Amplitude Modulation (AM)

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Baseband signal and Baseband Transmission

- Baseband signal refers to a signal that contains only the original information that is to be transmitted, without any additional frequency components.
- This means that the baseband signal has a frequency range from zero to some maximum frequency, and does not contain any higher-frequency components that could interfere with other signals or cause distortion.
- Baseband transmission refers to the process of transmitting a baseband signal directly over a communication channel without the use of any modulation.
- In other words, the baseband signal is transmitted over the channel at its original frequency range, without being modulated onto a carrier signal.

Advantages of Baseband Transmission

1. **Simplicity**: Baseband transmission is simple, and it does not require complex modulation and demodulation techniques. This makes it easier to implement and less expensive.
2. **Low bandwidth requirement**: Baseband transmission uses a low bandwidth, which makes it ideal for short-distance communication.
3. **Noise immunity**: Baseband transmission is less susceptible to noise and interference because it uses a low-frequency signal, which is less likely to be affected by external factors.
4. **High data rate**: Baseband transmission can support high data rates, which makes it suitable for transmitting large amounts of data quickly.
5. **Low power consumption**: Baseband transmission requires less power than other transmission methods, making it ideal for portable devices that have limited battery life.
6. **Compatibility**: Baseband transmission is compatible with digital devices, which means it can be used with a wide range of digital devices such as computers, smartphones, and tablets.

Limitations of Baseband Transmission

1. Limited Range
2. Susceptibility to Noise
3. Interference with Other Signals
4. Limited Bandwidth
5. Limited Application

What is Modulation?

- Modulation refers to the process of changing one or more properties of a signal in order to convey information from one place to another. In other words, modulation is a technique used to transfer information from a source to a destination by altering a carrier signal.
- Modulation is used in a wide range of communication systems, including radio, television, telephone, and data transmission systems.
- The process of modulation involves combining a high-frequency carrier signal with a lower-frequency message signal, which contains the information to be transmitted.
- By modulating the carrier signal in some way, the message signal can be transmitted over a long distance without being distorted or attenuated.

Types of Modulation

The most common types of modulation include:

1. Amplitude Modulation (AM): In AM, the amplitude of the carrier signal is varied in proportion to the amplitude of the message signal. AM is commonly used for radio broadcasting.
2. Frequency Modulation (FM): In FM, the frequency of the carrier signal is varied in proportion to the amplitude of the message signal. FM is commonly used for radio broadcasting as well as some television transmission.
3. Phase Modulation (PM): In PM, the phase of the carrier signal is varied in proportion to the amplitude of the message signal. PM is commonly used in some types of data transmission systems.
4. Pulse Modulation (PM): In PM, the message signal is represented by a series of pulses, which are then used to modulate the carrier signal. PM is commonly used in digital communication systems.

Need for Modulation

1. Reduces the height of an antenna
2. Efficient use of bandwidth
3. Long-distance communication
4. Interference reduction
5. Security
6. Compatibility
7. Multiplexing

Amplitude Modulation

- In AM, the amplitude of the carrier signal is varied in proportion to the amplitude of the message signal (also called the modulating signal) that contains the information to be transmitted. The resulting modulated signal is then transmitted over the communication channel.
- The basic components of an AM system include a message signal source, a carrier signal source, a modulator, a transmitter, a receiver, and a demodulator.
- The message signal source generates the message signal, which can be any analog signal such as an audio or video signal.
- The carrier signal source generates a high-frequency sinusoidal waveform, which is typically in the range of hundreds of kilohertz to several megahertz.
- The modulator is used to combine the message signal and the carrier signal, resulting in an amplitude-modulated signal. The modulated signal is then transmitted over the communication channel, which can be a wired or wireless medium.

Equation of AM

The high frequency signal whose characteristics is changed is called the *carrier* signal and the term *modulating* signal is used for the voltage in accordance with which the carrier is changed.
Let the carrier signal be represented by the equation as –

$$v_c = V_c \cos(\omega_c t + \theta) \tag{1}$$

where,
v_c = instantaneous value of carrier voltage.
V_c = maximum value of carrier voltage (amplitude)
ω_c = angular carrier frequency = $2\pi f_c$
θ = phase angle
t = time

Equation of AM (Contd....)

1. when amplitude of the carrier signal is varied in accordance with the instantaneous value of modulating signal, then the process is called **amplitude modulation**.
2. When frequency of the carrier signal is varied in accordance with the instantaneous value of modulating signal, then the process is called **frequency modulation**.
3. When phase of the carrier signal is changed in accordance with the instantaneous value of modulating signal, it is called phase modulation.

Let the modulating signal voltage is given by –

$$v_m = V_m \cos(\omega_m t) \tag{2}$$

where, ω_m is angular frequency of modulating signal and V_m is the amplitude of modulating signal.

Let the carrier voltage is –

$$v_c = V_c \cos \omega_c t \tag{3}$$

Equation of AM (Contd....)

In amplitude modulation, amplitude of the carrier does not remain constant but varies with the instantaneous value of modulating signal and varies with respect to time as –

$$V(t) = V_c + V_m \cos \omega_m t \tag{4}$$

where, $V_m \cos \omega_m t$ represents the variation in amplitude of carrier signal. Therefore, the instantaneous value of the modulated carrier voltage is given by –

$$v = V(t) \cos \omega_c t \tag{5}$$

Putting equation(4) in (5), we get,

$$v = [V_c + V_m \cos \omega_m t] \cos \omega_c t \tag{6}$$

$$\therefore v = V_c \left[1 + \frac{V_m}{V_c} \cos \omega_m t\right] \cos \omega_c t \tag{7}$$

$$\therefore v = V_c[1 + m \cos \omega_m t] \cos \omega_c t \tag{8}$$

where, $m = \frac{V_m}{V_c}$ is modulation index or modulation factor or depth of modulation

Equation of AM (Contd....)

$$\therefore v = V_c \cos\omega_c t + V_c m \cos\omega_m t \cos\omega_c t \tag{9}$$

Expanding the above equation (), we get,

$$v = V_c \cos\omega_c t + \frac{mV_c}{2}[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t] \tag{10}$$

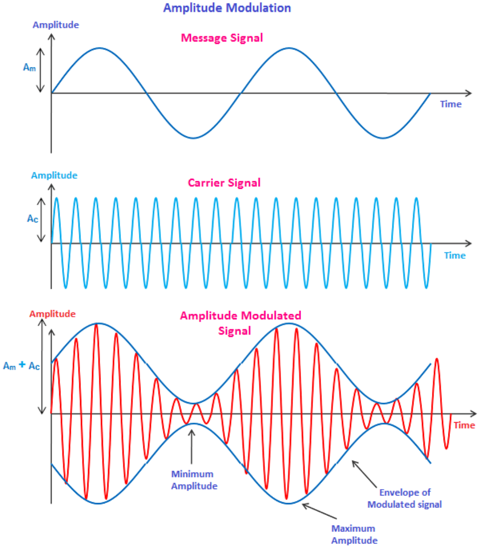
$$\therefore v = V_c \cos\omega_c t + \frac{mV_c}{2}\cos(\omega_c + \omega_m)t + \frac{mV_c}{2}\cos(\omega_c - \omega_m)t \tag{11}$$

Equation(11) represents the equation of AM wave.
From equation (11), it can be concluded that the AM wave contains the following frequency components :

1. Original carrier signal $V_c \cos\omega_c t$ having angular frequency ω_c.
2. Upper sideband term $\frac{mV_c}{2}\cos(\omega_c + \omega_m)t$ having angular frequency $(\omega_c + \omega_m)$.
3. Lower sideband term $\frac{mV_c}{2}\cos(\omega_c - \omega_m)t$ having angular frequency $(\omega_c - \omega_m)$.

Equation of AM (Contd....)

The AM wave can be drawn as –



Modulation Index of AM Wave

- Modulation index can also be called as *modulation factor* or *degree of modulation* and is a measure of degree of modulation. It is given by –

$$\text{Modulation Factor, } m = \frac{\text{Amplitude of modulating wave}}{\text{Amplitude of unmodulated carrier wave}}$$

- The value of modulation factor depends upon the amplitudes of carrier and signal.
- The modulation factor describes the depth of modulation i.e. the extent to which the amplitude of the carrier wave is changed by the signal.
- The practical value of modulation index for an AM system should be in between 0 and 1.
  Modulation factor determines the strength and quality of the transmitted signal.

1. The amplitude modulated wave consists of following frequency components:
   1. Original carrier signal $V_c \cos \omega_c t$ having angular frequency ω_c.
   2. Upper sideband term $\frac{mV_c}{2} \cos(\omega_c + \omega_m)t$ having angular frequency $(\omega_c + \omega_m)$.
   3. Lower sideband term $\frac{mV_c}{2} \cos(\omega_c - \omega_m)t$ having angular frequency $(\omega_c - \omega_m)$.

   The lower sideband and upper sideband terms are located in frequency spectrum on either side of the carrier at a frequency interval ω_m as shown below :
2. Thus amplitude modulation generates apart from the carrier with amplitude V_c, additional two sidebands on either side of the carrier frequency ω_c. They have amplitude $\frac{mV_c}{2}$.
3. In amplitude modulation, the actual message is present in two sidebands. The carrier signal does not carry any information.

Bandwidth of AM

- We know bandwidth can be measured by subtracting lowest frequency of the signal from the highest freqyency of the signal. For amplitude modulated wave, it is given by -

$$\begin{aligned} \text{BW} &= f_{USB} - f_{LSB} \\ &= (f_c + f_m) - (f_c - f_m) \\ &= 2f_m = 2W \end{aligned}$$

  where, W is the message bandwidth.
- Therefore the bandwidth required for the amplitude modulation is twice the frequency of the modulating signal.
- the bandwidth for AM wave is exactly twice the bandwidth of message (moduating) signal, since the bandwidth of message signal is f_m.

Power Relation in AM Wave

The AM wave consists of three components :

1. Original carrier signal $V_c \cos \omega_c t$ having angular frequency ω_c.
2. Upper sideband term $\frac{mV_c}{2} \cos(\omega_c + \omega_m)t$ having angular frequency $(\omega_c + \omega_m)$.
3. Lower sideband term $\frac{mV_c}{2} \cos(\omega_c - \omega_m)t$ having angular frequency $(\omega_c - \omega_m)$.

The total power in the modulated wave can be given as –

$$P_t = P_C + P_{LSB} + P_{USB} \tag{12}$$

Where,
P_C = Carrier power
P_{LSB} = Power in lower sideband
P_{USB} = Power in upper sideband.

$$\therefore P_t = \frac{V_{carrier}^2}{R} + \frac{V_{LSB}^2}{R} + \frac{V_{USB}^2}{R} \tag{13}$$

In the above equation, all three voltages are rms values and R is the resistance in which power is dissipated.
Therefore carrier poser is given as –

$$P_c = \frac{V_{carrier}^2}{R} = \frac{\left(\frac{V_c}{\sqrt{2}}\right)^2}{R} = \frac{V_c^2}{2R} \tag{14}$$

Similarly, power in sidebands can be given as –

$$P_{LSB} = P_{USB} = \frac{V_{LSB}^2}{R} = \frac{\left(\frac{mV_c/2}{\sqrt{2}}\right)^2}{R} \tag{15}$$

$$P_{LSB} = P_{USB} = \frac{m^2 V_c^2}{8R} \tag{16}$$

Power Relation in AM (Continued....)

From equation (12), (14) and (16), we get,

$$P_t = \frac{V_c^2}{2R} + \frac{m^2 V_c^2}{8R} + \frac{m^2 V_c^2}{8R} \tag{17}$$

$$\therefore P_t = \frac{V_c^2}{2R} + \frac{m^2}{4}\frac{V_c^2}{2R} + \frac{m^2}{4}\frac{V_c^2}{2R} \tag{18}$$

$$\therefore P_t = P_C + \frac{m^2}{4}P_C + \frac{m^2}{4}P_C \tag{19}$$

$$\therefore P_t = P_C\left[1 + \frac{m^2}{4} + \frac{m^2}{4}\right] \tag{20}$$

$$\therefore P_t = P_C\left[1 + \frac{m^2}{2}\right] \tag{21}$$

The above expression (21) gives total power of an amplitude modulated wave.

Total Current in AM Wave

Let,
I_C be the unmodulated carrier current.
I_t be the total modulated current of an AM wave.
R be the resistance.
We know that, the total power of an AM wave is given by –

$$P_t = P_C \left[1 + \frac{m^2}{2}\right]$$

$$\therefore \frac{P_t}{P_C} = 1 + \frac{m^2}{2}$$

$$\therefore \frac{P_t}{P_C} = \frac{I_t^2 R}{I_C^2 R} = \frac{I_t^2}{I_C^2} = 1 + \frac{m^2}{2}$$

$$\therefore I_t^2 = I_C^2 \left[1 + \frac{m^2}{2}\right]$$

$$\therefore I_t = I_C \sqrt{1 + \frac{m^2}{2}}$$

Modulation by Several Sine Waves

High frequency carrier signal can be modulated simultaneously by several low frequency modulating signal. This is a rule rather than an exception. If simultaneous modulating voltages $V_1, V_2, V_3........$ are used to modulate the carrier, then total modulating voltage can be given as –

$$V_t = \sqrt{V_1^2 + V_2^2 + V_3^2 + ...}$$

Dividing both sides by V_c, we get

$$\frac{V_t}{V_c} = \frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + ...}}{V_c}$$

$$\therefore \frac{V_t}{V_c} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + ...}{V_c^2}}$$

$$\therefore \frac{V_t}{V_c} = \sqrt{\frac{V_1^2}{V_c^2} + \frac{V_2^2}{V_c^2} + \frac{V_3^2}{V_c^2} + ...}$$

But, $\frac{V_t}{V_c} = m_t$, $\frac{V_1}{V_c} = m_1$, $\frac{V_2}{V_c} = m_2$ and $\frac{V_3}{V_c} = m_3$ and so on...

Efficiency of AM

The efficiency η of an AM system is given by the ratio of sideband power to the total power of the modulated wave.

$$\therefore \eta = \frac{\text{Sideband power}}{\text{Total power of AM wave}} \tag{22}$$

We know that the power in upper sideband and lower sidebands are –

$$P_{LSB} = P_{USB} = \frac{m^2 V_c^2}{8R}$$

$$\begin{aligned}
\text{Total power in sidebands} &= P_{LSB} + P_{USB} \\
\therefore \text{Sideband power} &= \frac{m^2 V_c^2}{8R} + \frac{m^2 V_c^2}{8R} \\
\therefore \text{Sideband power} &= \frac{m^2 V_c^2}{4R} = \frac{m^2}{2} \frac{V_c^2}{2R}
\end{aligned}$$

But, carrier power is –

$$P_C = \frac{V_c^2}{2R}$$

$$\therefore \text{Sideband power} = \frac{m^2 P_C}{2} \tag{23}$$

Total power in an AM wave is given by –

$$P_t = P_C \left(1 + \frac{m^2}{2}\right) \tag{24}$$

Therefore putting equation (23) and (24) in equation (22), we get,

$$\eta = \frac{\frac{m^2 P_C}{2}}{P_C \left(1 + \frac{m^2}{2}\right)}$$

$$\therefore \eta = \frac{m^2}{2\left(1 + \frac{m^2}{2}\right)}$$

Efficiency of AM (Contd....)

$$\therefore \eta = \frac{m^2}{2 + m^2}$$

$$\therefore \% \eta = \frac{m^2}{2 + m^2} \times 100$$

i.e. the efficiency of an AM wave is a function of modulation index.
When $m = 1$ i.e. for 100 % modulation,

$$\% \eta = \frac{1 \times 100}{2 + 1} = 33\%$$

i.e. for 100 % modulation, only 33 % power lies in sidebands which carry the information and remaining 67 % power is wasted in transferring the carrier signal, which does not contain any information.

Advantages of AM

1. Simple to implement: AM is a relatively simple modulation scheme and requires only basic equipment to transmit and receive signals.
2. Efficient use of bandwidth: AM uses the bandwidth efficiently, as it only requires a narrow bandwidth compared to other modulation techniques.
3. Compatible with existing equipment: AM signals can be easily received by most radio receivers, making it compatible with existing equipment.
4. Easy demodulation: The demodulation of an AM signal is simple and can be achieved using a simple diode detector circuit.
5. Low power consumption: The power consumption of an AM transmitter is relatively low compared to other modulation techniques.

Disadvantages of AM

1. Poor signal quality: The quality of an AM signal is susceptible to noise and interference, which can result in poor sound or image quality.
2. Limited bandwidth: The bandwidth of an AM signal is limited, which makes it unsuitable for transmitting high-quality audio or video signals.
3. Inefficient use of power: AM transmitters are not very efficient and can waste a significant amount of power.
4. Vulnerability to atmospheric conditions: AM signals are susceptible to atmospheric conditions, such as thunderstorms or solar flares, which can affect their quality and range.
5. Susceptibility to interference: AM signals are susceptible to interference from other radio signals, which can result in signal distortion and degradation.

Applications of AM

1. Radio Broadcasting: AM is widely used in radio broadcasting to transmit information such as music, news, sports, and other programming.
2. Television Broadcasting: In the early days of television broadcasting, AM was used to transmit the video signal. However, with the advent of modern digital television, AM is no longer used for this purpose.
3. Two-way Radio Communications: AM is also used in two-way radio communications such as air traffic control, police and fire services, and military communications.
4. Radar Systems: AM is used in radar systems for detecting and locating objects.
5. Medical Imaging: AM is used in medical imaging equipment such as ultrasound machines.
6. Electronic Music: AM has been used in electronic music to create unique sounds and effects.
7. Remote Controls: AM is used in remote control systems for operating devices such as garage doors, TVs, and toys.