ELEC 499 – Design Project Final Report

Power Line Data Transmission Project – The "Meter Man"

Team:
Amandeep Gill
Debraj Paul
Jian Huang

www.engr.uvic.ca/~jhuang

Supervisor:
Dr. Panajotis Agathoklis

April 2, 2004

Table of Contents

List of Tables and Figures

1. Team and Acknowledgements

1.1. Team Members

Our group for this project consisted of three undergraduate engineering students.

- Amandeep Gill, fourth year Electrical Engineering student
- Debraj Paul, fourth year Computer Engineering student
- Jian Huang, fourth year Computer Engineering student

1.2. Acknowledgements

We would like to acknowledge the efforts and contributions made by the lab technicians in the Electrical and Computer Engineering department at the University of Victoria, namely: Rob Fichtner, Paul Fedrigo, Lynn Palmer, and Duncan Hogg. We would also like to thank Dr. Panajotis Agathoklis for his time and for agreeing to take on this project. Thank you for your support in making this project a success.

2. Introduction

2.1. Background

Only when our electricity is gone do we realize how dependent on it we actually are. Power is the backbone of modern society. Power is a crucial ingredient for economic growth and prosperity for every nation and the people it supports. Electricity is consumed in every thing we do and it has become synonymous with life in the industrialized world. Our communications, transport, food supplies, and most amenities of homes, offices and factories depend on a reliable supply of electrical power. However, despite the technology and engineering that has gone into building the power grid infrastructure, today's technologies have placed even greater demands on already strained systems, leading to expensive outages that can cost millions of dollars.

There are two obvious ways to decrease the strain on the power line infrastructure: build more grids, or make the grids more efficient. In our opinion the latter is a better option because building more inefficient grids will not decrease the problems that we are faced with. How do we achieve more efficiency in the power grids? The answer that we believe is the key to this question is Power Line Data Transmission (PLDT). PLDT can ease the congestion and load on the power lines, and also, give the electric companies the chance to offer new services such as broadband internet access and Power-on-Demand. In this project, we focus on the application of PLDT to Power-on-Demand.

2.1.1. Power Line Data Transmission

PLDT is the art of sending data through power lines. The basic process involves three steps:

1. Modulate the data so that it can be sent over the transmission medium.
2. Transmit the signal in such a manner to reduce signal distortion.
3. Receive and demodulate the signal to extract the data.

A device that can achieve the above is called a Power Line modem. There are many types of modems in most homes today that allow us to communicate over the telephone and cable mediums. Modems are built specifically for their transmission medium, that is to say, a dial-up modem will not work on the cable (coax) medium. Each type of modem also employs some type of modulation/demodulation scheme, such as FSK, PSK, or ASK. The specifics of the project that we have created will be discussed later.

2.1.2. Power On Demand

Power-on-Demand means exactly what it sounds like- distributing power dependent on the demand and need. Electricity providers are turning to power-on-demand technologies to relieve the stress on the exhausted power grids. Energy providers do not want to build more and more complex and expensive grids, instead, they would like to focus their time and money into more efficient and long-term solutions. Power-on-Demand (PoD) is the solution that the electrical utility sector has been longing for. PoD systems can be implemented to supply the consumers on the grid with the amount of energy that they need at any time, and this amount can be varied at any moment. PoD systems can also be used between many utility companies to sell and buy excess generated power when needed. Thus, PoD systems involve communication between two parties. Our project, Meter Man, is one implementation of a PoD system.

2.2. Motivation

As technology advances and more technologies are developed and used by society, our demand for electricity will increase at unpredictable rates. In fact, on a daily basis power companies are faced with the challenge of distributing power through their power grids without disrupting the flow of electricity to other users. However, when there is a sudden increase in the demand for power in a part of the power grid then there can be disastrous effects. When the load is too great for a power grid there can be outages that can cost the economy millions of dollars and this is simply unacceptable. Many times it is not by fault of the power company that these outages occur, but mainly due to mechanical failures at certain nodes or unexpected increases in power consumption at particular nodes. Power-on-Demand can not decrease the occurrence of outages due to mechanical failures, but it can decrease the chances of outages occurring due to unexpected increases in demand for power.

Power-on-Demand is gaining support because of the functionality it purports. Using this technology, power companies can communicate with their large industrial clients on an ongoing basis and be assured that their power demands will be met. This will decrease the probability of an outage being caused by those clients and increase the efficiency of the power network. The motivation is simple – create efficient power networks by communication. If companies are successful in implementing Power-on-Demand systems, then this technology can be further developed to offer other services using Power Line Data Transmission.

2.3. Problem Definition

There is an opportunity to enhance the capabilities of the existing power line infrastructure using PLDT. This opportunity would lead to several positive outcomes:

- Efficient power distribution and network management

- Use the new technology to diversify the core practices by offering new services such as broadband access
- Lower the probability of costly and inconvenient power outages

In this project, we want to build a system to send and receive messages through the power lines. The messages will be used between two parties to communicate the need for more power.

To address this opportunity we developed the idea of Meter Man. Meter Man is a product that is based on the idea of PLDT. Meter Man uses communication techniques over power lines to communicate between two parties. We identified several requirements for this product, namely:

- Safely interface with power line
- Low bit error rate
- Low susceptibility to interference
- Frequency Shift Keying or Phase Shift Keying as modulation scheme
- Some kind of console to enter data and read data
- Isolate the power signal from the message signal

These requirements form the basis for the solution that we developed to address the problem of sending and receiving data over power lines.

2.4. Design Idea

2.4.1. Methodology

For this project we developed a high level idea and then worked down hierarchically to develop the individual pieces. The idea is simple – support communication through power lines by two parties. In Figure 1 we show the typical scenario of the Meter Man being used. We envision a system, where the consumer would go to Meter Man's interface and choose to increase or decrease his power consumption level, and Meter Man would send a signal to the electric company advising them of the change in demand. Overall, this implementation would be perfect for the distribution of power between two electric grids so that power outages could be avoided. For example, let us consider the case of a large car manufacturer that will be increasing output by 40% for five days. This would mean that the company would be using more power than usually expected. This increased usage would cause extra load on the power grid. Now, if several other manufacturers had similar demands then we would be in trouble. However, if the power company knew of the increased demand, then they could compensate for the extra demand ahead of time by ensuring that enough power is available.

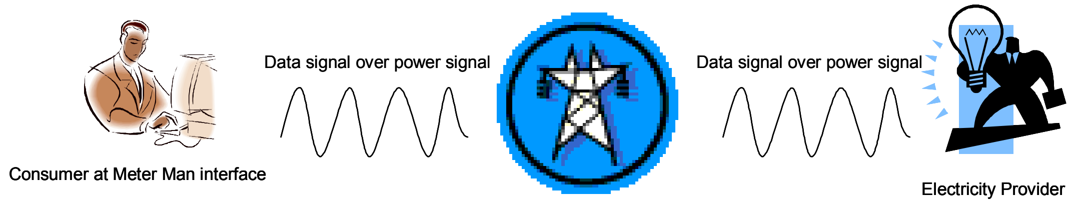

Figure 1. Meter Man Concept

2.4.2. Solution

The Meter Man system diagram is shown below in Figure 2. There are two basic units that are needed to facilitate the communication between the power company (vendor) and the consumer. The consumer unit would be located at the client's building and the vendor unit would be used by the power company.

The consumer unit consists of a personal computer, a PowerPC microcontroller, a digital-to-analog converter, and a transmitter. The vendor unit consists of a receiver circuit, an analog-to-digital converter, and a user console which could be another microcontroller and computer combo. The overall system that was envisioned is shown below, but the system that was implemented does not include the user consoles. Due to time constraints and because priority was given to the transmitter and receiver circuits, these consoles we not implemented.

The main focus of our design was the transmitter and receiver circuits that would allow us to send and receive data through the power line medium. These circuits will be discussed in greater detail in section **3.1 Circuit Design.**

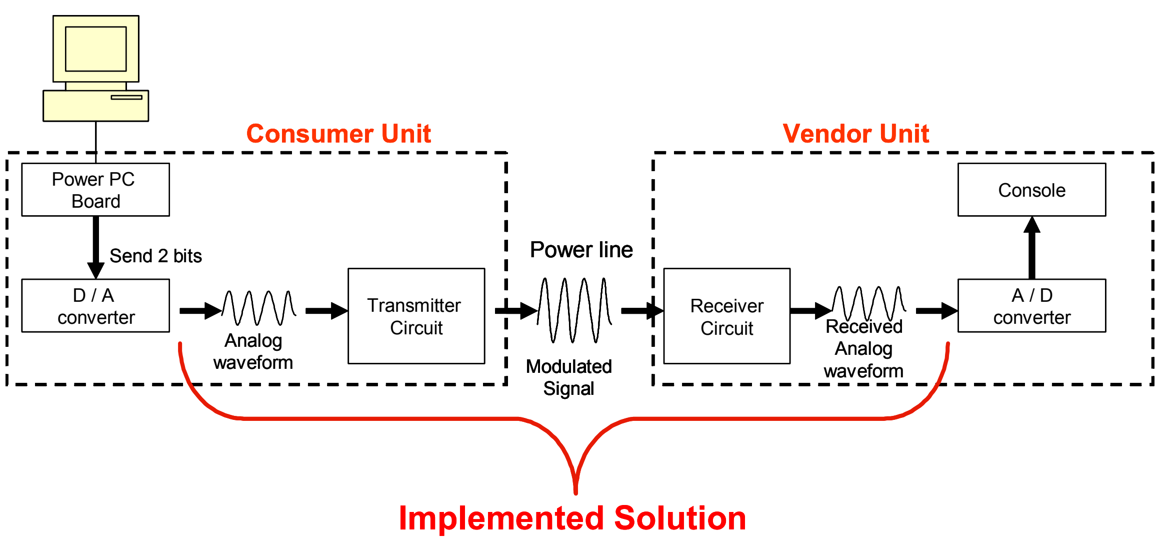

Figure 2. System Block Diagram

3. Discussion

3.1. Circuit Design

The Power Line communication system we developed contains two major components: the transmitter and the receiver. The transmitter is responsible for sending the signal to the power line. It includes the following stages: the signal modulation stage, the signal amplification stage, and the power line interface stage. The receiver is responsible for receiving the modulated signal from the power line and recovering it to the original message signal. It includes the following stages: the interface with the power line, the signal amplification stage, and the signal demodulation stage. The block diagram of the system is shown in Figure 3.

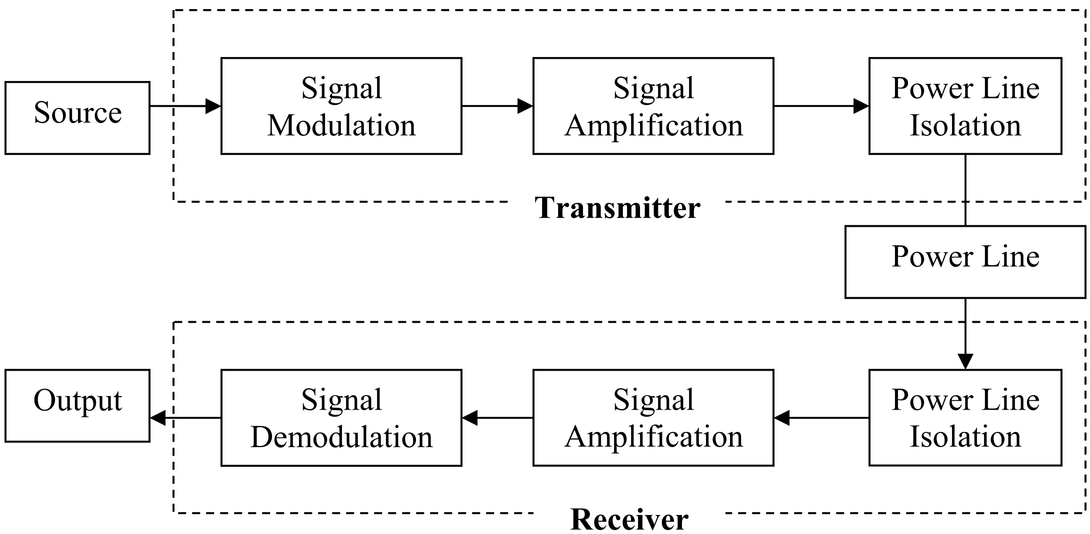

Figure 3. System Functional Block Diagram

The following three sections will discuss the three important parts of our design: the power line interface, the transmitter, and the receiver.

3.1.1. Power Line Interface (Isolation Circuit)

One of the most important parts of our power line transmitter and receiver is the Power Line Interface. Because our circuit has to connect to the 110V 60 Hz power line, without careful isolation, the rest of the circuit will be burnt easily.

The ideal isolation circuit should completely block the 60Hz signal, and pass the information signal. The information signal in our case is the frequency modulated signal. In our circuit, the carrier frequency was set to be around 70 kHz. Because the input signal has frequency ranging from

500 Hz to 5 kHz, the isolation should be able to pass the signal frequency ranging from 65 kHz to 75 kHz. The solution is to couple a 10 nF capacitor with an audio transformer.

Figure 4 shows the simulation circuit created in Micro-Cap. Figure 5 shows the AC simulation result of the isolation circuit. This circuit completely blocks the 60 Hz signal and passes the signal with frequency ranging from 50 kHz to 80 kHz. By placing this isolation circuit between the power line and the rest of the circuit, we ensure that the 110V power signal will not affect the transmitter and receiver circuit, and also, the information signal can be sent and received from the power line.

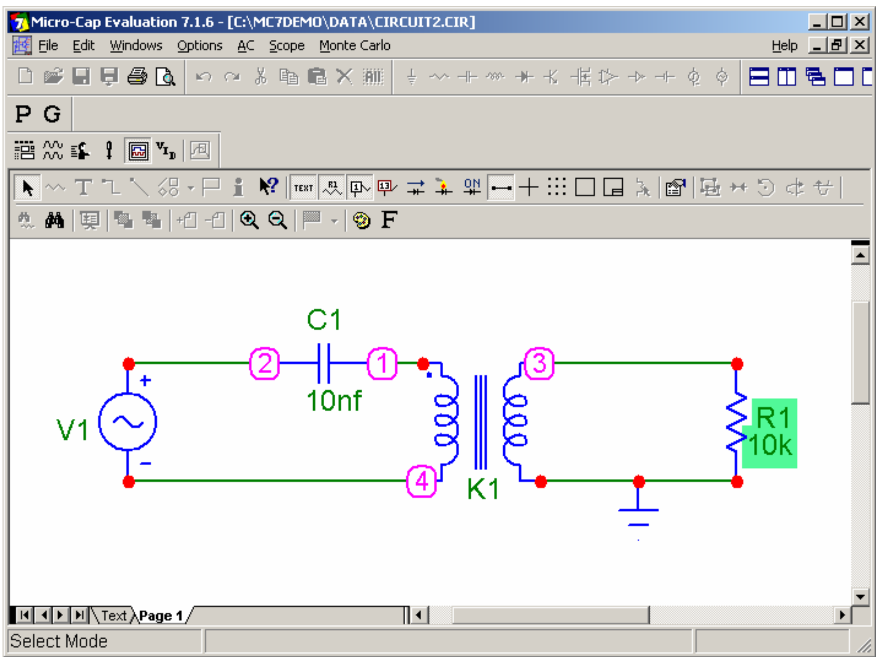

Figure 4. Isolation Circuit Simulation

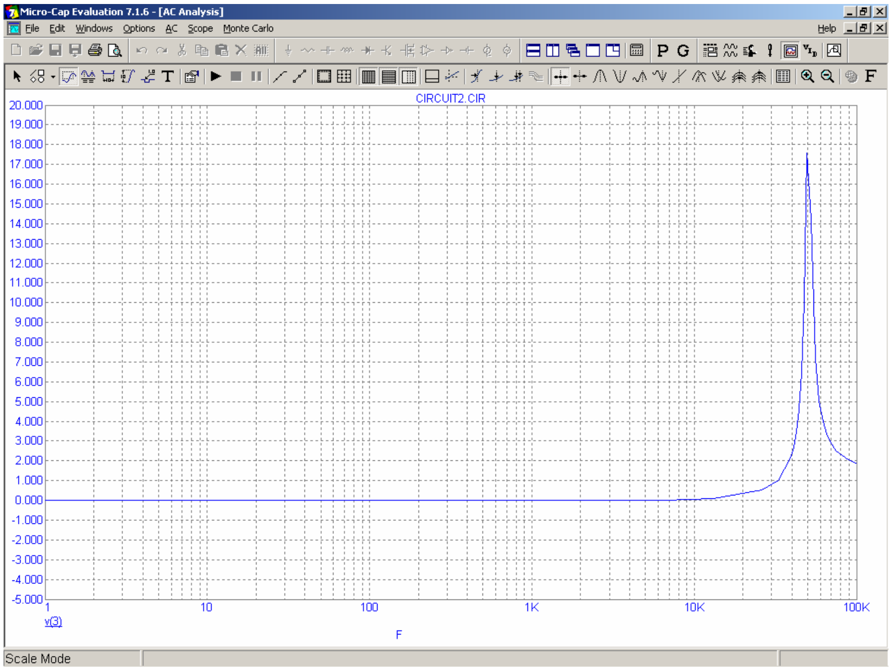

Figure 5. AC Simulation Result for the Isolation Circuit

3.1.2. Transmitter

The transmitter system includes the signal modulation circuit and the signal amplification circuit.

<u>Signal Modulation</u>

The LM566CN Voltage Controlled Oscillator was used to modulate the input signal. The LM566CN is a general purpose voltage controlled oscillator which may be used to generate square and triangular waves, the frequency of which is a very linear function of a control voltage. The frequency is also a function of an external resistor and capacitor (see appendix 3 for data sheet). The LM566 is very commonly used to build frequency modulation circuitry.

Figure 6 shows the completed frequency modulation circuit in our system. Pin 6 is connected to a timing resistor and potentiometer, which works with the timing capacitor connected with Pin 7 to control the modulation frequency. The potentiometer allows us to fine tune the carrier frequency to produce the best modulated signal. Pin 3 was used as the output which gives us the frequency modulated square wave. We chose the value of the timing capacitor and timing resistor so that a carrier signal would have a frequency around 70 kHz. This ensures that the modulated signal can be sent through the isolation circuit to the power line.

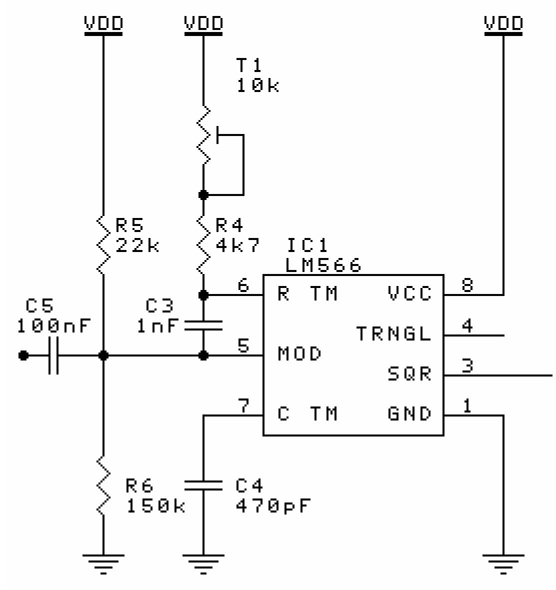

Figure 6. Modulation Circuit

Amplification Circuit of the Transmitter

The signal from the source is usually very small. Even after modulation, it is not strong enough for the receiver to receive because of the high inference of the power line noise. So, the modulated signal needs to be amplified before being sent through the power line. Figure 7 shows our amplification circuit for the transmitter.

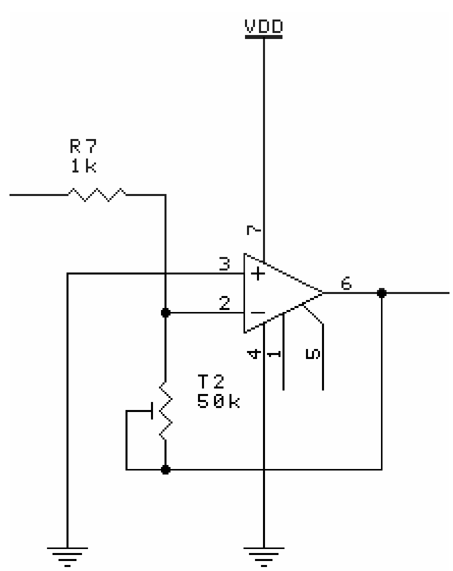

Figure 7. Transmitter Amplification Circuit

The NTE937 chip was chosen as the operational amplifier. The 50k potentiometer connected to Pin 2 allows us to adjust the amplification factor. Within the operational amplifier's operating limit, the output amplitude and the input amplitude have the following relationship:

$V_{out} = - R_{Potentiometer}/R_7 * V_{in}$

Figure 8 and Figure 9 show the simulation circuit and simulation result of the amplification circuit in Micro-Cap. A ratio of 5 was chosen for the resistance of the potentiometer and resistor R_7. The correct waveform was obtained from the simulation.

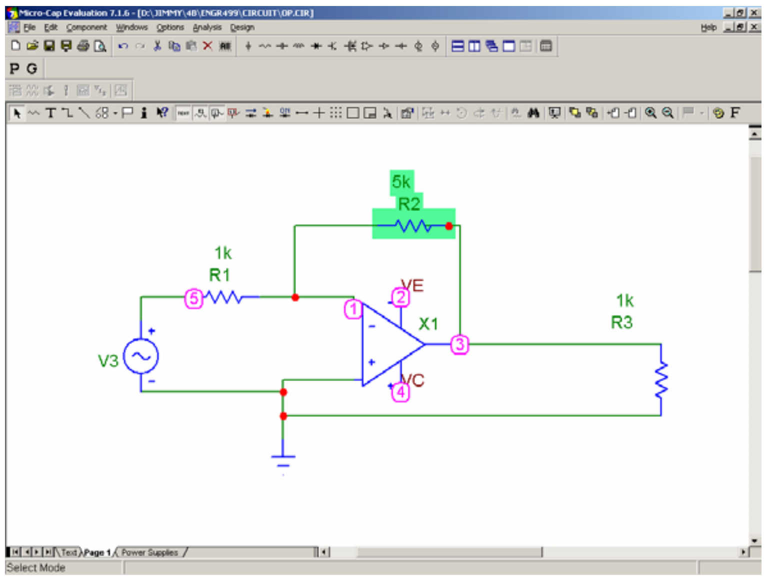

Figure 8. Simulation of the Amplification Circuit in Micro-Cap

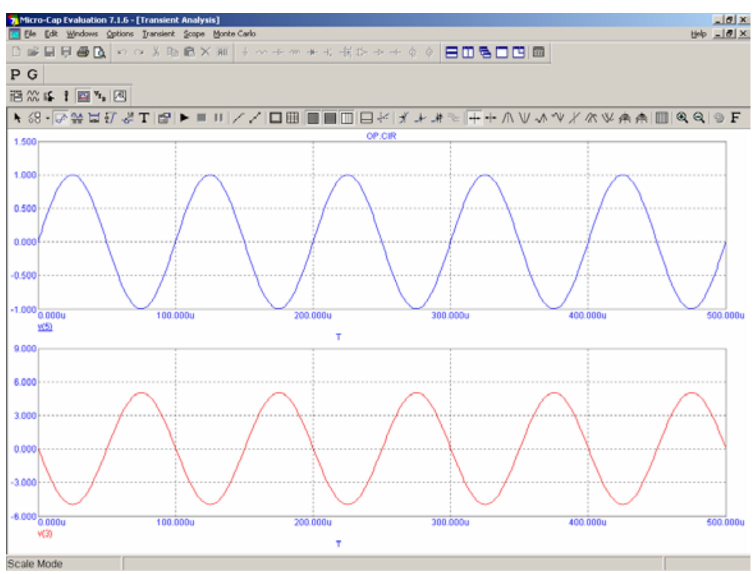

Figure 9. Simulation Result of the Amplification Circuit

3.1.3. Receiver Structure

The receiver system includes the signal amplification circuit, the signal demodulation circuit, and filters.

Amplification Circuit of the Receiver

The amplification circuit of the receiver is very similar to that of the transmitter. The only difference is that a regular 220k resister was used to replace the potentiometer. The schematic is shown in Figure 10.

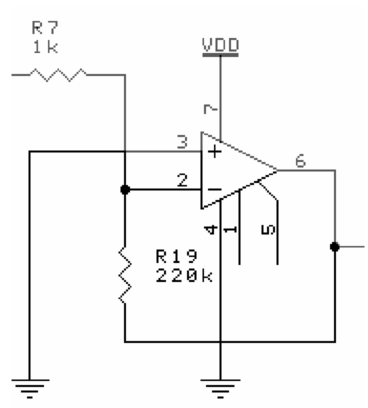

Figure 10. Amplification Circuit of the Receiver

Demodulation Circuit

Frequency modulation was used in our transmitter to modulate the input signal. In our receiver, this frequency modulated signal is recovered using a phase locked loop chip - the LM565. The LM565 is a general purpose phase locked loop containing a stable, highly linear voltage controlled oscillator for low distortion FM demodulation (see appendix 4 for data sheet). Figure 11 shows the demodulation circuit of the receiver.

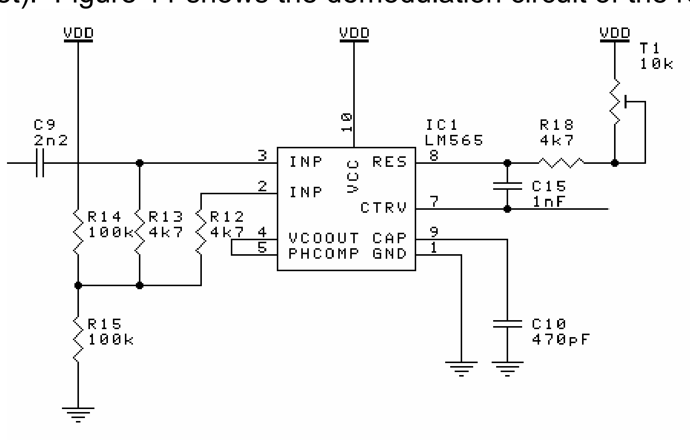

Figure 11. Demodulation Circuit

The timing capacitor (Pin9) value and the timing resistor (Pin8) values were set the same as the values in the modulation circuit so that the modulated signal can be recovered.

Filter Circuits

Two filters were implemented for the demodulation circuit. The first filter was designed to band pass the modulated signal which has a frequency range from 65 kHz to 75 kHz as discussed before. It is used to filter out any low or super high frequency noises from the power line. The schematic and simulation result are shown in Figure 12 and Figure 13 respectively. From the AC simulation result, we can see that signals with frequency from 65 kHz to 75 kHz can pass the filter and the power signal with frequency 60 Hz will be filtered out.

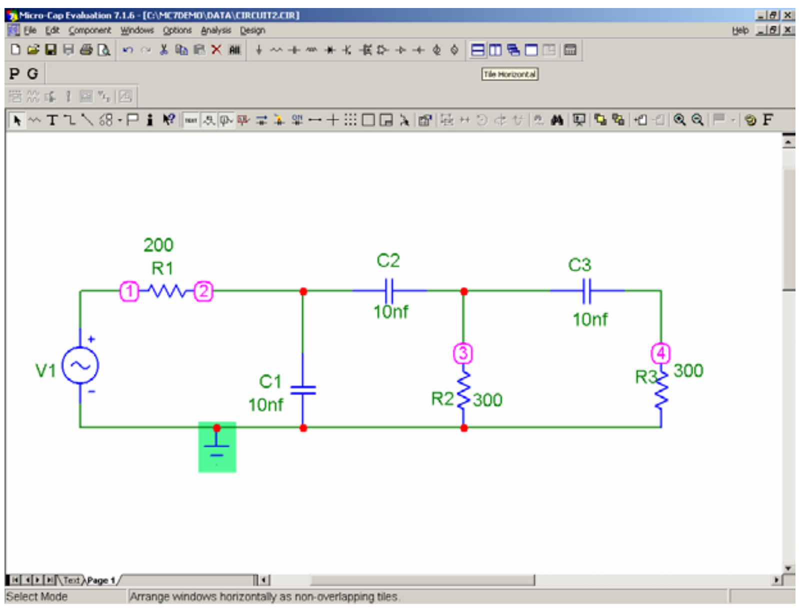

Figure 12. Band Pass Filter

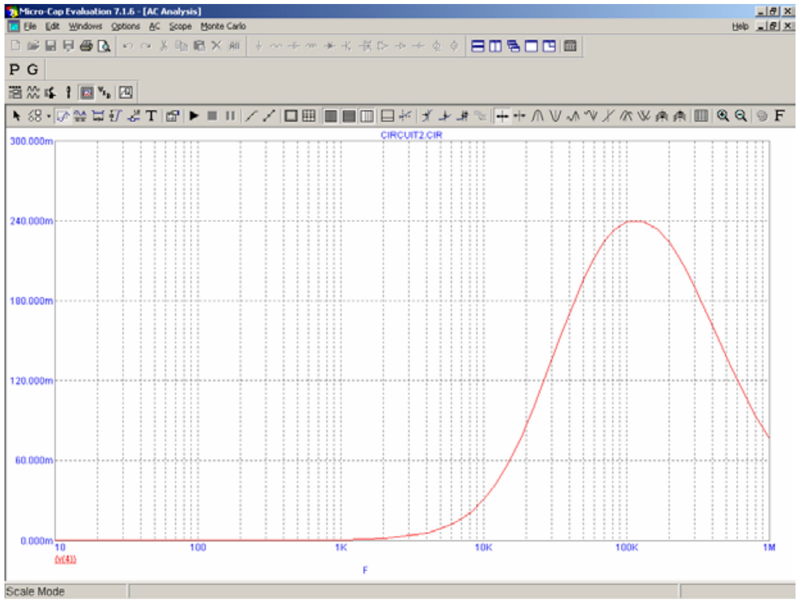

Figure 13. AC Simulation Result of the Band Pass Filter

The second filter is a low pass filter which is implemented to filter out the high frequency noise generated by the demodulation circuit. So the message signal, which has a frequency ranging from 500 Hz to 5 kHz, can be produced. The schematic and simulation results are shown in Figures 14 and 15 respectively.

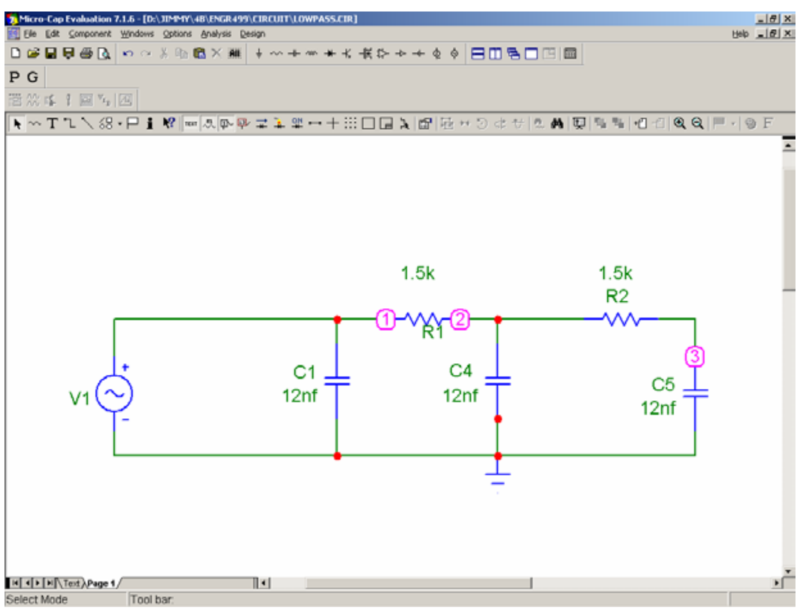

Figure 14. Low Pass Filter

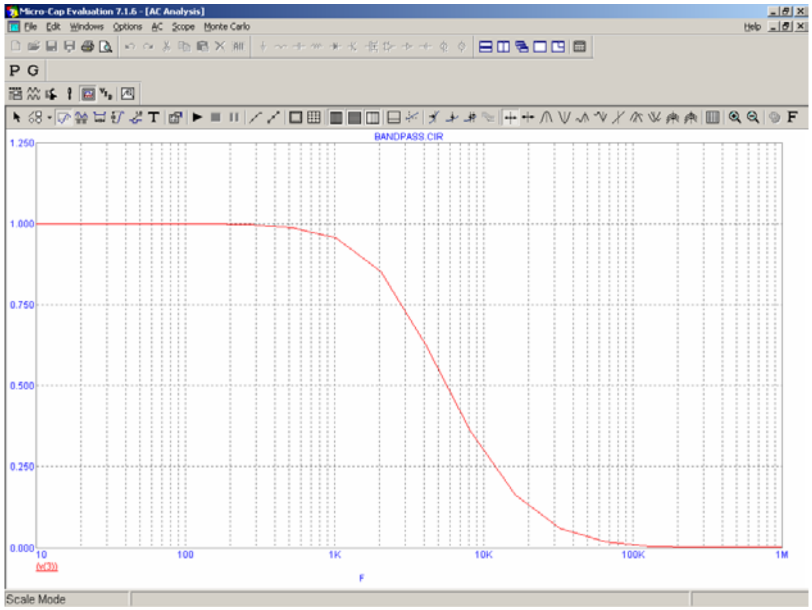

Figure 15. AC Simulation Result of the Low Pass Filter

The completed schematics of the transmitter and receiver are presented in Figures 16 and 17 respectively.

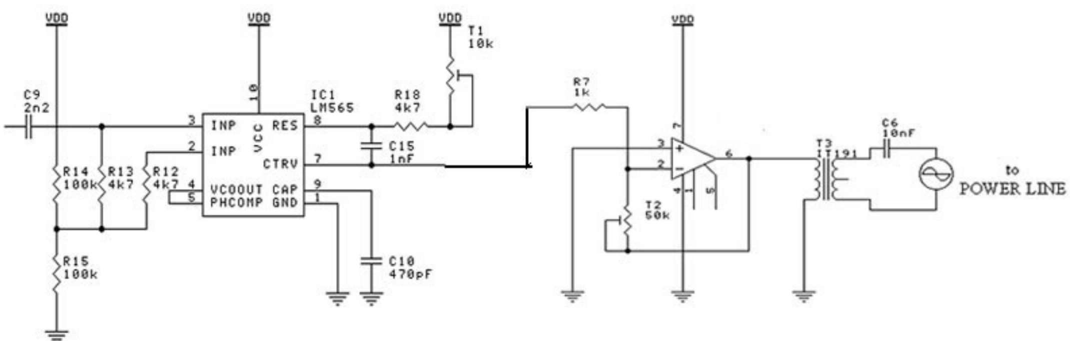

Figure 16. Transmitter Schematic

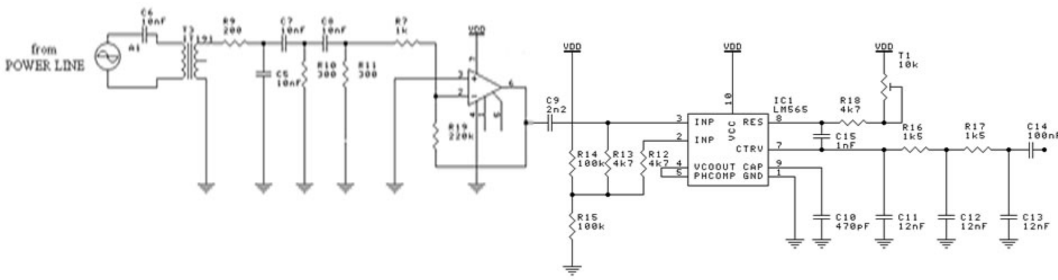

Figure 17. Receiver Schematic

Figure 18 and 19 show the implemented transmitter and receiver circuits on the breadboard.

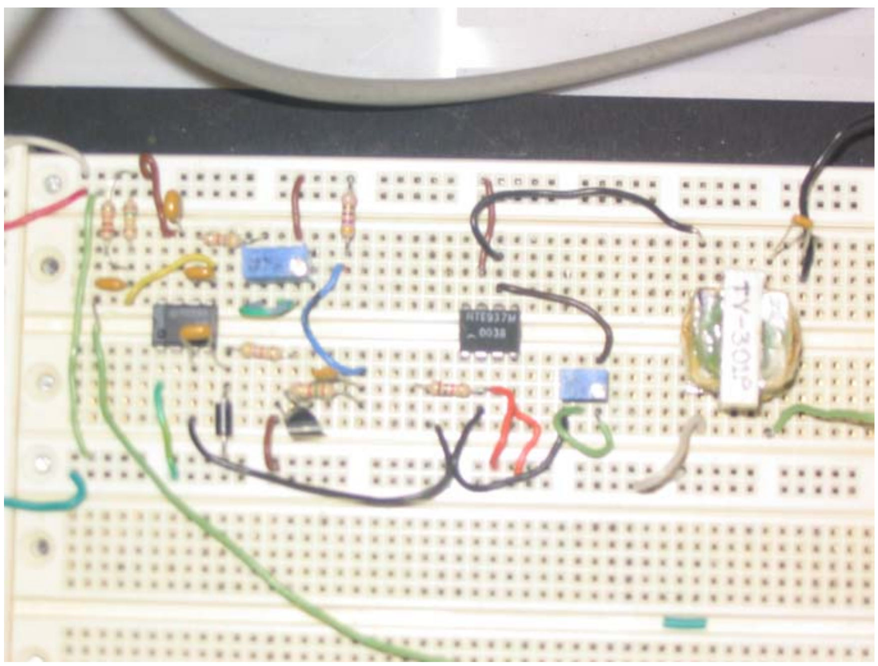

Figure 18. Transmitter Circuit on Bread Board

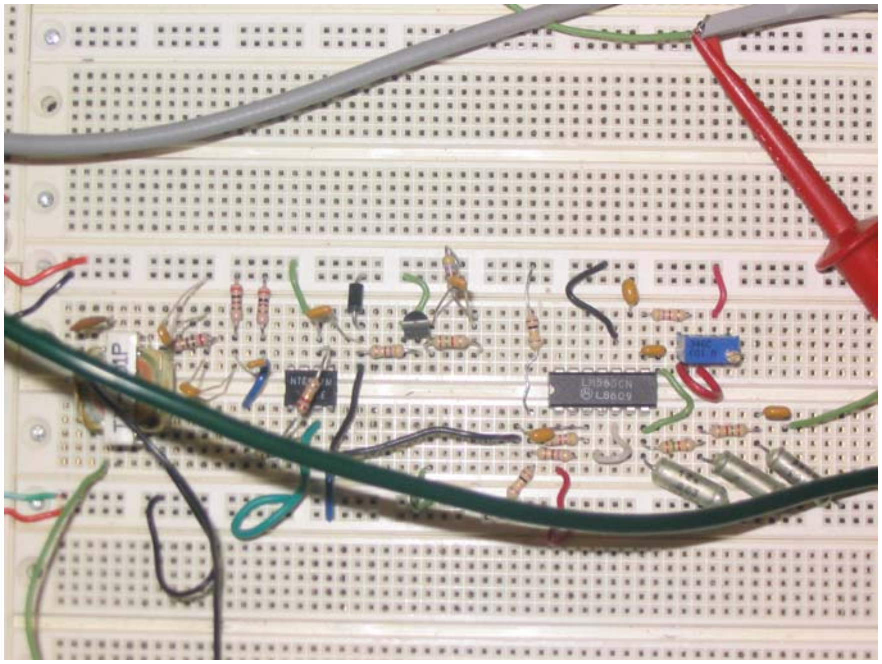

Figure 19. Receiver Circuit on Bread Board

3.2. Implementation

3.2.1. Input

A Function Generator was used to generate the input waveform (the message). In our design, waveforms with frequency ranging from 500 Hz to 5 kHz were chosen to be our input signals.

3.2.2. Implementation Problems

At first, 12V was applied to our circuit to power the IC chips. The chips did not function as well as we expected. After referring to the data sheets, we decided to use +6V and –6V as our power supply. This greatly improved the output signal.

The capacitor coupled with the transformation in the isolation stage was burnt two times. This occurred because the specifications for our transformers were not clear.

Amplitude of the input signal was first set to be 5 V, which is too high for the FM modulation circuit. As the result, the frequency of the carrier waveform was too low to be efficiently passed through the power line. This problem was solved by tuning down the input waveform to 500 mV.

3.3. Testing

The system was tested by using the equipment provided in the 499 project laboratory, namely a function generator and an oscilloscope to view the input and output waveforms. Before connecting to the power line, the FSK modulator and demodulator chips were individually tested. First the modulator circuit was connected as in Figure 6. By applying a sinusoidal waveform to the modulator input, we verified that an FSK waveform was created by the chip and displayed on the oscilloscope. Next, the output of the modulator was directly connected to the demodulation circuit in Figure 11. Now, we were able to observe the original sinusoidal message on the oscilloscope to affirm that both circuits worked together. After these cases were verified, we proceeded to test the entire system with signal propagation through the power line. Figure 20 describes the test arrangement with connection to the power line.

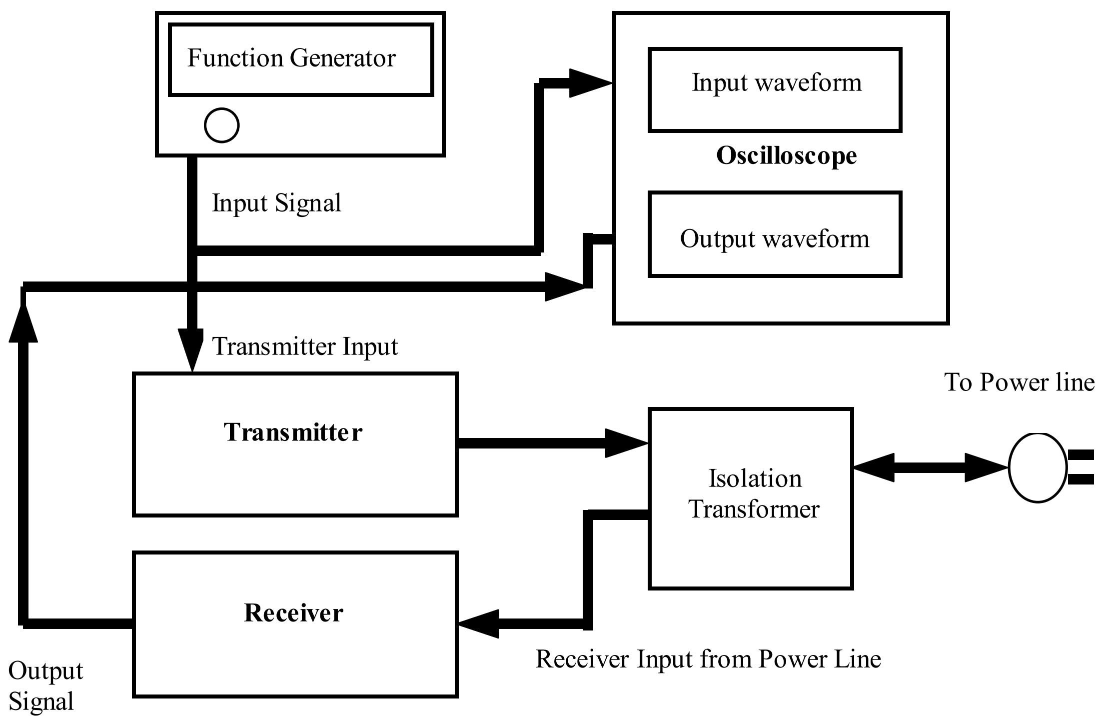

Figure 20. Testing Arrangement (arrows show direction of signal flow)

From Figure 20 it can be seen that the input signal is supplied from a function generator to the transmitter circuit. The input signal is also connected to the oscilloscope so it can be viewed and compared with the receiver output signal. The output of the transmitter was connected to an isolation transformer. The isolation transformer is directly plugged into the power line and its sole purpose is to prevent any inadvertent damage to the power line (and any devices connected to it) by the circuit. The isolation transformer is connected to the receiver, which then demodulates the signal

- which now has the added interference from the connection to the power line - and attempts to retrieve the input message. This retrieved message is also connected to the oscilloscope so it can be viewed.

Using the function generator, we supplied sinusoidal waves of various inputs and various amplitudes and observed the output waves on the oscilloscope. As expected we were able to retrieve the message signal and view it on the oscilloscope for frequencies ranging from 500 Hz to 5 kHz. The output observed by any other frequency was noise. Figure 21 shows a screen shot of the input and output signal at 4 kHz.

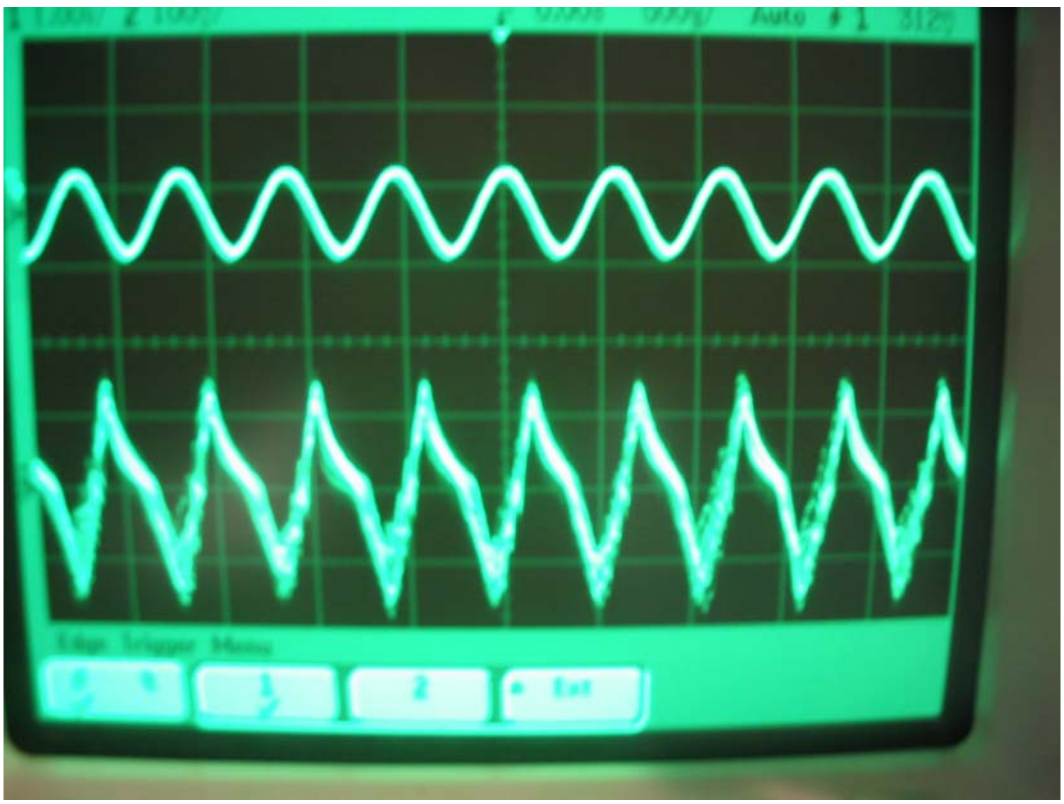

Figure 21. Input Signal Above, and Output Signal Below

The top waveform in the above figure is the input signal, and the bottom is the received signal. It is evident that the transmitted signal has some interference added to it, but the frequency of the waveform is the same as the input signal, so the message is still retrievable. We observed that varying the input frequency on the function generator immediately changed the frequency of the output waveform.

3.4. Improvements

The following subsections will discuss the improvements that can be made to increase the performance and usability of Meter Man. First, interference reduction techniques will be discussed. Next, we will introduce other hardware and software to interface with Meter Man to display the transmitted message more effectively to the user. Finally, methods to increase the data rate and bandwidth capabilities will be explored to investigate possibilities of using the current design into a high bandwidth data transmission product.

3.4.1. Interference Reduction

Since power lines are designed to send power, they are not optimized as transmission medium for data. Power lines typically have high amounts of noise, which causes signal distortion. This signal distortion increases the bit error rate (BER). The BER is defined as the ratio of incorrect bits demodulated by the receiver to the number of total bits received. Furthermore, power line signals are also subject to high amounts of attenuation. These factors are the primary reasons why power lines have not been adopted for mainstream data delivery.

To overcome these shortcomings of the power line, we can employ various methods to decrease the BER. The current prototype uses FSK to modulate the message signal. All existing modulation techniques have deteriorated performance under the presence of interference, but there exist techniques that have slightly better performance than FSK in noise. A technique called BPSK (Binary Phase Shift Keying) has better performance than FSK under noise. BPSK uses two phase differences in the modulated signal to distinguish between a 0 and 1. Figure 22 shows the performance of various modulation techniques under noise.

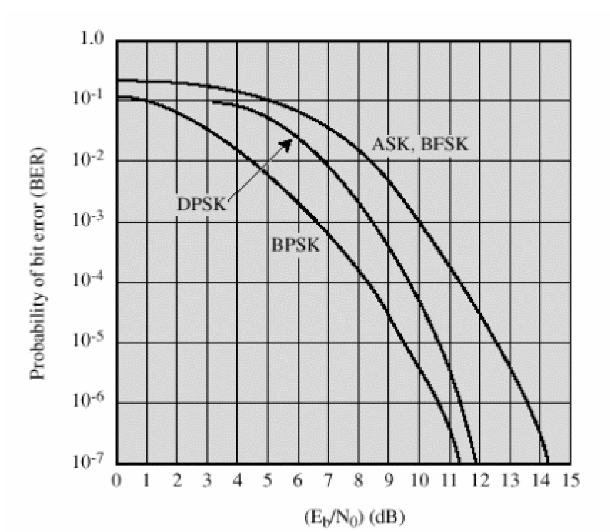

Figure 22. Probability of BER vs. Signal to Noise Ratio of the Channel

The ratio E_b/N_0 is known as the Signal to Noise Ratio (SNR). As we can see from the above figure, for a given SNR, BPSK has lower BER than FSK, DPSK, and ASK.

However, the theoretical results displayed in Figure 22 are not conclusive proof that BPSK will significantly decrease BER in Meter Man. Empirical testing will need to be done with the addition of a BPSK chip to the current circuit. A typical BPSK chip that can be used is a Max2900 (see appendix 5 for datasheet). The existing design will need to be modified - specifically capacitor and resistor values which control the parameters of the current FSK chip - to facilitate the addition of the new modulation chip.

Another way to get a better received signal is to improve the filter on the receiver. Currently, the prototype uses a high pass RLC filter. However, the power line is full of different interfering signals of varying harmonics. Some of these signals are of a high enough frequency to pass through the high pass filter. A more practical solution is to use an active band pass filter that will only admit a small range of frequencies. An integrated circuit chip can be purchased that performs this operation for fewer than twenty dollars. For example a second order active band pass filter chip (MAX267AEWG) costs $17.50 from Digi-Key. This chip would replace the passive first order RC circuit in the current design

3.4.2. Software Interface

The current design of Meter Man utilizes a Motorola PowerPC microprocessor to process any user inputs from a computer terminal. The prototype interface is not user friendly since only a HyperTerminal window accepts typed commands. Those commands are, in turn, used to change output pins on the PowerPC serial port to high/low and then a D/A converter is used to change that signal into an analog waveform to be transmitted.

To program the PowerPC board we would use the C programming language and MQX, which is a real time programming environment. However, a Graphical User Interface (GUI) would be better suited for the final version of Meter Man. Two different software interfaces would be required: one for the power company (vendor) and another for the consumer. This user interface software could be developed in Visual C++ or Java and then installed on client computers.

Still, MQX and C would be required to do all the low level programming of the interface software (i.e. changing the output pins on the Power PC board). Visual C++ or Java would be simply used to create the interface, and this interface would have to transparently communicate with the low level functions to display the data to the user. More investigation is required on the details of this communication.

3.4.3. Increasing Data Rate

Meter man was designed with the vision of laying the framework for other power line applications, including high-speed data transfer. The current design implements only two discrete message frequencies. Each frequency represents a binary ‘1’ or a binary ‘0’. If a third and fourth frequency were detectable by the receiver, then it could represent 10 and 11 respectively thus doubling the rate that data can be sent from the current design. By using a variation of BPSK called QPSK (Quadrature Phase Shift Keying), which is also fairly resilient to noise, we can double the data rate. QPSK is like BPSK where the differences in phases of the transmitted signal signify different bits, but instead of two phase changes, it employs four. These four phase differences map to four discrete bit patterns. QPSK is commonly used in high-speed communications such as cable modems.

A more ambitious method for bandwidth improvement is a method called Orthogonal Frequency Division Multiplexing (OFDM). OFDM is ideal for maximizing the utilization of the transfer channel (the power line). It allows several messages to be concurrently sent across a channel without inducing any extra interference between the transmitted messages. Currently, OFDM is being used in other high bandwidth applications including digital cable.

4. Conclusions

Society's demand for power will continue to grow as new technologies are invented. This is a reality of living in an industrialized age. However, the same technologies that are created to make our lives more comfortable, convenient, and safe can sometimes cause traumatic results. Our power suppliers are given the burden of supplying us with a constant power supply, but this burden can not always be met.

We proposed the idea of a device that would allow communication between the power suppliers and their large industrial clients in the hope that the communication would lower the probability of power failures. The interesting feature about the device is that it communicates solely through the power lines. This is an implementation of data transmission through power lines. A successful implementation of this type of technology would open the door to new data services that could also be provided through the power lines.

The implementation of the device, named Meter Man, began with the design of a transmitter and receiver circuit. The circuit would need to be able to receive data, modulate it, and then interface with the power line. We successfully created such a circuit using an FSK modulating chip and power amplifiers. The receiver was also built using a FSK demodulating chip and power amplifiers to interface with the circuit. The final step was to build filters that would allow us to retrieve the original message. Although we encountered several problems on the way, we were able to successfully design, simulate, and implement the transmitter and receiver circuits. The test data was discussed earlier in section 3.

We have also researched several ways to improve the system. By changing the modulation technique to BPSK we can reduce interference. If we change the modulation technique to QPSK we could double the data rate and reduce interference. The system would therefore function better with a QPSK chip. To further increase the data rate, OFDM could be employed to get the maximum utilization of the power line. To make the system user friendly we would need a graphical user interface. The GUI could be programmed in Microsoft Visual C++ or Java to communicate with the low level instructions in the PowerPC micro-controller to give a user-friendly interface for both the transmitter and receiver.

In conclusion, we accomplished the task that we set forth to do at the beginning of this project which was to send data over the power lines. Through the work we have done we learned about the high interference that must be overcome to make high-speed data transmission over power lines successful.

5. References

Thomas and Rosa, The Analysis and Design of Linear Circuits, New York: John Wiley & Sons, Inc., 2001.

ELEC 380 Class Notes

Design Notes, “Home Automation Circuits.” (Online article), Available at: http://www.designnotes.com/CIRCUITS/FMintercom.htm

Dallas Semiconductor, “MAXIM Max2900 Data Sheet.” Available at: http://www.maxim-ic.com/quick_view2.cfm/qv_pk/3186

6. Appendices

Appendix 1: Progress Report 1

Appendix 2: Progress Report 2

Appendix 3: LM566 Data Sheet

Appendix 4: LM565 Data Sheet

Appendix 5: Max2900 Data Sheet