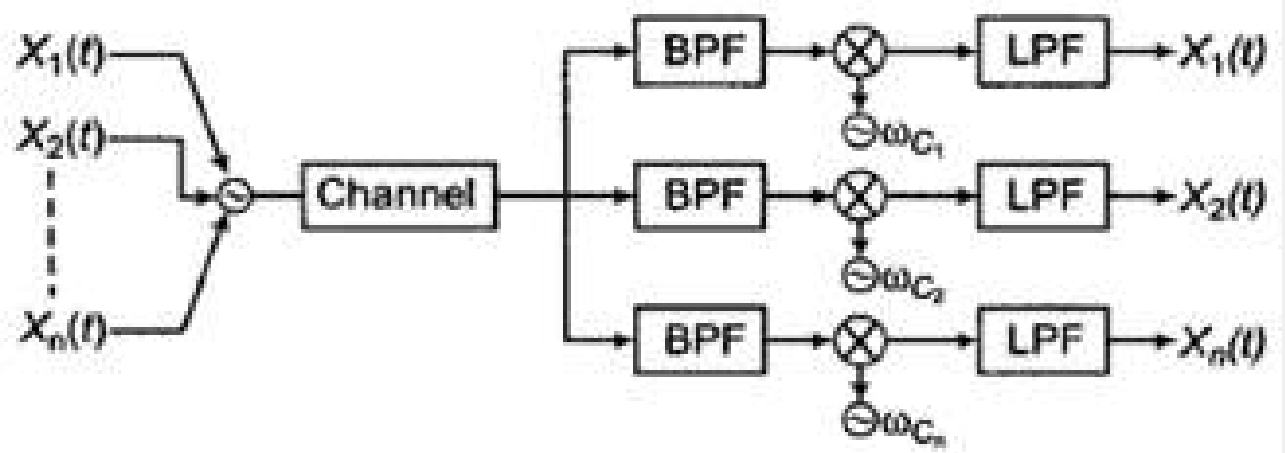
Multiplexing is a technique in which several message signals are combined into a composite signal for transmission over a common channel. In order to transmit a number of these signals over the same channel, the signal must be kept apart so that they do not interfere with each other, and hence they can be separated easily at the receiver end.



Block diagram representation of multiplexing

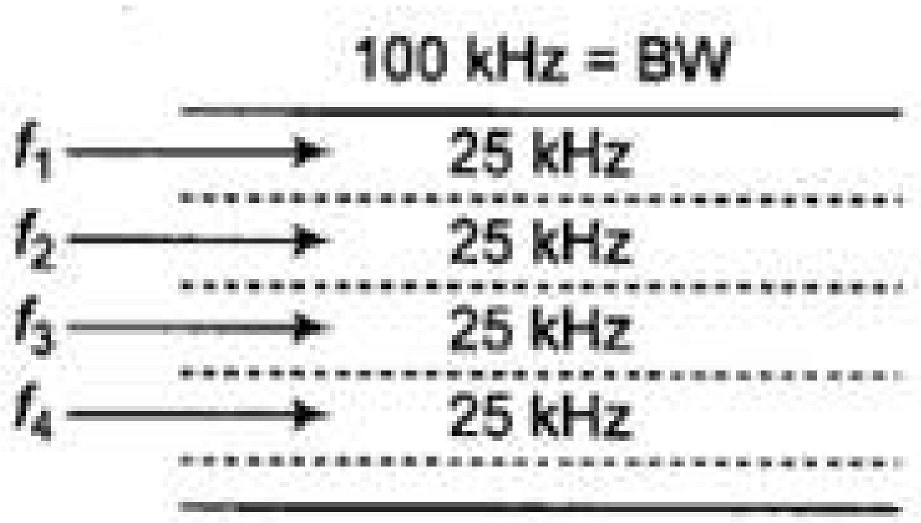
Different Ways of Multiplexing

Multiplexing is an important concept for the GATE CSE exam. Digital radio has developed ways in which more than one conversation can be accommodated (multiplexed) inside the same physical RF channel. There are three common ways of achieving this

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Divisional Multiple Access (CDMA)

Frequency Division Multiplexing

In FDMA, we divide the whole bandwidth of the channel into small segments and allot it to different users so that they can access the channel at the same time by using their allotted bandwidth.



FDM general diagram

Time Division Multiplexing

In TDMA, the whole time slot is divided among different users so that at a time only one user is accessing the channel.

Message 1	Message 2	Message 3	Messa

Key Points

- The bandwidth requirement in TDMA and FDMA is almost the same for the same number of users.
- The TDMA system can be used to multiplex analog or digital signals, however, it is more suitable for digital signal multiplexing.
- The communication channel over which the TDMA signal is traveling should ideally have an infinite bandwidth in order to avoid signal distortion. Such channels are known as band-limited channels.

Code Division Multiplexing (CDMA)

- Instead of splitting the RF channel into sub-channels or time slots, each slot has a unique code. Unlike FDMA, the transmitted RF frequency is the same in each slot, and unlike TDMA, the slots are transmitted simultaneously. In the diagram, the channel is split into four code slots. Each slot is still capable of carrying a separate conversation because the receiver only reconstructs information sent from a transmitter with the same code.

Digital Modulation Schemes

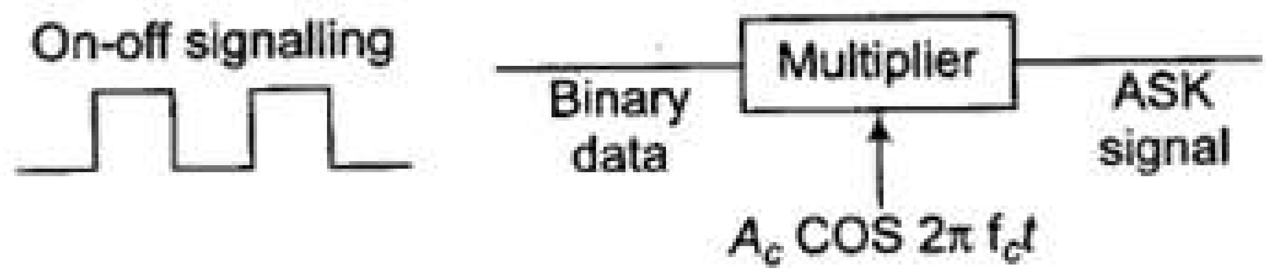
This is possible to transmit the analog signal i.e., speech, video, etc, in digital format. Some digital modulation schemes are given below.

Digital Carrier Modulation: Commonly used digital modulation schemes are

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK).

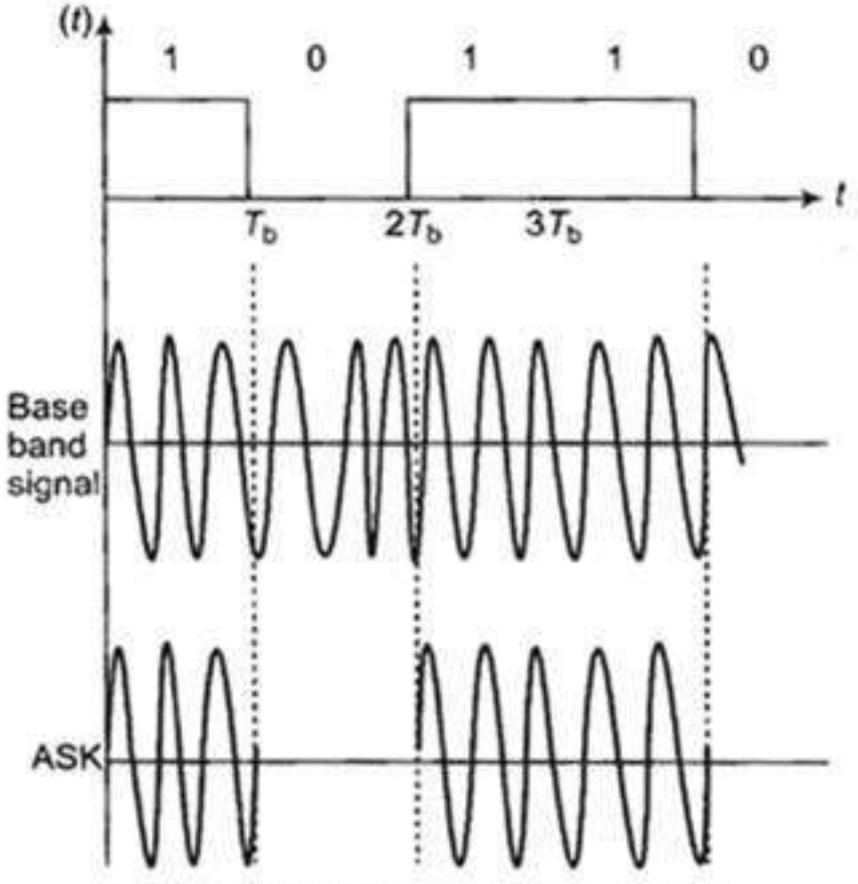
Amplitude Shift Keying (ASK)

- The amplitude of a high-frequency carrier is varied in accordance with digital data (0 or 1).



$S(t) = A_c \cos 2\pi f_c t;\ 0 \le t \le T_b$

$= 0$; otherwise

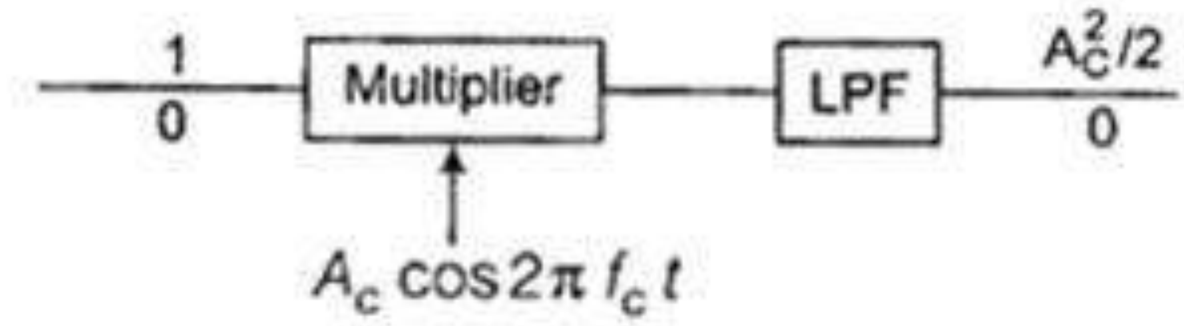


Digital modulated waveforms of ASK

- Bandwidth = 2 × $1/T_b$= 2 × bit rate
- For digital input 1 amplitude level is high and for digital input 0 amplitude level is low.
- The signaling used is on-off signaling.

Demodulation of ASK

- For binary digit 1, $A_c \cos 2\pi f_c t \times A_c \cos 2\pi f_c t = (A^2_c/2)[1 + \cos 4\pi f_c t]$



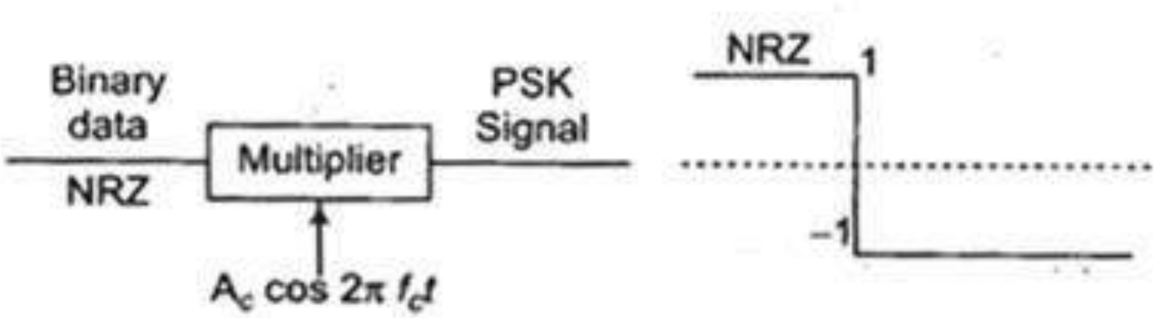
ASK demodulator

- Output of LPF = $(A^2_c/2)$
- For binary digit 0 output of LPF = 0
- In ASK, the probability of error (P_e) is high.
- In ASK, SNR is less.

Know More: Difference between Multiplexing and Demultiplexing

Phase Shift Keying (PSK)

- In phase shift, the keying phase of the high-frequency carrier is varied in accordance with digital data 1 or 0.



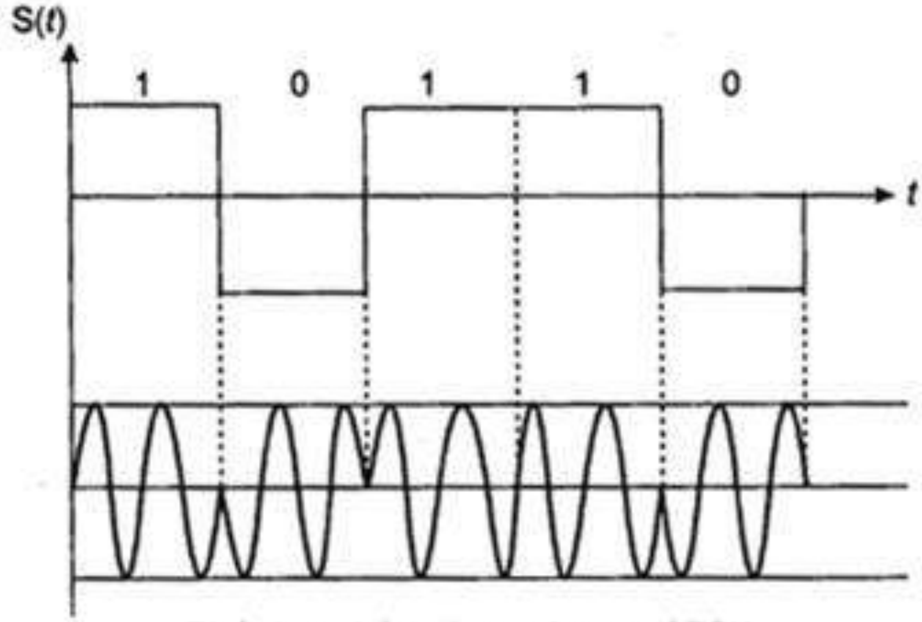
RSK modulator

PSK waveform

- NRZ signaling is used.

$S(t) = A_c \cos 2\pi f_c t$ for bit 1

$= – A_c \cos 2pf_c t$ for bit 0



Digital modulated waveforms of PSK

- The frequency of the carrier must be multiple of a bit rate.

$T_b = n/f_c$

$F_c = nr_b$

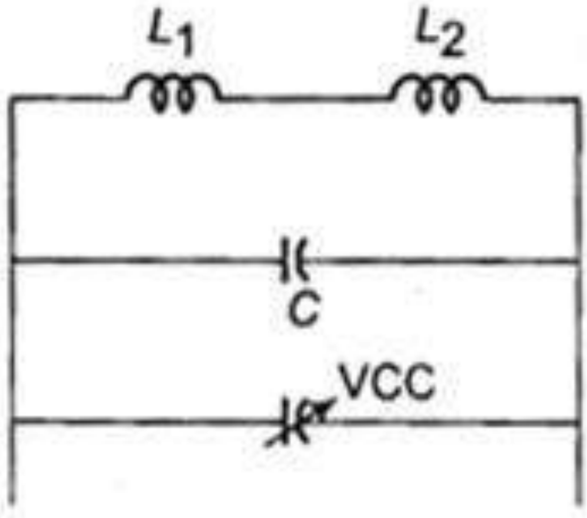
- In the case of PSK, the probability of error is less.
- In the case of PSK, SNR is high.
- Mainly used technique in wireless transmission.

Frequency Shift Keying (FSK)

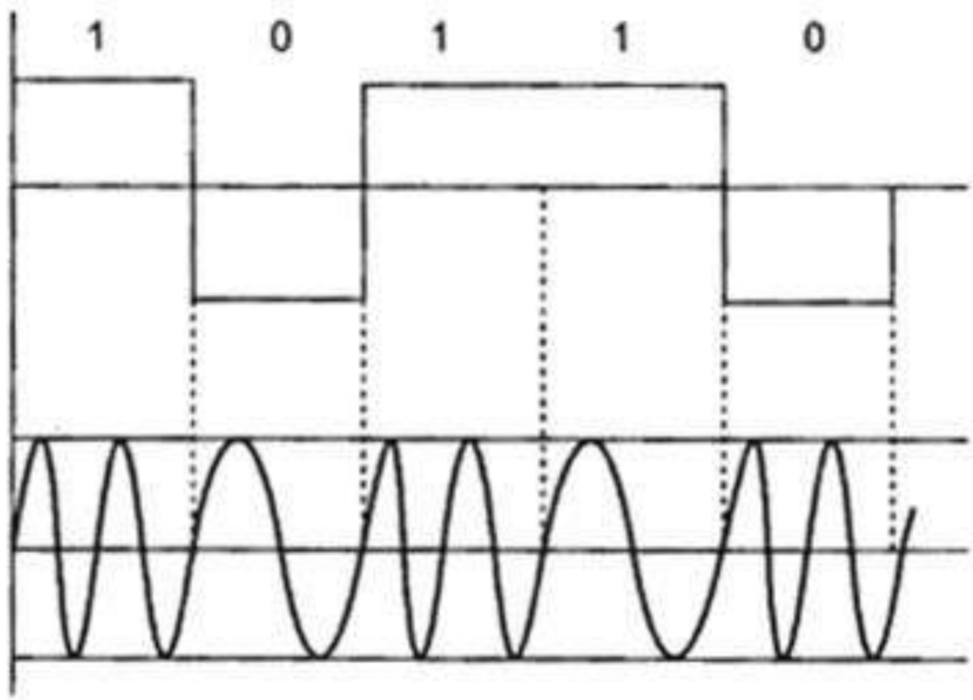
- In frequency shift keying, the frequency of the carrier is varied in accordance with digital data (1 or 0).
- For digital data 1 we use frequency f_1 and for digital data 0, we use frequency f_2.

$$\left.\begin{aligned} S(t) &= A_c \cos 2\pi f_1 t \quad 1 \\ &= A_c \cos 2\pi f_2 t \quad 0 \end{aligned}\right\} f_1 > f_2$$

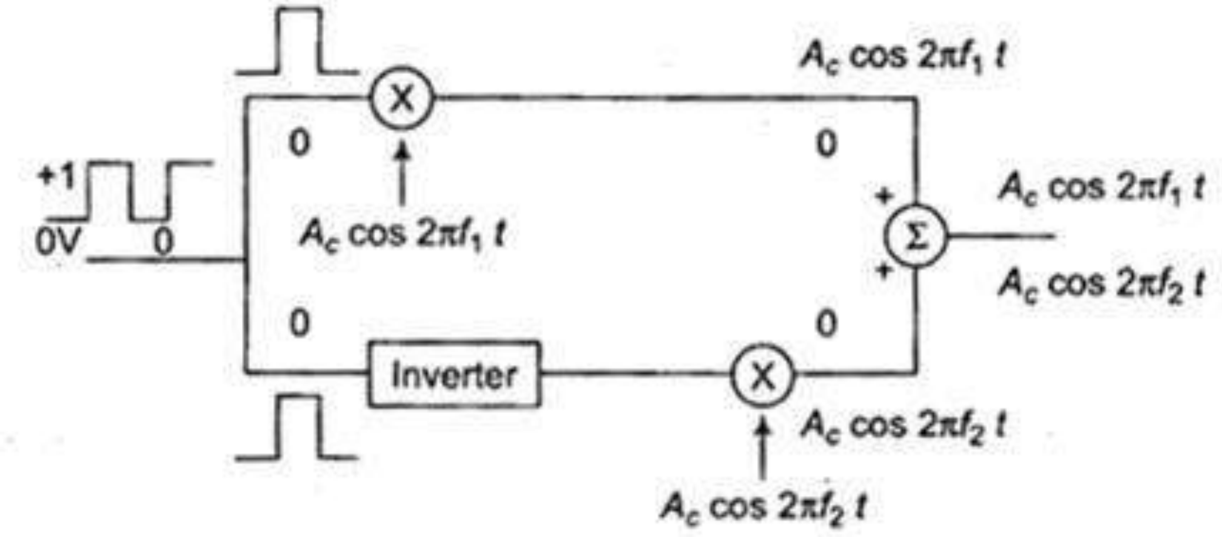
- NRZ signaling is used here
- VCO:The schematic diagram of VCO is given below



$$f = \frac{1}{2\pi\sqrt{(L_1+L_2)(C+C_1+C_2)}}$$

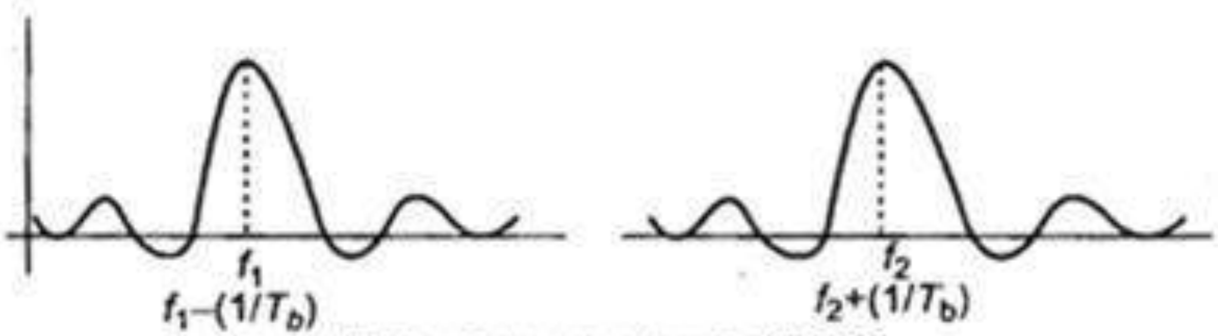


Digital modulated signal of FSK



Non-coherent detection of FSK

Bandwidth = $2\Delta f + 2f_m$



Frequency spectrum of FSK

Bandwidth = $f_1 + (1/T_b) - f_2 + (1/T_b)$

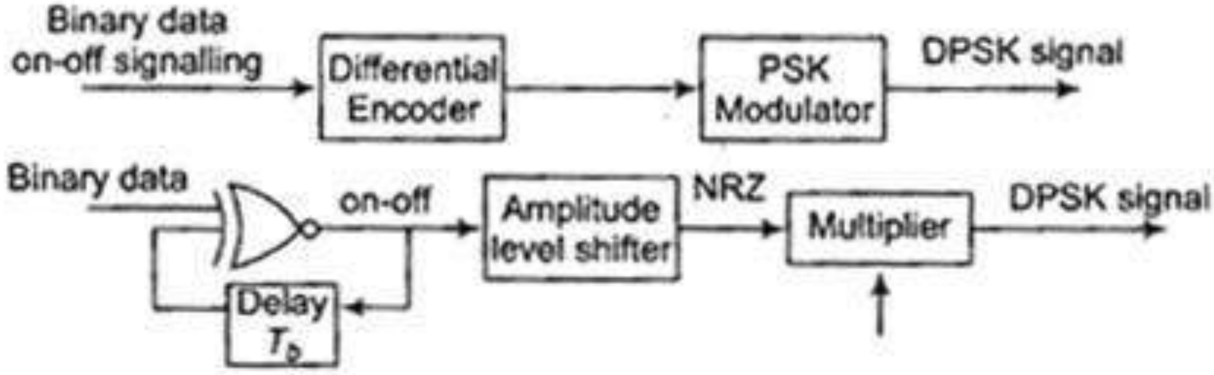
= $f_1 - f_2 + (2/T_b)$; $f_1 - f_2 = 2\Delta f$

Key Points

- In the case of FSK, P_e is less but SNR is high.
- Multiplexing is difficult in FSK.

Differential Phase Shift Keying (DPSK)

In PSK it needs a complicated synchronizing circuit at the receiver, this disadvantage of PSK is removed in DPSK.



Block diagram representation of detection of DPSK

$V_{DPSK}(t) = V(t)/V$

$A \cos \omega_0 t = \pm A \cos \omega_0 t$

Note: The advantage of DPSK over PSK is, DPSK does not require a coherent carrier for demodulation.

Comparison of Digital Modulation Schemes

Digital modulation schemes are used to modulate a digital signal onto an analog carrier signal for efficient transmission over a communication channel. There are several types of digital modulation schemes that differ in their complexity, data rate, and susceptibility to noise and interference.

Scheme	$S_1(t)$ and $S_2(t)$	BW	P_e	SNR	Complexity
Coherent ASK	$S_1(t) = A_c \cos 2\pi f_c t$ $S_2(t) = 0$	$2R_b$	high	low	high
Non-coherent ASK	$S_1(t) = A_c \cos \omega_c t$ $S_2(t) = 0$	$2R_b$	high	low	low
Coherent FSK	$S_1(t) = A_c \cos 2\pi f_1 t$ $S_2(t) = A_c \cos 2\pi f_2 t$ $(f_1 > f_2)$	$2R_b + (f_1 - f_2)$	moderate	high	high
Non-Coherent FSK	$S_1(t) = A_c \cos 2\pi f_1 t$ $S_2(t) = A_c \cos 2\pi f_2 t$	$> 2R_b$	moderate	high	low
Coherent PSK	$S_1(t) = A_c \cos \omega_c t$ $S_2(t) = -A_c \cos \omega_c t$	$2 R_b$	low	high	high
Non-coherent PSK	$S_1(t) = A_c \cos \omega_c t$ $S_2(t) = -A_c \cos \omega_c t$	$2R_b$	low	high	low