

AM Modulator and Ultrasonic Transceiver

In this lab you will construct a circuit to produce a 40kHz amplitude-modulated (AM) carrier, which is the final circuit block needed to complete our ultrasonic transceiver system. We will combine this modulator with the microphone circuit from Lab #2 and an ultrasonic transducer to make an AM transmitter. We will then combine the AM demodulator from Lab #3 with an ultrasonic transducer and the Audio amplifier from Lab #2 to make the receiver. The Power supply from Lab #1 will be used to power the receiver circuit.

By studying this document and experimenting with the components and circuits in the lab, try to understand the following:

- Use of multiplier circuits for modulation
- Relaxation oscillator design
- Use of filters for wave shaping
- Characteristics of ultrasonic transducers
- Some elements of acoustic wave propagation
- Basics elements of communication link design

As you construct the circuits, try to understand the role of each component, and how the choice of component value may influence the operation of the circuit.

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Pre-Lab Preparation

Read through the lab experiment and data sheets to familiarize yourself with the components and assembly sequence. Bring your solderless breadboard, soldering iron, tools, wire jumpers, audio-amplifier and power supply from lab #1-2, and AM Modulator from Lab #3.

Optional: simulate the modulator using Circuit Maker or MultiSim (circuit file available on the course web site).

Required Equipment List

Solderless breadboard and Wire jumper kit

Soldering iron and stand

Lab #1 Power Supply

Lab #2 Audio Amplifier and Microphone Circuit

Lab #3 Demodulator Circuit

Bench Function generator , power supply, and oscilloscope

Schedule for Lab #4

To stay on schedule, you must complete the lab in two sessions as follows:

Week #1: Complete Steps 1-2 (AM Modulator)

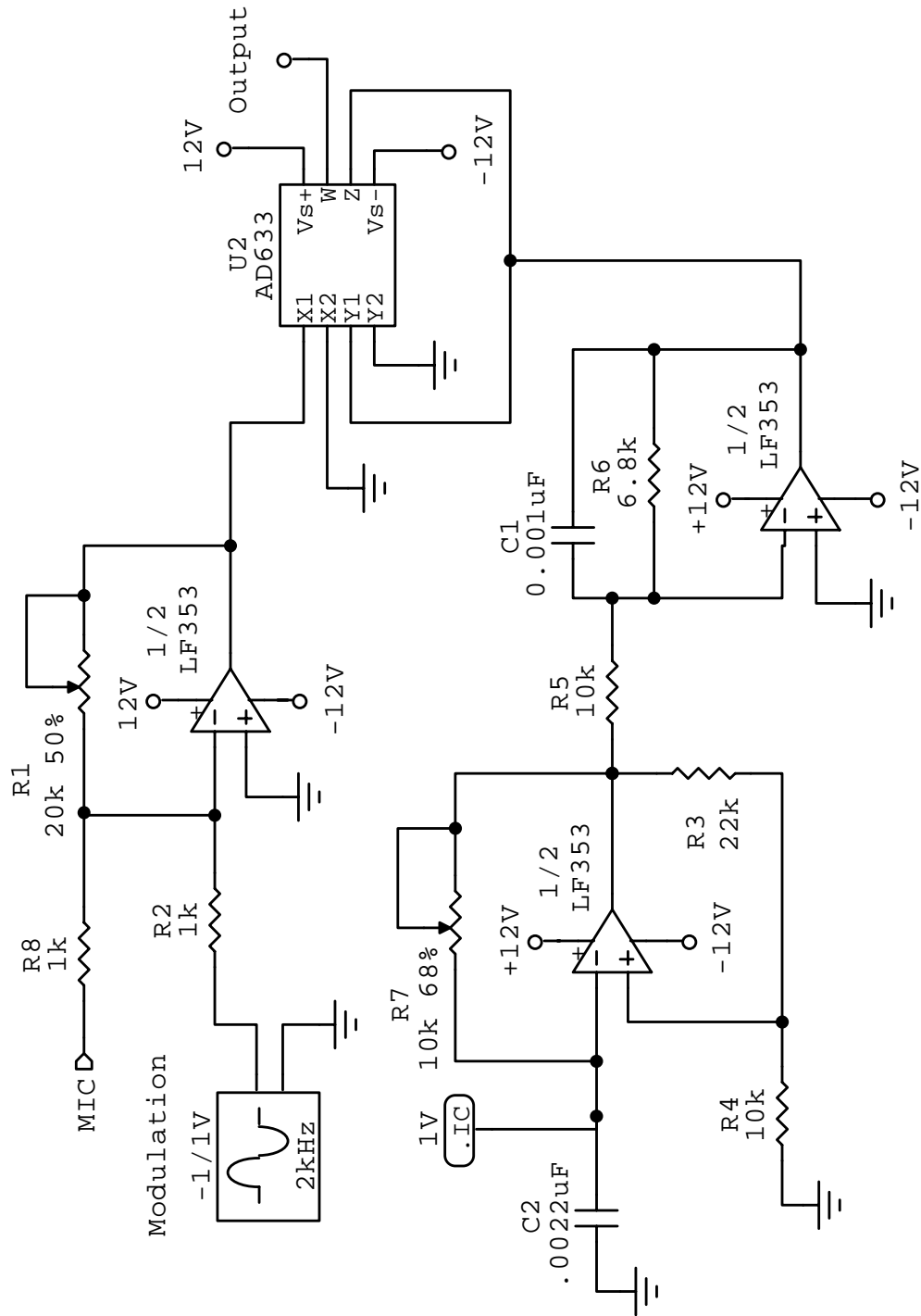
Week #2: Complete Steps 3-5 (Complete ultrasonic link)

Also: double check your kit against the parts list below . If you are missing parts, contact the ECE Shop to remedy the situation quickly.

Parts List

Qty	Description	Circuit
1	Jameco 40KHz Ultrasonic Transducers (T/R pair)	
1	AD633 Low Cost 4-Quadrant Analog Multiplier	
3	LF353 Dual Wide-band JFET Op-amp	
3	8-pin low-profile IC socket	
1	4.5" x 2.5" Vectorboard	
1	0.001uF capacitor (CKO5 low-volt. Ceramic)	C1
1	0.0022uF capacitor (CKO5 low-volt. Ceramic)	
6	0.1uF capacitor (CKO5 low-voltage ceramic)	
1	10k trimpot	R7
1	20k trimpot	R1
2	1kOhm 1/4W	R2
1	6.8kOhm 1/4W	R6
2	10kOhm 1/4W	R4-5
1	22kOhm 1/4W	R3
7	flea clips	
4 ft	#22 stranded wire (black)	
4 ft	#22 stranded wire (red)	

Schematic for Lab #4



Schematic for the AM modulator.

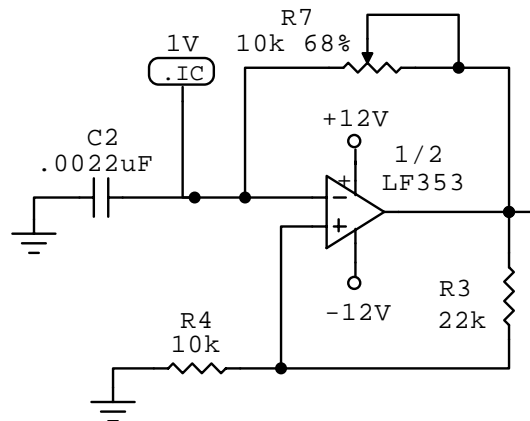
In-Lab Procedure

Follow the instructions below **CAREFULLY**. Failure to do so could result in serious damage to the lab equipment, destruction of parts, and possible injury to you and your lab partner.

- Each step begins with a check box like the one at the left. When you complete a step, check the associated box. At the end of this document is a **LAB RECORD** in which you will record key observations and results from the experiment. When you are finished with the lab, you must demonstrate a working circuit and a completed lab record, and get this signed and certified by one of the lab TAs.

Step 1 – Relaxation Oscillator

In class we discussed a simple oscillator circuit called a relaxation oscillator. We will use this topology to generate a 40kHz carrier signal for the AM modulator. The circuit is shown below. This oscillator derives its name from the periodic charging and discharging of the capacitor, which is sometimes referred to as a “relaxation” process. This circuit is also called an “astable multivibrator”, or simply a “square-wave generator”.



Relaxation oscillator.

The time-constant of the relaxation process is set by R7-C2. Resistors R3-R4 form a voltage divider that sets the critical value of capacitor voltage which causes the op-amp output to change sign. As we derived in class, the oscillation period is set by

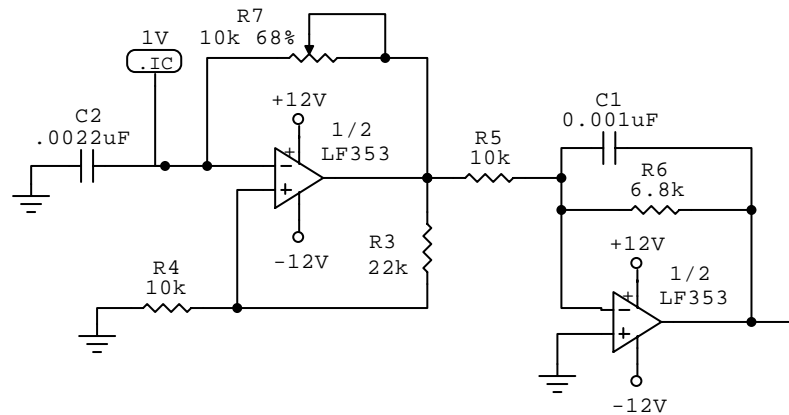
$$T = 2R_7C_2 \ln \left(1 + \frac{2R_4}{R_3} \right)$$

By making R7 a variable resistor (trimpot), we can easily adjust the oscillation period.

- First add your op-amp onto your breadboard and provide power connections and bias decoupling capacitors for each chip.
- Construct the relaxation oscillator circuit. Apply power and observe the output waveform on the oscilloscope. Adjust the trimpot so that your circuit generates a 40kHz signal, and

record this in the lab record. Note the output amplitude and the risetime slope or “slew-rate” on the waveform edges.

- Now add the integrating filter as shown below. The purpose of this circuit is simply to smooth out the sharp edges of the square-wave which can lead to ringing when we drive the ultrasonic transducer, which is a resonant piezoelectric device. We also use this stage to reduce the output amplitude to approximately 5 V peak. Record the output waveform in your lab record.



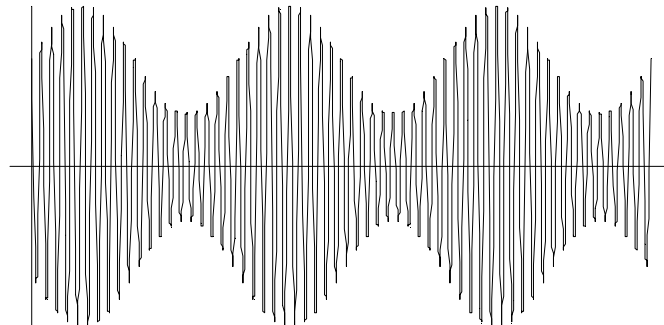
Oscillator with integrating buffer (bypass capacitors not shown).

Step 2 – AM Modulator

In the last lab we started discussing the basics of AM modulation, and built a circuit to *demodulate* the signal. Now we need to build a circuit to *generate* an AM modulated signal. If our information-bearing signal is represented as $v(t)$, and the carrier signal is represented as $\cos \omega_c t$, then the AM signal is given by

$$f_{AM}(t) = (1 + m v(t)) \cos \omega_c t$$

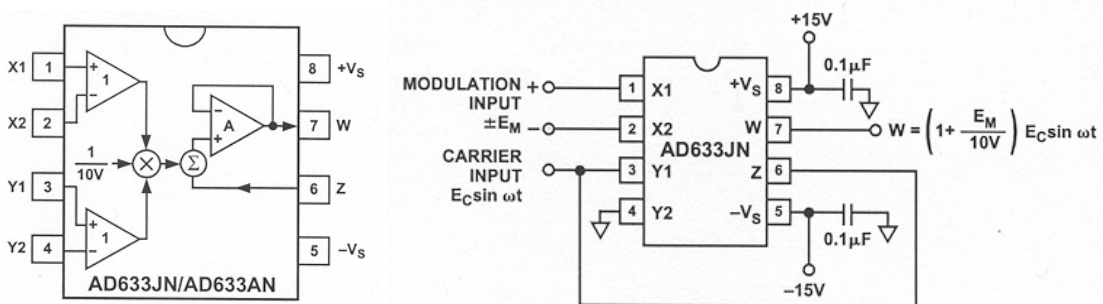
where m is the so-called *modulation index*, $0 < m \leq 1$. The figure below shows an AM modulated signal with $v(t) = \sin(\omega_c t / 20)$ and $m = 0.5$.



Amplitude modulated sine wave (sinusoidal modulation) with $m = 0.5$.

With reference to the above equation, we see that to generate an AM signal, we need to multiply the carrier sinusoid by our modulating signal. Multiplication of two signals is a

common requirement in electronics, and specialized multiplier circuits have been developed for this purpose. We will use a particularly simple and low-cost chip from Analog Devices, the AD633 4-Quadrant multiplier. At this time it would be appropriate to review the data sheet for this device, if you haven't done so already.



AD633 pin diagram and hookup for a linear AM modulator (from data sheet).

The pin diagram for the AD633 is shown above. The chip is designed to implement the following analog function:

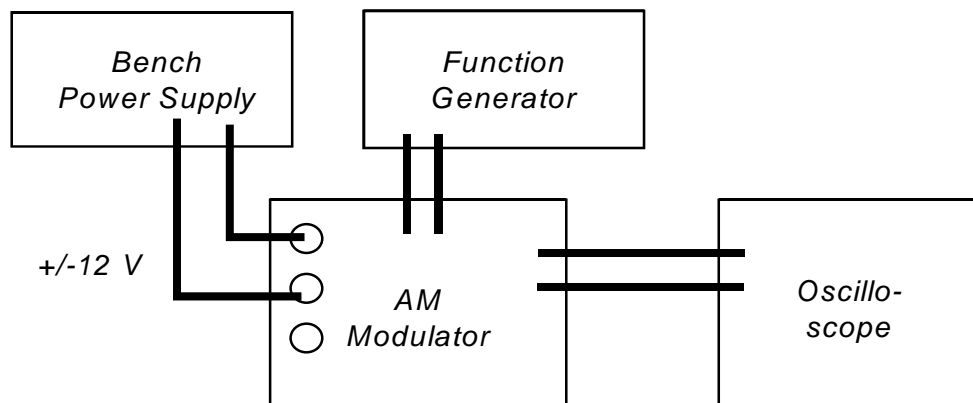
$$W = \frac{(X_1 - X_2)(Y_1 - Y_2)}{10} + Z$$

where the variables correspond to voltages on various pins of the device (see figure), and all are in units of Volts. If we ground X_2 and Y_2 and connect pins 8 and 3 so that $Y_1 = Z$, then

$$W = Y_1(1 + X_1/10)$$

Comparing this with our desired result, we can see that our AM signal can be obtained by making Y_1 the carrier and X_1 the modulating signal.

- Construct the AM modulator circuit as shown in the master schematic, with the AD633 configured as an AM modulator. Remember to add bias decoupling capacitors. The 20k trimpot (R1) is part of an inverting amplifier that controls the gain of the modulating signal and hence the modulation index.



- Test your circuit using the setup shown above. Use a 1kHz sinusoid from the bench function generator to provide a modulating signal. Adjust the function generator amplitude

and/or R1 to obtain nearly 100% modulation index, and record the waveform on the lab record.

- Now connect the microphone circuit from Lab #2 and test that you can AM modulate the carrier with your voice.

Step 3 – Hardwire the Transmitter Circuit

- Transfer your completed design to vectorboard. Be sure to including your microphone circuit from Lab #2, but do not connect it to the modulator just yet, as we will perform the initial testing using the function generator. Your board should have three power-supply connections (+/- 12V and GND), and two connections (Signal/Gnd) for hooking up the external function generator to the modulator. We will soon be adding the ultrasonic transducers.

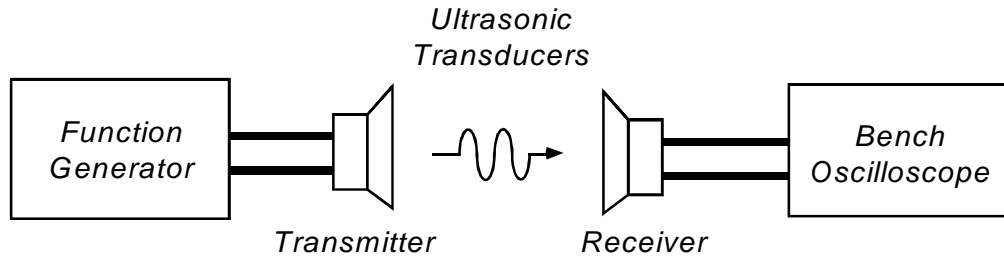
Step 4 – Ultrasonic Transducers

Now we have all the circuit components we will need to assemble our transceiver system. The last ingredient is the ultrasonic transducers: the devices that will generate or receive the ultrasonic wave. We will use a pair of transducers designed for operation around 40kHz.



Ultrasonic transducer attached to wire leads.

- Locate the transducers in your parts kit. They resemble the condenser microphones that we used in Lab #2. One is marked with a “T” to identify it as the transmitter. Solder wire leads to each as shown in the figure above. Use 18-24” of wire so that the transmitter and receiver can be well separated during operation.



Testing the ultrasonic transducers.

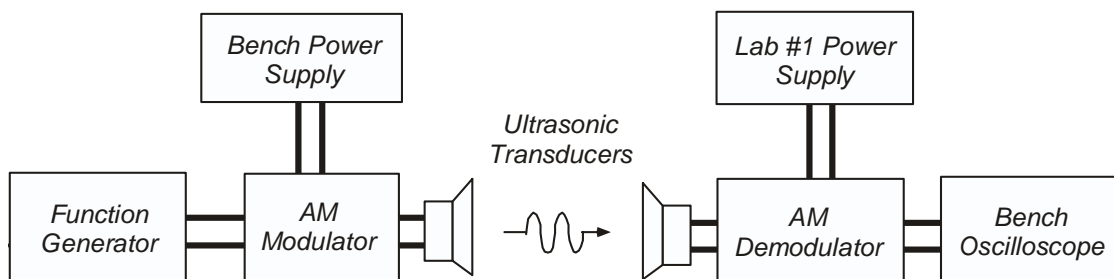
- Perform a simple test of the transducers as shown above. Drive the transmitter with a 10V (peak) sinusoid at 40kHz using the function generator, and observe the received signal on the oscilloscope. Experiment with varying separations and transducer orientations and observe the effect on the link loss.

Step 5 – Putting It Together

Now we are ready to start assembling the complete system! Be advised that this is probably the most difficult part of any engineering project. Components that seem to work in isolation often have a tendency to do strange and unpredictable things when hooked together into a larger system. Getting any complicated electrical system to work is a difficult art that is only mastered by experience and perseverance—not to mention a solid foundation in circuit theory!

The complete transmitter and receiver schematics are attached at the end of this document. You may wish to refer to these during the following steps.

- Lets first test our ability to transmit and receive an AM modulated signal and demodulate it. Connect your AM modulator and demodulator circuit blocks as shown below. The function generator will be used as the modulating signal, and we will observe the output on the oscilloscope.



Add the modulator and demodulator sections.

- Power up the circuit and test it with a 1kHz input signal, similar to the test from Step 2. If everything is working properly, the received and demodulated signal should be a close replica of the transmitted signal. Answer questions in the lab record, and demonstrate this

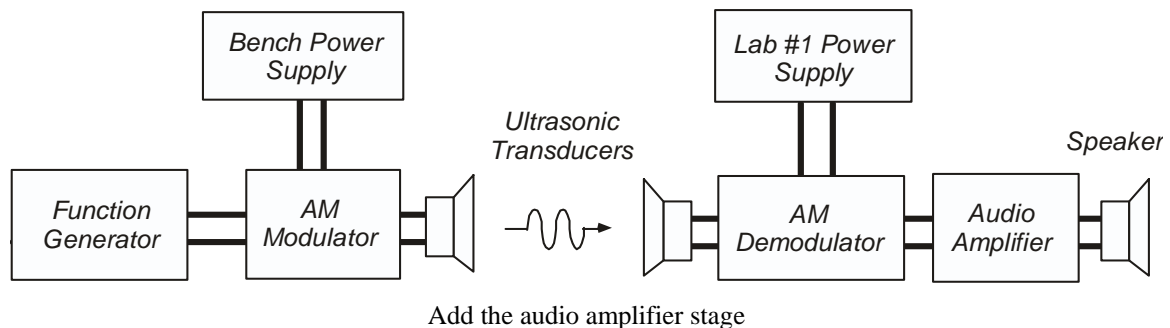
working link to the TA. Congratulations on your first working wireless transceiver system!

- For large separations between transducers, you may need some extra gain in your receiver just prior to the rectifier stage. There are several places in your circuit where you can adjust resistors to increase the gain as needed.
- Estimate the 3dB bandwidth of the link by sweeping the input signal frequency and observing the output signal strength. You may need to make some slight adjustments in the carrier frequency and modulation index (via the appropriate trimpots) in order to maximize the bandwidth and/or flatten the frequency response. When you have fine-tuned your system, record the 3 dB bandwidth in the lab record.

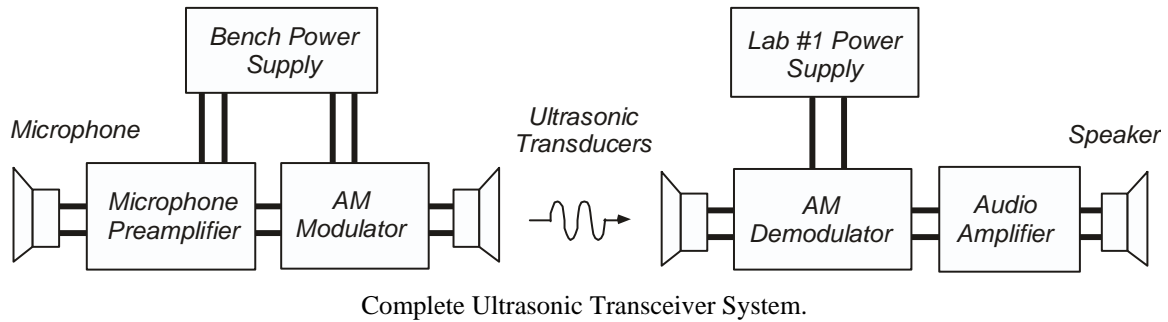
Step 6 – Adding the Amplifier and Microphone Stage

We can make the system more functional by incorporating our microphone and audio-amplifier circuits from Labs #1-2 to form a one-way voice communications channel. This last step will therefore combine all of your ECE 2C modules into one working system.

- First, add the audio amplifier as shown below. Use your power supply from Lab #1 to provide power to the receiver circuit. (In my prototype design, using separate supplies for the transmitter and receiver proved to be essential in order to minimize parasitic feedback coupling to the high-gain microphone preamplifier through the bias lines). Test your circuit by sweeping the input frequency over the audio spectrum and listening to the output. Demonstrate this working link to the TA.



- Finally, add the microphone preamplifier stage as shown below. This is the most problematic stage, since it introduces regenerative feedback due to pickup from the audio speaker. Try to separate the speaker from the microphone, and orient them so they face away from each other. Also be sure to remove the capacitor C2 from your microphone circuit. This is no longer necessary because of the limited bandwidth of the ultrasonic transducers.



- Start with the audio amplifier volume turned down and monitor the output of the AM modulator on the oscilloscope. Adjust the preamplifier gain (20k trimpot) so that a normal speaking voice yields a reasonably large modulation index. If you find that you have too much gain in your circuit (or not enough), adjust some of the resistor values accordingly. There is a well-stocked resistor cabinet in the lab near the door.
- Next, slowly increase the audio amplifier volume until an audible signal is received. Depending on the separation of the transducers and the orientation of your microphone and speaker, you may encounter feedback oscillations. Adjust your components as needed to maximize the audio output while maintaining oscillation-free operation. Demonstrate your working circuit to the TA.

Congratulations on completing the ECE 2C Labs!

Possible Improvements

Even under the best conditions, the performance of this system is limited, largely due to the quality of the microphone, ultrasonics transducers, and audio speaker. Nevertheless, the system incorporates most of the key features of any communications link. If you were able to get the system working, congratulations on a significant accomplishment in your electronics education!!

The limited bandwidth of the ultrasonic transducers is one of the key problems with this system, at least as far as analog audio transmission is concerned. Better transducers are available, of course, but they are expensive. One possible improvement that we mentioned in Lab #3 is to shape the frequency-response of the receiver circuit to compensate for the transducers. This would require a filter that has an increasing gain for higher frequencies to compensate for the reduced response of the transducers at higher frequencies. In fact, the tone-control circuit in Lab #2 is a simple way of accomplishing this. The use of AM modulation is also a limitation, better results could be used with other modulation formats, but at the expense of increased complexity in the hardware. For transmission of simple low-bit-rate digital information, such as in a remote control application, a pulse-code modulation format would be perfect.

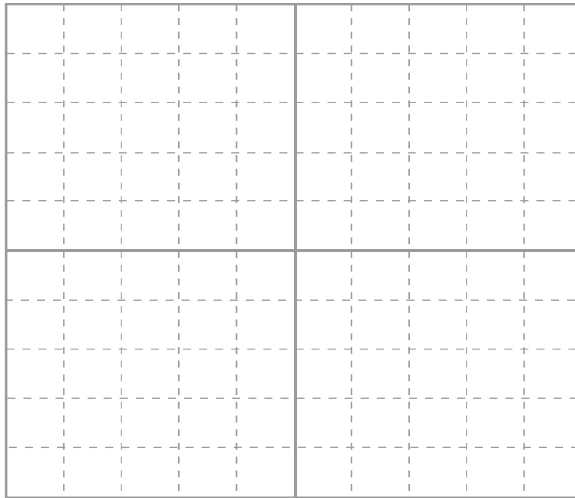
Lab 4 Record

Lab Section: _____

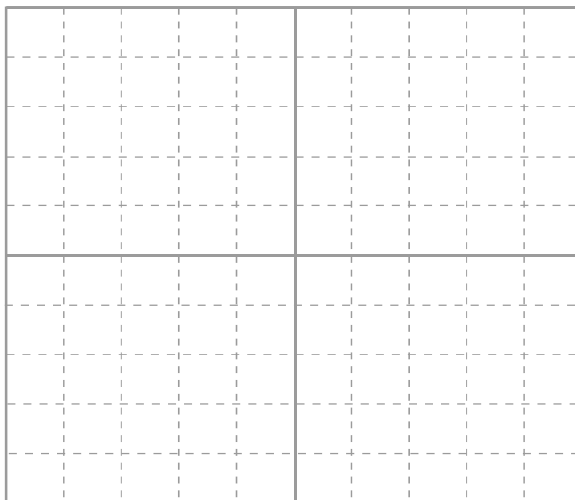
Names: _____

Step 1 – Relaxation Oscillator

Record the unbuffered 40kHz output waveform:

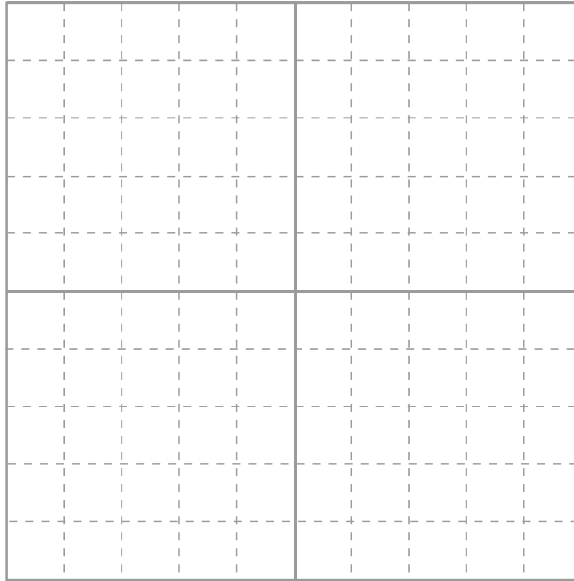
What is the slew rate on the leading and trailing edges: _____ V/ μ s

Record the buffered 40kHz output waveform:



Step 2 – AM Modulator

Record the output waveform of the AM modulator with a 1kHz modulating signal and 100% modulation index:



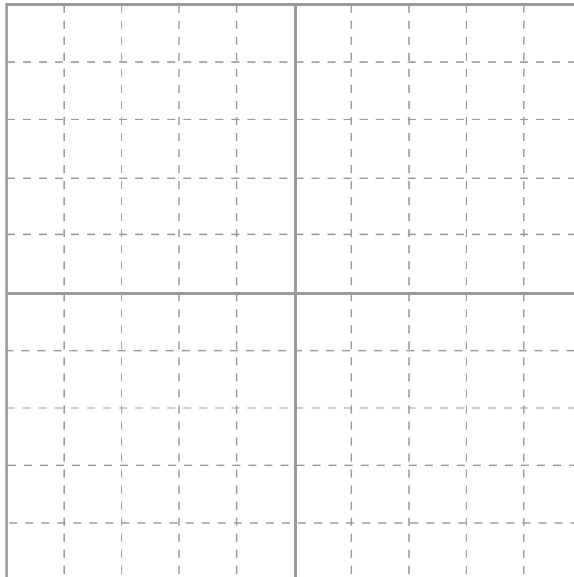
What input signal amplitude (pin X1 on the AD633)

is required for a 100% modulation index?

_____ V

Step 4 – Putting it together

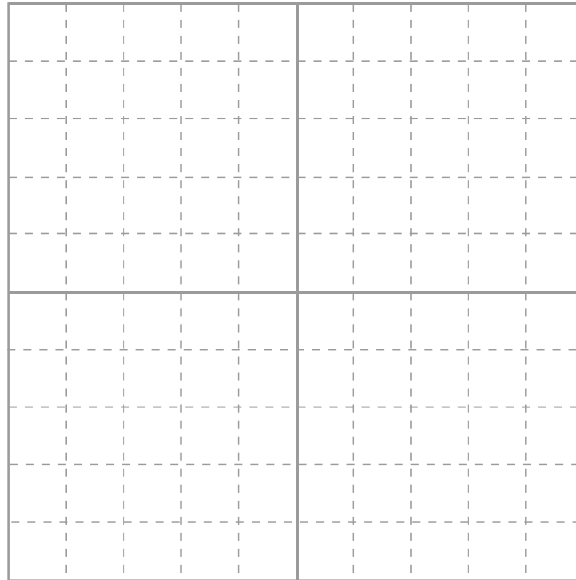
Record the input and output waveforms of the link for a 1kHz sinusoidal input signal.



What is the approximate link loss (V_{out}/V_{in}) for a
Transducer separation of 12'?

Estimate the 3dB (half-power) bandwidth of your circuit: _____ kHz

Record the input and output waveforms of the link for a 1kHz square-wave input signal.



TA Certification:

Step 4: Link working without audio amp? Yes [] No []

Step 4: Link working with audio amp? Yes [] No []

Step 5: Complete transceiver working? Yes [] No []

TA Signature: _____

Date: _____