PCM - ENCODING

modules

basic: none

advanced: PCM ENCODER

optional advanced: WIDEBAND TRUE RMS METER

preparation

The purpose of this experiment is to introduce the PCM ENCODER module. This module generates a pulse code modulated - PCM - output signal from an analog input message.

Please refer to the ***TIMS Advanced Modules User Manual*** for complete details of the operation of this module.

In this experiment the module will be used in isolation; that is, it will not be part of a larger system. The formatting of a PCM signal will be examined in the time domain.

The Lab Sheet, entitled ***PCM - decoding***, will illustrate the recovery of the analog message from the digital signal.

PCM encoding

The input to the PCM ENCODER module is an analog message. This must be constrained to a defined bandwidth and amplitude range.

The maximum allowable message bandwidth will depend upon the sampling rate to be used. The Nyquist criterion must be observed.

The message amplitude must be held within the range of the TIMS ANALOG REFERENCE LEVEL of ±2 volts peak. This is in keeping with the input amplitude limits set for all analog modules.

A step-by-step description of the operation of the module follows:

1. the module is driven by an external TTL clock.
2. the input analog message is *sampled* periodically. The *sample rate* is a sub-multiple of the external clock.
3. the sampling is a *sample-and-hold* operation. It is internal to the module, and cannot be viewed by the user [1]. What is held is the *amplitude* of the analog message *at the sampling instant.*
4. each sample amplitude is compared with a finite set of amplitude levels. These are distributed (uniformly, for *linear* sampling) within the TIMS ANALOG REFERENCE LEVEL. These are the system *quantizing* levels.

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[1] the *sample and hold* operation is examined separately in the Lab Sheet entitled ***Sampling with SAMPLE & HOLD***.

5. 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.
6. 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, $n = \log_2(L)$.
7. the code word is *assembled into a time frame* together with other bits as may be required (described below). In the TIMS PCM ENCODER (and many commercial systems) a single extra bit is added, in the least significant bit position. This is alternately a *one* or a *zero*. These bits are used by subsequent decoders for frame synchronization.
8. the *frames* are transmitted serially. They are transmitted at the same rate as the samples are taken. The serial bit stream appears at the output of the module.
9. also available from the module is a synchronizing signal FS ('frame synch'). This signals the *end* of each data frame.

the TIMS 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 7 through 0. These slots contain the bits of a binary word. The least significant bit (LSB) is contained in slot 0.

The LSB consists of alternating *ones* and *zeros*. These are placed ('embedded') in the frame by the encoder itself, and cannot be modified by the user. They are used by subsequent decoders to determine the location of each frame in the data stream, and its length. See the Lab Sheet entitled ***PCM - decoding***.

The remaining seven slots are available for the bits of the binary code word. Thus the system is capable of a resolution of seven-bits maximum. This resolution, for purposes of experiment, 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 frame synchronization bits, and the remaining four for the binary code word (in slots 4, 3, 2, and 1).

The only module required for this experiment is a TIMS PCM ENCODER.

Operation as a single channel PCM encoder is examined in this experiment. Operation as part of a two-channel PCM-TDM system will not be investigated here. See the Lab Sheet entitled ***PCM - TDM***.

experiment

1. select the TIMS companding A_4-law with the on-board COMP jumper (in preparation for a later part of the experiment).
2. locate the on-board switch SW2. Put the LEFT HAND toggle DOWN and the RIGHT HAND toggle UP. This sets the frequency of a message from the module at SYNC. MESSAGE. This message is synchronized to a sub-multiple of the MASTER CLOCK frequency. For more detail see the ***TIMS Advanced Modules User Manual***
3. use the 8.333 kHz TTL SAMPLE CLOCK as the PCM CLK
4. select the 4-bit encoding scheme
5. switch the front panel toggle switch to 4-BIT LINEAR (ie., no companding).
6. connect the V_{in} input socket to ground of the variable DC module.
7. connect the frame synchronization signal FS to the oscilloscope ext. synch. input.
8. start with a DC message. This gives stable displays and enables easy identification of the quantizing levels.

9. on CH1-A display the frame synchronization signal FS. Adjust the sweep speed to show three frame markers. These mark the **end** of each frame.
10. on CH2-A display the CLK signal.
11. record the number of clock periods per frame.

Currently the analog input signal is zero volts (V_{in} is grounded). Before checking with the oscilloscope, consider what the PCM output signal might look like when the DC input level is changed. Make a sketch of this signal, fully annotated. Then:

12. on CH2-B display the PCM DATA from the PCM DATA output socket.

Except for the alternating pattern of '1' and '0' in the frame marker slot, you might have expected nothing else in the frame (all zeros), because the input analog signal is at zero volts. But you do not know the coding scheme.

There *is* an analog *input* signal to the encoder. It is of zero volts. This will have been coded into a 4-bit binary *output* number, which will appear in *each* frame. It need not be '0000'. The *same* number appears in *each* frame because the analog input is *constant*.

The display should be similar to that of Figure 3 below, except that this shows five frames (too many frames on the oscilloscope display makes bit identification more difficult).

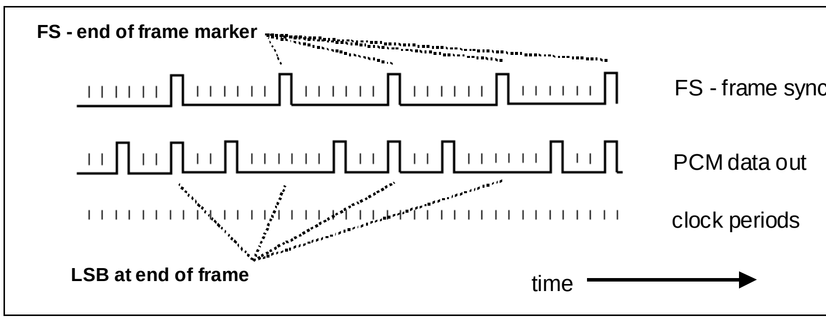

Figure 3: 5 frames of 4-bit PCM output for zero amplitude input

Knowing:

- the number of slots per frame is 8
- the location of the least significant bit is coincident with the end of the frame
- the binary word length is four bits
- the first three slots are 'empty' (in fact filled with zeros, but these remain unchanged under all conditions of the 4-bit coding scheme)

then:

13. identify the binary word in slots 4, 3, 2, and 1.

quantizing levels for 4-bit linear encoding

14. remove the ground connection, and connect the output of the VARIABLE DC module to V_{in}. Sweep the DC voltage slowly backwards and forwards over its complete range, and note how the data pattern changes in discrete jumps.

15. if a WIDEBAND TRUE RMS METER module is available use this to monitor the DC amplitude at V_{in} - otherwise use the oscilloscope (CH1-B). Adjust V_{in} to its maximum negative value. Record the DC voltage and the pattern of the 4-bit binary number.
16. 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, and the input amplitude at which the change occurred.
17. continue this process over the full range of the DC supply.
18. draw a diagram showing the quantizing levels and their associated binary numbers.

4-bit data format

From measurements made so far it should be possible to answer the following:

- what is the sampling rate ?
- what is the frame width ?
- what is the width of a data bit ?
- what is the width of a data word ?
- how many quantizing levels are there ?
- are the quantizing levels uniformly (linearly) spaced ?

7-bit linear encoding

It would take a long time to repeat all of the above Tasks for the 7-bit encoding scheme. Instead:

companding

This module is to be used in conjunction with the PCM DECODER in a later Lab Sheet. 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.

It can be shown that this sort of characteristic offers certain advantages, especially when the message has a high peak-to-average amplitude characteristic, as does speech, and where the signal-to-noise ratio is not high.

This improvement will not be checked in this experiment. But the existence of the non-linear quantization in the encoder will be confirmed.

In a later Lab Sheet, entitled ***PCM - decoding***, it will be possible to check the input/output linearity of the modules as a compatible pair.

periodic messages

Although the experiment is substantially complete, you may have wondered why a periodic message was not chosen at any time. Try it.

You will see that the data signal reveals very little. It consists of many overlaid digital words, all different.

One would need more sophisticated equipment than is assumed here (a digital analyzer, a storage oscilloscope, ability to capture a single frame, and so on) to deduce the coding and quantizing scheme from such an input signal.