Sysblocks

Communications and digital radio techniques

Teacher Guide

MATRIX

CP6125

Teacher’s notes

Learning objectives

On successful completion of this course, the student will be able to:

- set the trigger channel, trigger voltage and timebase for a Picoscope;
- give one reason for using amplitude modulation (AM) of a carrier signal rather than direct baseband transmission of an audio signal;
- describe the stages in the amplitude-modulation process;
- explain the reason for rectification and filtering in the demodulation process;
- explain the effect of right-shifting data in a register such as that in the ADC;
- explain why the amplitude-modulation process produces two sidebands in the frequency spectrum of the signal;
- calculate the interrupt frequency of a program given the system clock frequency and rollover value for the timer involved;
- name the three standard constituents of a phase-locked loop (PLL) subsystem and describe their function;
- explain why a PLL subsystem can be described as a ‘frequency-to-voltage’ converter;
- describe the behaviour of the PLL subsystem when ‘locked’ onto the input signal;
- describe the effect on the phase difference generated by the PLL subsystem of changing :
    - the input signal frequency;
    - the system bandwidth;
- for a PLL subsystem, explain what is meant by the terms:
    - lock-in time;
    - step response;
    - frequency tracking;
- state two advantages of frequency modulation (FM) over AM;
- explain why a FM modulator can be described as a ‘voltage-to-frequency’ converter;
- describe the effects on the modulated wave of increasing the amplitude and frequency of the input signal:
- describe the effect on the modulated wave of changing the system bandwidth;
- describe the use of a PLL subsystem as a FM demodulator;
- compare OOK and ASK as techniques for modulating digital data onto an analogue carrier;
- describe the effect of changing the break frequency of the receiver’s low-pass filter;
- create and interpret an ‘eye diagram’ to evaluate the quality of the OOK / ASK transmission;
- describe how digital data is conveyed using FSK and PSK;
- identify significant features of the frequency spectrum for a FSK transmission;
- create and interpret an ‘eye diagram’ to evaluate the quality of the FSK transmission;
- compare the relative merits of ASK, FSK and PSK communications;
- describe the features of the frequency spectrum of a PSK transmission;

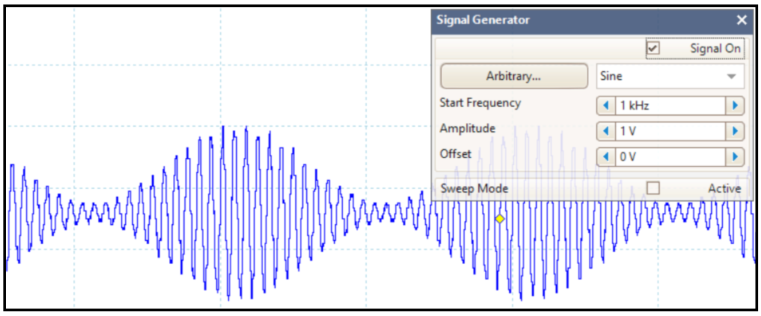
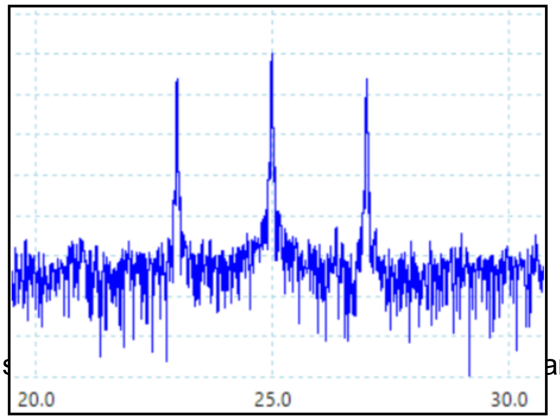
Learning objectives

On successful completion of this course, the student will be able to:

- describe how digital data is conveyed using QAM techniques;
- explain why QAM offers greater data transmission rates than other ASK, FSK and PSK;
- state the relationship between the **I** and the **Q** components of the modulated signal in QAM;
- explain the meaning of coherence in the context of digital communications;
- state the purpose of filtering in quadrature decoding of a QAM modulated wave;
- identify the four symbols of the 4-QAM modulation scheme;
- identify the symbols of the 8-QPSK modulation scheme;
- distinguish between constellation diagrams for the following modulation schemes:
    - BPSK;
    - 4-QAM
    - 8-QPSK
- explain the rationale behind spread-spectrum transmission;
- describe the features of DSSS communication;
- describe the result of using different PRBS's or different 'seeds' at the transmitter and receiver in DSSS communication;
- explain, in the context of digital communications, the meaning and significance of:
    - baud rate;
    - preamble;
    - group length;
    - BER.
- use Picoscope to measure the transmission time of a data packet;
- compare the performance of the following modulation schemes:
    - On Off Keying (OOK);
    - Amplitude Shift Keying (ASK);
    - Frequency Shift Keying (FSK);
    - Bi-phase Shift Keying (BPSK);
    - Quadrature Phase Shift Keying (QPSK);
    - 8-phase Shift Keying (8PSK).

Teacher’s notes

Communications and digital radio techniques

	Notes
Initial issue	Students will need access rights to local storage to allow Flowcode to create a number of associated files when they download and open the Flowcode programs.
Worksheet 1 Amplitude modulation	Concepts involved: *carrier* *modulation* *artefacts* *signal bit depth* *sidebands* The program uses an external signal to modulate (change some characteristic of) a carrier wave, generated internally. The worksheet details some of the maths involved and students may need support in understanding aspects such as left / right shifting data in a register and multiplying together two binary numbers. On the spectrum view, it may not be obvious why amplitude modulation produced two sidebands, one ‘upper’ and the other ‘lower’. The instructor could discuss the implications for AM broadcasting. The two Challenges are quite demanding and the instructor may decide to allocate them to specific, more able, students. Even for them, there may be need for additional support. They could be tasked with creating presentations to explain what they did to the rest of the group. Typical results are shown below, together with the ‘AWG’ settings panel:   2 kHz s ... arrier

<table>
<tr><th></th><th>Notes</th></tr>
<tr><td>Worksheet 2
AM
demodulation</td><td>

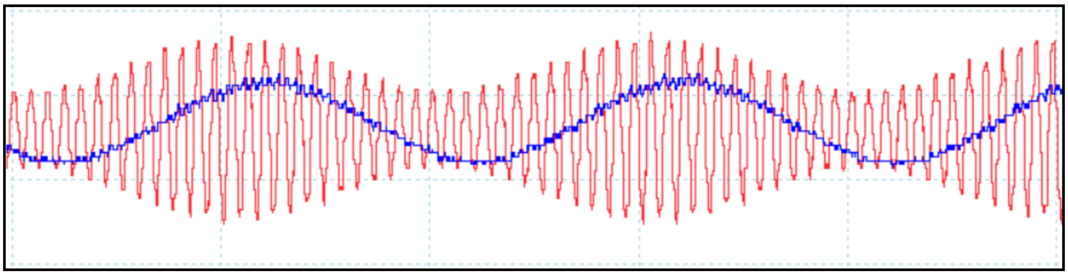
Concepts involved:

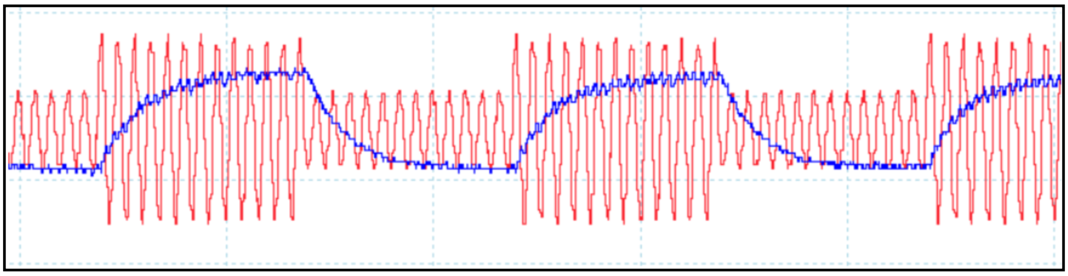
rectifier bandpass filter dynamic range bandwidth Fourier's theorem

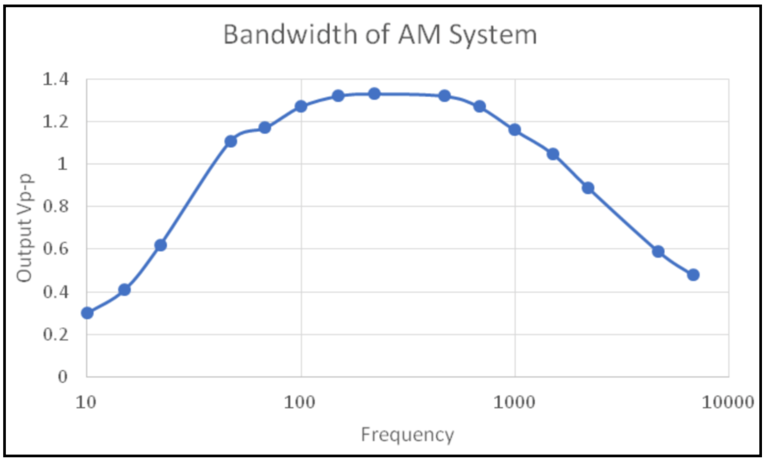
The worksheet starts by outlining the demodulation method. Depending on previous experience, students may find this straightforward or challenging. If they are familiar with analogue demodulation, they will recognise the stages in the process apart from the scaling that occurs after the bandpass filter.

Challenge results: the system bandwidth is fine for telephone quality speech but too low for good quality music.

Typical results are shown below:







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	Notes

Worksheet 3 Phase-locked loop

Concepts involved:

NCO *loop filter* *phase detector* *phase offset* *centre frequency*
depth of modulation *lock-in time* *step response*

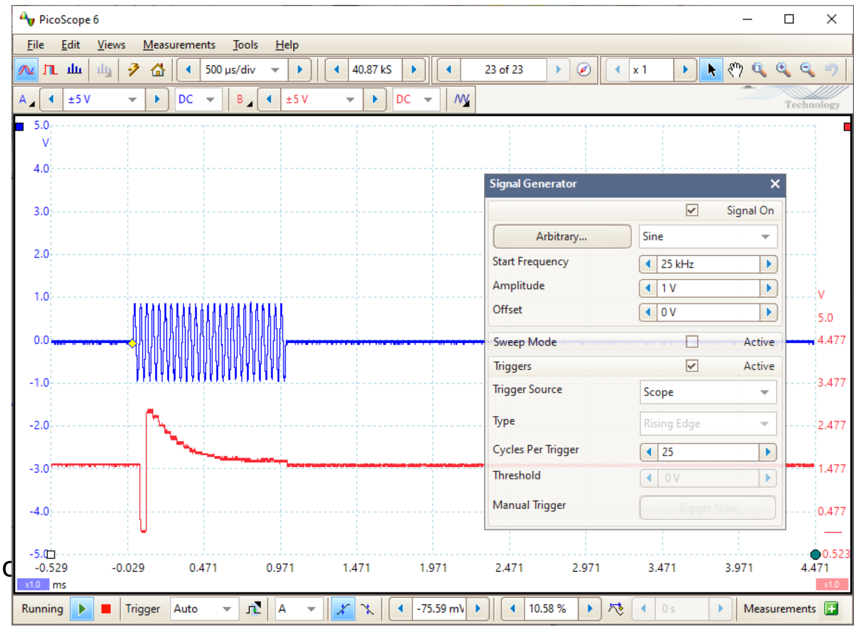
The instructor could start by reviewing uses of phase-locked loop (PLL) subsystems In the worksheet, students are taken through a series of tasks to investigate the PLL performance and factors that affect its ability to lock onto an input signal frequency.

The two options for the output from ‘OUT1’ are basically either the input to or output from the NCO.

The input to the NCO is a signal that is proportional to the frequency output. As the frequency of the SysBlocks input changes this control signal should go up and down. The NCO output is a nominally 25 kHz signal, and is called the ‘reference signal’. If the PLL is working correctly, this reference signal is the same frequency as the input to the SysBlocks board with a fixed phase offset.

Typical results:

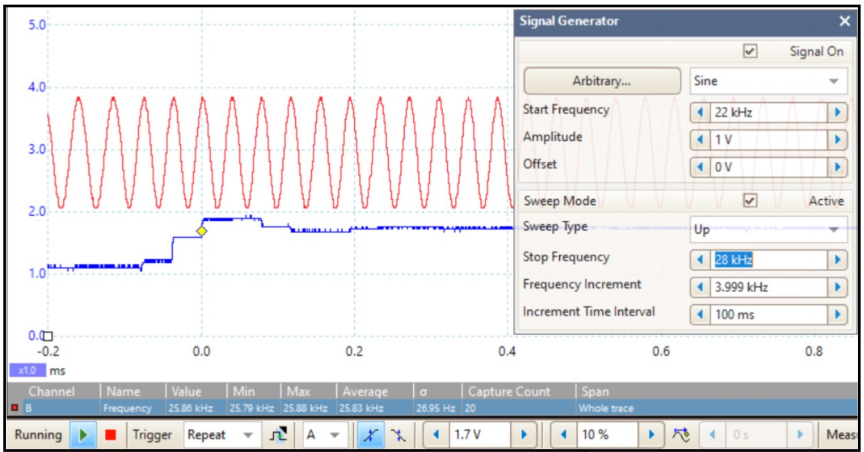
Input frequency kHz	Phase Offset		
	BW = 2.5kHz	BW = 5.0kHz	BW = 10kHz
15	No Lock	No Lock	No Lock
17.5	No Lock	No Lock	No Lock
20	No Lock	No Lock	Lock
22.5	No Lock	Lock	Lock
25	Lock	Lock	Lock
27.5	No Lock	Lock	Lock
30	No Lock	No Lock	Lock
32.5	No Lock	No Lock	



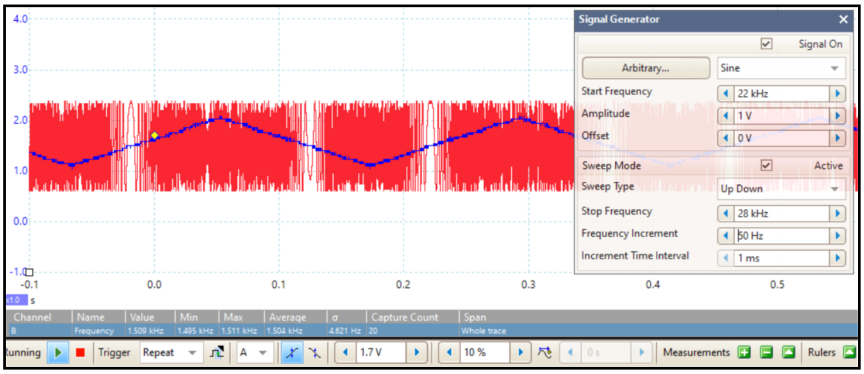
PLL error c … ck in time.

Teacher's notes

	Notes
Worksheet 3 Phase-locked loop	Typical results continued…



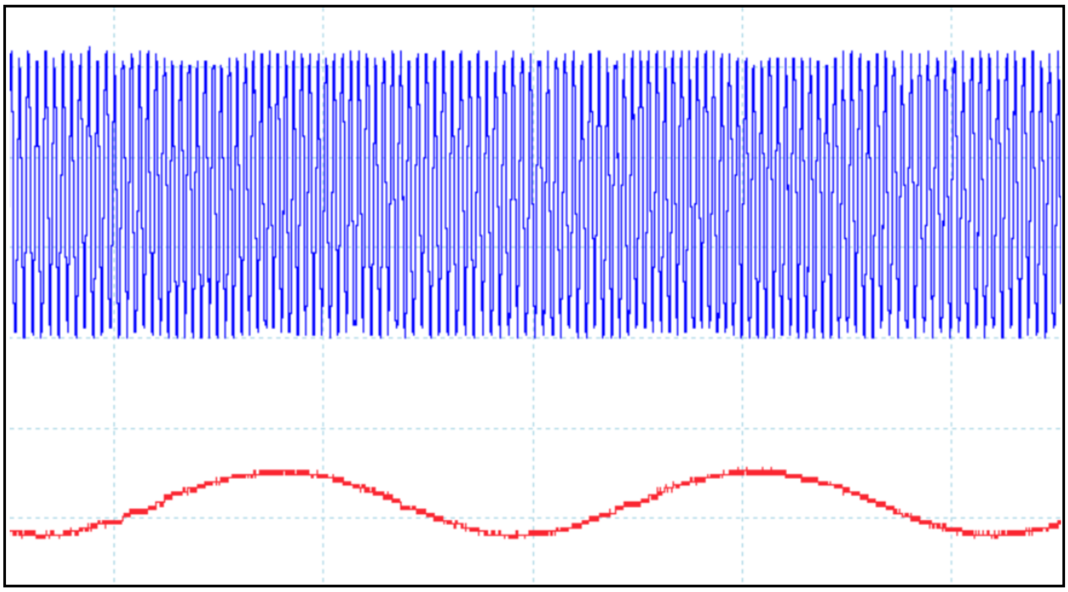
Response to step change in frequency



	Notes
Worksheet 4 Frequency modulation / demodulation	Concepts involved: *SNR* *frequency modulation* The worksheet covers both modulation and demodulation using FM. It starts by introducing and investigating a FM modulation program and then uses the PLL program from worksheet 3 to demodulate the signal. To start with, the input signal is a constant DC voltage. Then that is replaced by an AC signal. Finally, a 'real' signal, such as music or speech, is applied to the input so that the system's performance can be assessed.

Input Voltage	Output Frequency		
	BW = 2.5 /kHz	BW = 5.0 /kHz	BW = 10.0 /kHz
0.5	22.62	20.27	15.52
1	23.66	22.33	19.67
1.5	24.7	24.4	23.8
2	25.73	26.47	28

Typical results are shown below:



	Notes

Worksheet 5
Digital AM
OOK and ASK

Concepts involved:

OOK *ASK* *symbol* *eye diagram*

The instructor could introduce this topic by setting students the task of researching the relative advantages / disadvantages of OOK and ASK as transmission technologies.

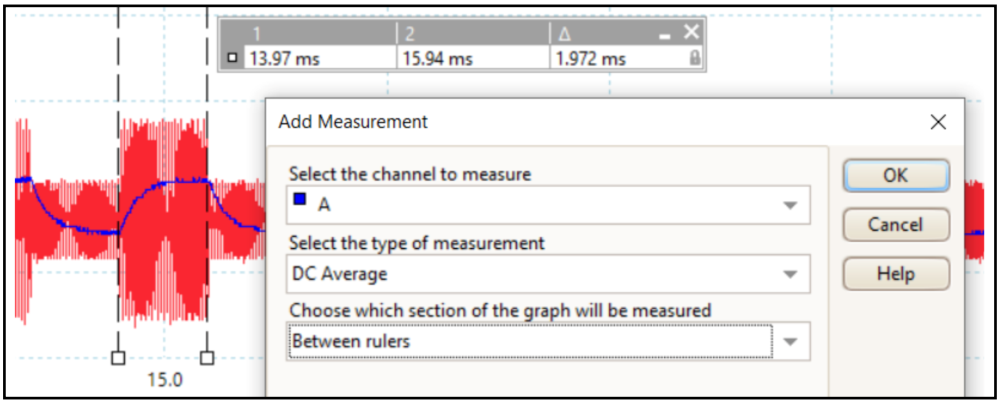
The worksheet itself allows direct comparison of the two by using each, in turn, to send and retrieve a data string. Once again, students use Picoscope or equivalent to make measure the signal, in this case measuring the average voltage of a chosen section of the trace. They may need help / reminding of how to do this.

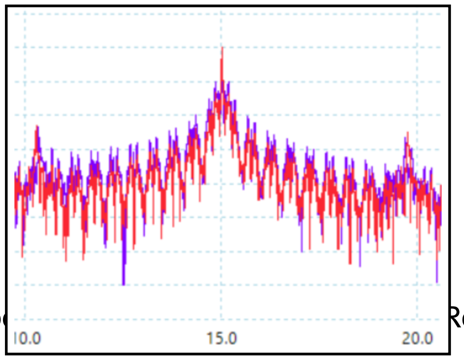
In the second challenge, they generate an ‘eye diagram’ on the oscilloscope and use it to assess the quality of the data transmission system. The instructor may need to support this part of the investigation or may choose to do this as a demonstration.

Typical results are shown below:

Symbol	DC Average / V	
	OOK	ASK
0	0.23	0.60
1	0.86	0.96

Average voltages for OOK and ASK symbols





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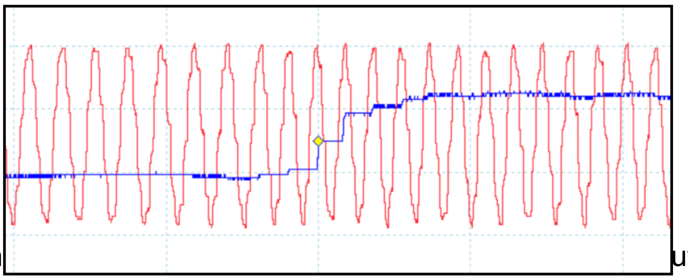
	Notes

Worksheet 6
Digital FM
FSK

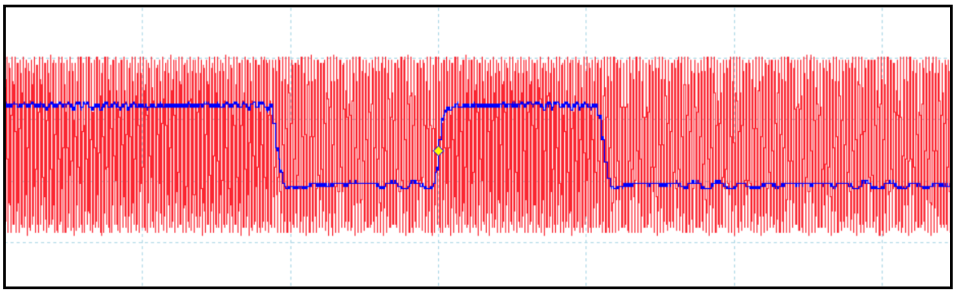
The instructor could introduce this topic by comparing FM and FSK.
The Wave Generator is given 181 samples. Having a prime number of samples causes a kind of dithering in the output signal which reduces unwanted stubs in the output spectrum. The figure of 181kHz is chosen for the interrupt frequency because it gives a base frequency of 1kHz to the Wave Generator and thus, the parameter of the ‘ModifyFrequency’ macro becomes the frequency in kHz.
The second challenge is a very open-ended one and the instructor could choose to do it as a group task.

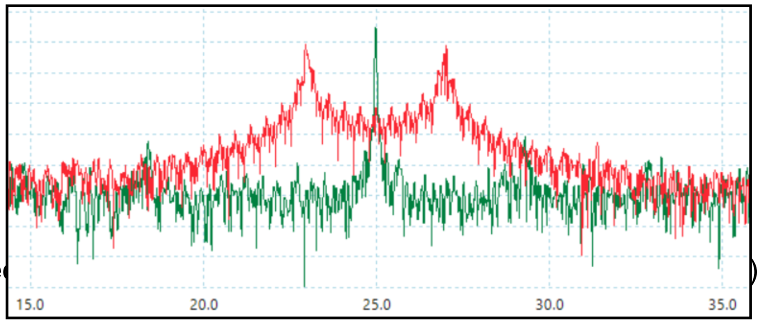
Typical results are shown below:

Symbol	Frequency /kHz	DC Average /V
None	25kHz	1.67
0	23kHz	0.8
1	27kHz	2.5



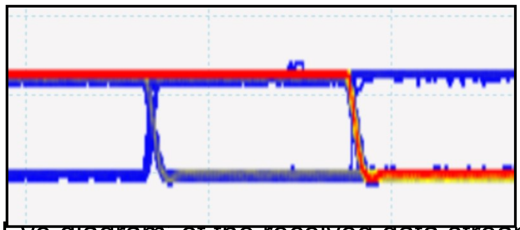
Change in utput (blue)



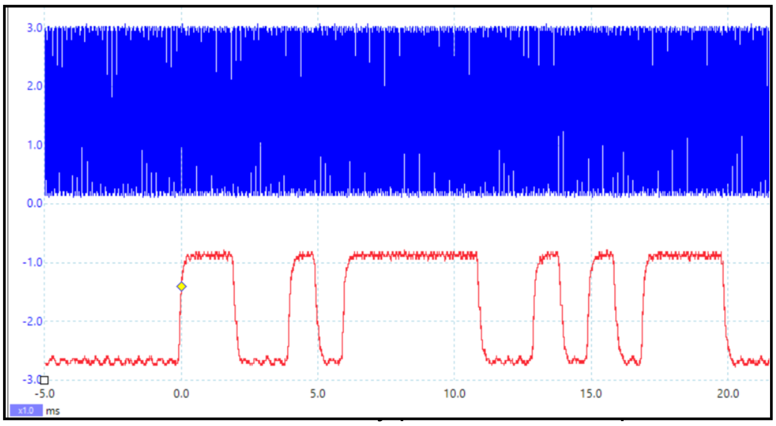


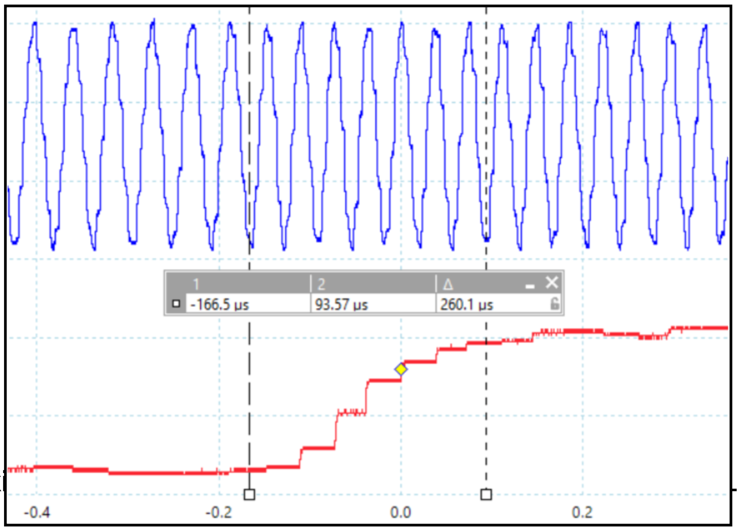
Spe)

	Notes
Worksheet 6 **Digital FM** **FSK**	Typical results.....



'Eye diagram' of the received data stream.





The maxi … to lock

	Notes

Worksheet 7
Digital modulation
PSK

Concepts involved:

PSK *BPSK* *the four trigonometry identities*

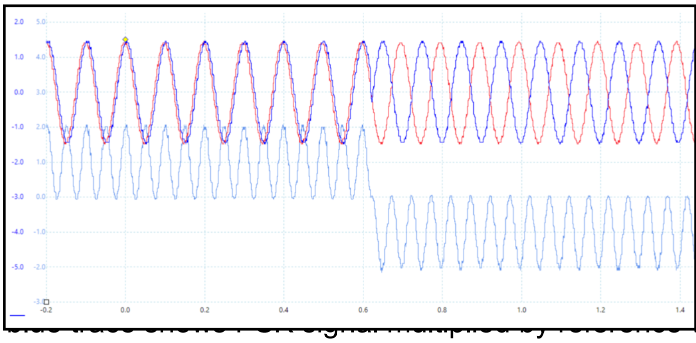
The instructor could start with a review of PSK applications and factors that determine the choice of frequencies or set this as a task for the students.

For those with a limited mathematical background, it may be necessary to spend time developing and exploring the trigonometrical identities used in the worksheet and in setting up the Math channel view.

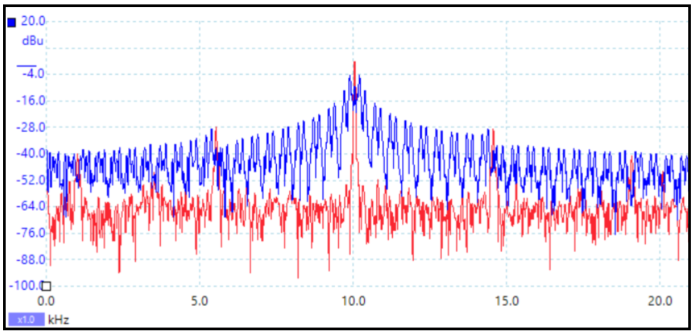
The method outlined for demodulating the signal may prove challenging for some.

The challenge, while not difficult to implement, may need support in its analysis.

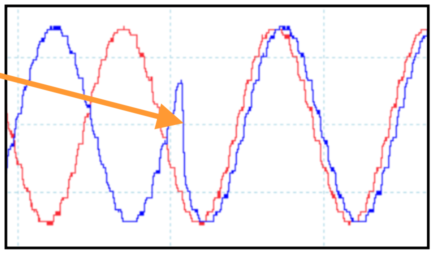
Typical results are shown below:



Pale [illegible] wave



Sharp transitions between states creates the high bandwidth.
A smoother transition would reduce bandwidth. However, smoothing the transitions or using pulse shaping would reduce the maximum data rate.

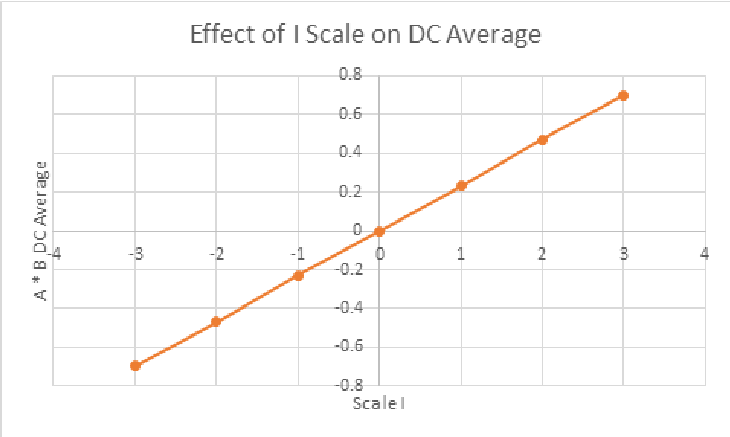


	Notes
Worksheet 8 Quadrature amplitude modulation	Concepts involved: *constellation diagram*, *in-phase (I) and quadrature (Q) signals*, *quadrature generator*

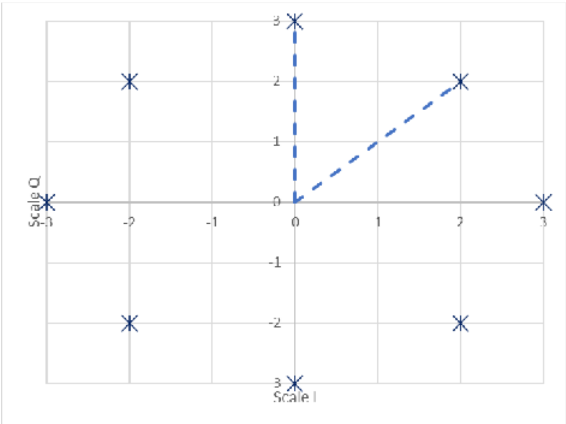
This worksheet shows students how varying the amplitude of **I** and **Q** signals varies the DC average voltage of **I** x **Q** and sets the scene for understanding how phase shift keying works.

Typical results for the investigation are given below:

Scale I	A * B Average
-3	0.77
-2	0.52
-1	0.255
0	0
1	0.255
2	0.516
3	0.77



Scale I	Scale Q	Phase A → B	A * B Amplitude	A * B DC Average
3	0	0	1.49	0.71
2	2	45	1.44	0.47
0	3	90	1.53	0
-2	2	135	1.46	-0.47
-3	0	180	1.48	-0.71
-2	-2	225	1.46	-0.47
0	-3	270	1.53	0
2	-2	315	1.44	0.47



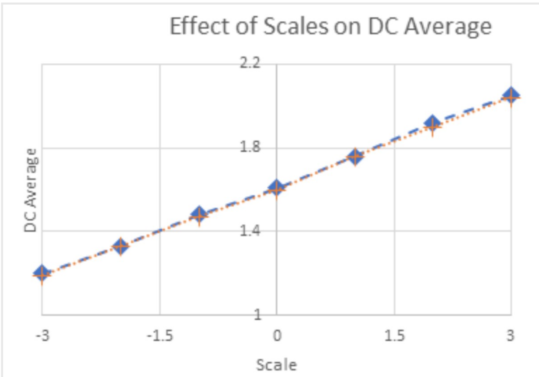
	Notes
Worksheet 9 Quadrature receiver	Concepts involved: *constellation diagram*, *in-phase (I) and quadrature (Q) signals*, *quadrature generator*

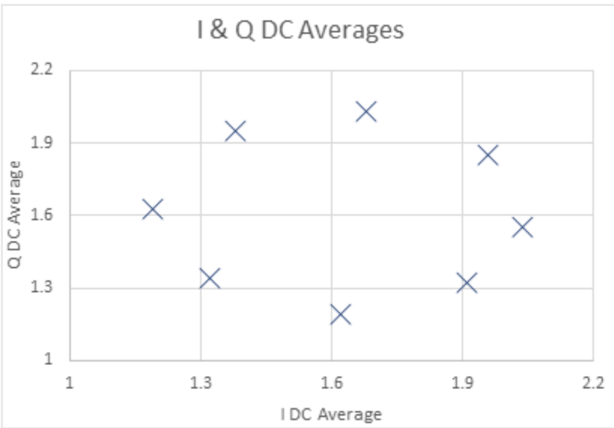
This worksheet shows how a receiver locked to the original transmission carrier can be used to reproduce the states of the phase shift and amplitude of the original **I** and **Q** signals.

Typical results for the investigation are given below:

Scale I	Scale Q	I DC Average	Q DC Average
-3	0	1.2	1.67
-2	0	1.33	1.65
-1	0	1.48	1.63
0	0	1.61	1.6
1	0	1.76	1.59
2	0	1.92	1.61
3	0	2.05	1.59

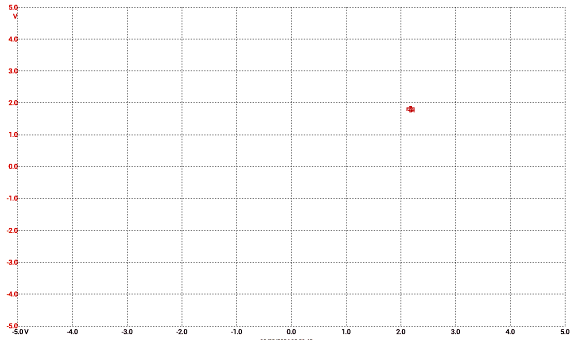
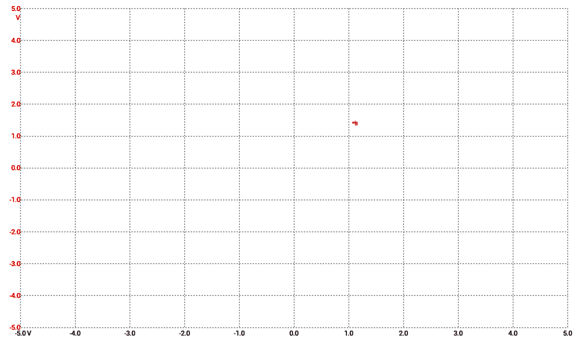
Scale I	Scale Q	I DC Average	Q DC Average
0	-3	1.61	1.19
0	-2	1.59	1.33
0	-1	1.62	1.47
0	0	1.6	1.6
0	1	1.63	1.76
0	2	1.62	1.9
0	3	1.64	2.04





Teacher’s notes

Communications and digital radio techniques

	Notes
Worksheet 10 Quadrature receiver	Concepts involved: *constellation diagram* *in-phase (I) and quadrature (Q) signals* *quadrature generator* This worksheet shows how **I** and **Q** signals at the transmitter can be recreated at the receiver. Students monitor the DC outputs of the **I** and **Q** signals. Typical results for the investigation are given below: I=3 Q=3  I=-3 Q=-3 

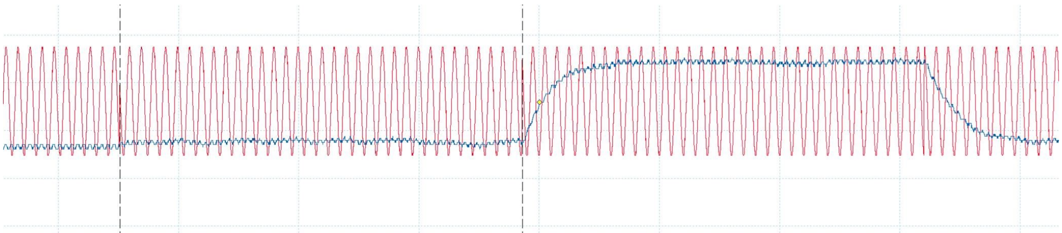
	Notes
Worksheet 11 Coherent detector	Concepts involved:

Concepts involved:

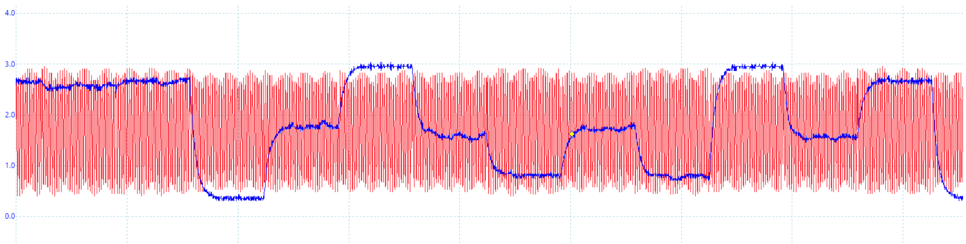
BPSK *QPSK* *4-PSK* *8-PSK*

Having understood the basic mechanism of regenerating **I** and **Q** signals, and having understood how PLL can regenerate a reference signal, students use a new set of programs that show how BPSK, QPSK, and 8PSK can be to be transmitted

Typical results.....



Phase changes: first with no data transition, second with data transition

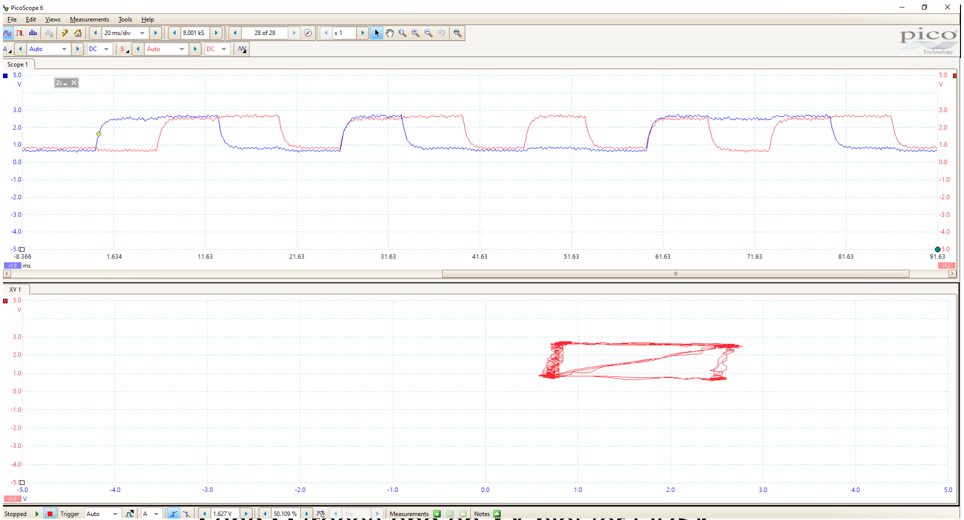


Teacher's notes

Communications and digital radio techniques

	Notes
Worksheet 12 Quadrature amplitude modulation	This worksheet looks in detail at the constellation diagrams for different modulation schemes.

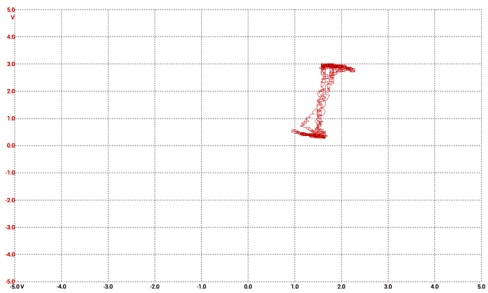
Typical results.....



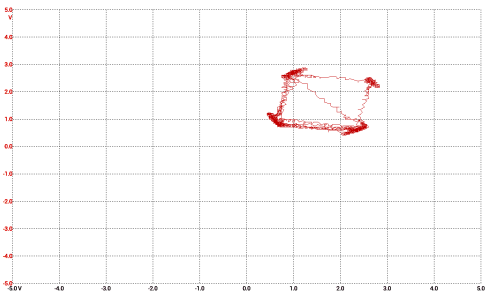
I and Q traces and an XY plot for QPSK

X-Y plots for:

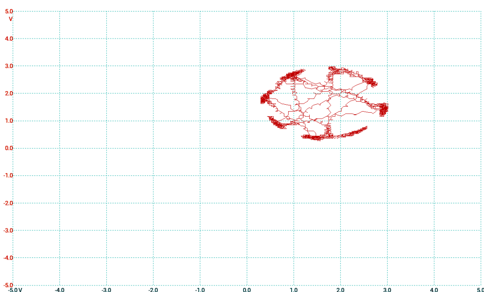
BPSK



4-PSK



8-PSK



	Notes

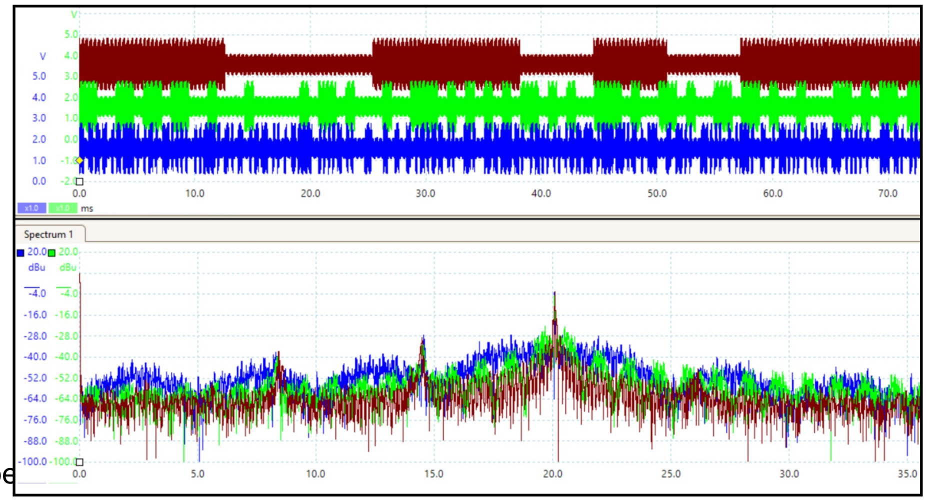
Worksheet 13
DSSS

Concepts involved:

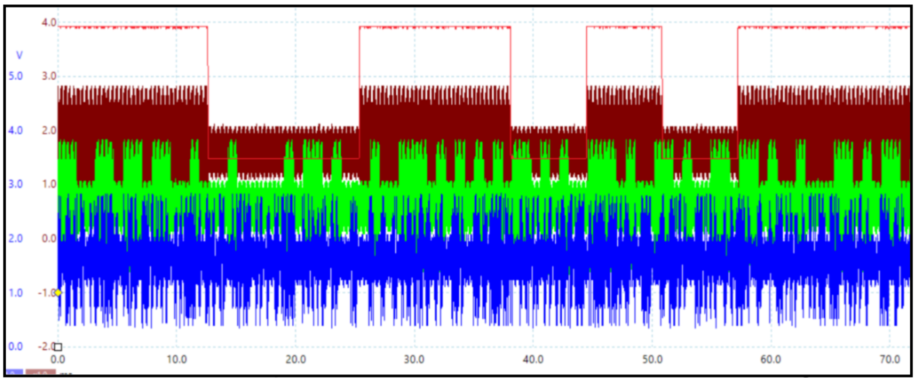
spread-spectrum techniques *PRBS* *PRBS seed*
FHSS *DSSS* *LFSR*

The concepts listed above are complex and require extensive explanation. This worksheet allows students to understand Spread Spectrum techniques. The worksheet starts by showing students the effects of multiplying the original signal by a variable frequency PRBS on the spectral plot of the transmission showing the peak spectral output falling and the energy in the signal spreading outwards from the carrier as the frequency of the PRBS increases.

Typical results for the investigation are given below:

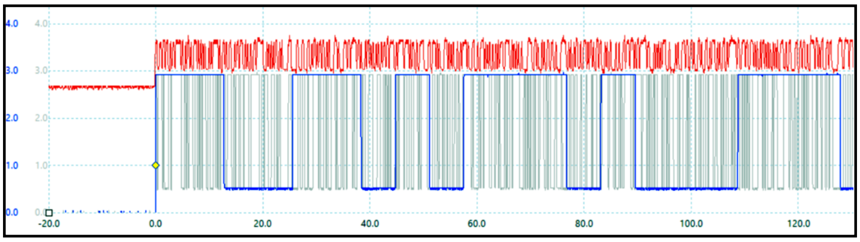


Spe (Blue)

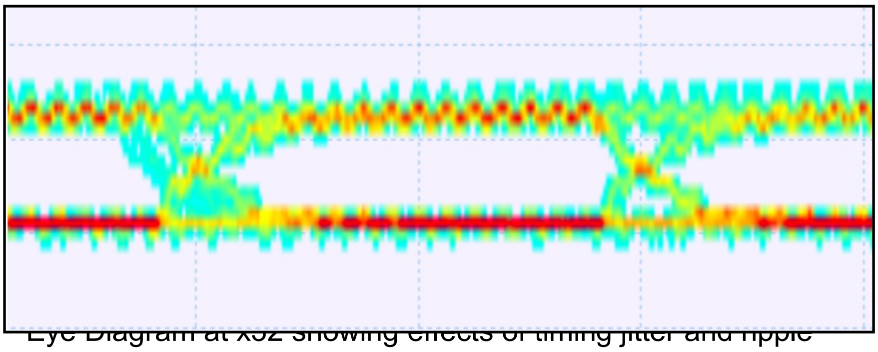


- not possible to recognise original data stream.

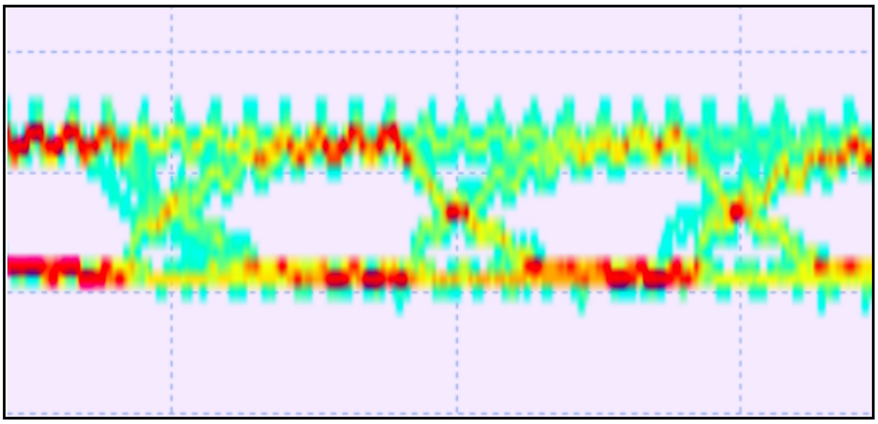
	Notes
Worksheet 13 DSSS	Typical results.....

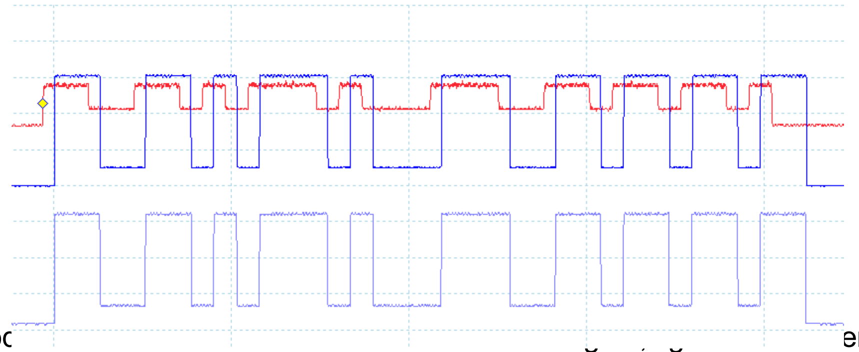
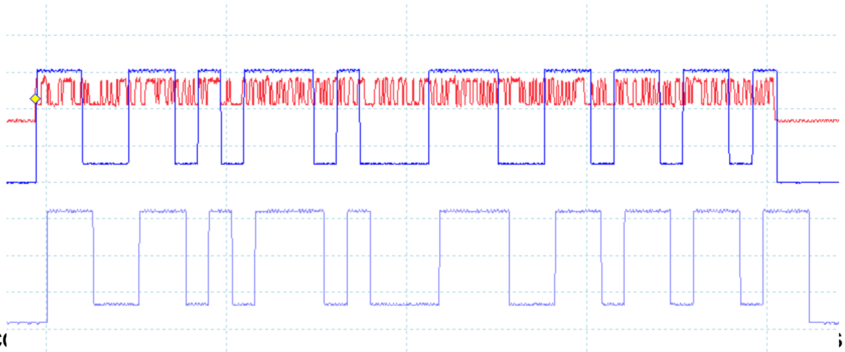
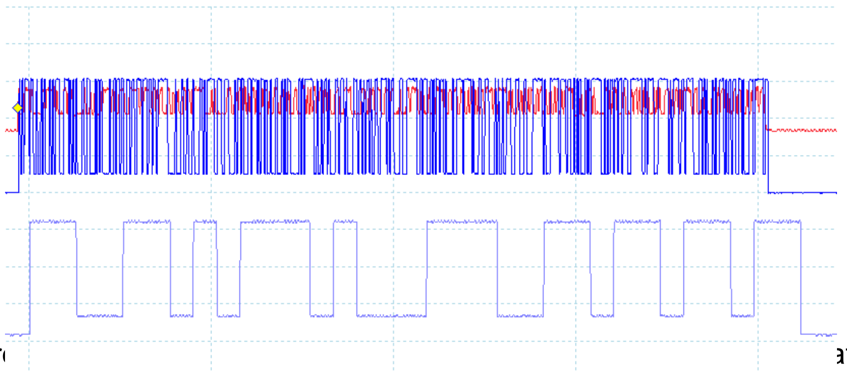


At 32 times, the raw signal appear to be noise



Eye Diagram at x32 showing effects of timing jitter and ripple



	Notes
Worksheet 14 DSSS decoding	This worksheet then takes student through the techniques of adding a multiplier to the original signal with a chosen seed or key, the reconstruction of the original signal, and the fact that without knowledge of the frequency of the PRBS and the key that the original signal is impossible to reconstruct Typical results for the investigation are given below:  Decoc … erence, dark blue = reconstructed original  Dec(… ;ignal, light blue = reference, dark blue = reconstructed original  Decoded r(… ated signal, light blue = reference, dark blue = reconstructed original

Teacher’s notes

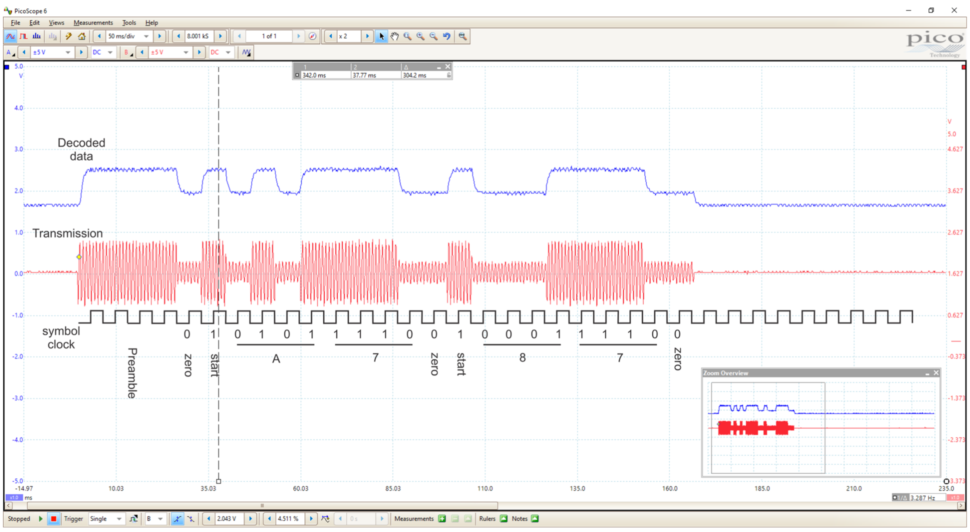
Notes

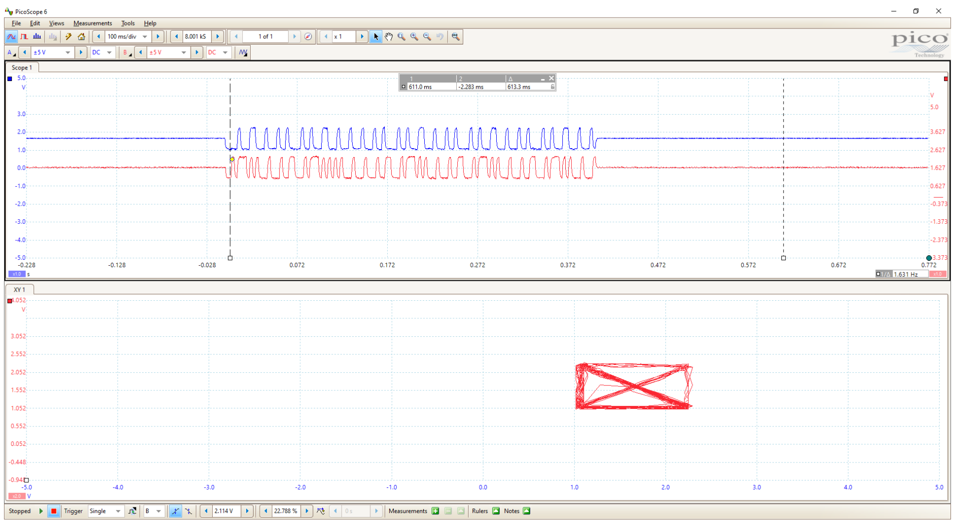
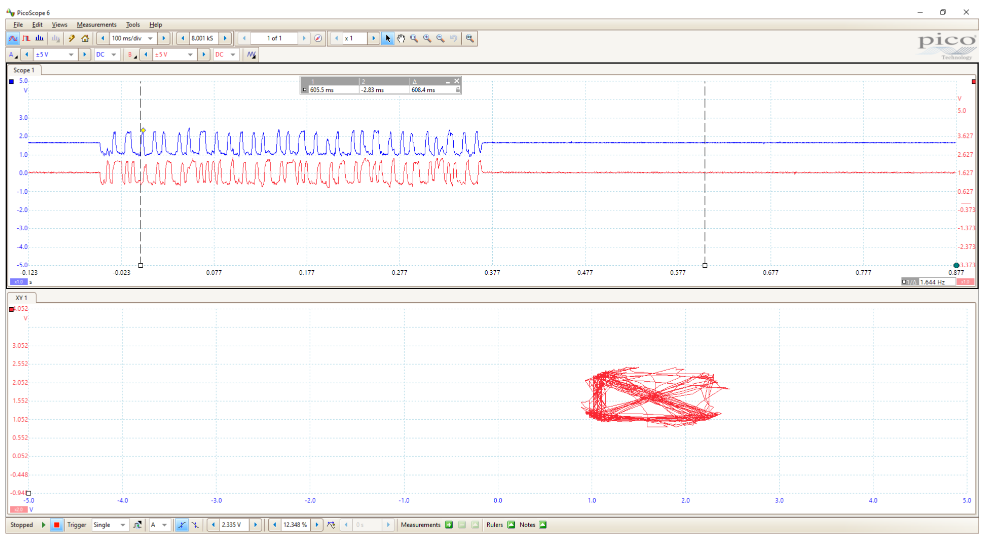
Worksheet 15 Communication systems

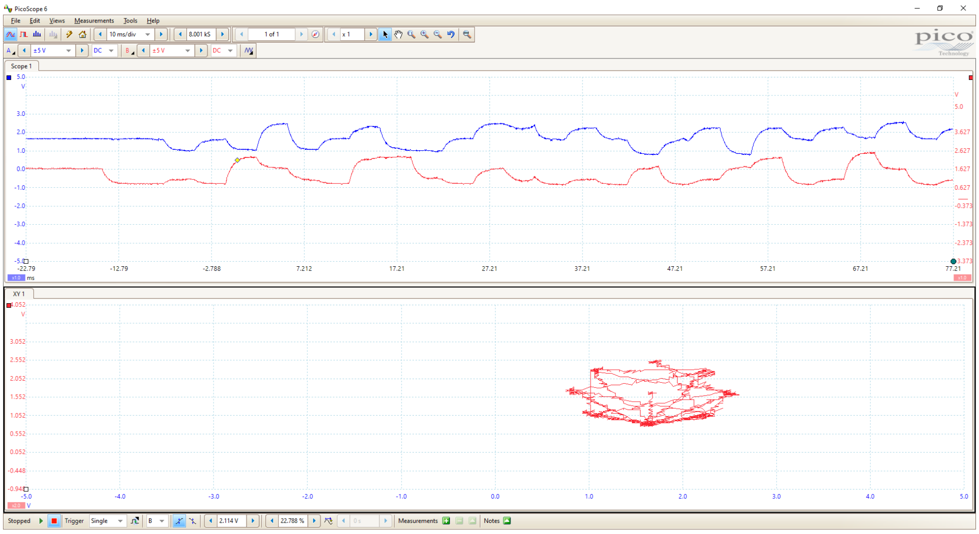
Typical results for the investigation are given below:

		Carrier	Baud rate	Preamble length	Group length	Tx length
		5	300	2	4	16
	OOK	ASK	FSK	BPSK	QPSK	8PSK
packet time in ms	608	608	610	613	413	272

	BER %				
Noise /dB	OOK	ASK	FSK	BPSK	QPSK
-24.08	0	0	0	0	0
-18.06	0	0	0	0	1.82
-14.54	0	0.26	0.26	0	1.3
-12.04	0.78	0.52	0	0	7.81
-10.1	2.6	4.17	2.08	15.62	8.33
-8.52	1.3	25	29.43	3.65	30.73
-7.18	1.04	2.6	5.73	3.39	50.52
-6.02	4.69	16.41	3.12	10.94	45.05
-5	20.05	5.47	4.95	15.62	38.02
-4.08	34.38	8.59	12.24	39.58	48.7
-3.25	28.39	35.16	34.38	47.4	53.91
-2.5	28.65	30.21	24.74	49.22	57.03
-1.8	33.85	36.2	33.33	54.95	49.74
-1.16	33.07	36.98	34.64	53.65	47.14
-0.56	34.9	35.68	35.94	26.56	58.59
0	35.68	38.54	33.59	31.25	46.88



	Notes
Worksheet 15 Communication systems	 QPSK, 5kHz carrier, 150baud, 2 preamble, 4 group, no noise, BER 0%  8PSK, 5kHz carrier, 150baud, 2 preamble, 4 group, with -14dB noise, BER 0%

	Notes
Worksheet 15 Communication systems	 8PSK, 5kHz carrier, 150baud, 2 preamble, 4 group, no noise, BER 0%  8PSK, 5kHz carrier, 150baud, 2 preamble, 4 group, with -14dB noise, BER 32%

Version control

15 02 24 First release