

# Module-Based, Hands-On Experiments for Digital Communications Laboratory

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## Abstract

Over the past decade, the field of digital communication has been gaining increasing attention with the fast paced advancements in the field. Therefore, graduating electrical engineers need more practical and technical skills to stay up with the technological advancements. This paper summarizes an ongoing effort at the University of Akron to address this need through the integration of a hands-on laboratory component into the digital communication classes. The laboratory experiments cover the generation of amplitude shift keying (ASK), frequency shift keying (FSK), and binary phase shift keying (BPSK) signals, the detection of different modulation techniques using coherent and non coherent receivers, pulse shaping of the baseband signal before modulation in order to increase the channel capacity, the importance of the decision making circuit to regenerate the transmitted signal, the effects of additive white Gaussian noise on the bit error rate at the receiver side. It also covered advanced topics such as the effects of error in synchronization, errors in the phase of recovered carrier, or the error in the threshold of the decision circuit on the quality of the demodulated signal.

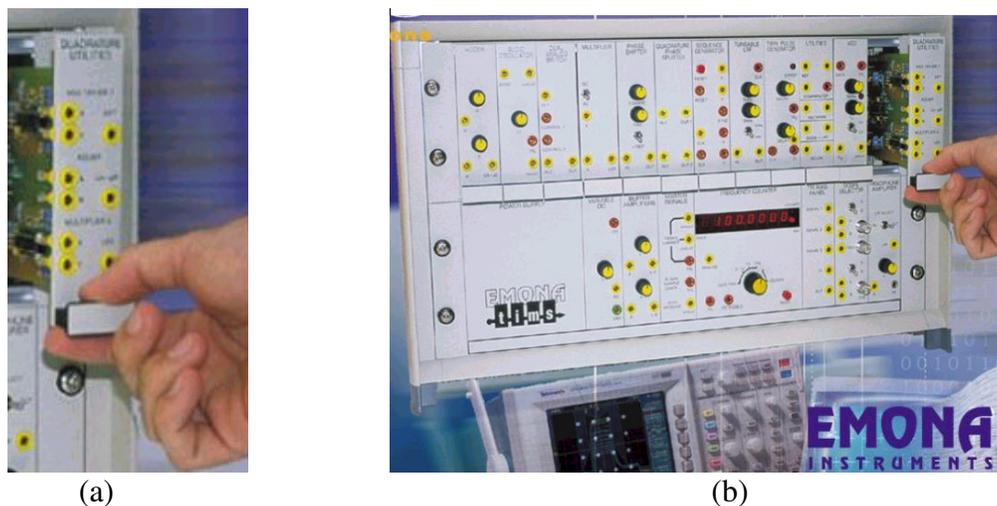
## Introduction

The digital communication topics usually include: digital modulation schemes, error correction coding techniques, and cost-performance issues associated with various communication systems [1-3]. These topics are currently taught in various formats at different schools. They are covered in exclusive “Digital Communications” classes in some schools while covered as part of a general “Communication Theory” or “Communication Systems” class in others. These classes are usually required for electrical engineering majors and can be taken as technical electives for computer engineering majors. Additionally, while the class is mostly offered at the senior-level, it is sometimes accredited towards a graduate degree. Many electrical engineering programs around the country cover the digital communication topics in a “lecture-only” class and some others include a simulation-based laboratory to provide the students with a chance to observe the communication waveforms and collect simulated results.

At the University of Akron a digital communication class is offered for both undergraduate and graduate students. The class is taught in an interactive environment by giving the students the ability to participate and add to the learning process through using online activities such as “Springboard”, Matlab coding for proof of concept realization and a final project that the students have to work on all through the semester utilizing the basic knowledge that they acquire throughout the course. Despite all that, we felt that the physical or practical implementation or experimentation dimension was still missing from the class.

While using software modeling of experiments would have added some insight and clarified the main concepts, the physical process of conducting the experiment by preparing the signals would be much more interesting. Also, using software in the lab experiments will make the debugging of code the biggest part of the lab, which isn't the goal behind a digital communication course. Using well-developed equipments designed to serve as experimental setup for educational purposes would be our best solution maximizing the learning with minimal time and effort. The only disadvantage of such a solution is that there should be enough funding to allocate to such systems.

In our case, the experiments were all implemented using a telecommunication instructional modeling system (TIMS) [4]. TIMS is a module-based telecommunications system that models mathematical equations representing electrical signals. Physically, TIMS is a dual rack system. The top rack accepts up to 12 Eurocard sized, compatible modules shown in Figure 1.



**Figure 1.** (a) Picture of the plug-in module (b) Picture of the TIMS system with the dual rack

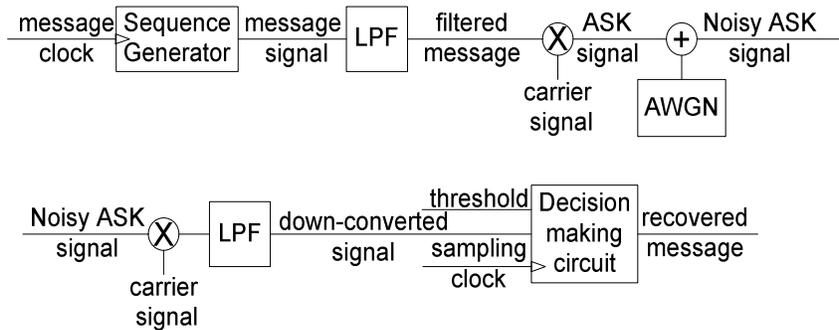
The lower rack houses a number of fixed modules, as well as the system power supply. The modules are very simple electronic circuits, which function as basic communications building blocks. Each module, fixed or plug-in, has a specific function; basic functions fall into three general categories: signal generation such as oscillators, signal processing such as multipliers, and filters and signal measurement such as frequency counters.

Modules are patched together via the front panel sockets using interconnecting leads to model the system under investigation. Any plug-in module may be placed in any of the twelve positions of the upper rack. All modules use the back plane bus to obtain power. The modules are designed so that they may be plugged-in or removed at any time, without turning off the system power. The modules are not locked into position and may need to be held while interconnecting leads are removed. It should be noted that no variable controls have calibration marks. This is intentional, as the philosophy behind TIMS is that students should setup and adjust systems by observing and measuring signals. This allows students to gain a deeper understanding, feel, and insight into the operation of a communications implementation.

The instructor can chose between different experiment setups using various modules. The modules are very well documented and can be easily used at other institutes. The cost of the setup needed to replicate the experiments described in this paper is only \$13,000 for one system with the basic plug-in modules and around \$500 for each additional module.

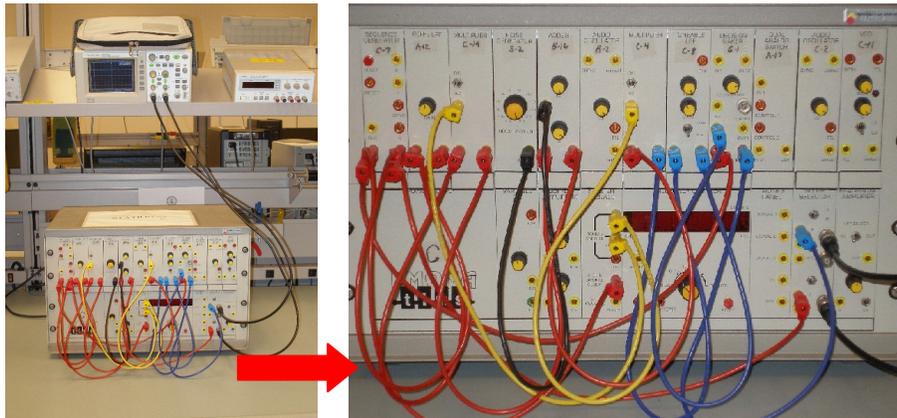
## Designed Experiments

To give an idea about the experiments that were performed, one of them is summarized below. The experiment covers ASK modulation/demodulation. It includes two different modulation techniques and one demodulation technique. In addition, it studies the effect of a bandlimited noisy channel on the quality of the recovered message.



**Figure 2.** The block diagram of the set-up for the ASK experiment

A block diagram of the setup used to implement this lab session is shown in Figure 2. At the transmitter side, a message signal is generated using a pseudo random sequence generator. To reduce the effect of the bandlimited channel, the message signal is filtered before modulation. The filtered message is modulated using one of the modulation techniques to produce the ASK signal. Noise of different power levels is added to the ASK signal using an additive white Gaussian noise generator. At the receiver side, the received signal is down-converted and sent to the decision making circuit to recover the original message. Figure 3 shows a picture of the TIMS system with the modules and connections necessary to implement the experiment.

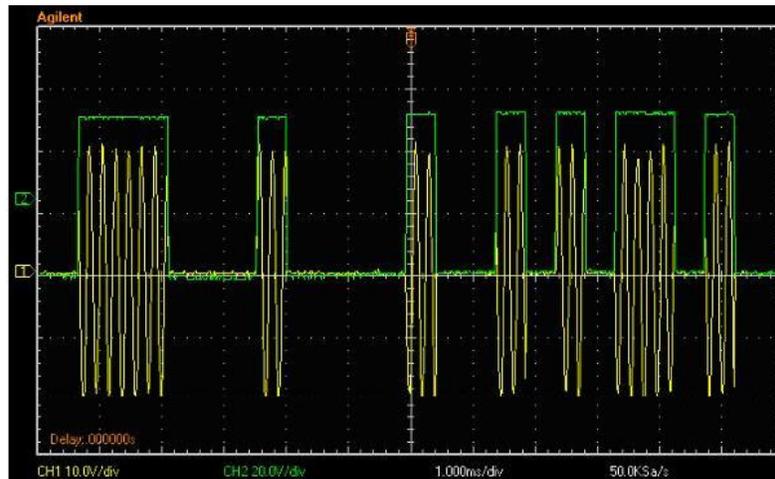


**Figure 3.** A picture of the TIMS system with the modules used in the ASK experiment

The most intuitive method to generate an ASK signal is performed through the use of an analog switch. A switch can be implemented to either “pass” or “block” a carrier signal. This way, the carrier signal is amplitude modulated, a binary “1” being the transmission of the carrier waveform, and a binary “0” being the lack of a carrier waveform.

To implement this method in TIMS, a 2 kHz sinusoid is fed into a sequence generator that generates a pseudorandom digital waveform, which will serve as the message bits. The

pseudorandom sequence is connected to the control of the analog switch so that the switch is clocked to the message bits. Finally, the input of the analog switch is supplied with an 8.33 kHz sinusoid from an audio oscillator that acts as a carrier signal. The outputs of the switch, along with the original digital message were captured using Agilent oscilloscope as shown in Figure 4. The problem with this intuitive method is that analog switches cannot usually pass high frequencies due to its slow response and hence the carrier frequency is limited to the audio range. This in turn limits the message signal to a very small bandwidth signal.

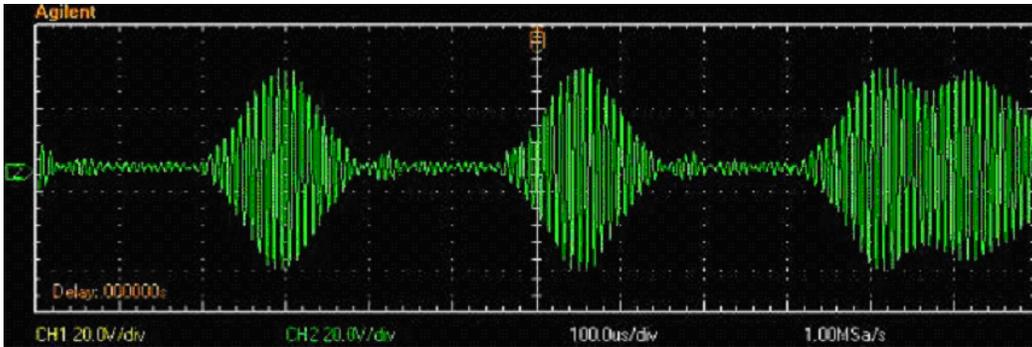


**Figure 4.** The output of the switch with the original digital message

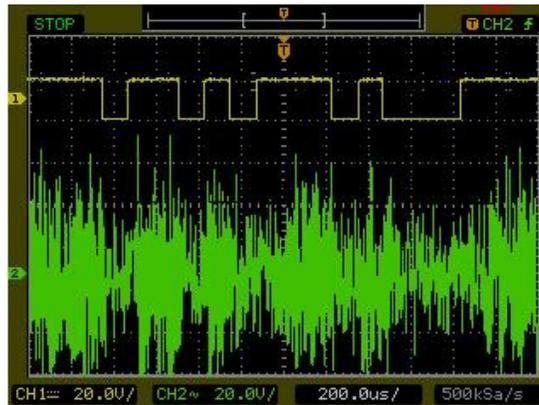
Message signals with larger bandwidths should be modulated using a more sophisticated technique such as an analog multiplier, for example. To implement this method in TIMS, the message signal is generated from a pseudorandom generator clocked at 8.33 kHz. The carrier signal is produced from a voltage controlled oscillator (VCO). Applying the proper voltage to the VCO, a carrier frequency of 110 kHz is achieved. Now that the two inputs are ready, their product is the ASK modulated signal.

The Fourier transform of the ASK signal is usually characterized by infinite frequency components. This is due to the abrupt change between symbols ‘1’ and ‘0’. As a result, ASK signals suffer from distortion after passing through a bandlimited channel. Due to the distortion effect, the signal at the receiver is smeared and can cause inter-symbol-interference errors in the recovered message. To solve this problem, it is better to bandlimit the message signal before sending it to the multiplier. This requires a Low Pass Filter (LPF) to remove the high frequency components from the waveform; the LPF used in this case was an elliptic LPF with a cut-off frequency of approximately 60 kHz, stopband attenuation of 50dB. Finally, the filtered message and the carrier signal are multiplied using the analog multiplier. The output from the multiplier is shown in Figure 5. Inspecting the output, students can easily notice the smooth changes between the different symbols. This technique can also be helpful in multiplexing more than one message signal over the same channel since each ASK signal will be limited to a fixed bandwidth.

To understand the effect of noise on the ASK signal, an additive white Gaussian noise is added to the signal (at varying levels). The transmitted signal at 22 dB of noise is shown in Figure 6 together with the message signal. Although the envelope of the transmitted signal resembles the message, it is difficult to correlate them at this high noise level. This is usually a cause of errors in the recovered signal, as will be seen in the experiment.

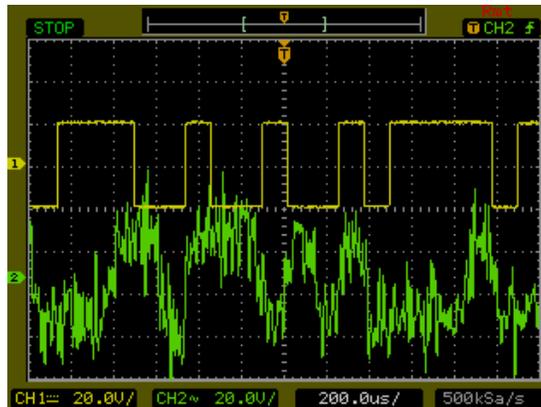


**Figure 5.** The output from the analog multiplier



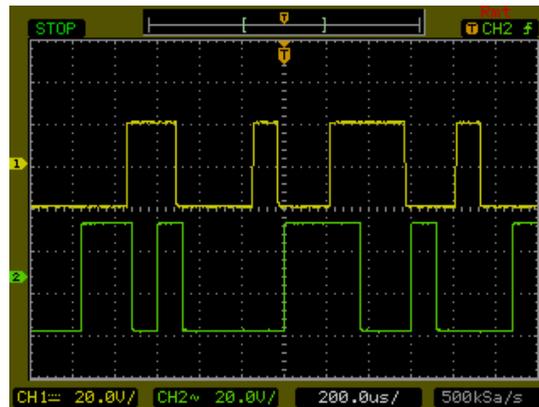
**Figure 6.** The ASK signal corrupted with AWGN

At the receiver side, the signal is down-converted back to baseband. This is done by multiplying the received signal with the recovered carrier signal and filtering it with a similar LPF that was used in the bandlimiting process. The waveform of the down-converted and filtered signal is shown in Figure 7. This signal is sent to the decision making circuit to recover the original message. The decision circuit samples the signal at a clock that is synchronized with that of the message signal. The samples are compared against a threshold to determine the transmitted message. The output of the decision circuit is the recovered message recreated without noise. Though no noise is present in the recovered message, error bits can be seen in the recovered message at low levels of signal to noise ratio.



**Figure 7.** The waveform of the down-converted and filtered signal.

Figure 8 shows the original message (green) compared with the recovered message (yellow). Two bit errors are evident at the beginning of the plot. This experiment can be easily tweaked to include the effects of other imperfections such as problems in the phase or frequency of the recovered carrier signal, synchronization problems in the clock used to sample the signal at the input of the decision making circuit, and mistakes in the threshold value used to decide between the two different symbols.



**Figure 8.** The recovered message compared with the original message

## Survey Results

In order to quantify the impacts and the benefits of these experiments and measure the laboratory effectiveness on the learning process of the students, a seven question survey was handed-in to the 19 students who took the class. For each question, students were asked to pick a number on a scale of 0 to 10, 0 being absolutely disagree while 10 being perfectly agree. The questions are shown below with statistics of the responses and drawn conclusions. Detailed distributions of the answers are shown in the pie charts in Figure 9.

**Question #1:** *Were the experiments relevant to the Material studied during the course?*

The mean of all the answers for this question was 9.52. This makes sense since the main motivation of having hands-on experiment is to facilitate the understanding of the theoretical material studied in class.

**Question #2:** *Were the experiments practically oriented (Discussing the techniques)?*

The mean of all the answers for this question was 8.68. This result also reinforces the fact that the laboratory sessions helped adding the missing dimension in this learning process.

**Question #3:** *Did the experiments aid in your understanding of the course material?*

The mean of all the answers for this question was 9.00. This was the main goal of the instructors.

**Question #4:** *Were the experiments user friendly & easy to use?*

The mean of all the answers for this question was 8.00. This result proves the argument that the more friendly the used equipments are, the more benefit is gained from the experiments.

**Question #5:** *If you were to rank this lab among different labs you have already had in other courses what would it rank 10 the highest, 0 the lowest?*

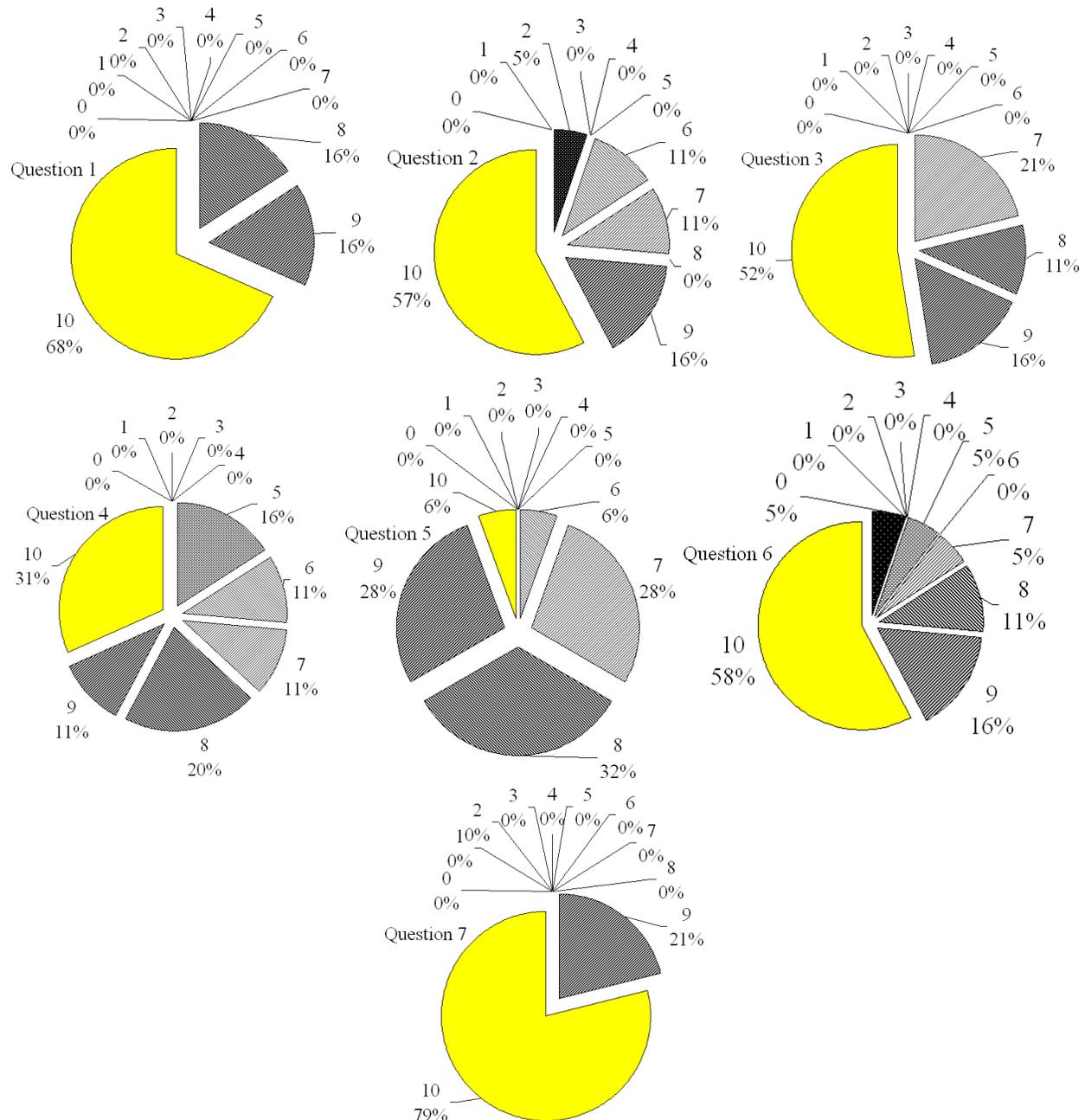
The mean of all the answers for this question was 8.00. This result validates the effectiveness of this lab.

**Question #6:** If you were to take the course again would you recommend having more experiments?

The mean of all the answers for this question was 8.60. This result also reinforces the idea that this lab was helpful and would be even more helpful if we included a wider range of experiments.

**Question #7:** Did the instructors have the required knowledge to supervise this lab?

The mean of all the answers for this question was 9.79.



**Figure 9.** Results of the conducted survey

## **Conclusion**

This paper presented a description of a laboratory component to be integrated with a digital communication class. The lab consisted of multiple hands-on experiments as opposed to software-based simulation labs. The experiments were built using commercially available setups and modules from TIMS. Student surveys showed that students who took the class enjoyed being in the lab and were very pleased with the outcomes of their learning experience.

## **References**

- [1] J. G. Proakis, *Digital Communications*, 4<sup>th</sup> Edition, McGraw-Hill, MA 2001.
- [2] R. Ziemer and R. Peterson, *Introduction to Digital Communication*, 2<sup>nd</sup>, Prentice-Hall, NJ, 2001.
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- [4] [www.tims.com.au](http://www.tims.com.au)