EXPERIMENT #9
FIBER OPTIC COMMUNICATIONS LINK

INTRODUCTION:

Much of data communications is concerned with sending digital information through systems that normally only pass analog signals. A telephone line is such a system. For such systems, modems are used to convert the digital signals into an analog form suitable for transmission.

A common medium used for transferring both digital and analog signals is the optical fiber. Fiber optic systems use a beam of light (which is really a high-frequency electromagnetic wave) as a carrier of information. Just like in radio, this "carrier" can be amplitude, frequency, or phase modulated.

Fiber optics have many advantages over wires. First, since there is no electrical signal, the security of communications is quite good. It's practically impossible to "tap" a fiber optic line without generating a sizeable signal disturbance, which would be easily detected at the receiver. Furthermore, because the communication isn't electrical, it is immune to induced noise such as AC power line hum or automobile ignition noise. Finally, since there is no electrical connection in a fiber optic cable, there's no need to share a common ground between transmitter and receiver. This effectively *DC isolates* the transmitter and receiver, which further reduces noise.

To achieve effective FM or PM in fiber optics requires precise control of the lightwave carrier frequency. Since LEDs are not stable frequency sources, lasers are used as the transmit source in FM or PM fiber optic applications. A frequency-modulated light wave is demodulated using optical heterodyning; the received light signal is "mixed" with a local oscillator (another laser signal) in a non-linear optical material. The result is a UHF radio signal which is then downconverted and detected using conventional superheterodyne techniques. Tremendous bandwidth (information capacity) can be obtained using these techniques, but they are quite unusual!

Amplitude modulation of lightwave signals is much easier to achieve because conventional LEDs and phototransistors can be used as emitters and detectors. LEDs are inexpensive compared to LASERs, and have a longer life expectancy. However, the optical power output of LEDs isn't as great as that of LASERs, and the light emitted by LEDs is spectrally "dirty" (many frequencies are present).

In AM, the information signal can be either a sine wave (analog modulation) or a square wave (digital modulation). Both techniques will be explored in this experiment. The digital form of the circuit will be used again for later experiments.

To send analog information, the operating current of a transmitting LED is made to vary in step with the amplitude of the information signal. This causes the light output to vary up and down with the information signal. This is exactly the same as the working of a conventional AM radio transmitter. To detect the AM signal, a phototransistor is used. The phototransistor acts as a light-dependent resistor. When the light level changes, the phototransistor's resistance changes, thus changing the receiver's current in step with the original information. A resistor in the receiver circuit converts this current back into a voltage that is a copy of the original information signal.

Digital information is also easy to send. Most systems simply turn the light on to indicate a logic "1" or *mark*, and turn the light off to indicate a logic "0" or *space*. Thus, a digital transmitter is nothing more than a switch that turns an LED on or off! At the receiver, the presence or absence of light is allowed to turn a phototransistor on and off; the resulting signal is conditioned (amplified) into a proper digital (usually TTL-level) signal.

The fiber optic emitter in this experiment uses infra-red light instead of visible light. This is done in order to reduce fiber optic signal loss, because the materials used for fiber optic cable transmit these lower frequencies better than visible light frequencies. Also, silicon photodetectors tend to have a "peak" in sensitivity somewhere in the IR region.

CIRCUIT ANALYSIS:

Figure 1 shows the analog fiber optic system. It's amazingly simple! R1 biases D1 (the SFH-450V LED) to mid-point bias at around 10 mA. C1 allows the AC input signal to enter from the generator, but blocks the DC which would interfere with the Q-point of D1. R2 sets the AC gain and input impedance of the circuit. Since the forward-biased diode has a small AC resistance (recall that r'd = 25 mV / ID = 25 mV/10 mA = 2.5 Ohms), a resistor is needed in order to limit the AC input current. As a bonus, R2 introduces *negative feedback* which *linearizes* the circuit, reducing distortion.

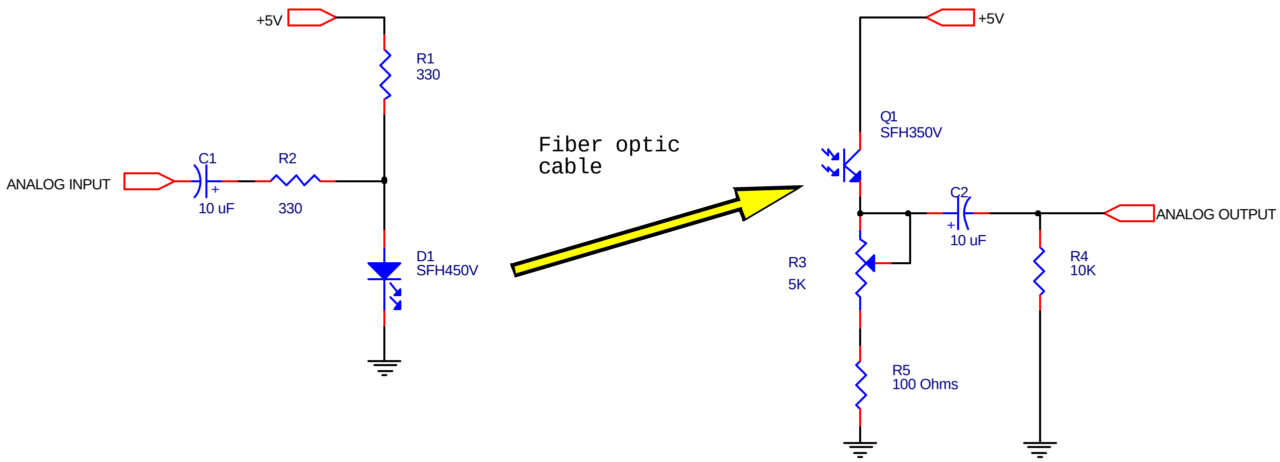


Figure 1: Analog Fiber Optic System

The analog receiver is also straightforward. Q1 (the SFH-350V phototransistor) receives the light that was launched by D1 into the optical fiber. This sets up a current in Q1 proportional to the optical input power (light level). This current creates a voltage drop across R3 and R5 which will follow the original input signal. There will be a DC level present because the light beam is "on" with zero information voltage; C2 removes the DC level, while letting the AC information signal pass. R4 is present to provide a DC return for the negative side of C2 so that a DC potential won't appear at the ANALOG OUTPUT.

Variable resistor R3 adjusts the DC Q-point of the receiver circuit. This adjustment is needed because of the possible variation in input optical power from unit to unit, as well as variation in the power gain of Q1.

Figure 2 is the digital version of the system. The digital signal enters pin 1 of U1a where it is inverted. Therefore, a mark or logic "1" causes U1a pin 2 to go low and turn on D1 through R1. A space or logic "0" conversely causes D1 to turn off. Thus, a digital signal causes the light beam to turn on and off in step with the 1 and 0 pattern being sent.

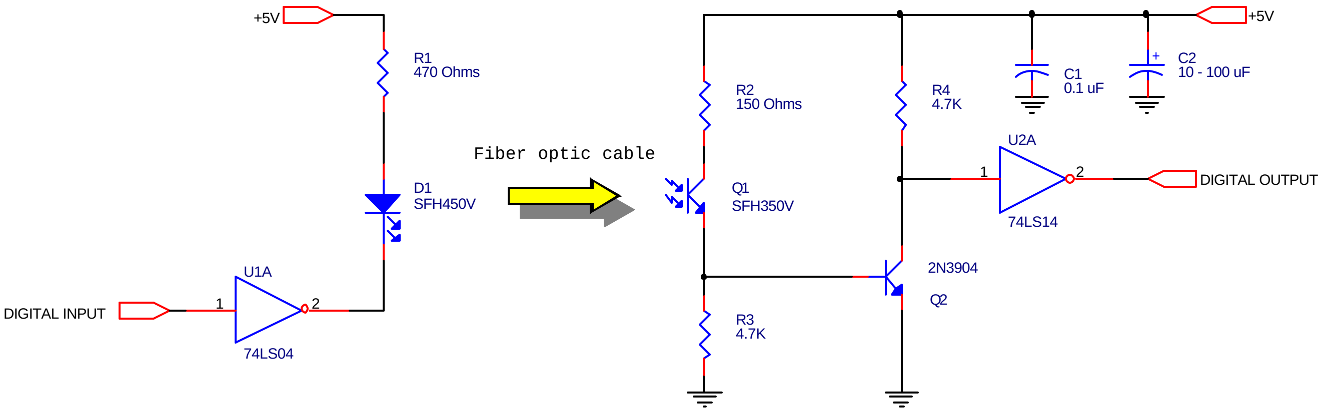


Figure 2: Digital Fiber Optic System

The digital receiver consists of Q1 (the photo detector diode), Q2 (a current amplifier), and U1b. Recall that a logic "1" is represented by the light beam being turned on. This means that when a logic "1" is sent, Q1 will be "on" and will saturate. When Q1 is turned on by the light wave, Q2 is also turned on (Q1's emitter current flows through the base of Q2). When Q2 turns on, it pulls the input of inverter U2a "low." U2a therefore outputs a logic "1" when the light beam is turned on.

When the light is turned off, Q1 turns off (it acts like an open circuit). With Q1 turned off, R3 pulls the base of Q2 towards ground, which turns off Q2. Q2 also appears as an open circuit at this point, and resistor R4 is now able to pull the input of U2a up to 5 Volts ("high.") The output of U2a is now low. Therefore, when the light source is off (a logic 0 is being sent), the receiver output is a logic zero.

For your reference, here are the pin-outs of the FO emitter and detector pair. Note that the two "spare" pins on the bottom of each device are not electrically connected. They improve mechanical stability when the device is mounted on a circuit board.

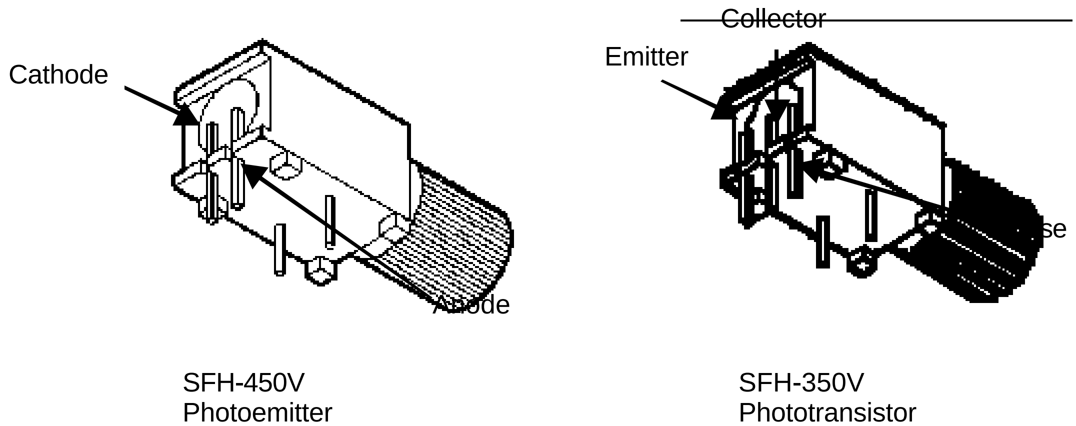


Figure 3: Pin-out of Fiber Optic Emitter and Detector Pair

LABORATORY PROCEDURE:

Name ____________________ Sign-off ________

PART I: Analog Fiber Optic Link

1. Build the analog circuit of Figure 1. Make sure to properly dress the fiber optic cable ends as shown in Figure 4. Failure to do this may make your circuits work marginally, or not at all!

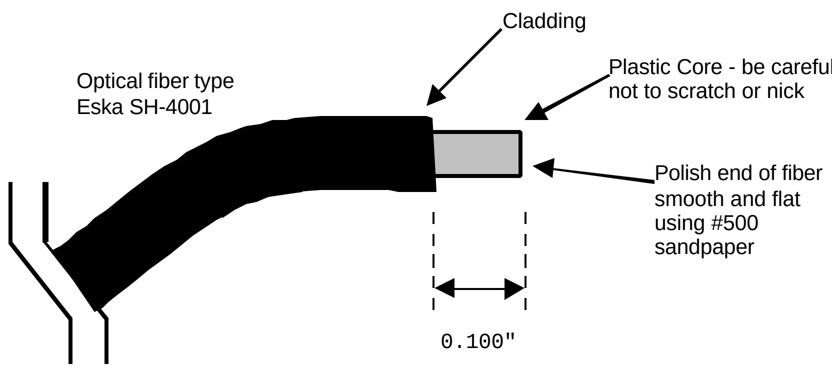


Figure 4: Dressing the Fiber Optic Cable Ends

2. Apply power to the circuit, but no signals yet. Check the voltage at the emitter of Q1:

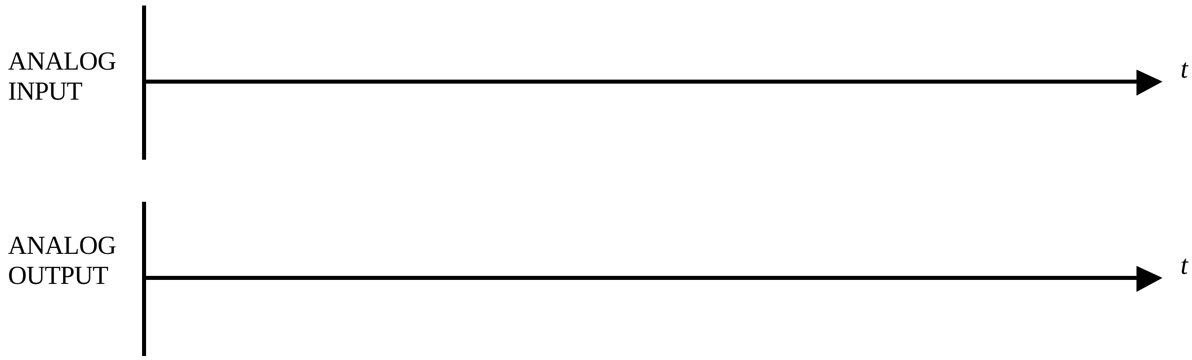
   - Adjust R3 until the voltage is 2.5 V +/- 0.5 V. If this adjustment goes OK, your receiver is working properly and you can proceed to step 3.

   - If there is NO voltage (or less than 0.5 V DC), there is something wrong! Either there is no optical output coming from D1 (measure its current to test), or Q1 is not getting turned "on" (not getting optical input, in backwards, etc.) Find the problem before continuing!

   - If the voltage seems to be "stuck" at or near 5 Volts, check to make sure that R3 is wired correctly, and that Q1 isn't shorted or in backwards.

3. Connect scope channel 1 to the circuit ANALOG INPUT, and channel 2 to the circuit ANALOG OUTPUT. Connect a signal generator to the ANALOG INPUT set for a 1 KHz, 1 V p-p SINE wave output.

4. Graph two cycles of the input and output waveforms. Show all important voltages and times. (If the output is not a clean sine wave, try adjusting the input amplitude up or down slightly).



5. Compute and report the *voltage gain* of the system. Show your calculation.

Recall that: $A_V = \dfrac{V_{out}}{V_{in}}$

Voltage gain: ___________ V/V

6. Increase the amplitude (voltage) of the signal generator until the ANALOG OUTPUT becomes distorted. Report how much signal could be received without distortion. There will be great variance from unit to unit!

Maximum ANALOG OUTPUT signal without distortion: ____________ Vpp

7. With the input amplitude adjusted for a clean sine wave output, increase the frequency of the signal generator until the output signal decreases by 3 dB from the 1 KHz output voltage value. Note: Recall that a 3 dB power decrease means 70.7% of the original voltage. Report this frequency; it is the bandwidth of the analog system.

-3dB Bandwidth of Analog System: ___________ KHz

PART II: Digital Fiber Optic Link

8. Build the digital fiber optic data link of Figure 2.

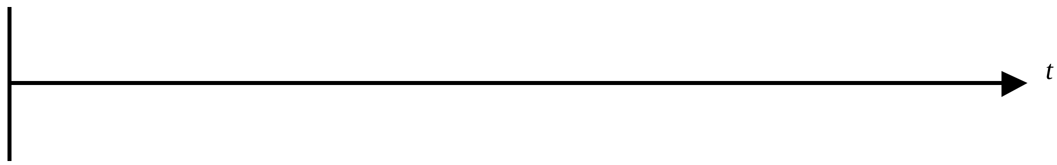
9. Connect scope channel 1 to the circuit DIGITAL INPUT, and channel 2 to the circuit DIGITAL OUTPUT. Connect a signal generator to the DIGITAL INPUT and set it for a 300 BPS, TTL SQUARE wave output.

TIP: Recall that since there are *two* bits in each square wave cycle, the frequency and equivalent data rate of a digital wave are related as follows:

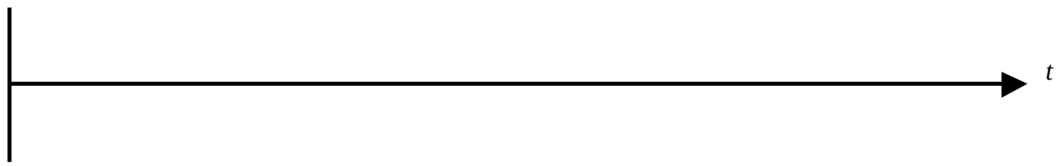
$BPS = 2 \times F$ Where F is the input frequency in Hz.

10. Apply power to the circuit, and graph two cycles of the input and output waveforms. *Both should appear as valid TTL signals.* Make sure to use DC coupling on the oscilloscope inputs. Show all important voltages and times on the graphs.

DIGITAL
INPUT



DIGITAL
OUTPUT



11. See how fast it can go! Increase the frequency of the data signal from the signal generator until the recovered square wave becomes distorted. You can consider the wave distorted if it:

- Has a duty cycle of less than 25% (or more than 75%)

- Has any round parts

- Has any other obvious defects (missing portions, etc).

Report this as a *maximum equivalent data rate*. How does it compare with commonly available telephone modems (e.g., 56 kbps units) or your home Internet connection? Remember to use the relationship given in step 9 to relate signal generator frequency to equivalent data rate.

Maximum equivalent data rate of digital link: ____________ kbps

QUESTIONS

1. What are two advantages of fiber optics over conventional transmission lines?

   1) ____

   2) ____

2. What type of modulation does the circuit of Figure 1 employ?

   ____

   ____

3. How does the circuit of Figure 2 represent 1s and 0s on the optical fiber?

   ____

   ____

4. What else have you learned in this experiment?

   ____

   ____

   ____

   ____

   ____

   ____