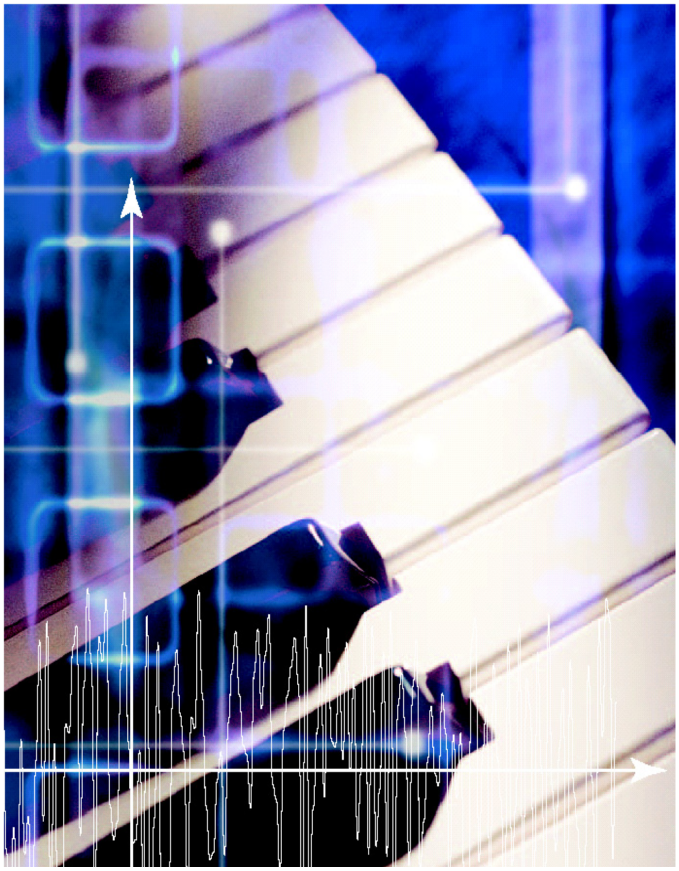


Creating Digital Music

Chapter 2 exposes students to some of the most important engineering ideas associated with the creation of digital music. Students learn how basic ideas drawn from the right triangle such as sines and cosines are fundamental to making computer music.

Infinity Labs

2.1 Plots of Speech
2.2 Generating Sine and Cosine Signals
2.3 Listening to Sines and Cosines
2.4 Measuring a Tuning Fork
2.5 Building the Sinusoidal MIDI Player
2.6 The Spectrogram
2.7 Sketch Wave with MIDI
2.8 Sketch Wave with Envelope Functions
2.9 Echo Generator
2.10 Sound Effects

Introduction

The laboratories in Chapter 2 experiment with sounds, which are audio signals. Audio signals are obviously important for speech and music, but they are also important for communications systems and many other applications. Signals from speech or music or mathematical computations can be changed or combined, and the results can be viewed as mathematical plots or listened to as sound from speakers.

The VAB blocks that work with sounds use both the DSP board and the computer. The most basic input block is a microphone block, which converts the pressure variation in the air that we hear as sound into a sequence of numbers that we can use for computations. The corresponding basic output block is the speaker block, which does the opposite conversion from a sequence of numbers into sound. Some laboratories use the microphone on the DSP board and others may use the microphone on the computer, so VAB has a block for each. There are also separate VAB blocks for the speakers connected to the computer and the speakers connected directly to the DSP board.

Sound input may also come from files stored on the computer as *.wav* files or from mathematical computation, which often uses sines and cosines. These sounds can be combined with sounds from the microphone using a variety of VAB blocks. Another commonly used output block is a plot of the sound signal as a function of time. The VAB display blocks that plot sound use the computer, so signals from the DSP board must be sent to the computer to be plotted on the worksheet. Note that in the worksheets red lines connect blocks using the DSP board and white lines connect blocks using the computer. Often in music or communications the frequency or the pitch of a sound is important, so there are VAB blocks which also display this information.

2.1 Plots of Speech

Lab Objectives

The objective of this lab is to see and explore the shape and form of your own voice, the sound of music, and other common sounds.

Textbook Reading

- This lab appears on page **44** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **33-44.**

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-01-01 Plots of Speech.Lst:** This worksheet allows you to see sound signals on your computer screen.

Worksheet Description

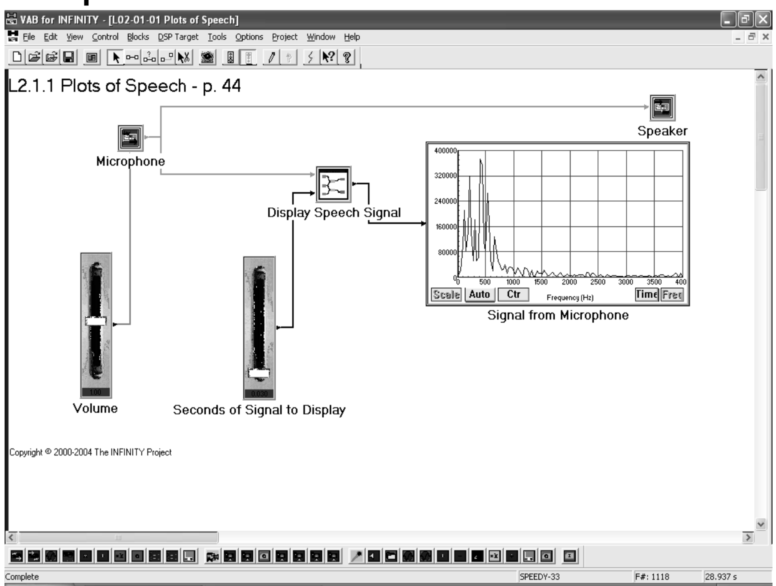


Figure 2.1 Plots of Speech

Open the worksheet *L02-01-01 Plots of Speech.Lst*. You should see something similar to Figure 2.1 above.

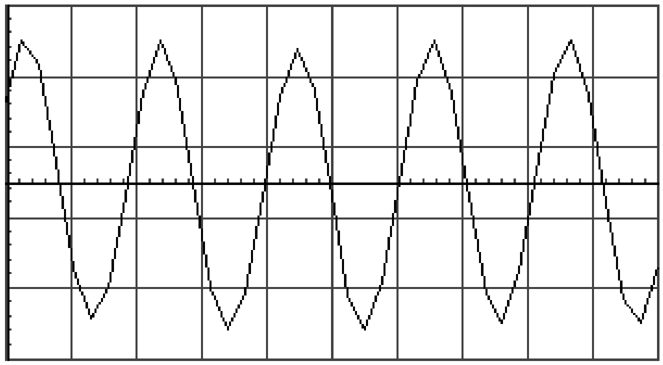
- **Microphone** – This block takes in a signal from the microphones on your DSP board.
- **Volume** – The Volume Slider block adjusts the gain of the microphone signal by multiplying it by a constant.
- **1 Channel Display with Buffer** – This block collects consecutive values from the signal it is fed so that they can be displayed on the PC in front of you.
- **Seconds of Signal to Display** – This block is a slider that controls how much of the signal you will see in the Display on your computer
- **Signal from Microphone** – This block displays the signal from the microphone.
- The blocks are connected together such that all signals flow from the left to the right.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Start the worksheet.
Step 2:	You should start seeing a signal being displayed on the Signal from Microphone display. The display has two axes; the x-axis is time, and the y-axis is the value of the signal.
	Q1: What do you notice? Is the signal moving a little or a lot?
Step 3:	Try speaking into the microphone.
	Q2: What happens?
Step 4:	The display doesn't show every part of the signal all the time; only the parts of the signal that fall within the y-axis range can be shown. Sometimes the signal is so large that it falls outside of this range. So, to get the y-axis to scale with the size of your microphone signal, click on **Auto** until it is greyed-out. Now, the y-axis should change depending on how loud the signal is. Talk loudly into the microphone.
	Q3: What happens to the scale?
Step 5:	Usually, we want a fixed y-scale, so to get a good scale for your voice, say “Ahhhhh” for a long time into the microphone while simultaneously clicking on **Scale**. Now, the y-axis limits should be fixed at a large value. When you talk into the microphone again, it should show both the loud and soft parts of your voice.

Steps	***Instructions (Continued)***
Step 6:	Another thing you can do with this worksheet is capture your voice as if it is frozen in time. To do this, halt the worksheet while you are talking into the microphone. You should see the part of your voice that the system recorded just before you stopped the worksheet. Move your mouse over the display near any part of the signal – it should give you the value of the signal and the time that it occurred. (Alternatively, click on the worksheet near the portion of the signal you want to measure.)
Step 7:	Now we are ready to do some experiments with your *Plots of Speech* worksheet. The first thing we will do is look at your voice over different time scales. The second slider on your worksheet allows you to control how much of your microphone signal is displayed. It should be set at its minimum value of 0.005 seconds. If not, move the slider to this value. Now, slowly move the slider up.
	Q4: What is happening on the display?
	Q5: What do you notice about the signal?
Step 8:	Move the slider to its top-most value. Now, talk into the microphone.
	Q6: Can you see individual words in the display?
Step 9:	Count “1, 2, 3..." in to the microphone to see the distinct words to be sure. You have total control as to how much of the microphone signal you can see. Adjust the slider until it shows a value of 1 second, and count using “one one-thousand, two one-thousand,.." and so on. Each count should roughly fit into a single display time.
Step 10:	Now, we are going to “zoom in” to your voice signal to see its fine structure. Adjust the Seconds slider to its minimum value of 0.005, say “ahhhh” as if you are having your throat examined.

Steps	***Instructions (Continued)***
	Q7: What do you see on the display?
Step 11:	Try saying "Ooooh" in a high-pitched voice.
	Q8: What is happening now?
Step 12:	You should see the signal repeat over and over. Signals that repeat over and over are called periodic signals. Musical instrument sounds are periodic signals, too.
Step 13:	To make a really clean periodic signal, whistle into the microphone.
	Q9: What do you see?

Steps	***Instructions (Continued)***
Step 14:	While whistling into the microphone, halt the worksheet to freeze the signal in the display. The signal should look something like the display below. Notice how smooth the signal is and how it repeats over and over. The time it takes for the signal to repeat is called its period.  **Figure 2.2** Signal for a whistle sound Using the mouse, calculate the period of the signal in the following way: 1. Move the mouse near a peak of the signal. 2. Write down the x-axis (time) and y-axis (amplitude) values near this point. 3. Move the mouse near the next peak of the signal in the display to the left of the value you just recorded. 4. Write down the x-axis (time) and y-axis (amplitude) values near this point. The y-axis value should be close to that you measured above. 5. Subtract the second value from the first. First Value: ____ Second Value: ____ Difference: ____ You should get a number in milliseconds.
	Q10: What is the period of your whistle?
	Another parameter of a periodic signal is its amplitude. The amplitude of the signal is the largest value away from zero that the signal has.
	Q11: What is the amplitude of your whistle?

<table>
<tr><th>Steps</th><th>Instructions (Continued)</th></tr>
<tr><td></td><td>Yet another parameter of a periodic signal is its fundamental frequency. The fundamental frequency of a periodic signal is related to its period T by

f = 1/T</td></tr>
<tr><td></td><td>Q12: What is the fundamental frequency of your whistle?</td></tr>
<tr><td>Step 15:</td><td>The fundamental frequency is what we recognize in music as the pitch of an instrument. By making signals that are periodic, we make music.

While it is somewhat of a burden to calculate the fundamental frequency of a signal using the period, it is the most accurate way to find its value. But there's another way: The Display has a button, called Freq, that calculates the spectrum of the signal that is fed to it. The spectrum displays all of the frequency components of one signal at one time. The x-axis of this display is in Hertz [Hz], and the y-axis is amplitude.

Click Freq with your frozen whistle signal. You should see something similar to Figure 2.3 below.

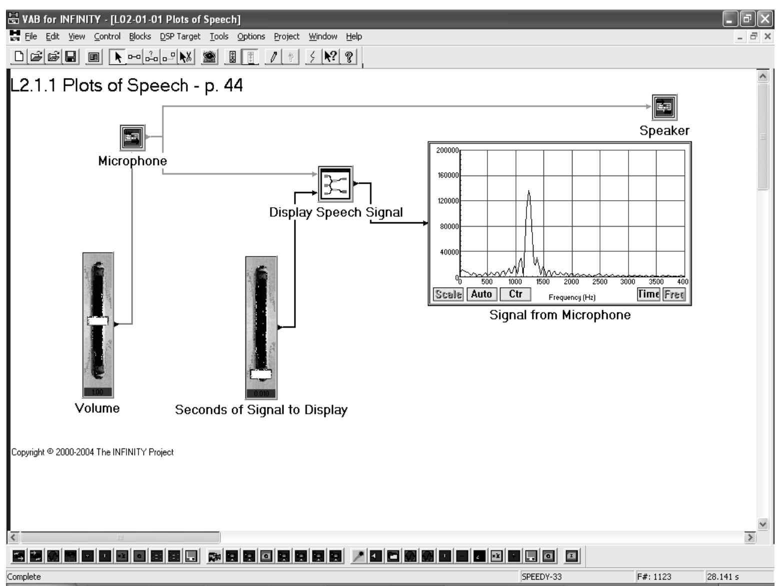


Figure 2.3 Plots of speech - Frequency

Notice how there's one large peak in the spectrum. For signals that are particularly simple such as your whistle, the peak of the signal should correspond to the fundamental frequency.

Use your mouse to find out the frequency of this peak in your display.</td></tr>
</table>

Steps	***Instructions (Continued)***
	Q13: Is it near the value that you calculated above for the fundamental frequency?
	Q14: What do you see in your plot? Does it look like Figure 2.3?
Step 16:	Now, run the worksheet again, and whistle into the microphone. Leave the display showing Frequency. See what happens as you whistle lower and then higher. If you can't whistle, say "oooh" in as steady a voice as you can manage.
	Q15: What is the highest fundamental frequency that you can whistle?
	Q16: What about the lowest?

Overview Questions

A: What is the period of the signal? How is it related to fundamental frequency?

B: What are the units of fundamental frequency?

C: What is a typical period of your voice? What about a whistle? How are these related to how high or low the fundamental frequencies are for these signals?

Summary

This lab has helped you take apart your voice and analyze its structure using the concepts of period and fundamental frequency. How can we use these ideas to make music? The labs later in this chapter help you do that.

2.2 Generating Sine and Cosine Signals

Lab Objectives

The objective of this lab is to show how sines and cosines can be used to make interesting and useful sounds. You are probably familiar with the sin(A) and cos(A) keys on a calculator. You probably also know that sines and cosines are connected to right triangles--but did you know that sin(A) and cos(A) can also be used to make the pure tones of simple music?

Textbook Reading

- This lab appears on page **65** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **44-65.**

Additional Materials

- Scientific Calculator

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-02-01 Generating Sine and Cosine Signals.Lst**: A virtual experiment in making and listening to sines and cosines.

Worksheet Description

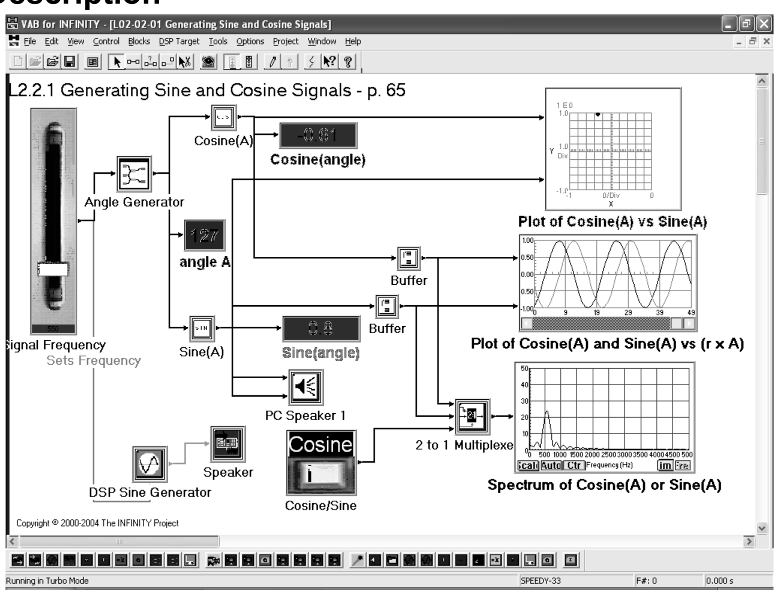


Figure 2.4 Generating Sines and Cosines

Open the worksheet *L02-02-01 Generating Sine and Cosine Signals.Lst.*

On the left side of this worksheet is a single slider that controls the rotational speed for the generation of the signals and the displays on the right side of the worksheet.

The angle generator block outputs an angle (between 0 and 359.9 degrees) as a function of time. Its input is the rotational speed which comes from the slider. So, we get numbers shown in the "angle A" display that go from 0 slowly up to 359.9 and then instantaneously go back to zero and start over again.

The fundamental frequency of a sound signal is the mathematical quantity that we associate with how "high" or "low" the pitch of a signal is. It is directly related to the period or repeating interval of the signal by the relation f = 1/T, where the period T is measured in seconds. The units of frequency are Hertz, or Hz for short.

The sin(A) and cos(A) blocks just evaluate the sine and cosine functions for the current value of x. We then do three things with these sin(A) and cos(A) values:

We display them on an x-y plot, with sin(A) controlling the x-axis and cos(A) controlling the y-axis.

We store the sin(A) and cos(A) values in a buffer that is like a digital recorder, keeping track of the most-recent values of these functions. The recorded signal is then sent to a display that shows the shapes of these functions over time.

The bottom plot shows the frequency content of the signals. Which function it is looking at depends on the position of the pushbutton switch next to it. This will be discussed further later.

The third display gives you a way to measure the fundamental frequency of the sinusoid.

Finally, there are two blocks near the bottom of the worksheet that run on the DSP processor board. Their job is to create and play an audio signal like the one that the sin(A) function is making on the screen.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Start the worksheet.
Step 2:	The displays on the right side of the worksheet should begin to change.
	Q1: What do you see in the first display?
	Q2: What is happening to the white dot?

Steps	***Instructions (Continued)***
Step 3:	As we explained in the Instructions section, the x-axis of this first display is being controlled by the sin(A) signal path, whereas the y-axis is being controlled by the cos(A) signal path. Stop the worksheet and write down the value in the “Angle” display. Then, using a calculator, calculate sin(A) and cos(A) from this number | ***Angle*** | ***Sin(A)*** | ***cos(A)*** | | | | |
	Q3: Do the sin(A) and cos(A) values match the x-axis and y-axis values of the white dot from this first plot?
Step 4:	Start the worksheet again and halt it after a short time. The “Angle” value should be different now. Repeat the above calculations for this new angle and record the information on the chart above in Step 3.
	Q4: Do the values match up in this case?
Step 5:	Let's look at the second plot. It shows the sin(A) and cos(A) functions over time.
	Q5: What is happening to the functions on this plot?

Steps	*Instructions (Continued)*
	Q6: How are they related to the motion of the white dot in the display above? Slow down the dot by moving the Signal Frequency slider to a value of 30 to make it easier to see.
	Q7: Which color is the cos(A) plot--the yellow line or the red one? How can you tell? Start and stop the worksheet several times to check.
Step 6:	Now we are ready to do some experiments with this worksheet. The slider gives you a special way to control the worksheet. Change the value of the slider so that it reads 750 and run the worksheet.
	Q8: What is happening to the white dot in the first display?
	Q9: How about the functions in the second display?
	Q10: How are these behaviors different from what you first saw when the slider gave a value of 500? How is the sound different?
Step 7:	Set the value of the rotating slider to 750, and listen to the resulting sound signal that is produced. Then, change the slider value to 1250.

Steps	***Instructions (Continued)***
	Q11: What happened to the sound signal?
Step 8:	Finally, look at the bottom display on the right as you are running the worksheet. It should have the shape of a single peak, because sine and cosine signals are functions of a single frequency. If it doesn't, click on the **Freq** button on the bottom of the display.
	Q12: How is the position of this peak related to the slider setting?
Step 9:	Starting from the "Cos" toggle button position, switch the toggle button position from **Cos** to **Sin** and back again.
	Q13: What happens to the bottom plot?
	Q14: Does this make sense to you?
Step 10:	Stop the worksheet. Close the worksheet.

Overview Questions

A: How are the functions cos(A) and sin(A) related to the motion of a rotating dot around a circle?

B: What do the sine and cosine functions look like when they are plotted as a function of time?

C: How are the functions cos(A) and sin(A) related to each other?

D: What happens to the shape of the signal in time when you increase the fundamental frequency of a sine or cosine signal? How does this action change the sound of these signals?

Summary

This lab connects circles, trigonometric functions, and sound waves. Sines and cosines were the first waveforms used in synthesizing music electronically, that is, without having some physical device vibrating back and forth. And, if you were good at moving the slider back and forth in this lab, you could make real music with it. There are better ways to control the frequency content of musical signals, though, as we'll soon learn.

2.3 Listening to Sines and Cosines

Lab Objectives

In previous labs, we have had a chance to see how sines and cosines are related to each other and to musical sounds. In this lab, we get a chance to really put sine and cosine signal generators through their paces. We can set their amplitudes. We can pick their frequencies. We can even adjust their phases. Which of these really matter when it comes to music? Discover for yourself in this lab.

Textbook Reading

- This lab appears on page **68** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **44-68.**
- Plotting Examples of Equation (2.12) for different amplitude values for A, frequency values for f, and time shifts d is good preparation for doing this lab.

Additional Materials

- Graphing Calculator

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-03-01 Listening to Sines and Cosines.Lst**: Allows you to make sine and cosine functions, plot them, and hear them as well.

Worksheet Description

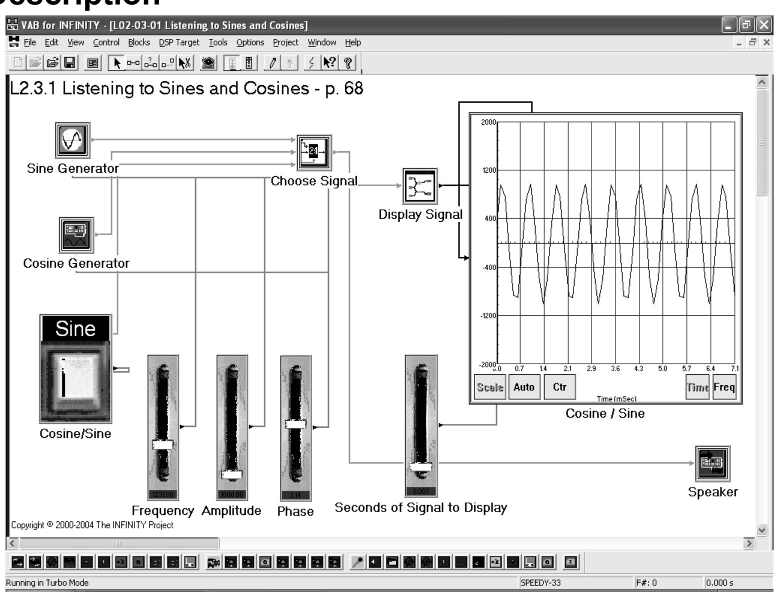


Figure 2.5 Listening to Sines and Cosines

Open the worksheet *L02-03-01 Listening to Sines and Cosines.Lst.*

The worksheet contains two blocks which generate the sine and cosine signals, respectively. When the worksheet is running, both signals are being generated, but you can only see one of them at any one time.

The button switch on the left of the worksheet controls which signal (sine or cosine) is being displayed and heard.

There are three sliders grouped on the lower left of the worksheet. These sliders control the amplitude, frequency, and phase of the cosine or sine signal that is selected.

The plot on the right shows the signal itself. Another slider next to the plot controls how much of the signal is displayed. Only the most-recent portion of the signal is displayed.

Music is made up of sounds that change in amplitude, frequency, and phase. The fundamental frequency of a musical sound is determined by its period, and we hear changes in frequency as changes in pitch.

The block on the bottom right of the worksheet is the Speaker block; it allows us to hear what the cosine or sine signals sound like.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Start the worksheet.
Step 2:	You should see a plot appear in the display on the right of the worksheet. You should also hear a sound.
	Q1: What is the display showing you?
	Q2: What does the signal sound like?
Step 3:	The slider nearest the display controls how much of the signal that is shown. Move this slider up and down and watch the display.
	Q3: Describe what you see in the display.
Step 4:	The parameters of the type of function that you see and hear is controlled by the sliders on the bottom of the worksheet as well as by the button switch. Click on the button switch until it shows a sine function. The button controls whether the function is a sine or cosine. Then, while watching the display, click on the button again.

Steps	***Instructions (Continued)***
	Q4: Why does it appear that the signal in the display does not change?
Step 5:	Listen to the sound carefully as you switch back and forth between the sine and cosine signals.
	Q5: Can you hear the any difference between these two signals?
Step 6:	We can calculate the fundamental frequency of the cosine or sine signals by measuring the period of the sine or cosine signal in the display and then using the relationship f = 1/T to calculate the frequency. But, since we have a slider that controls exactly how much of the signal is displayed, you can use the slider to measure the period. Set the Frequency slider to 500, the amplitude slider to 1000, and the Phase slider to 3.14. Next, adjust the Amount of Signal to Display slider so that a single cycle of the sine or cosine function is showing in the display.
	Q6: What is the period of the signal?
Step 7:	Using this period value, calculate the fundamental frequency of the signal.
	Q7: What is the fundamental frequency of the signal?
	Q8: How does the value of the fundamental frequency compare to the “dialed in” value in the Frequency slider?

Steps	***Instructions (Continued)***
Step 8:	Change the amplitude of the signal from 1,000 to 2,000.
	Q9: How does the signal in the display change as you adjust the amplitude?
	Q10: What about the sound of the signal?
Step 9:	Now, change the amplitude of the signal from 1,000 to 200. Change the phase of the signal from 3.14 radian to 0 radian.
	Q11: What has happened to the volume of the signal?
	Q12: Does the signal in the display change?
	Q13: What about the sound of the signal? How did it change?
Step 10:	Using a graphing calculator, plot the function {A cos(2 π f t)} from t = 0 to 0.003 seconds for the following values: A = 2,500, f = 1,200. Then, while the worksheet is running, select the **Cosine** function, change the amplitude of it to 2500, and change the frequency of it to 1,200 Hz. Finally, change the Amount of Signal to Display to 3 msec. Compare the signal in the display with what you see in your graphing calculator.

Steps	*Instructions (Continued)*
	Q14: How similar are they?
	Q15: What is different between the two plots?
Step 11:	The display on the right has the capability of calculating the spectrum of the signal provided to it. The spectrums show you the sinusoids that make up a signal. The position of the peaks of the spectrum are at the frequencies of these sinusoids. Click on the **Freq** button to activate this display mode. Describe what you see in the display. The position of the peak of the function you now see should correspond to the frequency of the sinusoid to which you are listening. Change the Frequency slider to a value of 400.
	Q16: What happened to the position of the peak in the display?
Step 12:	Now change the amplitude from a value of 2,500 to a value of 1,000.
	Q17: What has happened to the spectrum within the display? You may need to use the “Auto” scaling feature to get the spectrum to fit within the display. Click on the **Auto** button to change its scale.
Step 13:	While still looking at the spectrum, change the signal from a sine to a cosine, or, if you are using a cosine function, change it to a sine function.

Steps	*Instructions (Continued)*
	Q18: What happened to the plot in the display?
	Q19: What can you say about the spectrum of the cosine and sine signals of the same frequency?
	Q20: If you wanted to create a simple melody, like "Mary Had A Little Lamb," which of the sliders would you have to change with time: Frequency, Amplitude, or Phase?
Step 14:	Stop the worksheet. Close the worksheet.

Overview Questions

A: What are the names of the three parameters that define a sinusoidal signal?

B: Of these three parameters, which one changes the pitch of the sinusoid the most? Which one changes the sound of the sinusoid the least?

C: How can the spectrum be used to figure out the fundamental frequency of a sinusoid?

D: How is amplitude related to the loudness of a sinusoidal signal?

Summary

This lab allowed us to hear and adjust the shapes of the sine and cosine signals virtually in the VAB environment. By now, you can probably guess that frequency is very important in making musical sounds, and phase plays a much smaller role. In later labs, we'll let the computer control frequencies of sinusoids to make musical sounds.

2.4 Measuring a Tuning Fork

Lab Objectives

A tuning fork is a metal device that vibrates in such a way as to produce a sinusoidal sound of a precise frequency. Musicians, especially acoustic guitar players, use tuning forks to tune their instruments—hence their name. In this lab, we going to investigate the sound that a tuning fork makes; and we'll use a cosine generator to create a nearly-identical copy of the sound. This is an example of modeling: creating an artificial and mathematical version of a real-world phenomenon.

Textbook Reading

- This lab appears on page **69** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **65-69.**

Additional Materials

- Tuning Fork or the ability to whistle.

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-04-01 Measuring a Tuning Fork.Lst**: This lab allows you to recreate a tuning fork sound.

Worksheet Description

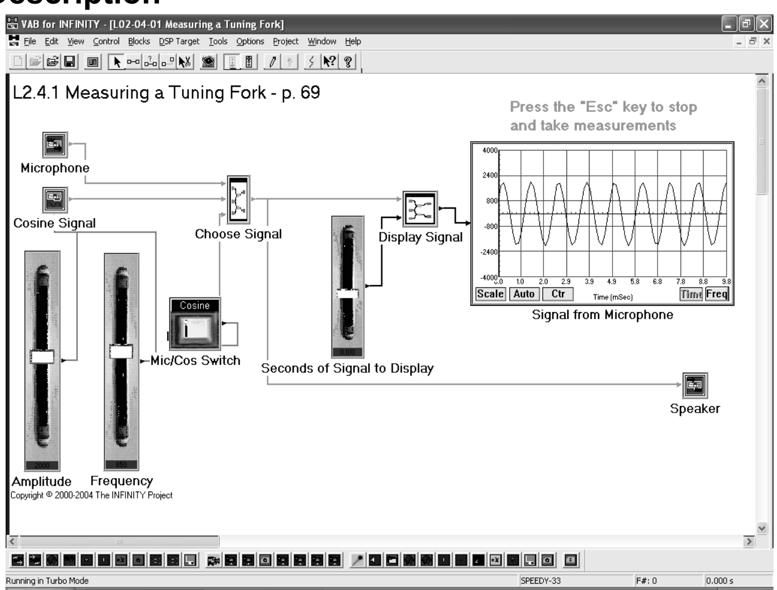


Figure 2.6 Measuring a Tuning Fork

Open the worksheet *L02-04-01 Measuring a Tuning Fork.Lst.*

This worksheet is very similar to the one used in Lab 2.3, “Listening to Sines and Cosines.” In fact, the main difference between it and the previous one is the Microphone block, which allows you to listen to and display the microphone signal as heard by the DSP board.

It has a block to generate a cosine signal. The two sliders on the bottom right allow you to change the amplitude and frequency of this cosine. The button just the right of these sliders allows you to choose which signal to see and hear on the worksheet - the microphone signal or the cosine signal.

The slider next to the plots controls how much of the microphone and cosine signals are displayed.

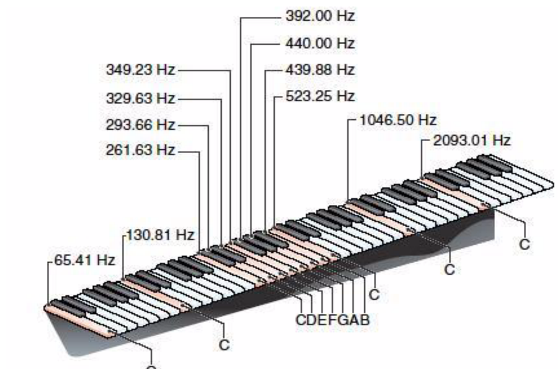
The block on the bottom right of the worksheet is the Speaker block; it allows us to hear what the cosine or sine signals sound like.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Start the worksheet.
Step 2:	Click on the **Mic/Cos Switch**. You should start hearing a soft tone coming out of the loudspeaker.
Step 3:	Using the frequency sliders, change the frequency of the cosine signal to 500 Hz, and measure the period of the cosine signal on the lower display on the right.
	Q1: What is the period of the cosine signal?
Step 4:	Now, change the amplitude of the signal so that it is equal to 1,000 and hit the **Freq** button on the lower display.
	Q2: At what frequency is the peak of the cosine signal located?
	Q3: Does this make sense?
Step 5:	The Mic/Cos switch can be used to switch between the cosine signal and the microphone signal. Set this switch to “Microphone” and talk into the microphone on the DSP board.
	Q4: What is happening in the upper display on the right?

Steps	***Instructions (Continued)***
Step 6:	Change the scale of the display by using the “Auto”, “Scale”, and “Ctr” controls so that your speech signal can fit in the display. These controls are buttons that can be pushed and set.Then, whistle into the microphone.
	Q5: What do you see in the display?
Step 7:	While whistling into the microphone, halt the worksheet.
	Q6: What is the period of your whistle?
Step 8:	Next, using the **Freq** button, measure the fundamental frequency of your whistle.
	Q7: What is the value of the fundamental frequency?
	Q8: How is it related to the period of your whistle?
Step 9:	Obtain a tuning fork from your teacher. You can whistle instead if you don’t have a tuning fork. Tuning forks make sound only after you cause the two bars or tines of the fork to vibrate. The best way to start them vibrating is to hit them on a rubber-type surface, like the bottom of your shoe. Then, hold the bottom end of the tuning fork against a hard surface like a tabletop. You should hear a nice loud tone. Practice getting sound from your tuning fork a few times so that you are ready to take measurements with the DSP board.

Steps	***Instructions (Continued)***
Step 10:	Now, we're ready to recreate the sound of your tuning fork or whistle. Set the “Mic/Cos Switch” to Microphone. Make the tuning fork or whistle sound. Hold the microphone near the surface where the fork meets the tabletop. You should see a nice-looking signal in the display.
	Q9: What does this signal look like?
Step 11:	By stopping the worksheet, you can freeze the display to take measurements.
	Q10: What is the period of the tuning fork or whistle signal?
	Q11: What is the frequency of the tuning fork or whistle signal?
	Q12: What is the amplitude of the tuning fork or whistle signal?
Step 12:	The cosine generator can be used to make a pretty accurate copy of the tuning fork signal or whistle. From the frequency and amplitude values that you calculated, change the frequency and amplitude of the cosine to match that of the sound. Now, set the switch to the “cosine” setting. You should start hearing the cosine signal from the loudspeaker. Make a sound with the tuning fork or whistle again.

Steps	*Instructions (Continued)*
	Q13: How similar are the tuning fork or whistle sound and the cosine signal sound?
	Q14: How similar are their signals in the display?
Step 13:	All tuning forks are designed to create a sound of a note on a piano. The figure below shows the frequencies of some common notes. (See also Figure 2.17, p. 53 in textbook). 
	Q15: What note is your tuning fork or whistle “tuned” to?
	Q16: Are the loudspeakers making the same sound?
Step 14:	Stop the worksheet. Close the worksheet.

Overview Questions

A: What type of signal does a tuning fork sound most resemble?

B: If you were to describe a tuning fork or whistle by the sound that it makes, which property is more important to describe--amplitude or frequency?

C: Suppose you wanted to make a digital tuning fork or whistle. What would you need?

Summary

A tuning fork is used by musicians to tune their instruments. This lab shows us that tuning forks make signals that are very close to sinusoids. The pureness of the sound is what makes the job of tuning the instrument easy.

2.5 Building the Sinusoidal MIDI Player

Lab Objectives

This lab is where you “put it all together” to make a fully-functioning digital band. You'll be able to choose your own music for it to play using MIDI (Musical Instrument Digital Interface) files. And, unlike other labs, you'll build this one from scratch by connecting blocks together.

Textbook Reading

- This lab appears on page **76** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **60-75.**

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-05-01 Building the Sinusoidal MIDI Player Parts.Lst:** Contains all the blocks needed to build the sinusoidal MIDI player.

Worksheet Description

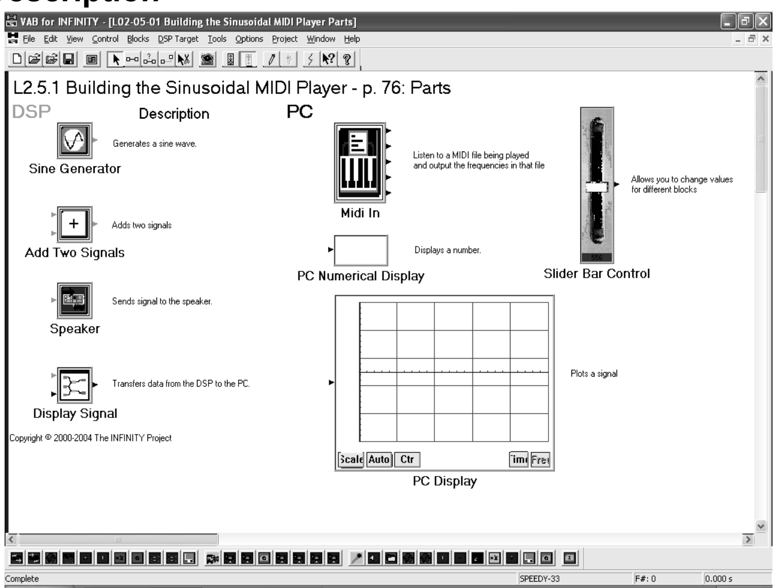


Figure 2.7 Building the Sinusoidal MIDI Player Parts

Open the worksheet *L02-05-01 Building the Sinusoidal MIDI Player Parts.Lst*. You should see something similar to Figure 2.7 above:

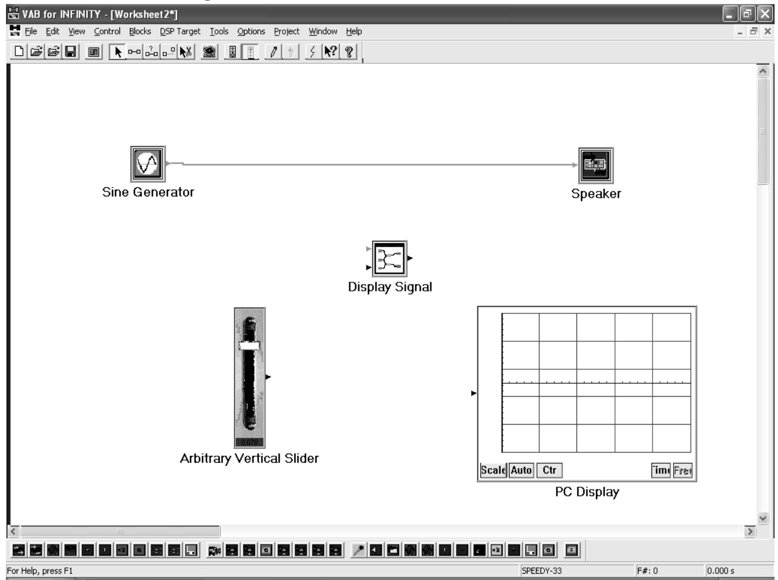
Unlike other worksheets that you've used in the past, this one won't run when you hit the green **Go** button. It has a set of blocks that you will use to build up your design. By cutting, pasting, and connecting these blocks together, you will make your own digital band.

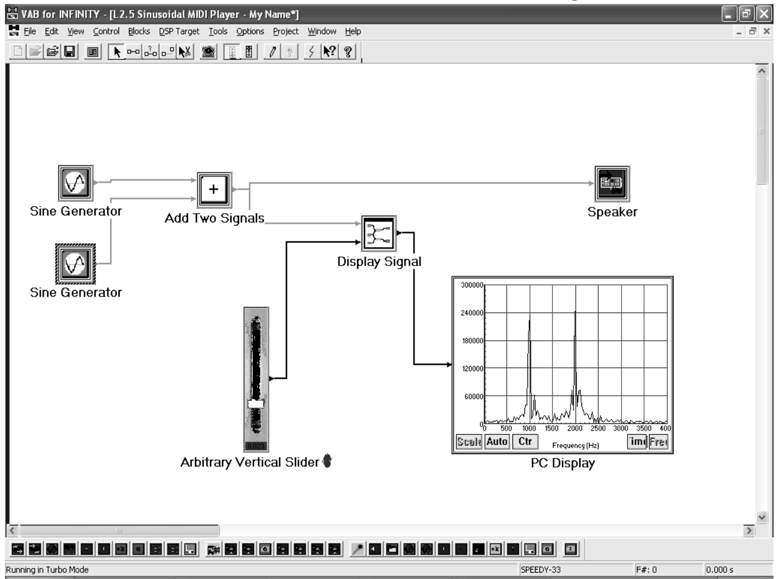
The blocks on the left are all DSP-based blocks; this means that they run on the DSP board. The ones on the right are all PC blocks; they run on the PC computer hardware and interact with the DSP board in useful ways. We'll need both types of blocks in our design.

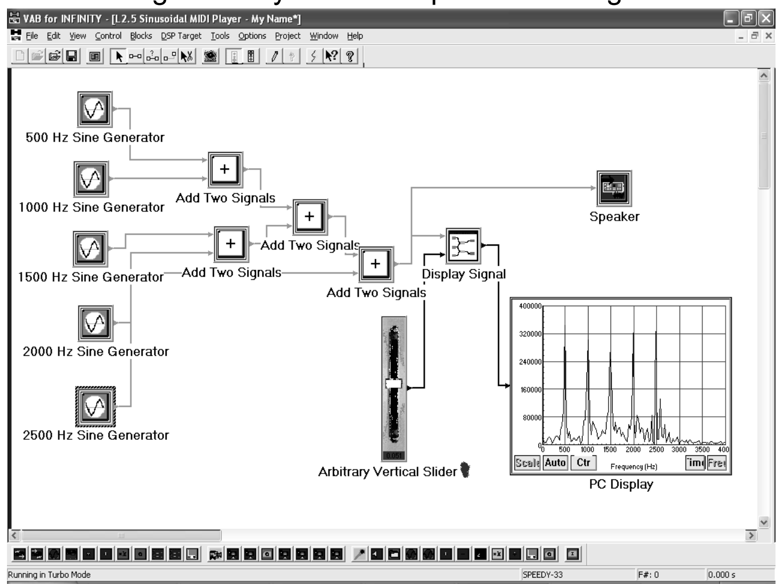
Laboratory Procedures

Steps	***Instructions***
Building Your Worksheet	

Steps	***Instructions (Continued)***
Step 1:	To give us a clean slate to work with, create a new worksheet by hitting the upper-most-left button on the toolbar of VAB. This will create a new worksheet that you can save to your own hard disk space on the PC. Save this worksheet, perhaps by using your name in the file, such as “Sinusoidal MIDI Player - (My Name).Lst”. You can switch back and forth between this new sheet you will build and the parts sheet by selecting them under the window menu.
Step 2:	As in most engineering designs, we'll start from a basic design and move to a more complicated but useful one. Our first design will simply play a single sinusoid out the loudspeaker, where we set the frequency and amplitude of the sinusoid. From the Lab 2.5.1 worksheet, copy the Sine Generator block and Speaker block to your new worksheet. Put the Sine Generator block on the left and the Speaker block on the right.
Step 3:	Let's connect these blocks together. To do so, move your mouse cursor to the second grouping of buttons on the VAB toolbar and click on the **Connect Blocks** button (two small squares connected by a single straight horizontal line). Now, you are ready to connect blocks together.
Step 4:	Click inside of the Sine Generator block, and after doing so, click on the Speaker block. A connection from the Sine Generator to the Speaker should appear. If it doesn't, repeat the clicking actions in Step 3 and 4. After you are done, go to the button with the arrow on it on the VAB toolbar to get back to **Select** (normal) mode.
Step 5:	Now, you should have a worksheet to make a single sinusoid play sound, but before we run it, let's set the amplitude and frequency of the sinusoid. Double-click on the Sine Generator block to open up its Parameter settings. Out of several entries there, you should see one for Amplitude and one for Frequency. Set the Amplitude to 3,000, and set the Frequency to a number that your instructor will give you (s/he can pick a frequency that is different for everyone, so that everyone can play a different note).
Step 6:	Now, you are all ready to make sound. Be careful. It could be very loud if your speakers are set too high, or you might not hear anything because your speakers are off. Make any necessary adjustments and click on **Go** to hear the sound your system makes. Stop the system once you've checked that it is working.

Steps	***Instructions (Continued)***
Step 7:	To see the sinusoidal signal your system is making, you will need the Display Signal, PC Display, and Arbitrary Vertical Slider blocks from your palette. Get these onto your worksheet by cutting and pasting these blocks into your new worksheet, and arrange them as shown in Figure 2.8 below:  **Figure 2.8** Screen of Step 7
Step 8:	By going through the same steps as in Step 3 and 4, connect the output of your Sine Generator to the top Display Signal input, the Arbitrary Vertical Slider to the bottom Display Signal input, and the Display Signal output to the PC Display. Be sure to click inside of the blocks to get the connections made (your instructor can help you with this part). Be sure to go back to **Select** mode before continuing
Step 9:	You should be all set to run your second worksheet design. Run this worksheet. You should see a sinusoidal signal on the PC Display. Adjust the Arbitrary Vertical Slider until you see a small (say four to seven) periods of the sinusoid.
Step 10:	Sketch the contents of the display, and label your axes carefully. What is the period of your sinusoid?

Steps	***Instructions (Continued)***
Step 11:	The Sinusoidal MIDI Player uses several sinusoids to make music. Right now, we only have one. So, let's add another Sine Generator to the worksheet. You can copy-and-paste the one that is already there if you want. We'll need the Add Two Signals block, though, from our palette. Once we have both of these blocks on your design worksheet, create the worksheet shown in Figure 2.9 below.  **Figure 2.9** Sine Generator added in Step 11
Step 12:	Change the frequency of the second Sine Generator to something different than the first (you can pick the frequency this time, but pick one between 200 Hz and 3 kHz). Once you have the new frequency selected, run the worksheet.
	Q1: Do you hear two sinusoids playing? Sketch the contents of the PC Display after you have stopped the worksheet.

Steps	*Instructions (Continued)*
Step 13:	Now we are ready to make the five-sinusoid MIDI Player. To do so, we'll need to cut-and-paste enough Sine Generator and Add Two Signal blocks to make five different sine functions and add all of their answers together to get one sound signal. Using similar methods as before, build the worksheet shown in Figure 2.10. You can change the text below each block by clicking on it—it is a good idea to relabel the blocks as you are building so that you can keep track of things.  **Figure 2.10** Screen capture of Step 13
Step 14:	Change the frequency of the third, fourth, and fifth Sine Generators so that you have five different frequencies for your Generators. Once you have done this, run the worksheet with the green **Go** button. You should hear all five notes playing at once--not very musical, but it is a proof-of-concept.
Step 15:	To make music, we'll need to have something change the frequencies of the Sine Generators over time. Here is where the MIDI In block comes in. Get this block from your palette, and place it to the left of your five Sine Generator blocks.
Step 16:	The five outputs of the MIDI In block will normally have the frequencies of the sinusoids to be played by the Sine Generators. In order to see the frequency values as actual numbers, we'll use five versions of the PC Numerical Display block from your palette. Create five of these Numerical Displays, and connect each of the outputs of the MIDI In block to its own Numerical Display. At the end of this step, you should have two separate sets of blocks: The MIDI In and Numerical Display blocks connected together; and the Sine Generator, Add, Display Signal, PC Display, and Speaker blocks connected together. You may need to rearrange some blocks in order to see things clearly at this point. Also, renaming the PC Numerical Displays to something meaningful, such as “Frequency 1", “Frequency 2", and so on will help you later.

<table>
<tr><th>Steps</th><th>Instructions (Continued)</th></tr>
<tr><td>Step 17:</td><td>Now, we are ready to have our MIDI In block control the frequencies of our Sine Generator blocks. To do so, we'll use a different connection type: a Parameter Connect button on the VAB toolbar. Put VAB into Parameter Connect mode, and connect each MIDI In output to its own Sine Generator block.

First, click on the output of the MIDI In block that you want to connect. Then, click in the center of the Sine Generator block you want to control. A dialog box should pop up asking you which variable you want to be controlled.

Select Frequency and close the dialog box. You should see a green connection appear between the MIDI In block and the Sine Generator block. Do this for all five MIDI In outputs and Sine Generators. The worksheet should look very similar to that in Figure 2.11.

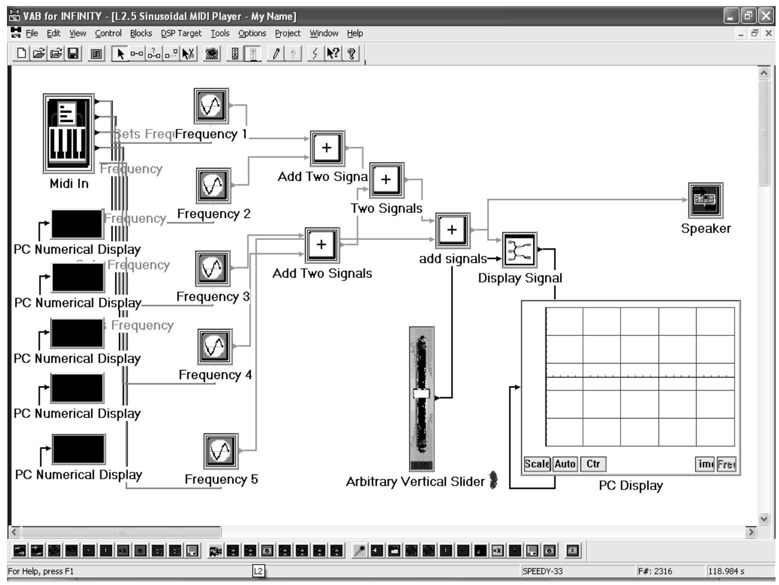
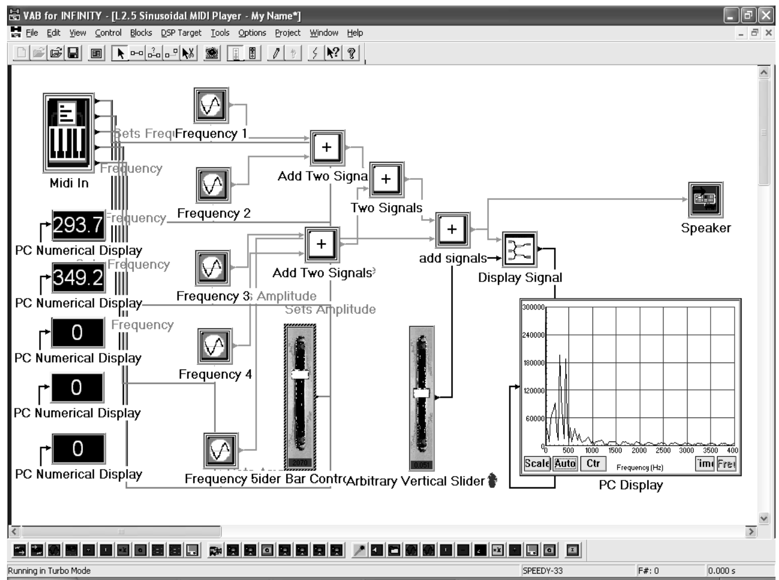


Figure 2.11 Screen capture of Step 17</td></tr>
<tr><td colspan="2">Running Your Worksheet</td></tr>
<tr><td>Step 18:</td><td>We are ready to play some music. By following directions from your instructor or by referring to Appendix B: Running MIDI VAB Labs at the back of this manual, get a song playing in MIDI Bar, and then start the VAB worksheet you've just created. You should see frequency values showing up in the PC Numerical Displays; you should hear sound coming from the speaker; and you should see the musical signal being displayed on the PC Display. If you don't see and hear all of these things coming from your worksheet, check with your instructor on your MIDI settings.</td></tr>
</table>

Steps	***Instructions (Continued)***
Step 19:	All of this music is getting quite loud. We need a way to adjust the volume of all of the Sine Generators in our Sinusoidal MIDI Player. Cut and paste the Slider Bar Control to the worksheet, and relabel this block Volume. Next, double click the slider to change its limits from 0 to 3,000 in 101 steps, and connect its output to the Amplitudes of all five Sine Generators using the Parameter Connect mode. Once you have done this, you will have the worksheet shown in Figure 2.12.  **Figure 2.12** Screen capture of Step 19
	Q2: In looking at the output of the Sinusoidal MIDI Player, does the signal ever look like a sinusoid of a single frequency? How many Frequencies are being detected at the output of the MIDI In block at such times?
Step 20:	The PC Display can display the Spectrum of the sound instead of its time waveform. Simply click on the **Freq** button until it is greyed out.
	Q3: How are the peaks of the spectrum related to the frequencies in the MIDI file?
Step 21:	For fun, go get some MIDI files of your favorite musical group. Your instructor will show you how to do this on the Web. How does your favorite music sound when it is being played with sinusoids?
Step 22:	Stop the worksheet. Close the worksheet

Overview Questions

A: Which of the following blocks is used to create the basic musical signals in the Sinusoidal MIDI Player? (i) Add Two Signals, (ii) Sine Generator, (iii) MIDI In, (iv) PC Numerical Display, (v) PC Display, (vi) Slider Bar Control.

B: Which of the following blocks is used to read in frequencies to play in the Sinusoidal MIDI Player? (i) Add Two Signals, (ii) Sine Generator, (iii) MIDI In, (iv) PC Numerical Display, (v) PC Display, (vi) Slider Bar Control.

C: Which of the following blocks is used to adjust the volume of the Sinusoidal MIDI Player? (i) Add Two Signals, (ii) Sine Generator, (iii) MIDI In, (iv) PC Numerical Display, (v) PC Display, (vi) Slider Bar Control.

D: How many adders are needed to add five Sine Generators together to make one signal to send to the Speaker block?

E: How could we make the Sinusoidal MIDI Player better? List all of the ways you might want to improve this design.

Summary

This lab showed you that sinusoids can play music. It also was probably your first “build-it” lab. We’ll have other “build-it” labs in later chapters as well.

2.6 The Spectogram

Lab Objectives

So far we have looked and listened to cosines. We look at them by plotting their amplitude vs. time. The frequency content or spectrum is a different way of looking at cosines that gives us more insight into what is in the signal. All the cosines we have worked with have a certain frequency. When we talk about the frequency content of a signal, we are asking: What cosines, if added up would give this signal?

Textbook Reading

- This lab appears on page **79** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **76-78.**

Engineering Designs and Resources

Worksheets used in this lab:

- **L02-06-01 The Spectrogram File Read.Lst**: Reads a wave file and displays the signal as well as its spectrogram.
- **L02-06-02 The Spectrogram Microphone.Lst**: Adds the chirp signal to the signal from microphone and displays the added signal as well as its spectrogram.

2.6.1 The Spectogram File Read

Worksheet Descriptions

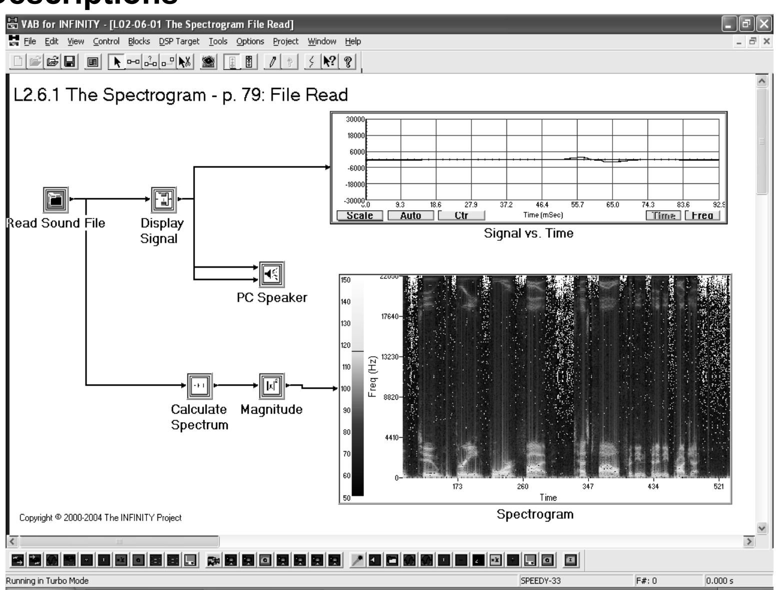


Figure 2.13 Spectogram File Read

Figure 2.13 shows the Spectrogram File Read worksheet. It's job is simple: Read in a sound file and compute its spectrogram.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Open up the worksheet *L02-06-01 The Spectrogram File Read.Lst*. Start the worksheet. You should start hearing the contents of the sound file coming out of your PC's computer speakers. You should also see some changes to the “Signal” and “Spectrogram” displays.
	Q1: Is there a relationship between the sounds that you are hearing and the color-coded contents of the “Spectrogram” display? Whenever the voice is silent, what do you see displayed in the “Spectrogram” display?
	Q2: Look at the spectrogram frequency range from 0 to 10000Hz. Yellow and white represent the strongest frequency content. Based on the colors, for this voice file estimate the percentage of the strong frequencies that are below 1,500 Hz. Estimate the percentage of strong frequencies that are between 1,500 Hz and 4,000Hz. Estimate the percentage of strong frequencies that are between 4,000 Hz and 10,000 Hz.
Step 2:	Sketch the bright part of the spectrogram between 0 and 4,000 Hz for the time when the voice is saying "one". Make similar sketches for the time when the voice is saying "two", "three", "four" and "five".
Step 3:	Stop the worksheet. Close the worksheet.

2.6.2 The Spectogram Microphone

Worksheet Description

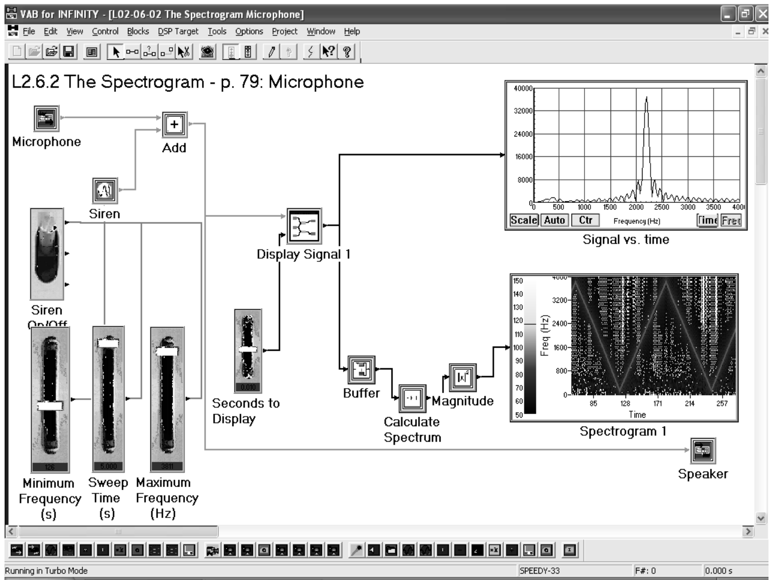


Figure 2.14 Spectrogram Microphone

Open the worksheet *L02-06-02 The Spectogram Microphone.Lst.*

Figure 2.14 above shows the Spectrogram Microphone worksheet. This worksheet creates a siren sound and mixes it with the signal coming from the microphone before displaying the signals two ways: (1) As a plot of either the signal's time or frequency content over a short time in the "Signal" display and (2) as a color-coded image in the "Spectrogram" display. We've seen displays of signals as functions before, but the Spectrogram gives us another way to visualize a signal.

Laboratory Procedures

Steps	*Instructions*
Step 1:	Start the worksheet.
Step 2:	Adjust the Minimum Frequency and Maximum Frequency sliders until they are at the same value (e.g. 2000 Hz). Then, turn on the "Siren" by flipping the "Siren On/Off" switch to its Up position.
	Q1: What do you hear out of the loudspeakers?

Steps	*Instructions (Continued)*
	Q2: What do you see in the “Spectrogram” display?
Step 3:	On the Signal Plot click the **Auto** button so that **Scale** is gray. This automatically adjusts the scale so you can see the whole plot. Click the **Freq** button so that it is grayed out.
	Q3: What do you see on the “Signal” plot? How does this plot relate to the frequency content of the signal being made?
Step 4:	Adjust the “Sweep Time” slider until it shows a value of 3 seconds, and then slowly adjust the “Maximum Frequency” to be 3 kHz.
	Q4: Describe what you see in the “Spectrogram” display.
	Q5: What do you hear coming from the loudspeakers? How does this sound relate to the “Spectrogram” display and the changing “Signal” display?
Step 5:	Set the “Siren On/Off” switch to its off position, and talk into the microphone.
	Q6: Describe what you see in the “spectrogram” display.
Step 6:	Stop the worksheet. Close the worksheet

Overview Questions

A: What is different about the spectrum of the signal and its spectrogram? Which one typically measures the frequency content of a signal over a very short time period? Which one displays the frequency content of the signal over a long time period?

B: What will a signal be and sound like if the spectrogram consists of just one horizontal line?

C: What does the spectrogram of a signal such as a human voice or a bird chirp look like? What functions do each of the lines on the spectrogram plot represent?

D: Plot the spectrogram of a single sinusoid with a frequency of 300 Hz.

E: Plot the spectrogram of the following signal:
$s(t) = 3 \cos(2 \pi 100 t) + 1.3 \cos(2 \pi 50 t) - 10 \cos(2 \pi 200 t)$. (Will students know how to plot the varying amplitudes?

Summary

The spectrogram is a way to see the frequency content of a signal over a long time, such as several seconds. It is a way to get a picture from a sound that tells us how a sound changes. Spectrograms of simple signals, such as sinusoids, look correspondingly simple, whereas the spectrogram of a complicated sound, such as your voice, can look very intricate. Try thinking of some ways to use the spectrogram in a real-world application.

2.7 Sketch Wave with MIDI

Lab Objectives

The Sinusoidal MIDI Player that you created and/or used in Lab 2.5 made music by adding sinusoids together. This lab takes that idea one step further by allowing you to specify the shape of the periodic signal that makes each note.

Textbook Reading

- This lab appears on page **85** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **81-85.**

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-07-01 Sketch Wave with MIDI.Lst**: Allows you to draw a waveform of your choice and plays a MIDI file using this waveform.

Worksheet Description

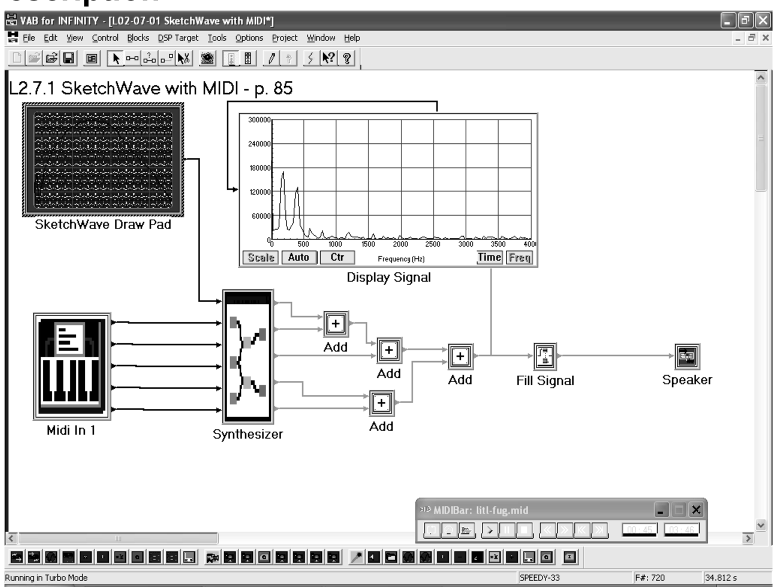


Figure 2.15 Sketchwave with MIDI

This worksheet is quite similar to the one you made in Lab 2.5: Building the Sinusoidal MIDI Player. The main difference is the Synthesizer block, which replaces the five Sine Generator blocks of the Sinusoidal MIDI Player. This block has six inputs: five for the five frequencies that the MIDI In block detects within the MIDI file at any one time, and one for the shape of the periodic function to play. The sketchpad in the upper left-hand corner of the worksheet is where you can sketch the waveform for the synthesizer.

Laboratory Procedures

Steps	***Instructions***
Step 1:	By following instructions in *A Beginner's Guide to Installing MIDI Tools and Running MIDI-VAB Labs* document, get a MIDI file ready to play using MIDI BAR and the parameter settings of the MIDI In block.

Steps	***Instructions (Continued)***
Step 2:	Load a single period of a sinusoidal function in the sketch pad.
Step 3:	Start MIDI BAR running, and then hit the green **Go** button in the VAB software. You should start hearing music playing out the loudspeakers of the DSP Kit.
	Q1: Does the music that you are playing sound similar to that of your Sinusoidal MIDI Player?
Step 4:	While the system is making music, re-sketch the periodic function p(t) in the sketch-pad.
	Q2: What is happening to the sound? Do changes in your sketch pad cause the music sound to change? What changes about the sound--the notes or the type of instrument being played?
Step 5:	Repeat Steps 2 and 3 for the triangle wave and square wave.
	Q3: How different do these sound from the sinusoid?
Step 6:	Try to sketch in the sketch pad one period of the saxophone sound in Figure 2.39 on page 87 of the class text.
	Q4: Do you hear music being played by saxophones? If not, what instruments have you created?
Step 7:	Stop the worksheet. Close the worksheet.

Overview Questions

A: How can the shape of a musical instrument sound be used to make multiple versions of that sound to play interesting music?

B: What block determines the period of the sound signals that the Synthesizer block creates: The sketchpad block or the MIDI In block?

C: Suppose you wanted to create a worksheet that would play both the sound of a sinusoid and the sound of a saxophone for every note of a MIDI file. How would you do it? Sketch out the block diagram for this design.

Summary

This is only one of many ways to synthesize sounds. Try and think of your own ways of improving the basic MIDI player.

2.8 Sketch Waves with Envelope Functions

Lab Objectives

This lab gives you a simple way to synthesize sounds using the equation s(t) = e(t) x p(t), where e(t) and p(t) are functions you sketch out with a mouse on “sketchpads” within a computer display. With a little effort, it is possible to make very realistic musical instrument sounds in this lab just by studying their coarse and fine signal shapes.

Textbook Reading

- This lab appears on page **92** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **82-92.**

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-08-01 Sketch Wave with Envelope Functions.Lst**: Creates a sound signal from sketches of its periodic and envelope functions.

Worksheet Description

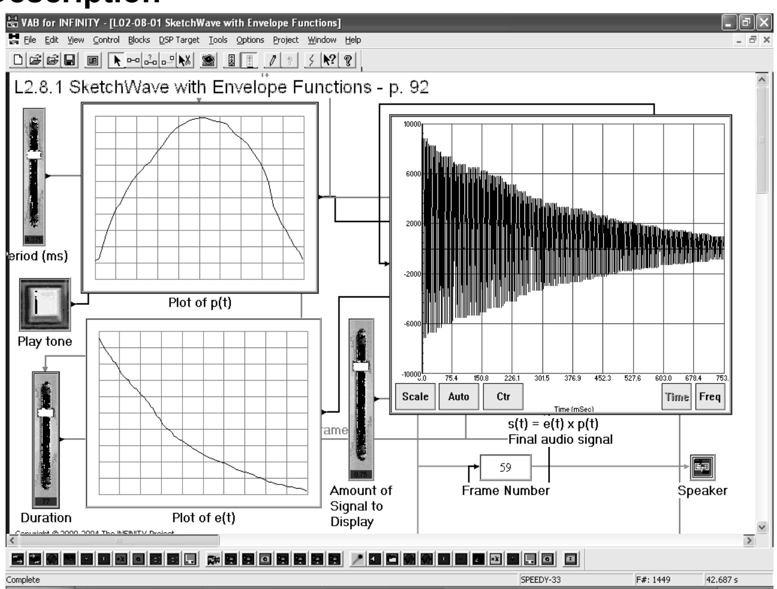


Figure 2.16 Sketch Wave with Envelope Functions

Open the worksheet *L02-08-01 Sketch Wave with Envelope Functions.Lst.*

Figure 2.16 above shows the worksheet used for this lab. The visible worksheet area is divided into roughly half, with the left side containing the user controls and the right side containing the worksheet's display and Speaker icon.

The two grid-like displays on the left of the worksheet are actually “sketchpads” similar to that used in Lab 2.7.1. Here is where you can draw functions for the periodic function p(t) and the envelope function e(t) of the sound you want to create with your computer mouse.

The two sliders “Period (ms)” and “Duration” control the period of the sound that you are making (or the time scale of the p(t) sketch) and the envelope duration (or the time scale of the e(t) sketch). The **Play Tone** button allows you to hear the result of your sketch--just click on this button and the worksheet will make your s(t) sound.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Start the worksheet.
Step 2:	Load the same sinusoidal shape a function in the p(t) sketchpad that corresponds to one period of a sinusoidal signal. Then, click **Play Tone**.
	Q1: What do you hear out the loudspeakers? What do you see in the display on the right? You may need to adjust the Amount of Signal to Display slider to “zoom in” on the sound. What have you created?
Step 3:	While keeping the same sinusoidal shape in the p(t) sketchpad, draw a function in the e(t) sketchpad that is approximately exponential from the upper left corner to the lower right corner. Then, click **Play Tone**.
	Q2: Describe in words what is happening in the display on the right and what you hear as well. How is this signal different from the one you made previously?
Step 4:	Adjust the “Duration” slider until the note that you play lasts about one second. Adjust the “Period” slider to 5 ms.

<table>
<tr><th>Steps</th><th>Instructions (Continued)</th></tr>
<tr><td></td><td>

Q3: What does your synthesized sound sound like? Compare the e(t) and p(t) functions you've created to those in Figure 2.15 on page 51 of the class text.

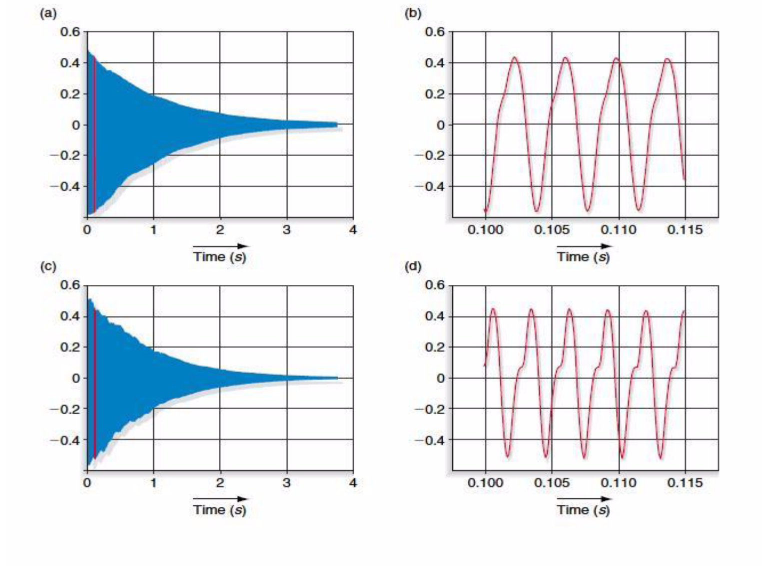


Figure 2.17 Figure on p. 51 of text.

Do they look similar? What instrument do you expect this synthesized sound to most resemble?

</td></tr>
<tr><td>

Step 5:

</td><td>

Draw a function that is similar to one period of the waveform in Figure 2.39(a) in the p(t) sketchpad, and draw a function that looks like an inverted “U” in the e(t) sketchpad. Adjust the Period slider to 2 ms, and play this sound.

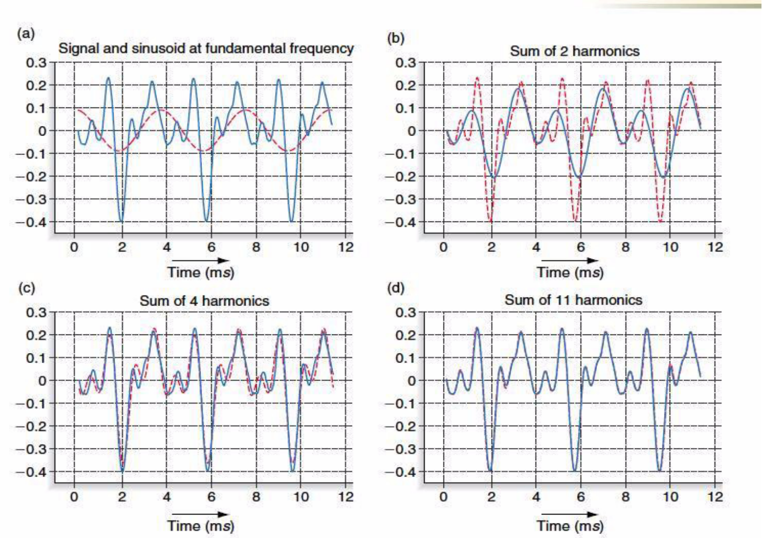


Figure 2.18 Figure 2.39 of text

</td></tr>
</table>

Steps	***Instructions (Continued)***
	Q4: What does this sound most resemble?
Step 6:	Now, move the “Period” slider to 4 ms and play the sound.
	Q5: What just happened to the sound?
Step 7:	Here's your opportunity to be a sound designer. Try drawing different waveforms for both p(t) and e(t) in their respective sketchpads. A good rule of thumb to follow when sketching p(t) is: the function should begin and end at the same value on the y-axis; also, the function does not need to repeat to sound musical. As for example e(t) functions, try the various functions in Figure 2.40 on page 89 of the text. Or, have a friend who plays an instrument bring it to class one day. You can use the “Plots of Speech” laboratory worksheet to capture the sound of the musical instrument and display its periodic function p(t) and its envelope function e(t). Using a printout or sketch of the “Plots of Speech” displays, draw your own p(t) and e(t) functions into the “SketchWave with Envelope Functions” worksheet and play the sound. How good is your synthesizer?
Step 8:C	Stop the worksheet. Close the worksheet.

Overview Questions

A: When synthesizing sounds using the s(t) = e(t) x p(t) method, which value determines the frequency of a sound, the period of its periodic function p(t) or the duration of its envelope function e(t)?

B: Describe the periodic portion of a piano note sound resemble?

C: Describe the envelope of a piano note sound?

D: Practically speaking, does changing the envelope function of a sound change the fundamental frequency of the sound?

Summary

This lab showed you that interesting musical sounds can be made by simply multiplying two functions together.

2.9 Echo Generator

Lab Objectives

Echo is what you experience when sound comes back to you after bouncing off of a distant wall, canyon, or other hard surface. You also sometimes hear echos caused by an equipment malfunction when making long distance telephone calls. This lab shows you how to simulate echo electronically using the Infinity Technology Kit.

Textbook Reading

- This lab appears on page **92** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **92-93.**

Engineering Designs and Resources

Worksheet used in this lab:

- **L02-09-01 Echo Generator.Lst**: Adds echo to any microphone signal.

Worksheet Description

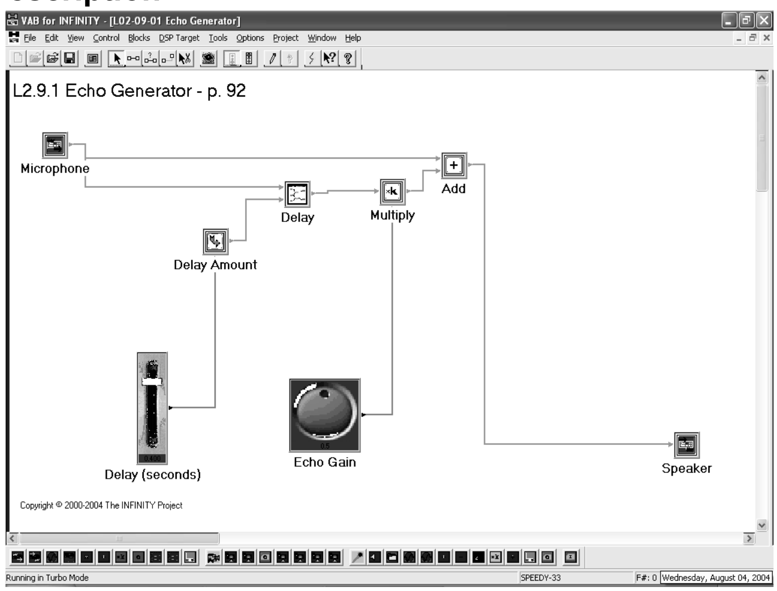


Figure 2.19 Echo Generator

Open the worksheet *L02-09-01 Echo Generator.Lst*. You should see the worksheet in Figure 2.19 above. Let's study this worksheet to see how it works.

On the left is a Microphone block. It senses sounds coming from the Infinity Technology Kit's left microphone. This signal is added to a copy of this signal that has been delayed by a time delay (specified by the slider on the lower left) and multiplied by a number (as specified by the knob in the lower middle portion of the worksheet). The sum of these two signals is sent to the speaker.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Start the worksheet, taking care to move the microphone away from the loudspeaker of the Kit to avoid feedback. Adjust the Delay slider to its maximum value of 0.5 seconds and the Echo Gain to one.
	Q1: Describe what you hear. What does an echo sound like?
Step 2:	Adjust the Echo Gain to different values between zero and two.
	Q2: How does the sound change?
Step 3:	Set the Echo Gain to one, and change the delay to a value of 0.03 seconds.
	Q3: Can you hear the delayed signal? What has happened?
Step 4:	Stop the worksheet. Close the worksheet.

Overview Questions

A: What is the smallest amount of delay for which you can tell there is a distinct echo for an echo gain of one?

B: Sound travels at approximately 332 meters per second. How far away must you be from a wall to have an echo delay of 0.5 seconds from sound reflecting off of that wall?

Summary

Echoes are caused by reflected sounds off of far away surfaces. Using sound, we can tell how far away something is, too.

2.10 Sound Effects

Lab Objectives

Echo is but one effect used by professional musicians to make great musical sounds. This collection of worksheets allows you to hear some of these other effects and explore their behaviors with your own voice.

Textbook Reading

- This lab appears on page **93** of the *Engineering Our Digital Future* textbook.
- Pre-requisite textbook reading before completing this lab: pp. **92-93.**

Engineering Designs and Resources

Worksheets used in this lab:

- **L02-10-01 Sound Effects Reverberation.Lst**: Adds a repetitive echo to a sound.

Worksheet Description

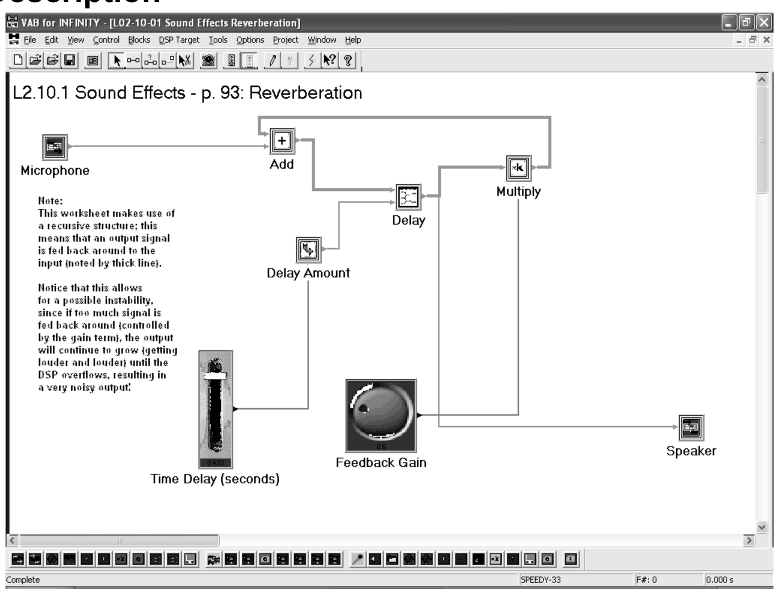


Figure 2.20 Sound Effects - Echo

Open the worksheet *L02-10-01 Sound Effects Reverberation.Lst* and examine its contents.

Notice that this worksheet is quite similar to the Echo worksheet in the last lab, except that the output of the adder is delayed, not its input, before the sum is added to the microphone input signal. By following the path of the adder output signal, you will see that it makes a loop - hence, we expect to hear echoes that repeat over and over.

Laboratory Procedures

Steps	***Instructions***
Step 1:	Set the Delay amount to 0.5 seconds, and set the Feedback Gain to 0.7.
Step 2:	Start the worksheet.

Steps	***Instructions (Continued)***
	Q1: Describe what you hear. How is this different from the Echo Generator's sound?
Step 3:	Adjust the delay to a value of 0.05 seconds.
	Q2: Describe what you hear. Does it sound different from the Echo Generator's sound with similar Delay and Gain values?
Step 4:	Set the Time Delay to 0.5 seconds, and set the Feedback gain to one.
	Q3: What happens? Do you expect this? Describe what is going on (after turning off the worksheet)
Step 5:	**Open** the worksheet *L02-10-02 Sound Effects Flanging.Lst*. This worksheet is like the Echo Generator worksheet, except that the fixed Delay has been changed to a variable delay controlled by a Cosine Generator. Run this worksheet and talk into the microphone. Then, blow air over the microphone to simulate a wind sound.
	Q4: What do you hear? How is what you hear related to the Delay value?
Step 6:	**Open** the worksheet *L02-10-03 Sound Effects Stereo Flanging.Lst*. This worksheet also has a variable delay like the Flanging worksheet, but it also has a time-varying balance from left to right speaker. Try running this worksheet, situating yourself between your two speakers.

Steps	***Instructions (Continued)***
	Q5: What do you hear? How is what you hear related to the Delay value?
	Q6: How is the stereo effect related to surround sound in movies?
Step 7:	Stop the worksheet Close the worksheet

Summary

In this lab you have had the opportunity to experiment further with musical sounds and different effects using your own voice.