PREPARATION

1- Digital Messages

In analog work the standard test message is the sine wave, followed by the two-tone signal for more rigorous tests. The property being optimized is generally signal-to-noise ratio (SNR). Speech is interesting, but does not lend itself easily to mathematical analysis or measurement.

In digital work a binary sequence, with a known pattern of ‘1’ and ‘0’, is common. It is more common to measure bit error rates (BER) than SNR, and this is simplified by the fact that known binary sequences are easy to generate and reproduce.

A common sequence is the pseudo random binary sequence.

Pseudo random binary sequences

The output from a pseudo random binary sequence generator is a bit stream of binary pulses; i.e., a sequence of 1`s or 0`s of a *known* and *reproducible* pattern.

The bit *rat*e, or number of bits per second, is determined by the frequency of an external *cloc*k, which is used to drive the generator. For each clock period a single bit is emitted from the generator; either at the ‘1’ or ‘0’ level, and of a single bit is emitted from the generator; either at the ‘1’ or ‘0’ level, and of a width equal to the clock period. For this reason the external clock is referred to as a *bit cloc*k.

For a long sequence the 1`s and 0`s are distributed in a (pseudo) random manner. The sequence pattern *repeats* after a defined number of clock periods. In a typical generator the *length* of the sequence may be set to 2^n clock periods, where n is an integer. In the TIMS SEQUENCE GENERATOR (which provides two, independent sequences, X and Y) the value of n may be switched to one of three values, namely 5, 8, or 11. There are *two* switch positions for the case n = 8, giving different patterns. The SYNCH output provides a reference pulse generated once per sequence repetition period.

This is *the start-of-sequence* pulse. It is *invaluable as a trigger source* for an oscilloscope.

Applications

One important application of the PRBS is for supplying a known binary sequence. This is used as a test signal (message) when making bit error rate (BER) measurements.

For this purpose a perfect *copy* of the *transmitted* sequence is required at the receiver, for direct comparison with the *received* sequence. This perfect copy is obtained from a second, identical, PRBS generator.

The second generator requires:

1. Bit clock information, so that it runs at the same rate as the first
2. A method of aligning its output sequence with the received sequence. Due to transmission through a bandlimited channel, it will be delayed in time with respect to the sequence at the transmitter.

In a laboratory environment it is a simple matter to use a 'stolen carrier' for bit clock synchronization purposes, and this will be done in most TIMS experiments. In commercial practice this bit clock must be regenerated from the received signal.

Viewing

There are two important methods of viewing a sequence in the time domain.

A- Snapshot

A short section, about 16 clock periods of a TTL sequence, is illustrated in Figure 1 below.

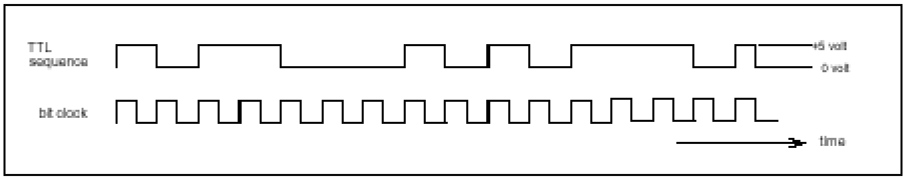


Figure 1: A sequence of length 16 bits

Suppose the output of the generator which produced the TTL sequence, of which this is a part, was viewed with an oscilloscope, with the horizontal sweep triggered by the display itself.

The display will not be that of Figure 1 above! Of course not, for how would the oscilloscope know which section of the display was wanted?

Consider just what the oscilloscope might show!

Specific sections of a sequence *can* be displayed on a general purpose oscilloscope, but the sequence generator needs to provide some help to do this.

As stated above, it gives a *start-of-sequence* pulse at the *beginning* of the sequence. This can be used to *start* (trigger) the oscilloscope sweep. At the end of the sweep the oscilloscope will wait until the next start-of-sequence is received before being triggered to give the next sweep.

Thus the beginning ‘n’ bits of the sequence are displayed, where ‘n’ is determined by the sweep speed.

For a sequence length of many-times-n bits, there would be a long delay between sweeps. The persistence of the screen of a general purpose oscilloscope would be too short to show a steady display, so it will blink. You will see the effect during the experiment.

B- Eye pattern

A long sequence is useful for examining ‘eye patterns’. These are defined and examined in this experiment but for understanding it you must first become familiar with some basic theory underlying in pulse transmission in bandlimited channels.

2- Pulse transmission

It is well known that, when a signal passes via a bandlimited channel it will suffer waveform distortion. As an example, refer to Figure 2. As the data rate increases the waveform distortion increases, until transmission becomes impossible.

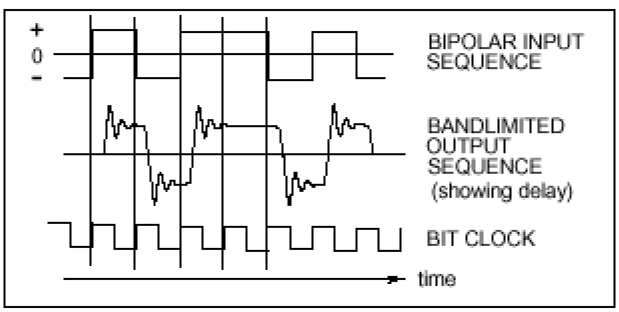


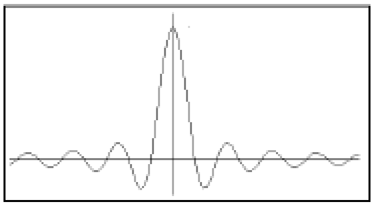
Figure 2: Waveforms before and after moderate bandlimiting

In this experiment you will be introduced to some important aspects of pulse transmission which are relevant to digital and data communication applications.

Issues of interest include:

- In the 1920s Harry Nyquist proposed a clever method now known as Nyquist`s first criterion, that makes possible the transmission of telegraphic signals over channels with limited bandwidth without degrading signal quality. This idea has withstood the test of time. It is very useful for digital and data communications.

The method relies on the exploitation of pulses that look like sin(x)/x - see the following Figure. The trick is that zero crossings always fall at equally spaced points. Pulses of this type are known as 'Nyquist I' (there is also Nyquist II and III).



- In practical communication channels distortion causes the dislocation of the zero crossings of Nyquist pulses, and results in *intersymbol interference* (ISI). Eye patterns provide a practical and very convenient method of assessing the extent of ISI degradation. A major advantage of eye patterns is that they can be used 'on-line' in real-time. There is no need to interrupt normal system operation.

- The effect of ISI becomes apparent at the receiver when the incoming signal has to be 'read' and decoded; i.e., a detector decides whether the value at a certain time instant is, say, '0' or '1' (in a binary decision situation). A decision error may occur as a result of noise. Even though ISI may not itself cause an error in the absence of noise, it is nevertheless undesirable because it decreases the margin relative to the decision threshold, i.e., a given level of noise that may be harmless in the absence if ISI, may lead to a high error rate when ISI is present.

- Another issue of importance in the decision process is *timing jitte*r. Even if there is no ISI at the nominal decision instant, timing jitter in the reconstituted bit clock results in decisions being made too early or too late relative to the ideal point. As you will discover in this experiment, channels that are highly bandwidth efficient are more sensitive to timing jitter.

3- Line Coding

In your course work you should have covered the topic of line coding at whatever level is appropriate for you. TIMS has a pair of modules, one of which can perform a number of line code transformations on a binary TTL sequence. The other performs decoding.

There are many reasons for using line coding. Each of the line codes you will be examining offers one or more of the following advantages:

1. *Spectrum shaping* and relocation without modulation or filtering. This is important in telephone line applications, for example, where the transfer characteristic has heavy attenuation below 300 Hz.
2. *Bit clock recovery* can be simplified.
3. *DC component* can be eliminated; this allows AC (capacitor or transformer) coupling between stages (as in telephone lines). Can control baseline wander (baseline wander shifts the position of the signal waveform relative to the detector threshold and leads to severe erosion of noise margin).
4. *Error detection* capabilities.
5. *Bandwidth usag*e; the possibility of transmitting at a higher rate than other schemes over the same bandwidth.

At the very least the LINE-CODE ENCODER serves as an interface between the TTL level signals of the transmitter and those of the analog channel. Likewise, the LINE-CODE DECODER serves as an interface between the analog signals of the channel and the TTL level signals required by the digital receiver.

TIMS Line Coding/Decoding modules

The two new modules to be introduced are the LINE-CODE ENCODER and the LINE-CODE DECODER.

You will not be concerned with how the coding and decoding is performed.

You should examine the waveforms, using the original TTL sequence as a reference.

In a digital transmission system line encoding is the final digital processing performed on the signal before it is connected to the analog channel, although there may be simultaneous bandlimiting and wave shaping.

Thus in TIMS the LINE-CODE ENCODER accepts a TTL input, and the output is suitable for transmission via an analog channel. At the channel output is a signal at the TIMS ANALOG REFERENCE LEVEL, or less. It could be corrupted by noise. Here it is re-generated by a *detecto*r. The TIMS detector is the DECISION MAKER module (this module will be examined in next experiment entitled *Detection and BER in Noisy Channel*).

Finally the TIMS LINE-CODE DECODER module accepts the output from the DECISION MAKER and decodes it back to the binary TTL format.

Preceding the line code encoder may be a source encoder with a matching decoder at the receiver. These are included in the block diagram of Figure 3, which is of a typical baseband digital transmission system. It shows the disposition of the LINE-CODE ENCODER and LINE-CODE DECODER. All bandlimiting is shown concentrated in the channel itself, but could be distributed between the transmitter, channel, and receiver.

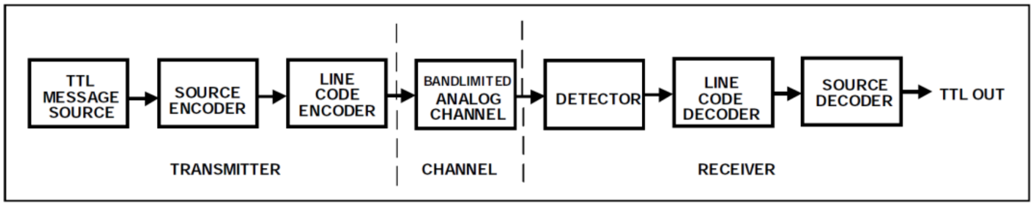


Figure 3: Baseband transmission system

The LINE-CODE ENCODER serves as a source of the system bit clock. It is driven by a *master clock* at 8.333 kHz (from the TIMS MASTER SIGNALS module). It divides this by a factor of four, in order to derive some necessary internal timing signals at a rate of 2.083 kHz. This then becomes a convenient source of a 2.083 kHz TTL signal for use as the *system bit clock*.

Because the LINE-CODE DECODER has some processing to do, it introduces a time delay. To allow for this, it provides a re-timed clock if required by any further digital processing circuits (eg, for decoding, or error counting modules).

Terminology

- the word *mark* and its converse *space*, often appear in a description of a binary waveform. This is an historical reference to the mark and space of the telegraphist. In modern day digital terminology these have become '1' and '0' as appropriate.
- *unipolar signaling*: where a '1' is represented with a finite voltage V volts, and a '0' with zero voltage. This seems to be a generally agreed-to definition.
- those who treat *polar* and *bipolar* as identical define these as signaling where a '1' is sent as +V, and '0' as -V. They append AMI when referring to three-level signals which use +V and -V alternately for a '1', and zero for '0' (an alternative name is pseudoternary).

You will see the above usage in the *TIMS Advanced Modules User Manual*, as well as in this text.

However, others make a distinction. Thus:

- *polar signaling*: where a '1' is represented with a finite voltage +V volts, and a '0' with -V volts.
- *bipolar signaling*: where a '1' is represented alternately by +V and -V, and a '0' by zero voltage.
- the term 'RZ' is an abbreviation of 'return to zero'. This implies that the particular waveform will return to zero for a finite part of each data '1' (typically half the interval). The term 'NRZ' is an abbreviation for 'non-return to zero', and this waveform will not return to zero during the bit interval representing a data '1'.
- the use of 'L' and 'M' would seem to be somewhat illogical (or inconsistent) with each other. For example, see how your text book justifies the use of the 'L' and the 'M' in NRZ-L and NRZ-M.
- two sinusoids are said to be antipodal if they are 180° out of phase.

Available line codes

For a TTL input signal the following output formats are available from the LINE-CODE ENCODER.

NRZ-L

Non return to zero - level (bipolar): this is a simple scale and level shift of the input TTL waveform.

NRZ-M

Non return to zero - mark (bipolar): there is a transition at the beginning of each '1', and no change for a '0'. The 'M' refers to 'inversion on mark'. This is a differential code. The decoder will give the correct output independently of the polarity of the input.

UNI-RZ

Unipolar - return to zero (unipolar): there is a half-width output pulse if the input is a '1'; no output if the input is a '0'. This waveform has a significant DC component.

BIP-RZ

Bipolar return to zero (3-level): there is a half-width $+V_e$ output pulse if the input is a '1'; or a half-width $-V_e$ output pulse if the input is a '0'. There is a return-to-zero for the second half of each bit period.

RZ-AMI

Return to zero - alternate mark inversion (3-level): there is a half-width output pulse if the input is a '1'; no output if the input is a '0'. This would be the same as UNI-RZ. But, *in addition*, there is a polarity inversion of every alternate output pulse.

Biϕ -L

Biphase - level (Manchester): bipolar ±V volts. For each input '1' there is a transition from +V to -V in the middle of the bit-period. For each input '0' there is a transition from -V to +V in the middle of the bit period.

DICODE-NRZ

Di-code non-return to zero (3-level): for each transition of the input there is an output pulse, of opposite polarity from the preceding pulse. For no transition between input pulses there is no output.

The codes offered by the line-code encoder are illustrated in Figure 4 below. These have been copied from the *Advanced Module Users Manual*, where more detail is provided.

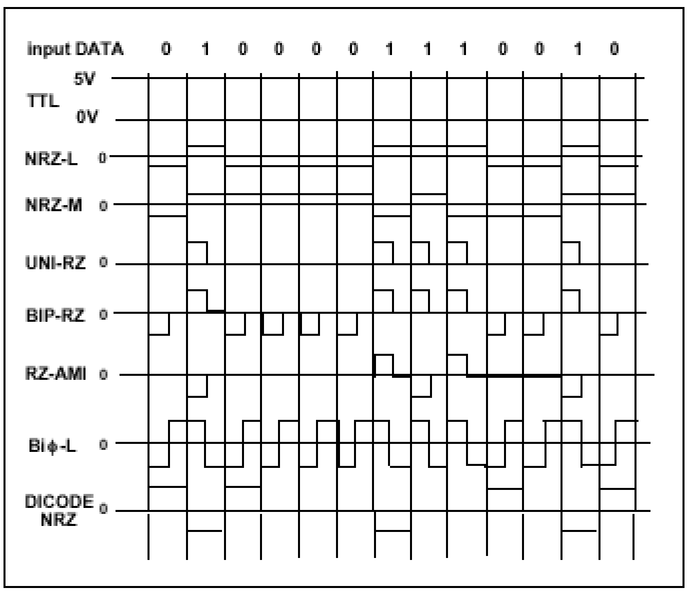


Figure 4: TIMS line codes

The output waveforms, apart from being encoded, have all had their amplitudes adjusted to suit a TIMS analog channel (not explicitly shown in Figure 4).

When connected to the input of the LINE-CODE DECODER these waveforms are de-coded back to the original TTL sequence.

Band limiting

No matter what the line code in use, it is not uncommon to bandlimit these waveforms before they are sent to line, or used to modulate a carrier.

As soon as bandlimiting is invoked individual pulses will spread out (in the time domain) and interfere with adjacent pulses. This raises the issue if inter-symbol interference (ISI).

A study of ISI is outside the intended scope of this text, but it cannot be ignored in practice. Bandlimiting (by pulse shaping) can be effected and ISI controlled by appropriate filter design.

An alternative approach, duobinary encoding, was invented by Lender.

Duobinary encoding

A duobinary encoder (and decoder) is included in the line code modules.

Duobinary encoding is also called correlative coding, or partial response signaling. The precoded duobinary encoding model implemented in the LINE-CODE ENCODER module is described in the *TIMS Advanced Modules User Manual*.