

Hands-On Learning

Microphone and Oscilloscope

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Introduction

A microphone can be used with an oscilloscope to see the waveforms of various sounds. The oscilloscope may be used to view the shape of the waveform, the spectrum or the frequency response of a loudspeaker or microphone. The speaker and microphone can be used to explore acoustic resonance in an air column¹.

In this lab exercise, we show the connections for two types of microphones, and an amplifier for these microphones.

Dynamic Microphone

A dynamic microphone consists of a flexible diaphragm attached to a coil of wire. The coil of wire is immersed in a magnetic field. When sound strikes the diaphragm it moves the coil, and the coil generates an electrical signal.

The operating equation is:

$$e = N \frac{d\phi}{dt} \text{ volts}$$

where e is the voltage generated, N is the number of turns on the coil, and $d\phi/dt$ is the rate of change of the magnetic flux in the coil.

A dynamic loudspeaker (which is the usual kind) works in reverse: a current through the coil causes the coil to move, which in turn moves the diaphragm, creating a sound wave.

A dynamic loudspeaker will function as a serviceable microphone. The audio quality is acceptable for speech. A loudspeaker is often used as a microphone in intercom applications.

The dynamic microphone is quite rugged and requires no external source of power, so it's simple to use. In normal operation the output electrical signal is in the order of a few tens of millivolts.

Electret Microphone

An electret is the electric analog of a magnet. It stores an electric field. In an electret microphone, there is a flexible, metal-coated diaphragm located near the electret. The diaphragm and the electret form the two plates of a capacitor.

Sound strikes the diaphragm and causes it to move. This changes the spacing between the two plates of the capacitor, which changes the capacitance. In effect, the charge on the capacitor is fixed, so the voltage changes at the terminals of the capacitor.

Now the equations: the capacitance of a parallel plate capacitor is:

$$C = \frac{\epsilon A}{S} \text{ Farads}$$

where ϵ is the dielectric constant (in this case, the dielectric constant of air), A is the area of the plates, and S is the spacing of the plates. Sound causes the spacing S to vary, which causes the capacitance to vary.

The charge on a capacitor is given by:

$$Q = CV$$

¹See for example the excellent lab exercise description *Standing Waves and Acoustic Resonance* by David Harrison at <http://faraday.physics.utoronto.ca/IYearLab/stwaves.pdf>

where Q is the charge (fixed, on the electret in this case), C is the capacitance, and V the terminal voltage of the capacitor.

Substituting from the first equation for C and rearranging to solve for the voltage, we have:

$$V = \frac{Q}{C} = \frac{Q}{\epsilon A} S$$

The quantities Q , ϵ and A are all constants. As the spacing S varies, so changes the terminal voltage.

The electret microphone is capable of very good fidelity. It can have a flat frequency response over the entire range of audio frequencies. However, the output impedance of the electret capsule is very high and must be buffered by an amplifier before driving any connecting wires. This is usually provided by a field-effect transistor (FET) inside the microphone capsule. The FET requires external power to operate - typically 1.5 to 5 volts at a few milliamps. (Some computer sound cards provide the necessary power for an electret microphone.)

Amplifier

The maximum sensitivity of the CGR-101 is 50mV per division. The output of the dynamic and electret microphones is much less, in the order of a few tens of millivolts. To be able to properly display the microphone signal, we need an amplifier.

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.

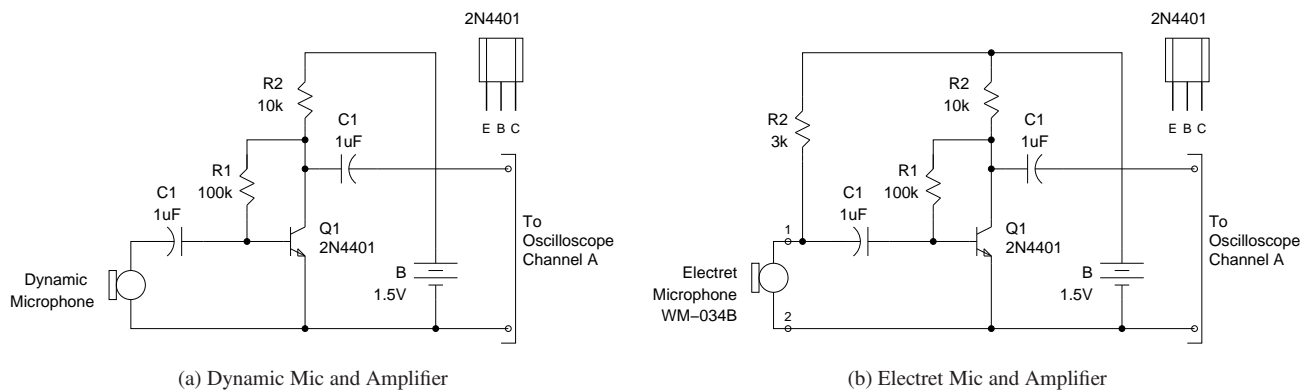


Figure 1: Microphone and Amplifier

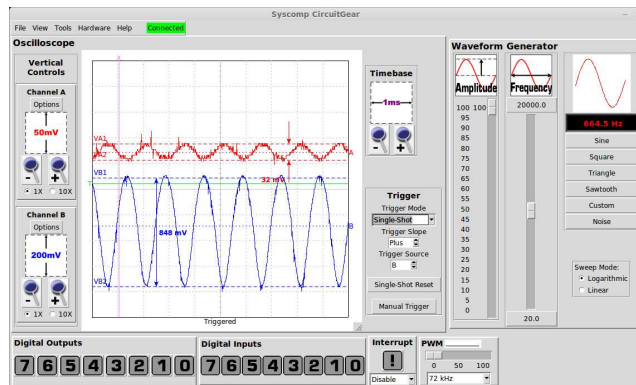
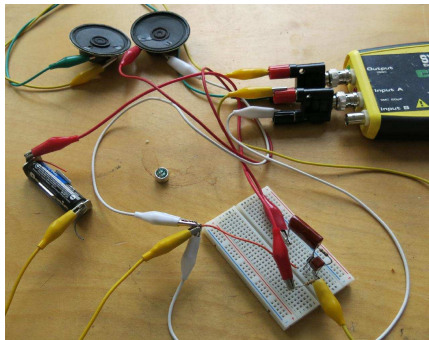


Figure 2: Amplifier Waveforms: Channel A, Input. Channel B, Output

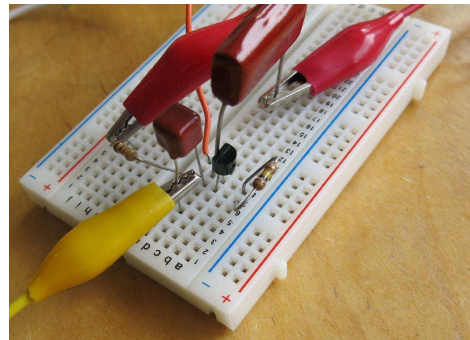
Referring to figure 1, the transistor Q1 is in the *shunt feedback* configuration. Because there is no emitter resistance, the collector voltage can swing almost the entire supply voltage, 1.5V, or $\pm 0.75V$. The collector-emitter voltage can drop below the base-emitter voltage, to the saturation voltage, 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 2. 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.



(a) Overview



(b) Amplifier Closeup

Figure 3: Microphone, Speaker and Amplifier

An overview of the test circuit is shown in figure 3(a).

The amplifier is connected to the microphone and oscilloscope by clip leads, which are prone to behave like antennas and pickup radio frequency signals. In this type of construction the circuit works well enough to prove the concept, but for permanent use you'd want to construct a tidier, more compact version with shielded input and output leads.

The two loudspeakers are at the top of the image. One is used as a dynamic microphone. The other is used as a loudspeaker, connected to the generator output of the CGR-101. The 1.5 volt battery powering the amplifier is to the left of the image. In the centre is the tiny electret microphone cartridge, not connected in this circuit.

A closeup of the amplifier circuit is shown in figure 3(b).

Applications

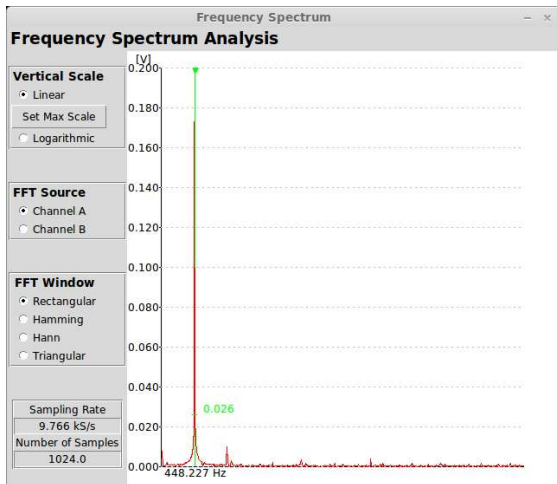
Figure 4 shows some ways in which the features of the CircuitGear CGR-101 can be used with a microphone input. In both cases, the sounds were generated by the loudspeaker, which was closely coupled to the microphone (an identical loudspeaker)

The waveform of a pure A440 tone is of course a sine wave. In spectral terms, this is one frequency only. Figure 4(a) shows the spectrum analysis display of an A440 tone.

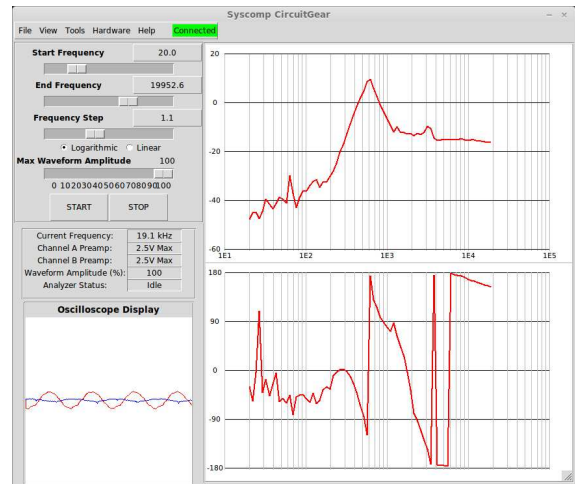
The CGR-101 also has the capability of measuring amplitude and phase response over a wide range of frequencies. Figure 4(b) shows the response of the microphone-loudspeaker pair. The phase response is not very helpful, but the amplitude response clearly shows the peak around 600 Hz corresponding to the mechanical resonance of the loudspeaker mass-spring system. This resonant frequency is an important parameter in loudspeaker enclosure design.

Projects

Once you have a working microphone-amplifier system and an oscilloscope like the CGR-101 to display the waveforms, here are some possible projects:



(a) Spectrum of A440



(b) Speaker Frequency Response

Figure 4: Applications

- Capture various sound waveforms and compare them. For example, what is the difference between a note from a piano and the noise of an air conditioner? How do the waveforms compare? How do the spectrum diagrams compare? (Hints: Use the CGR-101 oscilloscope on single-shot triggering to capture a waveform. The use screen capture or save the waveform to memory to obtain a permanent copy.)
- Run the frequency response curve for the loudspeaker-microphone in open space. Then put the microphone and loudspeaker in an enclosed space. Rerun the frequency response curve. Note and explain the difference between the two curves. One interesting variant of this is to use an enclosure that is acoustically resonant, such as a length of drain pipe.
- Capture and compare the same frequency (such as A440) from different musical instruments. Identify the differences in waveform and spectrum.
- Find a particularly annoying source of acoustical noise. Capture the waveform and run a spectrum analysis on it. See if you can identify and specific features of the noise. For example, are there tones (such as 60Hz and 120Hz) present in the noise?
- Capture an impulse waveform – such as caused by dropping the microphone onto a surface, or from a percussion instrument. Compare the waveform and spectrum with a pure tone.

Appendix: Estimating the Amplifier Gain

Ignore the feedback resistor for a moment. Then the open-loop (without feedback) gain of the amplifier is R_c/r_e , where R_c is the collector resistance and r_e the emitter incremental resistance².

As well, $r_e = 0.026/I_E$, where I_E is the emitter bias (DC) current. OK, let's work this backwards.

The voltage across R_c is about 0.75 volts DC. So the current through it is:

$$I_c = \frac{0.75}{R_c} = \frac{0.75}{10000} = 75 \times 10^{-6} \text{ amps}$$

Collector and emitter current are very nearly equal if the current gain is reasonably high (which it is in most small signal transistors, like this one.) Then the emitter incremental resistance is:

²The emitter incremental resistance is often called r'_e (pronounced are-eee-prime). It is the slope of the base-emitter diode current-voltage characteristic.

$$r_e = \frac{0.026}{I_E} = \frac{0.026}{75 \times 10^{-6}} = 346 \text{ ohms}$$

Now we can estimate the open loop voltage gain:

$$A_v = \frac{10000}{346} = 28.8 \text{ volts per volt}$$

What is the effect of the feedback resistor R_1 ?

Treating the transistor as an operational amplifier, the closed loop gain is R_f/R_i . In this case, $R_f = 100000$ ohms. R_i is the impedance of the loudspeaker, about 8 ohms. Then the closed loop gain would be $100000/8 = 12,500$ volts per volt. However, for the closed loop gain to apply, the open loop gain must be much larger than the closed loop gain – and in this case, it's not. Put another way, the gain is the lesser of the open and closed loop gains. In this case, that's the 28.8 volts/volt figure we calculated earlier.

The actual measured gain is 26.5 volts per volt, which is reasonably close to the predicted value.

Appendix: Amplifier Capacitors

Capacitor C1 blocks the transistor base terminal bias voltage from driving current through the low resistance of the microphone. Capacitor C2 removes the DC voltage at the output of the amplifier, so that the oscilloscope displays only the AC component of the signal.

We need to ensure that the reactance of the coupling capacitors – at the lowest operating frequency – is lower than their load resistance.

As shown in the VNA results, the frequency response of the loudspeaker-dynamic-microphone combination falls off below about 600Hz. The reactance slide rule³ shows that the reactance of the $1\mu\text{F}$ capacitors is about 300 ohms at 600Hz.

Capacitor C1 sees an impedance equal to the input impedance of the transistor amplifier, which is approximately equal to $\beta \times r_e$. With a minimum value for β of 20, the input resistance is at least 6900 ohms, so the impedance of C1 is much less than required.

Capacitor C2 sees an impedance equal to the oscilloscope input, which is about $1\text{M}\Omega$. So it too is much lower reactance than its load resistance.

For more on the design of amplifiers, you could read *Analog Circuit Design*, the eBook available through Syscomp.

References

The data sheet for the WM-034B electret microphone is here:

http://www.panasonic.com/industrial/components/pdf/em16_microphone%20schematic_dne.pdf

A diagram showing the pin locations on the WM-034B is here:

<http://www.ebay.com/itm/2x-Panasonic-WM-034CX-Omnidirectional-Electret-Condenser-Microphone-Cartridge-/400516992911>

³HP Memory Project - Virtual Slide Rule: http://www.hpmemory.org/pict/technics/applet/slide_rule/reactance.htm