MULTI-LEVEL QAM & PSK

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ACHIEVEMENTS: *demodulation of various m-QAM signals, including 16-PSK and 16-QAM. Detection of errors.*

PREREQUISITES: *completion of the experiment entitled **Signal constellations** in volume D1. Completion of the experiment entitled **QAM and 4-PSK** (this Volume) would be an advantage.*

ADVANCED MODULES: *M-LEVEL DECODER, ERROR COUNTING UTILITIES, NOISE GENERATOR, WIDEBAND TRUE RMS METER.*

EXTRA MODULES: *a total of two MULTIPLIER, two TUNEABLE LPF, and two ADDER modules.*

TRUNKS: *see your Laboratory Manager for details of signals at TRUNKS*

PREPARATION

This experiment is about the use of the quadrature amplitude demodulator for the demodulation of m-QAM and m-PSK signals.

A modulator which produces quadrature amplitude modulated (QAM) signals is examined in the analog experiment entitled *Phase division multiplex* (Volume A2), and a digital experiment entitled *QAM and 4-PSK* (this Volume). The more general m-QAM and m-PSK signals will be examined in this experiment.

the m-QAM generator

Figure 1 shows the block diagram of a multi-level encoder and a quadrature modulator. The first of these has been examined in the experiment entitled *Signal constellations* (Volume D1), which, it is assumed, you have completed.

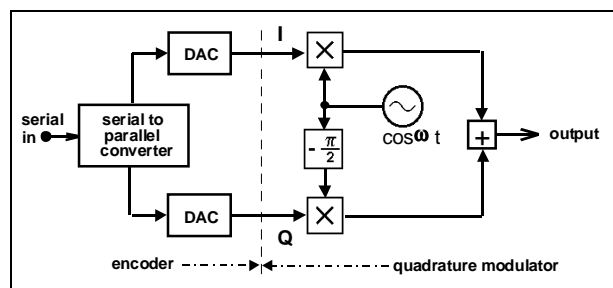That experiment also examined the multi-level decoder.

Figure 1: a multi-level QAM modulator

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the m-QAM demodulator

Figure 2 shows the block diagram of a quadrature demodulator and a multi-level decoder.
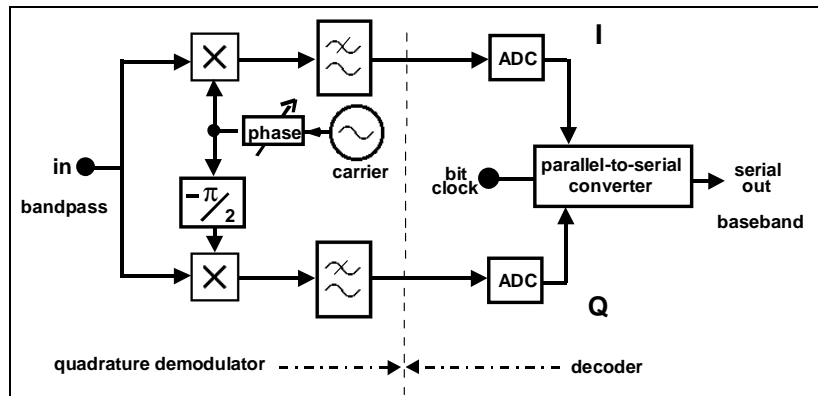

Figure 2: an m-QAM demodulator

carrier & bit clocks

Stolen carriers and bit clocks will be used at the demodulator.

As usual, while pursuing a major topic, one does not wish to become sidetracked by having to model carrier and bit clock recovery schemes. These have already been examined in the experiments entitled *Bit clock regeneration,* and *Carrier acquisition* (both in this Volume), and *Carrier acquisition and the PLL,* and *The Costas loop* (both in Volume A2).

carrier phasing

The local (quadrature) carriers to the two MULTIPLIER modules will be obtained from the MASTER SIGNALS module. These two will be connected *with the same relative phasing* as those at the transmitter.   This will save much time in investigating the many phase combinations possible at the receiver, only one of which will satisfy the condition for error-free decoding.

The only phase adjustment will be introduced by a single PHASE SHIFTER inserted in series with the bandpass input to the modulator [1].   The PHASE SHIFTER module is a *narrow band* device, introducing different amounts of phase at different frequencies. However, the QAM signal itself is also narrow band, and so this use of the PHASE SHIFTER is not entirely inappropriate. See Tutorial Question Q2.

Once error free decoding has been achieved the correct conditions at the demodulator are known, and the (approximate) single PHASE CHANGER scheme could be replaced with a precise method, namely a PHASE CHANGER in each carrier path. These two schemes are illustrated in block diagram form in Figure 3 below.

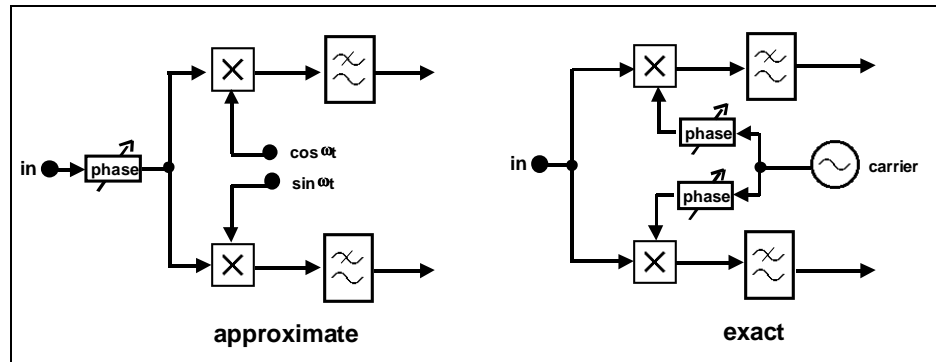[1] this differs from the method shown in Figure 2.

Figure 3: the two phasing schemes

decoder and error counting

The decoding is performed by the M-LEVEL DECODER module, acting on the **i** and **q** outputs from the demodulator. Correct alignment of the system, which requires carrier phase adjustment, is checked by counting errors.

The technique of error counting, using a reference sequence at the receiver, has been examined in detail in previous experiments [2]. In particular, and of direct relevance to *this* experiment, setting up for error free transmission using multi-level signalling and error detection instrumentation was described in the experiment entitled *Signal constellations* (Volume D1).

complexity

To build a complete system - encoder, modulator, noisy channel, demodulator, decoder and bit error rate measuring facilities - requires slots for more than 12 modules. The TIMS 301 rack provides 12 slots.

So in this experiment only the receiver will be modelled and examined. Several signals will be available at TRUNKS. These will be defined by your Laboratory Manager, and will be used for testing your receiver. All are based on 100 kHz carriers and 8.333 kHz bit clocks.

Their messages will be derived from SEQUENCE GENERATOR modules similar to your own, and of stated sequence lengths. So a reference message can be created at the receiver, and a sliding window correlator used for lining it up with the decoded sequence, as has been done in previous experiments.

It is unlikely that you could identify the signals at TRUNKS using only an oscilloscope. But you could identify them, using a lengthy trial and error process, by setting up the demodulator to be described and modelled in what follows. However, to save time, their descriptions, and locations at TRUNKS, will be defined by your Laboratory Manager.

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[2] in detail in *BER measurement in the noisy channel* in this Volume.

the noisy channel

To save rack space it might be thought that the channel filtering could be included at the transmitter end of the system. But it is necessary to add noise at the *input* to the channel, so that the noise will suffer the same bandlimiting as the signal.

For an alternative method, see Tutorial Question Q3.

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EXPERIMENT
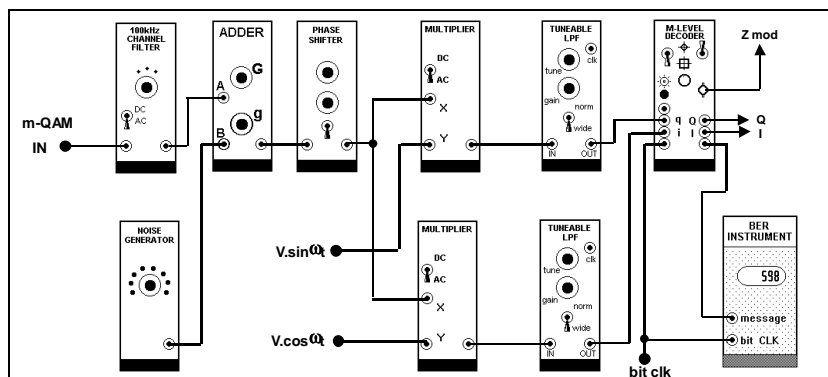
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The complete receiver is shown modelled in Figure 4 below.

Figure 4: model of the m-QAM demodulator and decoder

The error counting instrumentation is shown as a BER INSTRUMENT module. This is described in the experiment entitled *BER instrumentation macro model* (this Volume).

T1 *patch up the system of Figure 4. Be sure to connect the <u>cos</u> and <u>sin</u> outputs from the MASTER SIGNALS module as shown, since this matches their usage at the transmitter, and so preserves relative carrier phasing.*

T2 *select the bandpass channel from the 100 kHz CHANNEL FILTERS module.*

T3 *select the 4-QAM signal from TRUNKS. Connect it to the input of your receiver.*

T4 *initially introduce no noise to the input ADDER. Adjust the gain through this ADDER to give a TIMS ANALOG REFERENCE LEVEL signal (4 volts peak-to-peak) into the quadrature demodulator.*

T5 *connect the Z-modulation output signal to the Z-modulation input of the oscilloscope.*

The eye pattern is first used to adjust the decision instant (displayed as a bright spot on the oscilloscope trace - vary the intensity of the display for best spot visibility). The front panel DECISION POINT control on the M-LEVEL DECODER allows adjustment over a little more than one clock period. If it cannot be located at the desired point, step it across by pressing the HUNT button. For 4-QAM the next press of the button will return to the previous condition (there are two clock periods per frame), but for 16-QAM (for example) there are four clock periods per frame, and so four accessible regions, each of which can be reached by repeated presses of the button.

Use the same techniques as are described in the experiment entitled *Detection with the DECISION MAKER* (Volume D1). See Tutorial Question Q1.

T6 *look at the eye pattern at either (LPF) output of the demodulator.*

Even though two carriers may be available in phase-quadrature, there are many combinations in which they may be connected to the two multipliers for desired results. Connection in the manner shown in the model of Figure 4 will eliminate many of these (these connections duplicate those at the transmitter).

Since the properties of the input signal are known, you already know how many levels to expect in the eye pattern. For 4-QAM there should be 2 levels (in each of the **i** and **q** paths). If there are more than 2 levels, what adjustments are available to you ?

Only one. Think about it, then proceed.

T7 *adjust the phasing of the demodulator PHASE CHANGER until there are the expected number of levels in the eye pattern (<u>two</u> levels for 4-QAM). There will be <u>four</u> phases which will give this result - two positions of the front panel variable COARSE control, and two with the 180^0 toggle switch. How many will be correct ? How do they differ ? This cannot be decided yet.*

T8 *accept any one of the four phases of the previous Task.*

T9 *using the gain controls of the TUNEABLE LPF modules, adjust the levels of the signals to the **i** and **q** inputs of the M-LEVEL DECODER to result in 0 to +5 volt signals at the **I** and **Q** outputs.*

T10 *set up the M-LEVEL DECODER front panel toggle switches to accept the coding scheme of the TRUNKS signal.*

T11 *attempt to align the DATA output from the M-LEVEL DECODER with the X-output from the reference SEQUENCE GENERATOR. If there are continuous errors, the only system error (?) must be the demodulator carrier phasing.*

T12 *if there are errors, adjust to another phase, and repeat the previous Task. One, and only one, of the four possible phases should give error free transmission.*

T13 *examine the signal constellation of the demodulated signal.*

So far only the 4-QAM format has been decoded.

T14 *examine the other signals at TRUNKS. In each case, before error free decoding can be assured, it will be necessary to:*

a) *set the reference SEQUENCE GENERATOR to the same sequence length as that at the transmitter.*

b) *adjust the decision point on the eye diagram.*

c) *check for the correct number of levels in the eye diagram, and make a fine adjustment of the phasing if necessary.*

d) *repeat Tasks T7 to T13.*

noise and BER measurement

The system is now ready for the addition of system impairments in the form of noise.

Follow the procedures described in detail in the experiment entitled *BER measurements in the noisy channel* (this Volume).

Before making these measurements, however, now is the time to fine tune the system. The effectiveness of these adjustments can be judged by aiming for an improvement of the bit error rate. They should be made with a 'moderate' amount of added noise.

Note that if only 12 slots are available (in a single TIMS 301 rack), and 13 are required, it is possible to share one slot between the WIDEBAND TRUE RMS METER and the ERROR COUNTING UTILITIES modules. These two are not required simultaneously.

T15 *trim the DC offsets at the **Q** and **I** outputs of the M-LEVEL DECODER module (first read the appropriate section of the **Advanced Modules User Manual** for details, and/or seek the advice of your Laboratory Manager. These signals are the actual inputs to the decoder circuitry).*

You are now ready for BER measurements. Detailed instructions are outside the scope of this introductory experiment.

further experiments

bandwidth

So far no mention has been made of the bandwidth of these signals. Further experiments, at the very least, should be devised to compare the inter-relationships between channel bandwidth, data rates, and error rates.

PCM

Instead of using a SEQUENCE GENERATOR as a message source, a PCM ENCODER could be used. This would allow the transmission of an analog message over the system.

TUTORIAL QUESTIONS

Q1 there are two waveforms (*i* and *q*), and so two decision points, but the DECISION POINT control moves both points together. What does this say about the properties of the lowpass filters in the MULTIPLIER outputs ?

Q2 the method of carrier phase adjustment was made using a _single_ PHASE CHANGER in the input signal path to the demodulator. Was this reasonable ? This method was implemented due to the shortage of free slots in a single TIMS 301 rack. The method illustrated in Figure 2 would require two slots, whereas the suggested method only one.

Q3 to save rack slots at the receiver the channel filter could be placed at the transmitter. Noise could still be added at the receiver input. This would save a single rack slot. If the channel filter bandwidth was wider than the lowpass filters at the demodulator output, would not this be an acceptable method of bandlimiting the noise ? Compare the two methods. What problems might there be in each ?