Basic Guitar Setup 101 Abridged

Charles Tauber
Copyright 1996
Revised May 2015
charlestauber.com

“Things should be as simple as possible, but no simpler.”
- Albert Einstein
Preface to the 2015 Revision

The original version of this article, Basic Guitar Setup 101, was written in 1996 at a time when relatively little information was publicly available to the aspiring luthier, repair person or do-it-yourselfer. It was a time before Google, Youtube, Photobucket, Twitter and Facebook and the widespread use of multi-media on the internet: it was a time when internet discussion groups were text-only usenet newsgroups. Consequently, when this article was originally “published” to the usenet group rec.music.guitar.acoustic, it contained no pictures or illustrations since they were unsupported in the text-only format of usenet groups.

This article was written in response to the many repetitive questions that were posted to the usenet discussion forums. After repeatedly answering many of the same questions on the subject of guitar setup, I thought it expedient to put the answers down in a single article, rather than repeatedly address them one at a time. Once published, readers could then be pointed to the article, saving everyone time and effort. The article was well received and since then has been freely copied, posted elsewhere and referenced in other articles on the subject.

Since that time, many people have added to the available information on the subject. There are now many articles, some of which bear a remarkable resemblance to this one, as well as many how-to videos, photos, webpages and other on-line resources, all found via a simple search of the internet. Some of that information is wonderful and is information I wish I had had available when I was first learning. However, regardless of the amount of information now available, and the ease with which it can be found, the same questions are still being repeatedly asked in today’s discussion forums, making this article as relevant today as it was when it was first written.

This article, then as now, is intended as instruction for both those wanting to perform the work themselves as well as for those who do not want to do the work themselves but want to educate themselves to be able to speak knowledgeably with the luthier or technician who will do the work. As with previous revisions, you are welcome to share this article with any who are interested or quote portions of the article. In return I ask only that you provide me with credit as the author.

Over the years, this article had grown to near book-sized proportions to include information of relevance to aspiring luthiers and guitar design. In this revision, I have returned the article to its intended purpose of being a no-nonsense how-to guide dedicated to the basics of guitar setup. In so doing, I have removed most of the theoretical discussion, particularly of intonation and temperament, and eliminated discussion of the more “esoteric” subjects of compensated nuts and elements relevant to those who are designing guitars.

I hope you find the article useful. Should questions arise while reading the article, feel free to contact me at charlestauber@yahoo.ca.

Charles Tauber, May 2015
1. Introduction

This article is intended to provide an introduction to those wanting to understand the basics of adjusting a guitar to play well. These adjustments are called basic guitar setup. Once the basics of guitar setup are understood, one can use that knowledge to perform the work oneself or one can use that knowledge to better communicate with a professional who has been commissioned to do the work.

Those commissioning a professional luthier or repairperson to perform the setup work can expect to pay anywhere from about $50 to $150 for a professional setup. The variation in cost is due to the level of experience of the person doing the work, their geographic location and, sometimes, the level of demand for their work.

Many of the techniques and much of the theory that I have outlined within this article is based upon what I have learned from those generous enough to share with me what they knew. The techniques I have described are only one way of doing things; there is no one right method, though some methods are quicker and easier than others. What is more important than rigidly adhering to a set of techniques is to understand the theory behind the techniques. Understanding the theory provides you with a basis for separating the facts in guitar setup from the abundant mythology. Once you understand what you are trying to accomplish (the theory) you can adopt, or adapt, specific techniques for accomplishing each task.

While the following discussion strictly applies to steel string acoustic guitars, the basic theory is the same for classical and electric guitars, as well as a wide variety of other fretted string instruments. Also, be aware that, as the title of this article implies, the information contained in this article is an introduction to, rather than "the final word" on, guitar setup.

2. The Four Adjustments

There are four basic, universal adjustments that affect the playability of every guitar. These are as follows:

1. Adjusting the amount of relief (or "bow") in the neck
2. Adjusting the string height at the saddle
3. Adjusting the string height at the nut and
4. Adjusting the intonation.

These four adjustments are what I refer to as "basic guitar setup".

In contrast with "repair" work, which is work that may need to be uniquely performed on a specific instrument to maximize the playability of that particular instrument, setup work is a series of adjustments that need to be performed at least once on every guitar. Very few manufactures take adequate time to properly perform these adjustments. Even when manufacturers do, the setup is very general and aimed at the "average" player, rather than the specific preferences of an individual player. Thus, it is nearly always worthwhile for a guitar owner to have his or her guitar setup to suit his or her specific preferences.

Before discussing each of these four adjustments, along with the minimum of theory necessary to support the "how" and "why" these adjustments are made, lets look briefly at the tools required to make these adjustments.

3. Tools

Those intending to undertake the work themselves will need to acquire at least a minimum set of tools to assist them in conducting the work, as well as a minimum level of skill in using those tools, something that takes time to acquire. Whether or not one should undertake the work oneself depends upon one’s desire to do so and one’s aptitude for doing the work. For many guitar players, it is a much easier - and less frustrating - to pay a professional luthier or repairperson to do the work. That said, the individual might choose to perform only some of the simpler aspects of the setup - such as truss rod adjustment - and leave other aspects to a professional.
Despite what some luthier-supply houses would have you believe, basic setup work can be accomplished quite successfully using only a small number of simple, inexpensive tools. What tools one needs depends, in part, upon how much of the setup work one wants to do. A minimal set of tools sufficient to perform full setup work can be assembled from as little as $100 or so. However, if one intends to do a lot of setup work, the cost of purchasing a few specialized tools will more than pay for itself in the increased efficiency of using those tools.

A minimal set of tools sufficient for guitar setup work is shown below and consists of the following:
- Vice of your choosing to hold nuts and saddles
- X-Acto knife handle and saw blade
- Teardrop-shaped needle file
- Standard single-cut bastard mill file
- Standard woodworking file
- Short 6” metal ruler and a 36” long metal ruler, preferably calibrated in both inches and millimeters,
- Standard set of feeler gauges
- 0000 grade steel wool
- Various grits of sandpaper - 80 to 600 are useful
- Home-made sanding block
- Allen keys (metric and inch) and hexagonal socket wrenches for adjusting truss rods

In the 1990’s specialized, gauged files were introduced for filing nut slots. These files are available in a variety of widths intended to match the various diameters of guitar strings. More recently still, saws have been introduced that produce a kerf (cut width) that is equal to some common diameters of guitar strings. (The saws cut slots much faster than files do and is my preference.) Individual nut files sell for about $13 each, while individual saws sell for about $9 each. Buying a variety of sizes to match specific diameters of strings can quickly become an expensive investment for someone wanting to do only one or two setups. While these can save time for the professional performing many setups, an equally good job can be accomplished using the age-old methods of instrument makers prior to these specialized files and saws: a simple $10 set of needle files will work quite adequately. As with needle files, gauged files can be used with a stroke that widens the slot beyond the actual thickness of the file, allowing one file to produce a variety of slot widths, thereby reducing the number – and cost - of files necessary.

These days, there are many makes and models of electronic tuners from which to choose. Most tuners that are calibrated in cents – 1/100th of a semitone – are adequate for setting-up intonation. For those interested in “perfection”, and more detailed investigations into intonation, an expensive strobe tuner is required.
4. Neck Relief

When reduced to its simplest, the mechanics of the guitar is essentially a set of vibrating strings that are stretched across a (semi) rigid structure. To understand guitar setup, it is helpful to know a little about both the vibrating strings and the structure across which they are stretched.

The tension imposed on a guitar’s strings is maintained by fixing each end of the strings: one end at the head and the other at the bridge. While at rest, due to the tension imposed upon each string, each string forms a nearly perfect straight line between its end-supports - the nut at the head and the saddle at the bridge. For a guitar, the vibration of a string is initiated by displacing a string from its rest position - the straight-line position it assumes while it is at rest and under tension - and then releasing it. The elasticity of the string, and the tension imposed upon the string, causes the string to overshoot its natural rest position until it reaches nearly the same displacement in the opposite direction. Due to a "loss" of energy with each overshoot, the amplitude of the string diminishes (decays) until it eventually returns to its rest position.

The general shape assumed by the vibrating string is that of a shallow curve that begins at one end of the string, is a maximum at the string's mid span, and ends at the other end of the string. Thus, (theoretically) there is no displacement of the string at the nut or saddle, and there is a maximum displacement near the 12th fret, the string's theoretical midpoint.

The amplitude of a vibrating string depends upon several factors including string tension, string material and the initial displacement of the string (i.e. how heavily the string is plucked or struck). For example, the same set of strings when tuned below concert pitch will have a greater amplitude than when at pitch. Similarly, a lower tension string (such as "silk and steel", or light gauge), when tuned to pitch, will have a greater vibrating amplitude than a higher tension string (such as phosphor bronze, or medium gauge) tuned to the same pitch. Any string type will have a greater amplitude if struck harder (i.e. given a greater initial displacement). Thus, the amplitude of the vibrating strings will vary depending upon the type and gauge of strings used and the player's "style" of playing.

To accommodate the amplitude of the vibrating string, there are two options: either raise the height of the strings (the "action") sufficiently that the bottom of the vibrating strings do not touch the tops of the frets, or make the top of successive frets assume the shape of the vibrating string. The string height can be minimized by doing the latter, which reduces the distance that the strings must be depressed for fretting. This, in turn, makes the guitar easier to play.

Practically, the way in which the tops of successive frets are made to conform to the amplitude of the vibrating strings is to introduce a slight curvature to the neck. This curvature, which is a slight upward concavity, is usually referred to as neck "relief". The amount of neck relief required depends upon several factors, including string height, and, of course, string amplitude. If the string height is sufficiently great, no neck relief is required; the vibrating strings will clear the tops of the frets regardless. This, however, increases the distance that the strings must be depressed, which makes the guitar harder to play.

Since the amplitude of the vibrating string depends upon the type and tension of strings used and the "attack" used to displace the strings, the amount of neck relief must also depend upon these same factors as well as the individual preferences of the player. While there is no one universally correct setting for neck relief that accommodates all the variations of these factors, as a general guideline, approximately .010" of relief is typical. This is generally measured at a fret that is at the mid span of the neck (typically the 7th fret) and is the distance from the top of the fret to the bottom of a string when the string is fretted at the first fret and at a fret where the neck joins the guitar body, typically the 14th fret.
By simultaneously depressing a fully-tensioned string against the 1\textsuperscript{st} and 14\textsuperscript{th} fret, the string forms a straightedge spanning the 1\textsuperscript{st} and 14\textsuperscript{th} frets. Alternatively, a metal straightedge can be laid along the fingerboard (on top of the frets) and the distance measured from the top of the 7\textsuperscript{th} fret to the bottom of the straight edge.

I rarely measure the amount of relief. Instead, I prefer to use the index finger of my fretting (left) hand to hold down a string at the first fret and use my small finger of my right hand to hold down the same string at the fret where the neck meets the body. I then use the index finger of my right hand to press on the string directly above the 7\textsuperscript{th} fret. By pressing the string against the top of the 7\textsuperscript{th} fret I can visually gauge how much relief there is. With experience, it is unnecessary to measure that small distance with comparative devices, such as feeler gauges, calipers, or a dial indicator. Instead, it can be measured visually and by feel with sufficient accuracy and repeatability.

For a guitar equipped with an adjustable truss rod, adjusting the amount of neck bow is quite simple. While there are a number of designs of adjustable truss rods, each shares the same basic principles of operation. Specifically, when a threaded nut is tightened on a threaded metal rod, the resulting tension in the rod alters the curvature of the neck in which the rod is embedded. Adjustment of the rod involves tightening or loosening the nut on the rod.

Tightening the nut increases the tension in the rod, and consequently increases the amount that the rod counteracts the pull of the strings, thereby reducing the bow in the neck. In recent years, a “double-acting” rod has become popular in which tightening or loosening the nut will enable the rod to curve in either direction, rather than the single direction achievable with other designs.

The truss rod nut may be located at either end of the rod, at either the guitar’s head or from inside the sound hole. At the guitar’s head, the nut is often concealed under a small plastic or wooden plate, fastened with small screws. From the sound hole, the truss rod nut may be directly accessible through a hole in the cross brace, or may be located at the heel block, often accessible only by completely loosening the strings. To tighten or loosened the nut, you will require either an Allen key or specialized socket wrench. Standard Allen keys are available at most hardware stores and specialized socket wrenches for this purpose are available for several dollars from luthier supply houses. (Some manufacturers will include an appropriate wrench or key, particularly if they use a nonstandard arrangement.)

Since the amount of string tension imposed upon the neck changes the curvature (bow) of the neck, whenever possible, the adjustment should be done while the guitar strings are at full tension. Where this is not possible (e.g. some Fender electric guitars) it is an iterative process in which an adjustment is made with no string tension and then the measurement is taken after the strings are returned to full tension. This is repeated until the adjustment is correct.

The required number of turns of the nut depends upon the amount of bow in the neck, the truss rod design and its installation. Regardless, the adjustment required rarely exceeds one or two full turns of the nut, and is usually
less than one. Usually, when viewing the nut from the end at which it is adjusted, turning the truss rod nut clockwise tightens the nut and turning it counterclockwise loosens the nut. However, in some truss rod designs this may be reversed. Consequently, if in doubt, simply turn the nut half a turn in one direction to observe which direction tightens the nut.

Despite popular mythology, there is no need to turn the nut a quarter of a turn and then wait over night to see the result before making any further adjustment and waiting again over night, iteratively. Instead, simply turn the nut as necessary to provide the required relief.

Ensure that you are using the correct size of key or wrench for the nut, else you run the risk of damaging the nut and making further adjustment difficult. In some cases, some amount of force is required to turn the nut. Use common sense on the amount of force to apply. If in doubt, take the instrument to an experienced repair person who can instruct you on how to adjust the nut.

In addition to this adjustment, it is often helpful to sight down the neck - from nut to sound hole - to observe the "trueness" of the fingerboard and to identify any frets that may not be fully seated. A true fingerboard is one that has no bumps or hollows along its length (i.e. is "flat"). For guitars with a joint between the neck and the body, it is a common fault to have a hump in the fingerboard just beyond the joint, typically beyond the 14th fret. The truer the fingerboard, the lower the string height can be set before the strings buzz against the frets. For guitars with either no adjustable truss rod, or that have sufficiently untrue fingerboards, the remedy is the same; remove the frets and dress (true) the fingerboard, followed by refretting. This procedure is "involved" and takes a skilled repair person several hours to complete. Hence, truing of the fingerboard will not be discussed in this article. By contrast, adjusting the truss rod is a trivial adjustment that can be performed by the layperson in minutes.

It is very important to understand how changing the amount of bow in the neck affects the height of the strings relative to the tops of the frets. Ideally, from the point of view of ease of playing, the guitarist desires the fingerboard surface to be straight ("true") along its length and parallel (or nearly parallel) to the bottom of the guitar's strings. This would result in the strings maintaining a constant distance above the fingerboard along the fingerboard's entire length. This, in turn, would require a uniform effort to depress the strings and would provide the greatest ease of playing.

If a curvature (bow) is introduced into the fingerboard (and neck), the strings will no longer be a uniform distance from the tops of the frets; some places along the string will be closer to the frets, while others will be farther away.

If the curvature is concave upwards ("bowed"), the strings will be at their maximum height above the tops of the frets at the mid span of the curve, as shown in the lower of the two models shown in the figure above. Conversely, if the curvature is concave downwards ("back bowed"), the strings will be at their minimum height above the tops of the frets at the mid span of the curve, as shown in the upper model in the figure above. The characteristic symptom of an excessively bowed neck is a high action at the nut that becomes higher around the 7th fret. The characteristic symptom of a back-bowed neck is fret buzz in the middle frets, around the 7th fret, and buzzing of the open strings against the first fret. Often, action exhibiting either of these characteristics is a result of an incorrect neck bow, and is "fixed" by adjusting the bow in the neck.

It is important to note that the curvature of the neck affects the string height at both the nut and at the middle frets. It is, therefore, essential that the correct amount of neck bow be set before any adjustment of the string height at the nut or saddle. While the amount of bow affects the string height, it should not be used to
specifically attempt to adjust the string height at either the nut or saddle. Adjusting the amount of neck bow is a separate adjustment that must be made before and independent of adjusting the string height at the nut and saddle. This cannot be over emphasized. First set the correct amount of bow in the neck, then, once it has been set, leave it at that setting and then adjust the string height at the nut or saddle, if necessary.

4. Adjusting the String Height at the Saddle

The saddle height can be adjusted either before or after adjusting the string height at the nut. My preference is to adjust the string height at the saddle before adjusting the nut.

Most steel string acoustic guitars, as well as most electric and some classical guitars, have the top surface of the fingerboard domed (radiused) or arched across its width. (Many players find a domed fingerboard easier and more comfortable to play.) To achieve the correct height of each string, the contour of the top (bearing) surface of the saddle will generally follow the same curvature as the surface of the fingerboard. However, to accommodate the slight increase in string height towards the bass strings, the saddle contour deviates somewhat from the contour of the fingerboard. Regardless of whether or not the fingerboard has a radius, “compound radius” or is flat, no special gauges are required to measure or transfer this curvature to the saddle height/contour. The reason for this will become apparent.

Begin by measuring the distance from the top of the twelfth fret to the bottom of the sixth string while all of the guitar's strings are at full tension. One can use a standard ruler, feeler gauges, specialized string height gauge or other means to measure this distance. I find that measurements to the nearest 32\textsuperscript{nd} of an inch are sufficiently accurate, though others prefer 64\textsuperscript{ths} or even decimal measurements. Any method that measures with sufficient accuracy the distance from the top of the twelfth fret to the bottom of the string can be used. (No, despite “urban legend”, the thickness of a quarter or dime is not sufficiently accurate.) Repeat for each remaining string. Record each string height.

Although the ideal string height depends upon the preferences of the player and the type and construction of the guitar, a typical "good" playing string height ("action") for a steel string acoustic guitar is about 3/32" at the sixth (bass E) string and about 5/64" (2-1/2 32\textsuperscript{nds} at the first (treble E) string, as measured from the top of the twelfth fret to the bottom of the strings. The intermediate strings increase in string height gradually from the first to sixth strings. The increase in string height from one string to the next accommodates the increase in vibrating amplitude that accompanies the increase in string diameter. Due to the type of music played, the materials from which the strings are manufactured, the string tensions used and the type of guitar construction, classical guitars have a higher action, while many electric guitars have a lower action.

There are only three possibilities for the measured string height:

1. The strings are at the desired height,
2. The strings are higher than desired or
3. The strings are lower than desired.

In the first case, no adjustment is required. Each of the other two possibilities is discussed below.

**Strings Too High**

Using elementary geometry, it can be shown that a change in the string height at the twelfth fret requires about twice the amount of change at the saddle. For example, if a string height measured at the twelfth fret is 4/32", and the desired measurement is 3/32", the change in height at the saddle necessary to lower the string by 1/32"
at the twelfth fret is about 2/32". Using the measurements taken, calculate the amount that each string needs to be lowered at the saddle. Record that amount for each string.

Measure the amount of saddle height that is projecting above the top surface of the bridge. The saddle should project at least 1/16" from the top of the bridge, even after reducing the saddle height by the amount you have calculated necessary to achieve the desired string height at the 12th fret. This ensures that the strings exert a sufficient downward force on the saddle to prevent the strings from vibrating side-to-side on the top surface of the saddle. The side-to-side vibration often causes a string to rattle or be muted. If the 1/16" projection cannot be maintained, a neck reset, bridge pin hole ramping or shaving of the bridge may be necessary, which are "repair work" - rather than basic setup work - for either the professional repair person or the skilled amateur.

If a uniform reduction in string height is required for all strings, the amount that needs to be removed can be measured from the bottom surface of the saddle, and marked with a sharp pencil. The excess can then be removed, to the pencil line, using a file or sandpaper. If using a file, the saddle can be held upside-down in a vice.

If using sandpaper, it is considerably easier to keep the saddle bottom flat and square if a simple aid is used. A simple aid can be made from a reasonably flat surface, a sheet of 120 grit sandpaper and a block of wood or metal that has a flat face and an edge that is 90º to its face. The flat surface can be plate glass, marble, granite or even a piece of plywood. The sheet of sandpaper can be affixed to the flat surface with double-sided tape, masking tape, rubber cement, spray adhesive or similar adhesive. The block of wood or metal, about ½" x 3" x 6" or so, is placed with its face on the sandpaper and one side of the saddle is pressed against the edge of the block. While maintaining the saddle against the edge of the block, repeatedly pull the saddle towards you. Sliding the saddle back and forth across the sandpaper will have the tendency to round the bottom of the saddle. Flatness of the bottom of the saddle is more a function of sanding technique than it is of the absolute flatness of the sanding surface. If the guitar is fitted with an under-the-saddle piezoelectric transducer, it is essential for even response of the transducer that the bottom of the saddle be flat.

When you have sanded to the pencil line, the saddle can be reinstalled in the bridge, the guitar re-tuned and the string height checked. If the measurements and layout were performed accurately, it should be a once-through process, rather than an iterative trial-and-error - there should be no need to sand a bit, check string height, sand a bit more, check string height...

If the amount of reduction in string height is not uniform (i.e. from one string to the next), the reduction in saddle height is achieved by removing material from the top surface of the saddle, rather than the bottom. Before removing the saddle from the bridge, mark, using a sharp pencil, the location along the saddle at which each string crosses the saddle. Completely loosen all of the strings and remove the saddle from the bridge. Although the saddle should only fit snugly, but not tightly, its removal can often be facilitated with a pair of pliers. (Saddles should never be glued to the bridge. Should you encounter a saddle that is glued into the bridge slot, if it cannot easily be removed, the reduction in saddle height will need to be performed from the top of the saddle and while the saddle is still in the bridge.) Mark on the bottom of the saddle which end of the saddle is for the 1st string and which is for the 6th string.

From the top surface of the saddle, measure, and mark with a pencil, the calculated reduction in saddle height required for each string. A smooth curve can be drawn through the pencil marks on the face of the saddle - or the height of the saddle can be stepped, as you prefer. Measured this way, determining the curvature of the
fingerboard, and any attempt to match that curvature, are irrelevant. Instead, the saddle height where each string crosses the saddle is what it needs to be to produce the desired height for each string at the 12th fret.

Clamp the saddle in a vise and remove the excess saddle height with a file, filing to the drawn line. When this step is correctly completed, the top (string-bearing) surface of the saddle will be flat across its width and curved along its length.

A string supported by a relatively large, flat bearing surface will tend to vibrate from side to side over the width of the supporting surface. This causes the string to vibrate against the supporting surface, resulting in either a buzzing sound or a muted string. Chamfering the top edges of the saddle and rounding the remaining surface will reduce the width of the top surface of the saddle and prevent this. Premature string breakage at the point of contact of the saddle is the result of rounding the saddle to too sharp a point (too small a radius). Creating too extreme a point also results in premature wear of the saddle; a string will quickly wear a notch into the top of the saddle. Except in very certain circumstances, a guitar saddle should not be notched to accommodate the strings. A notched saddle is often the cause of poor intonation, buzzing and muted strings.

In addition to the importance of correctly shaping the top of the saddle, it is also very important to accurately locate where each string is supported, or "breaks", across the width of the saddle. Accurately locating where each string breaks over the saddle and shaping of the top surface of the saddle are discussed below in the section entitled Adjusting Intonation. Once the shaping of the saddle is completed, the saddle is returned to the bridge and the guitar retuned.

Strings Too Low
If the strings are too low, either a new, taller saddle can be made or the height of the existing saddle can be raised using shims. In making a new saddle one begins with an oversize saddle blank, and the process of completing the saddle is very similar to reducing the height of an overly tall saddle, as described above. Making a new saddle is beyond the scope of this article on basic setup.

Opinions are divided on whether or not the use of shims under a saddle affects the tone of a guitar. Some will insist that a saddle that is too low be replaced with a new taller one. Others find no reason not to shim an otherwise good saddle. Some believe that the shims should be glued in place, others not. (If you are taking your guitar to a repairperson for work, specify what you want to have happen if the saddle is too low - replace it or shim it. Shimming will usually cost less and it is unlikely you will hear a difference.)

Materials for shims can be plastic, wood, metal or paper, although I generally use hardwood veneers such as maple or rosewood. Shims are cut to the width of the saddle, and are stacked underneath the saddle in the slot in the bridge. Placing shims beneath a saddle reduces the amount of the saddle that sits within the slot in the bridge. Effectively, the depth of the slot is reduced by the thickness of the shims, which places a practical limit on the amount that a saddle can be shimmed. Ideally, a minimum of half of the total height of the saddle should be within the slot, with the remainder projecting above the top of the bridge. Provided that the saddle is the correct width for the slot, this ensures that the saddle is adequately supported and prevents the saddle from leaning under the pressure applied by the strings.

Some guitars are fitted with a saddle design that readily allows the saddle height to be adjusted. Generally, these arrangements consist of a saddle suspended between two threaded posts, the height of which can be adjusted using a screwdriver. While this arrangement makes it relatively easy to adjust the saddle height, it has a number of significant disadvantages, which explains why it is not more commonly used.

5. Adjusting String Height at the Nut
Once the neck relief and the string height at the saddle have been correctly set, the string height at the nut can be adjusted, if necessary. At the nut, each string sits in a slot cut into the top surface of the nut. The purpose of
the slots is to maintain the spacing of the guitar's strings and, in guitars without a "zero fret", to maintain the height of the strings at the nut. It should be noted that the intonation of a guitar in the first few frets is influenced by the height of the strings at the nut. An excessive height at the nut causes the notes of the first few frets to play sharp.

Qualitatively, the ideal string height at the nut for each string is the minimum vertical distance that just allows that vibrating string to clear the first fret. Any higher than this and the string is unnecessarily difficult to depress and plays out of tune; any lower and the string vibrates ("buzzes") against the first fret. Thus, the ideal string height at the nut depends upon the height of the first fret and the amplitude (at the first fret) of the unfretted vibrating string. Since the height of the fret wire varies from one manufacturer to the next, and one instrument to the next, and the amplitude of the vibrating string depends upon the player's attack and the type and tension of strings used, there is no universally correct dimension for string height at the nut. Instead, it is necessary to set the string height at the nut based upon the particular preferences of the player and the particulars of the individual instrument.

The first thing to determine is whether or not the string height at the nut requires adjustment. There are a number of ways of doing this, some qualitative and some quantitative; I prefer to use qualitative methods. Quantitative methods, which I will not discuss in detail here, involve measuring the height of the strings relative to a reference. Some people use the top of the first fret as the reference and measure the clearance (distance) between the top of the first fret and the bottom of each string. This can be measured with feeler gauges, vernier calipers or with specialized tooling for this purpose.

Qualitative methods involve determining by sight, feel and/or sound, rather than comparative measurement, whether or not the strings are too high or if they are too low. One common qualitative method is to fret a fully tensioned string at the second fret and observe its height above the top of the first fret: the distance should be about the thickness of a sheet of paper.

I prefer a different method. To begin with, check that the string height at the nut is not too high. The criteria I use to determine if the string height at the nut is too high is that the effort required to fret any or all strings at the first fret should not be greater than the effort required to do so at any other fret. One test of this is to play a barre chord at the first fret and at, say, the seventh fret. If it requires more effort to apply the barre at the first fret, then the nut is too high. (Recall that since you have already adjusted the bow in the neck and the string height at the saddle, the string height beyond about the third fret should already be as low as you prefer it.) Another test is to compare the amount of effort required to depress a single string against the first fret with the amount of effort necessary to depress the same string at the second fret while the string is still depressed at the first fret. This can be done by fretting a string at the first fret with the first finger of the left hand and noting the amount of effort required. Then, without lifting the first finger, depress the same string at the second fret with the second finger of the left hand. Compare the effort required in each case. If more effort is required to fret the first fret, the string height at the nut is too high.

Next, provided that the string height at the nut was not found to be too high, it is necessary to ensure that the string height at the nut is not too low. The usual symptom of a nut being too low is that an unfretted string will vibrate against the first fret when the string is plucked. This results in a buzzing sound. Qualitatively, the ideal string height at the nut is one in which if you pluck each open string slightly harder than you would during normal playing, the open string will just begin to vibrate against the first fret. To check that the strings are not too low, individually pluck each string quite firmly; the string should just begin to buzz when plucked slightly harder than it would be during normal playing. If it won't buzz at all, the strings are probably higher than they need to be; if it buzzes at less than normal plucking force, the string height at the nut is too low.

Lowering the String Height at the Nut
If you found that the string height at the nut was too high, the slots in the nut need to be deepened, thereby lowering the string height at the nut. (Removing the nut and sanding the bottom of the saddle to lower the slots
is only viable if the height of all of the strings needs to be uniformly reduced, which is rarely the case.) There are a variety of tools that can be used to deepen the slots in the nut, just as there are a variety of methods for determining when the slots are sufficiently deep to produce the desired string height. First we’ll discuss tools, then methods.

**Tools for Nut Slots**

The tools that I use to set string height are selected based upon the methods I use. These tools are a short (6” or less) straight edge (ruler), a standard set of feeler gauges, an X-Acto knife handle and saw blade and set of calibrated nut files, calibrated nut saws and/or a tear-drop needle file.

Feeler gauges are thin, accurately calibrated metal strips that are used for gauging the size of a gap. The feeler gauges need not be a special set; they can be obtained from any auto supply or hardware store or purchased from a luthier supply house.

Nut files are relatively expensive, special-purpose files that are manufactured to cut a round-bottomed slot of a particular width. Although a complete set of nut files includes widths ranging from .010" to .058", a less-expensive "starter" set consisting of .016", .025", .032" and .042" widths is adequate. In use, the files can be rocked side-to-side to produce slots to accommodate string diameters larger than the stated file size.

While nut files are quick and easy to work with and remove much of the guesswork from nut slot filing, they are expensive for someone planning on only setting up a single guitar or a small number of guitars. An excellent alternative is to use an X-Acto saw blade that attaches to a standard X-Acto knife handle and one or more needle files. The saw and handle are available at hobby shops, and on-line, and are inexpensive - under $10 - and are very useful in cutting nut and saddle materials and starting/roughing-in nut slots. The kerf of the saw is about .012”, ideal for cutting nut slots for the first and second strings - negating the need for the thinner nut files. The saw cuts aggressively, and is easier to control than nut files, making it ideal for “roughing” in nut slots before filing to the appropriate width.

Gauged nut saws, new to the market, are a little less expensive than nut files. They have the advantage of cutting much more quickly than files, but have the disadvantage that any one saw cannot be used to cut slots of varying sizes, unlike a single nut file that can be rocked side-to-side to produce slots of varying widths.

The needle files most useful for nut slot work are teardrop shaped. They can be purchased inexpensively individually or in sets at hardware stores, hobby shops and online. The teardrop files are available in at least two contours and can be used very effectively for cutting or shaping the slots in guitar nuts, particularly if the slots have been pre-cut using a saw.

**Methods**

The method I prefer for obtaining the desired depth of nut slots is very similar to that given by Dan Erlewine in his book *Guitar Player Repair Guide*. In this method, the height of each string is measured at the nut as the vertical distance from the top surface of the fingerboard to the bottom of each string. Generally, this is equivalent to the distance from the top of the fingerboard to the bottom of the nut slot.

I prefer this method to a variety of others for two main reasons. First, it usually eliminates any iteration - the need to deepen the nut slots, measure string height, deepen the slots some more, measure string height... Eliminating the iteration of trial-and-error makes the process quicker. The use of the feeler gauges as a hard depth stop also eliminates the possibility of inadvertently cutting a nut slot too deep and the resulting need to fill the slot, shim the nut or make a new nut.

The second reason that I prefer this method is that it is a direct adjustment: the thing being adjusted is the same thing being measured. Simply put, you are altering the same thing you are measuring, the distance from the top of the fingerboard to the bottom of the nut slot: there is a one-to-one relationship between the action performed
and its result. This is in contrast to a common method for setting string height at the nut that uses the top of the first fret as a reference datum from which to measure string height. Using the first fret as the reference, the distance from the top of the first fret to the bottom of each string is an iterative adjustment. This is an indirect method since the string height above the first fret is the result of an adjustment made elsewhere - that is, by deepening the nut slots.

Begin by measuring the height of the first fret. One way of measuring this is to place a straight edge on the top of the first two frets, so that it straddles the first and second frets, and then slide feeler gauges - individually, or stacked - between the fingerboard and the straightedge, until the gauges just fill the space between the fingerboard and the straight edge. (The straight edge runs parallel to the strings, while the feeler gages are inserted from the edge of the fingerboard parallel to the frets, midway between frets one and two.) A typical fret height is about .040”, but you will need to measure the actual fret height on the instrument being adjusted.

In theory, the ideal string height at the nut should be equal to the height of the first fret. In practice, I find that adding about .008” to the fret height works well to eliminate buzzing for those with a heavy attack, particularly on the bass strings. This total is the height above the fingerboard that each string should be. As an example, if your first fret height is .040”, add to that .008” for a total height above the fingerboard at the nut of .048”. (As a subtle adjustment, I often vary the nut height by about two or three thousandths of an inch from first to sixth strings, with the first string being lower than the sixth.) Stack the appropriate combination of feeler gauges to obtain a combined thickness of the correct value, in this example, .048”.

Lift the first string out of its slot and slide it towards the second string, letting the first string rest on the top of the nut. (If necessary, reduce the tension on the first string sufficiently that you can do so or use a tool that allows you to lift the tensioned string out of its slot.) With all but the first string at full tension, place the end of the stacked gauges on top of the fingerboard so that the edges of the gages are touching the nut. On fingerboards with a curvature, the gauges are inserted under the first string from the treble side of the fingerboard so that the length of the gauges runs parallel to the frets and all but the first half of an inch or so overhangs the edge of the fingerboard. On flat fingerboards, the gauges can be inserted from either edge of the fingerboard.

Using either a nut file, nut saw or the X-Acto saw, deepen the slot until you just begin to contact the top surface of the stack of feeler gauges with the file or saw. (You will immediately feel the saw’s or file’s first contact with the metal feeler gauge.) The slot should be filed (or cut) so that the string breaks over the nut at the leading edge of the slot - at the face of the nut nearest the fingerboard. This is accomplished by filing or sawing the slot at a downward angle from the fingerboard towards the head. Failure to have the string break at the leading edge of the nut can result in poor intonation and string buzz.

The width of the slot should be several thousandths of an inch larger than the diameter of the string. If the slot is too narrow, the string will bind in the slot, often causing premature string breakage. One symptom of a binding nut slot, in addition to frequent string breakage, is that the change in tension in the vibrating portion of the string does not occur smoothly when adjusting the tuning pegs; the string's pitch changes suddenly, lagging behind the adjustment in the tuning peg. Once you have filed to the appropriate depth, remove the stack of gages, reposition the first string and return the string to full tension. Check that the string is of the appropriate height using the methods previously described, adjusting the thickness of the stack of gauges and making the slot a little deeper, if necessary.
Repeat the process for the second string, sliding the stack of gages beneath the first string and extending under the third string. When completed, repeat the process for the third string, using a nut file, needle file or saw to deepen the slot. To adjust the height of the fourth string, insert the gauges from the bass side of the fingerboard and repeat the same process. Repeat for the fifth and sixth strings.

An often-debated question is what the profile of the bottom of the slot should be. Some argue a “V” shaped notch, others a round bottom, others a flat bottom. All work successfully if well cut and shaped.

**Raising the String Height at the Nut**

If you found that the string height at the nut was too low, or you cut the string slots too deep, the string height at the nut can be increased. One way of increasing the string height at the nut is to place a shim beneath the nut. To do this, remove the nut, cut a shim to the same width as the nut, glue the shim to the bottom of the nut and reglue the nut to the neck. (When removing a nut, it may be necessary to first cut the finish around the nut, if the finish extends onto the ends or side of the nut. Doing so will ensure that when the nut is removed the finish is not damaged.) Guitar necks are commonly made from mahogany or maple, and shims can easily be made from a matching veneer, and if necessary, the visible edge of the veneer can be stained with an appropriate color of felt tip marker.

Another more common – and easier - method of increasing string height at the nut is to fill the bottom of the nut slot with a mixture of bone dust - or dust of a material similar to that of the nut - or baking soda and cyanoacrylate glue, a mixture that will dry very hard. Once the nut has been shimmed or its slots filled sufficiently, the string height can then be lowered, if necessary, using the same procedure as described above.

6. **Adjusting Intonation**

Generally, intonation refers to the ability of an instrument to accurately achieve a set of desired pitches. An instrument with “good” intonation is capable of playing notes that are very close to the desired pitches. Guitars are nearly universally designed to conform to Equal Temperament, a set of pitches that intentionally trades producing pitches the ear hears as being “in tune” for the ability to play equally well in - or out of - tune in any key. Thus, even if a guitar is designed and setup to perfectly achieve the pitches of Equal Temperament, most people will hear it as sounding somewhat out of tune, though equally out of tune in all keys. Thus, it is important to distinguish between intonation – how closely an instrument is able to play the desired pitches – and temperament – what are the desired/target pitches. Both intonation and temperament are very complex and are beyond the focus of this article on practical basic guitar setup. However, if one is to have any hope of having a guitar sound reasonably in tune, one must start with having the guitar setup to accurately achieve the targeted pitches – Equal Temperament.

Let us begin with terminology. The *scale length* is a theoretical vibrating string length that is used to mathematically calculate the position of a guitar’s frets. The mathematics used to calculate the fret locations is based upon an idealized behavior of vibrating strings. The *actual vibrating string length* is, as the name implies, the actual, real-life length of a vibrating string, sometimes referred to as its *speaking length*. For a guitar to achieve “good” intonation, the actual vibrating string length will always differ from its scale length. The amount by which it differs is referred to as *compensation*. Compensation is a practical (and empirical) means for addressing the differences between the assumed idealized mathematical behavior of vibrating strings and how real strings actually vibrate in the real world.

The most common method for applying compensation is to move the saddle away from the nut by the amount of the required compensation, referred to as *saddle compensation*, or *compensation at the saddle*. For a guitar with compensation applied at the saddle, only, the actual vibrating string length will always be longer than its scale length.

The magnitude of the discrepancy – and compensation required – between the mathematical model of a vibrating string and its real-world counterpart depends upon a number of factors. These factors include the
materials from which a string is made, the vibrating length of the string, the stiffness of the string, the mass of the string, the tension imposed upon the string and the distance the string is depressed when fretted. As the strings on a guitar vary in pitch, tension, diameter, mass and string height, each requires its own unique amount of compensation. For example, on a guitar with six different strings, each string will require its own amount of compensation, a different amount than for the other five.

Fret positions are, as described above, determined without regard for the compensation that the strings will require. This means that the 12th fret, the octave of the open string, is located at precisely half of the theoretical - non-compensated - vibrating string length: the distance from the face of the nut (adjacent to the fingerboard) to the 12th fret is exactly half of the theoretical vibrating string length (scale length). On a string compensated only at the saddle, since the distance from the nut to the saddle is increased by the amount of the necessary compensation, the distance from the nut to the 12th fret is shorter than the distance from the 12th fret to the saddle by the amount of the compensation. Typically, the amount of compensation required is between about 3 mm (1/8") and 5 mm (3/16"), with the exact amount required depending upon the factors described above.

Assessing Intonation

The procedure most often used to adjust the intonation on a guitar is to alter the precise string length of each string until the pitches of two notes produced on the same string are identical. The two notes that are most often compared are the note produced by fretting a string at the 12th fret and the note produced by the harmonic at the 12th fret of the same string. These notes are both octaves of the open string and are in unison. It is important to note that harmonics are produced when a string is divided into a whole number of equal vibrating segments and that the pitches produced belong to Pythagorean or Just tuning. However, the frets are placed using a different scheme of target pitches, that of Equal Temperament. The only pitches where Equal Temperament and Pythagorean (Just) tuning produce notes of the same frequency (pitch) are at the unison (1:1) and the octave (1:2). Comparing the pitches of any fretted note to a harmonic other than the unison or octave is like comparing apples and oranges; they will not, and should not, be the same. This is particularly relevant during routine tuning of the instrument.

The two pitches - the 12th fret note and the 12th fret harmonic - can be compared with the unaided ear, although more accurate results can be obtained by using an electronic tuner. (Adequate, inexpensive electronic tuners are now widely available.) The intonation is correctly adjusted when the two pitches are identical. Practically, however, there is limit to the ability of the human ear to differentiate between differences in pitch. This varies depending upon the frequency (pitch) and intensity of the note as well as one's own physical limitations and musical training. To aid in quantifying deviations in frequency, a semitone has been divided into 100 parts, each part being called a cent. A well-trained musical ear can generally distinguish between frequencies as little as 2 cents apart. When setting the intonation, it is preferable to use an electronic tuner that is calibrated in cents.

Prior to performing any adjustment of the intonation, the intonation of the instrument should be accessed. Other than for a cursory check of the intonation, before assessing the intonation for the purpose of altering the setup, the string height at the nut and saddle should be correctly setup, since the compensation required is, in part, dependent upon string height. The assessment should be done using a new set of strings that are all tuned to the pitch at which they will usually be played. (All subsequent intonation adjustment should be done with the same new strings all tuned to pitch.) Strings, new or old, can play “false” producing inaccurate pitches either at individual locations or across the entire range of the string. This can be due to manufacturing errors, in the case of a new string that plays false or “wear and tear” as a result of being played.

Beginning with the sixth string, compare the 12th fret note to the 12th fret harmonic: record the discrepancy and repeat for each of the remaining strings. If, for any string, it is found that the discrepancy between the two notes is greater than a few cents - or audibly different - the vibrating string length for that string will require lengthening or shortening. Notes that sound sharp require the string to be lengthened, while notes that sound flat require the string to be shortened. If the notes are of the same pitch, no adjustment is required: the intonation of that string is properly setup.
The exact amount of compensation required is determined by trial and error. The correct amount results in the 12th fret note and 12-fret harmonic being exactly the same pitch. Practically, a simple way of adjusting the string length is to cut one-inch segments from the excess length of a set of guitar strings. By bending a short length of string into a "V" shape, it can be slid under the string - between the bottom of the string and the top of the saddle - and repositioned on the top of the saddle, as necessary, to change the vibrating string length until the pitches of the notes match. (To aid in inserting the "V" under one of the guitar strings, it is often necessary to loosen the string somewhat, insert the "V", and then return the string to pitch. Once under a string, a pair of pliers is often helpful in repositioning the "V".) The gauge of the string to use to make the "V" depends upon the gauge of the guitar string it will support and the shape of the top of the saddle: feel free to experiment and choose what works best for you. It is somewhat easier if the top of the saddle is flat across its width, as is the case with a new saddle or in some circumstances when lowering the saddle height. Once the "V" has been correctly located, its center can be marked with a sharp pencil on the top of the saddle. When this has been repeated for each of the strings, the saddle is removed from the guitar and the top of the saddle is shaped, typically with a file and/or sandpaper.

Shaping of the top of the saddle involves two components. The first is to bevel the top surface of the saddle so that each string breaks at its correct location on the width of the saddle. To achieve this, the length of the saddle can be divided into one segment for each string, and each segment beveled accordingly, or the top of the saddle can be filed in a continuous curve that passes through the correct breaking point for each string, giving a "wave". This sets the exact vibrating string length of each string.

The second component of shaping the top of the saddle is to provide a "clean" support for the string. This involves bringing the top of the saddle to a rounded point so as to support the string over a narrow area, while not being so sharp as to be easily grooved by the string or cause premature string breakage.

When the shaping is completed, the saddle can be returned to the bridge and the instrument brought to pitch and tuned.

A relatively frequent impediment to fully compensating a string is that the saddle is not of sufficient thickness to accommodate the range of compensation required from one string to the next. The very common example of this is the second ("B") string requiring more compensation than the thickness of the saddle will allow. As a result, the second string plays sharp. This is due to the fact that the second string on steel string acoustic guitars generally requires greater compensation than its immediate neighbors, and requires a string length for which the string should break behind (i.e. longer than) the thickness of the saddle. (For electric guitars and classical guitars, typically it is the third string, rather than the second, where this occurs.) Consequently, it is quite common to find steel string acoustic guitars whose second string is insufficiently compensated. One remedy to this problem is to use a thicker saddle that allows for greater compensation. Another remedy is to reposition the saddle.

With the relief set appropriately, the string heights at both nut and saddle set just how you want them, and the intonation set as best as it can be for the limitations of your particular instrument, you should now have an instrument that plays well and largely in tune. Happy playing.