Amplitude Modulation Fundamentals:

AM Concepts:

In AM, the information signal varies the amplitude of the carrier sine wave. The instantaneous value of the carrier amplitude changes in accordance with the amplitude and frequency variations of the modulating signal.

Figure (1) shows a single frequency sine wave intelligence signal modulating a higher frequency carrier. The carrier frequency remains constant during the modulation process, but its amplitude varies in accordance with the modulating signal. An increase in the amplitude of the modulating signal causes the amplitude of the carrier to increase. Both the positive and negative peaks of the carrier wave vary with the modulating signal.

The signals illustrated in Fig (1) & (2) show the variation of the carrier amplitude with respect to time and are said to be in the time domain.

Using trignometric functions, we can express the sine wave carrier with the simple expression

$$v_c = V_c \sin 2\pi f_c t$$

In this expression, v_c represents the instantaneous value of the carrier sine wave voltage.

V_c represents the peak value of the constant unmodulated carrier sine wave as measured between zero and the maximum amplitude of either the positive-going or the negative-going alterations.

f_c is the frequency of the carrier sine wave and

t is a particular point in time during the carrier cycle.

A sine wave modulating signal can be expressed with a similar formula

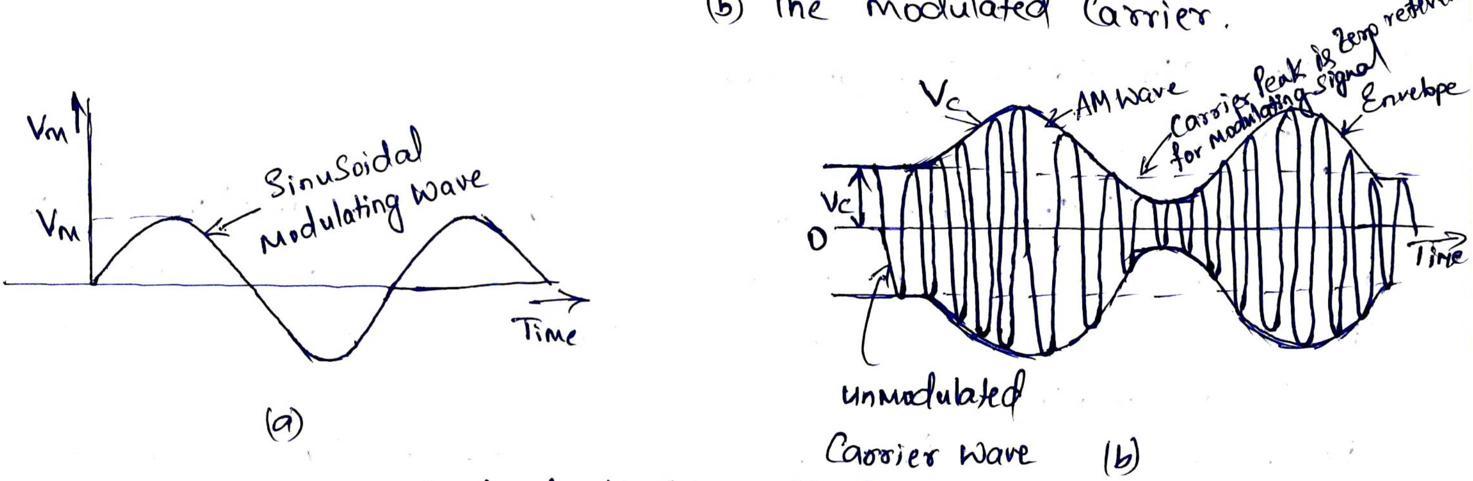
$$v_m = V_m \sin 2\pi f_m t$$

Where v_m = instantaneous value of information signal

V_m = Peak amplitude of information signal

f_m = frequency of modulating signal

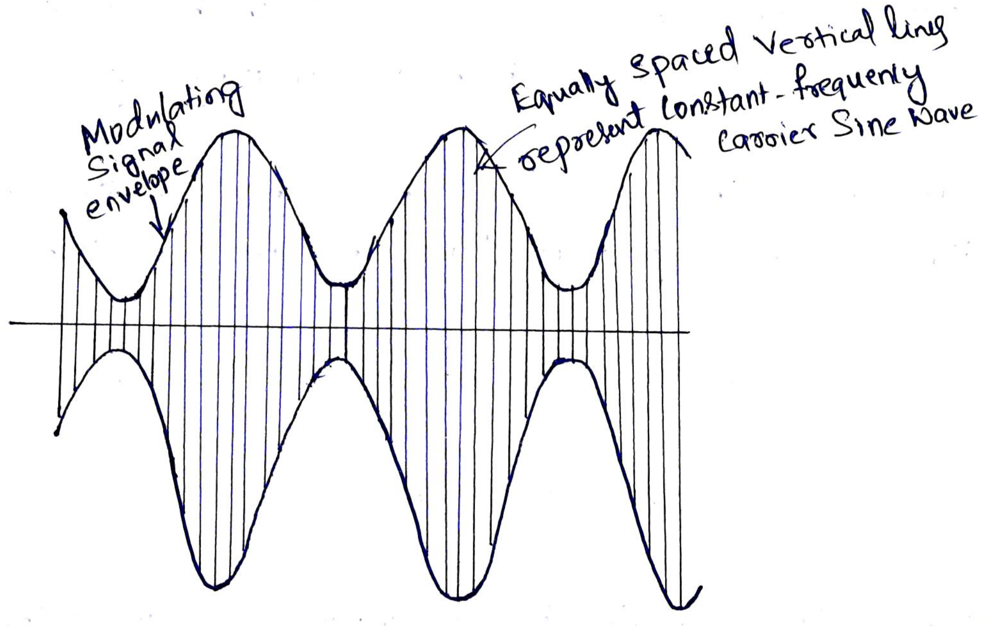
Figure (1) Amplitude modulation. (a) The modulating or information Signal (b) The modulated Carrier.



(a) (b)

Amplitude Modulation Fundamentals

Figure (2) A Simplified method of representing an AM high frequency Sine wave.



In Fig (1), the modulating Signal uses the peak value of the Carrier rather than zero as its reference point. The envelope of the modulating Signal varies above and below the peak Carrier amplitude. That is, the zero reference line of the modulating Signal coincides with the peak value of the unmodulated carrier. Because of this, the relative amplitudes of the carrier and modulating signal are important.

In general, the amplitude of the modulating Signal should be less than the amplitude of the Carrier. When the amplitude of the modulating Signal is greater than the amplitude of the Carrier, distortion will occur, causing incorrect information to be transmitted. In amplitude modulation, it is particularly important that the peak value of the modulating signal be less than the peak value of the carrier. Mathematically,

$$V_m < V_c$$

First, keep in mind that the peak value of the carrier is the reference point for the modulating signal; the value of the modulating signal is added to or subtracted from the peak value of the carrier. The instantaneous value of either the top or the bottom voltage envelope v_1 can be computed by using the equation

$$v_1 = V_c + v_m = V_c + V_m \sin 2\pi f_m t$$

which expresses the fact that the instantaneous value of the modulating signal algebraically adds to the peak value of the carrier. Thus, we can write the instantaneous value of the ~~either the top or bottom voltage envelope v_1 can be computed by using the equation~~

complete modulated wave v_2 by substituting v_1 for the peak value of carrier voltage V_c as follows

$$v_2 = v_1 \sin 2\pi f_c t$$

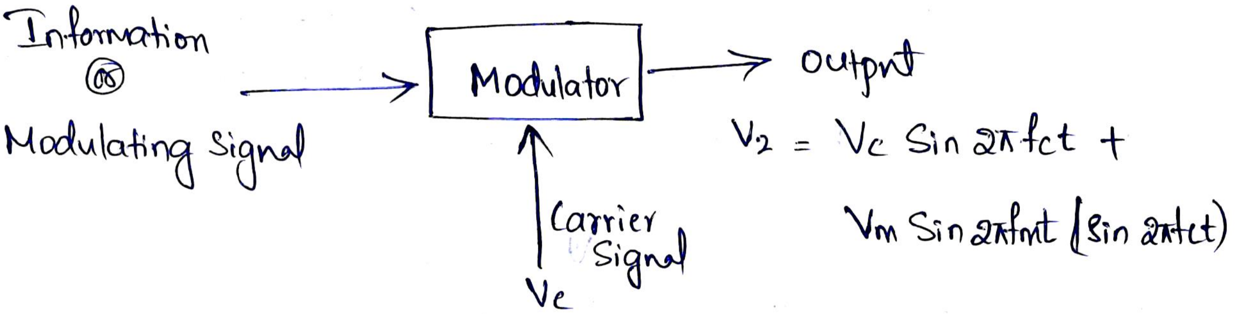
Now substituting the previously derived expression for v_1 and expanding, we get the following:

$$v_2 = (V_c + V_m \sin 2\pi f_m t) \sin 2\pi f_c t = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

Where v_2 is the instantaneous value of the AM wave (or v_{AM}), $V_c \sin 2\pi f_c t$ is the carrier waveform and $(V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$ is the carrier waveform multiplied by the modulating signal waveform.

It is the Second part of the expression that is characteristics of AM. A Circuit must be able to produce mathematical multiplication of the Carrier and modulating Signals in order for AM to occur. The AM wave is the product of the Carrier and modulating Signals.

Figure ③ Amplitude Modulator showing input and output Signals.



The Circuit used for producing AM is Called a modulator. Its two inputs, the Carrier and the modulating Signal, and the resulting outputs are shown in Fig ③. Amplitude Modulators Compute the Product of two analog Signals are also known as analog multipliers, mixers, Converters and product detectors (or) phase detectors. A Circuit that Changes a lower-frequency baseband (or) intelligence Signal to a higher-frequency Signal is usually Called a Modulator. A Circuit used to recover the original intelligence Signal from an AM wave is known as a detector (or) demodulator.

Modulation Index and Percentage of Modulation

For undistorted AM to occur, the modulating signal voltage V_m must be less than the carrier voltage V_c. Therefore, the relationship between the amplitude of the modulating signal and the amplitude of the carrier signal is important. This relationship, known as the modulation index m (also called the modulation factor or coefficient or the degree of modulation) is the ratio of

$$m = \frac{V_m}{V_c}$$

These are the peak values of the signals, and the carrier voltages in the unmodulated value.
Multiplying the modulation index by 100 gives the percentage of modulation.

Ex: $V_m = 7.5V$, $V_c = 9V$, $m = \frac{7.5}{9} = 0.833$

Percentage of modulation is $0.833 \times 100 = 83.33$.

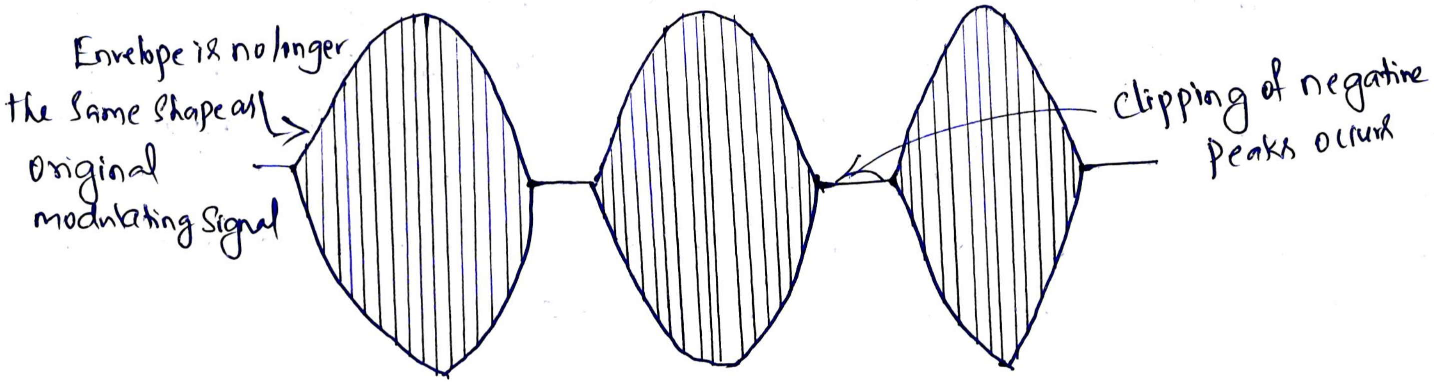
Overmodulation and Distortion

The modulation index should be a number between 0 and 1. If the amplitude of the modulating voltage is higher than the carrier voltage, m will be greater than 1, causing distortion of the modulated waveform.

Distortion of voice transmission produces garbled, harsh or unnatural sounds in the speaker.
Distortion of video signals produces a scrambled and inaccurate picture on a TV screen.

Simple distortion is illustrated in Fig ④. Here a sinewave information signal is modulating a sinewave carrier, but the modulating voltage is much greater than the carrier voltage, resulting in a condition called overmodulation.

Figure (4) Distortion of the envelope Caused by overmodulation where the modulating signal amplitude V_m is greater than carrier signal V_c.



As you can see, the waveform is flattened at the zero line. The received signal will produce an output waveform in the shape of the envelope. If the amplitude of the modulating signal is less than the carrier amplitude, no distortion will occur. The ideal condition for AM is when $V_m = V_c$, or $m = 1$, which gives 100 percent modulation. This results in the greatest output power at the transmitter and the greatest output voltage at the receiver, with no distortion.

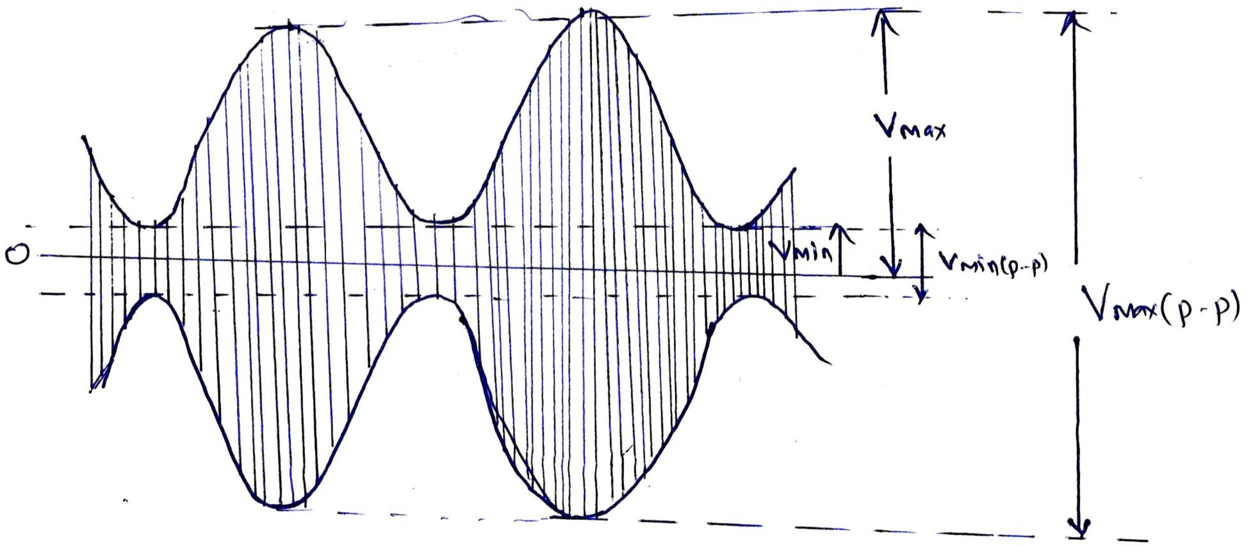
For example, during voice transmission voices will go from low amplitude to high amplitude. ~~This prevents~~ Normally, the amplitude of the modulating signal is adjusted so that only the voice peaks produce 100 percent modulation. This prevents overmodulation and distortion. Automatic circuits called compression circuits solve this problem by amplifying the lower level signals and supressing or compressing the higher level signals. The result is a higher average power output level without overmodulation.

Distortion caused by overmodulation also produces adjacent channel interference. Distortion produces a non sinusoidal information signal. According to fourier theory, any non sinusoidal signal can be treated as fundamental signal + harmonics. These harmonics also modulate the carrier can cause interference with other signals on channels adjacent to the carrier.

Percentage of Modulation:

The modulation index can be determined by measuring the actual values of the modulation voltage and the carrier voltage and computing the ratio.

Figure (5) An AM wave showing peaks (V_{max}) and troughs (V_{min})



When the AM signal is displayed on an oscilloscope, the modulation index can be computed from V_{max} and V_{min} as shown in Figure (5).

$$V_m = \frac{V_{max} - V_{min}}{2}$$

The peak value of the carrier signal V_c is the average of the V_{max} and V_{min} values:

$$V_c = \frac{V_{max} + V_{min}}{2}$$

The modulation index is

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

Example (1)

Suppose that on an AM Signal, the $V_{max(p-p)}$ value read from the graticule on the oscilloscope Screen is 5.9 divisions and $V_{min(p-p)}$ is 1.2 divisions.

(a) What is the modulation index ?

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{5.9 - 1.2}{5.9 + 1.2} = \frac{4.7}{7.1} = 0.662$$

(b) Calculate V_c, V_m and m if the Vertical Scale is 2V per division.

$$V_c = \frac{V_{max} + V_{min}}{2} = \frac{5.9 + 1.2}{2} = \frac{7.1}{2} = 3.55 \text{ @ } 2V/div$$

$$V_c = 3.55 \times 2V = 7.1V$$

$$V_m = \frac{V_{max} - V_{min}}{2} = \frac{5.9 - 1.2}{2} = \frac{4.7}{2} = 2.35 \text{ @ } 2V/div$$

$$V_m = 2.35 \times 2V = 4.7V$$

$$m = \frac{V_m}{V_c} = \frac{4.7}{7.1} = 0.662$$

Sidebands and the Frequency Domain

Whenever a carrier is modulated by an information Signal, new signals at different frequencies are generated as a part of the process. These new frequencies, which are called Side frequencies or Sidebands, occur in the frequency Spectrum directly above and below the Carrier frequency. More Specifically, the Sidebands occur at frequencies that are Sum and difference of the Carrier and modulating frequencies.

Side band Calculations

When only a Single-frequency Sine wave modulating signal is used, the modulation process generates two sidebands. If the modulating signal is a complex wave, such as voice or video, a whole range of frequencies modulate the carrier, and thus a whole range of sidebands are generated.

The upper sideband f_{USB} and lower sideband f_{LSB} are computed as

$$f_{USB} = f_c + f_m \quad \text{and} \quad f_{LSB} = f_c - f_m$$

Where f_c is the carrier frequency and f_m is the modulating frequency.

The Existence of Sidebands can be demonstrated mathematically, starting with the equation for an AM signal,

$$v_{AM} = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

By using Trigonometric identity,

$$\sin A \sin B = \frac{\cos(A-B)}{2} - \frac{\cos(A+B)}{2}$$

By Substituting in the above equation,

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2} \cos 2\pi t (f_c + f_m)$$

Where the first term is the carrier, second term containing the difference $f_c - f_m$ is the lower sideband and third term, containing the sum $f_c + f_m$ is the upper sideband.

For Example: Assume a 400-Hz tone modulates a 300-kHz carrier. The upper and lower sidebands are

$f_{USB} = 300,000 + 400 = 300,400\ Hz$ (or) $300.4\ KHz$

$f_{LSB} = 300,000 - 400 = 299,600\ Hz$ (or) $299.6\ KHz$

Frequency-Domain Representation of AM

Figure (7) shows the frequency-domain representation of AM signal. Here the horizontal axis represents frequency and the vertical axis represents the amplitudes of the signal.

A plot of signal amplitude versus frequency is referred to as a frequency-domain display. Spectrum Analyzer is used to display the frequency domain of a signal.

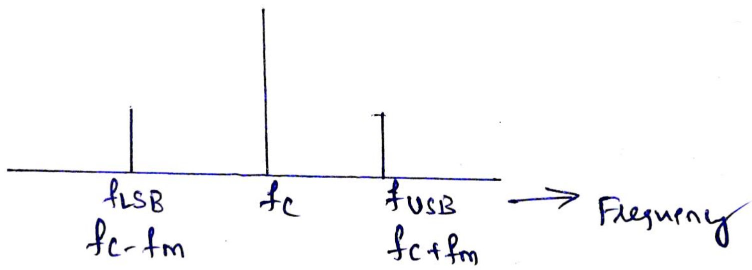


Figure (7): A Frequency domain display of an AM Signal

Whenever the modulating signal is more complex than a single sine wave tone, multiple upper and lower sidebands are produced by the AM process.

For Example, a voice signal consists of many sine wave components of different frequencies mixed together.

Voice frequencies occur in 300 - 3000 Hz range. (3KHz)
If the carrier frequency is 2.8 MHz (2800 KHz), then maximum and minimum sideband frequencies are

$f_{USB} = 2800 + 3 = 2803\ KHz$ & $f_{LSB} = 2800 - 3 = 2797\ KHz$.

Figure (9) illustrates the upper and lower sidebands of a voice modulated AM signal.

The total bandwidth is simply the difference between the upper and lower sideband frequencies.

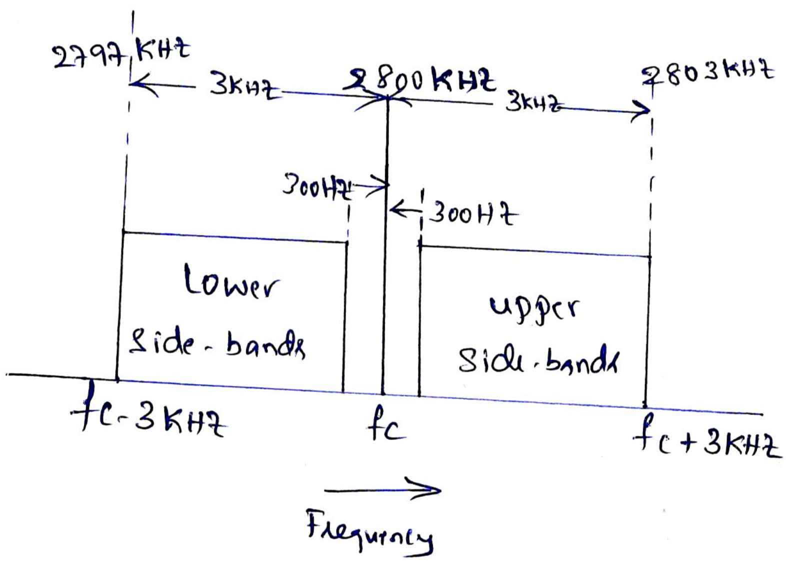
$$BW = f_{USB} - f_{LSB} = 2803 - 2797 = 6\,KHz$$

As we know, the bandwidth of an AM signal is twice the highest frequency in the modulating signal. $BW = 2f_m$, where f_m is the maximum modulating frequency.

In the case of a voice signal whose max freq is 3 KHz, the total bandwidth is simply

$$BW = 2(3\,KHz) = 6\,KHz.$$

Figure (9) The upper and lower sidebands of a voice modulator AM signal.



Example 2:

A standard AM broadcast station is allowed to transmit modulating frequencies upto 5 KHz. If the AM station is transmitting on a frequency of 980 KHz, compute the maximum and minimum upper and lower sidebands and the total bandwidth occupied by the AM station.

$f_{USB} = 980 + 5 = 985\,KHz$ $\quad$ $f_{LSB} = 980 - 5 = 975\,KHz$

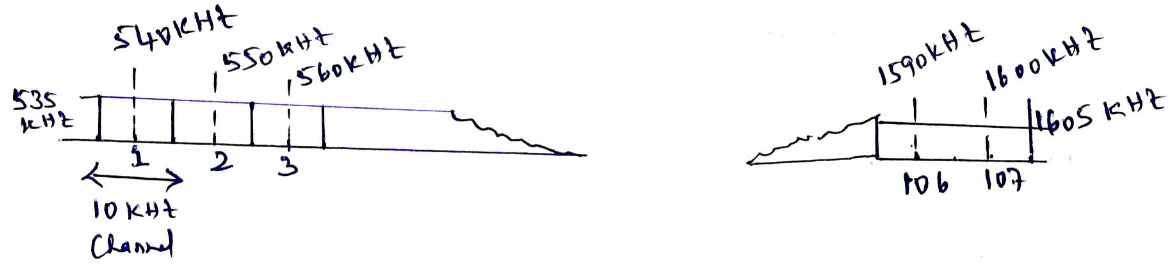
$BW = f_{USB} - f_{LSB} = 985 - 975 = 10\,KHz$ (or)

$BW = 2(5\,KHz) = 10\,KHz.$

An AM broadcast station has a total bandwidth of 10 KHz. In addition, AM broadcast stations are spaced every 10 KHz across the spectrum from 540 to 1600 KHz.

The sidebands from 535 KHz to 545 KHz forming a 10-KHz channel for the signal. The highest is 1595 KHz to 1605 KHz. There are a total of 107 10 KHz wide channels for AM radio stations.

Figure (10) Frequency Spectrum of AM broadcast band.



Pulse Modulation

When complex signals such as pulses or rectangular waves modulate a carrier, a broad spectrum of sidebands are produced. According to Fourier theory, complex signals are made up of a fundamental sine wave and numerous harmonic signals at different amplitudes.

Assume that a carrier is amplitude-modulated by a square wave that is made up of a fundamental sine wave and all odd harmonics as shown in Figure (11). As can be seen, pulses generate extremely wide-bandwidth signals.

Figure (12) shows the AM wave resulting when a square wave modulates a sine wave carrier. In (a) the percentage of modulation is 50 & in (b) it is 100.

Figure (11) Frequency Spectrum of an AM Signal modulated by a Square wave.

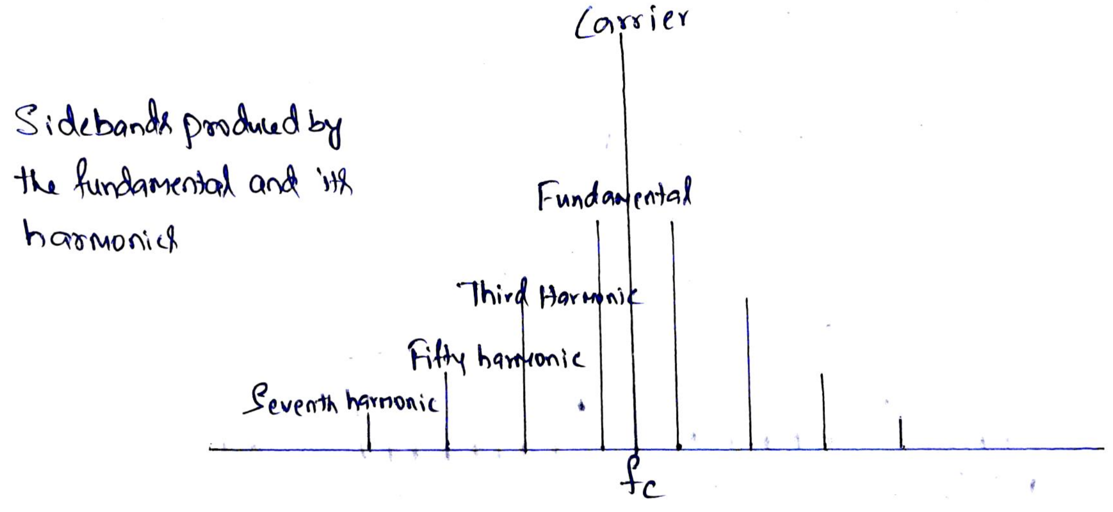
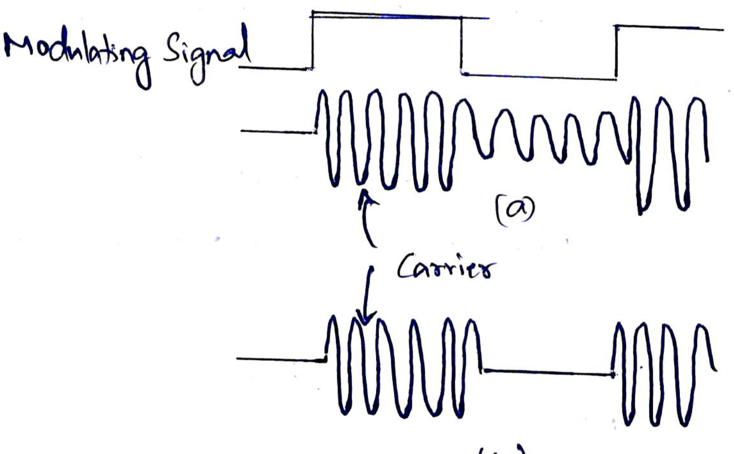


Figure (12) Amplitude modulation of a Sine wave Carrier by a pulse or rectangular wave is called amplitude-shift Keying. (a) Fifty percent modulation
(b) one hundred percent Modulation.

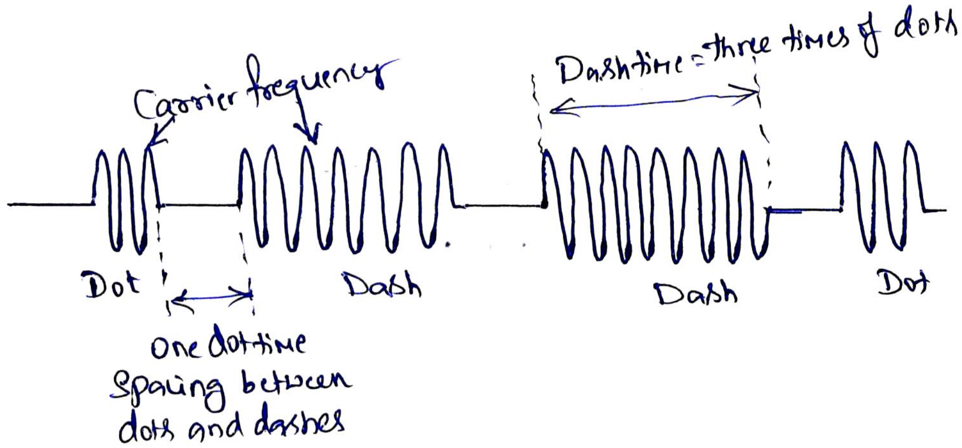


As in Fig (12) b, when the Square wave goes negative, it drives the carrier amplitude to zero. which is referred to as amplitude Shift Keying (ASK).

An example is the transmitting of Morse Code by using dots and dashes. A dot is a Short burst of Carrier and a dash is a longer burst of Carrier. Figure (13) Shows the transmission of the letter P.

The time duration of a dash is three times the length of a dot and the spacing between dots and dashes is one dot time. Code transmissions such as this are usually called continuous-wave (CW) transmissions or ON/OFF Keying (OOK).

Figure (13) Sending the letter P by Morse code. An example of ON/OFF Keying.



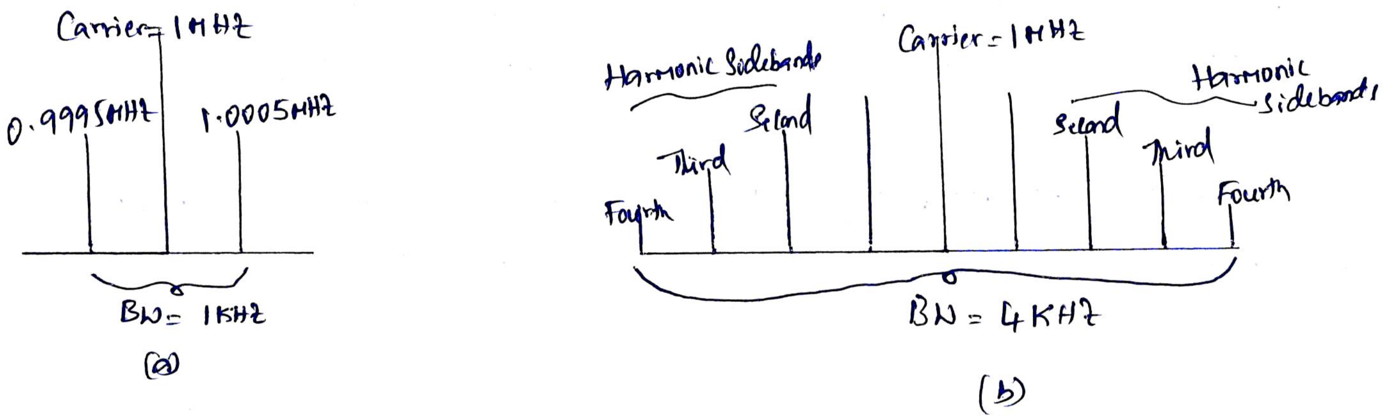
For example, the spectrum produced by a 500-Hz sine wave modulating a carrier of 1 MHz is shown in Fig (14)-a. The total bandwidth of the signal is 1 KHz. However, if the modulating signal is distorted, the second, the third, fourth and higher harmonics are generated. These harmonics also modulate the carrier, producing many more sidebands as illustrated in Fig (14)-b. Assume harmonic amplitudes beyond fourth are insignificant, then the total bandwidth is about 4 KHz instead of the 1KHz.

Such harmonic sideband interference is sometimes called splatter. Overmodulation and splatters are eliminated by gain control or amplitude limiting or compression circuits.

Fig (14) The effect of overmodulation and distortion on AM signal bandwidth.

(a) Sine wave of 500Hz modulating a 1 MHz carrier

(b) Distorted 500-Hz sine wave with significant second, third & fourth harmonics.



1.4. AM Power:

In radio transmission, the AM signal is amplied by a power amplifier & fed to the antenna with a characteristic impedance that is ideally, but not necessarily, almost pure resistance

The AM signal is really a composite of several signal voltages, namely the carrier & the 2 sidebands & each of these signals produces power in the antenna.

The total transmitted power P_T is simply the sum of the carrier power P_C & the power in the 2 sidebands P_{USB} & P_{LSB}.

$$P_T = P_C + P_{LSB} + P_{USB}$$

The Amplitude modulated signal is written as

$$v_{am} = \underbrace{V_C \sin 2\pi f_c t}_{\text{unmodulated carrier}} + \underbrace{\frac{V_M}{2}\cos 2\pi t(f_c - f_m)}_{\text{Lower side band}} - \underbrace{\frac{V_M}{2}\cos 2\pi t(f_c + f_m)}_{\text{upper side band}}$$

V_C & V_M are the peak values of the carrier & the modulating sine wave respectively.

For power calculations, rms values must be used for the voltages

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}} \quad \text{or} \quad V_{rms} = V_{peak} \times 0.707$$

$$v_{am} = \frac{V_C}{\sqrt{2}} \sin 2\pi f_c t + (V_M/2\sqrt{2}) \cos 2\pi t(f_c - f_m) - \frac{V_M}{2\sqrt{2}} \cos 2\pi t(f_c + f_m)$$

$$\text{Power } (P) = \frac{V^2}{R}$$

where P = o/p power
V = rms o/p voltage.
R = Resistance / load impedance [Antenna]

$$P_T = \frac{(V_C/\sqrt{2})^2}{R} + \frac{(V_M/2\sqrt{2})^2}{R} + \frac{(V_M/2\sqrt{2})^2}{R}$$

$$\boxed{P_T = \frac{V_C^2}{2R} + \frac{V_M^2}{8R} + \frac{V_M^2}{8R}}$$

$$V_M = m V_C$$

$$P_T = \frac{V_C^2}{2R} + \frac{(mV_C)^2}{8R} + \frac{(mV_C)^2}{8R} = \frac{V_C^2}{2R}\left(1 + \frac{m^2}{4} + \frac{m^2}{4}\right) = P_C\left(1 + \frac{m^2}{2}\right)$$

$$\boxed{P_T = P_C\left[1 + m^2/2\right]}$$

Find the total power of AM, if the carrier of an AM transmitter, 1000W & it is modulated 100 percent (m=1).

$$P_T = P_c\left(1+\frac{m^2}{2}\right)$$

$$P_T = 1000\left(1+\frac{1}{2}\right)$$

$$= 1000\times 3/2$$

$$\boxed{P_T = 1500W}$$

Note: For a 100% modulated AM transmitter, the total side band power is always ½ of the carrier power.

Ex: A 50 kW transmitter carrier with 100% modulation, then the side bands power is ½ of the P_c = ½ × 50kW = 25kW.

Each sideband will have 12.5kW of power.

So, the Total power would be $P_T = P_c + P_{USB} + P_{LSB}$

$= 50kW + 12.5kW + 12.5kW$

$$\boxed{P_T = 75kW}$$

Problem:

An AM transmitter has a P_c of 30W. The percentage of modulation is 85%. Calculate the (a) total power (b) The power in one side band

Soln: $P_c = 30W$, $m = 0.85$

$$P_T = P_c\left(1+\frac{m^2}{2}\right) = 30\left(1+\frac{0.85^2}{2}\right) = 40.8W.$$

$$P_{SB} = P_T - P_c$$

$$= 40.8W - 30$$

$$P_{SB} = 10.8W.$$

$$P_{USB} = P_{LSB} = \frac{P_{SB}}{2} = \frac{10.8}{2} = 5.4W.$$

NOTE! - In the real world, it is difficult to determine AM power by measuring the output voltage & calculating the power with the expression $P = V^2/R$. However, it is easy to measure the current in the load [Antenna]

∴ The o/p power is easily calculated using $P_T = I_T^2 R$ $\boxed{P = I^2 R}$

$$P_T = P_c\left(1+\frac{m^2}{2}\right)$$

$$I_T^2 R = I_c^2 R\left(1+\frac{m^2}{2}\right)$$

$$\boxed{I_T = I_c\sqrt{\left(1+\frac{m^2}{2}\right)}}$$

where I_c is the unmodulated carrier current in the load.

m = modulation index.

$$\left(1+\frac{m^2}{2}\right) = \frac{I_T^2}{I_c^2}$$

$$\frac{m^2}{2} = \frac{I_T^2}{I_c^2} - 1$$

$$m^2 = 2\left(\frac{I_T}{I_c}\right)^2 - 1$$

$$\boxed{m = \sqrt{2\left(\frac{I_T}{I_c}\right)^2 - 1.}}$$

Problem :- Find the total power required for the AM wave ~~for~~ which has 85% modulat~~ed~~. ~~index~~ AM transmitter, whose unmodulated carrier current is fed into a 50 Ω antenna load impedance is 10 A.

$m = 85\% = 0.85$

$R = 50\,\Omega$

$I_c = 10$ A.

$$I_T = I_c\sqrt{1+\frac{m^2}{2}}$$

$$= 10\sqrt{1+\frac{0.85^2}{2}}$$

$$I_T = 11.67\text{ A}$$

$$P_T = I_T^2 R = (11.67)^2 \times 50. = 6809\text{ W}.$$

$$\boxed{P_T = 6809\text{ W}}$$

Problem :- Find the modulation index if the unmodulated carrier is 2.2 A & the modulated antenna current is 2.6 A.

$$m = \sqrt{2\left(\frac{I_T}{I_c}\right)^2 - 1}$$

$I_T = 2.6$ A

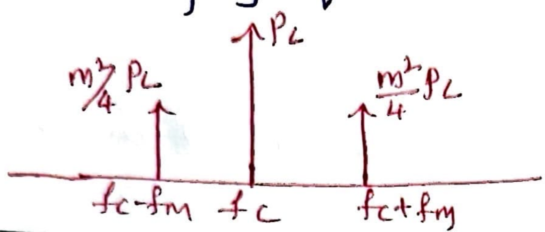
$I_c = 2.2$ A

$$m = \sqrt{2\left(\frac{2.6}{2.2}\right)^2 - 1} = 0.89$$

$m = 0.89 = 89\%.$

Power in each of the sideband $P_{SB} = P_{LSB} = P_{USB} = \frac{P_c m^2}{4}$

Time domain display of an AM wave (power) is as follows



Problem :-

An antenna has an impedance of 40Ω. An unmodulated AM sld produces a current of 4.8A. The modulation is 90%. Calculate (a) The carrier power (b) The total power (c) Side band power

Solⁿ: (a) $P_C = I^2 R = (4.8)^2 \times 40 = 921.6\,W$

(b) $I_T = I_C \sqrt{1 + \frac{m^2}{2}} = 4.8 \sqrt{1 + \frac{0.9^2}{2}} = 4.8 \sqrt{1 + \frac{0.81}{2}}$

$I_T = 4.8 \sqrt{1.405} = 5.7A$

$P_T = I_T^2 R = (5.7)^2 \times 40 = 1295A.$

(c) $P_{SB} = P_T - P_C = 1295 - 921.6 = 373.4W.$

$P_{USB} = P_{LSB} = \frac{P_{SB}}{2} = \frac{373.4}{2} = 186.7$ each sideband.

Problem :- The Transmitter experiences an antenna current change from 4.8A unmodulated to 5.1A what is the percentage of modulation?

Solⁿ: $m = \sqrt{2\left(\frac{I_T}{I_C}\right)^2 - 1} = \sqrt{2\left(\frac{5.1}{4.8}\right)^2 - 1}$

$m = 0.51$

$m = 51\%.$

NOTE : AM is still widely used because it is simple & effective. It is used in AM radio broadcasting, CB radio, TV broadcasting & aircraft tower communication

Eg:- Garage door openers & remote keyless entry devices on cars.

It is widely used in combination with phase modulation to produce QAM which facilitates high speed data transmissions in modems, cable TV & some wireless applⁿˢ

1.5 Single sideband modulation :-

In AM, 2-3rd of the transmitted power is in the power, which conveys no information.

The real information is contained within the sidebands.

To improve the efficiency of the amplitude modulation - is to suppress the carrier & eliminate one side band. The result is a single side band (SSB) signal.

Applns: Some types of electronic communication

Double Side band signals (DSB).

1. Suppress the carrier is the first step.
2. Consider both the side bands (USB & LSB)

} → DSB/DSSC.

Advantage :- No power is wasted on the carrier

DSSC is the algebraic sum of the 2 sinusoidal sidebands.

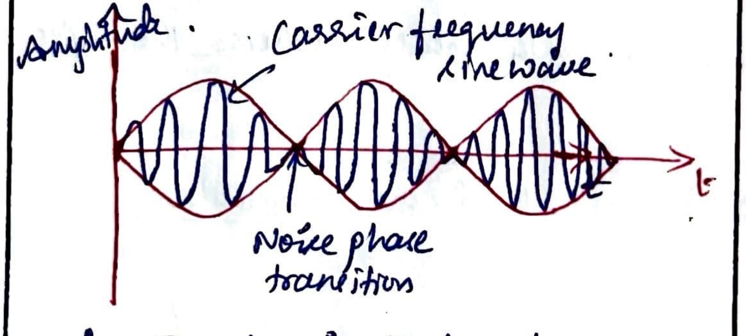


fig: Time domain display of a DSB AM signal.

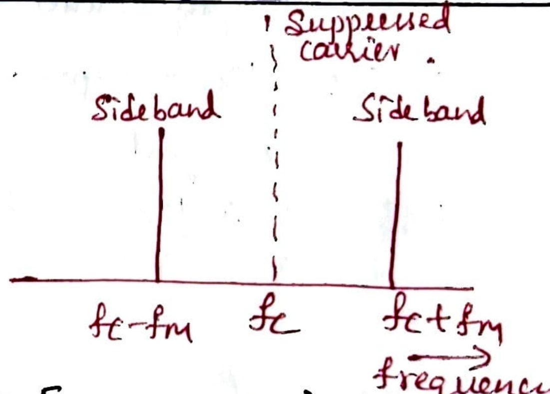


fig: Frequency domain display of DSB signal

* characteristics of a DSB signal is that the phase transitions occurs at the lower amplitude portions of the wave.
* There are 2 adjacent (-)ve going half cycles at the null points in the wave
* DSBSC. sigs are generated by a circuit called a balanced modulator.
* The purpose of the balance modulator is to produce the sum & difference frequencies but to cancel / balance out the carrier.
* Elimination of the carrier in DSBSC saves considerable energy.
* It is not widely used because the signal is difficult to demodulate ((recover) at the receiver.
* Appln: Transmission of the color information in a TV signal

Single side band signals (SSB).

The sidebands in the DSBSC are the sum & difference of the carrier & the modulating s/l. & information is present on both sidebands. As it turns out, there is no reason to transmit both sidebands in order to convey the information. So, one side band can be suppressed & the remaining sideband is called a single side band suppressed carrier s/l.

* Major benefits of SSB are

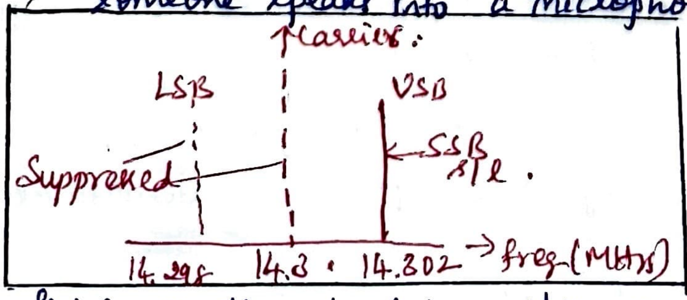
* The spectrum space of SSB occupies only ½ of that AM & DSB s/l. This conserves spectrum space & allows more s/ls to be transmitted in the same frequency band/range

* All the power can be channeled into the single side band producing a stronger signal that should carry farther & be more reliably received at greater distances
* SSB transmitter can be made smaller & lighter than an equivalent AM or DSB transmitter because less circuitry & power are used

* SSB s/ls occupy a narrower Bandwidth, which reduces the noise in the signal
* There is a less selective fading of an SSB s/l over long distance.
  All freq. comp. get affected equally
  multipath fading when the selected freq comp of the s/l is affected
  Fading: Significant variations in received s/l amp & phase over time/space

SSB s/l has some unusual characteristics

* when no information or modulating signal is present, no RF s/l is transmitted In standard AM transmitter the carrier is still transmitted even though it may not be ~~transm~~ modulated. This is the condition that might occur during a voice pause on an AM broadcast.
  Sidebands are generated only during the modulation process. e.g. when someone speaks into a microphone



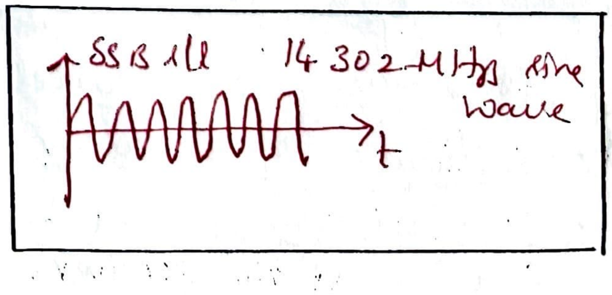


fig: An SSB s/l produced by a 2KHz sine wave modulating a 14.3 MHz sine wave carrier

Disadvantages of DSB & SSB

DSB & SSB s/ls are harder to recover or demodulate at the receiver.
Demodulation depends upon the carrier being present.
If the carrier is not present, then it must be regenerated at the receiver & reinserted into the s/l.
To faithfully recover the intelligence s/l, the reinserted carrier must have the same phase & frequency as those of the original carrier. This is ~~the~~ a difficult requirement when SSB is used for voice transmission, the reinserted carrier must have the same phase & frequency as those of the original carrier. This is a difficult requirement.
When SSB is used for voice transmission, the reinserted carrier can be made variable in frequency ~~so that it can be made variable in frequency~~ so that it can be adjusted manually while listening to recover an intelligible signal. This is not possible with some kind of data s/ls.
To solve this problem, a low-level carrier s/l is sometimes transmitted along with the 2 sidebands in DSB / a single sideband (SSB) because the carrier has a low power level, the essential benefits of SSB are retained but, a weak carrier is received, so that it can be amplified & reinserted to recover the original information. Such a low-level carrier is called as a pilot signal/carrier.
This technique is used in FM stereo transmissions as well as in the transmission of the color information in a TV picture.

Signal power considerations: -

An SSB transmitter sends no carrier, so, the carrier power is zero.
& o/p is expressed in terms of peak envelope power (PEP), the max power produced on voice amplitude peaks.

$$\boxed{PEP = V^2/R} = \frac{V_{rms}}{\sqrt{2}R}.$$

$$\boxed{PEP = V_s I_{max}}$$ - where V_s = Amplitude supply voltage
I_{max} = current peak.

$$\boxed{P_{avg} = \frac{PEP}{3} \text{ or } P_{avg} = \frac{PEP}{4}}$$

Min value   Max value

4

Problem: - An SSB transmitter produces a peak to peak voltage of 178 V across a 75 Ω antenna load. What is the PEP.

Solⁿ:

$$V_p = \frac{V_{p-p}}{2} = \frac{178}{2} = 89V.$$

$$V_{rms} = \frac{V_p}{\sqrt{2}} = \frac{89}{\sqrt{2}} = 62.9V.$$

$$Power = \frac{V^2}{R} = \frac{62.9^2}{75} = 52.8W.$$

PEP = 52.8W

Problem: - An SSB transmitter has a 24 V DC power supply. On voice peaks the current achieves a max of 9.3A. find the PEP & what is the average power of the transmitter.

Solⁿ:

$$PEP = V_s I_m = 24 \times 9.3 = 223.2 W.$$

Average power of the transmitter $P_{avg} = \frac{PEP}{3} = \frac{223.2}{3} = 74.4W$

$$P_{avg} = \frac{PEP}{4} = \frac{223.2}{4} = 55.8W$$

P_{avg} = 55.8 to 74.4W.

Amplitude modulators :-

AM are generally one of 2 types.

* Low level modulators
* High level modulators.

Low level modulators generate AM with small signals & must be amplified considerably, if they are to be transmitted

High level modulators produce AM at high power levels, usually in the final amplifier stage of a transmitter.

Low level AM :-

Diode modulator :- It is the one of the simplest amplitude modulators.

* It consists of a resistive mixing network, a diode rectifier & an LC tuned circuit.
* The carrier is applied to one i/p resistor & the modulating signal to the other.
* The mixed s/l appear across R_3.
* This network causes 2 s/ls to be linearly mixed.
* If both carrier & modulating signals are sinewaves, the waveform resulting at the junction of the 2 resistors is shown in fig(c). where carrier is riding the modulating signal. This signal is not AM. modulation is a multiplication process not an addition process.
* The composite waveform is applied to a diode rectifier. The diode is connected that it is forwarded biased by the positive going half cycles of the i/p wave
* During the (-)ve portions of the wave, the diode is cutoff & no signal passes. The current through the diode is a series of positive going pulse whose amplitude varies in proportion to the amplitude of the modulating s/l.

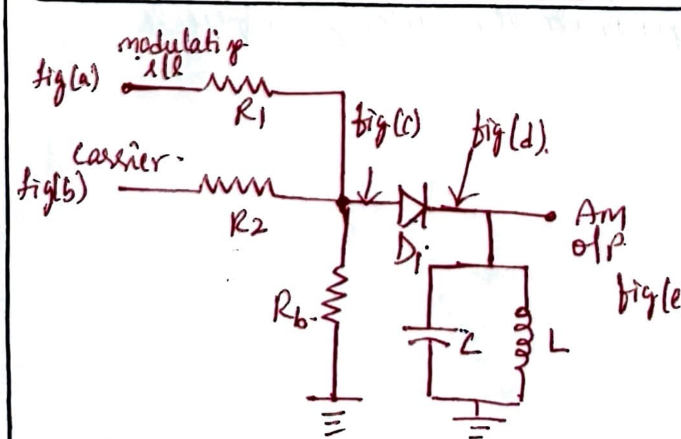


fig: Amplitude modulation with a diode

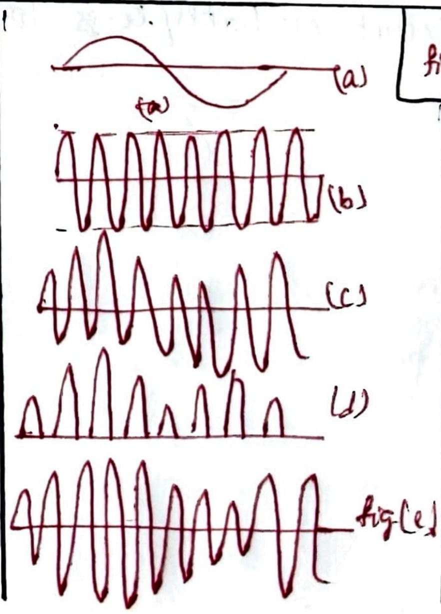


fig: waveforms in the diode modulator
(a) modulating s/l
(b) carrier s/l
(c) linearly mixed modulating s/l & carrier
(d) positive going s/l after diode D_1
(e) AM o/p s/l

The positive going pulses are applied to the parallel tuned circuit made of L & C. which are resonant at the fc

Each time the diode conducts, a pulse of current flows through the tuned cu

* The coil & capacitor repeatedly exchange energy, causing an oscillation / ringing at the resonant frequency.
* The Q of the tuned circuit should be high enough to eliminate the harmon & produce a clean sine wave & to filter out the modulating sig. & low enough that its Bandwidth accommodates the sidebands generated. This sig produces high quality AM.
* The Amplitude of the sigs are critical to proper operation because the nonlinear portion of the diode's characteristic curve occurs only at low level voltage levels signal levels must be low, less than a volt to produce AM.
* At higher voltages, the diode current response is nearly linear.
* The circuit works best with millivolt - level signals

Transistor modulator:

This modulator uses transistors & has gain. The Emitter base junction is a diode & a non-linear device. modulation occurs except that the base current controls a larger collector current. & ∴ the circuit amplifies. Rectification occurs because of the emitter base junction. This causes larger half-sine pulses of current in the tuned circuit.

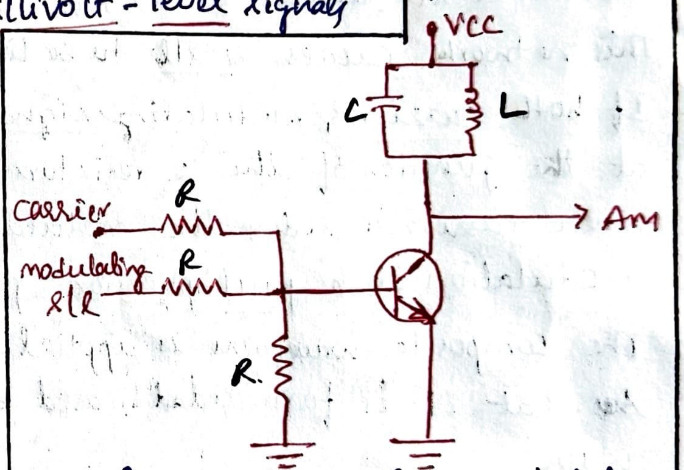


fig: Simple transistor modulator

The tuned circuit oscillates / rings to generate the missing half cycle.

Differential Amplifier:-

A differential amplifier modulator makes an excellent amplitude modulator. A typical circuit is shown in fig (a). Transistors Q_1 & Q_2 form the differential pair. & Q_3 is a constant current source.

The transistor Q_3 supplies a fixed emitter current I_E to Q_1 & Q_2, one half of which flows in each transistor. The o/p is developed across the collector resistors R_1 & R_2.

The o/p is a function of the difference b/n i/p V_1 & V_2.

$V_{out} = A(V_2 - V_1)$ where 'A' = circuit gain

The amplifier can also be operated with a single i/p. when it is done, the other i/p is grounded.

If $V_1 = 0$, $V_{out} = A(V_2)$.

If $V_2 = 0$, $V_{out} = -A(V_1)$

The o/p voltage can be taken b/n the 2 collectors, producing a balanced/differential output.

The o/p is also taken from the o/p of either collector to ground, producing a single ended o/p.

The 2 o/ps are 180° out of phase with each other.

If the balanced o/p is used, the o/p voltage across the load is twice the single ended o/p voltage.

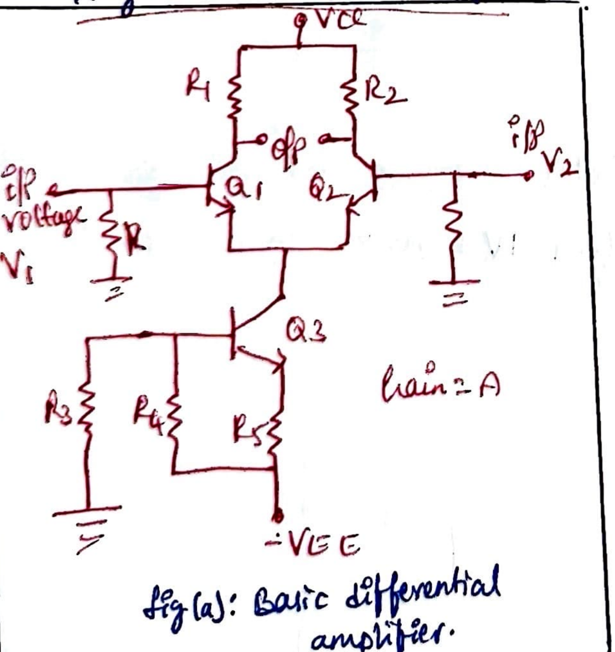


fig (a): Basic differential amplifier.

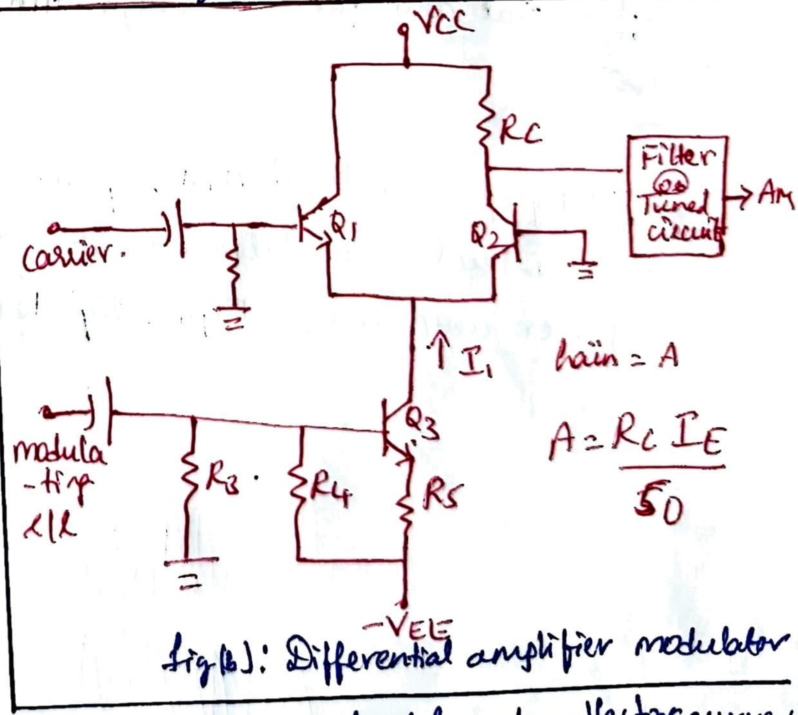


fig (b): Differential amplifier modulator

No special biasing circuits are needed, since the current value of collector current is supplied directly by the constant current source Q_3. in fig (a)

Resistors R_3, R_4 & R_5, along with with VEE, bias the constant current source Q_3

With no i/ps applied, the current in Q_1 equals the current in Q_2 which is $I_E/2$. The balanced o/p at this time is zero.

* The circuit formed by R_1 & Q_1 & R_2 & Q_2 is a bridge circuit
* when no i/ps are applied, $R_1 = R_2$ & Q_1 & Q_2 conducts equally.
∴ the bridge is balanced & the o/p b/n the collector is zero

If an o/p s/l V_1 is applied to Q_1, the conduction of Q_1 & Q_2 are affected. Increasing the voltage at the base of Q_1 increases the collector current in Q_1 & decreases the collector current in Q_2 by an equal amount. So, that the 2 currents sum to I_E.

Decreasing the i/p voltage on the base of Q_1 decreases the collector current in Q_1 & increases it in Q_2. The sum of the I_E is always equal to the current supplied by Q_1

The gain of a differential amplifier is a function of the emitter current & the value of the collector resistor.

$$A = R_C I_E / 50$$

Differential amplifier has a high gain & good linearity & it can be modulated 100%.

Amplifying low-level AM signals:-

In low-level modulator circuits, the s/ls are generated at very low voltage & power amplitudes. Typically less than W & power in milli watts.

High level AM:-

In high level AM, the modulator varies the voltage & power in the final RF amplifier stage of the transmitter. The result is high efficiency in the RF amplifier & overall high quality performance

Collector modulator:-

The o/p stage of the transmitter is a high power class 'C' amplifier & it conducts for only a portion of the positive half cycle of their i/p signal.

The collector current pulses cause the tuned circuit to oscillate at the desired o/p frequency.

∴ The tuned circuit reproduces the (-)ve portion of the carrier signal.

The modulator is a linear power amplifier that takes the low-level modulating s/l. amplifies it to a high power level.

The modulating o/p s/l is coupled through modulation transformer T_1 to the class 'c' amplifier.

The secondary winding of the modulation transformer is connected in series with the collector supply voltage Vcc of the class 'C' amplifier.

With a zero modulation i/p signal, there is zero modulation voltage across the secondary of T_1, the collector supply voltage is applied directly to the class 'C' amplifier, & the o/p carrier is a steady sinewave.

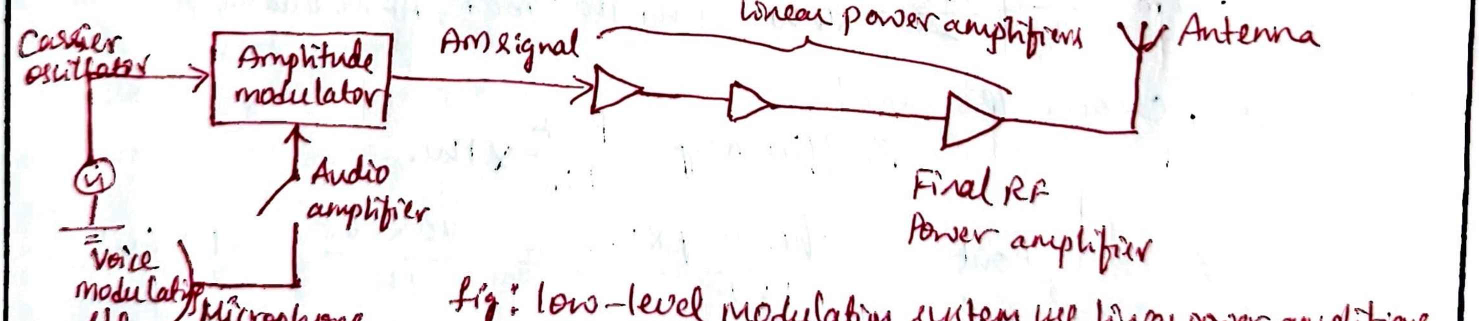


fig: low-level modulation system use linear power amplifiers to increase the AM s/l level before transmission

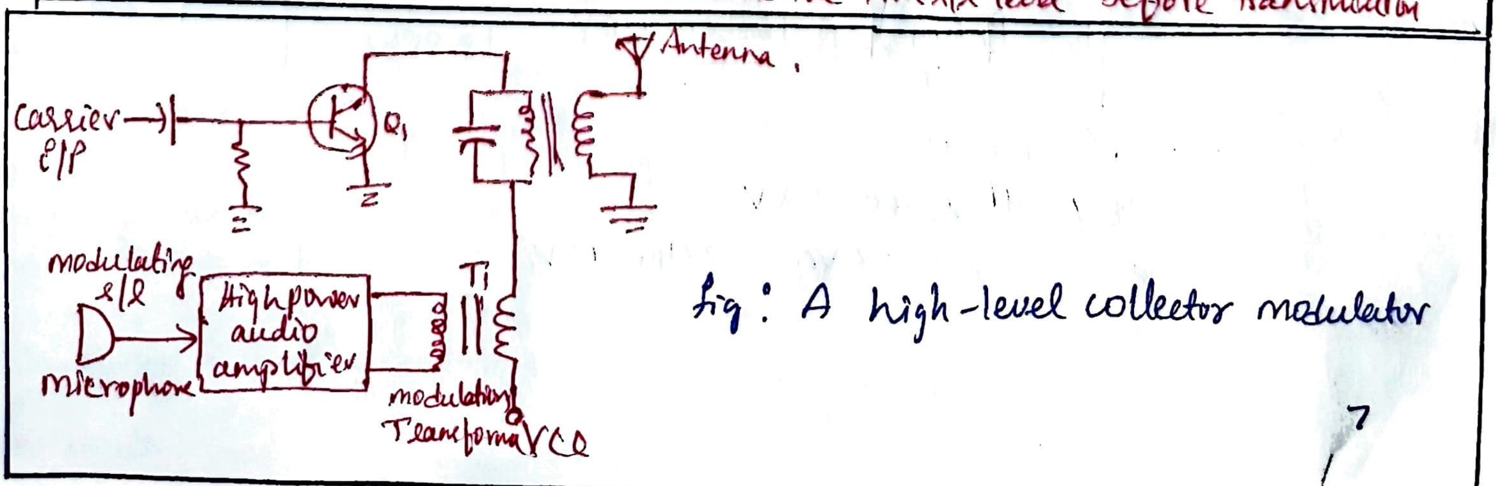


fig: A high-level collector modulator

when the modulating signal occurs, the AC voltage of the modulating across the secondary of the modulation transformer is added to & subtracted from the DC collector power supply.

This varying supply voltage is then applied to the class 'c' amplifier, causing the amplitude of the current pulses through the transistor Q_1 to vary

* when the modulation s/l goes positive, it adds to the collector supply voltage thereby increasing its value & causing higher current pulses & a higher amplitude carrier.
* when the modulation s/l goes negative, it subtracts from the collector supply voltage & decreasing its value. For this reason, class 'c' amplifier current pulses are smaller, resulting in a lower amplitude carrier o/p.

Problem :-

An AM transmitter use high level modulation of the final RF power amplifier which has a DC power supply voltage Vcc of 48V with a total current I of 3.5A. The efficiency is 70%. (a) what is the RF i/p power to the final stage
(b) How much Af power is required for 100% modulation
(c) what is the carrier o/p power
(d) what is the power in one sideband for 67% modulation.
(e) what is the max & min DC supply voltage swing with 100% mod^n

Sol^n: Given $V_{cc} = 48V$, $I = 3.5A$.

(a) DC i/p power $P_i = V_{cc} I = 48 \times 3.5 = 168W$.

(b). $P_m = \frac{P_i}{2} = \frac{168}{2} = 84W$. [for 100% mod^n, Af modulating power $P_m = \frac{1}{2} P_i$]

(c). Carrier o/p power

$$\% \text{ efficiency} = \frac{P_{out}}{P_{in}} \times 100.$$

$$P_{out} = \frac{\% \text{ efficiency} \times P_{in}}{100} = \frac{70 \times 168}{100} = 117.6W.$$

(d) Power in one sideband for 67% mod^n

$$P_s = \frac{P_c(m^2)}{4} = \frac{168 \times (0.67)^2}{4} = 18.85W$$

(e). min swing = 0

supply voltage $V_{cc} = 48V$.

Max swing $= 2 \times V_{cc} = 2 \times 48 = 96V$.

Amplitude Demodulators:

Demodulators / detectors are circuits that accept modulated signals & recover the original modulating information.

It is the key circuit in any radio receiver.

Diode detectors

The simplest & most widely used amplitude demodulator is the diode detector.

The AM signal is usually transformer coupled & applied to a basic half wave rectifier circuit consisting of D_1 & R_1.

The diode conducts when the (+)ve half cycles of the AM s/l occurs.

During the (-)ve half cycle, the diode is reverse biased & no current flow through it.

As a result, the voltage across R_1 is the series of (+)ve pulses, whose amplitude varies with the modulating s/l.

A capacitor C_1 is connected across the resistor R_1, effectively filtering out the carrier & thus recovering the original modulating signal.

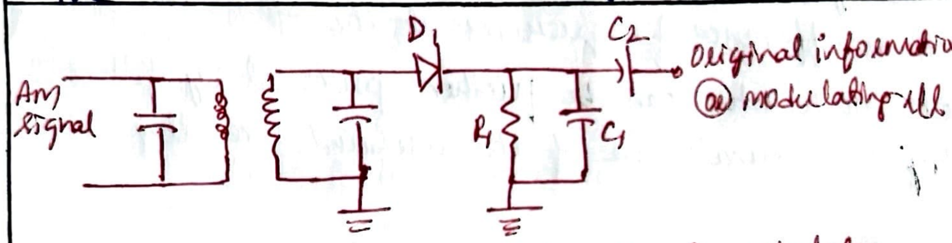


fig: A diode detector. AM demodulator.

The operation of a diode detector is analyzed in the time domain.

* On each (+)ve alternation of the AM s/l, the capacitor charges quickly to the peak value of the pulses passed by the diode.
* When the pulse voltage is zero, the capacitor discharges into resistor R_1
* The time constant of C_1 & R_1 is chosen to be long compared to the period of the carrier
* The capacitor discharge only slightly during the time that the diode is not conducting
* when the next pulse comes, the capacitor again charges to its peak value.
* when the diode cuts off, the capr again discharges a small amount of into the resistor
* The resulting waveform across the capacitor is a close approximation to the original modulating s/l

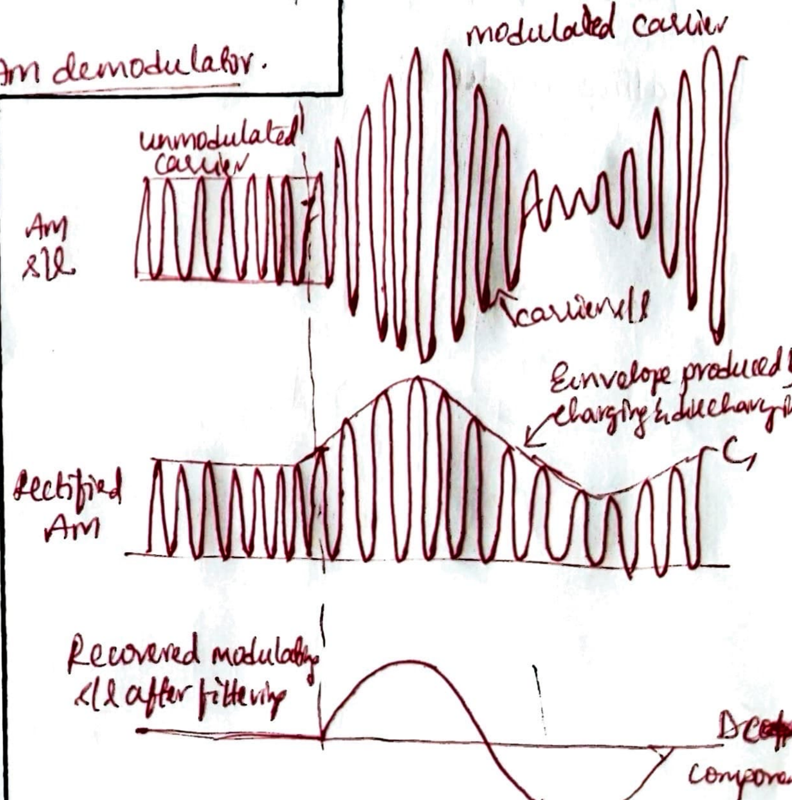


fig: Diode detector waveform.

The operation of the diode detector in frequency domain is as follows
Multiple signals are applied for the modulation.
Eg there are the carrier & sideband, which make up the i/p AM sig to be demodulated.
The components of the AM sig are the f_c, f_c+f_m, f_c-f_m.

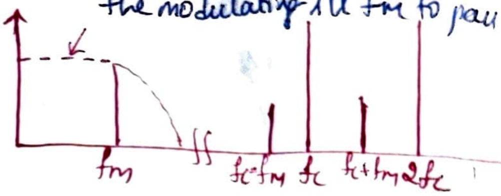


fig: o/p spectrum of a diode detector

The diode detector circuit combines these signals, creating the sum & difference sig

$f_c + (f_c+f_m) = 2f_c+f_m$
$f_c - (f_c+f_m) = -f_m$
$f_c + (f_c-f_m) = 2f_c - f_m$
$f_c - (f_c-f_m) = +f_m$

All these apper in the o/p
Since the f_c is very much high than f_m the carrier sig can be easily filtered out with a simple LPF

Balanced modulators:-

It is a circuit that generates a DSB signal, suppressing the carrier & leaving only the sum & difference frequencies at the o/p.
The o/p of a balanced modulator can be further processed by filters or phase-shifting circuitry to eliminate one of the sidebands resulting in an SSB sig.

Lattice modulators

Frequency division multiplexing

communication

In FDM, multiple s/ls share the bandwidth of a common communication channel. All channels have specific bandwidths & some are relatively wide. A co-axial cable, has B.W of about 1 GHz. The B.Ws of radio channels vary, & are usually determined by FCC regulations & the type of radio service involved.

Transmitter - multiplexers:

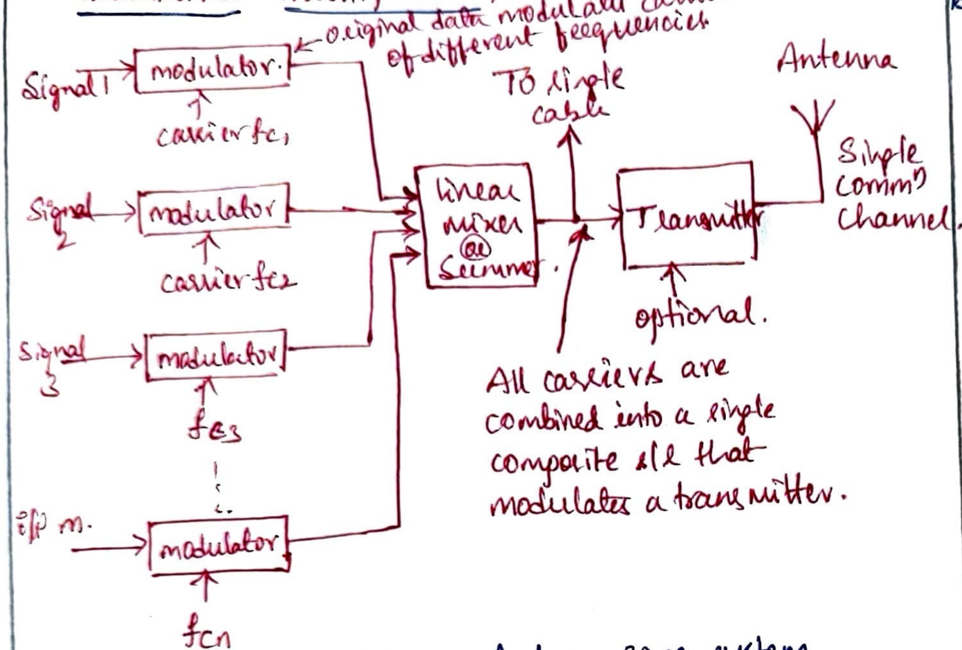


Fig: The transmitting end of an FDM system.

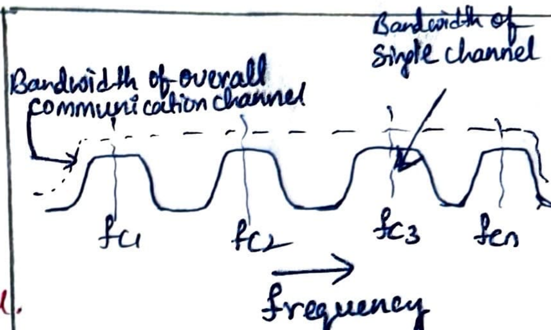


fig: Spectrum of an FDM s/l. The B.W of a single channel is divided into smaller channels

* Each s/l to be transmitted feeds a modulator circuit. The carrier for each modulator (fc) is on a different frequency.
* The carrier for each modulator (fc) is on a different frequency.
* The carrier ~~for each~~ frequencies are usually equally spaced from one another over a specific frequency range. These carriers are referred to as <u>subcarriers</u>
* Each i/p s/l is given a portion of the B.W.
* The FDM process divides up the bandwidth of the single channel into smaller, equally spaced channels, each capable of carrying information in sidebands

~~Receiver Demultiplexer~~:

* The modulator o/ps containing the sideband information are added algebraically in a linear mixer, no modulation / generation of sidebands takes place.
* The resulting o/p s/l is a composite of all the modulated subcarriers. This signal can be used to modulate a radio transmitter / can itself be transmitted over the single communication channel.