5b

Putting it all Together

….continuation of Lab 5a

In-Lab Procedure

At this stage you should have your transmitter circuit hardwired on a vectorboard, and your receiver circuit tested and debugged on a solderless breadboard.

5.1 Basic System Demo and Characterization

We are now ready to put together our complete communications link as shown in Figure 5-1. The transmitter and receiver each have their own separate power supply; one of these is the supply you built in ECE 2B. The output of the demodulator section on the receiver is connected to the audio-amplifier system that you built in an earlier lab.

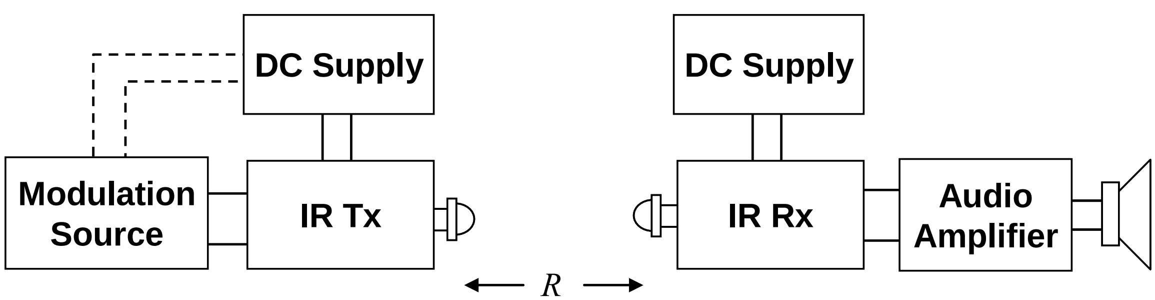

Figure 5-1 –System block diagram.

The modulation source can be the bench function generator, your microphone circuit, an iPod/MP3 player, or any other audio source. A simple sinusoidal tone from a function generator is best for testing the system initially, as we can sweep this source to determine the overall frequency response.

□ Construct the circuit in Figure 5-1 using the bench function generator as a modulation source. *This should be essentially the point at which you left off the previous lab.* Start with a transmitter-receiver spacing of around $R \approx 0.5\,\mathrm{m}$. Our ultimate goal will be to have the system operate well over a wide range of transmitter-receiver separations, but it is easiest to start with smaller separations and work our way up. Be sure to include ground connections between all circuits!

- □ Set the modulation source to a 1 kHz sinusoid, and adjust the amplitude so that the duty-cycle of the transmitted signal varies by around ±20% at the peak. It is not necessary to hit this modulation depth precisely; we just don't want to *over*-modulate the system at this stage.
- □ If the system is functioning properly you should be able to hear the tone on your audio speaker system (keep the volume down please!). Observe the output of the receiver system on the oscilloscope. You should observe a reasonably clean sinewave, although zooming in on the waveform will show some residual of the 40kHz carrier superimposed.

Do not proceed past this point until your system is functioning as a complete link. You may need to bring the transmitter and receiver a little closer together. You may also need to adjust potentiometer R23 in the signal-conditioning circuit.

- □ Determine the maximum range of your system by slowly moving the transmitter and receiver apart. Record this number.
- □ Experiment with the modulation depth (amplitude of the modulating signal) and record your observations.

5.2 Increasing the Operating Range

Directionality of the Emitter and Detector Diodes

The system requires that the transmitter LED is oriented towards the detector for best results. In fact the transmitter diode has strongly directional characteristics, as shown in Figure 5-2a. These kinds of plots show the *relative* intensity of the radiated signal that would be measured by an ideal detector that is moved in a circle of constant radius around the emitter.

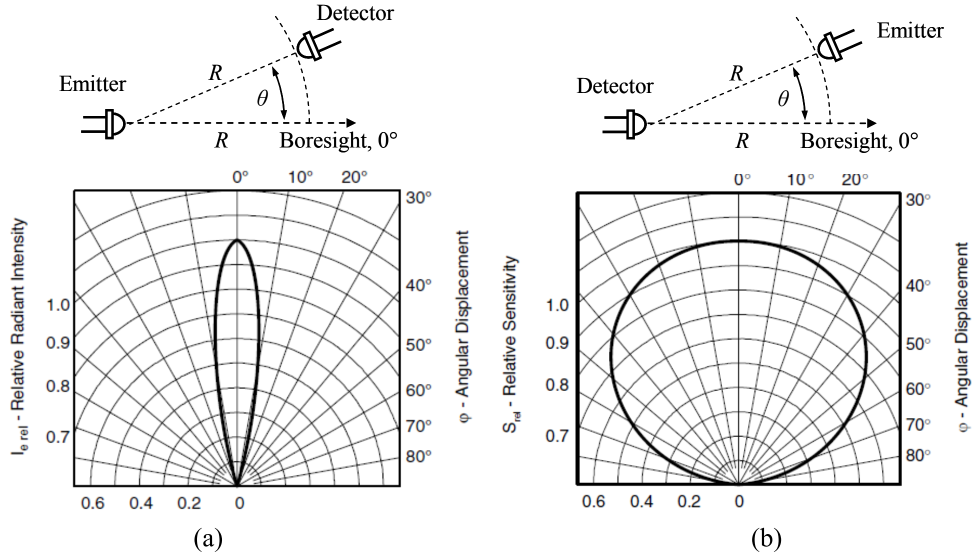

Figure 5-2 –(a) Directional characteristics or "radiation pattern" of the emitter diode. (b) Directional characteristics of the photodiode detector.

Such radiation pattern plots can be made for all kinds of radiators and detectors, including RF or high-frequency antennas, audio speakers, microphones, ultrasonic transducers, etc. For our particular IR emitter diode the direction of maximum intensity is directly in front of the diode at 0°. This is often referred to as the "boresight" position. The intensity falls off to half of its maximum (boresight) value at $\theta = \pm 10°$. In contrast the photodiode characteristics are significantly less directional, as shown in Figure 5-2b. In this case the detected signal would still be at 90% of the maximum for a ±30° misalignment. In both cases the directional behavior of the devices is influenced strongly by the lens that is part of the package, and is an intentional characteristic implemented by the manufacturer.

So for maximum range we must be sure to orient the emitter diode carefully in the direction of the receiver, but the alignment of the detector/receiver is less critical.

Increasing the Transmitted Signal

The next easiest thing we can do to increase the transmitter range is boost the amount of infrared signal that we are transmitting. According to the data sheet the radiation intensity of the IR emitter radiates is a function of the diode current. Figure 5-3 is reproduced from the data sheet; ignoring units, the trend is clear: more current equals more power! In Lab 4 it was suggested that you design the transmitter for a 50mA diode current. This can be manipulated by choosing a different resistor R9.

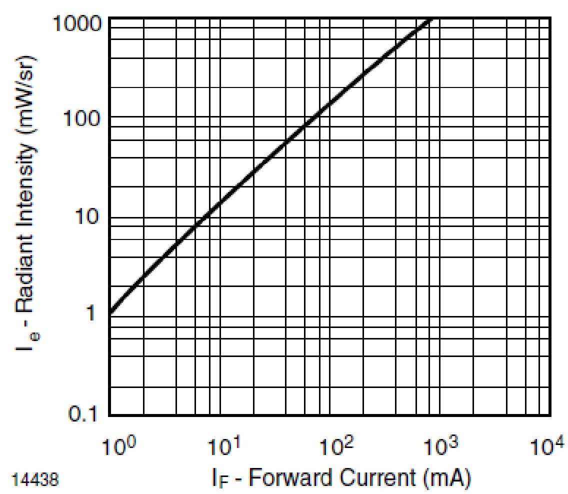

Figure 5-3 – IR radiation intensity versus diode current for the TSAL6100 emitter.

From simple conservation principles we can prove that the signal intensity will decrease with distance as $1/R^2$. So to double the communication distance we would need to quadruple the power. The graph in Figure 5-3 can give us the information we need to increase the distance by a specified amount, but remember that there are other considerations as well: the switching transistor Q2 will have some maximum specified current or power dissipation limits that must be honored. So be careful if you decide to boost your transmitter power! It is probably safe to increase the diode current to 100-150mA, but beyond that you will need to be careful.

Another simple but effective way to increase the power: use more LEDs!

□ *Optional*: Modify your transmitter board to boost the transmitter power in the manner(s) just described. Measure and record the new maximum operating range of your system.

Increasing the Receiver Gain

In the receiver circuit there are three gain stages following the photodiode detector stage; the gain of these stages is programmed by resistors R14, R16, and R20. These resistors give us three degrees of freedom for increasing the gain of the system and hence the maximum operating range. However, if we have *too* much gain in the front end, the potential for instability also increases (due to parasitic feedback paths such as through the power supply rails). So it is best to adjust these experimentally:

- □ Modify your receiver circuit to increase the gain in the system. As you add more gain, measure and record the new maximum operating range of your system. The quality of audible sound from the audio amplifier and speaker will help alert you to potential problems if there is too much gain in the system.

Note that adding more gain helps improve the performance of the system for large transmitter-receiver separations, but creates some problems when the transmitter and receiver are close together. We will address that in the next section using an optional AGC loop.

Final System Demonstration

With the adjustments above you should be able to increase the operating range of your circuit to at least 2-3 meters, possibly more depending on how much optical noise and interference is present in the lab. The last step is to demonstrate your link with a "real" audio signal, such as a voice or music waveform:

- □ Add your microphone circuit (or hook up your MP3 player) to the modulation input on the transmitter board. Note that you will probably need to make some small adjustments here in order to insure that the new signal provides sufficient modulation depth to the transmitted signal.
- □ Demonstrate your working system to the TA.

Congrats, you are finished with the mandatory part of Lab 5b!

5.3 More (Optional) Improvements

No circuit is ever perfect, and there are always more features that can be added. As a design engineer you will often be faced with this issue. Ultimately the cost, size, or other issues will dictate the "best" solution for a given problem.

A simple adjustment that you could make is adjusting capacitors C8-9 to improve interference rejection, if that is a limited factor in your system. In my prototype, increasing the cutoff frequency with C8-9 did indeed help eliminate some audible interference from a nearby compact fluorescent lamp. Another simple adjustment is to add more diodes in series with D1-2 to increase amplitude of demodulated signal.

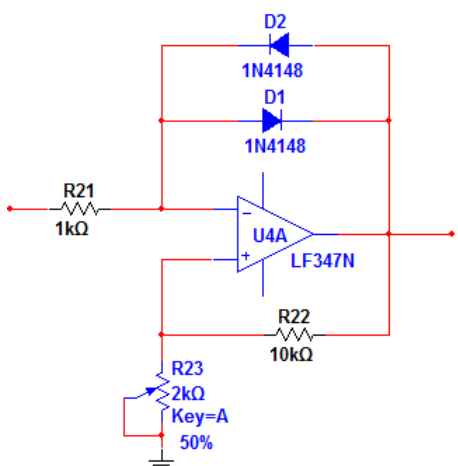

Figure 5-4 – Improved signal conditioning circuit employing hysteresis.

Improving the Signal Conditioning Circuit

A more sophisticated improvement that can help increase the range of the system is to improve the sensitivity of the threshold detector circuit in our system. One possibility is shown in Figure

5-4. This resembles the original threshold detector, except now the reference level is derived from the output state. This means that the crossing threshold will change depending on the state of the system, thus adding some hysteresis to the detector. This can significantly improve the noise immunity in the system, allowing the circuit to operate at somewhat lower crossing thresholds than we could use in the original circuit.

□ Optional: modify your signal conditioning circuit as suggested in Figure 5-4.

AGC Loop

In our experimentation we found that large transmitter-receiver separations required a lot of gain in the receiver, whereas small separations required less gain. This is a common problem in many communication systems, and one way to address this issue is to use an Automatic Gain Control (AGC) circuit. This is a circuit that senses the received signal and adjusts the gain depending on the strength of the signal, reducing the gain if the signal is strong, and increasing it if it is weak. This helps the receiver operate more consistently over a wide range of transmitter-receiver separations.

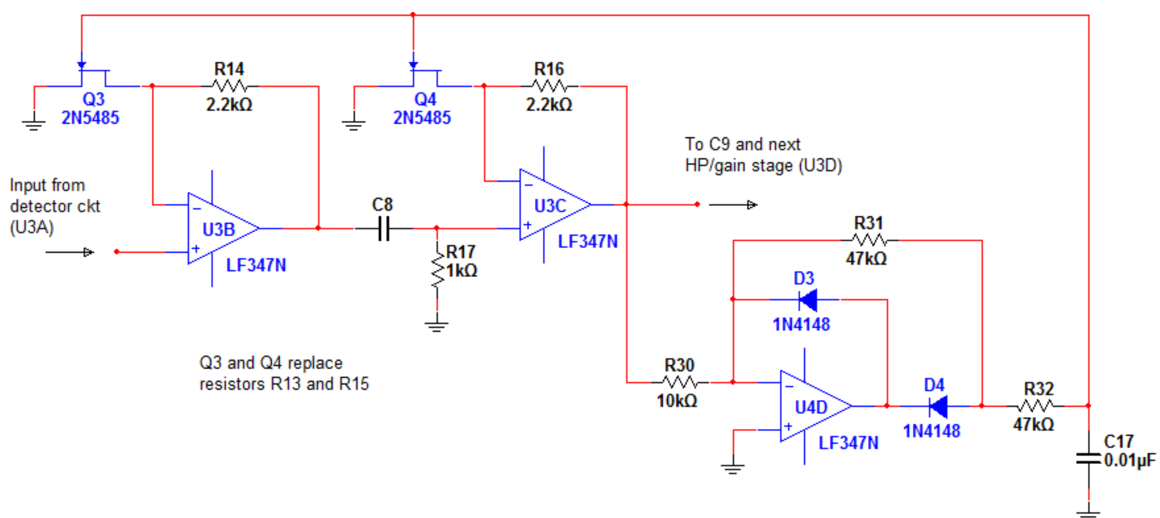

Figure 5-5 – Modification of receiver circuit to implement an AGC loop.

To make an AGC circuit we need two things: a voltage-controlled gain stage, and a circuit that senses the amplitude of the incoming signal. A popular way to implement a voltage-controlled gain stage is to use a FET biased in the ohmic region. In this region the FET behaves like a variable resistor, where the resistance value is set by the gate voltage. Figure 5-5 shows how we could modify the first two gain stages in our receiver to create a voltage-controlled gain, replacing resistors R13 and R15 by FETs.

To make the level-detector we can use the remaining un-used op-amp in U4 to create a simple half-wave rectifier and low-pass filter. This simply rectifies the incoming signal (after amplification) and generates a DC output voltage that is proportional to the peak amplitude of the amplified signal. The trick is how to feed that voltage back to the gate terminals of the gain-controlling FETs to accomplish what we want. For strong signals we want the system gain to DECREASE. Using the 2N5484 JFET, the gain will decrease if the gate is biased more *negatively*. So we configure the half-wave rectifier to generate a *negative* DC voltage.

In the AGC circuit of Figure 5-5, note that values for resistors R14 and R16 have been suggested. The resistance of the 2N5485 can be varied from about 150Ω at $V_{gs} = 0$ to >2kΩ at $V_{gs} = -4$ so with the specified values of R14 and R16 we can expect the gain of the AGC system to vary between <4 on the low end and to >250 on the high end. The actual gain values will depend on the particular device characteristics (Idss and Vpo). We can also influence the operation by varying the resistor R31, which controls how much DC control voltage we get for a given input signal amplitude. This allows us to optimize the operation for a particular range of transmitter-receiver distances:

- □ Optional, for Extra Credit: modify your receiver circuit to include a AGC loop as shown in Figure 5-5. Test the system over a range of transmitter-receiver distances; you will probably want to monitor the output of the final gain stage (U3D) in your receiver as you vary the distance, in order to help identify the optimal values for R14, R16, and R31.
- □ If you successfully implemented any of the modifications discussed in this section, be sure to demonstrate your improved receiver to the TA!

Congratulations!
You have now completed Lab 5b

