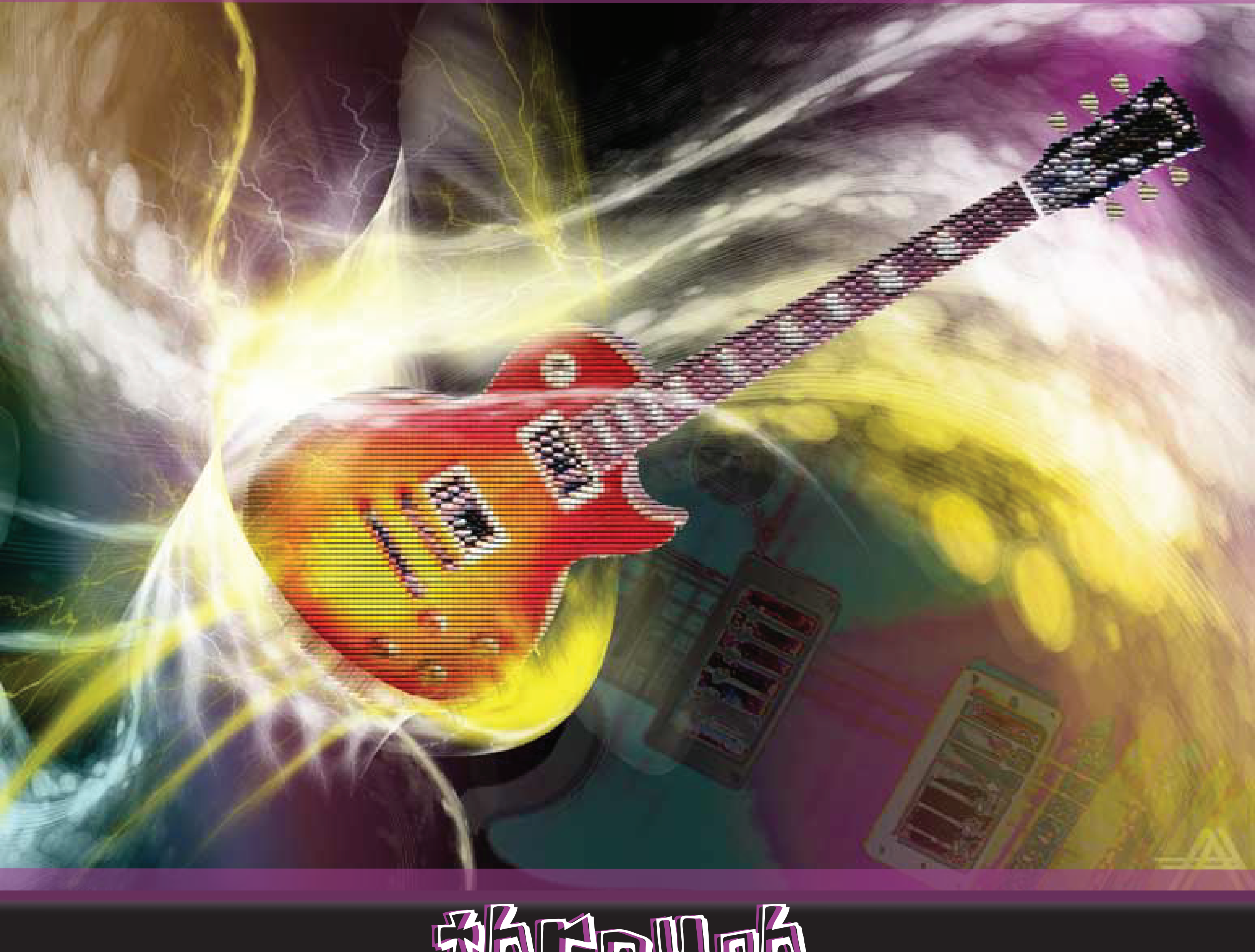
Innovative
STEM EDUCATION



through
GUITAR DESIGN MANUFACTURE

Faculty Professional Development
In Design, Construction, Assembly and Analysis of a Solid Body Guitar Design
NSF ATE DUE Grant 0903336

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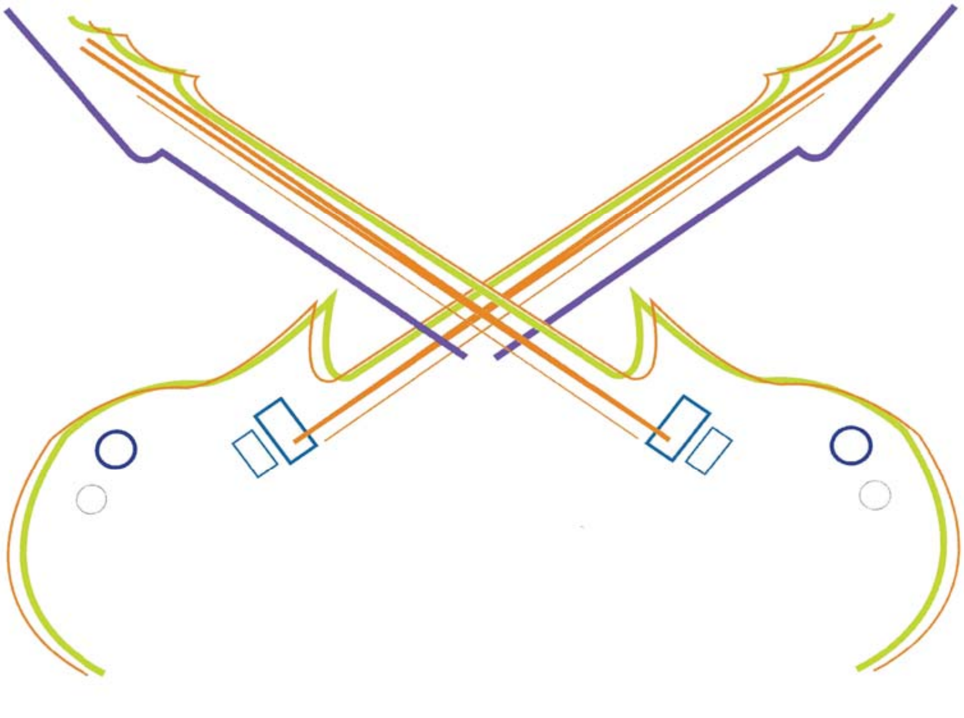
Exploring Innovative
STEM Education
Through

Guitar Design and Manufacture

Workbook

(Version 1006.1)



About Us

Guitars in the Classroom?

Absolutely.

This National Science Foundation STEM Guitar Project provides innovative professional development to high school and community college faculty in collaborative design and rapid manufacturing.

Faculty teams take part in an intense five day guitar design/build project. Each faculty member builds his/her own custom electric guitar and will engage in student centered learning activities that relate the guitar design to specific math, science and engineering topics. Participants leave this weeklong experience with their custom-made guitars, curriculum modules that can be immediately integrated into the faculty teams school curriculum, and much more.

Morning classroom sessions include the following:

- STEM Learning Activities in the following disciplines: Physical Science, Math, Engineering, CADD, CNC, RPT, Reverse Engineering, etc.
- Lab time for practical application
- Develop and share a STEM learning activity
- Remote design team exercise

Afternoon sessions include the following guitar build/hands-on activities:

- Guitar Body, neck, fret board selection and preparation
- Headstock design
- Fretting
- Electronic installation
- Neck installation and setup
- Intonation
- Rock Star Friday

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Learner-Centered Learning Objectives

Some institutions state that course learning objectives --what students will be able to do upon completion of the course-- must remain the same no matter who teaches the course. If that is the case, then your academic freedom means you decide *how* you'll help students achieve those outcomes. You will decide the **enabling objectives** [some institutions use the phrase "enabling objectives" to mean those things students learn to do along the way toward reaching learning objectives]. Teachers should identify and order these objectives as part of the course planning process. In any case, your best first step as you plan the course is to determine ***what students will be able to do upon successful completion of the course***.

Here are some general guidelines for the wording, organization, and tone to use as you craft objectives (adapted from Columbia College's website):

- Goals and objectives should be stated as student **outcomes** ("The student will…", or "You will be able to …").
- They may be **organized** according to the units of the course; if appropriate, include projects and options.
- They should correspond to the **professional standards** of the discipline and work environment the student is preparing to enter.

Describe your learning objectives using **active verbs** that indicate what students will need to do as the semester progresses. For example, in a course on history, one instructor told students they would acquire the "basic skills used by historians," which included the ability to:

- critically analyze primary documents
- identify an author's thesis and evaluate how well it is supported
- write a logical and coherent argument of your own.

The tone of a learning-centered syllabus should be informal and accessible. Personally, I recommend the phrase "you will be able to . . ." instead of "the student will be able to . . .". One other consideration is the decision to use "will" or "should." Check with your institution; in this litigious society, some educational institutions have decided that objectives should be stated as, "You should be able to . . ." because using "will" implies successful accomplishment merely due to attendance.

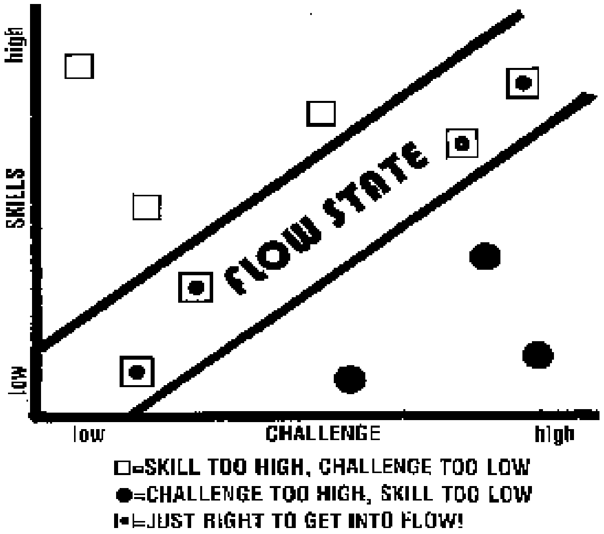
We refer many times to Bloom's Taxonomy. Visit the following website to help clarify how to define and phrase objectives so that you are requiring students to work at the higher levels of the Taxonomy: . The authors provide active verbs related to each of the levels in the Taxonomy. It is clear that "cite," "list," and "pronounce" verbs associated with Bloom's Knowledge level differ markedly from "diagram," "integrate," and "assess" verbs characteristic of Application, Analysis, Synthesis, and Evaluation.

"Integrating" as an activity clearly requires students to ***do something*** with the material. "List," on the other hand, requires only successful memorization and ability to say or write what has been memorized.

Use the following table to locate your objectives on Bloom's scale. The level of demand on students' abilities to think critically, solve problems, make connections rises as the chart moves from knowledge (lowest demand) up to evaluation (highest demand). Keeping the level required to complete your objective commensurate with your students' readiness to accomplish it means that you have set realistic, positive objectives -- ones that will result in success rather than frustration and loss of engagement.

There is no bad or good level in Bloom's Taxonomy, but there is appropriate vs. inappropriate. Knowledge-level learning activity and assessment are quite appropriate at the right times. For instance, learning the names of the parts of the digestive system and listing them on a test may be the right task at the right place in your physiology course. A student who missed this step might be forced into an inappropriate phrase in a real-world scenario. Assure that students know the basic vocabulary by employing a Knowledge-Level activity before moving to assignments that require students to do something with that knowledge.

It is important to give students the right challenge at the appropriate moment. If you ask too little, they lose interest. If you ask too much, they hit overload and can't process the information or complete the task. One way to set the cognitive load of a learning task is to select the verbs appropriate to student readiness. Choose the verbs from the list below that match what students are ready to do with the learning task you want to assign. For example, using the verb "name" (as in, "Name the parts of the digestive system"), means the cognitive load required of students will be lower than if the verb, "determine" (as in, "Determine potential causes for the peptic ulcer given the patient's medical history") is used. You want to manage the ***flow state*** to maintain momentum in the learning process:



The higher levels in Bloom correspond to higher levels of cognitive load. Students have to be skilled and prepared to handle demands made of them at the higher levels. Staged preparation, scaffolding, incremental familiarization, and graduated practice make the move upward possible. Abrupt shifts and inconsistent levels within an assignment or presentation will leave most students stranded. (For more see *Tests and Testing* in Module Seven).

Knowledge-Remembering previously learned materials

cite	label	name	reproduce
define	list	quote	pronounce
identify	match	recite	state

Comprehension-ability to grasp the meaning of material. Answers: who? what? when? where?

alter	discover	manage	relate
change	explain	rephrase	substitute
convert	give examples	represent	summarize
depict	give main idea	restate	translate
describe	illustrate	reword	vary
interpret	paraphrase	tell why	express

Application-ability to use learned material in new and concrete situations

apply	discover	manage	relate
classify	employ	predict	show
compute	evidence	prepare	solve
demonstrate	manifest	present	utilize
direct			

Analysis-ability to break down material into its component parts. Answers: how many? Which? What is?

ascertain	diagnose	distinguish	outline
analyze	diagram	divide	point out
associate	differentiate	examine	reduce
conclude	discriminate	find	separate
designate	dissect	infer	determine

Synthesis-ablity to put parts together to form a new whole. Answers why?

combine	devise	originate	revise
compile	expand	plan	rewrite
compose	extend	pose	synthesize
conceive	generalize	propose	theorize
create	integrate	project	write
design	invent	rearrange	
develop	modify		

Evaluation-ability to judge the value of material for a given purpose. Answers how can we improve? What would happen if?

appraise	conclude	critique	judge
assess	contrast	deduce	weigh
compare	criticize	evaluate	

The importance of keeping Bloom in mind as you create/define your learning objectives for the course and unit is clear. The added benefit is that our process of syllabus-making/course planning and its order of activities help you:

1. determine objectives in terms of student-doing
2. create assessments to measure achievement of objectives
3. create assignments and activities to facilitate student achievement of objectives.

Working in this way guides you constantly along the learning-centered path. Planning the order of the steps keeps your focus on student learning and not solely on the presentation of material:

“. . . one reason students do not learn may be related to the failure of many faculty to consider, articulate, and specify their expectations and objectives. Outcomes assessment forces academics to become student-centered.”

from Successful College Teaching by Baiocco & DeWaters, p. 158

http://www.4faculty.org/Demo/digdeeper/lc_learning_object.htm *by Mark Ferrer*

Science Learning Activity 1

The Decibel Scale

Students will practice calculating decibels based on the intensity of sounds.

Learning Objectives:

1. Students will calculate the sound level in decibels using logarithms.
2. Students will calculate the pressure of sound waves based on their intensity with respect to the threshold of hearing.
3. Students will extrapolate data from a chart to use in a mathematical analysis.

Materials Required:

- Calculator that can do logarithms and exponents.

References:

- http://www.coolmath.com/decibels1.htm. Accessed April 2010.
- http://physics.info/intensity/. Accessed April 2010.
- http://web.cvcaroyals.org/~rheckathorn/ (PPT on the Decibel Scale). Accessed April 2010.
- Serway, R. and Beichner, R. Physics for Scientists and Engineers. 5th Edition. pg. 526

Science Exercise 1

The Decibel Scale

Sound is a longitudinal or a compression wave. As energy travels through the air, the gas is compressed and rarefied. This transfer of energy exerts pressure on our ear drum. While humans are rather average when it comes to sound detection, we still can hear a range of intensities from 10^{-12} to 10^{4} W/m^{2} (well, at least until our eardrum bursts). If we compare this to light, it would be like being able to see from radio waves (10^{4}m) to x-rays (10^{-12}m)

The unit of intensity level was originally the *bel*, coined by Bell Labs in honor of Alexander Graham Bell. However, that proved to be too large a unit, so the decibel (dB), defined to be one tenth of the *bel*, is used. The equation for the decibel is given by the following:

$$(dB) = 10\log_{10}\frac{I}{I_0}$$

Below is a table with common sounds and their intensity level[1]:

Source of Sound	B (dB)	Intensity W/m^{2}
Nearby Jet Airplane	140	$1\text{x}10^{2}$
Jackhammer, threshold of pain	130	$1\text{x}10^{1}$
Rock concert	120	$1\text{x}10^{0}$
Lawn mower	100	$1\text{x}10^{-2}$
Busy traffic	80	$1\text{x}10^{-4}$
Vacuum cleaner	70	$1\text{x}10^{-5}$
Normal conversation	50	$1\text{x}10^{-7}$
Mosquito buzzing	40	$1\text{x}10^{-8}$
Whisper	30	$1\text{x}10^{-9}$
Tustling Leaves	10	$1\text{x}10^{-11}$
Threshold of hearing	0	$1\text{x}10^{-12}$

Taken and adapted from *Physics for Scientists and Engineers*. 7th Edition. Serway. pg. 481, ppt. from Dick Heckathorn's website: http://web.cvcaroyals.org/~rheckathorn/HONORS/web%20pages/Honors9.htm, and http://physics.info/intensity/.

Notes

A Fender guitar amp can produce a sound with an intensity of $1 \cdot 10^{-1}$ W/m^2 (at 10 inches away). Calculate the sound level (in dB) produced by the amp:

Calculate the sound level (in dB) perceived by someone standing ten inches away from two Fender guitar amps.

Increasing the intensity by a factor of two corresponds to a sound level increase of only __________ dB.

A rocket launch is capable of producing a sound intensity of $1 \cdot 10^{6}$W/m^2. Calculate the sound level in dB.

A sound level of 160 dB will instantly break an ear drum. As you remember, sound is produced by a vibrating object causing pressure differences in a medium such as air. As the vibrating object moves towards the ear, the gas molecules in the air move with a higher velocity. As the vibrating object moves away from the ear, the gas molecules in the air move with a smaller velocity. These moving gas molecules exert a pressure on the ear drum. The pressure on the ear is given by the following equation:

$$\Delta P_{\max} = \sqrt{2\rho v I}$$

Where v is the speed of sound in air (v = 343 m/s), and ρ is the density of air (1.2 kg/m^3).

Calculate the pressure exerted by a sound of that level.

If the area of the inner ear is 0.52 cm^2, what is the force exerted on the ear by a 160 dB sound?

Science Exercise 1 Solutions

A Fender guitar amp can produce a sound with an intensity of $1{\cdot}10^{-1}$ W/m^2 (at 10 inches away). Calculate the sound level (in dB) produced by the amp:

$$(dB) = 10\log_{10}\frac{I}{I_0} \qquad (dB) = 10\log_{10}\frac{(1\cdot10^{-1}W/m^2)}{(1\cdot10^{-12}W/m^2)} = 110dB$$

Calculate the sound level (in dB) perceived by someone standing ten inches away from two Fender guitar amps.

$$(dB) = 10\log_{10}\frac{I}{I_0} \qquad (dB) = 10\log_{10}\frac{2(1\cdot10^{-1}W/m^2)}{(1\cdot10^{-12}W/m^2)} = 113dB$$

Increasing the intensity by a factor of two corresponds to a sound level increase of only _____3_______ dB.

A rocket launch is capable of producing a sound intensity of $1{\cdot}10^{6}$W/m^2. Calculate the sound level in dB.

$$(dB) = 10\log_{10}\frac{I}{I_0} \qquad (dB) = 10\log_{10}\frac{(1\cdot10^{6}W/m^2)}{(1\cdot10^{-12}W/m^2)} = 180dB$$

A sound level of 160 dB will instantly break an ear drum. As you remember, sound is produced by a vibrating object causing pressure differences in a medium such as air. As the vibrating object moves towards the ear, the gas molecules in the air move with a higher velocity. As the vibrating object moves away from the ear, the gas molecules in the air move with a smaller velocity. These moving gas molecules exert a pressure on the ear drum. The pressure on the ear is given by the following equation:

$$\Delta P_{\max} = \sqrt{2\rho v I}$$

Where v is the speed of sound in air (v = 343 m/s), and ρ is the density of air (1.2 kg/m^3).

Calculate the pressure exerted by a sound of that level.

Hint: Students can look on the chart on the first page and infer that since a noise of 130 db corresponds to an intensity of 1x10^1, a noise of 140 corresponds to an intensity of 1x10^2, a noise of 150 should correspond with an intensity of 1x10^3, and a noise of 160 should correspond with an intensity of 1x10^4.

Students can use the definition of a logarithm to confirm this since log$_{10}$(1x10^4/1x10^{-12}) is 16. 16x10=160.

$$\Delta P_{\max} = \sqrt{2(1.2kg/m^3)(343m/s)(1\cdot10^{4}W/m^2)} = 2869.15Pa$$

If the area of the inner ear is 0.52 cm^2, what is the force exerted on the ear by a 160 dB sound?

$$P = \frac{F}{A} \qquad F = P\cdot A$$

Changing the area from cm^2 to m^2: $\frac{0.52cm^2}{1}\cdot\frac{(1m)}{(100cm)^2}^{2} = 5.2\cdot10^{-5}m^2$

$$F = (5.2\cdot10^{-5}m^2)\cdot(2869.15Pa) = 0.15N$$

Science Learning Activity 2

Big Ben Sound Demonstration

This demonstration illustrates two ways for sound waves to travel and relates these to the parts on an electric guitar. It is designed to engage students in a discussion of sound production and types of sound waves. Students are then asked to relate how transverse waves on a string can then be converted to longitudinal/compression waves via a speaker or other similar device

Learning Objectives:

1. Students will identify the regions where sound is transmitted using transverse and longitudinal waves.
2. Students will relate these regions to parts on an electric guitar and amplifier.

Materials Required:

1 Wire coat hanger
2 ~30cm pieces of string (kite string works well, but any thick string will do)
2 Waxed paper drinking cups (e.g., Dixie cups)
2 paper clips

References:

Addison, Pam. “Improving Ohio’s Physical Science Proficiency” class at Miami University, Middletown. June 2007.

Science Exercise 2

Tie one end of each piece of string to the metal coat hanger. Poke a hole in the bottom of each paper cup. Feed the loose end of one string up through the hole of the cup, tie around a large paperclip to secure. Repeat with the other string and paper cup.

To use:

Hold paper cups to both ears and let the hanger fall loose. Swing the hanger so it hits something hard, such as a desk. When the hanger strikes another hard surface, you will hear a sound like a clock chime. The audience will not hear anything, however.

I encourage you to make a class set; I have one hanger for each lab table for my students to try.

Possible Discussion Topics:

This would be a great activity to start a discussion of sound waves.

Q1: What type of waves traveled up the string to the bottom of the cup?

Q2: What is this analogous to on the electric guitar?

Q3: What type of waves traveled from the bottom of the cup to your ears?

Q4: How are the sound waves transferred from the bottom of the cup to your ears?

Q5: What is this analogous to on an electric guitar?

Science Exercise 2 Solutions

Q1: What type of waves traveled up the string to the bottom of the cup?
Transverse

Q2: What is this analogous to on the electric guitar?
Guitar strings

Q3: What type of waves traveled from the bottom of the cup to your ears?
Longitudinal/compression

Q4: How are the sound waves transferred from the bottom of the cup to your ears?
Transverse waves carry energy from the colliding hanger up through the string to the bottom of the cup. This causes the bottom of the cup to vibrate, which causes regions of compression and rarefaction in the air between the bottom of the cup and your ear.

Q5: What is this analogous to on an electric guitar?
Amplifier/Speakers

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Science Learning Activity 3

Dancing Laser Demo

This lesson demonstrates how sound is produced by a speaker and how sound is a longitudinal/compression wave. Many students have difficulty in understanding how a speaker produces sound. This demo should illustrate how the speaker diaphragm moves in order to create compression waves in air.

Learning Objectives:

At the end of this demo, students should be able to describe how the diaphragm of a speaker moves to create a longitudinal/compression wave in the air and interpreted by the ear as sound.

Materials Required:

- Old speaker(s) (nothing fancy, they just have to work)
- Radio, computer, etc. that speakers hook up to
- Small mirror (1” is fine)—these can be found at craft stores
- Tape
- String
- Laser pointer (one from the dollar store is fine)

References:

- Addison, Pam. “Improving Ohio’s Physical Science Proficiency” class at Miami University, Middletown. June 2007.
- http://www.soundonmind.com/files/speaker%20diagram%201%20-%20lables%20%28flat%29.png . Accessed April 2010.
- http://mypages.iit.edu/~smile/ph93jl.html
- http://www.exploratorium.edu/square_wheels/modulated_led.pdf
- http://www.xprt.net/~rcrowley/AVclass/Aud-Dcon.htm

Science Exercise 3

Dancing Laser Demo

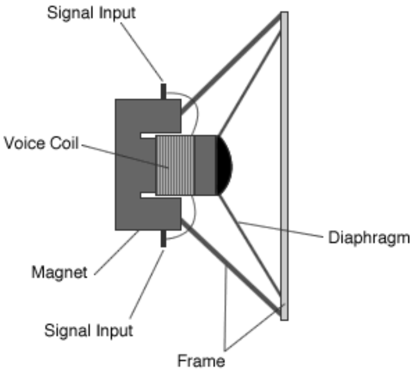

Image source:http://www.soundonmind.com/

Safety precautions:

- ✓ Take care to ensure that the laser never is shone in anyone's eyes.
- ✓ Test out the sound system before doing this demo in class. While use of bargain equipment is encouraged, please make sure the equipment is in good working order.
- ✓ Make sure the volume is set to a reasonable level before beginning.

Set-up:

If possible, remove speaker casing to reveal its internal structure. Hook up speakers to radio (or other device). Tape one end of the string to the back of the mirror. Tape the other end of the string to the top of the speaker so the mirror dangles in front of the diaphragm. Make sure the reflective side of the mirror is facing outward.

Fix the laser pointer so that it shines into the center of the mirror when the sound is off. The laser can be held stationary or can be taped down to a rigid surface.

Any music will work. Music that has a lot of bass will work the best (have

students bring in their favorite bass CDs that they like to have blaring in

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their $750 car with a $2500 stereo system with car parts vibrating off as they go down the road).

Turn lights off and the laser and music on. Watch the reflected laser "dance!"

Possible Discussion Topics:

- Have students identify parts of a speaker and describe what their function is (see diagram under the "Goals" heading).
- Have students explain why the reflected laser light is moving.
- Have students explain how the speaker produces sound.

Explanation:

The diaphragm creates regions of compression and rarefaction in the air; thus propagating a sound wave. The mirror moves in response to these vibrations. The stationary laser light is moved due to the moving mirror. This demo illustrates that sound is a longitudinal/compression wave.

Extension—Speak into the Speaker:

Show students how the speaker's function can be reversed. Connect speaker to an oscilloscope (the soundcard oscilloscope presented at the end of this Workbook by Christian Zeitnitz will work fine). If using a soundcard oscilloscope, it will need to be connected to a 1/8" jack. Have a student speak into a speaker and watch the electronic signal as it is displayed on the screen (this would work best if the computer was hooked up to a projector or to the TV via an AVerKey). Swap out the speaker and connect a microphone to the computer. Have a student repeat what was said into the speaker. Ask the class to consider why the signal display was similar. Explain that a dynamic microphone works in a similar way. For the speaker, an electronic signal triggers the diaphragm to move which causes compression waves in the air interpreted by the ear as sound. The dynamic microphone is the reverse of this process. The diaphragm on a dynamic microphone moves in response to sound (compression) waves in air. This causes the magnets to move which sends a current through the coil.

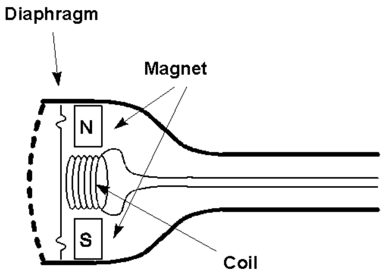


Image source: http://www.xprt.net/~rcrowley/AVclass/Aud-Dcon.htm

Science Learning Activity 4

Introductory Wave Behavior

Students will produce transverse and longitudinal waves using a Slinky or small, loose spring. Students will experiment with changing wave speed, frequency, and wavelength. Students will also determine what happens to the frequency of the wave when string tension is changed.

Learning Objectives:

By the end of this lesson, students should be able to:

1. Describe the difference between a transverse and a longitudinal (compression) wave
2. Identify areas of compression and rarefaction in longitudinal/compression waves
3. Identify the amplitude, wavelength, crest, and trough in a transverse wave
4. Explain boundary behavior of transverse waves
5. To understand the difference between transverse and longitudinal (compression) waves and to examine the wave characteristics of frequency and wavelength.

Materials Required:

- Regular-sized Slinky or similar small, lose spring

Caution: Do not stretch the Slinky to its maximum limit. This could cause permanent damage to the Slinky. Take care in keeping the Slinky in good condition.

References:

Mrs. Aker's Science Class archived files: http://www.fifeschools.com/cjh/staff/laker/filesarchive.htm. Accessed April 2010.

Physics Principles and Problems. Glencoe/McGraw-Hill. 2009.

Science Exercise 4

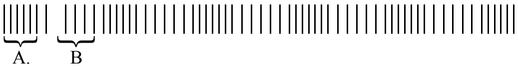
Introductory Wave Behavior

The two basic classes of waves are transverse and longitudinal (also known as compression waves). Both of these wave types play a role in producing sound from the electric guitar. Sound waves are longitudinal waves. Our ears detect the pressure differences in the air caused by the compression wave which is produced by the speaker. When a player plucks the strings of a guitar, a transverse wave is produced. In this activity, you will use a Slinky to model both types of waves.

Caution: Do not stretch the Slinky to its maximum limit. This could cause permanent damage to the Slinky. Take care in keeping the Slinky in good condition.

Longitudinal/Compression Waves:

Take one end of the Slinky and have a lab partner hold onto the other end of the Slinky. Spread the Slinky out about 2-3 meters (do not stretch the Slinky out completely!). Grab about 0.5 meters of Slinky coils and compress them in your hand. Quickly let go. Observe the compressions and rarefactions in the Slinky. You may have to try this a couple of times to get the hang of it. Your Slinky should look like this, where A is the compression and B is the rarefaction:



Which direction was energy transferred along the Slinky?

Did the Slinky coils move parallel or perpendicular to the way the wave/energy was moving?

Transverse Waves:

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Again, have one person hold the Slinky at the opposite end. Move the Slinky to one side, then back quickly to produce a wave pulse.

[1] To start the wave, you moved the Slinky left or right. Which way is the energy being transferred?

Sketch a diagram of the wave traveling on the Slinky and label the direction of the wave and the direction of the transferred energy:

[2] What does the word *transverse* mean? Why are these waves labeled as such?

[3] Flick the Slinky again with a quick left or right motion. Pay attention to how the wave travels along the Slinky. When the wave reaches your lab partner at the other end, how is the wave reflected? Does the wave return on the same side as it traveled down or on the opposite side?

[4] Stretch the Slinky out without damaging it so it is fairly taught. Give one end a good “karate chop,” either vertically or horizontally. Note how the wave behaves. Now move in closer to your lab partner so the Slinky is lose. Give the Slinky another good “karate chop” either vertically or horizontally. Note how the wave behaves. How does tension affect the wave?

Predict how a guitar string would sound if it were under too much tension and if it was not wound tight enough:

[5] Have one person hold the Slinky taught at one end. The other person needs to move the Slinky up and down quickly in order to create a wave train. Count how many wavelengths you are able to get. What do you have to do to increase the number of wavelengths? Decrease the number of wavelengths?

[6] Have one lab partner hold one end and another partner hold the Slinky at the opposite end. Try to flick the Slinky so that you both create a wave at the same time. Record what happens to the Slinky when both wave crests reach the center at the same time:

[7] Next, try to do the same thing, but instead, have one wave crest meet with a trough in the center. What happens to the Slinky when a crest and trough meet at the same point?

[8] Which type of waves travel along guitar strings?

[9] Which type of waves travel out of the amplifier and into a listener's ear?

Science Exercise 4 Solutions

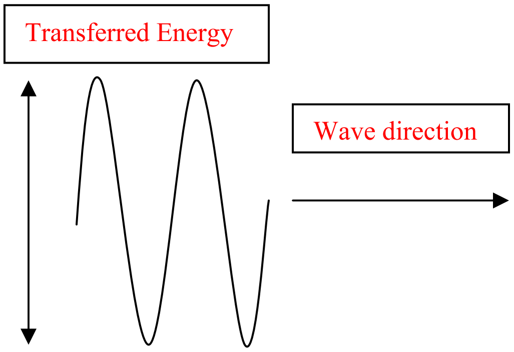
[1] Which direction was energy transferred along the Slinky?
Energy was transferred in the direction of the Slinky.

[2] Did the Slinky coils move parallel or perpendicular to the way the wave/energy was moving? Parallel to the energy.

II. Transverse Waves:
Again, have one person hold the Slinky at the opposite end. Move the Slinky to one side, then back quickly to produce a wave pulse.

[1] To start the wave, you moved the Slinky left or right. Which way is the energy being transferred?
Perpendicular to the Slinky.

Sketch a diagram of the wave traveling on the Slinky and label the direction of the wave and the direction of the transferred energy:



[2] What does the word *transverse* mean? Why are these waves labeled as such?
Transverse means perpendicular. (Ask students to consider what *transverse* means in geometry.) These waves are labeled as such because the energy is being transferred perpendicular to the direction of the wave.

[3] Flick the Slinky again with a quick left or right motion. Pay attention to how the wave travels along the Slinky. When the wave reaches your lab partner at the other end, how is the wave reflected? Does the wave return on the same side as it traveled down or on the opposite side?
When the wave strikes a boundary (the partner's hand), it will travel back on the opposite side. For example, if the wave crest was to the left of the person before it reflected off of her hand, the reflected wave crest would be to the right of the person's hand.

[4] Stretch the Slinky out without damaging it so it is fairly taught. Give one end a good "karate chop," either vertically or horizontally. Note how the wave behaves. Now move in closer to your lab partner so the Slinky is lose.

Give the Slinky another good “karate chop” either vertically or horizontally. Note how the wave behaves. How does tension affect the wave?
As tension increases, so should the speed of the wave.
Predict how a guitar string would sound if it were under too much tension and if it was not wound tight enough:
If a guitar string were under too much tension, it will have a higher pitch. If a guitar string were too loose, it will have a lower pitch.

[5] Have one person hold the Slinky taught at one end. The other person needs to move the Slinky up and down quickly in order to create a wave train. Count how many wavelengths you are able to get. What do you have to do to increase the number of wavelengths? Decrease the number of wavelengths?
Number of wavelengths will vary. To increase the number of wavelengths, the person should move her hand more frequently. To decrease the number of wavelengths, the person should move her hand less frequently.

[6] Have one lab partner hold one end and another partner hold the Slinky at the opposite end. Try to flick the Slinky so that you both create a wave at the same time. Record what happens to the Slinky when both wave crests reach the center at the same time:
When two crests collide, the amplitude should be twice as large as the two initial waves (constructive interference).

[7] Next, try to do the same thing, but instead, have one wave crest meet with a trough in the center. What happens to the Slinky when a crest and trough meet at the same point?
There should be a point of no disturbance in the center where the crest and trough meet. They should cancel each other out (destructive interference).

[8] Which type of waves travel along guitar strings?
Transverse waves

[9] Which type of waves travel out of the amplifier and into a listener’s ear?
Longitudinal/compression waves

Science Learning Activity 5

Determining String Tension Using Measured Frequencies

The purpose of this lab is to determine the tension of a guitar string using measured frequencies. Tension gauges are commercially available but are cost prohibitive for most high school and community college labs. This lab makes use of a free on-line oscilloscope or a hand-held tuner that displays frequency. Students measure the frequency, compare it to the theoretical (in-tune) frequency, calculate the tension on each string, and then calculate the total tension on the guitar due to the strings.

Learning Objectives:

In this lab, students will get to use their prior knowledge of transverse waves (velocity, wavelength, and frequency) and apply it to the electric guitar.

1. Measure the length, mass, and peak frequency for each guitar string
2. Calculate the velocity on the six guitar strings based on their data
3. Use the basic equation for the speed of a wave, $v=f\lambda$
4. Use the fact that the wavelength of the first harmonic is twice as long as the guitar string

Materials Required:

- Oscilloscope (may be accessed on-line) or hand-held tuner that displays frequency
- Electric guitar that is more or less in-tune

On-line oscilloscope may be downloaded from: http://www.zeitnitz.de/Christian/scope_en

References:

- http://www.noyceguitars.com/Technotes/Articles/T3.html {Feb. 9, 2010}
- Serway. *Physics for Scientists and Engineers*.
- Zitzewitz, *et al.* Physics *Principles and Problems.* Glencoe. Pg. 428
- http://www.physicsclassroom.com/Class/sound/u11l5b.cfm {March 25, 2010}
- http://www.sciencebuddies.org/science-fair-projects/project_ideas/Music_p010.shtml {March 29, 2010}
- http://www.harmony-central.com/articles/tips/pitch_vs_frequency/ {April 1, 2010}
- http://www.noyceguitars.com/Technotes/Articles/T3.html {April 1, 2010}
- 1 – French, M., A Pop Bottle and a Helmholz Resonator, *Experimental Techniques*, May/June 2005.
- 2 – Fletcher, N. and Rossing, T., The Physics of Musical Instruments, 2nd ed., Springer 1998, ISBN 0387983740

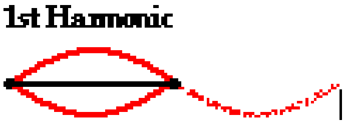


Image Source: http://www.physicsclassroom.com

- **Motion and Forces:** Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object. {pg. 179-180}

- **Interactions of Energy and Matter:** Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter. {pg. 180s}

Notes

Science Exercise 5

Determining String Tension Using Measured Frequencies

If a guitar string under tension ($\vec{F}_T$) is pulled to the side, then released, the tension causes the string to accelerate back toward the equilibrium position. According to Newton's second law, as the tension on the string increases, the acceleration increases. If the acceleration of the string increases, so should the velocity of the string. It is more difficult to accelerate a more massive string than a lighter one. The wave speed should also decrease as the mass per unit length (μ) increases.

The velocity of a string segment under tension is given by the following formula:

$$v = \sqrt{\frac{\vec{F}_T}{\mu}}$$

One can measure the tension directly using a tension gauge, however, these can be quite expensive. The velocity of a string is also given by:

$$v = \lambda f$$

where $\lambda = 2L$. Substituting 2Lf for *v*,

$$2Lf = \sqrt{\frac{F_T}{\mu}}$$

$$4L^2 f^2 \mu = F_T$$

Instead of *measuring* string tension, string length and frequency will be measured in order to calculate the tension on each string.

Measure the mass and length of each string. Record your answers in the table below:

String #	Mass (kg)	Length (m)	μ (kg/m)
1 (E)			
2 (B)			
3 (G)			
4 (D)			
5 (A)			
6 (E)			

Notes

Next, measure the peak frequency using an on-line oscilloscope or a hand-held guitar tuner that displays the correct frequency and the actual frequency on the guitar string.

String #	Measured Frequency (Hz)	Ideal Frequency (Hz)
1 (E)		329.63
2 (B)		246.94
3 (G)		196
4 (D)		146.82
5 (A)		110
6 (E)		82.4

Using the equations from page 1, calculate the tension on each string. Then calculate the ideal string tension in Newtons using the ideal tension in kg and multiplying by $9.8 m/s^2$. Add up the total tensions in each column for the guitar.

String #	Calculated Tension (N)	Ideal Tension (kg)	Ideal Tension (N)
1 (E)		7.35	
2 (B)		6.98	
3 (G)		7.53	
4 (D)		8.34	
5 (A)		8.84	
6 (E)		7.94	
Total Tension:			

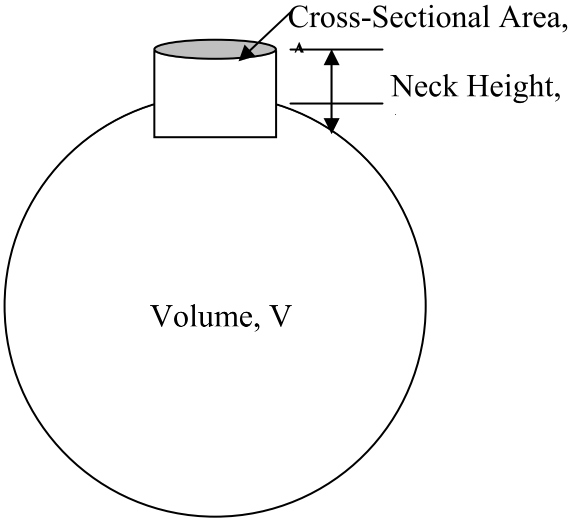
[1] Show using dimensional analysis that the units for the square root of the quantity tension divided by the mass per unit length are equal to the units for velocity.

[2] Dean Markley guitar strings have a length of 640mm. The first E string has a diameter of 0.254mm and a μ of $4.01 \cdot 10^{-4}$ kg/m. The tension on the string is 71.3N. Find the frequency of the fundamental note produced by plucking this string.

Using a Pop Bottle as a Helmholz Resonator

French and French

$$f = \frac{c}{2\pi}\sqrt{\frac{A}{tV}}$$



Note: the speed of sound in air is 343 m/sec

Notes

Position: 5.79 sec.

Length: 5.79 sec.

File name: pop1

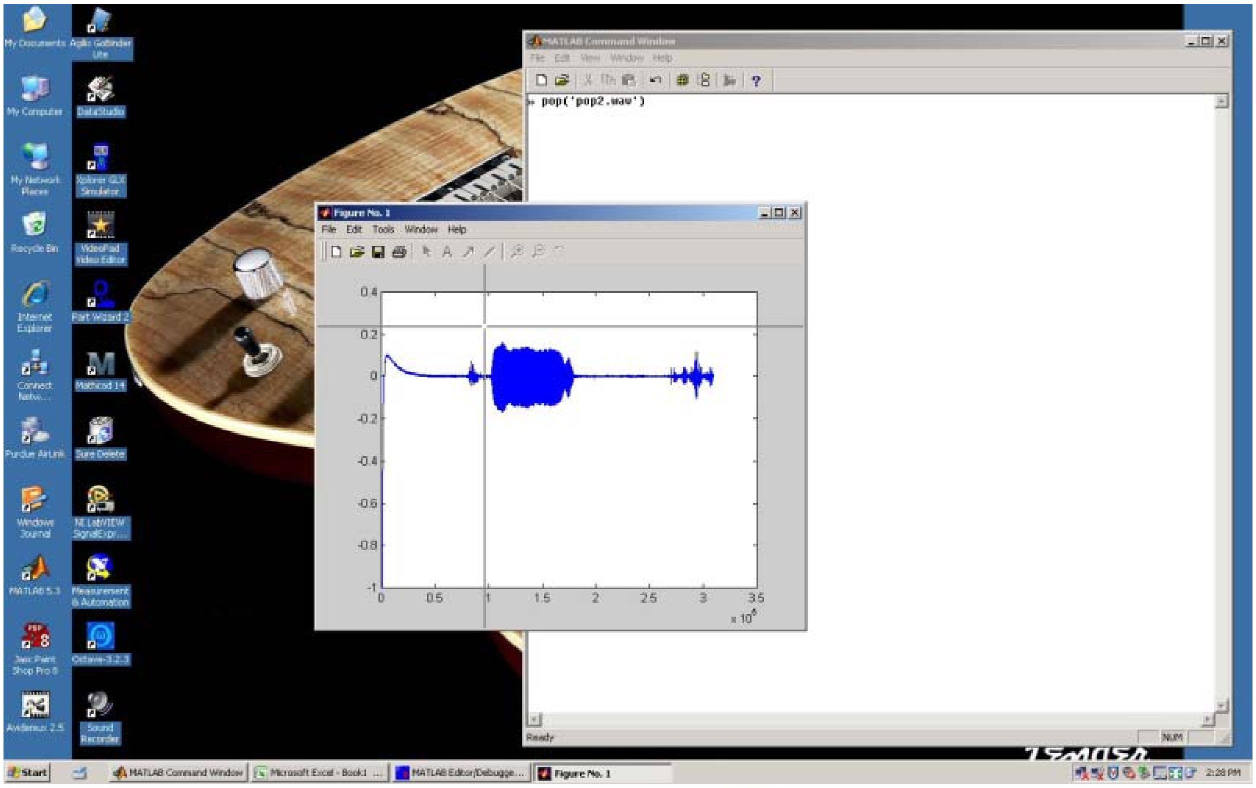
Save as type: Sounds (*.wav)

Format: PCM 44.100 kHz, 16 Bit, Stereo

Name: (untitled)

Format: PCM

Attributes: 48.000 kHz, 16 Bit, Mono 93 kb/sec



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>> pop('pop2.wav')
```

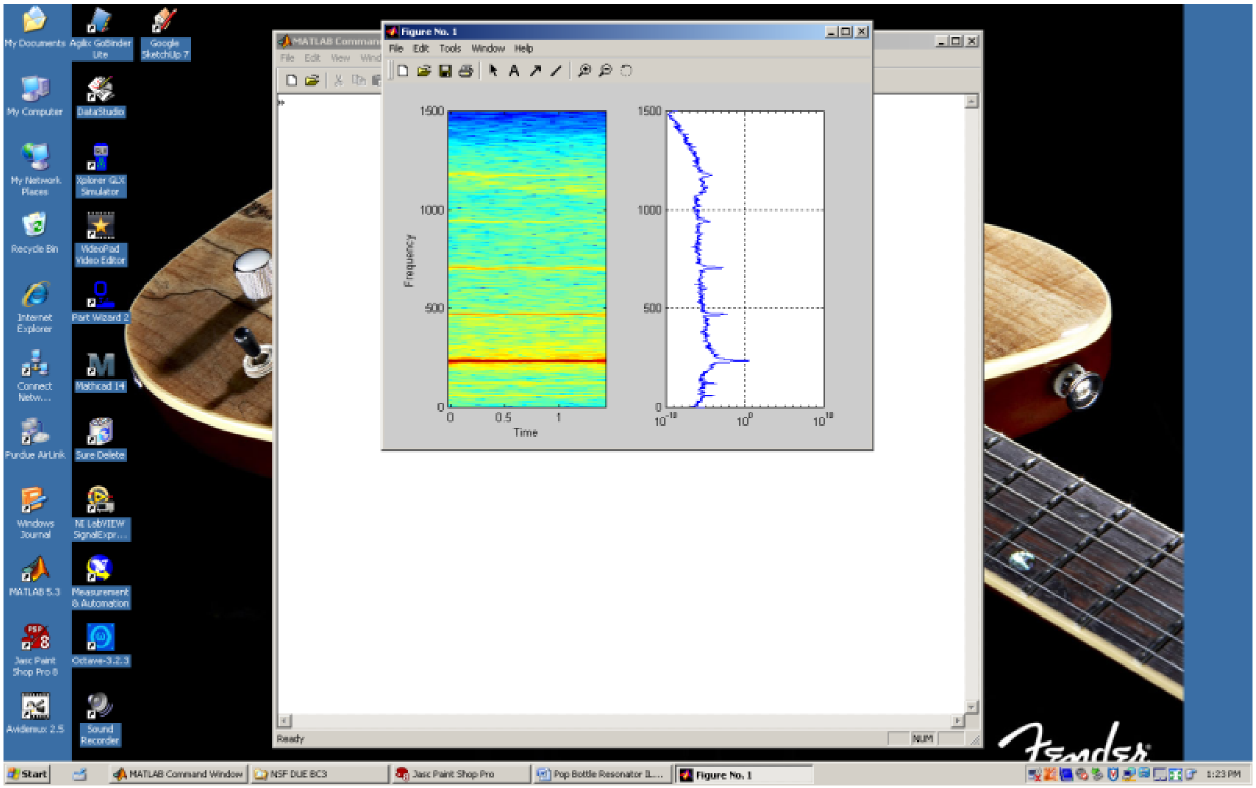
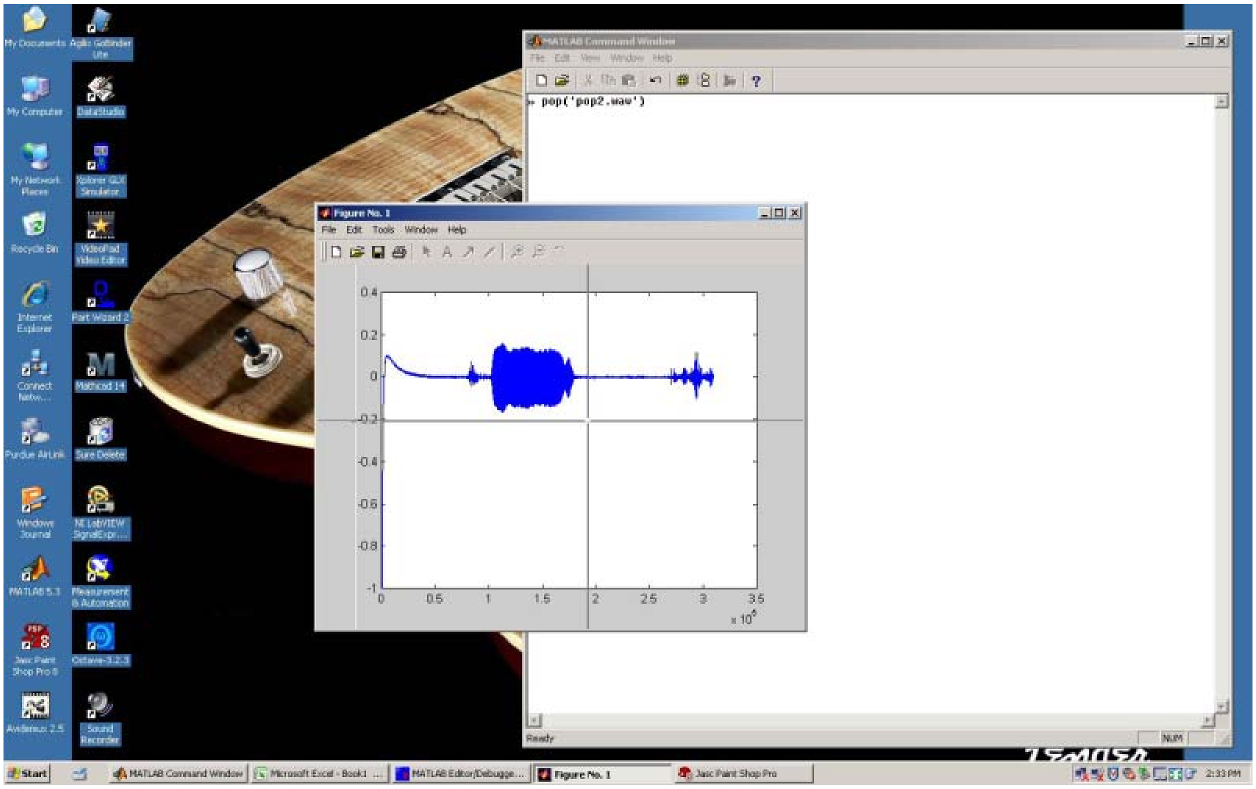
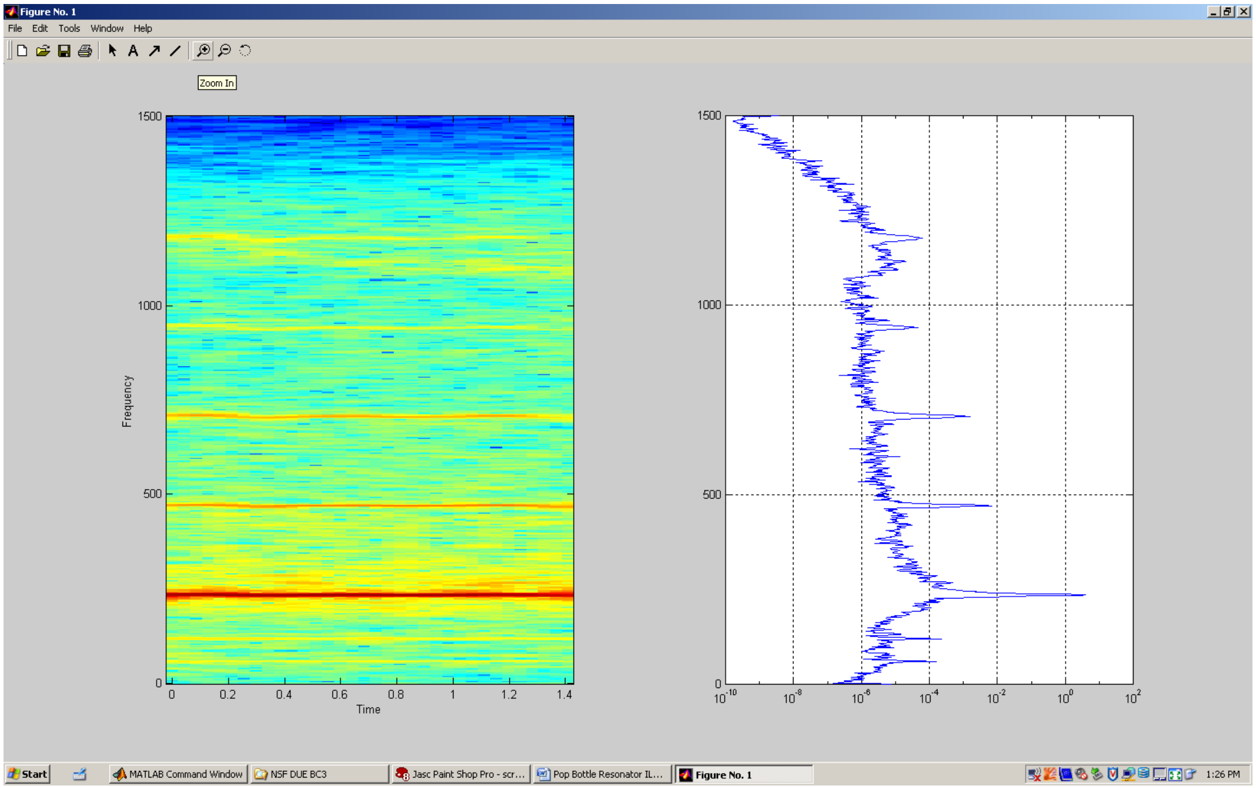


Figure No. 1
File Edit Tools Window Help
MATLAB Command Window
1500
1000
500
0
Frequency
0
0.5
1
Time
1500
1000
500
0
10^{-10}
10^{0}
10^{10}
Ready
NUM
Start
MATLAB Command Window
NSF DUE BC3
Jasc Paint Shop Pro
Pop Bottle Resonator II...
Figure No. 1
1:23 PM



```
» pop('pop2.wav')
```

MATLAB Command Window
File Edit View Window Help
Figure No. 1
File Edit Tools Window Help
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.5
1
1.5
2
2.5
3
3.5
$\times 10^{5}$
Ready
NUM
Start
MATLAB Command Window
Microsoft Excel - Book1
MATLAB Editor/Debugger...
Figure No. 1
Jasc Paint Shop Pro
2:33 PM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File Edit Tools Window Help
Zoom In
1500
1000
500
0
Frequency
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Time
1500
1000
500
0
10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2}
Start
MATLAB Command Window
NSF DUE BC3
Jasc Paint Shop Pro - scr...
Pop Bottle Resonator IL...
Figure No. 1
1:26 PM

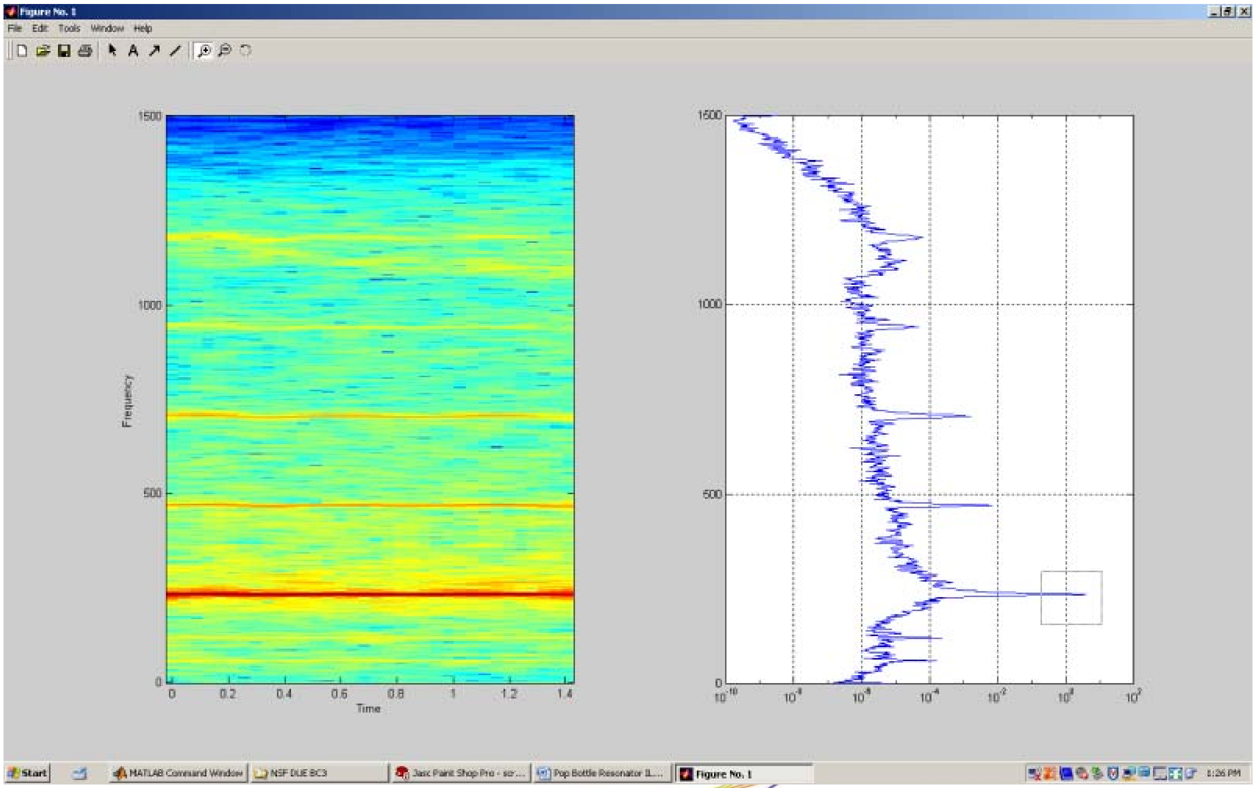


Figure No. 1
File Edit Tools Window Help
1500
1000
500
0
Frequency
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Time
1500
1000
500
0
10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2}
Start
MATLAB Command Window
NSF DUE BC3
Jasc Paint Shop Pro - scr...
Pop Bottle Resonator IL...
Figure No. 1
1:26 PM

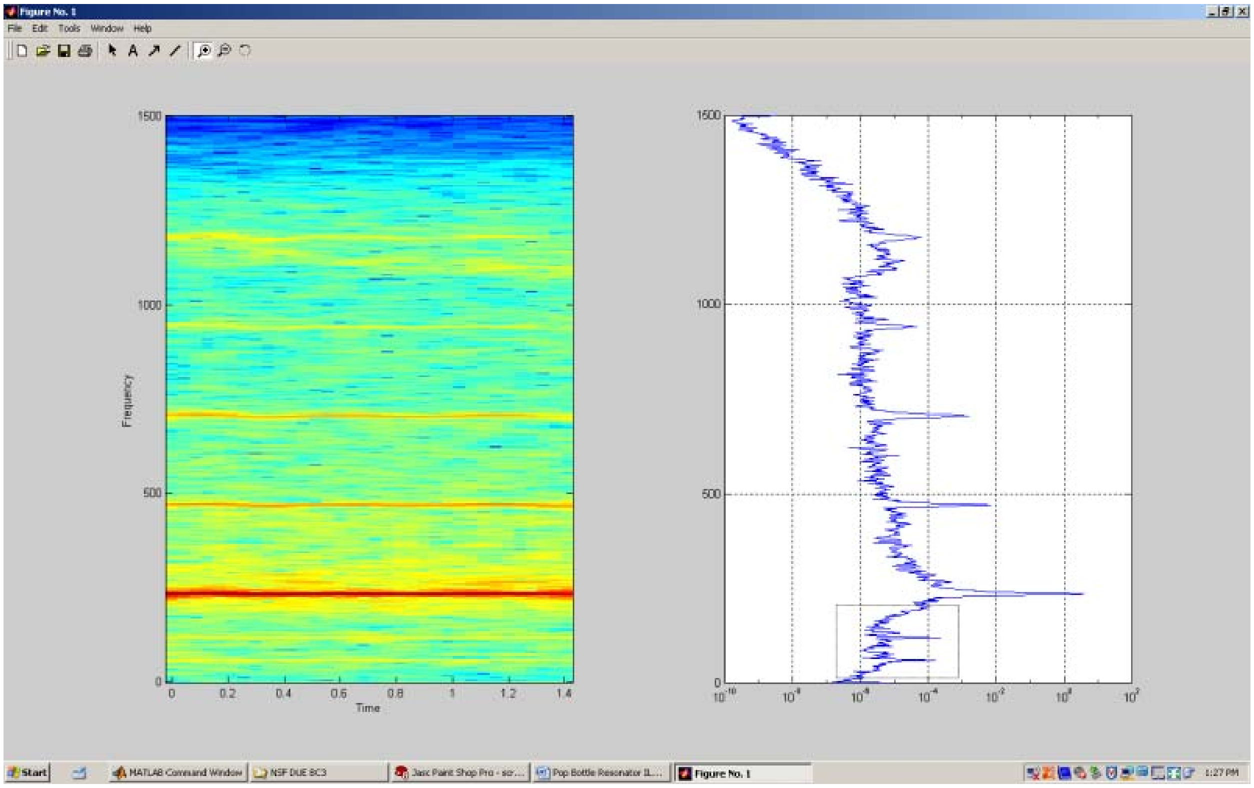


Figure No. 1
File Edit Tools Window Help
1500
1000
500
0
Frequency
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Time
1500
1000
500
0
10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2}
Start
MATLAB Command Window
NSF DUE BC3
Jasc Paint Shop Pro - scr...
Pop Bottle Resonator IL...
Figure No. 1
1:27 PM

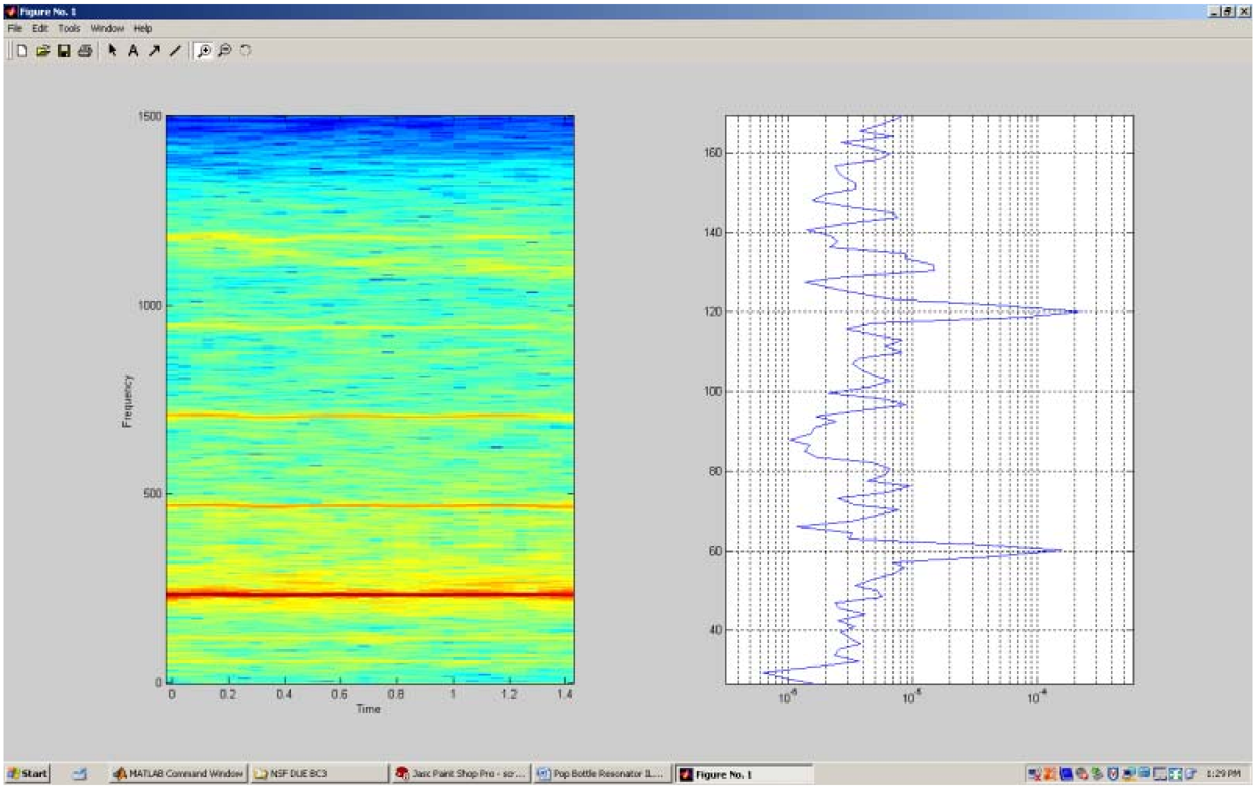


Figure No. 1
File Edit Tools Window Help
1500
1000
500
0
Frequency
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Time
160
140
120
100
80
60
40
10^{-6} 10^{-5} 10^{-4}
Start
MATLAB Command Window
NSF DUE BC3
Jasc Paint Shop Pro - scr...
Pop Bottle Resonator IL...
Figure No. 1
1:29 PM

Science Learning Activity 6

Standing Waves on a Guitar String

To understand how the frequency of waves on a string depends on factors such as the length of the string and harmonic number.

A guitar produces tones because of standing waves on a string. In this exercise, students will work in groups of three or more to study waves on a large piece of rope. While it is harder to see waves on a guitar string, they vibrate in a similar manner.

By the end of this lesson, students should be able to:

- Explain what is meant by the frequency of a standing wave
- Explain that the frequencies of harmonics are multiples of the fundamental frequency
- Explain that a shorter string has standing waves of a higher frequency

Learning Objectives:

In this lab, students will get to use their prior knowledge of transverse waves (velocity, wavelength, and frequency) and apply it to the electric guitar.

1. Measure the length, mass, and peak frequency for each guitar string
2. Calculate the velocity on the six guitar strings based on their data
3. Use the basic equation for the speed of a wave, $v=f\lambda$
4. Use the fact that the wavelength of the first harmonic is twice as long as the guitar string

Materials Required:

Clothesline or similar rope roughly 15 feet long, stopwatch
Guitar, Meter stick, Guitar Tuner
Fourier Synthesis Java Applet
http://homepages.gac.edu/~huber/fourier/

References:

"Physics", Douglas Giancoli, 6th ed., Prentice Hall, 2005.
http://davide.gipibird.net/A_folders/Theory/t1.html
Tom Huber, Physics Department, Gustavus Adolphus College, huber@gac.edu Revised: June 6, 2010
http://www.betterguitar.com/instruction/essentials/guitar_parts.html
“Engineering the Guitar: Theory and Practice”, R. Mark French, Springer, 2009

Science Exercise 6

Standing Waves on a Guitar String

National Science Standards:

- **Motion and Forces:** Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object. {pg. 179-180}
- **Interactions of Energy and Matter:** Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter. {pg. 180s}

Note: There are two different naming conventions for names of the standing waves – this can easily lead to confusion! Almost all textbooks for both physics or music will call the lowest mode, Figure 1(a), the Fundamental. Some texts, particularly physics texts, will also call Figure (a) the First Harmonic.

The second mode, Figure 1(b), might be called the Second Harmonic in some texts, but it might also be called the First Harmonic in other texts! Another name for this would be the First Overtone.

The third mode, Figure 1(c), again might be called either the Second or Third Harmonic, depending on the convention used.

Figure 1: Standing waves on a string

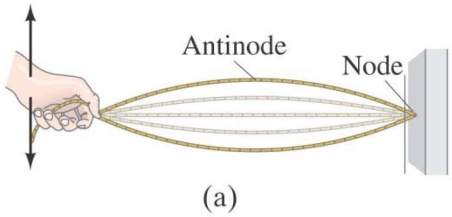


Figure 1(a): Fundamental Mode, Frequency f_1
Also sometimes called First Harmonic

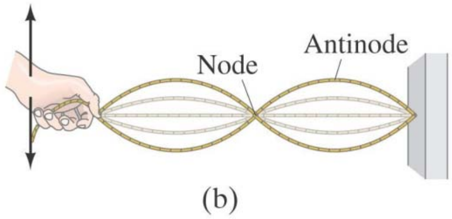


Figure 1(b): Second Mode, Frequency $f_2 = 2f_1$
Some texts call this the First Overtone,
Or the 2nd Harmonic (or sometimes the 1st Harmonic)

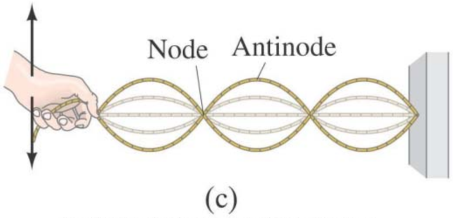


Figure 1(c): Third Mode, Frequency $f_3 = 3f_1$

For standing waves on a string, the two ends of the string are nodes (where the string is essentially motionless), and there are one or more antinodes (where the displacement is large) between the nodes.

The frequency, *f*, of a wave is defined as the number of times each second it goes through a full cycle. The units for frequency are “Hertz” or “Hz”, which is the number of cycles per second. For example, if a string is vibrating at 440 Hz, it means that it moves an entire cycle (wave up, to wave down, back to wave up) 440 times each second.

I. Fundamental Mode of Standing Waves on a String:

(a) Two lab partners should hold onto the ends of a rope about 10-15 feet apart. Back up until the rope is sagging only a few inches in the middle of the rope. One partner should hold the rope so that it doesn’t move (for example, hold your elbows close to your body and your hands with the rope right next to your chest). The other partner will move the rope up and down. Increase or decrease the frequency (how fast you vibrate the rope) until you get stable, large amplitude of the First Mode, as shown in Figure 1(a).

How many antinodes are there on the string for the fundamental mode _________

How many nodes are there for the fundamental mode ___________

(b) Once you have a large amplitude for the First Mode, use a stopwatch to time 10 seconds, and count the number of cycles of the wave. Divide the number of cycles in 10 seconds by 10 to get the frequency, which is the number of cycles per second.

_____________ Number of cycles in 10 seconds

_____________ Number of cycles in 1 second

_____________ Frequency of the Fundamental Mode in Hz

II. Second Mode of the String:

Now, without moving forward or backwards, speed up the rate that you are vibrating the rope until you form a stable pattern of the Second Mode, as shown in Figure 1(b). Again, count the number of cycles that occur in 10 seconds, and determine the frequency by dividing by 10.

How many antinodes are there on the string for the Second Mode _________

How many nodes are there for the Second Mode ___________

_____________ Number of cycles in 10 seconds

_____________ Frequency of the Second Mode in Hz

III. Third Mode of the String:

Finally, speed up the rate that you are vibrating the rope until you form a stable pattern of the Third Mode, as shown in Figure 1(c).

How many antinodes are there on the string for the Third Mode __________

How many nodes are there for the Third Mode ____________

_____________ Number of cycles in 10 seconds

_____________ Frequency of the Third Mode in Hz

Discuss: According to theory, the second mode should have twice the frequency of the fundamental, and the third mode should be about three times the frequency of the fundamental. Do your results agree with this prediction?

IV. Length of String

If the length of the string is shortened, the frequency of the standing wave will increase. Instead of holding the ends of the rope, move so that you are about half the distance apart from each other that you were originally. Shake the rope until you get it vibrating in its first mode. Use the same technique to measure the frequency of the standing wave.

_____________ Number of cycles in 10 seconds

_____________ Frequency of the Third Mode in Hz

Explain what happens to the frequency of the standing wave on a string when the length of the string is shortened. Explain how this relates to making notes on a guitar.

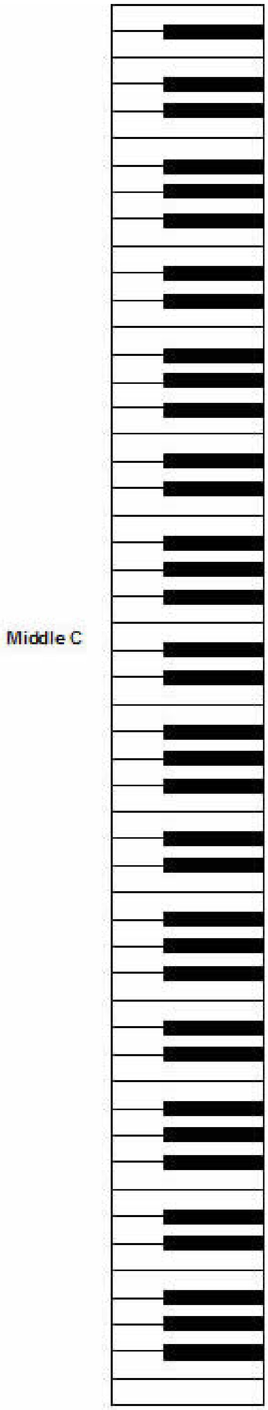
Problems:

[1] Sketch the standing wave when the string is vibrating in its 2nd mode. If a 64.8 cm long guitar string is vibrating in its 2nd mode, how far from the end is one of the nodes?

[2] Sketch the standing wave when the string is vibrating in its 3rd mode. If a 64.8 cm long guitar string is vibrating in its 3rd mode, how far from the end is one of the nodes?

[3] The fundamental frequency of the low E string on a guitar is 82.4 Hz. What is the frequency of the second and third modes of this string?

[4] The diagram on the following page shows the notes on a piano and the corresponding frequencies. The low E string on a guitar (82.4 Hz) is called E2 because it is the note corresponding to the 2nd E key on a piano. What notes do the second and third modes of this string correspond to?



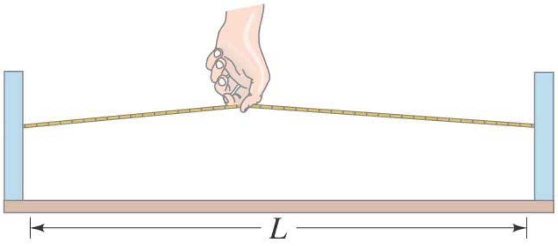
A0	27.5	A#0	29.135
B0	30.868		
C1	32.703	C1#	34.648
D1	36.708	D1#	38.891
E1	41.203		
F1	43.654	F1#	46.249
G1	48.999	G1#	51.913
A1	55.000	A1#	58.270
B1	61.735		
C2	65.406	C2#	69.296
D2	73.416	D2#	77.782
E2	82.407		
F2	87.307	F2#	92.499
G2	97.999	G2#	103.83
A2	110.00	A2#	116.54
B2	123.47		
C3	130.81	C3#	138.59
D3	146.83	D3#	155.56
E3	164.81		
F3	174.61	F3#	185.00
G3	196.00	G3#	207.65
A3	220.00	A3#	233.08
B3	246.94		
C4	261.63	C4#	277.18
D4	293.66	D4#	311.13
E4	329.63		
F4	349.23	F4#	369.99
G4	392.00	G4#	415.30
A4	440.00	A4#	466.16
B4	493.88		
C5	523.25	C5#	554.37
D5	587.33	D5#	622.25
E5	659.25		
F5	698.46	F5#	739.99
G5	783.99	G5#	830.61
A5	880.00	A5#	932.33
B5	987.77		
C6	1046.5	C6#	1108.7
D6	1174.7	D6#	1244.5
E6	1318.5		
F6	1396.9	F6#	1480.0
G6	1568.0	G6#	1661.2
A6	1760.0	A6#	1864.7
B6	1979.5		
C7	2093.0	C7#	2217.5
D7	2349.3	D7#	2489.0
E7	2637.0		
F7	2793.8	F7#	2960.0
G7	3136.0	G7#	3322.4
A7	3520.0	A7#	3729.3
B7	3951.1		
C8	4186.0		

Science Exercise 7

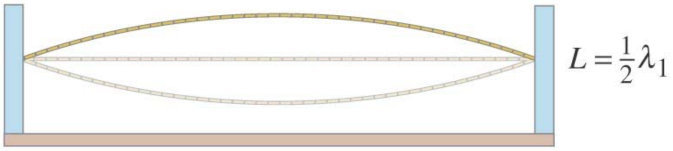
Standing Waves on a Guitar String

One purpose of this lab is to investigate the relationship between the length of strings on a guitar and the frequency. Another is to investigate harmonics of strings

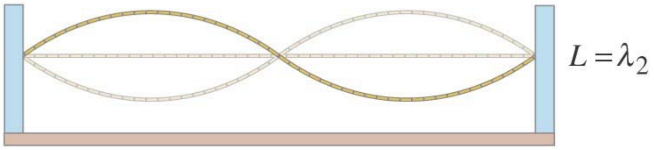
In a previous lab, you studied the shapes for the different modes of vibration of strings. You noticed that there were nodes (motionless points) at the two ends of the string. For the 2nd Mode, with twice the frequency of the fundamental, there was also a node at the center of the string.



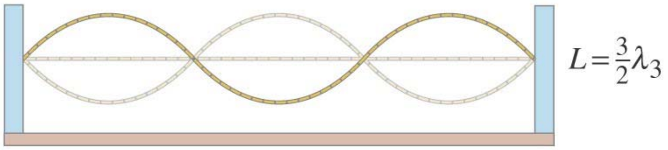
(a)



Fundamental or first harmonic, f_1



First overtone or second harmonic, $f_2 = 2f_1$



Second overtone or third harmonic, $f_3 = 3f_1$

(b)

There are a couple of key concepts to understand when discussing waves on a string:

Frequency (*f*) is the number of cycles of the string each second. This is measured in units of Hertz (Hz), which is another name for cycles per second.

Wavelength (λ, which is the Greek letter lambda) is the length of one full cycle of a wave. The wavelength of the fundamental standing wave λ_1 is twice the length of the string L, or $\lambda_1=2L$

Velocity (v) is the speed of the wave on the string. As we will find out in a subsequent lab, the speed of the wave increases as the tension in the string increases, and the speed decreases as the mass per unit length of the string increases (which is why the lower strings on the guitar are thicker – they can have a lower tone because there is more mass in the same length of string).

These three quantities are interrelated in the following equation:

$$v = f\,\lambda \tag{1}$$

Namely, the product of the wavelength times the frequency is equal to the speed of the wave. We can write this another way. Namely, by solving for the frequency, and noting that for the fundamental, the wavelength is given by $\lambda_1=2L$, the frequency of the fundamental can be written as

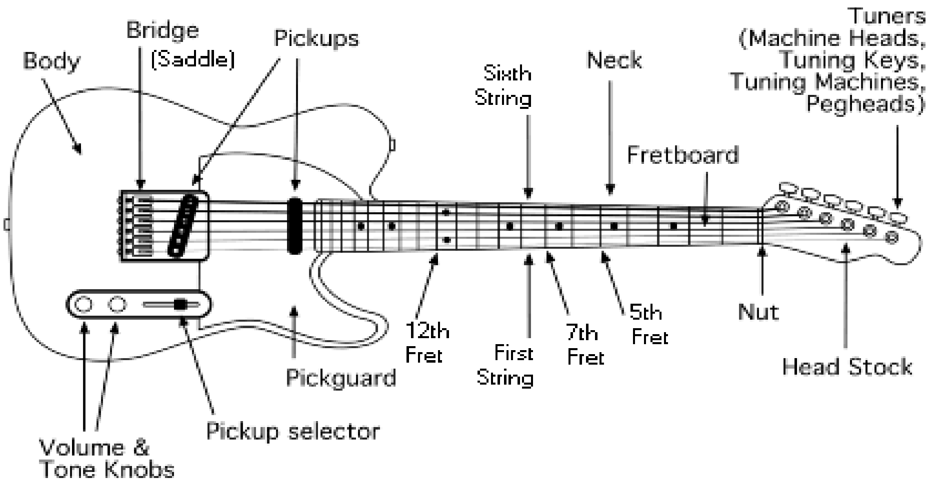
$$f_1 = v \,/\, 2L. \tag{2}$$

The frequencies of different modes are multiples of the fundamental frequency. For the n^{th} mode is

$$f_n = n\,(v \,/\, 2L) = n\,f_1\,. \tag{3}$$

where n=1,2,3,…

When you pluck a string, it will vibrate in many different harmonics at the same time. For example, if you pluck it near the center of the string, it will mainly vibrate in its fundamental mode, whereas if a string is plucked near the end, it will vibrate in many of the upper harmonics. As we will see in later labs, the combination of harmonics that are present in a sound wave is critical in determining what the tone will sound like.



Tuning the Guitar

For the 6th string on the guitar (the thickest string), measure the length of the string between the nut and the saddle, which is the part of the bridge that the string passes over.

Length of String from Nut to Saddle _________ inches __________ cm

Is the length of each string the same? ________________________________

Use an electronic tuner to tune your guitar. Starting with the 6th string on the guitar, pluck a note, and then turn the tuners until the note is in tune. The notes and their frequencies are listed in the table below

String	Note	Frequency
6th (Thick wound string)	E2	82.4 Hz
5th	A2	110.0 Hz
4th	D3	146.8 Hz
3rd	G3	196.0 Hz
2nd	B3	246.9 Hz
1st (Thin steel string)	E4	329.6 Hz

Varying frequency by changing length

As you observed in a previous lab, as the length of a string is decreased, the frequency gets larger. This can also be seen in Equation 2 – if the length L gets smaller, the frequency f will get larger. On a guitar, the length of the string can be changed by pressing a string against the neck with your finger. The string will touch a fret, so the effective length of the string would then be the distance from the fret to the saddle.

Locate the 5th fret on the guitar. Frets are numbered starting from the nut. On most guitars, there will be a dot on the neck between the 4th and 5th fret. Press your finger firmly on the 6th string between the 4th and 5th fret, so that the string is touching on the 5th fret. Play the note. It may take a little practice to get a clear tone from the guitar. What do you observe about this note (5th fret on the 6th string)? Is it higher or lower in pitch? Compare this note to the note that you get when you play the open note on the 5th string.

Now we can use Equation 2 to investigate how the fretboard is laid out to properly make notes on the guitar.

First, let us calculate the speed of waves on the string. Using algebra, solve Equation 2 so that the speed *v* is on one side of the equation, and the frequency *f* and length *L* are on the other side. (HINT: Multiply both sides of the equation by 2*L*).

$$f_1 = v / 2L.$$

$v =$ ________________

Using the length *L* (in cm) that you found in Part I, and the fundamental frequency f_1 of an E2 (82.4 Hz), calculate the speed of waves on the string.

$L =$ _________ cm $\qquad f_1 =$ ____________ Hz

$v =$ ________________ cm/second

This speed (in cm/seconds) is for the 6th string. In a later lab we will investigate how this speed changes when the tension in the string changes. Now, measure the distance from the saddle to the 5th fret on the 6th string.

$L_{\text{5th Fret}} =$ ____________ cm (from saddle to the 5th fret)

Plug this length and the speed of the wave above into Equation 2 to calculate the frequency of the note that you get when you play the note that is the 5th fret on the 6th string.

$f_1 = v / 2L_{\text{5th Fret}} =$ ____________ Hz

Compare this frequency to the frequency that you would expect for an A2. On the next page, you will find a table that has frequencies and corresponding notes. Discuss your results

Table 2.2. Equal Tempered Notes In The Human Hearing Range (Hz)

E_0	20.602	E_3	164.81	E_6	1318.5	E_9	10548
F_0	21.827	F_3	174.61	F_6	1396.9	F_9	11175
	23.125		185.00		1480.0		11840
G_0	24.500	G_3	196.00	G_6	1568.0	G_9	12544
	25.957		207.65		1661.2		13290
A_0	27.500	A_3	220.00	A_6	1760.0	A_9	14080
	29.135		233.08		1864.7		14917
B_0	30.868	B_3	246.94	B_6	1975.5	B_9	15804
C_1	32.703	C_4	261.63	C_7	2093.0	C_{10}	16744
	34.648		277.18		2217.5		17740
D_1	36.708	D_4	293.66	D_7	2349.3	D_{10}	18795
	38.891		311.13		2489.0		19912
E_1	41.203	E_4	329.63	E_7	2637.0	E_{10}	21096
F_1	43.654	F_4	349.23	F_7	2793.8		
	46.249		369.99		2960.0		
G_1	48.999	G_4	392.00	G_7	3136.0		
	51.913		415.30		3322.4		
A_1	55.000	A_4	440.00	A_7	3520.0		
	58.270		466.16		3729.3		
B_1	61.735	B_4	493.88	B_7	3951.1		
C_2	65.406	C_5	523.25	C_8	4186.0		
	69.296		554.37		4434.9		
D_2	73.416	D_5	587.33	D_8	4698.6		
	77.782		622.25		4978.0		
E_2	82.407	E_5	659.26	E_8	5274.0		
F_2	87.307	F_5	698.46	F_8	5587.7		
	92.499		739.99		5919.9		
G_2	97.999	G_5	783.99	G_8	6271.9		
	103.83		830.61		6644.9		
A_2	110.00	A_5	880.00	A_8	7040.0		
	116.54		932.33		7458.6		
B_2	123.47	B_5	987.77	B_8	7902.1		
C_3	130.81	C_6	1046.5	C_9	8372.0		
	138.59		1108.7		8869.8		
D_3	146.83	D_6	1174.7	D_9	9397.3		
	155.56		1244.5		9956.0		

In order to play a note that has twice the frequency, the string would need to be half as long as the open string. Divide the total string length by two to find the midpoint of the string.

L_{Midpoint} = ____________ cm

Measure this distance from the saddle. Is this midpoint of the string just about exactly above the 12th fret?

____

Play the note corresponding to the 12th fret on the 6th string. Discuss your results. In particular, for those of you with musical background, is this note an octave higher?

The frequency of an E2 is 82.4 Hz. What frequency is twice the frequency of an E2? According to the table at the end of this lab, what note is this? Look at other notes in this table. What do you observe about the frequency of notes that are an octave apart from each other?

One could actually use the table to calculate the fret position that would be needed for any note! We will investigate how to calculate fret spacings in a later lab exercise.

Harmonics of Waves on a Guitar String

Position the ball of your thumb near the midpoint (12th fret) of the 6th string; play the string by gently deflecting the string with the broad part of your thumb and releasing the string. This should be a very "round" tone. Compare this tone to the tone that you get when you pluck the same string with a stiff pick near the saddle; this should sound much more metallic. Experiment with plucking the string in different ways in different positions on the neck. Describe your observations

In your previous lab, you observed different modes for waves on a string. When you pluck the string with a broad thumb near the midpoint of the string, you are exciting mainly the fundamental mode.

To excite the 2nd mode, you need to make the midpoint of the string a node. To create a node at the midpoint of the guitar string, very gently set a finger on the string directly above the 12th fret; do not press down on the string. Gently pluck the string near the middle of the remaining section of the string. You should get a clear, ringing tone that will persist even after you gently remove your finger. Practice this until you can get a clear tone. Compare the pitch to what you get if you pluck the open string. Is there an octave difference between the tones? ___________________ Also compare the tone that you get by exciting this harmonic to the tone that you get if you conventionally play the note on the 12th fret by pressing the string all the way to the fingerboard and plucking. Discuss your results

To get the 3rd mode, you will need to create a node one third of the way along the string. First, calculate the length of one third of the string _____________ cm. Measure this distance from the nut of the guitar.

Which fret does this correspond to _______________

Play this harmonic by very gently placing your finger on the string above the 7th fret, and gently plucking the string. You should be able to get a clear tone. Does this correspond to any other open note on the guitar? Determine the frequency of this 3rd mode and look up this frequency in the table. Discuss your results

Problems:

[1] The first string on a electric guitar is 64.8 cm long, and is tuned to an E4. Using the table at the end of this lab, what is the frequency of this string? Using Equation 2, what is the velocity of the wave on this string?

[2] For the E string described in the previous problem, you want to play a concert A (440 Hz). Use the velocity that you determined from Problem 1 to determine how long you would want to make the string.

Science Exercise 8

Synthesis of Waves Using Harmonics

Any periodic wave can be built up from a combination of sine and cosine waves of different frequencies. The different tone quality (timbre) of sound waves from a musical instrument like a guitar comes from the amount of each of these harmonics.

We have seen in previous labs that there are certain fixed frequencies that occur for standing waves on a string, like a guitar. In particular, the frequencies of the standing waves are integer multiples of the fundamental. For the n^{th} mode is

$$f_n = n f_1 . \qquad (3)$$

where n=1,2,3,…

We also noted that depending on how we plucked the string, the pitch (note of the scale) could remain the same, but the tone quality could change from very “smooth” to very “metallic”. Even more changes result from running the output of an electric guitar through filters that modify the tone quality. Musicians use the word “timbre” to refer to the tone quality – the timbre is one of the main qualities that differentiates one musical instrument like a trumpet from another instrument such as a flute playing the same note. (Interesting note: The word “timbre” is generally pronounced with an “a” sound rather than an “i” sound, so the phonetic pronunciation is \□tam-bər)

The mathematician Joseph Fourier proved in the 1800’s that any wave can be built up from combinations of sines and cosines, so the technical term for this procedure is Fourier Synthesis.

There are a variety of tools that can be used to demonstrate how a periodic waveform can be built up from different combinations of sines and cosines. We will be using the applet

http://homepages.gac.edu/~huber/fourier/

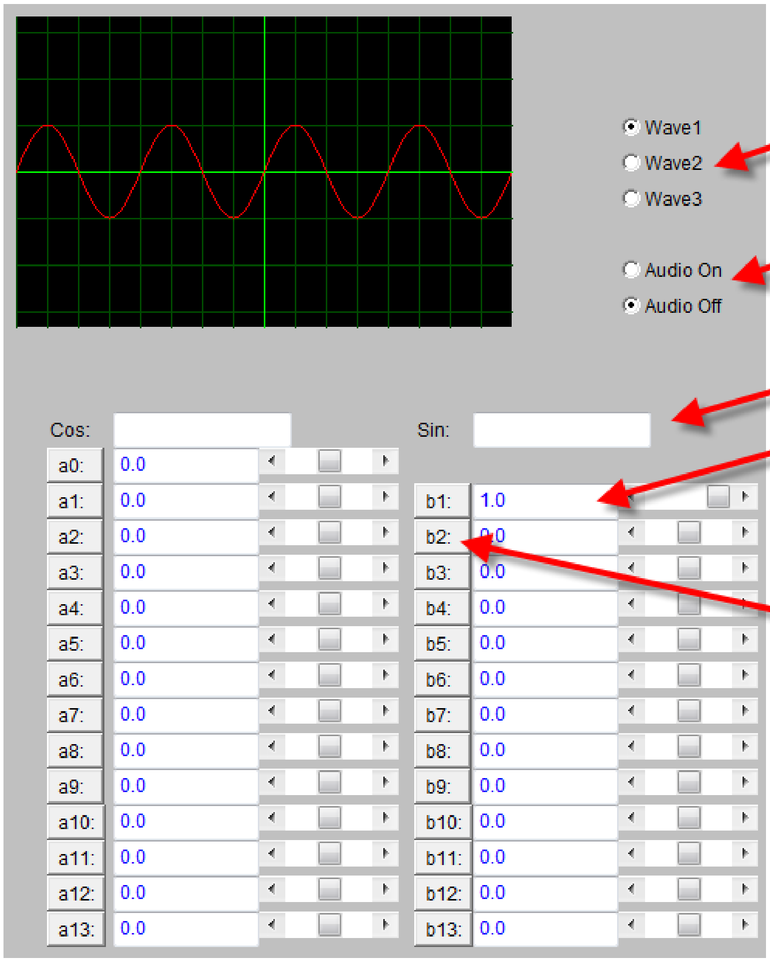
to illustrate this technique. This applet will allow you to modify the amounts of different harmonics, and it will draw the resulting waveform and play this through the computer speaker. This will allow you to see how changing the amounts of different harmonics changes the shape and sound of the wave.

I. Basic Operation of Fourier Synthesis Applet

Begin by loading the applet

http://homepages.gac.edu/~huber/fourier/

in your browser. Scroll down until you can see the applet as shown on the next page.



● Wave1
○ Wave2
○ Wave3

○ Audio On
● Audio Off

Cos:

Sin:

a0:	0.0		
a1:	0.0	b1:	1.0
a2:	0.0	b2:	0.0
a3:	0.0	b3:	0.0
a4:	0.0	b4:	0.0
a5:	0.0	b5:	0.0
a6:	0.0	b6:	0.0
a7:	0.0	b7:	0.0
a8:	0.0	b8:	0.0
a9:	0.0	b9:	0.0
a10:	0.0	b10:	0.0
a11:	0.0	b11:	0.0
a12:	0.0	b12:	0.0
a13:	0.0	b13:	0.0

Allows you to define three different waveforms

Allows you to turn the sound output on or off

Enter an equation such as
1/x or 0
Into this box

Enter coefficients by typing a number into the box, or by moving the slider

Coefficients can be set to zero by clicking on their label (clicking on b2 will set it to 0)

Begin by typing the 1 into the box for coefficient b1. The graph should display a sine wave, and the speaker should play a simple tone.

Move the b1 slider back and forth to change the amount of this tone. Notice that this can be either positive or negative, and the wave will flip over. Then click on the b1 button and this coefficient will go to zero.

Next move the a1 slider back and forth. The a1 coefficient adjusts the amount of the cosine wave, and the b1 coefficient adjusts the amount of the sine wave. Next, clear out both the a1 and b1, and adjust the b2 coefficient. Try other coefficients one at a time and describe your observations

Combining harmonics to make different tones

Start by clearing out all of the coefficients.
First, in the box for b1, type in the value 1.0

Next, in the box for b2, type in the value 0.5 .
Notice what happens to both the wave displayed on the screen, and the sound of the wave

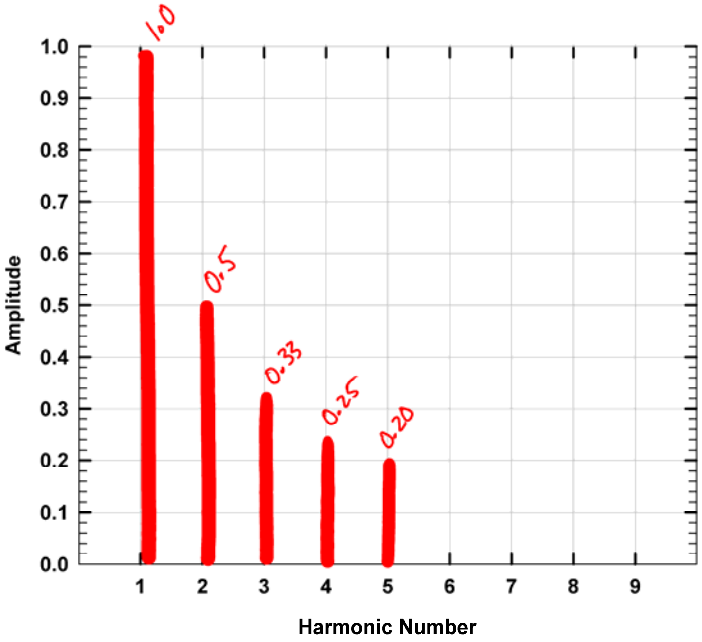
As you type in the coefficients below, observe what happens to the shape of the wave, as well as the sound of the wave. Note: the wave will get louder as more harmonics are added – we are mainly interested in the tone quality (or timbre) rather than the volume. You may also want to turn the audio off and then back on after you change harmonics to help you hear the entire waveform instead of the individual pitches.
Next, in the box for b3, type in the value 0.333
Next, in the box for b4, type in the value 0.25
Next, in the box for b5, type in the value 0.2

Describe your observations about both the sound and shape of the waveform as you add more harmonics. Does this sound almost a little like a clarinet?

Make a sketch of the waveform below

Now work backwards by eliminating harmonics, starting with b5 and working back to b1. Describe what you observe

Another way of understanding the waveform is to make a spectrum plot. This plot shows the amplitude of each harmonic as a function of the harmonic number. The plot below shows what this looks like.



Instead of continuing to enter coefficients, the Fourier Series Applet allows you to enter an equation and it will calculate all of the coefficients. If you look on the diagram on Page 2, there is a box to the right of the word Sine. Type the equation 1/x into this Sine box and press the Enter key. The applet should calculate all of the coefficients. Describe how the waveform changes when there are now 13 coefficients for this wave.

On the Spectrum Plot above, fill in the rest of the coefficients for the first 9 harmonics.

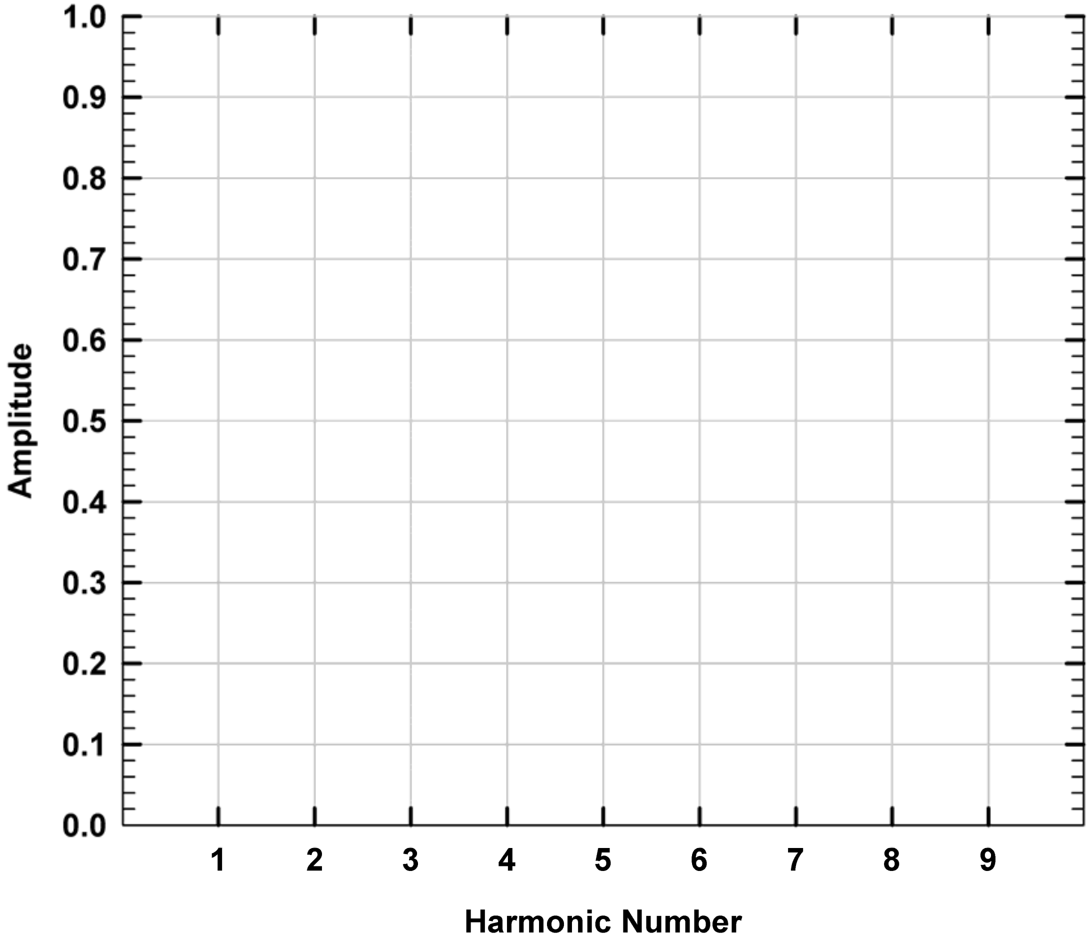
Next, select Wave 2. Clear all of the coefficients by putting a 0 into the Sine box. Then, enter in the same values from your graph above for the odd numbered coefficients (b1 = 1.0, b2=0.333, b5=0.20, …).

Sketch the waveform and describe what you think it would look like if you entered enough coefficients. Compare both the shape of the waveforms as well as the timbre of the sound produced.

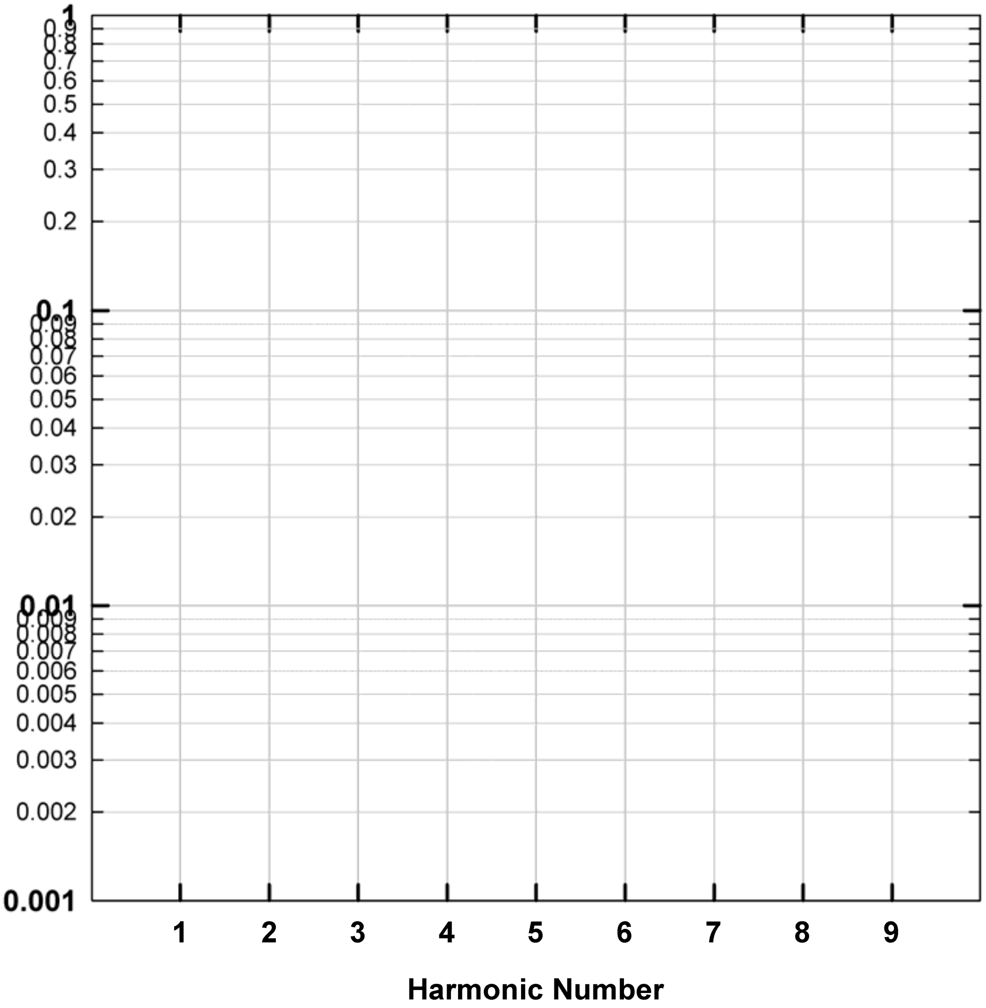
Select Wave 3, and try changing some of the coefficients from positive to negative or putting some of them into the coefficients for the cosine (such as letting b2=-0.333, a1=1.0). Try several different combinations. Obviously, the waveform has very different shape. However, with your eyes closed, have your lab partner switch between the two waveforms. Can you tell the difference?

Clear all the coefficients. Build a waveform where the odd numbered harmonics of cosine go as $1/x^2$. In other words, a1=1, a3=1/9, a5=1/25, … You can either do this by calculating the coefficients, or you can enter 1/(x^2) in the Cosine box and then set all the even numbered coefficients to zero. Sketch the resulting waveform and discuss your results.

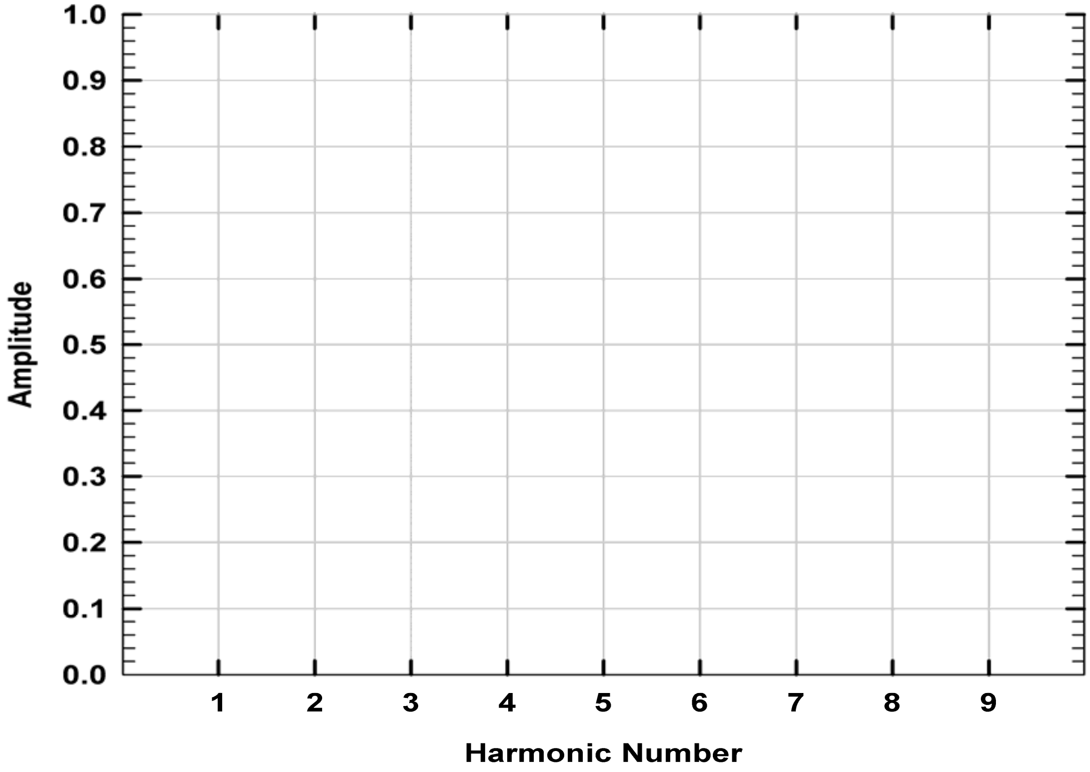
Make a spectrum plot of this wave.

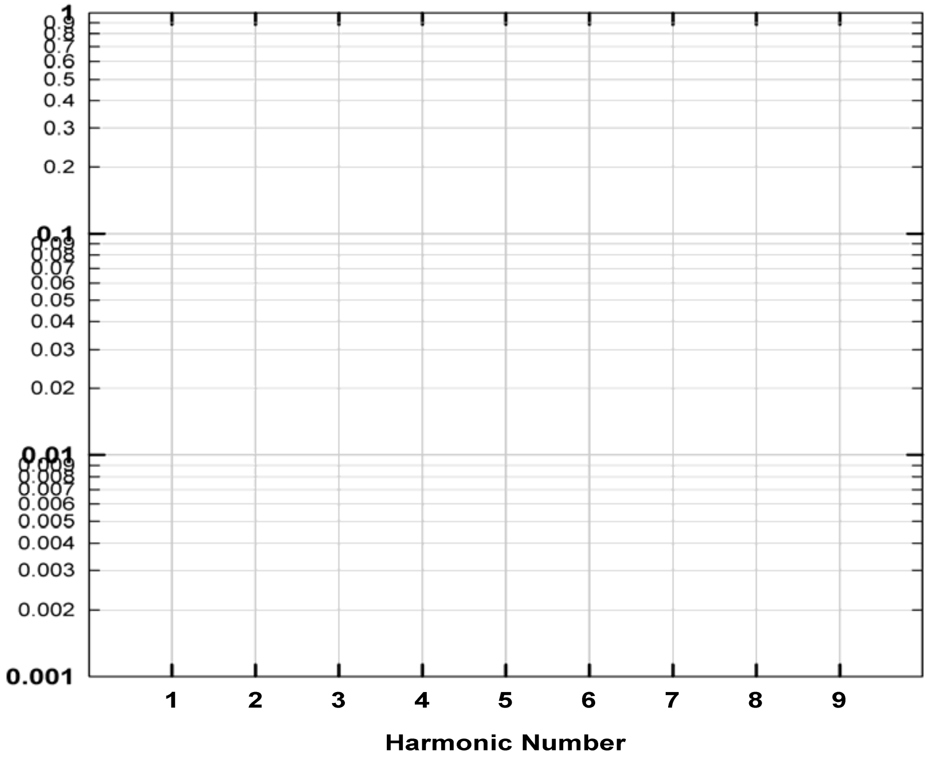


As you will note the coefficients for the higher harmonics quickly become very small and difficult to see. To make it easier to visualize these upper harmonics, it is easier to use a logarithmic scale for the vertical axis. As you will note the spacing between each division is not uniform. Instead, the scale repeats for each power of ten. This means that the upper harmonics, even though they are over 100 times smaller than the fundamental, still show up on the graph.



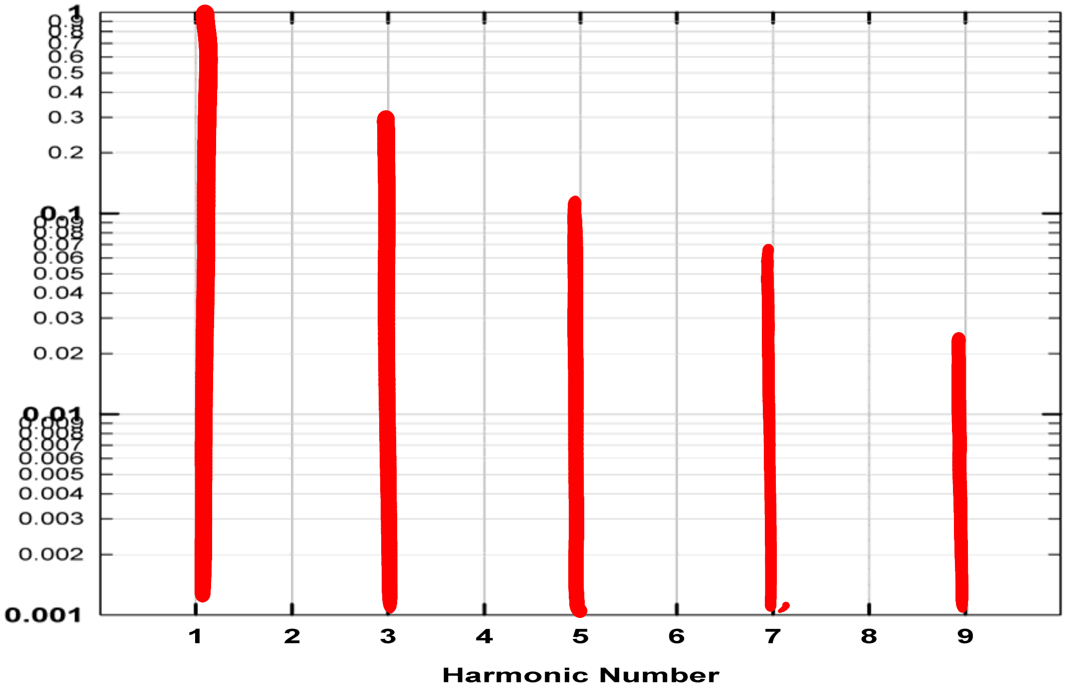
Now that you are familiar with running the program, experiment with different combinations of waves. For example, try comparing the timbre and wave shape for waves that have primarily low harmonics with almost no amplitude of high harmonics, to waves that have almost all high harmonics and almost no low harmonics. On the following pages sketch some of your results; both the wave graph, as well as the spectrum plots with either a linear or logarithmic scaled y axis. Feel free to make more copies of the spectrum plot page. Include sketches and discuss the results of your studies.


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Amplitude
1
2
3
4
5
6
7
8
9
Harmonic Number


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
1
2
3
4
5
6
7
8
9
Harmonic Number

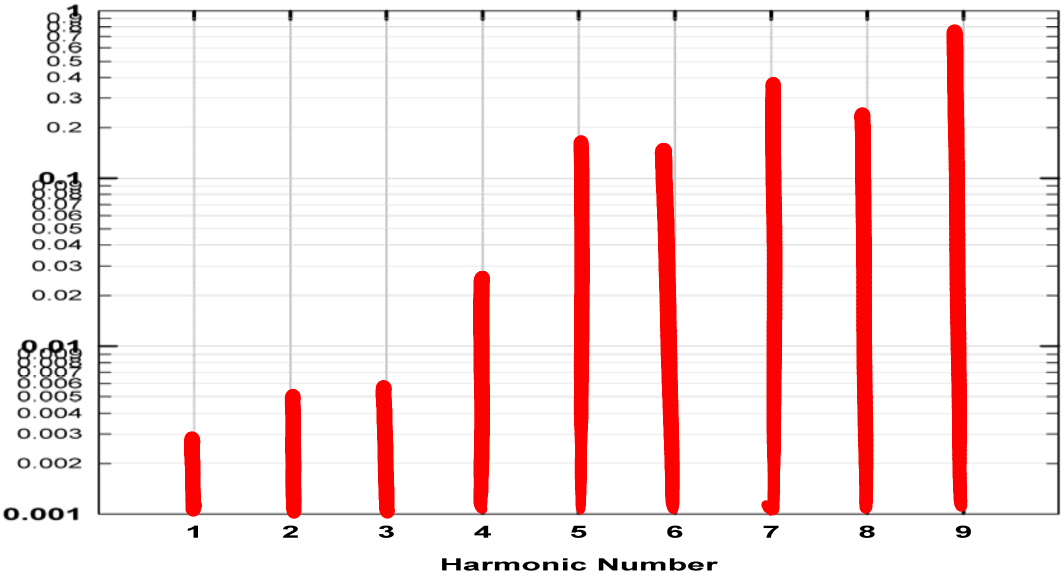
Questions:

[1] For a guitar that is plucked with a broad thumb towards the center of the string, the spectrum plot might look like this.



Based on your previous observations of standing waves on strings, why do you think that the even numbered harmonics would all be zero if you pluck the string near the middle?
HINT: Think about where nodes and antinodes are for even and odd numbered harmonics.

[2] Now consider a string that is plucked with a hard pick right next to the saddle. The spectrum plot for this might look like the following.



Why do you think that the lower harmonics are so much smaller than the upper harmonics when the string is plucked near the saddle? How would the timbre of this wave compare to the timbre of the wave from Problem 1? Explain why.

Math Learning Activity 1

Fret Spacing Calculation

Learning Objectives:

Student will demonstrate understanding of the concepts of string instrument scale length and how fret locations are determined by calculating the exact fret locations for the first five fret positions when given the scale length of the string instrument. The precise locations of frets on a fret board are essential to creating an instrument that plays in tune.

References:

- From http://www.cybozone.com/luthier/instruments/fretscale.html

“Pythagoras was first to experiment with determining scalar intervals... and later, in the 16th century, Vicenzo Gallelei was credited with developing the "rule of 18". . . used for centuries by instrument makers to determine the fret scale of their instruments. For any given vibrating string length they would simply divide the length of the string by 18... Yielding the distance from the nut to the first fret. By subtracting that figure from the original string length they arrived at a new shorter scale measurement which was then divided once again by 18 and resulted in the distance between the first and second frets. They continued in this manner until the entire scale was determined. Over the years several variations on this theme have been developed... The divisor has been refined, (based on a complex mathematical formula that utilizes the 12th root of 2) resulting in more accurate scales

$$p_c = \frac{(L - p_f)}{17.817} + p_f$$

Or written on one line, looks like
$p_{c=}(L - p_f) / 17.817 + p_f$

Where:
p_c is the current fret
p_f is the former, or previous fret
L is the scale length
17.817 is the constant for calculating fret positions based on the 12th root of 2

Problems 1-5: Determine the first 5 fret locations for a stringed instrument with a 25.5 inch scale length

Problems 6-10: Determine the first 5 fret locations for a stringed instrument with a 32.125 inch scale length.

You must show all your work neatly, so that it flows in a straight line. Formula, substitution, calculation, answer.

Notes

Math Exercise 1

Fret Spacing Calculation

Determine the first 3 fret locations for a stringed instrument with a 24” scale length.

Fret Spacing Example calculation

Fret position #1

L = 24” p_c = unknown p_f = 0” when working to determine the first fret.

$p_{c=}$ (L - p_f) / 17.817 + p_f
p_c = ((24” – 0”) / 17.817) + 0
= (24” / 17.817)
= 1.347

Fret position #2

L = 24” p_c = unknown p_f = 1.347” from the former, previous fret position

$p_{c=}$ (L - p_f) / 17.817 + p_f
p_c = ((24” – 1.347”) / 17.817) + 1.347”
= (22.653” / 17.817) + 1.347”
= 1.271” + 1.347”
= 2.618”

Fret position #3

L = 24” p_c = unknown p_f = 2.618”

$p_{c=}$ (L - p_f) / 17.817 + p_f
p_c = ((24” – 2.618”) / 17.817) + 2.618”
= (21.382” / 17.817) + 2.618”
= 1.2” + 2.618”
= 3.818”

Problems 1-5: Determine the first 5 fret locations for a stringed instrument with a 25.5 inch scale length

Problems 6-10: Determine the first 5 fret locations for a stringed instrument with a 32.125 inch scale length. You must show all your work neatly, so that it flows in a straight line. Formula, substitution, calculation, answer.

Math Learning Activity 2

Tuners and Gear ratios

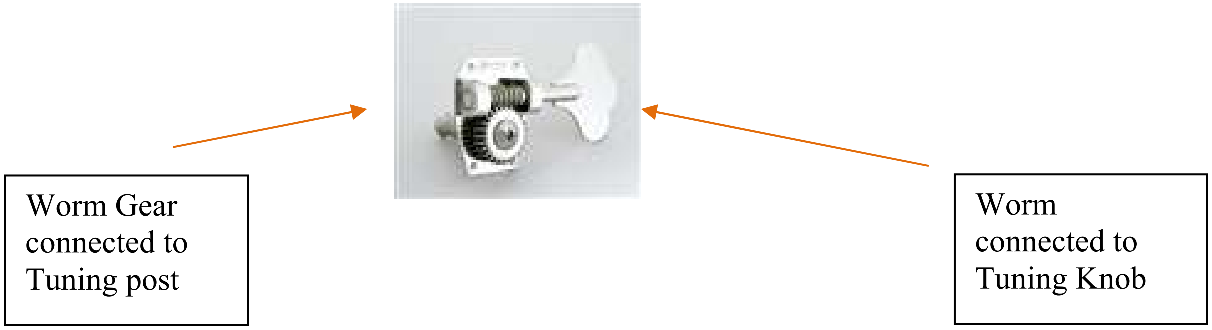
Reinforce concepts of ratios and pi by solving problems that deal with gear ratios and linear distances of rotational movement. This exercise applies the concepts of rotation translational movement and gearing ratios that are used in a guitar tuner.

Learning objectives:

1. Student will be able to explain how gear ratio can translate a small amount of effort into a greater force.
2. Student will be able to explain the difference between linear and rotational movement.
3. Student will be able to identify a worm gear and a spur gear and explain how they interact with one another
4. Student will be able to calculate how much string post has turned based on knob turn amount expressed as degrees or fractional turns.
5. Student will be able to calculate the linear distance of a string movement the post diameter, gearing ratio, and number of knob turns.
6. Student will be able to compare calculated prediction to real-world application.

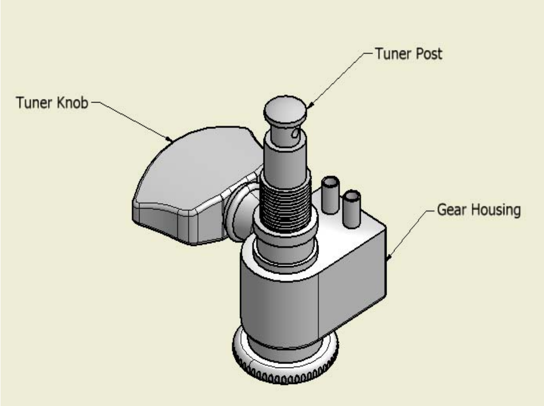
References:

http://www.allparts.com/HB5-Bass-Tuners-Nickel-p/tk-7754-001.htm



Bass Guitar Tuner

Image Source: http://www.allparts.com/HB5-Bass-Tuners-Nickel-p/tk-7754-001.htm



Math Principles covered:

Linear distance of string per turns of knob using given gear ratio:

$$L = \frac{T_k T_o C}{T_i}$$

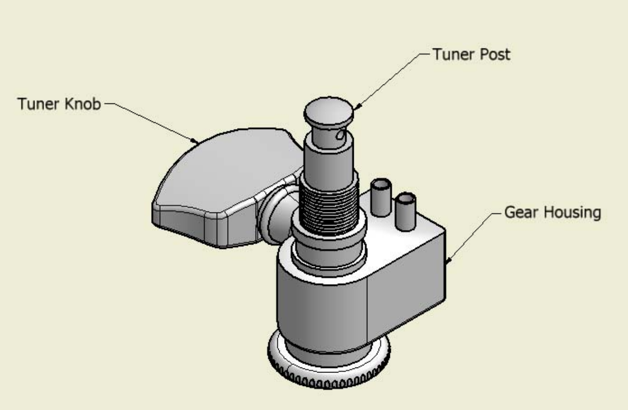
L = linear movement
T_k = knob turns
T_o = output shaft turns (from gear ratio)
T_i = input shaft turns (from gear ratio)
C = circumference of output shaft (where $C = 2\pi r$)

$L = (T_k \cdot T_o \cdot 2\pi r) \div T_i$
L = 3 knob turns * 1 output turn * 2 π .25inches / 14 input turns
L = 3 * 1 * 2 * 3.14 * .25” / 14
L = 4.71 inches / 14
L = 0.336 inches

Activity or class demonstration: Verify on a guitar by placing a black mark on a string at the nut position. Turn the knob the indicated number of turns in the calculation and measure the linear distance with a set of calipers to determine whether the calculation is reasonable.
If the measured amount is different than the equation calculation; students provide explanations for the difference. (i.e., string stretches; gear ratio is not exactly as printed, etc.)

Math Exercise 2

Tuners and Gear ratios



Gear ratios -- tuner gear ratio refers to the effect of how many turns of the tuner knob to have 1 complete turn of the post that has the guitar spring winds around

Equations: Circumference = 2 π r

Problem 1: The guitar tuner has a gear ratio of fourteen to one, what does that mean?

Problem 2: If there are 6 guitar tuners on a headstock with a 14 to one gear ratio a person attempts to tune a guitar. They first turn the knob 13 times to the left and then turn 5 times to the right. How many full turns and partial turns of the post were made after all the knob turns?

Problem 3: The post of the guitar tuner is .25” in diameter with a gear ratio of 15 to 1 how many turns will it take to wind 1 linear inch of guitar sting on the post?

For Problems 4-6: Tuner gear ratio 14 to 1, post diameter 3/16”, Solve the following problems using the above information.

Problem 4: if the tuner knob is turned 28 complete turns to the left how much guitar sting was wrapped on the post.

Problem 5 - if the tuner knob is turned 32 ½ turns to the left how much guitar sting was wrapped on the post.

Problem 6 - if the tuner knob is turned 18 complete turns to the right how much guitar sting was un-wrapped from the post.

Problem 7 - The gear tuner was turned 5 3/4 turns, the gear ratio is 14 to 1, how much has the tension changed if each 1/8” linear movement of guitar string the string tension changes by 1/2 lb.

Problem 8 - A tuner knob was turned 35 degrees to the left to bring the guitar into tune. With a gear ratio of 15 to 1 and a post diameter of .25” how much linear movement occurred to the guitar string?

Math Exercise 3

Area of the headstock

Create drawing of a headstock.

Break the headstock into geometric shapes and calculate the surface are of the headstock.

How many Gallons of paint will be needed to cover the headstock surface area, if the paint covers 150 square feet per gallon?

Measurements – develop a diagram where the items get measured

Pickup spacing as a percentage of scale length – measure bridge location to bridge pickup and express as percentage -- sound quality / tonality of pickup movement.

String spread bridge and nut, any 2 strings

Distance from nut to bridge – scale length pre-cursor

Width or neck at heel and nut

Body thickness

Metric English conversions – drill bits, fret dots etc

Fret Dots Sizing

Modulus of elasticity of high E string.

Centroid of guitar body –

Measure resistance on the potentiometers (image) minimum and max from the 4 pots (teams of 2) and chart the results

Nut – string force with the break angle on the nut. Develop a free body diagram of forces of a sting on the nut – simplified

Math Exercise 4

NECKS and FRET BOARD

Problem 4.1 Calculate

With the equation s- (s/ 2^ n/12) = d, find the distance from nut to the 9th and 11th fret.

s= scale length
n= fret #
d= distance from nut

Problem 4.2 Calculate the following

With the frequency equation- f = (t/u)^1/2/ 2L

f = frequency
t = tension force
u = mass per length
L = string length

a. What is the frequency of a note on a string, with a mass per length = 0.0002132 kg/ m, and pulled at force of 72.03N. The scale length is 26in or 0.6604m.

b. What is the tension force of a string with a frequency of 220hertz, a mass per length of 0.0002132 and a scale length of .6604m?

Problem 4.3

Research the number of frets found on an electric and acoustic guitar. Provide fret spacing formulas

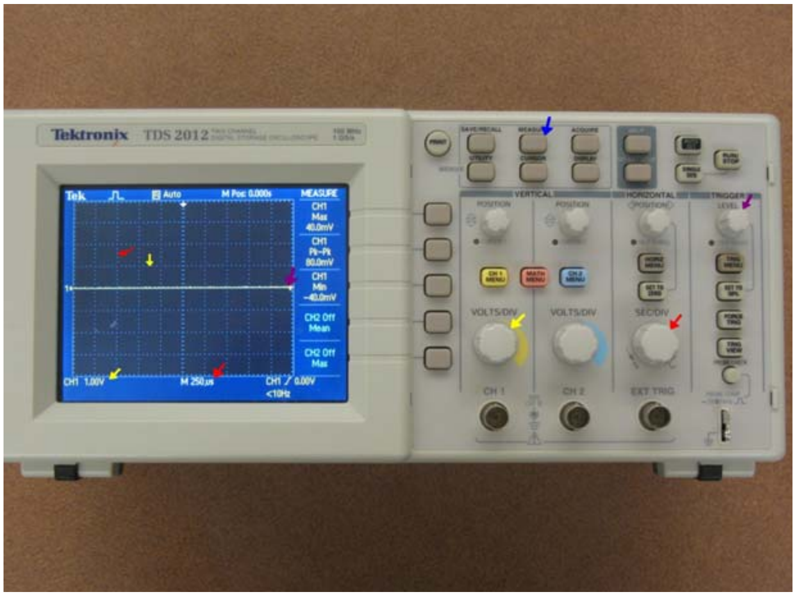
Electronics Exercise 1

Use an oscilloscope to measure frequency of the all six strings

Materials: Oscilloscope, oscilloscope probe, and a ¼” jack adapter (provided).

Deliverable: Excel spread sheet showing frequencies of all six strings.

The basics of the oscilloscope will be described so that the output wave from the guitar can be easily seen. Please read before you attempt the ILA.



- The yellow arrow will change your volts per a division
- The red arrow will change your time per a division
- Pushing the yellow or blue channel buttons will turn off and on the respective channels and give you a menu for each channel
- In the menu on the top box it should have AC coupling this is changed by pushing the gray button directly to the right of the box
- After the menu is set up push the measure button (blue arrow) and you will get your current screen.
- The position knobs will change the position where the wave is on the graph (this can make the wave go off of the graph and not be seen)
- The trigger level knob (purple arrow) should be tuned (little arrow) to the middle of the wave form.
- The period (time for one cycle) is how much time it takes the string to go up down and back up again or one revolution. **The reciprocal of that is the frequency.** Each note is assigned to a certain frequency which can be seen easily on an oscilloscope.

Connect the guitar to the oscilloscope. To do this plug the oscilloscope probe into CH. 1 slot at the bottom below the CH. 1 VOLTS/DIV knob. Once the probe is connected to the ¼" jack adapter (attach alligator clip of the probe to the black wire- ground) you can strum the guitar to see the waveform. If the VOLTS/DIV or SEC/DIV settings are not set properly the output will not be seen. Typically a guitar has about a 150mV$_{\text{pk-pk}}$ to 300mV$_{\text{pk-pk}}$ output therefore set the knob by setting the VOLTS/DIV to approx. 100mV (if strummed or plucked hard the string output peaks at about 600mV$_{\text{pk-pk}}$ to 800mV$_{\text{pk-pk}}$). The SEC/DIV setting will have to be calculated from the desired frequency.

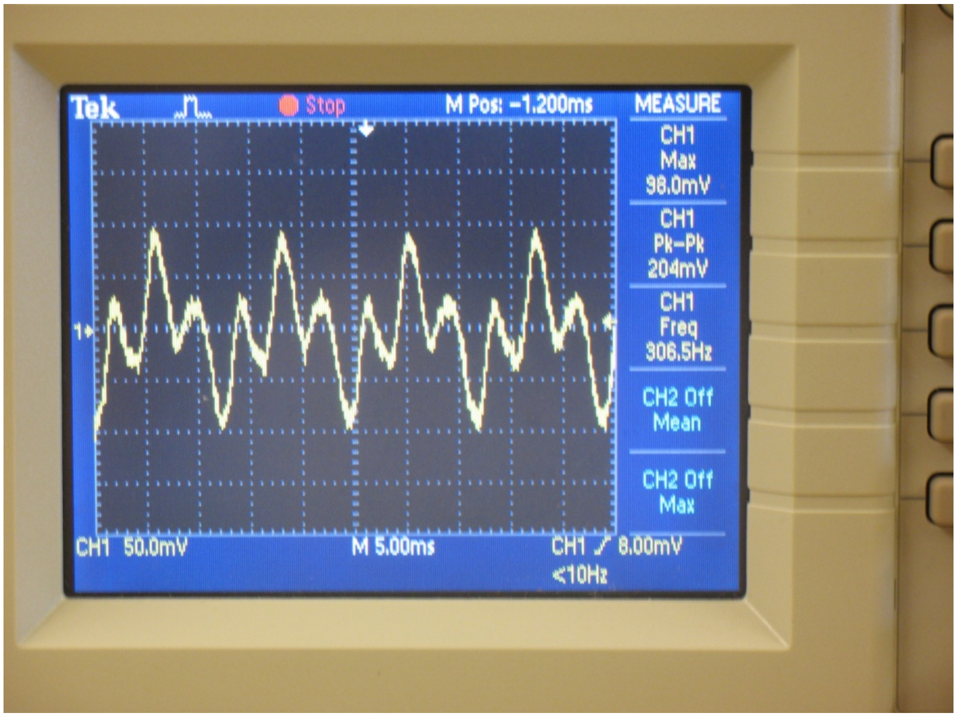
Period is found from the inverse of the frequency.

f = frequency T = period

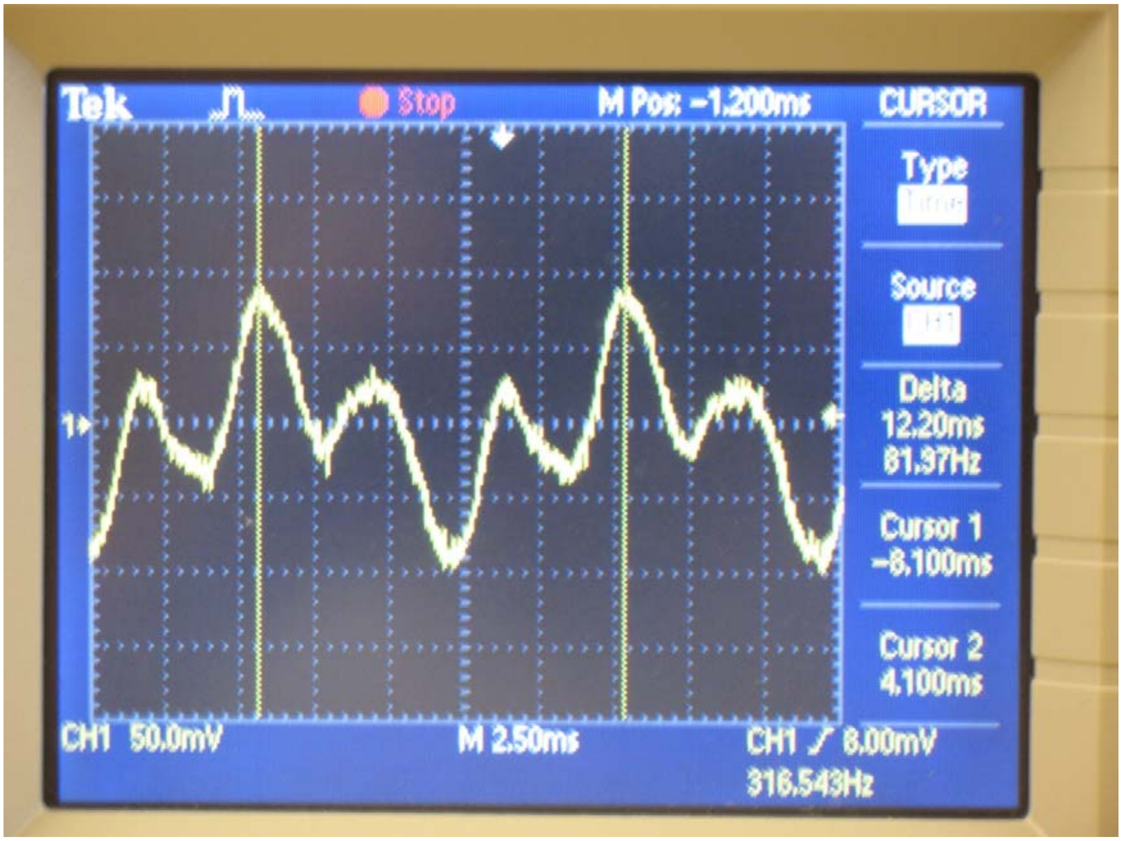
$$T = \frac{1}{f}$$

Once the period is found divide it by two and that should be about where the SEC/DIV should be set. If necessary adjust knob up or down to get the desired view.

NOTE: To freeze the waveform there is a button at the top right corner of the oscilloscope that reads "run/stop" push this button to freeze the current output.



Count the boxes on the graph or use the cursor button to determine the string's frequency.



The yellow vertical lines that are seen are accessed by the cursor button which is just below the measure button used earlier.

- Push cursor button to get a new menu to pop up on the right side of the graph.
- Push the button across from the "Type" and change it until it reads "Time"
- Push the button across from the "Source" and change it till it reads "CH1"
- The two position knobs for CH.1 and CH.2 control the vertical lines.
- Move the yellow vertical lines from one peak to the next as shown in the picture (be careful harmonics are sometimes pretty strong on the low strings and can be deceiving)
- "Delta" will indicate the period and frequency for the spacing between the yellow vertical lines.

Each note is assigned a certain frequency. Complete the list of string frequencies.

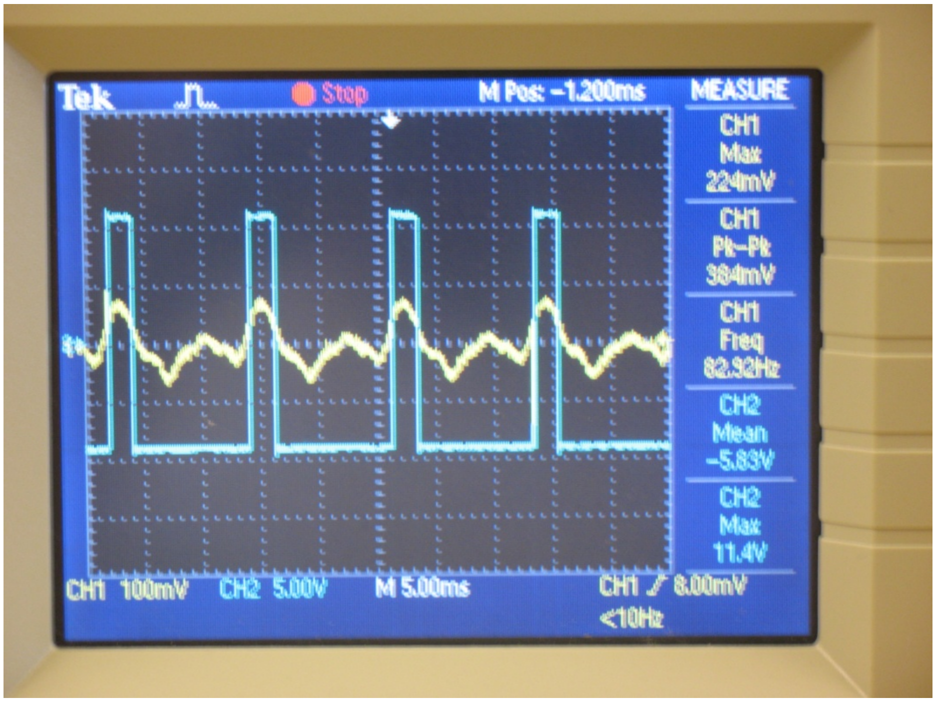
Low E - ___________
A - ___________
D - ___________
G - ___________
B - ___________
High E - ___________

A guitar’s intonated by strumming the string open (no frets) then strumming it holding down the twelfth fret (usually denoted by two fret dots). Intonation is more than just tuning it is changing the length of the string. The open string should be the given frequency above. The frequency should be doubled while pressing the string down at twelfth fret. If the frequency is higher, then increase the length of the string at the bridge, and if the frequency is lower, then shorten the length of the string.

Standard guitar tuning frequencies per string

1 (Highest)	**e'**	329.6 Hz
2	**b**	246.9 Hz
3	**g**	196.0 Hz
4	**d**	146.8 Hz
5	**A**	110.0 Hz
6 (Lowest)	**E**	82.4 Hz

A guitar tuner uses the same principles as an oscilloscope but needs to change those waves into computer language (pulses or high and low)



Here the yellow wave form is the output of the guitar and the blue wave form is almost like computer language. If measured from the positive edge to the next positive edge it should be the same period as the yellow wave form as it is from one peak to the next.

Technology Learning Activity 1

Reverse Engineering to Design a Mechanical Part (Neck Plate) for Electric Guitar Manufacture

In this lab, students will design a mechanical part (Neck Plate) for manufacture and apply it to the electric guitar. Students are to develop the dimension of size for the length, width and thickness of the neck Cover Plate for an electric guitar. Using these measurements the students will plan the detail drawings and prepare the design data for manufacture. Finally they are to use these data to then select and calculate the cutting tools, speeds and feeds required for the manufacture of the Neck Plate.

Learning Objectives:

1. The student will determine the measurements of size of the electric guitar Neck Plate.
2. Design through a technical sketch the size and location of the mounting holes of the guitar neck.
3. The students will develop the hole and countersink geometry with the intent of manufacturing the neck plate.
4. The students will devise a design/manufacturing plan.
5. The student will write a tool list listing calculated speed and feed requirements for the tools used in manufacture of the plate.

Materials Required:

Safety instruction as required, sketch pad and pencil, measuring tools such as rulers, dial calipers, calculator, CAD Software, electric guitar and or data of design and application intent of the neck plate.

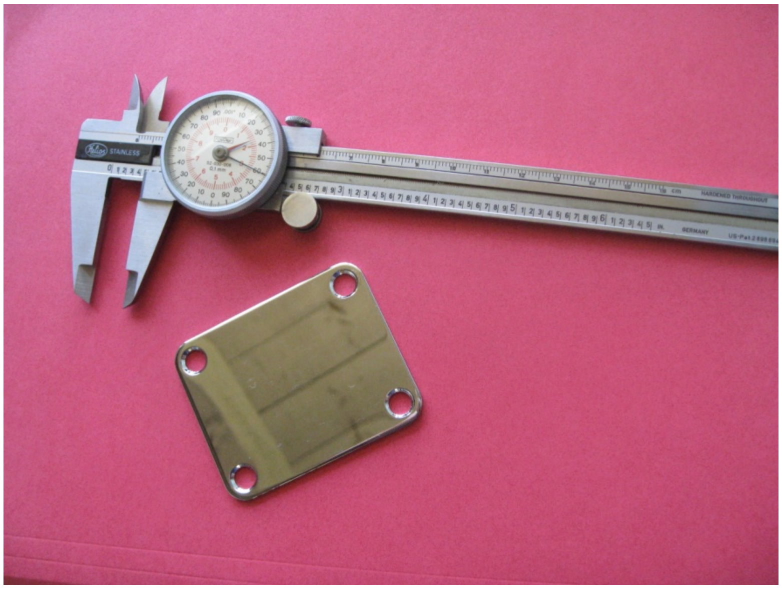
References:

http://new.industrialpress.com/products/category_feature/MH - Machinery’s Handbook
http://safety.seas.harvard.edu/services/shopsafety.html - Machine Shop Safety
http://www.engineeringtoolbox.com/machinability-metals-d_1450.html - Machinability of Metals
http://www.unbf.ca/ME/undergrad/Safe%20Operating%20Procedures/Function,_Safety,_and_Operation_of_the_Drill%20Press.pdf - Drill Press Operation

Technology Exercise 1

Reverse Engineering the Neck Plate

Using a measuring tool such as a dial caliper, metal scale or other appropriate tool, inspect the neck plate. (See the attached drawing for precise measurements.)
Sketch the neck plate with dimensions. Be sure to include on the orthographic drawing the important datum edges for later layout of the hole locations. See example figure of design sketch page and process planning.

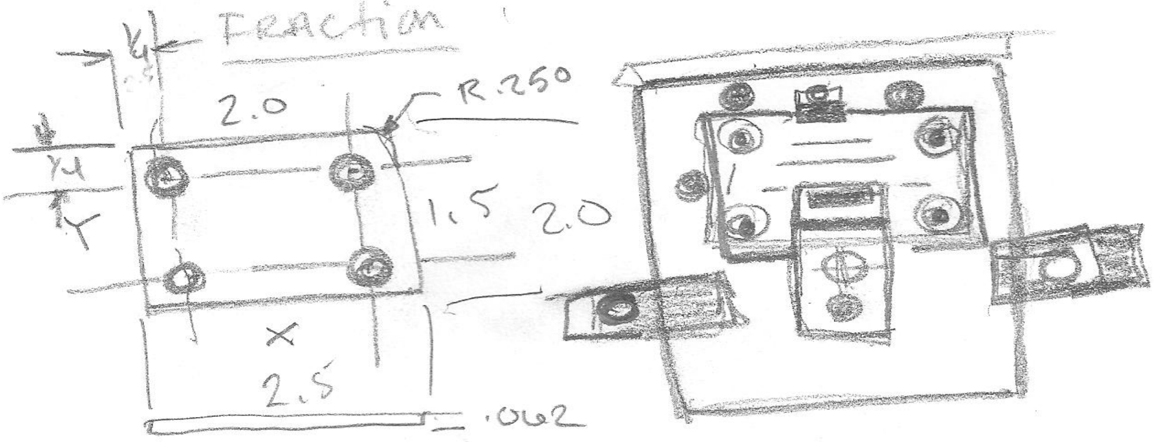


Notes

CNC

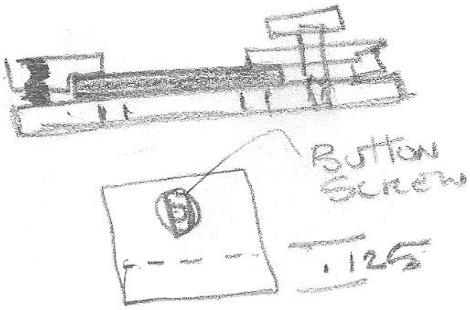
DRill
FIXTURE

NECK PLATE

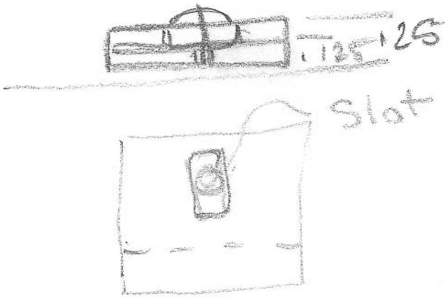


- Production Plan
  CNC

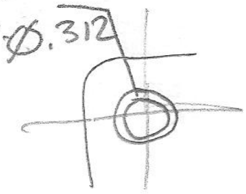
- Drill/c'sink G81
- DEBURR G82



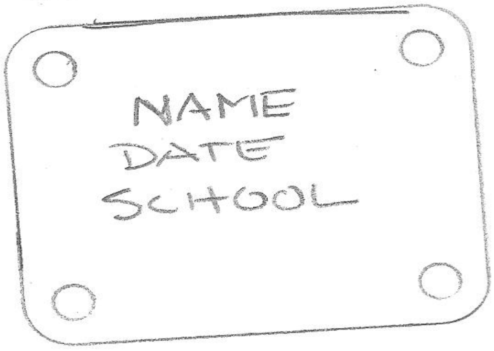
- ENGRAVE ?
  - NAME
  - DATE
  - CLASS/School

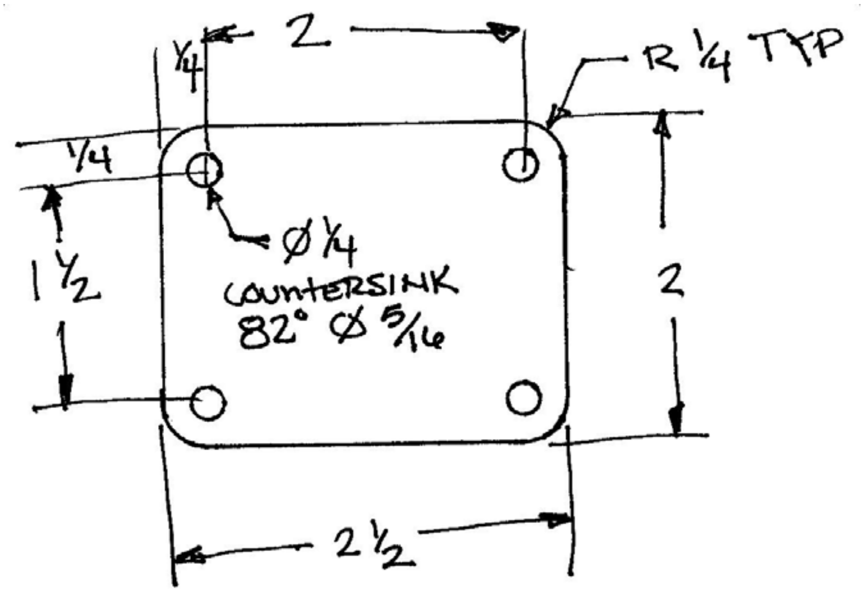


4 X ⌀.250
∨ 82° ⌀.312



.062 THK





GUITAR NECK SKETCH
MTL. MILD STEEL 1/16 THICK

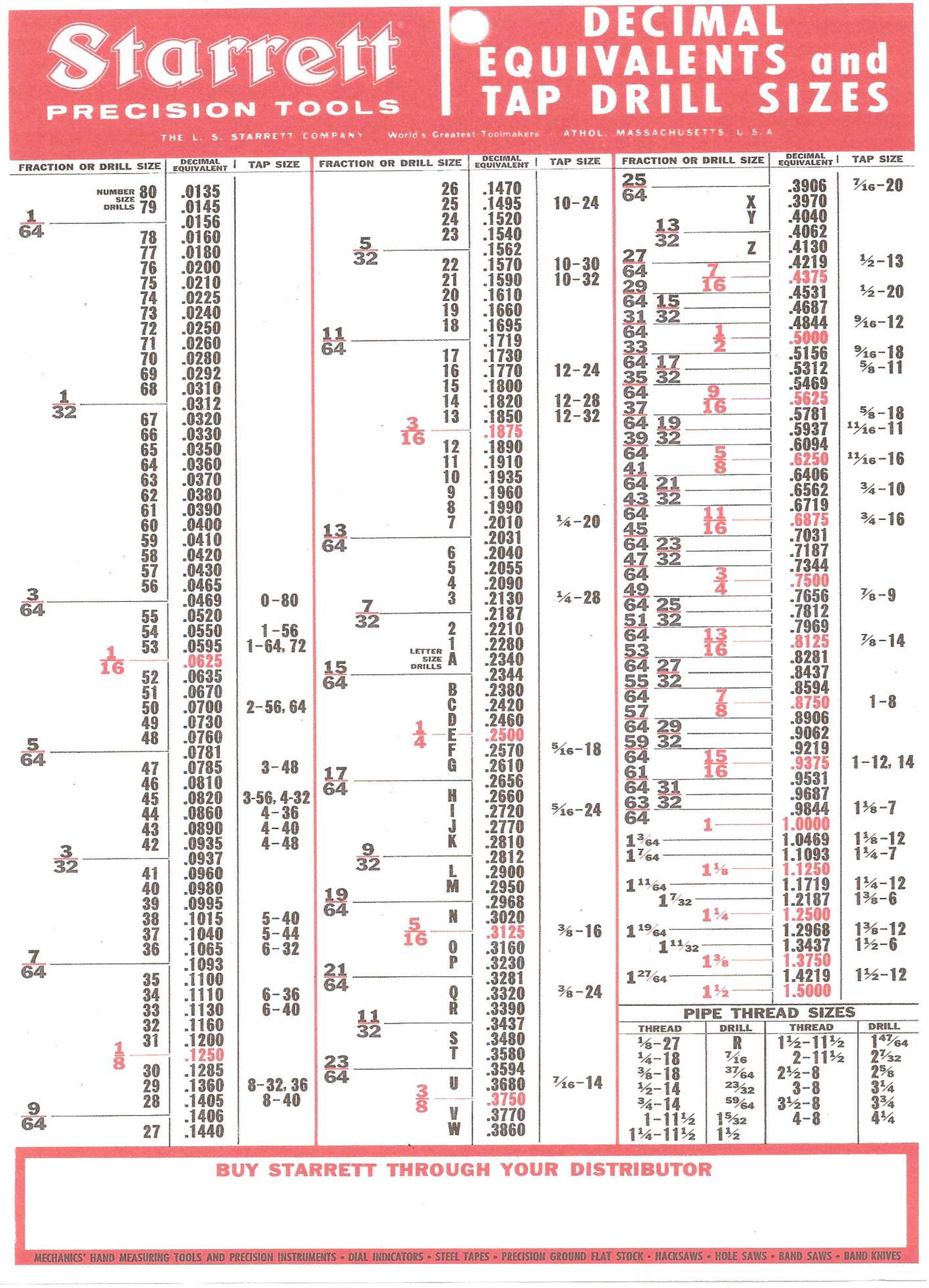
Design sketch example:

Change all fraction dimensions to their decimal equivalents using the attached chart.

Outside dimensions, length and width are fractional while the locations of the holes are identified by a three place decimal which increases the accuracy by limiting the tolerance.

The tolerance block from the CAD drawing shows tolerances as:
FRACTIONS ± (plus or minus) 1/16, This calculates to 1/8 total tolerance
.X ± .1 total tolerances of .2 inches
.XX ± .01   total tolerance of .02
.XXX ± .005   total tolerance of .010

As the number of decimal places increases a smaller total tolerance is allowed. This controls quality and allows for problem free assembly.



Starrett

PRECISION TOOLS

DECIMAL EQUIVALENTS and TAP DRILL SIZES

THE L. S. STARRETT COMPANY · World's Greatest Toolmakers · ATHOL, MASSACHUSETTS, U.S.A.

FRACTION OR DRILL SIZE	DECIMAL EQUIVALENT	TAP SIZE
NUMBER SIZE DRILLS 80	.0135	
79	.0145	
1/64	.0156	
78	.0160	
77	.0180	
76	.0200	
75	.0210	
74	.0225	
73	.0240	
72	.0250	
71	.0260	
70	.0280	
69	.0292	
68	.0310	
1/32	.0312	
67	.0320	
66	.0330	
65	.0350	
64	.0360	
63	.0370	
62	.0380	
61	.0390	
60	.0400	
59	.0410	
58	.0420	
57	.0430	
56	.0465	
3/64	.0469	0-80
55	.0520	
54	.0550	1-56
53	.0595	1-64, 72
1/16	.0625	
52	.0635	
51	.0670	
50	.0700	2-56, 64
49	.0730	
48	.0760	
5/64	.0781	
47	.0785	3-48
46	.0810	
45	.0820	3-56, 4-32
44	.0860	4-36
43	.0890	4-40
42	.0935	4-48
3/32	.0937	
41	.0960	
40	.0980	
39	.0995	
38	.1015	5-40
37	.1040	5-44
36	.1065	6-32
7/64	.1093	
35	.1100	
34	.1110	6-36
33	.1130	6-40
32	.1160	
31	.1200	
1/8	.1250	
30	.1285	
29	.1360	8-32, 36
28	.1405	8-40
9/64	.1406	
27	.1440	
26	.1470	
25	.1495	10-24
24	.1520	
23	.1540	
5/32	.1562	
22	.1570	10-30
21	.1590	10-32
20	.1610	
19	.1660	
18	.1695	
11/64	.1719	
17	.1730	
16	.1770	12-24
15	.1800	
14	.1820	12-28
13	.1850	12-32
3/16	.1875	
12	.1890	
11	.1910	
10	.1935	
9	.1960	
8	.1990	
7	.2010	1/4-20
13/64	.2031	
6	.2040	
5	.2055	
4	.2090	
3	.2130	1/4-28
7/32	.2187	
2	.2210	
1	.2280	
LETTER SIZE DRILLS A	.2340	
15/64	.2344	
B	.2380	
C	.2420	
D	.2460	
1/4 E	.2500	
F	.2570	5/16-18
G	.2610	
17/64	.2656	
H	.2660	
I	.2720	5/16-24
J	.2770	
K	.2810	
9/32	.2812	
L	.2900	
M	.2950	
19/64	.2968	
N	.3020	
5/16	.3125	3/8-16
O	.3160	
P	.3230	
21/64	.3281	
Q	.3320	3/8-24
R	.3390	
11/32	.3437	
S	.3480	
T	.3580	
23/64	.3594	
U	.3680	7/16-14
3/8	.3750	
V	.3770	
W	.3860	
25/64	.3906	7/16-20
X	.3970	
Y	.4040	
13/32	.4062	
Z	.4130	
27/64	.4219	1/2-13
7/16	.4375	
29/64	.4531	1/2-20
15/32	.4687	
31/64	.4844	9/16-12
1/2	.5000	
33/64	.5156	9/16-18
17/32	.5312	5/8-11
35/64	.5469	
9/16	.5625	
37/64	.5781	5/8-18
19/32	.5937	11/16-11
39/64	.6094	
5/8	.6250	11/16-16
41/64	.6406	
21/32	.6562	3/4-10
43/64	.6719	
11/16	.6875	3/4-16
45/64	.7031	
23/32	.7187	
47/64	.7344	
3/4	.7500	
49/64	.7656	7/8-9
25/32	.7812	
51/64	.7969	
13/16	.8125	7/8-14
53/64	.8281	
27/32	.8437	
55/64	.8594	
7/8	.8750	1-8
57/64	.8906	
29/32	.9062	
59/64	.9219	
15/16	.9375	1-12, 14
61/64	.9531	
31/32	.9687	
63/64	.9844	1 1/8-7
1	1.0000	
1 3/64	1.0469	1 1/8-12
1 7/64	1.1093	1 1/4-7
1 1/8	1.1250	
1 11/64	1.1719	1 1/4-12
1 7/32	1.2187	1 3/8-6
1 1/4	1.2500	
1 19/64	1.2968	1 3/8-12
1 11/32	1.3437	1 1/2-6
1 3/8	1.3750	
1 27/64	1.4219	1 1/2-12
1 1/2	1.5000	

PIPE THREAD SIZES

THREAD	DRILL	THREAD	DRILL
1/8-27	R	1 1/2-11 1/2	1 47/64
1/4-18	7/16	2-11 1/2	2 7/32
3/8-18	37/64	2 1/2-8	2 5/8
1/2-14	23/32	3-8	3 1/4
3/4-14	59/64	3 1/2-8	3 3/4
1-11 1/2	1 5/32	4-8	4 1/4
1 1/4-11 1/2	1 1/2		

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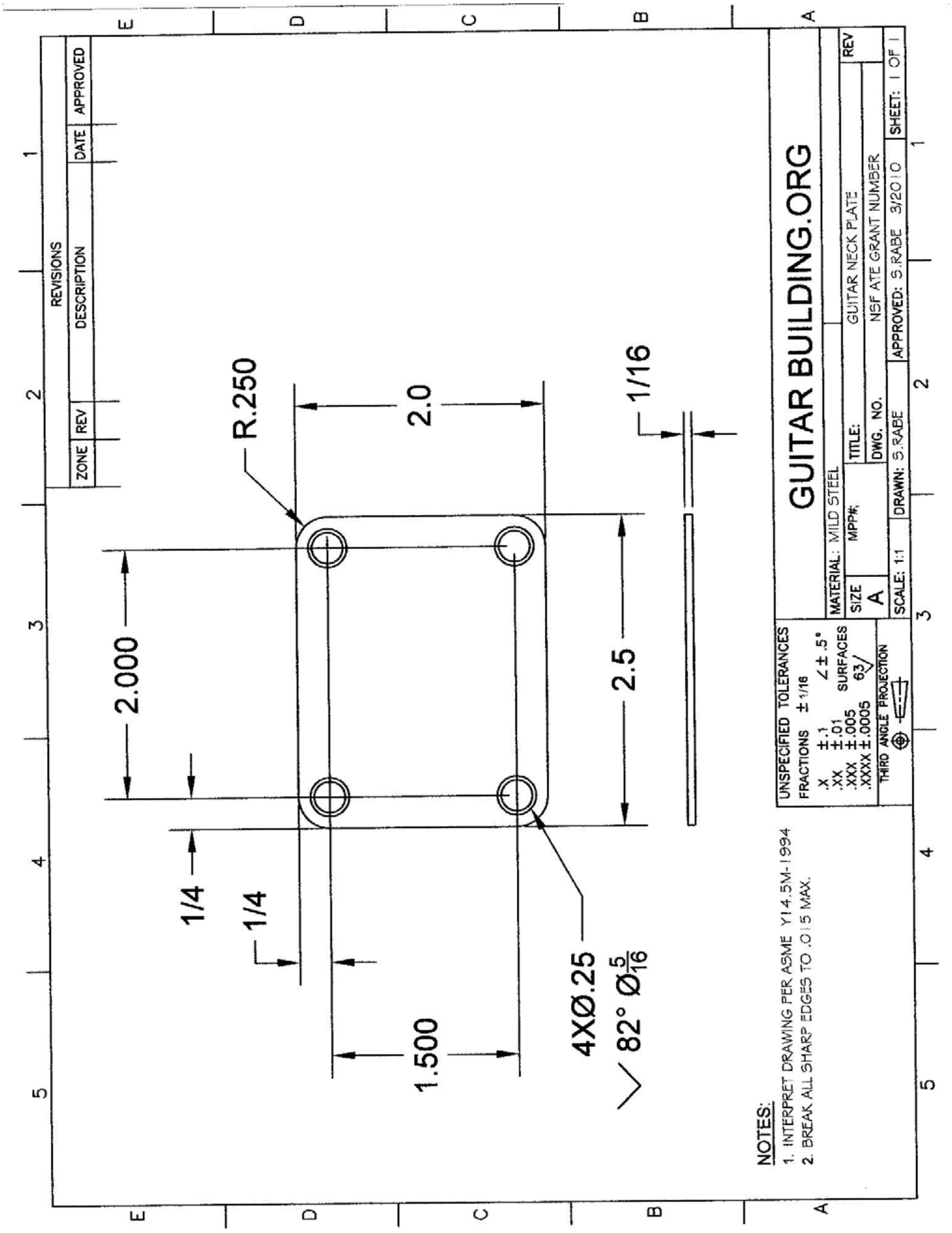
E
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REVISIONS
ZONE
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DESCRIPTION
DATE
APPROVED
R.250
2.0
1/16
2.000
2.5
1/4
1/4
4XØ.25
82° Ø5/16
1.500
NOTES:
1. INTERPRET DRAWING PER ASME Y14.5M-1994
2. BREAK ALL SHARP EDGES TO .015 MAX.
UNSPECIFIED TOLERANCES
FRACTIONS ±1/16
.X ±.1
.XX ±.01
.XXX ±.005
.XXXX ±.0005
∠±.5°
SURFACES 63
THIRD ANGLE PROJECTION
GUITAR BUILDING.ORG
MATERIAL: MILD STEEL
MPP#:
SIZE
A
TITLE: GUITAR NECK PLATE
DWG. NO. NSF ATE GRANT NUMBER
REV
SCALE: 1:1
DRAWN: S.RABE
APPROVED: S.RABE 3/2010
SHEET: 1 OF 1

Technology Exercise 2

Manufacturing Planning

The students will develop a plan for the manufacture of the neck plate.

1. List the tools required to layout the hole positions.
2. List the tools required for the drilling and counter sinking process.
3. Calculate a safe recommended spindle speed to drill and countersink the screw holes.
4. Show a safe material clamping plan for the drilling operation.

Accurate layout requires a few tools including a flat work surface clear of obstacles, layout fluid or other marking liquid to allow clear visibility of layout lines, a sharp scribe or awl or at least a paperclip opened to allow scratching the surface with one end of the wire.

1. Cover the mild steel part with a thin coat of layout fluid or colored marking pen.
2. Locate with a scale or dial caliper the center of the first hole of the four hole pattern. Scratch the surface color to show this location.
3. Using the caliper or scale measure from this point the remaining holes locations.
4. Check the locations to insure correct placement.

Drilling the holes can be done in several ways.
First if using a drill motor (electric hand drill) you should lightly center punch the hole locations.

1. lay the part on the flat table or other secure work surface. Align the center punch over the hole location. Strike sharply the center punch with a Ball Peen or machinist hammer. This will place a small dent or starting point for the twist drill to follow.

2. Electric hand drill motors come in many sizes and spindle speed ratings. The speed at which a twist drill should spin (RPM) depends on several factors:

   Part material must be determined to find the correct material cutting speed (CS), this is a number representing surface feet per minute or

Notes

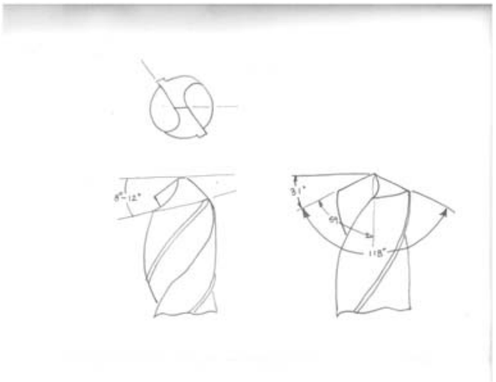
SFM. This value is developed from tests done to determine the machinability of a material against a known standard.

Knowing this value is important to control the heat at the cutting point which will protect the part and the cutting tool from overheating. Cutting speeds for various materials can be found in chart form in text books and Machinist handbooks. For mild steel we will use the value of 100 SFM.

The size (DIA) of the cutting tool or drill will next be used to correctly calculate the correct RPM for our drilling operation. The drawing shows a ¼ diameter drill hole this we change to its decimal equivalent .25 inches. The formula for converting this information to RPM or spindle speed is the following:

RPM = 4 X CS ÷ DIA

Example: Drilling a .5 (1/2 inch) diameter hole in mild steel with a CS of 100 RPM = 4 X 100 ÷ 1/2” works out to 400 ÷ .5 = 800 RPM



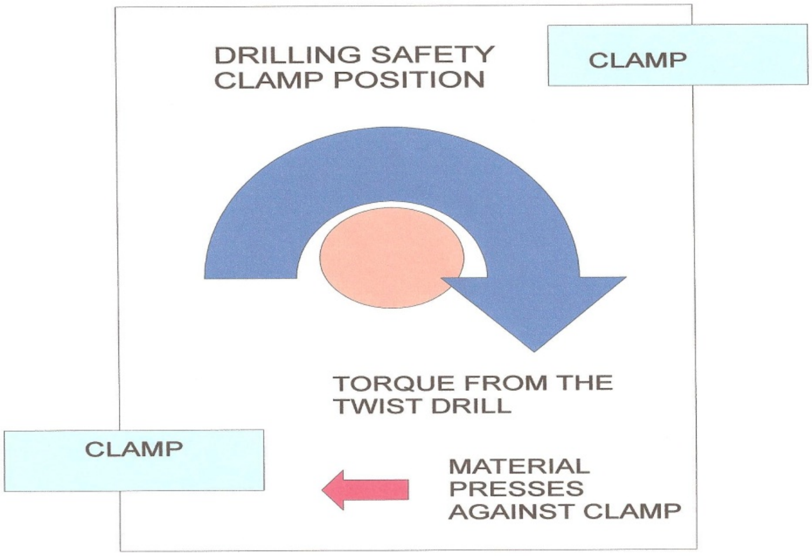
Drill point geometry

Safe clamping requires understanding the operation of the electric drill motor and the torque created by the cutting tool:

1. Never hold any work piece with your hands while drilling or cutting.
2. Use a back up piece of material when drilling through holes in thin material.
3. Know the direction of spin the cutting tool will produce as this is the direction the material will naturally spin.
4. Set up your clamps to hold against the spin, not to be pulled out of the clamp. See the attached example.
5. Ease up on feed pressure when the drill breaks through back surface.
6. Keep the correct RPM throughout the drilling process.

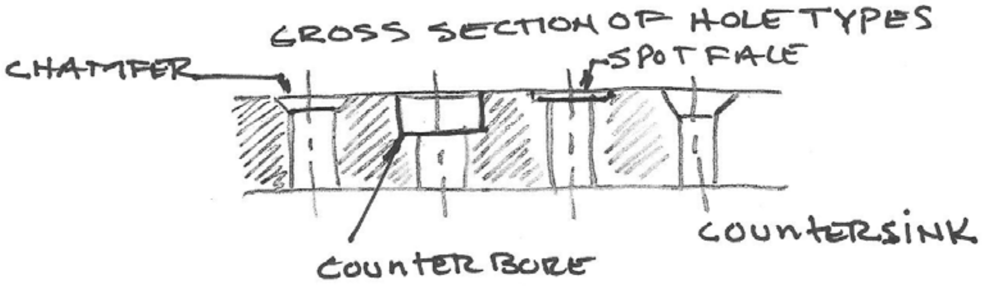
7. Watch for sharp edges and burrs on drilled holes.

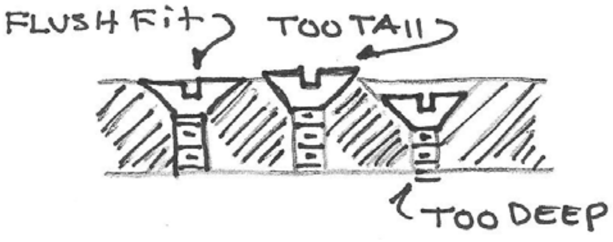
8. Deburr all cut edges and surfaces with a flat file or sand paper.



Secondary hole cutting operations such as the counter sink provides special shapes for locating the head of a screw or bolt. This is to protect you from rubbing or touching the screw head or catching the screw head on passing materials or objects.

The attached figure shows the Countersink tool and hole types:





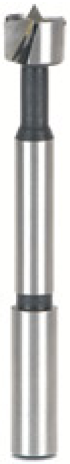
Countersinks are made in various standard angles. This provides options for the designer on the types of hole shapes required. The angle most commonly used for flat head or pan head screws is 82°. The standard screw head should be flush with the surface or slightly below, depending on the application. Countersinks are also used to deburr and chamfer holes.

The countersink operation follows the drilling of the holes. The countersink will locate in the drilled hole and its size may be dimensioned by the depth of the chamfer or the diameter of the chamfer. The neck plate countersink callout is 5/16 or .312 diameter. The spindle speed for the countersink tool is much slower than that of the twist drill and can be simply calculated at 1/3 that of the twist drill. This works out to 800÷3 = 233 RPM. Deburr all sharp edges and radius corners with smooth mill file.

The setup and spindle speed calculations should be discussed when drilling any feature of the guitar body or metal parts. When calculating for larger forstner bit and connecting holes for electrical wires one should revisit this section to review the safety and planning of the operations.

Drill point geometry

Countersink and hole geometry



Forstner bit

Technology Exercise 3

Head Stock and Tuners

Problem 3.1

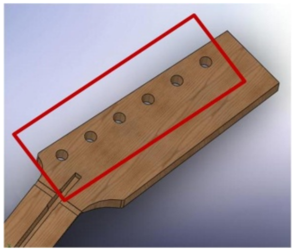
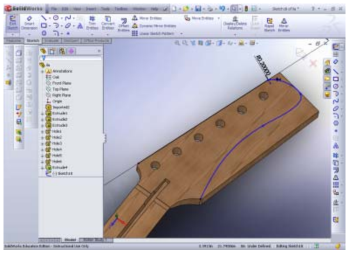
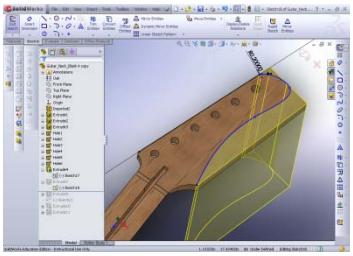
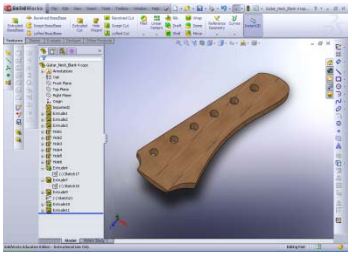
Research and report on a unique patented guitar headstock design. What are the unique characteristics of the design? Who owns the patent and when was it granted? Provide an image of the patented design.

Materials: Internet

Deliverable: One page report with image(s) and contribution to group discussion regarding unique and innovative headstock designs.

Project 3.2

Custom Headstock Design Using a 3D modeling program, design three custom headstocks. You will be provided with a 3D model of an in-line six head stock with tuner holes already located. The design of the headstock cannot go beyond the red rectangle shown in the diagram below. Although the headstock design is important for marketing, this is one of the few places on the guitar where you can customize your own designs. This activity can be enhanced by incorporating remote design teams and collaborative tools (for example: Skype, Adobe Connect, Streamline)

Red rectangle represents the “No Fly” zone. The new design should avoid this zone.

Materials: 3D CAD software, internet, sample guitar neck (optional), CAD file of neck/headstock

Deliverable: Provide a minimum of three headstock designs for an in line 6 style peg head. Using Streamline as our ftp storage site and post all designs in the appropriate folder.

Project 3.3

Create a physical model of the new custom headstock design using a rapid prototyping (RPT) system. As necessary, create the appropriate output file required by the rapid prototyping system (for example: SLA, STL).

Materials: 3D CAD software, RPT system

Deliverable: A scaled down RPT model (33%) of the new headstock design.

Project 3.4

Using a computer assisted manufacturing program (for example: CamWorks, MasterCam) create a CNC file to produce the customized headstock. If available run a tool path simulation.

Materials: CAM software, 3D model of new headstock design, machineable wax or desired stock.

Notes

Deliverable: The new headstock designed machined from 3D model.

Technology Learning Activity 2

3D Virtual Modeling

Sharing 3D files between different software programs is a common occurrence in industry. Therefore it becomes necessary to translate files from one program to another. CADD file formats that are commonly used are: DXF, IGES, STL, DWG, etc. When a file is not in the native file format the file must be translated or re-created. Use the provided 3D CAD files of the electric guitar along with a parametric 3D modeling program to create a virtual assembly using all the individual guitar components. Students will be able to properly assemble and print a virtual parametric assembly of the solid body electric guitar.

Demonstrate to the class how to operate the 3D modeling software to create an assembly file. Students should be shown how to open the software, save, print, place text, import parts and convert them to a compatible format.

Learning objectives:

1. Become more familiar with the components of the guitar and their relationship to one another
2. Use non-native file formats
3. Access necessary files to assemble the guitar
4. Create and save an assembly file in a 3D modeling software program
5. Use feature recognition to break model into individual features.
6. Define all constraints needed to create the assembly
7. Print exploded assembly drawing on a B (11x17) size sheet

Materials Required:

- 3D CAD files
- 3D parametric software (i.e. SolidWorks, Inventor, etc.)
- Printer

References:

http://en.wikipedia.org/wiki/solid_modeling

Technology Learning Activity 3

Capturing Design Intent in Guitar Design

Using the 3D CADD files for the body of the electric guitar, design a new guitar body style. Do not alter the neck pocket, pick-up pockets, bridge locations or electronics pocket. Keep the design within the overall dimensions of the 14 x 22 inch body blanks. Use the internet and the Guitar Primer to explore different body styles.

Learning objectives:

1. Define design intent.
2. Apply design intent to 3D CAD models of guitar components.
3. Differentiate between "built in intelligence" and "random design".
4. Use spreadsheets and equations to capture design intent.
5. Analyze the effects that capturing design intent has downstream manufacturing processes and machine-ability.

Materials Required:

3D CADD software, CADD file of body blank including no-fly zones.

References:

Design with Intent – Dan Lockton
http://architectures.danlockton.co.uk/2009/04/06/the-design-with-intent-toolkit/
http://www.allegromusic.ca/gtr_choose_EL_style.htm
http://en.wikipedia.org/wiki/Electric_guitar

Technology Learning Activity 4

Innovation Report

Each guitar manufacturer uses a unique feature, materials, processes, or innovation in their product to make their guitar stand out from the rest. These features, materials, processes, or innovations influence consumers to purchase these guitars by making them believe that the manufacturer makes the best guitar on the market. Students will select one guitar manufacturer and present, in writing and in speech form, one innovation, material or process that they believe is unique to that manufacturer (consider visiting your local music store). Students will submit a well written 2-3 page report with images, sketches or drawings if appropriate of the unique process, material, or innovation used by the specific manufacturer. Students will also prepare a presentation 3-5 minutes in length explaining the unique process, material, or innovation. The presentation should include a minimum of 3 visual aids.

Give students examples of brand name guitar manufacturers and sample design differences. Students should pick their own material, process or innovations, and not pick one that was used in the introduction to the lesson. You may also show students how to use any software they need for creating the presentation or report. Students may also be supplied with a list of some manufacturers to get them started.

Learning objectives:

1. Distinguish between materials and processes.
2. Find creditable resources on the internet
3. Create a presentation of materials or processes unique to companies.

Materials Required:

- Computer
- Internet
- Other publications

References:

www.gibson.com
www.fender.com
www.prsguitars.com
www.schecterguitars.com
www.washburn.com

Technology Learning Activity 5

Weight Calculation

Description: The weights and sizes of guitars vary from manufacturer to manufacturer. The weight depends on many things such as size shape and type of material. Material changes weight because materials have different densities. Today's software packages allow us to calculate mass properties.

Students will produce a chart or table that shows the overall length width and height of a guitar body. In addition provide the weight of three different body styles of electric guitars made from 3 different materials. Students will also show on the chart the mean calculation for each category.

Students will be given a CADD file of a typical electric solid body guitar and shown how to import it into your given software system. Use the software to do area calculations and density weight calculations. Students will use a spreadsheet program to create the chart. Lastly, students will be told the 3 materials they will use for calculations of their 3 body designs. These 3 materials can be Mahogany, Maple and Aluminum. Students will use CADD software to do the calculations and Spreadsheet software to create a neat, easy-to-read chart.

Learning objectives:

1. Calculate the weight of 3 solid bodies by using the mass properties provided by the CADD software
2. Create a chart that shows overall length, width and height of bodies as well as their weights.
3. Determine the mean weight and size of the 3 solid bodies.

Materials Required:

- Internet
- CADD files of electric guitar bodies
- Identify woods and other material to be used
- Spreadsheet program for creating chart or table

References:

www.tcc.edu/faculty/webpages/pgordy/Egr110/N110IL8.pdf

Technology Learning Activity 6

Package Design

You are employed at STEM guitars. Your responsibility is package design. Due to the high quality of your guitars many famous musicians have been drawn to your product. It is your task to design a package to hold 3 guitars, or 3 guitars in cases. If you are using cases you must specify all needed information about these cases. In the end you will present your design to your boss (the teacher) and sell your idea to them.

Students will do a 3 to 5 minute presentation using visual aids to explain their package design, how it functions, cost, and materials used. Students will also turn in all required drawings and research to teacher.

Students will be told what information they should have for you. This information will be organized using a spreadsheet program creating an easy to read chart with all necessary information. Students will also turn in a set of working drawings that follow engineering conventions. The following information should be included in the 3-5 minutes presentation cost of package, drawings of package, weight of package and guitars, what makes their package the best.

Learning objectives:

1. Design a shipping package
2. Create detailed engineering drawings for the package design
3. Create a parts list for all components needed and include in the Bill of Materials of the drawing
4. Calculate the cost of construction
5. Calculate the weight of the package design

Materials Required:

- Computer
- CAD software
- Spreadsheet software

Technology Learning Activity 7

Product shipping cost

The weights and sizes of material have a dramatic effect on product costs including the cost to ship products throughout the United States and the world. You are the owner of STEM guitar Inc. Customer needs 3 of your guitars shipped to them over night to the following address. Compare 3 companies shipping costs to get your customer the most economic shipping.
Students will print out a spreadsheet comparing three companies' estimates of shipping the package. The shipping estimate will including total weight, shipping method, and cost if using each carrier.
Students will use a guitar and their previously designed package designed in the previous problem and determine the cost to ship three (3) of these guitars over night from Pittsburgh Pennsylvania to Corona California.

Learning objectives:

Calculate the cost to ship 3 guitars in the student's previous package design between two locations.

Materials Required:

- Computer
- Internet
- Guitars

References:

www.ups.com
www.fedex.com
www.usps.com
www.dhl.com

Technology Learning Activity 8

Collaborative Project- Remote Design Teams

This project is a joint project that will emulate the challenges that occur when design teams are located in different parts of the country using different software tools.   The file format that will be used between the groups when sharing files is the native files created by the particular CAD software (SolidWorks or Inventor). A STEP file format may also be used. Design teams will use online collaboration tools like Skype (skype.com), Autodesk Streamline, WIMBA and Adobe Connect and email to share ideas.

Learning Objectives:

1. Identify on-line collaboration tools such as; Adobe Connect, Wimba, Skype, Blackboard, etc.
2. Determine best file format to use for file sharing between remote design teams
3. Define Rapid Prototyping Technology (RPT)
4. Provide a scaled physical prototype of design.

Materials Required:

CADD software ie; SolidWorks, Inventor, etc., CADD files for necessary guitar components, RPT technology if prototypes are required and headsets with mics.

References:

http://dspace.mit.edu/handle/1721.1/12957, http://www.iasdr2009.org/ap/Papers/Orally%20Presented%20Papers/Co-Design/Representing%20Reflective%20Practice%20in%20a%20Remote%20Design%20Collaboration%20Process.pdf , http://sixrevisions.com/project-management/the-remote-designer-how-to-work-while-on-the-road/, http://www.eetimes.com/showArticle.jhtml?articleID=18401607

Collaborative Project- Remote Design Teams

Phase I

Create a new set of sound holes based on a specific theme that the guitar will have. The sound hole cannot exceed the current sound hole design (tribal) surface area by more than 10%. A sample solid model in both SolidWorks, Inventor and or a DXF or IGES file will be provided to each group.

Phase II

Create a new bridge based on a specific theme to compliment the new sound hole design. The bridge has a “no fly zone” that will be discussed during the bridge project introduction. A sample solid model in both SolidWorks and Inventor will be provided to each group.

Phase III

Create a new design for the peg head portion of the guitar neck. Again, there is a “no fly zone” area on the model that will be provided. Teams are encouraged to consider themes. When considering the design of the peg head, more is not better.

Deliverables:

- All members must agree and sign off on the theme
- Each team member will generate a sketch of their application of the theme for the guitar body sound hole.
- 2 solid model variations (in SolidWorks or Inventor format) will be submitted from each team.
- Printed copies of the 2 design options submitted to the instructor.
- Outstanding themes and designs will be prototyped for the students on that team.

Wood Learning Activity 1

Moisture content of Wood Species

The moisture content of wood can change the weight, flexibility, and dimension of wood. These variables impact the characteristic sound and intonation as well as structural stability of a wooden instrument. Some wood species are more sensitive to moisture content changes than others. Therefore, instrument makers must be aware of how different wood species will behave to changes in moisture content; for instance, when moving an instrument from a humid climate to an arid climate.

In this lab you will compare the moisture content of different species of wood. In Method A, you will measure the piece of wood before and after placing it in a microwave for 30 seconds, then measure the change in dimensions with calipers. In Method B you will weigh the piece of wood before and after placing it in a microwave for 30 second and then note the change in the weight to see how much how much water was lost during the microwaving process.

Learning Objectives:

1. Use calipers or steel rule to accurately measure the size dimensions of wood before and after microwaving the wood for 30 seconds.
2. Compare wood species based on the dimensional change resulting from lower moisture content.
3. Use a balance to record weight change of wood before and after microwaving the wood for 30 seconds.
4. Compare woods species based on weight change resulting from lower moisture content.

Materials Required:

- Balance
- Steel metric rule (calipers)
- Set of rectangular samples of several wood species (labeled) small enough to fit in microwave

References:

http://guitarnotes.com/guitar/notes2/humidity
http://blog.customguitars.com/scotts_guitar_blog/2006/12/index.html
http://en.wikipedia.org/wiki/Tonewood
http://www.pawless.com/care.html

Wood Exercise 1

1. Prepare samples of different species of wood with the same dimensions then record the length, width, and height of each sample.
2. Submerge the wood samples in water for at least 2 hours.
3. Record the length, width, height and weight of each piece of wet wood.
4. Microwave the pieces of wood for 30 seconds then record the change in length, width, height, and weight.
5. Create a table showing the percent change in size and weight for each species of wood (before and after soaking, and after microwaving).

Discussion:

1. Which wood species is most sensitive to moisture content change?
2. Why was it important to know the moisture content of wood when building guitars?
3. Which part of a guitar would be most sensitive to wood content - the body, neck, or fret board?
4. How can you determine the amount of water that was lost during the microwave process by weighing the piece of wood?
5. Which method (size v. weight) do you think is more accurate? Why?
6. How do you think the relative humidity in the environment can affect a guitar?

Notes

Wood Learning Activity 2

Density of Wood Species

Quantitatively compare the densities of several wood species using two different methods:

- Relative buoyancies
- Measurements of actual volume

Formula: density = mass/volume
Density is a physical property of matter, as each element and compound has a unique density associated with it. Density defined in a qualitative manner is the measure of the relative "heaviness" of objects with a constant volume.

In this lab you will compare the densities of different species of wood. In Method A, you will be simply comparing and ranking the woods from most dense to least dense. In Method B you will make actual measurements and calculate numerical values for the density of each wood. Record all results and answer all discussion questions in your lab report.

Learning Objectives:

1. Determine the relative density of wood species using the measurement of buoyancy
2. Calculate the density of wood species using weight and volume measurements
3. Measure object sizes using the metric system

Materials Required:

- Graduated cylinder
- Balance
- Steel metric rule (optional dial calipers)
- Set of rectangular samples of several species (labeled) small enough to fit in graduated cylinder
- Additional set of labeled rectangular wood species (to remain dry).

References:

http://en.wikipedia.org/wiki/Density
http://www.engineeringtoolbox.com/wood-density-d_40.html
http://www.physics.ucla.edu/k-6connection/Mass,w,d.htm
http://www.physorg.com/news134193065.html

Notes

Wood Exercise 2

Procedure: Method A (Buoyancy)

1. Fill the graduated cylinder with water to a depth of 7 inches. Place a wood sample into the cylinder (zero-end down) and immediately record the depth to which each sample sinks (the deeper it sinks, the more dense the sample).
2. Repeat for each species of wood supplied.
3. Use your results to rank the woods from most dense (#1) to least dense.
4. Why was it important to measure immediately after placing the wood in the water? (What would probably happen if you waited a while?)
5. Test your hypothesis in question #4 and record the result.

Method B (Measurement)

1. Get a new set of dry samples.
2. Measure the mass of each sample on the balance and record it.
3. With the metric rule or dial caliper, measure the length, width and height in millimeters for each sample and record.
4. Calculate the volume of each sample with the formula: Volume = length x width x height. Record these values with appropriate units.
5. Now calculate the density of each sample with the formula: Density = mass/volume.
Record these values with appropriate units.
6. Do these values agree with your rankings from Method A?

Discussion:

1. Why was it important to get a whole new set of samples when beginning Method B? Explain.
2. Suppose the samples were not perfect rectangles. Try to describe a way to determine the volume of a sample if it were an odd shape.
3. Which method do you think is more accurate? Why?
4. Why would you care about wood density when considering the species for your guitar?

Notes

Board feet calculations of lumber

Rough Lumber information:

4/4 = 1” thick		144 cu inches = 1 board foot
8/4 = 2” thick		A board foot = a 12” wide board 1“ thick by 12” long

Calculate the following amounts of board feet.

Height	**Width**	**Length**	**Cu In**	**Board Feet**
4/4	6”	12’		
4/4	8”	10’		
5/4	14”	8’		
6/4	12”	10’		
8/4	8”	12’		
4/4	7.5”	10’8”		
8/4	13-3/4”	45”		
8/4	14”	22”		
4/4	14”	22”		
.75”	6”	24”		
.50”	10”	66”		
8/4	5-1/2”	87”		
8/4	8-3/8”	12’		
5/8”	6-5/8”	79-1/2”		
1-3/4”	9-1/4”	56”		

Solid Body Electric Guitar Design & Fabrication
Guitar Making Tools, Equipment, Supplies, & Consumables
Preliminary Budget

	Min. Startup Cost	Total: Class 12-15	Total: Class 16-22
"Must Have" Specialty Tools	$907.47	$1,839.32	$2,999.94
"Really Need" Specialty Tools	$756.83	$974.37	$1,363.78
Power and Hand Tools	$3,596.71	$4,222.07	$4,976.92
Supplies & Consumables	$3,043.79	$5,260.94	$7,345.70
Totals:	*$8,304.80*	*$12,296.70*	*$16,686.34*

Part name	Rank	Part No.	Potential Supplier	Min. Cost	Reqd Qty for Start up	Min. Startup Cost	Qty for Class Size of 12-15	Total: Class 12-15	Qty for Class Size of 16-22	Total: Class 16-22
"Must Have" Specialty Tools										
Fretting Kit	1	5345	Stewart Macdonald	$170.90	2	$341.80	3	$512.70	4	$683.60
12" Radius sanding blocks (8")	1	0417	Stewart Macdonald	$15.95	4	$63.80	7	$111.65	12	$191.40
12" Aluminum Radius-sanding Beam (18")	1	5643	Stewart Macdonald	$125.84	1	$125.84	3	$377.52	6	$755.04
Notched Straightedge (for guitars)	1	3814	Stewart Macdonald	$72.21	1	$72.21	2	$144.42	2	$144.42
Dual-grit Diamond Fret File (medium fretwire)	1	4455	Stewart Macdonald	$55.98	1	$55.98	3	$167.94	5	$279.90
Essential Nut Making Tool Kit	1	5350	Stewart Macdonald	$194.74	1	$194.74	1	$194.74	2	$389.48
Double-edge Nut Files (0.012" & 0.016")	1	4541	Stewart Macdonald	$25.45	0	$0.00	2	$50.90	3	$76.35
Double-edge Nut Files (0.026" & 0.032")	1	4542	Stewart Macdonald	$25.45	0	$0.00	2	$50.90	3	$76.35
Double-edge Nut Files (0.036" & 0.042")	1	4543	Stewart Macdonald	$25.45	0	$0.00	2	$50.90	3	$76.35
Nut & Saddle Shaping Files, Set of 2	1	4556	Stewart Macdonald	$25.25	0	$0.00	2	$50.50	4	$101.00
String Spacing Rule	1	0673	Stewart Macdonald	$20.95	0	$0.00	1	$20.95	2	$41.90
String Action Gauge (string/fretboard height gauge)	1	0670	Stewart Macdonald	$18.95	1	$18.95	2	$37.90	4	$75.80
Fairgate Center-finding Rule, 6" x 3/4"	1	23-106	Fashion Designers Place	$2.95	2	$5.90	4	$11.80	8	$23.60
Fret Saw, 20 TPI, 0.023 kerf, Pull ("Backsaw")	1	SWB	LMI	$28.25	1	$28.25	2	$56.50	3	$84.75
"Really Need" Specialty Tools										
Fret wire bender (3 roller type)	2	FWB	LMI	$69.95	1	$69.95	1	$69.95	1	$69.95
Precision Straightedge (18")	2	3850	Stewart Macdonald	$47.40	1	$47.40	2	$94.80	2	$94.80
Fret hammer	2	4895	Stewart Macdonald	$19.60	1	$19.60	2	$39.20	4	$78.40
7/8" Replacement plastic face (for fret hammer)	3	4896	Stewart Macdonald	$1.79	2	$3.58	2	$3.58	2	$3.58
7/8" Replacement brass convex face (for fret hammer)	3	4897	Stewart Macdonald	$7.83	2	$15.66	2	$15.66	2	$15.66
Fret Press System (caul, arbor press, support, 5 inserts)	2	4483	Stewart Macdonald	$164.72	1	$164.72	1	$164.72	2	$329.44
Fret/Fingerboard Leveling Files (Set of 3)	2	0860	Stewart Macdonald	$108.49	2	$216.98	2	$216.98	2	$216.98
Fret Leveler (6")	2	0862	Stewart Macdonald	$39.74	0	$0.00	3	$119.22	6	$238.44
Nut Vise	3	1816	Stewart Macdonald	$34.95	0	$0.00	0	$0.00	1	$34.95
Neck Support Caul	2	4479	Stewart Macdonald	$10.44	3	$31.32	6	$62.64	9	$93.96
Fret/Fingerboard Leveler (16")	2	4578	Stewart Macdonald	$43.67	1	$43.67	1	$43.67	1	$43.67
Amana In-Groove CNC Insert Engraving Tool (8 pc. Set)	4	AMS-209	toolstoday.com	$143.95	1	$143.95	1	$143.95	1	$143.95
								$0.00		$0.00
								$0.00		$0.00
Standard Tools (Power and Hand)										
Hand-Held Pneumatic Drum Sander (7-1/2" x 2-1/4")	1	H2882	Grizzly	$99.95	1	$99.95	2	$199.90	4	$399.80
Hand-Held Pneumatic Drum Sander (4" x 1-1/8")	2	H2881	Grizzly	$69.95	1	$69.95	2	$139.90	2	$139.90
1/2" HD Var Speed Reversible Drill (w/ handle)	1	3273-0VGA	Harbor Freight	$39.99	3	$119.97	5	$199.95	8	$319.92
3/8" Var Speed Reversible Drill (w/ handle)	2	3670-2VGA	Harbor Freight	$19.99	2	$39.98	4	$79.96	6	$119.94
5" Random Orbital Palm Sander (8 hole/hook & loop)	1	93431-1VGA	Harbor Freight	$29.99	2	$59.98	3	$89.97	4	$119.96
Ball Pein Hammer set (8, 12, 16, 24 and 32 oz.)	2	36523-9VGA	Harbor Freight	$7.97	1	$7.97	1	$7.97	1	$7.97
28 pc. Standard & Metric Open End Wrench Set	2	42955	Sears/Craftsman	$159.99	1	$159.99	1	$159.99	1	$159.99
44 Pc HD Screwdriver Set ("high end")	2	50089	Sears/Craftsman	$79.99	1	$79.99	1	$79.99	1	$79.99
13 Piece Screwdriver Set ("low end")	2	1847-1VGA	Harbor Freight	$11.99	1	$11.99	1	$11.99	1	$11.99
7 Piece Pliers Set (general use)	2	93363-0VGA	Harbor Freight	$16.99	1	$16.99	1	$16.99	2	$33.98
5 Piece Precision Pliers Set (soldering stations)	1	4807-8VGA	Harbor Freight	$5.97	3	$17.91	4	$23.88	6	$35.82
7" Wire Stripper with Cutter	1	98410-1VGA	Harbor Freight	$5.99	2	$11.98	3	$17.97	4	$23.96
Japanese Flush Cut Saw (12" OAL/Cuts on pull stroke)	1	39273-7VGA	Harbor Freight	$9.99	2	$19.98	3	$29.97	4	$39.96
9" Benchtop Bandsaw (62" Blade)	2	96980-2VGA	Harbor Freight	$139.99	0	$0.00	0	$0.00	1	$139.99
Oscillating Edge/belt Spindle Sander (Rigid)	2	EB4424	Home Depot	$199.00	1	$199.00	2	$398.00	2	$398.00
Steel Secure Storage Cabinet with 2 Full-Width Drawers	1	1UBW6	Grainger	$1,921.00	1	$1,921.00	1	$1,921.00	1	$1,921.00
5 pc. Wood Chisel Set	1	36859	Sears/Craftsman	$34.99	1	$34.99	1	$34.99	1	$34.99
170 Pc Drill Bit Set (Brad Point)	2	148082	Woodcraft	$59.99	1	$59.99	1	$59.99	1	$59.99
Bar Clamp, 12" x 3" Bessey EZS One Handed	2	845104	Woodcraft	$19.79	10	$197.90	12	$237.48	16	$316.64
Bar Clamp, 18" x 3" Bessey EZS One Handed	2	845105	Woodcraft	$22.49	10	$224.90	12	$269.88	16	$359.84
Plug Cutter, Tapered; 1/4" (for fret dots)	1	146724	Woodcraft	$10.99	2	$21.98	2	$21.98	3	$32.97
Rubber Bands, 17" x 1/4 Width; Pkg of 50	1	1PE12	Grainger	$8.11	2	$16.22	2	$16.22	2	$16.22
Round Plastic Receptacle Base, Capacity 55 Gallons	1	3H240	Grainger	$99.45	1	$99.45	1	$99.45	1	$99.45
Round Dolly (for round wast containers)	1	5W007	Grainger	$74.40	1	$74.40	1	$74.40	1	$74.40
Flat Plastic Receptacle Lid, (for 55 Gal Rnd Container)	1	4W017	Grainger	$30.25	1	$30.25	1	$30.25	1	$30.25

Preliminary Budget - Solid Body Electric Guitar Design Fabrication

Supplies and Consummables

Bona Novia Waterbased Floor Finish Gloss	1	WT230018002	online floor store	$39.99	1	$39.99	1	$39.99	1	$39.99
Bona Bonaseal Waterbased Floor Finish Sealer	1	WB200018005	online floor store	$37.60	1	$37.60	1	$37.60	1	$37.60
Bona Amberseal Waterborne Sanding Sealer	2	WB252018003	online floor store	$39.99	1	$39.99	1	$39.99	1	$39.99
Trash Can Liner, Capacity 55 Gallons, Gauge 0.670 Mils	1	2U383	Grainger	$72.10	1	$72.10	1	$72.10	1	$72.10
Digital Multimeter (8 Functions; 20 Ranges)	2	82141	Sears/Craftsman	$19.99	1	$19.99	2	$39.98	2	$39.98
Michigan Indust Tools-Helping Hand w/ Magnifier	1	7521	***[Google search]***	$9.30	2	$18.60	4	$37.20	6	$55.80
Fender Frontman 10G 10W Guitar Combo Amp (Black)	1	481602	Muscian's Friend	$59.99	1	$59.99	2	$119.98	2	$119.98
6-Ft. Shielded Cable, 1/4" Mono Plug to 1/8" Mono Plug	1	42-2433	Radio Shack	$5.99	1	$5.99	2	$11.98	2	$11.98
1/8" Right-Angle Adapter	2	274-372	Radio Shack	$3.59	1	$3.59	2	$7.18	2	$7.18
1/4" Mono Male x 1/4" Mono Male Cable 10 ft	1	099-0410-0xx	Muscian's Friend	$7.99	1	$7.99	2	$15.98	2	$15.98
Stikit Gold Paper Self-adhesive Abrasives (4 grit kit)		5770	Stewart Macdonald	$89.92	1	$89.92	1	$89.92	1	$89.92
Stikit Self-adhesive Abrasives (45ft x 2-3/4" x 120 grit)		5767	Stewart Macdonald	$23.59	2	$47.18	3	$70.77	4	$94.36
Stikit Self-adhesive Abrasives (45ft x 2-3/4" x 220 grit)		5768	Stewart Macdonald	$23.59	1	$23.59	2	$47.18	3	$70.77
Stikit Self-adhesive Abrasives (45ft x 2-3/4" x 320 grit)		5769	Stewart Macdonald	$23.59	1	$23.59	2	$47.18	3	$70.77
Sanding Sleeve A60 (7-1/2" x 2-1/4")		H3881	Grizzly	$3.95	4	$15.80	10	$39.50	15	$59.25
Sanding Sleeve A60 (1-1/8" x 4")		H3875	Grizzly	$3.95	4	$15.80	10	$39.50	15	$59.25
5" Sanding Disc, A120-A H&L 8 Hole, 100 pc.		H4077	Grizzly	$27.95	1	$27.95	1	$27.95	2	$55.90
5" Sanding Disc, A240-A H&L 8 Hole, 100 pc.		H4073	Grizzly	$26.95	1	$26.95	1	$26.95	2	$53.90
5" Sanding Disc, A320-A H&L 8 Hole, 100 pc.		H4071	Grizzly	$26.95	1	$26.95	1	$26.95	1	$26.95
5" Sanding Disc, A400-A H&L 8 Hole, 100 pc.		H4070	Grizzly	$26.95	1	$26.95	1	$26.95	1	$26.95
RIDGID Spindle Sanding Sleeve 10-pc		AC28400	Home Depot	$14.84	1	$14.84	2	$29.68	2	$29.68
SoftTouch Contour Sponge (Bx:20, Fine/320)		03075	Home Depot	$19.97	1	$19.97	1	$19.97	1	$19.97
SoftTouch Contour Sponge (Bx:20, SuperFine/500)		03076	Home Depot	$19.97	1	$19.97	1	$19.97	1	$19.97
Side Dot Rods (Blk, 10 pc; 5/64 (2 mm) DIA x 7.88")		LT-0496-023	AllParts	$6.50	3	$19.50	4	$26.00	6	$39.00
Side Dot Rods (Wht, 10 pc; 5/64 (2 mm) DIA x 7.88")		LT-0496-025	AllParts	$6.50	4	$26.00	5	$32.50	7	$45.50
Side Dot Rods (Red, 10 pc; 5/64 (2 mm) DIA x 7.88")		LT-0496-026	AllParts	$6.50	1	$6.50	1	$6.50	1	$6.50
Side Dot Rods (Cream, 10 pc; 5/64 (2 mm) DIA x 7.88")	3	LT-0496-028	AllParts	$6.50	1	$6.50	1	$6.50	1	$6.50
D'Addario EXL110 Regular Light Strings Bulk Pack (25)	1	103653978	Guitar Center	$89.99	0	$0.00	1	$89.99	2	$179.98
Nickel String Guides Bulk Pack, (50 pieces)	1	AP-0720-B01	All Parts	$85.00	0	$0.00	1	$85.00	2	$170.00
Chrome Strap Buttons Bulk Pack (30 Buttons w/ Screws)	1	AP-0670-B10	All Parts	$40.00	0	$0.00	2	$80.00	2	$80.00
String Ferrules for Guitar, Nickel (Bulk Pack, 50 pieces)	1	AP-0087-B01	All Parts	$50.00	0	$0.00	3	$150.00	3	$150.00
Hardwood: prototypes, 1st articles, & prelims/workshops	1		TBD	$300.00	1	$300.00	16	$1,100.00	25	$1,550.00
SBEG Electronics & Hardware Kit (Dual Humbuckers) http://ncmestorefront.mybisi.com/product/electronics-hardware-kit	1		NCME Storefront	$125.00	12	$1,500.00	16	$2,000.00	24	$3,000.00
Miscellaneous and incidental stuff			Various	$500.00	1	$500.00	1.5	$750.00	2	$1,000.00

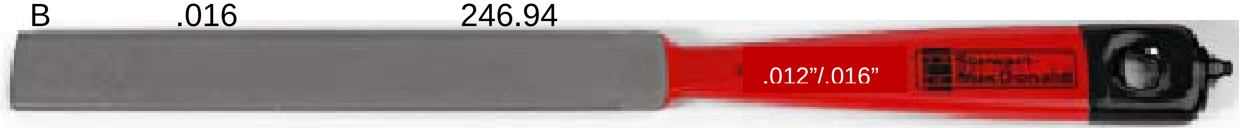
Vendor List	URL	Notes
AllParts	http://www.allparts.com	
Bona Store (on-line)	http://store.mybonahome.com	
Grainger	http://www.grainger.com	
Grizzly	http://www.grizzly.com	
Guitar Center	http://www.guitarcenter.com	
Harbor Freight	http://www.harborfreight.com	
Home Depot	http://www.homedepot.com	
Luthiers Mercantile	http://www.lmii.com/	10% off for Educaiton
Online Floor Store	http://www.onlinefloorstore.com	
Stewart Macdonald	http://www.stewmac.com	10% off possible
The Fashion Designers Place	http://www.fdpstore.com	10% off for Educaiton
ToolsToday	http://www.toolstoday.com	Educational discount offered

	ITEM	VENDOR	MANUFACTURER	PART #	UNIT	QTY	COST
							$0.00
	BODY						$0.00
	NECK						$0.00
	PICK UPS						$0.00
	VOLUME POT 250K						$0.00
	TONE POT 250K						$0.00
	CAPACITOR						$0.00
	JACK PLUG						$0.00
	JACK PLATE						$0.00
	NECK PLATE						$0.00
	PICKGUARD						$0.00
	TUNING MACHINES						$0.00
	FRETS (if not included in neck assy)						$0.00
	FRETBOARD (if not included in neck assy)						$0.00
	NUT (if not included in neck assy)						$0.00
	BRIDGE						$0.00
	STRINGS						$0.00
	TRUSS ROD (if not included in neck assy)						$0.00
	FRET DOTS (if not included in neck assy)						$0.00
						TOTAL	$0.00

Part Name	Quantity Required	unit price	extended price	supplier	part number
Body					
Pickups					
Pick Guard					
Tuning Machines					
Neck					
Frets					
Bret Board					
Nut					
Truss Rod					
Fret Dots					
Bridge					
Strings					
Neck Plate					
String Ferrules					
1/4" mono audio jack					
1/4" jack plate					
500k ohm pot					
strap knob					
3 way pickup switch					
micro ferret capacitor					

NUT FILES

STRING	**RADIUS**	**FREQUENCY - Hz**
B	.016	246.94
High E	.012	329.63
D	.032	146.83
G	.026	196.00
A	.036	110.00
Low E	.042	82.407



Making a sketch by tracing a digital picture.

1. Find a digital picture online or otherwise. (Must be digital to be uploaded onto a JPEG.)

2. If from web browser or online source, right click and select ‘save picture as’. Set a name and save it into a designated folder in your ‘x drive’.

3. Start up the program “Adobe Illustrator” found in your programs list in the folder Adobe Design Premium CS3.

4. Open the picture file.

5. When making an outline of another picture file, the first step is to create a second layer. This is where your outline will be held.

    To do this, select the layers tool button on the right side of the screen. It will be at the bottom.

6. The layer window will pop up. You first want to lock the first layer by checking the empty box next to an icon of an eye. If you click the right one a picture of a lock will appear. This will be the reference layer for your outline.

7. The next step is to create the aforementioned sketch layer. While in the layer toolbox, select the icon at the bottom next to the trash can (delete icon). This is the create new layer icon. If you did this correctly, the same toolbox will display two different layers (1 and 2). You do not need to lock the second layer.

8. You may now exit the layer toolbar, pertaining that you successfully created two layers and locked the reference layer.

    Note: You can toggle between layers by hitting the ctrl and y keys
    You can use the scroll wheel for vertical movement and hold the ctrl button with the scroll wheel for horizontal movement. To zoom in and out, use the ctrl and + or – keys.

9. You may now begin sketching your picture. Select the pen tool from the tools on the right. Make sure you are in your reference layer. The pen tool works through clicking and dragging. First find an anchor point, this is the starting point for the line segment you will draw, next find an endpoint. Click and hold at the endpoint and manipulate the line to fit the area you are tracing. When the trace line fits, you may let go. Re click the endpoint to make that the new anchor point and find a new end point and repeat the process until you are satisfied with your drawing.

10. You may check your work by toggling between layers using the ctrl and y keystroke. When you are done, **export** the file as an AutoCAD (dwg) file.

11. Start up solid works and open the dwg file. Remember you wont find it unless you are specifically looking for a dwg file.

12. A window will popup giving you a list of selections to use. Select import as a new part and click next. Click next to see your drawing, if you do not see an outline of your drawing in any of the next few windows, you messed up. Give up and raise your hand and a teacher will assist you shortly.
13. If done correctly you can hit finish and a sketch will appear in a solid works environment. Good Job.

Janka hardness

A measure of the hardness of wood, produced by a variation on the Brinell hardness test. The test measures the force required to push a steel ball with a diameter of 11.28 millimeters (0.444 inches) into the wood to a depth of half the ball's diameter (the diameter was chosen to produce a circle with an area of 100 square millimeters). In Janka's original test. the results were expressed in units of pressure, but when the ASTM standardized the test (tentative issue in *1922*, standard first formally adopted in *1927*), it called for results in units of force.

The results are stated in various ways in different countries, which can lead to confusion, especially since the name of the actual unit employed is often not attached. In the United States, the measurement is in pounds-force. In Sweden it is apparently in kilogram-force (kgf), and in Australia, Janka hardness ratings are either in newtons (N) or kilonewtons (kN). Sometimes the results are treated as units, e.g., “360 janka.”

The hardness of wood usually varies with the direction of the grain. If testing is done on the surface of a plank, with the force exerted perpendicular to the grain, the test is said to be of “side hardness.” Side hardnesses of a block of wood measured in the direction of the tree's center (radially), and on a tangent to the tree's rings (tangentially), are typically very similar. End testing is also sometimes done (that is, testing the cut surface of a stump would be a test of end hardness). The side hardness of teak, for example, is in the range 3730 to 4800 newtons, while the end hardness is in the range 4150 to 4500 newtons.

The most common use of Janka hardness ratings is to determine whether a species is suitable for use as flooring.

Notes on the table

The pale blue background indicates species growing in North America. Common names, of course, are unreliable; two or more species often have the same common name. We show the name preferred by the Forest Products Laboratory. Except as noted, all samples were tested at 12% moisture content, typical of air-dried wood. Wood varies; a sample picked at random is expected to have a side hardness between about 80% and 120% of the value shown. Blank cells occur where a wood is sold commercially but so far we have found no hardness data.

Side Hardness of Some Woods

Common name	Scientific name	side hardness, Janka test, at 12% moisture content	

		kilonewtons	pounds-force
afromosia	*Pericopsis elata*	7.1	1560
albarco	*Cariniana* spp.	4.5	1020
alder, red	*Alnus rubra*	2.6	590
alder, white	*Alnus rhombifolia*		
andiroba	*Carapa guianensis*	5.0	1130
angelin	*Andira inermis*	7.8	1750
angelique	*Dicorynia guianensis*	5.7	1290
apple	*Malus sylvestris*	7.7	1730
ash, black	*Fraxinus nigra*	3.8	850
ash, blue	*Fraxinus quadrangulata*	9.0	2030
ash, green	*Fraxinus pennsylvanica*	5.3	1200
ash, oregon	*Fraxinus latifolia*	5.2	1160
ash, pumpkin	*Fraxinus profunda*	4.4	990
ash, white	*Fraxinus americana*	5.9	1320
aspen, bigtooth	*Populus grandidentata*	1.9	420
aspen, quaking	*Populus tremuloides*	1.6	350
avodire	*Turraeanthus africanus*	4.8	1080
azobe	*Lophira aiata*	14.9	3350
baldcypress	*Taxcodium distichum*	2.3	570
balsa	*Ochroma pyramidale*		
banak	*Virola* spp.	2.3	510
basswood, American	*Tilia americana*	1.8	410
basswood, Carolina	*Tilia caroliniana*		
basswood, white	*Tilia heterophylla*		
beech, American	*Fagus grandifolia*	5.8	1300
benge	*Guibourtia amoldiana*	7.8	1750
birch, gray	*Betula populifolia*	3.4	760
birch, paper	*Betula papyrifera*	4.0	910

birch, river	*Betula nigra*		
birch, sweet	*Betula lenta*	6.5	1470
birch, yellow	*Betula alleghaniensis*	5.6	1260
boxelder	*Acer negundo*	3.2	720
bubinga	*Guibourtia* spp.	12.0	2690
buckeye, Ohio	*Aesculus glabra*		
buckeye, yellow	*Aesculus octandra*	1.6	350
buckthorn, cascara	*Rhamnus purshiana*	4.6	1040
bulletwood	*Manilkara bidentata*	14.2	3190
butternut	*Juglans cinerea*	2.2	490
buttonwood	*Conocarpus erectus*		
catalpa, northern	*Catalpa speciosa*	2.4	550
catalpa, southern	*Catalpa bignonioides*	2.4	550
cativo	*Prioria copaifera*	2.8	630
cedar, Alaska	*Chamaecyparis nootkatensis*	2.6	580
cedar, atlantic white	*Chamaecyparis thyoides*	1.6	350
cedar, Port Orford	*Chamaecyparis lawsoniana*	3.2	720
cedar, yellow		2.6	580
ceiba	*Ceiba pentandra*	1.1	240
cherry, black	*Prunus serotina*	4.2	950
chestnut, American	*Castenea dentata*	2.4	540
chinkapin, giant	*Castanopsis chrysophylla*	3.2	730
coffeetree, Kentucky	*Gymnocladus dioicus*	6,2	1390
cottonwood) balsam poplar	*Populus balsamifera*	1.3	300
cottonwood, black	*Populus trichocarpa*	1.6	350
cottonwood, eastern	*Populus deltoides*	1.9	430
courbaril	*Hymenaea courbaril*	10.5	2350
cuangare	*Dialyanthera* spp.	1.7	380
cypress, Mexican	*Cupressus lustianica*	2.0	460

degame	*Calycophyllum candidissimum*	8.6	1940
determa	*Ocotea rubra*	2.9	660
dogwood, flowering	*Cornus florida*	9.6	2150
Douglas-fir, coast	*Pseudotsuga menziesii*	3.2	710
Douglas-fir. interior west	*Pseudotsuga menziesii*	2.9	660
Douglas-fir, interior north	*Pseudotsuga menziesii*	2.7	600
Douglas-fir, interior south	*Pseudotsuga menziesii*	2.3	510
ekop	*Tetraberlinia tubmaniana*		
elder, blue	*Sambucus cerulea*	3.7	840
elm, american	*Ulmus americana*	3.7	830
elm, cedar	*Ulmus crassifolia*	5.9	1320
elm, rock	*Ulmus thomasii*	5.9	1320
elm, slippery	*Ulmus rubra*	3.8	860
elm, winged	*Ulmus alata*	6.8	1540
fir, balsam	*Abies balsamea*	1.8	400
fir, California red	*Abies magnifica*	2.2	500
fir, grand	*Abies grandis*	2.2	490
fir, noble	*Abies procera*	1.8	410
fir, pacific silver	*Abies amabilis*	1.9	430
fir, subalpine	*Abies lasiocarpa*	1.6	350
fir, white	*Abies concolor*	2.1	480
goncalo alves	*Astronium graveolens*	9.6	2160
greenheart	*Chlorocardium rodiei*	10.5	2350
hackberry	*Celtis occidentalis*	3.9	880
hackberry, netleaf	*Celtis reticulata*		
(hackberry) sugarberry	*Celtis laevigata*		
hemlock, eastern	*Tsuga canadensis*	2.2	500
hemlock, mountain	*Tsuga mertensiana*	3.0	680

hemlock, western	*Tsuga heterophylla*	2.4	540
hickory, bitternut	*Carya cordiformis*		
hickory, black	*Carya texana*		
hickory, nutmeg	*Carya myristicaeformis*		
hickory, pecan	*Carya illinoensis*	8.1	1820
hickory, sand	*Carya pallida*		
hickory, water	*Carya aquatica*		
hickory. mockernut	*Carya tomentosa*		
hickory, pignut	*Carya glabra*		
hickory, shagbark	*Carya ovata*		
hickory, shellbark	*Carya lacinosa*		
holly, American	*Ilex opaca*	4.5	1020
honeylocust	*Gleditsia triacanthos*	7.0	1580
hophornbeam, eastern	*Ostrya virginiana*	8.3	1860
hornbeam, American	*Carpinus caroliniana*	7.9	1780
hura	*Hura crepitans*	2.4	550
ilomba	*Pycnanthus angolensis*	2.7	610
incense-cedar	*Libocedrus decurrens*	2.1	470
ipe	*Tabebula* spp., lapacho group	16.4	3680
iroko	*Chlorophora* spp.	5.6	1260
jarrah	*Eucalyptus marginata*	8.5	1910
jelutong	*Dyera costulata*	1.7 (@15%)	390
juniper, alligator	*Juniperus deppeana*	5.2	1160
juniper, western	*Juniperus occidentalis*		
kaneelhart	*Licaria* spp.	12.9	2900
kapur	*Dryobalanops* spp.	5.5	1230
karri	*Eucalyptus diversicolor*	9.1	2040
kempas	*Koompassia malaccensis*	7.6	1710
keruing	*Dipterocarpus* spp.	5.6	1270

larch, western	*Larix occidentalis*	3.7	830
laurel, California	*Umbellularia californica*	5.6	1270
laurel, mountain	*Kalmia latifolia*	8.0	1790
lignumvitae	*Guaiacum* spp.	20.0	4500
limba	*Terminalia superba*	2.2	490
locust, black	*Robinia pseudoacacia*	7.6	1700
macawood	*Platymiscium* spp.	14.0??	3150
madrone, Pacific	*Arbutus menziesii*	6.5	1460
(magnolia) cucumber tree	*Magnolia acuminata*	3.1	700
magnolia, southern	*Magnolia grandiflora*	4.5	1020
(magnolia) sweetbay	*Magnolia virginiana*		
mahogany, African	*Khaya* spp.	3.7	830
mahogany, true	*Swietenia macrophylla*	3.6	800
manbarklak	*Eschweilera* spp.	15.5	3480
manni	*Symphonia globulifera*	5.0	1120
maple, bigleaf	*Acer macrophyllum*	3.8	850
maple, black	*Acer nigrum*	5.2	1180
maple, red	*Acer rubrum*	4.2	950
maple, silver	*Acer saccharimum*	3.1	700
maple, sugar	*Acer saccharum*	6.4	1450
marishballi	*Lincania* spp.	15.9	3570
merbau	*Intsia* spp.	6.7 (@15%)	1500
mersawa	*Anisoptera* spp.	5.7	1290
mesquite	*Prosopis* spp.		
mora	*Mora* spp.	10.2	2300
oak, black	*Quercus velutina*	5.4	1210
oak, cherrybark	*Quercus falcata* var *pagodifolia*	6.6	1480
oak, southern red	*Quercus falcata*	4.7	1060

oak, laurel	*Quercus laurifolia*	5.4	1210
oak, northern red	*Quercus rubra*	5.7	1290
oak, pin	*Quercus palustris*	6.7	1510
oak, scarlet	*Quercus coccinea*	6.2	1400
oak, shumard	*Quercus shumardii*		
oak, water	*Quercus nigra*	5.3	1190
oak, willow	*Quercus phellos*	6.5	1460
oak, bur	*Quercus macrocarpa*	6.1	1370
oak, chestnut	*Quercus prinus*	5.0	1130
oak, live	*Quercus virginiana*		
oak, overcup	*Quercus lyrata*	5.3	1190
oak, post	*Quercus stellata*	6.0	1360
oak, swamp chestnut	*Quercus michauxii*	5.5	1240
oak, swamp white	*Quercus bicolor*	7.2	1620
oak, white	*Quercus alba*	6.0	1360
obeche	*Triplochiton scleroxylon*	1.9	430
okoume	*Aucoumea klaineana*	1.7	380
opepe	*Nauclea diderrichii*	7.3	1630
osage orange	*Maclura pomifera*	9.1 (green)	2040 (green)
ovangkoi	*Goubertia ehie*		
para-angelim	*Hymenolobium excelsum*	7.7	1720
parana-pine	*Araucaria augustifolia*	3.5	780
pau marfim	*Balfourodendron riedelianum*		
peroba de campos	*Paratecoma peroba*	7.1	1600
peroba rosa	*Aspidosperma* spp., peroba group	7.7	1730
persimmon, common	*Diospyros virginiana*	10.2	2300
pilon	*Hyeronima* spp.	7.6	1700
pine, Caribbean	*Pinus* caribaea	5.5	1240

pine, eastern white	*Pinus strobus*	1.7	380
pine, jack	*Pinus banksiana*	2.5	570
pine, Jeffrey	*Pinus jeffreyi*	2.2	500
pine, limber	*Pinus flexilis*	1.9	430
pine, loblolly	*Pinus taeda*	3.1	690
pine, lodgepole	*Pinus contorta*	2.1	480
pine, longleaf	*Pinus palustris*	3.9	870
pine, ocote	*Pinus oocarpa*	4.0	910
pine, pinyon	*Pinus edulis*	3.8	860
pine, pitch	*Pinus rigida*	2.8	620
pine, pond	*Pinus serotina*	3.3	740
pine, ponderosa	*Pinus ponderosa*	2.0	460
pine, Monterey	*Pinus radiata*	3.3	750*
pine. red	*Pinus resinosa*	2.5	560
pine, sand	*Pinus clausa*	3.3	730
pine, shortleaf	*Pinus echinata*	3.1	690
pine, slash	*Pinus elliotti*		
pine, spruce	*Pinus glabra*	2.9	660
pine, sugar	*Pinus lambertiana*	1.7	380
pine, Table Mountain	*Pinus pungens*	2.9	660
pine, virginia	*Pinus virginiana*	3.3	740
pine, western white	*Pinus monticola*	1.9	420
piquia	*Caryocar* spp.	7.7	1720
primavera	*Tabebula donnell-smithii*	2.9	660
purpleheart	*Peltogyne* spp.	8.3	1860
ramin	*Gonystylus bancanus*	5.8	1300
redcedar, eastern	*Juniperus virginiana*	4.0	900
redcedar, southern	*Juniperus silicicola*	2.7	610
redcedar, western	*Thuja plicata*	1.6	350

redwood, old growth	*Sequoia sempervirens*	2.1	480
redwood, second growth	*Sequoia sempervirens*	1.9	420
robe	*Tabebul* spp., roble group	4.3	960
rosewood, Brazilian	*Dalbergia nigra*	12.1	2720
rosewood, Indian	*Dalbergia latifolia*	14.1	3170
sande	*Brosimum* spp., utile group	4.0	900
santa maria	*Calophyllum brasiliense*	5.1	1150
sapele	*Entandrophragma cylindricum*	6.7	1510
sassafras	*Sassafras albidum*	2.8	630
sepetir	*Pseudosindora palustris*	6.3	1410
serviceberry	*Amelanchier* spp.	8.0	1800
shorea	*Shorea* spp., baulau group	7.9	1780
(shorea) dark red meranti	*Shorea* spp., lauan-meranti group	3.5	780
(shorea) light red meranti	*Shorea* spp., lauan-meranti group	2.0	460
(shorea) white meranti	*Shorea* spp., lauan-meranti group	5.1 (@15%)	1140
(shorea) yellow meranti	*Shorea* spp., lauan-meranti group	3.4	770
silverbell, Carolina	*Halesia carolina*	2.6	590
sourwood	*Oxydendrum arboreum*	4.2	940
Spanish-cedar	*Cedrela* spp.	2.7	600
spruce, black	*Picea mariana*	2.3	520
spruce, Engelmann	*Picea engelmanni*	1.7	390
spruce, red	*Picea rubra*	2.2	490
spruce, Sitka	*Picea sitchensis*	2.3	510
spruce, white	*Picea glauca*	2.1	480
sucupira	*Bowdichia* spp.		
sucupira	*Diplotropis purpurea*	9.5	2140
sumac, staghorn	*Rhus typhina*	3.0	680

sweetgum	*Liquidambar styraciflua*	3.8	850
sycamore, american	Platanus occidentalis	3.4	770
tamarack	*Larix laricina*	2.6	590
tanoak	*Lithocarpus densiflorus*		
teak	*Tectona grandis*	4.4	1000
tomillo	*Cedrelinga catenformis*		870 (green)
tree-of-heaven	*Ailanthus altissima*	7.7	1731
tupelo, black	*Nyssa sylvatica*	3.6	810
tupelo. water	*Nyssa aquatica*	3.9	880
wallaba	*Eperua* spp.	9.1	2040
walnut, black	*Juglans nigra*	4.5	1010
white-cedar, northern	*Thuja occidentalis*	1.4	320
willow, black	*Salix nigra*		
witch hazel	*Hamamelis virginica*	6.8	1530
yellow poplar	*Liriodendron tulipifera*	2.4	540
yew. Pacific	*Taxus brevifolia*	7.1	1600

*Authorities differ significantly on the hardness of *Pinus radiata*, with published values as high as 792 lbs-force (3.5 kilonewtons) and as low as 625 lbf (2.8 kN).

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RESOURCES

Standards:
ASTM D1037-99. Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials.
ASTM D143-94(2000)e1 Standard Methods of Testing Small Clear Specimens of Timber.
ISO 3350:1975. Wood–Determination of static hardness.
ISO 3351:1975. Wood–Determination of resistance to impact indentation.

Janka hardness ratings can also be found at sites selling flooring, such as:

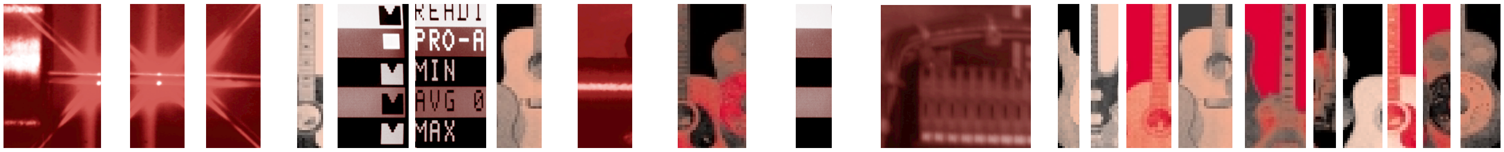
www.wflooring.com/Technical_Info/Species_Tech_Info/species_hardness.htm

www.zoltanfloors.com/tech.html

Some information sources say or imply, incorrectly, that Janka hardness is measured in units of pressure, such as pounds per square inch, and that side hardness is a synonym for Janka hardness.

D'Addario®

catalog supplement/string tension specifications



A complete technical reference for fretted instrument string tensions

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Introduction

String Tensions

This brochure was created to assist in selecting the ideal string for your instrument and playing style. Included in this brochure are tension tables and formulas to help you calculate what tension a particular string will have on your instrument.

Understanding what determines string tension.

In order to determine the tension at which a string will vibrate, you need three pieces of information: the Unit Weight, the Scale Length, and the Frequency of the string. You can use the charts in this brochure to get a pre-calculated tension for the D'Addario strings listed or you can use the formulas below to calculate the exact tension for any string using the scale length of your particular instrument. All of the charts illustrate string tensions for each string at a variety of pitches, in case you use alternative tunings.

UW- Unit Weight. In all the charts and formulas in the brochure, unit weight is expressed in pounds per linear inch (lb/in).

L- Scale Length. This is the vibrating length of the string. This is determined by measuring the distance from the nut to the bridge of the instrument in inches (in).

F- Frequency or pitch. This is the pitch at which you will be tuning the string expressed in cycles per second (Hertz).

On the following page are two fingerboard graphics detailing the various frequencies for the standard guitar and electric bass guitar.

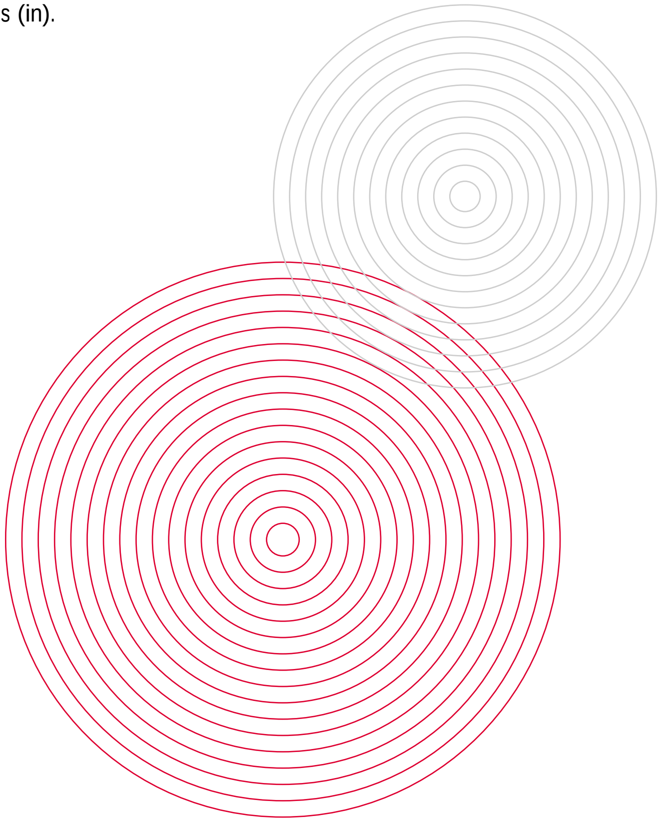
To calculate the tension of a string in pounds use the formula below, inserting the three variables described above:

T (Tension) = $(UW \times (2 \times L \times F)^2) / 386.4$

To convert the result into Newtons, simply multiply by 4.45.

If you know what tension you want the string to have, you can calculate the string unit weight. You can then use the charts in this guide to locate a string with approximately the same desired unit weight.

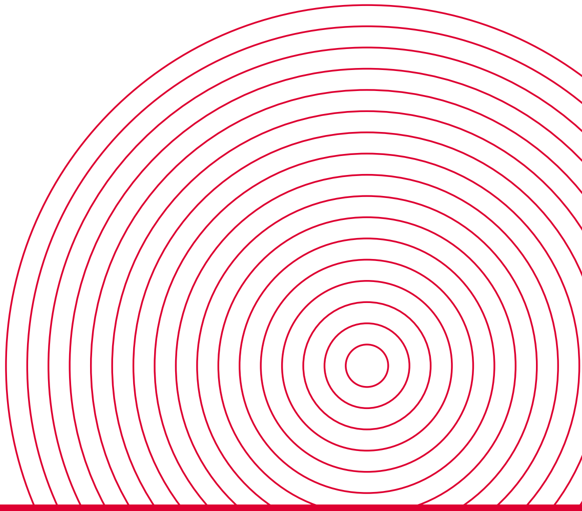
UW (unit weight) = $(T \times 386.4) / (2 \times L \times F)^2$



Scale Lengths

To calculate the exact tension for a string on your instrument, measure the scale length (nut to bridge) of your instrument and then use the formula on the previous page. The following scale lengths were used to determine the string tensions found on the tension charts in this brochure.

Acoustic/Electric/Classical Guitar = 25 1/2"
Electric Bass Guitar (Superlong Scale) = 36"
Electric Bass Guitar (Long Scale) = 34"
Electric Bass Guitar (Medium Scale) = 32"
Electric Bass Guitar (Short Scale) = 30"
Mandolin = 13 7/8"
Mandola = 15 7/8"
Mandocello = 25"
Mandobass = 42"
Banjo = 26 1/4" (19 5/8" for 5th string)



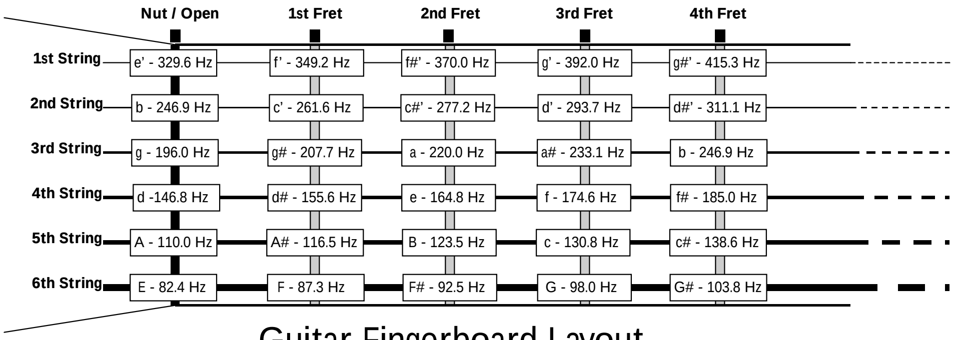
Fingerboard Legends for pitch and Frequency at standard Tuning

Guitar and Bass Guitar Fingerboard Legends

Use these graphics to determine the frequency (in Hertz) of the pitch you are looking for. Standard tunings were used for all guitar and electric bass guitar frequency measurements.

Pitch Notation

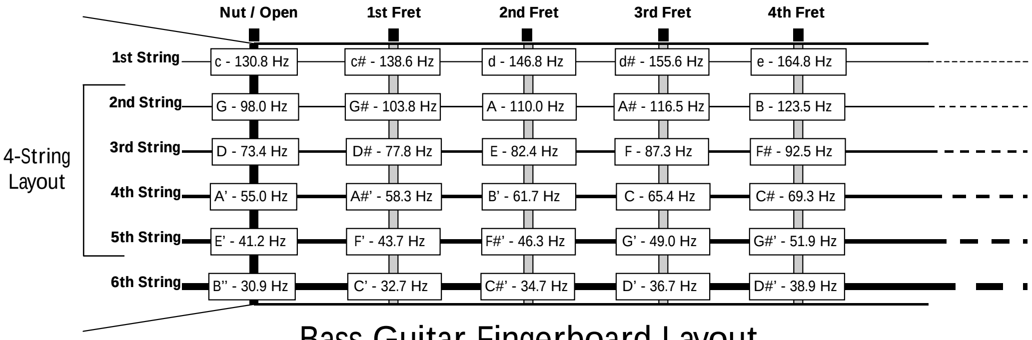
c' (Middle c) = 261.6 Hz
Note Above = d'
Note Below = b
Octave Above = c"
Octave Below = c
2 Octaves Below = C
3 Octaves Below = C'



	Nut / Open	1st Fret	2nd Fret	3rd Fret	4th Fret
1st String	e’ - 329.6 Hz	f’ - 349.2 Hz	f#’ - 370.0 Hz	g’ - 392.0 Hz	g#’ - 415.3 Hz
2nd String	b - 246.9 Hz	c’ - 261.6 Hz	c#’ - 277.2 Hz	d’ - 293.7 Hz	d#’ - 311.1 Hz
3rd String	g - 196.0 Hz	g# - 207.7 Hz	a - 220.0 Hz	a# - 233.1 Hz	b - 246.9 Hz
4th String	d -146.8 Hz	d# - 155.6 Hz	e - 164.8 Hz	f - 174.6 Hz	f# - 185.0 Hz
5th String	A - 110.0 Hz	A# - 116.5 Hz	B - 123.5 Hz	c - 130.8 Hz	c# - 138.6 Hz
6th String	E - 82.4 Hz	F - 87.3 Hz	F# - 92.5 Hz	G - 98.0 Hz	G# - 103.8 Hz

Guitar Fingerboard Layout

(Standard Tuning)



	Nut / Open	1st Fret	2nd Fret	3rd Fret	4th Fret
1st String	c - 130.8 Hz	c# - 138.6 Hz	d - 146.8 Hz	d# - 155.6 Hz	e - 164.8 Hz
2nd String	G - 98.0 Hz	G# - 103.8 Hz	A - 110.0 Hz	A# - 116.5 Hz	B - 123.5 Hz
3rd String	D - 73.4 Hz	D# - 77.8 Hz	E - 82.4 Hz	F - 87.3 Hz	F# - 92.5 Hz
4th String	A’ - 55.0 Hz	A#’ - 58.3 Hz	B’ - 61.7 Hz	C - 65.4 Hz	C# - 69.3 Hz
5th String	E’ - 41.2 Hz	F’ - 43.7 Hz	F#’ - 46.3 Hz	G’ - 49.0 Hz	G#’ - 51.9 Hz
6th String	B’’ - 30.9 Hz	C’ - 32.7 Hz	C#’ - 34.7 Hz	D’ - 36.7 Hz	D#’ - 38.9 Hz

Bass Guitar Fingerboard Layout

(Standard 6-String Tuning)

Acoustic or Electric Guitar

Plain Steel - Lock Twist

Item#	Unit Weight	g'	f'	e'	d'	c'	b	a	g
PL007	.00001085	11.2	8.9	7.9	6.3	5.0	4.5	3.5	2.8
PL008	.00001418	14.7	11.6	10.4	8.2	6.5	5.8	4.6	3.7
PL0085	.00001601	16.6	13.1	11.7	9.3	7.4	6.6	5.2	4.1
PL009	.00001794	18.6	14.7	13.1	10.4	8.3	7.4	5.8	4.6
PL0095	.00001999	20.7	16.4	14.6	11.6	9.2	8.2	6.5	5.2
PL010	.00002215	22.9	18.2	16.2	12.9	10.2	9.1	7.2	5.7
PL0105	.00002442	25.3	20.0	17.9	14.2	11.3	10.0	8.0	6.3
PL011	.00002680	27.7	22.0	19.6	15.6	12.3	11.0	8.7	6.9
PL0115	.00002930	30.3	24.0	21.4	17.0	13.5	12.0	9.5	7.6
PL012	.00003190	33.0	26.2	23.3	18.5	14.7	13.1	10.4	8.2
PL013	.00003744	38.7	30.7	27.4	21.7	17.2	15.4	12.2	9.7
Item#	Unit Weight	d'	c'	b	a	g	f	e	d
PL0135	.00004037	23.4	18.6	16.6	13.2	10.4	8.3	7.4	5.9
PL014	.00004342	25.2	20.0	17.8	14.1	11.2	8.9	7.9	6.3
PL015	.00004984	28.9	23.0	20.5	16.2	12.9	10.2	9.1	7.2
PL016	.00005671	32.9	26.1	23.3	18.5	14.7	11.6	10.4	8.2
PL017	.00006402	37.2	29.5	26.3	20.9	16.6	13.1	11.7	9.3
Item#	Unit Weight	b	a	g	f	e	d	c	B
PL018	.00007177	29.5	23.4	18.6	14.7	13.1	10.4	8.3	7.4
PL019	.00007997	32.8	26.1	20.7	16.4	14.6	11.6	9.2	8.2
PL020	.00008861	36.4	28.9	22.9	18.2	16.2	12.9	10.2	9.1
Item#	Unit Weight	a	g	f	e	d	c	B	A
PL022	.00010722	34.9	27.7	22.0	19.6	15.6	12.3	11.0	8.7
PL024	.00012760	41.6	33.0	26.2	23.3	18.5	14.7	13.1	10.4
PL026	.00014975	48.8	38.7	30.7	27.4	21.7	17.2	15.4	12.2

Plain Steel - Soldered Twist

Item#	Unit Weight	g'	f'	e'	d'	c'	b	a	g
KPL009	.00001794	18.6	14.7	13.1	10.4	8.3	7.4	5.8	4.6
KPL010	.00002215	22.9	18.2	16.2	12.9	10.2	9.1	7.2	5.7
KPL011	.00002680	27.7	22.0	19.6	15.6	12.3	11.0	8.7	6.9
KPL012	.00003190	33.0	26.2	23.3	18.5	14.7	13.1	10.4	8.2
KPL013	.00003744	38.7	30.7	27.4	21.7	17.2	15.4	12.2	9.7
Item#	Unit Weight	d'	c'	b	a	g	f	e	d
KPL014	.00004342	25.2	20.0	17.8	14.1	11.2	8.9	7.9	6.3
KPL016	.00005671	32.9	26.1	23.3	18.5	14.7	11.6	10.4	8.2
KPL017	.00006402	37.2	29.5	26.3	20.9	16.6	13.1	11.7	9.3
KPL020	.00008861	51.5	40.8	36.4	28.9	22.9	18.2	16.2	12.9

Plain Steel - Double Ball End

Item#	Unit Weight	g'	f'	e'	d'	c'	b	a	g
SPL009	.00001794	18.6	14.7	13.1	10.4	8.3	7.4	5.8	4.6
SPL010	.00002215	22.9	18.2	16.2	12.9	10.2	9.1	7.2	5.7
SPL011	.00002680	27.7	22.0	19.6	15.6	12.3	11.0	8.7	6.9
SPL013	.00003744	38.7	30.7	27.4	21.7	17.2	15.4	12.2	9.7
Item#	Unit Weight	d'	c'	b	a	g	f	e	d
SPL016	.00005671	32.9	26.1	23.3	18.5	14.7	11.6	10.4	8.2
SPL017	.00006402	37.2	29.5	26.3	20.9	16.6	13.1	11.7	9.3

XL - Nickelplated Steel Round Wound

Item#	Unit Weight	b	a	g	f	e	d	c	B
NW017	.00005524	-	18.0	14.3	11.3	10.1	8.0	6.4	5.7
NW018	.00006215	25.5	20.2	16.1	12.8	11.4	9.0	7.2	6.4
NW019	.00006947	28.5	22.6	18.0	14.3	12.7	10.1	8.0	7.1
NW020	.00007495	-	24.4	19.4	15.4	13.7	10.9	8.6	7.7
NW021	.00008293	34.0	27.0	21.4	17.0	15.2	12.0	9.6	8.5
NW022	.00009184	37.7	29.9	23.7	18.8	16.8	13.3	10.6	9.4
NW024	.00010857	44.6	35.4	28.1	22.3	19.8	15.8	12.5	11.1
NW026	.00012671	-	41.3	32.8	26.0	23.2	18.4	14.6	13.0
Item#	Unit Weight	f	e	d	c	B	A	G	F
NW028	.00014666	30.1	26.8	21.3	16.9	15.1	11.9	9.5	7.5
NW030	.00017236	35.4	31.5	25.0	19.9	17.7	14.0	11.1	8.8
NW032	.00019347	39.7	35.4	28.1	22.3	19.9	15.8	12.5	9.9
NW034	.00021590	44.3	39.5	31.3	24.9	22.2	17.6	14.0	11.1
NW036	.00023964	49.2	43.8	34.8	27.6	24.6	19.5	15.5	12.3
NW038	.00026471	54.3	48.4	38.4	30.5	27.2	21.6	17.1	13.6
Item#	Unit Weight	c	B	A	G	F	E	D	C
NW039	.00027932	32.2	28.7	22.8	18.1	14.3	12.8	10.1	8.0
NW042	.00032279	37.2	33.1	26.3	20.9	16.6	14.8	11.7	9.3
NW044	.00035182	40.5	36.1	28.7	22.7	18.0	16.1	12.8	10.1
NW046	.00038216	44.0	39.2	31.1	24.7	19.6	17.5	13.9	11.0
NW048	.00041382	47.7	42.5	33.7	26.8	21.2	18.9	15.0	11.9
NW049	.00043014	49.5	44.2	35.0	27.8	22.1	19.7	15.6	12.4
NW052	.00048109	55.4	49.4	39.2	31.1	24.7	22.0	17.4	13.9
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
NW054	.00053838	43.9	34.8	27.6	24.6	19.5	15.5	13.8	11.0
NW056	.00057598	46.9	37.2	29.5	26.3	20.9	16.6	14.8	11.7
NW059	.00064191	52.3	41.5	32.9	29.3	23.3	18.5	16.4	13.1
NW060	.00066542	54.2	43.0	34.1	30.4	24.1	19.2	17.1	13.5
NW062	.00070697	57.6	45.7	36.3	32.3	25.6	20.4	18.1	14.4
NW064	.00074984	61.1	48.5	38.5	34.3	27.2	21.6	19.2	15.3
NW066	.00079889	65.1	51.6	41.0	36.5	29.0	23.0	20.5	16.3
NW068	.00084614	68.9	54.7	43.4	38.7	30.7	24.4	21.7	17.2
NW070	.00089304	72.7	57.7	45.8	40.8	32.4	25.7	22.9	18.2
NW072	.00094124	76.7	60.8	48.3	43.0	34.1	27.1	24.1	19.2
NW074	.00098869	80.5	63.9	50.7	45.2	35.9	28.5	25.3	20.1
NW080	.00115011	93.7	74.4	59.0	52.6	41.7	33.1	29.5	23.4

XL - Nickelplated Steel Round Wound Steinberger

Item#	Unit Weight	b	a	g	f	e	d	c	B
SNW024	.00010857	44.6	35.4	28.1	22.3	19.8	15.8	12.5	11.1
SNW026	.00012671	-	41.3	32.8	26.0	23.2	18.4	14.6	13.0
Item#	Unit Weight	f	e	d	c	B	A	G	F
SNW032	.00019347	39.7	35.4	28.1	22.3	19.9	15.8	12.5	9.9
SNW036	.00023964	49.2	43.8	34.8	27.6	24.6	19.5	15.5	12.3
Item#	Unit Weight	c	B	A	G	F	E	D	C
SNW042	.00032279	37.2	33.1	26.3	20.9	16.6	14.8	11.7	9.3
SNW046	.00038216	44.0	39.2	31.1	24.7	19.6	17.5	13.9	11.0

XLS - Stainless Steel Round Wound

Item#	Unit Weight	b	a	g	f	e	d	c	B
XSG018	.00006588	27.0	21.5	17.0	13.5	12.0	9.6	7.6	6.8
XSG020	.00007919	-	25.8	20.5	16.2	14.5	11.5	9.1	8.1
XSG021	.00008774	-	28.6	22.7	18.0	16.0	12.7	10.1	9.0
XSG022	.00009731	39.9	31.7	25.2	20.0	17.8	14.1	11.2	10.0
XSG024	.00011501	-	37.5	29.7	23.6	21.0	16.7	13.2	11.8
XSG026	.00013419	-	43.7	34.7	27.5	24.5	19.5	15.5	13.8

XLS - Stainless Steel Round Wound

Item#	Unit Weight	f	e	d	c	B	A	G	F
XSG028	.00015493	31.8	28.3	22.5	17.8	15.9	12.6	10.0	7.9
XSG030	.00018203	37.4	33.3	26.4	21.0	18.7	14.8	11.8	9.3
XSG032	.00020398	41.9	37.3	29.6	23.5	20.9	16.6	13.2	10.5
XSG034	.00022729	46.6	41.6	33.0	26.2	23.3	18.5	14.7	11.7
XSG036	.00025198	51.7	46.1	36.6	29.0	25.9	20.5	16.3	12.9
XSG038	.00027804	-	50.8	40.3	32.0	28.5	22.6	18.0	14.3
Item#	Unit Weight	c	B	A	G	F	E	D	C
XSG040	.00031044	35.8	31.9	25.3	20.1	15.9	14.2	11.3	8.9
XSG042	.00033924	39.1	34.8	27.6	21.9	17.4	15.5	12.3	9.8
XSG046	.00040096	46.2	41.2	32.7	25.9	20.6	18.3	14.5	11.5
XSG048	.00043387	50.0	44.5	35.3	28.0	22.3	19.8	15.7	12.5
XSG050	.00046816	53.9	48.1	38.1	30.3	24.0	21.4	17.0	13.5
XSG052	.00050382	58.0	51.7	41.0	32.6	25.8	23.0	18.3	14.5
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
XSG054	.00056388	45.9	36.5	28.9	25.8	20.4	16.2	14.4	11.5
XSG056	.00060297	49.1	39.0	30.9	27.6	21.9	17.4	15.5	12.3
XSG070	.00092592	75.4	59.9	47.5	42.3	33.6	26.7	23.7	18.9

Half Round - Stainless Steel Half Round

Item#	Unit Weight	a	g	f	e	d	c	B	A
HRG022	.00011271	36.7	29.1	23.1	20.6	16.3	13.0	11.6	9.2
HRG024	.00012857	41.9	33.2	26.4	23.5	18.7	14.8	13.2	10.5
HRG026	.00014750	-	38.1	30.3	27.0	21.4	17.0	15.1	12.0
Item#	Unit Weight	f	e	d	c	B	A	G	F
HRG030	.00018970	38.9	34.7	27.5	21.8	19.5	15.5	12.3	9.7
HRG032	.00021100	43.3	38.6	30.6	24.3	21.7	17.2	13.6	10.8
HRG036	.00025650	52.6	46.9	37.2	29.5	26.3	20.9	16.6	13.2
Item#	Unit Weight	c	B	A	G	F	E	D	C
HRG039	.00029700	34.2	30.5	24.2	19.2	15.2	13.6	10.8	8.6
HRG042	.00033400	38.5	34.3	27.2	21.6	17.1	15.3	12.1	9.6
HRG046	.00039810	45.8	40.9	32.4	25.7	20.4	18.2	14.4	11.5
HRG052	.00049500	57.0	50.8	40.3	32.0	25.4	22.6	18.0	14.3
HRG056	.00056700	65.3	58.2	46.2	36.7	29.1	25.9	20.6	16.3

Chromes - Stainless Steel Flat Wound

Item#	Unit Weight	b	a	g	f	e	d	c	B
CG020	.00007812	32.1	25.4	20.2	16.0	14.3	11.3	9.0	8.0
CG022	.00009784	-	31.9	25.3	20.1	17.9	14.2	11.3	10.0
CG024	.00011601	-	37.8	30.0	23.8	21.2	16.8	13.4	11.9
CG026	.00013574	-	44.2	35.1	27.9	24.8	19.7	15.6	13.9
Item#	Unit Weight	g	f	e	d	c	B	A	G
CG028	.00014683	38.0	30.1	26.8	21.3	16.9	15.1	12.0	9.5
CG030	.00016958	43.9	34.8	31.0	24.6	19.5	17.4	13.8	11.0
CG032	.00019233	49.7	39.5	35.2	27.9	22.1	19.7	15.7	12.4
CG035	.00024197	62.6	49.7	44.2	35.1	27.9	24.8	19.7	15.6
Item#	Unit Weight	d	c	B	A	G	F	E	D
CG038	.00026520	38.5	30.5	27.2	21.6	17.1	13.6	12.1	9.6
CG040	.00031676	46.0	36.5	32.5	25.8	20.5	16.3	14.5	11.5
CG042	.00034377	49.9	39.6	35.3	28.0	22.2	17.6	15.7	12.5
CG045	.00040393	58.6	46.5	41.5	32.9	26.1	20.7	18.5	14.6
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
CG048	.00043541	35.5	28.1	22.3	19.9	15.8	12.5	11.2	8.9
CG050	.00047042	38.3	30.4	24.1	21.5	17.1	13.5	12.1	9.6
CG052	.00049667	40.5	32.1	25.5	22.7	18.0	14.3	12.7	10.1
CG056	.00059075	48.1	38.2	30.3	27.0	21.4	17.0	15.1	12.0
CG065	.00089364	72.8	57.8	45.8	40.8	32.4	25.7	22.9	18.2

pedal steel guitar

XLS - Stainless Steel Round Wound Pedal Steel

Item#	Unit Weight	g#	g	f#	f	e	d#	d	c#
SPS024	.00011501	30.2	26.9	24.0	21.3	19.0	17.0	15.1	13.4
SPS026	.00013419	35.2	31.4	28.0	24.9	22.2	19.8	17.6	15.7
SPS030	.00018203	47.8	42.6	37.9	33.8	30.1	26.8	23.9	21.3
Item#	Unit Weight	e	d#	d	c#	c	B	A#	A
SPS034	.00022729	37.6	33.5	29.8	26.6	23.7	21.1	18.8	16.7
SPS036	.00025198	41.7	37.1	33.1	29.5	26.2	23.4	20.8	18.6
SPS038	.00027804	46.0	41.0	36.5	32.5	29.0	25.8	23.0	20.5
Item#	Unit Weight	B	A#	A	G#	G	F#	F	E
SPS042	.00033924	31.5	28.0	25.0	22.3	19.8	17.7	15.7	14.0
SPS054	.00056388	52.4	46.6	41.5	37.0	33.0	29.4	26.2	23.3
Item#	Unit Weight	G	F#	F	E	D#	D	C#	C
SPS070	.00092592	54.1	48.2	43.0	38.3	34.1	30.4	27.1	24.1

acoustic guitar

Phosphor Bronze - Round Wound (EXP Coated and Uncoated)

Item#	Unit Weight	b	a	g	f	e	d	c	B
PB020	.00008106	-	26.4	21.0	16.6	14.8	11.8	9.3	8.3
PB021	.00008944	-	29.1	23.1	18.4	16.4	13.0	10.3	9.2
PB022	.00009876	40.5	32.2	25.5	20.3	18.1	14.3	11.4	10.1
PB023	.00010801	44.3	35.2	27.9	22.2	19.7	15.7	12.4	11.1
PB024	.00011682	-	38.1	30.2	24.0	21.4	16.9	13.5	12.0
PB025	.00012686	-	41.3	32.8	26.0	23.2	18.4	14.6	13.0
PB026	.00013640	-	44.4	35.3	28.0	24.9	19.8	15.7	14.0
PB027	.00014834	-	-	38.4	30.4	27.1	21.5	17.1	15.2
Item#	Unit Weight	f	e	d	c	B	A	G	F
PB029	.00017381	35.7	31.8	25.2	20.0	17.8	14.2	11.2	8.9
PB030	.00018660	38.3	34.1	27.1	21.5	19.2	15.2	12.1	9.6
PB032	.00021018	43.1	38.4	30.5	24.2	21.6	17.1	13.6	10.8
PB034	.00023887	-	43.7	34.7	27.5	24.5	19.5	15.4	12.3
PB035	.00025365	52.1	46.4	36.8	29.2	26.0	20.7	16.4	13.0
PB036	.00026830	55.1	49.0	38.9	30.9	27.5	21.9	17.3	13.8
Item#	Unit Weight	c	B	A	G	F	E	D	C
PB039	.00031125	35.8	32.0	25.4	20.1	16.0	14.2	11.3	9.0
PB042	.00036722	42.3	37.7	29.9	23.7	18.8	16.8	13.3	10.6
PB045	.00041751	48.1	42.9	34.0	27.0	21.4	19.1	15.1	12.0
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
PB047	.00045289	36.9	29.3	23.2	20.7	16.4	13.0	11.6	9.2
PB049	.00049151	40.0	31.8	25.2	22.5	17.8	14.2	12.6	10.0
PB052	.00055223	45.0	35.7	28.3	25.2	20.0	15.9	14.2	11.2
PB053	.00056962	46.4	36.8	29.2	26.0	20.7	16.4	14.6	11.6
PB056D	.00063477	51.7	41.0	32.6	29.0	23.0	18.3	16.3	12.9
PB059	.00070535	57.5	45.6	36.2	32.2	25.6	20.3	18.1	14.4
PB060	.00073039	59.5	47.2	37.5	33.4	26.5	21.0	18.7	14.9
PB062	.00077682	63.3	50.2	39.9	35.5	28.2	22.4	19.9	15.8
PB064	.00082780	67.4	53.5	42.5	37.8	30.0	23.8	21.2	16.9
PB066	.00087718	71.4	56.7	45.0	40.1	31.8	25.3	22.5	17.9
PB070	.00096833	78.9	62.6	49.7	44.3	35.1	27.9	24.8	19.7

Flat Tops - Phosphor Bronze Polished

Item#	Unit Weight	a	g	f	e	d	c	B	A
FT023	.00012568	40.9	32.5	25.8	23.0	18.2	14.5	12.9	10.2
FT024	.00013651	44.5	35.3	28.0	25.0	19.8	15.7	14.0	11.1
FT026	.00015894	-	41.1	32.6	29.1	23.1	18.3	16.3	12.9
FT028	.00017209	56.1	44.5	35.3	31.5	25.0	19.8	17.7	14.0
Item#	Unit Weight	f	e	d	c	B	A	G	F
FT030	.00019785	40.6	36.2	28.7	22.8	20.3	16.1	12.8	10.1
FT032	.00023852	48.9	43.6	34.6	27.5	24.5	19.4	15.4	12.2
FT035	.00027781	-	50.8	40.3	32.0	28.5	22.6	18.0	14.3
FT036	.00029273	60.1	53.5	42.5	33.7	30.1	23.8	18.9	15.0
Item#	Unit Weight	c	B	A	G	F	E	D	C
FT039	.00032904	37.9	33.8	26.8	21.3	16.9	15.0	11.9	9.5
FT042	.00036219	41.7	37.2	29.5	23.4	18.6	16.6	13.1	10.4
FT044	.00041047	47.3	42.1	33.4	26.5	21.1	18.8	14.9	11.8
FT045	.00042603	49.1	43.7	34.7	27.5	21.9	19.5	15.5	12.3
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
FT047	.00046166	37.6	29.8	23.7	21.1	16.7	13.3	11.8	9.4
FT053	.00055793	45.4	36.1	28.6	25.5	20.2	16.1	14.3	11.4
FT056	.00064108	52.2	41.4	32.9	29.3	23.2	18.5	16.4	13.1

80-20’S- 80/20 Brass Round Wound

Item#	Unit Weight	b	a	g	f	e	d	c	B
BW020	.00007862	-	25.6	20.3	16.1	14.4	11.4	9.1	8.1
BW021	.00008684	-	28.3	22.5	17.8	15.9	12.6	10.0	8.9
BW022	.00009600	39.4	31.3	24.8	19.7	17.6	13.9	11.1	9.9
BW023	.00010509	43.1	34.2	27.2	21.6	19.2	15.2	12.1	10.8
BW024	.00011353	-	37.0	29.4	23.3	20.8	16.5	13.1	11.7
BW025	.00012339	-	40.2	31.9	25.3	22.6	17.9	14.2	12.7
BW026	.00013253	-	43.2	34.3	27.2	24.2	19.2	15.3	13.6
BW027	.00014397	-	46.9	37.2	29.5	26.3	20.9	16.6	14.8
Item#	Unit Weight	f	e	d	c	B	A	G	F
BW029	.00016838	34.6	30.8	24.4	19.4	17.3	13.7	10.9	8.6
BW030	.00018092	37.1	33.1	26.2	20.8	18.6	14.7	11.7	9.3
BW032	.00020352	41.8	37.2	29.5	23.4	20.9	16.6	13.2	10.4
BW034	.00022752	46.7	41.6	33.0	26.2	23.4	18.5	14.7	11.7
BW035	.00024006	49.3	43.9	34.8	27.6	24.6	19.6	15.5	12.3
BW036	.00025417	52.2	46.5	36.9	29.3	26.1	20.7	16.4	13.0
Item#	Unit Weight	c	B	A	G	F	E	D	C
BW039	.00030063	34.6	30.9	24.5	19.4	15.4	13.7	10.9	8.7
BW042	.00034808	40.1	35.7	28.4	22.5	17.9	15.9	12.6	10.0
BW045	.00040245	46.3	41.3	32.8	26.0	20.6	18.4	14.6	11.6
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
BW047	.00043634	35.5	28.2	22.4	19.9	15.8	12.6	11.2	8.9
BW049	.00047368	38.6	30.6	24.3	21.6	17.2	13.6	12.1	9.6
BW052	.00053224	43.4	34.4	27.3	24.3	19.3	15.3	13.6	10.8
BW053	.00054852	44.7	35.5	28.1	25.1	19.9	15.8	14.1	11.2
BW056	.00061132	49.8	39.5	31.4	27.9	22.2	17.6	15.7	12.4
BW059	.00068005	55.4	44.0	34.9	31.1	24.7	19.6	17.4	13.8

Great American Bronze - 85/15 Brass Round Wound

Item#	Unit Weight	b	a	g	f	e	d	c	B
ZW022	.00009802	40.2	31.9	25.3	20.1	17.9	14.2	11.3	10.1
ZW024	.00011594	-	37.8	30.0	23.8	21.2	16.8	13.4	11.9
ZW025	.00012592	-	41.0	32.6	25.8	23.0	18.3	14.5	12.9
ZW026	.00013536	-	44.1	35.0	27.8	24.7	19.6	15.6	13.9
Item#	Unit Weight	f	e	d	c	B	A	G	F
ZW030	.00018507	38.0	33.8	26.8	21.3	19.0	15.1	12.0	9.5
ZW032	.00020839	42.8	38.1	30.2	24.0	21.4	17.0	13.5	10.7
ZW034	.00023316	47.8	42.6	33.8	26.9	23.9	19.0	15.1	12.0
ZW035	.00024610	50.5	45.0	35.7	28.3	25.3	20.0	15.9	12.6
ZW036	.00026045	53.4	47.6	37.8	30.0	26.7	21.2	16.8	13.4
Item#	Unit Weight	c	B	A	G	F	E	D	C
ZW040	.00032631	37.6	33.5	26.6	21.1	16.7	14.9	11.8	9.4
ZW042	.00035735	41.2	36.7	29.1	23.1	18.3	16.3	13.0	10.3
ZW044	.00038985	44.9	40.0	31.8	25.2	20.0	17.8	14.1	11.2
ZW045	.00040665	46.8	41.7	33.1	26.3	20.9	18.6	14.7	11.7
ZW046	.00042565	49.0	43.7	34.7	27.5	21.8	19.5	15.4	12.3
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
ZW050	.00050824	41.4	32.9	26.1	23.2	18.4	14.6	13.0	10.3
ZW052	.00054686	44.5	35.4	28.1	25.0	19.8	15.7	14.0	11.1
ZW054	.00058694	47.8	37.9	30.1	26.8	21.3	16.9	15.0	12.0
ZW056	.00062847	51.2	40.6	32.2	28.7	22.8	18.1	16.1	12.8

classical guitar

Pro•Arté - Laser Select Clear Nylon (EXP Coated and Uncoated)

Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J4301	.00002024	16.6	14.8	11.8	9.3	8.3	6.6	5.2	4.2
J4302	.00002729	22.4	20.0	15.8	12.6	11.2	8.9	7.1	5.6
J4303	.00004525	37.1	33.1	26.3	20.8	18.6	14.7	11.7	9.3
J4401/EXP	.00002243	18.4	16.4	13.0	10.3	9.2	7.3	5.8	4.6
J4402/EXP	.00003046	25.0	22.3	17.7	14.0	12.5	9.9	7.9	6.3
J4403/EXP	.00004989	40.9	36.5	29.0	23.0	20.5	16.3	12.9	10.2
J4501/EXP	.00002092	17.2	15.3	12.1	9.6	8.6	6.8	5.4	4.3
J4502/EXP	.00002827	23.2	20.7	16.4	13.0	11.6	9.2	7.3	5.8
J4503/EXP	.00004679	38.4	34.2	27.2	21.6	19.2	15.2	12.1	9.6
J4601/EXP	.00002161	17.7	15.8	12.5	10.0	8.9	7.0	5.6	4.4
J4602/EXP	.00002924	24.0	21.4	17.0	13.5	12.0	9.5	7.6	6.0
J4603/EXP	.00004795	39.4	35.1	27.8	22.1	19.7	15.6	12.4	9.8
J4701	.00002092	17.2	15.3	12.1	9.6	8.6	6.8	5.4	4.3
J4702	.00002827	23.2	20.7	16.4	13.0	11.6	9.2	7.3	5.8
J4703	.00004679	38.4	34.2	27.2	21.6	19.2	15.2	12.1	9.6
J4801	.00002161	17.7	15.8	12.5	10.0	8.9	7.0	5.6	4.4
J4802	.00002924	24.0	21.4	17.0	13.5	12.0	9.5	7.6	6.0
J4803	.00004795	39.4	35.1	27.8	22.1	19.7	15.6	12.4	9.8
J5101	.00002161	17.7	15.8	12.5	10.0	8.9	7.0	5.6	4.4
J5102	.00002924	24.0	21.4	17.0	13.5	12.0	9.5	7.6	6.0
J5103	.00004795	39.4	35.1	27.8	22.1	19.7	15.6	12.4	9.8

Pro•Arté - Laser Select Black Nylon

J4901	.00002092	17.2	15.3	12.1	9.6	8.6	6.8	5.4	4.3
J4902	.00002827	23.2	20.7	16.4	13.0	11.6	9.2	7.3	5.8
J4903	.00004679	38.4	34.2	27.2	21.6	19.2	15.2	12.1	9.6
J5001	.00002161	17.7	15.8	12.5	10.0	8.9	7.0	5.6	4.4
J5002	.00002924	24.0	21.4	17.0	13.5	12.0	9.5	7.6	6.0
J5003	.00004795	39.4	35.1	27.8	22.1	19.7	15.6	12.4	9.8

Pro•Arté - Silverplated Wound

Item#	Unit Weight	d	c	B	A	G	F	E	D
J4304	.00010203	14.8	11.7	10.5	8.3	6.6	5.2	4.7	3.7
J4305	.00015347	-	17.7	15.8	12.5	9.9	7.9	7.0	5.6
J4306	.00028881	-	-	-	23.5	18.7	14.8	13.2	10.5
J4404	.00011237	16.3	12.9	11.5	9.2	7.3	5.8	5.1	4.1
J4405	.00019521	-	-	20.0	15.9	12.6	10.0	8.9	7.1
J4406	.00034351	-	-	-	-	-	17.6	15.7	12.5
J4504	.00010754	15.6	12.4	11.0	8.8	7.0	5.5	4.9	3.9
J4505	.00018416	-	-	18.9	15.0	11.9	9.4	8.4	6.7
J4506	.00030632	-	-	-	-	19.8	15.7	14.0	11.1
J4604	.00011237	16.3	12.9	11.5	9.2	7.3	5.8	5.1	4.1
J4605	.00019521	-	-	20.0	15.9	12.6	10.0	8.9	7.1
J4606	.00031726	-	-	-	-	20.5	16.3	14.5	11.5
J4904	.00010754	15.6	12.4	11.0	8.8	7.0	5.5	4.9	3.9
J4905	.00018416	-	-	18.9	15.0	11.9	9.4	8.4	6.7
J4906	.00030632	-	-	-	-	19.8	15.7	14.0	11.1
J5004	.00011237	16.3	12.9	11.5	9.2	7.3	5.8	5.1	4.1
J5005	.00019521	-	-	20.0	15.9	12.6	10.0	8.9	7.1
J5006	.00031726	-	-	-	-	20.5	16.3	14.5	11.5

Pro•Arté - Flat Silverplated Copper Wound

J5104	.00013029	18.9	15.0	13.4	10.6	8.4	6.7	6.0	4.7
J5105	.00020135	-	-	20.7	16.4	13.0	10.3	9.2	7.3
J5106	.00035008	-	-	-	-	-	18.0	16.0	12.7

Pro•Arté - 80/20 Brass Wound

J4704	.00010616	15.4	12.2	10.9	8.6	6.9	5.4	4.9	3.8
J4705	.00017311	-	19.9	17.8	14.1	11.2	8.9	7.9	6.3
J4706	.00029100	-	-	-	-	18.8	14.9	13.3	10.6
J4804	.00011237	16.3	12.9	11.5	9.2	7.3	5.8	5.1	4.1
J4805	.00018171	-	-	18.7	14.8	11.7	9.3	8.3	6.6
J4806	.00030632	-	-	-	-	19.8	15.7	14.0	11.1

Pro•Arté Composite - Trebles

Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J4403C	.00005298	43.5	38.7	30.8	24.4	21.7	17.3	13.7	10.9
J4503C	.00004795	39.4	35.1	27.8	22.1	19.7	15.6	12.4	9.8
J4603C	.00005066	41.6	37.0	29.4	23.3	20.8	16.5	13.1	10.4

Pro•Arté Composite - Silverplated Copper Wound

Item#	Unit Weight	d	c	B	A	G	F	E	D
J4404C	.00011581	16.8	13.3	11.9	9.4	7.5	5.9	5.3	4.2
J4405C	.00020381	-	23.5	20.9	16.6	13.2	10.5	9.3	7.4
J4406C	.00036758	-	-	-	-	23.8	18.9	16.8	13.3
J4504C	.00009858	14.3	11.4	10.1	8.0	6.4	5.1	4.5	3.6
J4505C	.00017925	-	20.6	18.4	14.6	11.6	9.2	8.2	6.5
J4506C	.00033257	-	-	-	-	21.5	17.1	15.2	12.1
J4604C	.00011030	16.0	12.7	11.3	9.0	7.1	5.7	5.0	4.0
J4605C	.00020381	-	23.5	20.9	16.6	13.2	10.5	9.3	7.4
J4606C	.00035226	-	-	-	-	22.8	18.1	16.1	12.8

Pro•Arté Composite - Silverplated Copper Wound & Lightly Polished

J4504LP	.00009582	13.9	11.0	9.8	7.8	6.2	4.9	4.4	3.5
J4505LP	.00017066	-	19.7	17.5	13.9	11.0	8.8	7.8	6.2
J4506LP	.00031288	-	-	-	-	20.2	16.1	14.3	11.3
J4604LP	.00011168	16.2	12.9	11.5	9.1	7.2	5.7	5.1	4.1
J4605LP	.00019890	-	22.9	20.4	16.2	12.9	10.2	9.1	7.2
J4606LP	.00033914	-	-	-	-	21.9	17.4	15.5	12.3

D'Addario Classic - Rectified Clear Nylon

Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J2801	.00002065	16.9	15.1	12.0	9.5	8.5	6.7	5.3	4.2
J2802	.00002900	23.8	21.2	16.8	13.4	11.9	9.4	7.5	6.0
J2803	.00004602	37.8	33.7	26.7	21.2	18.9	15.0	11.9	9.4
J2901	.00001928	15.8	14.1	11.2	8.9	7.9	6.3	5.0	4.0
J2902	.00002803	23.0	20.5	16.3	12.9	11.5	9.1	7.2	5.8
J2903	.00004486	36.8	32.8	26.0	20.7	18.4	14.6	11.6	9.2
J3001	.00002065	16.9	15.1	12.0	9.5	8.5	6.7	5.3	4.2
J3002	.00002900	23.8	21.2	16.8	13.4	11.9	9.4	7.5	6.0
J3003	.00004602	37.8	33.7	26.7	21.2	18.9	15.0	11.9	9.4
J3101	.00002284	18.7	16.7	13.3	10.5	9.4	7.4	5.9	4.7
J3102	.00003022	24.8	22.1	17.5	13.9	12.4	9.8	7.8	6.2
J3103	.00004989	40.9	36.5	29.0	23.0	20.5	16.3	12.9	10.2

D'Addario Classic - Flat Sterling Silver Wound

Item#	Unit Weight	d	c	B	A	G	F	E	D
J2804	.00011030	16.0	12.7	11.3	9.0	7.1	5.7	5.0	4.0
J2805	.00021363	-	-	-	17.4	13.8	11.0	9.8	7.7
J2806	.00031726	-	-	-	-	20.5	16.3	14.5	11.5

D'Addario Classic - Silverplated Copper Wound

J2904	.00010203	14.8	11.7	10.5	8.3	6.6	5.2	4.7	3.7
J2905	.00015347	-	17.7	15.8	12.5	9.9	7.9	7.0	5.6
J2906	.00028881	-	-	-	-	18.7	14.8	13.2	10.5
J3004	.00010616	15.4	12.2	10.9	8.6	6.9	5.4	4.9	3.8
J3005	.00018416	-	-	18.9	15.0	11.9	9.4	8.4	6.7
J3006	.00030194	-	-	-	-	19.5	15.5	13.8	11.0
J3104	.00011512	16.7	13.3	11.8	9.4	7.4	5.9	5.3	4.2
J3105	.00019153	-	-	19.7	15.6	12.4	9.8	8.8	6.9
J3106	.00031726	-	-	-	-	20.5	16.3	14.5	11.5

Rectified Clear Nylon

Item#	Unit Weight	g'	f'	e'	d'	c'	b	a	g
NYL018	.00000916	9.5	7.5	6.7	5.3	4.2	3.8	3.0	2.4
NYL019	.00001020	10.6	8.4	7.5	5.9	4.7	4.2	3.3	2.6
NYL020	.00001130	11.7	9.3	8.3	6.6	5.2	4.6	3.7	2.9
NYL021	.00001246	12.9	10.2	9.1	7.2	5.7	5.1	4.1	3.2
NYL022	.00001368	14.1	11.2	10.0	7.9	6.3	5.6	4.5	3.5
NYL024	.00001628	16.8	13.4	11.9	9.5	7.5	6.7	5.3	4.2
NYL027	.00002060	21.3	16.9	15.1	12.0	9.5	8.5	6.7	5.3
NYL028	.00002216	22.9	18.2	16.2	12.9	10.2	9.1	7.2	5.7
NYL029	.00002377	24.6	19.5	17.4	13.8	10.9	9.8	7.7	6.1
NYL030	.00002543	26.3	20.9	18.6	14.8	11.7	10.4	8.3	6.6
NYL031	.00002716	28.1	22.3	19.9	15.8	12.5	11.1	8.8	7.0
NYL032	.00002894	29.9	23.8	21.2	16.8	13.3	11.9	9.4	7.5
Item#	Unit Weight	e'	d'	c'	b	a	g	f	e
NYL033	.00003078	22.5	17.9	14.2	12.6	10.0	8.0	6.3	5.6
NYL034	.00003267	23.9	19.0	15.0	13.4	10.6	8.4	6.7	6.0
NYL038	.00004081	29.8	23.7	18.8	16.7	13.3	10.6	8.4	7.5
NYL039	.00004298	31.4	25.0	19.8	17.6	14.0	11.1	8.8	7.9
NYL040	.00004522	33.1	26.3	20.8	18.6	14.7	11.7	9.3	8.3
NYL041	.00004751	34.7	27.6	21.9	19.5	15.5	12.3	9.7	8.7

Silverplated Copper Wound on Nylon

Item#	Unit Weight	g	f	e	d	c	B	A	G
NYL019W	.00005341	-	11.0	9.8	7.7	6.2	5.5	4.4	3.5
NYL020W	.00005341	-	11.0	9.8	7.7	6.2	5.5	4.4	3.5
NYL022W	.00006498	-	-	11.9	9.4	7.5	6.7	5.3	4.2
NYL024W	.00007408	-	15.2	13.5	10.7	8.5	7.6	6.0	4.8
NYL025W	.00007023	18.2	14.4	12.8	10.2	8.1	7.2	5.7	4.5
NYL026W	.00009438	-	-	17.3	13.7	10.9	9.7	7.7	6.1
NYL028W	.00010511	-	21.6	19.2	15.2	12.1	10.8	8.6	6.8
NYL029W	.00011667	-	-	21.3	16.9	13.4	12.0	9.5	7.5
NYL030W	.00012419	-	-	22.7	18.0	14.3	12.8	10.1	8.0
NYL031W	.00012821	-	26.3	23.4	18.6	14.8	13.2	10.4	8.3
Item#	Unit Weight	d	c	B	A	G	F	E	D
NYL033W	.00017913	-	20.6	18.4	14.6	11.6	9.2	8.2	6.5
NYL034W	.00019270	-	-	19.8	15.7	12.5	9.9	8.8	7.0
NYL035W	.00020667	-	-	-	16.8	13.4	10.6	9.4	7.5
NYL036W	.00022105	-	-	-	18.0	14.3	11.3	10.1	8.0
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
NYL040W	.00028260	-	18.3	14.5	12.9	10.2	8.1	7.2	5.8
NYL041W	.00028319	23.1	18.3	14.5	12.9	10.3	8.2	7.3	5.8
NYL042W	.00030466	24.8	19.7	15.6	13.9	11.0	8.8	7.8	6.2
NYL043W	.00033302	-	-	17.1	15.2	12.1	9.6	8.5	6.8
NYL045W	.00036470	-	-	18.7	16.7	13.2	10.5	9.3	7.4
NYL048W	.00041400	-	-	21.2	18.9	15.0	11.9	10.6	8.4
NYL050W	.00045369	-	-	23.3	20.7	16.5	13.1	11.6	9.2
NYL052W	.00049500	-	-	25.4	22.6	18.0	14.3	12.7	10.1
NYL054W	.00053793	-	-	-	24.6	19.5	15.5	13.8	11.0
NYL056W	.00059624	-	-	-	-	21.6	17.2	15.3	12.1

FOLK GUITAR

Black Nylon - Ball End

Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
BEB028	.00002161	17.7	15.8	12.5	10.0	8.9	7.0	5.6	4.4
BEB032	.00002778	22.8	20.3	16.1	12.8	11.4	9.1	7.2	5.7
BEB040	.00004873	40.0	35.6	28.3	22.4	20.0	15.9	12.6	10.0

Clear Nylon - Ball End

BEC028	.00002133	17.5	15.6	12.4	9.8	8.8	7.0	5.5	4.4
BEC032	.00002754	22.6	20.1	16.0	12.7	11.3	9.0	7.1	5.7
BEC040	.00004447	36.5	32.5	25.8	20.5	18.2	14.5	11.5	9.1

80/20 Brass Wound on Nylon - Ball End

Item#	Unit Weight	e	d	c	B	A	G	F	E
BEB031W	.00011650	21.3	16.9	13.4	12.0	9.5	7.5	6.0	5.3
BEB037W	.00018785	-	-	21.6	19.3	15.3	12.1	9.6	8.6
BEB045W	.00030850	-	-	-	-	25.1	19.9	15.8	14.1

Silverplated Copper Wound on Nylon - Ball End

BES031W	.00012271	22.4	17.8	14.1	12.6	10.0	7.9	6.3	5.6
BES037W	.00020258	-	-	23.3	20.8	16.5	13.1	10.4	9.3
BES045W	.00033257	-	-	-	-	-	21.5	17.1	15.2

ELECTRIC BASS GUITAR

XL - Nickelplated Round Wound Guitar/Bass

Item#	Unit Weight	f	e	d	c	B	A	G	F
NWB024	.00009959	28.3	25.2	20.0	15.9	14.2	11.2	8.9	7.1
NWB034	.00019915	-	50.4	40.0	31.7	28.3	22.5	17.8	14.1
NWB044	.00033751	-	-	67.8	53.8	48.0	38.0	30.2	24.0
Item#	Unit Weight	E	D	C	B'	A'	G'	F'	E'
NWB056	.00053791	34.0	27.0	21.4	19.1	15.2	12.0	9.6	8.5
NWB072 & -F6	.00092253	58.4	46.3	36.8	32.7	26.0	20.6	16.4	14.6
NWB084 & -F6	.00126465	80.0	63.5	50.4	44.9	35.6	28.3	22.5	20.0

XL - Nickelplated Round Wound

Long Scale

Item#	Unit Weight	b	a	g	f	e	d	c	B
XLB018P	.00007265	53.0	42.1	33.4	26.5	23.6	18.7	14.9	13.3
XLB020P	.00009093	66.3	52.7	41.8	33.2	29.6	23.4	18.6	16.6
XLB028W	.00015433	-	-	-	-	-	39.8	31.6	28.2
Item#	Unit Weight	c	B	A	G	F	E	D	C
XLB042	.00032252	66.0	58.9	46.7	37.1	29.4	26.2	20.8	16.5
XLB052	.00051322	-	-	-	59.0	46.8	41.7	33.1	26.3
Item#	Unit Weight	d	c	B	A	G	F	E	D
XLB032	.00019000	49.0	38.9	34.7	27.5	21.8	17.3	15.4	12.2
XLB035	.00022362	57.7	45.8	40.8	32.4	25.7	20.4	18.2	14.4
XLB040	.00029322	-	-	53.5	42.5	33.7	26.7	23.8	18.9
XLB045	.00037240	-	-	68.0	53.9	42.8	34.0	30.3	24.0
XLB050	.00046463	-	-	84.8	67.3	53.4	42.4	37.8	30.0
Item#	Unit Weight	F	E	D	C	B'	A'	G'	F'
XLB055	.00054816	50.0	44.5	35.3	28.1	25.0	19.8	15.7	12.5
XLB060	.00066540	60.7	54.1	42.9	34.1	30.3	24.1	19.1	15.2
XLB065	.00079569	72.6	64.7	51.3	40.7	36.2	28.8	22.9	18.2
XLB070	.00093218	85.0	75.7	60.1	47.7	42.5	33.7	26.8	21.3
XLB075	.00104973	95.7	85.3	67.7	53.7	47.8	38.0	30.2	24.0
XLB080	.00116023	105.8	94.3	74.8	59.4	52.9	42.0	33.3	26.5
XLB085	.00133702	121.9	108.6	86.2	68.4	60.9	48.4	38.4	30.6
Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
XLB090	.00150277	54.4	43.2	34.3	30.5	24.2	19.2	17.2	13.6
XLB095	.00169349	61.3	48.7	38.7	34.4	27.3	21.7	19.4	15.3
XLB100	.00179687	65.0	51.6	41.1	36.5	29.0	23.0	20.5	16.3
XLB105	.00198395	71.8	57.0	45.3	40.3	32.0	25.4	22.7	18.0
XLB110	.00227440	82.3	65.3	52.0	46.2	36.7	29.1	26.0	20.6
XLB120	.00250280	90.6	71.9	57.2	50.8	40.3	32.0	28.6	22.7
XLB125	.00274810	99.5	79.0	62.8	55.8	44.3	35.2	31.4	24.9
XLB130	.00301941	109.3	86.8	69.0	61.3	48.7	38.6	34.5	27.3
XLB135	.00315944	114.4	90.8	72.2	64.2	50.9	40.4	36.1	28.6
XLB145	.00363204	131.5	104.4	83.0	73.8	58.5	46.5	41.5	32.9
XLB120T	.00250280	90.6	71.9	57.2	50.8	40.3	32.0	28.6	22.7
XLB125T	.00274810	99.5	79.0	62.8	55.8	44.3	35.2	31.4	24.9
XLB130T	.00301941	109.3	86.8	69.0	61.3	48.7	38.6	34.5	27.3
XLB135T	.00315944	114.4	90.8	72.2	64.2	50.9	40.4	36.1	28.6
XLB145T	.00363204	131.5	104.4	83.0	73.8	58.5	46.5	41.5	32.9

Short Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
XB045S	.00037240	52.9	42.0	33.3	26.4	23.6	18.7	14.8	13.2
XB050S	.00049956	71.0	56.3	44.7	35.5	31.6	25.1	19.9	17.7
XB065S	.00079569	-	89.7	71.2	56.5	50.3	39.9	31.7	28.2
XB070S	.00106585	-	-	95.4	75.7	67.4	53.5	42.5	37.8

XL - Nickelplated Round Wound (cont.)

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
XB080S	.00116023	46.2	41.2	32.7	26.0	20.6	18.3	14.6	11.6
XB085S	.00145122	57.8	51.5	40.9	32.5	25.8	23.0	18.2	14.5
XB100S	.00179687	71.6	63.7	50.6	40.2	32.0	28.4	22.5	17.9
XB105S	.00214990	85.7	76.3	60.6	48.1	38.3	34.0	27.0	21.4

Medium Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
XB040M	.00029322	47.4	37.6	29.9	23.7	21.1	16.7	13.3	11.8
XB045M	.00037240	60.2	47.8	37.9	30.1	26.8	21.3	16.9	15.0
XB050M	.00046463	75.1	59.6	47.3	37.5	33.4	26.5	21.1	18.8
XB060M	.00066713	-	85.6	67.9	53.9	48.0	38.1	30.2	26.9
XB065M	.00079569	-	-	81.0	64.3	57.3	45.4	36.1	32.1
XB070M	.00093218	-	-	94.9	75.3	67.1	53.2	42.3	37.6

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
XB075M	.00105407	47.8	42.5	33.8	26.8	21.3	19.0	15.0	11.9
XB080M	.00116023	52.6	46.8	37.2	29.5	23.5	20.9	16.6	13.2
XB085M	.00127548	57.8	51.5	40.9	32.5	25.8	23.0	18.2	14.5
XB095M	.00167838	76.1	67.7	53.8	42.7	34.0	30.2	24.0	19.0
XB100M	.00179687	81.5	72.5	57.6	45.7	36.4	32.3	25.7	20.4
XB105M	.00198395	90.0	80.1	63.6	50.5	40.2	35.7	28.3	22.5

Superlong Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
XB040SL	.00029322	-	47.6	37.8	30.0	26.7	21.2	16.8	15.0
XB045SL	.00037240	-	60.5	48.0	38.1	33.9	26.9	21.4	19.0
XB050SL	.00046463	-	75.4	59.9	47.5	42.3	33.6	26.7	23.7
XB060SL	.00066540	-	-	85.7	68.0	60.6	48.1	38.2	34.0
XB065SL	.00079569	-	-	-	81.4	72.5	57.5	45.7	40.6
XB070SL	.00093218	-	-	-	95.3	84.9	67.4	53.5	47.6

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
XB075SL	.00104973	60.2	53.6	42.6	33.8	26.9	23.9	19.0	15.1
XB080SL	.00116023	66.6	59.3	47.1	37.4	29.7	26.4	21.0	16.6
XB085SL	.00133702	76.7	68.3	54.3	43.1	34.3	30.4	24.2	19.2
XB090SL	.00150177	86.2	76.7	60.9	48.4	38.5	34.2	27.1	21.5
XB095SL	.00169349	97.2	86.5	68.7	54.6	43.4	38.6	30.6	24.3
XB100SL	.00179687	103.1	91.8	72.9	57.9	46.0	40.9	32.5	25.8
XB105SL	.00198395	113.8	101.3	80.5	63.9	50.8	45.2	35.9	28.5
XB110SL	.00227461	130.5	116.2	92.3	73.3	58.3	51.8	41.1	32.6

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
XB125SL	.00274810	111.5	88.5	70.4	62.6	49.7	39.4	35.2	27.9
XB130SL	.00301941	122.5	97.3	77.4	68.8	54.6	43.3	38.7	30.6
XB145SL	.00363204	147.4	117.0	93.1	82.7	65.6	52.1	46.5	36.9
XB125TSL	.00274810	111.5	88.5	70.4	62.6	49.7	39.4	35.2	27.9
XB130TSL	.00301941	122.5	97.3	77.4	68.8	54.6	43.3	38.7	30.6
XB145TSL	.00363204	147.4	117.0	93.1	82.7	65.6	52.1	46.5	36.9

XL - Nickelplated Round Wound Steinberger

Long Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
SXL045	.00037240	68.0	53.9	42.8	34.0	30.3	24.0	19.1	17.0
SXL050	.00046463	84.8	67.3	53.4	42.4	37.8	30.0	23.8	21.2
SXL065	.00079569	-	-	-	72.6	64.7	51.3	40.7	36.2
SXL070	.00093218	-	-	-	85.0	75.7	60.1	47.7	42.5

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
SXL080	.00116023	59.4	52.9	42.0	33.3	26.5	23.6	18.7	14.8
SXL085	.00133702	68.4	60.9	48.4	38.4	30.6	27.2	21.6	17.1
SXL100	.00179687	92.0	81.9	65.0	51.6	41.1	36.5	29.0	23.0
SXL105	.00198395	101.5	90.4	71.8	57.0	45.3	40.3	32.0	25.4

XL - Nickelplated Round Wound Steinberger (cont.)

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
SXL130	.00301941	109.3	86.8	69.0	61.3	48.7	38.6	34.5	27.3

Half Round - Pure Nickel Half Round

Long Scale

Item#	Unit Weight	d	c	B	A	G	F	E	D
NHR030	.00019977	51.5	40.9	36.5	28.9	23.0	18.2	16.2	12.9
NHR040	.00031672	-	64.8	57.8	45.9	36.4	28.9	25.7	20.4
NHR045	.00039328	-	80.5	71.8	56.9	45.2	35.9	32.0	25.4
NHR050	.00046898	-	96.0	85.6	67.9	53.9	42.8	38.1	30.2

Item#	Unit Weight	F	E	D	C	B'	A'	G'	F'
NHR055	.00058122	53.0	47.2	37.5	29.7	26.5	21.0	16.7	13.3
NHR060	.00070573	64.4	57.3	45.5	36.1	32.2	25.5	20.3	16.1
NHR065	.00080500	73.4	65.4	51.9	41.2	36.7	29.1	23.1	18.4
NHR070	.00096476	88.0	78.4	62.2	49.4	44.0	34.9	27.7	22.0
NHR075	.00103455	94.4	84.1	66.7	53.0	47.1	37.5	29.7	23.6
NHR080	.00118785	108.3	96.5	76.6	60.8	54.1	43.0	34.1	27.1
NHR085	.00138122	126.0	112.2	89.1	70.7	62.9	50.0	39.7	31.6

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
NHR090	.00140885	51.0	40.5	32.2	28.6	22.7	18.0	16.1	12.8
NHR095	.00166888	60.4	48.0	38.1	33.9	26.9	21.4	19.1	15.1
NHR100	.00185103	67.0	53.2	42.3	37.6	29.8	23.7	21.2	16.8
NHR105	.00205287	74.3	59.0	46.9	41.7	33.1	26.3	23.5	18.6
NHR110	.00220548	79.8	63.4	50.4	44.8	35.5	28.2	25.2	20.0
NHR130	.00301941	109.3	86.8	69.0	61.3	48.7	38.6	34.5	27.3

Short Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
NHR045S	.00039328	55.9	44.3	35.2	27.9	24.9	19.7	15.7	13.9
NHR065S	.00080500	-	90.7	72.0	57.2	50.9	40.4	32.1	28.6

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
NHR080S	.00118785	47.3	42.1	33.5	26.6	21.1	18.8	14.9	11.8
NHR100S	.00185103	73.8	65.7	52.2	41.4	32.9	29.3	23.2	18.4

Medium Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
NHR045M	.00039328	63.6	50.4	40.0	31.8	28.3	22.5	17.8	15.9
NHR065M	.00080500	-	-	82.0	65.0	57.9	46.0	36.5	32.5

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
NHR080M	.00118785	53.9	47.9	38.1	30.2	24.0	21.4	17.0	13.5
NHR100M	.00185103	83.9	74.7	59.4	47.1	37.5	33.3	26.4	21.0

Superlong Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
NHR045SL	.00039328	80.5	63.8	50.7	40.2	35.8	28.4	22.6	20.1
NHR065SL	.00080500	-	-	-	82.3	73.3	58.2	46.2	41.1

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
NHR080SL	.00118785	68.2	60.7	48.2	38.3	30.4	27.1	21.5	17.0
NHR100SL	.00185103	106.2	94.5	75.1	59.6	47.4	42.2	33.4	26.6

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
NHR130SL	.00301941	122.5	97.3	77.4	68.8	54.6	43.3	38.7	30.6

Chromes - Stainless Steel Flat Wound

Long Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
CB040	.00032716	59.7	47.4	37.6	29.8	26.6	21.1	16.7	14.9
CB045	.00039763	72.6	57.6	45.7	36.3	32.3	25.6	20.4	18.1
CB050	.00047855	87.3	69.3	55.0	43.6	38.9	30.9	24.5	21.8
CB055	.00056769	103.6	82.2	65.2	51.8	46.1	36.6	29.1	25.9
CB060	.00070108	-	101.5	80.6	63.9	57.0	45.2	35.9	31.9
CB065	.00080655	-	-	92.7	73.6	65.5	52.0	41.3	36.7
CB070	.00093374	-	-	107.3	85.2	75.9	60.2	47.8	42.5

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
CB075	.00100553	51.5	45.8	36.4	28.9	23.0	20.4	16.2	12.9
CB080	.00120719	61.8	55.0	43.7	34.7	27.6	24.5	19.5	15.4
CB085	.00138675	71.0	63.2	50.2	39.8	31.7	28.2	22.4	17.7
CB090	.00148896	76.2	67.8	53.9	42.8	34.0	30.2	24.0	19.1
CB095	.00173288	88.7	78.9	62.7	49.8	39.6	35.2	27.9	22.2
CB100	.00189041	96.8	86.1	68.4	54.3	43.2	38.4	30.5	24.2
CB105	.00204302	104.6	93.1	74.0	58.7	46.7	41.5	32.9	26.1
CB110	.00226455	115.9	103.2	82.0	65.1	51.8	46.0	36.5	29.0

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
CB132	.00314193	113.7	90.3	71.8	63.8	50.6	40.2	35.9	28.4

Superlong Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
CB040SL	.00032716	66.9	53.1	42.2	33.5	29.8	23.6	18.8	16.7
CB045SL	.00039763	81.4	64.6	51.2	40.7	36.2	28.7	22.8	20.3
CB060SL	.00070108	-	113.8	90.3	71.7	63.9	50.7	40.2	35.8
CB065SL	.00080655	-	-	103.9	82.5	73.5	58.3	46.3	41.2

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
CB075SL	.00100553	57.7	51.4	40.8	32.4	25.8	22.9	18.2	14.4
CB080SL	.00120719	69.3	61.7	49.0	38.9	30.9	27.5	21.8	17.3
CB095SL	.00173288	99.4	88.5	70.3	55.8	44.4	39.5	31.3	24.9
CB100SL	.00189041	108.5	96.6	76.7	60.9	48.4	43.1	34.2	27.1

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
CB132SL	.00314193	127.5	101.2	80.5	71.6	56.8	45.1	40.2	31.9

ProSteels - ProSteel Round Wound

Long Scale

Item#	Unit Weight	d	c	B	A	G	F	E	D
PSB032	.00020465	52.8	41.9	37.4	29.6	23.5	18.7	16.6	13.2
PSB040	.00029409	-	-	53.7	42.6	33.8	26.8	23.9	19.0
PSB045	.00036457	-	-	66.5	52.8	41.9	33.2	29.6	23.5
PSB050	.00042635	-	87.3	77.8	61.7	49.0	38.9	34.6	27.5
PSB055	.00058296	-	-	-	84.4	67.0	53.2	47.4	37.6

Item#	Unit Weight	F	E	D	C	B'	A'	G'	F'
PSB060	.00067781	61.8	55.1	43.7	34.7	30.9	24.5	19.5	15.5
PSB065	.00073365	66.9	59.6	47.3	37.6	33.4	26.6	21.1	16.8
PSB070	.00087014	79.4	70.7	56.1	44.5	39.6	31.5	25.0	19.9
PSB075	.00095857	87.4	77.9	61.8	49.1	43.7	34.7	27.5	21.9
PSB080	.00111879	102.0	90.9	72.1	57.3	51.0	40.5	32.1	25.6
PSB085	.00124034	113.1	100.8	80.0	63.5	56.5	44.9	35.6	28.3

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
PSB090	.00151382	54.8	43.5	34.6	30.8	24.4	19.4	17.3	13.7
PSB095	.00156550	56.7	45.0	35.8	31.8	25.2	20.0	17.9	14.2

ProSteels - ProSteel Round Wound (Cont.)

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
PSB100	.00169349	61.3	48.7	38.7	34.4	27.3	21.7	19.4	15.3
PSB105	.00183626	66.5	52.8	42.0	37.3	29.6	23.5	21.0	16.6
PSB110	.00218579	79.1	62.8	50.0	44.4	35.2	28.0	25.0	19.8
PSB125	.00263432	95.4	75.7	60.2	53.5	42.5	33.7	30.1	23.8
PSB130	.00277435	100.4	79.7	63.4	56.4	44.7	35.5	31.7	25.1
PSB145	.00327321	118.5	94.0	74.8	66.5	52.8	41.9	37.4	29.6

Short Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
PSB045S	.00036457	51.8	41.1	32.6	25.9	23.1	18.3	14.5	12.9
PSB065S	.00073365	-	82.7	65.6	52.1	46.4	36.8	29.2	26.0

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
PSB080S	.00111879	44.6	39.7	31.5	25.0	19.9	17.7	14.0	11.1
PSB100S	.00169349	67.5	60.1	47.7	37.9	30.1	26.8	21.3	16.9

Medium Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
PSB045M	.00036457	58.9	46.8	37.1	29.5	26.2	20.8	16.5	14.7
PSB065M	.00073365	-	-	74.7	59.3	52.8	41.9	33.3	29.6

Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
PSB080M	.00111879	50.7	45.1	35.9	28.5	22.6	20.1	16.0	12.7
PSB100M	.00169349	76.8	68.3	54.3	43.1	34.3	30.5	24.2	19.2

Superlong Scale

Item#	Unit Weight	d	c	B	A	G	F	E	D
PSB032SL	.00020465	-	47.0	41.9	33.2	26.4	20.9	18.6	14.8
PSB040SL	.00029409	-	-	-	47.7	37.9	30.1	26.8	21.3
PSB045SL	.00036457	-	-	-	59.2	47.0	37.3	33.2	26.4
PSB050SL	.00042635	-	-	87.2	69.2	54.9	43.6	38.8	30.8

Item#	Unit Weight	F	E	D	C	B'	A'	G'	F'
PSB060SL	.00067781	69.3	61.7	49.0	38.9	34.6	27.5	21.8	17.4
PSB065SL	.00073365	75.0	66.8	53.0	42.1	37.5	29.8	23.6	18.8
PSB070SL	.00087014	89.0	79.3	62.9	49.9	44.4	35.3	28.0	22.3
PSB075SL	.00095857	98.0	87.3	69.3	55.0	49.0	38.9	30.9	24.6
PSB080SL	.00111879	-	101.9	80.9	64.2	57.1	45.4	36.0	28.7
PSB085SL	.00124034	126.8	113.0	89.7	71.2	63.3	50.3	40.0	31.8

Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
PSB090SL	.00151382	61.4	48.8	38.8	34.5	27.4	21.7	19.4	15.4
PSB095SL	.00156550	63.5	50.4	40.1	35.7	28.3	22.5	20.1	15.9
PSB100SL	.00169349	68.7	54.6	43.4	38.6	30.6	24.3	21.7	17.2
PSB105SL	.00183626	74.5	59.1	47.0	41.8	33.2	26.3	23.5	18.6
PSB110SL	.00218579	88.7	70.4	56.0	49.8	39.5	31.4	28.0	22.2
PSB130SL	.00277435	112.6	89.4	71.1	63.2	50.1	39.8	35.5	28.1

Acoustic Bass Guitar

Phosphor Bronze - Round Wound

Long Scale

Item#	Unit Weight	B	A	G	F	E	D	C	B'
PBB045	.00041330	-	59.8	47.5	37.7	33.6	26.6	21.2	18.8
PBB065	.00086394	-	-	-	78.8	70.2	55.7	44.2	39.4
Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
PBB080	.00130940	67.0	59.7	47.4	37.6	29.9	26.6	21.1	16.8
PBB100	.00197902	101.3	90.2	71.6	56.9	45.2	40.2	31.9	25.3
Item#	Unit Weight	A'	G'	F'	E'	D'	C'	B''	A''
PBB130	.00324696	117.5	93.3	74.2	66.0	52.3	41.5	37.1	29.4

Mandolin Family Strings

Mandolin

Item#	Unit Weight	f''	e''	d''	c''	b'	a'	g'	f'
J6201	.00002215	21.5	19.2	15.2	12.1	10.8	8.5	6.8	5.4
J6202	.00004342	42.2	37.6	29.8	23.7	21.1	16.8	13.3	10.6
Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J6203	.00011024	26.8	23.9	19.0	15.0	13.4	10.6	8.4	6.7
J6204	.00022308	54.2	48.3	38.3	30.4	27.1	21.5	17.1	13.6
Item#	Unit Weight	f''	e''	d''	c''	b'	a'	g'	f'
J6701	.00002680	26.1	23.2	18.4	14.6	13.0	10.3	8.2	6.5
J6702	.00004342	42.2	37.6	29.8	23.7	21.1	16.8	13.3	10.6
Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J6703	.00011462	27.9	24.8	19.7	15.6	13.9	11.1	8.8	7.0
J6704	.00027459	-	59.4	47.2	37.4	33.4	26.5	21.0	16.7

Mandolin Family Strings (cont.)

Item#	Unit Weight	f''	e''	d''	c''	b'	a'	g'	f'
J7401/EXP	.00002680	26.1	23.2	18.4	14.6	13.0	10.3	8.2	6.5
J7402/EXP	.00004984	48.5	43.2	34.3	27.2	24.2	19.2	15.3	12.1
Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J7403/EXP	.00013550	32.9	29.3	23.3	18.5	16.5	13.1	10.4	8.2
J7404/EXP	.00032850	-	-	56.5	44.8	39.9	31.7	25.1	20.0
Item#	Unit Weight	f''	e''	d''	c''	b'	a'	g'	f'
J7501/EXP	.00002930	28.5	25.4	20.1	16.0	14.2	11.3	9.0	7.1
J7502/EXP	.00005671	55.1	49.1	39.0	30.9	27.6	21.9	17.4	13.8
Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
J7503/EXP	.00013550	32.9	29.3	23.3	18.5	16.5	13.1	10.4	8.2
J7504/EXP	.00034500	-	-	59.3	47.1	41.9	33.3	26.4	21.0

Mandolin - Flat Tops

Item#	Unit Weight	f''	e''	d''	c''	b'	a'	g'	f'
FT7401	.00002680	26.1	23.2	18.4	14.6	13.0	10.3	8.2	6.5
FT7402	.00005313	-	-	-	-	25.8	20.5	16.3	12.9
Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
FT7403	.00015881	38.6	34.4	27.3	21.7	19.3	15.3	12.2	9.6
FT7404	.00032915	-	-	-	44.9	40.0	31.7	25.2	20.0

Mandola

Item#	Unit Weight	b'	a'	g'	f'	e'	d'	c'	b
J7601	.00004984	31.7	25.2	20.0	15.9	14.1	11.2	8.9	7.9
J7602	.00012640	-	-	-	40.2	35.8	28.4	22.6	20.1
Item#	Unit Weight	a	g	f	e	d	c	B	A
J7603	.00025365	32.0	25.4	20.2	18.0	14.3	11.3	10.1	8.0
J7604	.00055000	69.4	55.1	43.7	39.0	30.9	24.5	21.9	17.4

Mandola - Flat Tops

Item#	Unit Weight	b'	a'	g'	f'	e'	d'	c'	b
FT7601	.00005999	38.2	30.3	24.0	19.1	17.0	13.5	10.7	9.5
FT7602	.00013642	-	-	-	43.4	38.7	30.7	24.4	21.7
Item#	Unit Weight	a	g	f	e	d	c	B	A
FT7603	.00027838	35.2	27.9	22.1	19.7	15.7	12.4	11.1	8.8
FT7604	.00055787	70.4	55.9	44.4	39.5	31.4	24.9	22.2	17.6

Mandocello

Item#	Unit Weight	b	a	g	f	e	d	c	B
J7801	.00011528	-	36.1	28.7	22.7	20.3	16.1	12.8	11.4
J7802	.00028330	-	-	-	-	-	39.5	31.4	28.0
Item#	Unit Weight	A	G	F	E	D	C	B'	A'
J7803	.00056166	44.0	34.9	27.7	24.7	19.6	15.5	13.8	11.0
J7804	.00121779	95.3	75.7	60.0	53.5	42.4	33.7	30.0	23.8

Mandobass

Item#	Unit Weight	B	A	G	F	E	D	C	B'
J7901	.00046015	128.2	101.7	80.7	64.0	57.1	45.3	35.9	32.0
J7902	.00071558	-	158.1	125.5	99.6	88.7	70.4	55.9	49.7
Item#	Unit Weight	C	B'	A'	G'	F'	E'	D'	C'
J7903	.00159126	124.3	110.6	87.9	69.8	55.5	49.3	39.1	31.1
J7904	.00302935	236.6	210.6	167.3	132.8	105.6	93.9	74.5	59.2

Banjo & Loop End String Tensions

Ball End - Plain Steel

Item#	Unit Weight	g'	f'	e'	d'	c'	b	a	g
J6901B	.00001794	20.0	15.9	14.2	11.3	8.9	8.0	6.3	5.0
J6902B	.00002680	29.9	23.8	21.2	16.8	13.3	11.9	9.4	7.5

Item#	Unit Weight	b	a	g	f	e	d	c	B
J6903B	.00003744	16.6	13.2	10.5	8.3	7.4	5.9	4.7	4.2
J6904B	.00007830	-	27.6	21.9	17.4	15.5	12.3	9.7	8.7

Item#	Unit Weight	c''	b'	a'	g'	f'	e'	d'	c'
J6905B	.00001794	19.6	17.5	13.9	11.0	8.7	7.8	6.2	4.9

Loop End - Plain Steel

Item#	Unit Weight	a'	g'	f'	e'	d'	c'	b	a
LE008	.00001418	20.0	15.8	12.6	11.2	8.9	7.1	6.3	5.0
LE009	.00001794	-	20.0	15.9	14.2	11.3	8.9	8.0	6.3
LE010	.00002215	-	24.7	19.6	17.5	13.9	11.0	9.8	7.8
LE011	.00002680	-	29.9	23.8	21.2	16.8	13.3	11.9	9.4
LE012	.00003190	-	35.6	28.3	25.2	20.0	15.9	14.1	11.2

Item#	Unit Weight	f'	e'	d'	c'	b	a	g	f
LE013	.00003744	33.2	29.6	23.5	18.6	16.6	13.2	10.5	8.3
LE014	.00004342	38.5	34.3	27.2	21.6	19.2	15.3	12.1	9.6
LE015	.00004984	44.2	39.4	31.3	24.8	22.1	17.5	13.9	11.0
LE016	.00005671	50.3	44.8	35.6	28.2	25.1	20.0	15.8	12.6
LE017	.00006402	56.8	50.6	40.1	31.9	28.4	22.5	17.9	14.2
LE018	.00007177	63.6	56.7	45.0	35.7	31.8	25.3	20.0	15.9

Loop End - Nickelplated Steel Round Wound

Item#	Unit Weight	c'	b	a	g	f	e	d	c
LE018W	.00006003	-	26.6	21.1	16.8	13.3	11.9	9.4	7.5
LE020W	.00007282	-	-	25.6	20.3	16.1	14.4	11.4	9.1
LE022W	.00008879	-	39.3	31.2	24.8	19.7	17.5	13.9	11.0
LE023W	.00009739	-	43.2	34.3	27.2	21.6	19.2	15.3	12.1
LE024W	.00010857	-	-	38.2	30.3	24.1	21.4	17.0	13.5

Item#	Unit Weight	g	f	e	d	c	B	A	G
LE026W	.00012316	34.4	27.3	24.3	19.3	15.3	13.7	10.8	8.6
LE028W	.00014311	40.0	31.7	28.3	22.4	17.8	15.9	12.6	10.0
LE030W	.00016792	46.9	37.2	33.2	26.3	20.9	18.6	14.8	11.7
LE032W	.00018902	52.8	41.9	37.3	29.6	23.5	21.0	16.6	13.2
LE034W	.00021145	-	46.9	41.7	33.1	26.3	23.4	18.6	14.8
LE036W	.00023520	-	52.1	46.4	36.8	29.3	26.1	20.7	16.4
LE038W	.00026026	-	-	51.4	40.8	32.4	28.9	22.9	18.2
LE040W	.00028933	-	64.1	57.1	45.3	36.0	32.1	25.5	20.2
LE042W	.00031703	-	70.3	62.6	49.7	39.4	35.2	27.9	22.1

Item#	Unit Weight	d	c	B	A	G	F	E	D
LE044W	.00034606	54.2	43.0	38.4	30.4	24.2	19.2	17.1	13.6
LE046W	.00037640	59.0	46.8	41.7	33.1	26.3	20.9	18.6	14.7
LE048W	.00040806	63.9	50.8	45.2	35.9	28.5	22.6	20.1	16.0
LE049W	.00042438	66.5	52.8	47.1	37.3	29.6	23.5	20.9	16.6
LE052W	.00047533	-	59.1	52.7	41.8	33.2	26.3	23.5	18.6
LE054W	.00053073	83.1	66.0	58.8	46.7	37.1	29.4	26.2	20.8
LE056W	.00056832	-	70.7	63.0	50.0	39.7	31.5	28.1	22.3
LE059W	.00063211	99.0	78.6	70.1	55.6	44.1	35.0	31.2	24.8

Loop End - Phosphor Bronze Round Wound

Item#	Unit Weight	b	a	g	f	e	d	c	B
LE018PB	.00006835	-	-	19.1	15.1	13.5	10.7	8.5	7.6
LE020PB	.00007894	-	27.8	22.0	17.5	15.6	12.4	9.8	8.8
LE022PB	.00009571	-	33.7	26.7	21.2	18.9	15.0	11.9	10.6
LE023PB	.00010471	-	36.8	29.2	23.2	20.7	16.4	13.0	11.6
LE024PB	.00011352	-	39.9	31.7	25.2	22.4	17.8	14.1	12.6

Item#	Unit Weight	f	e	d	c	B	A	G	F
LE026PB	.00013285	29.4	26.2	20.8	16.5	14.7	11.7	9.3	7.4
LE028PB	.00015514	34.4	30.6	24.3	19.3	17.2	13.6	10.8	8.6
LE030PB	.00018215	40.4	36.0	28.5	22.7	20.2	16.0	12.7	10.1
LE032PB	.00020573	45.6	40.6	32.2	25.6	22.8	18.1	14.4	11.4
LE034PB	.00023532	-	46.5	36.9	29.3	26.1	20.7	16.4	13.0
LE036PB	.00026350	58.4	52.0	41.3	32.8	29.2	23.2	18.4	14.6
LE038PB	.00029110	-	-	45.6	36.2	32.3	25.6	20.3	16.1
LE040PB	.00032463	-	64.1	50.9	40.4	36.0	28.6	22.7	18.0
LE042PB	.00036248	-	-	56.8	45.1	40.2	31.9	25.3	20.1

Item#	Unit Weight	d	c	B	A	G	F	E	D
LE045PB	.00041278	64.7	51.3	45.8	36.3	28.8	22.9	20.4	16.2
LE047PB	.00044815	-	55.7	49.7	39.4	31.3	24.8	22.1	17.6
LE049PB	.00048575	-	60.4	53.9	42.7	33.9	26.9	24.0	19.0
LE052PB	.00054457	85.3	67.7	60.4	47.9	38.0	30.2	26.9	21.3
LE053PB	.00056386	-	70.1	62.5	49.6	39.4	31.2	27.8	22.1
LE056PB	.00062711	-	78.0	69.5	55.2	43.8	34.7	31.0	24.6
LE059PB	.00069554	109.0	86.5	77.1	61.2	48.6	38.5	34.3	27.2

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Musical Note Frequencies - Guitar and Piano

The table below lists all acoustic guitar note frequencies, and most piano note frequencies, in Hertz (cycles-per-second).

The Piano octave groupings have a pale blue background (key of C).
The Guitar octave groupings have a pale yellow background (key of E).
Other major key octave groupings are shown in other colors.

Guitar Notes - Musical Frequencies Table

Chromatic Scale 12 half-notes per octave			-			**Diatonic Scales (Major) (8 notes per octave)**					**Note Frequency Hz.**	1.999999901 (12 times root 2 below)
Piano Octaves	**Guitar Octaves**	**Note # Key of E**	-	**Guitar String**	-	**Key of E**	**Key of G**	**Key of A**	**Key of C**	**Key of D**	Piano Octaves	12th Root of 2
-	-	-		-		-	-	-	-	-	-	-
E2	E	1		**# 6**		do (1)	-	so (5)	-	re (2)	**82.407**	1.05946309
F2	F	2					ti (7)	la (6)	fa (4)	mi (3)	87.31	1.05946309
F#	F#	3				re (2)	-	-	-	-	92.50	1.05946309
G2	G	4				mi (3)	do (1)	ti (7)	so (5)	fa (4)	98.00	1.05946309
G#	G#	5				-	-	-	la (6)	-	103.83	1.05946309
A2	A	6		**# 5**		fa (4)	re (2)	do (1)	-	so (5)	**110.00**	1.05946309
A#	A#	7				-	mi (3)	-	ti (7)	la (6)	116.54	1.05946309
B2	B	8				so (5)	-	re (2)	-	-	123.47	1.05946309
C3	C	9				la (6)	fa (4)	mi (3)	do (1)	ti (7)	130.81	1.05946309
C#	C#	10				-	-	-	-	-	138.59	1.05946309
D3	D	11		**# 4**		ti (7)	so (5)	fa (4)	re (2)	do (1)	**146.83**	1.05946309
D#	D#	12				-	la (6)	-	mi (3)	-	155.56	1.05946309

E3	E	1				do (1)	-	so (5)		re (2)	164.81	1.05946309
F3	F	2				-	ti (7)	la (6)	fa (4)	mi (3)	174.61	1.05946309
F#	F#	3				re (2)	-	-	-	-	185.00	1.05946309
G3	G	4		**# 3**		mi (3)	do (1)	ti (7)	so (5)	fa (4)	**196.00**	1.05946309
G#	G#	5				-	-	-	la (6)	-	207.65	1.05946309
A3	A	6				fa (4)	re (2)	do (1)	-	so (5)	220.00	1.05946309
A#	A#	7				-	mi (3)	-	ti (7)	la (6)	233.08	1.05946309
B3	B	8		**# 2**		so (5)	-	re (2)	-	-	**246.94**	1.05946309
C4	C	9				la (6)	fa (4)	mi (3)	do (1)	ti (7)	**261.63**	1.05946309
C#	C#	10				-	-	-	-	-	277.18	1.05946309
D4	D	11				ti (7)	so (5)	fa (4)	re (2)	do (1)	293.67	1.05946309
D#	D#	12				-	la (6)	-	mi (3)	-	311.13	1.05946309
E4	E	1	-	**# 1**		do (1)	-	so (5)	-	re (2)	**329.63**	1.05946309
F4	F	2		1st fret	-	-	ti (7)	la (6)	fa (4)	mi (3)	349.23	1.05946309
F#	F#	3		2nd fret		re (2)	-	-	-	-	369.99	1.05946309
G4	G	4		3rd fret		mi (3)	do (1)	ti (7)	so (5)	fa (4)	392.00	1.05946309
G#	G#	5		4th fret		-	-	-	la (6)	-	415.30	1.05946309
A4	A	6		5th fret		fa (4)	re (2)	do (1)	-	so (5)	**440**	1.05946309
A#	A#	7		6th fret		-	mi (3)	-	ti (7)	la (6)	466.16	1.05946309
B4	B	8		7th fret		so (5)	-	re (2)	-	-	493.88	1.05946309
C5	C5	9		8th fret		la (6)	fa (4)	mi (3)	do (1)	ti (7)	523.25	1.05946309
C#	C#	10		9th fret		-	-	-	-	-	554.37	1.05946309
D5	D	11		10th fret		ti (7)	so (5)	fa (4)	re (2)	do (1)	587.33	1.05946309
D#	D#	12		11th fret		-	la (6)	-	mi (3)	-	622.25	1.05946309
E5	E	1		12th fret		do (1)	-	so (5)	-	re (2)	659.26	1.05946309
F5	F	2		13th fret		-	ti (7)	la (6)	fa (4)	mi (3)	698.46	1.05946309
F#	F#	3		14th fret		re (2)	-	-	-	-	739.99	1.05946309
G5	G	4		15th fret		mi (3)	do (1)	ti (7)	so (5)	fa (4)	783.99	1.05946309
G#	G#	5		16th fret		-	-	-	la (6)	-	830.61	1.05946309
A5	A	6		17th fret		fa (4)	re (2)	do (1)	-	so (5)	**880.00**	1.05946309
A#	A#	7		18th fret		-	mi (3)	-	ti (7)	la (6)	932.33	1.05946309
B5	B	8		19th fret		so (5)	-	re (2)	-	-	987.77	1.05946309
C6	C	9		20th fret		la (6)	fa (4)	mi (3)	do (1)	ti (7)	1,046.50	1.05946309
C#	C#	10		21st fret		-	-	-	-	-	1,108.73	1.05946309
D6	D	11		22nd fret		ti (7)	so (5)	fa (4)	re (2)	do (1)	1,174.66	1.05946309
D#	D#	12		23rd fret		-	la (6)	-	mi (3)	-	1,244.51	1.05946309
E6	E	1		24th fret		do (1)	-	so (5)	-	re (2)	1,318.51	1.05946309
F6	F	2		25th fret		-	ti (7)	la (6)	fa (4)	mi (3)	1,396.91	1.05946309
F#	F#	3				re (2)	-	-	-	-	1,479.98	1.05946309
						(1)= Tonic (4)= Sub-dominant			(5)= Dominant (7)= Seventh		**261.63 = Middle C**	

Each horizontal line = 1 half-note = 1 fret
Chromatic Scale = Each half-note is 5.95% higher in frequency than the previous note.
1 octave = 12 half-notes = doubling of frequency

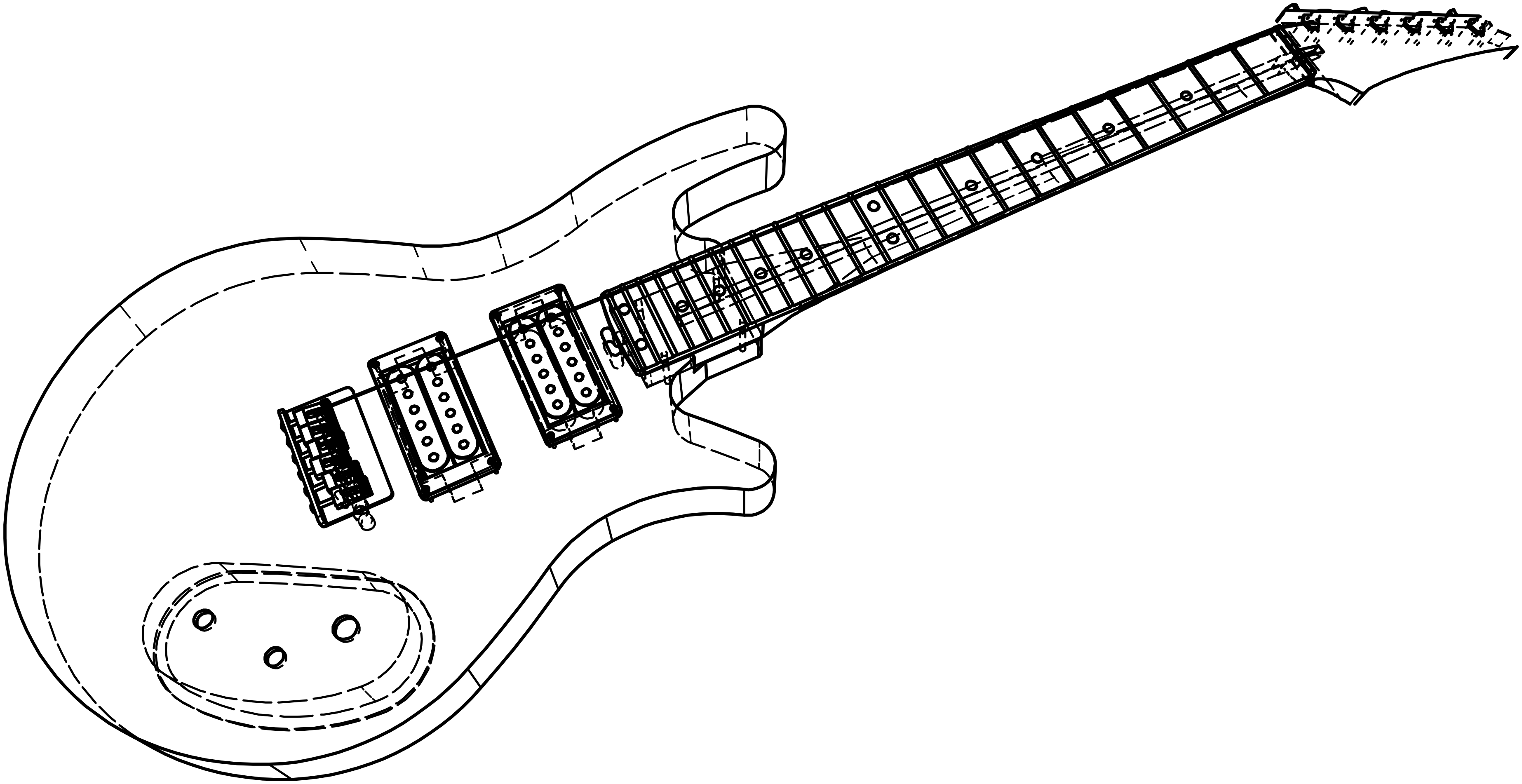
50	50	50	10	80	10	60	60	60	60	60	65	75

top of page

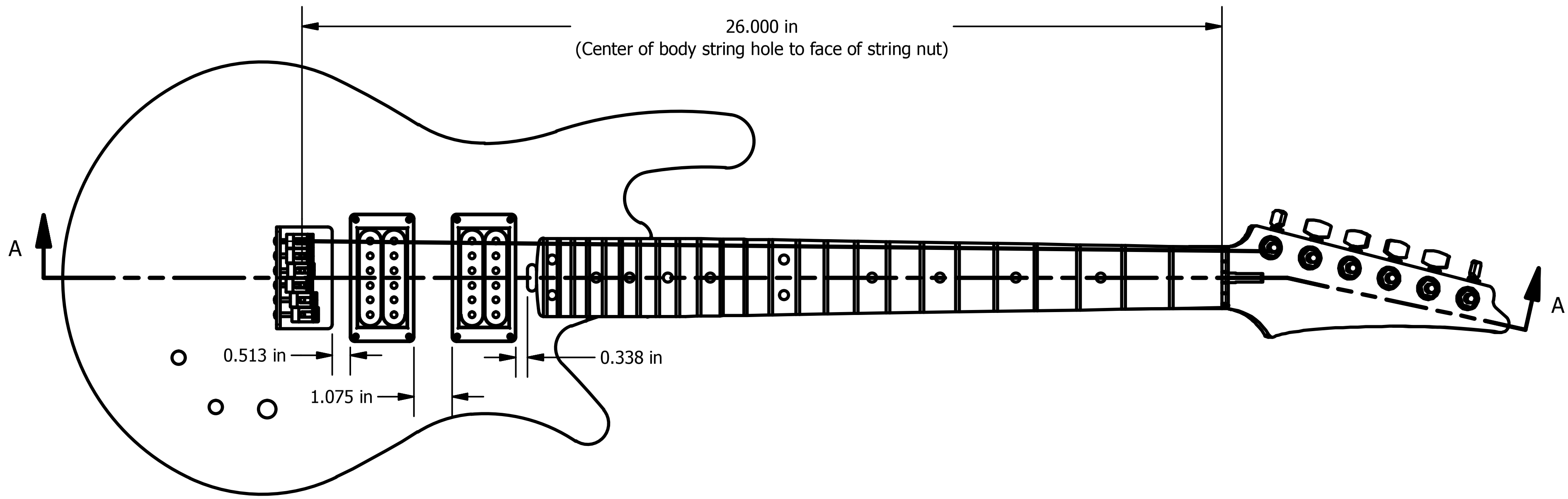
Vaughn's Summaries

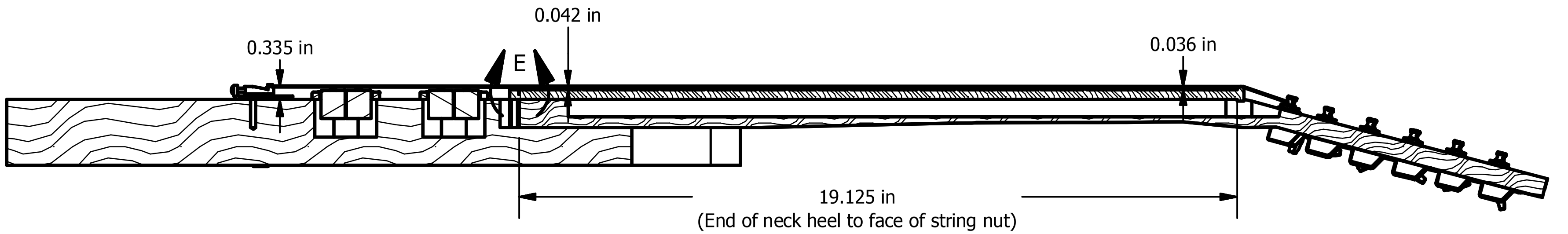
http://www.vaughns-1-pagers.com

This Vaughns 1-Pagers Music Note Frequency Chart web page was updated on 2010-04-14.

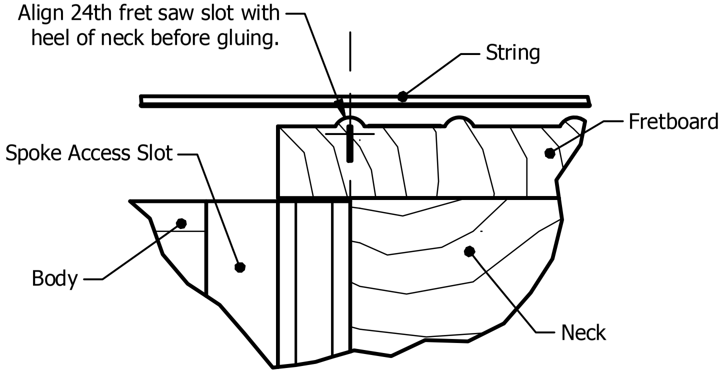


DRAWN Philip Smith	12/21/2009	NOTE: Features common to ALL 25-1/2" scale length guitars.
CHECKED		
QA		TITLE
MFG		
APPROVED		PLM/STEM GUITAR STANDARDS
		SIZE A · DWG NO PRODUCTION_STANDARDS VER 1 · REV
		SCALE · SHEET 1 OF 6



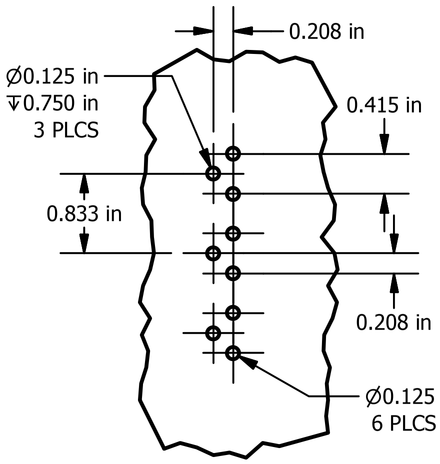


SECTION A-A

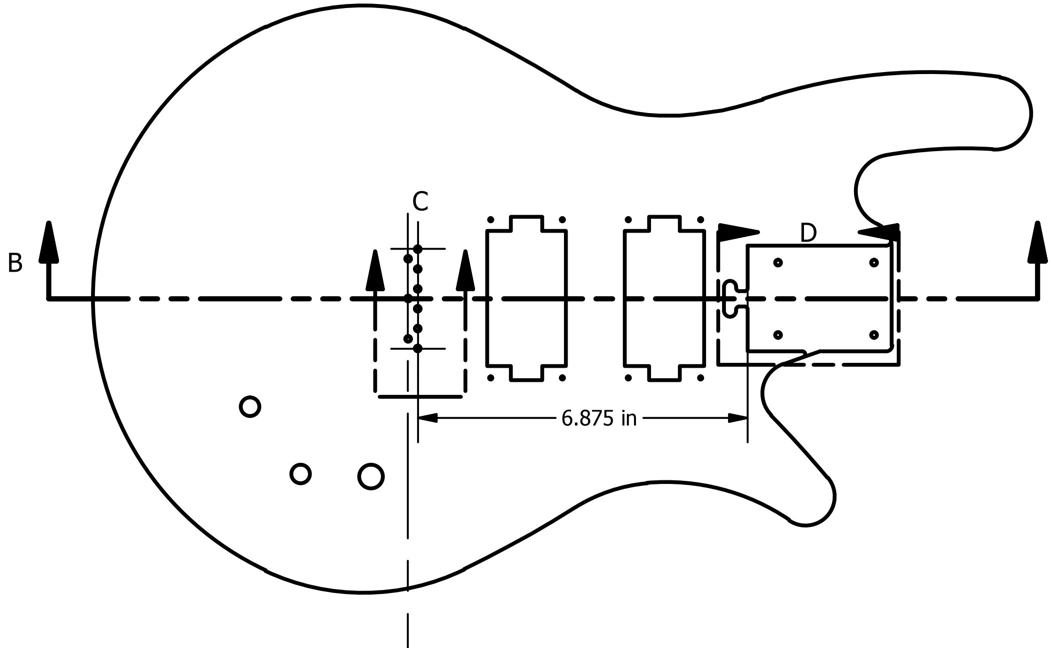


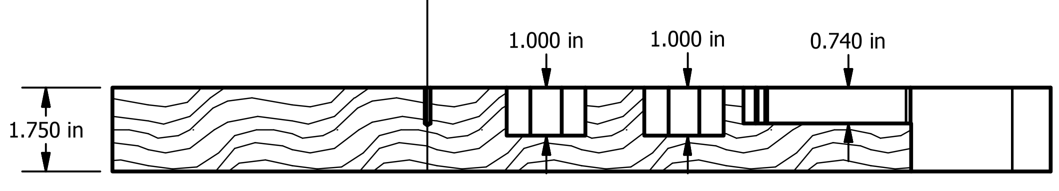
DETAIL E
FRETBOARD ASSEMBLY ALIGNMENT

DRAWN Philip Smith	12/21/2009	NOTE: Features common to ALL 25-1/2" scale length guitars.			
CHECKED					
QA		TITLE			
MFG		PLM/STEM GUITAR STANDARDS			
APPROVED					
		SIZE A		DWG NO PRODUCTION_STANDARDS VER 1	REV
		SCALE		SHEET 2 OF 6	

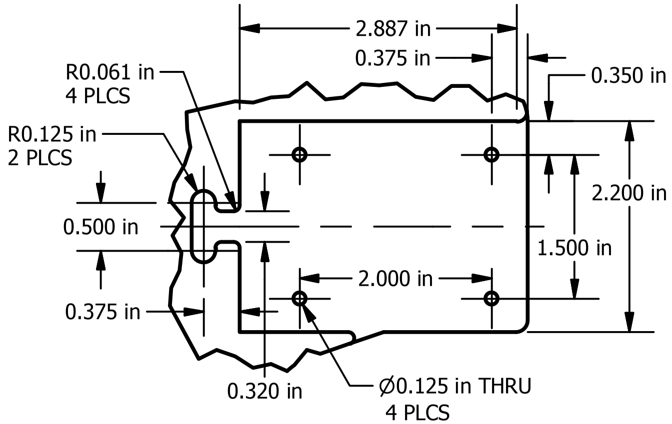


DETAIL C
BRIDGE MOUNT (TYPICAL)
SCALE 1 / 2

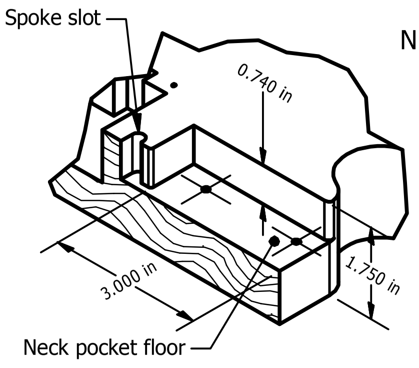




SECTION B-B
SCALE 1 / 4



DETAIL D
NECK MOUNT (TYPICAL)
SCALE 1 / 2



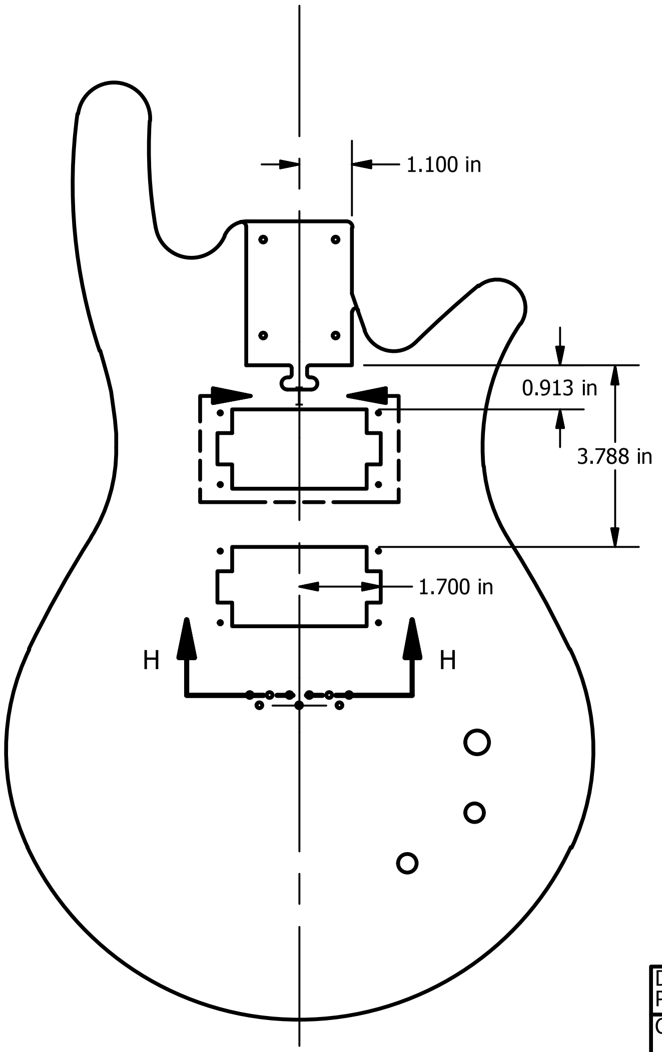
DRAWN Philip Smith	12/21/2009
CHECKED	
QA	
MFG	
APPROVED	

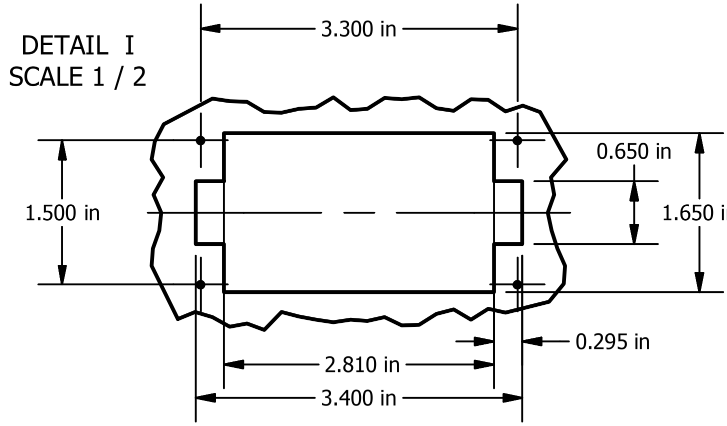
NOTE: Features common to ALL 25-1/2" scale length guitars.

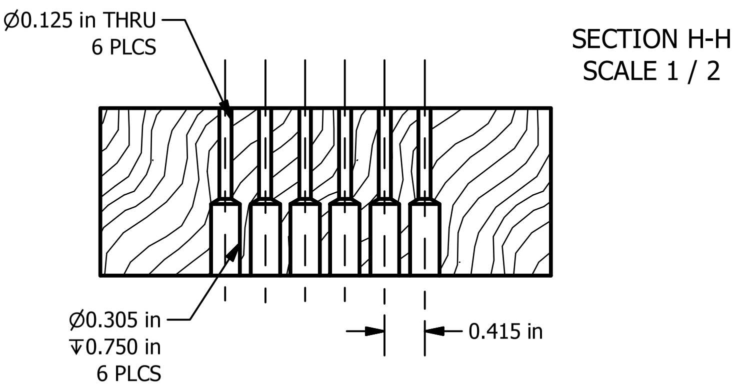
TITLE
PLM/STEM GUITAR STANDARDS

SIZE	DWG NO	REV
A	PRODUCTION_STANDARDS VER 1	

SCALE		SHEET 3 OF 6







DRAWN Philip Smith	12/21/2009
CHECKED	
QA	
MFG	
APPROVED	

NOTE: Features common to ALL 25-1/2" scale length guitars.

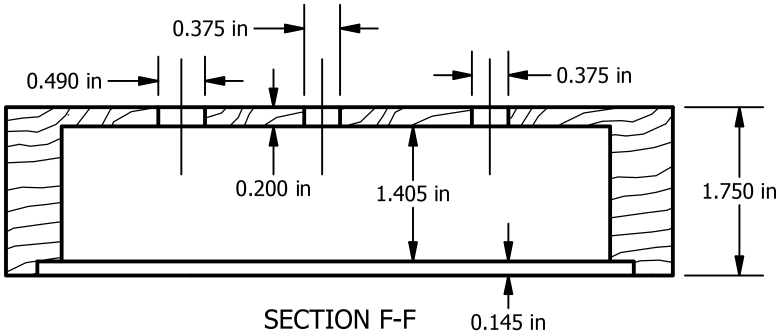
TITLE

PLM/STEM GUITAR STANDARDS

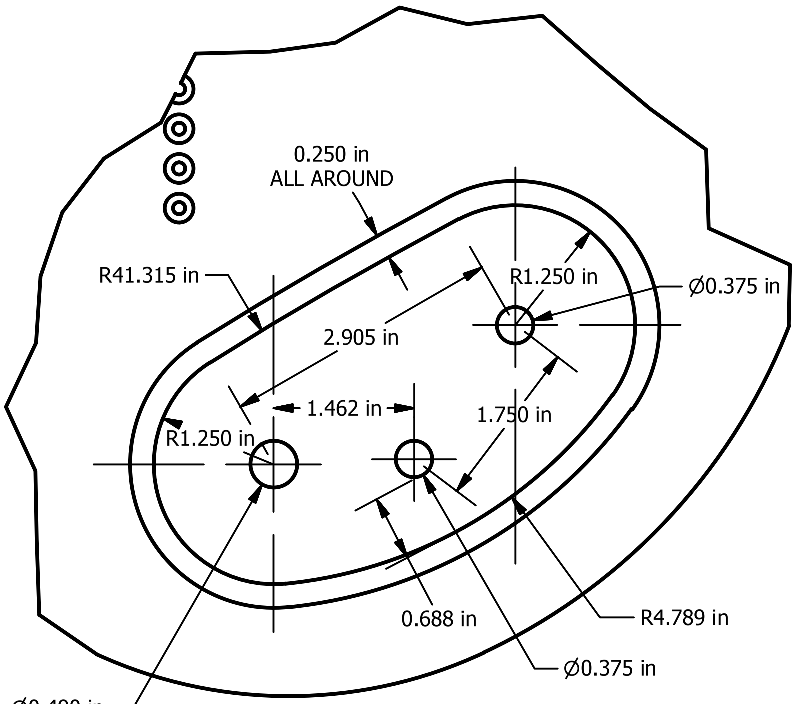
SIZE	DWG NO	REV
A	PRODUCTION_STANDARDS VER 1	

SCALE

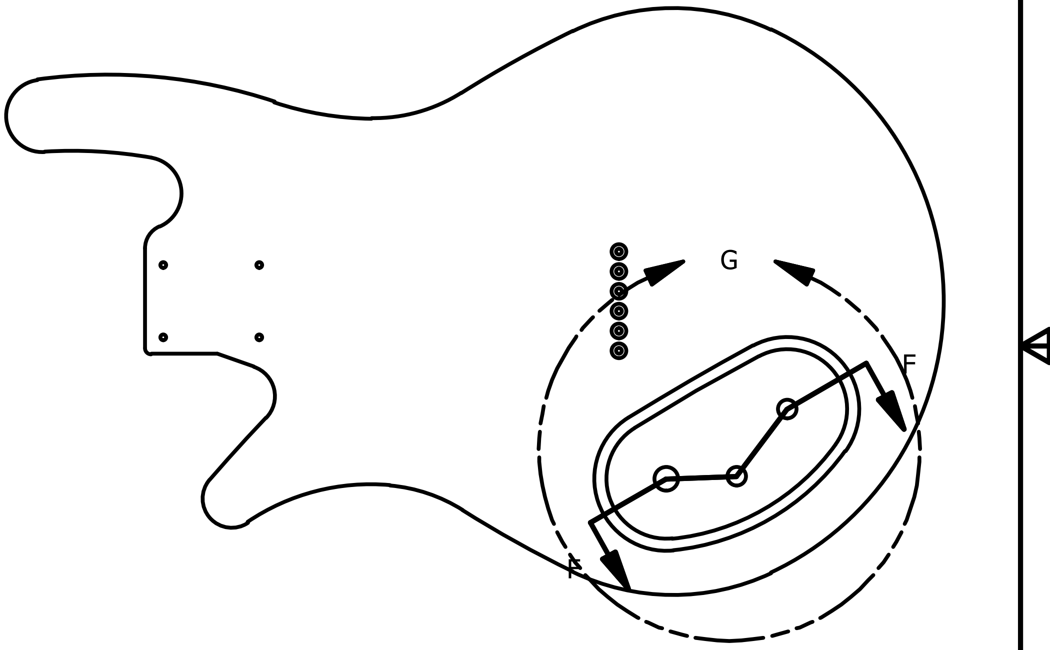
SHEET 4 OF 6



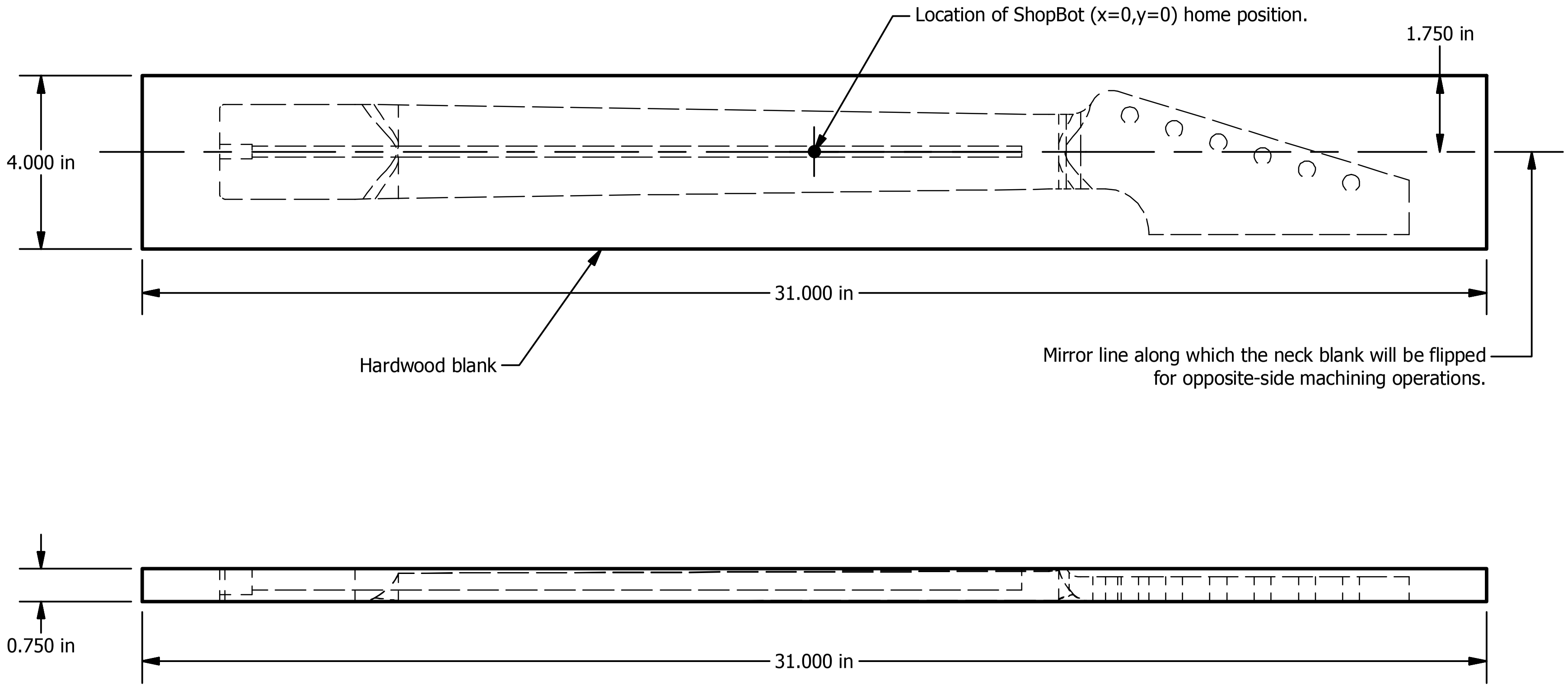
SECTION F-F
SCALE 1 / 2



DETAIL G
SCALE 1 / 2



DRAWN Philip Smith	12/21/2009	NOTE: Features common to ALL 25-1/2" scale length guitars.
CHECKED		
QA		TITLE
MFG		PLM/STEM GUITAR STANDARDS
APPROVED		
		SIZE A · DWG NO PRODUCTION_STANDARDS VER 1 · REV
		SCALE · SHEET 5 OF 6



DRAWN Philip Smith	12/21/2009
CHECKED	
QA	
MFG	
APPROVED	

NOTE: Features common to ALL 25-1/2" scale length guitars.

TITLE
PLM/STEM GUITAR STANDARDS

SIZE A
DWG NO PRODUCTION_STANDARDS VER 1
REV
SCALE
SHEET 6 OF 6

Inhalt
Projekte
Soundcard Scope
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English
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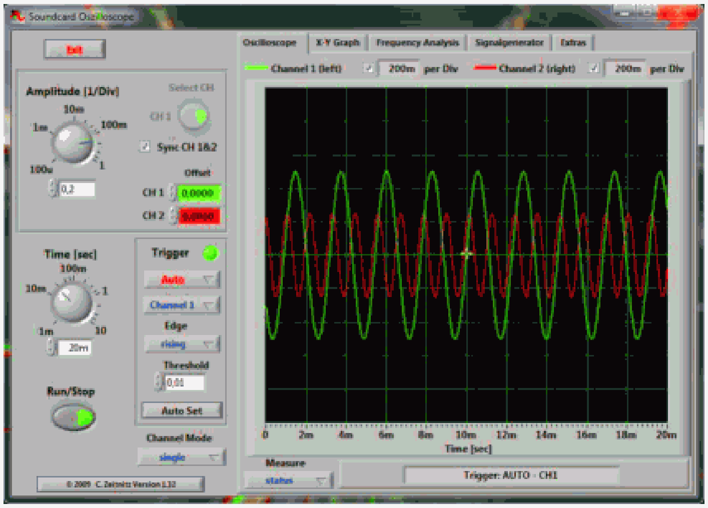
WaveIO
Know How
Intern
Kontakt

Soundcard Oscilloscope

deutsche Version



Author: Christian Zeitnitz

Main features:

The Soundcard Oscilloscope receives its data from the Soundcard with 44.1kHz and 16 Bit resolution. The data source can be selected in the Windows mixer (Microphone, Line-In or Wave). The frequency range depends on the sound card, but 20-20000Hz should be possible with all modern cards. The low frequency end is limited by the AC coupling of the line-in signal. Be aware, that most microphone inputs are only mono.

The oscilloscope contains in addition a signal generator for 2 channels for Sine, Square, Triangular and Sawtooth wave forms in the frequency range from 0 to 20kHz. These signals are available at the speaker output of the sound card. These can be fed back to the oscillocope in order to generate Lissajous figures in the x-y mode.

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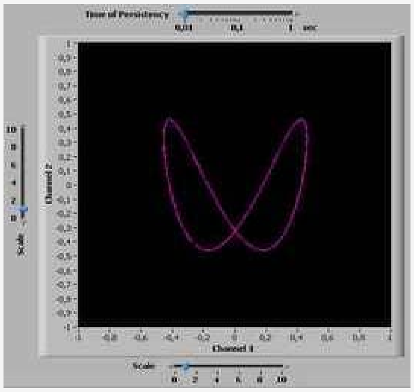
Additional features



- Trigger modes: off, automatic, normal and single shot
- Triggerlevel can be set with the mouse
- The signals of the two channels can be added, subtracted and multiplied
- x-y mode
- Frequency analysis (Fourier spectrum)
- Frequency filter: low-, high- and band-pass
- Cursors to measure amplitude, time and frequency in the main window
- Audio Recorder to save data to a wave file
- For multi soundcard system, the used card can be selected in the settings tab

The program has completely been written in LabView (™ by National Instruments). For the actual Sound I/O part the WaveIO package by the same author has been used.

Signal Sources

The signals for the oscilloscope can be internal to the computer (MP3 player, function generator etc.) or from external sources (line-in, microphone). For external sources care has to be taken, not to exceed the voltage range of the inputs. The range is usually only ±0.7V !! If higher voltage need to be analyzed, a voltage divider has to be used. Additional protection diodes are recommended in order to avoid any damage to the sound card and to the computer.

Requirements

This program will run on Windows 2000/XP/Vista computers with a sound card and 30MByte space on disk. It will not install on older versions of Windows. The speed requirements are not very hard. A 1GHz machine is suffient. On slower CPUs the load on the system might lead to reduced responsiveness of the system.

Terms of usage and licenses

This Software and all previous versions are NO Freeware!

- The use of the software and of the documentation is granted free of charge for private and non-commercial use in educational institutions
- Any commercial application requires a corresponding license (see below)
- Distribution and sale of the program is prohibited. Contact the author in order to obtain a resale license.

If you like to support the further development of this program please obtain a private license by following this link

Commercial usage: In order to obtain a commercial license follow this link

All right reserved.

Downloads

Instructions: Unpack the file into a directory of your choice and run the setup.exe program. Enjoy !

Version 1.32

- Changes
  - New cursor to measure the signal properties (when the acquisition is stopped) including an onscreen display of the corresponding time and amplitudes
  - First version which can be licensed
    - Private license to support the further development of the program
    - Commercial license for the usage in companies and non-public educational institutions
- Version 1.32 of the program (all languages): scope_132
- Only the english manual of version 1.32

Version 1.31

Please uninstall any previous version of the scope software before installing this version

- Changes
  - The different graphs (Oszilloscope, XY-Graph und frequency spectrum) can be stored as graphic files as well as a data files (CSV-file)
  - Time- und amplitude cursor can be activated simultaniously
- Version 1.31 of the program (all languages): scope_131 (ca. 25MB)
- Only the english manual for version 1.31

Version 1.30

- Changes
  - Improved stability on slower computers
  - The offset of the signal can now be set with the mouse directly on the signal screen
  - Optional automatic on-screen frequency and amplitude measurement
  - Possibility to measure the transfer function between two signals
  - French and czech Versions available
- Acknowledgement
  - Thanks to Francis Brouchier for providing the french translation
  - Thanks to Jakub Jermár and Leoš Dvorák for providing the czech version

Version 1.24

- Changes
  - Bug in re-sampling routine removed
    - Re-sampling effects only the display and not recorded wave forms
    - For long time settings the time scale was wrong!
    - This bug is present in ALL prior versions!
  - Multiple language version (english, german)
  - Persistence of the XY-Graph adjustable
  - Amplitude of frequency analysis graph scales automatically (can be disabled)
  - Program remembers the selected sound card for input and output
  - Display of sound properties/mixer from the Extras tab works now on Vista
- Acknowledgement
  - Thanks to Helio and the american teachers for spotting the mentioned bug

Due to a bug in the re-samlping of data (thanks Helio), all versions prior to 1.24 should be updated!

Version 1.23

- ***Update to Version 1.24***

Version 1.22

- Changes
  - Peak hold function in frequency analysis
  - Signal generator allows now to generate white noise and a frequency sweep
  - Cue points are no longer written to the .wav file by the sound recorder. The Media Player was confused by these extra data

Version 1.21

Version 1.20

- The Audio Recorder had some unwanted features:
  - Minimal time window on file was 50ms long
  - Trigger was sometimes not stored on the file

- Update to Version 1.21

Version 1.10

Version 1.04

Final Remarks

The program requires a correctly installed and configured soundcard on your Windows computer. In case of problems consult the manual and the frequently asked question.

If you still have a software related problem send mail to C.Zeitnitz

Guitar Manufacturing Production Notes

This document contains the manufacturing processes instituted at
Sinclair Community College
Dayton, Ohio

Prepared by: Philip D. Smith Jr.
March 26, 2010

Table of Contents

Body & Neck Blanks

Body Blanks

Materials

The body blanks used for this project are constructed from combinations of hardwoods, and designed to offer the strength required for almost 100lbs of applied string tension. To help eliminate the possibility of accidentally placing a weak piece of lumber in a position requiring full strength, there are no softwoods used in this project.

Typical hardwoods employed are poplar, Brazilian mahogany, white maple, ambrosia maple, hickory, bubinga, oak, and sassafras. (This list is non-exclusive)

Construction

Body blanks are glued together in “packs,” with the grains running primarily along the centerline of the guitar body. The overall dimensions of the pack are **22” long** by **14” wide** by **1.750” thick**. Note that the critical dimension is the thickness of the blank: the tooling is designed around this thickness.

Optimally, the center block (or “main beam”) must be at least 4” inches wide in order to support the neck, pickup pockets, and bridge. All other pieces can vary in width. It is not advised to create the main beam by laminating wood strips; the reason is that the laminates will shrink over time at different rates, thus causing stresses in the center block that could result in separation.

Tolerances

The maximum allowable variation of the body blank thickness is +/- 0.025”

The ramifications of falling outside of this tolerance will mean that the electronics cavity will be machined incorrectly. This will produce a deck thickness that is either too thin (<0.175”) or too thick (>0.225”) for the proper mounting of the potentiometers and pickup switch.

The body blank widths and lengths can vary as much as 1” without problem since they will be trimmed in the machining processes. (It is critical to be aware that some material **must be** available in order to properly secure the blanks during the machining process)

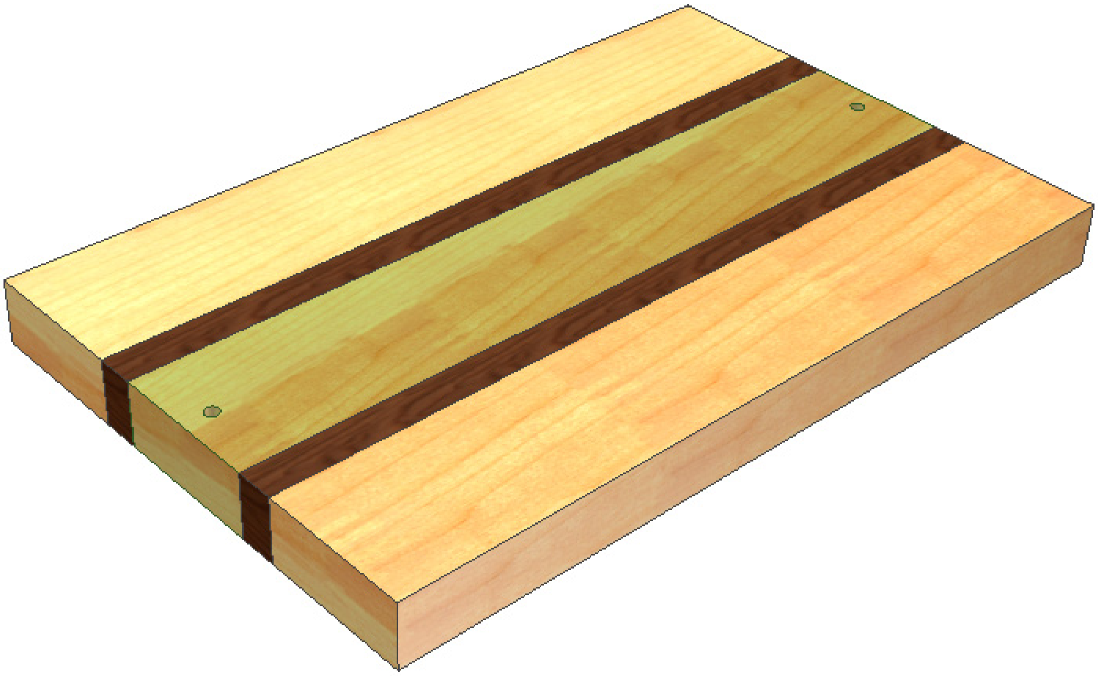
Securing for Machining

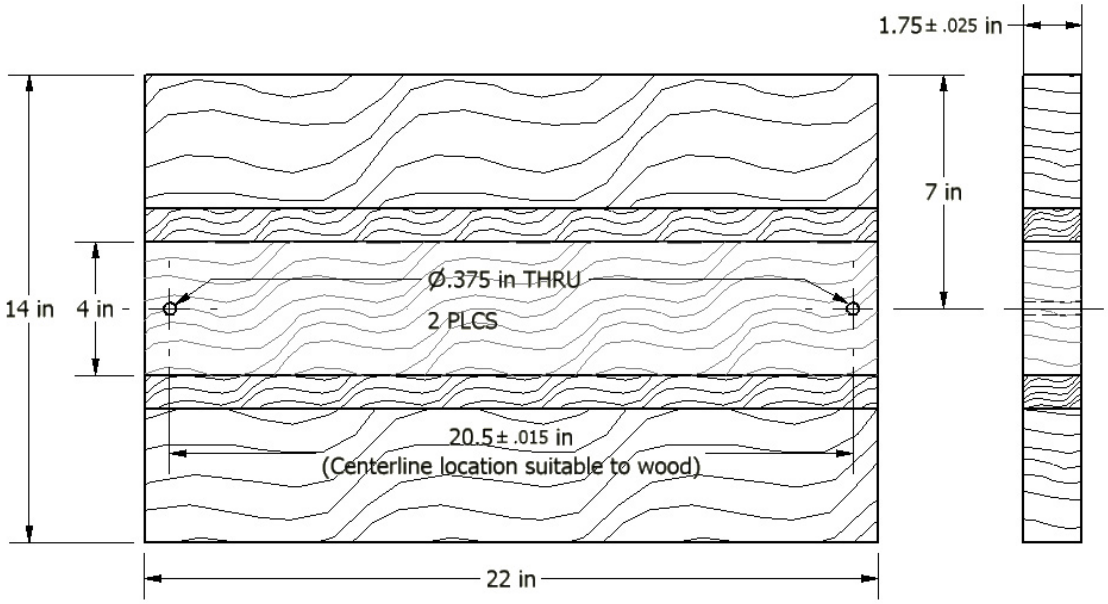
The blank can be secured in ANY fashion, but there must be at least 20”x13” (based around the center of the blank) of available material for machining. The milling cutter WILL strike holding devices within this envelope.

The optimal mounting practice is to place threaded studs along the centerline of the body blank. It has been determined that only two are required, and finish results are extremely satisfactory.

Also note that since there is full-depth drilling, do not use steel as a base plate (aluminum or other soft material is satisfactory)

Body Blank Diagrams





Body Blank Tooling Requirements

The following machine tooling is used in the processing of the bodies:

- ***1/4” diameter, straight-end mill with a length of 2-1/2” and a cutting length of 1”***
- ***Craftsmen 1/8” diameter hex-drive (Sears Item# 00964056000, Model# 64056.) with the mounting shank machined down to 0.250” diameter to allow it to be used in the Shopbot’s router or spindle head.***

The milling cutter should extend at least 1.75” beyond the bottom of the lowest point of the milling head’s chuck. This is to ensure that there is ample clearance for machining the electronics cavity.

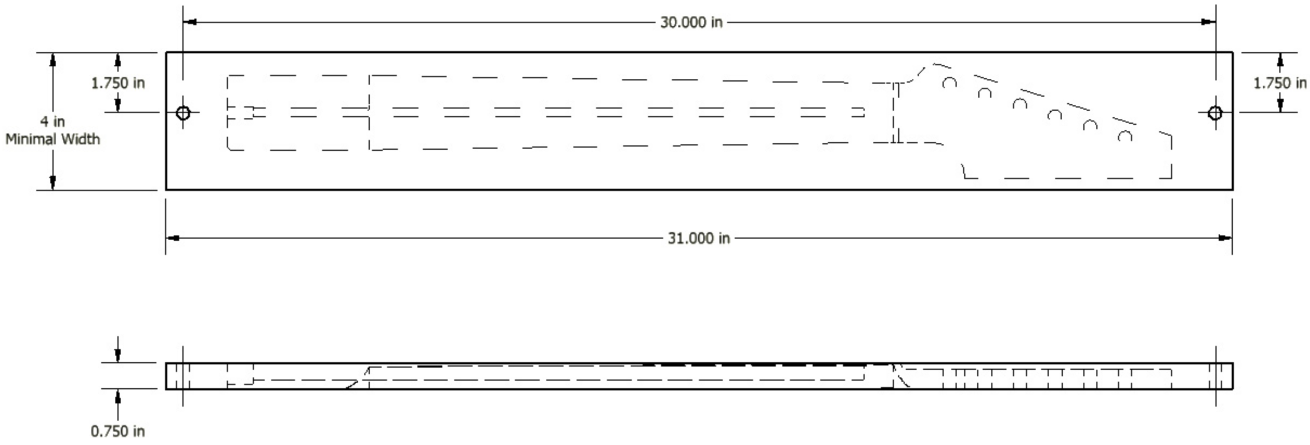
The drill bit must be able to reach 2” below the bottom of the lowest point of the milling head’s chuck. This is to allow for full-depth drilling of the string and neck mount holes.

Neck Blanks

Materials

The neck blanks are made from a single piece of white maple, **31” long** by **4” minimal width** by **0.750” thick**. Since the centerline of the neck is offset due to allowances made for the headstock, and to reduce material waste, the mirroring line falls approximately 1-3/4” from one edge of the blank.

Neck Blank Diagrams



Tolerances

The maximum allowable variation of the neck blank thickness is +/- 0.010”

The ramifications of falling outside of this tolerance will mean that the truss rod slot will machine through the back of the neck, or the headstock will be too thick for the tuners to be properly mounted.

The neck blank widths can vary over 4”; however, the blank lengths must be over 30” to allow for proper profile machining of the outer edges. As with body machining, some excess material must be available for securing during machining.

Securing for Machining

The blank can be secured in ANY fashion, but there must be at least 28”x4” (based around the center of the blank) of available material for machining. The milling cutter WILL strike holding devices within this envelope.

The optimal mounting practice is to place threaded studs along the centerline of the neck blank. It has been determined that only two are required, and finish results are extremely satisfactory.

Since there is full-depth milling, **do not use steel as a base plate!** It HIGHLY RECOMMENDED that you use a hardwood consumable beneath the blank since the milling tool path plunges beyond the thickness of the neck blank to a depth of 0.900”. Therefore, it is advisable for your consumable to be at least 1/2” thick. (We use a maple consumable that is 3/4” thick.)

Neck Blank Tooling Requirements

The following milling cutters are used in the processing of the necks:

- ***1/4” diameter, straight-end mill with a length of 2-1/2” and a cutting length of 1”***
- ***1/2” diameter, ball-nosed mill with a length of 2-1/2” and a cutting length of 1”***

The 1/4” straight-end milling cutter should extend at least 1.5” beyond the bottom of the lowest point of the milling head’s chuck. This is to ensure that there is ample clearance for machining the full-depth profile.

The 1/2” ball-nosed milling cutter must be able to reach 1” below the bottom of the lowest point of the milling head’s chuck. This is to allow for full-depth contouring of the neck back.

Important Computer Requirements

The ShopBot controller requires the full attention of the commanding computer system. Errant miscommunication between the desktop computer and the control box (black computer-like tower connected directly to the ShopBot) can lead to the ShopBot performing unexpected cuts.

In order to ensure that the ShopBot controller has the dedicated attention of your desktop computer:

- ***Disable all virus scanners***
- ***Remove the computer from the network***
- ***Disable Window's Automatic Update Service***
- ***Disable all screen savers***
- ***Disable/Remove webcams and their associated software***
- ***Uninstall all software that provides automatic updates (I.E. Adobe Acrobat, QuickTime, etc.)***
- ***Remove any unnecessary tasks from the registry tree: HKLM\Software\Microsoft\Windows\Current Version\Run AND from HKCU\Software\Microsoft\Windows\Current Version\Run***
- ***Remove all scheduled tasks (C:\Windows\Tasks)***
- ***Remove unnecessary programs from Start/Programs/Startup folder***
- ***Set power management scheme for full power (no hibernation or sleep)***
- ***Do not run any other software other than ShopBot applications during cutting operations.***

Lesson #_____

Title_____________________________

Synopsis of lesson:

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Learning Objectives:

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Materials Required:

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References:

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Build Procedure Listing

Body – No fly zone is neck attachment pocket flat surface

- ☐ Shape surfaces (personal choice)
- ☐ Scrape flat surfaces
- ☐ Route edges if desired
- ☐ Prefit parts - Pick-up (may need to use chisel to widen slot)
- ☐ Drill jack hole (7/8”)
- ☐ Drill access to pickup pockets (long bit)
- ☐ Sand surfaces
  - o Start with 150
  - o Once end grain areas are smooth move to 220/240 on body

Create custom neck plate on laser cutter

Neck – No fly zone is neck attachment surface, truss rod slot, nut slot and fret board surface

- ☐ Sand machining marks from back of neck (150 grit)
- ☐ Design headstock
- ☐ Have headstock cut out
- ☐ Neck to headstock transition sanding (careful do not sand much off) (150 grit moving to 220)
- ☐ Flatten fret board surface by sanding on a granite block
- ☐ Insert truss rod (file surfaces if needed for truss rod to lay flat)
- ☐ See Fret Board preparation

STOP!!!!

- ☐ 8. Once fret board and the neck have the alignment holes positioned then add glue to the surfaces (wipe off extra with damp cloth)
- ☐ 9. Clamp fret Board to Neck - use 5-6 clamps

Fret Board Preparation

- ☐ Flatten Fret board on granite block
- ☐ Drill 2 holes using wire drill bit at Fret 2 and Fret 17
- ☐ Tap t pins into neck for alignment purposes
- ☐ Pull t-pins to make sure you can get them out once glue is applied
- ☐ Align T-pins on fretboard and neck (always check twice)
- ☐ Resume Neck assembly!

Applying surface finish to body and neck

- ☐ Sand surfaces to 220 grit sandpaper
- ☐ Apply sanding sealer to body or neck/fretboard (personal choice on application to fretboard, I recommend it to keep the fretboard clan during finishing)
- ☐ Lightly sand the first sealer coat with 220 grit paper
- ☐ Apply sealer again and let dry
- ☐ Lightly sand with 220 grit sand paper again
- ☐ Apply surface finish and let dry
- ☐ Lightly sand using 320 grit sand paper
- ☐ Apply finish sand and let dry sand with 320 grit again
- ☐ Apply finish sand and let dry sand with 400 grit again
- ☐ Apply finish sand and let dry sand with 600 grit again
- ☐ Apply final finish coat

Electronics (complete after applying surface finish to Body)

- ☐ Pre fabricate wiring Harness - Potentiometers, capacitor and wires for jack
- ☐ Make sure soldering iron is hot (tin tip)
- ☐ When fabricating harness pre-wire harness and heat connection location, touch solder to connection and coat connection pull solder away then pull heat away (Do NOT blow on connection)
- ☐ Optional: Use metallic tape and line electronics pocket for grounding (make sure pickup and jack hole is not covered)
- ☐ Insert wiring harness into guitar and tighten nuts down, hand tight
- ☐ Attach pickups to body – use pilot holes for ring screws
- ☐ Solder in pickups to wiring harness (Cover guitar body to prevent solder dripping)
- ☐ Solder jack connection in place
- ☐ The Big test!!! Plug into the amp, take a screw driver and tap the pickups and see if they make noise. If not there is a wiring problem….. if there is , congratulations move on to the next step

Final assembly

1. Neck - fretboard
    - ☐ Sand fretboard (150 grit then finish sand with 220 and 320 paper just a few finish strokes) to 12” radius using PSA sand paper and a sanding block (Use Chalk)
    - ☐ Cut fret wire to size (2.75-3” long)
    - ☐ Press fretwire into place (Easy Hulkster not too much pressure)
    - ☐ Make sure all frets are seated
    - ☐ Nip off the ends of the fret wire with the cutters
    - ☐ Apply a drop of super glue to each fret (both sides of fret board

- ☐ Apply blue painters tape to fretboad between the frets
- ☐ Use a fret file to bevel the fret edges and make them flush to the fret board
- ☐ Apply sharpie marker to the frets
- ☐ Use 220 grit sand paper and run it over the frets sanding away the sharpie marker
- ☐ Check the frets again by using a straight edge and then applying sharpie to suspect frets
- ☐ Make sure all of the sharpie is sanded off
- ☐ Use small diamond files to dress the frets (TAKE YOUR TIME) round the edges of the frets
- ☐ Use stick sander to finish the rounding process
- ☐ Remove tape from fret board and clean with Naptha
- ☐ Apply a light coat of surface finish if desired.
- ☐ Attach Tuning machines to headstock (tap and tighten)

2. Body
    - ☐ Press in ferrules using drill press or tap in with hammer
    - ☐ Attach Bridge to body
    - ☐ Fasten neck to body using neck plate and screws
3. Nut
    - ☐ Test fit of Nut in Nut slot (file if necessary)
    - ☐ Mark edges of neck on nut
    - ☐ Use flat pencil to mark Nut slots No fly zone by laying on frets and creating arched line)!
    - ☐ Sand the nut material so it fits flush with the neck do not sand the top)
    - ☐ Measure in 1/8” from both ends of the nut and mark the nut with pencil
    - ☐ Use string layout gauge and lay out the rest of the string positions
    - ☐ Use a nut file (.016) to cut small groves in the nut
    - ☐ Use nut files to cut groves of correct sizes based on string sizes (low E .046 High E .012) Not too deep yet!
    - ☐ String guitar and place nut

BUTLER COUNTY COMMUNITY COLLEGE

Butler County Community College
107 College Drive
Butler, PA 16002
724.287.8711

Sinclair Community College

Sinclair Community College
444 West Third Street
Dayton, OH 45402
800.315.3000

Purdue University
West Lafayette, IN 47907
765.494.4600

Ventura College
4667 Telegraph Road
Ventura, CA 93003
805.654.6400

New Philadelphia High School
343 Ray Avenue NW
New Philadelphia, OH 44663
330.364.0644

COLLEGE OF THE REDWOODS

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7351 Tompkins Hill Road
Eureka, CA 95501
800.641.0400

Southern Wells High School
9120 South 300 West
Poneto, IN 46781
765.728.2496

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