Electronic Instrumentation
ENGR-4300 Fall 2003

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)	________
Practical Skills and 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. ______________________(______)**

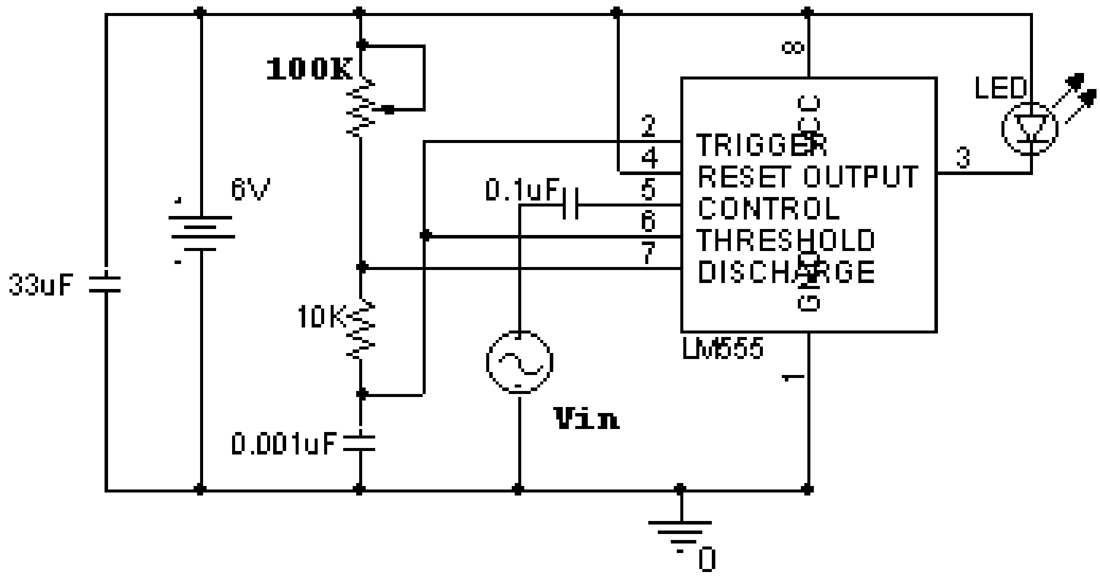
3. ______________________(______) **4. ______________________(______)**

5. ______________________(______)

Background

The basic system design comes from *The Laser Cookbook* by Gordon McComb.

The Transmitter
The transmitter circuit is based on a 555 timer chip.

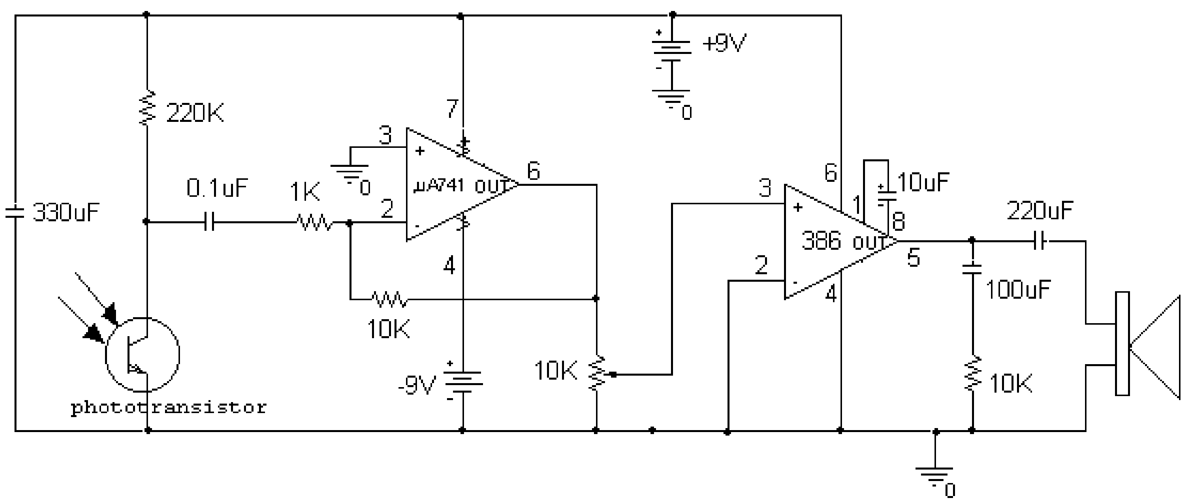


We test the transmitter with a sine wave from the function generator and a typical audio source. You can download a song of your choice and use Winamp to play it on the computers in the studio. You can test the audio jack, which is under the front cover of your machine, with headphones. (We will have some headphones available.) You can also bring in your own portable audio source, if you would like. Please test your circuit with the function generator to make sure it works correctly before hooking it to the computer.

The signal from the audio source modulates the width and frequency of the pulses output by the 555 timer astable multivibrator circuit which drives the LED. In the 555-timer spec sheet, this is called pulse position modulation. It is also frequently described as pulse frequency modulation, as in the figure above. The optical signal from the LED is aimed toward the phototransistor in the receiver circuit.

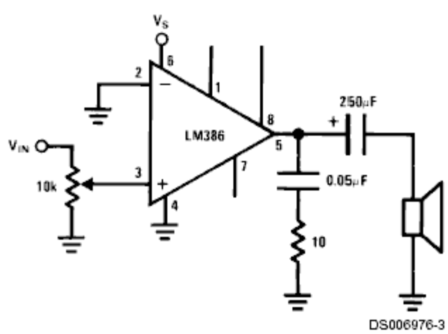
The Receiver

The receiver circuit is a slight modification of a very standard audio amplifier circuit built around a 386 amplifier chip. The receiver takes the input from the phototransistor reconstructs and amplifies the signal and outputs it to the speaker.

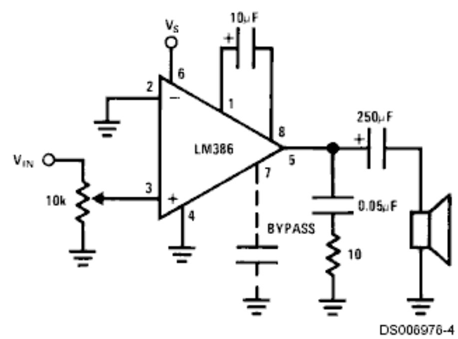


You should already be familiar with the portion of the circuit which reads the light pulses (phototransistor) and the pre-amp (741 inverting amplifier). The final part of the circuit is based on one of the two standard audio amplifier configurations pictured below. The capacitor between pins 1 and 8 adds additional gain. You may or may not need it depending upon your design.

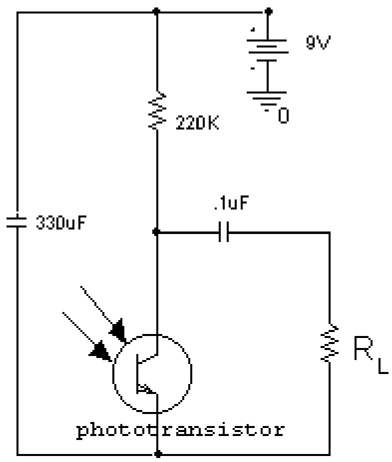
Amplifier with Gain = 20
Minimum Parts



Amplifier with Gain = 200



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. 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. It is recommended that you build the transmitter in stages. In the first stage, just build the piece with the phototransistor, add a load resistor (1K works well) and check to see if it works. Once you have this working, you will be able to add the pre-amp and move the load resistor. Finally, you can put on the audio amplifier. This approach usually saves students (and staff) a lot of debugging headaches.



Here are the pin-outs for the 555 timer, the 741 op-amp and the 386 audio amplifier.

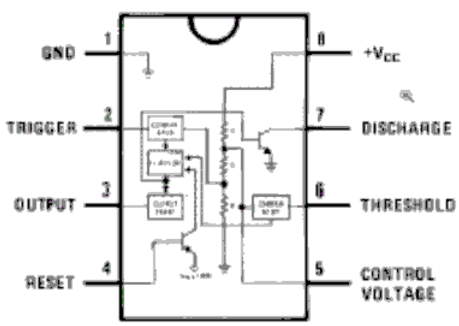


Figure SM-1: 555 Timer Pinouts

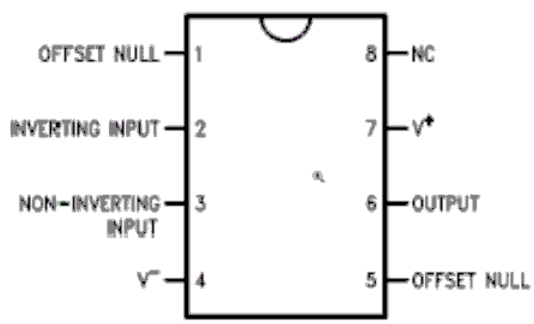
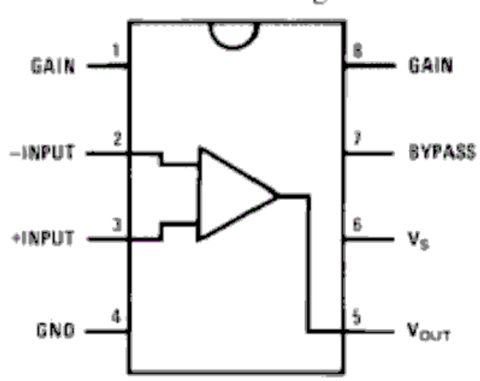


Figure SM-2: 741 Op-Amp Pinouts

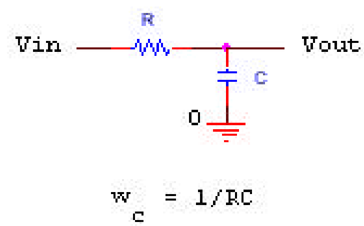


Your Design Goal

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 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 this signal, it is only necessary to average it. 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 is an improvement over the original circuit. Note that the circuit can drive either a speaker or a set of headphones.

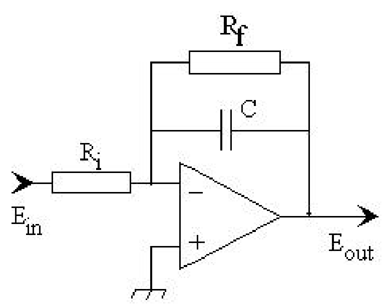
Below is a picture of a passive (approximate) integrator. It only works at high frequencies:

For $\omega >> \omega_c = 1/RC$, $V_{out} = \frac{1}{RC}\int V_{in}\,dt$.



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 does not work well at very low frequencies:

For $\omega >> \omega_c = 1/(R_f C)$, $V_{out} = \frac{-1}{R_i C}\int V_{in}\,dt$.



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*.

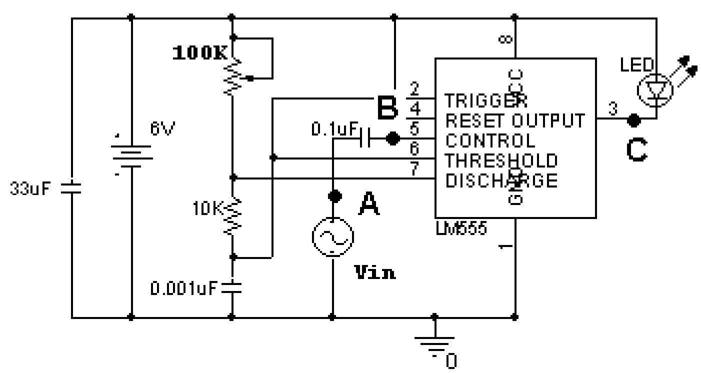
Personal Stereo _____________ Witnessed ________________
Function Generator __________ Witnessed _________________
Min. Freq. ________ Best Freq. ________ Max. Freq. _________

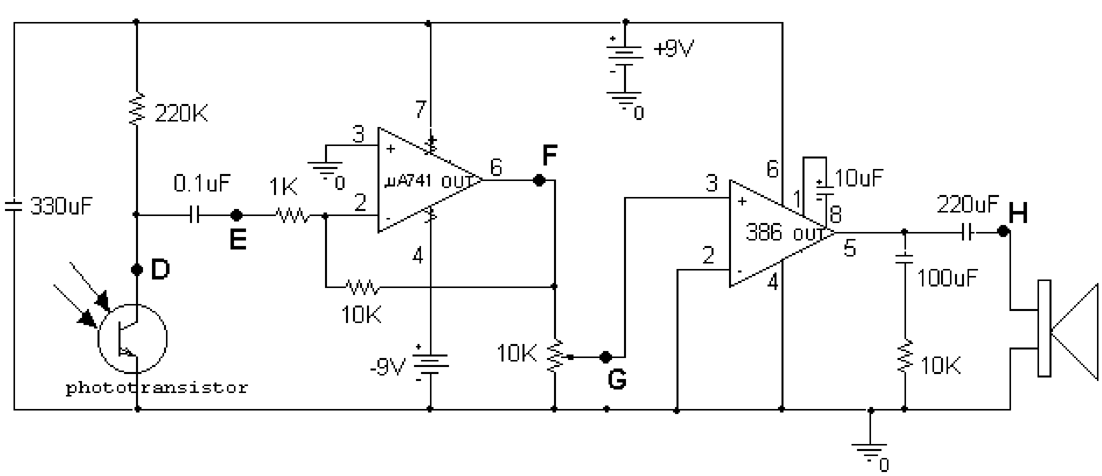
Basic Design Quality: Poor Fair Good Excellent _______

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.

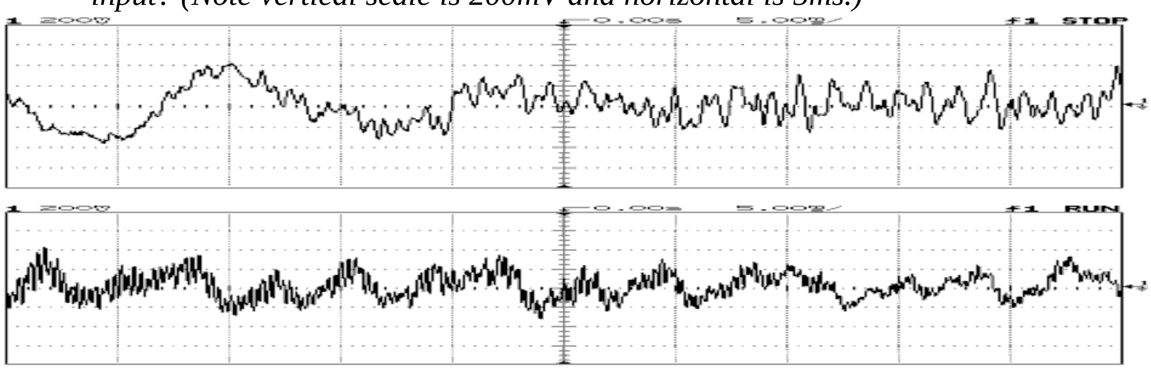
- *Refer to the figure below. There are several blocks in the circuit, each defined by an input point and an output point. How does the circuitry between the two points (the block) effect the input? For example, capacitor A (Block D-E) between the photo-transistor and the inverting amplifier (receiver 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 take an average over many pulses (or a maximum) and get a useable value for frequency.*
   - *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? (Note vertical scale is 200mV and horizontal is 5ms.)*



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. . Take plots comparing Vin and Vout for each block. Use this information to demonstrate that the functional block works as it should.*
   - *Don't forget to measure voltages with respect to ground*
   - *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 for each of the points listed below. You do not need to have these signed.*

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. You do not need to have these signed.

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 affect the signal?*
   - *Choose a place to put your integrator which has little or no DC offset*
   - *Trying to integrate a signal which is already partially integrated may result in loss of signal*
   - *Passive Integrator: Choose your component values so that your passive integrator properly integrates the input audio signal, noting the equations given and your average input frequency. Include your calculations.*
   - *Choose the component values for the op-amp configuration so that you obtain the gain you need to hear the signal.*
   - *Active Integrator: It is possible to combine the integrator and the inverting op-amp. How will this effect the original gain? Include your calculations.*

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. 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?

- *Sampling Frequency - 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?*
- *By-Pass Capacitors – 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?*
- *Op-Amp Integrator – 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?*
- *Component Tweaking – 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. Take plots comparing Vin and Vout for block (E-F) and the whole system.*
   - *You may take other blocks, if you think you need them to demonstrate how your design changed the functionality of the system. Use this information to demonstrate that the new functional block works as it should.*
   - *This part of the project is very important. Take good data for at least the points listed below You do not need to have these signed..*

Function Generator:

Block (E-F):_____ ***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. You do not need to have these signed.

Audio:

Block (E-F):_____ ***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 that there are limitations in how much PSPice can be used to model this circuit. Since you cannot model the transmission of light, you should handle the transmitter and receiver separately. You can use a DN4148 diode to represent the LED output from the transmitter. You can use a voltage source set to the approximate amplitude, frequency and offset of the signal from the phototransistor to model the receiver input. Also there is no PSpice model for this 386 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 include an appropriately size resistor to represent the load from the audio amplifier, note why your output is off by some factor, and describe 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.*

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

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://ist-socrates.berkeley.edu/~phylabs/bsc/PDFFiles/bsc13.pdf*
- *A simple design that performs a similar function is discussed at: http://www.mitedu.freeserve.co.uk/Circuits/Interface/irext4.htm*

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. Include only the web addresses or book titles (authors, etc.) where information was obtained. Extract only the useful information.*

3. Include any spec sheets you have used.

Practical Skills and Attendance (5 pts) As in the last project, you will be tested as an individual on one of the following:

A. Questions on Project Theory
   1. Describe the transmitter and how it modulates the signal
   2. Describe the receiver and how it demodulates the signal with the integrator
   3. Describe the function of the bypass and DC blocking capacitors
   and why they work. (Hint: How do they behave at low and high frequencies.)

B. Questions on Equipment

1. Set the function generator to an amplitude and frequency representative of the audio signal on page 8.
2. Compare the signal at any two points on the transmitter and/or receiver using the ‘scope without using autoscale.
3. Use the ‘scope to determine the sampling frequency of the transmitter.
4. Hook up a circuit to the appropriate power source(s).

C. Questions on Circuits

1. Change the gain of the inverting amplifier.
2. Change the frequency of the 555-timer circuit.
3. Wire, debug and demonstrate that a portion of either circuit works.
4. Replace a removed part correctly.

D. Questions on PSpice/Agilent Intuilink

1. Take a picture or data with Agilent Intuilink software
2. Input and test one of the circuits (or a portion thereof) in PSpice
3. Demonstrate that the data in the PSPice model corresponds to data taken from the actual circuit.
4. Set up and perform analyses in PSpice (transient, AC sweep, DC sweep).
5. Use PSpice traces and cursors.