Experiment 12 – PCM encoding

Preliminary discussion

As you know, digital transmission systems are steadily replacing analog systems in commercial communications applications. This is especially true in telecommunications. That being the case, an understanding of digital transmission systems is crucial for technical people in the communications and telecommunications industries. The remaining experiments in this book use the Emona Telecoms-Trainer 101 to introduce you to several of these systems starting with *pulse code modulation* (PCM).

PCM is a system for converting analog message signals to a serial stream of 0s and 1s. The conversion process is called *encoding*. At its simplest, encoding involves:

- Sampling the analog signal's voltage at regular intervals using a sample-and-hold scheme (demonstrated in Experiment 11).
- Comparing each sample to a set of reference voltages called *quantisation levels*.
- Deciding which quantisation level the sampled voltage is closest to.
- Generating the binary number for that quantisation level.
- Outputting the binary number one bit at a time (that is, in serial form).
- Taking the next sample and repeating the process.

An issue that is crucial to the performance of the PCM system is the encoder's clock frequency. The clock tells the PCM encoder when to sample and, as the previous experiment shows, this must be at least twice the message frequency to avoid aliasing (or, if the message contains more than one sinewave, at least twice its highest frequency).

Another important PCM performance issue relates to the difference between the sample voltage and the quantisation levels that it is compared to. To explain, most sampled voltages will not be the same as any of the quantisation levels. As mentioned above, the PCM Encoder assigns to the sample the quantisation level that is closest to it. However, in the process, the original sample's value is lost and the difference is known as *quantisation error*. Importantly, the error is reproduced when the PCM data is decoded by the receiver because there is no way for the receiver to know what the original sample voltage was. The size of the error is affected by the number of quantisation levels. The more quantisation levels there are (for a given range of sample voltages) the closer they are together and the smaller the difference between them and the samples.

A little information about the PCM Encoder module on the Emona Telecoms-Trainer 101
The PCM Encoder module uses a PCM encoding and decoding chip (called a *codec*) to convert analog voltages between -2V and +2V to an 8-bit binary number. With eight bits, it's possible to produce 256 different numbers between 00000000 and 11111111 inclusive. This in turn means that there are 256 quantisation levels (one for each number).

Each binary number is transmitted in serial form in *frames*. The number's most significant bit (called bit-7) is sent first, bit-6 is sent next and so on to the least significant bit (bit-0). The PCM Encoder module also outputs a separate *Frame Synchronisation* signal (*FS*) that goes high at the same time that bit-0 is outputted. The *FS* signal has been included to help with PCM decoding (discussed in the preliminary discussion of Experiment 13) but it can also be used to help "trigger" a scope when looking at the signals that the PCM Encoder module generates.

Figure 1 below shows an example of three frames of a PCM Encoder module's output data (each bit is shown as both a 0 and a 1 because it could be either) together with its clock input and its *FS* output.

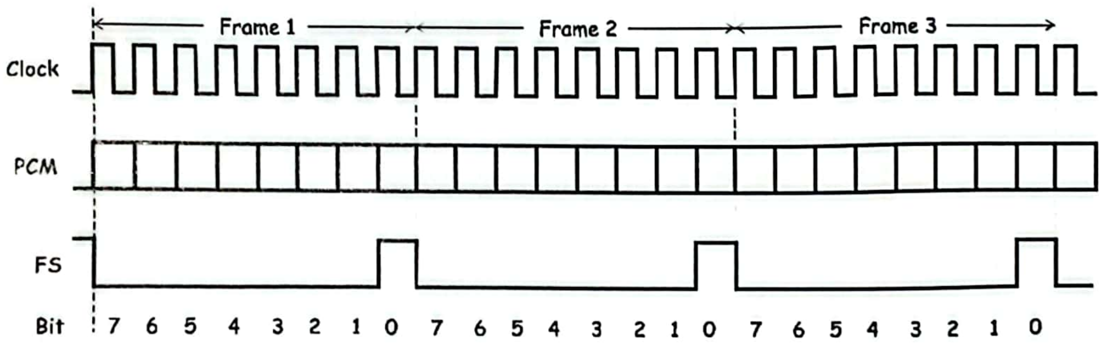

Figure 1

The experiment
In this experiment you'll use the PCM Encoder module on the Emona Telecoms-Trainer 101 to convert the following to PCM: a fixed DC voltage, a variable DC voltage and a continuously changing signal. In the process, you'll verify the operation of PCM encoding and investigate quantisation error a little.

It should take you about 1 hour to complete this experiment.

Equipment

- Emona Telecoms-Trainer 101 (plus power-pack)
- Dual channel 20MHz oscilloscope
- three Emona Telecoms-Trainer 101 oscilloscope leads
- assorted Emona Telecoms-Trainer 101 patch leads

Procedure

Part A – An introduction to PCM encoding using a static DC voltage

1. Gather a set of the equipment listed above.

2. Set up the scope per the instructions in Experiment 1. Ensure that:

   - the *Trigger Source* control is set to the *CH1* (or *INT*) position.
   - the *Mode* control is set to the *CH1* position.

3. Locate the PCM Encoder module and set its *Mode* switch to the *PCM* position.

4. Connect the set-up shown in Figure 2 below.

   Note: Insert the black plugs of the oscilloscope leads into a ground (*GND*) socket.

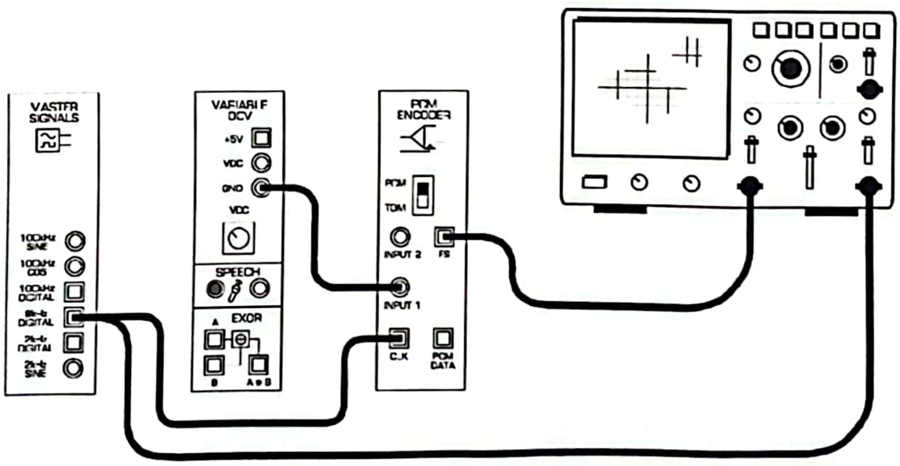

Figure 2

The set-up in Figure 2 can be represented by the block diagram in Figure 3 below. The PCM Encoder module is clocked by the Master Signals module's *8kHz DIGITAL* output. Its analog input is connected to 0V DC.

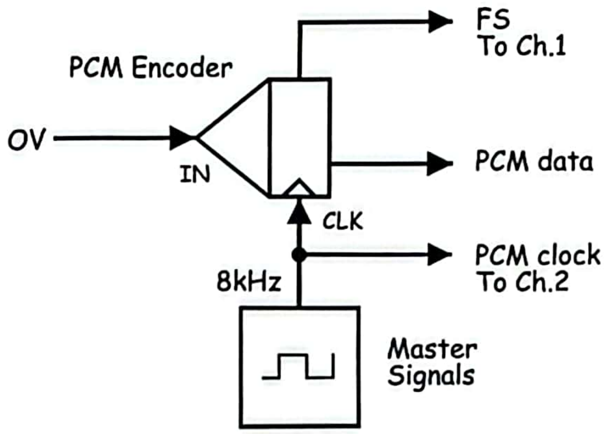

Figure 3

5. Adjust the scope's *Timebase* control to view three pulses of the PCM Encoder module's *FS* output.

6. Set the scope's *Slope* control to the "-" position.

Setting the *Slope* control to the "-" position makes the scope start its sweep across the screen when the *FS* signal goes from high to low instead of low to high. You can really notice the difference between the two settings if you flip the scope's *Slope* control back and forth. If you do this, make sure that the *Slope* control finishes on the "-" position.

7. Adjust the scope's *Horizontal Position* control so that the start of the trace aligns with the left-most vertical line on the screen.

8. Set the scope's *Timebase* control to the *0.1ms/div* position.

9. Adjust the scope's *Variable Sweep* control until the *FS* signal looks like the signal in Figure 4.

   Note: This control is called different things on different scopes. If you can't find it or if you're not sure you have the right control, ask the instructor for assistance.

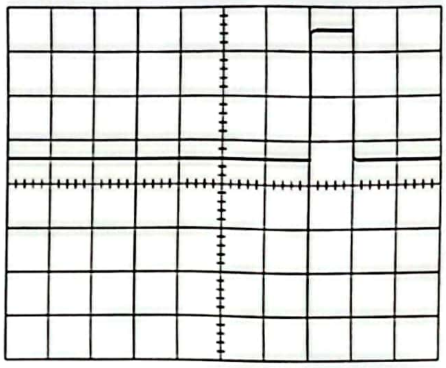

Figure 4

Adjusting this scope's control in this way will make it easier for you to draw the waveforms that you'll be asked to shortly. However, you should be aware that the screen's horizontal divisions are no-longer equal to the *Timebase* control's setting. In other words, the scope's *Timebase* is no-longer calibrated. This is a problem when measuring the period of signals and so you must return the control to its locked position at the end of the experiment.

10. Set the scope's *Mode* control to the *DUAL* position to view the PCM Encoder module's *CLK* input as well as its *FS* output.

11. Draw the two waveforms to scale in the space provided on page 12-8 leaving enough room for a third digital signal.

    Tip: Draw the clock signal in the upper third of the graph paper and the *FS* signal in the middle third.

Ask the instructor to check your work before continuing.

12. Connect the scope's Channel 2 input to the PCM Encoder module's output as shown in Figure 5 below.

Remember: Dotted lines show leads already in place.

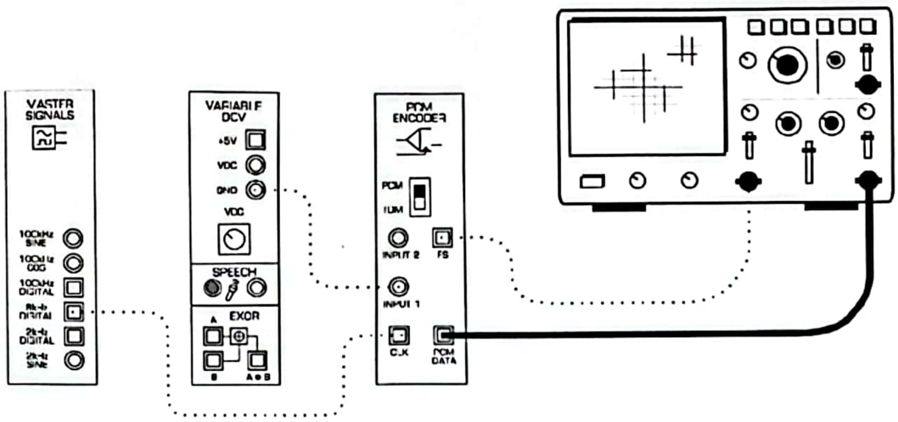

Figure 5

This set-up can be represented by the block diagram in Figure 6 below. Channel 2 should now display 10 bits of the PCM Encoder module's data output. The first 8 bits belong to one frame and the last two bits belong to the next frame.

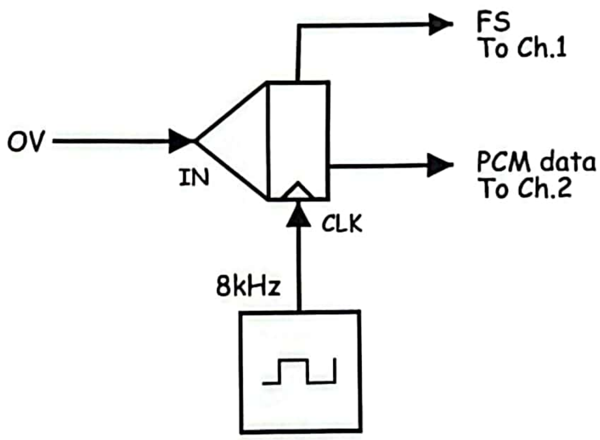

Figure 6

13. Draw this waveform to scale in the space that you left on the graph paper.

Tip: If you're having trouble triggering the CRO set its *Trigger Source Coupling* control to the *HF REJ* position.

Ask the instructor to check your work before continuing.

Question 1
Indicate on your drawing the start and end of the frame. **Tip:** If you're not sure where these points are, see the preliminary discussion.

Question 2
Indicate on your drawing the start and end of each bit.

Question 3
Indicate on your drawing which bit is bit-0 and which is bit-7.

Question 4
What is the binary number that the PCM Encoder module is outputting?

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Question 5
Why does the code change even though the input voltage is steady?

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Question 6
Why does the PCM Encoder module output this code for 0V DC and not 0000000?

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☑ Ask the instructor to check your work before continuing.

Part B - PCM encoding of a variable DC voltage

So far, you have used the PCM Encoder module to convert a fixed DC voltage (0V) to PCM. The next part of the experiment lets you see what happens when you vary the DC voltage.

14. Set the scope's *Mode* control to the *CH1* position.

15. Set the scope's *Trigger Source* control to the *EXT* position.

16. Set the scope's *Trigger Source Coupling* control to the *HF REJ* position.

17. Modify the set-up as shown in Figure 7 below.

    Note: Notice that a third input on the scope is being used. This input is usually labelled *EXT* or *EXTERNAL* but its position varies from one scope to another. If you can't find it, ask the instructor for help.

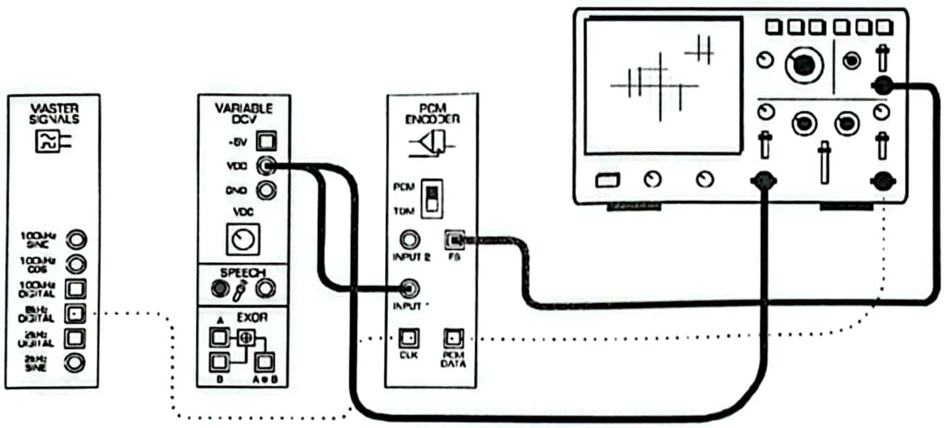

Figure 7

This set-up can be represented by the block diagram in Figure 8 on the next page. The Variable DCV module is used to let you change the DC voltage on the PCM Encoder module's input. The scope's external trigger input is used so that you can view the DC voltage on its *Channel 1* input as a stable display.

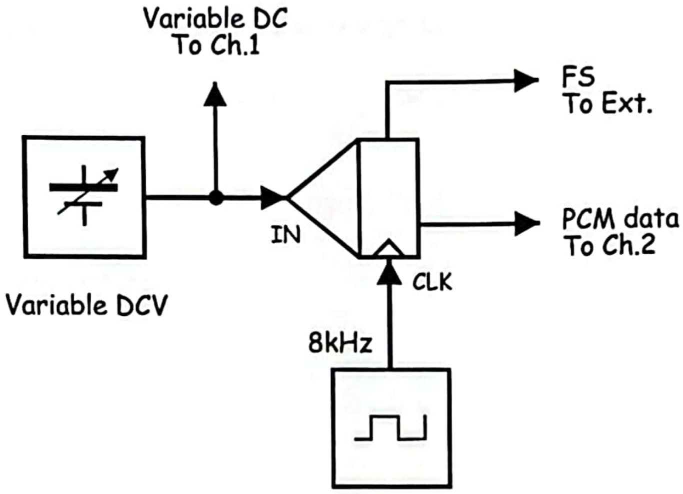

Figure 8

18. Set the scope's Channel 1 *Vertical Attenuation* control to the *1V/div* position.

19. Set the scope's Channel 1 *Input Coupling* control to the *GND* position.

20. Use the scope's Channel 1 *Vertical Position* control to align the Channel 1 trace with one of the horizontal lines on the scope's screen.

    Note: This line on the scope's screen is now your zero volt reference which you can use to see whether the Variable DCV module's output is positive or negative.

21. Set the scope's Channel 1 and Channel 2 *Input Coupling* controls to the *DC* position.

22. Set the scope's *Mode* control to the *DUAL* position.

23. Adjust the Variable DCV module's *Variable DC* control until the PCM Encoder module outputs the code that you drew earlier.

24. Use the scope to measure the Variable DCV module's output voltage.

    Note: It should be very close to 0V.

Ask the instructor to check your work before continuing.

25. Turn the Variable DCV module's *Variable DC* control clockwise while watching the scope's display.

Question 7
What happens to the Variable DCV module's output?

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Question 8
In what way does the binary number that the PCM Encoder module outputs change?

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Ask the instructor to check your work before continuing.

26. Continue to turn the Variable DCV module's *Variable DC* control clockwise and stop the moment the PCM Encoder module's output is 11111111.

27. Use the scope to measure the Variable DCV module's output voltage. Record your measurement in Table 1 on the next page.

28. Return the PCM Encoder module's output to the code for 0V.

29. Turn the Variable DCV module's *Variable DC* control anti-clockwise while watching the scope's display.

Question 9
What happens to the Variable DCV module's output?

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Question 10
What happens to the binary number that the PCM Encoder module is outputting?

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30. Continue to turn the Variable DCV module's *Variable DC* control anti-clockwise and stop the moment the PCM Encoder module's output is 00000000.

31. Measure and record the Variable DCV module's output voltage.

Table 1

PCM Encoder's output code	PCM Encoder's input voltage
11111111	
00000000	

Question 11
Based on the information in Table 1, what is the maximum allowable amplitude (peak-to-peak) for an AC signal on the PCM Encoder module's *INPUT*?

Ask the instructor to check your work before continuing.

Part C – Quantisation

This next part of the experiment lets you investigate quantisation.

32. Return the Variable DCV module's *Variable DC* control to about the middle of its travel.

33. See if you can vary the *Variable DC* control left and right without causing the output code to change.

The sampled voltage can be changed without causing the output code to change because it is compared to a set of quantisation levels but there are a finite number of them. This means that, in practice, there's a range of sample voltages for each quantisation level.

Question 12
What's the name for the difference between a sampled voltage and its closest quantisation level? **Tip:** If you're not sure, see the preliminary discussion.

It's possible to work how far apart a PCM encoder's quantisation levels are using the information you've gathered so far. To do so, answer the following question.

Question 13
Calculate the difference between the quantisation levels in the PCM Encoder module by subtracting the values in Table 1 and dividing the number by 256 (the number of codes).

Question 14
To reduce quantisation error it's better to have

- ☐ fewer quantisation levels between ±2V.
- ☐ more quantisation levels between ±2V.

Ask the instructor to check
your work before continuing.

Part D – PCM encoding of continuously changing voltages

Now let's see what happens when the PCM encoder is used to convert continuously changing signals like a sinewave.

34. Return the scope's *Trigger Source* control to the *CH1* (or *INT*) position.

35. Return the scope's *Trigger Source Coupling* control to the *AC* position.

36. Set the scope's Channel 1 and Channel 2 *Vertical Attenuation* controls to the *2V/div* position.

37. Locate the VCO module and set its *Range* control to the *HI* position.

38. Turn the VCO module's *Frequency Adjust* control fully anti-clockwise.

    Note: The VCO module will be used to provide the PCM Encoder module with a 50kHz (approx) clock.

39. Disassemble the current set-up.

40. Connect the set-up as shown in Figure 9 below.

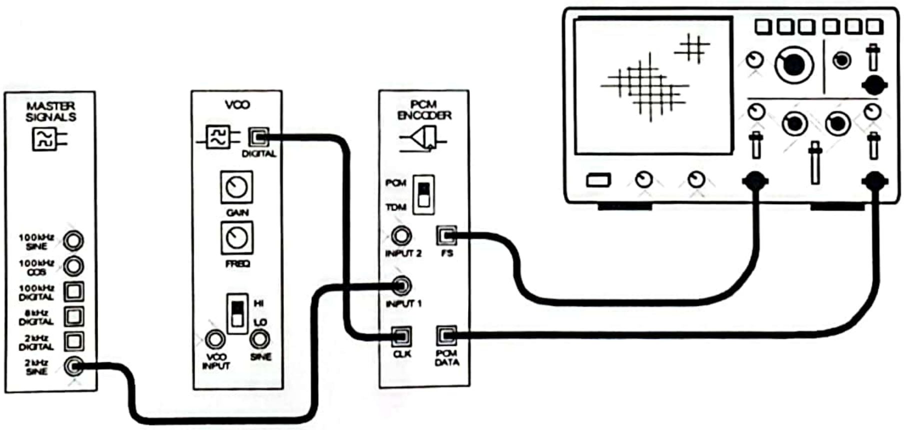

Figure 9

41. Set the scope's *Timebase* control to the *50μs/div* position.

42. Watch the PCM Encoder module's *PCM DATA* output on the scope's display.

Question 15
Why does the PCM DATA change continuously?

Ask the instructor to check your work before continuing.

43. Return the scope's *Variable Sweep* control to the detent (locked) position.

Ask the instructor to check your work before finishing.