M-ary ASK

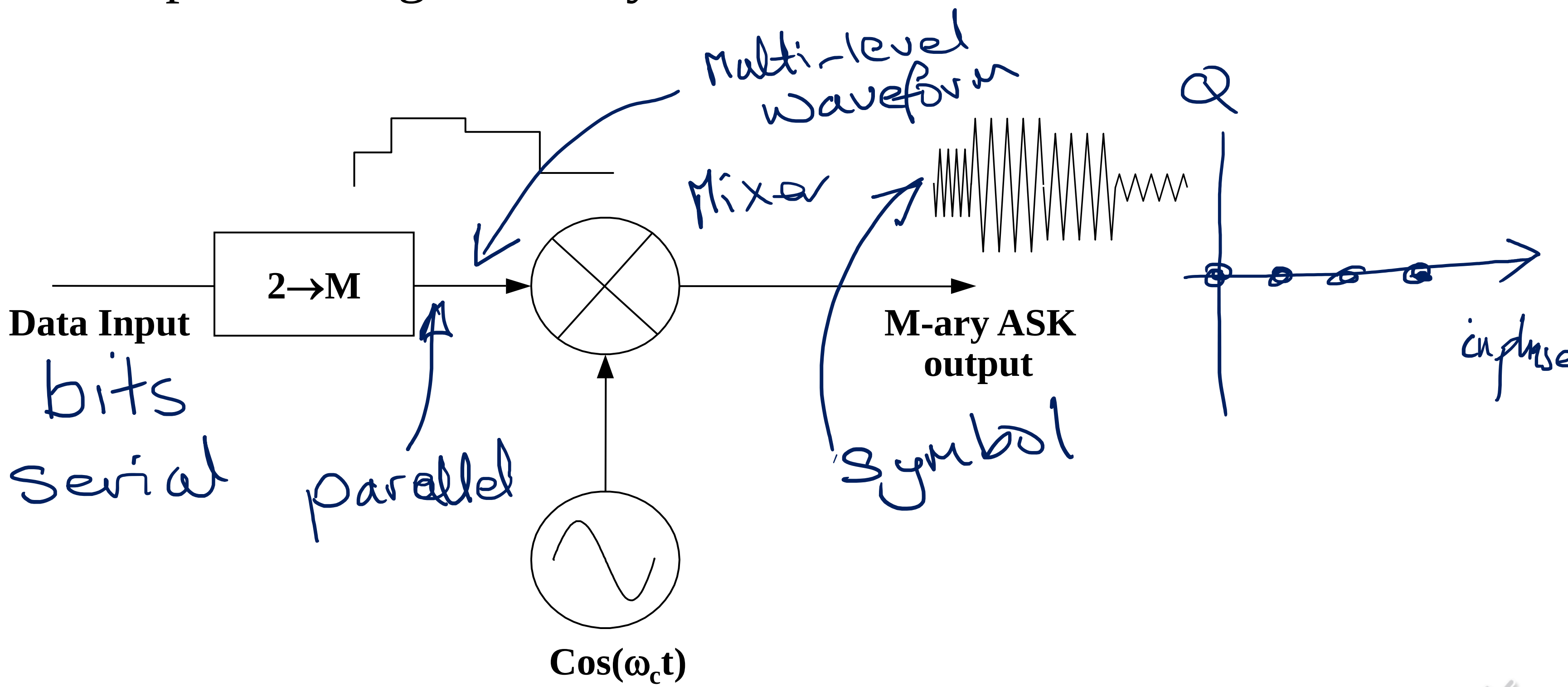
M-ary Signaling

- So far, we have considered ASK, FSK and PSK only in terms of Binary Signaling.
- We know that for baseband signaling, M-ary signaling offers higher spectral efficiency at the penalty of increased SNR requirement.
- We will now consider M-ary ASK, M-ary FSK and M-ary PSK.

→ QAM

M-ary ASK

- M-ary ASK maps b bits of data to one of 2^b different amplitude levels.
- A circuit for implementing an M-ary ASK source is shown below.

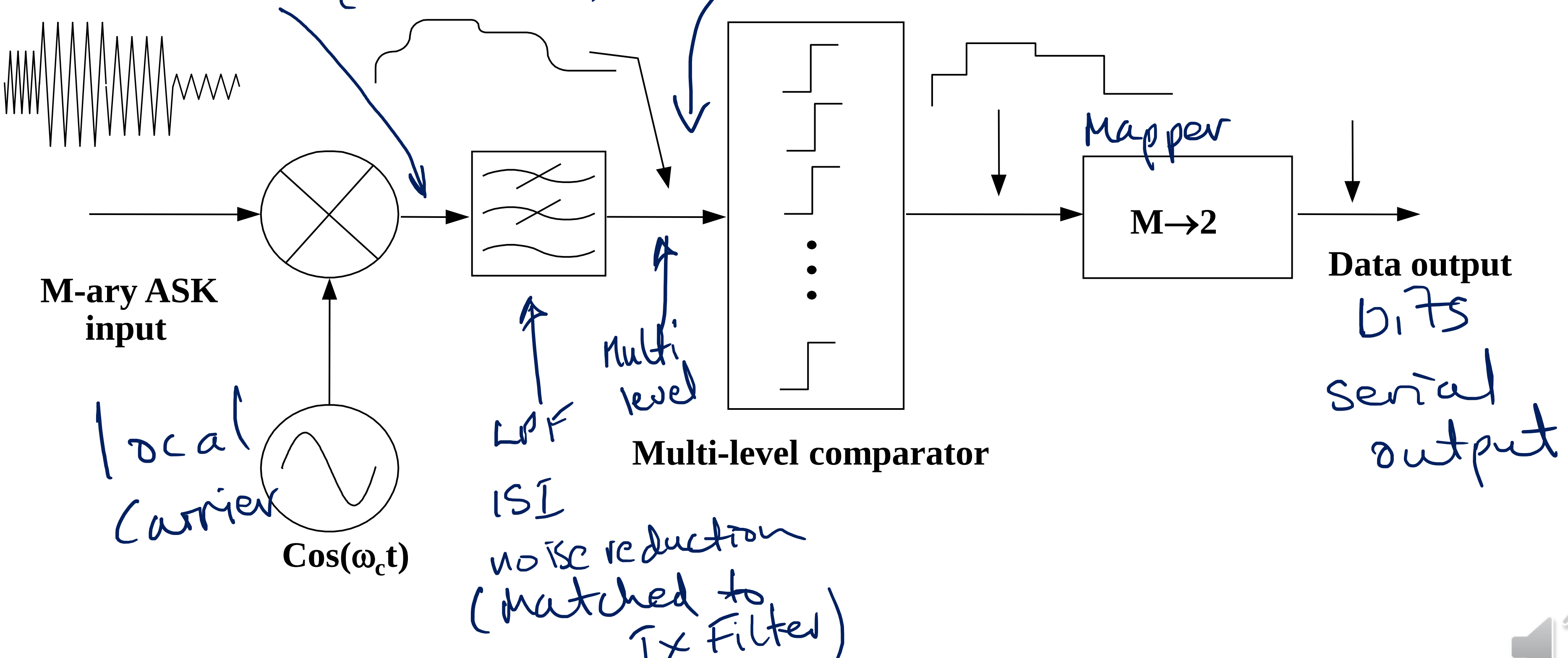


M-ary ASK

- The circuit for implementing an M-ary coherent ASK detector is shown below.

difference Frequency (baseband)

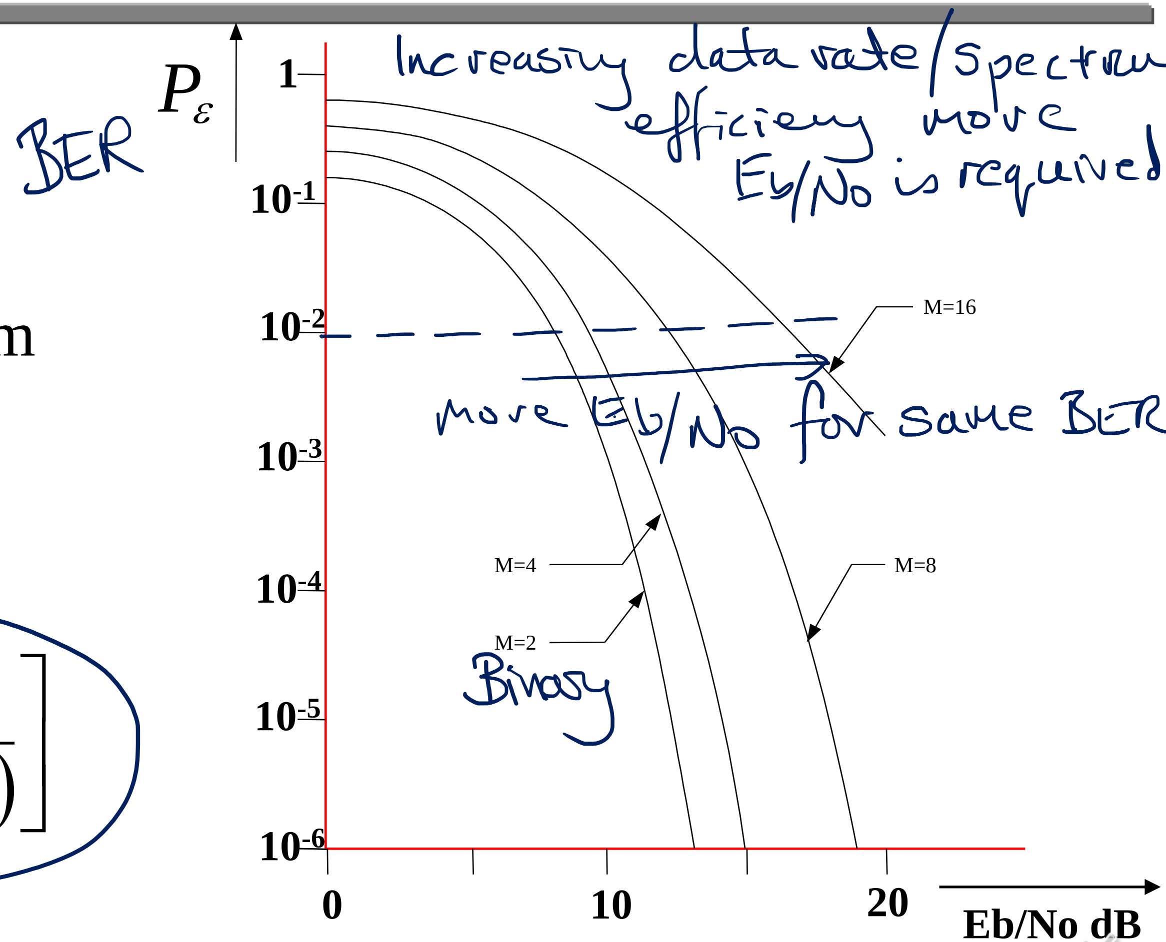
parallel (Symbols



M-ary ASK

- With M-ary ASK there is no opportunity to exploit orthogonality.
- Thus, when we move away from binary ASK, we immediately pay a penalty in terms of BER.

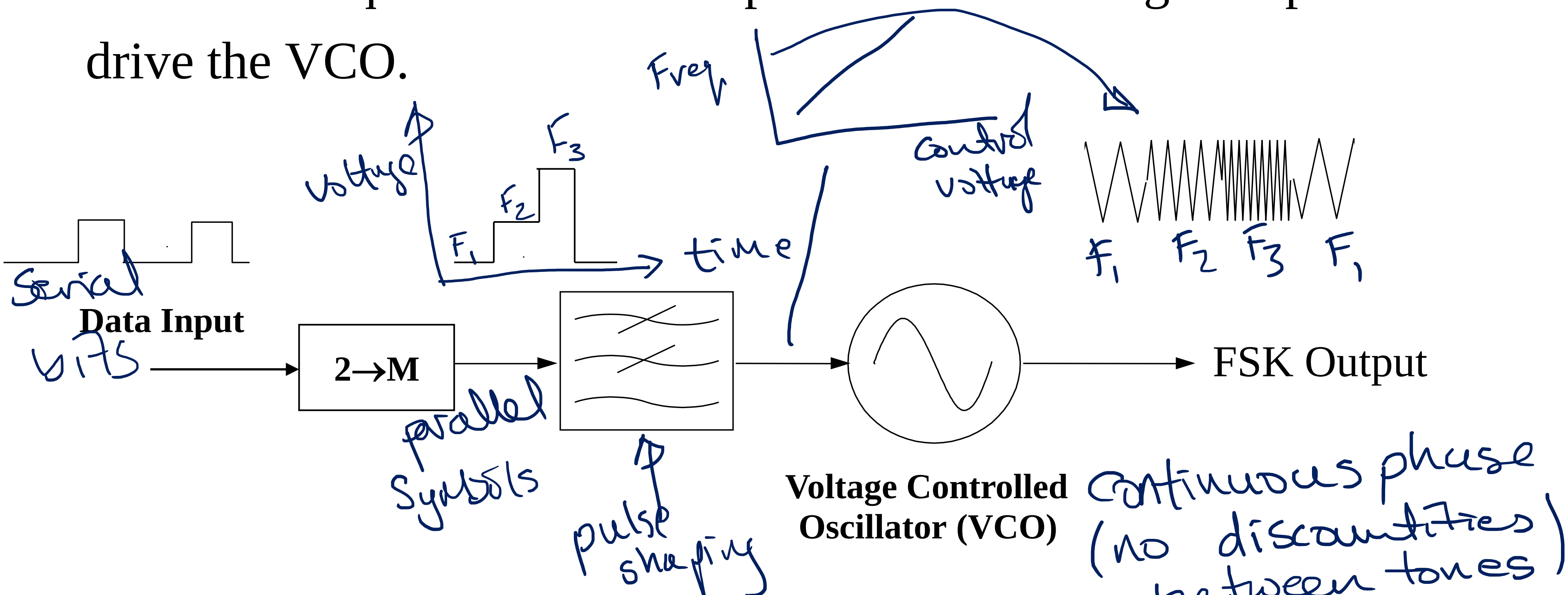
$$P_s = \frac{M-1}{M} erfc\left[\frac{3E_b}{N_o(M^2-1)}\right]$$



M-ary FSK

M-ary FSK

- M-ary FSK maps b bits to one of 2^b different frequencies.
- M-ary FSK is modulated in a similar fashion to binary FSK. The only additional requirement is to map the b bits to a single amplitude level to drive the VCO.



Orthogonal FSK Signals

- For binary FSK the criteria for Orthogonal frequencies was that they be separated by a multiple of one half of the modulating symbol rate. This holds true for M-ary FSK Thus a set of M orthogonal FSK signalling frequencies is given by $a_m(t)$:

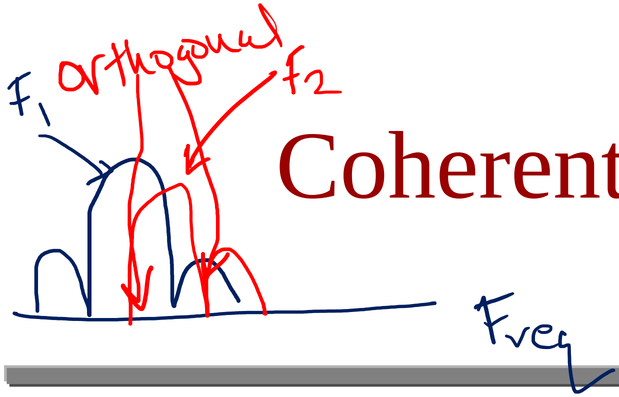
$$a(t) = cos\left(2\pi t\left(f_c + \frac{m}{2T_S}\right)\right)$$

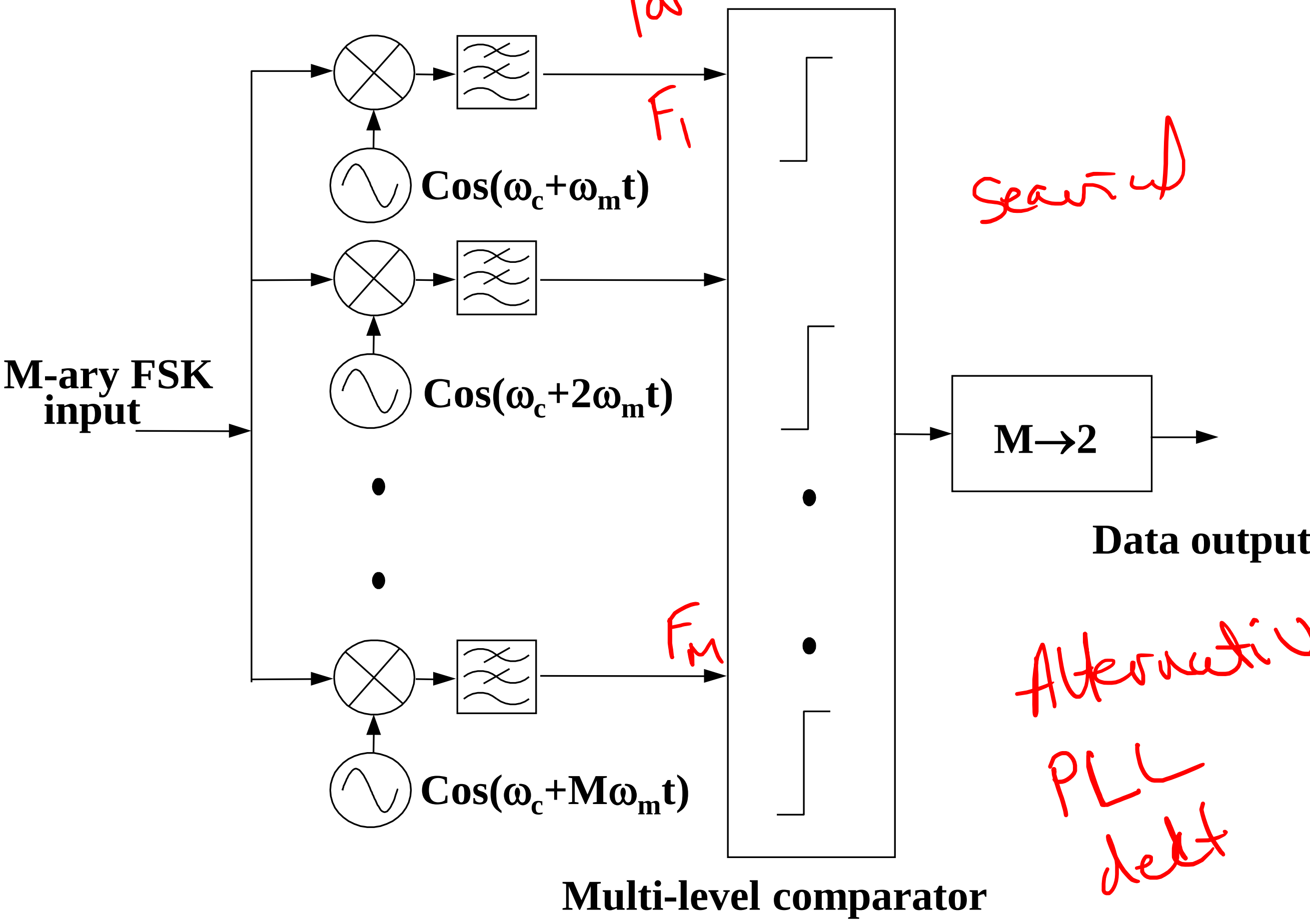
$T_s = 1ms$

$M = 1, 2, 3, 4$ etc

Tone		
	500Hz	F_1
	1000Hz	F_2
	1500Hz	F_3
	2000Hz	F_4

Coherent M-ary FSK Detection



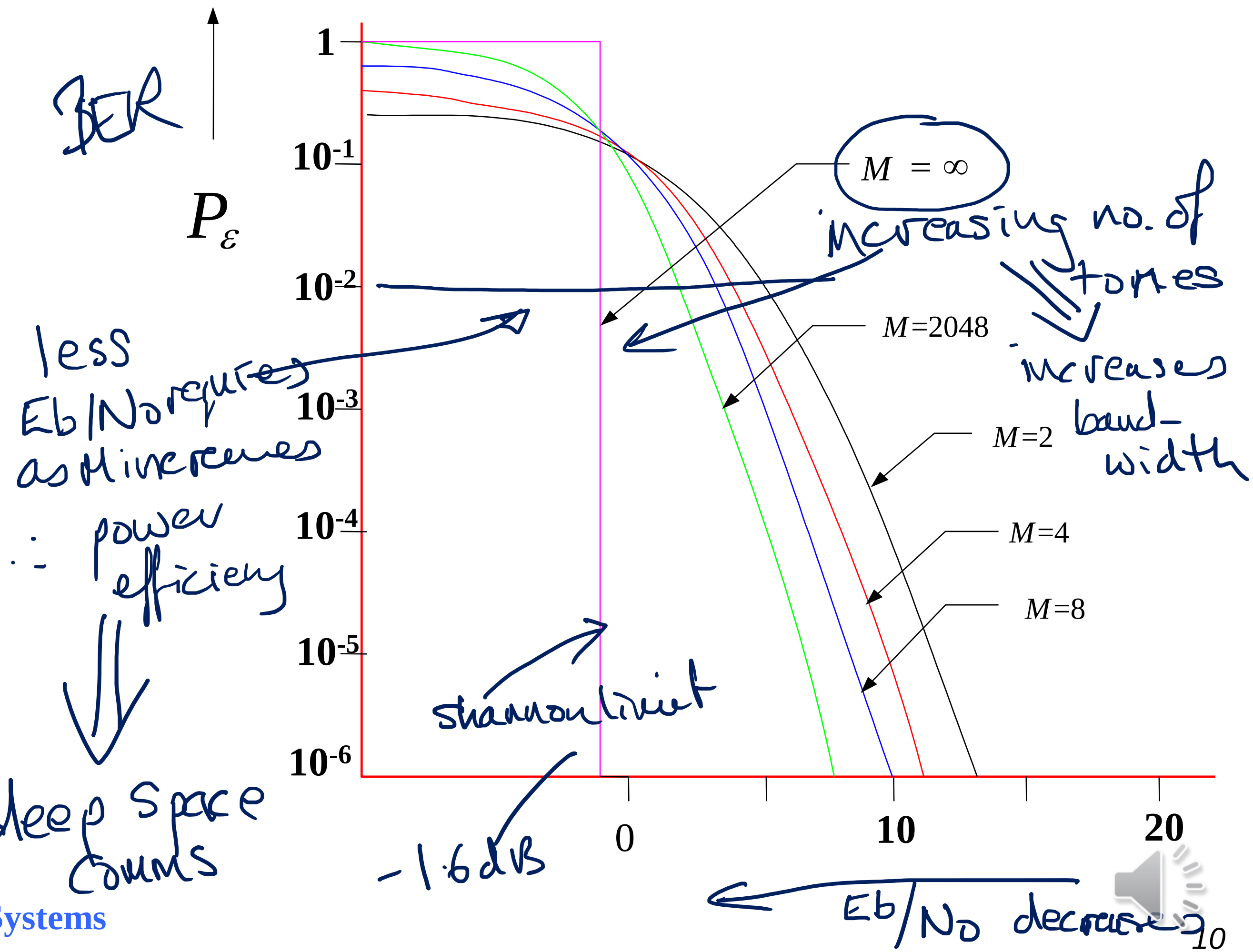


Alternative PLL dect

As the FSK signals are orthogonal, the integrator (low pass filter), will give zero output, over the sample period, when the input signal to the mixer, is equal to any other frequency, except the frequency of the local oscillator.

BER vs. Eb/No and Spectral Efficiency of M-ary FSK

- For FSK, the Eb/No requirement for a given BER goes down as M increases.
- However, since the bandwidth requirement increases linearly with M (while the capacity increases according to $\log_2 M$) the spectral efficiency actually decreases. This is the other way round compared to most forms of modulation



QPSK & DQPSK

Orthogonal Signalling by Quadrature Phase Shift Keying (QPSK)

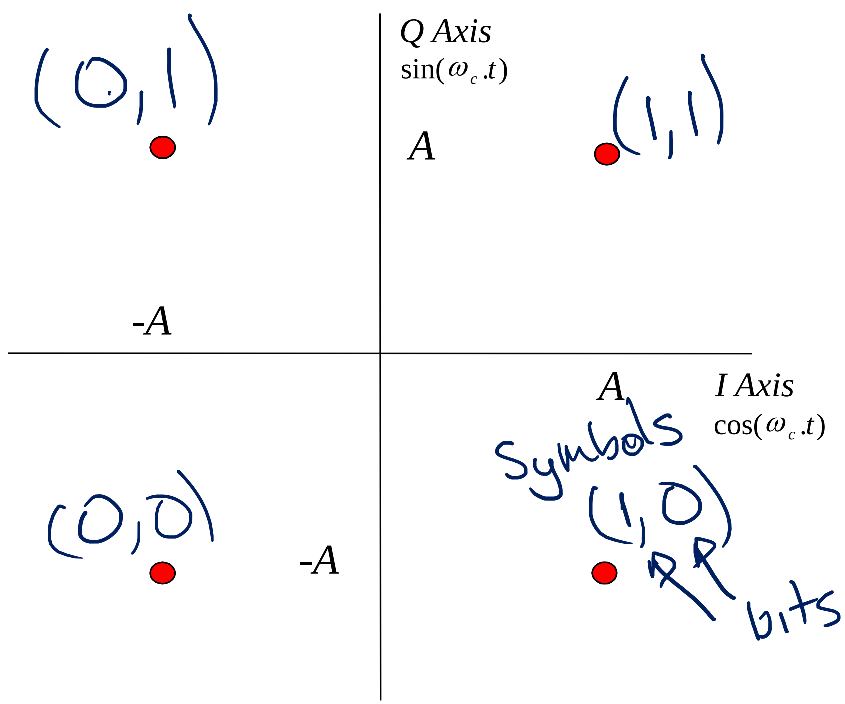
- It is possible to transmit orthogonal signals on the same transmission link, without one set of signals affecting the detection of the other.
- Two pairs of phase symbol states which have orthogonal properties are: BPSK inphase BPSK Quadrature

$$+/- A.\cos(\omega_c t) \text{ and } +/- A.\sin(\omega_c t)$$

- Thus, cos and sin waves of the same frequency are orthogonal to each other. We can exploit this to improve the spectral efficiency of PSK.

Quadrature Phase Shift Keying (QPSK)

- Constellation diagram for QPSK is shown below.

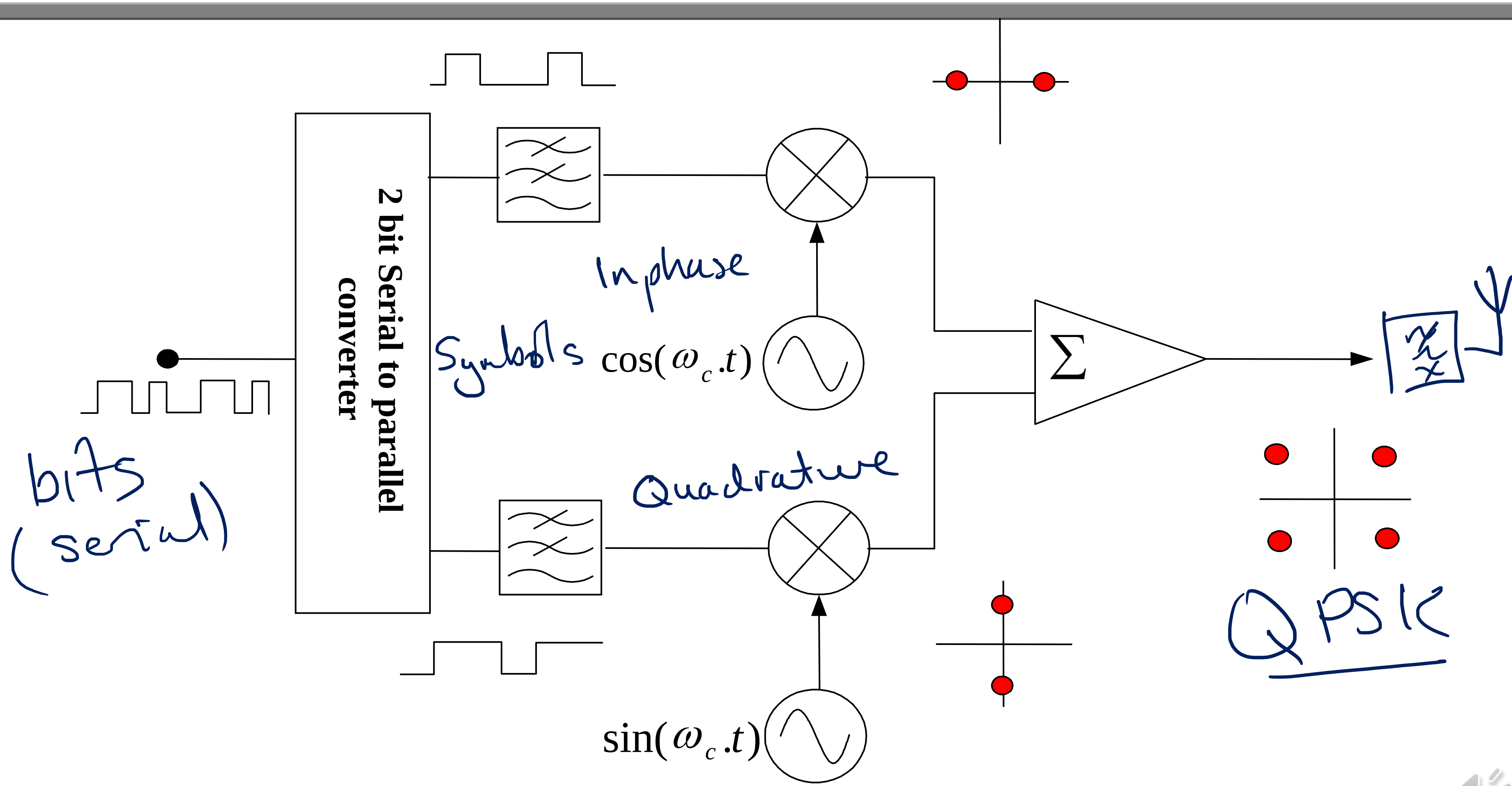


- It is possible to transmit these two binary PSK signals in quadrature, and achieve 4-ary PSK, with no increase in bandwidth requirement.
- Thus, the spectral efficiency may be doubled without increasing the Eb/No requirement.
- QPSK is 4-PSK

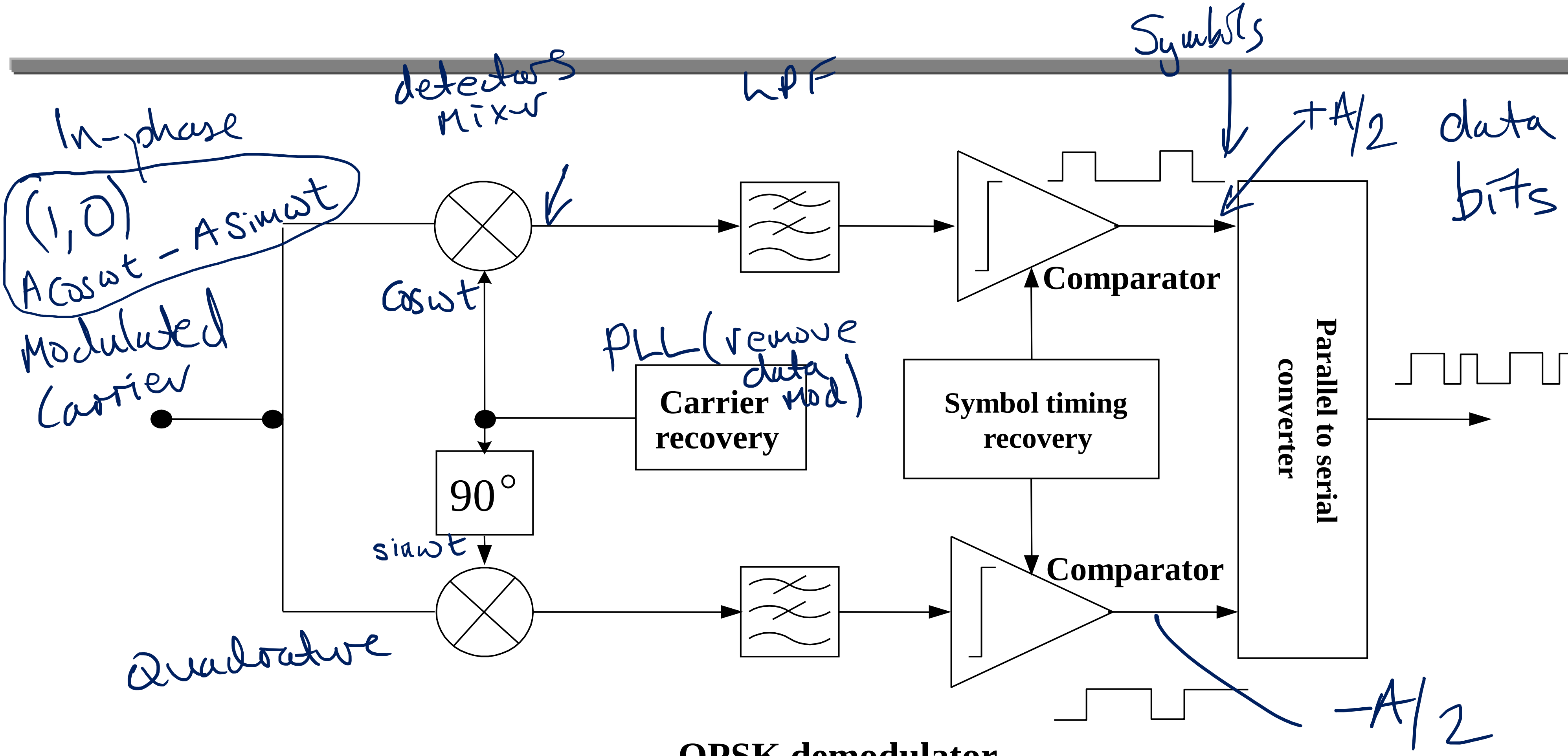
2 bits per symbol

$\boxed{\text{2 bits/s/Hz spectral efficiency}}$

Generation of Quadrature Phase Shift Keying



Detection of QPSK (1)



QPSK demodulator

Detection of QPSK (2)

- Assume we are sending the symbol 1 0, this means that the transmitted signal is given by:

$$\overbrace{+A\cos(\omega_c.t) - A\sin(\omega_c.t)}^{\text{Symbol}}$$

- The output of the I path is given by:

$$+A\cos(\omega_c.t)\cos(\omega_c.t) - A\sin(\omega_c.t)\cos(\omega_c.t)$$

$$= \frac{A}{2}\left(\cos(2.\omega_c.t) + 1 + \sin(2.\omega_c.t)\right) + 0$$

$$= +\frac{A}{2}$$

- Where the LPF removes the double frequency terms

Detection of QPSK (3)

- The output of the Q path is given by:

$-A$

$$+A\cos(\omega_c.t)\sin(\omega_c.t)-A\sin(\omega_c.t)\sin(\omega_c.t)$$

$$=\frac{A}{2}\left(\sin(2.\omega_c.t)-1+\cos(2.\omega_c.t)\right)$$

DC

$$=-\frac{A}{2}$$

- Again, the double frequency components are removed by the LPF

Detection of QPSK (4)

- ‘1’ has been recovered in the I channel and the ‘0’ has been recovered in the Q channel.
- A parallel to serial converter now reconstructs the data stream.
- To retain the good error performance of QPSK it is important that the phase relationship be retained precisely. Otherwise, there will be ‘crosstalk’ between BPSK streams, which will degrade performance.

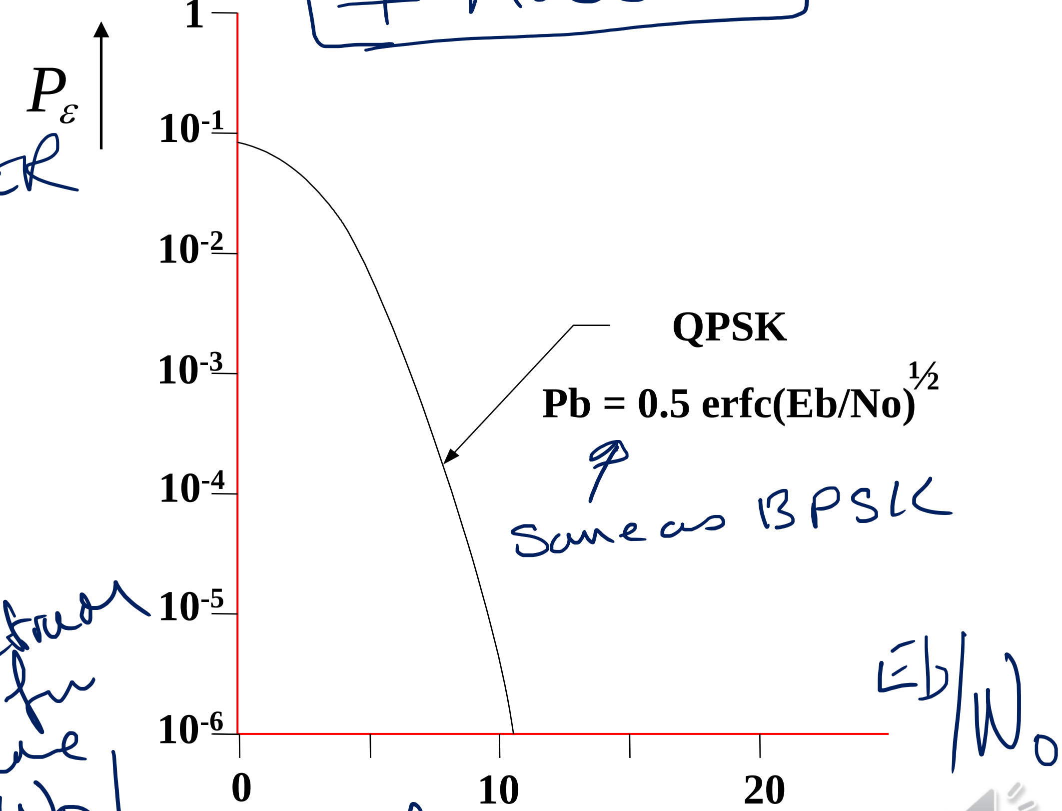
BER vs Eb/No of QPSK

- The BER performance of QPSK is shown below.

+ AWGN

- QPSK requires the same Eb/No as BPSK and Polar Baseband
- QPSK allows the designer to recover the 2 bits/second/Hz efficiency of a binary baseband data stream, without suffering a BER performance degradation

Double spectrum Efficiency for the same Eb/No | BER performance.



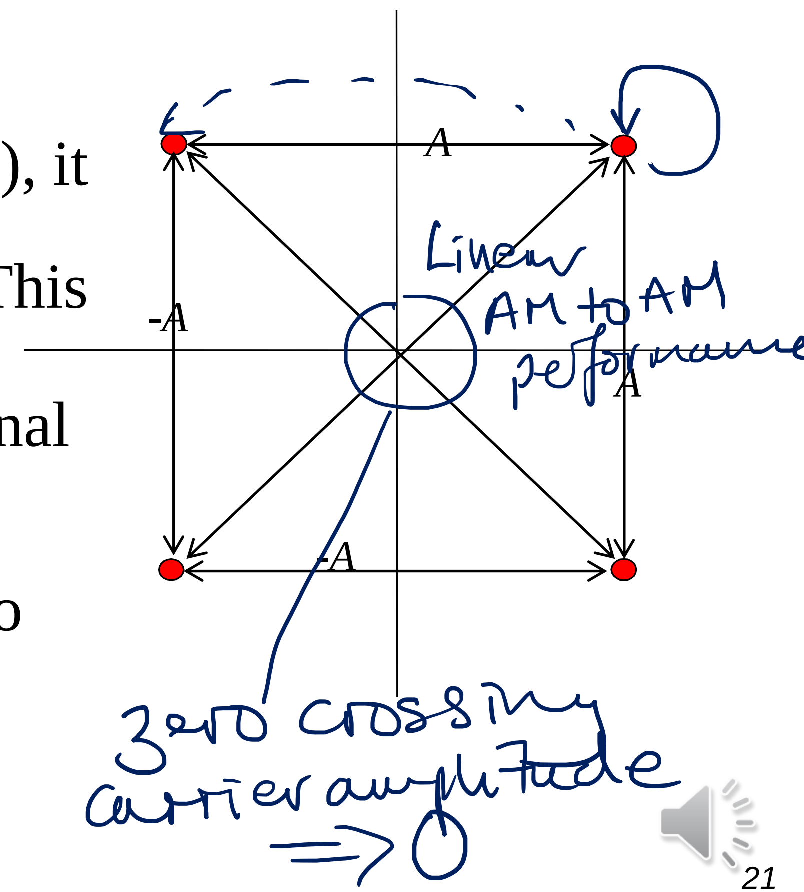
Differential QPSK

- As with BPSK, problems arise with the regeneration of the carrier phase in conventional PSK and QPSK systems. A training sequence to resolve ambiguities can be used.
- With differential QPSK the phase of the current bit is compared with the phase of the previous bit overcoming the need for a training sequence.
- The reference signal is now a signal contaminated by noise, and not a low noise oscillator, the BER performance of Differential QPSK is inferior, to true QPSK.
- Approximately 2dB more energy is required for DQPSK when compared with QPSK for the same error performance

π /4 QPSK (1)

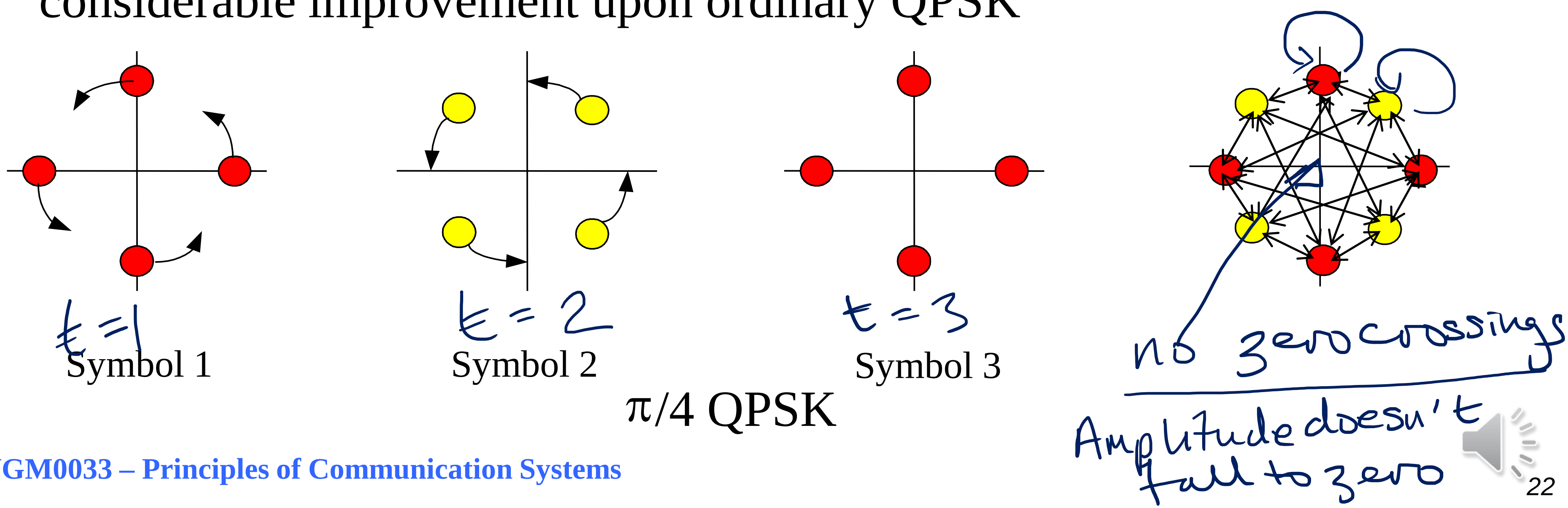
- It is important, when using mobile radio equipment to make the transmitter power amplifier as efficient as possible.
- As the most efficient power amplifiers are essentially non-linear (e.g. class C amplifiers), it is useful to employ a modulation method in which the amplitude is essentially constant. This is termed constant envelope modulation.
- QPSK is not constant envelope, since the signal envelope will pass through zero when the symbol to be transmitted has a phase 180° relative to the previous symbol. a transition to the symbol

Standard QPSK



π /4 QPSK

- π/4 QPSK prevents zero crossings by rotating the symbol set by 45° at each symbol transition.
- If viewed on a constellation diagram, this effect can be seen.
- Note that this is still not constant amplitude modulation but it is a considerable improvement upon ordinary QPSK



π/4 QPSK

Offset QPSK

- This type of modulation is similar to π/4 QPSK.
- Here the input stream to one of the 2 quadrature PSK modulators is delayed by half a symbol period. In this way, the envelope of the modulation signal does not go through zero.
- The BER performance of π /4 QPSK and Offset QPSK is identical to QPSK, in AWGN

M-ary PSK & QAM

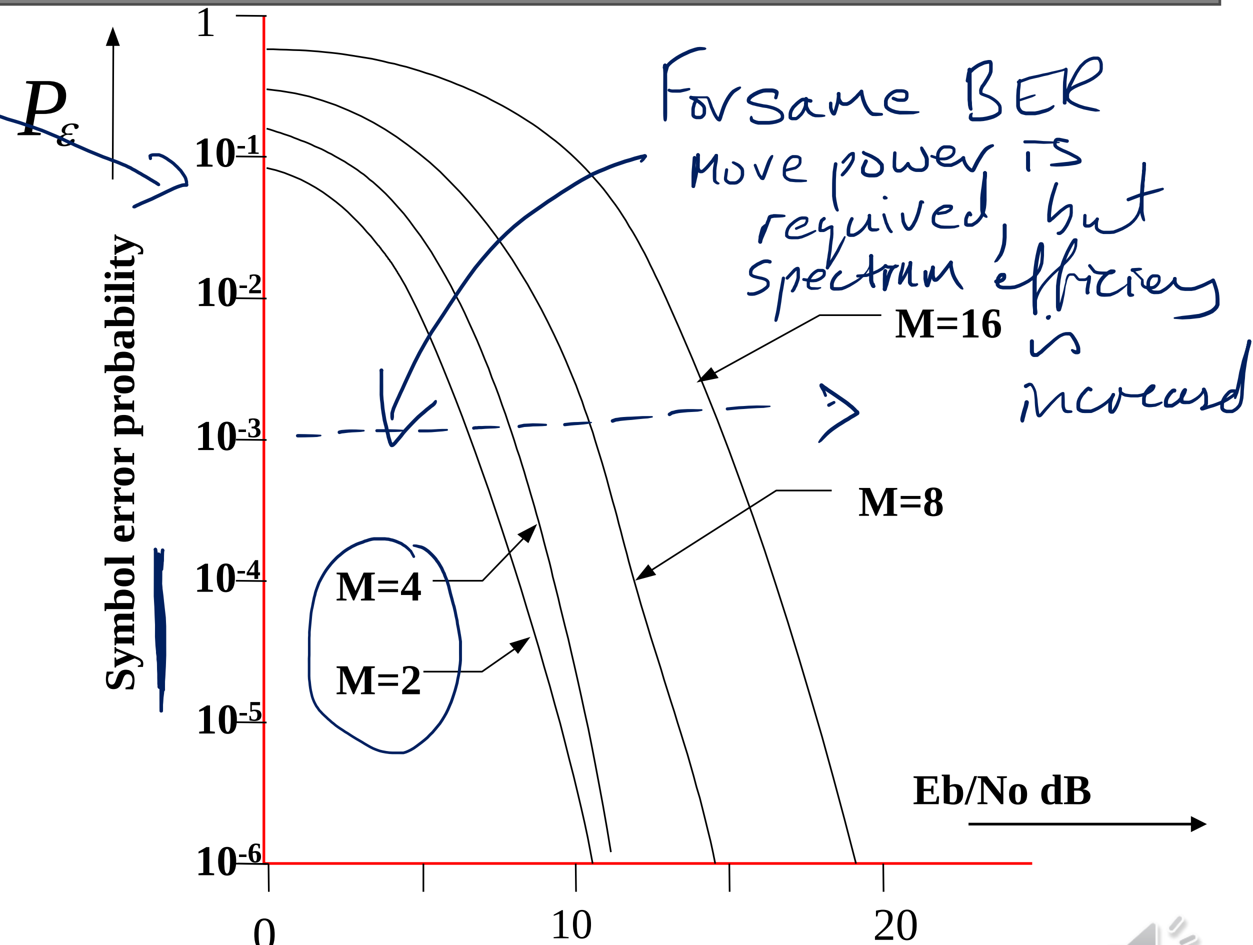
M-ary PSK

- QPSK (M=4) is the only modulation format which can simultaneously improve both bandwidth efficiency when compared with BPSK (M=2) without requiring an increase in SNR for the same BER threshold.
- Increasing the number of symbol states to M>4 results in an increase in bandwidth efficiency at the expense of increase in BER (for a fixed E_b/N_o) or, an increased E_b/N_o to retain the BER.

Symbol Error Probability for M-ary PSK

$$P_s = erfc\left[\frac{E_s}{N_o}\sin\left(\frac{\pi}{M}\right)\right]$$

$$P_b = \frac{P_s}{\log_2 M}$$



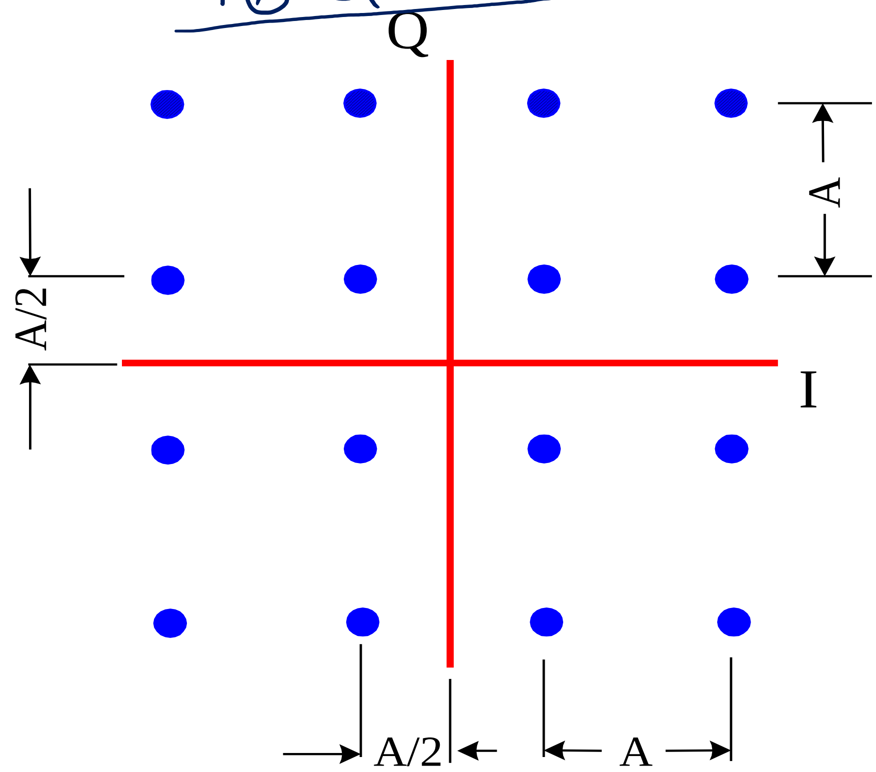
For same BER more power is required, but spectrum efficiency is increased

Quadrature Amplitude Modulation (QAM)

4 bits per Symbol

- Thus far we have only considered modulators that alter a single property of a carrier wave to transmit information.
- A modulation method that combined symbol types could give an improved performance in the inevitable trade off between bandwidth efficiency, and noise performance.
- The most common example of this strategy is QAM. QAM amplitude modulates two quadrature signals. Thus both amplitude and phase of the signal are altered.

16 QAM



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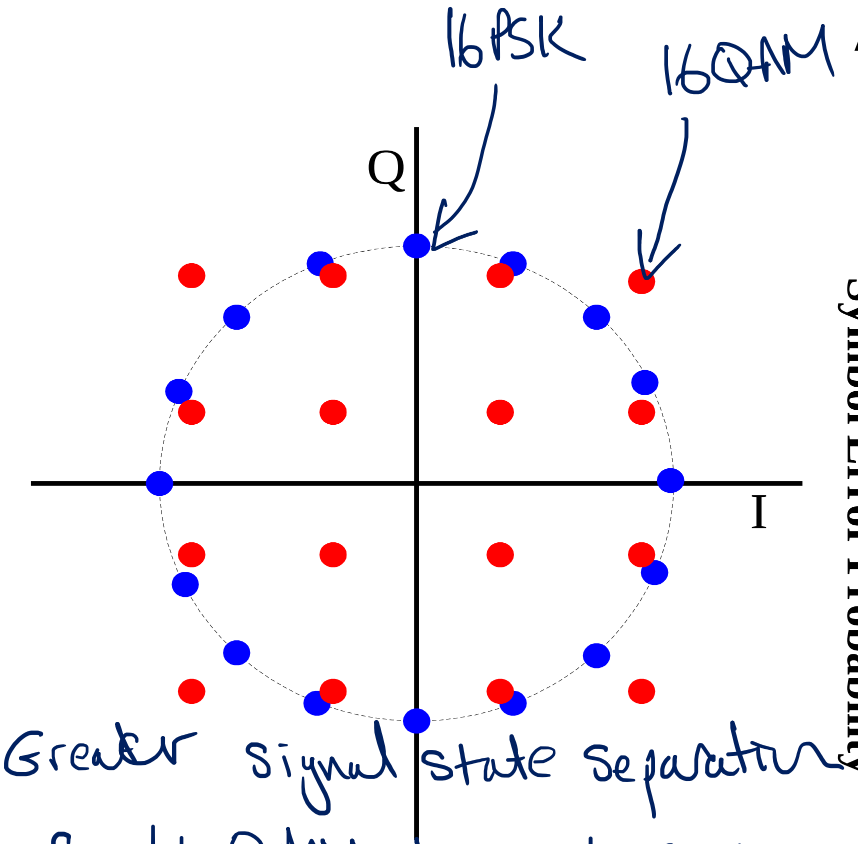
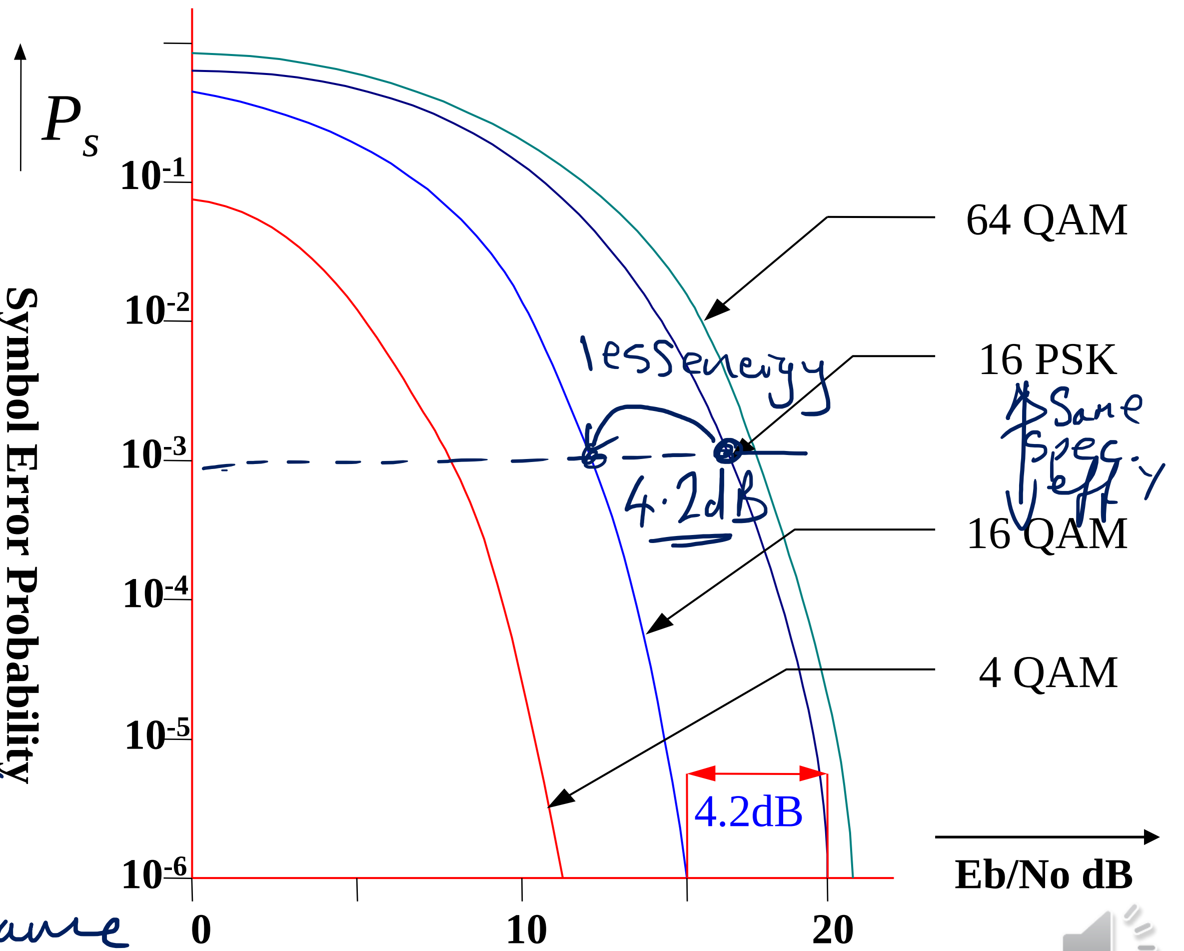
QAM & M-ARY PSK Comparison





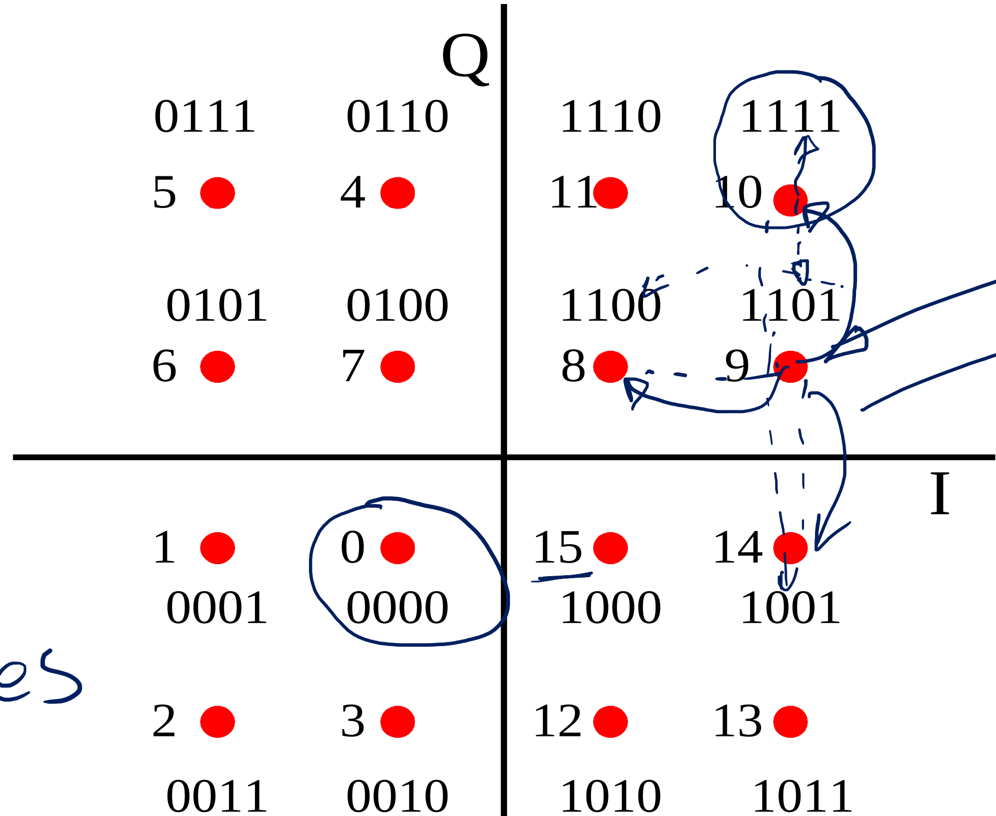
Greater signal state separation for 16 QAM than 16 PSK
⇒ better noise performance

Gray coding

- Gray coding is a way of ensuring that if an error occurs in a data transmission, that the effect of the error is minimized.
- This can be done because the most likely source of error will be a mistake between adjacent states.
- With Gray coding the difference between adjacent states is only ever one bit.

	Non Gray coded	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

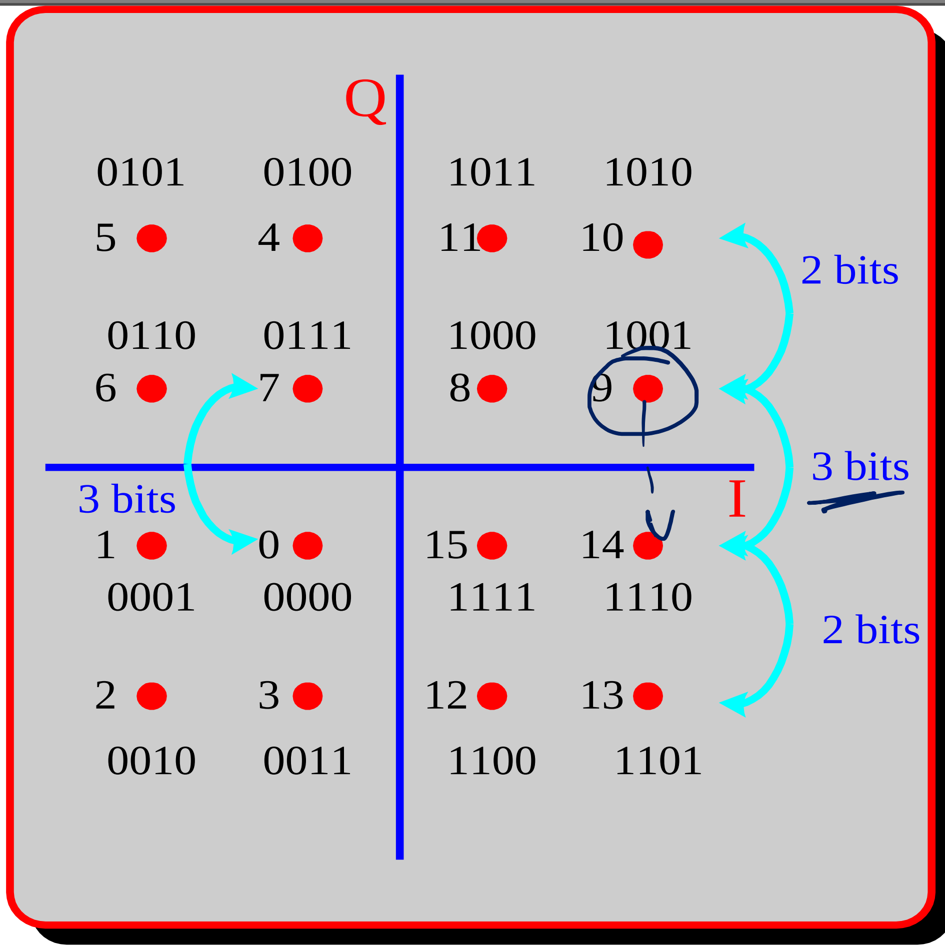
Application of Gray coding to 16-QAM



Only one bit changes between adjacent signal states

⇓ Good for Error protection scheme.

Non Gray coded 16-QAM



Comparison of Modulation types (1)

Capacity / bandwidth

bit/s/Hz

< 10^{-6} in AWGN

Modulation Format	Bandwidth efficiency (C/B)	log2 (C/B)	Error free Eb/No
16 PSK	4	2	18dB
16 QAM	4	2	15dB
8PSK	3	1.585	14.5dB
4PSK	2	1	10.1dB
4QAM QPSK	2	1	10.1dB
BFSK	1	0	13dB
BPSK	1	0	10.5dB
4FSK	1	0	11dB
8FSK	0.75	-0.4	9dB

best

Poor

More energy (Poor)

Less energy

good

Trade-off.

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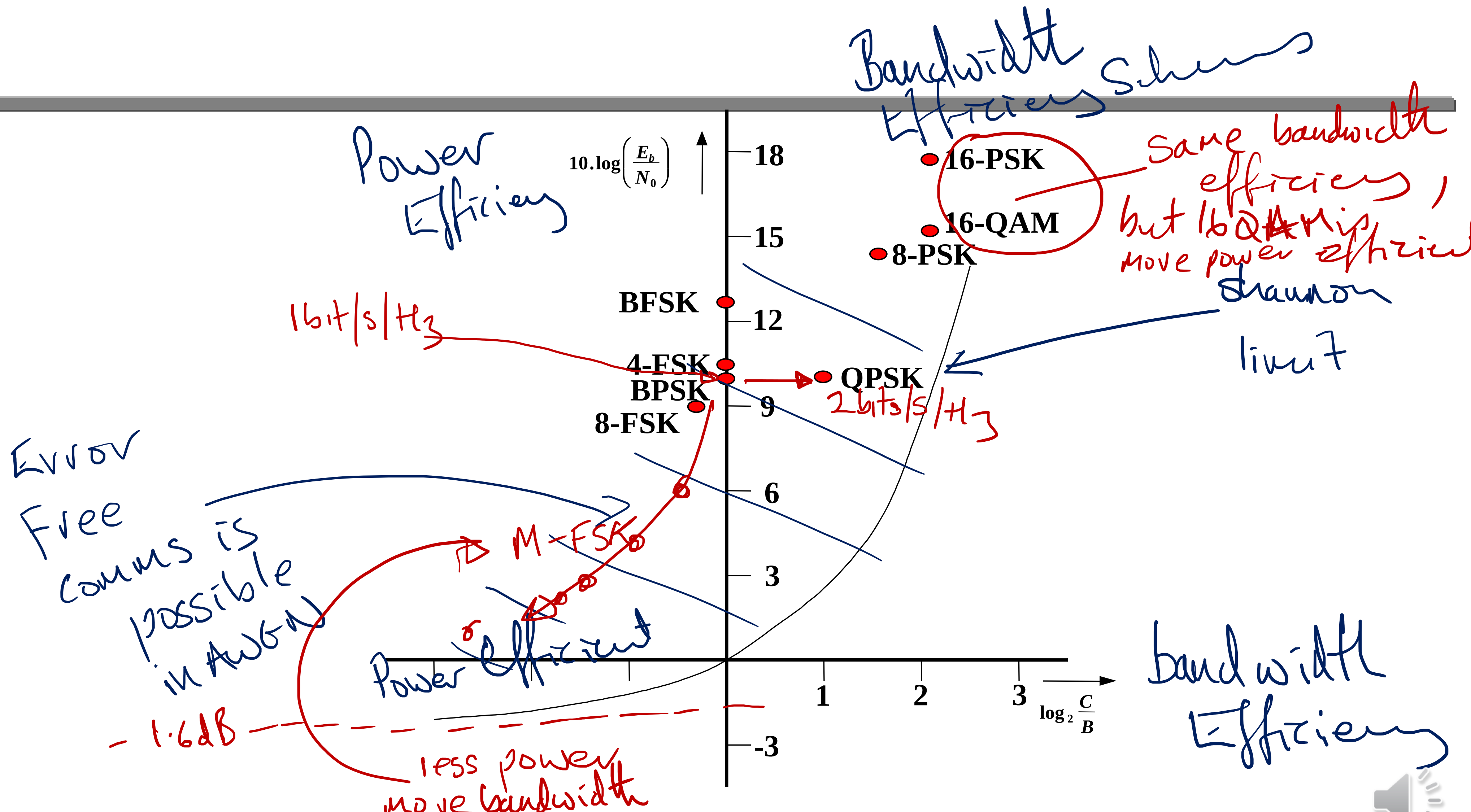
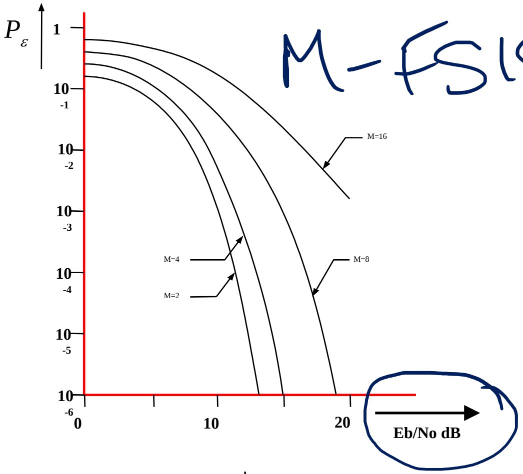
Comparison of Modulation types (2)



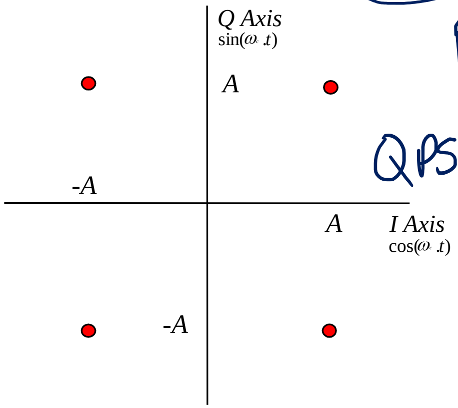
Comparison of Modulation types (3)

- For practical systems, the choice of modulation scheme is typically between Binary FSK, QPSK and QAM.
- It can be seen from the Shannon Curve that Binary FSK offers a relatively poor trade-off of spectral efficiency against power requirements. However, it is a constant envelope modulation scheme which is well suited to very low cost applications. It has been widely used in the past.
- QPSK offers a superior trade-off of spectral efficiency against power requirements. In its $\pi/4$ form it is reasonably easy to implement. $\pi/4$ QPSK has gained in popularity for low to medium cost applications in recent years.
- QAM offers the highest spectral efficiency and the best trade-off with signal power requirements. Thus, it is typically the modulation scheme of choice when spectral efficiency is more important and increased cost more acceptable.

Bandpass Digital Modulation

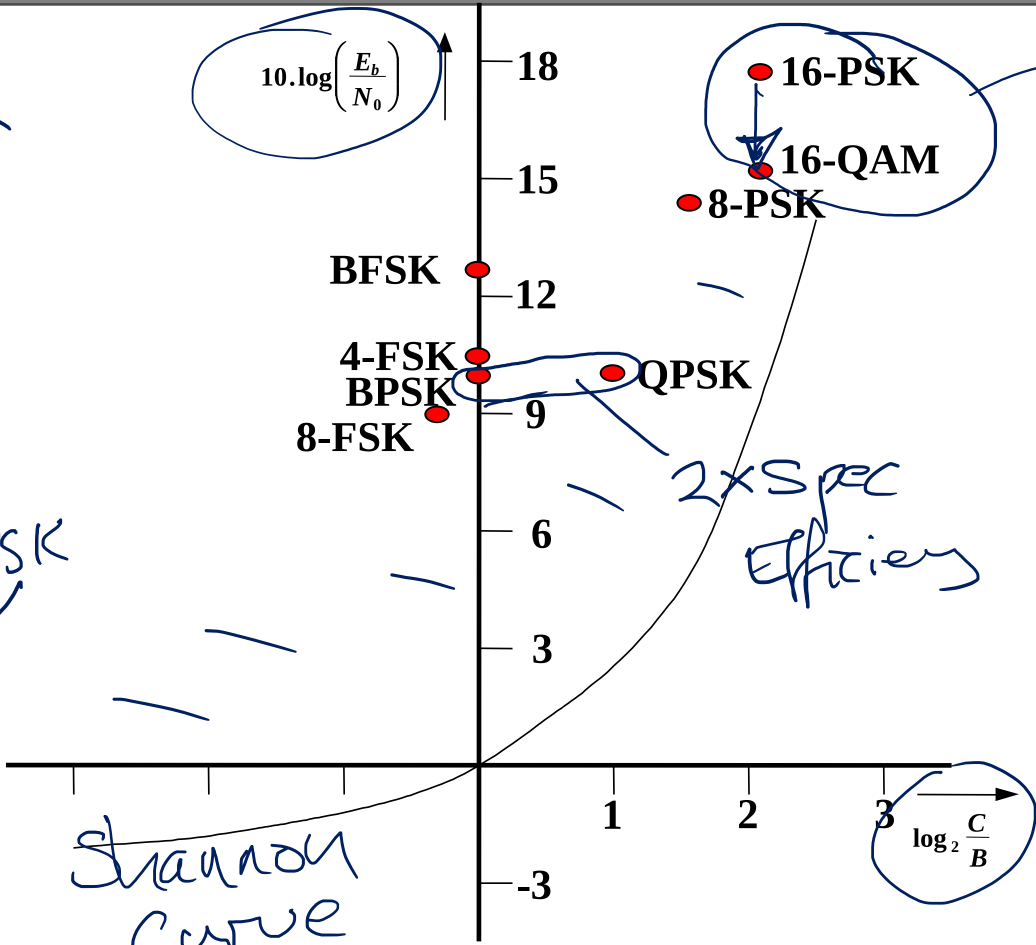


M-FSK



BPSK

QPSK



2×Spec Efficiency

Shannon Curve