Sampling and Quantization

Module-1

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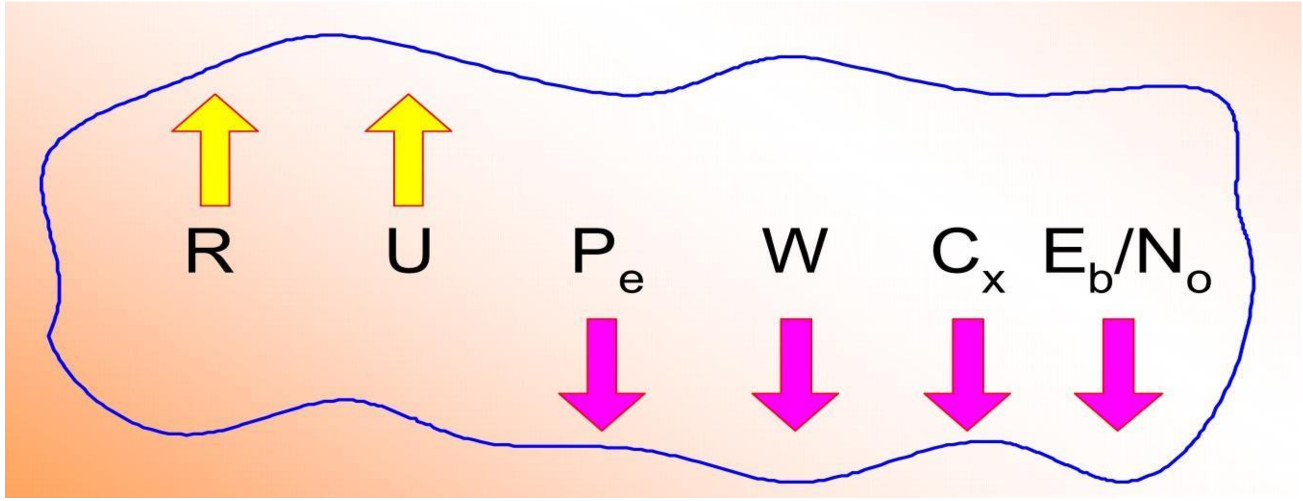
Topics to be discussed

- Model of digital communication system and bandwidth of signals
- Sampling
- Types of Sampling
- Quantization
- Types and Characteristics of Quantization
- Quantization error and Quantization noise
- Reconstruction of a message from its samples

Goals in Communication System Design

- To maximize transmission rate, R
- To maximize system utilization, U
- To minimize bit error rate, P_e
- To minimize required systems bandwidth, W
- To minimize system complexity, C_x
- To minimize required power, E_b/N_0



Digital Signal Nomenclature

- **Information Source**
  - Discrete output values eg.Keyboard
  - Analog signal source eg.output of a microphone
- **Character**
  - Member of an alphanumeric/symbol (A to Z, 0 to 9)
  - Characters can be mapped into a sequence of binary digits using one of the standardized codes such as
    - **ASCII:American Standard Code for Information Interchange**
    - **EBCDIC: Extended Binary Coded Decimal Interchange Code**

Digital Signal Nomenclature

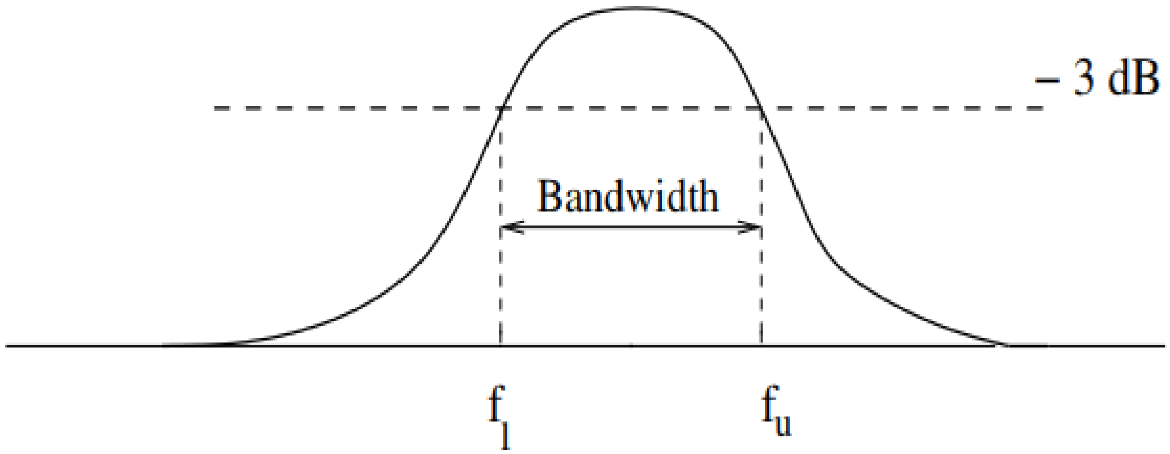
- **Digital Message**
  - Messages constructed from a finite number of symbols; eg, printed language consists of 26 letters, 10 numbers, “space” and several punctuation marks. Hence a text is a digital message constructed from about 50 symbols
- **M - ary**
  - A digital message constructed with M symbols
- **Digital Waveform**
  - Current or voltage waveform that represents a digital symbol

Digital Signal Nomenclature

- **Bit Rate**
  - Actual rate at which information is transmitted per second
- **Baud Rate**
  - Refers to the rate at which the signaling elements are transmitted, i.e. number of signaling elements per second.
- **Bit Error Rate**
  - The probability that one of the bits is in error or simply the probability of error

Bandwidth

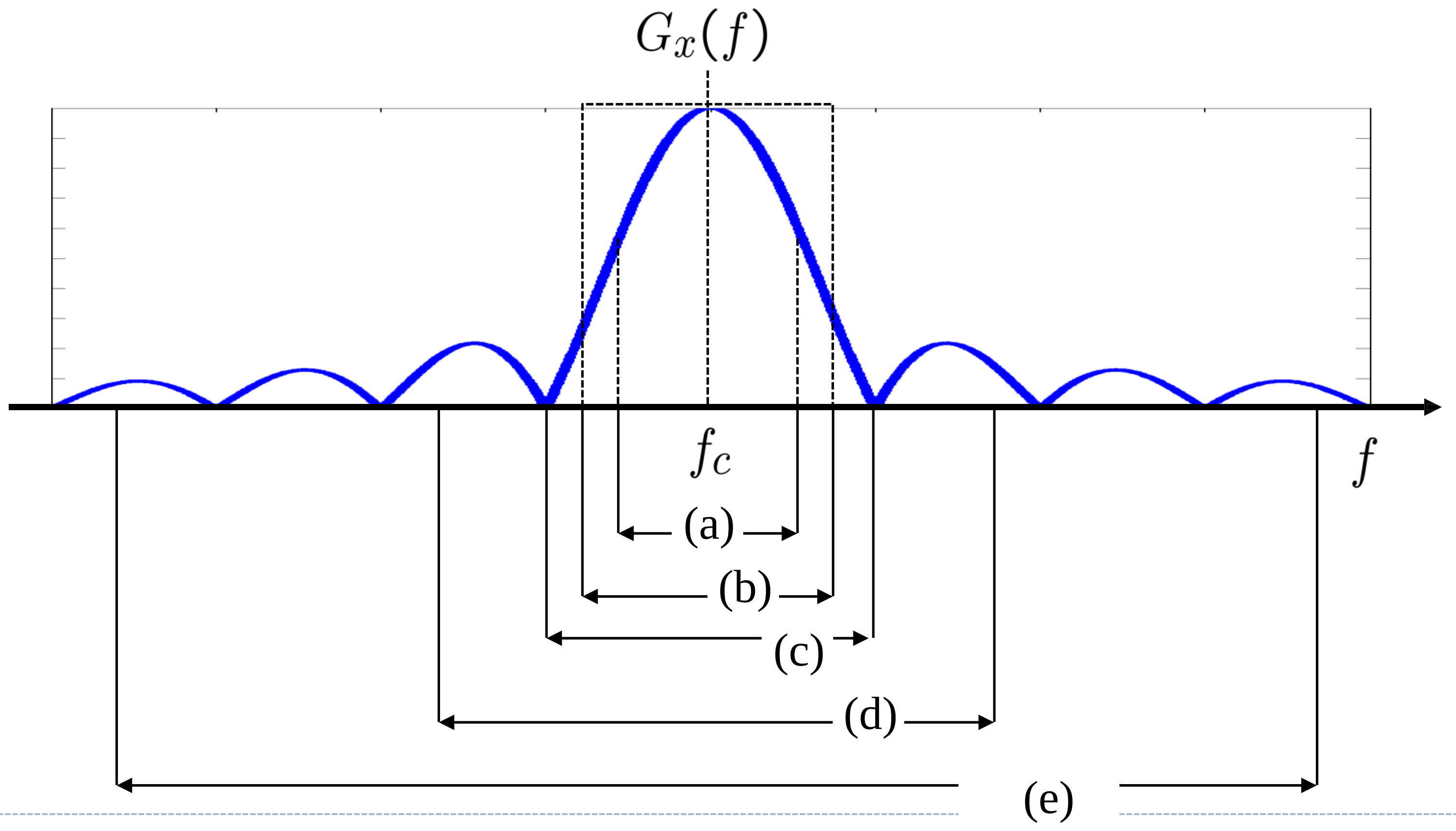
- Bandwidth is defined as a band containing all frequencies between upper cut-off and lower cut-off frequencies



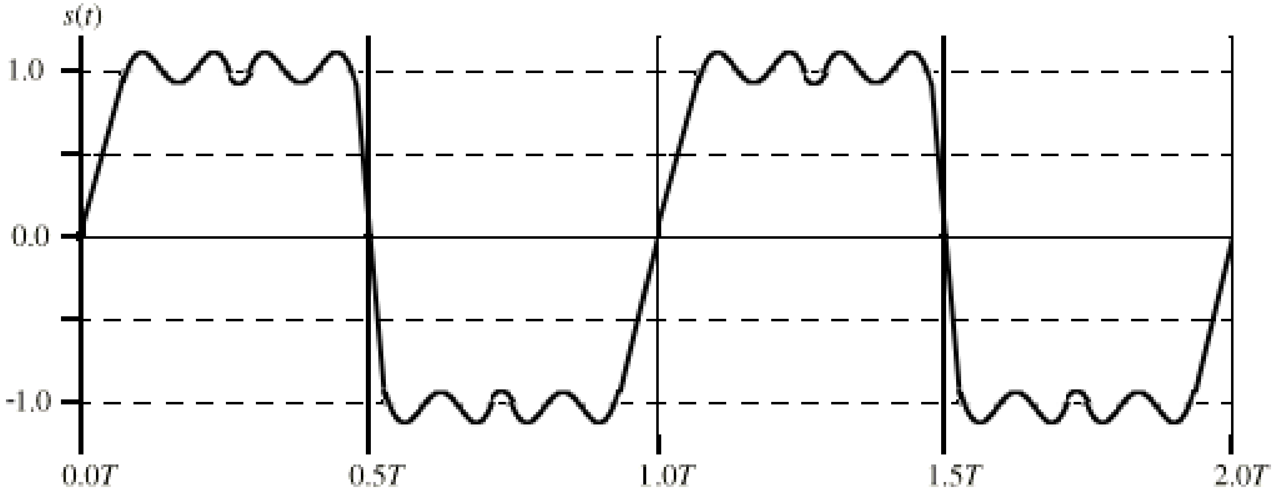
$$BW \quad f_b = f_u - f_l$$

Different definition of bandwidth

a) Half-power bandwidth
b) Noise equivalent bandwidth
c) Null-to-null bandwidth
d) Fractional power containment bandwidth
e) Bounded power spectral density
f) Absolute bandwidth

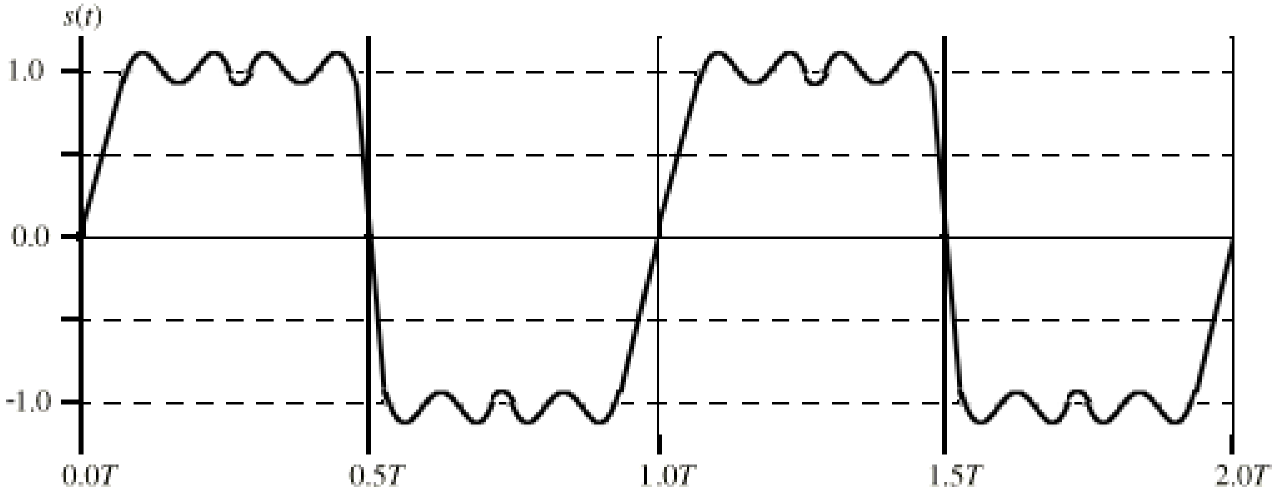


Ex(1): Sine Wave 1



$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$$

Ex(1): Sine Wave 1

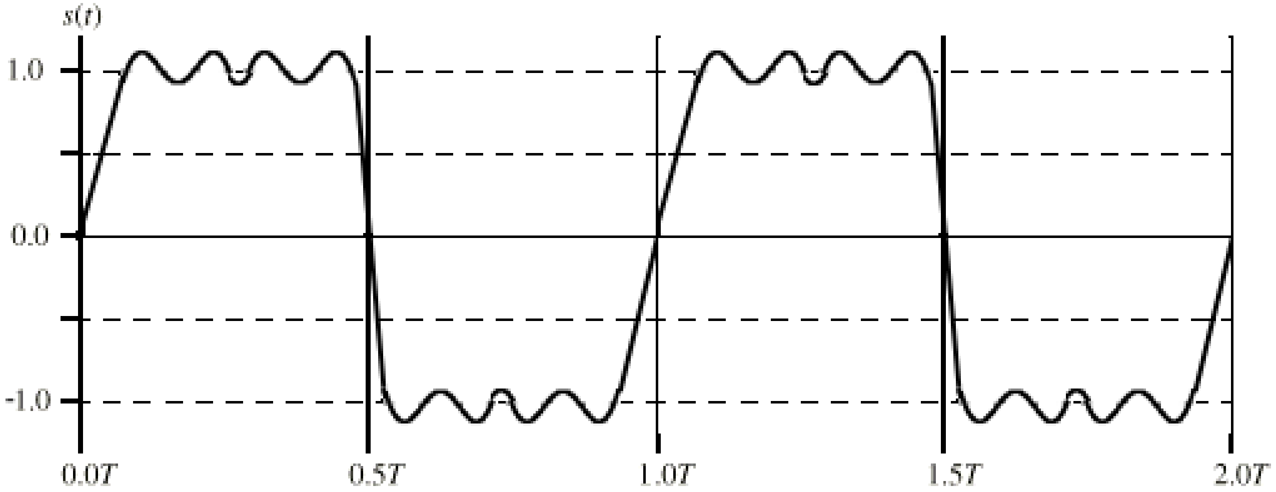


$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$$

Bandwidth=5f-f =4f
If f=1Mhz, then the bandwidth = 4Mhz

T=1 microsecond; we can send two bits per microsecond so the data rate = $2 * 10^6$ = 2Mbps

Ex(2): Sine Wave 2



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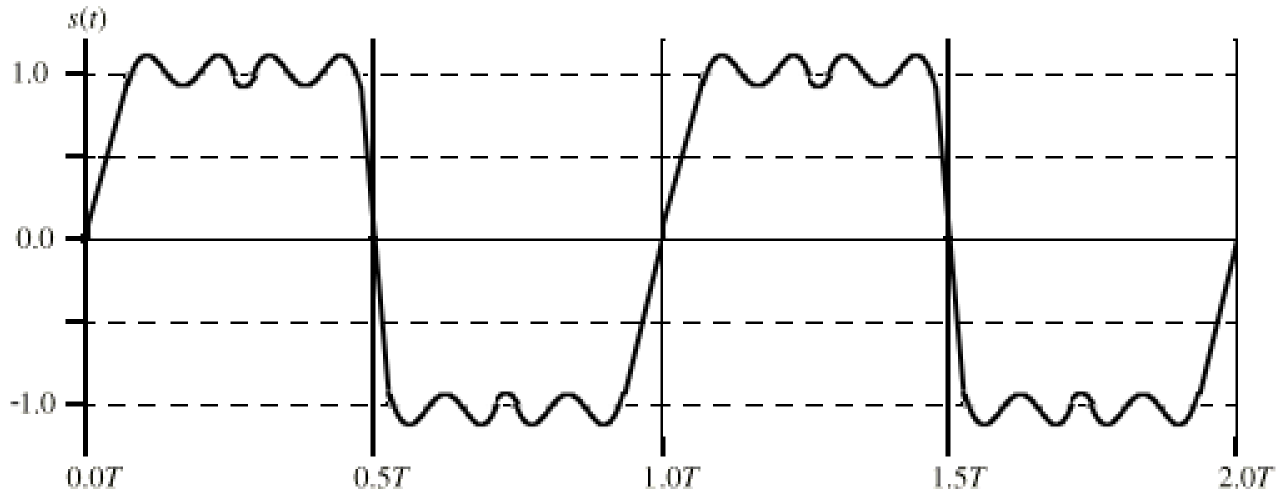
Ex(2): Sine Wave 2



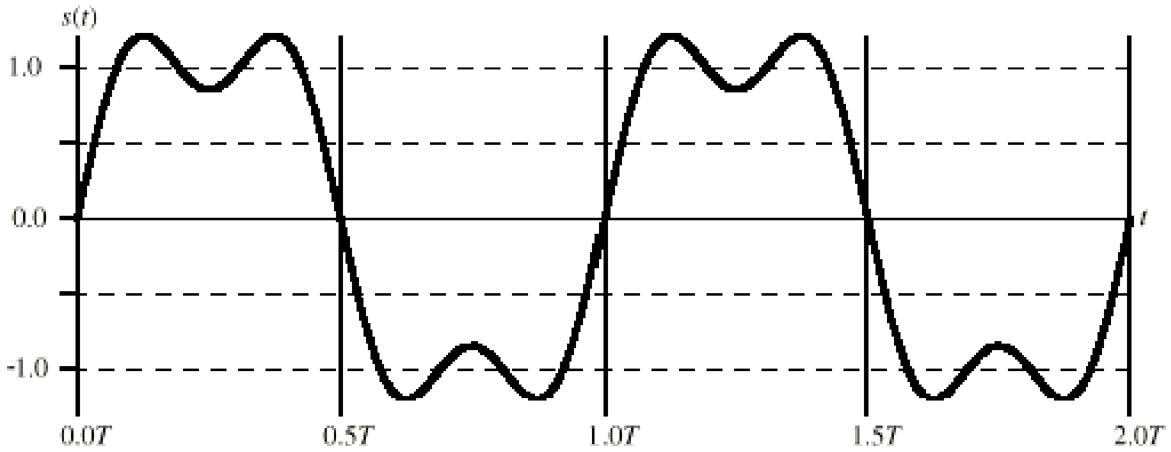
$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$$

Bandwidth=5f-f =4f
If f=2Mhz, then the bandwidth = 8Mhz

T=0.5 microsecond; we can send two bits per 0.5 microseconds or 4 bits per microsecond, so the data rate = 4 * 10^6 = 4Mbps

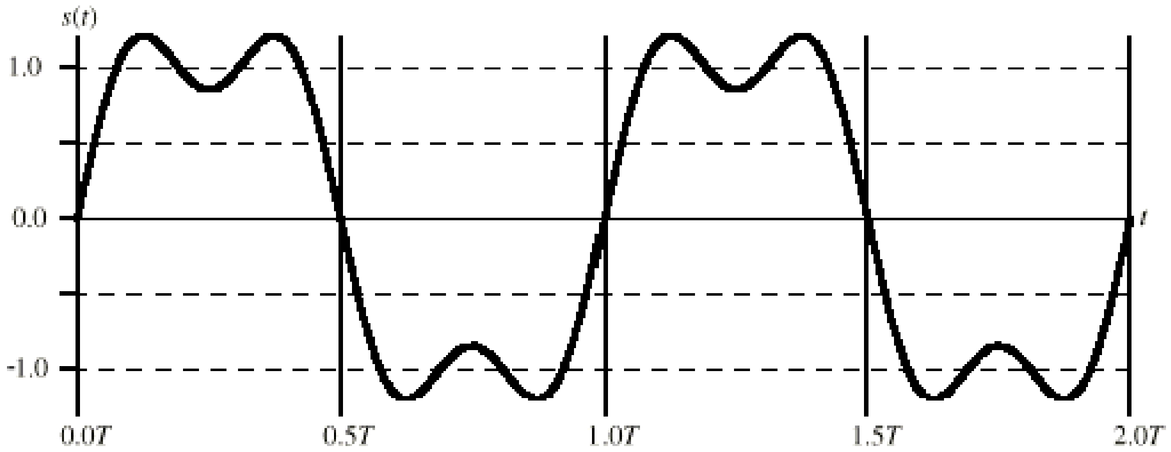
Double the bandwidth, double the data rate!

Ex(3): Sine Wave 3



$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t)]$$

Ex(3): Sine Wave 3



$$s(t) = 4/\pi[\sin(2\pi ft) + 1/3\sin(2\pi(3f)t)]$$

Bandwidth=3f-f =2f
If f=2Mhz, then the bandwidth = 4Mhz

T=0.5 microsecond; we can send two bits per 0.5 microseconds or 4 bits per microsecond, so the data rate = 4 * 10^6 = 4Mbps

Still possible to get 4Mbps with the “lower” bandwidth, but our receiver must be able to discriminate from more distortion!

Shannon's information capacity theorem

Shannon's theorem gives the relationship between the channel bandwidth and the maximum data rate that can be transmitted over a noisy channel .

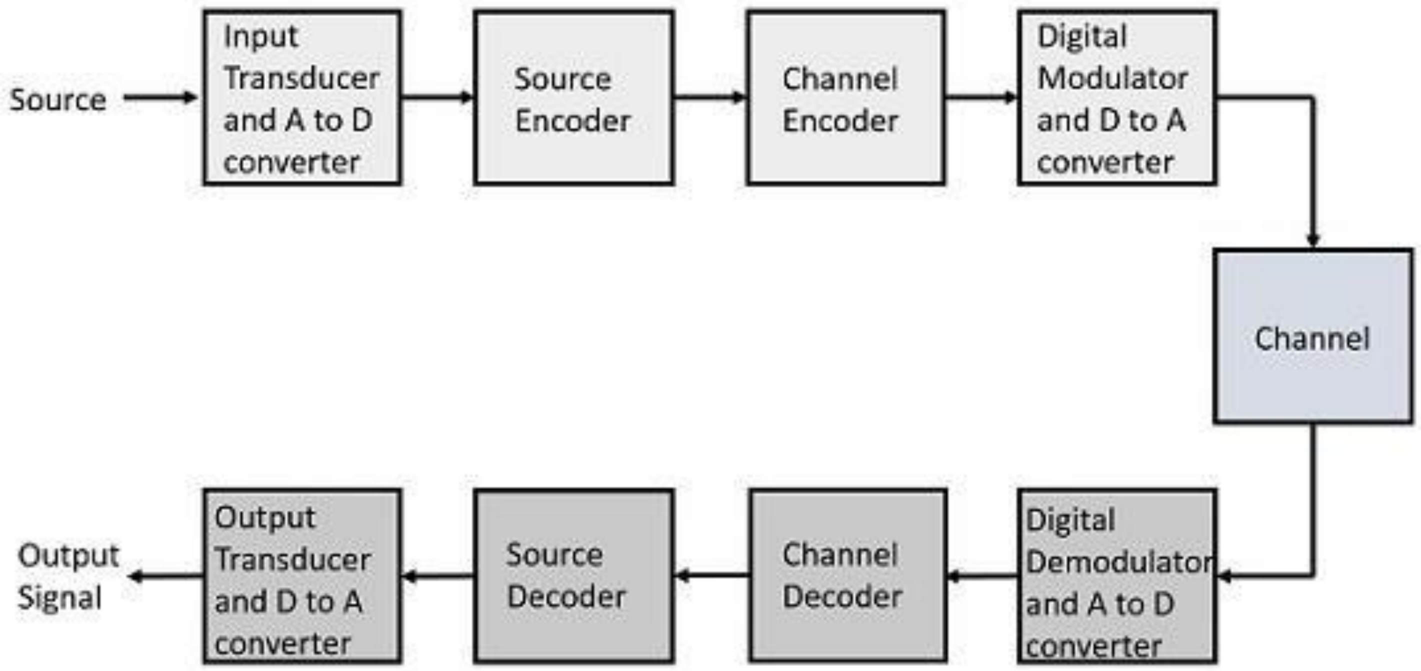
Shannon's Theorem

$$I = B\log_2(1+\frac{S}{N})$$

I: channel capacity (maximum data-rate) (bps)
B : RF bandwidth
S/N: signal-to-noise ratio (no unit)

Model of digital communication system

- The elements which form a digital communication system is represented by the following block diagram for the ease of understanding.



Basic Elements of a Digital Communication System

Model of digital communication system

Source

- The source can be an **analog** signal.
- **Example**:A Sound signal

InputTransducer

- This is a transducer which takes a physical input and converts it to an electrical signal (**Example**: microphone).
- This block also consists of an **analog to digital** converter where a digital signal is needed for further processes.
- A digital signal is generally represented by a binary sequence.

Model of digital communication system

Source Encoder

- The source encoder compresses the data into minimum number of bits.
- This process helps in effective utilization of the bandwidth.
- It removes the redundant bits (unnecessary excess bits, i.e., zeroes)

Channel Encoder

- The channel encoder, does the coding for error correction.
- During the transmission of the signal, due to the noise in the channel, the signal may get altered
- Hence to avoid this, the channel encoder adds some redundant bits to the transmitted data.
- These are the error correcting bits.

Model of digital communication system

Digital Modulator

- The signal to be transmitted is modulated here by a carrier.
- The signal is also converted to analog from the digital sequence, in order to make it travel through the channel or medium.

Channel

- The channel or a medium, allows the analog signal to transmit from the transmitter end to the receiver end.

Digital Demodulator

- This is the first step at the receiver end.
- The received signal is demodulated as well as converted again from analog to digital.
- The signal gets reconstructed here.

Model of digital communication system

Channel Decoder

- The channel decoder, after detecting the sequence, does some error corrections.
- The distortions which might occur during the transmission, are corrected by adding some redundant bits.
- This addition of bits helps in the complete recovery of the original signal.

Source Decoder

- The resultant signal is once again digitized by sampling and quantizing so that the pure digital output is obtained without the loss of information.
- The source decoder recreates the source output.

Model of digital communication system

Output Transducer

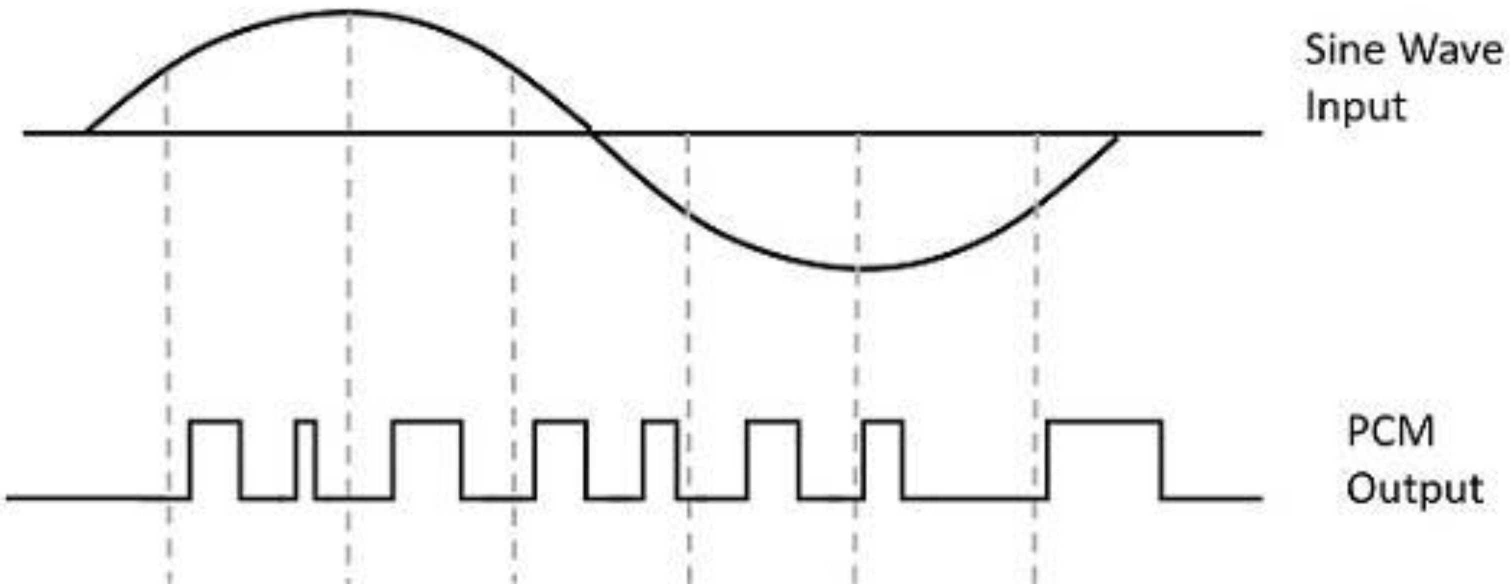
- This is the last block which converts the signal into the original physical form, which was at the input of the transmitter.
- It converts the electrical signal into physical output (**Example**: loud speaker).

Output Signal

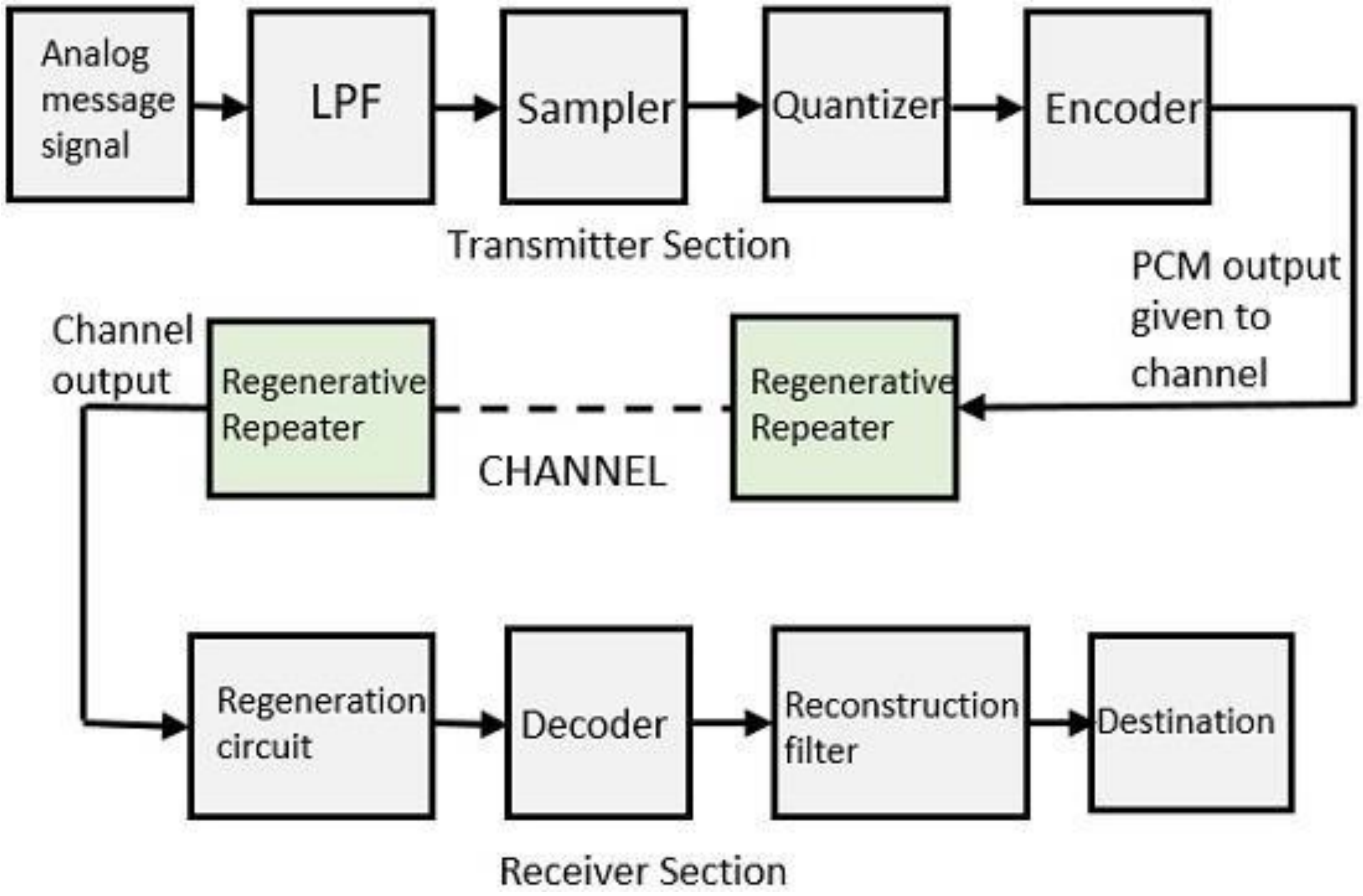
- This is the output which is produced after the whole process.
- **Example** – The sound signal received.

Glimpse of Pulse Code Modulation

- There are many modulation techniques, which are classified according to the type of modulation employed.
- Of them all, the digital modulation technique used is **Pulse Code Modulation (PCM)**.



Glimpse of Pulse Code Modulation



Analog to Digital Conversion Blocks in DCS