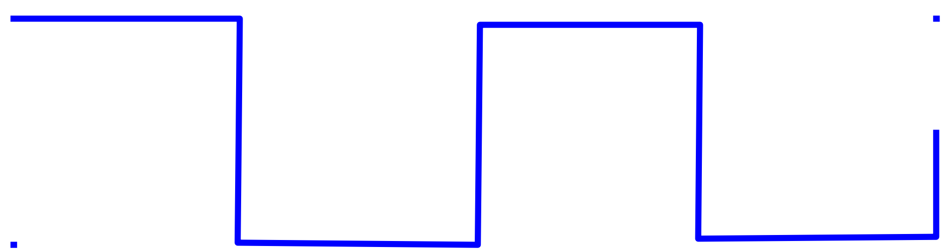
CMP4204
Wireless Technologies

Lecture 3

Digital Modulation



Diarmuid Ó Briain
CEng, FIEI, FIET, CISSP

diarmuid@obriain.com

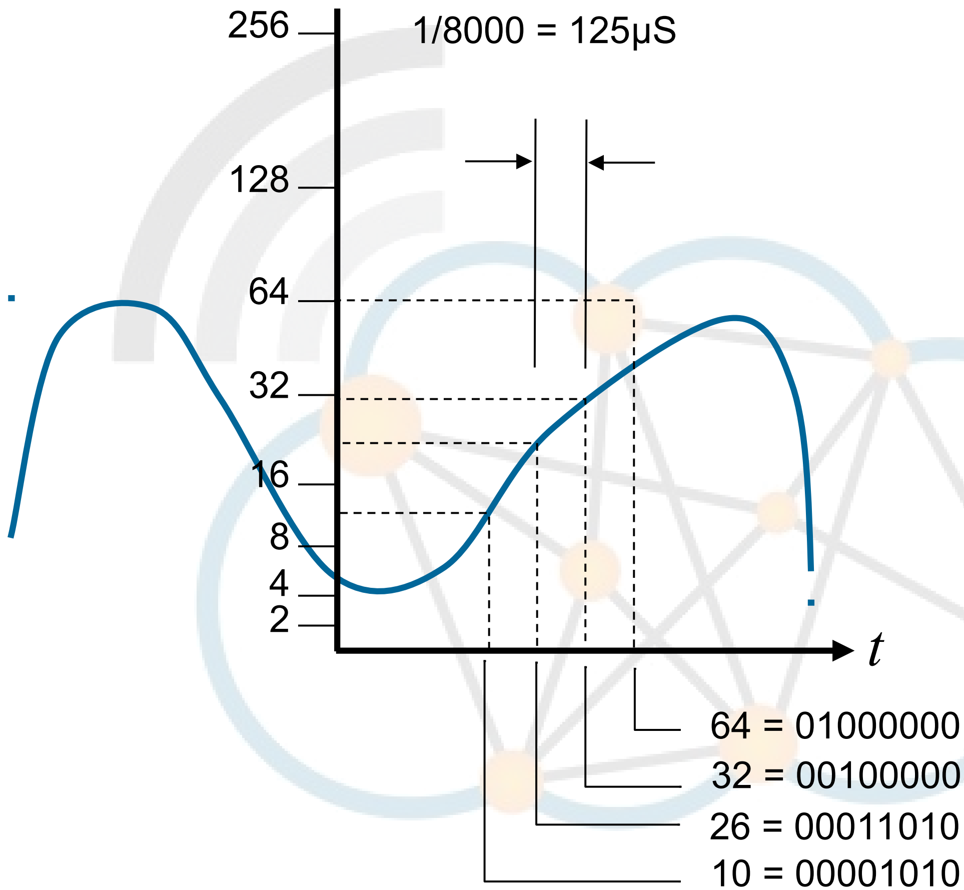
Modulation

- Modulation describes a range of techniques for encoding information on a carrier signal, typically a sine-wave signal. A device that performs modulation is known as a modulator.
- Modulation techniques include:
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Single Sideband Modulation (SSB)
  - **Phase Modulation (PM)**
  - **Quadrature Amplitude Modulation (QAM)**
  - **Orthogonal Frequency Division Modulation (OFDM).**

Pulse Code Modulation (PCM)

- Pulse Code Modulation (PCM) is a digital representation of an analogue signal.
- It is not a modulation of the same type as those in Lecture 1, as they carried an analogue signal on an analogue carrier.
- In this case we carry an analogue signal in digital form.

Pulse Code Modulation (PCM)



00001010 00011010 00100000 01000000

Pulse Code Modulation (PCM)

- The signal is sampled at a sampling frequency (f_s). This means the value of the signal, a sample, is captured at uniform distances T (= $1/f_s$).
- Every sample is quantised to a series of symbols in a code in which there are a discrete number of possible symbol values.
- Where the number of possible values is two, the code is said to be a binary code.

Pulse Code Modulation (PCM)

- The sampling rate is governed by Nyquist Theorem which states that
- "*Converting from an analogue signal to digital, the sampling frequency must be greater than twice the highest frequency of the input signal in order to be able reconstruct the original perfectly from the sampled version*"

Digital Communications

Digital to Analogue Modulation

Diarmuid Ó Briain
CEng, FIEI, FIET, CISSP

diarmuid@obriain.com

Digital Modulation

- Communication system constraints:
  - Limited available bandwidth.
  - Limited permissible power in the desired frequency range.
  - Inherent noise level of the system.
- Digital modulation schemes:
  - More information capacity.
  - Compatibility with digital data services.
  - Higher data security.
  - Better quality communications.
  - More rapid system availability.

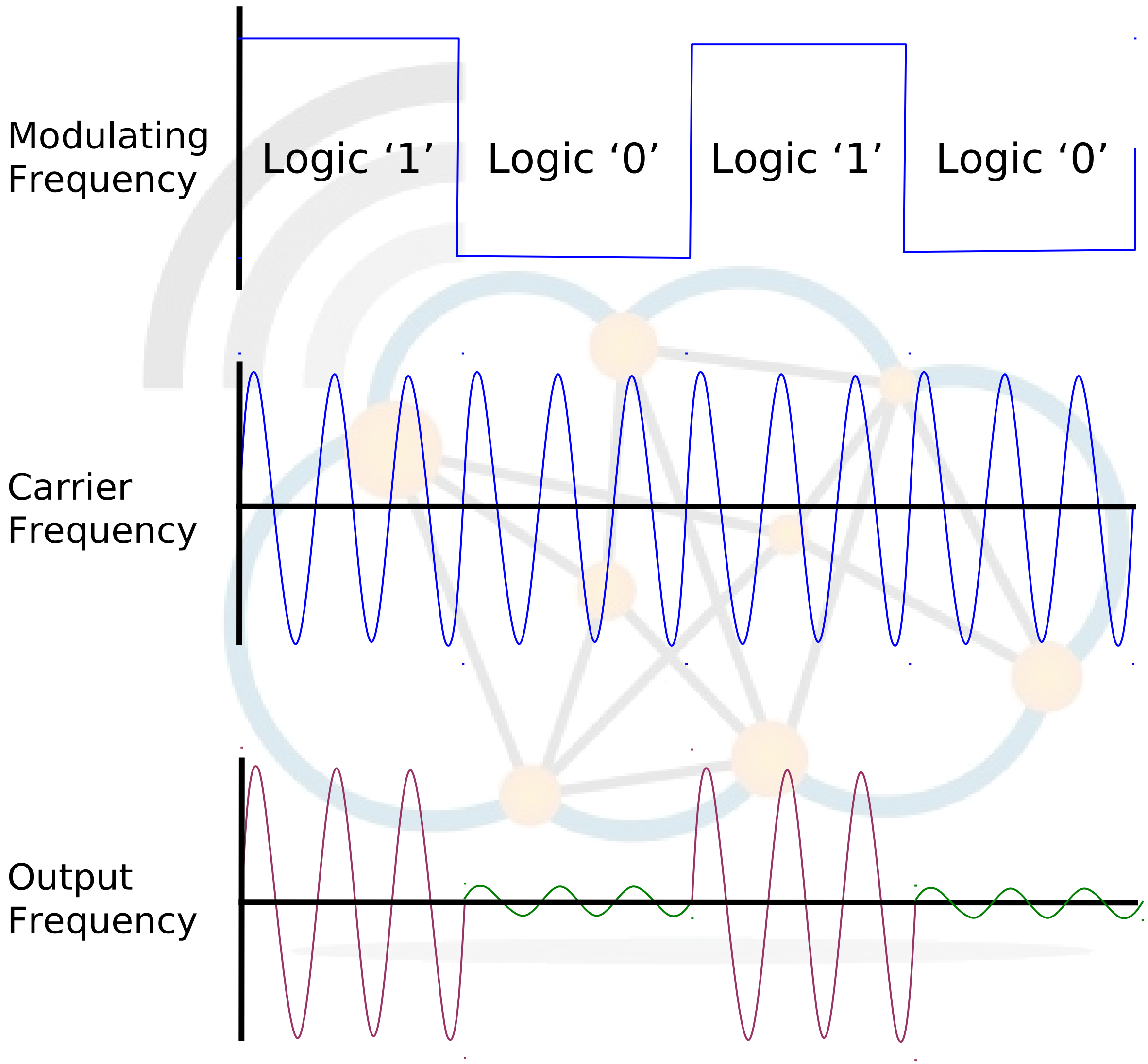
Digital Modulation

- Analogue systems use a lot of spectrum to transmit/ receive information, limiting the number of users.
- More complex hardware could be used to transmit/receive the same information over less bandwidth in digital systems.
- However complex hardware is difficult to design, test, and build.
- This is the so called “simplicity / bandwidth trade off”.

Digital Modulation

- The only difference between analogue modulation and digital modulation is that digital modulation restricts the modulating baseband signal to discrete states rather than allowing the modulating signal to take on any value between a maximum and a minimum value.
- When AM, FM or PM are used in a digital modulation scheme the names become ASK, FSK and PSK.
- The SK stands for shift keying and is derived from the telegraph key.
- The modern use implies shifting between discrete states.

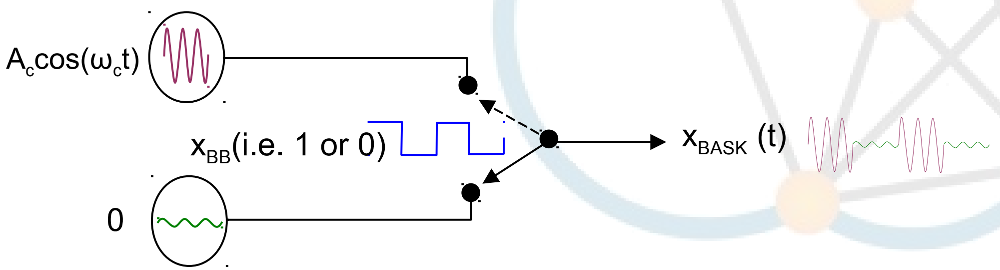
Amplitude Shift Keying (ASK)



ASK Constellation

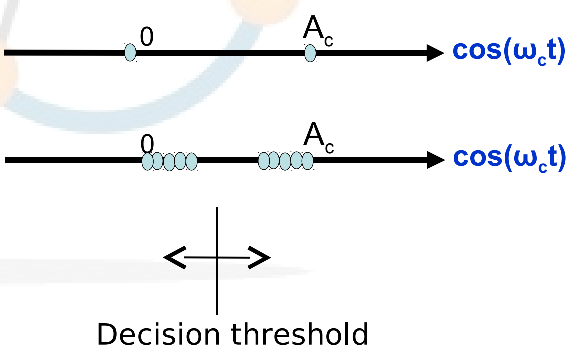
- 2 amplitudes
- 2 signal types
- 2 signal types represent 1 bits/line condition
- 1 bits per baud signalling

BASK Modulator

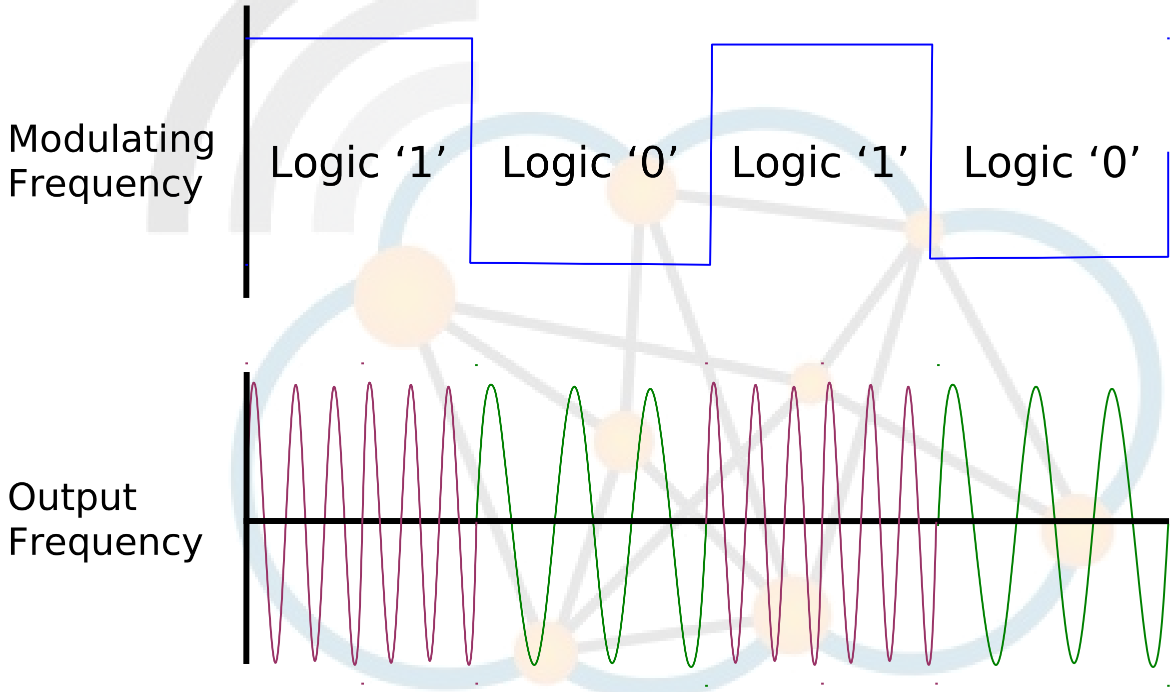


$x_{BASK}(t) = A_c[mx_{BB}]\cos(\omega_c t)$ where $m = 1$ *(modulation index)*

BASK Constellation Diagram



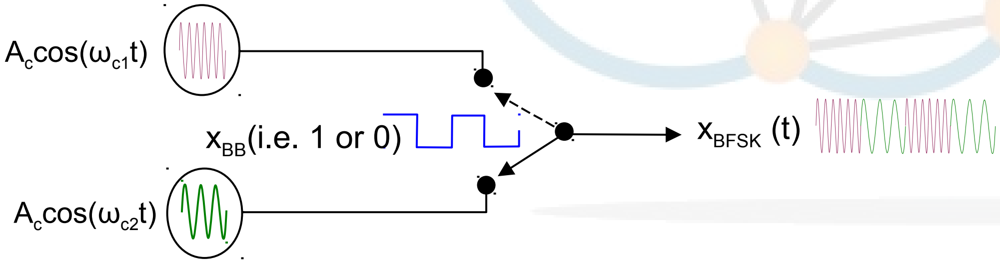
Frequency Shift Keying (FSK)



BFSK Constellation

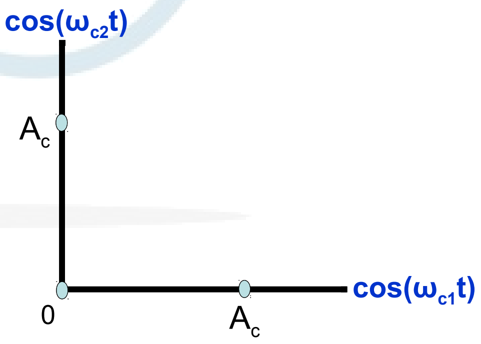
- 2 frequencies
- 2 signal types
- 2 signal types represent 1 bits/line condition
- 1 bits per baud signalling

BFSK Modulator

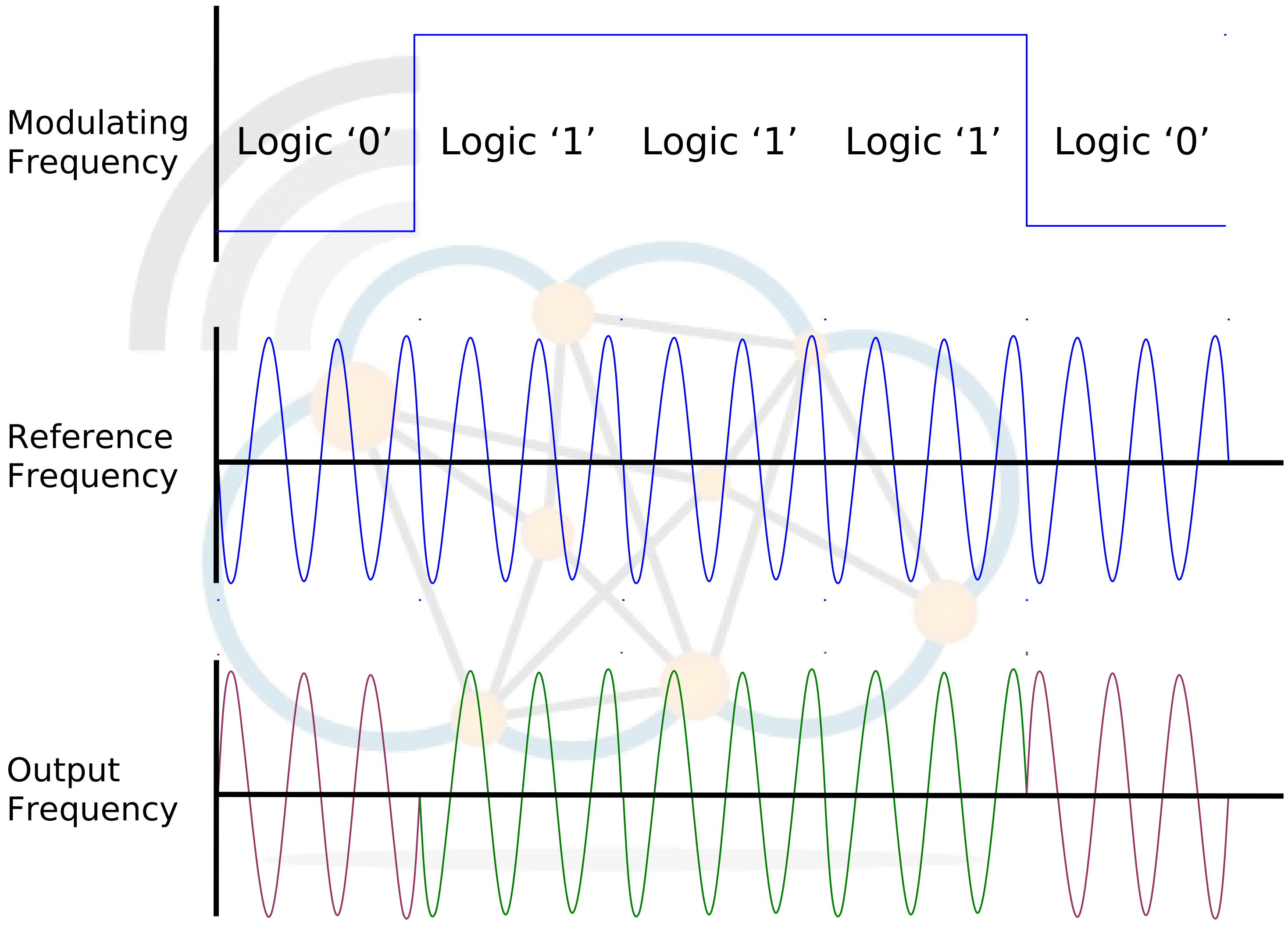


$x_{BFSK}(t) = A_c \cos(\omega_{c1}t)$ or $A_c \cos(\omega_{c2}t)$

BFSK Constellation Diagram

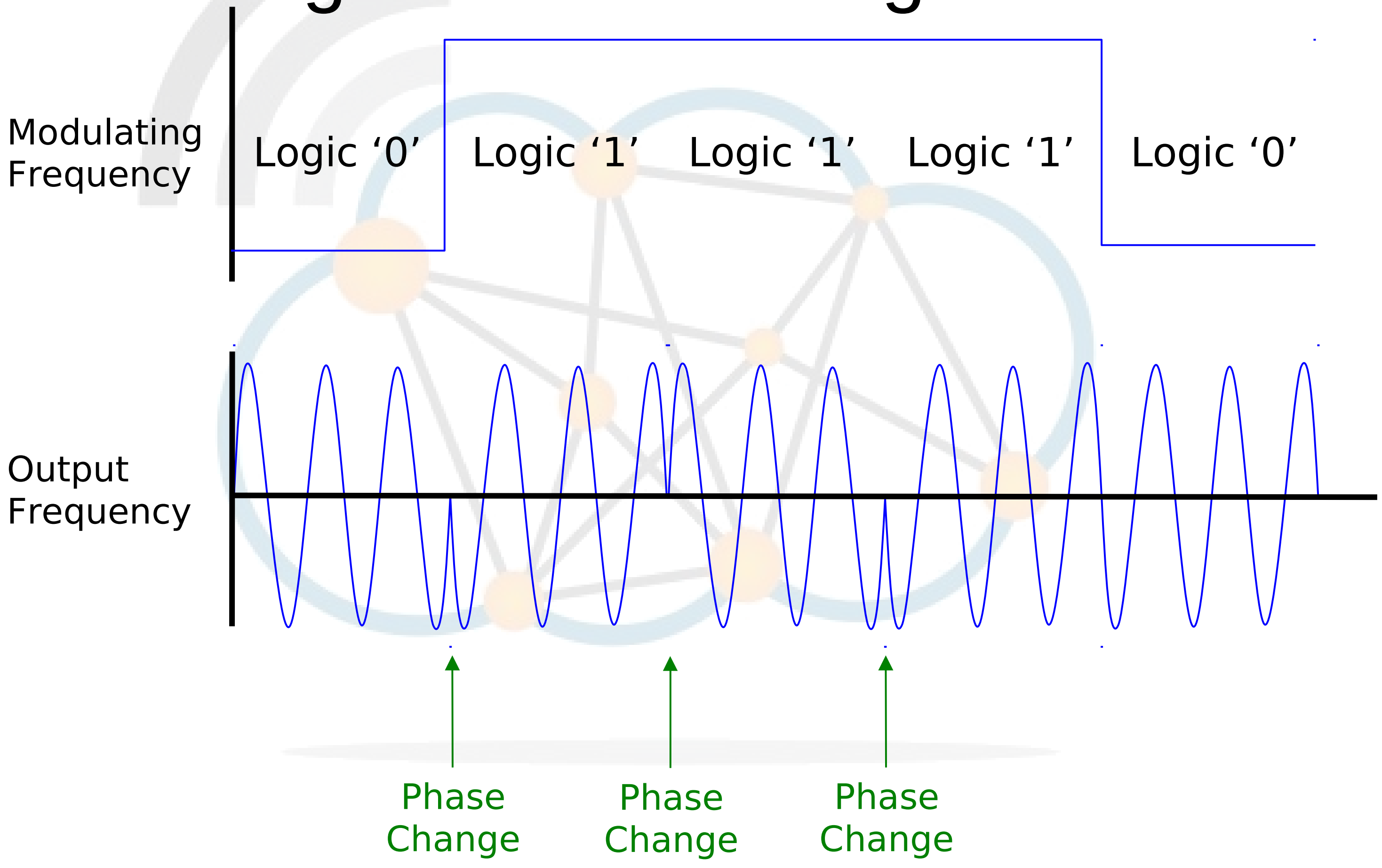


Phase Shift Keying (PSK)



Differential Phase Shift Keying (DPSK)

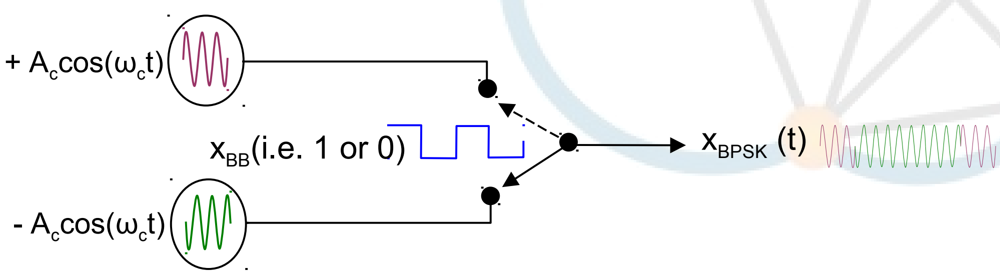
- A phase change indicates a logic ‘1’, no phase change indicates a logic ‘0’.



BPSK Constellation

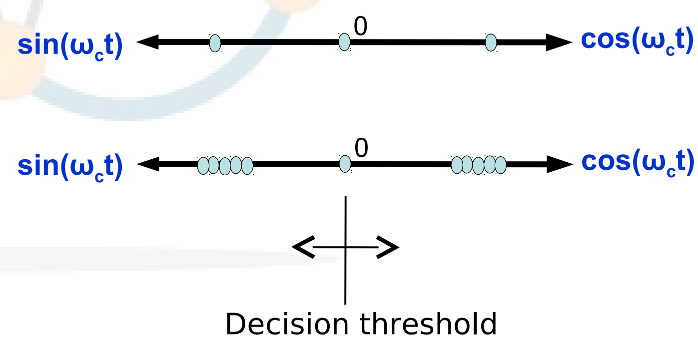
- 2 phase shifts
- 2 signal types
- 2 signal types represent 1 bits/line condition
- 1 bits per baud signalling

BPSK Modulator

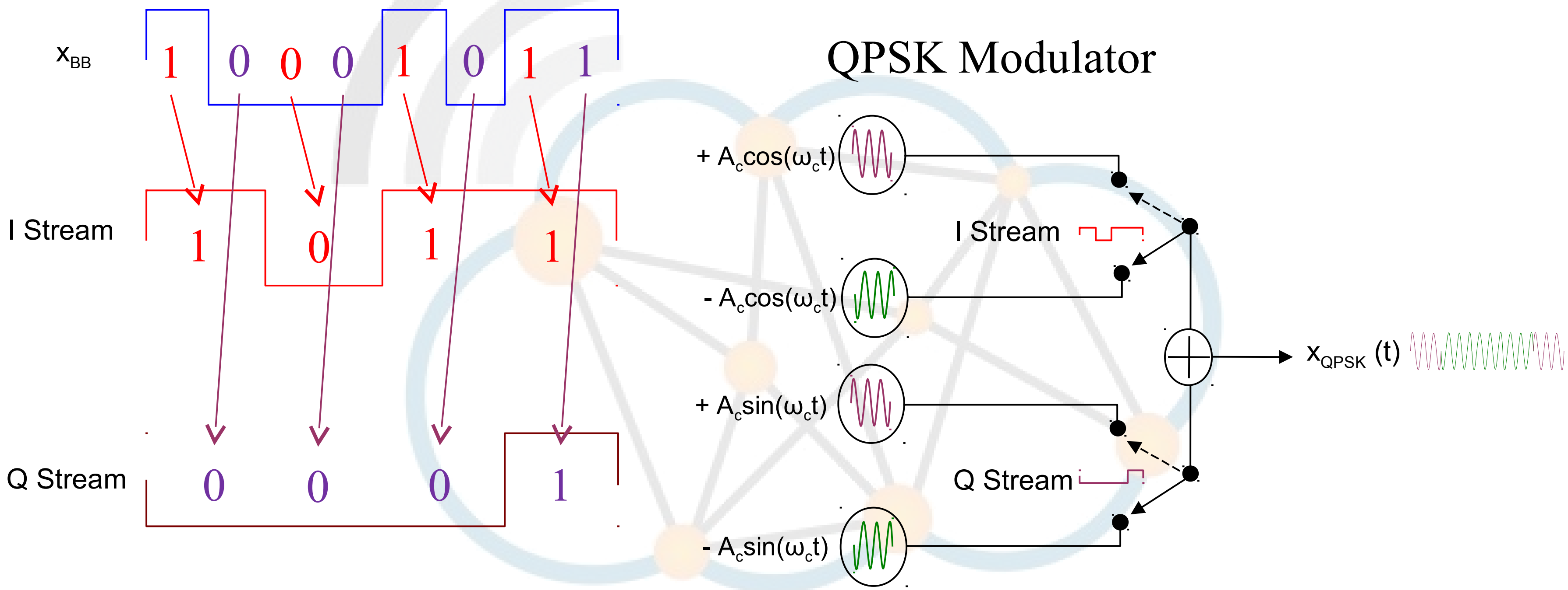


$x_{BPSK}(t) = A_c \cos[\omega_c t + \Phi]$ where $\Phi = 0$ or 180^o

BPSK Constellation Diagram



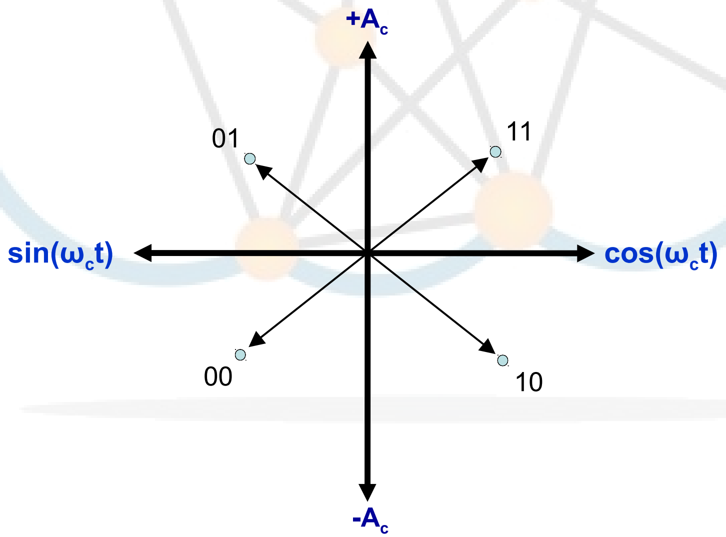
Quadrature Phase Shift Keying (QPSK)



Quadrature Phase Shift Keying (QPSK)

- 4 phase shifts
- 4 signal types
- 4 signal types represent 2 bits/line condition
- 2 bits per baud signalling

QPSK Constellation Diagram



Quadrature Differential PSK (QDPSK)

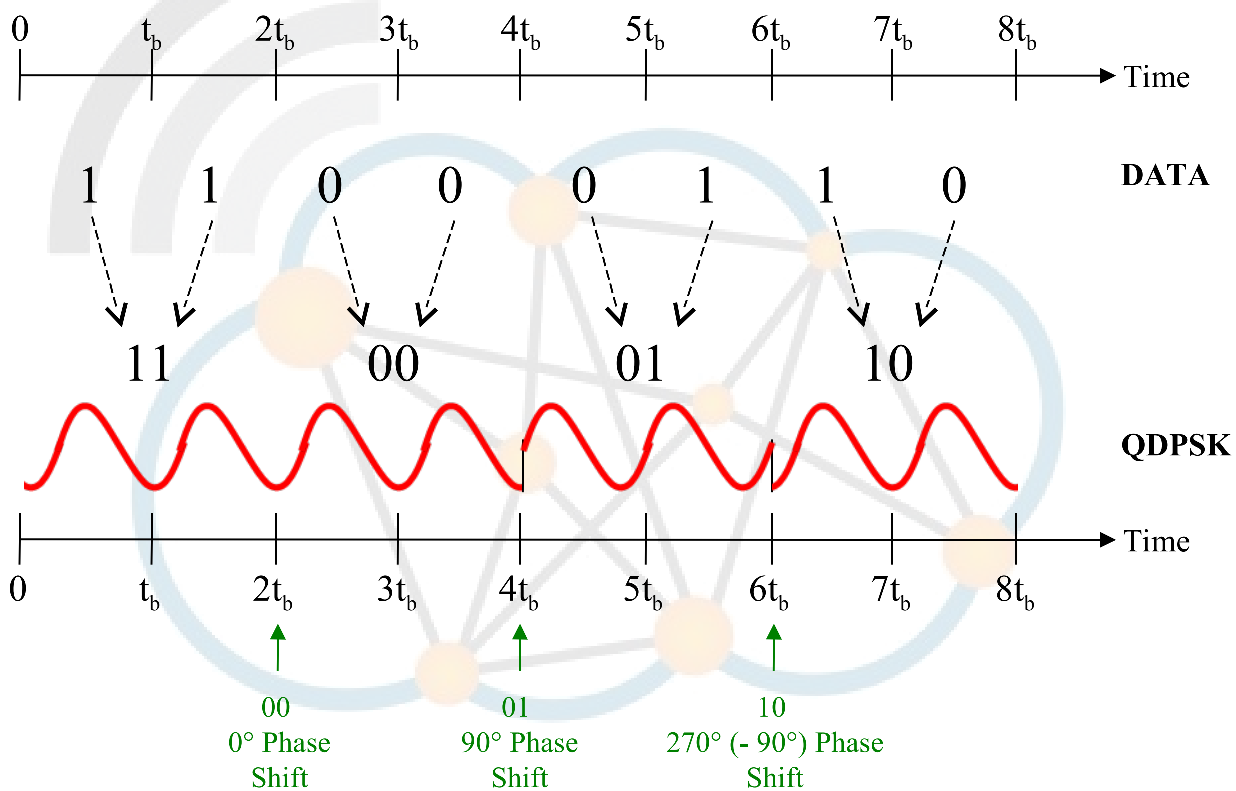
QDPSK

0° - 00

90° - 01

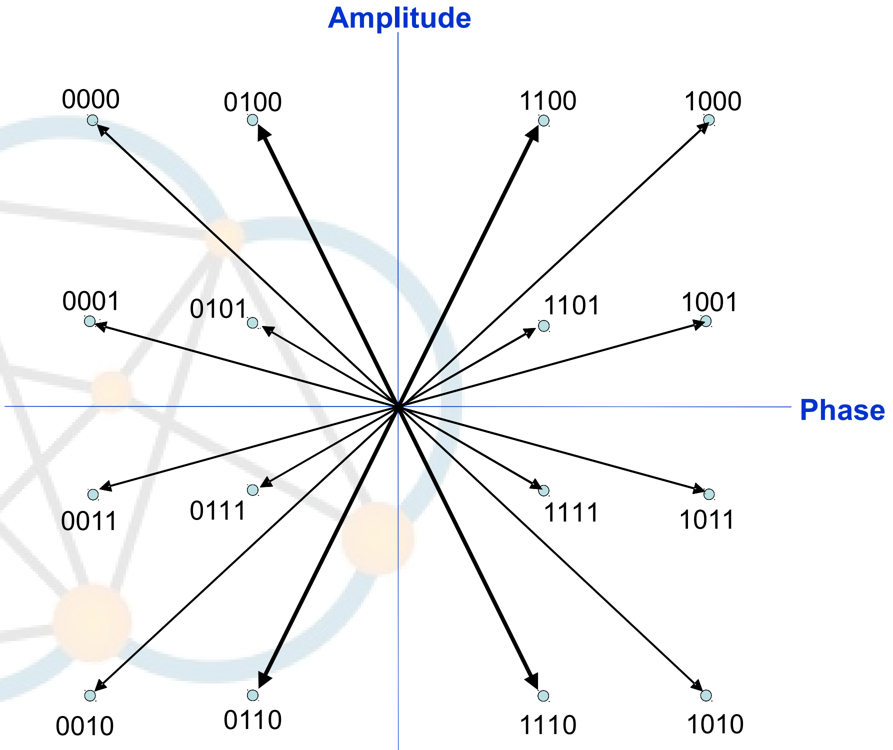
180° - 11

270° - 10



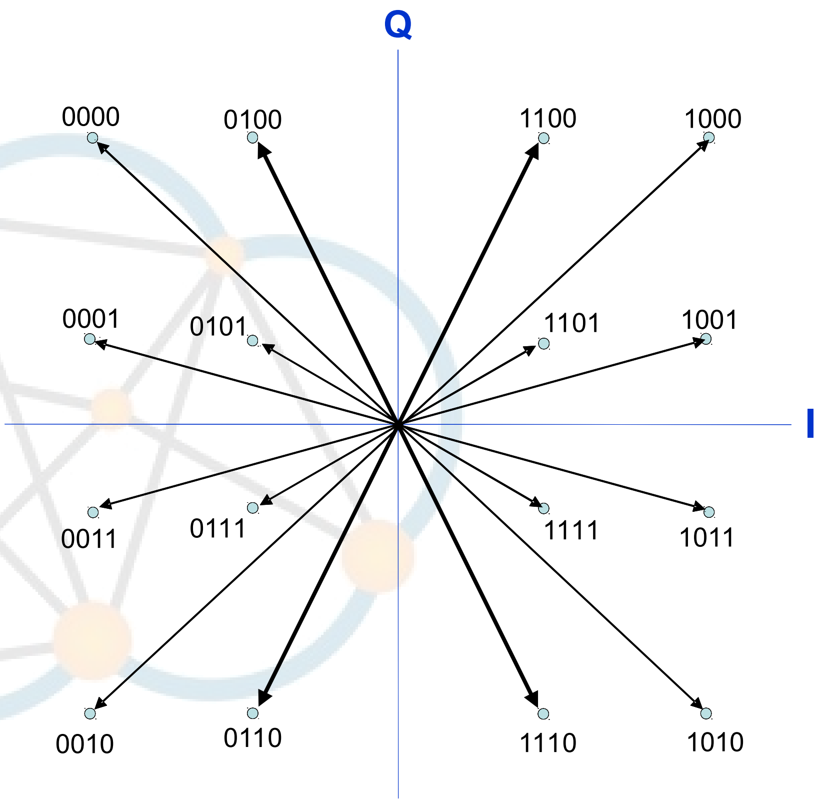
Quadrature Amplitude Modulation (QAM)

Bit value	Amplitude	Phase shift
0000	2	0° (360°)
0001	1	0° (360°)
0010	-2	0° (360°)
0011	-1	0° (360°)
1100	2	90°
1101	1	90°
1110	-2	90°
1111	-1	90°
1000	2	180°
1001	1	180°
1010	-2	180°
1011	-1	180°
0100	2	270° (-90°)
0101	1	270° (-90°)
0110	-2	270° (-90°)
0111	-1	270° (-90°)



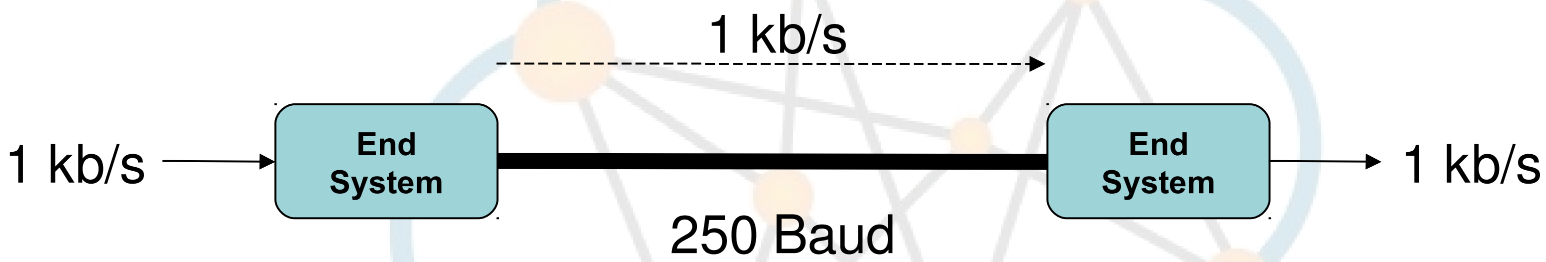
Quadrature Amplitude Modulation (QAM)

- There are four I values and four Q values and therefore 16 possible states for the signal.
- It can transition from any state to any other state at every symbol time.
- Since $16 = 2^4$, four bits per symbol can be sent; this consists of two bits for I and two bits for Q.
- The symbol rate is one fourth of the bit rate and it is more efficient than BPSK, QPSK.
- Note that QPSK is the same as 4QAM.



Information/Bit Rate

- The average number of end user bits transferred per second, in one direction.
- It is the frequency of a system bit stream.



Symbol Rate

- Signalling/Symbol Rate
  - The symbol rate is the gross bit rate, inclusive of channel coding overhead, divided by the number of bits transmitted in each symbol.
  - Symbol rate is measured in symbols per second, hertz (Hz), or baud (Bd).
  - The term baud is synonymous with symbol rate.
    - Less frequently used today as it has in the past been commonly misused to mean bit rate or data rate.

$$\text{Symbol rate} = \frac{\text{Bit rate}}{\text{Number of bits transmitted with each symbol}}$$

Baud rate

- A baud is the unit of symbol rate, the number of distinct symbol changes (signalling events) made to the transmission medium per second in a digitally modulated signal.
- The symbol rate (baud) is distinct from the bit rate (bit/s).
- One symbol can carry more than one bit of information.
- A 3 kb/s modem that transmits symbols that each carry three bits should be described as operating at 1 kBd (kilobaud).

Symbol Rate

- BPSK Symbol rate == Bit rate
- QPSK Symbol rate == (Bit rate)/2
- 16QAM Symbol rate == (Bit rate)/4

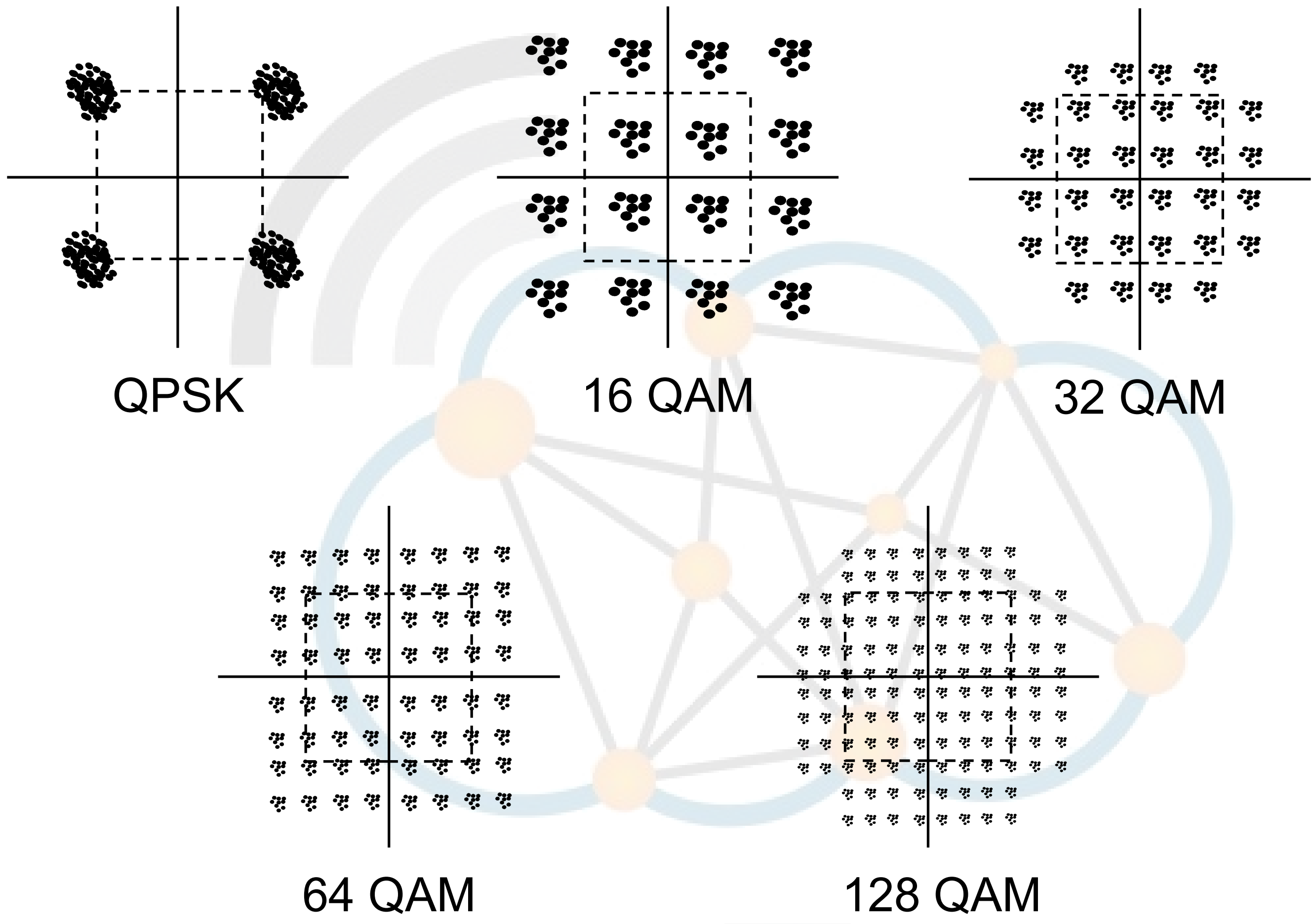
- Example:
  - If one bit is transmitted per symbol, (BPSK), then the symbol rate would be the same as the bit rate ⇒ 80 kbits per second.
  - If two bits are transmitted per symbol, (QPSK), then the symbol rate would be half of the bit rate ⇒ 40 kbits per second.

Bandwidth efficiency

- Bandwidth efficiency describes how efficiently the allocated bandwidth is utilised or the ability of a modulation scheme to accommodate data, within a limited bandwidth.

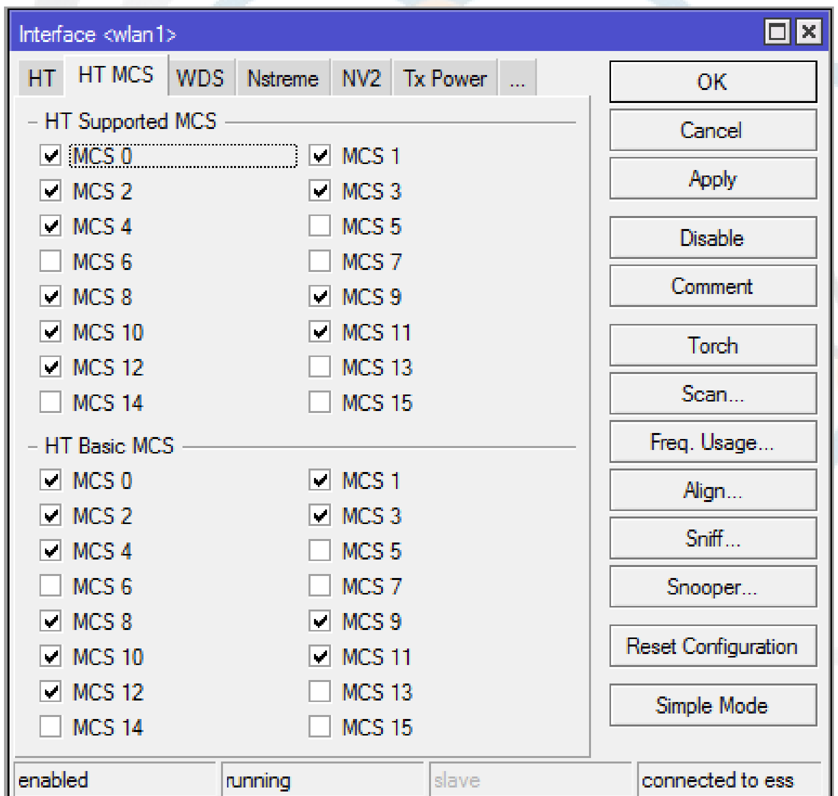
  - BPSK 1 bit/second/Hz
  - QPSK 2 bits/second/Hz
  - 8PSK 3 bits/second/Hz
  - 16 QAM 4 bits/second/Hz
  - 32 QAM 5 bits/second/Hz
  - 64 QAM 6 bits/second/Hz
  - 128 QAM 7 bits/second/Hz
  - 256 QAM 8 bits/second/Hz

Modulation patterns



Disable 64 QAM

[admin@MikroTik] > **interface wireless set 0 rate-set=configured ht-basic-mcs=mcs-0,mcs-1,mcs-2,mcs-3,mcs-4,mcs-8, mcs-9,mcs-10,mcs-11,mcs-12 ht-rxchains=0,1 ht-supported-mcs=mcs-0,mcs-1,mcs-2,mcs-3,mcs-4,mcs-8, mcs-9,mcs-10,mcs-11,mcs-12**



Thank You

Diarmuid Ó Briain
CEng, FIEI, FIET, CISSP

diarmuid@obriain.com