SIGNAL CONSTELLATIONS

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ACHIEVEMENTS: *an introduction to the M-LEVEL ENCODER and M-LEVEL DECODER modules; the signal constellations of m-QAM and m-PSK. Decoding.*

PREREQUISITES: *a theoretical introduction to m-QAM and m-PSK.*

ADVANCED MODULES: *M-LEVEL ENCODER, M-LEVEL DECODER, ERROR COUNTING UTILITIES, a total of two TUNEABLE LPF and two SEQUENCE GENERATORS.*

PREPARATION

This experiment will serve as an introduction to later experiments which use a quadrature amplitude modulator to generate m-QAM and m-PSK signals.

In these applications the modulator requires a pair of multi-level analog signals derived from a single serial binary data stream.

To derive these two signals TIMS uses the M-LEVEL ENCODER module.

At the demodulator a complementary module, the M-LEVEL DECODER, is used.

These two modules will be examined in this experiment, independently of the quadrature amplitude modulator and demodulator with which they will later be associated.

Their purpose will be better understood if you are first reminded of their role in a quadrature modulator and quadrature demodulator.

terminology

The two outputs from the M-LEVEL ENCODER are referred to as the **I** and **Q** signals. Here the '**I**' and the '**Q**' refer to **i**nphase and **q**uadrature, which describe the phase of the carriers of the DSBSC modulators to which they are connected.

The upper case 'M' in the module names is intended to imply that the **I** and **Q** output signals are '**M**ulti-level'. This is not a common usage of the symbol 'M'.

It is not the same as the lower case 'm' used here in the abbreviations m-PSK and m-QAM. The 'm' in these names refers specifically to the number of points in the constellation diagram (to be defined later), and is derived from the number of bits, **L**, in the frame (defined later), determined by the encoding process.

You will see that:

$$m = 2^{\mathbf{L}}$$

the quadrature modulator

As a reminder, a block diagram of a quadrature modulator is shown in Figure 1. This configuration appeared in the experiment entitled *Phase division multiplex* (within *Volume A2 - Further & Advanced Analog Experiments*), and in Weaver`s SSB systems. It is common to many communications systems, and will be seen again in later digital experiments.

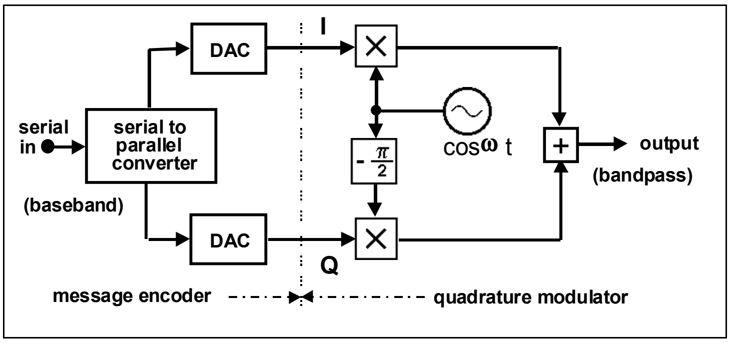


Figure 1: an m-QAM modulator.

encoding

To generate the two multi-level analog signals mentioned above the input serial binary data stream is segmented into frames (or binary words) of **L** bits each, in a serial-to-parallel converter.

For a particular choice of **L** there will be $m = 2^L$ unique words.

From each of these words is generated a unique pair of analog voltages, one of which goes to the **I**-path, and the other to the **Q**-path, of the quadrature modulator.

A typical arrangement is illustrated in block diagram form in Figure 1 above.

No bandlimiting is shown in Figure 1, but in practice this would be introduced either at the input to each multiplier (possibly in the form of a pulse shaping filter), or at the output of the adder, or both.

demodulation

A quadrature demodulator is illustrated in Figure 2. Remember the input signal is a pair of DSBSC, added in phase quadrature. It is the purpose of the demodulator to recover their individual messages, which are presented to the two inputs of the decoder. If the DSBSC phasing at the transmitter is ideally in quadrature, then the single phase adjustment shown is sufficient to separate the messages of the two signals.

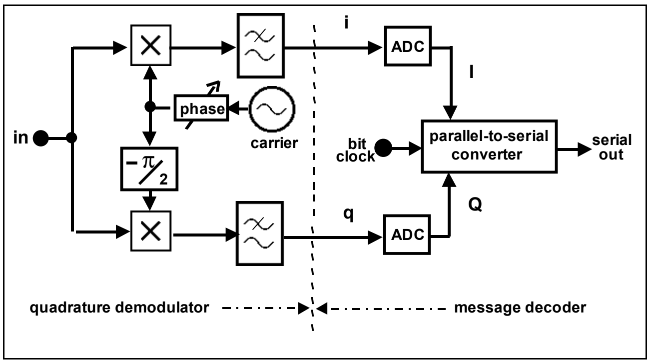


Figure 2: an m-QAM demodulator

decoding

Each arm of the decoder is presented with a bandlimited analog waveform.

The decoder has a bit clock input (stolen in the experiment, else derived from the incoming signal in practice) and knows beforehand the number of bit periods (L) in a frame.

Each waveform is sampled once per frame, and a decision made as to which of the possible levels it represents. This will give a unique pair of levels, which represents a binary word of L bits. This decoded word is output as a serial binary data stream.

constellations

Associated with these signals are phasor diagrams, and signal constellation diagrams.

The phasor diagram is one of the many ways in which some of the properties of these *bandpass* signals can be illustrated.

Each phasor represents the output signal during each of the frames.

The signal constellation diagram shows the location of the *tips* of these phasors on the complex plane.

It is displayed when the two *baseband* multi-level signals **I** and **Q** are connected to the X and Y inputs of an oscilloscope (in X-Y mode).

These signals can come from the encoder output, or from the decoder [1] input. The first of these shows the constellation under ideal conditions. The second shows the constellation after the signal has passed through the channel.

In the second case the display can be used to reveal much about the impairments suffered by the signal.

Like the eye diagram, the constellation diagram displays, in real time, the on-line signal. To obtain these diagrams there is no need to interrupt normal transmission.

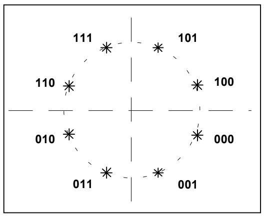
[1] the decoding process is described later

Much research has gone into the optimum location of these points in the constellation, in order to obtain the most desirable properties - or combination of properties.

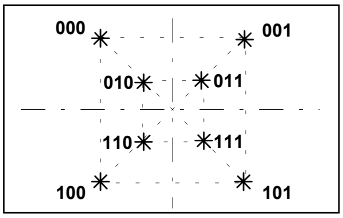
naming conventions

Typically the signal constellation is a symmetrical display. Depending upon the disposition of the points in the display so the resulting modulated signal has different properties, and is given different names.

For example, the points could be in a circle - such as in m-PSK, or in a square grid, as in m-QAM. These constellations are illustrated below in Figure 3, for the case m = 8. In these cases the binary serial data stream has been encoded using frames of three bits.



8-PSK



8-QAM

Figure 3: constellation diagrams

The three-bit words located near each point are the bits in the frame with which each point is associated.

more information

For further theoretical detail on these signals and systems see your Text book.

You can find more technical information about the M-LEVEL ENCODER and M-LEVEL DECODER modules in the *Advanced Modules User Manual*.

EXPERIMENT

M-LEVEL ENCODER module

The arrangement to be examined first is that designated as the 'message encoder' of Figure 1, together with a message source. These are modelled in Figure 4 below.

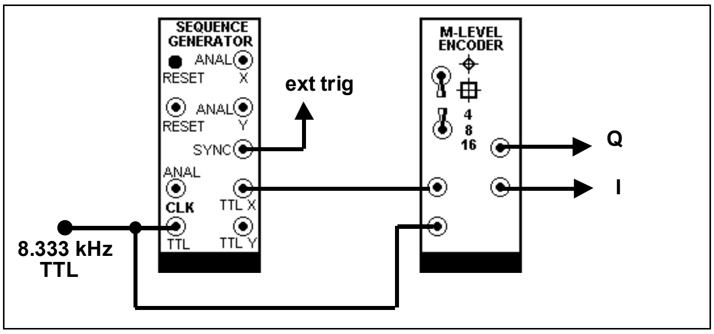


Figure 4: the encoder with 4-QAM selected

As shown, the input is a serial binary data stream from a SEQUENCE GENERATOR. The multilevel **I** and **Q** output signals would go to the quadrature modulator (typically preceded by identical lowpass filters).

T1 *obtain an M-LEVEL ENCODER module. Before plugging it in ensure that the on-board jumper J3 is in the 'NORMAL' position.*

The purpose of each of the sockets and controls on the front panel should be self-explanatory.

T2 *patch up the arrangement of Figure 4. Start with a short sequence from the SEQUENCE GENERATOR (both toggles of the on-board switch SW2 should be UP), and select 4-QAM from the M-LEVEL ENCODER.*

constellations

T3 *predict the appearance of the constellation diagram, and then display it on the oscilloscope (the **I** and **Q** signals connect to the X and Y inputs of the oscilloscope to represent the complex plane with the imaginary axis vertical).*

coding schemes

You will now deduce the coding scheme of the 4-QAM signal. This can be done by examining simultaneously the input data and each one of the **I** and **Q** output signals in turn. The encoder will have arbitrarily selected the frame start point in the incoming serial binary data stream. Each frame will contain two data bits (for the 4-QAM case).

The first requirement, when looking at the input serial binary data stream, is that you must decide where a frame starts. This would be easy if there was not a processing delay (of several clock periods at least) between the end of the frame and the start of the encoded **I** or **Q** output.

Some heuristics will be necessary.

Remember, you *do* know the frame length.

T4 *display the input serial stream and the **I** output signal. Deduce the coding scheme used to map the input data to the output. Repeat for the **Q** output. Record the magnitude of the delay between the frame and the corresponding encoded output (as a function of the input data clock period). There will not necessarily be the same delay for other constellations.*

As time permits the previous two Tasks could be repeated for other constellations. Note that, for larger constellations, it would be necessary to increase the sequence length. Explain.

T5 *examine the constellations of each of the other signals available from the M-LEVEL ENCODER. Notice the result of using a short sequence.*

eye patterns

T6 *display the eye patterns for all of the possible signals from the encoder. Note and record the number and magnitude of the voltage levels involved. Remember, to view all possible levels, long sequences are necessary. Explain.*

If you previously displayed the eye patterns before first bandlimiting the signals, so be it. But more representative patterns result if bandlimiting is first introduced.

T7 *view the eye patterns of the previous Task with bandlimiting, if not already done so.*

Having acquainted yourself with the encoder properties, those of the decoder may now be examined.

M-LEVEL DECODER module

The decoder would normally be provided with the inphase and quadrature outputs from a quadrature amplitude demodulator. These would be noisy, bandlimited baseband signals. Each must be ‘cleaned up’ and their absolute levels adjusted so as to be suitable for analog-to-digital decoding.

The ‘cleaning up’ and decoding is performed by the M-LEVEL DECODER module.

Figure 5 is a model of the m-QAM decoder shown in block diagram form in Figure 2. Its operation will now be examined.

The **I** and **Q** signals from the encoder are shown bandlimited by a pair of lowpass filters, the better to simulate the output of a typical quadrature demodulator.

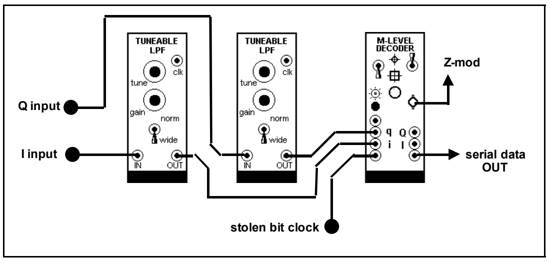


Figure 5: decoder - switched for 4-QAM

Obtain an M-LEVEL DECODER module. Before plugging it in ensure that the on-board RANGE jumper is in the 'HI' position (suits a clock between 4 kHz and 10 kHz). The purpose of each of the sockets and controls on the front panel should be self-explanatory, except perhaps for those associated with the HUNT facility. This will be introduced below.

T8 *patch up the decoding model of Figure 5. Set the front panel switches to decode 4-QAM. Initially, at least, set both the TUNEABLE LPF modules to maximum bandwidth.*

eye diagrams

The decision point can be moved with the front panel DECISION POINT control. The amount of movement is a little over one bit period. The point can be moved in coarse (one bit period) steps with the HUNT [2] button. Whilst the HUNT LED is alight (for about 1 second), further presses of the HUNT button are ineffective.

T9 *display an eye diagram of either the **Q** or **I** channel, and choose your decision point. This will provide an opportunity to observe the operation of the HUNT button.*

T10 *confirm the **I** and **Q** signals from the M-LEVEL DECODER are sample-and-held versions of the **i** and **q** inputs (determined at the sampling instant).*

These 'cleaned up' **I** and **Q** waveforms are passed to the analog-to-digital converter of the decoder.

The decoder makes its decisions on absolute voltage levels, so these must be set correctly. This involves varying the amplitude of the signals at the **i** and **q** *inputs* so that those at the **I** and **Q** *outputs* [3] have a peak-to-peak amplitude of 5 volts. Ideally the minimum of this signal should be zero volts.

In this experiment the filter gain controls can be used for level adjustment.

In later experiments (especially when noise is present) you may choose to fine trim the zero level. In this case the minimum to maximum excursion should be set to

[2] for more detail on the HUNT LED see the *Advanced Modules User Manual*.

[3] the I and Q signals (the result of a sample-and-hold operation on the i and q inputs) are the inputs to the analog-to-digital converter of the decoder

exactly 5 volts, and the absolute level of the minimum set to exactly 0 volts using the on-board trimming resistors RV1 and RV2.

T11 *vary the levels at the* ***i*** *and* ***q*** *inputs of the M-LEVEL DECODER using the gain controls of the TUNEABLE LPF modules. These should be adjusted so that the signals at the* ***I*** *and* ***Q*** *outputs have minimum to maximum values of 5 volts. The minimum should ideally be zero volts.*

T12 *display and record the absolute voltage levels of the* ***I*** *(and* ***Q****) signals for the various constellations available from the M-LEVEL ENCODER. See Tutorial Question Q3.*

T13 *confirm there is agreement between the* ***I*** *and* ***Q*** *outputs from the encoder and the* ***I*** *and* ***Q*** *outputs from the decoder.*

T14 *confirm there is agreement between the serial data input to the M-LEVEL ENCODER and the corresponding output from the M-LEVEL DECODER.*

With a short sequence it is relatively simple to check for data errors, using the oscilloscope, as in the last Task. With longer sequences it is more difficult, and tedious.

error checking

Instrumented error checking involves a comparison of a reference sequence and the decoded data stream.

Sequence comparison techniques have been examined in earlier experiments [4]. They use a synchronised and aligned reference sequence at the receiver. This sequence is compared, in an X-OR gate, with the decoded sequence.

Any output from the X-OR gate represents errors.

T15 *implement an automated method of setting the system to confirm there is error free decoding. A suggested model is shown in Figure 6 below.*

[4] for example, in the experiment entitled *BER instrumentation macro model.*in *Volume D2 - Further and Advanced Digital Experiments.*

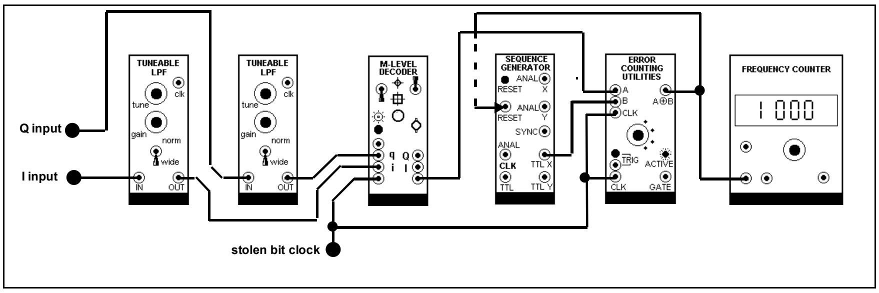


Figure 6: decoder with error counting

Notice that, during setting up, the GATE of the FREQUENCY COUNTER is left permanently open by there being no connection to the TTL ENABLE socket.

T16 *repeat any or all of the above, as appropriate, with a longer sequence and different constellations.*

TUTORIAL QUESTIONS

Q1 *sketch a section of an input sequence, and the corresponding encoded Q output signal from the M-LEVEL ENCODER switched to 4-QAM. Show clearly the framing, and the delay you measured between each frame and the coded output.*

Q2 *show, in tabular form, the relationships between each frame word, and the corresponding **Q** and **I** output levels from the M-LEVEL ENCODER, for 4-PSK.*

Q3 *how many levels are there from each of the outputs of the M-LEVEL ENCODER module for an 8-PSK signal ? If these cover the range ±2.5 volts, specify the levels for each of the points in the constellation of Figure 3. Repeat for other constellations. Compare with measurements.*