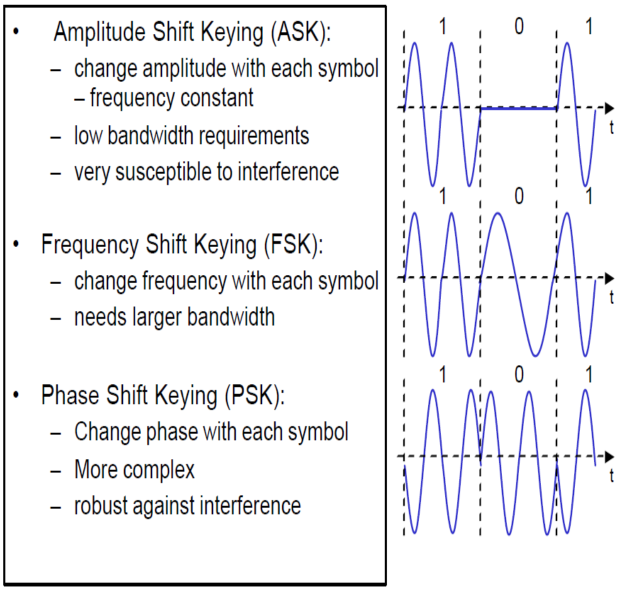
Digital Modulation Techniques

- In digital communication, modulating signal is binary data or an M-ary encoded version.
- This modulates, carrier usually sinusoidal, with fixed frequency.
- **Data**– digital computer output or PCM
- **Channel** – telephone channel, microwave link, etc.
- Three basic modulation techniques
    - Amplitude shift keying (ASK)
    - Frequency shift keying (FSK)
    - Phase shift keying (PSK)

Special cases of AM, FM & PM

- Low pass channel: Like 0 Hz to f_m
  Ex. Baseband channel
- Band Pass Channel: Band of frequencies not from 0 Hz
  Ex. Telephone channel, radio link etc.



Amplitude shift keying (ASK) or On-Off keying:

Pulse shaping required to remove spectral spreading

Effected by noise, and interference.

Frequency shift keying (FSK):

- Expanded to M-ary scheme (multiple frequencies as different states).

Phase shift keying (PSK):

- PSK or BPSK has better performance than ASK and BFSK.
- BPSK can be expanded to M-ary employing multiple phases, and amplitudes as different states.

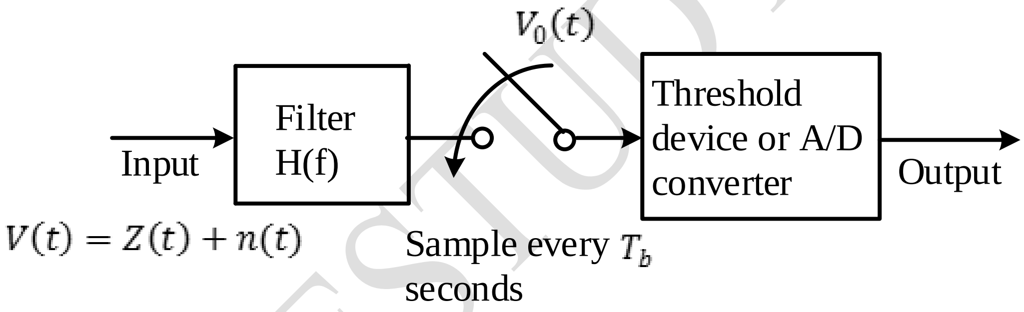
Detection:

To extract symbols from the waveform.

- Coherent detection
- Non coherent detection

Coherent detection or Synchronous detection

Basic Receiver Structure:



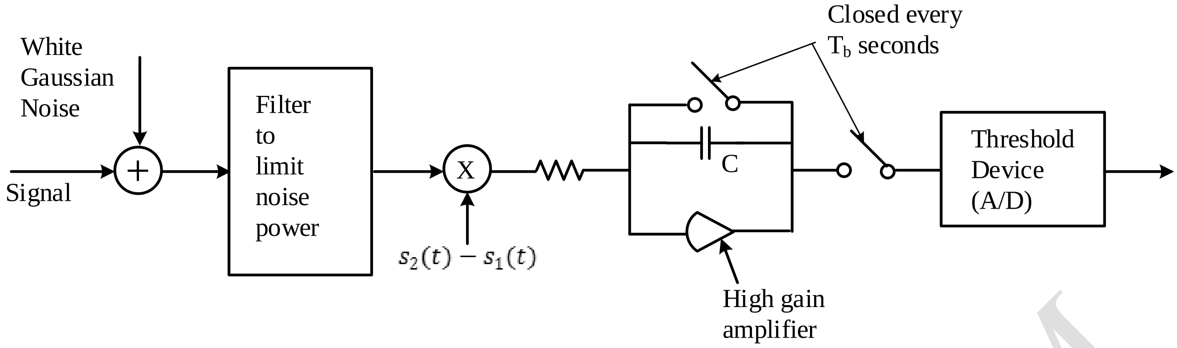
- A filter, sampler and threshold device
- Sampled value compared against predetermined threshold and bit is detected
- Due to noise receiver makes error. Then error probability is determined.
  - Requires replica carrier at the receiver.
  - Received signal and replica carrier are cross correlated using information contained in their amplitude and phase

Optimum receiver: Yields minimum probability of error.

Matched filter: Optimum receiver is called matched filter when noise at receiver is white

- Implemented as integrate and dump correlation receiver.
- It has filter, sampler and threshold device.

Correlation receiver: It is also called as integrate and dump filter



Integrate and dump filter or correlation receiver

- Here integrator has to be reset i.e. capacitor is discharged or dumped at end of each signaling interval to avoid ISI
- RC >>T_b

Non Coherent detection:

Requires no reference wave, does not exploit phase reference information.

Differential phase shift keying (DPSK)

Frequency shift keying (FSK)

Amplitude shift keying (ASK)

Less complex than coherent detection but has worse performance.

DPSK: Non coherent version of PSK. It is differentially coherent modulation method. The input sequence of binary bits is modified such that next bit depends upon the previous bit.

Advantages: Less complex circuitry than PSK. It is commonly used for medium speed data transmissions.

DPSK requires about 1 dB more power than coherent PSK for the same bit error rate.

Limitations: Errors appear in pairs since previous bit is used to detect the next bit.

M-ary Signaling

- It contains more than two signals and each represents more than single bit of information.

- For signal of size M
  $No. of\ bits\ (n) = log_2 M\ per\ signal$
- Bandwidth for M-ary scheme
  $$BW = \frac{BW\ for\ binary\ scheme}{log_2 M}$$
  For M-ary PSK
  $$BW = \frac{2R_b}{log_2 M}$$

Bit rate & Baud rate:

Bit rate is number of bits per sec

Baud rate is number of signal units per sec.

Baud rate is less than or equal to bit rate

Bit rate is important in computer efficiency.

Baud rate is important in data transmission.

$$Baud\ rate = \frac{Bit\ rate}{No. of\ bits\ per\ signal\ unit}$$

$$= \frac{Bit\ rate}{log_2 M}$$

Example – The bit rate of signal is 3600. If each signal unit has 6 bits, what is baud rate?

Soln. $Baudrate = \frac{3600}{6} = 600\ bauds/sec$

Probability of Error (Pe):

- Performance of digital communication system is measured in terms of probability of symbol error.
- Pe ranges from 10^{-4} to 10^{-7} in practical systems.
- Q (z) is the Q function, the area under normalized Gaussian function
- Now it is replacing earlier used error function.
- A factor of $\sqrt{2}$ need be noticed between the two.

$$Q(z) = \int_{z}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-y^2/2}\, dy \quad (1)$$

$$\frac{1}{2} erfc\left(\frac{y}{\sqrt{2}}\right) = Q(y) \quad (2)$$

$$\frac{1}{2} erfc(\mu) = \frac{1}{\sqrt{\pi}} \int_{\mu}^{\infty} e^{-z^2/2}\, dz \quad (3)$$

Geometric representation of Modulation Signal - Constellation diagram:

- It is graphical representation of complex envelope of each possible symbol state.
- X-axis represents in phase component
  Y-axis quadrature component of the complex envelope.
- The distance between signals on a constellation diagram tells how different the modulation waveform are and how easily receiver can differentiate between then.

BPSK: Phase changes between bits

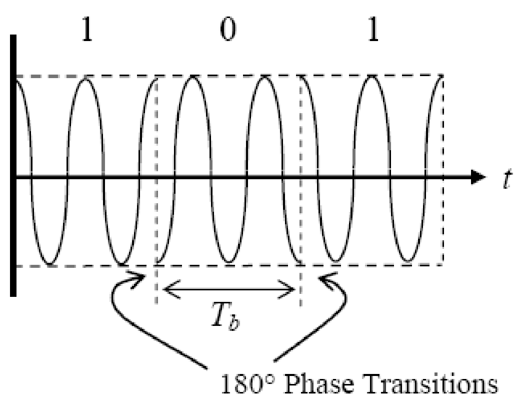
Phase changes of 180^0 for each bit.

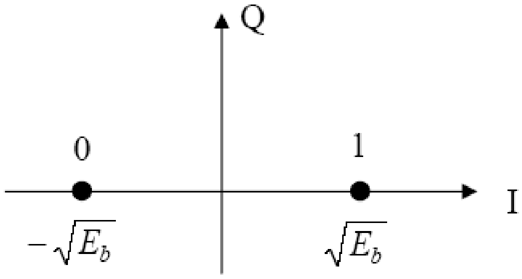
$$s_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t$$

$$s_2(t) = -\sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t$$

$for\ 0 \le t \le T_b$

- Graphical representation of the complex envelop of each possible symbol state





QPSK: Quadrature phase shift keying

- Interpreted as two independent BPSK
- Large envelope variations occur due to abrupt phase transitions, thus requiring linear amplification.

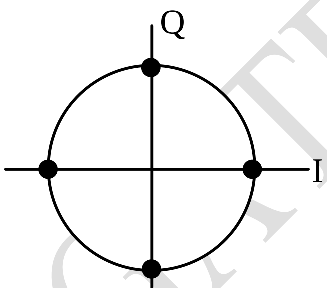
Advantages:

Bandwidth requirement of QPSK is reduced to half of BPSK, since two bits are transmitted in a single modulation symbol. So information rate can be higher

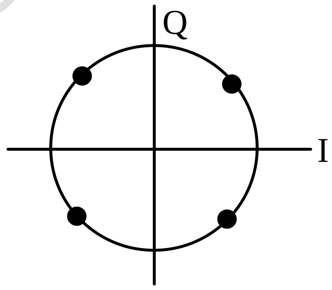
Problem – What is the bit rate of 1000 baud 16 QAM signal?

Soln. 16 QAM has $log_2 16 = 4\ bits$

$$Bit\ rate = 4 \times 1000 = 4000\ bits/sec$$



Carrier phases
{0, π/2, π, 3π/2}



Carrier phases
{π/4, 3π/4, 5π/4, 7π/4}

Other Schemes

MSK:

Minimum shift keying (MSK): continuous phase modulation scheme where modulation carrier has no phase discontinues and frequency change occurs at carrier zero crossing.

GMSK

- Gaussian minimum shift keying (GMSK) is continuous phase FSK (constant envelope scheme) an alternative to QPSK
- RF BW is controlled by Gaussian low pass filter bandwidth
- GMSK allows efficient class C non-linear amplifier to be used.
- Due to reduced side lobe energy of GMSK, channel spacing can be tighter for GMSK when compared to MSK.

Comparison of Digital Modulation Schemes:

Complexity of transmitting equipment for PSK, FSK and ASK are very little different.

- At receiver coherent schemes are more complex. Amongst non-coherent DPSK is more complex.
- If bandwidth is most important then VSB is the best.
- If power requirement is important then coherent PSK or DPSK is most desirable.
- If equipment complexity is limiting then non-coherent schemes.

Summary:

- PSK is often used as it provides efficient use of RF spectrum.
- $\pi/4$ QPSK reduces envelope variation of signal.
- High level M-ary schemes (such as 64 Q AM) are very BW efficient but more susceptible to noise and require linear amplification.
- Constant envelope schemes (such as GMSK) allow for non-linear power efficient amplifiers.
- Coherent reception provides better performance but requires a more complex receiver.

Comparison of Binary Digital Modulation Schemes

Modulation Scheme	$s_1(t), s_2(t)$	BW	Probability of error (P_e)	Comments
Coherent ASK	$s_1(t) = A\cos\omega_c t$ $s_2(t) = 0$	$\cong 2\,R_b$	$Q\left(\sqrt{\frac{E_b}{2\eta}}\right)$ or $\frac{1}{2}erfc\left(\sqrt{\frac{E_b}{4\eta}}\right)$	Rarely used
Non Coherent ASK	$s_1(t) = A\cos\omega_c t$ $s_2(t) = 0$	$\cong 2\,R_b$	$\frac{1}{2}exp\left(-\frac{E_b}{8\eta}\right)$	Rarely used
Coherent FSK	$s_1(t) = A\cos\omega_1 t$ $s_2(t) = A\cos\omega_2 t$	$> 2\,R_b$	$Q\left(\sqrt{\frac{2\times 0.6\,E_b}{\eta}}\right)$ or $erfc\left(\sqrt{\frac{0.6\,E_b}{\eta}}\right)$	2.2 dB more power required than PSK Requires more Bandwidth.
Non Coherent FSK	$s_1(t) = A\cos\omega_1 t$ $s_2(t) = A\cos\omega_2 t$	$> 2\,R_b$	$\frac{1}{2}exp\left(-\frac{E_b}{4\eta}\right)$	No advantage over PSK, so seldom used
Coherent PSK	$s_1(t) = A\cos\omega_c t$ $s_2(t) = -A\cos\omega_c t$	$\cong 2\,R_b$	$Q\left(\sqrt{\frac{2\,E_b}{\eta}}\right)$ or $\frac{1}{2}erfc\left(\sqrt{\frac{E_b}{\eta}}\right)$	3 dB power advantage over ASK
Non Coherent PSK DPSK	$s_1(t) = A\cos\omega_c t$ $s_2(t) = -A\cos\omega_c t$	$\cong 2\,R_b$	$\frac{1}{2}exp\left(-\frac{E_b}{\eta}\right)$	DPSK is non-coherent version of PSK, but only little inferior than coherent PSK (1 dB more power)

P_e – Probability of error, $\eta/2$ – two sided noise PSD, T_b – bit duration, R_b is bit rate

$$Energy\ (E_B) = \frac{A^2 T_b}{2}, where\ A - carrier\ amplitude$$