Demonstrating Acoustic Resonance: with the CircuitGear CGR-101 and Power Supply PSM-101

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Abstract

In this paper, we describe low cost apparatus for demonstrating acoustic resonance in an open or closed tube. The equipment uses the Syscomp CircuitGear CGR-101 signal-generator/oscilloscope to generate and display the acoustic signals.

Both the generator and oscilloscope have features that allow very precise measurement of frequency - digital readout of generator frequency, ability to zoom in on a range of generator frequencies, and lissajous display on the oscilloscope.

Introduction

A sound wave is a displacement of air molecules that propagates at the speed of sound (about 340 metres/sec at sea level and room temperature). This displacement of air molecules is accompanied by changes in pressure, which the human ear or a microphone detects as sound.

The sound pressure is at a maximum when the rate of change of the displacement of air molecules it at its maximum. Conversely, when the displacement pauses (to change direction) the pressure is zero. For a sinusoidal variation in displacement the pressure is co-sinusoidal, that is, lags the displacement by 90°.

Now consider a sound wave that is launched down a tube of some finite length. When the wave reaches the end of the tube, there is a change in the properties of the medium conducting the wave. There might be a barrier or the tube might be open to the atmosphere. In electrical terms we say that there is a *discontinuity in impedance*. This causes a reflected wave to travel up the tube. This reflection occurs whether the tube is open or closed at the end, but the nature of the reflection is different.

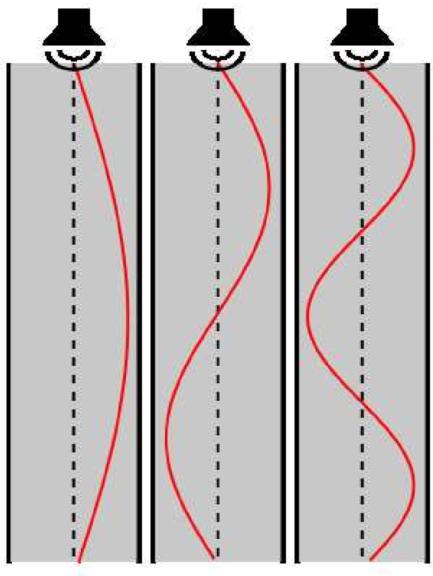


Figure 1: Pressure Distribution in an Open Tube: Source: Xavier Snelgrove, [2]

If the reflected wave is in phase with the incident wave they reinforce and create a *standing wave* in the air column. Where the incident and reflected waves add together (are *in phase*), they create an *antinode* (maximum amplitude point) in the pressure. Where they are out of phase, the incident and reflected waves cancel, creating a *node* (minimum amplitude point) in the pressure.

There is a minimum frequency for the resonance, referred to as *the fundamental* frequency. Additional resonances occur at multiples of this frequency, which are called *harmonics of the fundamental*.

If the driving frequency is swept over a range, there will be peaks in amplitude of the waveform at the fundamental and harmonic resonant frequencies.

Open Tube

The pressure distribution in an open tube is shown for the first three resonant frequencies in figure 1.

At the fundamental frequency, the maximum pressure occurs mid-column. At the second harmonic, a null occurs at mid-column and there are two maxima, at the 1/4 and 3/4 points in the column. At the third harmonic, maxima occur at the 1/6, 3/6 and 5/6 points in the column.

Consider an area of high pressure moving down the column. At the end of the column, the high pressure area vents into the atmosphere. Momentum of the air mass creates a low pressure area behind it, and the low pressure area now propagates back up the tube. In other words, the phase of the incident inverts at the opening to create the reflected wave. (Reference [3] has an excellent animation illustrating the behaviour of a sound wave in an open and closed tube.)

The resonant frequencies are given by [2]:

$$f = \frac{nv}{2L}$$

where f is the frequency in Hz, n is an integer (1,2,3...), v is the velocity of sound in air, and L is the length of the tube.

(For precision, the effective length of L is affected by the column diameter: L becomes $L + 0.8D$ where D is the diameter.)

Closed Tube

A closed tube resonates at frequency:

$$f = \frac{nv}{4L}$$

where f is the frequency in Hz, n is an odd integer (1,3,5...), v is the velocity of sound in air, and L is the length of the tube.

(Again, there is a correction term. The effective length of L is affected by the column diameter: L becomes $L + 0.4D$ where D is the diameter.)

In all cases of closed tube resonance, the pressure is at a maximum at the closed end. (This follows from the fact that the displacement of the air molecules must be zero.)

A high pressure area moving down the tube reflects off the rigid close end, so the phase of the reflected wave is the same as the phase of the incident wave.

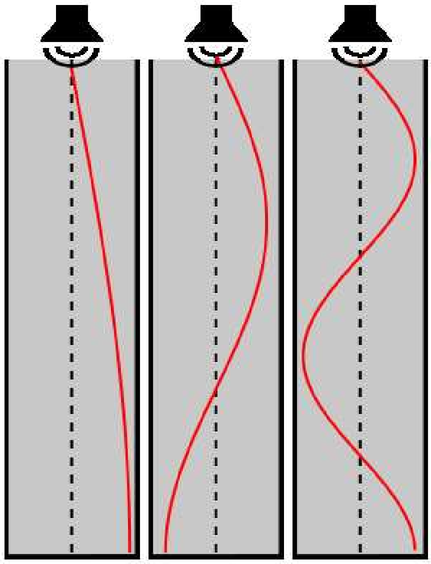


Figure 2: Pressure Distribution in a Closed Tube: Source: Xavier Snelgrove, [2]

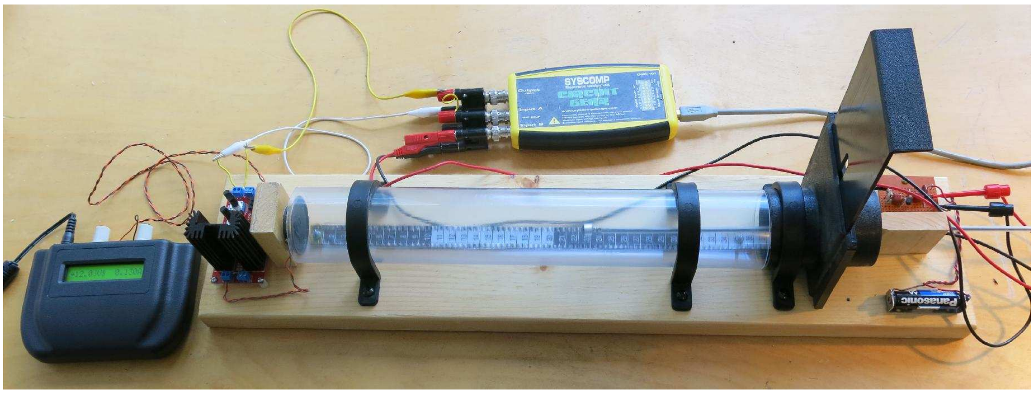
Resonance Apparatus

Figure 3 shows apparatus for demonstrating the resonance of an air column.

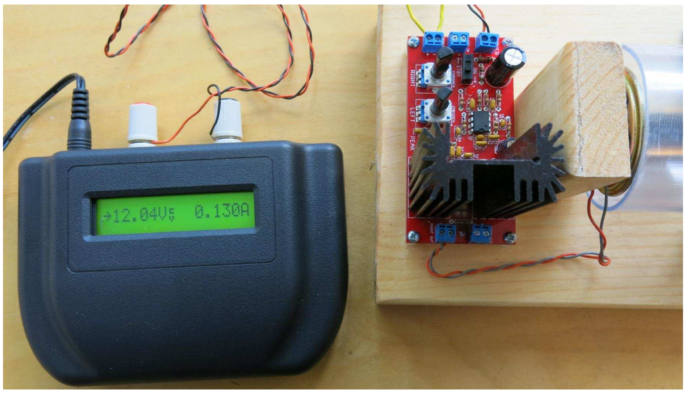
Figure 3(a) shows an overview. The air column is a clear plastic tube approximately 5cm in diameter and 40cm long. (see *Sources* below for suppliers of these components). A small loudspeaker [7] at the left end creates sound waves in the column. An electret microphone WM-034 [8], [9] is mounted on semi-rigid plastic tubing, which is supported in such a manner that it can be moved to various points inside the tube. RG-174 shielded cable brings the microphone signal through the tubing to the microphone preamplifier. A measuring tape on the inside of the tube helps position the microphone.

A *gate* at the right end of the tube can be in the open or closed position to show the acoustic behaviour for open and closed tubes.

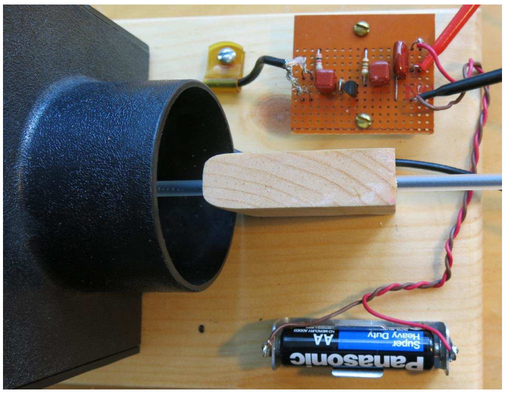
At the top of figure 3(a) is the Syscomp CGR-101 CircuitGear oscilloscope and signal generator. Operated from a personal computer host via a USB connection, the CGR-101 generates the audio signal. It also displays the loudspeaker and microphone waveforms. Figures 5 and 6 show examples of the CGR-101 user interface.



(a) Apparatus



(b) Power Supply and Audio Power Amplifier



(c) Microphone Amplifier

Figure 3: Acoustic Resonance Apparatus

Figure 3(b) shows the Syscomp PSM-101 power supply, which provides 12VDC to the Sparkfun audio power amplifier [6]. The power amp is a stereo unit: only one channel is used in this application. Each power amplifier output is a *bridged* drive, which means that the speaker terminals are driven in antiphase. (For a given output voltage, this quadruples the power in the loudspeaker.) When monitoring the loudspeaker voltage, you cannot connect an oscilloscope ground to either speaker terminal. Connect the oscilloscope between one of the amplifier output terminals and the amplifier ground.

The amplifier includes a volume control for each channel and a standby switch which mutes the output.

Figure 3(c) shows the microphone preamplifier and its 1.5 volt battery power supply. Notice the semi-rigid tubing which passes through a wood block, with a friction fit. The tubing can be slid left and right to position the microphone.

Microphone Amplifier

The maximum sensitivity of the CGR-101 oscilloscope is 50mV per division. The output of the electret microphone is much less, in the order of a few tens of millivolts. The microphone signal must be amplified to display it properly.

The electret microphone uses a 1.5 volt supply, so it would be convenient if the amplifier could use the same supply voltage. This is too small a supply voltage for most op-amps, but a single transistor amplifier can be made to work.

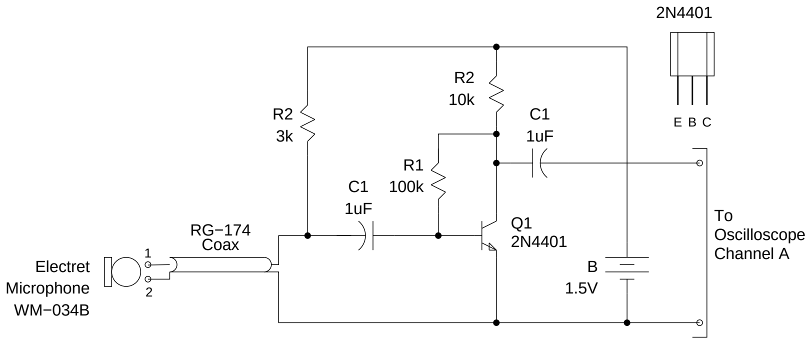


Figure 4: Microphone and Amplifier

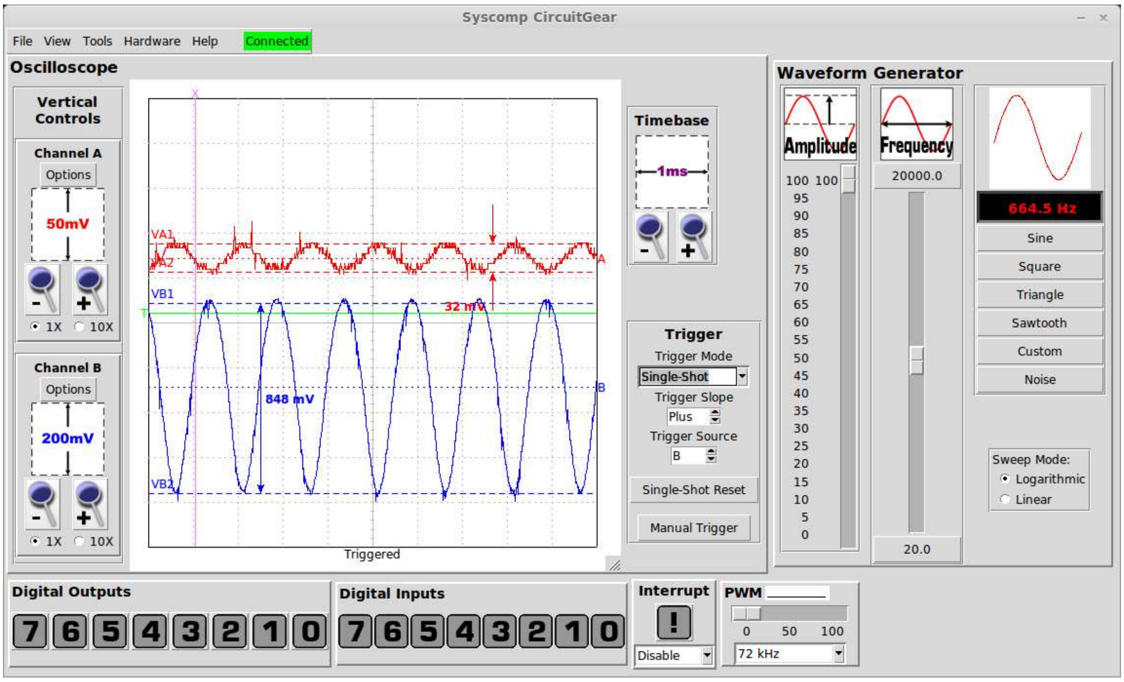


Figure 5: CGR-101 Screen Shot: Amplifier Waveforms: Channel A, Input. Channel B, Output

Figure 4 shows the schematic of the microphone preamplifier. The transistor Q1 is in the *shunt feedback* configuration. Because there is no emitter resistance, the collector voltage can swing almost the entire supply voltage, 1.5V, or ± 0.75V. The collector-emitter voltage can drop below the base-emitter voltage, to the saturation voltage, around 0.1 volts.

There is very little current through the feedback resistor R1, so the voltage at the base – approximately 0.7 volts – is the same at the collector. This puts the quiescent voltage at the collector at about half the supply voltage. If the collector voltage rises, the base current increases, and that tends to drive the collector voltage back down. Thus the feedback resistor R1 acts as a mechanism for bias stabilization.

The waveforms for the amplifier are shown in figure 5. According to the measurement cursors, the input signal is about 32mV peak-peak. The output is 848 mV peak-peak, which gives a voltage gain of 26.5 volts/volt.

With a 1.5 volt supply and at a resonant frequency the preamplifier may overload, resulting in a clipped output waveform. One should then reduce the loudspeaker signal by reducing the generator output amplitude.

The microphone amplifier was assembled on a small piece of Veroboard [10].

Loudspeaker Resonance

The loudspeaker is a mass-spring system which resonates at some frequency. The amplitude of the loudspeaker cone increases around the resonant frequency. (One of the purposes of a loudspeaker enclosure is to control that resonance.) The acoustic output of the loudspeaker decreases rapidly as the frequency is lowered below resonance.

In this project it's important to be able to recognize the loudspeaker resonance and differentiate it from acoustic resonances in the tube.

To measure the resonant frequency of the loudspeaker, connect the loudspeaker to the output of the CGR-101 waveform generator. The internal impedance of the generator is 150Ω, which is large compared to the speaker impedance. In this direct connection from a high resistance source, the voltage across the loudspeaker is proportional to its impedance.

Then sweep the frequency while monitoring the voltage across the loudspeaker. In this case, we found the loudspeaker resonance to be exactly 500Hz.

The loudspeaker resonance can be differentiated from an acoustic resonance. Monitor the loudspeaker voltage and microphone signal while sweeping through the loudspeaker resonance. The signals should increase and decrease in unison. In contrast, when sweeping through an acoustic resonance frequency the microphone signal goes through a maximum (increases and then decreases) while the loudspeaker signal does not change amplitude.

Measuring Resonant Frequency

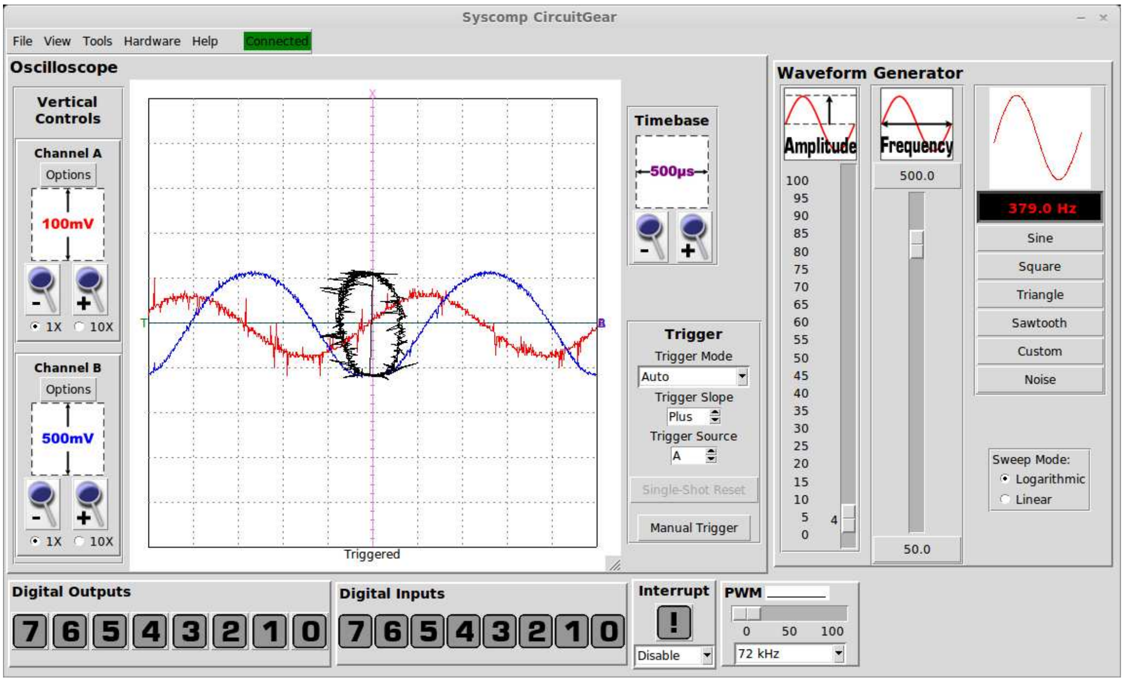


Figure 6: CGR-101 Screen Shot: Resonance Display

Figure 6 shows a typical display of an acoustic resonance. The red trace is the loudspeaker signal. The blue trace is the microphone signal.

A very precise measurement of resonant frequency can be obtained using a *lissajous* display [5]. A Lissajous figure is an XY plot of the voltages of the two oscilloscope channels. For example, if the two signals have the same amplitude and phase, then the resultant display will be a straight line with $+45^\circ$ slope. If the two signals differ in amplitude and phase, then the lissajous figure is an ellipse.

The black circle on the oscilloscope screen in figure 6 is the lissajous figure at resonance. The air column is at resonance when the axis of that ellipse is exactly vertical, that is, the speaker signal and the microphone signal are 90° out of phase.

The CGR-101 waveform generator has useful features for adjusting the frequency. One can change the maximum and minimum settings for the frequency slider so that, for example, the range is between 100 and 500Hz. Click on the box at the top or bottom of the slider and enter a new maximum or minimum value for the slider. This allows the operator to *zoom in* on a particular range of frequencies. As well, one can directly enter the oscillator frequency by clicking on the frequency display.

Results

The acoustic resonances are easy to detect – from the loudness of the sound, the amplitude of the microphone waveform, and the shape of the lissajous figure.

Tube Configuration	Mode	Measurement Point	Predicted Frequency, Hz	Measured Frequency, Hz
Open	Fundamental (F)	$1/2L$	340	380.4
	2F	$1/4L$	680	783
	3F	$1/2L$	1020	1103
Closed	Fundamental (F)	L	194	Note 1
	3F	L	582	507
		L		Note 2
	5F	L	970	1109

Note 1: Exciting the closed tube at 184 Hz causes frequency doubling in the tube at 365 Hz.

Note 2: There is an additional strong resonance at 753Hz. This is double the open column fundamental frequency, so may be related to imperfect sealing of the air column at the ends.

The open tube resonances were reasonably close to the predicted values. (A correction for the *actual* vs *nominal* speed of sound might increase the accuracy.)

The closed tube resonances show some anomolies - possibly because there is a slot in the gate, and an open area around the loudspeaker.

Sources

- Loudspeaker, microphone, power amplifier, test leads
  Creatron, 349 College Street, Toronto.
  `www.creatronic.com`
- Plastic tube, clamps, gate: *Dust Collection Network*
  Lee Valley Tools, 590 King St W, Toronto.
  `https://www.leevalley.com`
- Centimetre tape measure
  Absolute Dollar, Gerrard Square, Gerrard Street, Toronto.
  `http://www.wikito.org/Absolute_Dollar_-_Gerrard_Square`
- Syscomp CircuitGear CGR-101 Oscilloscope, Syscomp PSM-101 DC Power Supply:
  Syscomp Electronic Design, Toronto
  `www.syscompdesign.com`
- Veroboard. Appears to be available from Amazon. Search for:
  Veroboard and *Prototype Universal Stripboard 8"x16" (205x410mm) 13000hole Epoxy Fiber*
  Be wary of the the knockoff products.

- Semi-rigid tubing
  Johns Photo-Hobby, 2188 Danforth Avenue, Toronto
  http://www.johnshobbies.ca/main

References

[1] *Air Column Resonance*
Carl R. (Rod) Nave, Department of Physics and Astronomy, Georgia State University
http://hyperphysics.phy-astr.gsu.edu/hbase/waves/opecol.html#c1

[2] *Acoustic Resonance*
http://en.wikipedia.org/wiki/Acoustic_resonance

[3] *Open vs Closed pipes (Flutes vs Clarinets)*
http://www.phys.unsw.edu.au/jw/flutes.v.clarinets.html

[4] *Standing Waves and Acoustic Resonance*
David Harrison, University of Toronto, October 1999
http://faraday.physics.utoronto.ca/IYearLab/stwaves.pdf

[5] Lissajous Figure
http://en.wikipedia.org/wiki/Lissajous_figure

[6] Audio Amplifier Kit - STA540
https://www.sparkfun.com/products/9612

[7] Speaker - 0.5W (8 ohm) COM-09151
https://www.sparkfun.com/products/9151

[8] Data sheet for the WM-034B electret microphone.
http://www.panasonic.com/industrial/components/pdf/
em16_microphone%20schematic_dne.pdf

[9] Pin locations on the WM-034B microphone.
http://www.ebay.com/itm/2x-Panasonic-WM-034CX-
Omnidirectional-Electret-Condenser-Microphone-Cartridge-/400516992911

[10] Veroboard
http://en.wikipedia.org/wiki/Veroboard