High Bandwidth RF Over Fiber Optics

6.101 Project Proposal

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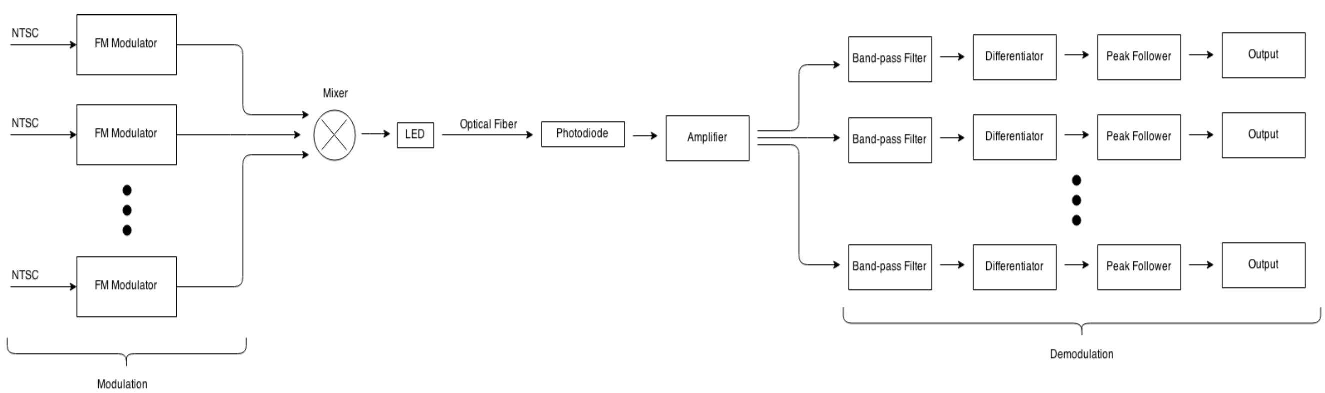
Overview

Our goal with this project is to transmit multiple, high bandwidth signals over a fiber optic cable with low signal degradation.

Block Diagram



To help illustrate how our circuit will achieve this goal, we created a block diagram that breaks our project down into its major components. In the first stage, you can see multiple NTSC signals leading into a series of FM modulation circuits. NTSC is a relatively high-bandwidth video standard that we will use as our canonical input signal.

These frequency modulated signals are then mixed together where they vary the current through an infrared LED. This light then passes through an optical fiber over some arbitrary distance.

On the other end of the fiber, a photodiode turns fluctuations in light intensity into fluctuations in current which can then be amplified for additional processing. A bandpass filter then divides the incoming signal into channels to be demodulated.

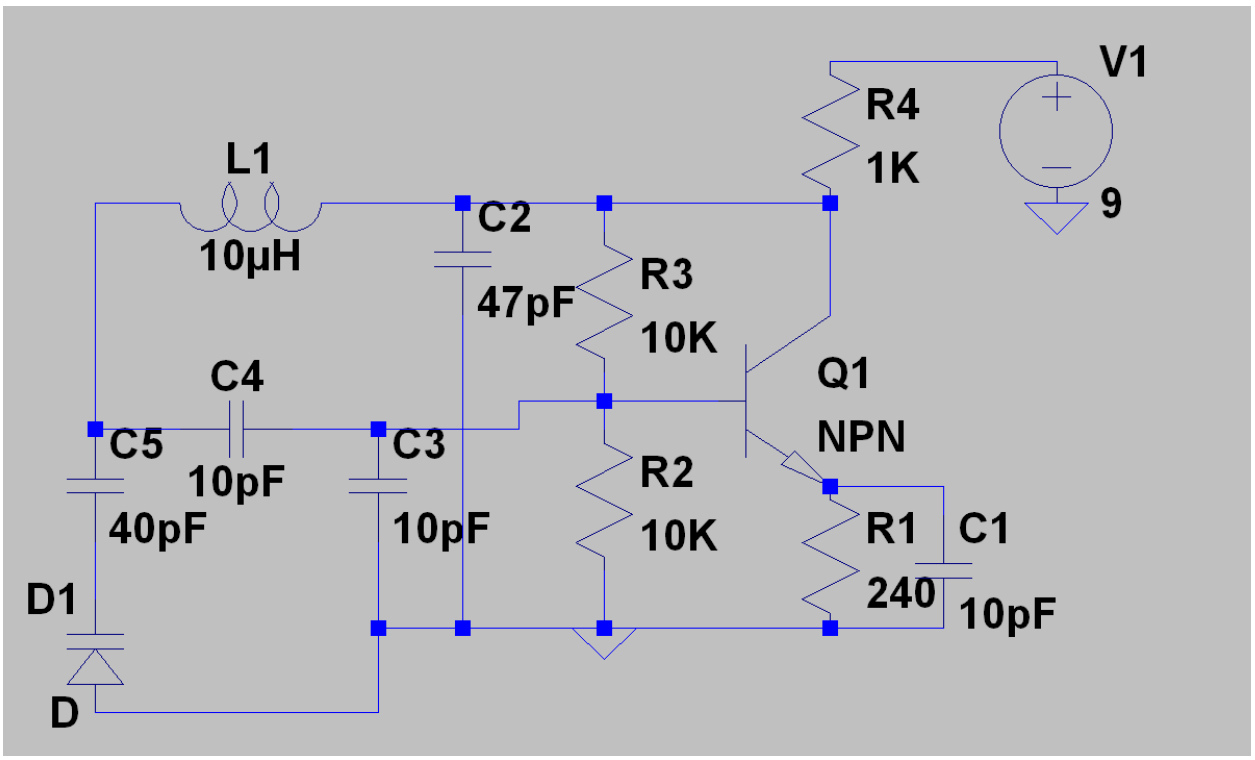
Once these channels are demodulated, the input signal is (hopefully) reconstructed.

FM Modulation

The process of FM modulation and transmission consists of modulating a harmonic oscillation in accord with an input voltage signal. Mathematically, this takes the form of:

$$V_{fm} = A\cos(\omega c + \int_0^t V_i(t)\, dt)$$

Naturally this can be accomplished with a Voltage Controlled Oscillator or VCO. There are many types of VCO, but the two most common are the Hartley and Colpitts type oscillator. In our project, we are using a Vackar oscillator: a very stable derivative of the Colpitts oscillator.



The modulated signal is output on the collector of the BJT. The actual frequency modulation occurs due to the varactor diode, labeled D1 in the above schematic. The varactor diode changes its capacitance according to its reverse voltage, which is conveniently our input signal.

Parasitics in the Modulator

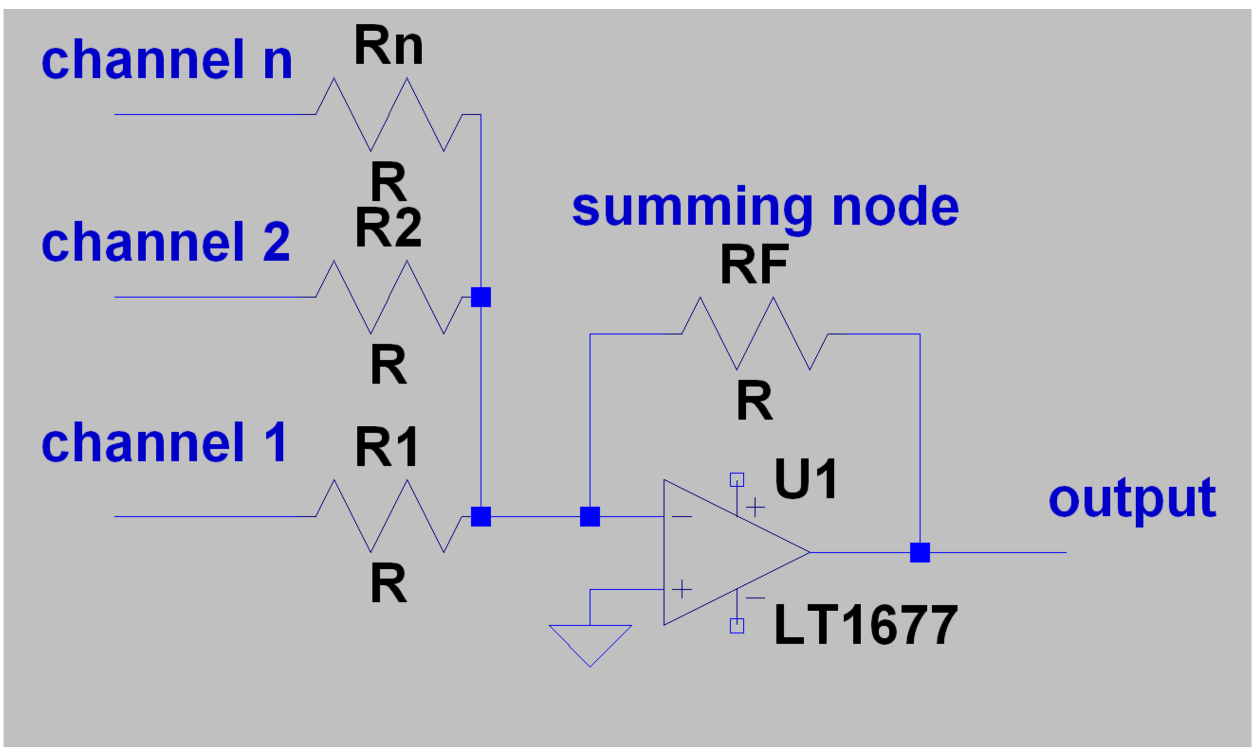
As it turns out, nothing is perfect and every single component in a circuit has unintentional parasitic resistance, inductance, and capacitance associated with it. We've empirically determined that the most detrimental parasitic in the above oscillator is the **e**quivalent **s**eries **r**esistance of the inductor (we may refer to it as ESR from now on). ESR increases with frequency. For example, we measured the ESR of one 5uH inductor at DC and it was 5 Ohms. At 12MHz it was 340 Ohms. This value was large enough that it actually prevented the VCO from oscillating at all. In addition, inserting this parasitic into SPICE simulation produced the same result. We hope this means that if we can measure our parasitics, SPICE simulation should still be accurate. In order to deal with this shortcoming we are going to be using RF inductors which have max ESR's of ~3 Ohms. The simulation tells us this should be OK.

FM Mixing

Because of the linearity of the Fourier transform operation, we can simply add all of the FM channels using a single Op-Amp.

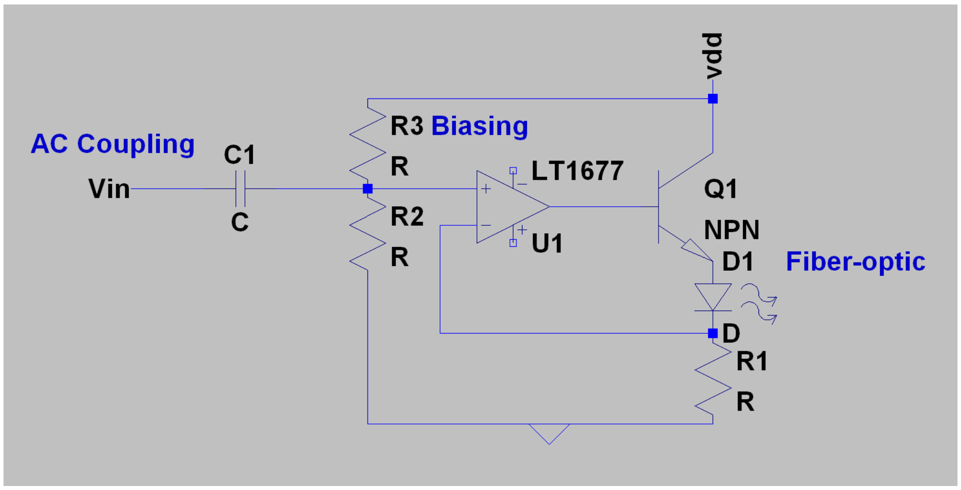
$$x_1(t) + x_2(t) + x_n(t) = X_1(jw) + X_2(jw) + X_n(jw)$$

Since our channel frequencies are far enough apart, there will be no overlap of their spectra. The summation circuit uses an op amp with a huge gain-bandwidth product. These days we are fortunate that a few dollars can buy you a few GHz!



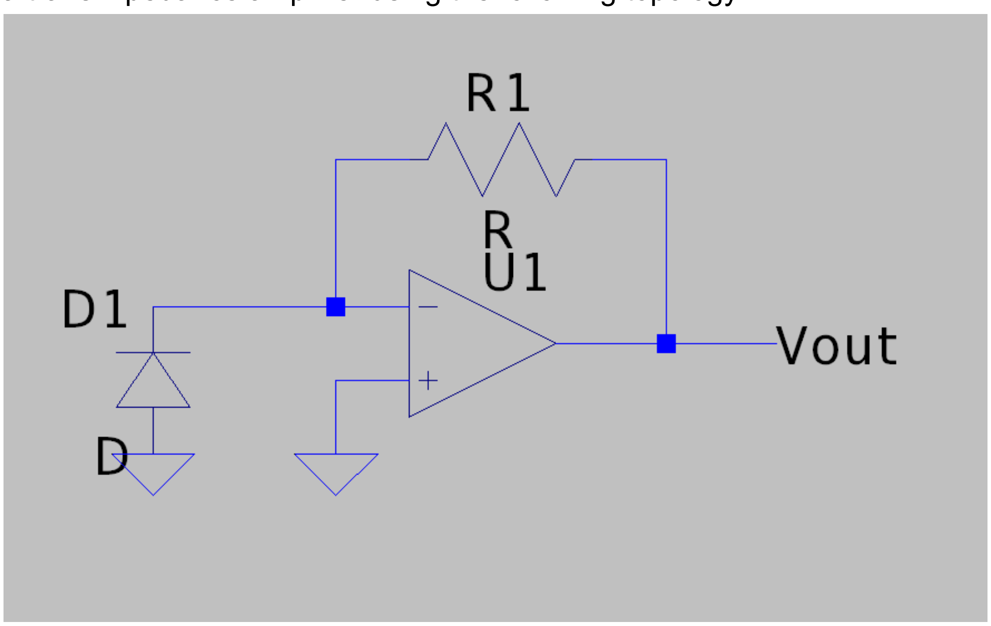
Fiber-optic Transmission

The fiber optic transmitter is just an LED. To drive it we need a Voltage Controlled Current Source or VCCS. A simple topology with feedback on the emitter of a bjt will suffice.



Transimpedance Amplifier

After coming over a potentially long fiber optic cable, we can't count on the light's intensity alone to drive much current. To turn small amounts of current into a useful voltage, we construct a transimpedance amplifier using the following topology.



$$V_{out}/I_D = -R_1 .$$

FM Demodulation

Once the signal is amplified, our goal is then to separate out each channel and perform demodulation. We can accomplish this one of two ways:

1. Asynchronous demodulation. First, for each channel we run the incoming signal through a bandpass filter to make sure that we are only demodulating the signal we're interested in. Next, we run the signal through a differentiator. This turns the problem into the much more familiar challenge of amplitude demodulation. Just like in our first lab of the semester, all we have to do is run the signal through a peak-follower circuit that traces its envelope.
2. Synchronous demodulation. This is a much trickier option that uses a phase-locked-loop (PLL). PLLs are very difficult to make by hand, so we would like to avoid this option if at all possible.

Differentiator

To differentiate our signal, we will use an RF opamp in the following configuration:

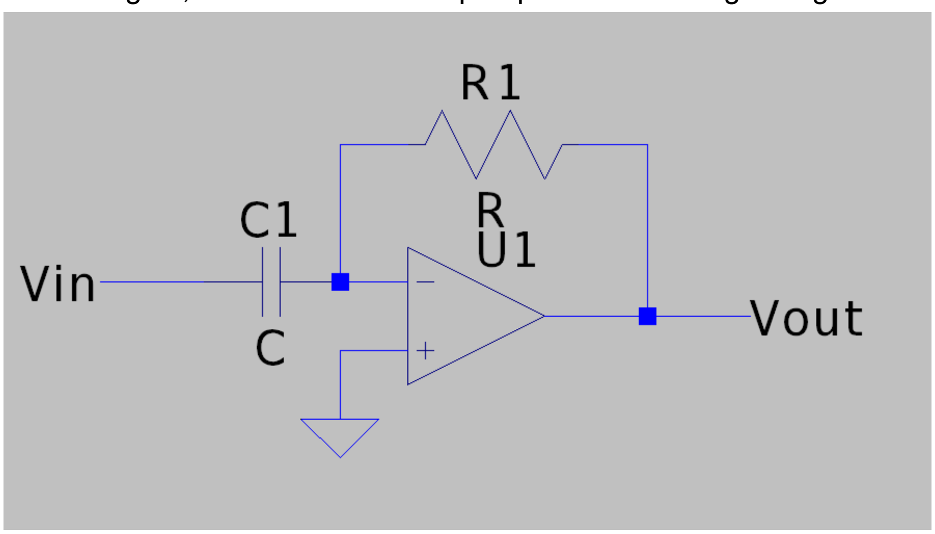


Photo: Wikimedia Commons

A little bit of math shows that:

$$V_{out} = -RC\frac{dV_{in}}{dt}.$$

This is due to the current/voltage relationship of the capacitor.

Labor Breakdown

Since the project divides so naturally into a modulation step and demodulation step:

1. Yanni will design and construct the transmitter.
2. Max will design and construct the receiver.