9A: ADDING SOUND SIGNALS

INTRODUCTION

Both loudness and pitch are complicated subjective phenomena. The purpose of this lab is to give you some direct personal experience of some of the hearing phenomena. This lab should also give you more practice using the oscilloscope as a measurement tool.

NOTES ON THE EQUIPMENT

At your station you will find some of the equipment which has already been hooked up for you: a dual-function generator, a headphone box, an oscilloscope, and a frequency counter. The function generators can be connected to a mixing amplifier, which combines (adds) two signals so you can hear them at the same time. The combined signals are displayed on channel 1 of the oscilloscope (and audible through the headphones). You can control the frequency and amplitude of each independently, or eliminate them from the combined signal by selecting "OUT."

Another thing you need to know is that the mixing amplifier can only put out so much power. If you ask for more power, the amplifier will simply clip off the top and bottom of the output signal, which you will hear as a nasty buzzing sound. You can solve this problem by turning down the amplitudes of the generators.

DECIBELS

As you should know from the previous lab, a decibel is a number (with no units) which compares two numbers. A decibel is always a comparison to some reference value, and is meaningless unless you know what that reference value is. A typical reference value for sound pressures is pressure of the softest sound the average person can hear. To get the decibel value, you divide your value by the reference value, take the logarithm, and multiply by 20.

\[ dB = 20 \log \left( \frac{p}{p_0} \right) \]

For example, if a sound pressure is 2000 times the reference pressure, it has a value of

\[
\begin{align*}
\text{dB} &= 20 \log \left( \frac{p}{p_0} \right) \\
&= 20 \log (2000) \\
&= 20 \times 3.3 \\
&= 66 \, \text{dB},
\end{align*}
\]

which is about the level of sound near a busy street when compared to the threshold of hearing.
With voltages, it is common to take the largest typical voltage as the reference, which means that the other voltages will be a negative number of decibels in comparison. For example, if the reference signal has an amplitude of 3 volts, then a signal with an amplitude of 1 V is

\[
\text{dB} = 20 \log \left( \frac{V}{V_0} \right) \\
= 20 \log \left( \frac{1}{3} \right) \\
= 20 \times -0.477 \\
= -9.5 \text{ dB}
\]

compared to the fundamental. When you put a number less than 1 into your calculator and push “log,” it will automatically give you a negative number, but it is important that you know what positive and negative decibel mean.

**PITCH AND SOUND LEVEL**

In a rough way, we can say that perceived pitch corresponds to frequency. However, a number of other factors besides frequency can affect pitch perception. In *The Science of Sound*, Rossing discusses several of these factors, such as the duration of the sound, whether or not other sounds are present, etc. Many observers report changes in pitch if the loudness of the sound changes dramatically. However, this effect differs from person to person. Use one generator to see if you notice such pitch changes.

1. Use the scope to set the frequency to exactly 1000 Hz: figure out the period of a 1000 Hz signal and then adjust the frequency knob of Generator 1 until you have that period on the scope.

2. Listen to the sound on the headphones, listening particularly to the pitch. Then change the amplitude of Generator 1. **Do you notice any change in pitch? If so, is the softer signal higher or lower in pitch than the loud one?**

3. Repeat this procedure for 200 Hz and 10k Hz. Each time, set the frequency exactly using the scope.

4. **Rossing** says that most people hear a rise in the pitch of high frequency sounds as they get louder, but a drop in pitch of low frequency sounds as the get louder, with little noticeable change at middle frequencies. **Do you follow this pattern?**
MASKING

The presence of a loud sound can make it impossible to hear another softer sound. This is called **masking**. It is easier for a sound to mask a sound of similar frequency than a sound of very different frequency. Also signals at lower frequency can better mask a weaker signal at higher frequency than vice versa. Follow the steps outlined below:

1. Use the scope to set the frequency of the Generator 1 to **500 Hz**. This will be your masking signal. Then set it "OUT".

2. Set the other generator (Generator 2) to produce a **500 Hz** sine signal which is down **30 dB** from the other generator. It means the amplitude of this signal is $10^{\frac{30}{20}} = 10^{1.5} = 32$ times smaller than that of the masking signal.

3. Can you hear the softer tone? Turn the frequency dial of the Generator 2 all the way up, which will allow you to hear the soft, high tone.

4. Turn the Generator 1 back IN. Then reduce the frequency of the second generator until you can no longer hear the soft tone. If you do not hear both signals when they are widely separated in frequency, repeat steps 2 through 4 with the two signal differing in power by **20 dB** rather than 30 dB.

5. **What is the frequency difference between the two generators?** Please, indicate what the difference in power of the two signals is.

BEATS

When you are presented with two different pitches at once, what you hear depends on how different the two frequencies are. If the frequencies are very different, you will hear the two frequencies as separate tones. However, if the two frequencies are only different by a few Hz, you will hear only one pitch which gets alternately louder and softer, called “beating.”

Actually, the “beat frequency” (the number of times per second that the sound gets loud) has a simple relationship to the frequencies of the two pitches which are being added. If you have two tones, $f_1$ and $f_2$, which have almost the same frequency, and you add them together, you hear a single tone half way in between which is beating at a rate $f_b = f_2 - f_1$.

HEARING BEATS

1. To hear beats the most clearly, you need the two tones to have the same amplitude. Set you oscillators so that each one produces a **1000 Hz** tone (set as accurately as you can with the scope) with an amplitude of **5 V** peak-to-peak. Then turn them both on at the same time (turn down the headphone volume to eliminate distortion if you need
to). You should clearly hear the beating, and you should see it on the scope, too. If you don’t, ask your instructor.

2. Vary the frequency of one of the oscillators. Make it so that the tones are very far apart and then slowly bring them together. When you get into the range where you hear beating, notice that the closer the frequencies are together, the slower the beats.

3. Determine the beat frequency: Adjust the oscillators so that you hear beats which are fast but which are still slow enough for you to count. Count the number of beats that occur in 30 seconds, and divide by 30 to get the number of beats per second.

4. Now check to see that this is the same as the difference in the two signal frequencies. To measure them accurately enough, you will have to use the frequency counter. Turn it on.

   This measurement has to be very accurate, so you need to find the button on the counter labeled GATE (sec.) and switch it to the setting called 10.0. This tells the counter to count the signal for 10 seconds, which allows it to tell you the frequency to the nearest 0.1 Hz. Measure and record frequencies for both generators to that precision.

5. Now subtract the two frequencies. Is the difference in the two original frequencies the same as the beat frequency?

6. Since you are done using the 10 second gate, switch the frequency counter’s gate switch back to the 1 second position.

**Fused, Rough, and Separate Tones**

Any two frequencies are characterized by the difference between the two frequencies. In science, differences are often notated using the capital Greek letter • (delta). So the difference between two frequencies $f_1$ and $f_2$ is written $\bullet f = f_2 - f_1$. If the two frequencies are sufficiently close together, you hear a single tone which is beating at a rate equal to $\bullet f$. This is only true, however, if the frequencies are very close together.

If the frequencies are very different, you hear them as two completely separate tones, and there is no beating.

Somewhere in between “very close together” and “very far apart” is a region of transition. In this region, the tones are fused into a single tone which has a “rough” quality, and it is not possible to hear distinguishable beats.
You can use your lab set-up to determine just what it means for two sounds to be “close together” or “far apart.”

1. Set both generators to within a few Hz of 1000 Hz. You can do this quickly using your frequency counter.

2. Listen to the tones. As you listen, turn up the frequency on one generator as far a you can by turning the dial, to about 2000 Hz. Notice that you can clearly hear two distinct tones. Now slowly bring the upper frequency back toward 1000 Hz. As you do this, keep your attention fixed on the lower tone. Eventually you will reach a point where you can no longer hear the lower frequency as a separate tone. Instead, you will hear a single sound with a rough texture. When you get there, stop and record the frequencies of the two tones. Calculate $f$. This difference is called the fusion frequency.

3. Listen again, and keep lowering the upper frequency until you can hear beats. This means you can hear a fluttering in the tone at a definite rate, though it will be too fast for you to count.

   Once again, record the frequencies and calculate $f$. This is the maximum beat frequency.

4. You have now determined the fusion frequency and the maximum beat frequency for a “center frequency” of about 1000 Hz. (The center frequency is the frequency half way in between $f_1$ and $f_2$.) Repeat this experiment at 200 Hz and at 5000 Hz. That is, determine the fusion frequency and the maximum beat frequency when the center frequency is around 200 Hz and around 5000 Hz.

5. Is the maximum beat frequency about the same at each center frequency? Are the fusion frequencies the same at each center frequency?

6. Read the attached page from The Science of Sound by Rossing. Does your experiment agree with the text?