Electronic Instrumentation
ENGR-4300 Fall 2002

Project 2: Optical Communications Link

For this project, each group will build a transmitter circuit and a receiver circuit. It is suggested that 1 or 2 students build and test the individual components of the transmitter and 1 or 2 students build and test the individual components of the receiver. However, all students should work together in developing design improvements and testing the overall system. The fundamental goal of this project is to figure out how this combination of circuits works.

Grading

Introduction (1 pt)	________
Basic Design Implementation (2 pts)	________
Basic Design Analysis (4 pts)	________
Final Design (3 pts)	________
Final Design Implementation (4 pts)	________
Analysis and Comparison (4 pts)	________
Personal Responsibility (1 pt)	________
Creativity (0-2 pts extra credit)	________
Appendix (1 pt)	________
Group Total (20 pts)	________
Individual Attendance (5 pts)	

Be sure that you have all of your experimental data signed by a TA or instructor. Also, read this document very carefully and make sure you have done <u>*everything*</u> *you have been asked to do. It is a good idea to highlight each of the tasks listed so you don't miss any.*

Circuit diagram checked ______. Personal responsibilities checked ______.

Names: (Grade)

1. ______________________(______) **2.** ______________________(______)

3. ______________________(______) **4.** ______________________(______)

5. ______________________(______)

Background

The basic system design comes from *The Laser Cookbook* by Gordon McComb. The transmitter circuit is based on a 555 timer chip.

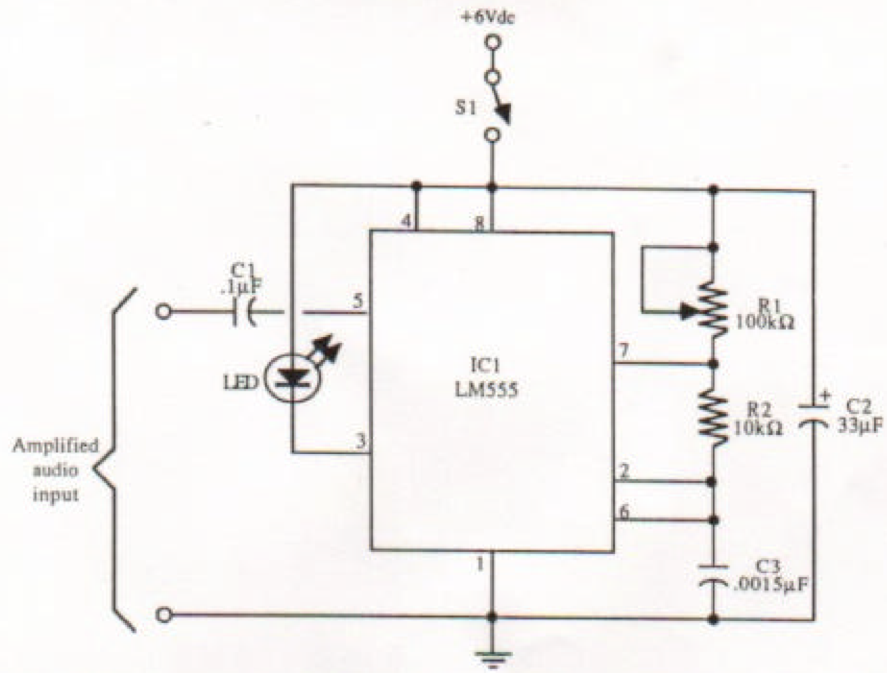


FIG. 13-1. *Schematic diagram for the pulse frequency modulated LED transmitter. Adjust frequency by rotating R1. With components shown, frequency range is between 8 and 48 kHz.*

The audio source usually used is the earphone output from a portable tape or CD player. The sample circuit in the studio uses an old AIWA tape player. The tape used is by a group named *Boys Night* Out, which is mostly a bunch of engineers and scientists from Oak Ridge National Laboratory. Note, that for testing, winamp should be available on your test machine and the audio jack is under the front cover. We will have some headphones available. You can also bring in your own portable audio source.

The signal from the audio source modulates the width of the pulses output by the 555 timer astable multivibrator circuit which drives the LED. This is called a Pulse Position Modulator. (See the 555-timer spec sheet for details.) The optical signal from the LED is aimed toward the phototransistor in the receiver circuit. The receiver circuit is a slight modification of a very standard audio amplifier circuit built around a 386 amplifier chip. (See Figure SM-4 in the supplementary materials section of this write-up.) The pre-amp for this circuit is a simple inverting 741 op-amp configuration. The pinouts for the three chips used in this project can be found in the supplementary materials section at the end of this write-up (Figures SM-1, SM-2 and SM-3).

The only power source necessary for the transmitter circuit is 6 volts from either a DC power supply or from four 1.5 volt batteries. The sample circuit in the studio uses four AA cells. The power for the receiver circuit is ±9 volts from either a DC power supply or two 9 volt batteries. Again, the sample circuit in the studio uses batteries, primarily so that it can operate anywhere. Please note the *bypass capacitors* included in both circuits. A capacitor found across the DC power leads is an open-circuit at DC but a short circuit at high frequencies. These help to reduce high frequency noise found on the leads from the power supplies. If your output sounds like nothing but noise, you have probably forgotten to include them. Once you get your circuit working, you should remove the capacitors and see what happens. Also, you can experiment with different size capacitors and see how this affects sound quality.

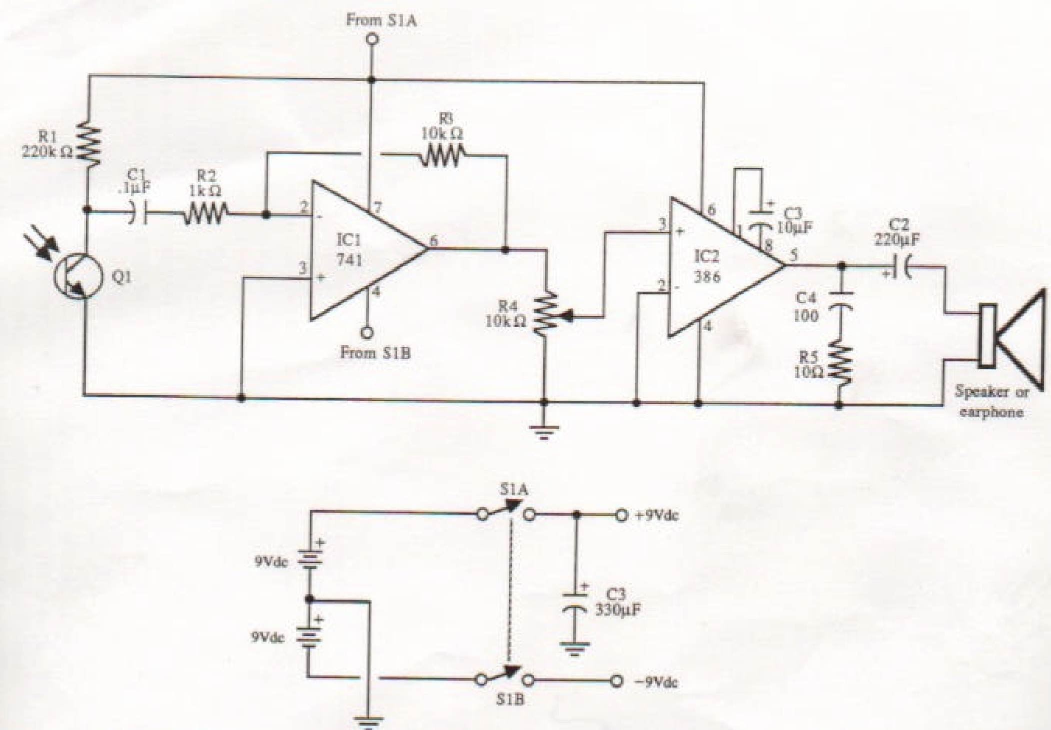
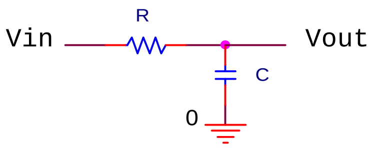


FIG. 13-5. *The universal laser light detector. The output of the LM386 audio amplifier can be connected to a small 8-ohm speaker or earphone. Two 9-volt batteries provide power. Decrease R1 to lower sensitivity; increase R3 to increase gain of the op amp (avoid very high gain or the op amp might oscillate).*

Besides getting these circuits to work, the key goal of this project is to reverse engineer the basic design to understand how it works. The receiver detects the pulse width modulated signal from the transmitter LED, amplifies it back to the level the audio amplifier needs to see, sends it through an audio amplifier to a speaker where it can be heard. To demodulate a pulse-position-modulated-signal, it is only necessary to average the signal. The basic circuit design provides this functionality more-or-less by accident. To better understand how the circuit works, the circuit is to be fully tested and modified to separate the averaging functionality from amplification. Crudely, a signal proportional to a time average can be obtained using a passive integrator. Thus, you are to insert a passive integrator into the receiver before the inverting op-amp to isolate this function. Adding the passive integrator will attenuate the signal level somewhat. To make up for this, the gain of the 741 inverting op-amp can be increased. For those of you willing to read ahead, it is possible to combine integration and amplification by building an active integrator using the 741. Either approach is fine. The modified circuit is to be tested to be sure that it still does about as well as the original circuit. Note that the circuit can drive either a speaker or a set of headphones.

Below is a picture of a passive (approximate) integrator. It only works at high frequencies:

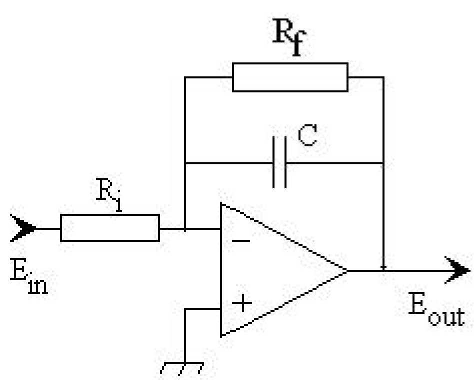
For $\omega >> \omega_c$, Vout = (1/RC)   Vin dt



$w_C = 1/RC$

Below is a picture of an active integrator, which we will cover in experiment 8. Note that this also amplifies the signal and can be used in place of the inverting amplifier in the circuit. This also only works as an integrator at high frequencies:

For $\omega >> \omega_c$, Vout = ($-1/R_iC$)   Vin dt.



$\omega_c = 1/(R_iC)$

Project Report

Your project report should address your design, analysis of your design, how you implemented your designs, how well they worked, problems encountered, additional materials and information used and what each group member contributed.

Introduction (1 pt): Introduce and describe the goals of the project.

1. General Problem Statement: Using the given design of an optical transmitter/receiver, design, build and test an optical link for an electrical signal in the audio frequency range. Once the transmitter-receiver combination is working, test and modify it to determine HOW it works.

2.. List at least two of the educational issues we have been addressing in this course that you encountered in this project.

Basic Design Implementation (2 pts): To test out your designs, you must first build the basic transmitter and receiver.

1. First build the circuits as they are shown on the diagrams above (at least as close as you can).

The component choices in the diagrams can be changed if you find you do not have an exact match, but we will have only a limited number of additional components available. That should not deter anyone from thinking about how to improve the circuits. As a general rule of thumb, use the information you obtained in previous experiments to determine the component values.

2. When you successfully transmit and receive an audio signal using a personal stereo and the function generator as sources, you will receive the full 2 points.

Successful transmission of the audio signal requires only that it can be understood. For the function generator (with output levels comparable to the personal stereo), your group must determine the minimum and maximum discernible frequencies and the frequency that is best reproduced. These judgments are somewhat qualitative.

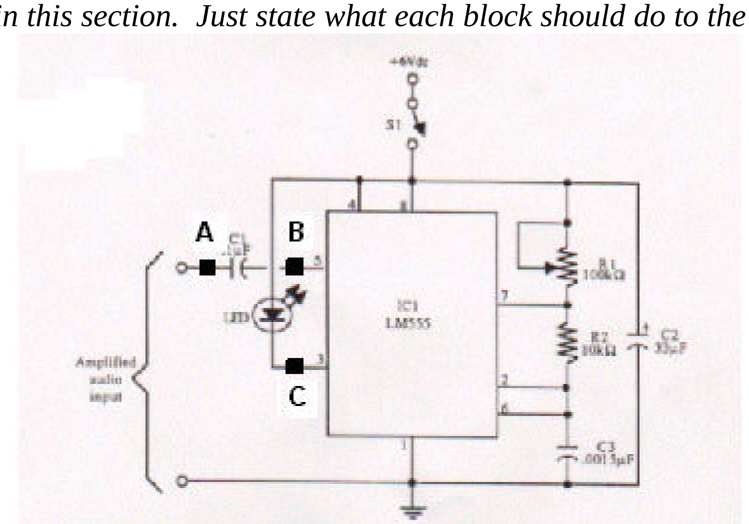
Personal Stereo _____________ Witnessed ________________
Function Generator __________ Witnessed _________________
Min. Freq. ________ Best Freq. ________ Max. Freq. _________

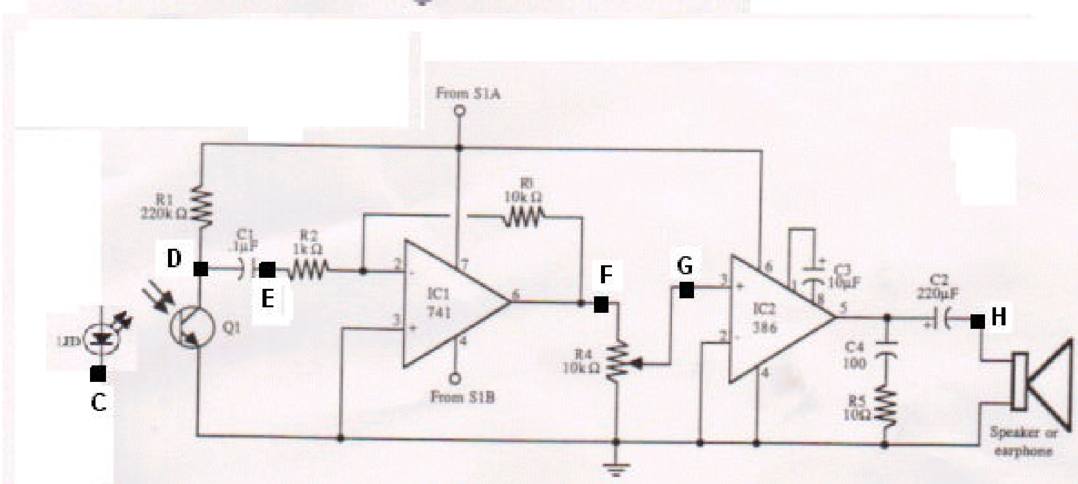
Basic Design Quality: Poor Fair Good Excellent _______

Basic Design Analysis (4 pts): Describe your basic project design and determine how it works.

1. Identify each functional part of the two circuits and then explain the functionality of each part of these sub-circuits.

Refer to the figure below. There are several blocks in the circuit, each defined by an input point and an output point. How does the circuitry between the two points (the block) effect the input? For example, capacitor A (Block D-E) between the photo-transistor and the inverting amplifier (receiver circuit) is there to block the DC bias voltage found at the top of the photo-transistor. This voltage is necessary for the transistor to work, but it carries no signal information. Also, if the DC bias was connected to the input of the pre-amp, it will be amplified along with the AC signal and very likely saturate the amplifier. To show that the capacitor is doing what it is supposed to, you should measure the voltage at its input and at its output. (There are two other DC blocking capacitors in the circuit.) To identify the functionality of all the sub-circuits, draw a block diagram for both the transmitter and the receiver. Do not do any analysis in this section. Just state what each block should do to the signal.



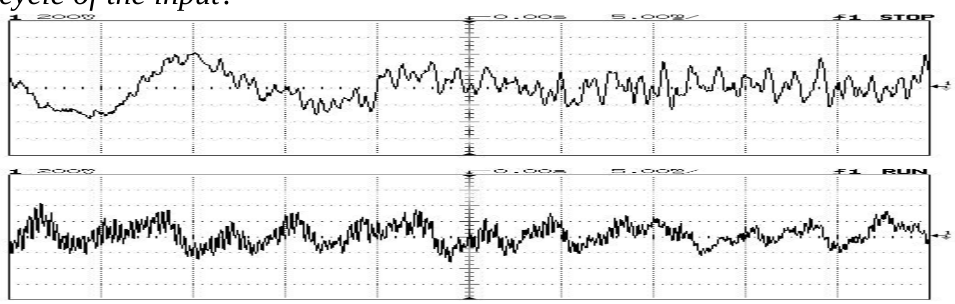


2. What is your sampling frequency?

From the 555-timer output, you should be able to get a rough idea of the sampling frequency. Since the signal is pulse-position modulated, your sampling frequency will depend upon the amplitude of the input voltage when each sample is taken, so there will not be an even set of pulses like you had in experiment 7. You can however, take an average over many pulses and get a useable value for frequency. Note that the sampling frequency must be higher than the frequency of the input signal or you will not be able to recreate the signal.

3. How can you model the input signal with the function generator?

The signal levels used from the function generator should be typical of the output wave of the audio device you are using. The function generator is much easier to work with than the complex signal from the tape or CD player. However, we still need to see the circuits work with the regular audio signal. What is the amplitude and frequency of the sample audio pictured below? Is your audio device comparable? What are the frequencies that your circuit should be designed to work at? About how many samples are you getting per cycle of the input?



4. Verify that the sub-circuits in your basic design are working as predicted.

Set the function generator at a representative frequency. For each block (defined between two points), display the input voltage on channel 1 of the scope and the output voltage on channel 2. Don't forget to measure voltages with respect to ground. Take plots comparing Vin and Vout for each block. Use this information to demonstrate that the functional block works as it should. Also make a plot of the Vin (output from function generator) and Vout (output to speaker) for the entire system. This part of the project is very important. Take good data and have it checked off below. If you cannot get a good picture of Vout and Vin on the same plot. You can make two plots and explain why.

Function Generator: (required)

Block (A-B) : _______ **Block(B-C): ______** **Block(C-D):_____**
Block (D-E) : _______ **Block(E-F): ______**
Block(F-G):______ **Block (G-H) : _____** **System(A-H): _____**

5. Take any audio data that you feel is required to demonstrate that the circuit is functioning correctly.

Audio: (*italics* required – others as needed)

Block (A-B) : _______ Block(B-C): ______ Block(C-D):_____
Block (D-E) : _______ *Block(E-F):* ______
Block(F-G):______ Block (G-H) : _____ *System(A-H):* _____

Final Design (3 pts): Improve your basic design. Although the inverting op-amp performs some integration and makes the signal audible, you can improve the quality by adding a real integrator to the circuit. You may also be able to improve signal quality by making other changes.

1. Add an integrator to your circuit.

At what point should you place your integrator? Could it be placed at more than one point? What values should you use for your components? How does the integrator effect the signal?

Choose a place to put your integrator which has little or no DC offset. Also, trying to integrate a signal which is already partially integrated may result in loss of signal. Choose your component values so that your passive integrator properly integrates the input audio signal. Noting the equations given and your average input frequency. Choose the component values for the op-amp configuration so that you obtain the gain you need to hear the signal. Note, as mentioned above, it is possible to combine the integrator and the inverting op-amp. How will this effect the original gain?

2. Draw a neat, complete circuit diagram of your design with the integrator.

Be sure that you clearly label each component on your diagram. Include the part number for the photo-transistor and the impedance of the speaker. You can draw the circuit by hand or use Pspice. If you choose to use Pspice, you can model the LED with a regular diode and the phototransistor with a VSIN source set up to look like the signal from the transistor. Pspice does not include the 386 amplifier, you can either model this by hand or substitute a 741 in the appropriate configuration with a proportional gain. (You probably won't be able to get the actual gain, since the 386 is a power amplifier and the 741 will saturate. CLEARLY note the difference.) Once you have completed this diagram, have it checked by a TA or instructor and have them note that they have done so.

3. Develop a plan for testing your design.

Your plan should include taking data at important points in the final circuit and showing that the signal sent to the audio amplifier properly tracks the original audio signal. This *should not be a complicated plan, just a clear, specific plan. Basically, you should ask yourself what the purpose should be for an audio communication system. What data would you use to show that the system is working well? What data do you need to verify that the blocks are functioning correctly? Test your design under at least two conditions. For example, test it with the LED and phototransistor as close together as possible and as far apart as you can obtain a discernible signal.*

4. Some other things to consider, if time permits. (None is required.) If you try any of these things, include any predictions about what you believe will happen in this section of the report. What should happen and why?

<u>Sampling Frequency</u> - *You can increase the sampling frequency to give you more samples per cycle of the input frequency. How would this affect the quality of the signal? Are the values of other components affected by the change? At what part of the circuit can you see the difference? Can you lower the sampling frequency and still get an audible signal? About where is the lowest you can go? Look up typical audio sampling rates on the internet. What is the minimum you see there? What is CD quality?*

<u>By-Pass Capacitors</u> – *If you remove the by-pass capacitors, what happens? What kinds of changes can you make by varying their value. At about what capacitance do you get the best signal? At what capacitance is the signal lost?*

<u>Op-Amp Integrator</u> – *You can use an op-amp integrator instead of a passive integrator. You can even use the same op-amp by modifying the inverting amplifier. What happens to the gain, if you make this change? Why? How can you compensate for it?*

<u>Component Tweaking</u> – *You can try making small changes to the components in your circuit to get slightly better response. Consider the capacitors and resistors in the circuit. What effect would increasing or decreasing each one have? Can you find any that might make a difference? Is your signal not loud enough? Is there too much high frequency noise? Is there a low frequency hum? Note that after the 386 amplifier, there is capacitor/resistor pair attached to ground. This is a filter. Is it low or high pass?*

Final Design Implementation (4 pts): Build the circuit you designed.

1. Carry out the plan you made above.

Wire the circuit in your design. Change the values of R and C in your integrator to see if you can get any better response.

2. Design changes.

Did you make any changes to the original design or experiment with changes? What did you try? What worked and what didn't? What is your final design after the changes?

3. Discuss what problems were encountered during the implementation of your project.

How did you solve the problems? Include advice you would offer to someone who wished to avoid these problems in the future. Do not discuss design changes here. Rather, you should discuss, for example, problems you had with wiring or due to misunderstandings of how individual components worked.

4. Verify that the sub-circuits in your final design are working as predicted.

Set the function generator at the representative frequency used for your basic design. For each block (defined between two points), display the input voltage on channel 1 of the scope and the output voltage on channel 2. Don't forget to measure voltages with respect to ground. Take plots comparing Vin and Vout for each block. Use this information to demonstrate that the functional block works as it should. Also make a plot of the Vin (output from function generator) and Vout (output to speaker) for the entire system. This part of the project is very important. Take good data and have it checked off below. If you cannot get a good picture of Vout and Vin on the same plot. You can make two plots and explain why. Note that some of these blocks may not have changed at all from the previous design. (For example, if you did not try to change the sampling frequency, the transmitter data does not have to be retaken.) Put an X in any boxes that you do not have to take data again for.

Function Generator: (required)

Block (A-B) : _______ Block(B-C): ______ Block(C-D):_____
Block (D-E) : _______ Block (E-F):_____ (E-E') ____ (E'-F) ____
Block(F-G):______ Block (G-H) : _____ System(A-H): _____

5. Take any audio data that you feel is required to demonstrate that the circuit is functioning correctly and that you have improved the signal by the addition of the integrator.

Audio: (*italics* required – others as needed)

Block (A-B) : _______ Block(B-C): ______ Block(C-D):_____
Block (D-E) : _______ *Block (E-F):*_____ (E-E') ____ (E'-F) ____
Block(F-G):______ Block (G-H) : _____ *System(A-H):* _____

6. Have your TA or instructor verify your final design is functioning and indicate the quality.

Final Design Quality: Poor Fair Good Excellent _______

Analysis and Comparison (4 pts) Discuss how well your improvements worked and support your discussion with calculations, graphs, PSpice simulations, and common sense reasoning

1. Analyze the functionality of each part of the circuits you have built.

Now you are to analyze each block, preferably by hand or you can use PSpice. For example, determine the gain of each amplifier block. For the 386, this requires looking it up in the specification sheet you can find through the course website. Be sure you understand the function of the feedback capacitor connected to the 386, since it is likely you will not need it in your final design. Find the application page of the 386 spec sheet and compare the circuit used here and the ones found there. (Some of this information is included at the end of this write-up.) Note also, that there is no PSpice model for this amplifier, so if you do the analysis that way, you must be very careful to either handle the last part of the circuit by hand or be very careful to note why your output is off by some factor, what it should look like and why.) Do not forget to consider the circuit with and without the integrator.

2. Compare your experimental results to the theoretical results.

How do the signals at the input and output of each block compare to what the theory says you should expect. Do the gains match? Does the DC offset go away?

3. Compare your basic design to your final design.

How closely do the final and initial designs compare to each other. Can you see any improvements in the signals? It is not necessary to do extensive analysis here. Just do the analysis necessary to show that your final design performance makes sense. For example, you might take your input and output signals from tests done with the function generator and try to re-plot them using Excel to show how similar they are. It is very important that you demonstrate the operation of your design to a TA or instructor and have them sign your data. Show them the procedure you are following. Describe the overall performance of your design in terms of such parameters as detectable signal, frequency response, fidelity, etc. Use all of the information you have acquired for your circuits. For example, you should have plots of both the input signal and the signal seen at the speaker input or the signals at any other part of the receiver, should they be easier to work with. Describe the similarities and differences between these signals.

You should also note anything that looks non-ideal about the performance of the signals, including incorrect gains, noise, distortion, etc. For each of the measurements made, there should be some discussion regarding which features of the data make some sense, which do not and why. How do these problems differ between the initial and final design?

Personal Responsibilities (1 pt): A short paragraph should be written describing what each group member contributed to the project design, analysis, construction and testing.

1. When doing this and other projects, you must break down the tasks to be performed and assign each of them to specific members of your group.

For example, one person should be responsible for developing the testing procedures that you use to show that your design works. If, in your group, you each shared equally in everything, you will get only one point for this section of the report. It is perfectly all right for everyone to work on everything, but there always has to be one person responsible for each task. At some point during class time, explain the breakdown in tasks to a TA or instructor and have them indicate that they have done so on the front page.

2. Note you will also receive an individual participation grade based on attendance.

Appendix (1 pt): Include any background materials you used in the preparation of your design.

1. Two helpful websites:

A design similar to the one we will be building is discussed at: http://www.danevans.demon.co.uk/irlink.html. A simple design that performs a similar function is discussed at: http://materials.ecn.purdue.edu/~msecrc/test/MRSEC/Index.html

2. Find some additional information

The web has many sites on optical communication, the components we have used, etc. For example, find the properties of a typical small speaker (resistance, inductance, capacitance, frequency response, etc.). Please do not just attach spec sheets to your report. Extract only the useful information.

3. Include any spec sheets you have used.

Supplementary Information

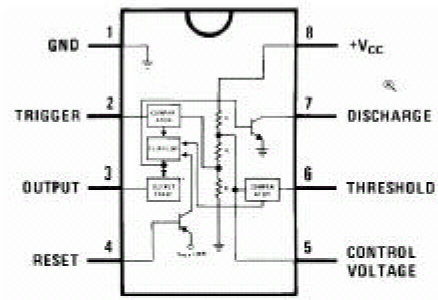


Figure SM-1: 555 Timer Pinouts

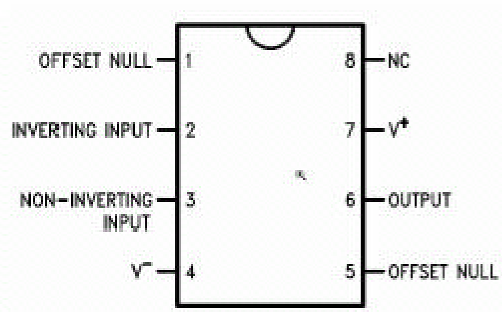


Figure SM-2: 741 Op-Amp Pinouts

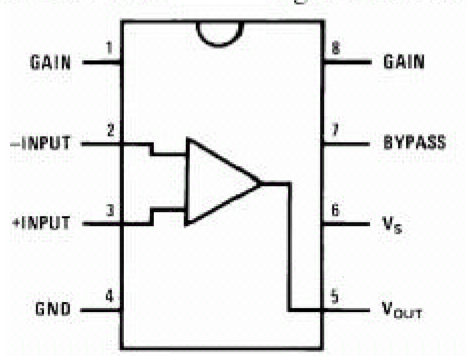


Figure SM-3 Audio Amp Pin outs

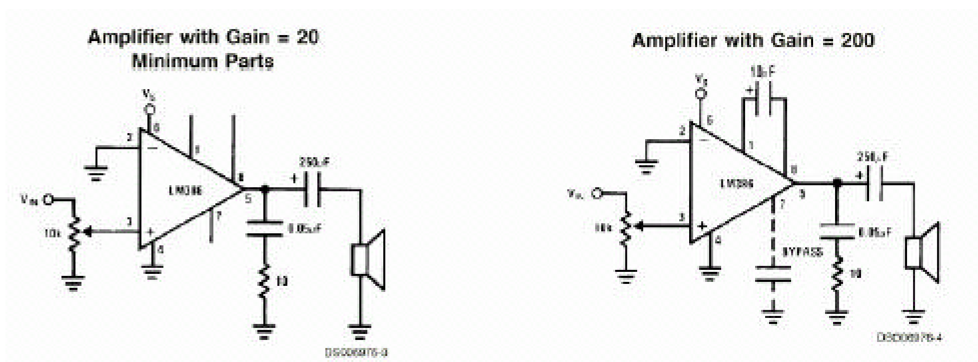


Figure SM-4: Standard audio amplifier configurations using the 386. Note that the capacitor between pins 1 and 8 control the gain. For this project, it has usually not been necessary to include this capacitor, since the gain is generally large enough without it. However, there has been a good deal of variability in the performance of the 396 chips, so you should test the circuit with and without the capacitor to see what works better..