Analog Modulation

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Amplitude Modulation

Amplitude of the carrier signal (high frequency) is varied with the amplitude of modulating signal keeping frequency and the phase of the carrier fixed.

Single Tone Modulation (Sinusoidal Signal)

- Modulating Signal

$$v_m(t) = V_m \cos\omega_m t$$

where, ω_m = Modulating frequency

V_m = Amplitude of modulating signal

- Carrier Signal

$$v_c(t) = V_c \cos\omega_c t$$

where, ω_c = Carrier frequency

v_c = Amplitude of carrier signal

Remember:

- $\omega_c >> \omega_m$
- f_m = 50 Hz - 15 kHz ; f_c = 535 kHz - 1605 Hz
- AM broadcast range is 535 MHz - 1605 MHz.

Amplitude-Modulated (AM) Signal

$$v_{AM}(t) = [V_c + K_a V_m \cos\omega_m t]\cos\omega_c t$$

or

$$v_{AM}(t) = V_c[1 + m_a \cos\omega_m t]\cos\omega_c t$$

$$\boxed{m_a = K_a \frac{V_m}{V_c}}$$

where, m_a = Modulation index

= Depth of modulation

= Percentage modulation

K_a = Constant of proportionality, and depends upon circuit from where AM signal has been generated

Note:

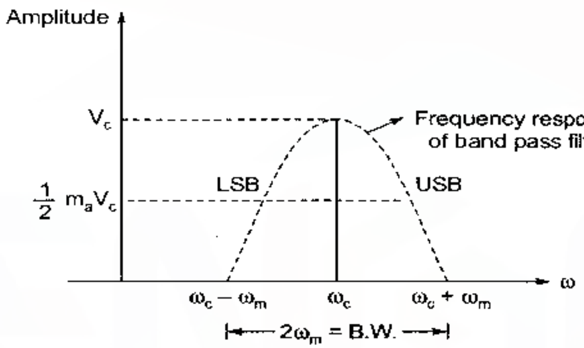
- Unless specified take $K_a = 1$ then $m_a = \frac{V_m}{V_c}$.
- Practically $0 < m_a < 1$, generally take value of $m_a = 0.45$ to 0.6.
- If $m_a = 0$ then unmodulated signal.
  If $m_a = 1$ then 100% modulated signal.

Representation of Various AM Signal

1. AM-DSB/FC

It is a standard signal

$$v_{AM}(t) = \underbrace{V_c \cdot \cos\omega_c t}_{\text{Free carrier}} + \frac{1}{2} m_a V_c \left[\underbrace{\cos(\omega_c + \omega_m)t}_{\text{Upper side band}} + \underbrace{\cos(\omega_c - \omega_m)t}_{\text{Lower side band}}\right]$$



Spectrum of AM-DSB/FC sigal

Important Points:

- AM-DSB/FC signal represents standard AM signal which requires maximum amount of power and maximum bandwidth for its transmission.
- Such system is used for broadcast purpose since its circuit configuration is simplest.
- Carrier carries no information. USB and LSB carry equal information since both have same frequency component with reference to the centre frequency ω_c.
- For the transmission of such signal, a band pass filter is used, having centre frequency of ω_c and a bandwidth of 2 ω_m.
- For the transmission of such signal, a band pass filter is use, having centre frequency of ω_c and a bandwidth of 2 ω_m.

- Total power required for transmission of AM-DSB/FC

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

$$\boxed{P_t = P_c\left(1 + \frac{m_a^2}{2}\right)}$$

where, P_c = Carrier power
P_{USB} = Upper side band power
P_{LSB} = Lower side band power

Note:

If carrier is modulated by several modulating signals then over all modulation index:

$$\boxed{m_a = \sqrt{m_{a1}^2 + m_{a2}^2 + \cdots m_{an}^2}}$$

2. AM-DSB/SC

$$v_{AM}(t) = \frac{1}{2} m_a V_c \left[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t\right]$$

3. AM-SSB/FC

$$v_{AM}(t) = V_c \cdot \cos\omega_c t + \frac{1}{2} m_a V_c \left[\cos(\omega_c \pm \omega_m)t\right]$$

USB
LSB

4. AM-SSB/SC

$$v_{AM}(t) = \frac{1}{2} m_a V_c \left[\cos(\omega_c \pm \omega_m)t\right]$$

Different AM System: At $K_a = 1$

System	P_t	P_s (saved power)	BW	% power saving	Complexity	SNR
AM-DSB/FC	$P_c\left(1+\frac{m_a^2}{2}\right)$	–	$2\omega_m$	–	Min.	Max.
AM-DSB/SC	$P_c \times \frac{m_a^2}{2}$	P_c	$2\omega_m$	67%	↓	Low
AM-SSB/FC	$P_c\left(1+\frac{m_a^2}{4}\right)$	$P_c + \frac{m_a^2}{4}$	ω_m	16%	↓	High
AM-SSB/SC	$P_c \times \frac{m_a^2}{4}$	$P_c\left(1+\frac{m_a^2}{4}\right)$	ω_m	83%	Max.	Min.

Note:

- AM-DSB/FC system is the best from the circuit configuration point of view. It has least complexity in the circuit but requires maximum bandwidth as well as maximum power.
- AM-SSB/SC system is the worst from the circuit complexity point of view. It has maximum complexity in the circuit but power and bandwidth requirement are minimum.
- AM-DSB/FC system are used for broadcast purpose whereas AM-SSB/SC system is used for point to point communication.

- Transmission Efficiency

$$\eta = \frac{\text{Useful power}}{\text{Total power}}$$

$$\boxed{\eta = \frac{P_s}{P_T} \times 100\%}$$

Case-1: AM-DSB/FC

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

If $m_a = 1$ then $\eta = 33\%$.

Case-2: AM-DSB/SC

$$\eta = 100\%$$

- Percentage power savings

$$\boxed{\%\ \text{Power saving} = \frac{\text{Power saved}}{\text{Total power}}}$$

Case-1: AM-DSB/SC

$$\boxed{\%\ \text{Power saving} = (1-\eta) = \frac{2}{2+ma^2}}$$

Case-2: AM-SSB/SC

$$\boxed{\%\ \text{Power saving} = \frac{4+ma^2}{2(2+ma^2)}}$$

Note:

- For full carrier system the transmission efficiency depends upon modulation index (m_a).
- For full carrier system the maximum efficiency is only 33% for maximum modulation index of unity.
- For suppressed carrier system the transmission efficiency is always independent of modulation index and is always 100%.

Multi Tone Modulation (Non Sinusoidal)

Representation of Various AM-Signal

1. AM-DSB/FC

Standard signal

In time domain

$$\boxed{v(t) = (A + f(t))\left[\frac{1}{2}\left(e^{j\omega_c t} + e^{-j\omega_c t}\right)\right]}$$

In frequency domain

$$\boxed{V(\omega) = \frac{1}{2}\left[\{F(\omega-\omega_c) + F(\omega+\omega_c)\} + \pi A\{\delta(\omega-\omega_c) + \delta(\omega+\omega_c)\}\right]}$$

2. AM-DSB/SC

Standard signal

In time domain

$$\boxed{v(t) = f(t)\left[\frac{1}{2}\left(e^{j\omega_c t} + e^{-j\omega_c t}\right)\right]}$$

In frequency domain

$$\boxed{V(\omega) = \frac{1}{2}\left[F(\omega-\omega_c) + F(\omega+\omega_c)\right]}$$

Important Points:

- In suppressed carrier signal, the free carrier is absent.
- Modulation represents frequency translation. Therefore original spectrum centered about zero frequency if translated to frequency spectrum centered at ω_c.
- Using modulation any low pass signal is modulated to band pass signal.
- Negative frequencies in the original spectrum have no physical meaning.

These are represented since

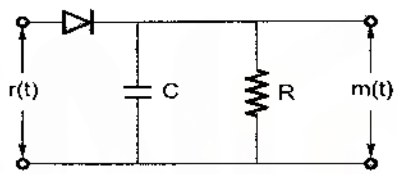
(a) The frequency spectrum of any signal is always an even function of ω and therefore negative and positive frequencies occurs in pair.

(b) Any negative frequency can be made a positive frequency by frequency translation or using modulation.

AM Modulators and Demodulators

- Product modulation is used for generation of AM waves using non linear devices.
- Switching modulator is also used for generation of AM waves.
- Balanced modulator and ring modulators are used for generation of DSB-SC waves.
- SSB wave is generated using analog multiplier and band pass filter.
- Filter method and phase shift methods are also used for generation of SSB wave.
- Enveloped Detector

  It is used for detection of AM wave.



r(t) is received signal and m(t) is message signal and for better reception RC must be selected such as

$$\frac{1}{f_c} << RC << \frac{1}{\omega}$$

where, ω is bandwidth of message signal (in Hz).

Note:

- Demodulation of DSB-SC and SSB waves is done using coherent carrier signal at receiver.
- Envelope detector can also be used to recover message by passing received VSB signal through it.

Angle Modulation

Angle Modulation
- Phase modulation (PM)
- Frequency modulation (FM)

Phase Modulation (PM)

In phase modulation the phase of the carrier is varied in accordance with instantaneous value of the amplitude of the modulating signal keeping the amplitude and frequency of the carrier fixed.

General Expression

$$v_{PM}(t) = A\cos[\omega_c t + K_p f(t)]$$

where, $f(t)$ = Modulating signal

K_p = Phase sensitivity or phase deviation

Frequency Modulation (FM)

In frequency modulation the frequency of the carrier is varied in accordance with the instantaneous value of the amplitude of modulating signal keeping amplitude and phase of the carrier fixed.

General Expression

$$\boxed{V_{FM}(t) = A\cos\left[\omega_c t + K_f\int f(t)dt\right]}$$

where, $f(t)$ = Modulating signal

K_f = Frequency sensitivity

If $f(t) = V_m \cos\omega t$

then $\boxed{V_{FM}(t) = A\cos[\omega_c t + m_f \sin\omega_{mt}]}$

where, $m_f = K_f \dfrac{V_m}{\omega_m}$ = Modulation index

Note:

- A pure PM signal or a pure FM signal cannot be obtained since the phase change or the frequency change are inter-related.
- In PM the modulation index is directly proportional to the amplitude of the modulating signal where as the modulating index in the FM depends upon the amplitude as well as the frequency of modulating signal.

- Total Power Required for FM Signal

$$v_{FM}(t) = A\cos\left[\omega_c t + K_f \int f(t)dt\right]$$

$$\boxed{P = \frac{A^2}{2}}$$

- Frequency Deviation

$$\boxed{\delta = m_f\,\omega_m}\ \text{rad/sec.}$$

or $$\boxed{\delta = m_f\,f_m}\ \text{Hz}$$

δ represents total bandwidth require for the transmission of FM signal.

Note: ....

- Bandwidth require for FM signal is always more than the bandwidth require for the AM signal.
- ω_m control the spacing between two successive sideband.
- The modulation index (m_f) controls the number of significant sidebands.

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FM Standards

Remember: ....

- Carrier frequency = 88 MHz – 108 MHZ
- Maximum frequency deviation = ±75 kHz
- Intermediate frequency (I.F.) fi = 10.7 MHz

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- Bandwidth

Practical bandwidth required is given by Carson's rule

$$\boxed{B.W. \cong 2\omega_m(m_f + 1)}\ \text{rad/sec.}$$

or $$\boxed{B.W. \cong 2(\delta + \omega_m)}\ \text{rad/sec.}$$

Case-1: Narrow band FM (NBFM)

$$\boxed{m_f << 1}$$

$$\boxed{B.W. \cong 2W_m}$$

Case-2: Wide band FM (WBFM)

$$\boxed{m_f >> 1}$$

$$\boxed{B.W. \cong 2\delta}$$

It is used in FM radio broadcast.

Note: ....

- Same bandwidth required for AM-DSB system.
- NBFM used in mobile radio.

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Remember: ....

- The modulation index determines the number of sidebands. Components have significant amplitudes.
- In FM, the total transmitted power always remains constant, but with increased depth of modulation, the required bandwidth, is increased.
- Deviation ratio is the shift in carrier frequency from its resting point compared to the amplitude of the modulating voltage.
- A deviation ratio of 5 is the maximum allowed in commercially broadcast FM.

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Angle Modulators and Demodulators

- FM wave can be generated using VCO caused direct method.
- FM wave can be generated using varactor diode.
- FM and PM both can be generated using reactance tubes.
- Another method is first generate narrow band FM then pass through it frequency multiplier.
- Demodulation is normally done using PLL.

Remember: ....

The FM system requires larger bandwidth and therefore the information is transmitted through larger number of frequency components or larger number of sidebands. Therefore the quality of recovered signal using FM system is much better as compare to that using AM system. Therefore FM system is Hi-Fi system and therefore has the ability to reproduce same quality of signal which was actually transmitted.

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Superheterodyne receiver

(i) **Sensitivity:** It is the minimum signal that should be present at input of a receiver to get standard output. It depends on gain of the receiver.

(ii) **Selectivity:** It is the ability of a receiver to reject the unwanted frequency component.

(iii) **Fidelity:** It is the ability of the receiver to reproduce all the frequency component at the output of the receiver.

- **Intermediate frequency**

$$\boxed{f_i = f_l - f_s}$$

where, f_l = Local oscillator frequency

f_s = desired signal frequency

- **Image frequency**

It is undesired frequency and to be rejected.

$$\boxed{f_{si} = 2f_l - f_s}$$

$$\boxed{f_{si} = f_s + 2f_i}$$

where, f_{si} = image signal frequency

- **Image Signal Rejection**

$$\boxed{\alpha = \sqrt{1 + Q^2 \rho^2}}$$

where, $\alpha_{dB} = 20 \log \alpha$

$$\rho = \left(\frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}\right)$$

Q = Quality factor

Note:

- If two tuned circuit are connected in cascade then $\alpha = \alpha_1 \cdot \alpha_2$.
- The image signal rejection represents the ratio of desired signal amplitude to the amplitude of undesired signal.
- For any good radio receiver the parameter α must have high value.

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