

The Acoustics of the Guitar

The science behind acoustic guitar tone

What are the magical properties that make a quality guitar sound so spine-tingling good? When you strip away the tradition, the romance, and a little luthier voodoo, the answer is firmly grounded in science...



Acoustic guitars are fundamentally designed to convert the mechanical energy of string vibration into pressure waves that are transmitted to the ear through the air.

How does the guitar produce sound? A player plucks a string and sets the string into a complex pattern of vibration that consists of a fundamental and many partials. The string moves few molecules of air – certainly not enough to create pressure waves of a significant magnitude the ear could easily pick up. Very little of the sound heard from a guitar comes directly from the vibrating strings. Rather, the strings transmit the energy to the soundboard via the saddle. The saddle acts as a selective filter, allowing only some frequencies of the vibrating string through to the soundboard. The board imposes its own characteristics on the frequencies it receives, suppressing some and enhancing others. The air in the cavity and the structural members also influence the sound by interacting with the soundboard.

Let's take for an example an open string played on an acoustic guitar. When the string is plucked with a pick (or finger), the pick initially puts a kink into the string.

With just a little more pressure, the string slides off the pick. Next, the kink traverses the length of the string, hitting the saddle. Here the kink transfers some of its energy through the saddle to the bridge, which then meters the energy to the flexible soundboard, or top, of the guitar. The kink is immediately reflected back toward the nut. Because the nut is set on the solid and stable neck, little of the kink's potency dissipates there.

The kink is reflected back and forth from nut to saddle. On each traverse, the kink transfers some energy through the saddle. The string finally comes to rest after transmitting all its energy to the soundboard and, to a lesser extent, to the air surrounding the string.

The speed with which the kink travels depends on the mass per unit length (the thickness) and the tension of the string. The combination of the speed of the kink with the distance it travels - that is, the length of the string - defines the rate of vibration. Thus, a kink that makes 440 round trips a second produces the A above middle C. This is the "A=440 hertz", or "A 440", known to all musicians and represents the fundamental tone of that string.

The guitar string actually vibrates in a much more complex manner than we have described so far. While oscillation at 440 hertz, the string is also vibrating in halves, near 880 hertz. Simultaneously, the string vibrates in thirds, near 1320 hertz; in fourths, near 1760 hertz; and so on. These various modes of vibrations are known as partials, overtones or harmonics.

Strings would like to oscillate as closely as possible to harmonic partials, or whole-number multiples of the fundamental. In practice, the partials do not occur at precisely those simple ratios, because strings have thickness (mass) as well as length, which lends them "inharmonic," or an inability to vibrate harmonically.

Because the string has modes of vibration other than the fundamental, the saddle must deal with the energy of all the partial vibrations as well as the fundamental vibrations.

Here's where the saddle comes into play: The saddle tends to be discriminating. It governs the strength of the excitations produced by some partials and may deny others any access to the soundboard. It also meters the rate at which energy is transferred from the string to the board.

The efficiency with which the saddle-performs these chores depends on what is called the impedance match between the string and the soundboard. A perfect impedance match, with no obstruction or reflection from the saddle, would allow all the energy of the vibrating string to be transferred to the board at once. The result would be a loud and not too musical "bang", with no sustain. A poor impedance match would have just the opposite effect. It would take a long time for the energy or the vibration string to dissipate (sustain), but little sound would be heard.

The challenge is to balance the impedance of the strings with the guitar top, combined with the right musical filtering, provided by the saddle, to allow the *appropriate* frequencies to excite the soundboard (tone) while *denying access* to other frequencies and keeping them in the string (sustain).

The soundboard's efficiency depends on its shape, thickness, mass distribution and grain pattern as well as the characteristics of the bridge and the bracing glued to the underside of the soundboard. A good luthier will meticulously sculpt the bracing to "voice" the guitar.

The soundboard is like a loud speaker and can vibrate at the significant frequencies. But it also has eigenmodes, or normal