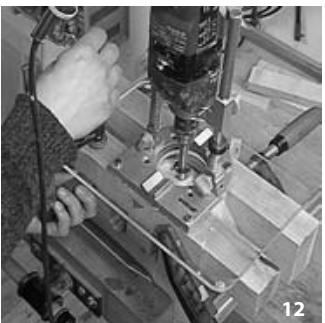
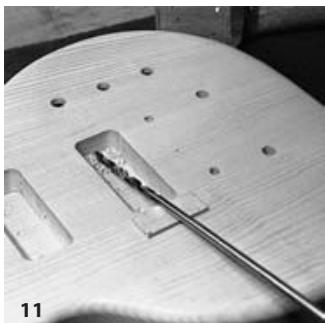
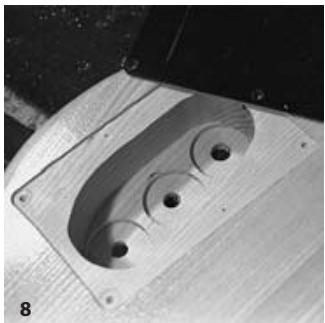
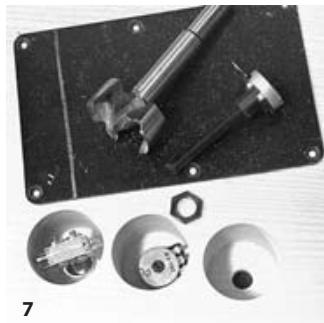
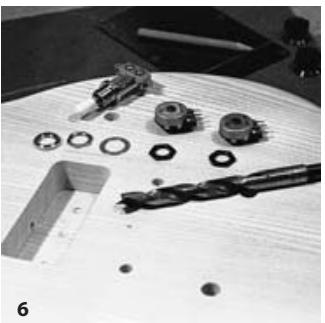
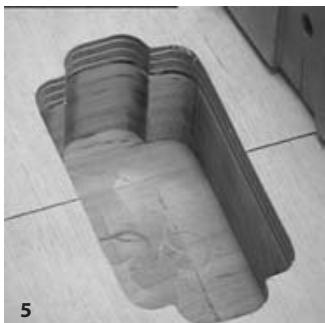
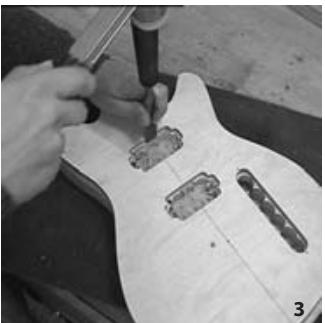
Other pickup shapes require templates for cutting out the cavity. You can either buy finished pickup cavity templates or you can make your own. These templates should be made very accurately and should be slightly larger than the cavities are to be. Corners can be drilled and tidied up with a hand saw and a file (2). Cavities for humbucking pickups are shaped according to the mounting rings used (see drawing on opposite page).

If you have got a ready-made pickguard, you can also use that as a template for making a template for cutting out the pickup cavity (3). Fasten the ready-made pickguard (which already has a suitable pickup cut-out) onto the material used for the template and rough-cut the shape of the cut-out on a drill press. Then use a small-diameter flush-trimming cutter bit with end-mounted ball bearing in a table-mounted router. This will give you a 1:1 template of the pickup cut-out. To make sure the ball bearing rides against the pickguard well, insert a sheet of veneer or a piece of cardboard under the pickguard. The cutter bit should be able to follow the whole of the outline; where this is not possible, as in the corners, some filing will have to be done later.

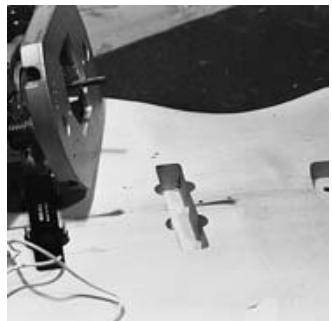
Cutting out rectangular pickup shapes is fairly straightforward: fasten a couple of not-too-narrow pieces of wood around the pickup cavity cover (as shown in picture 4), making sure to leave a bit of room on two of the four sides so that the pickup doesn't sit in the cavity too tight. Again pre-drilling is necessary before cutting out the cavity with a router.

Copying an already-existing pickup cavity

The shape of the pickup cavity could also easily be copied from an already-existing guitar body by fastening the pre-drilled template on top of the cavity and then cutting out the shape with a plunge router fitted with a small-diameter flush-trimming cutter with end-mounted ball bearing.



It is advisable to pre-drill pickup cavities before cutting them out (1). Again set the stop to the point of the bit. Small-radius corners or round pickup "ears" are best pre-drilled (1) using bits that have the right radius. Remove most of the remaining wood with a Forstner bit (2,3) and a chisel to keep stress on the router bit low. Then cut out the cavity using a flush-trimming cutter with shank-mounted ball bearing (4,5). The few millimeters still left due to the point of the drill bit can be routed off at the end.



Routing the control cavity

For mounting the pots and switches in a control cavity on the back of the body holes have to be drilled into the body from the front. Drill each hole with the same diameter as the thread diameter of the component fitted in it (6). After that cut a cavity for the controls from the back of the body, using a Forstner drill bit (7). It is important that you drill deep enough to allow screwing the mounting nut onto the thread. By doing so only a thin layer of wood will be left in the cavity area of the body. It is not necessary to make the whole of the control cavity bottom equally thin - the areas where no pots or switches are fitted can be made less deep (8).

Routing corners

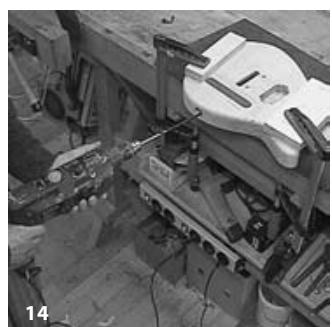
The great radius of a ball-bearing-guided flush-trimming cutter bit makes it impossible to rout tight corners. You could, however, use an ordinary 6mm ($1/4"$) bit and carefully rout the top of the corners first and then set the bit lower so that its shank serves as a stop, although it would be better to pre-drill small radii before routing.

Carved-top guitars require special pots with extra-long thread shaft. However, standard pots can be used if these are mounted on a plate as shown in picture (9); the plate is then simply screwed to the bottom of the control cavity. To make it possible for the plate to lie flat on the bottom of the cavity, despite its projecting mounting nuts, small recesses have to be drilled into the bottom of the cavity for these nuts.



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The hole linking several pickup cavities is best drilled starting from the neck pocket (10). The link to the control cavity has to be drilled at a very flat angle (11), using a piece of veneer or card-board under the drill shank to protect the body. Use an extra-long, 6mm ($1/4"$) drill bit for drilling these channels.



14

Drill the jack socket hole with a 25mm (1") Forstner bit. If you have access to a drill press, fasten the body upright and drill the hole from above. Alternatively, you can put the body in an upright position in a vise and clamp two thick pieces of wood to it as shown in picture 12. This will give you a solid surface for a stand-mounted power drill. How deep the hole has to be made depends on the jack socket used. If you don't have a drill press or a stand for your power drill, you can also drill the hole by hand as shown in picture 13. Finally, drill a smaller hole to the control cavity for the jack socket wires (14). Remember to also drill a hole from the control cavity to the bridge for the ground wire.



1



2

Assembling the guitar

After you had to wait and be patient for so long, the time has finally come to test-fit the individual components of your guitar. Reward yourself now and assemble the guitar provisionally; by doing so you might find out about mistakes you may have made, mistakes that at this stage are still fairly easy to correct. Wiring (for details see the following pages) and testing the electronic components should also be part of test-fitting.

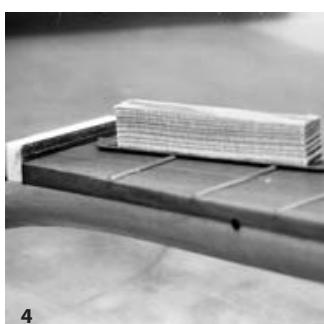
Careful readers may have noticed that the guitar shown above was already assembled at a much earlier stage than we have meanwhile arrived at in this book. After finishing, the guitar will have to be put to one side and should not be touched for some time. So if you just can't wait and are desperate to play your guitar, do it now, but not before you haven't first washed your hands properly. Traces of grease and dirt on the wood are very difficult to remove.

Mounting the hardware

For mounting all tuners on one side of the peghead ("6-in-line") a rule will help to get an evenly-spaced layout (1). Pre-drilling the holes for the small mounting screws is an absolute must. Use adhesive tape on the drill bit as a depth stop to prevent drilling through the peghead. Most tuners are screwed on from above.



3



4

Mark the correct nut height by placing a pencil cut in half along its length (3) or a knife blade (4) flat on the frets (if you haven't bought a finished nut, that is, of course). Halving the pencil is best done on a belt sander. To make a knife mark more clearly visible on a light-colored nut blacken the nut with, for instance, a pencil before making the mark. Radiused fingerboards require an accordingly-shaped nut. For this a belt sander is best used, but a file will also do. Bone nuts produce a distinctive smell which will probably remind you of your last dentist's appointment. File or sand the nut down to about 1mm above the marked line and round off the top edge of the nut on the peghead-side.

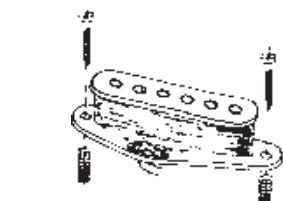
Mount the pickups with screws and springs either on the pickguard (5) or directly on the body (6). Fitting the electronic parts is definitely a lot easier if you use a pickguard as this allows fitting and removing all parts (including the pickups) from above and as a compact unit. Pickups are always mounted with springs to create the counter-pressure needed for pickup height adjustment (7).

Humbucking pickups are always screwed onto a mounting ring which is then screwed onto the body (8,9,10). The spring makes it easier to raise or lower the pickups by means of screws. Such mounting rings, which are oddly enough called rings although they are rectangular in shape, come in various heights and with flat or round bottom. Use the four holes in the corners for screwing the mounting ring to the body, and the two holes in the center of the narrow side of the mounting ring for screwing the humbucker to the ring. Fasten the humbucker with two long screws and two springs to make it adjustable for height. Schaller pickups are fastened with two screws on either side, eliminating any possibility of tilting the pickup (- another example of German thoroughness). The special Schaller mounting rings have three holes on their two narrow sides to make it possible to mount any humbucking pickup. As with all screwholes that are drilled into the body pre-drilling is required (11).

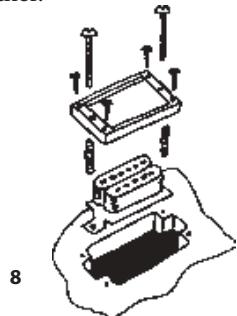
Correct stringing of the guitar helps to keep it in tune. See the section on set-up for details. Don't clip the strings for test-fitting; instead, leave them longer and wind them around the tuner shafts several times. When fitted a second time the thin strings often break right at the point at which they are bent at the tuner shaft hole. If this happens you will still be able to use the string, provided you have wound enough of it as a reserve around the tuner shaft. Pass each string through its respective hole in the bridge and then pull it as far as the ball-end permits. Then bend about 10mm ($\frac{1}{2}$ ") of the string end at a right angle towards the tuner knob and put this 10mm ($\frac{1}{2}$ ")-part of the string into the tuner shaft hole. Next turn the tuner knob away from the body while still tensioning the string with the other hand until the tuner shaft takes over. When the string is lightly stretched, put it on its saddle before tensioning it further.



5



6



8



7



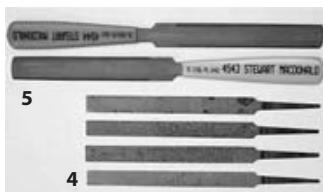
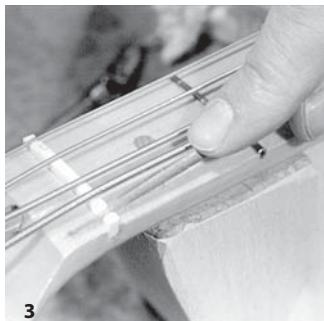
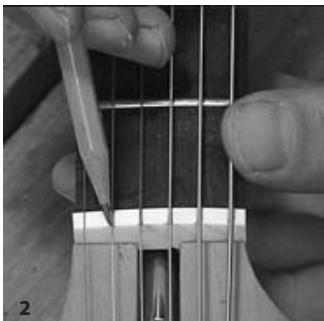
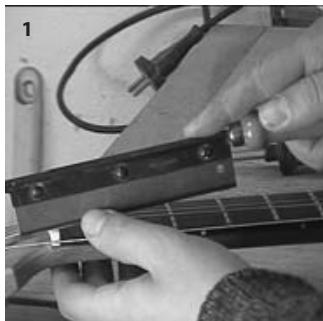
9



10



11



Nut files

It is advisable to use expensive special nut files. *Grobet* (4) in Switzerland and *Ibanez* in Japan are manufacturers of such files, which are available from most suppliers of instrument-building tools. These special nut files have teeth only at their edges and produce accurate, round-bottomed nut slots.

Stewart Macdonald's double-edge nut files (5) cut on the edges only, and taper from a thickened center to a different thickness on each cutting edge. They produce a v-shaped slot with a round bottom.

You don't have to buy all file sizes for making slots of different widths: wider slots can also be formed by simply rolling a file side-to-side.

The thinnest nut files available are as thin as sawblades and therefore very fragile. The following four file sizes would make a good basic starter set: .016"/.025"/.032"/.042" (0.4 / 0.6 / 0.8 / 1mm). It is also possible to cut out the slots with a saw first and continue with a nut file.

Accurately filed nut slots are essential for guiding the strings and ensuring clean intonation. Start stringing the guitar with the two outer strings and cut small grooves into the nut, just big enough to hold the strings in position (1). Remember that we designed the guitar with the two outer nut slots at least 3.5mm from the ends of the nut. Then place the other four strings at even distances between those two outer strings. Stretch the strings lightly, holding them in position with your fingers. When you look at the strings you should have the impression that they are spaced out evenly - mathematical precision is less important than the optical impression. This means that the thinner strings have to be placed slightly closer to each other and that the space between strings should gradually increase towards the bass strings. Spreading out the strings in this way may be a detail but will definitely have a positive effect on the playability of the neck. When the correct string positions have been found, mark the position of both sides of each string with a very fine pencil or a knife (2).

Nut slots should be made so that the strings seat nicely in them; they should be round-bottomed and not deeper than half the string diameter. The slots can be formed with round files of equal diameter as the strings (3) or, better still, with special nut files (4,5). With the tapered shape of a small needle file you will have all the diameters needed for making the three bass string slots of a bass guitar. Hold the file at a slight angle (so that it is higher over the fingerboard) to get a good front edge of the nut for the strings to be bent at. To prevent the strings from getting stuck during tuning it is a good idea to make the slots increasingly wider towards the peghead-side of the nut and to leave them just wide enough for the strings to fit in at the front edge of the nut.

When you move a string left or right or press it down, its bending point must never be in the slot but exactly on the front edge of the slot. Poorly-made nut slots will produce unpleasant rattling noises which can easily be mistaken for fret buzzes. So before you blame your fretwork, check the nut slots first as they might well be the source of the problem.

The slots for the thinner strings can be cut with a saw although sawing will not give round-bottom slots. But that's OK. Wider slots can be made by rolling the saw side-to-side.

Saw or file the slots until they are just a little higher than you want them to be. Make them the right height later when the guitar is finished and ready to be set up. Finish work on the nut for the time being by sanding and/or polishing it with a small buffing wheel in a drill press.

Wiring the electronics

Now heat the soldering iron and place the body on a piece of carpet and cover as much of the body surface as possible to prevent doing damage to it.

When you do the wiring it is advisable to use differently-colored wires to avoid unnecessary confusion and to facilitate keeping track of all the wires. Use cold colors such as black or blue for ground wires and warm ones such as red, orange or yellow for signal-carrying (hot) wires.

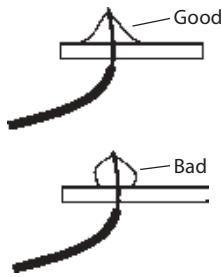
Braided wire is ideal because it consists of numerous very thin strands of wire and because it is very flexible. Use shielded wire whenever the wire length is greater than about 4 inches. With shorter wires it is not worth bothering since the braided shield will have to be removed on both ends to lay open the conductor wire. Shielded wire consists of an insulated conducting wire surrounded by a braided wire which, when connected to ground, acts as a protective shield against unwanted hum and noise that would spoil the sound coming from the amp. If you want to solder, say, the pickup wire to the pot, you first have to strip a short piece of the end of the wire of its insulation. This can be done with special wire strippers but equally well with a knife. Cut up the insulation very carefully to not damage the thin strands of wire inside, and remove the plastic insulation with the nails of your thumb and index finger. On insulated wires remove about an inch of the insulation before disentangling the braided wire. Start pulling out the individual strands of wire not at the end but at the point where the insulation starts again (i.e. about an inch from the end). A fine sewing needle is ideal for this. After that twist the individual strands together to form a thin wire and apply solder on its end. Then also strip the inner wire of its insulation over a length of about $1/5$ " (5mm) and again apply solder on its end and also on the pot lug. For soldering, hold the wire to the point to which it is to be soldered or, if possible, put it through an eyelet, and then hold the soldering iron so that it heats both parts that are to be joined. The solder will soon begin to flow and connect both parts. You will get an even better joint by adding a bit of solder (not too much, though!) after a few seconds. This can, however, only be done with the help of another person - your two hands aren't enough for this purpose.

Soldering

The standard method of forming electrical connections between building components and wires in electronic circuits is soldering. This type of soldering by which two metals are connected with solder is called soft soldering. Use an electrical soldering iron with a power of about 30 to 45 watts. Solder is available at all electronics stores. It is typically 1mm in diameter and consists of a flux core surrounded by a tin-lead alloy. Rosin is often used as a flux to make the solder flow more easily. Because they contain lead, the fumes developing during soldering are toxic and should, if at all possible, not be breathed in. This can, however, never be completely avoided - after all, you have to hold your head over the soldered joint to be able to see what's going on.

The tip of the soldering iron ought to be tinned and kept clean. Clean the tip by moistening it with water and then wiping it in a sponge. Always pre-tin both parts of a soldered joint by holding the hot soldering iron against the wire and by applying solder between the tip of the iron and the wire. When the temperature is right, the solder will spread evenly. A vise might be useful in place of a "third hand" (which is frequently needed for soldering).





When carrying out soldering work on heat-sensitive semiconductor components such as diodes or integrated circuits (ICs) the soldering time must not exceed five seconds.

If, however, you manage to somehow hold the wire in place, as for example in an lug hole or in a small vise, you will have both hands free for soldering. Leave the solder joint to cool without moving any of the parts just joined.

A good soldered joint will never resemble a drop or a lump or look dull. If, however, this is the case, too little heat may have been used for soldering and you will have to reheat the joint, adding a bit of solder until it flows properly. Badly-soldered joints are the reason behind loose contacts - which almost inevitably lead to unpleasant noises - or behind completely interrupted connections. The illustrations on the right show the cross-sections of a good and a bad soldered joint. In the bottom drawing the solder looks dull and has the shape of a lump. Such a "cold" soldered joint is produced when the solder is not hot enough. A bad connection is the result.

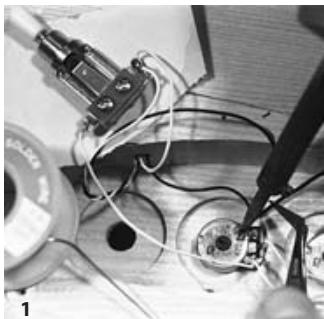
It is unfortunately often the case that soldered joints have to be unsoldered to make changes to the wiring. Removing solder from the hole of an eyelet is always a problem. If you try to push a new, tinned wire through hot solder, the twisted-together wire strands often come apart again. Special pumps or wires for removing solder are commercially available. A simple trick that will also do is to heat the solder and to force the tip of a pencil through it. The graphite of the pencil will then remove the solder and open up the eyelet.

If through lack of care the tip of the soldering iron should get in touch with a neighboring contact an unwanted connection may be produced. Such joints can only be "broken" with an unsoldering pump.

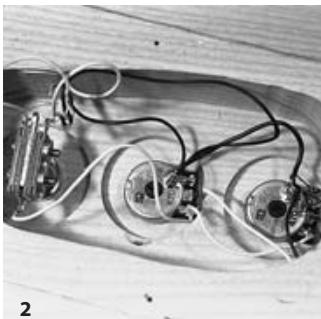
Equipment for wiring your guitar

The picture on the left shows the equipment needed for wiring. A 30 to 45-watt soldering iron (1) and rosin-core solder (2) are recommended for soldering. Wire cutters (3) for cutting and special wire strippers (4) for removing the insulation from wire are quite useful, too, although a knife (5) will also do. A pair of tweezers (6) or small pliers can be useful for holding the wire. An unsoldering pump (7) or special unsoldering wire (8) are needed for removing solder. With an ohmmeter (9) badly-made connections and other problems can be traced. Faulty contacts, however, are also easy to identify by connecting an electric light bulb and a battery in series. But digital multimeters have meanwhile become so cheap that everyone can afford them anyway. Most multimeters have a beep tone that can be switched on so that a signal is given off when two points of a circuit are connected.

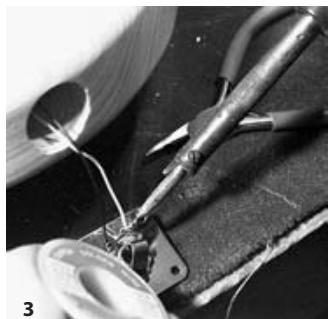




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2



3

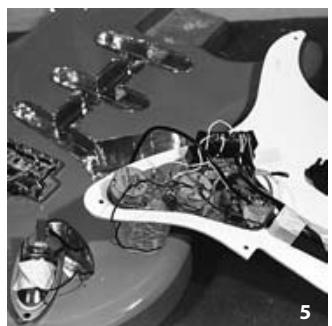


To provide better shielding the casing of all potentiometers has to be grounded. Heat the casing with the soldering iron (1) before applying a small lump of solder, making sure that the solder melts on the casing, i.e. that it is hot enough. This is the case if it is of a silvery color and flows nicely and by itself over the casing. If it hasn't been heated sufficiently, the solder will form a lump. When the solder is hot enough, solder the tinned wire to the casing. If several wires are soldered to one point, it is advisable to twist and solder them together before soldering them on (2). Try to keep wires as short as possible to minimize the likelihood of any hum occurring.

The output jack is last to be wired. Make sure to leave the wires long enough to not unnecessarily complicate the soldering (3). By mounting all control parts on a pickguard or an electronic cover plate wiring and servicing is made easier (4).

Shielding the electronics

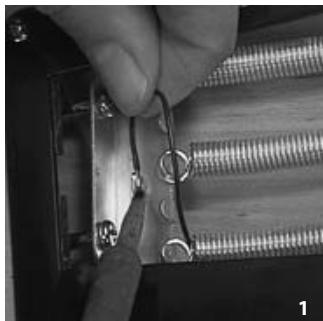
The electronics can be shielded by spraying on two coats of conductive shielding paint. Such paint is available from guitarmakers' suppliers such as *Stewart-MacDonald*. Alternatively, you could also use self-adhesive or non-adhesive copper foil (5). Aluminium foil should be avoided because it is almost useless for this purpose. If you use non-adhesive foil, fasten it with spray glue. What is important is that the areas shielded with paint or foil are all connected to ground. The wires can be soldered to the foil or paint in the same way as to the pot casings (see above). Picture 6 shows a cord plugged into a jack and a probe of an ohmmeter clamped to the rear contact point of the jack. As you can see, I am holding the other lead to the foil in the middle control cavity. The multimeter shows a zero ohms reading, which means that the foil-ground connection is fine. No matter against which part of the foil exactly you hold the probe, there always has to be a connection. The foils are grounded with three wires: one of them connects to the foil in the control cavity, another one to the hole in the jack and the third one to the foil on the



5



6



Active electronics example

The picture above shows a parametric equalizer installed on a printed circuit board and mounted in the control cavity with spacers. The 9-volt battery is fastened in the control cavity using special holders. There are also separate battery compartments with lid that you can buy to make access to the battery easier. Make sure that all parts of the electronics are fastened safely in the control cavity so that they remain in place even when exposed to shaking.

pickguard. The individual foils are connected with each other so that only one lead is required for each area. Another lead connects with the spring cavity of the tremolo unit to ensure the strings are grounded as well (1).

Electronic cavity covers made of metal should also be grounded. Do so by gluing copper foil on a wooden or plastic cover and connect the foil to the ground point of the jack with a wire. Make sure to leave the ground lead long enough so that you can take off the cover if you want to. Grounding the control cavity cover in this way reduces hum, which is important as any interference is passed on to the electronics of the guitar via the body of the player.

The guitar is ready for finishing if after this first provisional assembly everything is fine. Look out for the following:

- Can all parts be fitted easily?
- Is the weight of the guitar distributed evenly and does it sit comfortably on your body?
- Is the neck contour fine or does any wood have to be removed in one place or another?
- Is it possible to set a low string action?
- Does the circuit work?
- Does it sound as hoped for?

If this is the case, disassemble the guitar again and store the individual parts in a safe place. The small screws needed are best stored in a magnetic bowl

Preparing for finishing

The time has now come for a kind of “cosmetic surgery” on your guitar by giving it a protective coating that will highlight the beauty of the wood. If you have so far worked with great care and used highly-figured wood, there is really no reason why you should want to hide the grain by painting it; wood is, after all, a beautiful material whose beauty increases with age. But tastes differ and you might well prefer a colored finish or a body with an unusual motive.

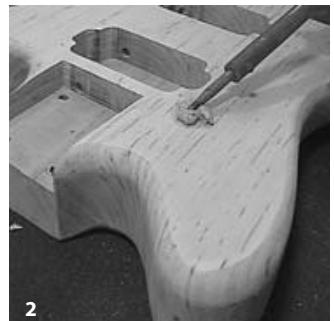
In theory, your guitar can also be left without a finish. Unfinished guitars will, however, sooner or later turn greyish-brown in all areas where they are handled, and this is not really a color particularly pleasant to look at. The neck, which is constantly exposed to hand sweat during playing, would be particularly affected by this. In practice, it is therefore virtually inevitable to apply a protective coating, not least because this enhances the natural beauty of the wood and makes it easier to keep the guitar in a good condition. Another argument in favour of finishing a guitar is that this slows down the moisture exchange considerably; with a protective coating the wood is less “active”. The

finish coating should, however, not be thicker than necessary for fulfilling its protective function as a thick coat weakens and suppresses vibrations over and above what is necessary.

Every foresighted instrument-builder will protect the surface of his/her instruments. A guitar kept in a living-room environment obviously needs less worrying than one often used for concerts and in many different places.

Repairing dents

When wood fibers are only compressed, as in the case of dents, the surface can be repaired by steaming: moisten a piece of paper tissue, put it over the dent and press the hot tip of a soldering gun on the tissue (2). This produces steam, which in turn swells the compressed fibers and makes the dent almost invisible.



Finish-sanding

The first thing to do before applying the finish is to fine-sand the surfaces of the guitar. Always sand in the direction of the grain, starting with 150- and continuing with 220-grit paper. If you want, you can use even finer paper, but the difference will be hardly noticeable on the finished product. Sanding can stop when no more scratches, dents or other uneven areas can be detected when inspecting the wood very closely from all directions and against the light. This is extremely important, so do the checking really carefully: any blemishes not dealt with at this stage, no matter how minor, will come out much more clearly later on an otherwise perfectly smooth and glossy surface.

Surface imperfections are easier to detect by wiping naphtha or lacquer thinner on the wood surface. The wiped-on liquid will evaporate after some time and reveal any defects that may still be left.

Never use steel wool if you intend to use water-soluble products for finishing: no matter how well you clean the surface, there will always be tiny bits left which will begin to rust and cause black spots on the surface. Use a sanding sponge or pad or synthetic steel wool instead.

Masking

All parts that are not to be finished, such as the rosewood fingerboard shown on the right, have to be carefully masked. The sides of the fingerboard can be sprayed as well or masked as shown in the picture.



Stains made from bark

You can make your own "environmentally-friendly" stains from bark. Such stains would be particularly well-suited for an electric guitar built in an "environmentally-friendly" way, one which is perhaps even played over an amplifier powered by solar (or maybe some day even cosmic) energy. To make bark stain you need small pieces of bark from branches ideally sawn off trees between May and October as this is the time in which trees grow and produce sap. The sap content of trees is said to be highest in times of waxing moon (i.e. between new moon and full moon); these times are therefore ideal for collecting bark. When you have got enough bark, fill a glass container (with lid) about two-thirds with bark pieces. Then add a 5 per cent hot soda solution, i.e. 1 part of soda powder and 19 parts of water, so that all of the bark is covered, put the lid on the container and leave the solution to stand for three days. After that time bring it to the boil and leave it to simmer for about an hour. Use an enameled pot for boiling - the stain must not get in touch with metal! After about an hour filter the liquid through a cloth into a glass container (with lid) and then leave it to cool. Such bark stains often give different shades of brown; what exactly the eventual color is going to be also depends on the type of wood that is stained.



1

Staining

When a wood surface becomes wet its fibers swell, causing the initially smooth surface to feel rough again after drying. To prevent this happening or at least limit this effect when a wet finish is applied, wet the surface with a cloth or a sponge, using tepid water. Then wait for about half an hour until the wood has completely dried, before sanding the surface with 220-grit paper. Repeat once or, if you like, twice. Such "sponging" or "whiskering" before applying the stain or finish is particularly important when using water-based products for finishing as these swell the fibers particularly strongly. Finally brush or vacuum off any sanding dust from the pores. By gently wiping the surface with special cloths even very fine dust particles can be removed. Such useful, slightly adhesive cloths are available wrapped in foil from paint stores.

If necessary at all, you can now start applying the stain. Staining emphasizes the wood's grain and gives it a particular tone. Applying stain directly to bare wood can, depending on the type of wood, impart a warm tone to the guitar: yellow, brown and slightly reddish tones applied moderately support and enhance the natural beauty of the wood. Stains of the same type can also be combined with each other for custom colors. The light-colored and rather uninteresting pattern of ordinary, straight-grained maple in particular is improved by staining.

Aniline dye stains are easy to use, give more even results and make coloring wood generally easier. They come in the shape of alcohol- or water-soluble powders and are available in a wide variety of colors. Since only very small amounts of them already give very intense colors, it is advisable to add only very small quantities of powder at a time to the solvent, best with the tip of a knife - or else you might end up with a darker stain than intended. Differently-colored stains can be mixed together for custom colors.

Dissolve water-soluble powder in normal or, better still, in distilled water. I use ordinary, cold tap water. Use denatured alcohol for dissolving alcohol-soluble powder and mineral spirits or lacquer thinner for oil dye. Always test the mixture on a piece of scrap wood first and also put on an oil or lacquer-finish to get as realistic an impression as possible. Even the type of finish used - water-base or lacquer - will make for a difference in color. A lot of guitarbuilders apply a wide range of different colors and intensities on a piece of scrap wood and then oil or lacquer-finish it. This can then serve as a useful guide for deciding what tone to eventually go for.

In the picture on the left (1) you can see me applying vintage amber stain directly to maple. This stain is to make the wood appear yellowish and resemble a maple neck which has aged

over several years. The stain is applied evenly all over the wood with a cloth or a sponge and is then left to dry. Don't be fooled by the dirty-greyish color of the dried stain: it won't begin to "shine" until it has been oil- or lacquer-finished. All water-based stains and lacquers raise the wood fibers. This is not that much of a problem on surfaces finished with clear lacquer: simply sand them with fine-grit paper. If, however, a colored coat is applied, the evenness of the color tone will be changed by the rising wood fibers. This effect can be limited by wiping the wood with a wet cloth and sanding the surface after drying, as described above. Repeat several times if you like. Surfaces treated in this way will be far less rough after the application of stains or water-based finishes. Alcohol-based color stains and a few other special stains do not raise the fibers. Stains can be sprayed, wiped or brushed on.

Sunburst finishes

Sunburst finishes also give very attractive surfaces; with this finishing technique a gradual transition in the color of the body (from darker at the edges to brighter towards the center) is obtained. Sunbursts are easiest to apply evenly on a slightly wet surface, but if you want to save time you can also apply them directly to the wood. If you should have applied too much aniline stain, simply wipe off the excess. Aniline powders can, however, also be added to lacquer later to give a colored coat between two coats of clear lacquer that is totally different in appearance from a coat applied to bare wood.

Filling the grain

Filling the grain of open-grained timbers is an important measure to take to get a completely smooth surface. Such surfaces, which should ideally mirror like glass, are very common on guitars of all kind and buyers often expect this to be the case. Some types of wood such as maple, basswood or alder have a close-grained surface to which a finish can be applied directly. Other types such as oak, mahogany, ash, walnut, rosewood and others have an open-grained structure, i.e. larger pores that are easily recognizable with the naked eye. These surfaces require filling of the pores before any smooth finish is applied.

But keep in mind that using a grain filler is not an absolute must; not using one will, for instance, preserve something of the natural beauty and feel of the wood. But if you want a mirror-flat surface on open-grained woods, there is really no way around grain fillers.

There are special hard-curing grain fillers, or paste-wood fillers, for this purpose which speed up finishing and save material into the bargain. If no grain filler was used, the thin coats of finish would keep soaking into the pores during drying and a lot of coats would have to be applied and a ridiculous amount of material spent. All this can be avoided by using a grain filler, which contains quartz or silica dissolved in an oil/ varnish- or water-based finish. They are therefore not the same as wood putty, which uses wood dust as a bulking agent.

Grain fillers come in thick pastes which, mixed with water or mineral spirits, form a creamy substance that is then applied with a plastic spreader or a coarse cloth such as burlap. Apply it in any direction you want and push the filler into the pores. Then remove the excess by rubbing across the grain with a coarse cloth. Leave the filler to harden and then repeat this process

until most of the pores are filled. Water-base grain fillers have the advantage of curing very quickly. Another good thing about them is that they are non-flammable and can therefore be ordered in America and shipped to countries such as my home-country Austria where “grain fillers” or “paste-wood fillers” are difficult or impossible to obtain. Because water-based grain fillers harden very quickly, you should never apply them on too large an area at a time. Use a filler that is darker in color than the wood you want to fill.

Finishing

Applying oil

Oiling the guitar is a simple and quick way of finishing. Some guitarbuilders just oil their guitars and leave them untreated otherwise, which gives the surfaces a very natural look and feel. Oiled surfaces, however, offer only little, if any, protection at all against moisture exchange and are also less durable. On the other hand oil finishes are very easy to repair.

There are different types of oil which you can use: the good old raw linseed oil, boiled linseed oil, or tung oil to name but a few. Tung oil (also called China wood oil) is produced from the tung nut, and five or more coats give only a little more protection than boiled linseed oil. There are also blends of different types such as Danish Oil or teak oil.

Raw linseed oil takes very long to cure and is therefore not suitable; use boiled linseed oil instead, as it contains additives to make it cure more quickly. Boiled linseed oil is easy to apply but cures rather soft. Apply it with a cloth or brush it on, wiping off the excess after half an hour (1). Boiled linseed oil that has been heated flows even better, soaks into the pores more deeply and is therefore a good choice for the first coat: heat a pot of water to about 150 degrees Fahrenheit (65° C), then remove it from the heat source and put the finish container into it. Don't use a brush for applying heated oil, as it ruins the bristles.

Three to four coats give a satin surface, seven or more coats a slight sheen. If you do not want to apply any wax, leave the surface to dry for a few days and then polish it, using a cloth over a block of softwood.

Finishing the body and the neck with Danish Oil (2) saves time, gives good results and can therefore only be recommended. Danish Oil is an oil-varnish blend. It cures to a satin sheen and is much more protective than boiled linseed oil while being just as



easy to apply: two to three coats are totally sufficient; allow each coat to dry for several hours. Instead of buying Danish Oil you can make your own by mixing one part of varnish, one part of boiled linseed oil and one part of mineral spirits. It's always a good idea to pour everything through a paint strainer to remove impurities and undissolved residue.

Polymerized oils can be made from any curing or semi-curing oil by heating them to approximately 500 degrees Fahrenheit (250 degrees Celsius) in an oxygen-free environment. They cure to a fairly hard and glossy surface. Their short curing time, however, makes them more difficult and time-consuming to apply. The fact that they are quite expensive is less of a problem considering the small surfaces of a guitar. Polymerized oils are applied very thinly and each coat should be allowed to dry a sufficiently long time. During these periods of drying a thin film can and, in fact, should form on the surface. Polymerized oil is, for instance, used for oiling gun stocks. As such it is available from hunting stores.

Applying wax

A thin coat of wax can, but does not necessarily have to, be applied after the wood has been oiled. Applying such a coat results in better protection and a satin surface that feels very smooth. Regular rewaxing will be required, especially around the neck. Fortunately, this is not a difficult job at all, and it ought to be part of the routine maintenance and care of your instrument anyway. Pure beeswax or any commercially available paste wax are suitable for use on guitars.

Lightly wet the oiled surface with lacquer thinner or mineral spirits. Then dip a folded-up piece of 0000 steel wool or a synthetic alternative such as 3M's *ScotchBrite* (4) into paste wax and rub it evenly onto the surface, pressing only lightly to avoid rubbing open the thin, hardened topcoat of oil. By roughening up the surface with steel wool the surface is made larger so that the wax coat bonds to it better.

After applying the wax use a clean cloth to polish the surface to a flat sheen. If too much wax has been applied, the surface will become sticky and everything but a wafer-thin layer will have to be polished off. If a surface has become dull, remove the wax with mineral spirits and then reoil and rewx the surface.



Always dry oily rags out-of-doors: when wet they can self-ignite!

Applying Danish Oil

First and second coat: apply plenty of oil with a cloth, wipe off the excess after about 10 minutes and then allow to dry for several hours or overnight.

Third coat: apply the oil and sand the wood while still wet (from the oil) with 320-grit paper; wipe off any excess oil after 10 minutes and leave to dry for 24 hours.

How to best apply tung oil and other polymerized oils

First coat: pour some oil into a container and dip a cloth in it; apply the oil thinly and allow to cure for at least 24 hours.

Second and third coat: proceed as with first coat; wipe on the oil and leave each coat to cure for at least 24 hours.

Fourth coat: only pressing lightly, smooth the surface in long, even movements, using 220-grit paper and removing the dust very carefully with a cloth; apply the fourth coat of oil very thinly; the wood can absorb less now; leave to dry for more than 24 hours.

Fifth coat: only pressing lightly, smooth the surface with 320-grit paper to an even, flat sheen; use 0000 steel wool for areas that are difficult to get to; remove any dust very carefully; apply the fifth coat very thinly with a lint-free cloth and leave to dry again for more than 24 hours.

Sixth (final) coat: apply the oil very thinly and evenly with a lint-free cloth, starting by wiping in circles and finishing with long zig-zag movements; after about two weeks' time raise the sheen of the surface to a high-gloss finish by first smoothing it lightly with 600-grit wet/dry paper and water before wiping it off and polishing it with white polishing paste, applying the paste with a pad.



1

French polishing

French polishing is the quite work-intensive technique of applying shellac with a cloth pad. This very old finishing method gives particularly good results on mahogany, but also on other types of wood. In French polishing shellac is applied by moving the pad in sequences of circles and figure eights, using a bit of oil as a lubricant. French polishing has a reputation of being very difficult - apparently only experts are capable of doing it. I don't agree. The first time I tried French polishing I was very pleasantly surprised by the results I achieved and watching the gloss slowly develop was a very satisfying experience indeed. To me French polishing is a great and extremely rewarding technique - so why not give it a try? Besides, shellac is not affected by hand sweat and can withstand temperatures of up to about 80 degrees Celsius (176 degrees Fahrenheit). It is, however, quite easily damaged by alcohol. Surfaces thus damaged are fairly straightforward to repair, though. Avoid using alcohol-based stains under a shellac topcoat as this will cause the stain to be dissolved by the alcohol contained in the shellac mixture, which will lead to patches forming on the surface.

If you are interested in a video demonstration of french polishing, I can recommend the video by *Jeff Jewitt*. Details can be found in the literature section.

Shellac

Shellac is a natural resin secreted by insects in India onto tree branches. Workers collect the branches of these trees and scrape off the raw shellac before melting and straining it to remove any impurities contained in it. Shortly before becoming solid one part of the substance is worked into a thin sheet; both hands and feet are used for this (if you have ever made filo pastry at home, you can probably picture how this is done - although this doesn't mean I use my feet to make filo pastry!). After it has become solid the shellac is broken up into small, thin flakes and then shipped around the world. While it still is an important product today, shellac was once used for French polishing on almost all acoustic guitars before nitrocellulose lacquer was invented. The fact that shellac was replaced entirely by lacquer for guitar-finishing purposes doesn't mean that it has any other drawbacks than its time-consuming application. It is, in fact, a rather good choice for finishing an electric guitar as it is a quite tough finish. Shellac can be brushed or sprayed on. If you spray it, remember to take the usual safety precautions.

Dissolve the thin shellac flakes (1) by simply pouring them into alcohol and shaking the solution repeatedly before leaving the flakes to dissolve overnight. Always prepare only the amount that is needed for a particular job as it will not keep very long. A simple test to show whether old shellac can still be used or not is to leave a small drop of the solution to cure overnight; if it doesn't cure but remains gummy, pour it away. Different shellac-alcohol mixtures are commonly used: a mixture of a 1/4 pound of shellac flakes dissolved in 1 pint of alcohol is called a "2-cut" solution; the same solution can be produced by simply putting the shellac flakes into a glass container and filling it up with alcohol to twice the height of the flakes.

The fact that shellac contains wax can be a problem for certain applications. If the solution is, however, left to stand for a sufficiently long time inside a container, the wax will slowly settle to the bottom and it will be possible to pour out the clear, pure shellac. The difference between wax-free and pale, natural shellac is obvious on the wood as well: natural shellac produces a warm, beautiful color tone whereas dewaxed shellac hardly changes the color of the wood.

Because dewaxed shellac has the advantage of bonding very well with almost any type of surface and coating, it is a very good choice for sealer coats. Even oiled or oily surfaces are easy to finish if a coat of dewaxed shellac is applied before.

Synthetic finishing materials

Synthetic finishing materials are made up of a binder, pigments, a solvent and additives. Often additives are mixed in to improve flow-out and to prevent skinning and foaming. Others serve as stabilizers, UV-absorbers, and so on.

Nitrocellulose lacquer contains nitrocellulose as a binder. This type of finish has been very popular over the years for finishing guitars, but as more and more commercial guitar manufacturers have developed a "green conscience", it is increasingly becoming replaced by water-soluble or other types of less harmful finishes. Nitrocellulose lacquer dries very quickly and can be brushed or sprayed on.

Waterborne finishes can nowadays compete with solvent-based ones.

Conversion finishes are particularly durable and mostly used for industrial purposes. They can sometimes consist of two separate components, the finish and the catalyst, which have to be mixed together before use.

One major disadvantage of almost all finishes is the high amount of toxic, flammable synthetic solvents contained in them. Elements such as benzol, toluol, xylol, ester, ether, ketone, acetone, aromatic carbohydrates and others cause health damage. Some types of finish contain a particularly high amount of solvents, like nitrocellulose lacquer with 75 per cent. When working with such highly-flammable finishes care must be taken to ensure that rooms are well ventilated, a respirator mask is worn and explosion-proof equipment is used. These problems do not exist when using water-based finishes. Today good-quality waterborne finishes can compete with and replace the far more toxic solvent-based ones.

Coloring clear finishes

Sometimes a colored transparent finish may be desirable. To color clear finishes add small amounts of aniline pigments. Such powders are available for both water-based and solvent-based finishes. Simply dissolve the powder by stirring it into the finish and then filter it through a cloth to ensure any not fully dissolved parts are removed. A clear finish tinted in this way remains transparent and leaves the wood texture visible. First seal the wood surface with a clear coat, then sand it before applying as many tinted coats as required until you get the desired tone. Finish off by applying several clear coats for protection.

Nitrocellulose lacquer

Although environmentally problematic, nitrocellulose lacquer has long been the first choice in instrument-building. This type of finish cures as a result of the evaporation of the solvent. One major advantage of nitrocellulose lacquer is its ability and readiness to completely dissolve even a fully cured coat of lacquer applied underneath and to homogeneously bond with it. This makes it so easy to polish. Blemishes such as orange-peel noticeable after the application of lacquer can easily be corrected by simple respraying of the surface. Nitrocellulose lacquer is almost hassle-free in its application and can be washed off with lacquer thinner at any time in case anything should go wrong. As with other finishes it is advantageous to spray it on in a "normal"-climate environment. Nitrocellulose lacquer gives the wood a warm, pretty color as it ages, imparting a very special tone to the wood. It fills uneven areas and forms an evenly mirroring topcoat, thus making scratches and other wood defects less visible.

Sanding sealers

A sanding sealer can be applied as a basecoat under a finish. The soap-like additives contained in sanding sealers make sanding easier but also weaken adhesion to the finish coats. This is why you should never apply more than one coat of sanding sealer under any finish. Using such easier-to-sand sanding sealers is important in the furniture industry where large surfaces have to be finished and sanded. They are not at all needed on guitars, though; use a thinned finish for the first coat instead.

Water-based finishes

The quality of water-based finishes, or water bases, has improved over the years; you can now find quite unproblematic products on the market although they are often still quite difficult to work with. Water-bases are tiny droplets of finish emulsified in water which interlock while curing. Don't be fooled by the cloudy, milky color of the finish inside the can, and don't draw any conclusions from this about the eventual color. When applying two coats of water-based finish on top of each other, the one applied earlier has to be allowed to fully cure first to prevent water from remaining in the lower of the two coats. Water-based finishes cure only slowly and the surface remains soft and gummy for some time before fully hardening. Down-sides of water-based finishes are their extreme sensitivity to high humidity during their application or the fact that they are less easy to polish because the individual coats dry one after the other, patches can develop if one coat is rubbed off partially. Water-based finishes do not change the color of the wood. They need a very smooth surface because they bridge pores and scratches and thus create air pockets that refract light at various angles, making scratches more visible.

Using a brush

A well-applied brushed finish is arguably better than a badly-applied sprayed one. Unless you use cans, spraying a guitar always requires a lot of preparation, a suitable room and expensive equipment. You should really seriously ask yourself if a brushed finish wouldn't also meet your own personal demands, especially because they require far less in the way of preparation and are also much cheaper. For only a small part of the money you would otherwise have to spend on spraying equipment you can already buy the best brushes available on the market. Always use soft, good-quality brushes and remove any loose bristles before you start painting by hitting the brush against the edge of the workbench or against your palm. Then dip the brush in lacquer thinner, wipe it off and clean it with a clean cloth. If you prepare the brush in this way, the finish will flow better and also the cleaning afterwards will be easier.

Brushed finishes can be of a very high quality if a few things are heeded. Only dip about one third of the brush into the finish and then squeeze the bristles gently against the edge of the container, taking care not to wipe off the brush to prevent air from getting into the finish via the brush, which would lead to bubbles forming on the surface. Hold the brush at a maximum angle of 45 degrees to the surface and spread the finish with long, even strokes, making sure that the material flows slowly and gently from the bristles onto the surface. Between their bristles all brushes have a small cavity from which the material can flow. Only the front third of the brush ought to be in contact with the wood. Practise on scrap wood first to find out whether the material flows well; add a thinner if necessary. When applying the finish to the body start brushing at some distance from the edges and brush towards them to ensure that any excess material doesn't run down the sides of the body. Then place the brush back at the point where you started and paint towards the opposite edge. When you reach the edge slowly raise the brush, as if imitating a plane taking off. Finally, brush the finish onto the sides. Don't move the brush too quickly - good results will only be achieved if you take your time and do the brushing-on slowly. Also, never brush over a coat that is still wet. When the first coat feels dry, brush on a second and then wait for one to two hours before finish-sanding the surface with 400-grit wet/dry paper and a bit of water. After that apply another coat before sanding it again as above. Repeat this process as often as necessary until the surface is smooth and free from blemishes, but avoid applying too many coats. Flat, satin and semi-gloss finishes are the ones easiest to apply; gloss finishes require more careful work and attention.

Water-based finishes are best brushed on with a special brush with flagged bristle ends.



Keeping brushes in good shape contributes significantly to good finishing results. Often cheap brushes are bought because one assumes that it won't be possible to clean a brush sufficiently well after use anyway. This is, however, a totally wrong assumption. The following instructions for cleaning are intended to give you long-lasting delight with more expensive, good-quality brushes; always carry out all steps of the cleaning process whenever a brush has been used and don't just leave a brush soaked in a solvent-filled container overnight, not even if you intend to continue painting the next day already. Follow these instructions and you will be rewarded with brushes that remain in perfect shape. First remove any material left on the brush by squeezing it against the walls of the container. Then wash the bristles in a sufficient amount of thinner and, wearing protective gloves, massage them thoroughly with your hands. After this twirl the brush between the palms of your hands so that any solvent left is removed. Don't worry about using too much solvent for washing the brush: it won't go off and you can use it again later. If you leave it to stand until the solid particles have settled to the bottom of the container, you can pour it through a coffee filter and get fairly clean solvent again for the next time you need some. After the brush has been thus rough-cleaned, wash it properly in a mixture of plenty of warm water and a bit of hair shampoo by running your fingers through the bristles (commercials will tell you what shampoo to use!). Then wash out the solvent with running water. Repeat and rinse the bristles a second and a third time with fresh water. Finally, carefully wrap the bristles in paper and put a rubber band or adhesive tape around it to hold the paper in place. This will ensure that the bristles remain straight while the brush is not used.

Conversion finishes

Conversion finishes are particularly hard and durable and fast-drying; only two coats are usually needed. They harden in a chemical reaction and individual layers do not dissolve each other. Like water-based finishes they are therefore less easy to rub. Before applying a conversion finish it often has to be mixed with a catalyst (for details always refer to instructions on the can). Only prepare as much of the mixture as you will be able to use within eight hours. Conversion finishes have a few disadvantages as well: their fumes are toxic, their shelf life is limited (once a can is opened it has to be used within 12 months) and they are not cheap.

Using foam rollers

Using foam rollers also gives good results. They are cheap and produce an even finish. Pour some well-stirred-up finish material into a small tub (available from paint stores). Spread the finish thinly and evenly on the roller by rolling it in the tub, wipe off the excess at the edge of the tub and apply the finish all over the wood, moving the roller evenly. I only use such rollers once and don't even try to clean them with solvents; all solvents have to be somehow disposed of as well (in practice they are, sadly, often poured down the drain and end up in the sewers), and even with large amounts of them the rollers could not be cleaned properly anyway. I think that my approach does less damage to the environment. If you put a used roller into a plastic bag and squeeze out the air to make the roller stay soft, you will be able to use it for another coat so that not more than two rollers will be needed in most cases.



Wiping on varnish

You should brush on a sealer coat first. Make the sealer by thinning one part varnish with two parts of high-quality mineral spirits or turpentine. Use the sealer liberally. Let it soak in for about a minute and remove the residue with a clean cloth. After 24 hours of drying you're ready to wipe on the varnish.

Virtually any varnish can be applied with a cloth. Just thin it to a 50/50 mixture with high-quality mineral spirits or turpentine. Pour it into a shallow pan. Make a small pad of cotton cloth filled with cheesecloth and tie it together with a rubber band. Dip the pad into the varnish and tap it to the sides of the pan lightly so that nothing is dripping off the cloth. Apply the finish in a circular motion and work quickly because the thin layers dry rapidly. Finish with light strokes with the grain. Let the surface dry overnight. Apply the next coats in the same way. Four coats should be the minimum.

Before leveling the finish with 600-grit wet-or-dry sandpaper the final coat should be left to dry for 48 hours.

Polish the surface with 0000 steel wool. When it has a dull sheen lubricate the steel wool with mineral oil and rottenstone and rub the surface for several minutes. Remove the grease with a clean cloth and you're done.

Varnish

Varnish is difficult to spray and is therefore mostly applied by brush. It is far more durable than a pure oil finish. Bar-room tables, for instance, are varnish-finished. Varnish is basically oil that has been cooked with natural resins such as rosin, amber or copal. Depending on the oil-to-resin ratio the results will be harder or softer. This is how, for example, violin varnish is produced. Nowadays polyurethane is commonly used in place of natural resins. Varnish also cures coat by coat and does not bond with coats applied underneath. Since it takes a long time to cure, an absolutely dust-free environment is essential. There are special brushes with bristles forming a tapered, chisel-edged end which are particularly suited for applying varnish.

In Austria, where varnish is virtually unknown, there was none the less a product called "*Bernsteinlack*" (*Bernstein* = amber) produced by the company *Auro* available (1). Unfortunately this product was discontinued in the meantime.

Use turpentine for thinning natural resin varnishes. Mineral spirits, which are made from petroleum, are often not even suitable for cleaning brushes.

All coats of varnish, apart from the first, should be applied very slowly and should rather flow off the brush than actually be brushed on. If you are interested in a video demonstration of how to correctly apply varnish, I can recommend the video by *Jeff Jewitt*. Details can be found in the literature section.

By thinning varnish with mineral spirits or turpentine you get what is called "wiping varnish", which is easy to apply with a cloth.

Wiped-on varnish

Instead of using a brush you can also wipe varnish on just like the oil finishes described previously. Because wiped-on varnish layers are thinner and dry quicker than brushed-on layers dust has less chance to adhere. Wiped-on finishes show less application marks which are easier to remove when being polished. Another advantage is that you have more control over the final thickness. Finishes should not be thicker than necessary with musical instruments. Because varnish coats protect better than oil finishes I would recommend it for finishing a neck.

My favorite finishing choice

If you are looking for a good, durable finish that is easy to apply without special equipment, I would recommend Danish Oil for the body and wiped-on varnish for the neck.

Spray finishing

When working indoors with highly-flammable lacquers certain safety precautions obviously need to be taken. This is a major disadvantage of spraying. Water-based finishes do not produce any of the potentially explosive fumes and clouds of dust. A well-ventilated room and a spraybooth for removing fumes from the air are needed. Any lights and ventilators in the spraying area must be explosion-proof as the cloud of fumes is highly flammable. If you need extra lighting, this is best provided by two normal lamps mounted to the right and left of you, and at some distance behind your back. The picture on the right shows one possibility of building a spraybooth around a window in a workshop or some other suitable room. The finish is best sprayed on in a room free from any sanding dust. If you do not have access to such luxury as a separate room for spraying, make sure that any other room used is properly cleaned before you start spraying (2).

I built my own spraybooth around a window by mounting a fan on a plywood board, masking both casements with cardboard and covering the top of the booth with another piece of cardboard (3). Just before I start spraying I spray a bit of water over the floor to bind any dust particles that might be there. The table is fitted with a small turntable.

Spraying has to be done in a low-humidity (not higher than 70 per cent) environment and ideally at room temperature or warmer. If the temperature is too low, the room should be heated. All potentially spark-producing appliances such as electric fan-heaters with thermostat must be switched off during spraying (danger of explosion!).

Out-of-doors spraying is of course also possible; do so only in warm, dry weather, though. No particular safety precautions are required for this, and you won't even need a spraybooth, although it will then be more difficult to keep the surrounding air clean. Another problem might be insects ending up on your guitar after being attracted and killed by the fumes of the finish material.

Using spray cans

Using spray cans is a cheap alternative to using expensive, complex color spraying systems: the cans are readily available, the propellant gases destroying the ozone layer are no longer a problem nowadays as they have been replaced by less harmful ones, and after use the empty cans can be disposed of as toxic waste so that no cleaning is required, either. Systems that allow using separate propellant gas cans are even more versatile: you can fill the cup with any finishing material yourself or custom-mix any color. With such systems you will, however, have to clean



2



3

Explosion-proof fans

Explosion-proof fans have special aluminium rotor blades which cannot give off sparks when getting in contact with dust particles contained in the finish fumes. The entire motor is sufficiently well protected against overspray. Unfortunately, these special fans are very expensive and difficult to get hold of. A good and cheap alternative would be to have an external motor and a long V-belt for driving the fan propeller and to make sure that the motor is at some distance from the room in which the spraying is done.



Spray cans

The picture above shows the cans needed for finishing. Can lids are easy to remove with a screwdriver. The can on the left (1) is a grey primer for finishing the body; next to it there is a can of blue paint (2) in a quantity big enough for spraying all the coats of the body. Using a primer improves adhesion of the finish to the wood and makes it easier to sand by filling uneven areas much better.

One can of nitrocellulose lacquer (3) is sufficient for spraying one neck.

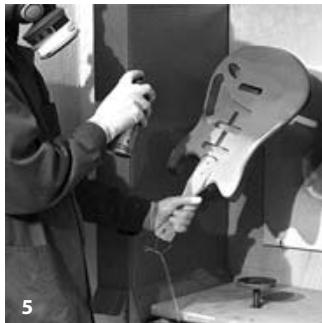
the jar as well as the nozzle very properly after use. Small, cheap spraying systems or airbrush equipment can also be used very effectively.

Shake the can well before use until you can hear the small steel mixing-balls inside it that help to mix the color. If you then continue shaking for another two minutes, the material should be mixed well enough to be ready for spraying. Using cans also has its disadvantages, though: it is difficult to control the amount of material that is sprayed on; there are no in-betweens: the can will either spray or it won't; a distance of at least 30cm (1foot) should be kept to avoid applying too much material in too short a time; and also the spray pattern (width and shape) cannot be adjusted.

When you start spraying never point at the body of the guitar as the can might at the beginning "spit out" larger lumps of color, which are not really needed on the body. Always start spraying close to, but off, the body and then move the can over the wood. I usually start with the sides. To do this I place the body on a turntable (4) and then hold the can at a uniform distance while turning the whole assembly in a full circle (360 degrees). Before pressing the trigger I point slightly away from the body with the can and then spray into the air for a short while. When turning the table the can has to be moved closer to the body in the cutaway and waist areas and further away again in the other, wider areas to ensure an even finish. As mentioned above, a minimum distance of about 30cm (1foot) has to be kept at all times. Resist the temptation of applying too much material: this would only make it run off like water and would produce drips and runs which would require a lot of sanding later that could be avoided.

For spraying the body top and bottom a handle provisionally mounted on the body is useful (5). Spray in strips from one side to the other and beyond the edge of the body, and then follow the same line back again. Ideally, a new stroke sprayed ought to overlap the previous one by half. For best results, hold the spray gun perpendicular to the surface and at a uniform distance from it; make sure to keep enough distance, and don't rock the gun from side to side. With this in mind, work your way from the top to the bottom. To reduce the risk of the can "spitting out" material spray everything in one pass; don't stop and start again, but keep going even if a bit of material may get lost at the edges – these are insignificant amounts which should not worry you. The first coat doesn't need to completely hide the wood texture. Spraying several thin coats instead gives far better results and is much safer.

After you have sprayed three coats, stop and allow to dry for half an hour.



A handle can also be mounted on the neck. Spray on three layers (6); in my case each layer consists of two thin coats, one sprayed on right after the other. After each layer wait for half an hour before spraying on another. After three layers (i.e. three times two coats) have been applied, turn the can upside down and continue spraying until only propellant gas is released. While you wait between layers, it is not necessary to clean the nozzle (by turning the can upside down). You should, however, always cover the can with the lid while a layer is drying.

Always wait until the finish has dried completely before sanding off any drips, drops, runs or other defects; wiping off a wet finish only makes things worse. If the finish looks like orange peel, the can was held too close to the surface and too much material was sprayed on so that it could not flow properly.



6

Using a spray gun

For conventional color spraying a compressor capable of generating a constant pressure of 25 to 80 psi is required. A constant pressure is easier to maintain with larger compressors. When using a spray gun the finish material is sprayed on at a high pressure, with a lot of mist being produced and at a great loss of material (20-30% efficiency only). Spray guns can be priced very differently, but the more expensive models (7) are certainly worth their money. Cheaper guns do not allow a sufficiently precise fan pattern adjustment so that a professional-looking surface can't be achieved, at least not when applying color coats. Clear nitrocellulose lacquer gives quite good results even with cheap equipment.



7

HVLP spray systems (8) are a good alternative to spray-finishing with a compressor. Here the pressure required to atomize the finish material is generated by a turbine sounding like a noisy vacuum cleaner. When spraying with HVLP systems the color fan is wrapped into a cone of air so that less overspray is created and the finish is laid onto the surface very softly. They are therefore more efficient (65-90% of the material ends up on the surface) and allow for cleaner work. Although with such systems you can spray less material in a given time than with compressor-supplied guns, this drawback only really matters when working with large surfaces. Another disadvantage of HVLP systems is the fact that air comes blowing out of the gun continuously, even when the trigger is released; this can raise a lot of dust. An HVLP gun can, however, also be supplied with air by a large, powerful, expensive compressor. In this case the high-pressure air must be sent through a regulator transforming high pressure into high volume. Turbine-supplied HVLP systems are ideal for occasional spraying jobs as required by guitarbuilders. If you don't already have a compressor, get yourself an HVLP system. For the average



8

Storing the nozzle parts

A clean nozzle is extremely important if the spray gun is to function properly. After cleaning all the removable parts of the spray nozzle I store them in lacquer thinner in a screw-top glass jar. Don't store gaskets in lacquer thinner as they become porous.



Proper thinning

Finishes may require thinning to be suitable for use with a spray gun. The viscosity of a finish material can be measured with a special cup (viscosity cup) available from paint stores. Such cups are funnel-shaped containers that allow measuring the time liquid materials take to flow out of the container. Immerse the funnel fully into the material and start a stopwatch the very moment you pull out the funnel. For details of flow-out times consult the finish manufacturer's instructions. The ideal temperature for the material, the wood and the environment is room temperature.

Another far simpler method of determining the right viscosity is to watch the material run off a stirring stick back into a container: when it stops running off in one single stream and starts to break cleanly into drops, the viscosity is right. By adding solvents the viscosity can be altered. A lot of finishes, however, already come in thinned form and are all ready for spraying; with some others you have to add 10 per cent of thinner.

user the Wagner "FineCoat" HVLP system (see picture 8 on previous page), which is widely available, will do the job perfectly well.

The way you hold and move the gun during spraying determines the results that you will get. The ideal spraying distance is about 6 to 10 inches (15 to 25cm). If you hold the gun any closer than that, the particles will hit the surface with too much energy, resulting in an uneven surface. If, on the other hand, the gun is held further away, the material will dry before hitting the surface and will not flow very well; also, a lot of mist will be produced. HVLP spray guns usually have to be held closer to the surface that is to be sprayed than conventional guns. Keep moving the gun evenly from one side to the other, each stroke overlapping the previous one by half. Avoid rocking the gun from side to side; instead, move it from one side to the other at a uniform distance and strictly parallel to the surface. Make sure that the material hits the surface at right angles at all times, even when spraying horizontal surfaces. If the gun is not held perpendicular to the surface, the spraying distance will not be the same in all areas, resulting in an uneven build.

The spray pattern can be varied by adjusting the amounts of air and fluid that are discharged; the thinner the material is, the less air is needed to atomize it. First close both the air- and fluid-adjustment knob all the way; the exact location of these screws varies from gun to gun and can be found out from the operating instructions. Then open the air-adjustment knob about one-quarter and begin spraying. Continue spraying, while opening the fluid-adjustment knob, until you get a wet coat. The air-to-fluid ratio is right when the material begins to flow well on the surface. If you wish to increase the amount of fluid (finish material) that is sprayed on, increase the airflow and with it the amount of fluid that is discharged. Always test-spray on a piece of scrap cardboard first. The optimum balance depends on pressure, the viscosity of the material and the desired fan pattern.

Sanding the finish

After the first couple of coats have been applied use 320-grit sandpaper to sand the surface smooth and to remove all runs, sags and drips. Wet/dry sandpaper can be used. The advantage of wet-sanding is that this doesn't produce any dust. Use tepid water and add a bit of washing-up liquid to make sanding easier. Wipe off the sanded-off wet dust at regular intervals. On finished fingerboards the areas between the frets can be smoothed with a scraper.



Before the final coat is sprayed on, the guitar should be sanded particularly well. The final coat is best sprayed with a mixture made up of equal parts of thinner and nitrocellulose lacquer. This will give a surface that is easy to rub afterwards.

After applying the final coat hang the parts of the guitar in a dry, warm place and do not touch them for several weeks.

Several weeks later

No matter how well a surface has been finished - it won't look perfect until it has been buffed and polished. Polishing turns the surface into one single homogeneous area by reducing the size of the scratches on the surface, making them finer and finer until they are no longer visible to the human eye. However, before it can be polished a surface has to have hardened well: lacquer or water-based finishes take at least three weeks to fully cure as the solvents have to evaporate from all the coats of finish - and this just won't happen overnight. As long as the finish material can still be smelt in the drying room it has not yet fully cured.

In the picture on the left you can see me wet-sanding the body one haircut later, after about three weeks' of drying (of the body, not the hair!). Good lighting is essential for polishing. Before you start sanding, leave the paper (400-grit wet sandpaper) soaked in water overnight. When you do the sanding the next day, do so using water with a few drops of washing-up liquid in it. Wipe off the water at regular intervals and check the surface against some source of light by looking at it at an angle. Some areas will look flat, others, deeper spots which have so far escaped the sandpaper, will be shiny. To get a high-gloss finish all the shiny areas have to be sanded and thus removed. When this has been achieved and the whole surface has an even sheen, move on to 600- and 800-grit paper. Sanding can be done in all directions, i.e. in swirls or in straight lines, as long as you do not rub through the coats. If this should, however, happen, a few more coats have to be applied.



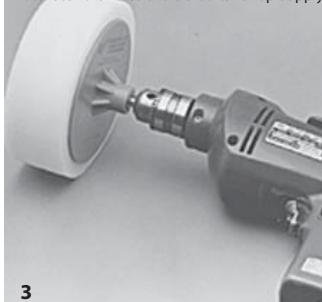


1

Photo: Stewart-MacDonald's Guitar Shop Supply



2



3



4



5

Polishing the finish

To get a gloss finish you have two options: you can either move on to using a polishing compound, or you can continue sanding with 1000-, 1200- and 2000-grit wet paper. If you don't want a gloss finish, you can use 0000 steel wool or synthetic wool to rub the finish to a low sheen.

Like toothpastes, polishing compounds contain tiny abrasive particles. They come in various degrees of fineness. Make sure to use silicone-free ones - otherwise problems might occur during refinishing. Since almost all of these polishing compounds are normally used for polishing car paints, you should be able to get hold of them fairly easily from automobile body-shop suppliers. Although their staff will probably not know a lot about nitrocellulose lacquer, ask for advice none the less. I personally use the rather expensive "*Finesseit*" polishing compound by 3M. The ralley strip at the bottom of the bottle clearly shows what this product is intended for.

Ordinary polishing compounds can also be made at home by mixing water and rottenstone. The latter, which was once used for cleaning high-grade steel and silver, has now disappeared from our kitchens, but can still be found in paint stores.

If you want, you can do the polishing by hand only; however, using a machine will save a lot of time. Foam (1) or lamb's-wool polishing pads (2) which can be attached to a random orbit sander or a power drill (3) are commercially available. Put a lump of polishing compound on the pad and then spread it on the surface with the machine switched off. Then start the machine and keep polishing until the surface begins to mirror as the polish is broken down and turns into dry dust. Make sure that any excess polish is wiped off carefully before moving on to a finer grit; use a new polishing pad if possible, or wash the one previously used properly.

Finish polishing by hand. With this simple equipment and a bit of patience an excellent finish can be achieved (4). It may take a little longer, but as for quality it won't be second to surfaces finished with a buffering wheel. Some areas of the body such as the cutaways or parts of the neck can only be buffed by hand (5).

Metal parts, such as home-made bridges, are best sanded with wet paper: keep sanding in the same direction, using increasingly finer grits of paper until all fine scratches have gone. For finishing brass parts there is a special finish by the name of "Zapon"; nickel or anodized parts don't require any further finishing. They can be cleaned with chrome or metal polishes available from household goods stores.



Material needed for a nitrocellulose lacquer finish

Above you can see what is needed for finishing a surface with nitrocellulose lacquer: nitrocellulose thinner, sealer (which, as mentioned above, can be substituted with thinned lacquer), a can of nitrocellulose lacquer, polishing compound, rubbing pads, 400- to 1200-grit wet/dry sandpaper and a masking tape (from left to right).

Buffing wheels

Buffing pads make it possible to polish the finish particularly quickly and to access areas that would otherwise be difficult to get at. With a buffering wheel you can move from sanding with 600-grit paper straight on to buffering and get a high-sheen finish. Buying such a tool will, however, only pay off if you build guitars in large quantities – there is certainly no need for the amateur guitarbuilder to have one.

Polishing compounds also come in bars of various grades of fineness. These bars are rubbed onto the rotating pad. The object to be polished is carefully and lightly pressed against the pad from below and moved from one side to the other. Be careful, though: the high speed of the rotating wheel can easily cause the finish to overheat and lead to bubbles forming on the surface. With the wheel it is unfortunately also very easy to rub through all coats of the finish very quickly. Never even attempt to hold any of the body's edges against the wheel – the force of it could send the guitar flying to the floor.

Before moving on to a finer grade of polish remove any remaining polish from the wheel by running it against the edge of a wooden stick. Better still, use two separate wheels, one for each polish.

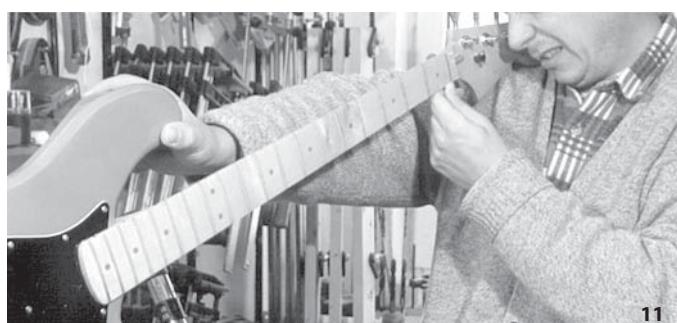
The optimum speed is 700 to 1000 rotations per minute (rpm).



Photo: Stewart-MacDonald's Guitar Shop Supply

Fret dressing tools

- 1 Sharpening stone
- 2 Knife blade with handle
- 3 Needle files
- 4 Top: concave diamond fret file; bottom: *Gurian* fret file; its angled handle facilitates fret-dressing over the body on guitars with glued-in necks.
- 5 Straight edges in various lengths for checking if frets are level
- 6 Blue textmarker
- 7 Fret-leveling file
- 8 0000 steel wool
- 9 Feeler gauges



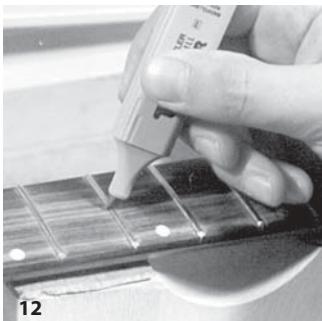
Tightening the truss rod nut

Never tighten the truss rod adjustment nut by more than a quarter of a turn, and always do it very, very carefully: there is nothing more annoying than a broken thread or truss rod. If nothing moves at all, this is a definite sign that something is wrong with the truss rod. A correctly installed truss rod already works after only a slight turn of the nut.

Allow some time until a new truss rod tension has consequences on the neck. Sometimes you can speed things up by laying the neck on your knees and "bending" it in the right direction.

Fret dressing

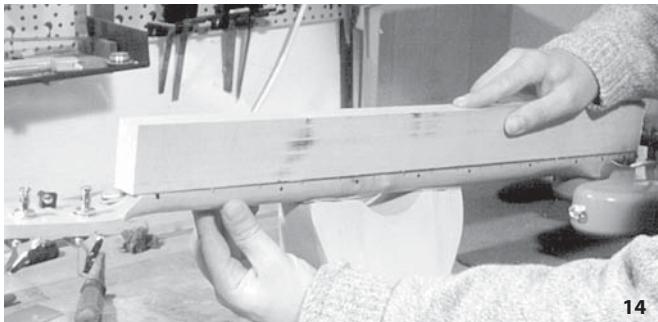
Before you start with fret dressing adjust the neck by means of the truss rod so that it is as straight as possible (10). Place a straight edge on the neck and tighten the truss rod adjustment nut until the edge rests on one point only in the middle of the neck and begins to rock lightly. Now untighten the nut again until the edge stops rocking. This is the point at which the neck is straight. Since the frets are not level yet, it is also important to check the straightness of the neck by sighting along the fingerboard (11). When doing this I just lift the guitar at the body and not at the neck. The straighter the neck is adjusted now, the less will have to be removed later when dressing the frets.



12



13



14



Rocking neck rest

The neck rest above is extremely useful for holding necks in position while different kinds of work are carried out on a guitar. This rest can rock and can therefore adapt well to any guitar. With a bandsaw such neck rests can be cut out from a glued-together block of hardwood. The cork-lined top surfaces on which the neck rests offer excellent protection against damage. Make sure the neck rest is wide enough at its base to keep it from falling over sideways.

The frets can now be colored with a blue textmarker (12).

Using a flat-surfaced sharpening stone, a commercially available fret-leveling file (13) or a home-made fret file (see drawing below) work all frets until metal reappears on them. An alternative would be to use a long straight-planed piece of wood (14), about 25mm (1") in width, onto the edge of which a strip of 120-grit sandpaper is glued with spray glue. The piece of wood used should be slightly longer than the fingerboard.

On compound-radius fingerboards you should always work radially, in the direction of the strings. You can also do this on a cylindrically-radius fingerboard: this will lead to a small compound radius being formed on the frets. Conversely, if you want to keep the cylindrical radius of the fingerboard, always work strictly parallel to the neck center line (which means that you will partly have to file on "air").

Check the progress you make with dressing the frets at regular intervals; do so by placing a straight edge along the length of the fingerboard. Short edges are suitable for checking shorter areas. It is strongly advisable to mask the entire fingerboard with adhesive tape. This will mean a little more work now, but will be appreciated later as it is definitely less time-consuming to tape off the fingerboard than having to remove fret-dressing marks and scratches from the fingerboard.

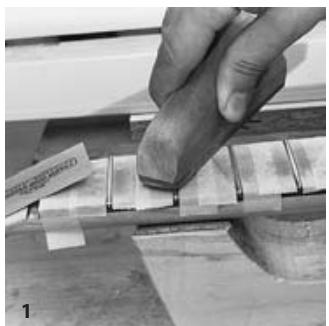
Home-made fret leveling file

Rough dimensions:

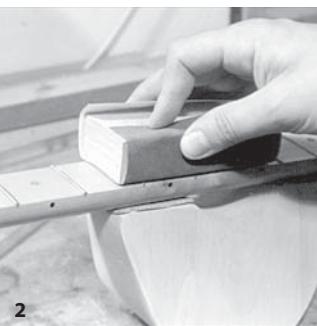
Width: 20mm ($\frac{3}{4}$ ')

Length: 150mm-200mm (6"- $7\frac{3}{4}$ ')

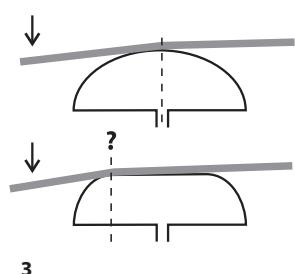
—Wood
—Mounting tape
~8mm ($\frac{5}{16}$ ") glass
\Sandpaper



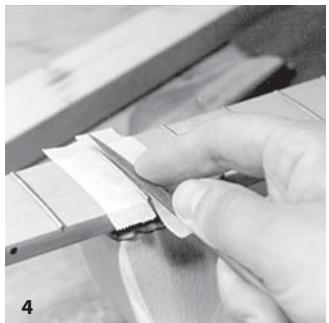
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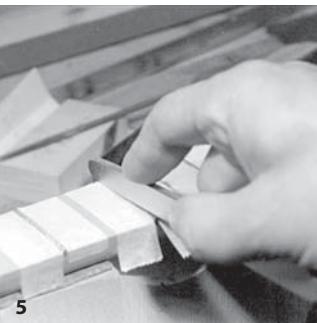
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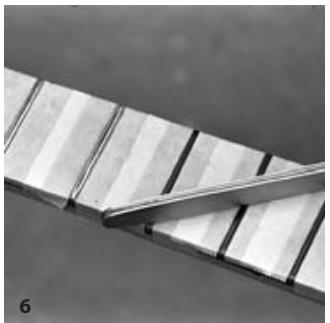
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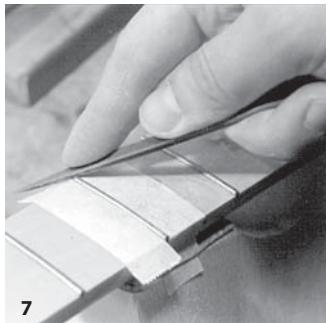
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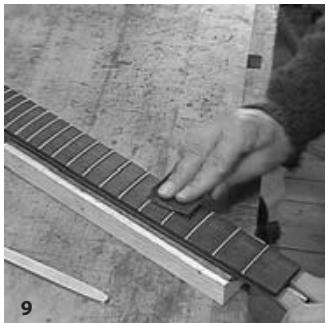
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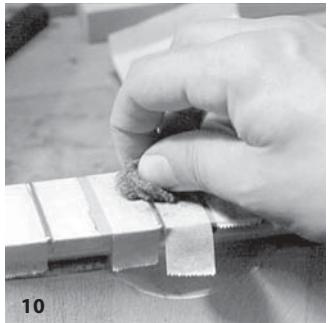
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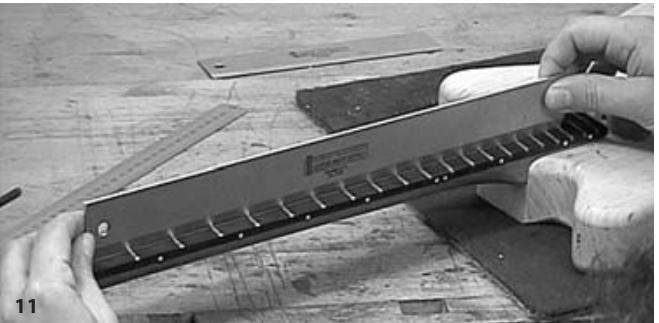
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9



10



11

Using a short straight edge check the frets once more three by three. If the edge should rock, the point of the middle fret on which the edge rests is too high and has to be reworked with a file (1). Do so until the rocking stops. One or two strokes of the file will do. Carry out such checks across the width of each fret, then move on by one fret and continue until all frets on the fingerboard have been checked. The higher you move up the fingerboard, the closer the distances between the frets will get and ever-shorter edges will be needed. Finally, remove the worst filing marks with 320-grit sandpaper and a sanding block (2).



Next the fret crowns have to be re-rounded. If they were left in the state they're in after leveling, the strings would not be pressed against the frets exactly in the middle and all the precision work of cutting the fret slots would have been in vain (3). Color the frets once again – the color helps to control the progress made - and round the crowns with a suitable file. Some guitarbuilders use only a triangular file and no other tools for crowning the frets (4). These special files have rounded corners so as to avoid marring the fingerboard. Move the file over the frets very quickly, working alternately on the two sides of the frets.

Fret files are concave and available for various fretwire sizes. The file shown in picture 5 is diamond-coated, comes in 150-grit and 300-grit versions and leaves fewer "chatter marks" than conventional fret files (which can obviously also be used).

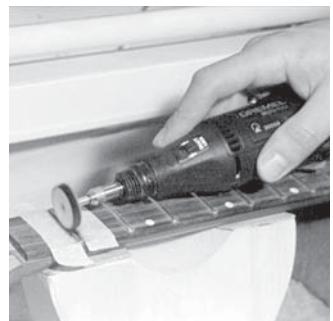
Make sure to leave a narrow line across the top of the fret crowns (6); after all the hard work put into leveling the frets their height must not be tampered with now.

Any burrs that could mar the player's fingers are removed by carefully filing the ends of the frets with a triangular file (7) and subsequently rounding them with a fine fret file (8).

Any filing marks on the fret crowns are removed with a folded piece of 600-grit sandpaper (9). Hold the paper between two fingers as you move it over the frets. Finish by polishing all the frets first with 000 steel wool (10) and then each fret separately with 0000 steel wool until they begin to shine.

Check at regular intervals if the frets are perfectly level (11).

Oiling the fingerboard surface
All fingerboards except lacquered maple ones require thorough cleaning and the application of a thin coat of fingerboard oil (available from guitarmakers' suppliers) or gun stock oil before the guitar parts are finally assembled.

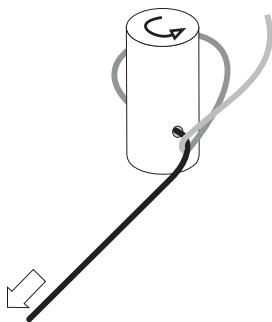


Fret polishing
Professionals additionally polish their frets to a high sheen with a buffering wheel. A very good alternative would be to polish each fret individually to a high gloss with metal polish applied on a small buffering wheel mounted on a *Dremel* (or similar) tool. Make sure to mask the fingerboard beforehand and remember that glue can be dissolved if a fret gets too hot!



Stringwinder

Stringwinders are useful tools that make stringing the guitar considerably faster.



Stringing a guitar with a Floyd Rose tremolo.

An exception to the description on the right is when stringing a guitar with a *Floyd Rose* or similar tremolo. In this case the string is threaded into the tuner shaft hole first and then clamped and cut at the tremolo unit (the ball end side is at the peghead).

Set-up

The set-up jobs described in the following are specific adjustments for each individual guitar. All set-up jobs should be done carefully, without rushing and in the order in which they are described here. A badly set-up instrument can make the most perfectly-built guitar sound like scrap metal.

Stringing the guitar

String the guitar very carefully; badly strung guitars tend to go out of tune rather easily. Only wind as many turns of string as necessary around the tuner shafts.

Place the guitar on a work surface and anchor the first string at the bridge. Then pass the string over the nut and past "its" tuner and tension it by hand. To ensure that the string is long enough for fitting but at the same time as little of the string as possible has to be wound around the shaft work out the approximate string length required as follows: at the 12th fret hold your fingers (use four fingers under the bass and three under the treble strings) between the string and the fret, lightly stretch the string and place it on the tuner shaft. Then bend the string at the tuner shaft hole at an angle of 90 degrees towards the hole and pass it through the hole or, if your tuner shafts are slotted, put it into the slot; then wind the string around the shaft in a clockwise direction. When doing this pass the string under the part of it which was passed through the hole, bend it upwards and then tighten it by pulling. Continue by turning the tuners in an anticlockwise direction until the string is tensioned. Fit the other strings in the same way. If I have managed to confuse you with this description, just look at the figure on the left and everything should become clear. Note that the winding directions given above apply to right-hand-side tuners and will of course be reversed when fitting strings to tuners on the left-hand side of the guitar. When the guitar is on your shoulders you should be able to raise the pitch of the strings by turning the tuner knobs in an away-from-the-body direction.

With bass tuners and some kinds of guitar tuners the guitar is easier to string: simply pass each string to the tuner and clip it, leaving it a little longer to allow for a few windings on the shaft. Stick the string end into the hole in the tuner shaft, bend it and then wind it up. Make sure to place each winding under the previous one around the shaft to get a sufficient angle at the nut. Placing the final winding at the bottom is particularly important on guitars with *Fender*-style pegheads.

Locking tuners make stringing very easy indeed: simply pass the string through the hole, tension it lightly, lock it and then tune it. When using a fine-tuning tremolo with locking nut the strings are fitted as usual (i.e. wound onto the tuner shafts), and then rough-tuned before being clamped at the nut and the tremolo. The strings will go out of tune again, but this can be corrected with the fine-tuning screws of the tremolo unit.

When using headless tuners the ball-end with the smaller ball is anchored at the head-end of the guitar and the one with the larger ball at the tuning unit. After only a few turns the guitar will be in tune and the tuning will remain very stable as there are no string windings which could settle.

Tuning

After tuning, the full string pull becomes effective on the neck. When setting up the guitar always use strings identical with the ones you will use later. Electronic tuners are extremely useful for tuning. Chromatic tuners are a bit more expensive but also offer some advantages: no switching is required during tuning, and you can also use them for tuning other instruments such as flutes, saxophones, violins, cellos, etc. As the expression “bringing the strings *up* to the correct pitch” implies, the right tone should be approached from below to eliminate any possible influence from the tuner play. If a string is sharp, turn it down first and then approach the correct pitch from below.

Newly-fitted strings go out of tune again quickly; they need time to “settle”. This time can be shortened by carefully stretching the strings after they have been tuned a first time. Then retune them and stretch them again, and continue like this until the string remains in tune.

Using harmonics for tuning is an alternative tuning method which relies on the fact that it is easier for the human ear to distinguish between high-pitched tones than between low-pitched ones. Producing harmonics on the guitar takes some practicing – here's how to do it: lightly touch the string above a particular fret (see list on the right) – do not actually press it down –, pluck it and then quickly take the finger off the string. A high-pitched, sustained vibrating tone will be produced. This method has the advantage that it allows producing two tones in quick succession which can be heard simultaneously and can therefore be compared. If necessary, they can be brought up to the same pitch by turning one of the tuners while both harmonics can still be heard. Basses are tuned one octave lower than guitars.

Tuning by ear

With the following method you can tune your guitar without an electronic tuner:

- (1) Tune the open A string with the help of a reference tone from a tuning fork or another tuned instrument.
- (2) Press down the bass E string on the 5th fret and tune it to the same pitch as the open A string.
- (3) Press down the A string on the 5th fret and tune the open D string to the same pitch.
- (4) Press down the D string on the 5th fret and tune the open G string to the same pitch.
- (5) Press down the G string on the 4th fret and tune the open B string to the same pitch.
- (6) Press down the B string on the 5th fret and tune the open treble E string to the same pitch.

To check the tuning compare the two open E strings with each other.

Fine-tuning by ear

Harmonics produced at the following fret positions have to be identical in pitch:

- (1) 5th fret of bass E string and 7th fret of A string
- (2) 5th fret of A string and 7th fret of D string
- (3) 5th fret of D string and 7th fret of G string
- (4) G string just under the 5th fret and 7th fret of B string
- (5) 5th fret of B string and 7th fret of treble E string.

When two harmonics are almost identical in pitch, a slow vibration can be clearly heard which only disappears when both tones are perfectly equal in pitch.

Often electronic tuners react much better to harmonics than to a “normally played” string.



Adjusting the neck relief

A neck with a light bow leaves more room for the vibrations of the strings. Any adjustment made only applies for the set of strings that is fitted at the moment the truss rod is adjusted as it compensates exactly the pull exerted by a particular set of strings and keeps the neck bow within certain limits. Any later change of the string gauge also calls for a readjustment of the neck bow. However, before you embark on adjusting the neck relief, tune the guitar and then put it away and leave it to "work" overnight: the pull of the strings will take some time to become effective. Then retune the guitar and place a straight edge over the first 13 frets, holding the guitar in the playing position. It is important to hold the guitar and not to have it lying flat on a surface as the weight of the neck alone would already lead to distortions in adjustment. If you place a capo on the first fret, you will have one hand free for checking the straightness with a feeler gauge (1). If you press down a string after the 12th fret, it is dead straight and can be used in place of a straight edge to check the straightness of the neck. The recommended distance (neck relief) between the top of the sixth fret and the bottom of the straight edge or string depends on the scale length and the string gauge. Shorter scale lengths and thinner strings produce less strong vibrations while long scales and bass strings require more room for vibrating. Guitars can have a relief of 0.25 to 0.3mm (0.01" - 0.013"); 0.5mm (0.02") is recommended for basses. The neck bow can be rough-adjusted by pressing down a string at the 1st and 13th fret and by tapping it with a finger at the 6th fret and then making any adjustment that may be necessary. Always loosen the strings before turning the truss rod nut. Adjust the truss rod so that the distance is right: turning the adjustment nut in a clockwise direction gives the neck a backbow and reduces this distance; if the distance between the strings and the frets is too small, the adjustment nut has to be untightened by turning it in an anticlockwise direction. Never turn the nut by more than a quarter of a turn at a time. After each truss rod adjustment the strings have to be retuned and the full pull of the strings has to be reestablished. The neck bow may change in the course of the other adjustments yet to be made and described below; it may therefore be necessary to carry out the above adjustment procedure several times. But once the guitar is completely set up and the neck relief is right no further adjustments are needed and the truss rod is best left untouched. The truss rod will only require readjusting when strings of a different gauge are fitted on the guitar. And finally: the truss rod must never be used for setting the action – its only purpose is to adjust neck relief.

Some guidelines for the neck relief

Distances from the top of the 6th fret to the bottom of the straight edge (or string):

Guitar: 0.25 - 0.3mm (0.01" - 0.013")
Bass: about 0.5mm (0.02")

Under no circumstances should a truss rod be abused for setting the action - its only purpose is to counteract the pull of the strings by keeping a neck either completely straight or in a light concave bow.

Setting the string height at the nut

At the nut the distance between the bottom of the strings and the fingerboard surface should be no greater than the fret height. An action that is too high in the nut area will lead to a wrong intonation, the pitch becoming too high as the string is tensioned too strongly when pressed down at the first fret. Besides, the guitar will be uncomfortable to play because of the fingers having to press harder and the strings feeling stiff. The fret-height line drawn on the nut comes in handy now: file the nut slots down to this line. See the section on how to make the neck for details of how this is best done. Use a saw for deepening the slots for the thin strings and special nut files for the other slots. The slots for the bass strings can also be made deeper with a needle file. Take each string out of its slot and put it into a neighboring one before you deepen the slots. On radiused fingerboards the height of the strings has to follow its curve and the strings must all be equally high above the fingerboard. If you press down the strings one by one now, you should need the same amount of pressure for each string. Deepen the nut slots if necessary until all strings feel similar. There should only be very little room for the strings over the first fret when pressed down between the 2nd and 3rd fret.

If the action is set too low, the vibrations cause the strings to touch the frets and produce unwanted noises. If by mistake a nut slot has been made too deep, replace the missing material with a drop of super glue, allow it to harden overnight and then redo the slot. If all nut slots are too deep, glue a suitable piece of hardwood veneer under the nut and then file the slots down to the right depth. Cardboard or similar materials should not be glued under the nut as they would only dampen the transmission of vibrations. To prevent making nut slots too deep feeler gauges of fret height should be placed under the fret file (2). To measure the fret height drill a hole into a small piece of wood or metal and then place this piece on the frets. Using the depth gauge of the caliper the distance from the fingerboard surface can be measured through the hole. The fret height is then easy to work out by subtracting the thickness of the piece from the value measured. A lot of guitarbuilders set the action at the nut without taking any precise measurements – they just go by the impression they get when pressing down the strings.

Another important thing is to make the slots slightly lower towards the peghead side so that the strings rest exactly on the front edge of the nut (the zero-fret position) and not somewhere further back, which would be tantamount to a lengthening of the scale and would guarantee intonation problems. To make the slots lower towards the peghead side, hold the file or saw at an angle. The nut slots should be made to precisely match the strings, i.e. have the same curve and not be too wide. When you

Correct nut slots

Round nut slots should not surround more than one half of the strings.



The bottom of V-shaped nut slots also has to correspond to the string diameter and needs to be curved, too.



Use of feeler gauges

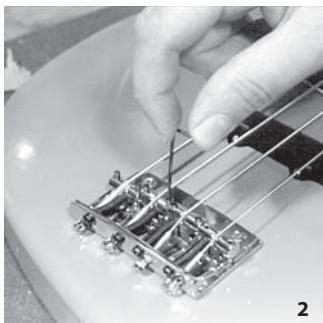
You can avoid making nut slots too deep by placing feeler gauges of fret height under the nut file. This enables you to get the slot depth absolutely right.

A zero-fret makes nut-filing easier

Filing nut slots is very easy indeed if you make a zero-fret: the slots then only serve to guide the strings and you only need to get their width right - their depth becomes insignificant. To ensure the strings rest only on the zero-fret the nut slots have to be made deeper than the zero-fret.



1



2

move a string sideways it must not move at all in the nut. The strings must be bent right at the nut edge and there must not be any sharp edges anywhere either that could possibly damage the strings. Only one half of the strings should actually be in the slots; the top half of each string should protrude.

Setting the action

The action is the distance between the frets and the strings, which is usually measured at the 12th fret. Setting it is always a compromise between a low position – the lower the action, the easier the guitar is to play - and a high-enough position to keep the strings from rattling against the frets. Before the action is set the frets obviously have to be filed level (see above).

When the action is set high, the guitar is less likely to make unwanted noises but is also less comfortable to play as more pressure is needed to press down the strings. Intonation also suffers from an action that is set too high, and the neck will be more strongly exposed to the bending forces. Finally, the height of the action also depends on the way the instrument is played: somebody who strikes the strings forcefully will no doubt need to have the action set rather high. On electric guitars the action is set lower than on acoustics - electrics sound quite loud already even when struck only lightly.

Put the guitar into the playing position and place a rule with a zero-mark right at its edge onto the 12th fret (as shown in picture 1) and measure the height to the lower edge of each string. You can also use a feeler gauge or short pieces of scrap strings for measuring. Then slowly set the action on the bridge to the desired height. On most bridges the action can be set with a small allen key (2). The saddles should remain approximately horizontal. Other types of bridge can only be adjusted for height as a whole by means of wheels; individual strings can then only be raised or lowered by filing down individual saddle slots. On radiused fingerboards the action has to follow the radius.

You don't have to set all strings to the same height; the thinner, more highly tensioned treble strings vibrate less and can therefore be set lower than the bass strings. As a guideline set the action so that it increases from 1.5mm ($\frac{4}{64}$ ") at the treble E string to 2mm ($\frac{5}{64}$ ") at the bass E string on a guitar. The values given here are just guidelines, but obviously the action can always be set lower if the style of playing and the frets permit. Since the strings on basses vibrate more strongly, the action has to be set higher as well, namely to 2.5 to 3mm ($\frac{6}{64}$ " - $\frac{7}{64}$ "). These figures are only averages and can, of course, be slightly varied according to the personal requirements of the individual player. All adjustments have to be checked after a couple of days when the neck has adapted to the action.

Some guidelines for the action

Distances between the top of the 12th fret and the bottom of the strings:

For guitars: 1.5 - 2mm ($\frac{4}{64}$ " - $\frac{5}{64}$ ")
For basses: 2.5 - 3mm ($\frac{6}{64}$ " - $\frac{7}{64}$)

After tuning check each string at each fret for unwanted noises. If any such noise can be heard on an open string, the string probably doesn't rest properly on the nut or the bridge. Often nut or bridge slots that have not been given enough attention are the reason for noises sounding like rattling on the frets. If the noise disappears when you additionally press down the string behind the nut, the problem can be attended to by carefully filing the guilty nut slot, or, if that is no longer possible, by replacing the nut. So find out first what causes the noise before you raise the action or start working the frets with a file.

If a fret turns out to be the cause of the problem, try pressing down the string at all frets, starting at the first and then working your way up the fingerboard. The fret at which the rattling noise disappears is the cause of the problem: it is too high and must be filed down carefully. But quite often the guilty fret is not all that obvious; it may well be situated in a totally unexpected area. The electrical conductivity of steel strings can be used to find out any frets that are too high. Hold one probe of an analog ohmmeter to the string behind the bridge or the nut. Then pluck this string and hold the second probe to one fret after the other. Wherever the string touches the fret an electrical current can flow and the ohmmeter needle will move and show a low resistance value.

If there are unwanted noises caused by the frets, the strings have to be removed again and the guilty frets have to be redressed. Fasten any loose frets with a blow of the fretting hammer or by gluing them down with super glue.

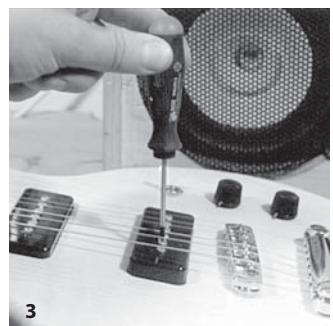
Adjusting the pickup height

By adjusting the pickup height (3,4) you can balance the sound of the instrument. Pickups that are close to the strings give a greater output and make the guitar louder and bassier. The closer the strings are to the pickup, the greater the effect of magnetic interference on the strings' vibrations, and in particular on the wound strings, will be. The clarity of the sound will suffer as a result of the strings no longer being able to vibrate freely. So a compromise between minimum interference and maximum output has to be found. The traditional single-coil pickup with strong magnets right inside the coil is particularly affected by such unwanted interference. This is why single-coils should never be fitted closer than 3 to 5mm ($1/8$ " - $3/8$ ") to the strings. This does, however, not apply to active single-coils, which don't have a strong magnetic field. Humbuckers with magnets under the coils have to be mounted 1.5 to 3mm ($1/16$ " - $1/8$ ") from the strings. The pickups should not be mounted further than necessary from the strings as this only reduces the output and weakens the pickup signal in relation to the level of electrical noises such as hum. To ensure that both coils of the humbucker are at equidistance from the strings the pickup has



**Setting the action
on radiused fingerboards**

On radiused fingerboards the action has to follow a radius. This means that the saddles on the bridge have to be set higher in the middle. The action has also to increase from the treble to the bass string.



3



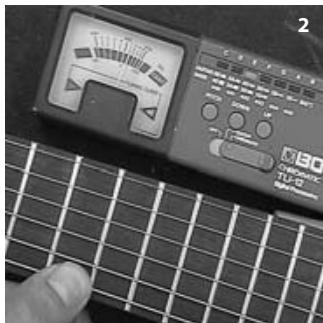
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to be adjusted parallel to the strings (1). For this purpose the bottom side of the mounting ring may have to be shaped accordingly.

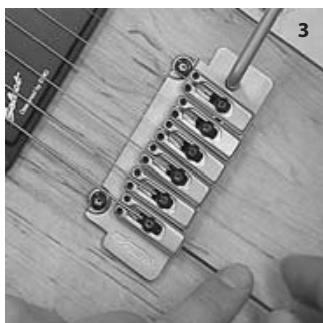
Now play the guitar and listen out for strings that are louder or basses that dominate. Ideally, all strings should produce the same level of volume. To compensate for any differences in volume level between the thicker and thinner strings or to boost bass or treble tones the pickup can also be set lower under the bass strings than under the treble strings. The closer the pickup is placed to the strings, the more the basses will be boosted.

The output volume of individual strings can be increased or reduced by means of adjustable polepieces. These should, if possible, also be set following the fingerboard radius. If the guitar has more than one pickup, a good balance between the individual pickups should be aimed at as well. A pickup mounted on the bridge produces less output; by fitting it closer to the strings or setting the front pickup lower it can, however, be made to sound as loud as the front pickup.



Setting the intonation

The intonation can be set by ear or with a tuner. The purpose of setting the intonation is to make the pitch of each string at every fret as accurate as possible as far as the equal-tempered tuning system allows. This is necessary to counteract the increase in pitch which results from the strings being tensioned when pressed down. The treble strings are more affected by this than the bass strings. To compensate for this change in pitch the length of the freely-vibrating strings has to be increased slightly. With a chromatic tuner you can check the pitch of each individual string at each fret. In doing so you will find that the amount of pressure with which the strings are pressed on the fingerboard strongly affects their pitch. Reaching a precise pitch is virtually impossible if the action is too high. In that case you will only get it by pressing the strings only lightly and exactly onto each fret. This is why, as already mentioned above, the action should be set



rather low. The height of the frets also has an influence on the pitch of a string that is pressed down: the higher a fret is, the more the strings will be tensioned when pressed down and the more they will go out of tune.



Tune the guitar and compare the pitch of a string pressed down at the 12th fret (2) and its harmonic at the

12th fret. This harmonic is exactly twice as high in pitch as the open string and should also be identical in pitch with the string pressed down at the 12th fret. The job now is to make the pitch of a string pressed down at the 12th fret exactly the same as the pitch of its respective harmonic. If the pitch at the 12th fret is lower, the vibrating length of the string is too long and has to be reduced by moving the saddle. If, on the other hand, the string pressed down at the 12th fret sounds higher than its harmonic, its vibrating length has to be increased (3,4). Any changes made at the bridge to increase or reduce the vibrating length of a string will also inevitably change the tuning of the string. So before you continue checking the intonation make sure to tune the guitar first. Carry out this procedure for each string or pair of strings, depending on which bridge you use. To set the intonation very accurately hold the guitar in the playing position as gravity can have an influence.



Correctly-adjusted bridge

In the picture above you can see the typical saddle arrangement of an electric guitar with "normal" action after the intonation was correctly set.

Your self-made guitar

So there we are: the long, hard work of building your own electric guitar has borne fruit – it is finally finished. Even if the action should change within the next few days or weeks and the whole setting-up process should have to be repeated, don't worry too much about it: it is normal for a guitar to take some time to adapt to the pull of the strings and to reach a balance.

All the guitar needs from now on is careful treatment and sufficient attention. Expose it to cold, heat or moisture and it will suffer. It dislikes sudden changes in climate as much as being left lying in a car overnight, and it is best transported in a case or a well-padded bag. Musical instruments have, in that respect, a mind of their own, but they will be faithful and reliable friends and reward the loving care they are given with a beautiful sound.

Send me a picture of your self-made guitar

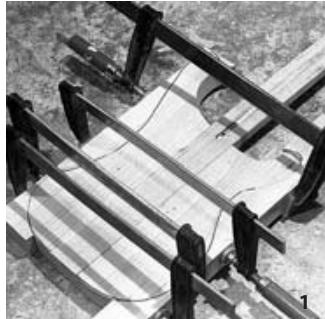
If you have come this far and you are a proud owner of a self-made guitar, it would be great if you could send me a photo of it (either on real paper or in electronic form). I would like to show it together with a short description on my web site: www.BuildYourGuitar.com



Enjoy the first guitar you have built yourself. I would be surprised if it were to remain the last ...

Material needed

For making a straight-through neck you need a long neck blank that is thicker than the body (50mm/2", for instance). This block can be made up of one piece or can be glued together from several strips. The entire block has to be at least as wide as or even wider than the neck at the end of the fingerboard. The body halves will be glued to either side of the neck.



Straight-through neck

Although building a guitar with straight-through neck might appear easier than building one with bolted-on neck, it is actually the more difficult type to build. If you are going to build a straight-through-necked guitar, a bandsaw and a jointer are an absolute must and the sides of the neck block and the body have to be planed perfectly flat.

Everything else can be done as usual. Remember: when making a through-necked guitar you always have to move and work the whole guitar, which basically means more trouble and more work, requires more space and is overall more difficult.

The peghead can be made in the same way as on bolted-on or glued-in necks. In the above picture I simply cut it directly from the neck block at an angle of 10 degrees. The neck should be 19mm ($\frac{3}{4}$ ") thick (leave it slightly thicker to start with, just to make sure) between the neck-body transition area and the nut. Just before the point where the neck and the body meet the neck block has to reach body thickness. To make it easier to shape this curved transition area, choose a curve radius identical with one of your sanding drums. Then cut out the body sides. It is also advisable to smooth the cutaways at this stage.

The pieces left over from cutting out the body can be used as clamping cauls for gluing on the body sides (1). By putting a layer of cork in between you can compensate for any irregularities. The pictures shows a neck that was glued into the body at an angle of only a few degrees to the body surface. For determining the necessary angle it is very important that you make a full-scale drawing on a large sheet of paper. The protruding parts of the neck at the back and the front of the body are sanded down later (3). To get the best action possible you might, however, also glue in the neck at a 0-degree angle and further sand down the part of the neck block after the fingerboard. For details, please refer to the section on design and the following section.

Straight-through necks are shaped in much the same way as other types of neck; only the area where the neck "melts" into the body is slightly more difficult to deal with (2).

Sand protruding parts down to body surface



3 The neck block has to be thicker than the body. It is glued in slightly angled.

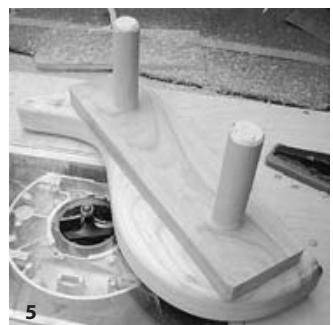
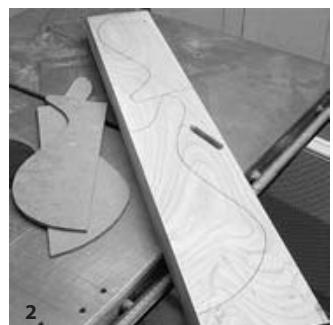
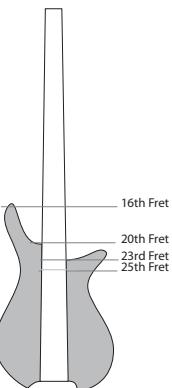
Making a neck-through headless bass

I designed this bass full-scale on a computer monitor using *CorelDraw* before printing the outlines of the body wings onto several separate sheets of paper. By putting a check into the "tile"-box in the print window I got four sheets that could be taped together. I chose the huge cherry plank on the left (1) for the body wings because of its promising grain pattern. After removing wormholes, knots, splits and cracks, and subsequent sawing and planing, all that remained was a narrow piece of wood just long enough to make up the two body wings (2). Three of the four faces were jointed square to each other before the blank was thickness-planed to 45mm (1 $\frac{3}{4}$ ").

After carefully bandsawing the body to shape (3) I smoothed as much as possible on a disc sander (4) before finishing the job with the drum sander. I didn't use the router for smoothing the sides because the relatively small pieces would have brought the fingers dangerously close to the bit. You could try it with safety handles, as shown below (5), but the irregular grain pattern of the body wings makes it very difficult to get smooth sides anyway.

I decided to shape the body wings as separate pieces and before gluing them to the neck blank. This way I didn't have to move around the whole guitar, which I always find quite annoying.

I rounded off the edges with an elliptical round-over bit, 57mm (2 $\frac{1}{4}$ ") in diameter. I didn't take any risks and guided the small pieces of wood that were to become the body with safety handles (5) which I simply taped to the body pieces with two long strips of thin double-stick tape. I rounded off each edge separately in at least three passes. Be extremely careful at the left corners: start the cut about half an inch or so from the corner and cautiously move the wood towards it, i.e. in the "wrong" routing direction. Better round off the last bit by hand than to expose the corner to the revolving bit, which could literally take the whole job out of your hands.





To assist positioning the body wings when gluing them to the neck I drilled two 8mm (5/16") dowel holes into each body wing side (1).

As I have already mentioned it is important to take the bridge height into account early enough when building a neck-through guitar. You can build in a small angle, as described earlier, or you can make a step at the fingerboard end. I opted for the latter, and, after measuring the minimum saddle height - which turned out to be 14mm - and a fingerboard thickness of 6mm made the above drawing.

For making the neck I prepared an almost perfect maple blank (2) with a closed, straight grain pattern: 52mm (2") thick, 80mm (3") wide and 1 meter (3 feet) long. If you aren't making a headless bass, as I am here, add 20cm (8") for the peghead.

I decided to have the truss rod adjustment nut at the head end and to have it covered by the head part of the tuning unit. It is possible to drill an access hole into the head part, but since removing and putting on strings is quite easy on a headless guitar, removing the head part each time when an adjustment is required should be no problem. I was also anxious not to spoil such expensive hardware.

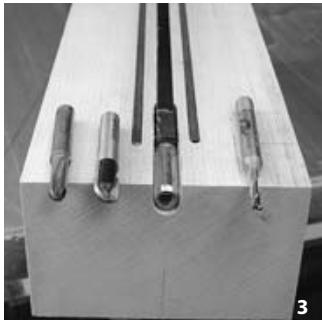
I cut the truss rod slot with a 6mm round-bottom bit (accurately fitting to the truss rod to be used) in order to leave as much wood as possible. An 8mm round-bottom bit made room for the adjusting nut. To add extra stiffness I decided to install two 1¹/₈"x 3¹/₈"x 24" carbon fiber rods in the neck. I used a 1¹/₈" bit for cutting the channels, glued the rods in with wood glue and sanded them flush to the surface (3).

I bought an ebony fingerboard that was already slotted and radiused. For gluing it on the neck I used the simple clamping caul shown in picture 4 (left of the neck blank): under pressure the two cork strips adapt to the fingerboard radius, thus assuring a thin, tight glue line. The slots provide room for the tiny wire brads that keep the fingerboard from slipping during gluing.

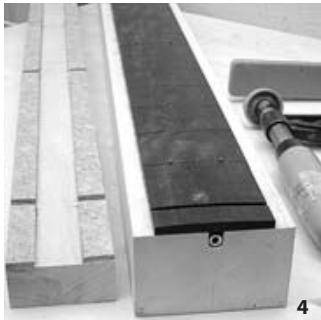
Finally, I transferred the taper of the neck onto the neck blank and carefully planed it on the jointer (5).



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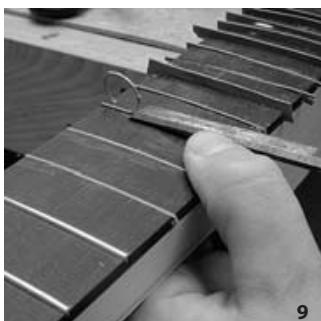
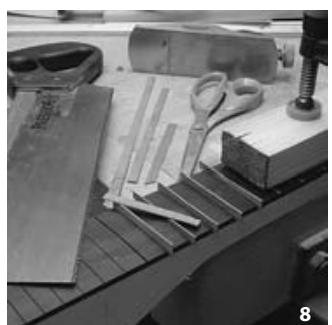
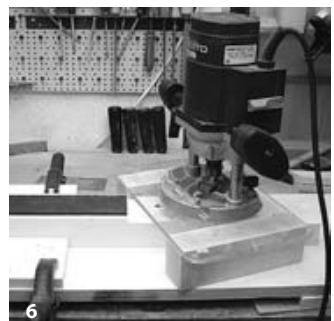
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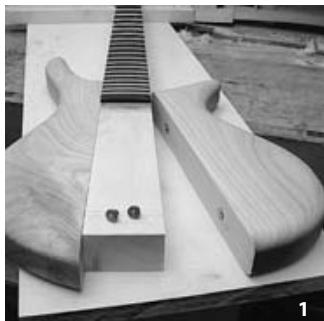
The body offset is best made with a jointer that allows lowering the infeed table by the seven millimeters that are required. Since I didn't have access to such a jointer, I routed the body part down to the right thickness using a big surface trim bit as shown in picture 6.

I used the *Stewart Macdonald* fretting arbor in my drill press for installing the frets. First I seated the fret ends by pressing them in with a tight radius caulk (in this case the radius was 12"). Then I seated the entire fret with a caulk matching the 16" fretboard radius (7). Finally the fret was set firmly on both ends and all the way across the board.

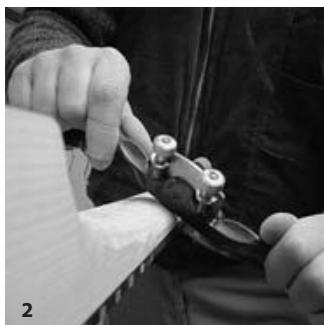
After installing 12 frets I got bored and filled the remaining fret slots with mahogany veneer strips that I had sanded to a thickness matching exactly the width of the fret slots. In this way I got a „normal“ and a fretless bass in one instrument, which I quite like. Such a bass model was already produced by *Ibanez* back in 1983 (or be it without commercial success), so I can't claim to be the inventor of a new model.

Well, to tell you the truth, filling the slots with exactly-matching veneer strips is what I should have done. Since the veneer I had at hand was slightly thicker, I decided to widen the slots with a backsaw (8). However, after gluing in the strips and cutting them flush with a chisel (9) I was not satisfied with my sloppy cuts and had the great idea of using the table saw to cut new, wider slots. Since the neck blank was already tapered, I had to adjust the rip fence accordingly. The first cut was made with confidence - and turned out as not being parallel to the frets. It is in moments like these that I feel like giving up guitarbuilding forever. The extremely wide mahogany inserts that you can see in the pictures on the facing page prove that I somehow managed to correct the slanted cut. Can anything be learned from this? Do as much as possible while the neck blank is square! The same applies when it comes to cutting the neck to thickness (10) which is ideally done *after* installing the frets (I had only 12 frets to install, so it worked for me although I did things the other way round).

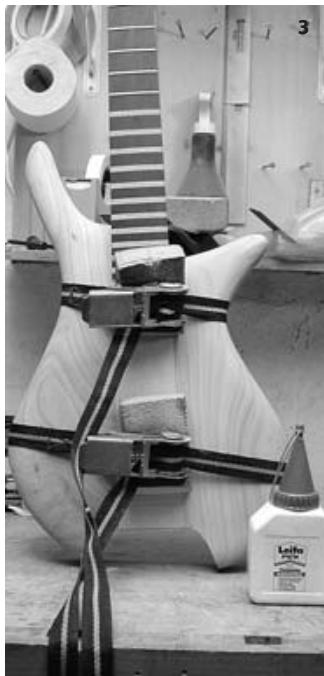




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I marked the holes for the body wing dowels on the neck blank with metal dowel hole markers (1). Such markers are commercially available (at least in my part of the world). For drilling the holes into the neck blank I used the same set-up as on the body wings. If you want to use the drill press, note that the neck blank surfaces are slanted and that the table has to be tilted to get holes that are square to the surface. My “drill-stand method” automatically takes care of that.

Before I glued on the body wings I marked their upper ends on the neck blank and shaped as much of the neck profile as possible (2). Rough-shaping the body-neck transition is also easier without the wings glued on.

I glued on the body wings with the help of two straps such as those commonly used for tying up baggage (3). They give sufficient strength, are gentle to the wood and adapt very readily to the already-shaped body. Since most of the shaping had already been done, little in the way of sanding was required after this.

The other steps of work involved in building a neck-through headless bass don't differ from bolt-on-neck guitars and are described in detail throughout this book.



A visit to ...



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Steve Jarman guitars



Steve Jarman is a guitarbuilder who lives with his wife and their two kids in Bexleyheath, Kent (to the south-east of London).

Although I have never met him in person – we met via the Internet and kept in touch by sending each other the odd e-mail – Steve was kind enough to send me a few photos as well as some information which I'd like to share with you here and now.

Steve works in London where he installs computer systems. In his spare time he builds and repairs instruments. Besides that, he also plays drums in his own band "KUDOS". Among his clients are some London session and country musicians.

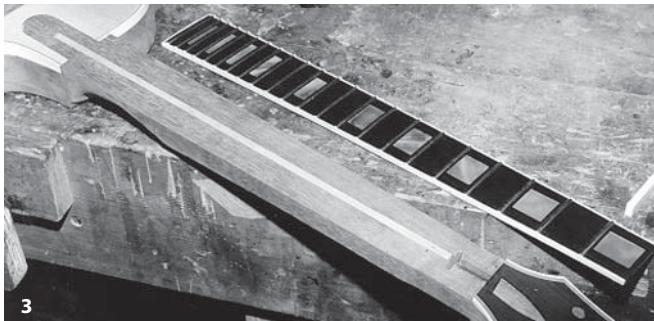
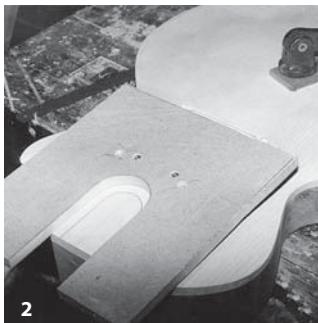
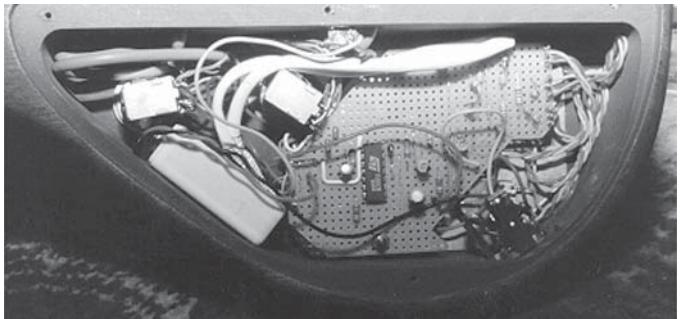
Steve learnt about working with wood from his father and then taught himself how to build instruments by reading books and learning by experience. He feels very indebted to the English guitarbuilder David Cammish from whom he learnt a great deal. When he was only 12, he built his first electric guitar from the wood of an old school-desk. Steve told me that that first guitar of his, though being a bit uncomfortable to play, still looked pretty good. After that he built a bass and a double-neck guitar. Because he didn't have enough money at the time, he would use the same hardware on all his instruments – these could therefore never be played all at the same time! The first order he received was for the body of a double-neck guitar; this was followed by orders for repair jobs, refretting or refinishing. The first complete instrument he built was a bass for the bass player in his band. Through his job in London he met different guitar players for whom he was happy to fulfil their wish to have a "personal" instrument. Steve's guitars cost roughly £1,000, but unusual requests are obviously more expensive.

In his garden Steve built his own 12-square-meter (4m x 3m) workshop. In front of it he has a strong compressor in a weather- and soundproof casing for supplying the workshop with compressed air.

When building his guitars he tries to do as much as possible himself. He even designs and builds the electronics of his guitars

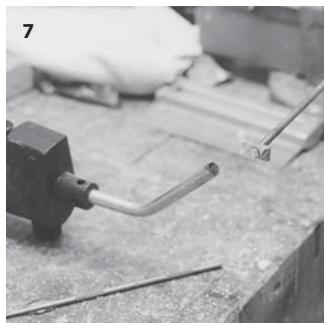
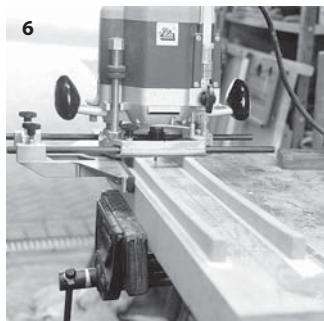
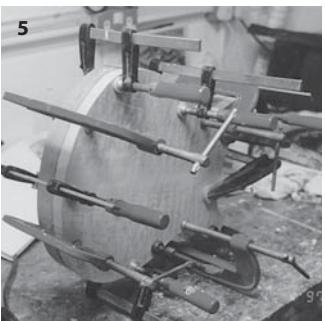
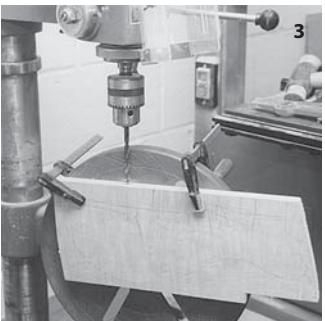
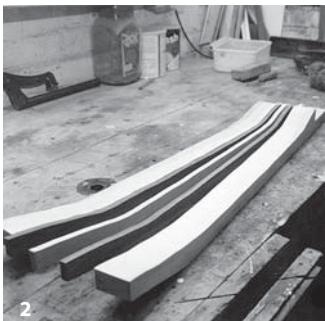
himself, tailoring everything to the individual needs. Although most of his clients order copies of well-known models, Steve's guitars are always tailor-made to the individual. The client is invited to come and play on the guitar after it has been test-assembled for the first time and Steve marks all the areas that feel uncomfortable during playing with a pencil. Then he disappears in his workshop to work on the neck, and when he returns the procedure starts all over again. With a bit of luck these individual adjustments can be made within two to three hours and a very pleased client will leave, "grinning from one ear to the other", as Steve says.

Such a standard of service would obviously not be available when buying an off-the-peg instrument.



Les Paul copy
(1) The electronic channels are cut before the top is glued on.
(2) Template screwed down at the front-pickup position for cutting out the neck pocket. Note that the template has been raised on one side by inserting a shim.
(3) The neck is glued into the body before the fingerboard is glued on.
(4) Steve at work scraping the fingerboard binding flush with a knife.





PRS copy

(1) (2) The neck consists of several strips glued together with the help of several clamps.

(3) Drilling dowel holes into the sides of the body-top halves. The dowels facilitate positioning the two halves when gluing them together.

(4) Cutting the electronic channel before gluing on the top with the help of plenty of clamps (5). After the pickup cavities have been routed this channel becomes accessible again.

(6) Routing a curved truss rod channel.

(7) Hard-soldering (brazing) of the truss rod anchor. This anchor nut must under no circumstances come loose later.

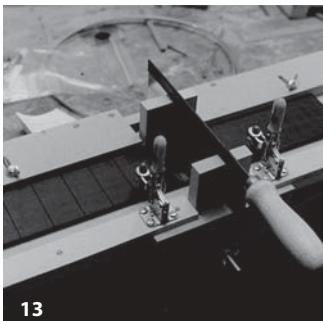
(8) The body and the neck before being glued together. Note the small step at the end of the neck heel which will extend under the front pickup to make the gluing area larger.



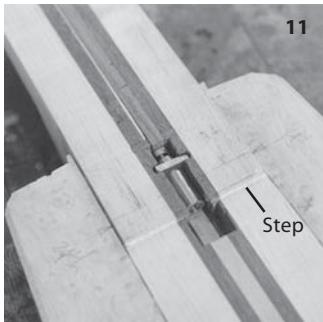
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13



11

(9) If the router is mounted separate from the body, a domed surface will not be a problem for routing a binding rabbet, and the rabbet will be evenly deep and parallel to the sides. If the router can additionally be moved up and down, even different-height sides will not be a problem. In that case a stop stopping the router at the top edge of the body will be required, though.

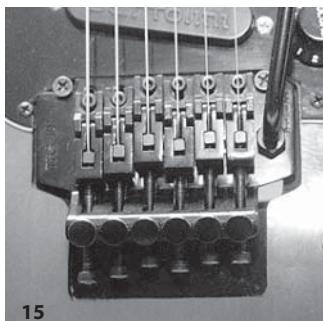
(10) The inner purfling is glued on with acetone first, then the binding.

(11) Cavity for access to truss rod adjustment nut on a headless bass with straight-through neck. The small step at the end of the fingerboard, which is needed because of the height of the bridge, is clearly visible.

(12) Planing the peghead flat with a plane before veneer is glued on.



12



15

(13) Steve's jig for cutting the fret slots: the saw remains perfectly vertical at all times and all the fret slots become evenly deep because four distance blocks stop the saw. Similar jigs are commercially available from guitarmakers' suppliers. Steve, however, had already invented his own before he became aware that they already existed! In the section on making the neck I explained how to cut fret slots with a tablesaw and a template fastened on the top side of the fingerboard. With a jig such as Steve's you can achieve the same result by fastening a fret template on the bottom side of the fingerboard. Put the template plus fingerboard into an index pin fastened at the side of the jig and move it on fret by fret after a slot has been cut.

(14) Template for routing out a cavity under a suspended tremolo. To allow bending a tremolo backwards a cavity has to be cut into the body under the tremolo.

(15) A mounted Floyd Rose tremolo with cut-out cavity. The strings are clamped at the nut and the tremolo and the guitar remain in tune even after extreme operation of the tremolo. With the fine tuners on the tremolo the strings can be tuned after clamping.



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Sadowsky guitars

Sadowsky Guitars is based in a quite unusual place for guitar-builders: on the tenth (top) floor of an old skyscraper on Broadway / 48th Street, close to Times Square, in the middle of New York City. Roger Sadowsky started building acoustic guitars in 1972 and then worked in the repair trade in Philadelphia for 5 years before founding his own company on Broadway in 1979. Around 1980/81 he first thought of developing his own guitar models and building them, but found that among his clients and on the market in general there was a particularly great demand for Fender basses. They were liked best by sound engineers in recording studios because they caused little trouble. As a result, *Fender Jazz Basses* or *Precision Basses* were generally preferred for recording.

Roger Sadowsky's basses are identical in shape with the *Jazz Bass* but have a slightly smaller body than the original and are therefore somewhat lighter. While the neck is almost a copy of the original, the shape of the peghead is unique and the trademark of his models. With these models he reflects the predominantly conservative tastes of bass and guitar players, and success has proven him right.

The door to the workshop is open for everybody from 9 to 5, Mondays to Fridays, and visitors are always welcome. Sadowsky employs five full-time staff and one part-time worker. The workshop is split up into several sections. Expensive wood with beautiful grain pattern is stored on the corridor next to the entrance. Another area serves as a repair-workshop and a third one is equipped for spray-finishing in the course of repair jobs, a dust collector exhausting the dust and fumes from the 10th floor straight into the clean air of New York. The main area of work of *Sadowsky Guitars* is repairing guitars; this also explains its rather unusual and expensive location: being situated so close to all the big recording studios on Broadway is indeed a great advantage when an urgent repair job is called for.



In the picture on the right you can see Roger Sadowsky filing a bone nut, and the one below shows Ken Fallon, the Vice-President of *Sadowsky Guitars*, at work, tuning and setting the intonation of an acoustic guitar that has just been repaired.

Repaired instruments are stored in a separate room, and the bodies are fine-sanded in another. In the rear of the company premises there is a showroom where one of each of the models that can be ordered should be on display on the wall, waiting for a potential buyer to check them out. The walls are covered with greeting cards and pictures of musicians singing the praises of Sadowsky's instruments. Seeing so many well-known stars gathered there in this way was very impressive.

Before visiting *Sadowsky Guitars* I had expected to find all stages of the guitarbuilding process gathered there, on the New York premises. But like many other major guitarbuilding companies *Sadowsky Guitars* has moved with the times and has "outsourced" many steps of work: well wrapped up, the different parts leave the house several times to be given their final shape in workshops all over America. Neck blanks and fingerboards are sent to a CNC-router from where the custom-built necks return, with installed truss rod and glued-on and slotted fingerboard. Only first class timbers are used. The maple necks are made from flatsawn timber. The truss rods are ordinary compression rods. Rosewood or pau ferro are used for the fingerboard. The neck is then fine-sanded and fitted with frets on the 10th-floor premises in New York. Particular care is given to fret dressing.

The picture on the right shows Norio Imai, who, after attending a guitarbuilding school in Japan, joined Roger Sadowsky in 1990 and has been working for him ever since. Here he is busy dressing the frets. Being a left-hander, he finds working with the fret press with its right-hand side arm difficult; he therefore prefers the traditional method of knocking the frets in with a hammer. Otherwise all the frets at *Sadowsky Guitars* are pressed in. The neck that Norio is working on has some tiny imperfections which have been pencil-marked by the boss himself and need to be corrected.

The bodies are also routed outside New York. After returning there, the alder or swamp ash bodies, often with a figured maple top with pretty grain pattern, are carefully fine-sanded. Then the bodies and the necks leave the New York premises again for finishing before they return one more time for assembly, setting-up and testing. All being well, they are then sold and never to return again.

One of the specialities of Roger Sadowsky's guitars is the built-in active electronics system. The picture on the right shows Chris Swope fitting such active electronics on the bass of one of Sadowsky's clients. Chris, who started as an amateur guitarbuilder, has been working for *Sadowsky Guitars* since 1995. Before applying for work with his present employer he built his first



guitars by assembling ready-made *Warmouth* necks and bodies. He told me that he considered the fact that he had had no special training when he joined *Sadowsky Guitars* as an advantage because he could learn everything from scratch and did not have to change any of his ways of doing things. All the work at *Sadowsky Guitars* is done with the greatest care. With his good reputation at stake Roger Sadowsky understandably demands work of the highest quality from his employees – a 3000-dollar guitar obviously has to be near-perfect.

Sadowsky Guitars also builds *Strat*-style guitars with beautiful curly-maple tops. Another model which is in high demand is a feedback-free Electric Nylon String Guitar with piezo pickup.

PRS guitars

Paul Reed Smith Guitars
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PRS Guitars is based in the U.S. state of Maryland, about two hours east of Washington D.C. by car. Soon after Annapolis and after crossing the 4-mile (7km)-long bridge spanning Chesapeake Bay you get to Stevensville, where the *PRS* factory is situated within a large industrial park on the outskirts of town. When I was there, the air in this area was unpleasantly muggy and humid. A huge gas tank in front of the building is needed to heat the factory and to keep the humidity of the air inside the factory at a constant level (55 per cent). There are guided tours every Tuesday, Wednesday and Thursday starting at 1:30 p.m.

Paul Reed Smith, the founder of the company, is himself a musician; he built his company, which now employs more than 70 people and is known across the globe, virtually out of nothing. He built his first guitar as a school project and got an "A" for it; it is now on display in the lobby of the factory.

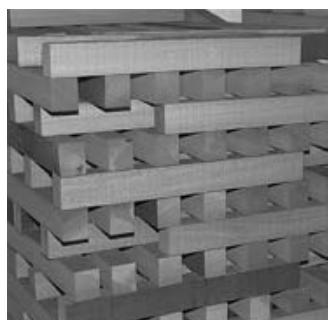
Being a good cross between a *Fender Stratocaster* and a *Gibson Les Paul* with a scale length of its own (25"), *PRS Guitars* combine "the best of two worlds". The beautiful timbers used, the first-class finishing, the quality of work and the good sound have earned these guitars world-wide fame. But to get there was not easy. Paul Reed Smith writes that when he started he used to



hang around for hours at the local concert arenas trying to make friends with the roadies who set up the stage, hoping to get a backstage pass which would enable him to peddle his guitars to whoever was playing that night and to have them checked out by a star. In this way he would manage to sell about one guitar in ten nights. With his first guitars he drove around, from music shop to music shop, until he had got enough orders to start his own company. With the help of his wife, assistants, engineers, lawyers, salesmen, machinists and friends he acquired the necessary know-how and capital enabling him to finally found *PRS Guitars*.

These days *PRS Guitars* has its own wood buyers who supply the company with wood from all over the world. In well-heated rooms this wood is then rough-cut to the dimensions needed for the bodies and the necks, as well as being stored and dried to about 5 per cent moisture content. In the so-called "private stock" the most-beautifully-grained wood can be found, which is only used for the tops of very special guitars. I also saw big stacks of first-class rosewood fingerboards, just waiting to be used.

The bodies are glued together with a special UV-glue that hardens within 60 seconds when exposed to an electric current. Most *PRS* guitars have a maple top glued onto a mahogany body. After the body has been rough-cut on the bandsaw it is moved to a CNC (computerized, numerically controlled) milling machine.





The rough-cut neck is then dried a second time now. Its strange-looking shape makes stacking easier.

PRS Guitars uses computer-controlled milling so that the typical *PRS* body shapes can be cut from the blanks in a very short time. The movements of the milling machine, moving line by line and layer by layer over the wood surface, can be followed in a long coordinates list displayed on a computer screen.

The router table with the body fastened on it can be moved forward, backward and sideways, and the router itself can be raised or lowered by computer. The whole appliance is placed behind two glass sliding doors and has a system for collecting wood chips integrated into it.

But before the curve is routed, the body is placed with the top facing downwards on the table and the body, the electronic cavity and the tremolo spring cavity are cut out.

In the same (computer-controlled) way the necks plus angled peghead are cut from one single block of wood.

By manufacturing the guitars on the assembly line, where a lot of people do the same bit of specialized work every day, 700 guitars are made each day. The workers have a four-day, 40-hour working week.

After the body has been routed it just needs fine-sanding.

Because the body has two horns and the front pickup is fitted right next to the end of the fingerboard, the neck has a specially-shaped heel which allows inserting the heel under the neck pickup. Small pieces of wood are glued to the peghead to save material. After the truss rod has been installed the fingerboard is glued on and the entire neck is fine-sanded. The frets are pressed in after the application of a bit of glue on the fret ends.

PRS Guitars' great speciality is finishing. All bodies are stained with a mixture of water- and alcohol-based stains to highlight the pretty grain pattern of flamed maple or curly maple. Before the finish is applied all the grease is removed from the wood by wiping on naphta and at the same time the "highlighted" surface is carefully inspected for flaws. The man who does this (pictured on the left) takes his job very seriously.

The top of the body and the fingerboard are masked with tape and several coats of finish are applied. Regular sanding is required in between coats. These are applied in the following order: first three coats of polyester finish, then the color coats and finally four coats of polyurethane finish. The thickness of





each coat is carefully measured and all coats are applied as thinly as possible. After the final coat has been applied the guitar is hung up for some time and allowed to dry before being buffed and polished to a perfect finish on big buffing wheels.

The mounting of the electronics made me think of an operating room: the entire body as well as the neck and the peghead of the guitar were fully covered with a cloth and only the control cavity was visible.

PRS Guitars even winds its own pickups. On the self-developed winding machine three coils can be wound at a time before they are fitted together in pairs as humbuckers. As I noticed with envy, *PRS Guitars* has no difficulty getting hold of flat magnets – the large quantities they need put them in a better position in that respect than the smaller guitarbuilder who needs much smaller quantities. All kinds of flat magnets, ceramic ones as well as Alnico 2, 4 and 5, are there, all ready for use.

The wound pickups are exposed to a vacuum in a hot wax-bath; this serves to remove any air from, and to better saturate, the windings. The wax is kept from getting too hot by means of glass marbles floating in it and cooling it down.

As so often with things you enjoy, the guided tour I took part in at *PRS Guitars* was over far too soon. And although I got a good general idea of what goes on there, some questions about details I wanted to ask only came to mind when it was too late.

Taking pictures in the finishing room was not permitted for reasons of safety. If you are interested, *PRS* will send you a 15-minute "factory video tape" (VHS-NTSC format; cost: approx. US\$ 5) that will also give you an insight into the production process at *PRS Guitars*.

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rec.music.makers.builders

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LUTHIERS-ORGANISATIONS

Two American associations that hold sessions and workshops. For an annual member fee you'll get a magazine four times a year which is full of interesting and inspiring articles written by members.

Guild of American Luthieries (GAL), 8222 S. Park Ave., Tacoma, WA 98408, USA, www.luth.org

Association of Stringed Instruments Artisans (ASIA), 14 S.Broad St., Nazareth, PA 18064, USA, www.guitarmaker.org

Suppliers

Finding suppliers of materials you need can be quite laborious; however, the relevant technical magazines, both national and international ones, and their advertisement sections can be a useful way of getting what you want. The "Yellow Pages" might be another one. How easy or difficult it is to get hold of the materials you need, may, unfortunately, depend very strongly on the area where you live. International mail-order firms could be one way out of this problem. A lot of things can also be obtained from music shops, or be it at a higher price.

Suppliers mentioned in the book

Stewart-MacDonald's Guitar Shop Supply, 21 N. Shafer St., Box 900, Athens, OH 45701, USA

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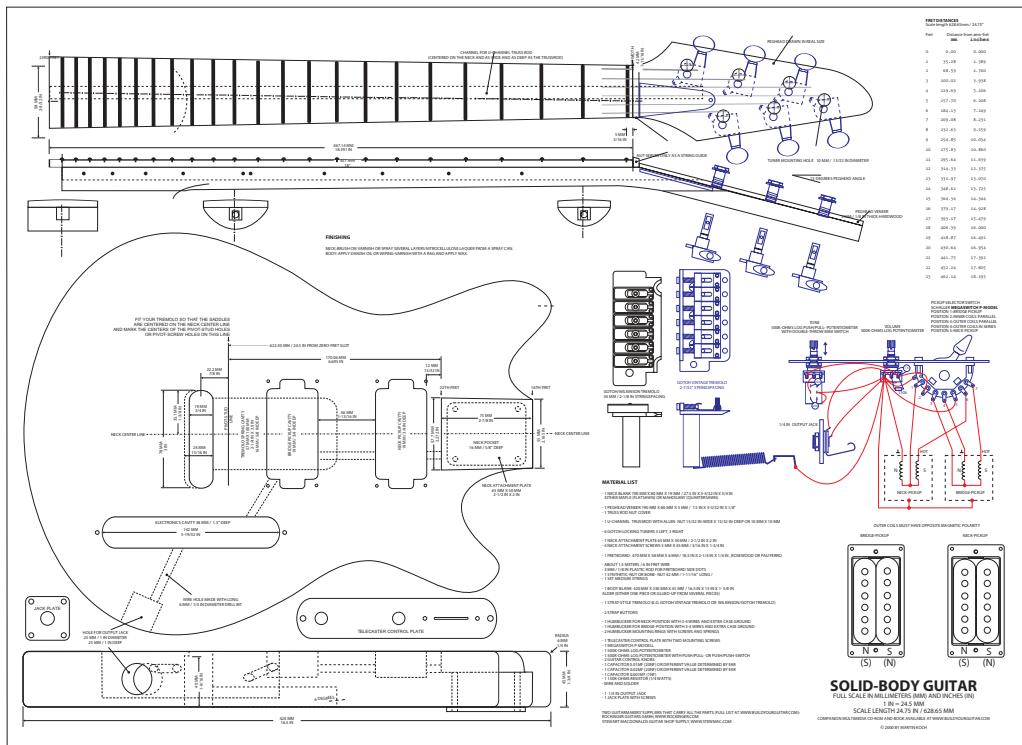
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Additional instruction materials

The author also offers additional instruction materials:



Solid-Body Guitar Plan

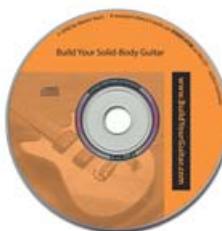
Full-scale plan for a 2-humbucker guitar with tremolo and bolt-on neck (shown on page 81)

- 24.75" scale length - Separate fingerboard - Fret placement chart - All measurements in inches and millimeters -

Bolt-on neck - Angled peghead - Locking tuners - Zero-fret - Straight string line from the saddles to the tuners

- U-channel truss rod - Head-end truss rod adjustment - Two humbuckers - Push/Pull Potentiometer

- Strat-style tremolo - Wiring diagram (PRS-circuit) - materials list



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Find more information about this products at the web site www.BuildYourGuitar.com

Acknowledgements

Thanks to all those who have so willingly shared their knowledge with me and kept answering my questions, and to those who, through sharing their ideas and suggestions, have helped me to make progress. Here are a few names of guitarbuilders who I have never had the chance to meet personally, but who I have been in contact with via the Word Wide Web and who, through emails, have contributed to expanding my guitarbuilding knowledge. Thanks in particular to:

Steve Jarman, guitarbuilder, Bexleyheath, Kent, GB

Thomas Dramm, DRAMM-Guitars, Asbach, Germany

Thomas Stratmann, Stratmann Guitars, Hannover, Germany

Thanks also to *Bruce Johnson* for his stimulating articles in the Internet-newsgroup *rec.music.makers.builders* and the German author *Helmut Lemme* for sharing his guitar electronics knowledge.

Thanks once more to *Thomas Dramm* for reading the German version so carefully, and for his many suggestions and to *Cara Smith* for her support in correcting mistakes of the English version.

Many thanks to my good friend *Franz Luttenberger*, who very conscientiously translated this book from German into English. Without him this book would have stayed very regional.

And last but not least, I would like to thank my wife *Brigitte* for her support in correcting mistakes and help in taking pictures.



Even the busiest author has to leave his/her workplace from time to time, but not everyone has a co-author that takes over his/her place immediately. So if you find misspellings or such meaningful letter/sign combinations as "b, „fvdzf", ... don't blame me - blame Markus, who was eleven months old at the time when this book was being finished.