

UNIVERSITY of PENNSYLVANIA
DEPARTMENT of ELECTRICAL and SYSTEMS ENGINEERING

Electrical Circuits and Systems II Laboratory
ESE206

Lab 1: Digital Fiber Optical Transmitter and Receiver

Goals:

- Exploring the optical part of the spectrum to transmit information.
- Exploring the interface between the optical and electrical frequency regimes.
- Getting familiar with fiber optic communications, including elements such as LED and photocell (photo resistor).
- To give an introduction to dispersion.

Introduction:

Many of you know that an AM radio works by taking a high frequency carrier signal and modulating its amplitude giving rise to the acronym Amplitude Modulation (AM). This seems to be a bit of a bother. Couldn't we just take an audio signal and send it out directly? In principle we could. There are radio antennas which operate over entire audio spectrum (20 Hz to 20 KHz) from extremely low frequency (ELF) communications used in submarines to low frequency (LF) signals used in navigation, but it would be a remarkable waste and not particularly effective.

First of all, everyone who would be transmitting and listening would be able to hear what everyone else was saying. There would be no means of separating the signals from each other. With AM radio you can listen to a broadcast of the Eagle's game 1110 KHz while your parents can listen to news broadcast at 1120 KHz. Within the frequency spectrum these two signals are remarkably close, but still clearly separated allowing your radio to efficiently separate out the one you want.

For two, the world looks remarkably different to different frequencies in the electromagnetic spectrum.

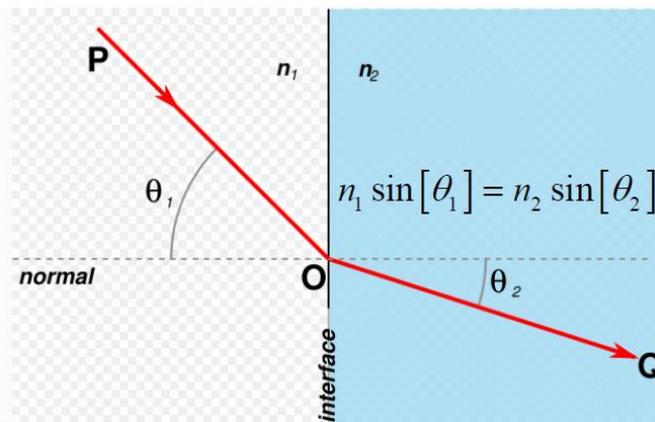
- Submarines will tow extremely long ELF antennas because ELF will penetrate ocean water while a submarine will never hear the Eagle's game broadcast on commercial radio frequencies
- Visible light penetrates the ozone layer where ultraviolet radiation is reflected back into space.
- The ionosphere and the earth's surface both appear to be reflective to radar (~1GHz) allowing radar signals to bounce back and forth reaching well over the horizon.
- Ultraviolet light is absorbed by glass and is the portion of the spectrum that damages your eyes. Richard Feynman knew this and watched the first atomic explosion through the windshield of a car. (Hint: if there is ever an atomic explosion, just hide)

The end result for communications is that the world looks like a bunch of bandpass filters. If you transmitted audio signal directly without the use of a single carrier frequency and some form of modulation, the result to the listener would be nothing like what the sound you intended.

This all seems to be a funny introduction to a fiber optics lab, but fiber optics can be viewed as a form of AM communication. In this lab we'll use a green LED (5.6 THz) as a carrier signal to transmit information at about 1 KHz. We'll all be using the same carrier frequency because we'll all be using the same color LED. This would normally cause problems. However, we'll be clever and direct the transmitted signal directly to intended receiver.

We'll do this using fiber optics. The fiber is a waveguide for an electromagnetic signal just the same as a wire, but because different material properties of metal and glass at different frequencies, they don't work in each others frequency regime. For instance you will never be able to shine light down a metal wire and you'll never be able to send a 1 KHz signal down a glass fiber. However the key point is that they are both waveguides transferring electromagnetic energy from one point to another.

The electromagnetic energy is guided down a wire because of the interface of the metal with the air. A very similar phenomenon occurs in fiber optics. You might have had the experience of being just under water watching the reflection of light off of the interface between water and air. If you descend deeper and look up a sharper angle, you'll find that you can see outside the water and the light does not reflect.



This is a product of Snell's Law, which you might remember from basic physics. Snell's law governs refraction, the bending of light as it goes from one medium to another. If the light is going from a region of a higher refractive index to one with a lower refractive index, θ_2 will always be greater than θ_1 . At a certain angle of θ_1 , known as the critical angle, θ_2 will be equal to 90° , its maximum value. Any values of θ_1 greater than this will result in a reflected beam. This is called *total internal reflection*.

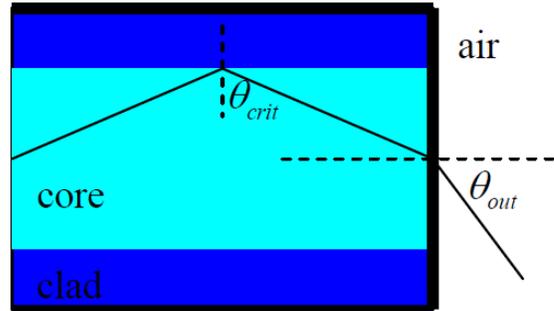
Wires have insulation to prevent accidental coupling of energy into other things. Similarly, fiber optics actually consist of two layers for the same reason. The outer layer (called the cladding) has a slightly lower index than the inner layer (called the core). This way light can bounce back and forth without relying on an interface outside of the fiber.

The difference in the refractive between the cladding and the core govern the fiber behavior. If the difference is large, light with a large range of angles will happily bounce back and forth to the other end, but if the difference is small only a narrow range (with θ_1 near 90°) can bounce back and forth without escaping to the outside world. This also makes it easier to couple light into the end of the fiber since the fiber will be more accepting of different angles.

Yet we find that manufacturers actually make the difference in the refractive indices very small. This seems counter intuitive until we consider data transmission. Light which bounces back and forth many times will take much longer to reach the fiber end than light which travels directly. This results in dispersion, the spreading of a signal. By keeping the indices close, only a limited (but more importantly) narrow range of angles can propagate down the fiber making sure that a light pulse remains a pulse.

Prelab:

1. If $n_{core} > n_{clad}$ find the critical angle θ_{crit} .
2. If $n_{core} > n_{clad} > n_{air}$, determine the angular range that will be coupled into the end of the fiber from outside. In other words, suppose you illuminate the core of the fiber from all angles. First, the light will refract because of the core-air interface. A certain portion of it will be beyond the critical angle inside the core while some of it will simply escape into the cladding be lost.
3. While all rays will travel with the same speed c/n , where is the *speed* of light while n is the index of refraction of the material in which it propagates, depending on the angle of the ray, it will travel with a different *velocity* down the fiber. If $n_{core} > n_{clad}$, find the ratio of the velocities between the fastest and the slowest rays.



Turn in the prelab at the start of the lab session. Copy the calculation results in your lab notebook for use during the lab.

Lab Experiment

[Equipment:]

1. HP multimeter HP 34401A
2. Agilent Function/Arbitrary Waveform Generator 33521A
3. Power supply
4. Agilent mixed-signal Oscilloscope MSO7034B
5. Fiber optic element
6. LED to fiber coupling element
7. Photocell to fiber coupling element
8. Two LM741 Op-Amps
9. Two green LEDs
10. Photoresistor (photo cell)
11. Potentiometer (10K)

In-Lab Experiment:

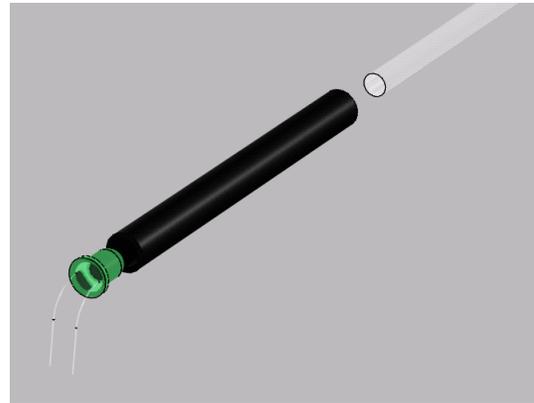
Build a Digital Optical Transmitter:

To light the optical fiber we will use a “Green LED- 1.9 V, 3 mA.” We will flagrantly ignore the 3 mA and drive it at a dangerous **10 mA**. Throughout this lab we will operate between a positive rail of +7 (V) and ground. What value should we use for R_{LED} ?

The proliferation of fiber optics over the past decade has resulted at least in part from connector technology. Now-a-days you can connect fiber optical components as easily as you would connect an ethernet cable to your computer. While very convenient, it isn't very satisfying or illuminating (bad pun), and so we will build our own coupling elements.

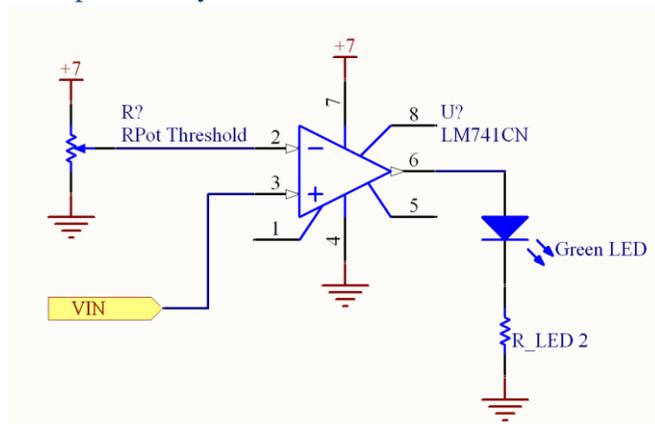
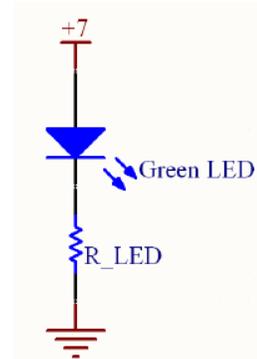
Further information on couplers can be found at [here](#). The goal of a coupler is to get as much light into the fiber as possible. If the core diameter is only a couple microns across (1 micron = 1/1000 mm), this is not an easy task. We are using a fiber with a core diameter of close to 3 mm.

To couple the LED to the fiber, assemble the fiber the parts as shown to the right. Push the fiber through until it is up against the LED. The plastic of the fiber is pretty stiff. To keep it from pulling the LED out of your bread board, you can pin it down with small “U” shaped wires. Do you see a bright green light coming out of the end of your fiber? Pass a laser mouse over the middle section of the fiber. Do you see any red light coming out of the end? Why or why not? What advantages does this afford optical fibers over traditional copper wires?



Over what angles do you see the light exiting the fiber? The manufacturer's web site claims that the core has an index of refraction 1.492 while the cladding has an index of refraction of 1.402. Of course air has an index of refraction close to 1. At what angle would you expect to see a cone of light coming out of the fiber end if it were trapped between the cladding core interface? (be careful: refraction occurs at the fiber end) How does this compare with you measured result?

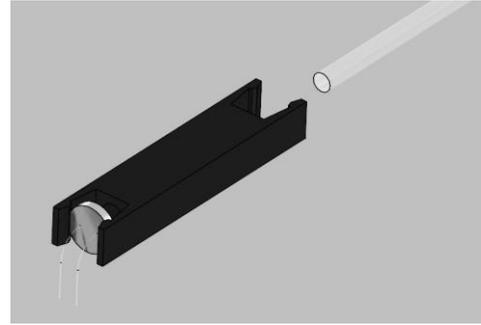
Remember that not all rays travel down the fiber at the same velocity. Given a signal of infinitesimal pulses, what is highest frequency you could send down your cable if it were 1 km long so that you still had some fraction of the time in which the output is dark? What advantages does having a small difference in refractive indices offer in this regard?



Rather than drive the LED directly from the rail, drive it with an opamp using the circuit shown to right. **What is the function of this circuit?** Apply a sine wave ($f=10\text{ Hz}$, $V_{pp} = 5\text{ V}$, $V_{off} = 3.5\text{ V}$) at **VIN**. This simulates an extremely poor digital signal that could be generated from a circuit. **Roughly, to where should R_Pot Threshold be set?** Capture the output voltage at the top of your LED as a function of the input voltage.

Build a Digital Optical Detector:

Assemble the other end of the fiber with another metal sleeve, a fiber coupler, and your photocell as shown to the right. Push the metal sleeve into the plastic housing until it is all the way in and then insert the fiber until it is about to come out the opening of the hole on the other side. Once again, the fiber optic element is very stiff so it helps to hold it down with some pcb headers to keep it from pulling out your photocell.

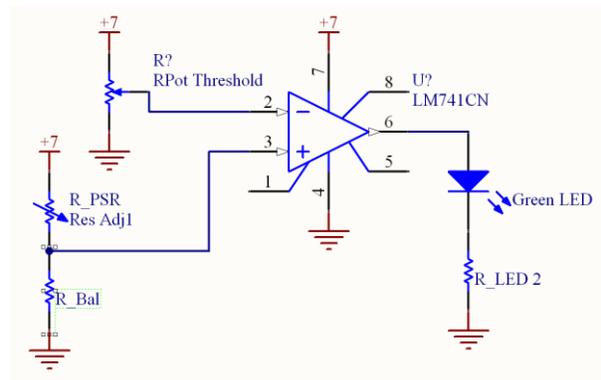


Reduce the frequency at **VIN** to 0.5 Hz while you measure the resistance of the photosensitive resistor.

What is the resistance when the fiber is lit and unlit respectively? Cover the top with a piece of black electrical tape. Now what is the on and off resistance respectively, and how does this relate to signal to noise ratio?

Illuminate a middle section of the fiber with an optical mouse. **Does this change the on and off resistance?**

Build the circuit to the right around your photocell. Now you should have two such circuits on your protoboard, one transmitting and one receiving. Choose an appropriate value for **R_Bal** so that when **R_Pot** is set to 50%, a change in the state of the fiber will result in a change in the state of the output LED. **Is this circuit good processing digital or analog signals?**



Begin to increase the frequency at **VIN**. How fast can you transmit digital data down this cable?

Use a DC Offset to Improve Bandwidth:

When the LED is driven by a square wave with no DC offset, the data transmission frequency is limited. This is because the LED does not turn on until a certain threshold voltage has been reached (in this case, about 2.1 V). One way to allow for faster data transmission speeds is to use a DC-offset so that the LED is always on, and the AC signal merely changes the brightness of the LED. By carefully tuning the potentiometer in the comparator at the receiver, it is possible to capture digital information from the changing brightness.

For this part of the experiment, the LED will be powered directly by the function generator. Use a square wave with a 50% duty cycle and a frequency of at least 2 kHz, and adjust the offset voltage and amplitude of the signal and the resistance of the receiver potentiometer until the data is

successfully transmitted. Make sure not to set the DC offset higher than about 2.5 volts, in order to avoid burning out the LED.

What offset voltage and amplitude are necessary? How high can you increase the frequency while maintaining data transmission? What happens to the duty cycle of the output signal, compared to that of the input signal?

To hand-in

Write your lab report (according to the [guidelines](#)) summarizing the experiment and results obtained in the lab.

The Lab report is an important part of the laboratory. Write it carefully, be clear and well organized. It is the only way to convey that you did a great job in the lab. The typewritten report is due at the beginning of the next lab section. Please consult the [Grading Policies](#) at <http://www.seas.upenn.edu/~ese206/#GRADING>

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January 17, 2007

Edited:

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