Department of Electrical and Electronic Engineering (EEE)
Bangladesh University of Engineering and Technology (BUET)

EEE 310: Communication Laboratory

EXPERIMENT NO: 7
PULSE CODE MODULATION (PCM) ENCODING AND DECODING

OBJECTIVES:

A. Modeling communication systems using Telecommunication Instructional Modeling System (TIMS) Module

B. Demonstration of generation of PCM signals by PCM encoders

C. Demonstration of reconstruction of message signals from PCM signals using PCM decoders

EQUIPMENT:

No.	Equipment	Quantity
1	TIMS Module	1
2	PCM Encoder Module	1
3	PCM Decoder Module	1
4	Adder Module	1
5	LPF Module	1
6	Digital Oscilloscope	1
7	Connecting Cables	---

PRE-LAB READING:

1. What is PCM and what are the three steps in PCM?
2. How can a message be recovered from PCM signal?
3. What is the main difference between uniform and non-uniform quantization?
4. What is the inefficiency of uniform quantization in terms of fixed step size?
5. Why is the non-uniform quantization needed?
6. How can signal generation and recovery be carried out for non-uniform quantization?
7. Read the TIMS manual entry for the PCM Encoder, PCM Decoder, and tuned low-pass filter (TLPF) modules.

BACKGROUND:

A. TIMS

TIMS is a rack and module system (shown in Figure 1), in which each module performs a basic signal processing or communication function. Movable modules can be plugged into any of the identical slots located at the upper part of the rack. They can then be connected with other modules using cables plugged into the front panels to create a variety of systems. Several fixed modules are located in the lower part of the rack. These provide common signals and measurement facilities. Both external oscilloscopes and PCs can be connected for displaying the signals.

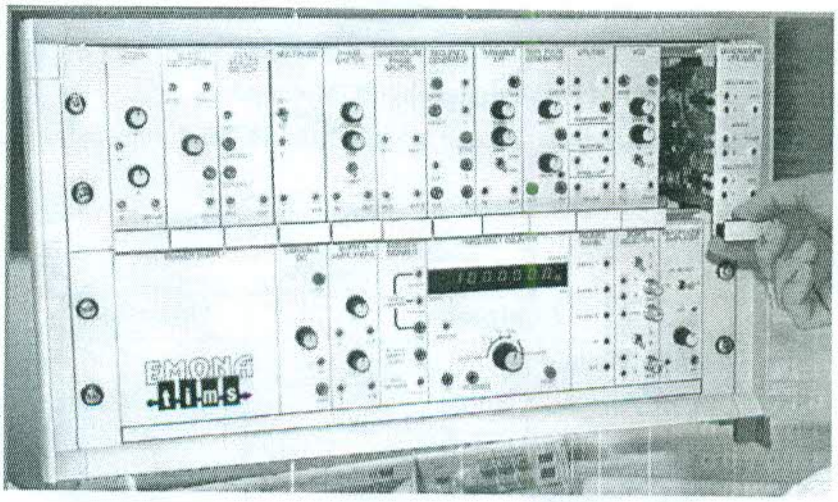

Figure 1: Front view of TIMS

B. PCM Encoding

In the PCM ENCODER, the input analog message is sampled periodically. Each sample amplitude is compared with a finite set of amplitude levels. These are distributed (uniformly, for linear sampling) within the range [-2V, 2V]. These are the system quantizing levels. Each quantizing level is assigned a number, starting from zero for the lowest (most negative) level, with the highest number being (L-1), where L is the available number of levels.

Each sample is assigned a digital (binary) code word representing the number associated with the quantizing level which is closest to the sample amplitude. The number of bits "n" in the digital code word will depend upon the number of quantizing levels. In fact, $n = \log_2(L)$.

The code word is then assembled into a time frame together with an added single extra bit in the least significant bit (LSB) position. This is alternately a one or a zero. These bits are used by the subsequent decoder for frame synchronization (FS). The frames are transmitted serially and the serial bit stream appears at the output of the module. The FS signals the end of each data frame.

C. PCM Decoding

Upon reception, the PCM DECODER extracts a frame synchronisation (FS) signal from the data itself, or uses an FS signal stolen from the transmitter. It then extracts the binary number, which is coded (and quantized) amplitude of the sample. After identifying the quantization level, it generates a voltage proportional to this amplitude level and presents this voltage to the output V_{out} for the duration of the frame under examination. Message reconstruction can be achieved by low-pass filtering.

D. Companding

The PCM ENCODER module can incorporate compression into its encoding scheme. The PCM DECODER module can introduce the complementary expansion. The processes of compression and expansion are combinedly referred to as companding.

E. PCM Time Frame

Each binary word is located in a time frame. The time frame contains eight slots of equal length, and is eight-clock periods long. The slots, from first to last, are numbered from 0 (right most) to 7 (left most). These slots contain the bits of a binary word. The LSB is contained in slot 0.

The LSB consists of alternating ones and zeros. They are used by subsequent decoder to determine the location of each frame in the data stream and its length.

The remaining seven slots are available for the bits of the binary code word. Thus, the system is capable of a resolution of seven-bit maximum. This resolution can be reduced to four bits (by front panel switch). The 4-bit mode uses only five of the available eight slots – one for the embedded FS bits, and the remaining four for the binary code word in slots 4, 3, 2, and 1 as shown in Figure 2.

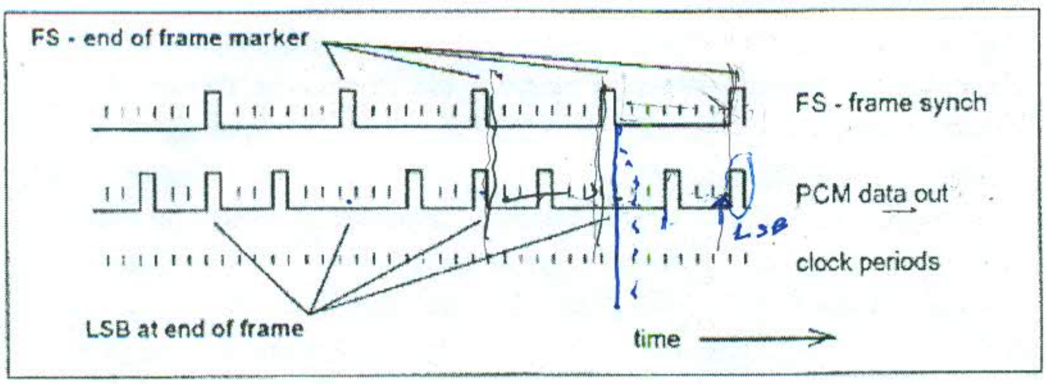

Figure 2: Five frames of 4-bit PCM output for zero amplitude input

PROCEDURE:

The experimental setup is shown in Figure 3.

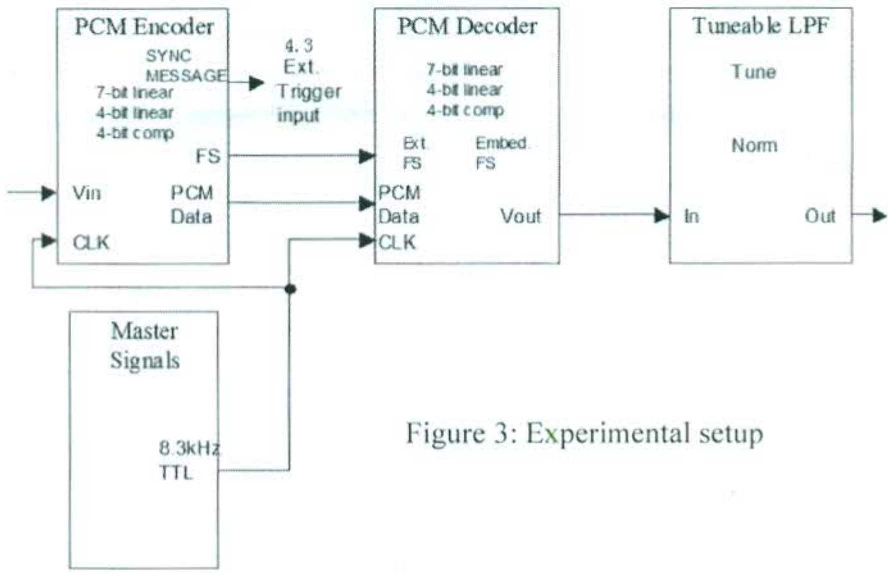

Figure 3: Experimental setup

A. PCM Encoder (Transmitter)

a) Quantization Levels for 4-bit Linear Encoding

1. Using the front panel toggle switch, select the 4-bit LINEAR coding scheme. Use CH1-A and CH2-A to display the frame synchronization signal FS and the PCM data, respectively. Set the Scope sweep speed to show a few frames on the screen, and use the signal FS as the trigger signal to obtain a stable trace. Then, record the measurements.
2. Connect the V_{in} input of the encoder to the output of the VARIABLE DC module. Sweep the DC voltage slowly backwards and forwards over its complete range, and note how the data pattern changes in discrete jumps.
3. Starting with a maximum negative DC value, the corresponding code word is "0000", so only the embedded alternating "0" and "1" bits (for remote FS) in the LSB position should be seen. Slowly increase the amplitude of the DC input signal until there is a sudden change to the PCM output signal format. Record the format of the new digital word in slots 4, 3, 2, and 1, and the input amplitude at which the change occurred. Continue this process over the full range of the DC supply. Draw a diagram showing the quantizing levels (voltage) along the *x*-axis and their associated binary numbers (i.e., decimal equivalent) along the *y*-axis. When finished, return the DC to its maximum negative value (control fully anti-clockwise).
4. From the measurements, determine the sampling rate, frame width, ~~frame~~ width of a data bit, width of a data word and the number of quantizing levels. Are the quantizing levels uniformly (linearly) spaced?

b) 7-bit Linear Encoding

5. Change to 7-bit linear encoding by use of the front panel toggle switch. Make sufficient measurements so that you can answer all of the questions in the 4-bit linear.

c) Companding

6. The PCM encoder is to be used in conjunction with the PCM decoder. As a pair they have a companding option. There is compression in the encoder, and expansion in the decoder. In the encoder this means the quantizing levels are closer together for small input amplitudes – that is, in effect, that the input amplitude peaks are compressed during encoding. At the decoder the "reverse action" is introduced to restore an approximate linear input/output characteristic.

7. Make the necessary measurements to determine the characteristics of the 4-bit companding used in the module. To do this, using the front panel toggle switch, select the 4-bit companding coding scheme. Then, repeat procedures (1)-(4) and answer all the questions.

B. PCM Decoding (Receiver)

8. Use the front panel toggle switch to select the 4-bit LINEAR for both encoding and decoding modules. Ensure that the FS SELECT toggle switch on the receiver is set to EXT.FS.

9. Use CH1-A and CH2-A to display the PCM encoder output and the sample-and-hold output V_{out} of the PCM decoder, respectively.

10. Slowly vary the DC output from the VARIABLE DC module back and forth over its complete range. Observe the behaviour of the two traces. The input to the encoder moves continuously. The output from the decoder moves in discrete steps. These are the 16 amplitude-quantizing steps of the PCM ENCODER. Draw up a table relating input to output voltages.

11. Reset the coding scheme on both modules to 7-bit. Sweep the input DC signal over the complete range as before. Notice the "granularity" in the output is almost un-noticeable compared with the 4-bit case. There are now $2^7 = 128$ rather than 24 steps over the range.

12. Repeat procedures (8)-(10) using 4-bit companding coding scheme.

C. Periodic Message and its Reconstruction

13. Remove the DC signal from the input V_{in} of PCM encoder and connect the SYNC MESSAGE of the PCM encoder to an ADDER input. Adjust the gain of this ADDER to have an amplitude of 2 $V_{p\text{-}p}$ from its output. Use this SYNC MESSAGE for external

triggering, instead of FS. Slow down the oscilloscope sweep speed to 1 ms/cm. Observe and record the FS signal.

14. Low-pass filtering of the waveform at the output of the decoder will reconstruct the message, although theory shows that it will not be perfect. It will improve with the number of quantizing levels. In this experiment, select normal position and turn the tune control of the TLPF to a fully anti-clockwise position to reduce its cut-off frequency to a minimum.
15. Use the front panel toggle switches (on both modules) to select 4-bit LINEAR. Obtain the PCM Decoder output, quantizing characteristic, and reconstructed message from the TLPF output. Use the FFT feature of the oscilloscope to obtain the spectra of the original message, PCM Decoder output and reconstructed message for this coding scheme. Record your observations and comment upon them.
16. Change the front panel toggle switch of both the PCM Encoder and the PCM Decoder from 4-bit to 7-bit and then to 4-bit companding. Similar to 4-bit LINEAR coding, repeat the procedure (13) – (16) and explain the change to the waveform of the PCM Decoder output and TLPF output for each of these two coding schemes.
17. Make a comparison between the 4-bit linear, 7-bit linear, and 4-bit companding coding schemes. Give your reasons for the distortion (if any) of the recovered message.

REPORT:

1. Answer all the questions asked throughout the procedure.

2. Given an audio signal with spectral components in the frequency band 300 to 3000Hz, assume that a sampling rate of 8 kHz will be used to generate a PCM signal. Design an appropriate PCM system, as follows.

(a) Draw a block diagram of a PCM system including the transmitter, channel, and receiver.

(b) Specify the number of uniform quantization levels needed and the zero-crossing channel bandwidth required, assuming that the peak signal-to-noise ratio (SNR) at the receiver output needs to be at least 30 dB and the polar NRZ signaling is used.

(c) Discuss how non-uniform quantization can be used to improve the performance.

Hint: SNR (dB) = $6.02n + 4.77$, where n is the number of bits in the PCM word.

Reference: Communication Systems (5^{th} edition) – S. Haykin and M. Moher