Senior Design Project: Converting an Analog Transceiver into a Digital one

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Abstract

The Capstone Senior Design Project that is offered to graduating seniors in engineering programs in the United States is a critical part of the students' development. A goal of this course is to give students a feel for the work environment outside, in terms of a critical analysis of a design problem, drawing on resources to arrive at alternative solutions; and, then deciding on a particular solution. In addition, project management is involved and the students decide on dates to reach different milestones in accomplishment of the overall task. A vital part in this process is to find the right project match such that the student can apply theory learnt in previous courses (along with other available resources) to design a product with practical implications. This is the ideal outcome for a Senior Design Project, because it provides the handshaking between the student's theoretical knowledge and a practical world. Thus, it provides a strong demonstration showing how an engineering knowledge can be put to practical use in the society. This paper will describe a Senior Design Project that accomplishes this handshaking very effectively. A group of two students were given an existing FM analog transceiver radio set. The goal was to design and build the necessary subsystems to interface with the existing radio set such that digital information can be sent and received. The paper will examine some of the problems faced by these undergraduate students and show how they overcame them.

I. Introduction

The Department of Engineering at the University of Denver was donated a microwave transceiver set by the Natural Gas company, Kinder Morgan Inc. The transceiver set donated was previously used by Kinder Morgan to meet their communications needs to transmit and receive analog voice and telemetry information. Kinder Morgan was able to dispense with these microwave transceivers because of the company's decision to upgrade their communication system from analog to digital, which offered them a tremendous increase in communication capability in transmitting data. Thus, the goal of this senior design project was to take the donated analog communication system and design around it the hardware interfaces that would allow the transmission of digital information across it. In a nutshell, we would like to send a digital bit stream on one side of the communication link and receive that bit stream on the other. Such a project presents a daunting task for undergraduate students with little or no practical design experience. They would have done theoretical course work in both communications and electronics, two courses that are very important to the completion of this project. But, alas, they lack the practical design applications know-how, which integrates theory and the real world. Of course, the experience that a student would gain by taking on and completing such a task would be tremendous in the development of professional self-confidence. It introduces the process whereby the engineer will use his knowledge and available resources to build a product for his workplace (after graduation). Two seniors jumped at the opportunity to do this project, their names were: Brian Toronyi and Hideyuki Maruhashi.

In our Senior Design course, the students are expected to treat the assigned problem like they would a customer's request. They are expected to provide several alternative solutions, and examine the pros and cons of each solution. Then, pick one of the solutions for implementation and defend their choice. After, which the students should provide a plan showing how they will work towards completing the project, giving pertinent time line to finish different modules, time line for integration and testing, as well as the time to hand over the completed project. The project runs over three quarters, so they will make presentations at different times—one in the preliminary stage, one in the middle, and one at the end of the project cycle where they are expected to deliver a finished product. The goal behind the Senior Design Project course is to give the students a feel for the workplace that they will be going to. In the workplace one is assigned a problem, and its solution may require a group effort. The group will study the problem and arrive at alternative solutions. The solutions will be compared using different cost factors and based on the cost factors one solution will be selected. The group will then, appropriately assign different task to each member. Performance charts with time lines will be used to track the accomplishment of different parts of the project as well as the time for the integration and testing of all modules, and the ultimate delivery date for the final product. Of course, through all this, we want our students to use the knowledge they have learnt in courses as well as available resources to solve a real engineering problem in their field. This is important because it gives them a feel for how engineering knowledge can be used in our everyday lives. In this paper, the focus will be on the engineering experience.

II. Design

Figure 1 shows a picture of the donated transceiver set, which consists of an FM modulator/demodulator. The transmitter operated at a RF frequency around 6 G Hz and a power level of 0.5 W.

In the preliminary stage, the students examined different modulation techniques that can be used to transmit digital information. Alternative solutions examined were: Quadrature Amplitude Modulation, Phase-Shift Keying, and Frequency Shift Keying.[1-3] Because of time constraint as well as the complexity involved in the other schemes, they decided to design a Binary Frequency Shift Keying (BFSK) modulation system.

The next step in the process was to determine how they could incorporate BFSK into the existing microwave radio set to transmit and receive digital information. This calls for an examination of the microwave radio set. The analysis of the microwave transmitter showed them that it takes a baseband signal, upconverts the signal to microwave frequency and transmits. On the receiver side, the microwave signal is received and downconverted back to baseband. Thus, based on these findings, they decided that two subsystem interfaces were needed, one at the transmitter and another at the receiver. At the transmitter, they need to design and build a modulator to convert the digital data stream into appropriate baseband waveforms that the microwave transmitter can send. At the receiver, they needed to design and build a demodular/detector to convert the baseband waveforms back into a digital data stream. The following sections address

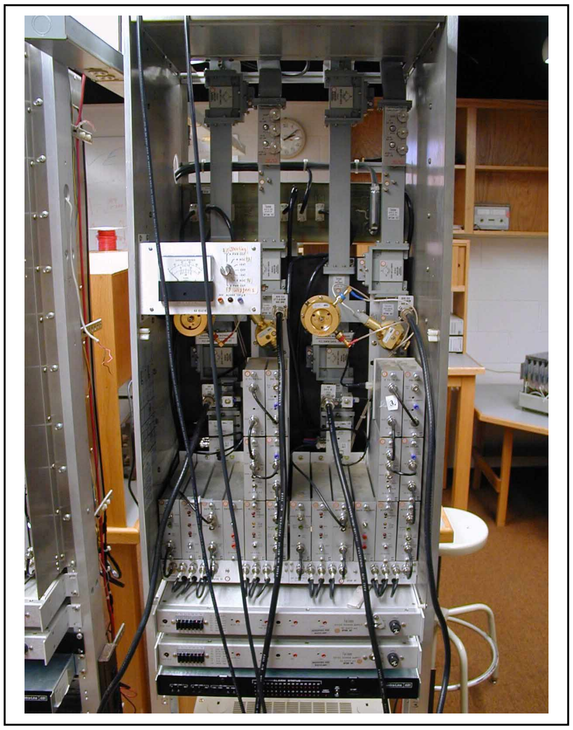

Figure 1. Microwave Transceiver.

the functional blocks that were designed and built to accomplish modulation, and demodulation/detection. In addition, a brief discussion of the design process is included.

A. Modulator

The modulator takes the digital message and converts it into the analog baseband waveforms. Based on the students' decision to use BFSK modulation, the baseband signaling requirement was two frequency tones where one tone would represent a binary one and the other a binary zero.[4] The frequency tones chosen were 124 K Hz and 395 K Hz to represent the transmission of a one and a zero, respectively. Two oscillators were designed and built to generate these frequencies. The modulator also included a switch which connects one of the oscillators (depending on which bit was being transmitted) to the baseband input of the microwave transmitter. A semiconductor switch was used because the design required a device that has a fast response time which was capable of keeping up with the digital data rate. The block diagram of the modulator is shown in Figure 2. The baseband signal was upconverted by the microwave radio and transmitted via waveguide to the receiver.

B. Demodulator/Detector

At the receiver for the microwave radio link, the incoming signal was downconverted to its baseband waveforms. The baseband waveforms were passed to the input of the modulator/ detector, which is composed of the functional blocks shown in Figure 3. To simplify the design, one baseband filter was used to detect the active waveform (which can be either a 124 K Hz or 395 K Hz windowed sinusoid). A bandpass filter was used to determine which baseband

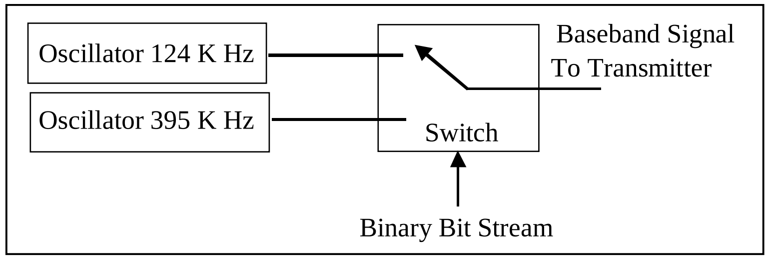

Figure 2. Modulator.

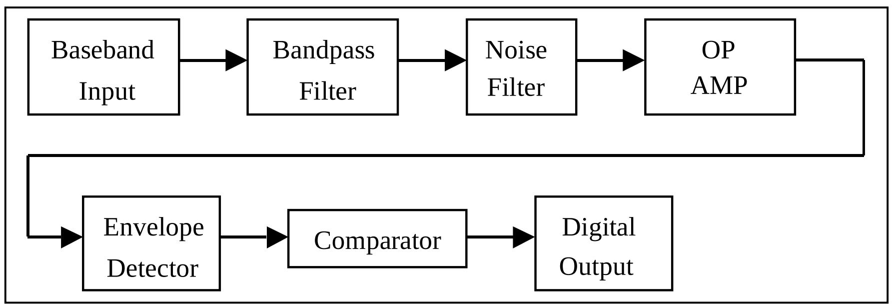

Figure 3. Demodulator/Detector.

waveform was active.[4-5] The bandpass filter was centered at 124 K Hz. It was designed such that the peak frequency response at 124 K Hz and the response at the mid-frequency point between 124 and 395 K Hz was a ratio of 10:1 or better. This part of the project, like the modulation subsystem interface before presented several challenges to the students. 1) They had to design and build the bandpass filter. 2) Analyze the spectra for a windowed sinusoid. The students were surprised in the beginning, while analyzing the spectra for their received signal on a Spectrum Analyzer. They observed two sinc spectra centered at 124 and 395 K Hz instead of two lines spectra at these center frequencies. So they had to figure out why the Spectrum Analyzer (SA) showed a sinc spectra for each tone. They sat down with the problem and came to the realization that the transmitted signal was a windowed sinusoid, i.e., a sinusoid multiplied by a rectangular window in the time domain. In the frequency domain, the tone would be represented by single line (at its cycle rate) while the window function would be represented by a sinc function. Now, from their Signals and Systems course they knew that the multiplication of two signals in the time domain was equivalent to a convolution in the frequency domain.[6] Thus, convolving the line spectrum with the sinc spectra generates a sinc spectra centered at the line frequency. This explain the observation on the SA. This was definitely an eye opening experience for a couple of undergraduate students. 3) The 10:1 ratio between the peak and mid-point frequency was an engineering judgement on their part to make certain that there was good frequency separation between the desired tone at 124 K Hz and the alternative tone at 395 K Hz. 4) During preliminary experiments, they found out that the signal leaving the bandpass filter was very noisy, and in addition, it contained a pilot tone that was sent by the microwave transmitter. These cause the envelope detector/comparator circuit to behave in an unpredictable manner. Thus, a noise filter was inserted to suppress the noise sources and an operational amplifier (OP AMP) was used to boost the signal level after suppression. The output signal from the OP AMP was passed to an envelope detector to produce a dc signal level. The dc signal was used to trigger a comparator to provide the output digital data. Based on experiments, it was found that the dc voltage level with the 125 K Hz (395 K Hz) tone acting alone was 3.3 V (0.55 V). Thus, the comparator was designed to trigger at a reference level of (3.3 + 0.55)/2 or 1.93 Vdc. Therefore, a voltage above 1.93 V will cause the comparator to produce a output level of 5 Vdc (which presents the binary bit one), while a value below 1.93 V will cause the comparator to output 0 Vdc (which represents the binary bit zero).

III. Results

Figure 4 shows the setup used for testing the design. It consists of a function generator (data source), modulator, microwave transceiver, demodulator/detector and an oscilloscope (data monitor). The function generator was set to produce a periodic square wave with a duty cycle of 50%. The high level in the square waveform represents a binary bit one, while the low level a binary bit zero. This signal was used to simulate the digital bit stream that was sent, which consisted of an alternating pattern of ones and zeros. This signal was passed to the modulator which produces one of two sinusoidal frequencies depending on the input bit. The sinusoid produced was upconverted to microwave frequency and transmitted to the receiver where it was downconverted to the original waveform. This downconverted signal was then passed to the demodulator/detector where the binary information was recovered. Outputs from the function generator and the demodulator/detector were connected to a two-input oscilloscope for monitoring (viewing).

Table 1 gives a qualitative description of the waveforms viewed on the oscilloscope. The generator output frequency provides the data rate of the digital information. Thus, if the function generator frequency was set to 14 K Hz, the simulated data rate would be 28 K bits per second

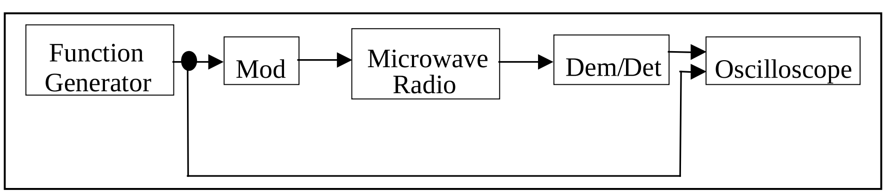

Figure 4. Test setup.

Table 1. Comparison of waveforms.

Data Rate (K bps)	Comparison of received and transmitted signal
28	Identical
30	Identical
32	Identical
34	Identical
36	Identical
38	slight distortion
40	More distortion
42 and above	extreme distortion

(bps). This interpretation is based on the fact that one complete square wave cycle (from the function generator) consists of two half cycles with a high and a low level. The high and low levels can be considered as being representative of a binary one and zero, respectively. Therefore, there are two data bits per cycle of square wave. The table shows that at lower data rates the transmitted and received waveforms were identical. As the data rate increases the shape of the received waveform became increasingly distorted, and performance appreciably degraded at data rates above 42 K bps.

IV. Conclusion

The students gained a tremendous amount experience that bridged the gap between book theory and its application in the real world while working on this project. It gave them an insight into the connection between the analog and digital world since the design required them to work in both. There were many subtleties in the field of communication that they came across and developed an understanding for as the project progresses. One of these was the sinc spectra generated when a sinusoid is switched on and off. Although, not the focus of this paper, the students gained invaluable lessons on how the real engineering world works in terms of the following: 1) choosing between alternative solutions, 2) working as an effective team member, 3) time management and scheduling, and 4) integration and testing of a product. Lastly, the students satisfied the criteria for the success of this project, which was to use the existing analog transceiver set to send and receive digital information.

Bibliography

1. Proakis, J. Digital Communications, 2nd Edition, New York: McGraw-Hill (1995).
2. Couch, L. Digital and Analog Communication Systems, 5th Edition, New Jersey: Prentice Hall (197).
3. Lathi, B. Moderm Digital and Analog Communication Systems, 3th Edition, New York: Oxford University Press (1998).
4. Roden, M. & Carpenter, G. Electronics Design, 3rd Edition, California: Discovery Press (1997).
5. Huelsman, L. An introduction: Active and Passive Analog Filter Design, New York: McGraw-Hill (1993).
6. Soliman, S. & Srinath, M. Continuous and Discrete Signal and Systems, 2nd Edition, New York: Prentice Hall (1998).

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George Edwards received the B.S., M.S., and Ph.D. degrees in electrical engineering form the University of South Florida in 1985, 1989 and 1996, respectively. From 1990 to 1994 he worked at Precision Systems in St. Petersburg, Florida, where he was involved in research and development of real-time DSP algorithms in speech processing and recognition. Since 1997, he has been an Assistant Professor in the Department of Engineering at the University of Denver. His research interests include cellular communication, personal communication systems, modeling and performance analysis of communication networks, and the application of fuzzy logic and neural network in communication.