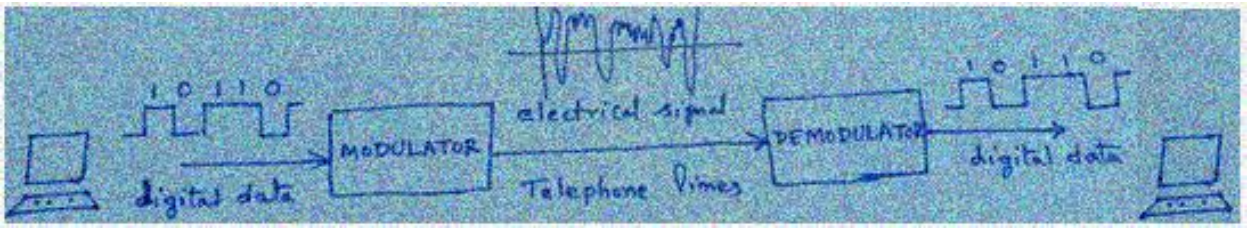
MODEM

Computer data is binary in nature and consists of sequence of 1s and 0s. Telephone lines are analog in nature and can carry only analog electrical signals. So devices called MODEMs are needed to transmit data over telephone lines.

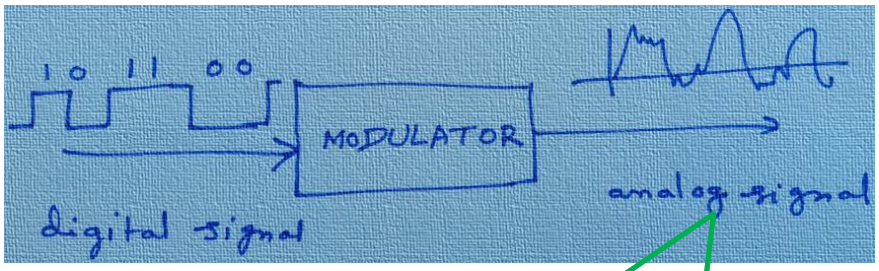


MODEM = MODulator + DEModulator

- A computer without MODEM is like a dog without bones
- A computer without MODEM is like a car without petrol
- Two computers nearby can be connected directly. This connection is called **NULL modem**.

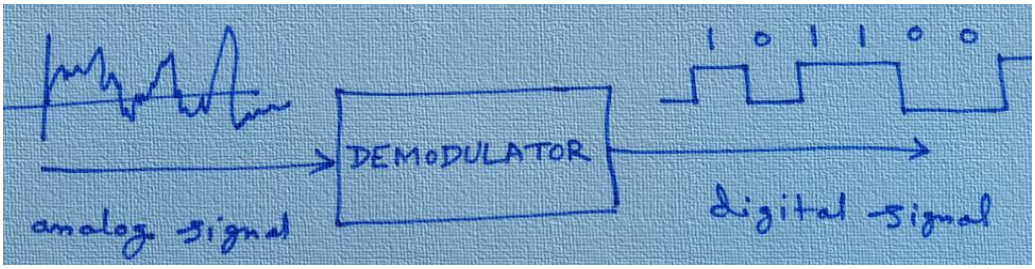
Modem consists of two sub-units called **modulator** and **demodulator**

Modulator converts digital signal into analog signal.



Analog signal is a continuous signal. Note that 'Majority of signals in the world around us are in analog form'. Voice is best example of analog signal. Other examples are: heart beat signal, temperature, atmospheric pressure etc.

Demodulator converts analog signal back to digital signal. Remember that computer can understand only digital signal.



NOTE: Modulation is the process of adding carrier to modulating signal. Demodulation is the process of removing carrier from modulated signal. (Refer my video lecture on **Modulation in Electronic Communication System**).

Various **digital modulation techniques** used for conversion of analog to digital and vice-versa are:

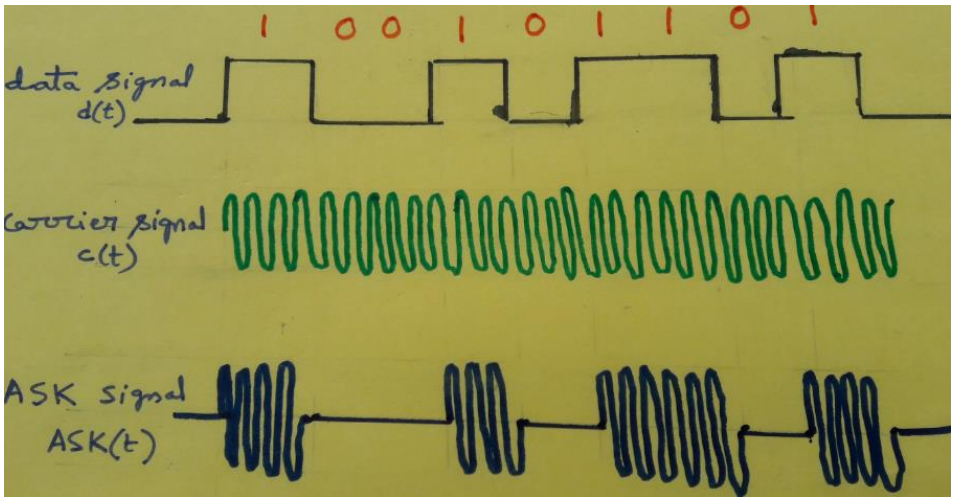
- ASK (Amplitude Shift Keying)
- FSK (Frequency Shift Keying)
- PSK (Phase Shift Keying)
- QPSK (Quadrature Phase Shift Keying)
- QAM (Quadrature Amplitude Modulation)

ASK (Amplitude Shift Keying)

ASK is also known as 2-level ASK, because number of amplitude changes = **2**.

Other names: **OOK** (On – Off Keying), **BASK** (Binary Amplitude Shift Keying)

ASK modulation waveforms are shown below:



Data signal d(t)

Carrier signal c(t)

FSK signal FSK(t)

As the name suggests, in ASK the amplitude of the carrier is changed according to data signal d(t). Note that d(t) is an input data signal.

ASK rule:

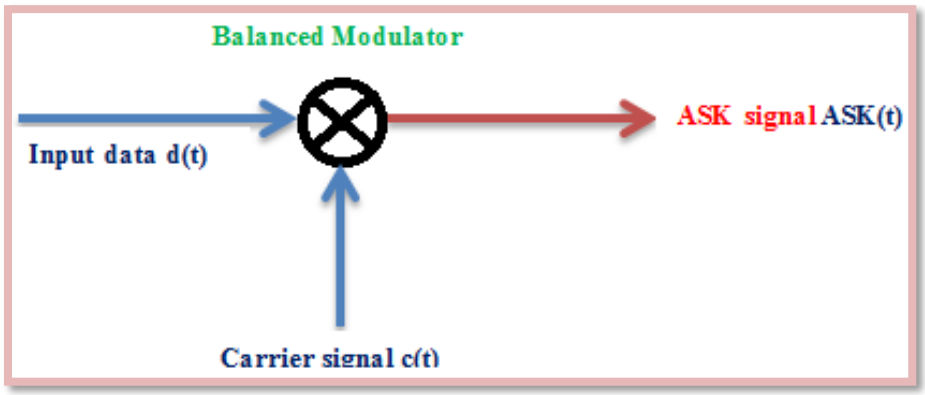
- Bit 1 is represented by high amplitude
- Bit 0 is represented by low amplitude

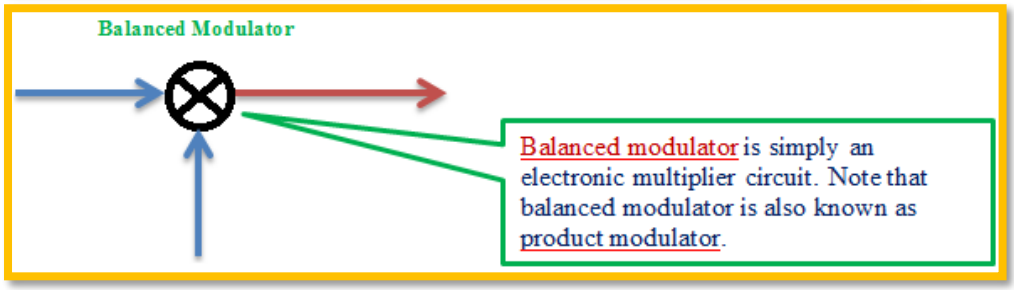
ASK features are as follows:

- Number of amplitude changes = Number of amplitudes used = **2**
- Constant variables: **Frequency** and **Phase** of the carrier
- Changing variable: **Amplitude** of carrier
- Number of bits transmitted at a time = 1

NOTE: If the incoming bit from computer is 1, then high amplitude (say 5V) is transmitted. If the incoming bit from computer is 0, then low amplitude (say 0V) is transmitted.

ASK Modulator: ASK modulation using balanced modulator is shown below. Remember that modulation is the process of adding carrier to the information signal.





$d(t) = data\ signal \longrightarrow\ consists\ of\ 1^s\ and\ 0^s$

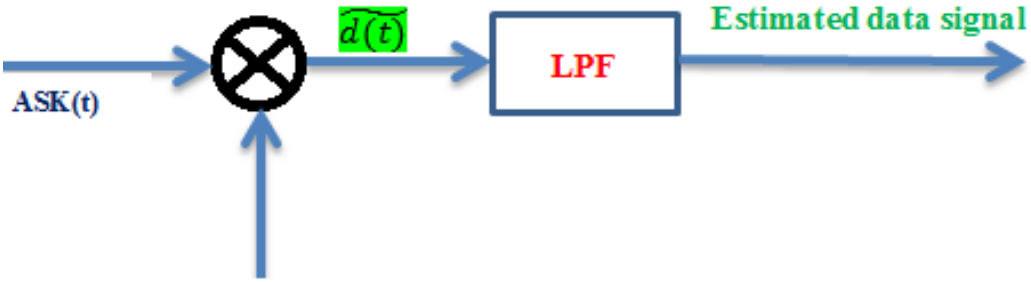
$c(t) = A_c \cos 2\pi f_c t$

Remember that balanced modulator multiplies data signal d(t) and carrier signal c(t). So,

$ASK(t) = d(t) * A_c \cos 2\pi f_c t$

ASK Demodulator

Note that demodulator is also known as detector. Remember that demodulation is the process of removing carrier from modulated signal. Demodulator is used to estimate the received signal. If bit **1** is transmitted, **1** should be received. If **0** is transmitted, **0** should be received. Otherwise there is no meaning of communication.

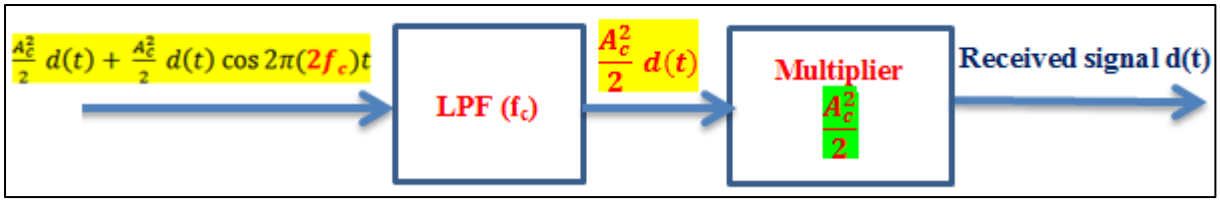


$$c(t) = A_c \cos 2\pi f_c t$$

$$\widetilde{d(t)} = ASK(t) * c(t)$$
$$= d(t) * A_c \cos 2\pi f_c t * A_c \cos 2\pi f_c t$$
$$= A_c^2\, d(t) * \cos^2 2\pi f_c t$$
$$= A_c^2\, d(t) \left\{ \frac{1 + \cos 4\pi f_c t}{2} \right\}$$
$$= \frac{A_c^2}{2}\, d(t) + \frac{A_c^2}{2}\, d(t) \cos 4\pi f_c t$$

Formula: $\cos^2 x = \frac{1 + \cos 2x}{2}$

Now this signal is passed through LPF (Low Pass Filter) with cut-off frequency f_c



LPF passes all frequency components below cut-off frequency f_c and removes all frequency components above f_c. So, $\frac{A_c^2}{2}\, d(t)$ $\cos 4\pi f_c t$ *is removed after passing through LPF*. Because, $\cos 4\pi f_c t = \cos 2\pi(2f_c)t$ and the frequency of this signal is $2f_c$.

NOTE: ASK is very sensitive to noise and has limited application in data transmission (low bit rates up to 100 bps). Remember that changing amplitude of carrier is dangerous as amplitude changes are very susceptible to noise. That means noise easily attacks information signal.

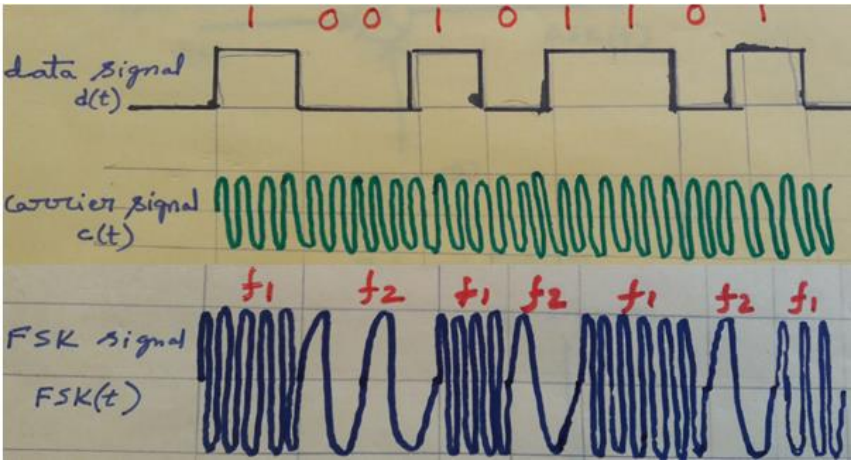
NOTE: In ASK, modulating voltage (i.e., input voltage) is used to vary amplitude of the carrier.

FSK (Frequency Shift Keying)

FSK is also known as 2-level FSK, because number of frequency changes = **2**.

Other name: **BFSK** (Binary Frequency Shift Keying)

FSK modulation waveforms are shown below:



Data signal d(t)

Carrier signal c(t)

FSK signal FSK(t)

FSK rule:

- Bit 1 is represented by high frequency (f_1) carrier signal
- Bit 0 is represented by low frequency (f_2) carrier signal

No matter if bit 0 is represented by low frequency signal and vice versa.

FSK features are as follows:

- Number of frequency changes = Number of frequency used = **2**
- Constant variables: **Amplitude** and **Phase** of the carrier
- Changing variable: **Frequency** of carrier
- Number of bits transmitted at a time = 1

NOTE: If the incoming bit from computer is 1, then high frequency signal (say f_1) is transmitted. If the incoming bit from computer is 0, then low frequency signal (say f_2) is transmitted.

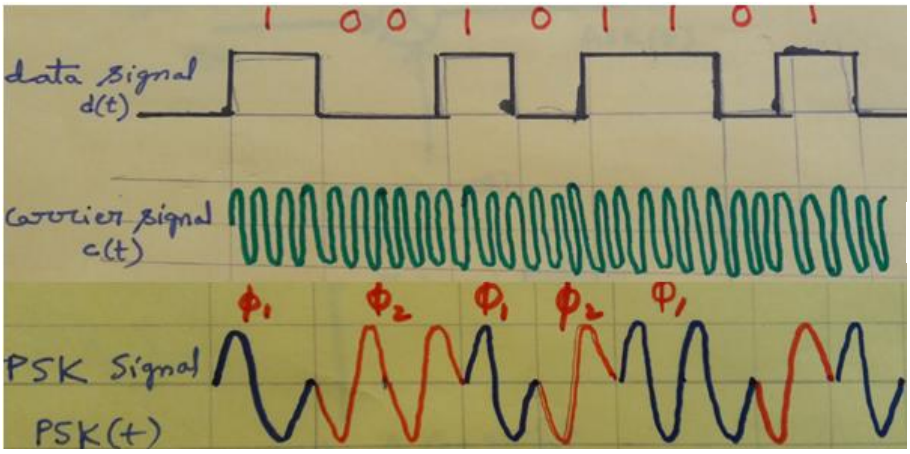
NOTE: In FSK, modulating voltage (i.e., input voltage) is used to vary frequency of the carrier.

PSK (Frequency Shift Keying)

PSK is also known as 2-level PSK, because number of phase changes = **2**.

Other name: **BFSK** (Binary Frequency Shift Keying)

PSK modulation waveforms are shown below:



Data signal d(t)

Carrier signal c(t)

PSK signal PSK(t)

PSK rule:

- Bit 1 is represented by some phase ($\emptyset_1$) carrier signal
- Bit 0 is represented by some other phase ($\emptyset_2$) carrier signal

PSK features are as follows:

- Number of phase changes = Number of phases used = **2**
- Constant variables: **Amplitude** and **Frequency** of the carrier
- Changing variable: **Phase** of carrier
- Number of bits transmitted at a time = 1

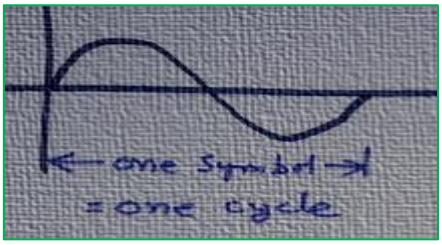
NOTE: If the incoming bit from computer is 1, then carrier with phase (say $\emptyset_1$) is transmitted. If the incoming bit from computer is 0, then carrier signal with phase (say $\emptyset_2$) is transmitted.

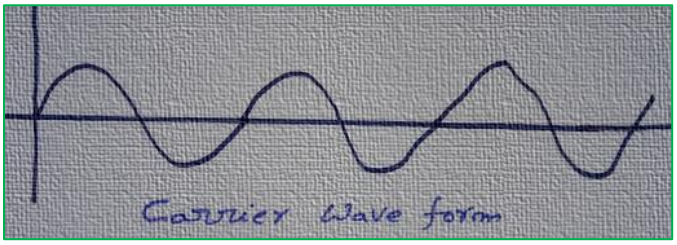
Multi-level Modulation

Ordinary modulation techniques such as ASK, FSK and PSK are 2-level modulation schemes. They can transmit only 1- bit/sec.

To increase the bit rate (or data rate), we should be able to transmit more than 1-bit per second. This can be achieved by using multi-level modulation techniques. BAUD RATE is an important term related to multi-level modulation.

Baud rate: is defined as number of symbols per sec. Example of one symbol of carrier waveform is shown below:





Generally, in 2-level modulations, only 1-bit can be transmitted in one cycle or symbol. In multi-level modulation, we can transmit more than one bit per symbol.

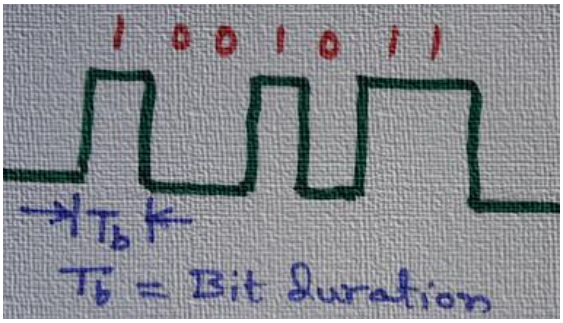
2 level modulation ⟶ $2 = 2^1$ ⟶ **1** bit per symbol is transmitted
4 level modulation ⟶ $4 = 2^2$ ⟶ **2** bits per symbol is transmitted
8 level modulation ⟶ $8 = 2^3$ ⟶ **3** bits per symbol is transmitted etc.

Bit Rate: Bit rate is the number of bits transmitted per sec. Note that bit rate is also known as data rate. Its unit is bps (bits per sec).

Note that bit rate depends on the width of the pulse (T_b). See below figure for relationship between bit rate and pulse width (T_b).

Baud rate = Number of symbols per sec.
Bit rate = Number of bits per sec.

$$Bit\ rate = baud\ rate\ x\ bits\ per\ symbol$$



We should be able to transmit more bits/sec.

T_b = bit duration = bit time
Data rate $R = \frac{1}{T_b}$

If T_b = 0.1 msec, then $R = \frac{1}{T_b} = \frac{1}{0.1x\ 10^{-3}} = 10\ kbps$

Q. A serial pulse train has a 70 µsec bit duration. What is the data rate in bits per second?

Solution:

Bit duration Tb = 70 µsec = $70\ x\ 10^{-6}\ sec$

$$\therefore Data\ rate\ R\ = \frac{1}{T_b} = \frac{1}{70\ x\ 10^{-6}} = 14285.7\ bps = 14.285\ kbps$$

Q. A digital communication system uses 6000 bps bitrate. If each signal unit (i.e., symbol) carries 4 bits, what is the baud rate?

Solution:

Give bit rate R = 6000 bps

$$Bit\ rate = baud\ rate\ x\ bits\ per\ symbol$$

Therefore,

$$baud\ rate = \frac{Bit\ rate}{Number\ of\ bits\ per\ sec} = \frac{6000}{4} = 1500\ baud/sec$$

Q. An analog signal carries 3 bits in each signal unit (i.e., symbol). If 1000 signal units are sent per second, find the baud rate and the bit rate.

Solution:

Baud rate = 1000 baud/sec
Number of bits per symbol = 3

$$baud\ rate = 1000\ baud/sec$$

$$Bit\ rate = baud\ rate\ x\ bits\ per\ symbol\ = 1000\ x\ 3 = 3000$$

HOME WORK

1. Draw waveforms of 4-ASK modulation
2. Draw waveforms of 4-FSK modulation
3. Draw waveforms of QPSK (= 4 PSK modulation)
4. Derive Fourier Transform of a pulse with duration T = 10 msec shown below. Assume amplitude of pulse = 5 V.