# Development of Software Defined Communication Systems for Improving Technical Education in Thailand

Poompat Saengudomlert, Natthaphob Nimpitiwan, and Pakorn Ubolkosold
Bangkok University-Center of Research in Optoelectronics,
Communications, and Control Systems (BU-CROCCS)
9/1 Moo 5, Paholyothin Road, Klong Luang, Pathum Thani 12120, Thailand
E-mail : poompat.s@bu.ac.th, natthaphob.n@bu.ac.th, pakorn.u@bu.ac.th

**Abstract**: Due to high prices of imported laboratory equipment for teaching and learning digital communications, several educational institutes in Thailand (as well as some neighboring countries) are facing problems of equipment shortage. A lot of students end up learning from textbooks without actual experiments, causing them to lack confidence in their knowledge. Fortunately, reprogrammable digital electronics, in particular field programmable gate arrays (FPGAs), are becoming cheaper with higher computational powers. Universities can now use them to develop communication systems for laboratory equipment. This article describes such activities at Bangkok University-Center of Research in Optoelectronics, Communications, and Control Systems (BU-CROCCS), Thailand.

*Keywords*— **digital communications, laboratory, software defined, field programmable gate array, digital-to-analog converter, analog-to-digital converter**

## 1. Introduction

The lack of equipment for teaching and learning of digital communications, considered as an important technical subject in the age of digital information, has been a weakness in several educational institutes in Thailand (as well as some neighboring countries). While such equipment may be imported, their high price tags would allow at most 2−3 sets of equipment to be shared by 20−30 students in a typical classroom. Without sufficient hands-on experiences, a lot of students lack confidence in their knowledge obtained from textbook-based learning and from simulation software.

Recently, several universities around the world have developed their own digital communication laboratories using the software defined approach [1], [2], [3]. In this approach, a common set of hardware can be used for different experiments, with its functionalities changed through software, i.e., hardware programming. Consequently, the software defined approach can provide laboratory equipment with modest costs.

One key hardware component in software defined communication systems is a field programmable gate array (FPGA), which is a digital electronic device that can be used to perform digital signal processing (DSP). An FPGA is, in principle, configured by a hardware description language, e.g., Verilog [4]. However, several commercial software packages, e.g., MATLAB, allow users to program the hardware indirectly with a more user-friendly syntax or graphical user interface (GUI) [5].

This article describes activities at Bangkok University-Center of Research in Optoelectronics, Communications, and Control Systems (BU-CROCCS) towards developing software defined communication systems to be used as laboratory kits in educational institutes in Thailand, and possibly in neighboring countries later on. Section 2 presents the overall system structure, main hardware components, and key transmission system parameters. Section 3 shows example data signals that can be generated from the developed system. Section 4 discusses actual uses of the developed laboratory kits. Finally, section 5 provides a summary as well as directions for future development.

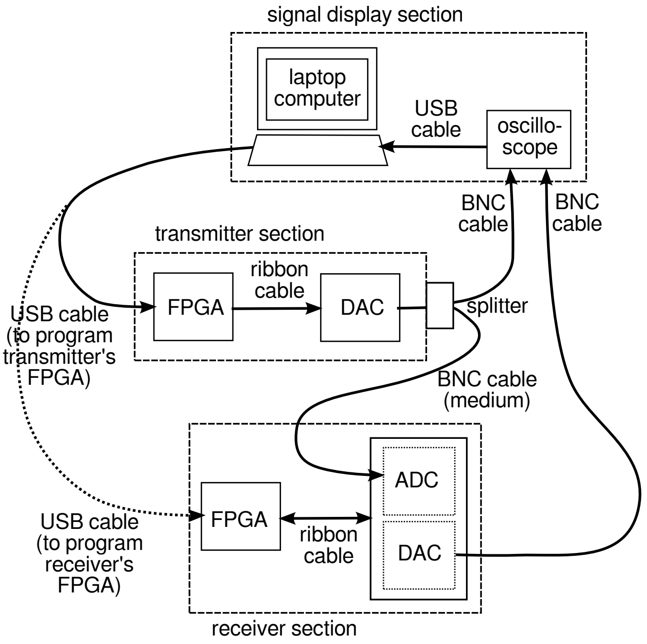

Figure 1. Structure of the developed software defined communication system

## 2. System Components and Parameters

The developed software defined communication system has the structure as shown in Fig. 1. In particular, since FPGAs are digital devices and analog signals are needed for data transmissions over the transmission line (coaxial cable in this case), we developed in BU-CROCCS a digital-to-analog converter (DAC) to be used by the transmitter. In addition, we developed an analog-to-digital converter (ADC) to be used by the receiver.

The transmitted signal is split such that one copy goes to the receiver while the other is fed to an oscilloscope for signal display. Another DAC is used by the receiver to send the

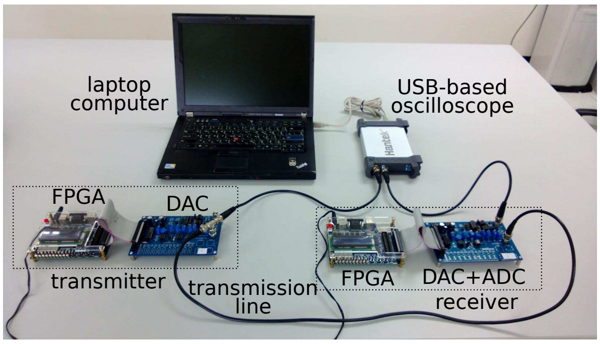

Figure 2. Actual software defined communication system developed in BU-CROCCS

Table 1. Communication system parameters

| Parameter | Value |
|---|---|
| Bit rate | 1 − 10 kbps |
| Carrier frequency | 1 − 5 kHz |
| No. quantization bits | 10 bit/sample |
| Sampling rate | 100 kHz |
| Pulse shape | rectangular |
| Modulation format | PAM, PWM, PPM<br>ASK, FSK, PSK, QPSK |

received signal or a processed signal to the same oscilloscope for comparison with the transmitted signal.

Fig. 2 shows the actual hardware used to implement the system in Fig. 1. Table 1 lists key system parameters of the developed communication system. Note that the supported modulation formats include pulse amplitude modulation (PAM), pulse width modulation (PWM), pulse position modulation (PPM), amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK), and quadrature PSK (QPSK).

DE0 Development and Education boards, which contain Altera's Cyclone III FPGAs, are used in the development [6]. Hardware programs for the FPGAs are written in Verilog, and compiled using Quartus II Web Edition v12.1, which is available for free [7].

## 3. Example Data Signals

Fig. 3, 4, and 5 show example data signals for binary PAM, ASK, and FSK modulations, respectively. In each figure, the top graph (in yellow) is the transmitted signal while the bottom graph (in green) is the received signal. In addition, the oscilloscope is set at 0.5 V/Div for the signal value (vertical axis), and at 2 ms/Div for time (horizontal axis).

The system is set to transmit data bits in groups of 10, with preamble signals between consecutive groups. The preamble part has a higher amplitude than the data part. This higher amplitude serves two purposes. First, students can easily see from the oscilloscope display the beginning of each data frame (consisting of 10 bits). Second, the receiver can use it for timing synchronization so that data bits can be detected and displayed through LED lamps on the receiver's FPGA.

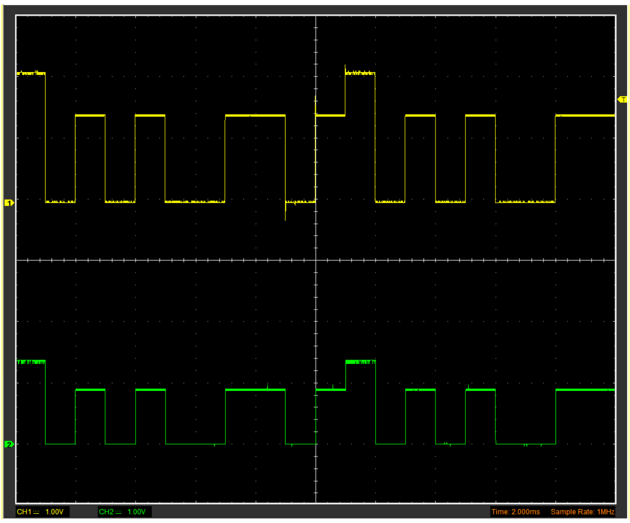

Figure 3. Transmitted and received PAM signals

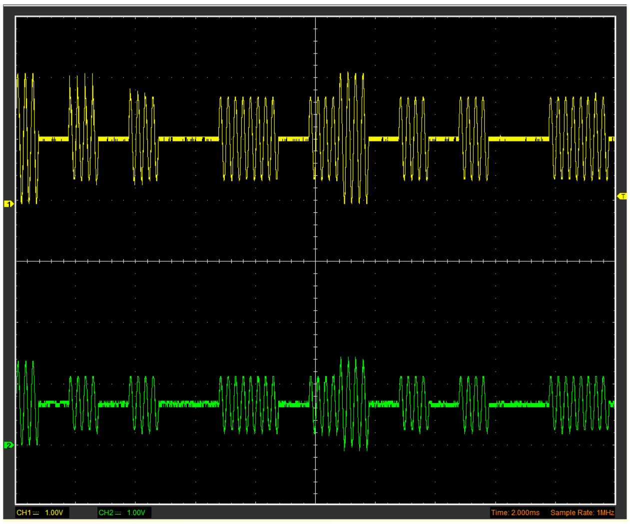

Figure 4. Transmitted and received ASK signals

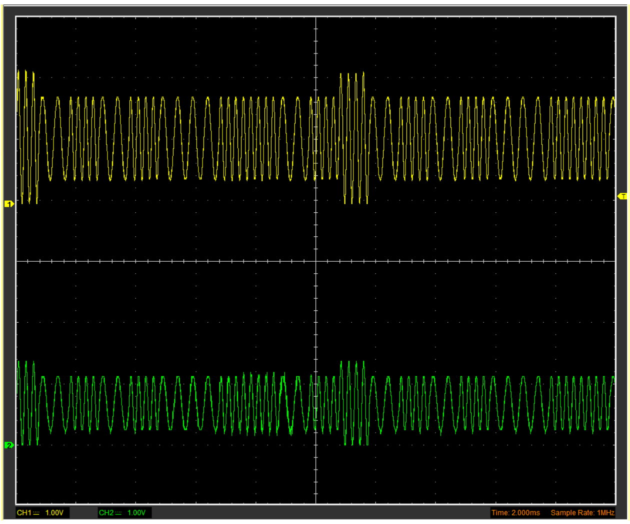

Figure 5. Transmitted and received FSK signals

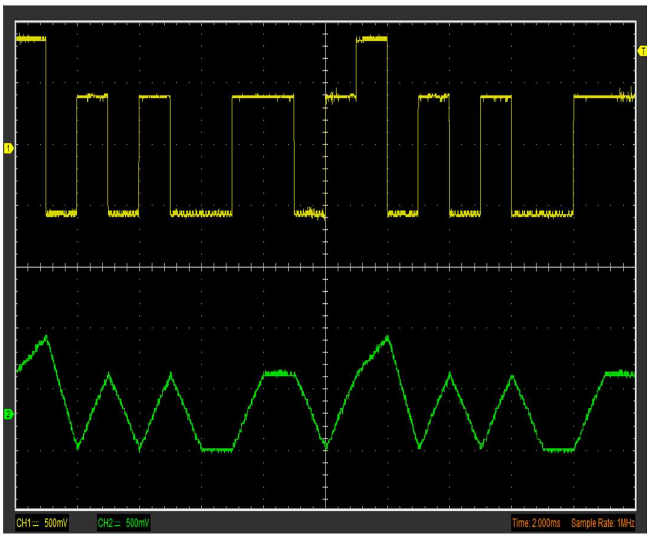

Figure 6. Transmitted PAM signal and matched filter output at the receiver

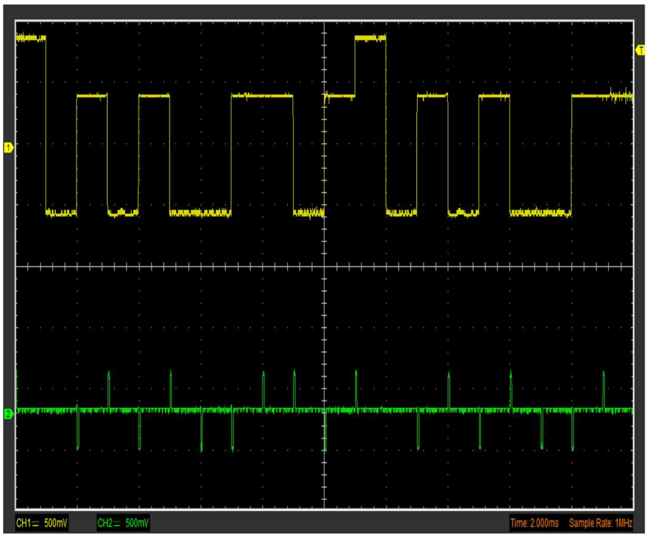

Figure 7. Transmitted PAM signal and samples taken from matched filter output at the receiver

In Fig. 3, 4, and 5, the transmitted group of 10 bits are 0101001101. It can be seen from Fig. 3 that, in binary PAM, bit 1 is mapped to a rectangular pulse with a positive value, while bit 0 is mapped to a negative value. For binary ASK in Fig. 4, bit 1 is mapped to a carrier signal (sinusoidal) with a high amplitude, while bit 0 is mapped to a low amplitude. Finally, for binary FSK in Fig. 5, bit 1 is mapped to a carrier signal with a high frequency, while bit 0 is mapped to a low frequency.

Students can themselves select the 10 bits in each frame through setting the 10 slide switches on the transmitter's FPGA. This feature of the developed system allows for interactive learning experiences in which students can change the data bits and observe changes in the transmitted data signal instantaneously.

Figure 8. Deliveries of laboratory kits to two instructors in two vocational schools in Thailand

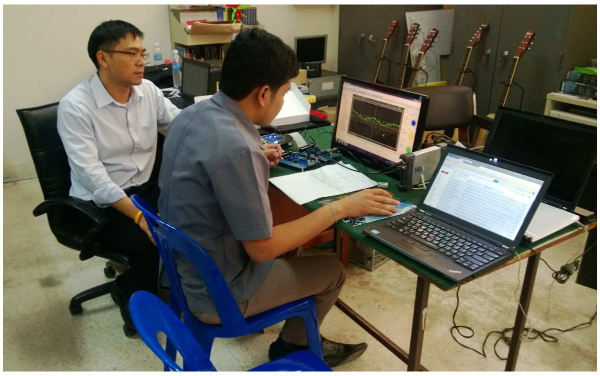

Figure 9. On-site training to one instructor prior to actual teaching using laboratory kits

In addition to observing the transmitted and received signals, as shown in Fig. 3, 4, and 5, students can observed various steps of signal processing at the receiver. For example, Fig. 6 shows the output from the matched filter at the receiver (in green) with respect to the transmitted signal (in yellow). Fig. 7 shows the signal samples taken from the matched filter output at the receiver (in green). Note that these samples are used for detection of data bits. For each sample, if the value is above the threshold value for detection (shown as the mean value in Fig. 7), the corresponding detected bit is 1. Otherwise, the detected bit is 0. In Fig. 7, we can see that the detected bits in each frame are 0101001101.

## 4. Actual Uses of the Developed System

The developed system was used on a trial basis by instructors at two vocational schools in Thailand. Fig. 8 shows laboratory equipment deliveries to the two vocational schools. The equipment were arranged as laboratory kits each of which can be contained in a backpack for ease of transport.

On-site trainings were provided to the instructors before they applied laboratory kits in teaching the fundamentals of digital communications, as shown in Fig. 9. Fig. 10 shows classroom environments during actual uses of laboratory kits during the first half of 2015. Students worked in groups to perform various experiments.

Based on the feedback from the two instructors (Ekkaphot Keawklai and Samanathorn Poompimol), students enjoyed using the laboratory kits in performing various experiments. In addition, the laboratory kits helped maintain student interest in the subject, which can be quite abstract without actual

Figure 10. Classroom environments during actual uses of laboratory kits

Figure 11. Participants of seminars on software defined laboratory kits for teaching and learning the fundamentals of digital communications

experiments. Finally, the laboratory kits were easy to use, and could demonstrate several concepts as effectively as imported laboratory equipment.

After the actual uses in two vocational schools, BU-CROCCS organized hands-on seminars in several occasions in order to gain further experiences in using the developed laboratory kits. The audience in these seminars include both Thai and international students, as shown in Fig. 11. Based on the feedback obtained from these seminars, participants found the laboratory kits easy to use. Several expressed their satisfaction in eventually "seeing" what they have learned from textbooks, and encouraged the use of these laboratory kits in actual teaching.

## 5. Conclusion

We developed software defined communication systems to be used as laboratory kits for teaching and learning the fundamentals of digital communications. The software defined approach helps keep the development cost low since the same set of hardware can be used for different experiments through hardware programming. In our development, we purchased FPGAs from Altera to perform DSP and constructed DACs together with ADCs. While the data rates are modest, the systems are based on the same fundamentals as high-rate systems, and can be used to alleviate the lack of laboratory equipment in Thailand as well as in some neighboring countries.

Future activities include the development of other types of transmission medium, including the use of wireless antennas and optical fibers. In addition, various kinds of signal distortion, e.g., noise and dispersion, can be demonstrated by the laboratory kits. Finally, activities that allow students to modify hardware programs for DSP will be considered.

### Acknowledgement

The authors would like to thank Thailand Research Fund (TRF) for sponsoring this development project under the contract number RDG5740028.

### References

[1] D.G. Michelson, D.W. Matolak, and W. Tong (Ed.), "Communications education and training: Software defined radio," *IEEE Communications Magazine*, vol. 52, no. 5, pp. 182–209, May 2014.

[2] J. Mitola et al. (Ed.), "Software defined radio – 20 years later: Part 1," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 22–71, September 2015.

[3] H. Hu et al. (Ed.), "Software defined radio – 20 years later: Part 2," *IEEE Communications Magazine*, vol. 54, no. 1, pp. 10–57, January 2016.

[4] S. Brown and Z. Vranesic, *Fundamentals of Digital Logic with Verilog Design, 3rd Edition*, McGraw-Hill, 2013.

[5] MathWorks, "FPGA Design and SoC Codesign," available at www.mathworks.com/solutions/fpga-design/

[6] Terasic, "Altera DE0 board," available at www.terasic.com.tw/cgi-bin/page/archive.pl?Language=English& No=364

[7] Altera, "Quartus II Web Edition v12.1," available at https://wl.altera.com/download/software/quartus-ii-we/12.1