VIDEO 13.4. SOUND AS AN ANALOG SIGNAL: LOUDNESS, PITCH AND SHAPE

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DR. JONATHAN VALVANO: Let's talk about sound.

We're going to see sound from two perspectives.

We're going to see some from the generation.

How do we generate sound?

And then we're going to look at sound and how we perceive it,

and how the perception happens.

Our micro controller is going to control.

It will use our DAC to convert the digital to analog.

And then we'll use a speaker to generate the sound.

The sound is a air pressure.

And so we're going to have pieces of air at high pressure followed

by pieces at low pressure.

High pressure, low pressure, high pressure, low pressure.

And this sound is going to-- this pressure

wave is going to traverse the air.

And our ears are going to perceive it.

The ear drum will oscillate, and we'll

touch the nerves in our ear

and our brain will perceive the sound.

DR. RAMESH YERRABALLI: So some perceived this way, visualize this way,

is change in air pressure.

DR. JONATHAN VALVANO: Yes.

And if we look at this air pressure, we can visualize it

as an oscillation of pressure.

And so, we can see that at any given spot,

the air pressure is going to oscillate with respect to time.

The other way that we can perceive sound, or understand sound,

is the fact that this pressure wave actually travels.

And so this pressure is also oscillates in space.

So the wave actually propagates away from the generator to the perceiver.

DR. RAMESH YERRABALLI: So now that we've looked at what sound is,

let's look at the properties of sound.

First, we know that sound can be visualized as a wave.

DR. JONATHAN VALVANO: And so there are properties of this wave.

One of the obvious properties is the period of this wave.

And one over this period is the frequency.

And when we talk about sound, we define this frequency

as the pitch, high pitch or low pitch.

DR. RAMESH YERRABALLI: The second property of sound, or in a wave,

is the amplitude.

In the context of sound, we call this loudness.

DR. JONATHAN VALVANO: So if the sound is much louder, it will be bigger.

DR. RAMESH YERRABALLI: That is correct.

So, let's take a simple note, a sound that all of us can relate to,

an A-note on a piano or a keyboard.

DR. JONATHAN VALVANO: This A note is going

to oscillate and 440 cycles per second, so we'll call it 440 Hertz.

If we were to go down an octave to the octave below, we get another A note,

and it oscillates at one half that frequency, or 220 Hertz.

If we go 1 octave up, then it'll oscillate twice that, or 880 Hertz.

DR. RAMESH YERRABALLI: So we can have notes in between things.

Let's look at some notes that are useful and make a nice sound.

The note G which is at 392 Hertz, the note E, which is 329.6 Hertz,

and the note C which is 261.6 hertz.

You will see that these numbers have a relationship when

you do the lab for this class, this particular module.

DR. JONATHAN VALVANO: Yeah, in the lab, where

it's going to use these four notes to generate a piano.

DR. RAMESH YERRABALLI: So, we saw sound can be described by three properties-

the frequency of sound, the amplitude, or the loudness of sound,

and there's a third property, which is the shape of sound.

DR. JONATHAN VALVANO: So if you wanted to listen to a trumpet,

you would see that the trumpet wave looks different than the sine wave

that we drew in the last picture.

The shape of this sound is different.

It still oscillates, but it's not as regular as the pure tone

that we did in the last slide.

DR. RAMESH YERRABALLI: So let's put all of these things together.

We're going to build a system that will produce sound

by converting digital signal to an analog sample.

We'll hook up a speaker that'll produce sound that we can listen to.

DR. JONATHAN VALVANO: All right let's go.

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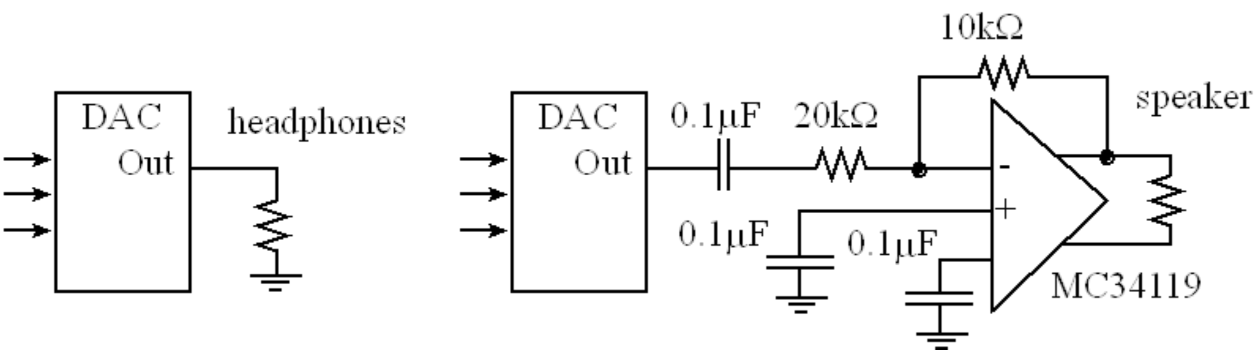

Figure 13.7. DAC allows the software to create music. For more information on the audio amplifier, refer to the data sheet of the MC34119. http://users.ece.utexas.edu/~valvano/Datasheets/MC34119.pdf (http://users.ece.utexas.edu/%7Evalvano/Datasheets/MC34119.pdf)

The quality of the music will depend on both hardware and software factors. The precision of the DAC, external noise, and the dynamic range of the speaker are some of the hardware factors. Software factors include the DAC output rate and the complexity of the stored sound data. If you output a sequence of numbers to the DAC that form a sine wave, then you will hear a continuous tone on the speaker, as shown in Figure 13.8. The **loudness** of the tone is determined by the amplitude of the wave. The **pitch** is defined as the frequency of the wave. Table 13.2 contains frequency values for the notes in one octave. The frequency of the wave, f_{sin}, will be determined by the frequency of the interrupt, f_{int}, divided by the size of the table n. The size of the table in Program 13.1 is n=16.

$f_{sin} = f_{int} / n$

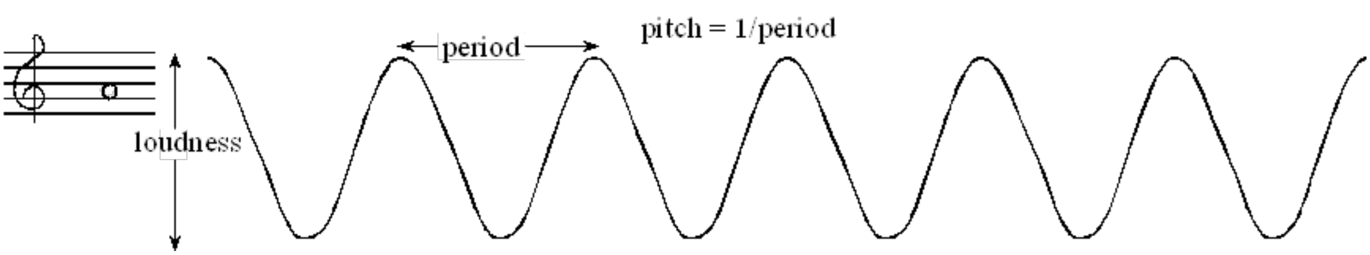

Figure 13.8. The loudness and pitch are controlled by the amplitude and frequency.

The frequency of each musical note can be calculated by multiplying the previous frequency by $\sqrt[12]{2}$. You can use this method to determine the frequencies of additional notes above and below the ones in Table 13.2. There are twelve notes in an octave, therefore moving up one octave doubles the frequency.

Note	frequency
C	523 Hz
B	494 Hz
B^b	466 Hz
A	*440 Hz*
A^b	415 Hz
G	392 Hz
G^b	370 Hz
F	349 Hz
E	330 Hz
E^b	311 Hz
D	294 Hz
D^b	277 Hz
C	262 Hz

Table 13.2. Fundamental frequencies of standard musical notes. The frequency for 'A' is exact.

Figure 13.9 illustrates the concept of **instrument**. You can define the type of sound by the shape of the voltage versus time waveform. Brass instruments have a very large first harmonic frequency.

Figure 13.9. A waveform shape that generates a trumpet sound.

The **tempo** of the music defines the speed of the song. In 2/4 3/4 or 4/4 music, a **beat** is defined as a quarter note. A moderate tempo is 120 beats/min, which means a quarter note has a duration of ½ second. A sequence of notes can be separated by pauses (silences) so that each note is heard separately. The **envelope** of the note defines the amplitude versus time relationship. A very simple envelope is illustrated in Figure 13.10. The Cortex™-M processor has plenty of processing power to create these types of waves.

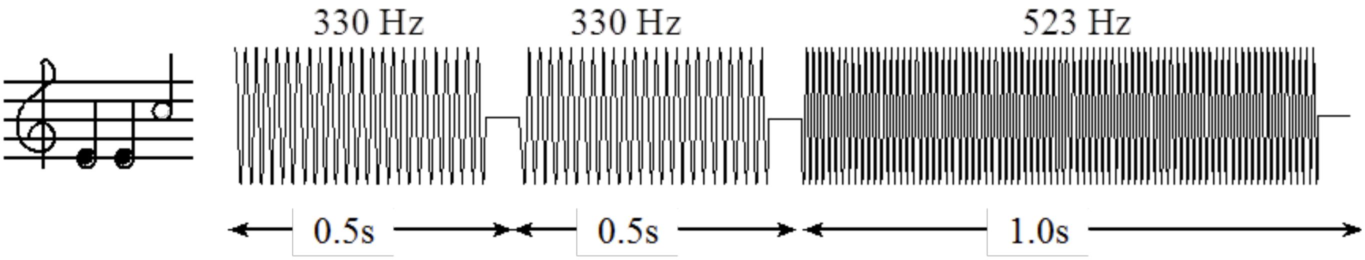

Figure 13.10. You can control the amplitude, frequency and duration of each note (not drawn to scale).

The smooth-shaped envelope, as illustrated in Figure 13.11, causes a less staccato and more melodic sound. This type of sound generation is possible to produce in real time on the Cortex™-M microcontroller.

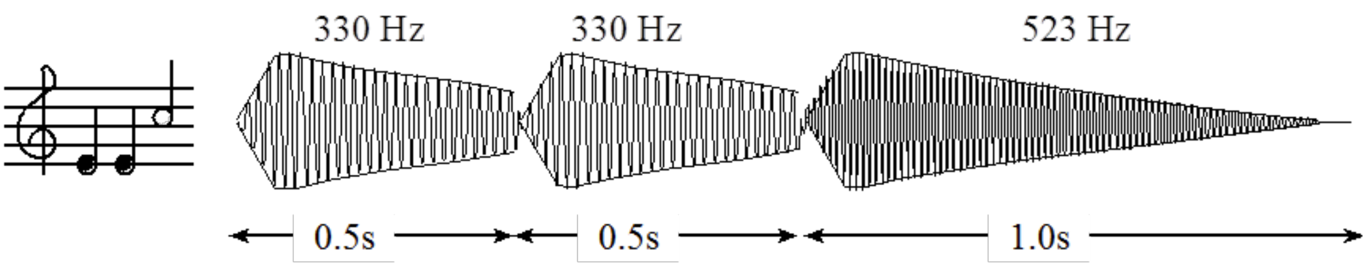

Figure 13.11. The amplitude of a plucked string drops exponentially in time.

A **chord** is created by playing multiple notes simultaneously. When two piano keys are struck simultaneously both notes are created, and the sounds are mixed arithmetically. You can create the same effect by adding two waves together in software, before sending the wave to the DAC. Figure 13.12 plots the mathematical addition of a 262 Hz (low C) and a 392 Hz sine wave (G), creating a simple chord.

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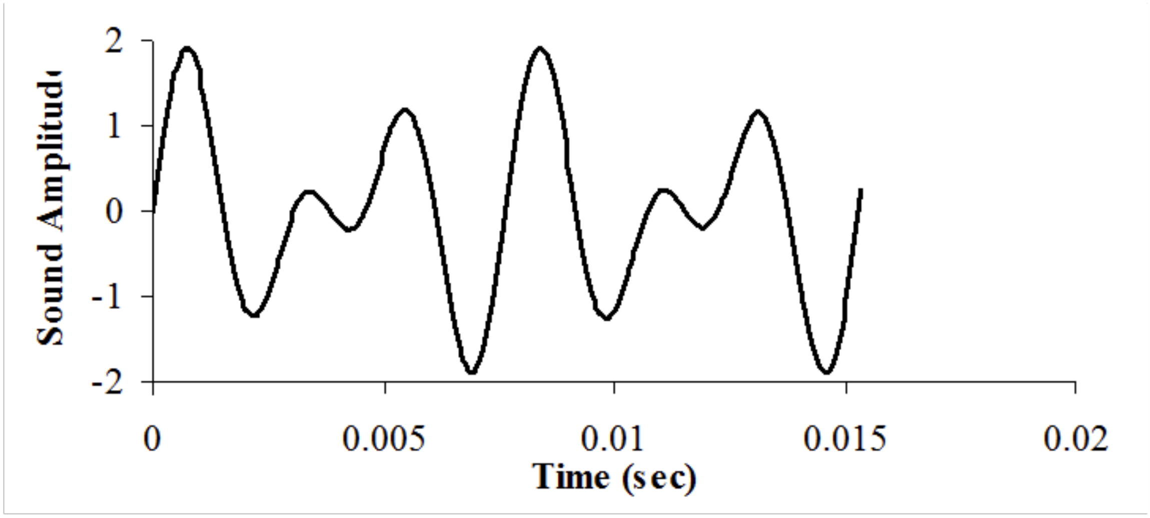

Figure 13.12. A simple chord mixing the notes C and G.

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