# FM Audio Over Fiber Optics

*6.101 Project Proposal*

**Yanni Coroneos and Max Justicz**

## Overview

Our goal with this project is to transmit multiple, potentially high bandwidth signals over a fiber optic cable with low signal degradation. In the case of audio, this type of project is useful in practice because it allows for the use of just a single fiber optic cable between all of the speakers in a room. By using RF over fiber optic instead of varying wavelengths of light, there are enormous cost savings to be had; the machines to splice fibers are very expensive!

## Block Diagram

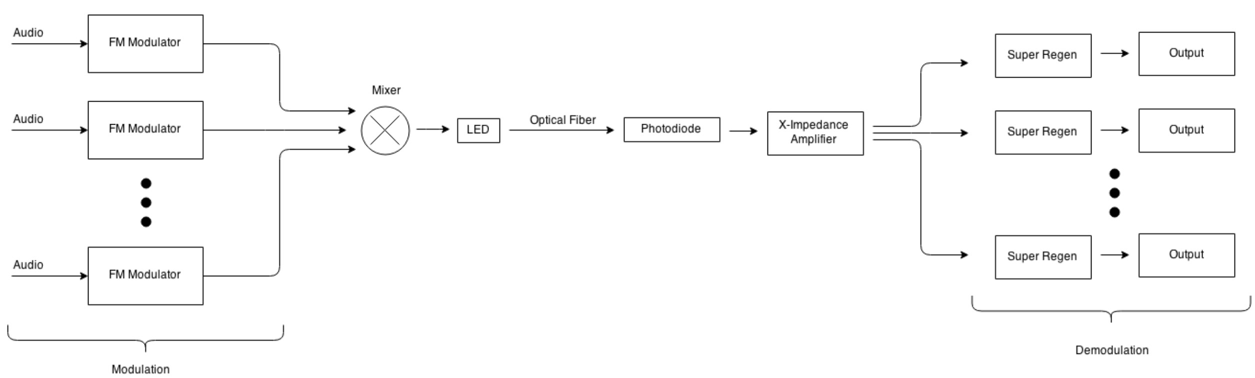


*Figure 1 - block diagram of expected functionality*

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 of Figure 1, you can see multiple audio signals leading into a series of FM modulation circuits. While in the future we might be able to achieve the transmission of higher bandwidth signals, audio serves a practical purpose and makes for a good demonstration.

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

On the other end of the fiber, a photodiode turns fluctuations in light intensity into fluctuations in current. These tiny amounts of current are turned into measurable voltages using a transimpedance amplifier. A bandpass filter then divides the incoming signal into channels to be demodulated using a super regenerative receiver.

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:

$$V_{fm} = A\cos(\omega c + \int_0^t V_i(t)\,dt) \quad (1)$$

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 crystal oscillator for its large Q. Paired with a varactor diode, this allows for a very stable frequency modulated signal derived from crystal pulling.

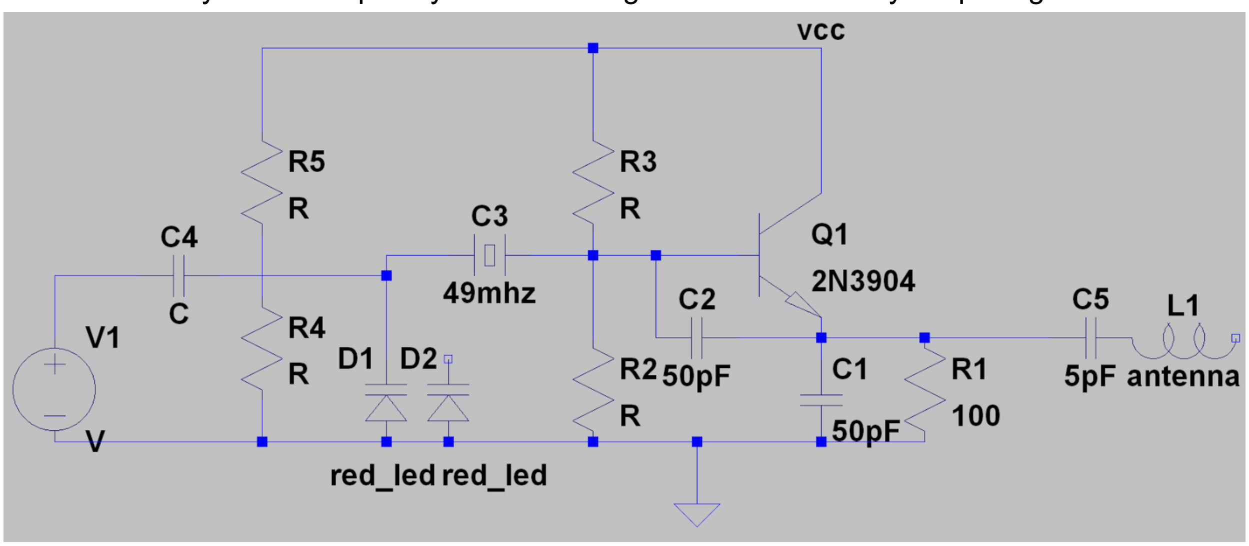


*Figure 2 - crystal-based FM transmitter*

The modulated signal is output on the emitter 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. The change in capacitance shifts the crystal's resonant frequency just slightly, which creates the FM 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 ESR should still permit oscillation.

## FM Mixing

Because of the linearity of the Fourier transform operation, we can simply add all of the FM channels and transmit using a single BJT

$$x_1(t) + x_2(t) + x_n(t) = X_1(jw) + X_2(jw) + X_n(jw) \tag{2}$$

Since our channel frequencies are far enough apart, there will be no overlap of their spectra. The summation circuit uses a simple 2N3904 with a transition frequency of 100MHz, the same as the LED transmitter.

## Fiber-optic Transmission

The fiber optic transmitter is just an LED. To drive it we need a Voltage Controlled Current Source or VCCS. A biased BJT is just that. The transmitter will be biased to 20mA because it exhibits linearity in that region:

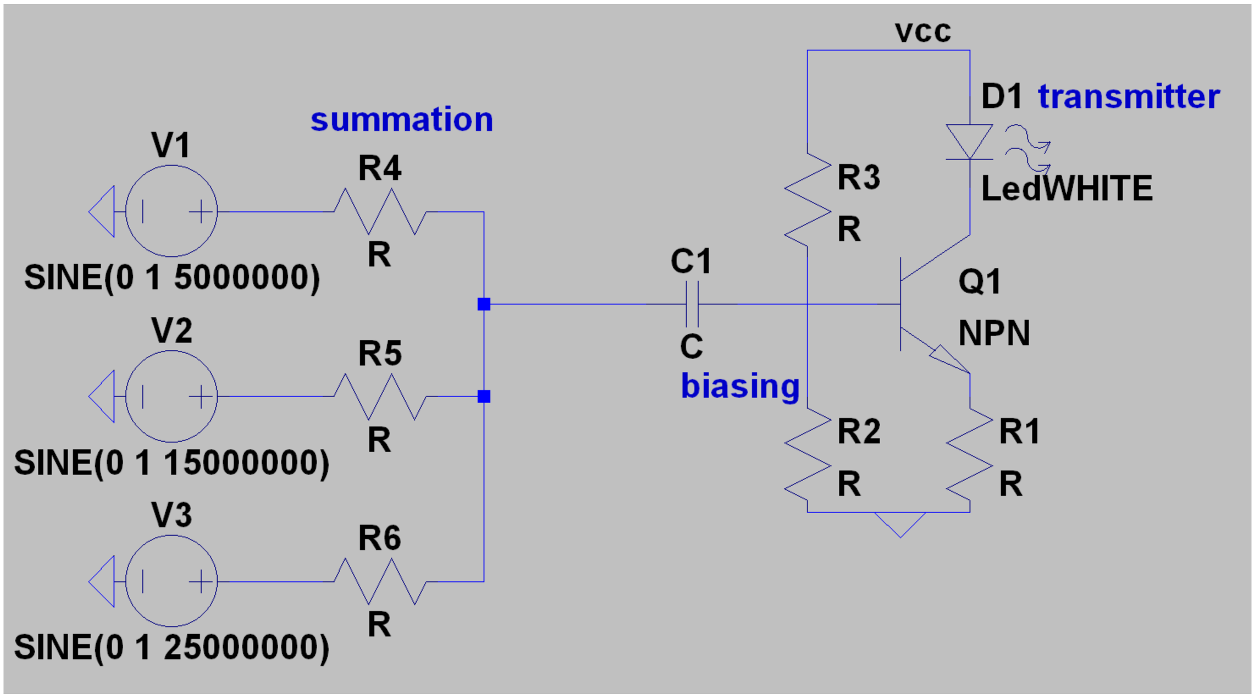


*Figure 3 - voltage controlled current source*

On the left of Figure 3 you can see multiple voltage sources representing FM signals. Currents sum across the resistors and capacitor C1 AC couples the two stages. From there the biased BJT acts as a current source to drive the LED.

## 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.

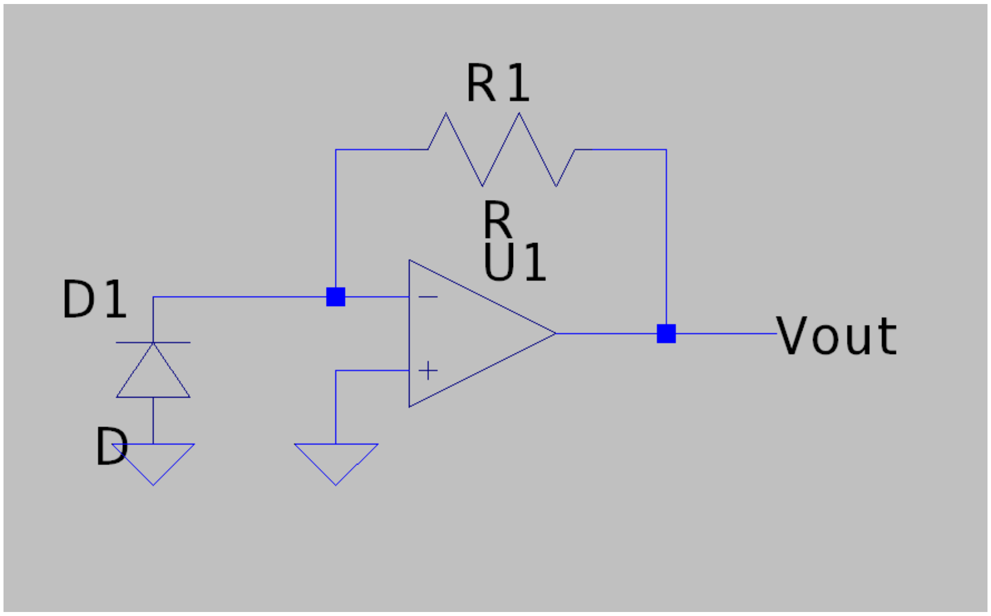


*Figure 3 - transimpedance amplifier*

$$V_{out}/I_D = -R_1 \qquad (3)$$

The circuit works because any current coming from the diode must flow entirely through R1 thanks to our virtual ground. To counteract any differences in voltage between the inverting and noninverting inputs to the op amp, Vout has to rise, turning our tiny current source into a measurable voltage source.

## 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. In our case, this means using a super regenerative receiver as described in the next section to slope-detect the FM signal.
2. Synchronous demodulation. This is a much trickier option that can involve the use of a phase-locked-loop (PLL). PLLs are very difficult to make by hand, so we would like to avoid this if at all possible.

## Super Regenerative Receiver

To demodulate our signal, we use the super regenerative receiver topology below:

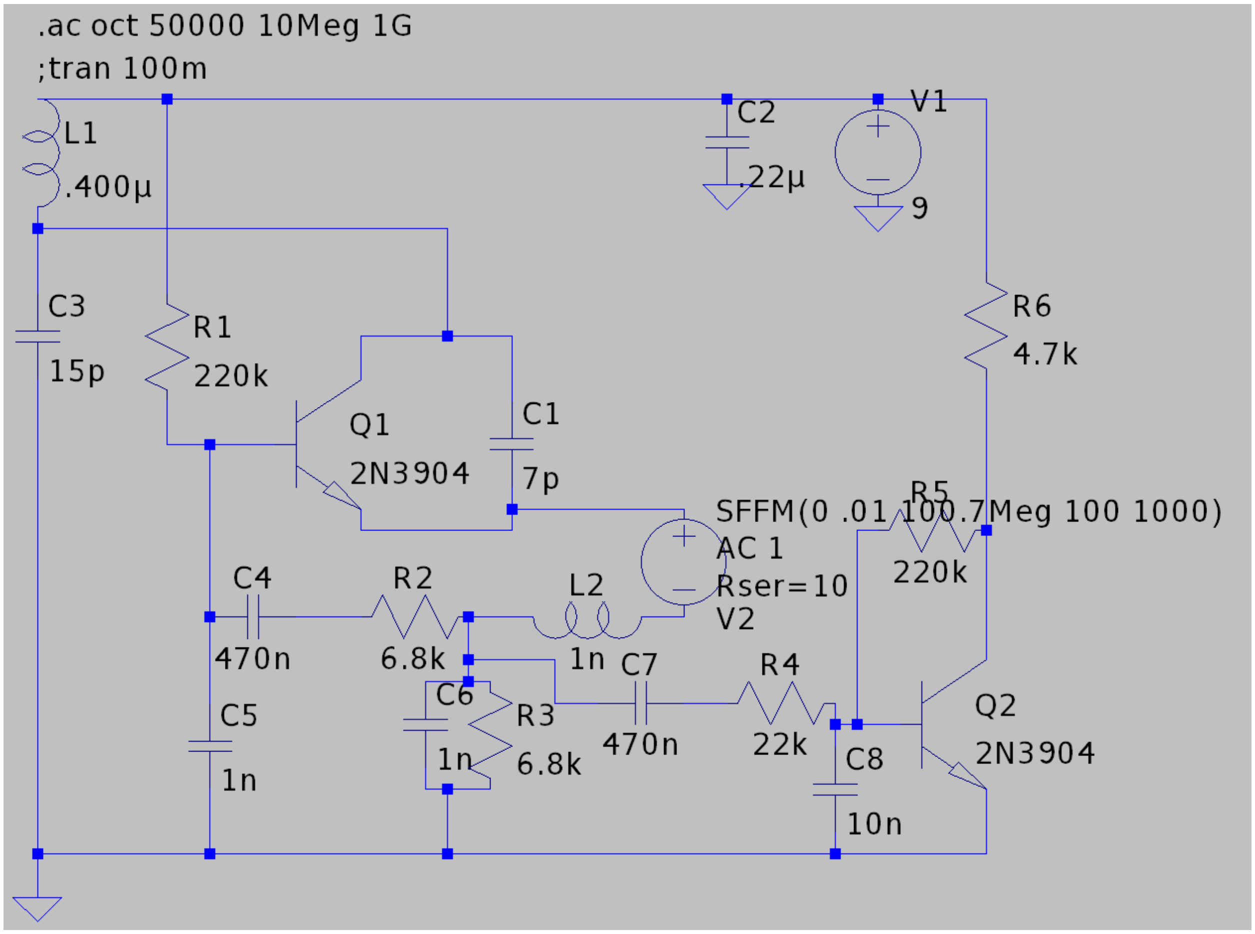


*Figure 4 - super regenerative receiver*

The circuit's oscillator is excited by incoming FM signals (represented here by the voltage source in the middle of the diagram). Thanks to the relatively high Q of the oscillator, this allows for FM demodulation via slope detection. Signals that deviate from the carrier frequency are slightly attenuated, allowing us to extract the original signal.

This circuit is a considered a super regenerative receiver thanks to the "quenching circuit" that resets the oscillator at about 20kHz. Since the receiver is most sensitive when it's just starting up, this gives improved signal quality over a plain regenerative receiver. The design of this type of receiver as used for wideband FM and AM reception was made possible through the excellent article available at [1].

As an interesting aside, [1] notes that this circuit is usually terrible at receiving narrow-band FM, the type we are dealing with here. However, since we are modulating at much lower frequencies (~50MHz instead of ~100MHz), we use a larger inductor and thus have a significantly higher Q. This higher Q means we are more sensitive to subtle variations in frequency, and receiving narrow-band FM then becomes more practical. Empirically and through simulation we have shown that this variation on the original circuit works well and allows us to recover the original signal.

## Labor Breakdown

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

1. Yanni will design and construct the transmitter. In particular, this includes:
    a. Construction of the FM transmitter circuit [Week of April 12]
    b. Construction of the voltage controlled current source/mixer [Week of April 19]
2. Max will design and construct the receiver. This involves:
    a. Construction of the transimpedance amplifier [Week of April 12]
    b. Construction of the super regenerative receivers [Week of April 12]
3. Both of us will:
    a. Design PCBs for our respective modules [Week of April 19]
    b. Integrate our designs together [Week of April 19]

## Conclusion

In the end, we hope to have a functional multi-channel transmitter/receiver pair that can simplify our lives by letting us use just one cable for many signals. Based on our experience in constructing these types of circuits, we expect a few areas to give us some trouble. The FM transmission might be tricky because of the aforementioned parasitics. While our transmission circuit uses a highly accurate crystal to create its carrier frequency, the demodulation circuit relies on a tuned LC/BJT oscillator that might drift over time. Nonlinearities in the fiber optic transmitter module itself might also cause some problems. At the very least, we hope to present a series of radio transmitter/receiver pairs that demonstrate the spirit of the original project proposal.

## Sources

[1]: http://www.ke3ij.com/superrgn.htm