Course Material

ANALOG & DIGITAL COMMUNICATION

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Name of the Course : **Analog and Digital Communication**

Name of the Unit : **Amplitude and Angle Modulation**

Name of the Topic : **Review of signals and systems and Amplitude modulation systems**

Review of signals and systems

AIM & OBJECTIVES

- To understand the representation of Discrete and Continuous signals.
- To understand the fundamental characteristics of Signals and Systems

PRE-TEST MCQ

1. A signal is a physical quantity which does not vary with _______

a) Time
b) Space
c) Independent Variables
d) Dependent Variables

2. Most of the signals found in nature are _________

a) Continuous-time and discrete-time
b) Continuous-time and digital
c) Digital and Analog
d) Analog and Continuous-time

3. Determine the fundamental period of the following signal sin60t.

a) 1/60 sec
b) 1/30 sec
c) 1/20 sec
d) 1/10 sec

4. Energy signal has zero average power and power signal has zero energy.

   a) True
   b) False

5. Euler's identity $e^{j\theta}$ is expanded as _____

   a) Cosθ + j sinθ
   b) Cosθ – j sinθ
   c) Cosθ + j sin2θ
   d) Cos2θ+j sinθ

PREREQUISITES

Basic Knowledge of Signals & Systems.

THEORY

The word 'signal' has been used in different contexts in the English language and it has several different meanings. In this subject, we will use the term signal to mean a function of an independent variable that carries some information or describes some physical phenomenon.

Often (not always) the independent variable will be time, and the signals will describe phenomena that change with time. Such a signal can be denoted by $x(t)$, where t is the independent variable and $x(t)$ denotes the function of t.A signal is a pattern of variation that carry information. Signals are represented mathematically as a function of one or more independent variable.

A picture is brightness as a function of two spatial variables, x and y. In this Lecture signals involving a single independent variable, generally refer to as a time, t are considered. Although it may not represent time in specific application. A signal is a real-valued or scalar-valued function of an independent variable t.

Some of the Examples:

- ❖ Electrical signals --- voltages and currents in a circuit
- ❖ Acoustic signals --- audio or speech signals
- ❖ Video signals --- intensity variations in an image
- ❖ Noise: unwanted signal

Continuous-Time Signals

Most signals in the real world are continuous in time, as the scale is infinitesimally fine.

E.g. voltage, velocity, Denote by $x(t)$, where the time interval may be bounded (finite) or infinite

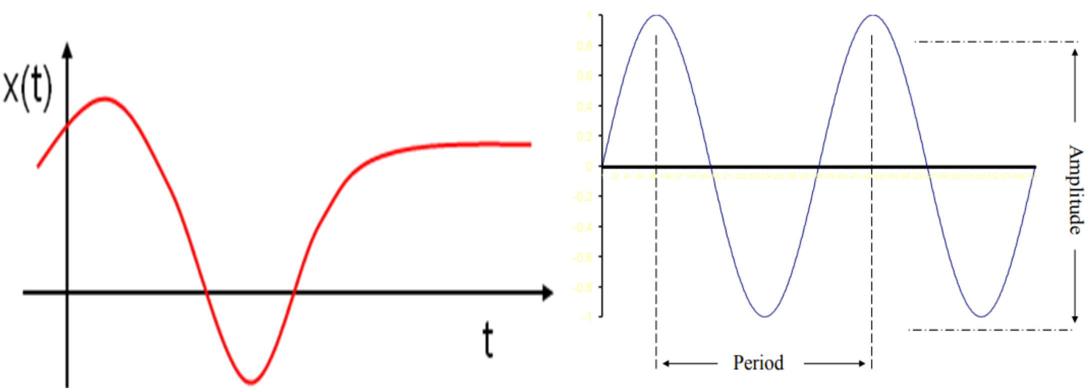


Figure 1.1: Continuous Time signal

Discrete-Time Signals

Some real world and many digital signals are discrete time, as they are sampled.

E.g. pixels, daily stock price (anything that a digital computer processes) Denote by $x[n]$, where n is an integer value that varies discretely.

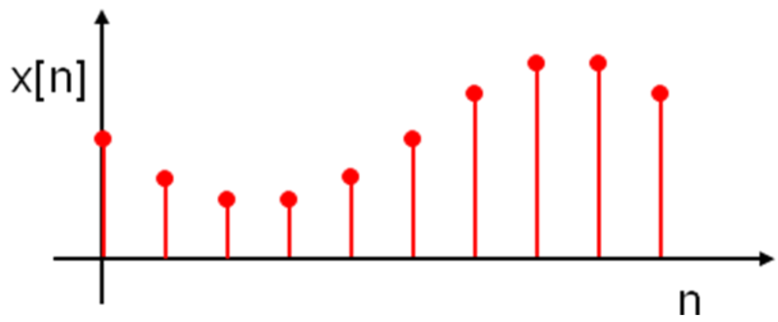


Figure 1.2: Discrete Time signal

Classification of Signals

- Deterministic & Non Deterministic Signals
- Periodic & A periodic Signals
- Even & Odd Signals
- Energy & Power Signals

Deterministic signals

Behavior of these signals is predictable with respect to time. There is no uncertainty with respect to its value at any time. These signals can be expressed mathematically.

For example Sinusoidal, Exponential, Unit step signal are deterministic signal.

Non Deterministic or Random signals

Behavior of these signals is random i.e. not predictable with respect to time. There is an uncertainty with respect to its value at any time. These signals can't be expressed mathematically.

For example: Thermal Noise.

Periodic and Non-Periodic Signals

Given x(t) is a continuous-time signal , x (t) is periodic if $x(t) = x(t + T_o)$ for any T and any integer n.

Example: $x(t) = A\cos(\omega t) = A\cos[\omega(t+T_o)] =$

$A\cos(\omega t+\omega T_o) = A\cos(\omega t+2\pi) = A\cos(\omega t)$ (Note: $T_o = 1/f_o$; $\omega=2\pi f_o$)

For non-periodic signals $x(t) \neq x(t + T_o)$. A non-periodic signal is assumed to have a period $T = \infty$.Example of non periodic signal is an exponential signal.

Even and odd signals:

One of characteristics of signal is symmetry that may be useful for signal analysis.

Even signals are symmetric around vertical axis, and Odd signals are symmetric about origin.

Even Signal: A signal is referred to as an even if it is identical to its time-reversed counterparts; $x(t) = x(-t)$.

Odd Signal: A signal is odd if $x(t) = -x(-t)$. An odd signal must be 0 at $t=0$, in other words, odd signal passes the origin.

Energy Signal

A signal with finite energy and zero power is called Energy Signal i.e. For energy signal $0<E<\infty$ and $P=0$

Signal energy of a signal is defined as the area under the square of the magnitude of the signal.

$$E_x = \int_{-\infty}^{\infty} |x(t)|^2 \, dt$$

Power Signal

Some signals have infinite signal energy. In that case it is more convenient to deal with average signal power.

For power signals $0<P<\infty$ and $E=\infty$

Average power of the signal is given by

$$P_x = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} |x(t)|^2 \, dt$$

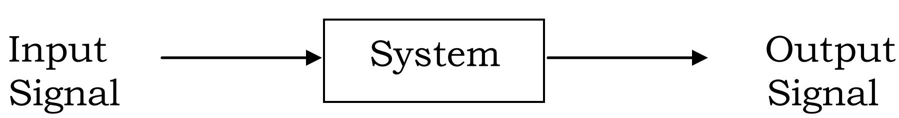
Applications

- ❖ Transmission of information (signal) over a channel
- ❖ Speech and audio processing
- ❖ Multimedia processing (image and video)
- ❖ Underwater acoustic
- ❖ Biological signal analysis
    - o Brain signals (EEG)
    - o Cardiac signals (ECG)
    - o Medical images (x-ray, PET, MRI)
- ❖ Active noise cancellation -- Headphones used in cockpits

SYSTEM

Systems process input signals to produce output signals. A system takes a signal x(t) or x(n) as the input (stimulus, excitation, etc.), modifies and processes the signal, and produces a signal y(t) or y(n) as the output (response).

This process can be modeled mathematically as an operator applied to the input to produce an output.



A communication system is generally composed of three sub-systems, the transmitter, the channel and the receiver. The channel typically attenuates and adds noise to the transmitted signal which must be processed by the receiver.

Some examples of system:

- Electrical/electronic circuit: voltage/current signal to the input port, voltage/current from the output port
- Neuro-visual system: processing light input (photons) and generating action potential (electro-chemical signal)
- Glucose metabolism: converting glucose and oxygen to carbon dioxide and water, and generating heat energy
- TV set: converting electromagnetic signal as input and generating sound and image signal as output.

POST-TEST MCQ

1. For an energy signal __________

    a) E=0
    b) P= ∞
    c) E= ∞
    d) P=0

2. Discrete time signal is derived from continuous time signal by _____________ process.

    a) Addition
    b) Multiplying
    c) Sampling
    d) Addition and multiplication

3. Noise generated by an amplifier of radio is an example for?

    a) Discrete signal
    b) Deterministic signal
    c) Random signal
    d) Periodic signal

4 .Y (t) = x (2t) is ________

a) Compressed signal
b) Expanded signal
c) Shifted signal
d) Amplitude scaled signal by a factor of 2

5. The time period of continuous-time sinusoidal signal is given by _____

a) $T = 2\pi / w$
b) $T = 2\pi / 3w$
c) $T = \pi / w$
d) $T = \pi / 2w$

CONCLUSION:

Upon completion of this, Students should be able to

- Understand the representation of Discrete and Continuous signals.
- Understand the Classification of Signals.
- Understand about the System.

REFERENCES

1. Simon Haykins and Barry Van Veen, Signals and Systems, John Wiley & Sons, 2004.

2. P.Ramesh Babu & R.Anandanatarajan, signals and systems, 4th edition, SciTech Publication private limited, 2009.

ASSIGNMENT

1. How to represent Analog and Discrete Signals.
2. Explain the classifications of signals.
3. Explain system with example.

Amplitude Modulation Systems

AIM & OBJECTIVES

- To understand Modulation and its importance.
- To understand Amplitude Modulation system.

PRE-TEST MCQ

1. Medium which sends information from source to receiver is called

   a) Transmitter
   b) Transducer
   c) Loudspeaker
   d) Channel

2. Telephones send information through wires in form of ________

   a) Radio signals
   b) Electrical signal
   c) Electromagnetic waves
   d) Microwaves

3. Cell phones sent information in form of ________

   a) Microwaves
   b) Electrical signals
   c) Infrared Waves
   d) Radio waves

4. What is the role of the transmitter in the communication system?

   a) to decode a signal to be transmitted
   b) to convert one form of energy into other
   c) to detect and amplify information signal from the carrier
   d) to produce radio waves to transmit data

5. Sin wave is ________

a) Aperiodic Signal
b) Periodic Signal
c) Random Signal
d) Deterministic Signal

PREREQUISITES

Basic Knowledge of Electronic Devices and Signals & Systems.

THEORY

Introduction to Modulation:

Modulation is the process of superimposing a low frequency signal on a high frequency carrier signal. The process of modulation is defined as varying the RF carrier wave in accordance with the information in a low frequency signal. Modulation is defined as the process by which some characteristics such as amplitude, frequency and phase, of a carrier is varied in accordance with instantaneous value of the modulating signal.

Need for Modulation:

The following are the factors which emphasize the need for modulation

- Antenna Height
- Narrow Banding
- Poor radiation and penetration
- Diffraction angle
- Multiplexing

If two musical programs were played at the same time within distance, it would be difficult for anyone to listen to one source and not hear the second source. Since all musical sounds have approximately the same frequency range, from about 50 Hz to 10 KHz. If a desired program is shifted up to a band of frequencies between 100 KHz and 110 KHz, and the second program shifted up to the band between 120 KHz and 130 KHz, Then both programs gave still 10 KHz bandwidth and the listener can (by band selection) retrieve the program of his own choice. The receiver would down shift only the selected band of frequencies to a suitable range of 50Hz to 10 KHz.

A second more technical reason to shift the message signal to a higher frequency is related to antenna size. It is to be noted that the antenna size is inversely proportional to the frequency being radiated. This is 75 meters at 1 MHz but at 15 KHz it has increased to 5000 meters a vertical antenna of this size is impossible.

Types of Modulation:

The main function of the carrier wave is to carry the audio or video signal from the transmitter to the receiver. The resulting wave due to superimposition of audio signal and carrier wave is called the modulated wave.

The sinusoidal carrier wave can be given by the equation

$$V_c = V_c \sin(\omega_c t + \theta) = V_c \sin(2\pi f_c t + \theta)$$

Where V_c – Maximum Value, f_c – Frequency and θ – Phase Relation.

Since the three variables are the amplitude, frequency and phase angle, the modulation can be done by varying any one of them. Thus there are three modulation types namely:

Amplitude Modulation (AM) – a change in the amplitude of the carrier voltage (V_c), with all other factors remaining constant.

Frequency Modulation (FM) – a change in the carrier frequency (f_c) with all other factors remaining constant.

Phase Modulation (PM) - a change in the carrier phase angle (θ).

Amplitude Modulation

The method of varying amplitude of a high frequency carrier wave in accordance with the information to be transmitted, keeping the frequency and phase of the carrier wave unchanged is called Amplitude Modulation. The information is the modulating signal and it is superimposed on the carrier wave by applying both of them to the modulator. Figure1.3shows the process of amplitude modulation.

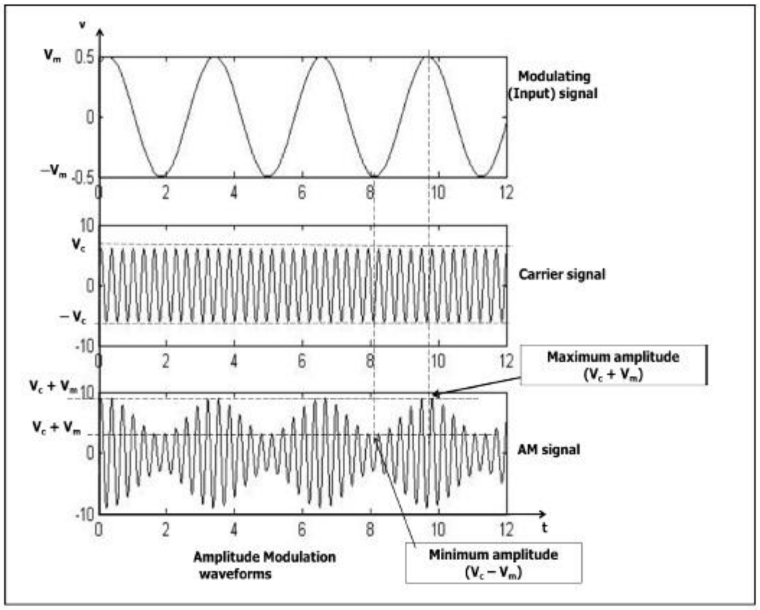


Figure 1.3: Amplitude Modulation

As shown above, the carrier wave has positive and negative half cycles. The carrier consists of sine waves whose amplitudes follow the amplitude variations of the modulating wave. The carrier is kept in an envelope formed by the modulating wave.

Analysis of AM Carrier Wave

Let $c(t) = A \sin \omega_c t$ and $m(t) = M (\cos \omega_m t + f_m)$

Where

$c(t)$ – Instantaneous value of the carrier

A – Peak value of the carrier

ω_c – Angular velocity of the carrier

$m(t)$ – Instantaneous value of the modulating signal

M – Maximum value of the modulating signal

ω_m – Angular velocity of the modulating signal

f_m – Modulating signal frequency

It must be noted that the phase angle remains constant in this process. Hence it can be ignored. The amplitude of the carrier wave varies at f_m.

The amplitude modulated wave is given by the equation

$y(t) = [1 + m(t)]\ c(t)$

$= [1 + M (\cos \omega_m t)]\ A \sin \omega_c t$

$= [1 + M \cos (2\pi f_m t)]\ A \sin (2\pi f_c\ t)$

$= A \sin (2\pi f_c\ t) + AM/2 \sin (2\pi(f_c + f_m)t) + AM/2 \sin (2\pi(f_c - f_m)t)$

The ratio of M/A is the modulation index given by 'm'. The above equation represents the sum of three sine waves. One with amplitude of 'A' with frequency of f_c , the second one with an amplitude of AM/2 and frequency of $(f_c + f_m)$ and the third one with an amplitude of AM/2 and frequency of $(f_c - f_m)$. In practice the angular velocity of the carrier is greater than the angular velocity of the modulating signal ($f_c >> f_m$). Thus, the second and third terms are more close to the carrier frequency.

Frequency Spectrum of AM Wave

Lower side frequency = $(f_c - f_m)$

Upper side frequency = $(f_c + f_m)$

In Figure 1.4, the frequency components present in the AM wave are represented by vertical lines approximately located along the frequency axis. The height of each vertical line is drawn in proportion to its amplitude. Since the angular velocity of the carrier is greater than the angular velocity of the modulating signal, the amplitude of side band frequencies can never exceed half of the carrier amplitude. Thus there will not be any change in the original frequency, but the side band frequencies $(f_c - f_m)$ and $(f_c + f_m)$ will be changed. The former is called the upper side band (USB) frequency and the later is known as lower side band (LSB) frequency. It is clear that the carrier component does not transmit any information.

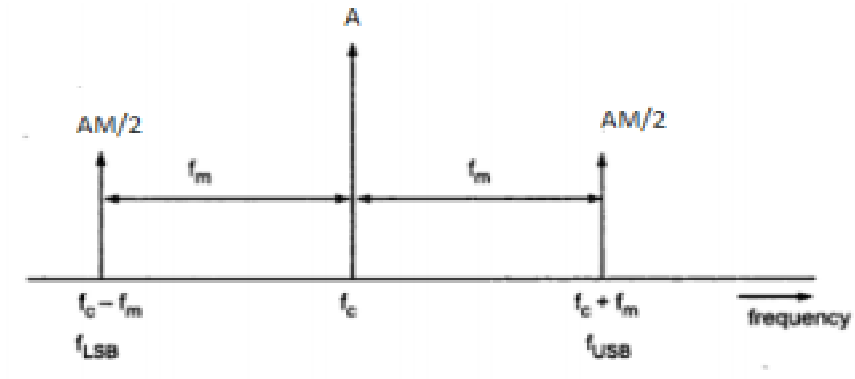


Figure 1.4 Frequency Domain Representation of AM Wave

Two side banded frequencies will be produced when a carrier is amplitude modulated by a single frequency. Thus an AM wave has a band width equal to twice the signal frequency produced. When a modulating signal has more than one frequency, two side band frequencies are produced by every frequency. Similarly for two frequencies of the modulating signal 2 LSB‘s and 2 USB‘s frequencies will be produced. The total bandwidth is equal to twice the higher modulating frequency.

Modulation Index (m)

The ratio between the amplitude changes of carrier wave to the amplitude of the normal carrier wave is called modulation index. It is represented by the letter ‘m‘.

m = M/A.

Percentage modulation, % m = m*100 = M/A * 100

The percentage modulation lies between 0 and 80%. Generally the value of ’m‘ lies between 0 and 0.8. The value of ‘m’ determines the strength and the quality of the transmitted signal. But if the value of ‘m’ exceeds unity, the transmitter output produces erroneous distortion.

Bandwidth of AM

The bandwidth of a complex signal like AM is the difference between its highest and lowest frequency components and is expressed in Hertz (Hz). Bandwidth deals with only frequencies.

Bandwidth = (fc – fm) – (fc + fm) = 2 fm

Power Relations in an AM wave

A modulated wave has more power than had by the carrier wave before modulating. The total power components in amplitude modulation can be written as:

$$P_{total} = P_{carrier} + P_{LSB} + P_{USB}$$

The power levels in carrier and sidebands

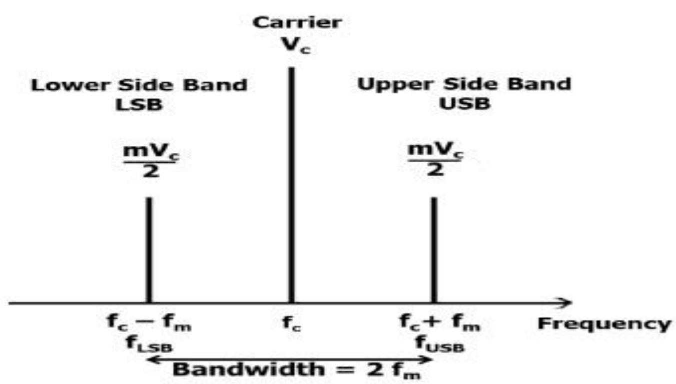


Figure 1.5 Power Levels in Carrier and Sidebands

There are three components in the AM wave. They are Unmodulated carrier, USB & LSB.

Total $P_{AM} = P_c$ + Power in USB +Power in LSB

If R is the load, then Power in AM = $V^2{}_c/R + V^2{}_{LSB}/R + V^2{}_{USB}/2$

Peak carrier Power = V^2c/R

Peak Voltage = V_c, therefore RMS voltage = $Vc/\sqrt{2}$

RMS carrier power $=1/R\,[V_c/\sqrt{2}]^2 = V^2_c/\,2R$

	Carrier power	Upper side band	Lower sideband
Peak value	Vc	$\frac{mV_c}{2}$	$\frac{mV_c}{2}$
RMS Value	$\frac{V_c}{\sqrt{2}}$	$\frac{mV_c/2}{\sqrt{2}} = \frac{mV_c}{2\sqrt{2}}$	$\frac{mV_c/2}{\sqrt{2}} = \frac{mV_c}{2\sqrt{2}}$
Power (RMS)	$\frac{1}{R}\left[\frac{V_c}{\sqrt{2}}\right]^2 = \frac{V_c^2}{2R}$	$\frac{1}{R} \times \left[\frac{mV_c/2}{\sqrt{2}}\right]^2 = \frac{m^2V_c^2}{8R}$	$\frac{1}{R} \times \left[\frac{mV_c/2}{\sqrt{2}}\right]^2 = \frac{m^2V_c^2}{8R}$

Advantages of Amplitude Modulation

- Amplitude modulation is economical as well as easily obtainable
- It is so simple to implement, and by using a circuit with fewer components it can be demodulated.
- The receivers of AM are inexpensive because it doesn't require any specialized components.

Disadvantages of Amplitude Modulation

- The efficiency of this modulation is very low because it uses a lot of power.
- This modulation uses amplitude frequency several times to modulate the signal by a carrier signal.
- This declines the original signal quality on the receiving end & causes troubles in the signal quality.

POST-TEST MCQ

1. Amplitude modulation is

   a. Change in amplitude of carrier according to modulating signal
   b. Change in frequency of carrier according to modulating signal
   c. Change in amplitude of modulating signal according to carrier
   d. Change in amplitude of carrier according to modulating signal frequency

2. The ratio between the modulating signal voltage and the carrier voltage is called?

   a) Amplitude modulation
   b) Modulation frequency
   c) Modulation index
   d) Ratio of modulation

3. What is the percentage of modulation if the modulating signal is of 7.5V and carrier is of 9V?

   a) 100
   b) 91
   c) 83.33
   d) 0

4. AM waves are represented by which equation?

   a) [1 + m(t)].c(t)
   b) [1 – m(t)].c(t)
   c) [1 + m(t)].2c(t)
   d) [1 + 2m(t)].c(t)

5. The AM spectrum consists of

   a. Carrier frequency
   b. Upper side band frequency
   c. Lower side band frequency
   d. All of the above

APPLICATIONS

- ❖ Air Band Radio
- ❖ Broadcast transmissions
- ❖ It is used for HF radio links

CONCLUSION:

Upon completion of this, Students should be able to

- ❖ Understand the modulation technique.
- ❖ Understand the Amplitude Modulation system.
- ❖ Understand the Frequency spectrum of AM.
- ❖ Understand the sidebands and its power.

REFERENCES

1. Dr.Sanjay Sharma, "Analog and Digital communication", seventh edition, K KATARIA & amp; SON'S publication, 2017.
2. Haykin.S and Michel Moher," Introduction to Analog and Digital communication", Second edition, John Wiley and sons Inc, 2012.

ASSIGNMENT

1. Explain Modulation and its importance.
2. Explain Amplitude Modulation with AM signal.
3. A modulating signal $m(t) = 10\cos(2\pi\times10^3\, t)$ is amplitude modulated with a carrier signal $c(t) = 50\cos(2\pi\times10^5\, t)$. Find the modulation index, the carrier power and the power required for transmitting AM wave.
4. Calculate the percentage modulation in AM if carrier amplitude is 20V and the modulating signal is of 15V.