Guitar Pickup Location Activity

**Description of Activity**

* The purpose of this activity is to understand how the tone of the guitar is affected by the placement of the pickup on the guitar.
* This activity is suitable for High School students.

**Learning Objectives:**

1. Students will formulate a hypothesis concerning the effect of the placement of the pickup on an electric guitar.
2. Students will measure the effects of pickup location on the output levels of a guitar.
3. Students will calculate the output level of a string based upon pickup location.
4. Students will evaluate the location of a pickup and the effect on signal output as a result of calculation and computer simulations.

**Standards:**

List The Common Core Math, Next Generation Science Standard and/or SME Competency Gaps.

Engineering Design-

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Mathematics –

Energy

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Forces and Interactions

HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

MP.4 Model with mathematics. (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4)

[CCSS.Math.Content.HSF-IF.C.7e](http://www.corestandards.org/Math/Content/HSF/IF/C/7/e) Graph exponential and logarithmic functions, showing intercepts and end behavior, and trigonometric functions, showing period, midline, and amplitude.

[CCSS.Math.Content.HSF-LE.A.2](http://www.corestandards.org/Math/Content/HSF/LE/A/2) Construct linear and exponential functions, including arithmetic and geometric sequences, given a graph, a description of a relationship, or two input-output pairs (include reading these from a table).

**Materials Required:**

* Functioning Electric Guitar with multiple pickups.

**Safety:**

**safetys:**

* Caution: electrons my fire across synapse forming new neurological pathways.

**References:**

* <http://www.stormriders.com/guitar/telecaster/guitar_wood.pdf>
* [http://www.professorstring.com/string\_physics.php#](http://www.professorstring.com/string_physics.php)
* <http://www.till.com/articles/PickupResponse/>
* [**Response Effects of Guitar Pickup Mixing**](http://www.till.com/articles/PickupMixing/index.html), J. Donald Tillman, July 2000.  A companion to this article, this is an analysis of mixes of two and three pickups.
* [**Pickup Response Demonstration Applet**](http://www.till.com/articles/PickupResponseDemo/index.html), J. Donald Tillman, July 2000.  A Java applet that graphically demonstrates pickup response curves based on the equations in this article.

**Activity:**

**Background History**

For years guitar manufacturers have been placing multiple pickups onto electric guitars. Many of these placements have become iconic for the sounds the guitar produces by the people who play them. But what does it all mean for us as we try to understand how guitars are designed and built. Is there a difference at all in the sound produced or is it a marketing ploy by guitar manufactures. For this activity we will try to understand the relationship between pickup location and output signals generated by a pickup and to answer the question does it really matter?

**Technical Background**

Electric Guitars produce the majority of their sound through electronic amplification. The Sound you hear from an acoustic guitar is produced by the strings vibrating and resonating through the body and soundbox. The sound you hear from an electric guitar is an amplified signal through a speaker. So how does the signal get to the amplifier? The string's vibrational energy and natural frequency are captured with a magnetic transducer or pressure transducer. As the string moves through the magnetic field a signal is produced. The greater the movement or amplitude of the string, the greater the output signal will be.

As any string vibrates it is fixed at each end called Nodes. On a guitar the Nodes are at the Nut and the Bridge. Harmonics also produce Nodes along the length of the string. The maximum movement is called the anode and is located ½ way between two nodes.

## Pickups and a vibrating string

Figure 1 is a drawing of a string such as you would find on an electric guitar or electric bass.  The nut is on the left, the bridge is on the right and three pickups are positioned in typical "neck", "middle" and "bridge" locations.  The drawing is to scale horizontally, but not vertically.  The string "scale length", or distance between the nut and the bridge, is 25.5 inches.  The neck, middle and bridge pickups are positioned 6.375, 3.875 and 1.625 inches from the bridge respectively.  These values are directly modeled after the Fender Stratocaster.

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| Figure 1 |
| Figure 1.  A vibrating open string with a scale length of 25.5 inches and three pickups located at 6.375 inches (neck), 3.875 inches (middle) and 1.625 inches (bridge). |

The blue strips in the drawing designate the output level of the vibrating string sensed at the pickup positions.  Not surprisingly, the output increases as the pickup position approaches the center of the string.

**Explore**

Why do you think there are multiple pickups on an electric guitar?

Describe what you think will happen if you switch between pickups on the Guitar and play a note?

Plug in the guitar and select the bridge pickup. Now switch to the Neck Pickup and strum again. Can you hear a difference between the two? Describe the difference.

What factors do you think affect the sound an electric guitar makes?

**Gather Data**

Let’s try to gather data from our guitar to isolate some key elements and determine what is really happening.

(All measurements are taken from the bridge and are in Inches)

Scale Length:\_\_\_\_\_\_\_\_\_\_\_\_\_

Distance to Bridge Pickup:\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Distance to Neck Pickup:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Fundamental Frequency:\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (Open E String 82Hz)

Now that we have the specifics for our guitar let’s look at some calculations for a better understanding of what is happening. We will be using some formulas arranged by *J. Donald Tillman.*

**Pickup response due to position**

The task here is to derive an equation to describe the variations of the frequency response of a pickup due to the position of the pickup along the length of the string. First we'll assume that the pickup senses the string motion at exactly one point, then we'll move on from there.

V*pickup*=sin(π X*pickup* / L*vib*)

Where:

V*pickup* is the relative displacement velocity, and thus the relative pickup output level, at this point on the string. A value of 1.0 is the maximum.

X*pickup* is the position of the pickup, the distance between the bridge and the center of the pickup in inches.

L*vib* is the vibrating length of the string in inches. For a harmonic, use the distance from the bridge to the first node. For the fundamental mode on an open string, this is the scale length.

Solve for each of the two pickups on your guitar using the open E String.

Neck Pickup V*pickup* =

Bridge Pickup V*pickup* =

Does the result reflect the difference in the sound you hear from the guitar.

**Pickup Response Plot**

Figure 4 is a plot of this function on a linear frequency horizontal scale and dB amplitude vertical scale.  There are null points in the response every **Fnode** Hz, where **Fnode** is:

Fnode= LscaleFopen/Xpickup

**1Fnode** is also the pitch of the string if the string was fretted at the pickup location.

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| --- |
| Comb filter |
| Figure 4. Pickup response plotted with linear frequency and dB amplitude. |

This curve is called a "comb filter" because the frequency response shape resembles the teeth of a comb.  Comb filter responses are often associated with time delays (echoes, flange effects, chorus effects).

Calculate the Fnode Position for each Pickup on your guitar using the open E string.

Neck Pickup Fnode=

Bridge Pickup Fnode=

Is there a difference?

You can actually model this plot using an online resource at <http://www.till.com/articles/PickupResponseDemo/index.html>

Enter in the values for your guitar and see the impact this has on each of the 16 harmonics.

Evaluate the impact of placing the pickup at a 1” compared to 6” what impact does this have on the output signal?

**Quiz:**

1. **Why is there more than one pickup on most electric guitars?**
   1. **Looks cool**
   2. **Adds Symmetry to the guitar top**
   3. **Adds a different tonal output**
   4. **Pickup manufacturers want to sell extra pickups**
2. **Which pickup has the greater output signal?**
   1. **Neck Pickup**
   2. **Bridge Pickup**
   3. **Middle Pickup**
   4. **They are all the same**
3. **A guitar with a movable pickup would change the tone of the guitar.**
   1. **True**
   2. **False**
4. **What is producing the output signal on an Electric Guitar?**
   1. **Sound Waves**
   2. **Magnetic Transducer**
   3. **Resonance**
   4. **Potentiometer**
5. **The movement of the string is called**
   1. **Displacement Velocity**
   2. **Electrical Induction**
   3. **Magnetic Induction**
   4. **Sound Waves**
6. **What is the fundamental frequency of an open E string?**
   1. **62Hz**
   2. **82Hz**
   3. **164Hz**
   4. **314Hz**
7. **The frequency of the string increases as you get closer to the bridge of the guitar.**
   1. **True**
   2. **False**
8. **What is the ideal placement for a pickup on a guitar?**
   1. **1.000” from the bridge**
   2. **3.1415” from the bridge**
   3. **6.378” from the bridge**
   4. **It depends on the desired tone**
9. **The location on the wave where the largest amount of string movement occurs is called the.**
   1. **Anode**
   2. **Node**
   3. **Fnode**
   4. **Max-node**
10. **How would changing the pickup location affect the output signal of an electric guitar.**
    1. **Moving the pickup away from the bridge produces a warmer tone.**
    2. **Moving the pickup closer to the bridge produces a warmer tone.**
    3. **Moving the pickup away from the bridge changes the key up.**
    4. **Moving the pickup closer to the bridge changes the key down.**

**Quiz:Key**

1. **Why is there more than one pickup on most electric guitars?**
   1. **Looks cool**
   2. **Adds Symmetry to the guitar top**
   3. **Adds a different tonal output**
   4. **Pickup manufacturers want to sell extra pickups**
2. **Which pickup has the greater output signal?**
   1. **Neck Pickup**
   2. **Bridge Pickup**
   3. **Middle Pickup**
   4. **They are all the same**
3. **A guitar with a movable pickup would change the tone of the guitar as the pickup is moved.**
   1. **True**
   2. **False**
4. **What is producing the output signal on an Electric Guitar?**
   1. **Sound Waves**
   2. **Magnetic Transducer**
   3. **Resonance**
   4. **Potentiometer**
5. **The movement of the string is called**
   1. **Displacement Velocity**
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6. **What is the fundamental frequency of an open E string?**
   1. **62Hz**
   2. **82Hz**
   3. **164Hz**
   4. **314Hz**
7. **The frequency of the string increases as you get closer to the bridge of the guitar.**
   1. **True**
   2. **False: the frequency remains the same along the string**
8. **What is the ideal placement for a pickup on a guitar?**
   1. **1.000” from the bridge**
   2. **3.1415” from the bridge**
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**Reviewing Faculty Cohort Members:**

* Include at least two names and schools of reviewing faculty cohort members (refer to email list for faculty cohort member email addresses).