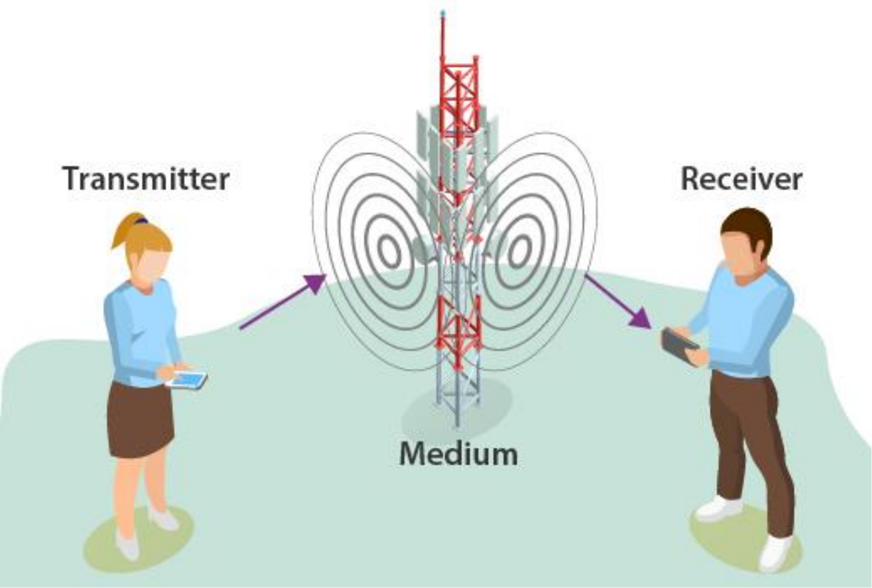
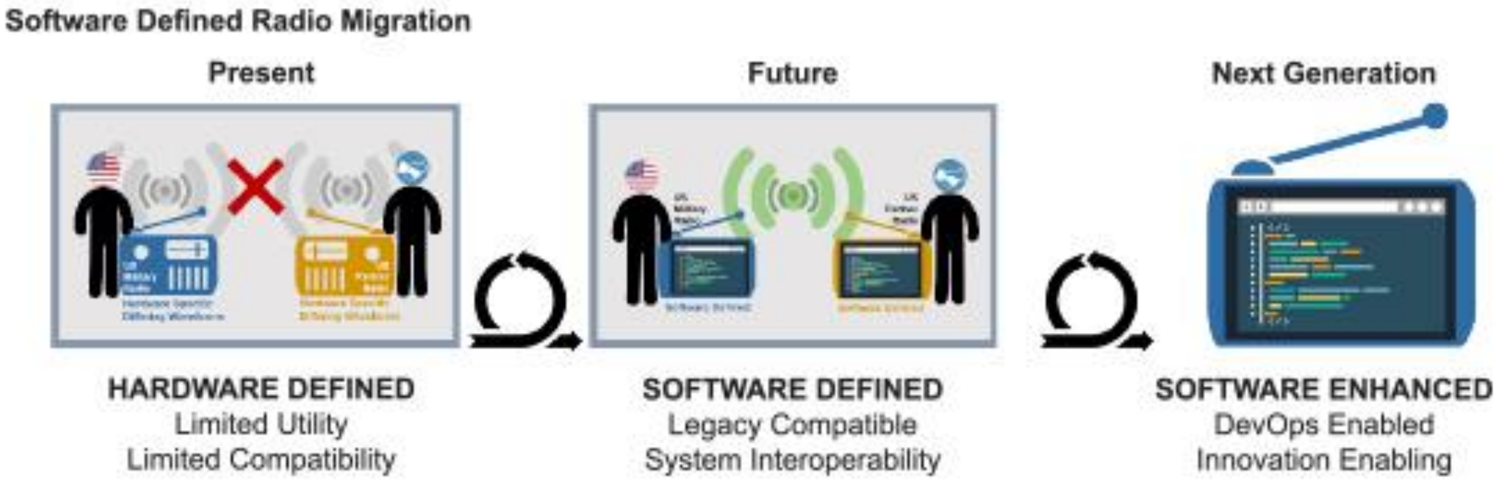


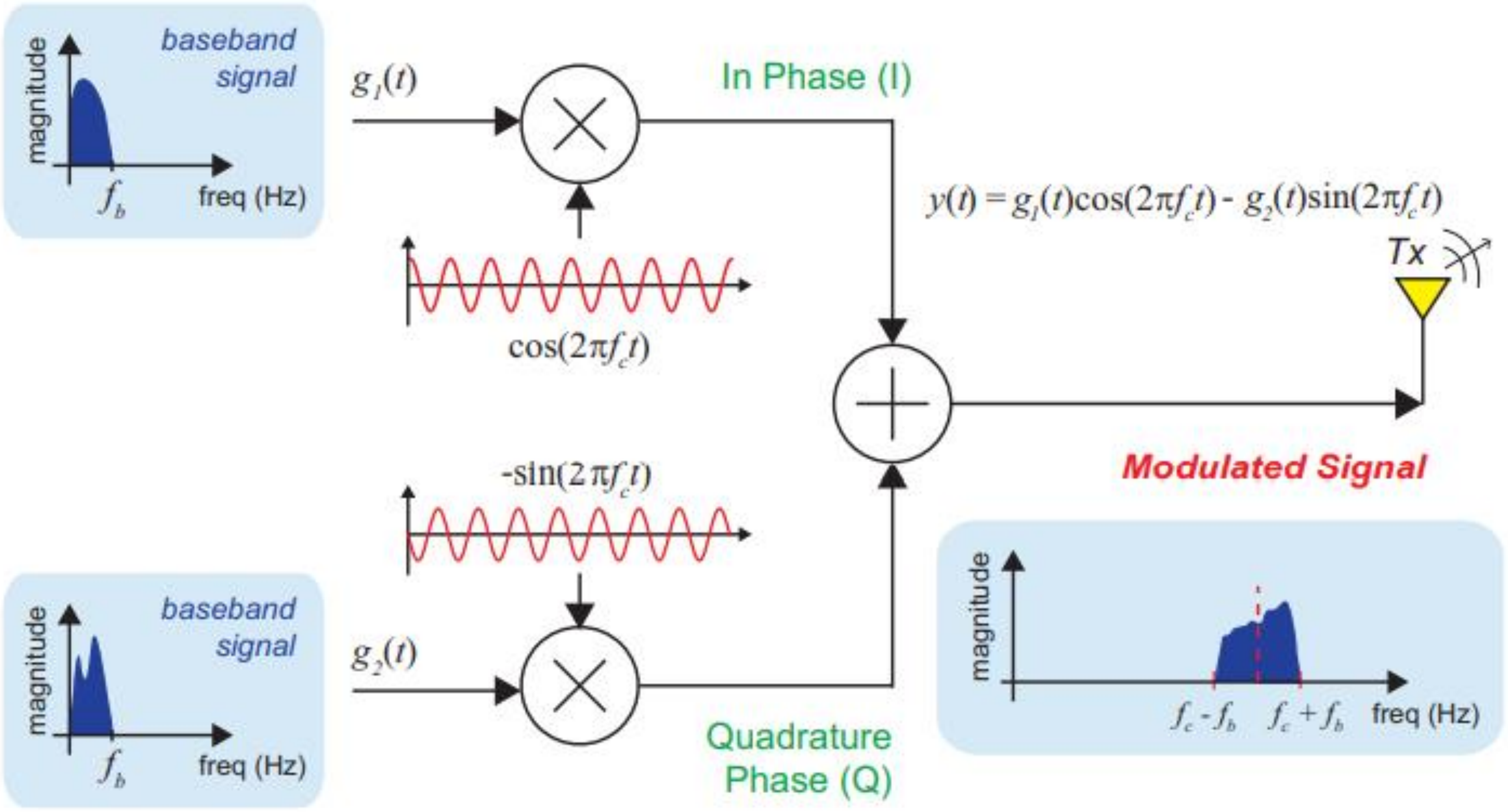


23AID203-Software-defined Communication System
Unit-3

Sirisha Tadepalli

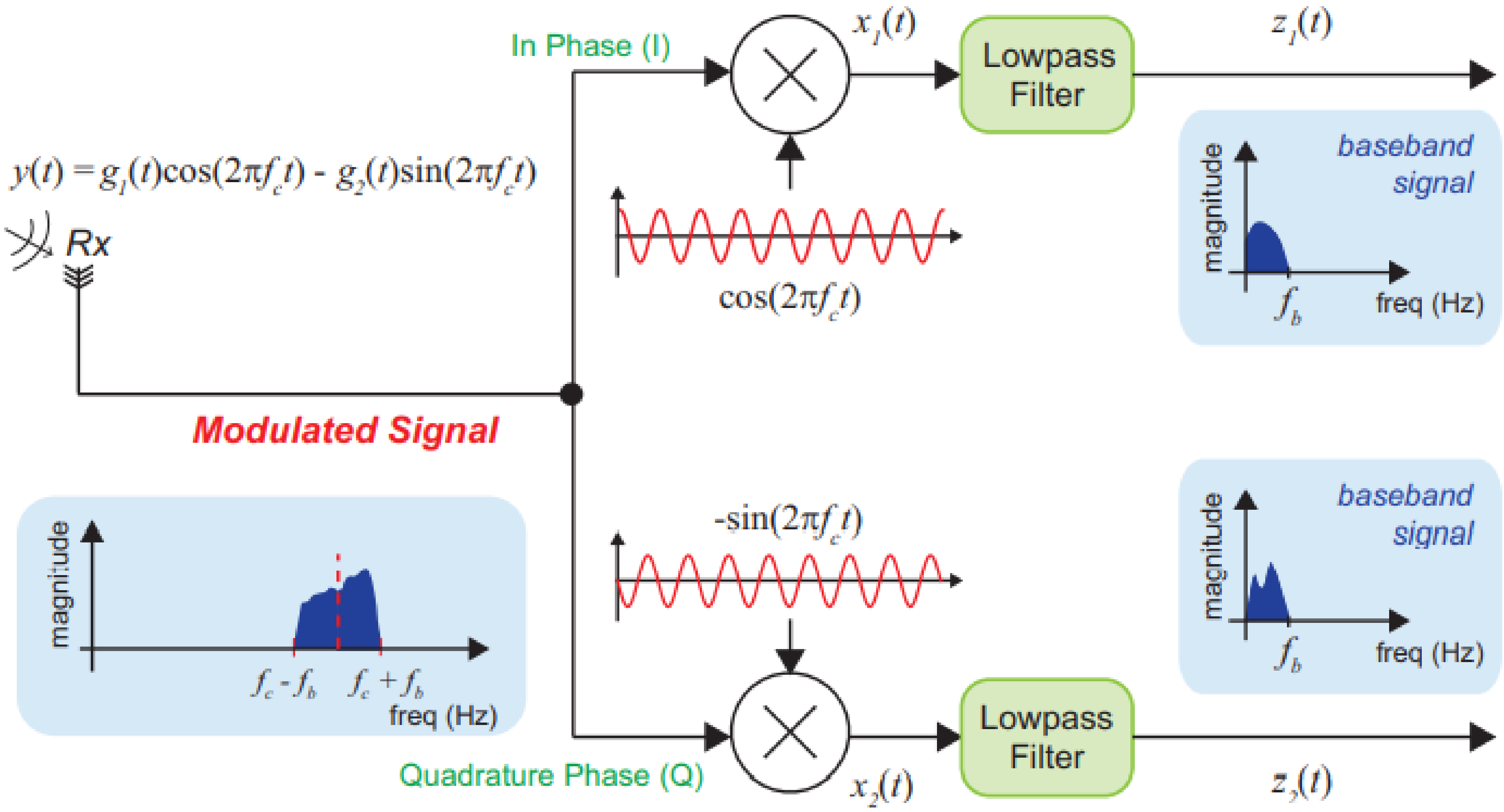
Quadrature Amplitude Modulation (QAM)

- **Quadrature amplitude modulation** (**QAM**) is the name of a family of digital and analog modulation methods widely used in modern communication systems to transmit information.
- It conveys two analog message signals, or two digital bit streams, by changing (*modulating*) the amplitudes of two carrier waves, and one carrier is phase-shifted by 90^0. Therefore, it is a modulation scheme that combines amplitude and phase modulation to create a signal
- In standard AM, to transmit a signal of bandwidth fb Hz, we require a bandwidth of 2fb Hz.
- We can achieve more BW-efficient signaling by presenting quadrature modulation, in which we can transmit two signals of bandwidth fb Hz, both on the same carrier frequency, but carrier phases are separated by 90 degrees.



By convention the cosine modulating channel is referred to as the *In-Phase* or *I*-channel or '*real*' channel, and the sine modulating channel is referred to as the *Quadrature Phase* or *Q*-channel or '*imaginary*' channel. Note that '-sine' is one quadrant or 90° or $\pi/2$ radians away from the 'cosine', hence the name *quadrature*; $-\sin(2\pi f_c t) = \cos(2\pi f_c t + \pi/2)$.

Quadrature Demodulation



We can now demonstrate with some simple trigonometry that the quadrature ampltitude modulated (QAM) receiver will work, and allow the $g_1(t)$ and $g_2(t)$ transmitted baseband signals to be recovered from the received $y(t)$ signal.

For the I (In Phase, or cosine) channel, the output after the cosine demodulator is:

Since:

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

$$\sin A \cos A = \frac{\sin 2A}{2}$$

$$
\begin{aligned}
x_1(t) &= y(t)\cos(2\pi f_c t) \\
&= \left[g_1(t)\cos(2\pi f_c t) - g_2(t)\sin(2\pi f_c t)\right]\cos(2\pi f_c t) \\
&= g_1(t)\cos^2(2\pi f_c t) - g_2(t)\sin(2\pi f_c t)\cos(2\pi f_c t) \\
&= \frac{1}{2}g_1(t)[1 + \cos(4\pi f_c t)] - \frac{1}{2}g_2(t)\sin(4\pi f_c t) \\
&= \frac{1}{2}g_1(t) + \cancel{\left[\frac{1}{2}g_1(t)\cos(4\pi f_c t) - \frac{1}{2}g_2(t)\sin(4\pi f_c t)\right]}
\end{aligned}
$$

lowpass filtered terms

After lowpass filtering the cosine channel output is: $z_1(t) = \mathrm{LPF}\{x_1(t)\} = 0.5g_1(t)$

Similarly for the Q (Quadrature Phase or sine) channel,

$$
\begin{aligned}
x_2(t) &= y(t)(-\sin(2\pi f_c t)) \\
&= \left[g_1(t)\cos(2\pi f_c t) - g_2(t)\sin(2\pi f_c t)\right](-\sin(2\pi f_c t)) \\
&= [-g_1(t)\cos(2\pi f_c t)\sin(2\pi f_c t)] + g_2(t)\sin^2(2\pi f_c t) \\
&= -\frac{1}{2}g_1(t)\sin(4\pi f_c t) + \frac{1}{2}g_2(t)[1 - \cos(4\pi f_c t)] \\
&= \frac{1}{2}g_2(t) - \left[\frac{1}{2}g_1(t)\sin(4\pi f_c t) + \frac{1}{2}g_2(t)\cos(4\pi f_c t)\right]
\end{aligned}
$$

lowpass filtered terms

Therefore, after lowpass filtering and scaling: $z_2(t) = \mathrm{LPF}\{x_2(t)\} = 0.5g_2(t)$.

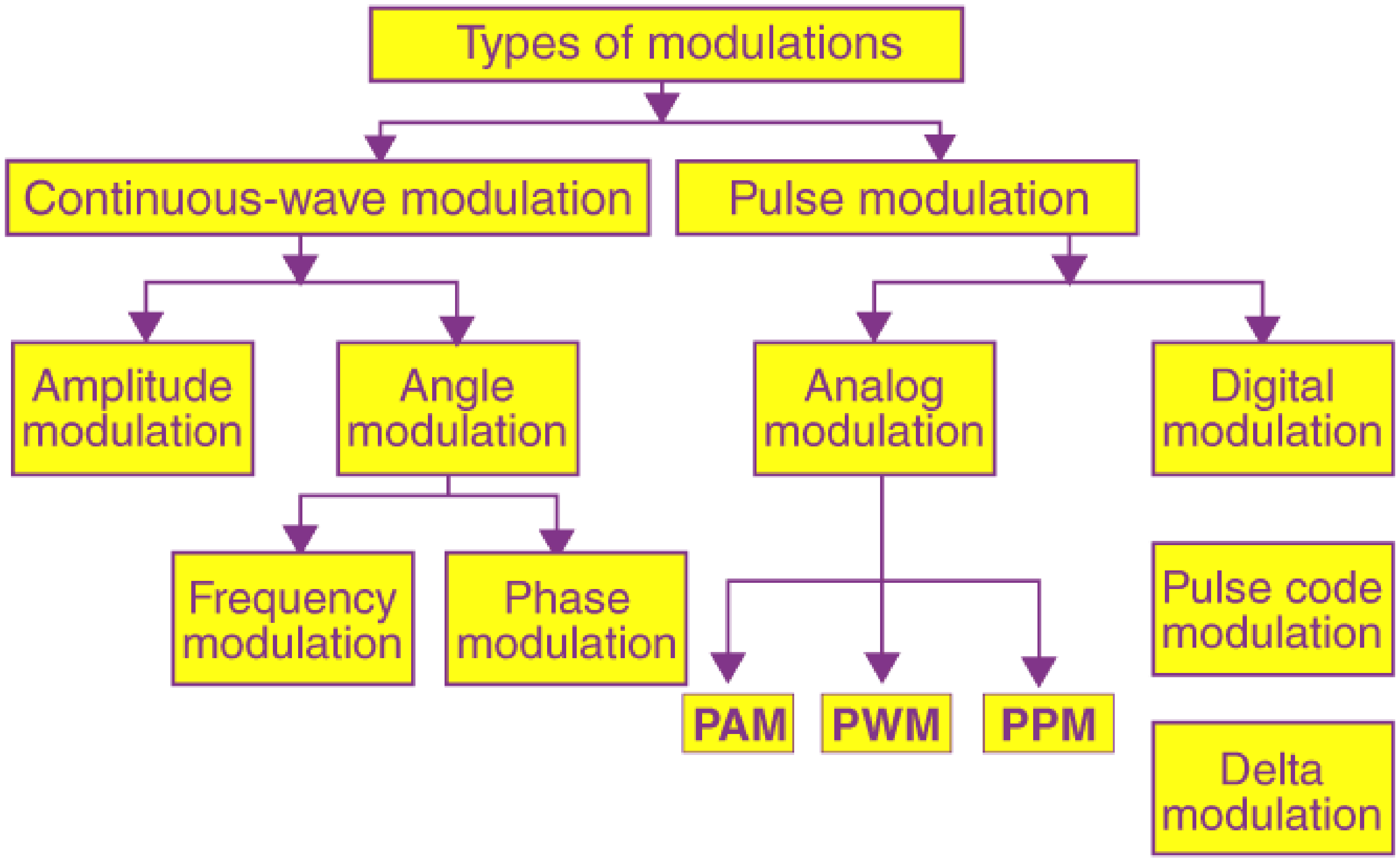
Applications of QAM

- QAM is used in digital communications systems, such as 802.11 Wi-Fi standards, satellite communication systems, and mobile radio.
- Cable television: QAM is used to deliver video, audio, and data over cable networks. For example, 64 QAM and 256 QAM are used in digital cable television and cable modem applications in the US.
- Wireless and cellular technology: QAM is used in broadband digital cellular standards, such as LTE and WiMAX. QAM is preferred in wireless device technology because it provides higher data rates, noise immunity, wide bandwidth, and low error values.
- Public safety standards: QAM is used in public safety standards, such as TETRA.
- TV white spaces: QAM is used in TV white spaces, such as cognitive WRAN.
- Internet Protocol cable television: QAM is used in Internet Protocol cable television.

Pulse Analog Modulation Schemes

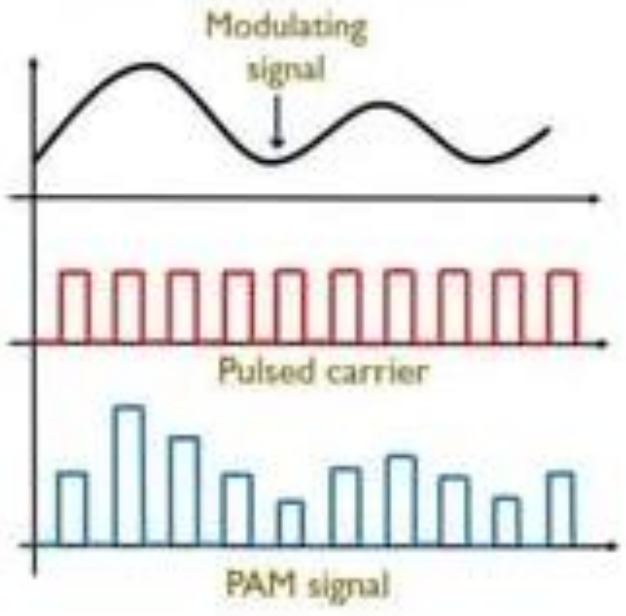
Pulse analog modulation schemes – Types

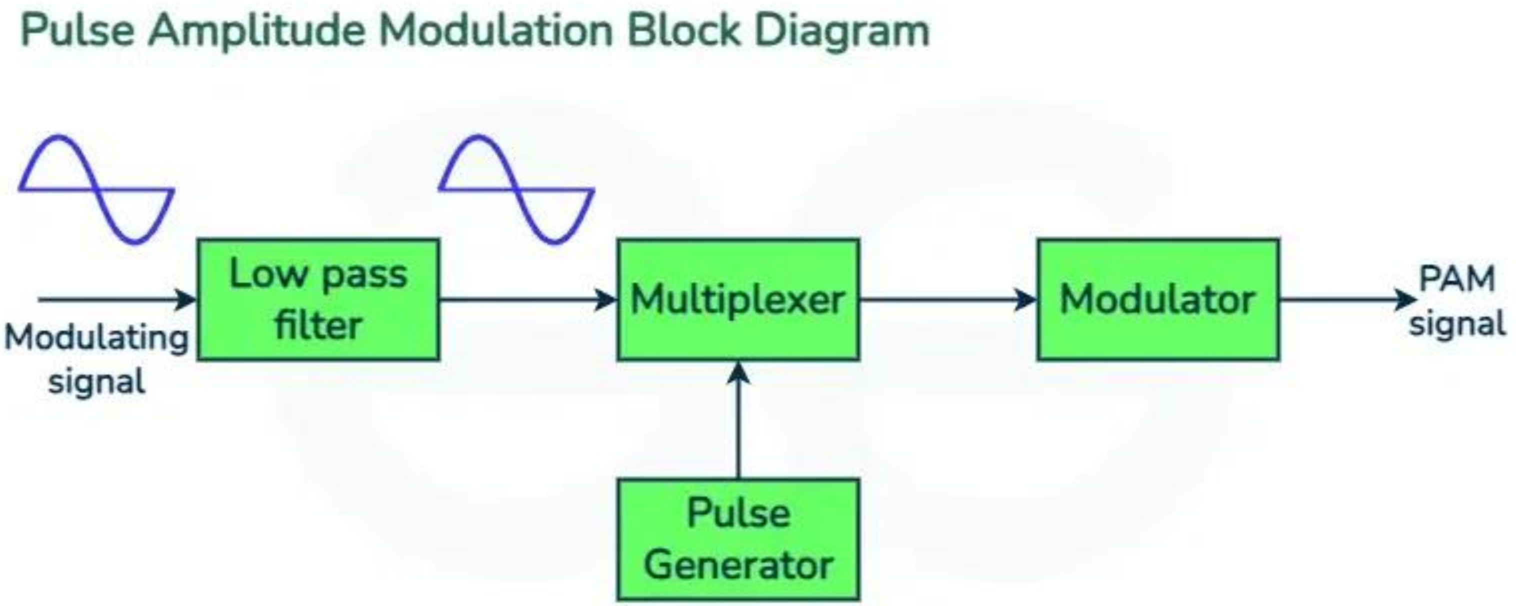
1. Pulse Amplitude Modulation (PAM)
2. Pulse Width Modulation (PWM)
3. Pulse Position Modulation (PPM)



Pulse Amplitude Modulation (PAM)

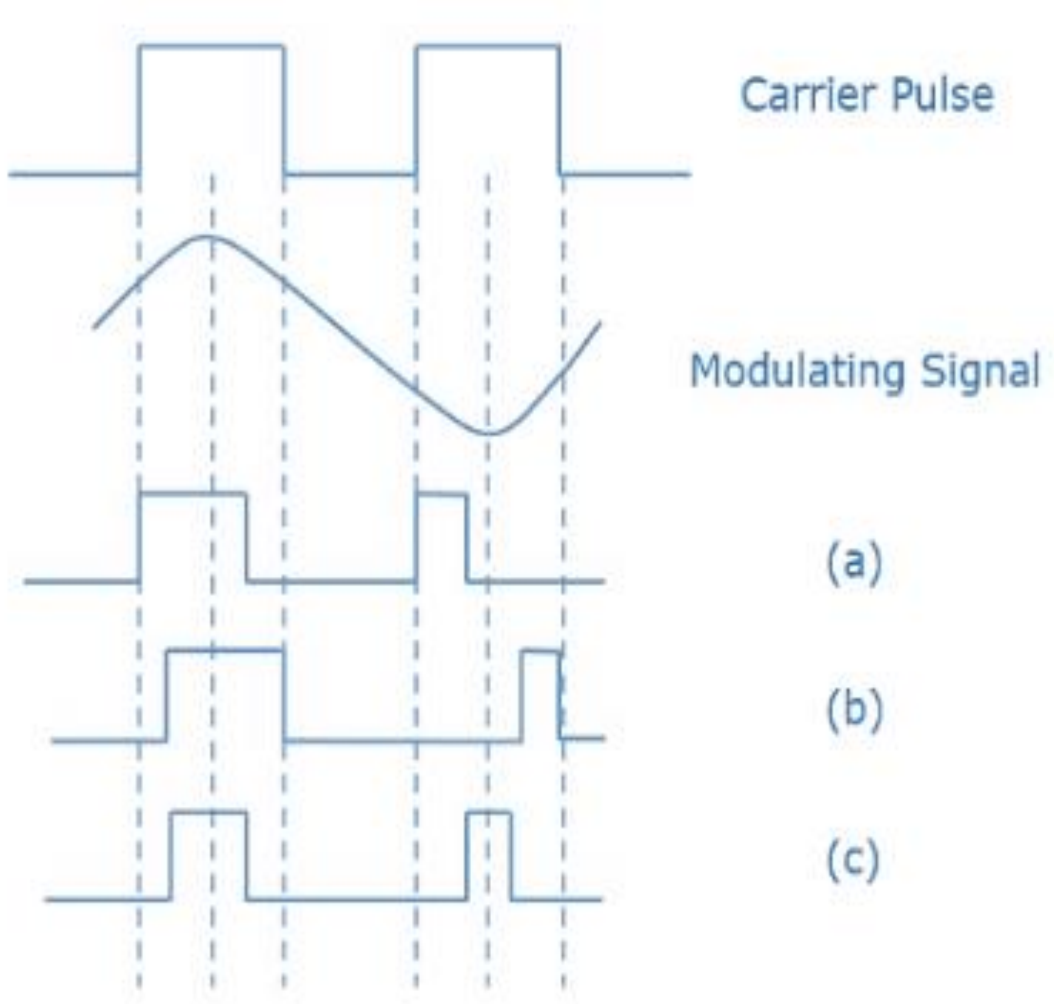
- **Pulse Amplitude Modulation (PAM)** is an analog modulating scheme in which the amplitude of the pulse carrier varies proportional to the instantaneous amplitude of the message signal.
- The information signal, usually analog, is used to modify a binary (on/off) or pulsed carrier in some way.
- Applications: Ethernet connectivity, Microcontrollers, Graphics cards,





Pulse Width Modulation (PWM)

- **Pulse Width Modulation (PWM)** or **Pulse Duration Modulation (PDM)** is an analog modulating scheme in which the duration or width of the pulse carrier varies proportional to the instantaneous amplitude of the message signal.



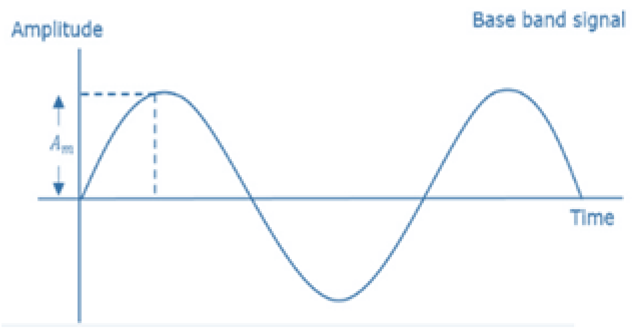
a)The leading edge of the pulse being constant, the trailing edge varies according to the message signal.

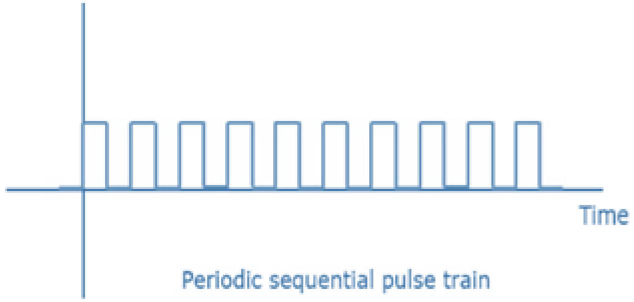
b)The trailing edge of the pulse being constant, the leading edge varies according to the message signal.

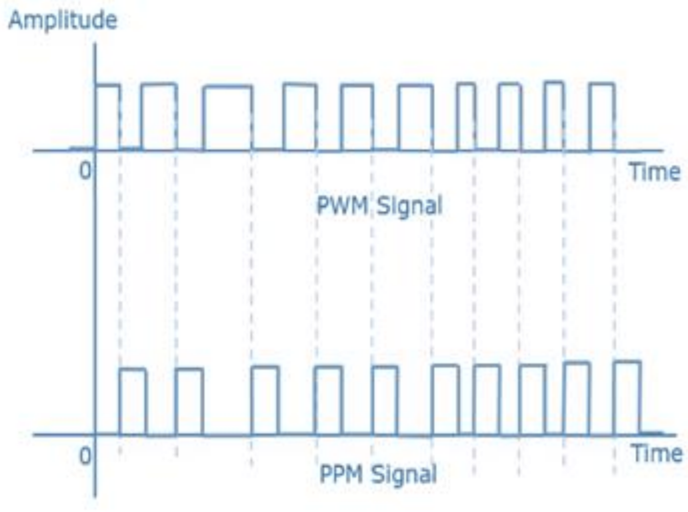
c)The center of the pulse being constant, the leading edge and the trailing edge varies according to the message signal.

Pulse Position Modulation (PPM)

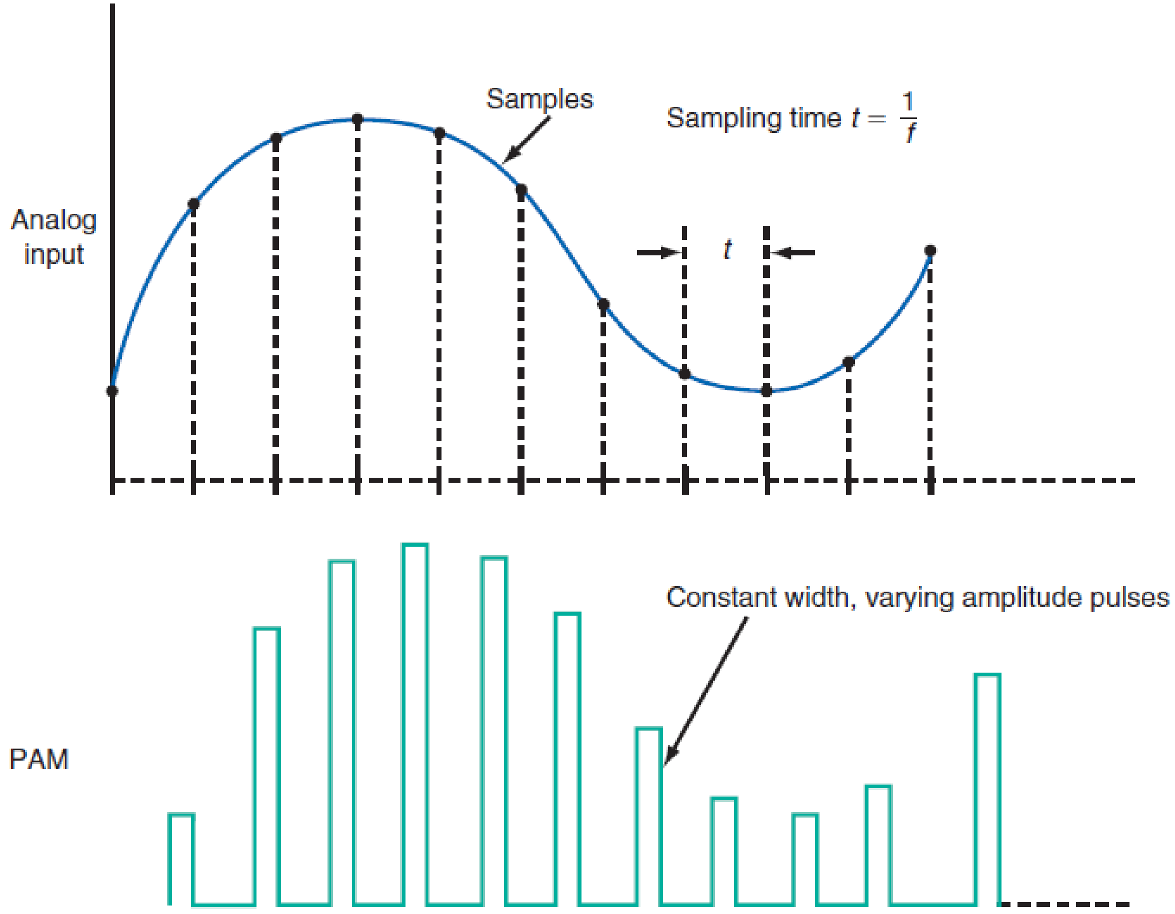
- **Pulse Position Modulation (PPM)** is an analog modulating scheme in which the amplitude and width of the pulses are kept constant, while the position of each pulse, with reference to the position of a reference pulse varies according to the instantaneous sampled value of the message signal.

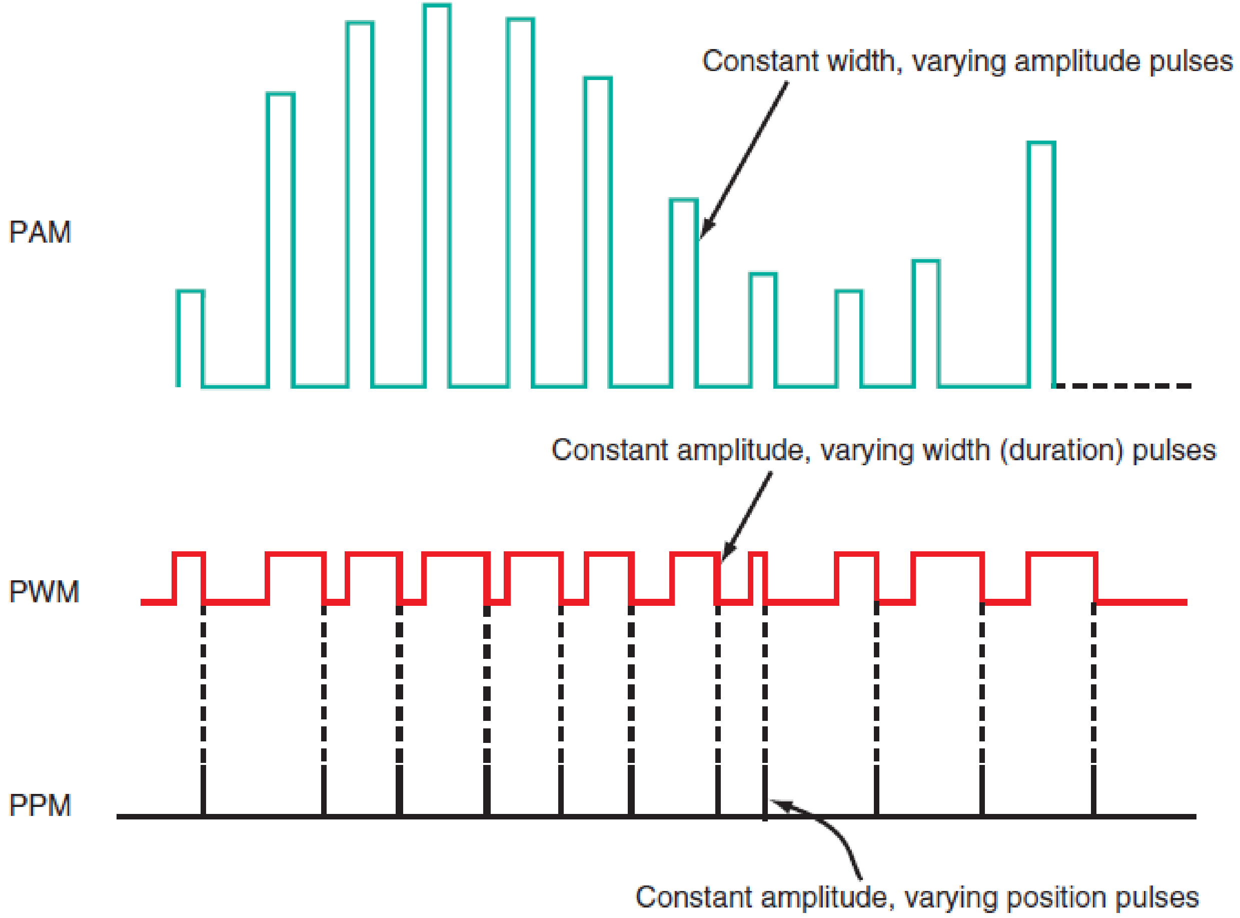




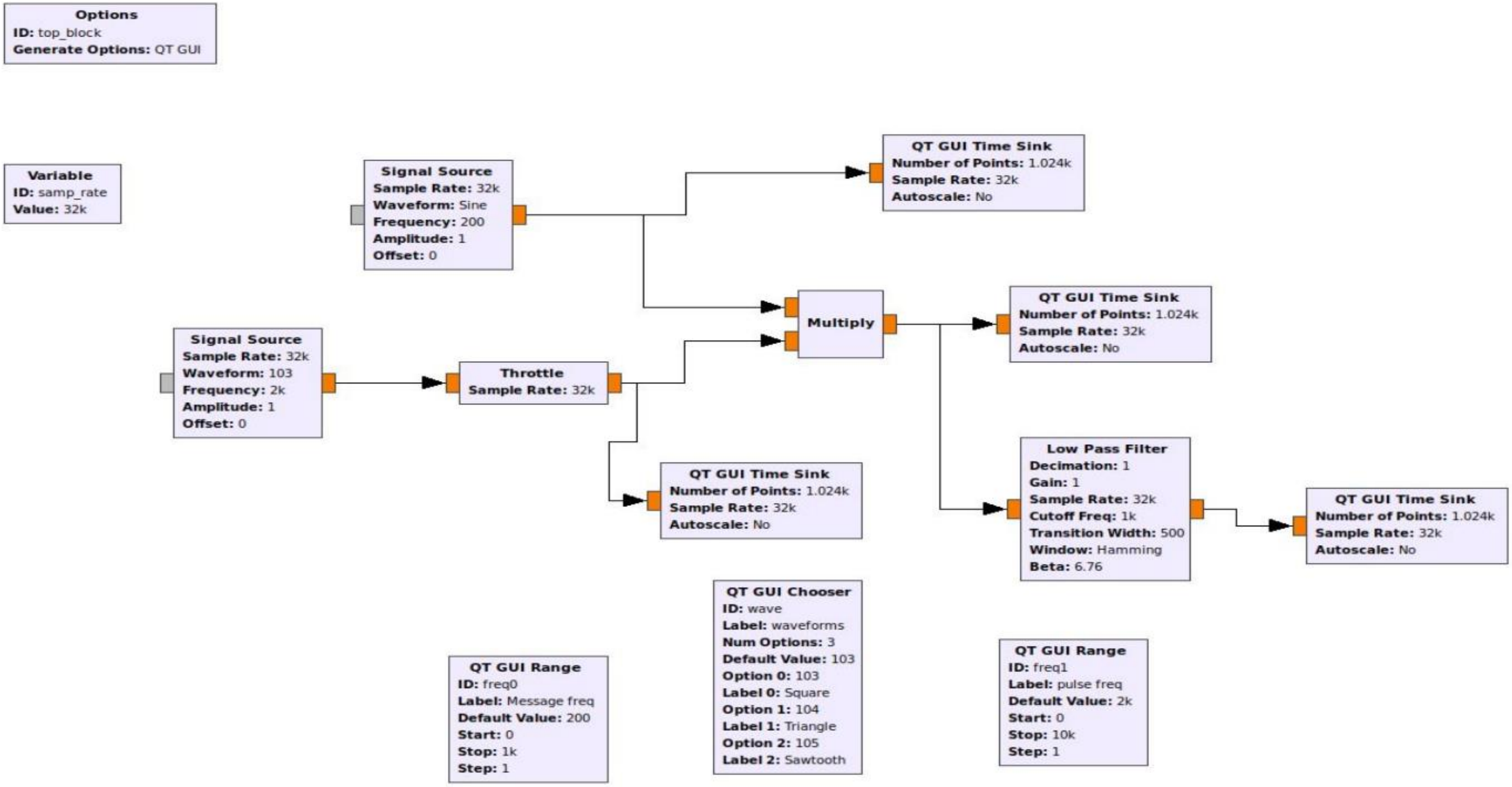


Pulse position modulation is done in accordance with the pulse width modulated signal. Each trailing of the pulse width modulated signal becomes the starting point for pulses in PPM signal. Hence, the position of these pulses is proportional to the width of the PWM pulses.

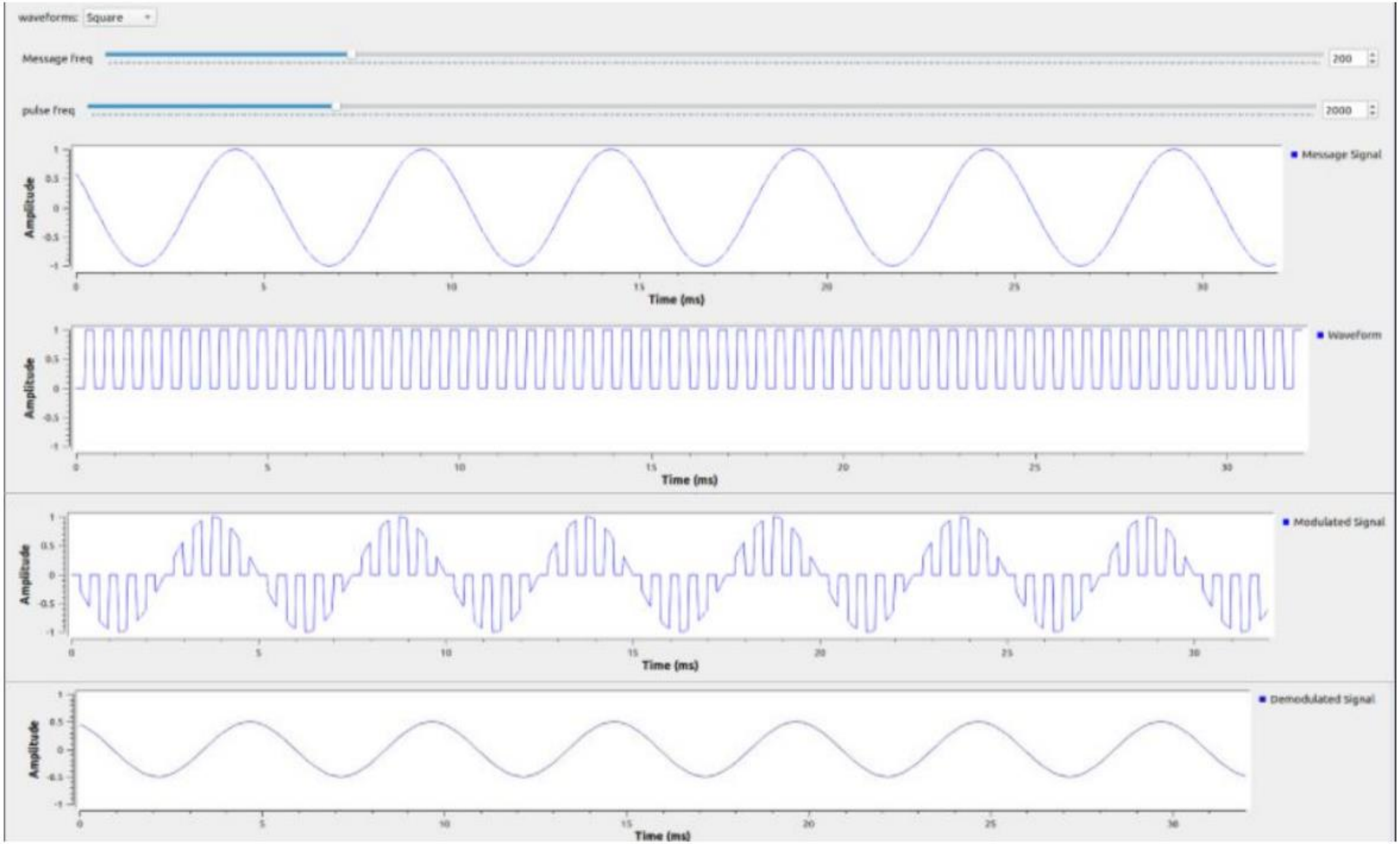

Samples
Sampling time $t = \frac{1}{f}$
Analog input
t
PAM
Constant width, varying amplitude pulses


PAM
Constant width, varying amplitude pulses
Constant amplitude, varying width (duration) pulses
PWM
PPM
Constant amplitude, varying position pulses

PAM Generation –Using GNU Radio Companion



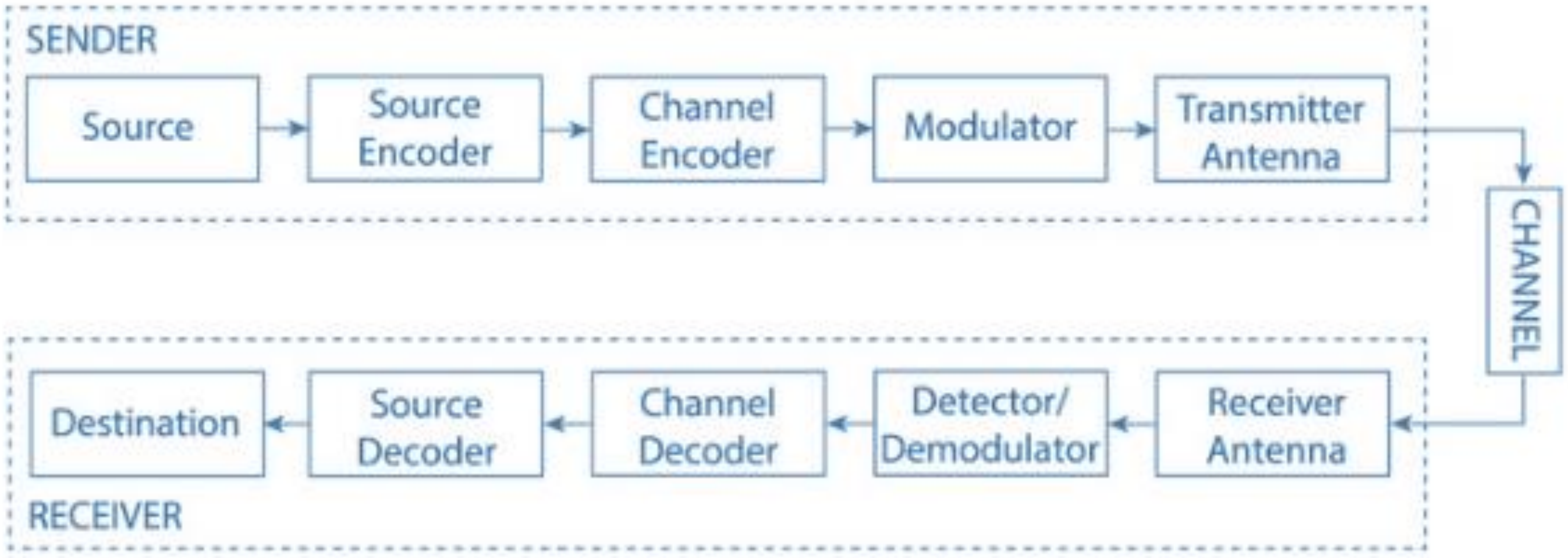
PAM Generated (Time Sink) –Using GNU Radio Companion



- List of Modulation Techniques to be implemented in the coming lab using GNU radio
- VSB-AM
- FM and NBFM
- PM
- QAM
- PAM and
- PCM

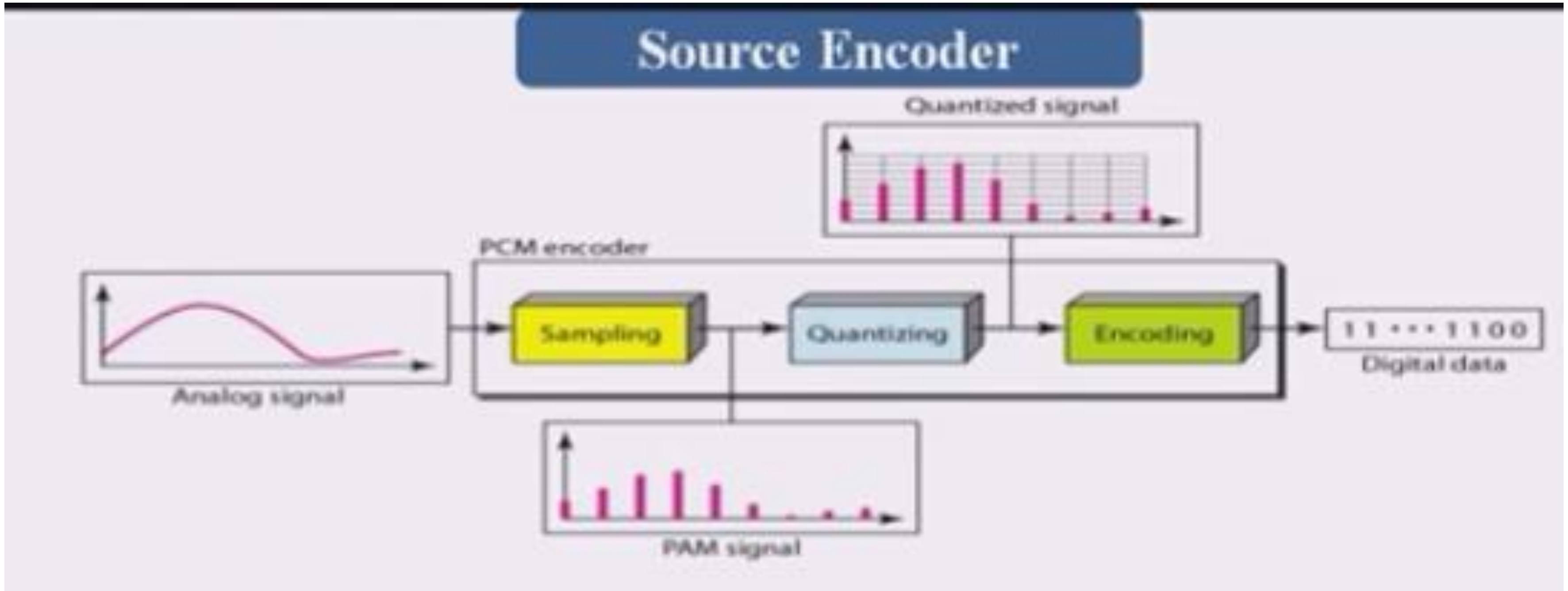
Digital Communication Systems

Block Diagram of Digital Communication System



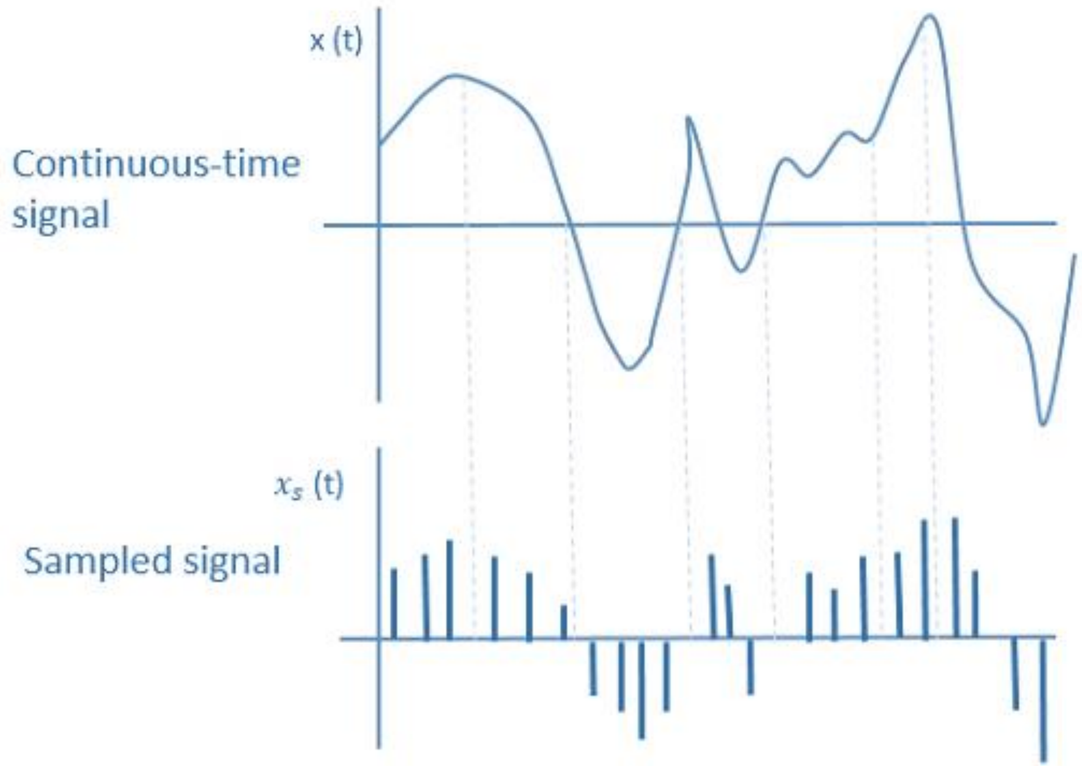
- **Source:** It can be voice, audio, video etc
- **Source encoding:** The process of mapping from original source to a bit

- Source encoder consists of 3 units as follows

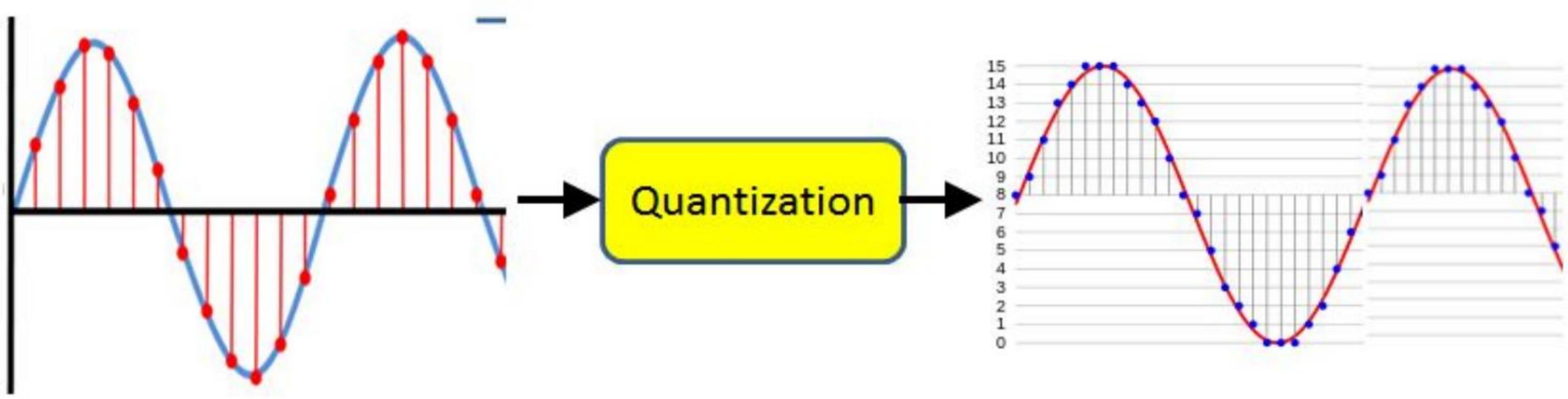


Sampling

- It is the process of measuring the instantaneous values of continuous-time signal in a discrete form
- When a source generates an analog signal and if that has to be digitized, having **1s** and **0s** i.e., High or Low, the signal has to be discretized in time.
- This discretization of analog signal is called as Sampling



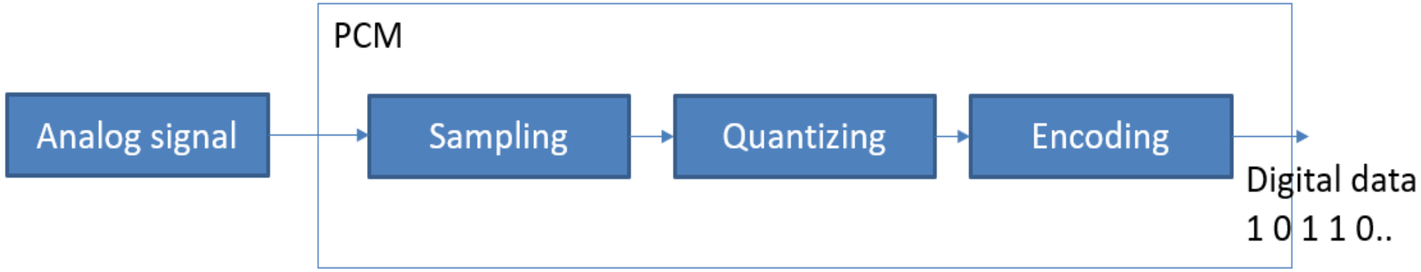
- **Quantization:** Converting the amplitude of analog signal to a digital value
- Quantization is representing the sampled values of the amplitude by a finite set of levels, which means converting a continuous-amplitude sample into a discrete-time signal.

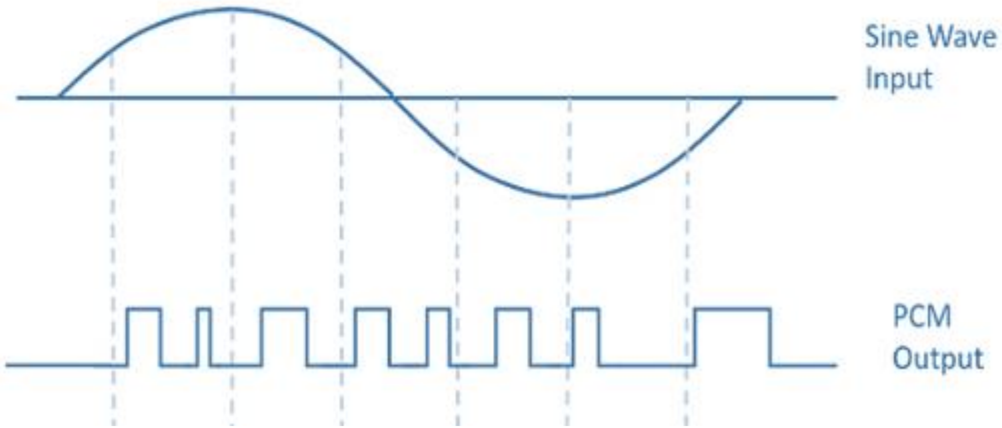


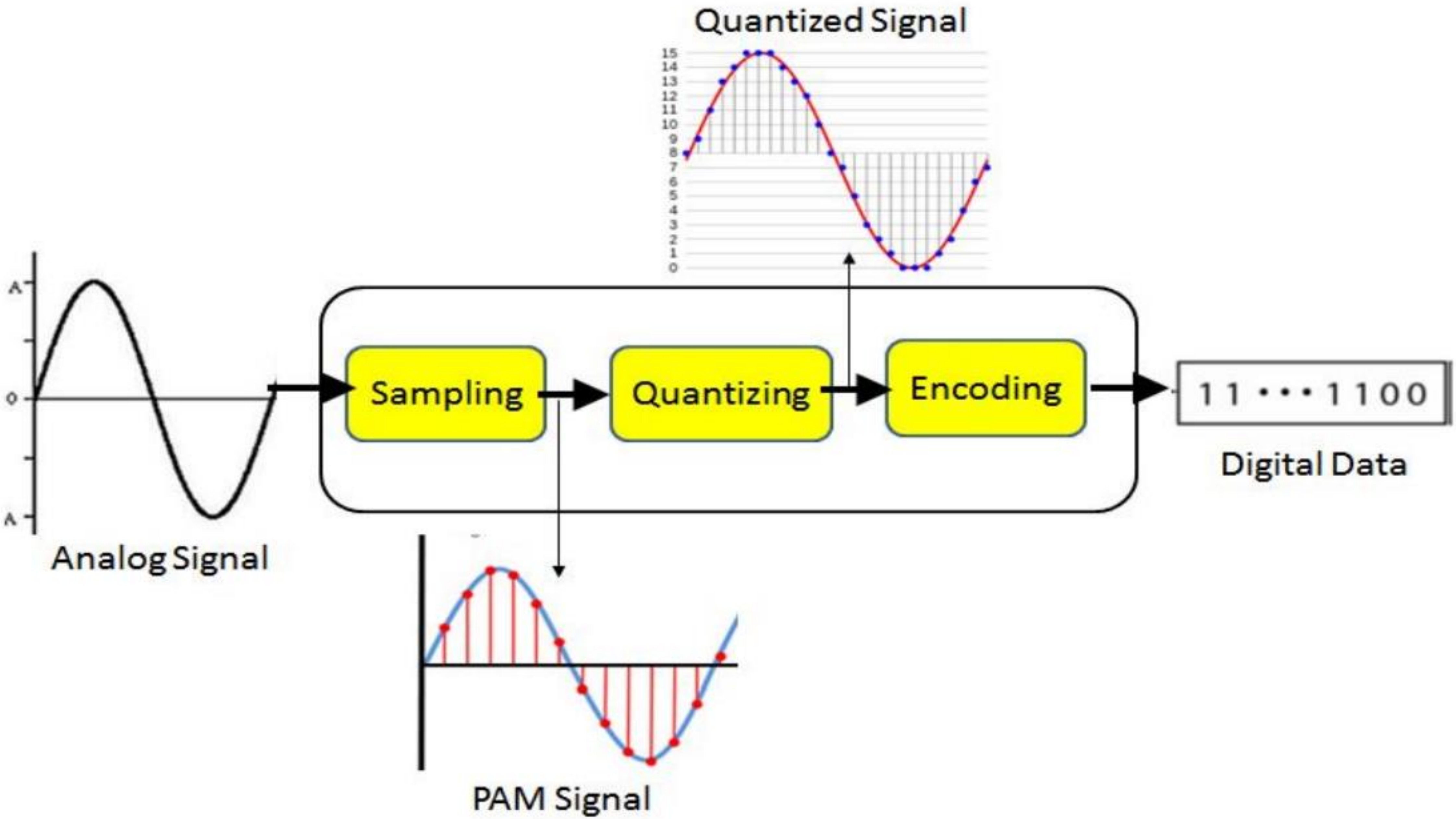
- Encoding: Assigning a binary code to each finite amplitude

Pulse Code Modulation (PCM)

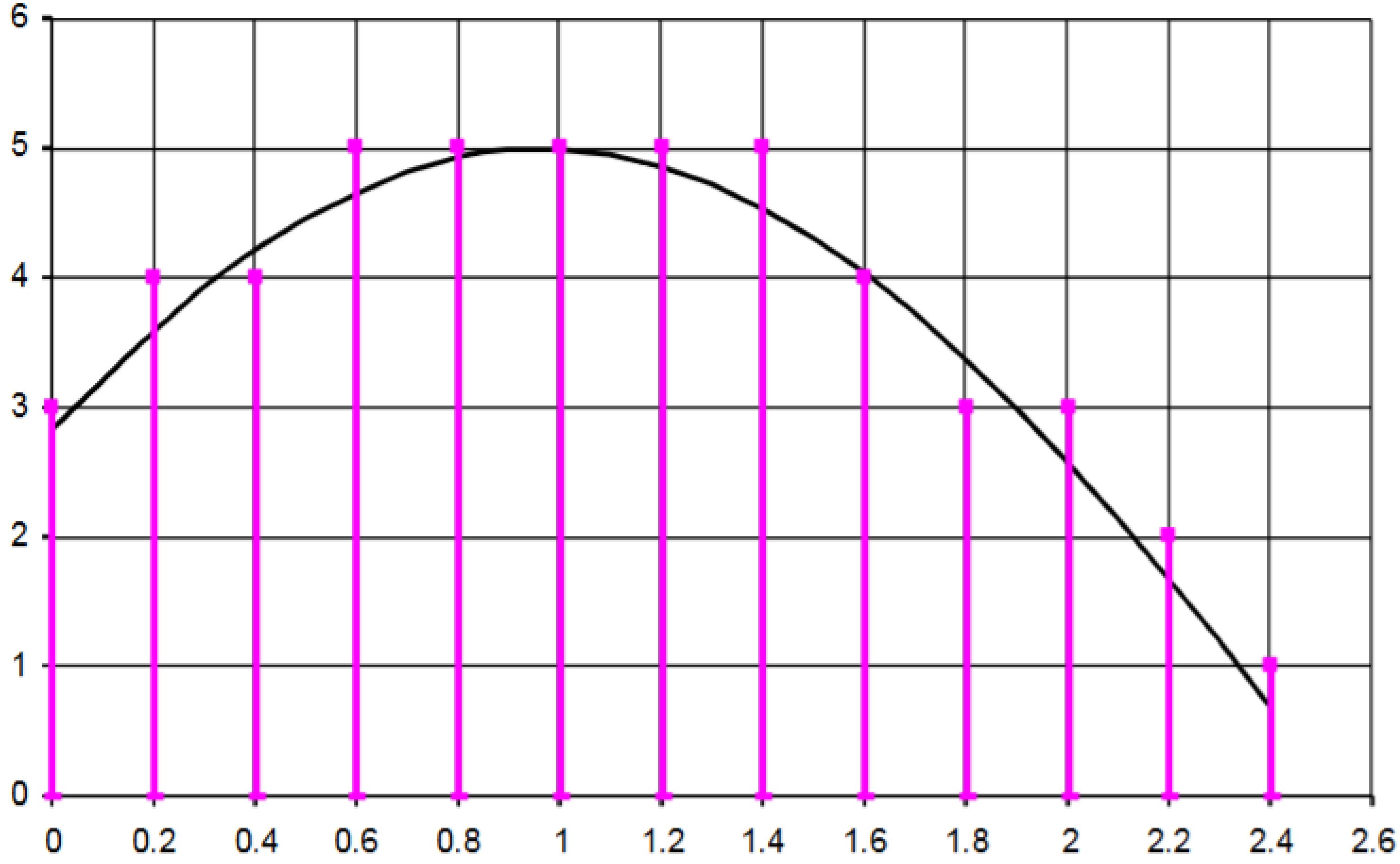
- It's a type of encoding scheme used in digital communication
- Belongs to digital modulation scheme
- A signal is pulse code modulated to convert its analog information into a binary sequence, i.e., **1s** and **0s**.
- The output of a PCM will resemble a binary sequence.
- Pulse Code Modulator circuit consists of Sampling, Quantizing and Encoding



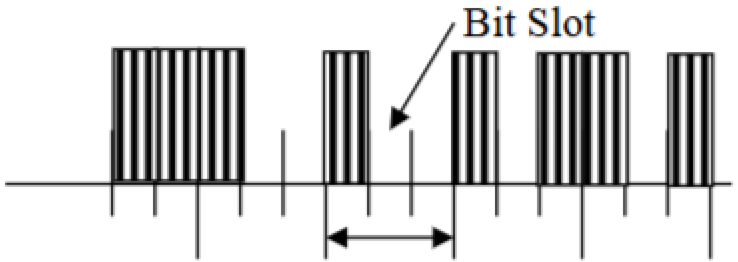



Quantized Signal
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
A
0
A
Analog Signal
Sampling
Quantizing
Encoding
11 • • • 1100
Digital Data
PAM Signal

Pulse Code Modulation



Actual	2.823212	3.58678	4.207355	4.660195	4.927249
Code	3	4	4	5	5
Binary-Coded	011	100	100	101	101



Important Relations in PCM

Consider an n-bit PCM system where n represents the number of bits/sample

Number of quantization level = 2^n

$$\Delta = step\,size = \frac{V_{pp}}{No\ of\ \ Quantization\ level}$$

$$Q_e = sampled\,value - qumatized\,value$$

$$Q_{e(\max)} = \frac{\Delta}{2}$$

$$Bit - rate,\ r\ \ or\ \ R_b = sampling\,rate \times n = \frac{1}{T_s} \times n = \frac{1}{T_b}$$

$$Bit\,duration, T_b = \frac{T_s}{n}$$

$$BW = \frac{1}{T_b}$$

An analog signal whose amplitude varies from 0 to 10 V is bandlimited to 4kHz and transmitted through the channel using 5-bit PCM. The sampling rate is 50% higher than the Nyquist rate. Calculate all parameters of PCM

Sol.

$$n = 5$$

$$L = 2^n = 2^5 = 32$$

$$\Delta = \frac{V_{pp}}{L} = \frac{10}{32} = 0.3125$$

$$f_m = 4kHz$$

$$Nyquist\ rate = 8000\ samples / \sec$$

$$Sampling\ rate = f_s = \frac{1}{T_s} = 50\%\ higher\ than\ Nyquist\ rate$$

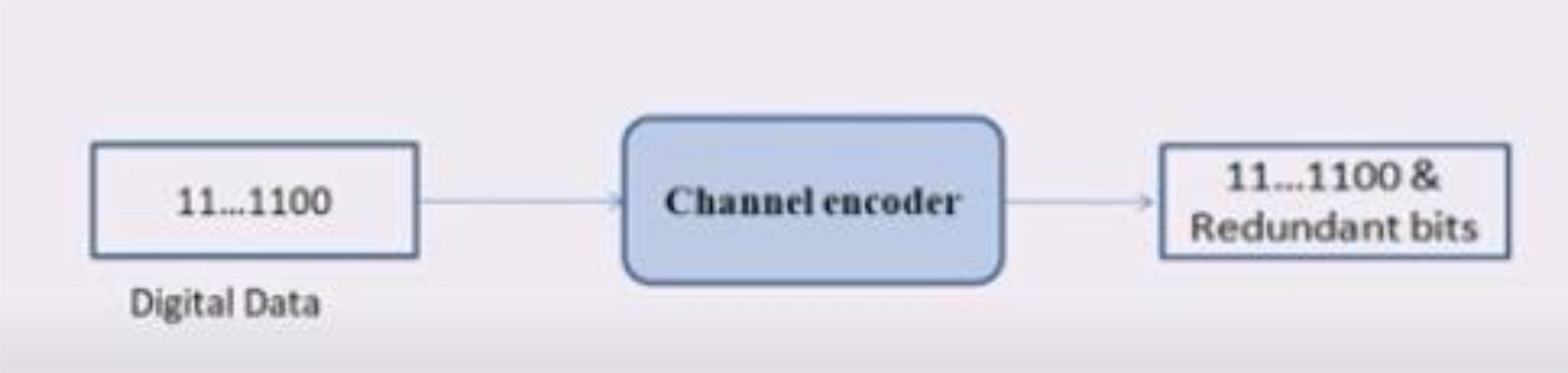
$$= 1.5 \times 8000 = 12000\ samples / \sec$$

$$Bitrate, R_b = \frac{1}{T_s} \times n = 12000 \times 5 = 60000\ bps = 60kbps$$

$$Bandwidth = 60\ kHz$$

A message signal $m(t) = 4\cos(8\pi 10^3 t)$ is sampled at Nyquist rate and transmitted through the channel using 3-bit PCM. Calculate all parameters of PCM. If the sampled values are 3.9, 2.4, 0.5, -2.4, -3.1 and -4; determine the quantizer output, encoder output and quantization error for each sample ?

- **Channel encoder:** protect the information bits by introducing redundancy into the information bit sequence and producing longer bit sequences consisting of coded bits.
- Examples of error correcting codes include Hamming code, Reed-Solomon code, Reed-Muller code, convolutional code, turbo code, LDPC code, polar code, etc..



- **Digital modulator:** It maps the binary sequences (coded bits) into a transmission signal
- Examples of digital modulation schemes are ASK, FSK, PSK etc
- **Channel:** Is the abstraction of the physical medium that carries the transmitted signal to the destination. Various kinds of channels are used including wires, optical fibers, EM wave radiation, etc.
- **Digital demodulator:** Process the received signal from the channel to produce bit estimates
- **Channel decoder:** Process the estimated bits and exploit the controlled redundancy introduced by the channel encoder to estimate the information bits
- **Source decoder:** Converts the bit sequence to message estimate

Bit rate and symbol rate

- **Bit rate (R)** is the frequency of a system bit stream. (Number of bits/seconds)
- For example, a radio with an 8-bit sampler, sampling at 10 kHz for voice. The basic bit stream rate in the radio, would be eight bits multiplied by 10K samples per second, or 80 Kbits per second (Kbps).
- The **symbol rate** is the bit rate divided by the number of bits that can be transmitted with each symbol. (it is the number of symbols/second)

$$\text{Symbol rate} = \frac{\text{bit rate}}{\text{the number of bits transmitted with each symbol}}$$

- If one bit is transmitted per symbol, as with BPSK, then the symbol rate would be the same as the bit rate of 80 Kbits per second.
- If two bits are transmitted per symbol, as in QPSK, then the symbol rate would be half of the bit rate or 40 Kbits per second.
- Symbol rate is sometimes called **baud rate (r)**.
- Total number of symbols (elements), L=2^n (n=number of bits per symbol)

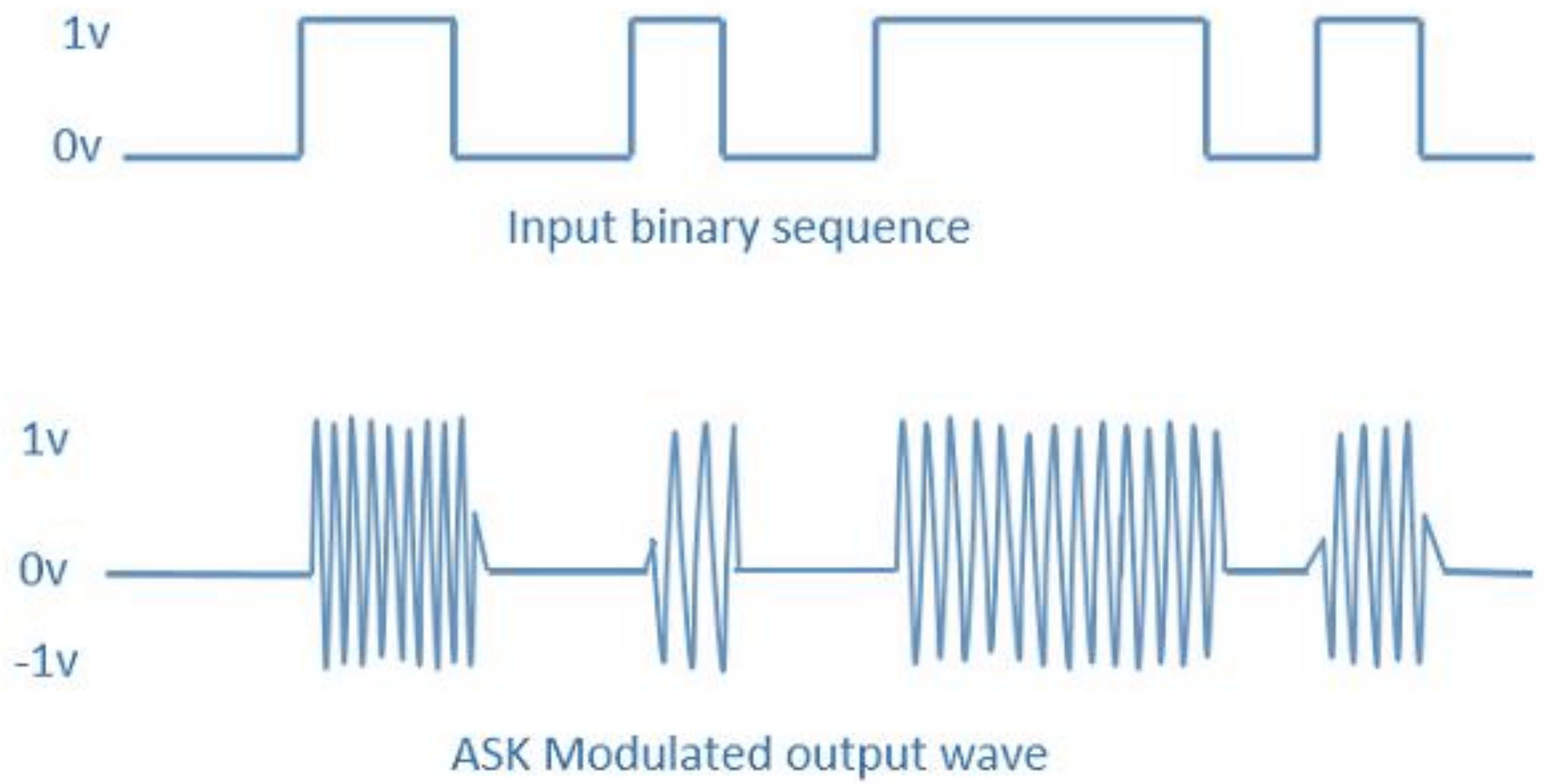
Digital Carrier Modulation Schemes

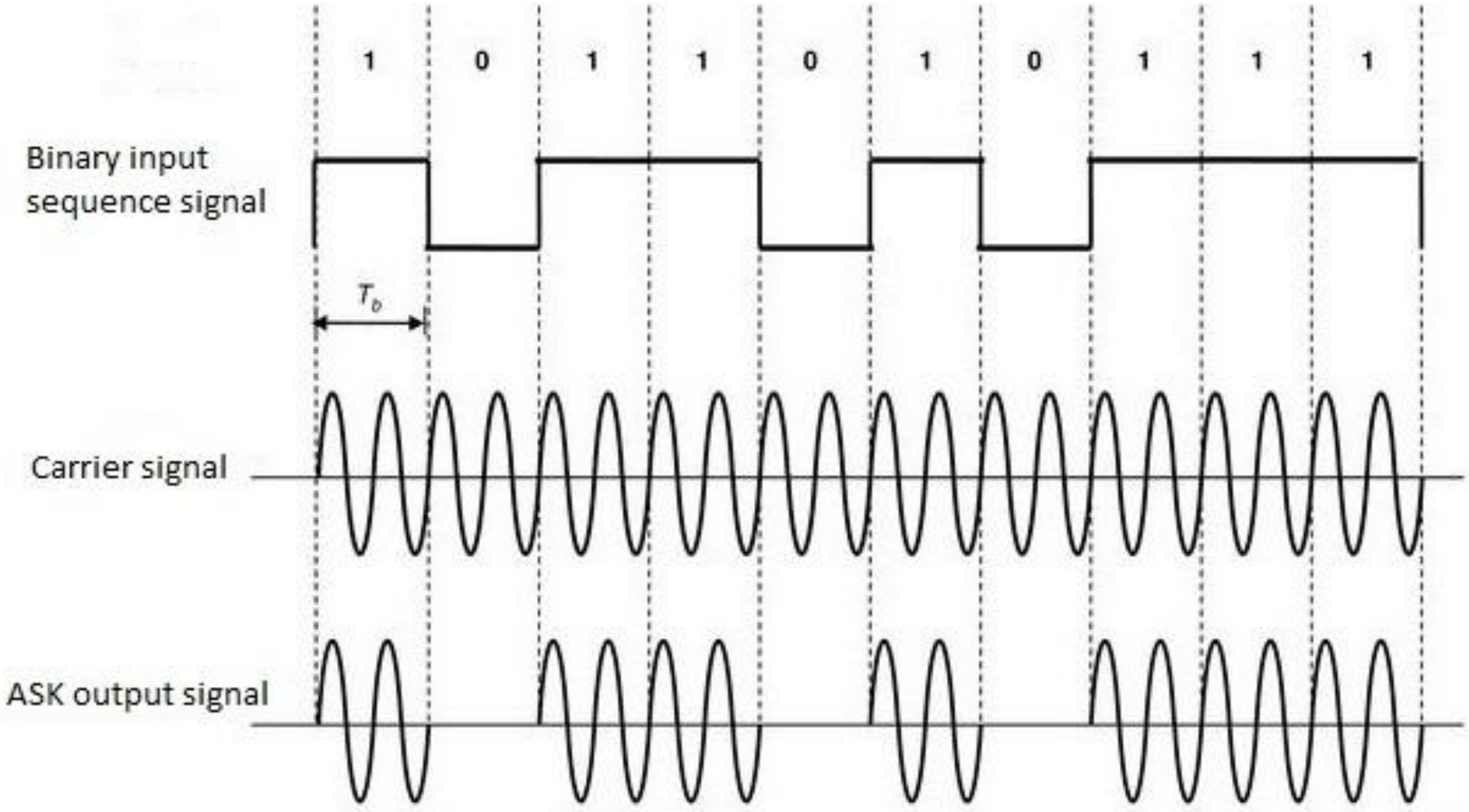
1. Binary Signaling
    1) Amplitude Shift Keying (ASK)
    2) Frequency Shift Keying (FSK)
    3) Phase Shift Keying (PSK)

2. M-ary Signaling
    1) Quaternary PSK (QPSK)
    2) 8PSK
    3) 16PSK
    4) 4FSK ….. etc

Amplitude Shift Keying (ASK)

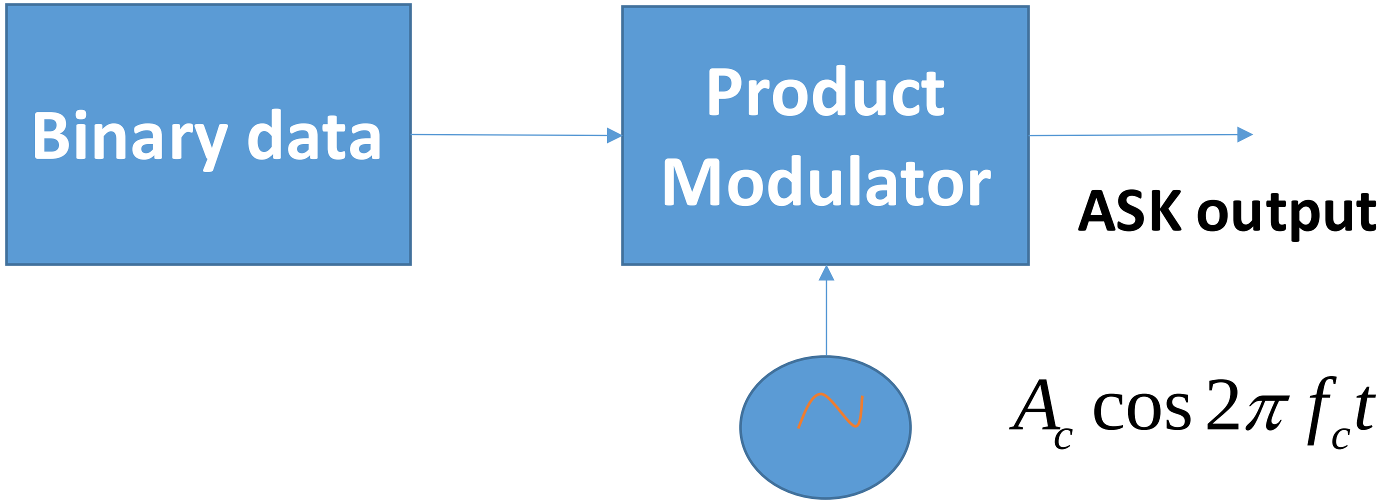
- ASK is the digital modulation technique in which the amplitude of the carrier signal varies according to the discrete digital changes.
- The binary signal when ASK is modulated, gives a zero value for LOW input and gives the carrier output for HIGH input.





Binary ASK is also known as ON-OFF Keying (OOK)

ASK Modulator Circuit



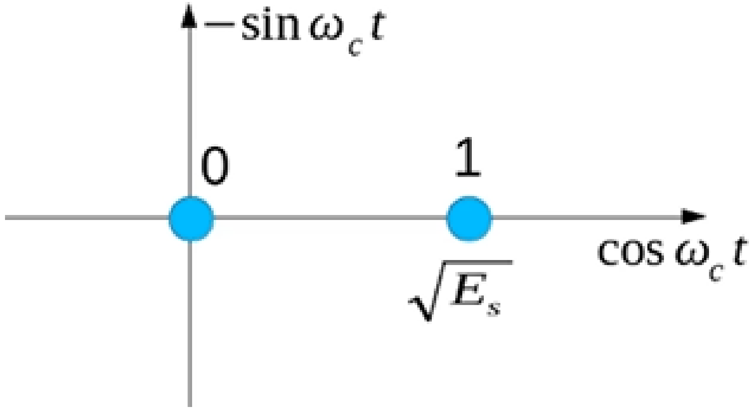
$$A_c \cos 2\pi f_c t$$

$$S_1(t) = A_c \cos 2\pi f_c t \quad \text{---- Binary 1}$$

$$S_2(t) = 0 \quad \text{---- Binary 0}$$

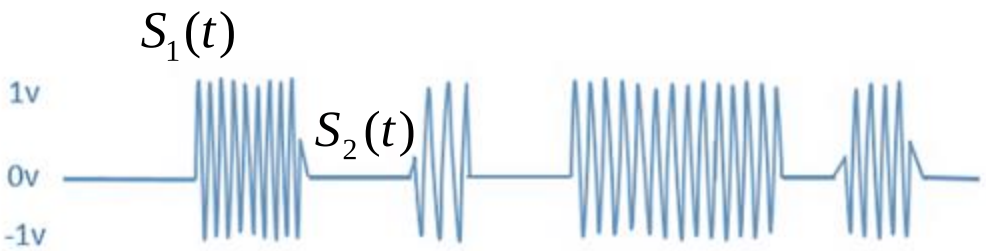
Constellation diagram

- Symbols represented as vectors

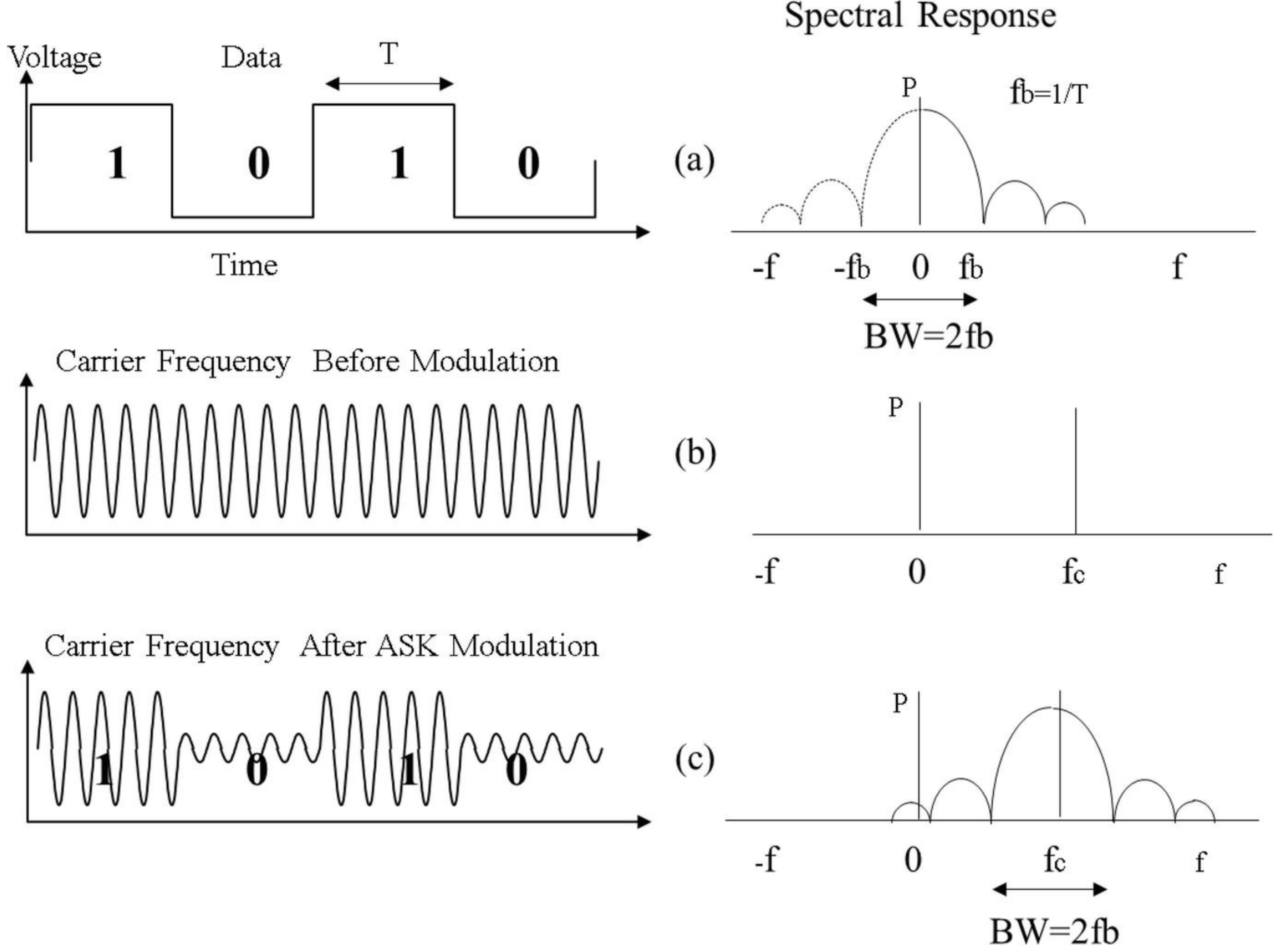


1 bit per symbol. Es is the energy of the bit

Input binary sequence



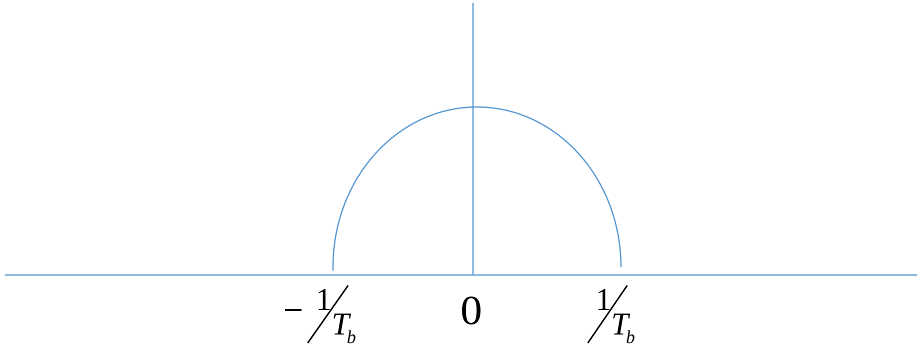
ASK Modulated output wave

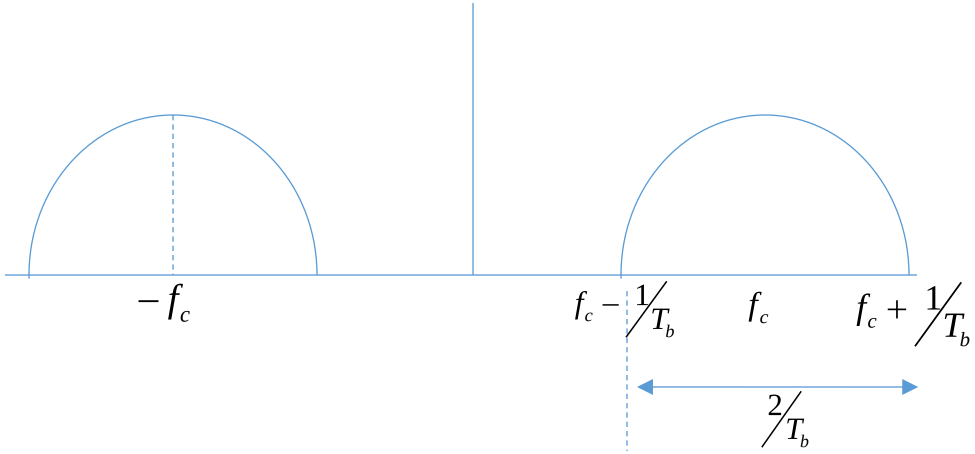


Spectral Response
Voltage
Data
T
1
0
1
0
Time
(a)
P
fb=1/T
-f
-fb
0
fb
f
BW=2fb
Carrier Frequency Before Modulation
(b)
P
-f
0
fc
f
Carrier Frequency After ASK Modulation
1
0
1
0
(c)
P
-f
0
fc
f
BW=2fb

Bandwidth of binary ASK

$$BW = \frac{2}{T_b} = 2 * Bit\ rate$$





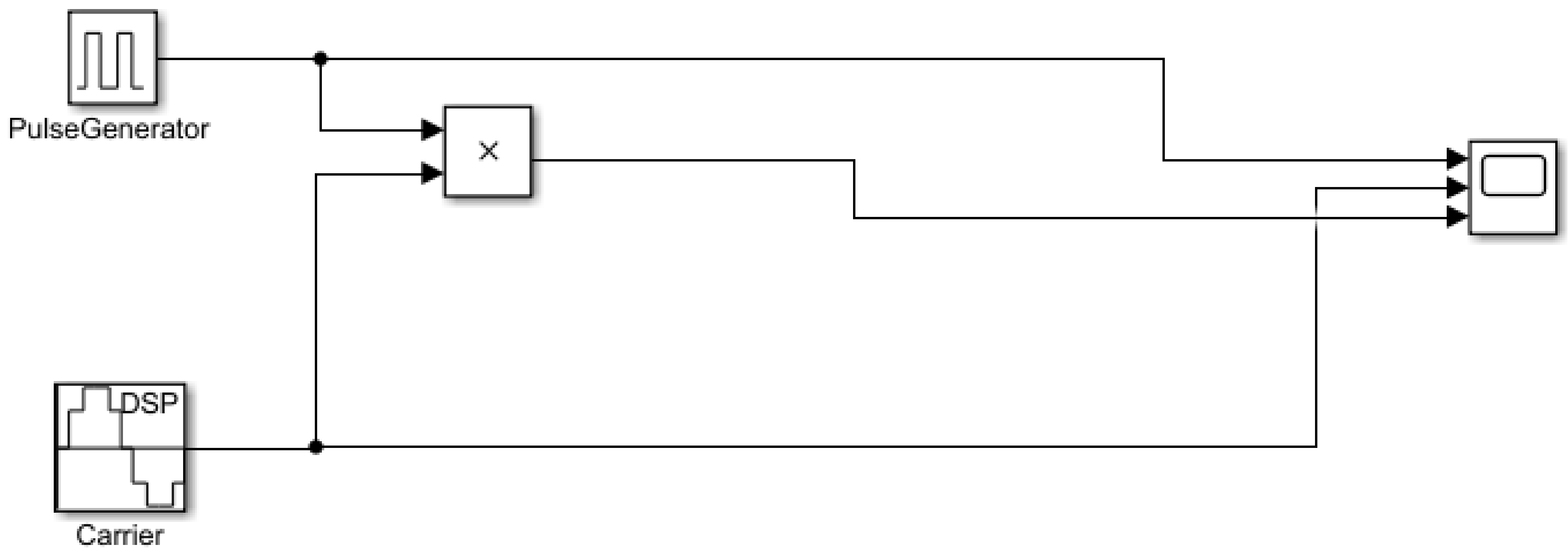
Energy

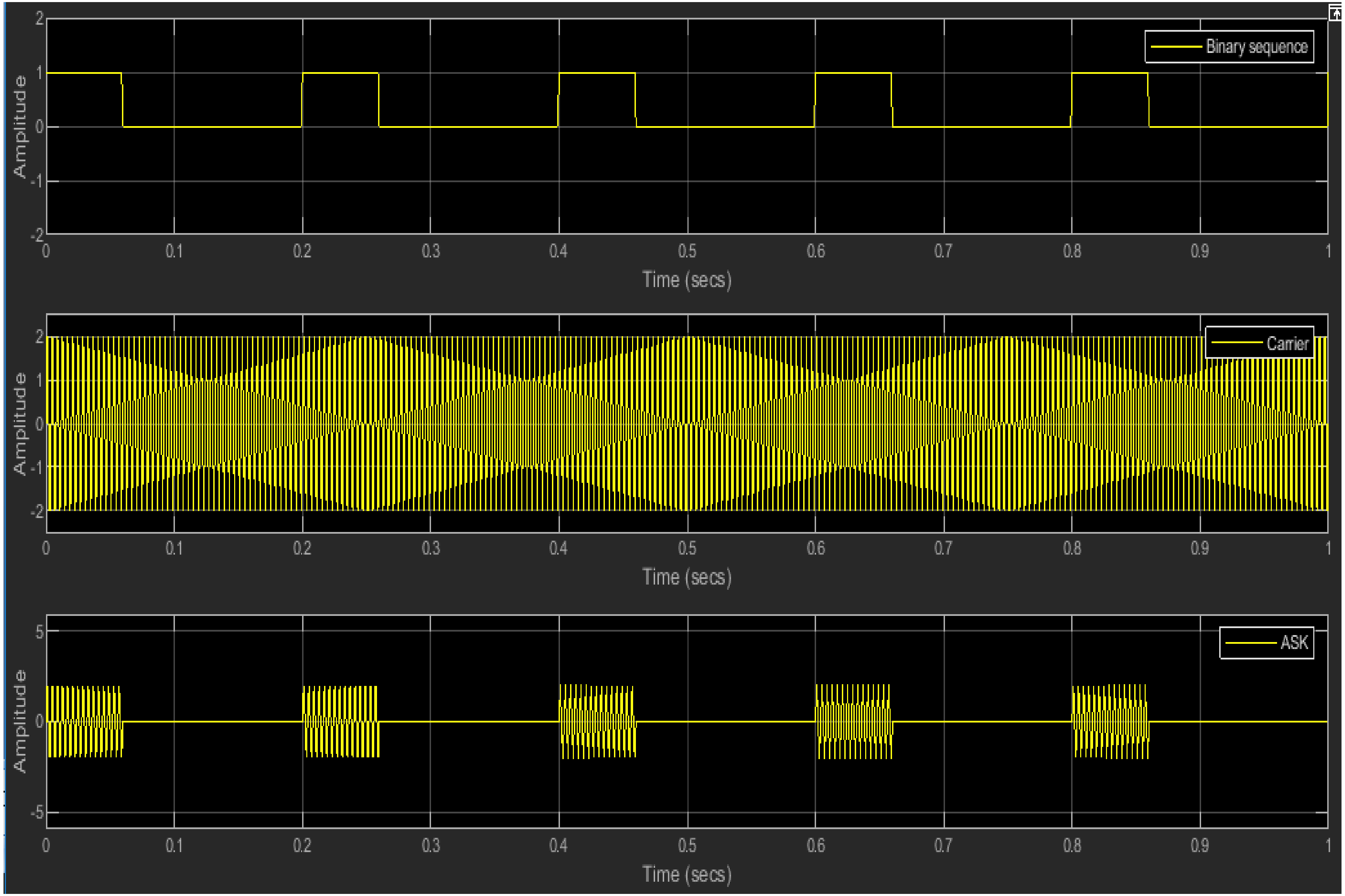
$$E_b \ \ or\ \ E_s = P \times T = \frac{A_c^2}{2} \times T_b \quad for\ \ '1'$$

$$= 0 \quad for\ \ '0'$$

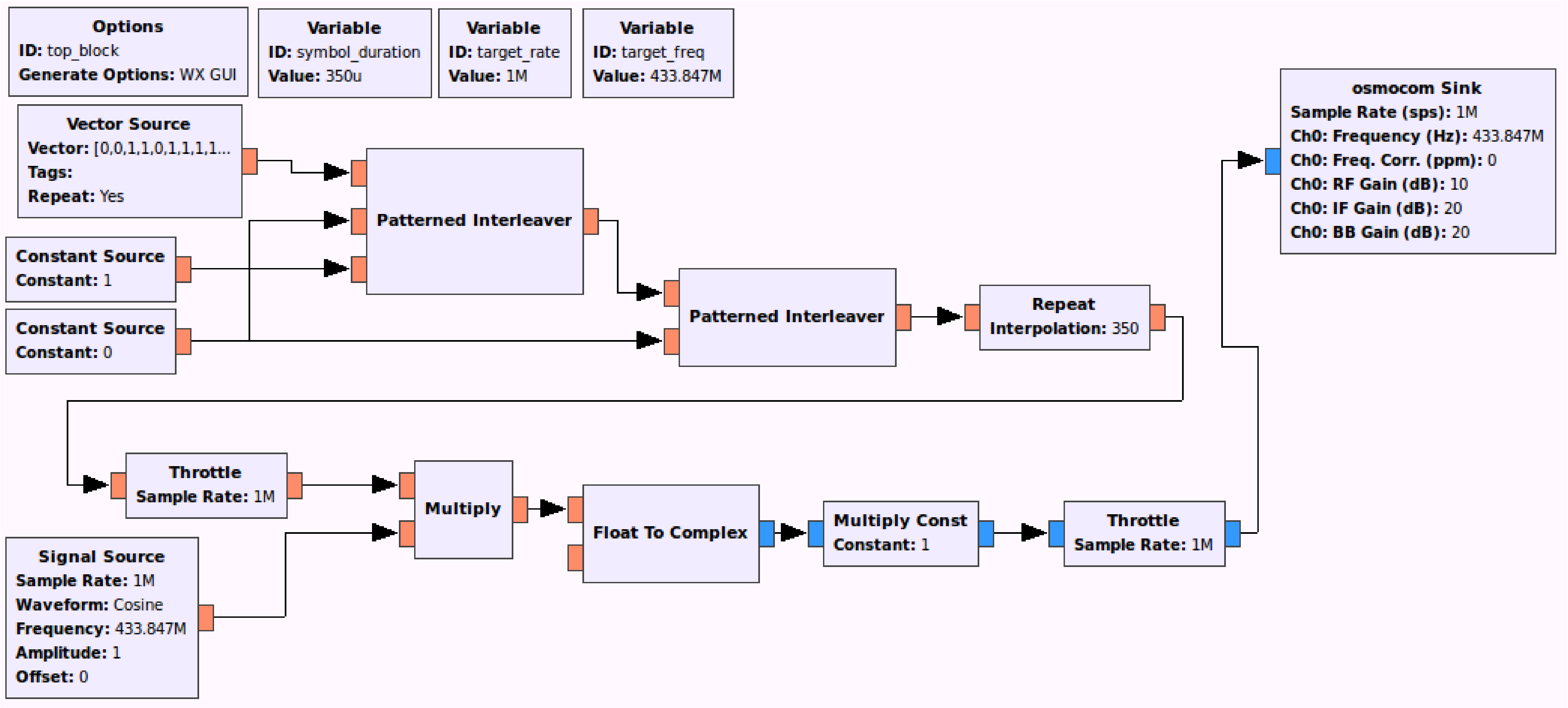
$$A_c = \sqrt{\frac{2E_b}{T_b}}$$

ASK




Binary sequence
Amplitude
Time (secs)
Carrier
Amplitude
Time (secs)
ASK
Amplitude
Time (secs)

ASK using GNU Radio companion



ASK Demodulation

1. Non-coherent ASK demodulation
2. Coherent ASK demodulation

Non-coherent ASK demodulation

- Basically an envelope detector
- Half-wave rectifier delivers a positive half output.
- Low pass filter suppresses the higher frequencies and detects the envelope
- Comparator delivers a digital output