The Ultimate Guide to Guitar Intonation

By Steve Blundon

Guitar setup specialist Steve Blundon goes through all the gory details and nuanced processes of guitar intonation.

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As guitar players, we’ve all experienced the “unmusicalness” that comes from an instrument not being in tune with itself. From D chords that refuse to work harmoniously with G chords, to divergent notes in the upper frets, it’s a condition that causes incredible frustration. Yet, the techniques and tools required to ease the pain of poor guitar intonation are simple.

Armed with a reasonable understanding of the condition, and a dependable methodology to measure frequency, anyone can intonate their own instrument.
This guide is designed to make the intonation process as easy and enjoyable as possible. The end result being a firm concept of intonation principles, and a much better sounding guitar that’s a tuneful pleasure to play.

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**What is Guitar Intonation?**

In a nutshell, guitar intonation is a condition where the instrument is in tune with itself across its full tonal range.

In order to understand guitar intonation, it’s important to realize that the playing field we’re working on is artificially level. By that I mean we’re using a fretboard with immovable points of contact that are not
necessarily in the ideal spots for optimal musicality - note by note, or string by string.

Mass production, uniformity and conformity have stacked the deck. A typical fretboard is divided into nice neat sections that work more mathematically, rather than musically, for a given scale length. This is not necessarily a bad thing, but it does influence the outcome we’re trying to achieve.

EQUAL TEMPERED TUNING

A standard guitar is fretted in such a way to accommodate what’s known as “equal temperament tuning” where the octave is divided into twelve equal semitones, or individual rations of frequency. We can think of each of these portions as 100 percent of a given note. This is convenient as it allows us to evenly space out each note across the fretboard.

But convenience comes at a price. The underlying problem is that this arrangement is not entirely harmonious in the absolute sense, which makes pure guitar intonation a bit tricky.
Frets and Enemies

Take for example two notes found in a common root position D chord: The D on the second string third fret, and the F#, first string second fret. Together constituting a major third interval.

A WORKING EXAMPLE

If you have a ready-tuned guitar handy, play those two notes together and listen carefully. You probably don’t notice anything out of the ordinary except for a bit of roughness in the interplay of the two notes together. Certainly not enough to curdle milk.

Now detune the first string by a fraction. If you have a decent tuner, measure a decrease in pitch of 14.46% of a semitone. Once the first string is adjusted down, play those same two notes together and you’ll notice they’re remarkably harmonious, far more pleasant sounding. In fact, we could consider those two notes to be more “intonated”.

Under normal tuning conditions though, we have become accustomed to hearing intervals of all kinds working in a forced relationship confined to an equalized tuning system. Nonetheless, this is our accepted standard and we need to work with it.
COMPENSATION AND OTHER FACTORS

In practice, truly accurate guitar intonation is greatly influenced by a number of important factors. We have to account for conditions that govern mass, tension, and frequency for each string. Another way to say this is that we have to *compensate* for things like string gauge, string height or action, and individual string tension so that each note sounds in tune when fretted.

The main idea here is compensation. This was the inspiration for adjustable saddles on a typical modern guitar bridge:

*Tune-o-matic bridge design.*

Or the staggered notches found in most modern acoustic guitars:
Acoustic '80s saddle with staggered notches.

To understand the need for compensation, let’s look at a simple illustration of a string at rest and a string in motion.

A string at rest is a straight line between two “nodes”, the nut and the bridge:

A string at rest between the nut and the bridge or "two nodes."

When a string is struck, bowed or excited in some way to produce sound, it’s deflected from it’s naturally straight resting condition. As it vibrates, think of it as an arc stretched between the same two nodes:
A vibrating string can be thought of as an arc between the same two nodes in the previous image.

When you measure the length of the string at rest and compare it with the overall length of the string in an arc, there’s a difference:

\[
\text{Overall length of arced string} \rightarrow \\
\text{Overall length string at rest} \rightarrow
\]

Difference in length between guitar strings at rest and in an arc.

This difference in overall length is what we’re compensating for to achieve intonation. Therefore, guitar intonation is based on this simple principle: The more string gauge and tension influence deflection, the more compensation is required.

*The more string gauge and tension influence deflection, the more compensation is required.*

In practice, we adjust the individual string saddles forward to shorten string length, or backward to extend string length.
Forward to shorten string length or backward to extend string length.

But how do we determine which direction to adjust the string? This is the question that most guitar players have trouble with.

DETERMINING ADJUSTMENT DIRECTION

It’s important to understand that we’re only dealing with two conditions, whether a note is sharp or flat. All you really need to remember is one of those conditions, like one side of a coin, the other will fall into place by default. Still, we need to have an idea of how to make the adjustment depending on whether we come up heads or tails.

To boil the concept down to its essentials, we’ll use some simple illustrations to help you form an opinion: One string and a single note as an example.
Here’s a rudimentary example of a single string which spans between the nut and the bridge, our given scale length. The vertical line on the string marks a fretted note in the upper register.

String with a vertical line marking a fretted note on the upper register.

Let’s say our fretted note reads sharp. In terms of overall string length, what does that tell you? It tells you that the fretted note “sees” the string as too short.

Reading the note as sharp or too short.

In order to correct the shortfall, we add some length to the string.
Corrected by adding length.

If, in our example, the note were flat, we would simply move in the other direction.

Once you understand the overall concept, it applies across the board - to all strings, and to all notes that require intonation.

Factors that Affect Guitar Intonation

There are many things that will push guitar intonation down a black hole. The worst offenders are:

- **Finger pressure**. Try to use an even finger pressure that matches your style.
  
  If you're a light player, use a light touch. If you're more aggressive in your playing, adjust your approach accordingly.
• **Fret wear.** Worn frets are terrible for intonation. Since the intonation point has to be dead middle of the fret’s width, any deviation due to wear will give you false readings. The difference may be a small amount, but it will make accuracy fall outside the bulls-eye.

• **Cheap, imperfectly manufactured strings.** I’ve experienced this a number of times, where the windings on a string were inconsistent, even loose, making intonation absolutely impossible - I mean impossibly impossible. Even worse, they tend to come in batches from the manufacturer. If there’s one bad string in a set, chances are a set pulled from the same lot will have exactly the same problem. Therefore it’s best to try a different brand altogether if you suspect this is the core of a severe intonation issue.

• **Un-stretched new strings.** If you don’t take the initial elasticity out of fresh strings, at least one good stretch, you are trying to intonate rubber bands - good luck!

• **Old strings.** By far the number one reason you will wind up chasing your tail. Old strings have so many bad things going on I simply can’t list them all. Unless you’re using a new set of strings from a reputable manufacturer, you’re
working with a question mark. Considering the relatively low cost of an average set of strings, it makes sense to eliminate the possibility that the strings themselves may be part of the problem.

- **Lastly, a poor setup.** I must make this absolutely clear: Your results will be influenced by the condition of the nut, the amount of neck relief and overall string height. I refer to this combination as the *Perfect Triangle of Action*; all the elements working well together in a state of balance. If I had to pick one that had a more dominating impact on intonation, I’d have to say the nut. In my experience, an improperly cut nut will destroy any attempt at accurate intonation. This is also why I recommend eliminating it entirely as a primary reference point when going through the process.

**What Tools Do I Need?**

We’re going to need a few good tools: a relatively good, sensitive tuner - analog or digital, and some modest hand tools like screwdrivers.

As for the tuner, you’ll need one that features a high degree of sensitivity and provides subtle visual cues. A tuner with a needle and percentage range for pitch is ideal. The finer the tuner’s ability to read frequency, the
better your results will be. If you use an app, the accuracy will depend much on the quality of your device’s microphone. Stick with a unit that is known for producing good results, not just cheap and easy to use.

SOME EXAMPLES

*Online Guitar Tuner:*

https://www.proguitar.com/tools/guitar-tuner/web-app

*Korg CA-40 Large Display Chromatic Tuner with Large Display:

Below is a simple quartz tuner with an analog needle that I’ve used for many years:
Using an extremely fine, expensive tuner is not absolutely necessary, but helpful if you have access to one. Over-sensitive tuners can tend to make the process of guitar intonation much harder than it has to be. Especially when you factor in things like finger pressure, humidity, body heat etc.

Bridges Over Troubled Waters

While there are many different types and styles of guitar bridges, the hand tools required are simple and will go a long way. Let’s break it down into the most common examples:

ELECTRIC GUITARS
Typical tools required for electric guitar adjustments are:

- **3/16" flat head screwdriver** for tune-o-matic and vintage type bridge
- **#1 phillips screwdriver** for Strat & Tele style bridges
- **2.5 mm Allen wrench** for locking system saddle screws

**SEMI-ACOUSTIC & HOLLOW BODY GUITARS**

For many semi-acoustic and hollow body instruments, the bridge will often have some form of compensation built in, if not a completely adjustable unit. Because it’s usually held in place by string pressure, the entire bridge can also be shifted forward or backward to further zero in on the best position for precise intonation.

**ACOUSTIC GUITARS**

Even though acoustic guitars have what is known as fixed intonation, which is non-adjustable, I’ve included the group here to round out the examples.

If you’re the adventurous type and do feel your acoustic’s intonation could be better, there’s nothing stopping you from experimenting with different string gauges - right down to individual strings. With a bit of
tinkering and patience, acoustic guitar intonation can be better suited to the player.

How do I intonate my guitar?

Now that we understand what intonation is, the factors that influence guitar intonation and the tools required, let’s look at getting it done.

INTONATING USING A TUNER

Let’s start with the A string. In particular, the fifth fret which is a D note. Cue the D note up on your tuner so that it’s spot on pitch. Next, go to the 17th fret on the A string. This is the octave for the same D note. If your intonation is set correctly, the tuner should register exactly the same position as that of the fifth fret D - no difference.

If the higher note registers sharp, the fretted note is telling you that it “sees” the scale length as being too short; we have to move the saddle further back to make the string longer. How much longer will depend on the amount of compensation required.

Be sure to take note of where the saddle sits before you turn the intonation screw, then repeat the process, and compare the next measurement with how much the saddle moved. You’ll have to
experiment through a couple of attempts, but the exercise will give you a pretty good gauge to anticipate where the saddle should wind up.

Taking the above example into account, you should follow how the same process applies to the remaining strings. In practice, you can use natural notes, sharps or flats. The end result being that every note should exactly match it’s corresponding octave on the same string.

**PRO TIP:** If you strike the first octave harmonic above the note you’re intonating, it produces the exact same frequency as the resulting fretted octave note. This comes in handy as the tuner’s output will not bounce as much, plus the technique cleans up a lot of rumble when intonating bass notes.

Here’s a video going through the process as described above:

**Intonating by Ear**

While the addition of the visual elements from a tuner certainly helps, it’s not absolutely necessary. After all, we’re trying to refine what we hear, not what we see. In other words, all visual input has to be reconciled with our ears.
Due to interference from competing resonant peaks, masked frequencies, cancellations, and other factors, a tuner will often get confused. We wind up in situations where even the best tuner will simply not pick up a frequency. You've probably experienced the phenomenon yourself many times.

As guitar players, we should all be familiar with the method of using the combination of open string, fretted string cross-referencing to tune our instruments. We're basically trying to get two notes to sound in unison without any waves. It's a fundamental technique which we all turn to when the tuner simply isn't available, because your buddy borrowed it and promised to give it right back... or the battery died... or the darn thing just isn't cooperating.

The fact is, barring an available tuner, this same primitive approach can be used to achieve highly accurate guitar intonation. I'll give you a couple of examples where I regularly resort to these old-school tactics to get the job done. Typically found in the polar opposites of the low-end and high-end ranges of our instruments.
Dealing with Deep Low-End Intonation

When it comes to intonating low frequencies, one troublesome source is often the low E on a four-string bass. Or even worse, the low B on a five-string bass. If I get the sense that my tuner is doing the funky chicken, I immediately plug the instrument straight into my amp and make a few adjustments to the amp's settings. I shape the instrument’s output to be as lean as possible - easy if you have active tone shaping controls - by eliminating as much low-end rumble as I can. The amp is then tweaked to enhance any “beats” I hear in the comparative notes.

Using a low E string as an example, I’ll use the third fret G, and compare that against the open first string G itself. There should be no perceived beats or waves in the output.

Next, I’ll go up the neck on the fourth string to the G at the 15th fret and compare that with the open first string G. Again, there should be no waves in the output. If there are, a slight bend of the 15th fret G referenced against the open G string will tell me if the intonation point needs to be lengthened or shortened: An increase in beats means the string length is already too short, the reverse should be obvious.
Intonating Problematic High-End Frequencies

I’ve found this same “dropout” type of tuner deficiency popping up when trying to work with fine strings on the guitar as well, particularly the first string. Instruments that have a thin natural sound, typically those with single coils, can be problematic like this. While I don’t necessarily count on the instrument’s controls to shape the output (I just leave them wide open), I rely on the amp to tell me what’s going on.

In cases like this, distortion is your friend. The sawtooth waveforms help to accentuate what we’re listening for - waves or beats in our referenced notes. Use a fairly aggressive amount of distortion to shine a good light towards revealing the frequency content.

SIDE NOTE: If you play metal, the very nature of the tones are heavily distorted; frequencies modified in a very powerful, controlled manner. In order for the guitars to work together in a metal band, they must be perfectly intonated. See the irony?

Carrying on, use the third fret on the first string, a G note, and compare that with the third string open G - they should sound even and in unison. Then compare the first string 15th fret G with the open third string again. If the intonation point is spot on, you should hear the notes in
perfect unison again. If they aren’t, use the same technique I described in the bass example: Bend the fretted string a little when referencing to gauge whether it’s sharp or flat, then adjust accordingly.

The Benefit of Visual Cues

Whether you intonate exclusively using a tuner or your ears, the strings on the saddles should have a predictable visual pattern of steps. Starting on the bass side low E, the A string saddle should be forward about a 16th of an inch, and the D string a 16th forward again. A plain G string is then about a 16th backward from the D saddle, the B string forward a 16th, and we finish up with the first string a 16th forward again.

Think of it like three steps forward, then another three steps forward after a step back:

_______-_______-_______-_______-_______

For semi-acoustics and fully acoustic guitars, those with a wound third string, the pattern is four and two:

_______-_______-_______-_______
Bass guitars follow more of an arc. The saddle positions gradually decrease from about an eighth of an inch between the low E and A strings, progressively down to roughly a 16th between the D and G strings:

If your saddles do not match these predictable patterns, chances are good that you do not have accurate intonation. I would question the quality of the strings or suspect some other factor in play that will eventually cause you grief.

In closing this section, all of the above examples are based on many years of observation derived from installing and intonating thousands of sets of strings. I trust this experience will help guide you as you work to intonate your own instrument.

Conclusion

The guitar intonation methods described here are those that have worked faithfully and consistently for me for many years, but they are
not the end-all-be-all. The reason I say this is to clarify that there is no absolute definitive way of intonating a guitar. Instead, I would say there are many ways to intonate the instrument so as to please the player’s taste. The latter depending on how sensitive the individual is to sound and vibration, their playing style, the inherent nature of the instrument, etc.

Throughout this guide I’ve attempted to share my own insights gathered from years of practical experience and research. In doing so, I certainly hope you’ve gained some insight into what intonation is, and how it does not need to be an intimidating secretive process. I also hope you will find intonating your own instrument easier, quicker, and your playing experience that much more enjoyable.

If you have questions about guitar intonation or about the process I’ve outlined here, feel free to leave them in the comments section below.