# A Real-time *N*-Channel PCM Transmission System Test Bed


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***Abstract*—Virtual instruments (VIs) and circuit-emulating graphical programming have enabled unprecedented teaching, measurements/instrumentation and prototyping possibilities across multidisciplinary applications. A task to develop a virtual instrument experiment platform for the pulse code modulation (PCM) technique has been implemented using the NI LabVIEW FPGA. The software simulation results were validated by interfacing the VI platform with a hardware carrying real-time signals. A sweep of sampling rate and bit depth was carried out to investigate the fidelity of the recovered signal vis-à-vis the original analogue input. Furthermore, the experimental setup involved deploying the NI FPGA digital electronics board and DAQ hardware. The integrated embedded system enabled our students to investigate and analyse the performance and validity of different transmitted signals and the transmission media. This novel real-time communication system was developed for the first time for the communication engineering course unit and the students found it very interesting implementing a VI for the PCM scheme and practically verifying their findings. This experimental learning and teaching (L&T) platform can be extended to accomplish adaptive and real-time multiplexed multiple-channel PCM telephone system.**



***Keywords— ADC/DAC, communication experiment, course development, embedded system, FPGA, learning, teaching, PCM, TDM.***


## I. Introduction

Pulse code modulation is a technique for information transmission in which an analogue signal is periodically sampled using sample and hold switch, coded using analogue-to-digital (ADC) and transmitted (usually serially) [1, 2] . A multiple-channel PCM system involves sampling each channel in turn and transmitting the codes usually in a time division multiplexed (TDM) frame. Receiving PCM signals initially involves decoding the digital signal stream using the digital-to-analogue (DAC), de-multiplexing the TDM frame into separate channels and filtering each signal to obtain the recovered signals.

Several modulation schemes (such as the amplitude modulation (AM) and frequency modulation (FM)) are utilised for simulating digital and analogue communications using the NI LabVIEW field programmable gate array (FPGA). However, available literature reveals that there are very few attempts regarding the embedded simulation of the PCM. As an example, Whalen used the Haskins Laboratories' system to study the PCM method of digitising analogue signals in digital audio and in speech enhancement [3]. Some techniques simulated the PCM system using Simulink©, to test the validity of the sampling theorem and the quantization levels. Also, an experiment to implement the electronics of a baseband system that uses PCM to transmit audio signals digitally has been carried out [4]. Akar et al have proposed a web-based real-time virtual laboratory to support analogue and digital communications course [1]. The authors studied the PCM code sequence using different coding schemes, different frequencies of the input and different quantization levels. Each one of these works has its own merit but none of the existing research works analyses the PCM scheme with real-time signals. Also, no existing studies consider the development of a *N*-channel PCM system as a test bed for communication system experimentation and applications.

## II. The PCM Experiment Design

### A. Introduction

Simulation provides an environment to physically evaluate and test a system performance a priori practical deployment. During the learning process, a simulation software can be used to link between theory and real-life applications and it helps to explain system attributes. The PCM simulation involved setting the sampling rate and bit depth for a given analogue signal; the transmitter, sample and hold, ADC, DAC and receiver blocks were designed and simulated. In this work, the NI LabVIEW FPGA was adopted as a simulation environment for the multiple-channel TDM PCM telephone system as it offers a dynamic and real-time interface for data processing and analysis applications. The operation and performance of the simulated system was evaluated and analysed using ELVIS II and FPGA boards. Figure 1 shows a general block diagram of the PCM system. The PCM data stream can be transmitted serially via any wireline and wireless transmission media.

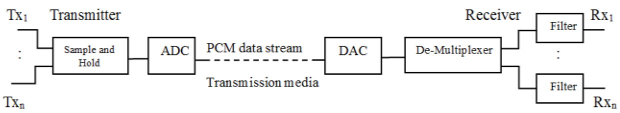


Fig. 1. A *N*-Channel PCM System

### B. The Real-time PCM Experiment Design

Figure 2 shows a block diagram that demonstrates the main VI components used in the design. The ADC and DAC VIs were found directly in the function palette of the NI LabVIEW; other VIs such as the 'Sample and Hold,' 'Multiplexing' and 'De-Multiplexer' were designed. The number of channels can be altered by adding more input signals. The system can recover the original signal (via a receiver VI) and be reset (using a toggle switch).

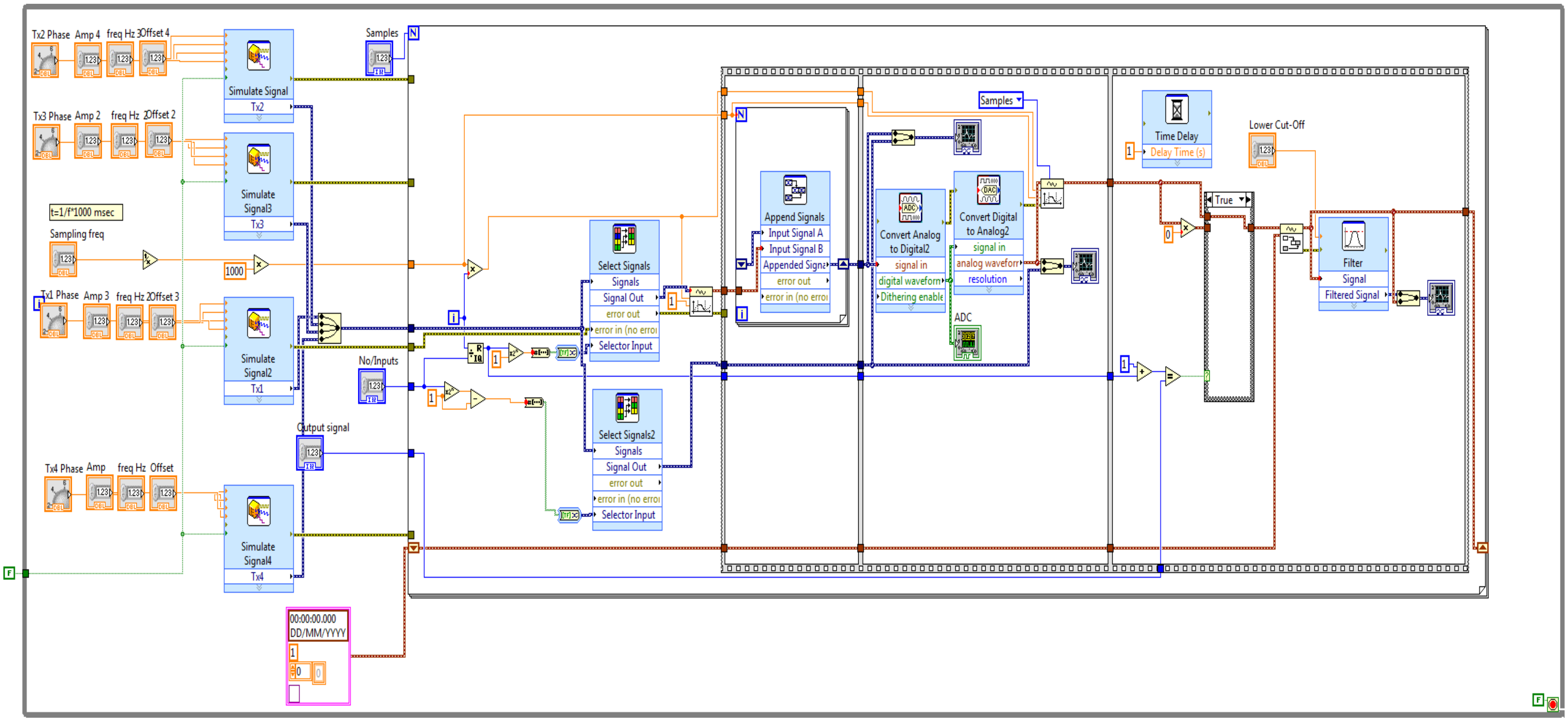


Fig. 2. A 4-Channel PCM Graphical Programming Code

## III. MEASUREMENT AND ANALYSIS OF THE PCM SYSTEM

The integrated real-time empirical-simulated system can be used to characterise the performance of a PCM telephone system. Sampling, quantisation, encoding, system linearity, Nyquist theorem, filtering and frequency limitations of the system can be investigated. The feasible channel measurements include:

- observing the ADC and DAC processes and measuring the dynamic linear range of the system;
- observing the DC performance of the TDM frame and measuring the sampling rate;
- observing the system linearity through quantisation, sampling rate, filtering and signal-to-noise ratio; and
- studying the frequency response of the PCM system.

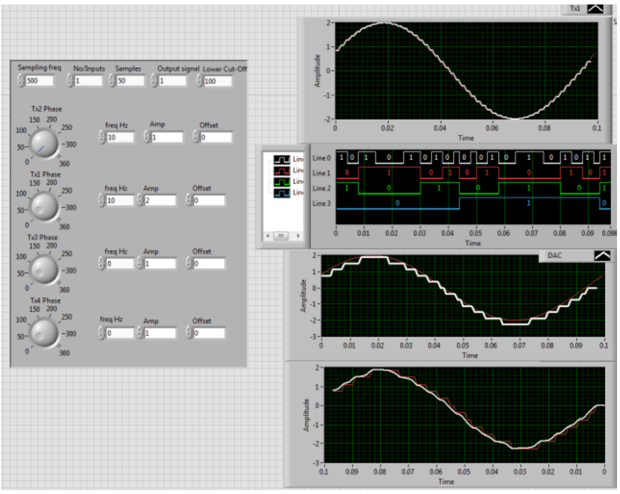

Fig. 3. Quantisation with a 3-bit ADC/DAC

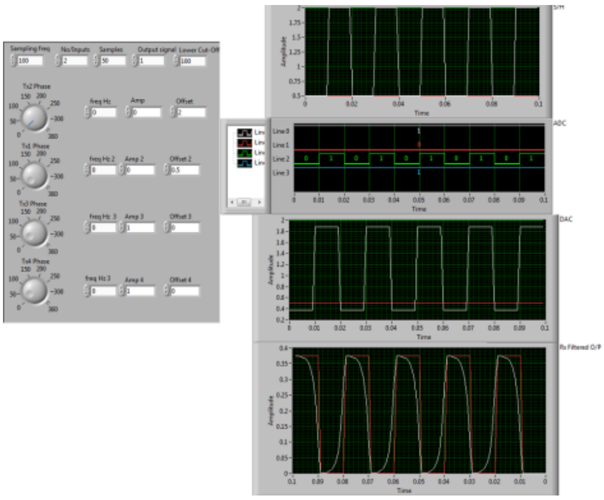

Fig. 4. The TDM Frame Output

The LabVIEW front panels of Figs. 3 to 5 demonstrate the various measurements of the PCM system. Figure 3 shows the system quantization with ADC/DAC resolution of 4-bits and its impact on the system linearity. Figure 4 determines the sampling rate of the ADC by measuring the time interval between the start of two subsequent frames. Figure 5 illustrates the TDM frames of four continuous signals. These experimental results also show the filtered output. All these measurements were compared with the oscilloscope output to study and evaluate the performance of the designed digital system with its analogue counterpart.

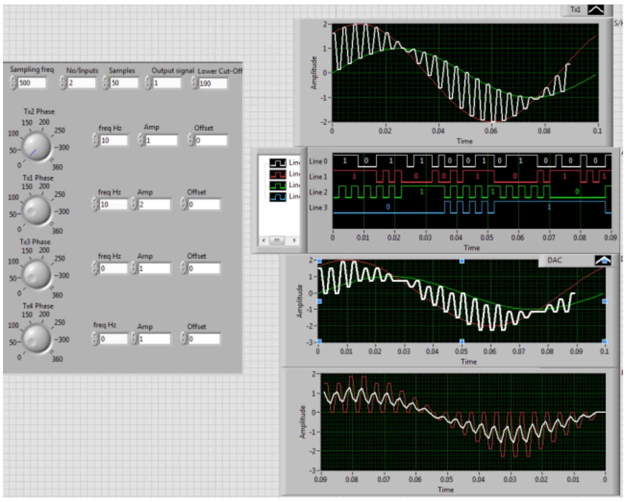

Fig. 5. Sampling of 4-Channel TDM Frame

## IV. REALTIME PCM TRANSMISSION HARDWARE TEST BED

We utilised an integrated ELVIS II and NI digital electronic FPGA board and a data acquisition (DAQ) module for our real-time PCM signal conditioning, measurement and control. The simulated system was designed for both a development computer and a real-time operating system implementation (Fig. 6). It can interface different real-time transducer signals (such as voice using micro-electromechanical system (MEMS) microphone) to test their performance and observe the real-time signal recovery at the receiver front-end. A real-time voice signal was illustrated through the input channels using MEMS microphone. The recovered voice on the receiving side was measured and analysed. The ELVIS II board can also be used to connect various embedded transmission media to test their performance; model external noise absorption; and investigate signal attenuation, delay and security. A dynamic link library was utilised for the advanced analysis of real-time MEMS-based transducer signals.

Fig. 6. NI FPGA DE Board connected to PC and Oscilloscope

## V. RESULTS

Several analyses were carried out to test the developed real-time PCM system. These include system linearity, the dynamic range, filtering, frequency response, and the effects of system's non-linearity on the output signal. Figure 7 shows the linearity analysis of the transmitter and receiver voltages, which can be set through the ADC/DAC quantization property.

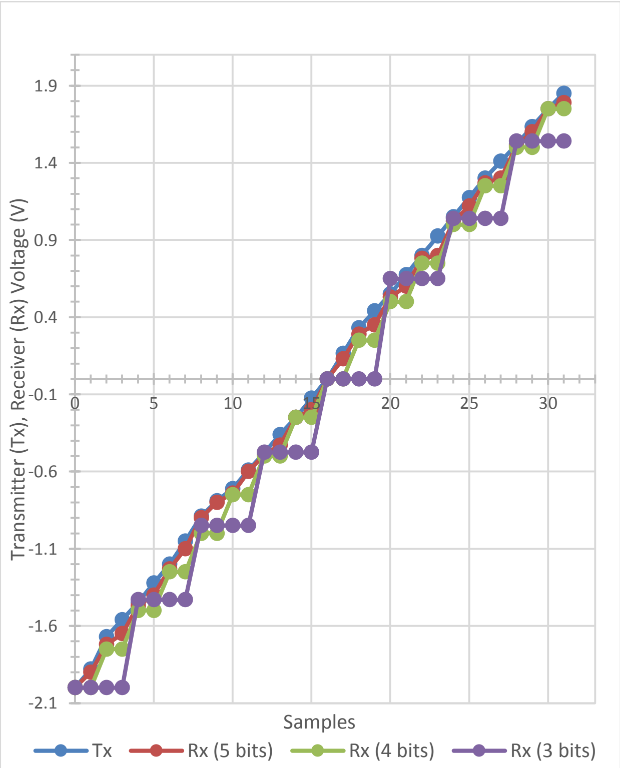


Fig. 7. Linearity analysis of transmitter and receiver voltages

In our test bed analysis, we investigated a range of bit resolutions; Fig. 7 shows a sample for 3-, 4-, and 5-bit resolutions. The smoothness of the recovered signal increases with the signal resolution (Fig. 7). The results indicate that this test bed can be used to carryout various investigations of the smoothness of the recovered signal. Moreover, we used various analogue filter configurations such as Butterworth and Chebyshev with different orders to test the frequency response of our system. Figure 8 illustrates a 2-order Butterworth filter and a 2-order Chebyshev filter. We also used digital filter configuration to test the performance of our test bed.

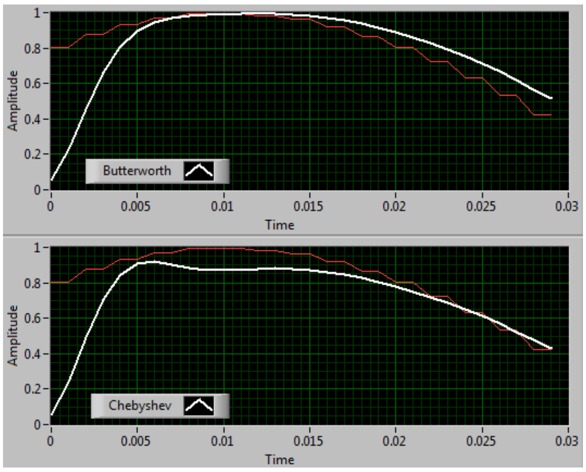


Fig. 8 Butterworth and Chebyshev responses

Figure 8 describes the time-domain response for the Butterworth and Chebyshev filter techniques implemented on our PCM system. In the passband (at 100 Hz), the signal attenuation for the Chebyshev is approximately -18 dB less than the Butterworth response.

## VI. CONCLUSION

This paper presents the design, development and implementation of a real-time multi-channel time division multiplexed PCM telephone system. The experimental setup deployed an integrated embedded NI LabVIEW FPGA platform in the system design and signal analyses. This approach enabled us to implement a circuit-emulating hardware in the loop with other third-party devices and software packages. Hence, educators and learners can design, reconfigure and analyse the processing of simulated and real-life audio signals. This experimental test bed also provides a reliable platform for investigating the performance of a transmission media.

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