Xi'an Jiaotong-Liverpool University
西交利物浦大学

EEE220 Instrumentation and Control System

2018-19 Semester 2

Dr. Qing Liu

Email: qing.liu@xjtlu.edu.cn

Office: EE516

Department of Electrical and Electronic Engineering

11 March, 2019

Lecture 7

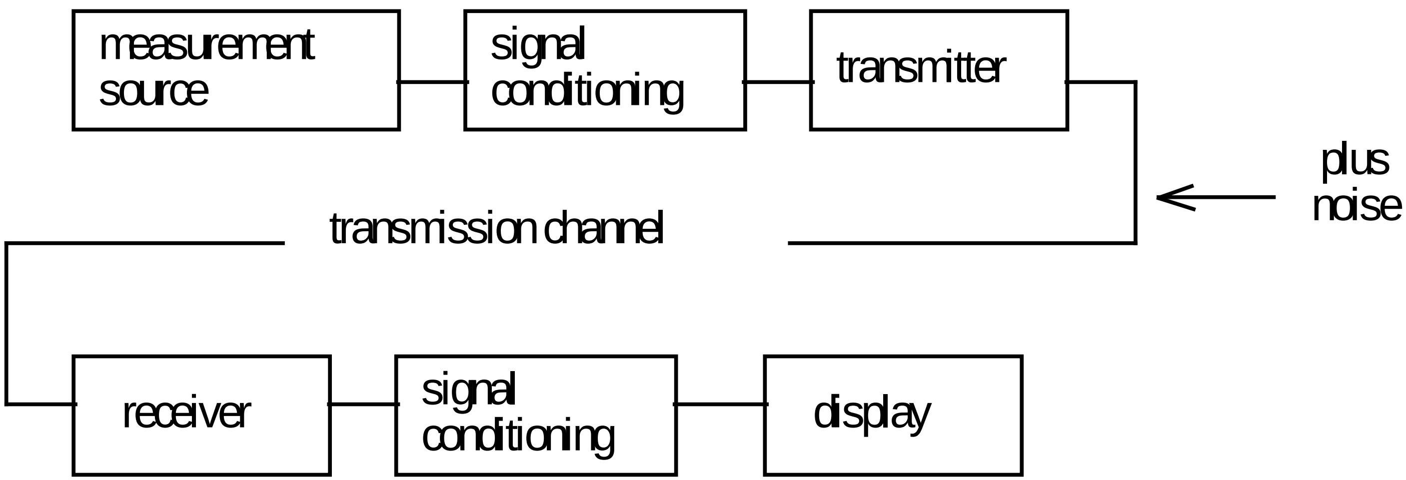
Outline

Communication System

- ❑ **Typical System**
- ❑ **Transmission Path**
- ❑ **Signal Modulation**

Typical System

- The transducer and associated signal conditioning (bridge circuit, amplifier etc) is only part of the full measurement system;
- A typical system involves numerous components in the field of electrical engineering including circuits, electronics, electromagnetics, signal processing, microprocessors, and communication networks.



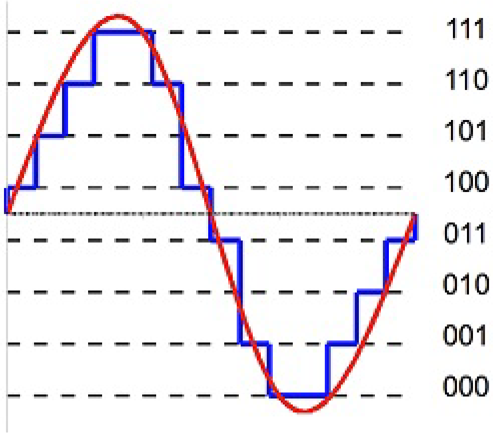
- A communication system coveys information from its source to a destination some distance away.

Information Categories: Analog vs. Digital

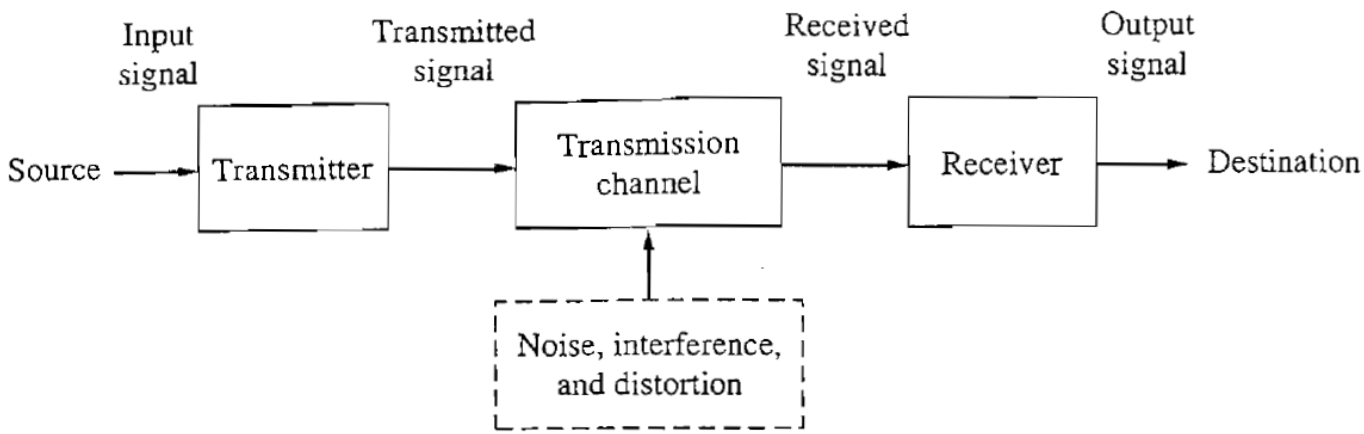
There are many kinds of information sources, and information appears in various forms. Information can be identified into two categories: **Analog** and **Digital**.

- An **analog** message is a physical quantity that varies with time, usually in a smooth and continuous fashion.
  - example: acoustic pressure produced when you speak;
  - Since the information resides in a time-varying waveform, an analog communication system should deliver this waveform with a specific degree of fidelity;

- A **digital** message is an ordered sequence of symbols selected from a finite set of discrete elements.
  - example: keys you press on a computer keyboard;
  - Since the information resides in discrete symbols, a digital communication should deliver these symbols with a specified degree of accuracy in a specified amount of time



Elements of A Communication System



- The **transmitter** processes the input signal to produce a transmitted signal suited to the characteristics of the transmission channel (modulation, coding);
- The **transmission channel** is the electrical medium that bridges the distance from source to destination;
- The **receiver** operates on the output signal from the channel in preparation for delivery to the transducer at the destination (amplification, demodulation, decoding, filtering).

- Every transmission channel introduces some amount of transmission **loss** or **attenuation**, the signal power progressively decreased with increasing distance. Attenuation is undesired since it reduces signal strength at the receiver;

- More serious is **distortion**, **interference** and **noise** which appear as alternations of the signal shape.

  - **Distortion**: waveform perturbation caused by imperfect response of the system to the desired signal itself. It disappears when the signal is turned off;

  - **Interference**: contamination by extraneous signals from human sources – other transmitters, power lines, switching circuits and so on;

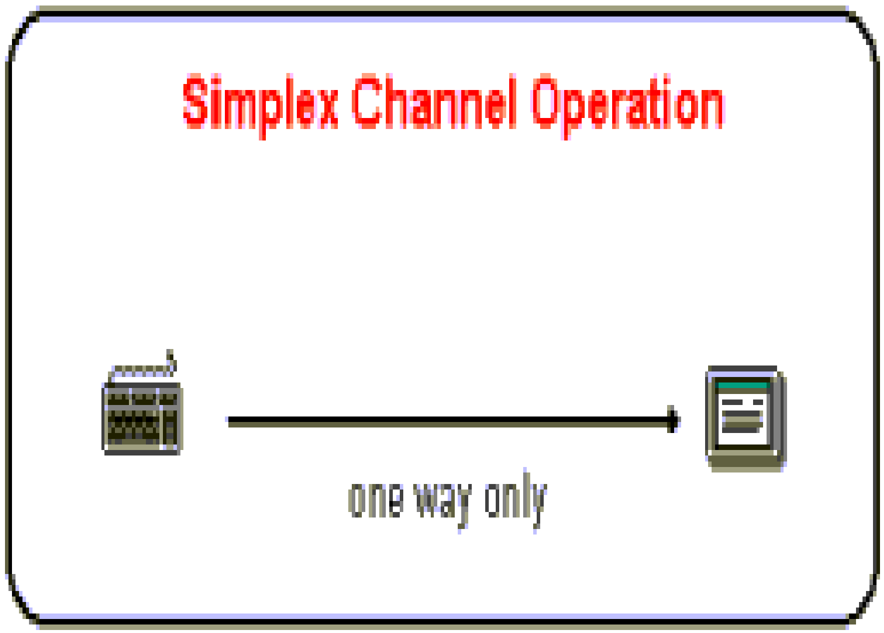
  - **Noise**: random and unpredictable electrical signals produced by natural processes both internal and external to the system. Filtering reduces noise contamination, but there inevitably remains some amount of the noise that can not be eliminated. This noise constitutes one of the fundamental system limitations.

Simplex, Half and Full Duplex System

Simplex

- Data in a simplex channel is always one way.

Simplex channels are not often used because it is not possible to send back error or control signals to the transmit end.

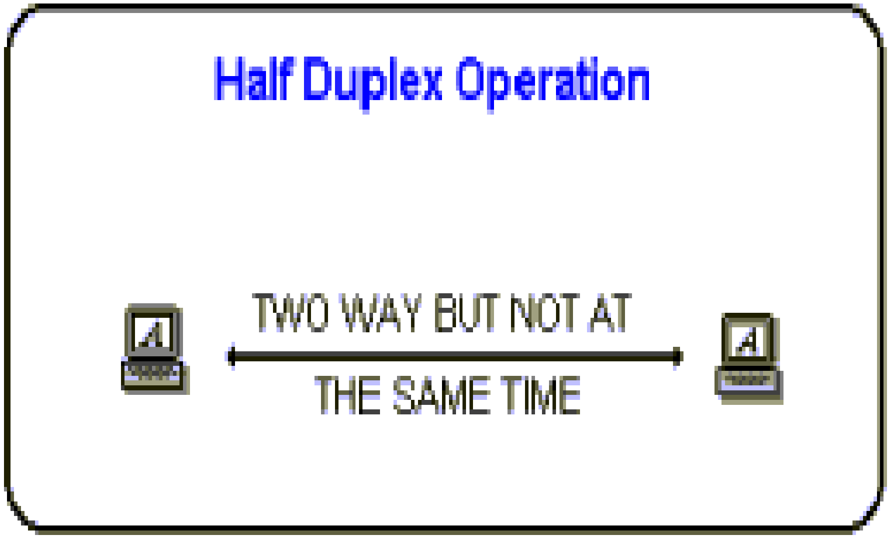


It's like a one way street. Example of simplex transmission is Television, or Radio.

Half-duplex

- Data can be sent and received, but not at the same time (i.e. only in one direction at a time)

The channels share the same frequency range for both transmission and reception of data within the available bandwidth. It allows transmission in either direction but not at the same time.

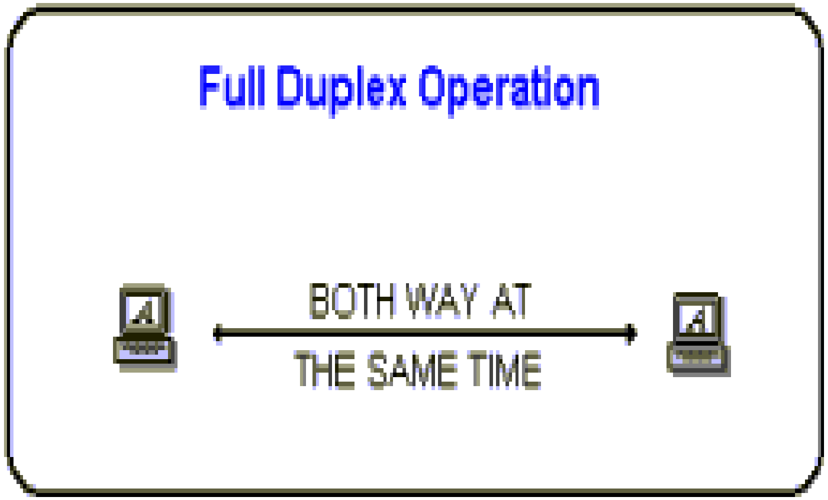


One example of half-duplex is talk-back radio. Only one person can talk at a time.

Full Duplex

- Data can be transmitted in both directions simultaneously.

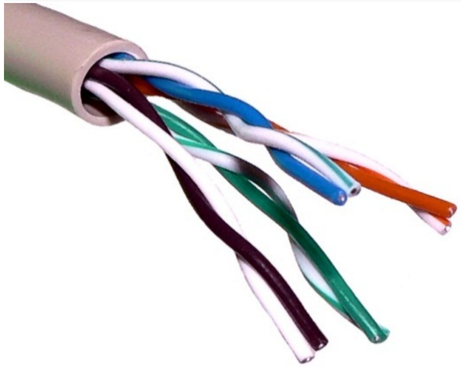
Full-duplex requires one part of the available bandwidth to be dedicated to transmission and another part to reception. In the world of data communications, full duplex allows both way communication simultaneously.



Its like a two lane bridge on a two-lane highway. An example is mobile phone.

Typical Transmission Medium and Loss

Transmission Medium	Frequency	Loss dB/km
Open-wire pair (0.3 cm diameter)	1 kHz	0.05
Twisted-wire pair (16 gauge)	10 kHz	2
	100 kHz	3
	300 kHz	6
Coaxial cable (1 cm diameter)	100 kHz	1
	1 MHz	2
	3 MHz	4
Coaxial cable (15 cm diameter)	100 MHz	1.5
Rectangular waveguide (5 × 2.5 cm)	10 GHz	5
Helical waveguide (5 cm diameter)	100 GHz	1.5
Fiber-optic cable	3.6×10^{14} Hz	2.5
	2.4×10^{14} Hz	0.5
	1.8×10^{14} Hz	0.2



- Besides, signal transmission by **radiowave propagation** can eliminate the long cables. It's commonly employed for long-distance communication at frequencies above about 100 MHz.

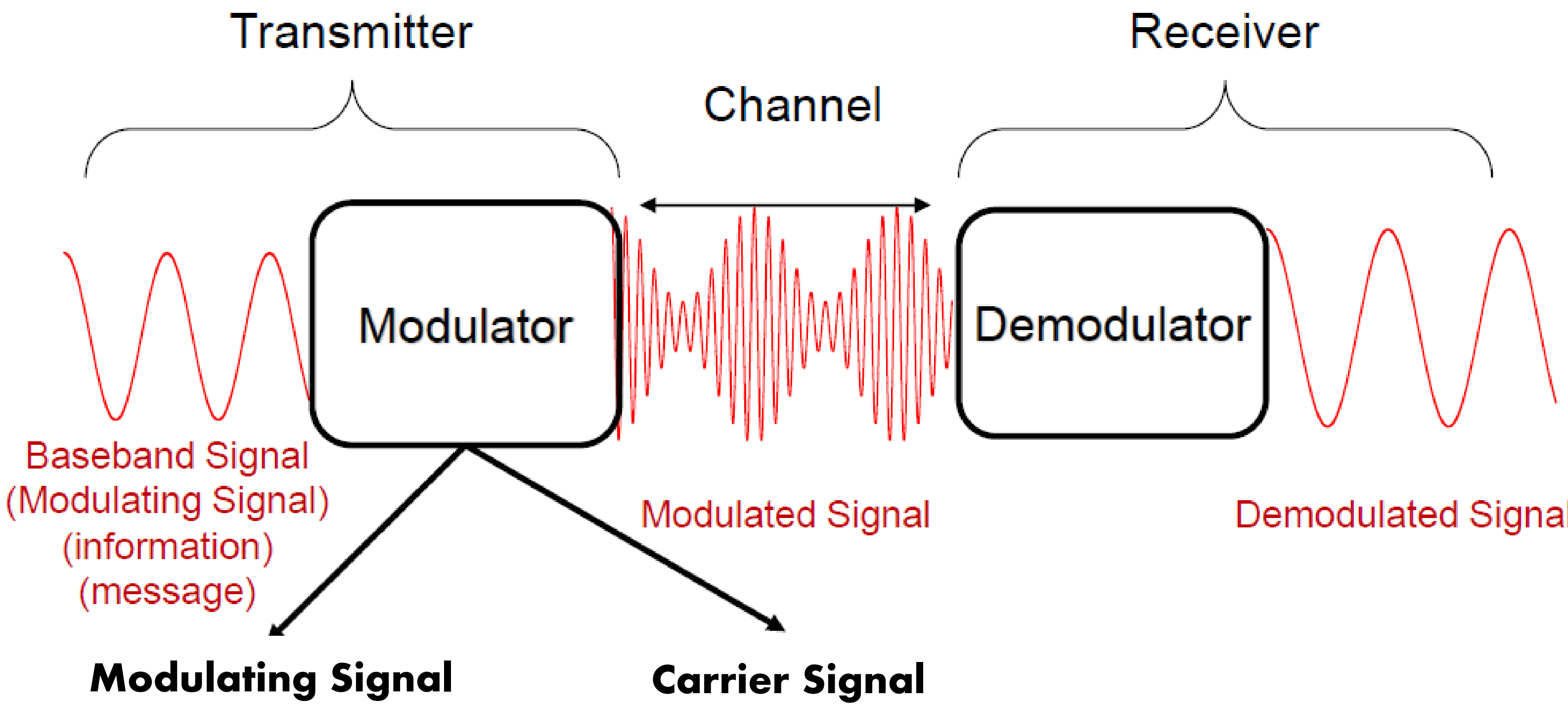
$$L = \left(\frac{4\pi\ell}{\lambda}\right)^2 = \left(\frac{4\pi f\ell}{c}\right)^2$$

in which λ is the wavelength, f the signal frequency, and c the speed of light.

What is Modulation?

Modulations are operations performed at the transmitter to achieve efficient and reliable information transmission.

- Modulation involves two waveforms: a modulating signal that represents the message, and a carrier wave that suits the particular application;
- Modulation is a reversible operation, i.e., the message can be retrieved by the complementary process of **demodulation** at the receiver.



Why Modulation?

The primary purpose of modulation in a communication system is to generate a modulated signal suited to the characteristics of the transmission channel.

Practical benefits of modulation:

- ✓ **For efficient transmission**: signal transmission over appreciable distance always involves a traveling electromagnetic wave; the transmission efficiency depends upon the frequency of the signal been transmitted;
- ✓ **To overcome hardware limitations**: performance of hardware often depends upon the frequency involved, modulation permits designer to place a signal in some frequency range that avoids hardware limitations (cost and availability);
- ✓ **To reduce noise and interference**: certain types of modulation have the valuable property of suppressing both noise and interference;
- ✓ **For frequency assignment**: allows receiving many signals at the same time, but the desired signal can be separated from the other signals by filtering;
- ✓ **For multiplexing**: modulation allows multiplexing which is the process of combining several signals for simultaneous transmission on one channel.

Types of Modulation

Continuous-wave (CW) modulation system:

- ❖ **Amplitude Modulation (AM)**
- ❖ **Frequency Modulation (FM)**

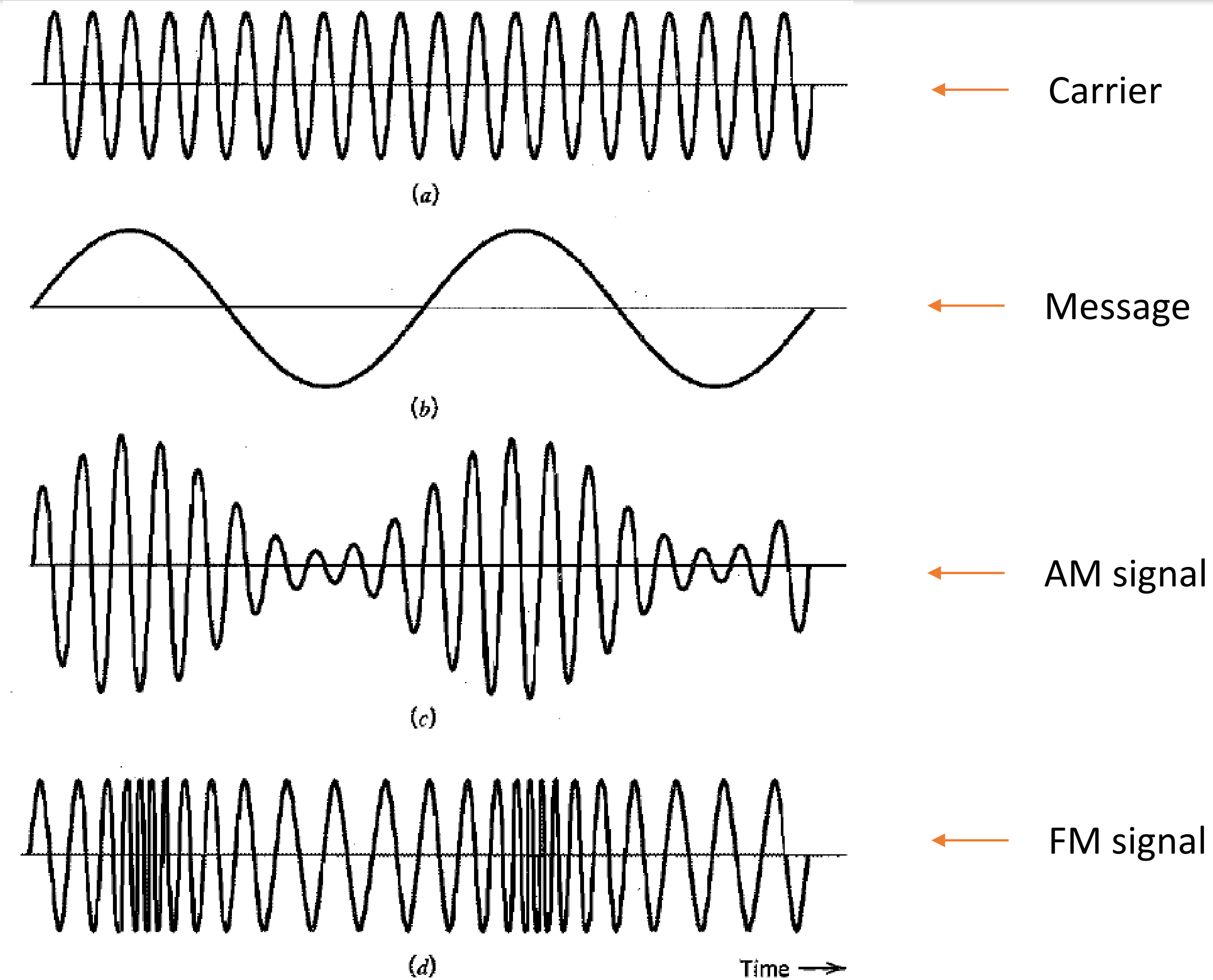
- The carrier in these systems is often a sinusoidal wave modulated by an analog signal (smooth and continuous).
- Involves direct frequency translation of the message spectrum.

Digital modulation system:

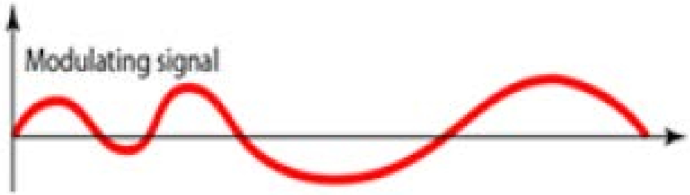
- ❖ **Pulse Code Modulation (PCM)**

- An electric signal satisfying certain requirements can be reproduced from an appropriate set of instantaneous samples;
- Sampling makes it possible to transmit a message in the form of pulses, rather than a continues signal.

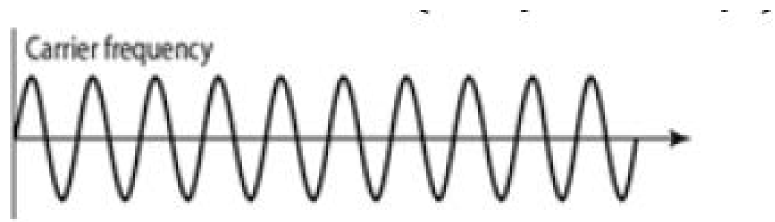
AM vs. FM



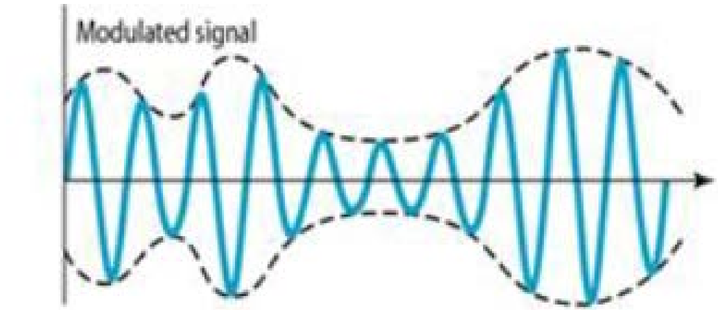
Amplitude Modulation (AM)



Message (modulating signal)



Carrier



Modulated signal

The unique property of AM is that the **envelope** of the modulated signal has the same shape as the message.

Modulation Index

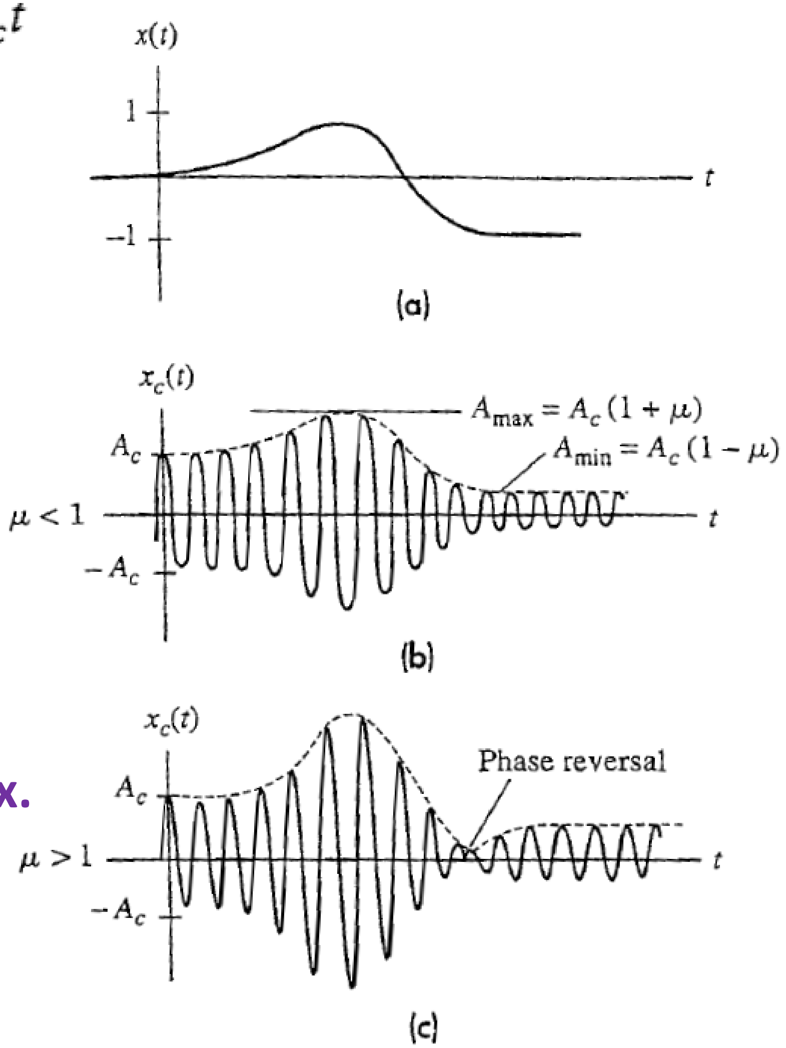
Assume message signal is $x(t)$, carrier is $A_c \cos \omega_c t$

Modulation by $x(t)$ produced the modulated envelop:

$$A(t) = A_c[1 + \mu x(t)]$$

Completed AM signal is:

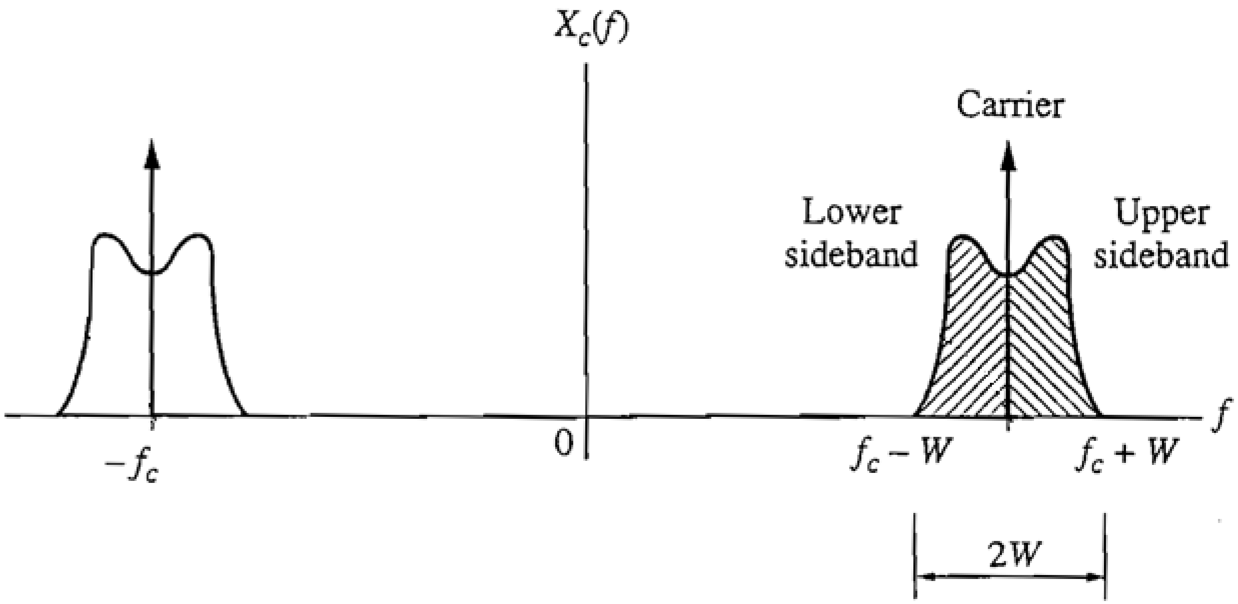
$$x_c(t) = A_c[1 + \mu x(t)] \cos \omega_c t$$



$\boldsymbol{\mu}$ is a positive constant called **modulation index.**

$\boldsymbol{\mu} < 1$: Under-modulation.
$\boldsymbol{\mu} > 1$: Over-modulation with phase reversals and envelop distortions;

AM Spectrum



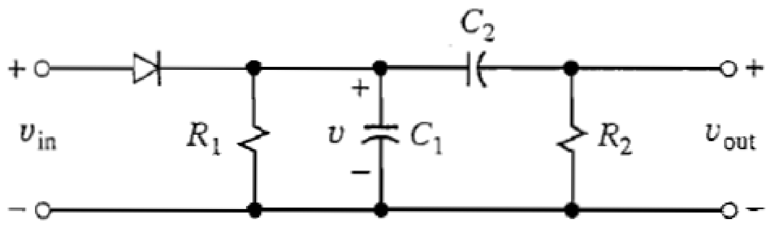
The AM spectrum consists of carrier-frequency impulses and symmetrical sidebands centered at $\pm f_c$.

The presence of upper and lower sidebands accounts for the name of double-sideband amplitude modulation. It also accounts for the AM transmission bandwidth:

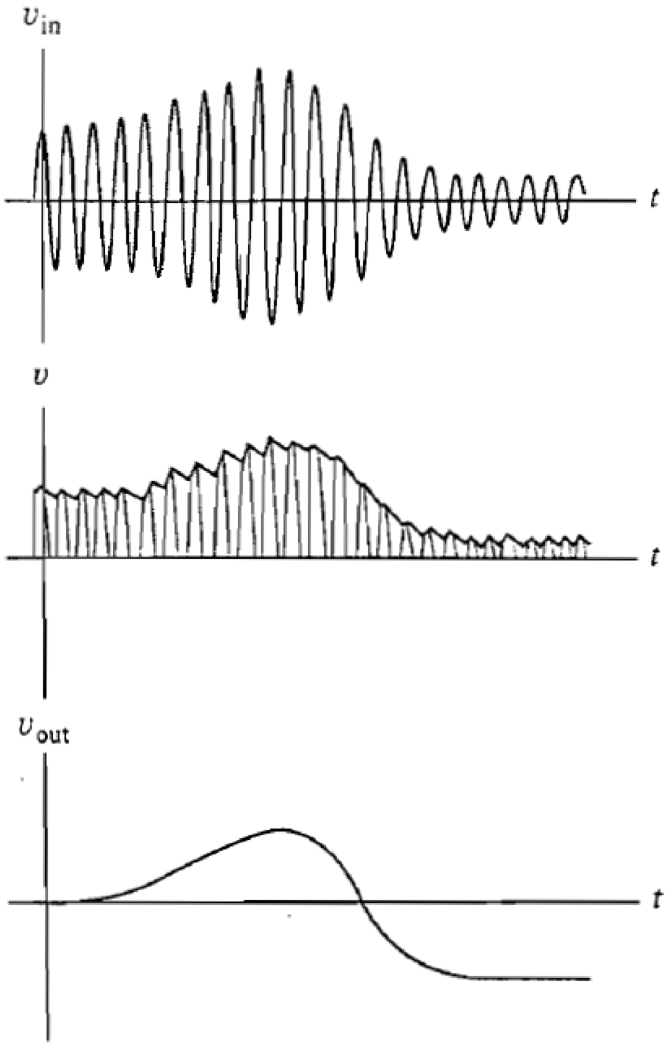
$$B_T = 2W$$

where W is the bandwidth of the original signal $x(t)$. Note that AM requires **twice** the bandwidth needed to transmit original message $x(t)$ at baseband without modulation.

Envelop Detector



(a)



(b)

Frequency Modulation (FM)

Frequency modulation, or conversion, is also used to shift a modulated signal to a new carrier frequency (up or down) for amplification or other processing.

In this case, frequency of the output (modulated signal) (f_o) is varied with change in the amplitude of modulating signal (message)(A_m):

$$f_o = f_c + kA_m$$

where f_o = instantaneous modulated frequency
f_c = carrier frequency
A_m = modulating signal amplitude

$$\Delta f = f_o - f_c = kA_m$$

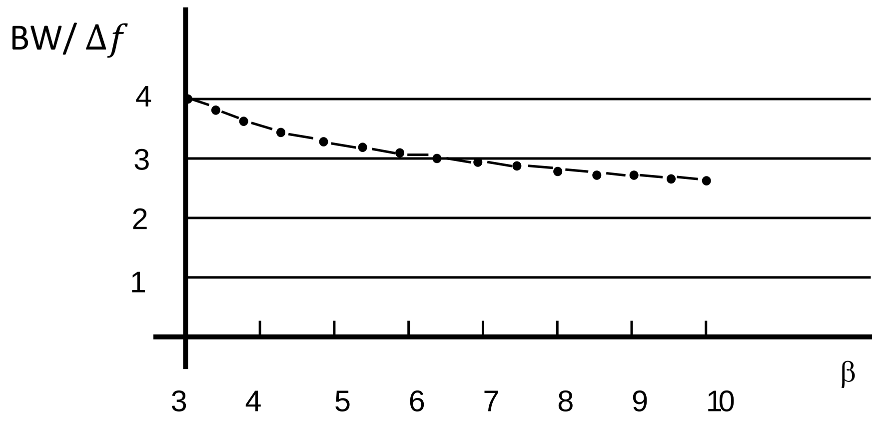
Δf is called the frequency deviation.
$\Delta f_{\_max} = kA_{m\_max}$ is the maximum frequency deviation.

The bandwidth (BW) occupied by an FM signal is dependent upon the modulation index: β and is usually greater than for AM.

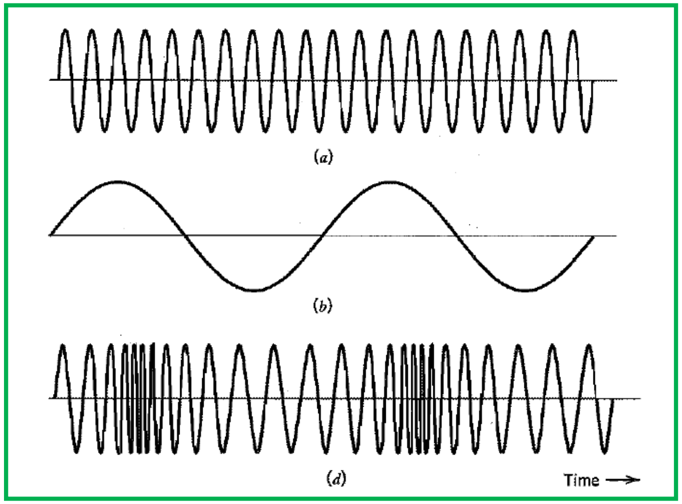
$$\boldsymbol{\beta} = \frac{maximum\ frequency\ deviation}{maximum\ modulating\ signal\ frequency} = \frac{\Delta f\_max}{f_m}$$

For $\beta < 0.2$, BW ~ $2f_m$ (same as AM)
For $\beta > 10$, BW ~ $2(\Delta f + f_m)$

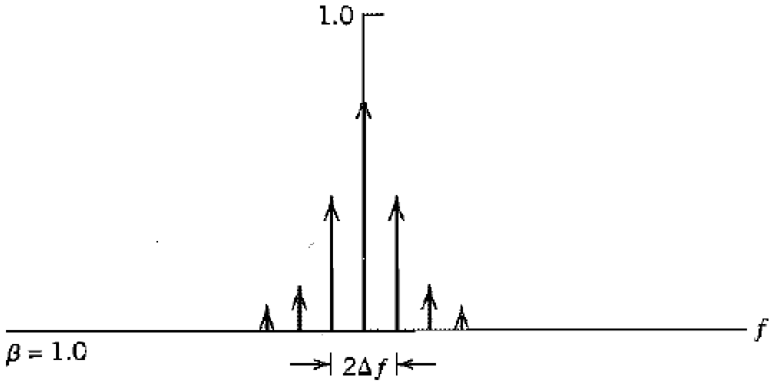
For $\beta \in [3,10]$ the bandwidth can be estimated from the graph below.

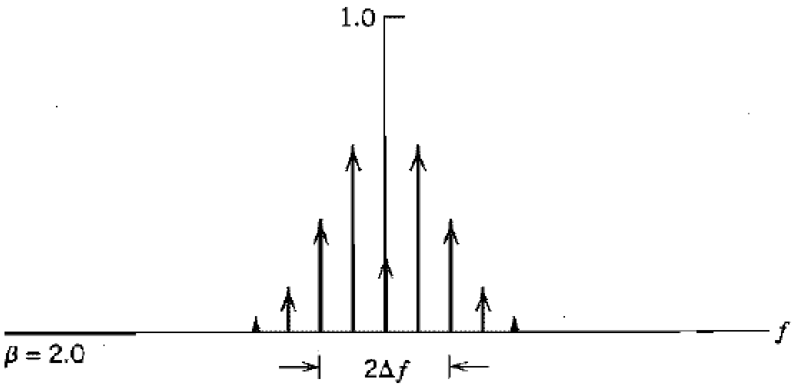


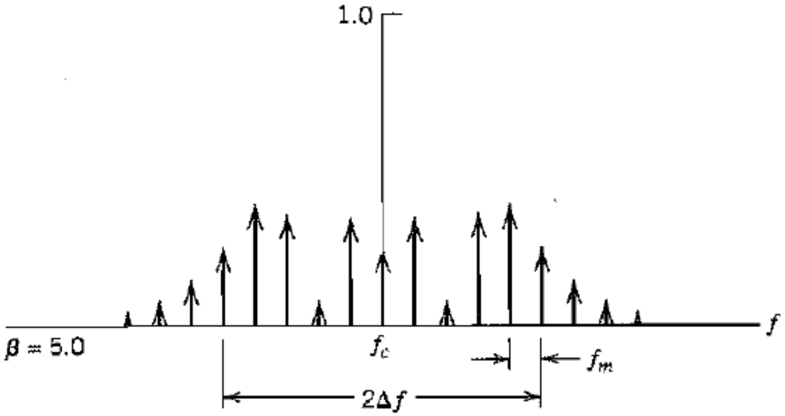
FM Spectrum



Spectra of an FM signal, normalized with respect to the carrier amplitude.







Pulse Code Modulation (PCM)

Pulse Code modulation (PCM) converts continuous-time signal into a sequence of pulses (discrete-time signal).

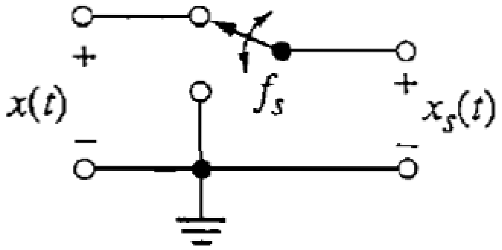
Advantages:

- The transmitted power can be concentrated into short bursts instead of being generated continuously; thus the system designer has greater latitude for equipment selection, and may choose devices such as lasers and high-power microwave tubes that operates only on a pulsed basis;
- The time interval between pulses can be filed with sample values from other signals, a process called time-division multiplexing (TDM).

Disadvantages:

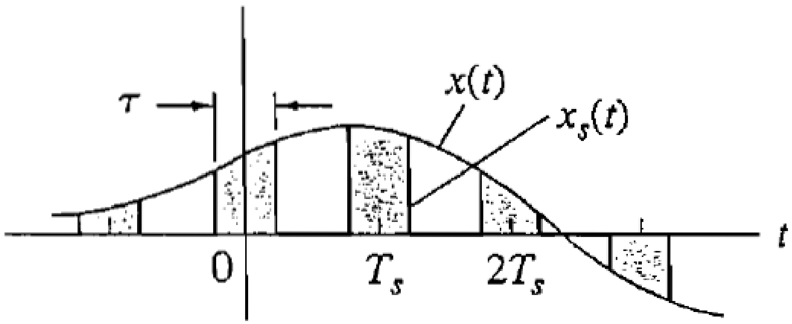
- Require very large transmission bandwidth compared to the message bandwidth.

Sampling



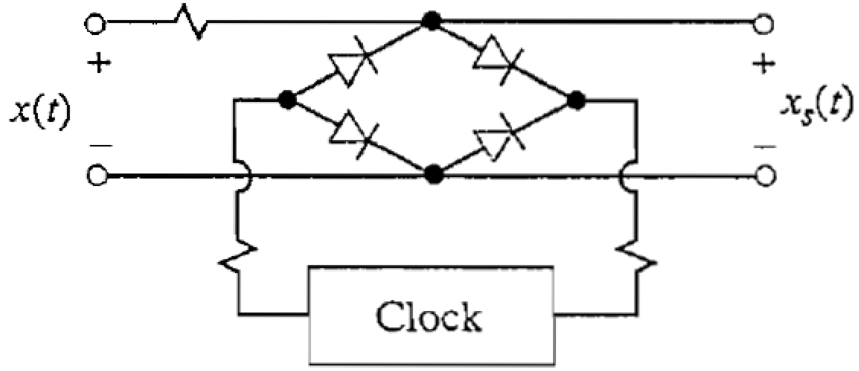
(a)

Functional Diagram



(b)

Waveforms



(c)

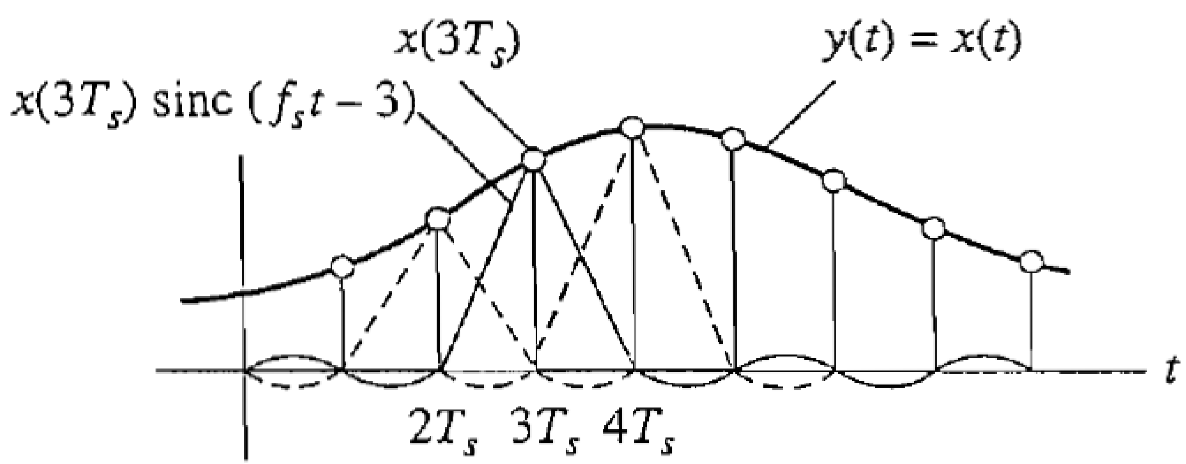
Circuit realization with diode bridges

Nyquist or Shannon's Sampling Theorem

Nyquist criterion or Shannon's sampling theorem:

When the signal is reconstructed from the samples, it is only when the sampling rate is at least **twice** that of the highest frequency in the analogue signal that the original analogue signal can be completely reconstructed.

Nyquist rate: twice the highest frequency in the analogue signal.

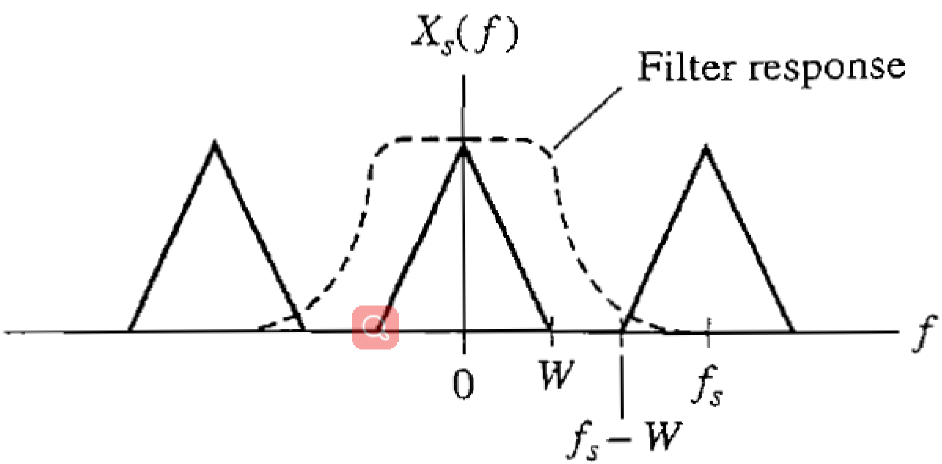


Ideal reconstruction.

Practical Sampling and Aliasing

Practical sampling differs from ideal sampling in three obvious aspects:

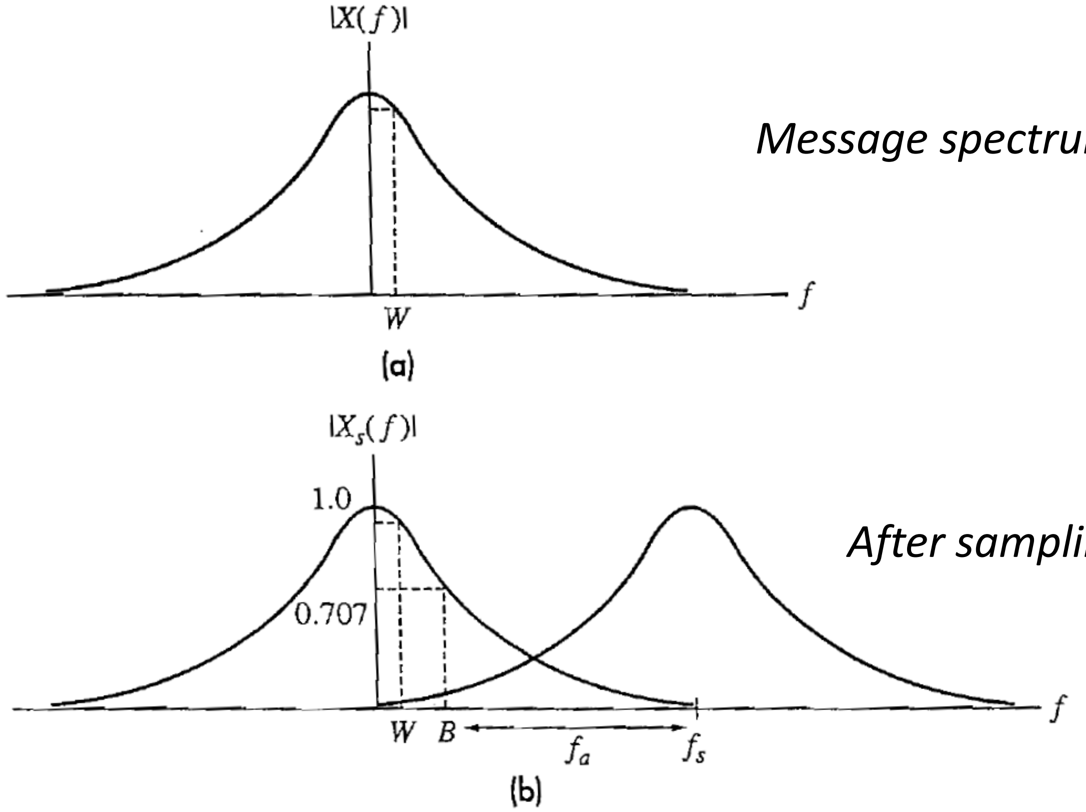
1. The sampled wave consists of pulses having finite amplitude and duration, rather than impulses;
2. Practical reconstruction filters are not ideal filters;



Practical reconstruction filter.

Aliasing

3. The messages to be sampled are timelimited signals whose spectra are not and cannot be strictly bandlimited. – leads to more troublesome effect known as **aliasing**.

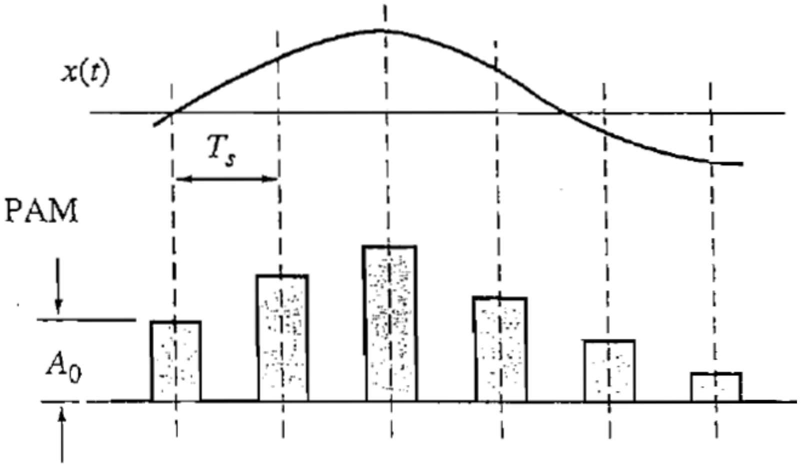


Message spectrum.

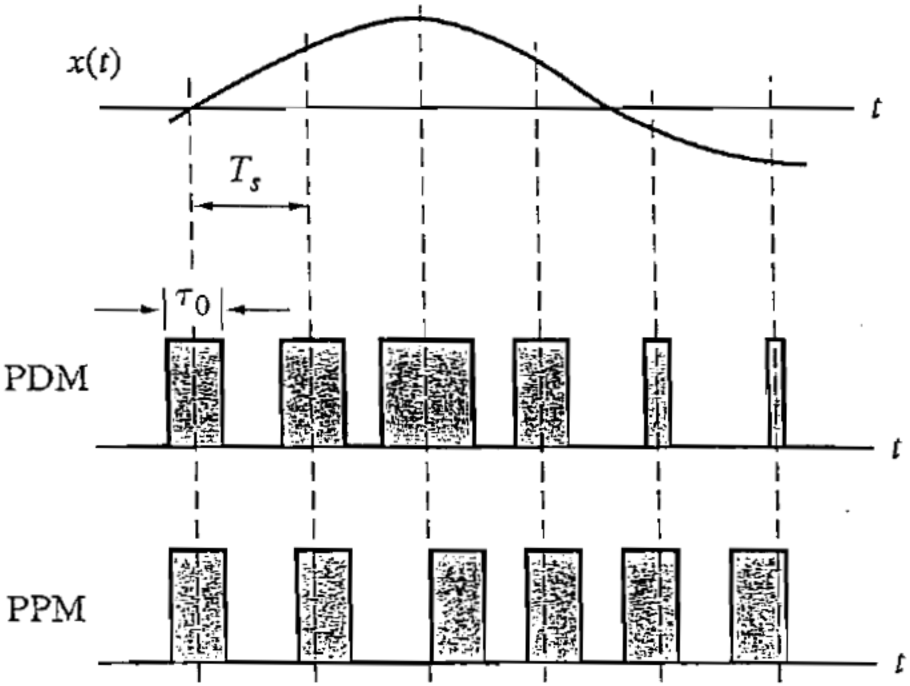
After sampling.

Types of PCM

PAM
(Pulse Amplitude Modulation)



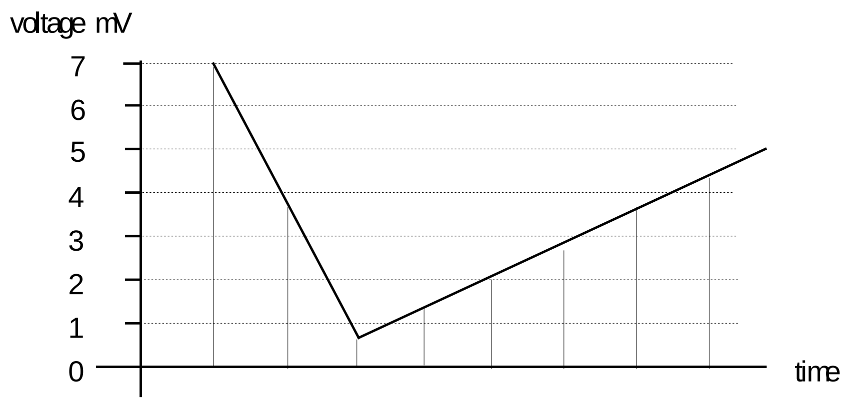
PTM
(Pulse Time Modulation)



PDM: Pulse Duration Modulation;
PPM: Pulse Position Modulation.

Covert to Binary Code

The sampled values are then converted into a binary number using an ADC (analogue to digital converter) so the samples are represented by groups of binary pulses, corresponding to the 0s and 1s.



Sampled voltages	7	3	0	1	2	2	3	4	(mV)
Binary equivalent	111	011	000	001	010	010	011	100	(3-bit code)

In practice, a code with more bits would be used. The number of bits (N) used to code the signal determines the **resolution** of the system.

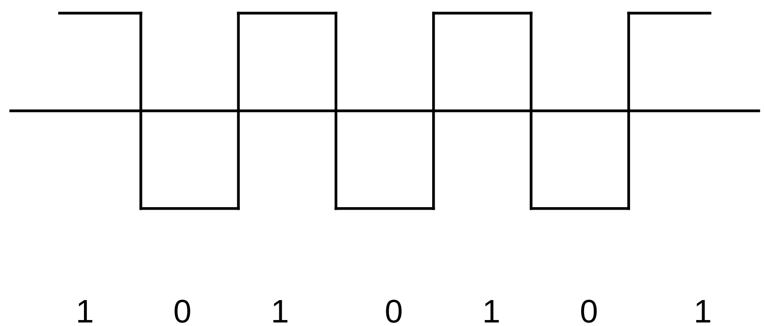
$$Resolution = \frac{Signal\ Range}{2^N - 1}$$

Transmission Bandwidth Required

The bandwidth required to transmit this signal depends upon the bandwidth of the original signal (f_m: Maximum frequency) and the number of bits used to represent the signal (N).

Number of bits per second = sampling frequency x number of bits per sample

$$= 2 \times f_m \times N \text{ (at least)}$$



Since there are two bits coded for each cycle of the fundamental frequency of the square wave, then

bandwidth required = number of bits per sec / 2 $= f_m \times N$

Example 7.1

Consider a thermocouple giving an output of 0.5 mV/^{o}C, what will be the word length required when its output passes through an ADC if temperatures from 0^{o}C to 200^{o}C to be measured with a resolution of 0.5^{o}C?

The full-scale output from the sensor is:

$$200 \times 0.5 = 100\ mV$$

With a word length n, this voltage will be divided into $\frac{100}{2^n - 1} mV$ steps.

For a resolution of 0.5^{o}C, we must be able to detect a signal from the sensor of:

$$0.5 \times 0.5 = 0.25\ mV$$

Thus we require:

$$0.25 = \frac{100}{2^n - 1}$$

Hence $n = 8.6$. Thus a 9-bit word length is required.

Thank You !