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AMPLITUDE MODULATION

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In order that a radio signal or "radio carrier" can carry information it must be changed or modulated so that the information can be conveyed from one place to another. There are a number of ways in which a carrier can be modulated; one of the commonly used is changing the amplitude. This is called Amplitude Modulation.

Amplitude Modulation was in use since 1901 when Reginald Fessenden transmitted a spark signal. Transmission was successful for few hundreds of meters; however the quality of audio was not so good. Thus latter continuous sine wave was generated and used. This improved the quality of signal. From then AM signals were widely used for voice transmission.

Amplitude Modulation Applications

Amplitude modulation is used in a variety of applications. Even though it is not as widely used as it was in previous years in its basic format it can nevertheless still be found.

- **Broadcast transmissions:** AM is still widely used for broadcasting on the long, medium and short wave bands. It is simple to demodulate and this means that radio receivers capable of demodulating amplitude modulation are cheap and simple to manufacture.
- **Air band radio:** Very high frequency transmissions for many airborne applications still use AM. It is used for ground to air radio communications as well as two way radio links for ground staff as well.
- **Single sideband:** Amplitude modulation in the form of single sideband is still used for High frequency radio links. Using a lower bandwidth and providing more effective use of the transmitted power this form of modulation is still used for many point to point HF links.
- **Quadrature amplitude modulation:** AM is widely used for the transmission of data in everything from short range wireless links such as Wi-Fi to cellular

telecommunications and much more. Effectively it is formed by having two carriers 90° out of phase.

Amplitude Modulation Basics

An AM signal can be generated by varying the amplitude of the signal in line with the variations in intensity of the sound wave. In this way the overall amplitude or envelope of the carrier is modulated to carry the audio signal. Thus the envelope of the carrier can be changed in line with the modulating signal.

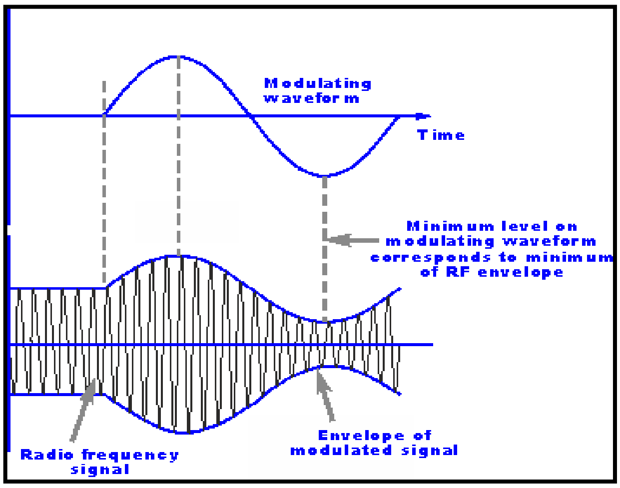

Fig: Amplitude Modulated wave

The major advantage of Amplitude Modulation is the easy to demodulate. The demodulation process of AM requires only a simple diode detector circuit. Here the diode is used to rectify the signal such that only one half of the radio signal is allowed to pass through it. The capacitor removes the RF part leaving only audio signal. This signal can be fed to the amplifier such that they can be amplified further. As a result the cost of AM receiver is very less. Modulating an AM signal can be achieved in a number of ways. Essentially the simplest is to pass the RF carrier and the modulating signal into a mixer. The resulting output will be the required amplitude modulated signal. Demodulation of AM can similarly be undertaken in a number of ways. The simplest is the simple diode detector.

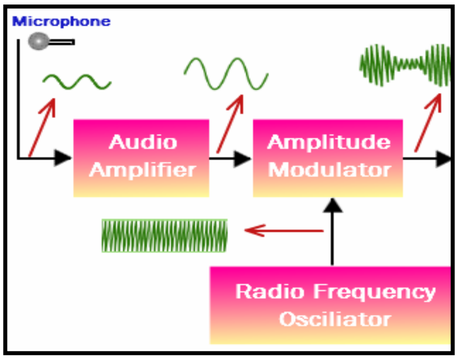

Fig: AM modulation block diagram

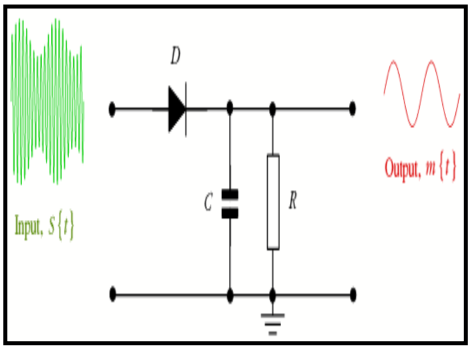

Fig: AM demodulation block diagram

Equations involved in Amplitude Modulation

Basically AM has 2 input signals; one is the high frequency carrier signal usually in the range of RF spectrum and the other is the modulating signal or the information signal, which is low frequency signal. The output modulated signal will be the product of these two signals.

Carrier signal equation: This signal can be any sinusoidal wave with RF frequency. This can be represented by the equation below:

$$\boxed{C(t) = C \sin(\omega c + \phi)}$$

Where:

$\omega c/2\pi$ is the carrier frequency in Hz.

C is the amplitude of carrier signal.

ϕ is the phase of the signal at the start of reference time.

Modulating signal equation: This signal is a single tone continuous sine or cosine wave. This can be represented by the equation below:

$$\boxed{m(t) = M \sin(\omega m + \phi)}$$

Where:

$\omega m/2\pi$ is the modulating frequency in Hz, here $\omega m < \omega c$

C is the amplitude of modulating signal.

ϕ is the phase of the signal at the start of reference time.

Modulated signal equation: As the modulated signal is the product of carrier and modulating signal thus it can be represented as shown below:

$$\boxed{y(t) = [A + m(t)].\, c(t)}$$

Where:

y (t) is the modulated wave.

A is the amplitude of the modulated wave.

Substituting the equation of m (t) and c (t) in y (t), we get

$$\boxed{y(t) = [A + M\cos(\omega m\, t + \phi\,].\, \sin(\omega c\, t)}$$

Solving the above equation using trigonometric identities, we get

$$\boxed{y(t) = A.\sin(\omega c\, t) + M/2\,[\,\sin((\omega c + \omega m)\, t + \phi) + M/2\,[\,\sin((\omega c - \omega m)\, t - \phi)}$$

Where:

Carrier signal is represented by **(A. sin (ωc t))**

Upper sideband is represented by **M/2 [sin ((ωc + ωm) t + ϕ).**

Lower sideband is represented by **M/2 [sin ((ωc - ωm) t - ϕ).**

The sidebands are separated from the carrier by a frequency equal to that of the tone.

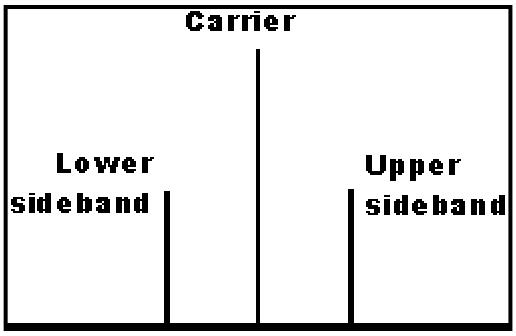

Fig: Sidebands on an amplitude modulated carrier

when modulated with a single tone

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Amplitude Modulation Spectrum and Bandwidth

The amplitude modulation spectrum usage and bandwidth are critical for most applications. The bandwidth that an amplitude modulated space occupies determines the number of transmissions that can be accommodated within a certain band, and also the levels of interference caused to other users. With pressure on the radio spectrum increasing, and the number users increasing in many areas, the bandwidth of an amplitude modulated signal is important.

The amplitude modulated signal consists of a carrier with two sidebands that extend out from the main carrier. This results from the modulation process. It is found that if the carrier is modulated with a 1 kHz tone, for example, two sidebands each 1 kHz away from the carrier will appear. A 5 kHz tone would produce sidebands 5 kHz away from the carrier. The sidebands produced by the modulation of a carrier by a typical audio signal will extend out from the carrier as shown in figure below; the highest audio frequencies in the audio bandwidth will be furthest away from the carrier. Thus the bandwidth of the signal can be seen to be twice that of the highest audio transmitted:

Signal bandwidth B = 2. Audio bandwidth

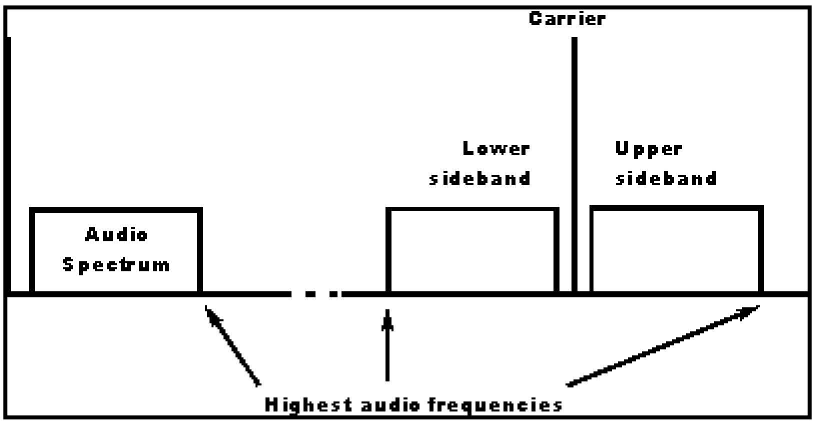

Fig: Effect of audio bandwidth on overall amplitude modulation signal bandwidth.

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To ensure that an amplitude modulated signal does not create spurious emissions outside the normal bandwidth it is necessary to ensure that the signal does not become overmodulated; this is a conditions that occurs when the modulation exceeds 100%. At this point the carrier breaks up and intermodulation distortion occurs leading to large levels of unwanted noise spreading out either side of the carrier and beyond the normal bandwidth. This can cause interference to other users. If over-modulation occurs, the carrier becomes phase inverted and this leads to sidebands spreading out either side of the carrier.

Modulation Index

The amplitude modulation, AM, modulation index can be defined as the measure of extent of amplitude variation about an un-modulated carrier. As with other modulation indices, the modulation index for amplitude modulation, AM, indicates the amount by which the modulated carrier varies around its static un-modulated level. When expressed as a percentage it is the same as the depth of modulation. In other words it can be expressed as:

$$\boxed{\text{Modulation index } m = \frac{M}{A}}$$

Where:

A is the carrier amplitude.

M is the modulating signal amplitude

From this it can be seen that for an AM modulation index of 0.5, the modulation causes the signal to increase by a factor of 0.5 and decrease to 0.5 of its original level.

Depth of modulation index: The percentage of modulation index is called the depth of modulation index. It is the product of modulation index and 100. i.e a modulation index of 0.5 is equal to the modulation depth of 50%.

Always modulation index should be less than or equal to 1, because M is always less than A. When the modulation index reaches 1.0, i.e. a modulation depth of 100%, the carrier level falls to zero and rise to twice of its non-modulated level.

If modulation index is greater than 1, then distortion occurs due to over modulation. The carrier experiences 180° phase reversals where the carrier level would try to go below the zero point. These phase reversals give rise to additional sidebands resulting from the phase reversals (phase modulation) that extend out, in theory to infinity. This can cause serious interference to other users if not filtered.

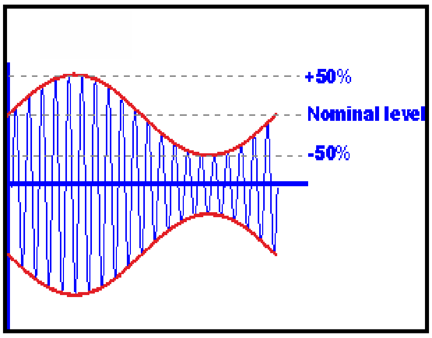

Fig: Amplitude modulated index of 0.5

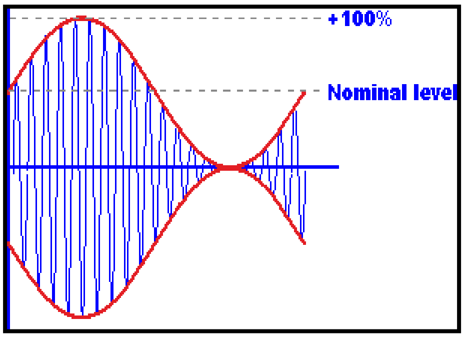

Fig: Amplitude modulated index of 1.0

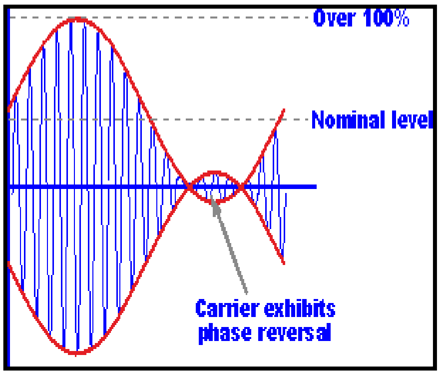

Fig: Amplitude modulated index of more than 1.0

i.e. over-modulated

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Amplitude Modulation Power Efficiency

Though the main advantage of AM is its simplicity, the disadvantage lies in its power efficiency. The power efficiency of AM is low as compared to other modulation techniques. Even in the maximum modulation possible i.e. with 100% modulation, the power efficiency is less.

Transmitted power in AM is the sum of carrier power, lower sideband power (LSB) and upper sideband power (USB).

$$\boxed{\mathbf{P_T = P_C + P_{LSB} + P_{USB}}}$$

Where:

P_T = Transmitted Power.

P_C = Carrier Power.

P_{LSB} = Lower sideband Power.

P_{USB} = Upper sideband Power.

When the carrier is modulated sidebands appear at either side of the carrier in its frequency spectrum. Each sideband contains the information about the audio modulation. To look at how the signal is made up and the relative powers take the simplified case where the 1 kHz tone is modulating the carrier. In this case two signals will be found 1 kHz either side of the main carrier. When the carrier is fully modulated i.e. 100% the amplitude of the modulation is equal to half that of the main carrier, i.e. the sum of the powers of the sidebands is equal to half that of the carrier. This means that each sideband is just a quarter of the total power. In other words for a transmitter with a 100 watt carrier, the total sideband power would be 50 watts and each individual sideband would be 25 watts. During the modulation process the carrier power remains constant.

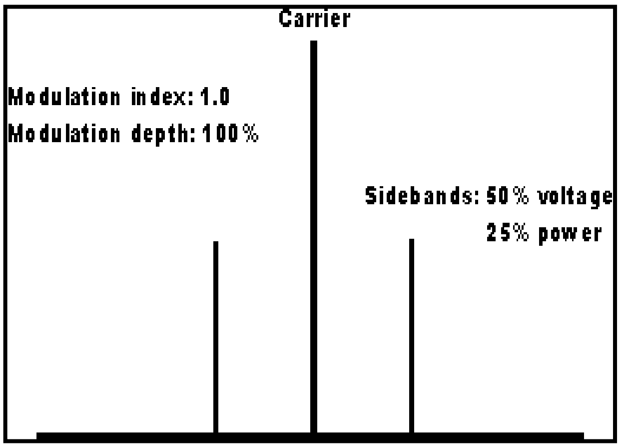
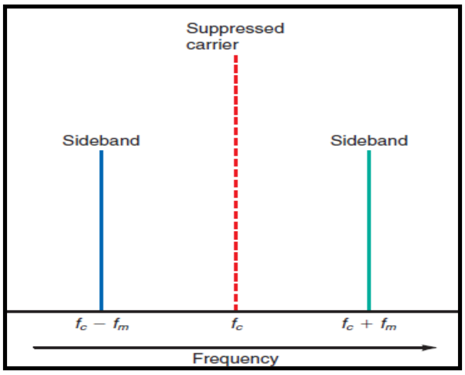


Fig: Level of sidebands of amplitude modulated signal

The carrier signal does not contain any information bits. Thus transmitting it is wastage of power as 50% of total transmitted power is used to transmit carrier. Also both the LSB and USB have same information thus transmitting it twice also reduces power efficiency. Thus to increase the power efficiency, a method in which the carrier and one of the sideband is eliminated is used. This is known as Double sideband and Single Sideband modulation.

Double Sideband, DSB Modulation

In AM, 2/3 rd of the transmitted power is carrier, which conveys no information. To increase the efficiency we have to suppress carrier and eliminate one of the sideband frequency. The first step in generating an SSB signal is to suppress the carrier, leaving the upper and lower sidebands. This type of signal is referred to as a double-sideband suppressed carrier (DSSC or DSB) signal. The benefit, of course, is that no power is wasted on the carrier. The envelope of this waveform is not the same as that of the modulating signal, as it is in a pure AM signal with carrier. A unique characteristic of the DSB signal is the phase transitions that occur at the lower-amplitude portions of the wave.



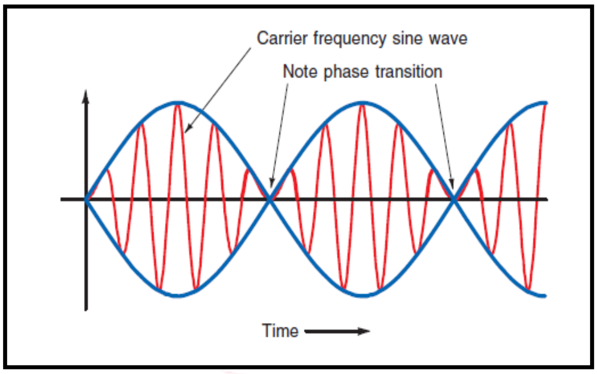


Fig: spectrum of DSB

Fig: DSB signal

DSB is generated by a balanced modulator. The main disadvantage of DSB is that it's difficult to demodulate at the receiver side. It is mainly used to transmit color information in TV signal.

Single Sideband, SSB Modulation

Single sideband modulation is a form of amplitude modulation. As the name implies, single sideband, SSB uses only one sideband for a given audio path to provide the final signal. Single sideband modulation, SSB, provides a considerably more efficient form of communication when compared to ordinary amplitude modulation. It is far more efficient in terms of the radio spectrum used, and also the power used to transmit the signal.

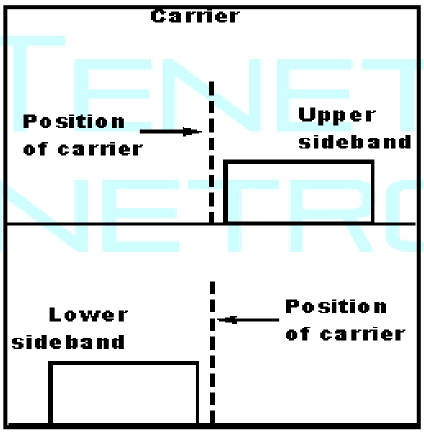


Fig: Single sideband modulation

showing upper and lower sideband signals

In SSB modulation carrier as well as any one of the sidebands will be removed. Thus increases the power efficiency. A single sideband signal therefore consists of a single sideband, and often no carrier. Either the upper sideband or lower sideband can be used. There is no advantage between using either the upper or lower sideband. The main criterion is to use the same sideband as used by other users for the given frequency band and application. The upper sideband is more commonly used for professional applications.

Types of SSB, single sideband modulation

There are number of different formats of single sideband modulation that are used:

- **Single sideband suppressed carrier, SSBSC*:*** SSBSC is the form of single sideband modulation that is most widely used for communications applications on the HF portion of the radio spectrum. There is only one sideband - the other sideband and the carrier are both removed. Having no carrier, this needs to be re-inserted within the receiver. Any slight differences in carrier re-insertion frequency give rise to changes in pitch of the audio. However it gives the most efficient spectrum and power usage of any single sideband modulation format.
- **Single sideband reduced carrier:** This form of single sideband modulation removes one sideband, but retains a small amount of carrier. The reduced carrier element can then be used to lock a local oscillator for carrier re-insertion and the demodulation of the sideband with the correct audio pitch. Naturally the power efficiency of this form of single sideband modulation is not as high as single sideband suppressed carrier.
- **Single sideband full carrier:** This form of single sideband modulation is normally used where receivers may not have the ability to re-insert the carrier - it can be demodulated using a simple diode detector. However, having one sideband only, it occupies only half the bandwidth. Power efficiency is very poor, because the full carrier is required, but only one sideband is present to carry the modulation.

- **Single sideband vestigial carrier:** Vestigial sideband is a form of single sideband modulation where one sideband is present, but the other has been only partly cut off or suppressed. Vestigial sideband is used for analogue AM television transmission and is used to reduce the overall bandwidth while still keeping one sideband with the lower frequency information.

- **Independent sideband, ISB:** This form of single sideband is not strictly "single" sideband because it has two sidebands. However each sideband carries different modulation, and therefore provides a doubling in the spectrum efficiency.

SSBSC power measurement

When the power for amplitude modulated signals is measured, a steady measurement is obtained regardless of the modulation, the power averaged over a second or less is constant. This is not the case for single sideband suppressed carrier. As no carrier is present, the sideband only appears when modulation is present, and its power is proportional to the audio at that instant.

In DSB modulation, though there is no information signal even then the spectrum will be displayed with only carrier. But this of no use as the carrier does not contain any information. But in SSB this waste of power will be eliminated as the spectrum will be displayed only when there is information signal.

As a result the power of the transmission is limited by the peak handling capability of the transmitter. Accordingly a measurement known as the peak envelope power, PEP is used. The peak envelope power needs to be measured by a power meter with a short time constant - thermal ones do not respond fast enough. However today there are many power sensors and meters that will respond sufficiently quickly to enable peak envelope powers to be measured.

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