

**Information Transmission Using
Frequency Modulation in a Wireless RF
Link**

EECS 330 Project

December 11, 2002

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Introduction

Purpose

This project offers students a chance to expand their knowledge of and experience with wireless communications systems. Unlike the other laboratory experiments of EECS 330, which were based on pre-planned individual experiments, this project requires research and planning by the participants. The purpose of this project is to design and implement an FM (Frequency Modulation) transmission and reception system after researching the relevant theory.

Project Goals

The goals of this project were to become familiar with the basics of FM communication. In our experiments, we want to experiment with and demonstrate the operation of a Phase Locked Loop (PLL) FM demodulator, a voice/music communications system, and a simple data communications system.

FM Basics

The need for modulation

There are two fundamental types of communication systems: *baseband* systems and *passband* systems. In baseband systems, signals are transmitted without any changes to their frequencies. Passband communication systems, on the other hand shift the frequency spectrum of signal to a new frequency location, the *carrier frequency*.

The human voice has strong components with frequencies of the order of 1 kHz and less. Transmitting such a signal using electromagnetic waves with a baseband system would lead to a number of problems. These problems include:

1. **Antenna length.** In order for an antenna to efficiently radiate energy, it must be longer than $\lambda/10$, where λ is the wavelength of the radio waves. From the relation between frequency and wavelength, it can be seen that

$$\lambda = \frac{c}{f}$$

Where f is the frequency of the signal and c is the speed of light. For a 1 kHz signal,

$$\lambda = \frac{3 \times 10^8 \text{ m/s}}{10^3 \text{ s}^{-1}} = 300 \text{ km}$$

Thus, for efficient radiation of energy, an antenna for this system must be 30 km in length. Such an antenna would be very difficult and expensive to implement.

2. **Interference.** If two signals were to be transmitted over baseband in the same geographic region, they would interfere with each other, and both signals would be distorted.

3. **Signal Efficiency.** Signals transmitted in baseband have a lot of noise and interference associated with them, which results in lower signal efficiency and poor signal propagation.

In order for radio communication to be feasible these problems need to be dealt with, and the solution is to shift the frequency of the transmitted signals to a higher frequency.

Modulation is the process of shifting the frequency of a signal so that the resulting signal is in a desired frequency band. This is done by using a high frequency *carrier signal* to transmit a lower frequency *information signal*. In other words, the information signal *modulates* the carrier signal to the desired frequency. Two common types of modulation are **Amplitude Modulation (AM) and Frequency Modulation (FM)**. A third type, **Phase Modulation (FM or PM)** is very similar to FM and is often used to mean the same as FM.

Advantages of Modulation

1. It is obvious from the wavelength formula that increasing frequency results in a lower wavelength, and consequently a shorter antenna length. This makes it possible to build smaller radio transmitters, receivers and antennas.
2. To avoid interference, signals can be modulated into non-overlapping frequency bands and then transmitted over the same channel. This removes interference and at the same time allows many signals to be transmitted at the same time.
3. Modulation shifts signals to regions with low noise and interference, increasing signal efficiency.

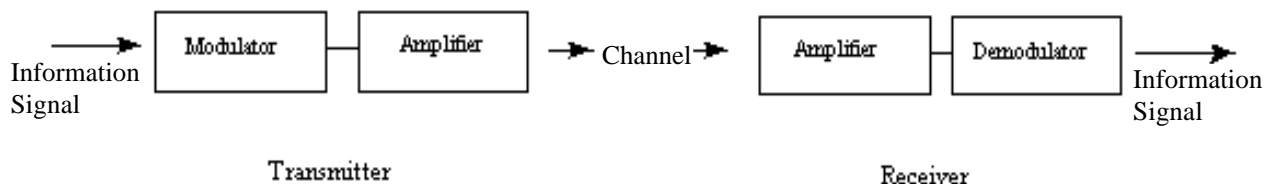


Figure 1. Block diagram representation of a passband communication system.

Frequency Modulation (FM)

In frequency modulation, the information signal modulates the carrier frequency about its original value.

Let us consider a signal, $j(t) = A \cos(q(t))$ where $q(t)$ is the generalized angle and a function of t . This angle can be represented as $q(t) = \omega_c t + q_0$. The *instantaneous frequency* of the signal is

$$\omega_i(t) = \frac{dq}{dt}$$

$$q(t) = \int_{-\infty}^t \omega_i(u) du$$

There are two possibilities of modulating this signal using a modulating signal $m(t)$. One possibility is to vary the angle $\theta(t)$ linearly with $m(t)$. This technique is called *phase modulation*. The other possibility is to vary the instantaneous frequency $\omega_i(t)$ linearly with the modulating signal. This technique is frequency modulation. Thus, in FM,

$$\omega_i(t) = \omega_c(t) + k_f m(t)$$

Here, $\omega_c(t)$ is the reference carrier frequency and k_f is a constant. The angle is now given by:

$$q(t) = \int_{-\infty}^t [\omega_c + k_f m(u)] du$$

$$\Rightarrow q(t) = \omega_c(t) + k_f \int_{-\infty}^t m(u) du$$

The FM wave is then given by $\mathbf{j}_{FM}(t) = A \cos \left[\omega_c(t) + k_f \int_{-\infty}^t m(u) du \right]$

For easier calculations and without losing generality, let $m(t) = B \cos(\omega_m t)$. Then,

$$\mathbf{j}_{FM}(t) = A \cos[\omega_c(t) + B \sin(\omega_m t)]$$

$$\beta = \frac{\Delta \omega}{\omega_m} = \frac{\Delta f}{f_m}$$

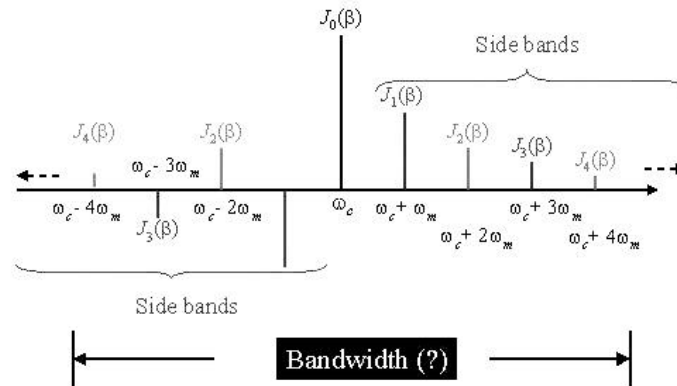
Here β is the FM modulation index, where ω_m is the modulating frequency and $\Delta \omega$ is the frequency deviation.

The *sidebands* are the frequency components of the signal that are not at the carrier frequency. The *bandwidth* of the signal is commonly determined using the following criterion. Sidebands with amplitudes less than 1% of the carrier bandwidth are ignored in bandwidth calculation. A standard rule of thumb for calculating the bandwidth of an FM signal based on the 1% criteria is called Carson's Rule.

$$BW = 2 \cdot (\text{Peak Deviation} + \text{Highest Frequency})$$

The spectrum of f_{FM} appears below where ω_c is the carrier frequency and ω_m is the modulating frequency. The power and frequency of the higher harmonics are based on the modulation index.

FM Spectrum



<http://www.shu.ac.uk/ocr/teaching/ppp/FM/sld013.htm>

Mixers and Multipliers

An important component in modulation and radio frequency devices is the mixer or multiplier. In most circuits designers strive for linearity, but mixers and multipliers work on non-linearity. As the name implies, a multiplier uses non-linear circuit components, usually diodes, to multiply two signals together. The result is a slew of harmonics and other frequencies arithmetically related to the frequencies of the original waveforms. A more specific type of multiplier is called a mixer. A mixer is made especially to produce only the sum and difference of the root frequencies. Mixers are most usually thought of as operating on sinusoidal signals so an example of the output of a mixer fed with two frequencies, f_c & f_o , would look like:

$$\cos(2pf_c t) \times \cos(2pf_o t) = \cos(2p[f_c + f_o]t) + \cos(2p[f_c - f_o]t)$$

Phase-Locked Loop (PLL)

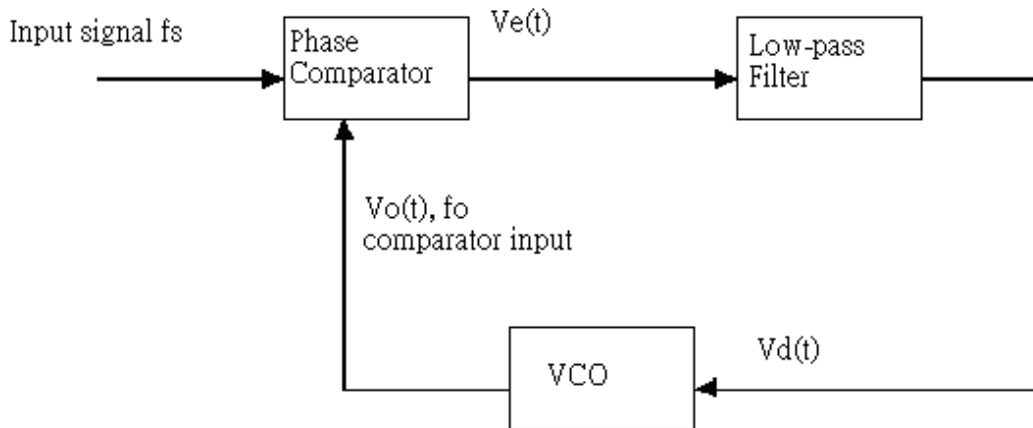
A phase-locked loop (PLL) is a closed loop frequency control system based on the detection of phase difference between the input and the output signals of the controlled oscillator. The oscillator is constantly adjusted to match phase and thus lock on the frequency of an input signal.

In addition to locking a particular frequency, a PLL can be used to generate a signal, modulate or demodulate a signal, reconstruct a signal with less noise, or multiply and divide a frequency. PLLs are used in wireless communication very often, especially where the signals are transferred by frequency modulation or phase modulation. They can also be used on amplitude modulation.

The PLL is the best frequency demodulator because it can remove noise and interference with its low-pass filter and its highly linear output can faithfully reproduce the original modulating signal.

PLL Fundamentals

A PLL is made up of three parts: phase comparator, a voltage-controlled oscillator (VCO), and a low-pass filter. These three parts are connected to form a close loop negative frequency feedback system. The phase comparator, in the simplest sense, is a mixer. A block diagram of a PLL is shown below:



Block Diagram of PLL

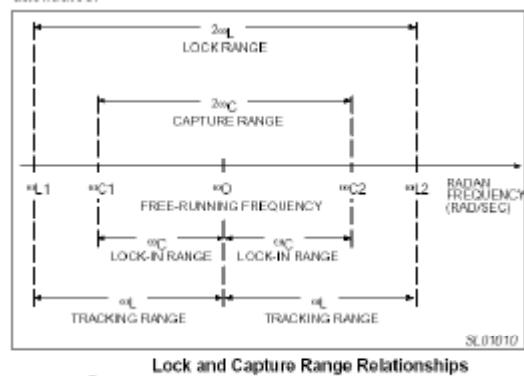
With no frequency applied to the PLL system, the error voltage ($V_e(t)$) at the output of phase comparator is zero. The output voltage of low-pass filter ($V_d(t)$) is also zero, which makes the VCO to operate at a set frequency f_0 called center frequency. When an input signal is applied to the PLL system, the phase comparator compares the frequency and the phase with the frequency and phase of VCO, and generates the error voltage with the frequency and phase difference between the input signal and the VCO. The error voltage is then filtered by the low-pass filter and applied to the control input of the VCO. $V_d(t)$ varies in order to reduce the difference of the frequency between the signal input and VCO. When the frequency of VCO is quite close to that of the input signal, the closed-loop nature of PLL immediately forces VCO to lock the frequency with the signal input.

So when the PLL is locked, the VCO frequency is almost exactly same as signal input except for a finite phase difference. The change of input frequency causes a phase or frequency shift and produces an error voltage which forces the VCO to track the input and reduce the difference between the input and the output to be zero. If there is no input, the output is the free-running frequency of the VCO.

Lock Range & Capture Range

The lock range of a PLL is the range of frequencies over which a PLL is able to track an initially locked input frequency. If the input signal leaves the lock range, the PLL will be unable to follow it frequency and returns to run at its free-running frequency. This is known as becoming unlocked.

The capture range of a PLL is the limit of frequencies over which a PLL will accept and lock onto an input signal starting from the unlocked or free-running condition. Generally the capture range is narrower than the lock range and it makes the PLL look like a bandpass filter. The loop filter also determines how fast the input signal can change and still keep lock. The narrower the loop filter bandwidth, the smaller the allowable phase error. This makes the response slower and the capture range narrower.



Applications

The applications of PLLs are lock-in measurement (equipment), frequency synthesizers, radio engineering, telecommunication, and motor/drive speed/position controls. The application we will be using the PLL for is FM demodulation. When the input to the PLL is an FM signal always within the given capture range, the output voltage of the low-pass filter V_d is proportional to the frequency shift of the FM signal away from its center carrier frequency. Therefore, this output signal is the demodulated source signal.

Experiment Goals

The main goal of the experiment is to understand how phase-locked loop works for FM communication and how FM communication transmits the data. We broke the lab into parts in order to achieve our goals step by step.

We first started the experiment by finding the lock range and the capture range of the PLL, and that is also the goal for this part of the experiment. We expected the lock range to be greater than the capture range. The next step was to test the system by determining the bandwidth of a single audio frequency transmission and the bandwidth of multiple frequencies. We could then use the system to transmit a broad-band signal such as music or voice. For the last part of the experiment, we transmitted text data. The goal for this part of the experiment was to test if text data could be transmitted successfully after being modulated to sound. We expected the transmitted data and the original data to be identical.

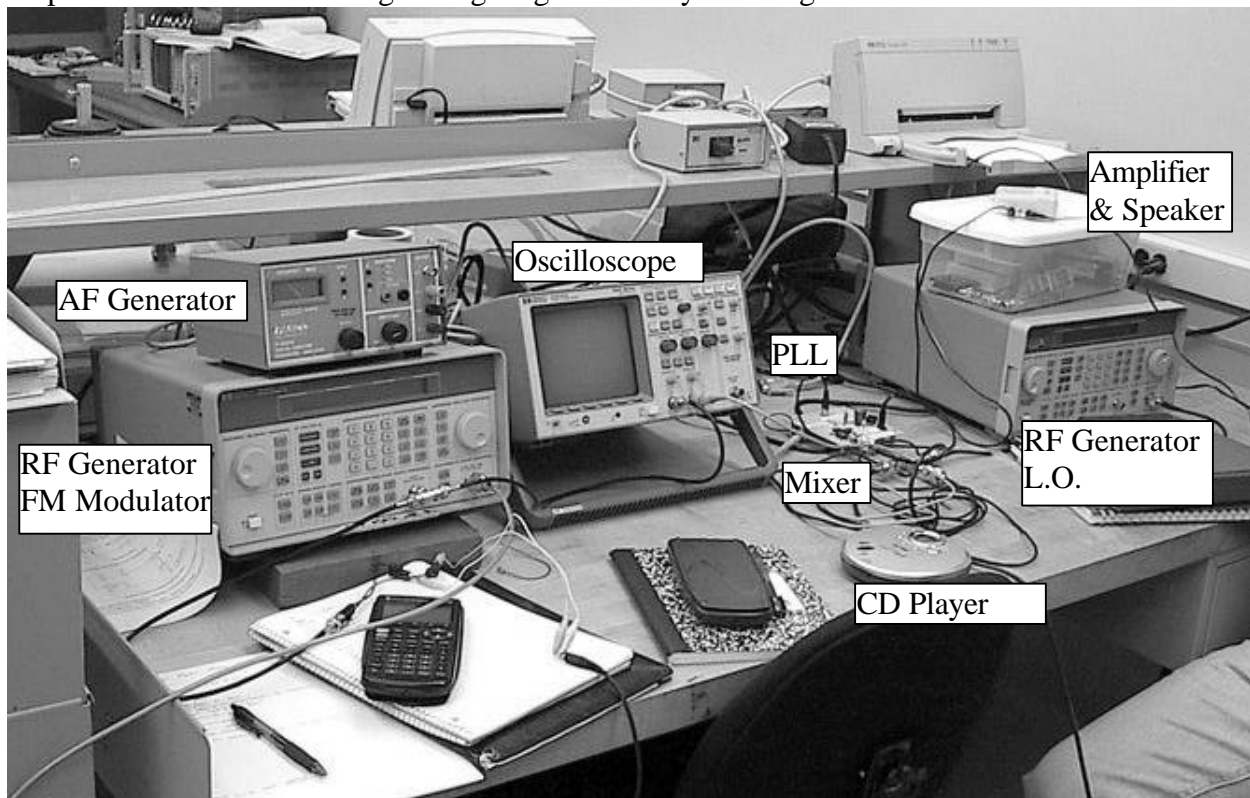
Lab Setup

- | | |
|--|---------------------|
| - 2 RF digital signal generators | - 1 AF generator |
| - 2 Parabolic dish antennas tuned for 1.95 GHz | - 1 Cd player |
| - 1 Mixer | - 1 Computer |
| - 1 Phase-locked loop (PLL) demodulator | - 1 Small amplifier |
| | - 1 Small speaker |

Basic Setup

We use the FM generator with the default setup of $f_c = 1.95$ GHz at 5.0dBm, internal modulation at 1 kHz and $\Delta f = 400$ kHz. The output of FM generator is connected to one of the parabolic dish antenna. The other parabolic dish antenna is connected to the input of RF local receiver. The output of the mixer is connected to the phase-locked loop (PLL). The output of the PLL and the original modulating signal from RF generator are both connected to the oscilloscope.

The FM generator is used to generate RF signals. By connecting it to the antennas, the RF signals could be transmitted through the air to the receiving end. The receiving end is connected to the local oscillator which generates the RF signal. The receiver uses the mixer to multiply the transmitted signal with the RF signal from the local oscillator. The output of the mixer is connected to the PLL, which demodulates the original signal. The oscilloscope shows both the output of the PLL and the original signal generated by the RF generator.



Extended Setup

The basic setup could only be used to determine the lock range and the capture range. For the rest of the experiment, the basic setup is the same, however, more equipment is needed to do other parts of the lab.

The second part of the experiment is to investigate the bandwidth of the audio frequency. Thus the audio frequency (AF) generator is connected to the input of the RF generator and the oscillator. The frequency generated by AF generator changes during the whole process.

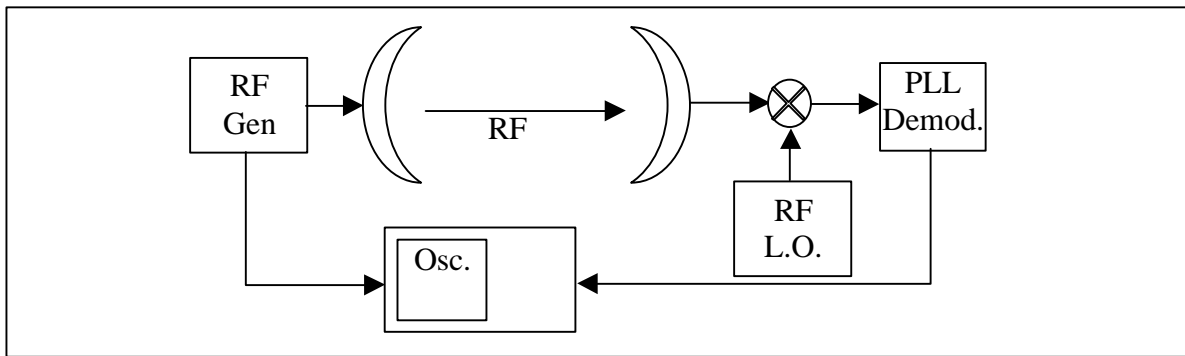
Instead of using an AF generator that only generates a single frequency signal, we used a CD player to generate a signal with multiple frequencies and determine the bandwidth of the signal. Besides the CD player, we also hook a small amplifier and a speaker to the PLL so that we could listen to the received signal.

The last part of the experiment required a computer with MATLAB. The computer is used to transmit and receive the data by running a MATLAB program called incoherent_modem. The program could convert the text file into sound and transmit it by connect the computer's line out to the RF generator. On the receiving side, the program could decode the transmitted sound back into a test file by connecting the PLL to the line in connector on the computer.

Experiment 1: PLL Operation: Lock and Capture Range

Setup and Procedure

The purpose of this experiment is to investigate the Lock ($2f_L$) and Capture ($2f_C$) Range of the PLL demodulator board. The experiment uses the default setup with the FM generator source set to $f_C = 1.95$ GHz at 5.0 dBm, internal modulation at 1 kHz and $\Delta f = 400$ kHz. The FM generator output is connected to the parabolic antenna. The receiver uses a mixer to multiply the signal from the receiving antenna with the RF signal from the local oscillator (L.O.). The PLL takes the output of the mixer, and demodulates the original signal. The output of the PLL and the original modulating signal from the RF generator are viewed on the oscilloscope (Osc.). A block diagram of the setup is:



The PLL is stated as having a center frequency of 2.3 MHz so therefore, the L.O. is initially set to $f_{LO} = f_C + \Delta f = 1.95$ GHz $-$ 2.3 MHz = 1.9477 GHz. At this setting the input to the PLL should contain a 2.3MHz centered FM signal mixed down from 1.95GHz along with other higher frequency components. Once it is established the system works, the only two blocks of concern are the RF L.O. and the PLL demodulator. By varying the Δf component, the input frequency to the PLL is changed and the lock and capture range can be investigated.

The lock limits are found by shifting Δf until the signal is no longer recovered. Then as Δf is brought back to its starting point, the frequency at which the signal is recovered is the capture limit. This procedure is repeated for both increasing and decreasing Δf .

Laboratory Data

$f_{RF} = 1.95 \text{ GHz @ } 5.0 \text{ dBm: FM modulation @ } 1 \text{ kHz}$

$f_{LO} = 1.95 \text{ GHz} + df @ 5.0 \text{ dBm: No modulation}$

	Baseband	Harmonic	Harmonic
Lock: df_{lower}	-3.3228 MHz	-1.445 MHz	+3.745 MHz
Lock: df_{upper}	-1.8818 MHz	+0.009 MHz	+5.165 MHz
Lock: df_{range}	1.441 MHz	1.454 MHz	1.420 MHz
Lock: df_{center}	-2.602 MHz	-0.718 MHz	+4.455 MHz
Capture: df_{lower}	-3.2042 Mhz	-----	-----
Capture: df_{upper}	-1.940 Mhz	-----	-----
Capture: df_{range}	1.2642 MHz	-----	-----
Capture: df_{center}	-2.5721 MHz	-----	-----

Lock Range: 1.441 MHz

Capture Range: 1.2642 MHz

Analysis

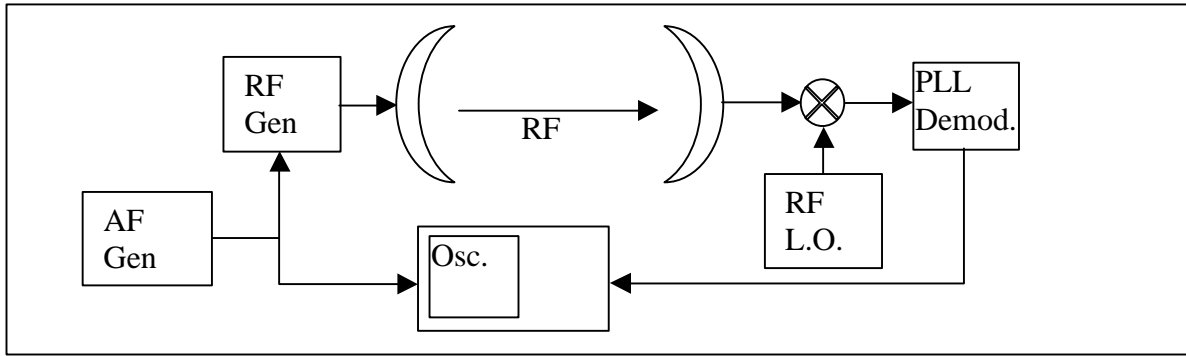
As expected, the lock range is larger than the capture range. It is interesting to note that although the geometric center of the lock and capture ranges differed only slightly from each other, they were both significantly different from the stated center lock frequency. Fortunately this is no cause for alarm.

In the data table under the column Harmonic 1 and Harmonic 2, it appears as if more than one lock range exists (capture range was not measured in these conditions). However, it is unlikely that the PLL itself has more than one lock range. More likely is that the additional ranges are a result of harmonics generated in the mixer because the mixer does contain non-linear elements. The center frequencies are not spaced evenly between each range, but the lock range is identical.

Experiment 2: System Audio Frequency Bandwidth

Setup and Procedure

In the first experiment, a 1 kHz sine wave generated internal to the RF source was used to FM modulate the 1.95 GHz RF carrier wave. Transmitting a constant 1 kHz sine wave is not very interesting or useful thing. If one desires to transmit an audio signal, such as music or voice, it would be advantageous to know the audio frequency response and bandwidth of the FM system. For this experiment, almost the same setup is used, with the addition of an audio frequency signal generator. The signal generator feeds the modulation input on the RF generator and is displayed on the oscilloscope. The frequency of the AF generator is then varied while measurements of the received signal amplitudes are measured to generate data for a Bode plot.



Laboratory Data

$f_{RF} = 1.95 \text{ GHz @ } 5.0 \text{ dBm}$: external FM modulation
 $f_{LO} = 1.95 \text{ GHz} - 2.602 \text{ MHz @ } 5.0 \text{ dBm}$: No modulation

See Plot “Audio Frequency Response of RF FM communication system”

Analysis

The system has a relatively flat pass-band that extends from a 3.5 Hz to 10 kHz giving a system bandwidth of about 10 kHz. Below the lower cutoff frequency, response drops at 38 dB/dec. or 11.5 dB/octave. Above the cutoff frequency, response drops at just over 27dB/dec. or 8 dB/octave. This mimics the response of a two pole, two zero system. It is also interesting to note that above 58 kHz, the oscilloscope loses tracking on the signal altogether.

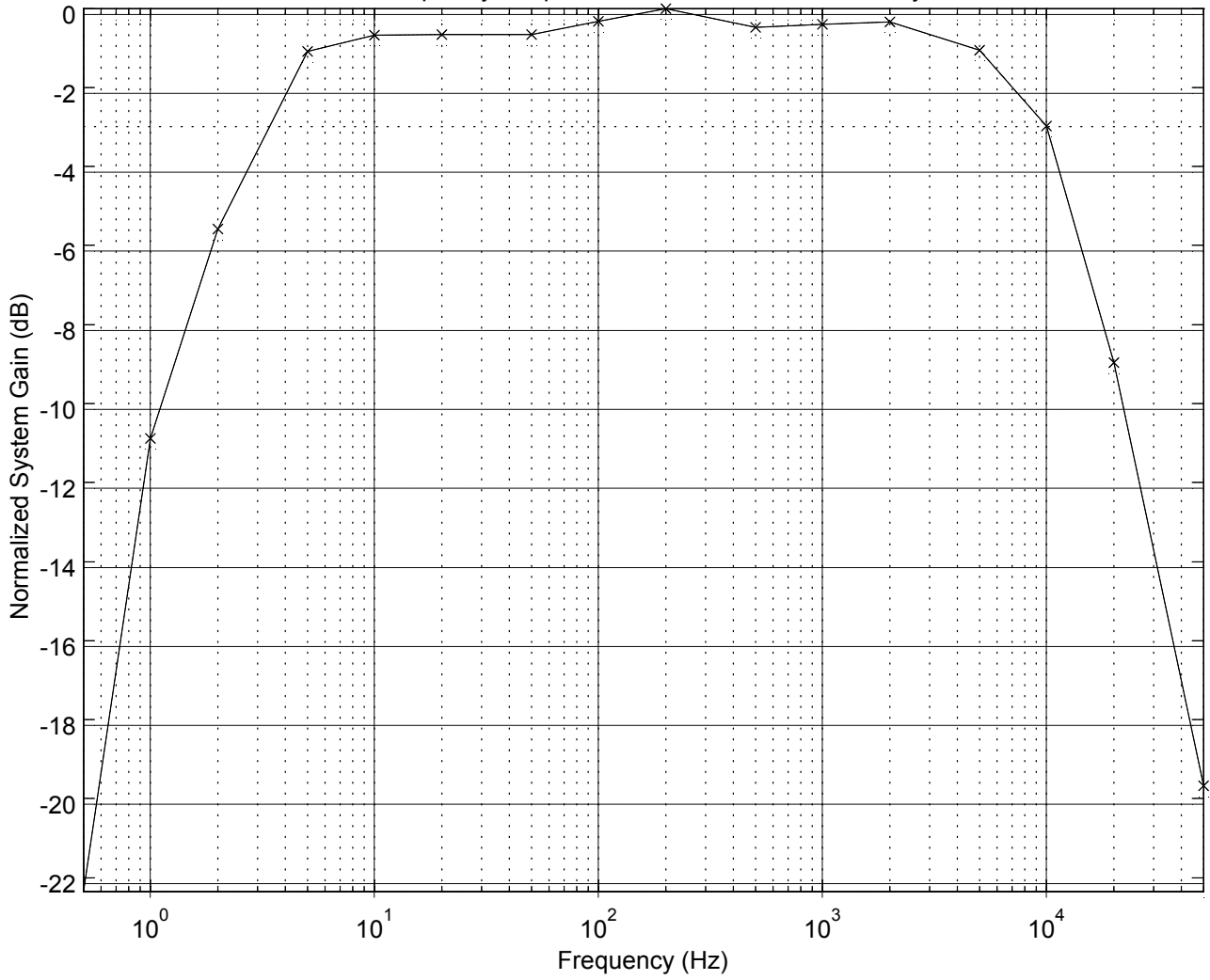
It would seem that this system could easily transmit intelligible voice signals (300 Hz-3 kHz) and medium quality music signals. For any general audible sound, transmitting over this system would eliminate the high frequency components over 10 kHz. The next step would be to test the system using multiple frequencies, and hence a music signal.

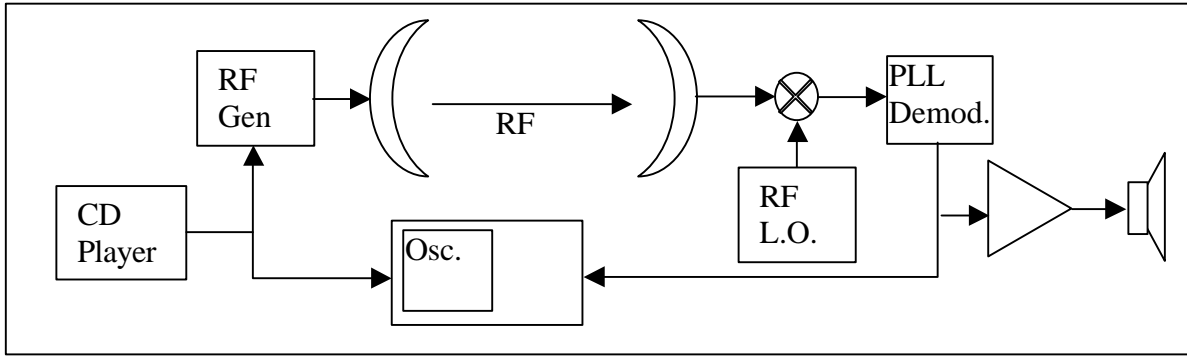
Experiment 3: Transmission of Music

Setup and Procedure

This experiment is an extension of the last experiment. Instead of using a single frequency signal generator as an audio signal source, a Red-Book compliant portable CD-Audio player is used. In addition, a small amplifier and speaker is added and connected to the output of the PLL demodulator so the received signal can be heard.

Audio Frequency Response of RF FM communication system





Laboratory Data

$f_{RF} = 1.95 \text{ GHz @ } 5.0 \text{ dBm}$: external FM modulation

$f_{LO} = 1.95 \text{ GHz} - 2.602 \text{ MHz @ } 5.0 \text{ dBm}$: No modulation

No Data. Transmission, reception and playback of music was successful.

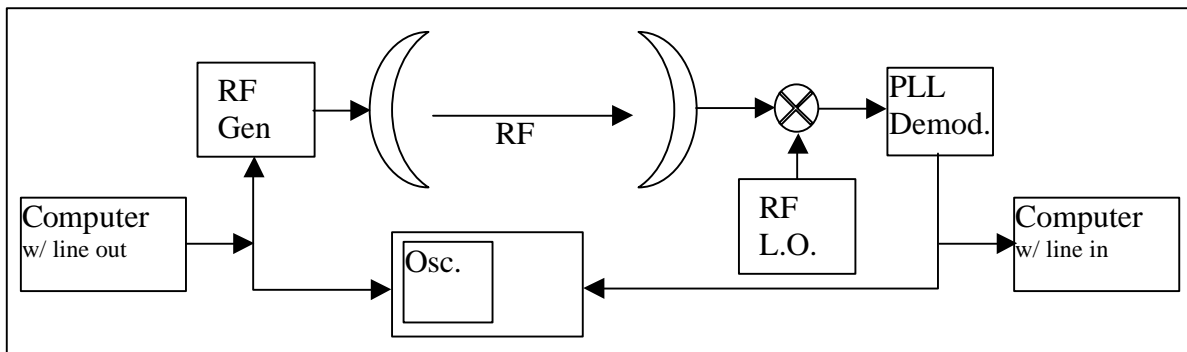
Analysis

Transmission of audio over the wireless link was an easy extension of experiment 2. However, the CD player provided a stereo signal and the wireless link was only able to transmit one of those channels at a time because it is a monaural link. Furthermore, the approximate bandwidth of the CD player is 22 kHz, but the RF link was only able to transmit the lower half of the frequency spectrum. This was not a limitation as the output amplifier and speaker were of very low quality with a significantly smaller bandwidth than any other component in the system. Information on the commercial FM system can be found in Appendix A.

Experiment 4: Transmission of Data

Setup and Procedure

A 1.95 GHz wireless RF link is far outside the commercial FM frequency range used for the transmission of music. It might therefore be useful to attempt to transmit digital data over a wireless link as another use of this system. For this experiment, the modulation source is the audio output line from a computer and the demodulated output from the PLL is sent to the audio line input on a computer. Only one computer was used in this experiment by utilizing the simultaneous audio input and output capabilities of the machine.



The computer needs to run a MATLAB program called `incoherent_modem`, available at <http://people.ece.cornell.edu/scaglione/acousticmodem.htm>. This program contains two applets aptly named Transmitter and Receiver. In the simplest sense the Transmitter program takes an ASCII text file and creates a sound pattern that represents the input text. On the other hand, the Receiver program records sound from the line input on the computer and listens for the sound pattern created by the Transmitter. When it finds the pattern, it decodes the sound back into text and stores it in a text file on the computer. The program actually is very complex and uses orthogonal frequency division multiplexing (OFDM) among other things. A more detailed description can be found in Appendix B.

Laboratory Data

$f_{RF} = 1.95 \text{ GHz @ } 5.0 \text{ dBm}$: external FM modulation
 $f_{LO} = 1.95 \text{ GHz} - 2.602 \text{ MHz @ } 5.0 \text{ dBm}$: No modulation
Data transmission was successful.
See Appendix D for sample transmitted data.

Analysis

There is no analysis for this experiment. Data was successfully transmitted over a 1.95GHz wireless link using OFDM to modulate data to sound, FM to modulate sound to RF, and a PLL to do FM detection and demodulation.

Summary

The first step in this project was to research frequency modulation and communication systems, since they have not been covered in class. The next step involved deciding which experiments to perform, and what to demonstrate in lab. After this was done, we had to decide what experimental setup to use in order to meet our experimental goals.

Our first experimental task was to determine the PLL lock and capture range, which we were able to do so without any problems. Some interesting observations arose while performing these measurements. The lock and capture ranges were slightly different from the stated ones. The next task was to determine the system audio frequency bandwidth, which was found to be approximately 10 kHz, starting at 3.5 Hz up to 10 kHz. We found this by using a 1 kHz sine wave to modulate our 1.95 GHz carrier. From these results it can be easily seen that audio signals in the 300 Hz to 3 kHz range can easily be transmitted using the apparatus. Naturally, any frequency components above 10 kHz would be eliminated. Our next step was to attempt to transmit music over the link.

Music transmission was fairly simple after we transmitted the sine wave over the link. One drawback was that our wireless link can only transmit one channel at a time, and so we did not get a stereo signal. Also, since our system has a bandwidth of about 10 kHz, and the CD player we used has a bandwidth of about 22 kHz, we were only able to transmit over the lower half of

the CD player's frequency spectrum. The final experiment that was performed was data transmission over the wireless link, which was achieved using a MATLAB program called `incoherent_modem`, and a computer with simultaneous audio input and output capabilities. We were able to transmit data over our communication link without any loss of information

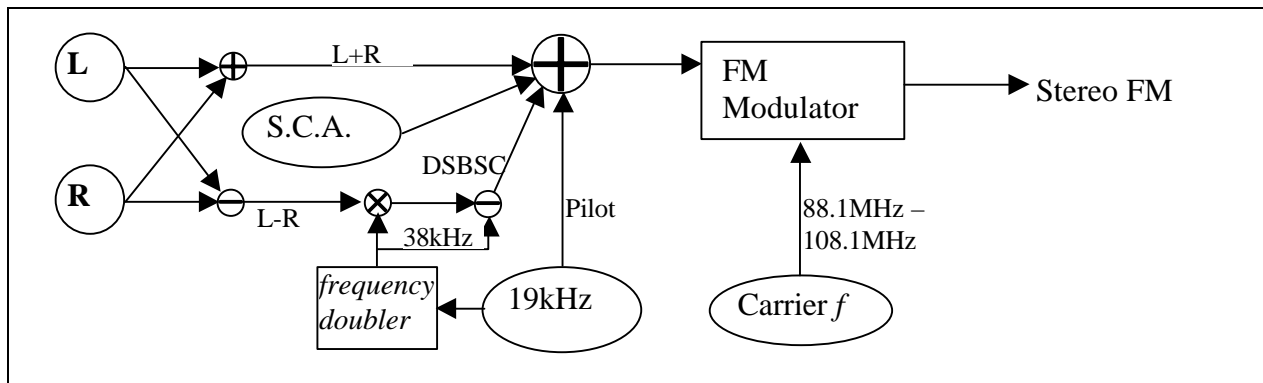
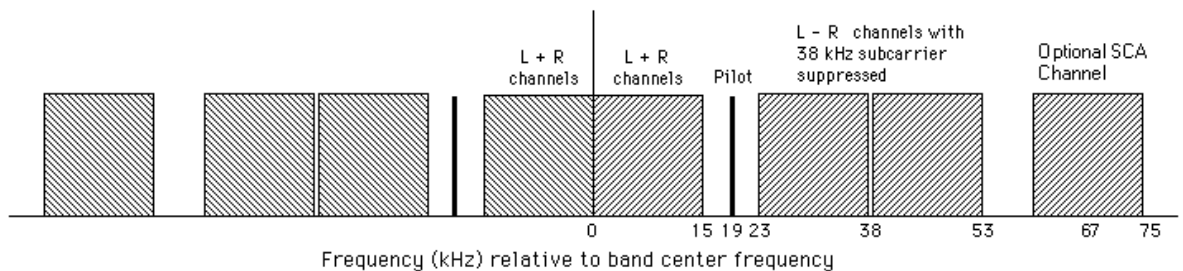
Overall, this project was an interesting design experience, giving excellent insight into the fundamentals of communication systems, parabolic antennas, phase lock loops, mixers, frequency modulation and FM transmission and receiving systems. From a practical point of view, it gave us the opportunity to put concepts that were learned in class to use in real world applications. From a theoretical point of view, the project introduced us to the building blocks of FM communication systems and helped reinforce what was learned in class.

Appendix A: The Commercial FM Broadcast System

The transmission of audio information over radio using frequency modulation (FM) is done every day around the world. In the United States, there is a system for commercial FM broadcast that is significantly more complex and higher fidelity than the hardware used in this lab experiment.

The commercial FM broadcast (FM radio) band extends from 88.1 to 108.1 MHz and is broken into 100 channels with 200 kHz of separation between channel centers. Each channel, centered on a carrier wave, deviates at maximum 75 kHz from the center frequency leaving a 25 kHz “guard” band on either side to minimize interference with the other channels (remember the Bessel function distribution of frequencies in FM). FM radio has an audio bandwidth of 15 kHz, so a band-limited audio source can be FM modulated to transmit a monaural signal. However, what makes FM radio more interesting is that it supports the capability to transmit stereo information along with an auxiliary side channel using subcarriers.

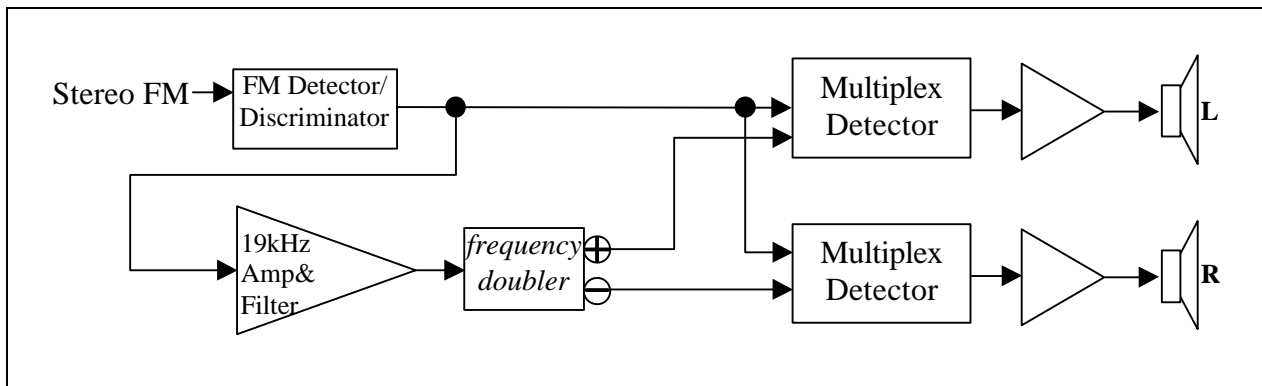
In a stereo FM transmitter, the left (L) and right (R) channels are summed to produce an L+R monaural channel. This is normally what is received by any mono FM receiver and doesn’t use any subcarriers. To transmit stereo, the transmitter creates an L-R difference channel and mixes it with a 38 kHz subcarrier. Transmitting the subcarrier would waste power, so it is suppressed by subtracting it from the signal. The signal created is specifically called Double Side Band Suppressed Carrier (DSBSC). In order to regenerate the 38 kHz subcarrier in the receiver, a 19 kHz pilot signal is also added to the mix. The 19 kHz pilot is doubled to create the 38 kHz subcarrier. Also, a third channel called the “SCA” or “Subsidiary Carrier Authorization” is sometimes transmitted as well. This channel is not received by consumer equipment but by some businesses for commercial free background music. The resulting base-band frequency spectrum (prior to FM modulation) and a block diagram of a transmitter are given below:



The receiver operates a reverse order to the transmitter. After demodulation to base-band, the signal can be filtered to 15 kHz, amplified and reproduced on a speaker for listening to the L+R channel. This is what is done in mono FM radios and allowed the stereo functions of the system to be backwards compatible with the first FM radios. To listen to a stereo transmission, a narrowband amplifier picks out the 19 kHz pilot signal and doubles it to get the 38 kHz subcarrier. It can then mix the L-R channel down to base-band and filter it to 15 kHz. To recover the original L and R channels, the L+R and L-R channels are added and subtracted resulting in:

$$L = \frac{(L+R)+(L-R)}{2} \qquad R = \frac{(L+R)-(L-R)}{2}$$

Stereo FM receivers use a technique called multiplex detection to combine the mixing, filtering and summing functions. A multiplex detector is fed the combined base-band signal and the amplified 38 kHz subcarrier. Whether the output of the multiplex detector is the left or right channel depends on the phase of the 38 kHz subcarrier. A block diagram of a commercial FM receiver (after band selection) is shown below.



Appendix B: Incoherent Modem

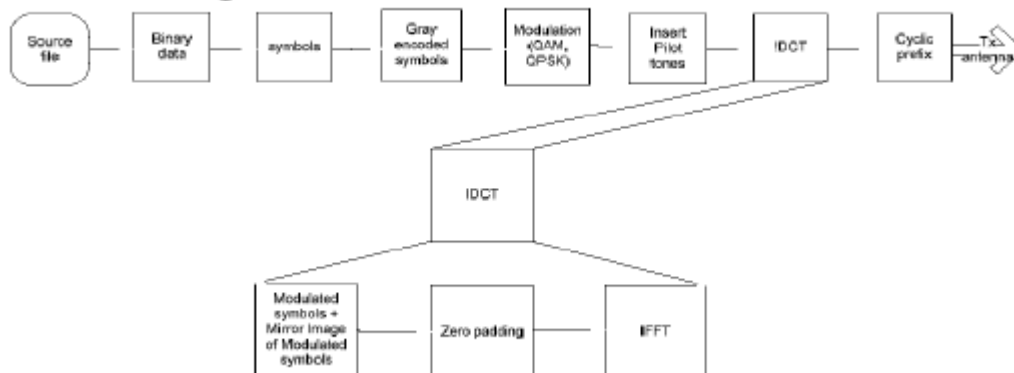
Three graduate students at Cornell University (Francisco Bastidas, Rahul Kopikare and Gaëlle Protat) developed a Matlab program for an acoustic modem as part of their graduate requirements. The program, referred to as `incoherent_modem` along with their sixty-four page design project report is available at <http://people.ece.cornell.edu/scaglione/acousticmodem.htm>. Experiment four of this lab utilized `incoherent_modem` slightly differently than intended.

The abstract on the report explains exactly what `incoherent_modem` is:

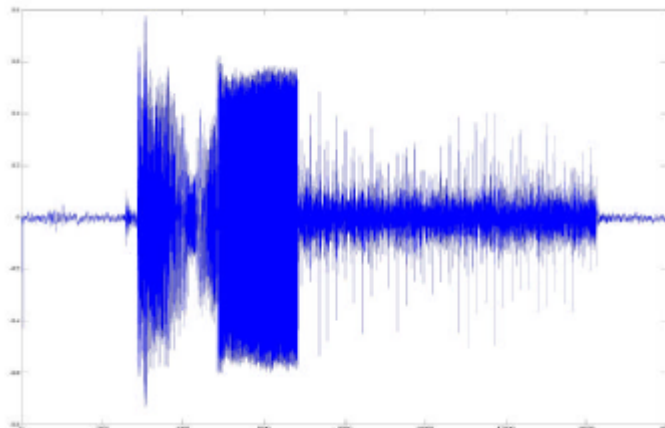
This project aim was to build wireless software modem for data communication between two computers using an acoustic interface in the voice frequency range...

This goal was attained both in an incoherent scheme and in a coherent scheme. Build under Matlab code, our modem uses OFDM (orthogonal frequency division multiplexing) modulation, synchronization by LMS sequence, channel estimation (no equalizer) via pilot tones. The symbols are either PSK or ASK for a constellation size of 2 or 4. To optimize the probability of error, these symbols were mapped using Gray mapping.

3.1 Block Diagram of the Transmitter



Below is a representation of the output of the transmitter including three distinct sections: synchronization, channel estimation, and OFDM encoded data.



Appendix D: Sample Transmitted Data

This is EECS330 Lab section 005, fall 2002
rf fm data transmission
James
Aneesh
YC

This is EECS330 Lab section 005, fall 2002
rf fm data transmission
James
Aneesh
YC

This is EECS330 Lab section 005, fall 2002
rf fm data transmission
James
Aneesh
YC

This is EECS330 Lab section 005, fall 2002
rf fm data transmission
James
Aneesh
YC

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Appendix D: References

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Appendix A

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Appendix B

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Appendix E: Time Sheet and Executive Summary

Activity	James	Yin-Chien	Aneesh
Independent Research	9	5	6
Laboratory Work	6	5	6
Group Meetings	5	5	5
Report Write-up	8	6	8
TOTAL	28	21	25

James Glettler

I am a senior undergraduate in electrical engineering. My interests are in electro-acoustic systems and digital signal processing. In this lab experiment, I was responsible for determining the lab procedure and writing the associated section of the report, along with the section on mixers. I was also responsible for finding the Matlab program for transmitting and receiving data. I assisted with research on FM communication and I assisted my group members with performing the in lab experiments. I also prepared the final report and presentation slides.

We have not concealed any violations of the honor code.

Yin-chien Hou

I am a junior undergraduate majoring in electrical engineering. My field of interest is fiber optics. For the lab experiment, I was responsible for writing the assigned part of the report. I also did part of the researching on our lab topics and helped to perform the experiment during the lab time. I provided and operated the computer needed to run the MATLAB program for transmitting and receiving the data.

We have not concealed any violations of the honor code.

Aneesh Khullar

I am a senior undergraduate in electrical engineering. My interests are in control systems, digital signal processing and circuits. In this lab, I was responsible for the introduction, which included providing a general overview of frequency modulation. I was also responsible for the conclusion. In lab, I helped my group members with performing the experiments. I also integrated my group members' work with mine into the project report.

We have not concealed any violations of the honor code.
