NEED FOR MODULATION

MODULATION

Modulation is a process of mixing a signal with a sinusoid to produce a new signal. This new signal, conceivably, will have certain benefits over an un-modulated signal. Mixing of low frequency signal with high frequency carrier signal is called modulation.

$$f(t) = A\sin(\omega t + \phi)$$

we can see that this sinusoid has 3 parameters that can be altered, to affect the shape of the graph. The first term, A, is called the magnitude, or amplitude of the sinusoid. The next term, ω is known as the frequency, and the last term, ϕ is known as the phase angle. All 3 parameters can be altered to transmit data.

The sinusoidal signal that is used in the modulation is known as the **carrier signal**, or simply "the carrier". The signal that is used in modulating the carrier signal (or sinusoidal signal) is known as the "data signal" or the "message signal". It is important to notice that a simple sinusoidal carrier contains no information of its own.

In other words, we can say that modulation is used because some data signals are not always suitable for direct transmission, but the modulated signal may be more suitable.

TYPES OF MODULATION

amplitude modulation

a type of modulation where the amplitude of the carrier signal is modulated (changed) in proportion to the message signal while the frequency and phase are kept constant.

frequency modulation

a type of modulation where the frequency of the carrier signal is modulated (changed) in proportion to the message signal while the amplitude and phase are kept constant.

phase modulation

a type of modulation where the phase of the carrier signal is varied accordance to the low frequency of the message signal is known as phase modulation.

Why Use Modulation?

Clearly the concept of modulation can be a little tricky, especially for the people who don't like trigonometry. Why then do we bother to use modulation at all? To answer this question, let's consider a channel that essentially acts like a bandpass filter: both the lowest frequency components and the highest frequency components are attenuated or unusable in some way, with transmission only being practical over some intermediate frequency range. If we can't send low-frequency signals, then we need to shift our signal up the frequency ladder. Modulation allows us to send a signal over a bandpass frequency range. If every signal gets its own frequency range, then we can transmit multiple signals simultaneously over a single channel, all using different frequency ranges.

Another reason to modulate a signal is to allow the use of a smaller antenna. A baseband (low frequency) signal would need a huge antenna because in order to be efficient, the antenna needs to be about 1/10th the length of the wavelength. Modulation shifts the baseband signal up to a much higher frequency, which has much smaller wavelengths and allows the use of a much smaller antenna.

BASEBAND AND WAVELENGTHS

A **baseband** (low frequency) signal would need a huge antenna because in order to be efficient, the antenna needs to be about 1/10th the length of the **wavelength**. **Modulation** shifts the **baseband** signal up to a much higher frequency, which has much smaller **wavelengths** and allows the use of a much smaller antenna.

FREQUENCY MODULATION

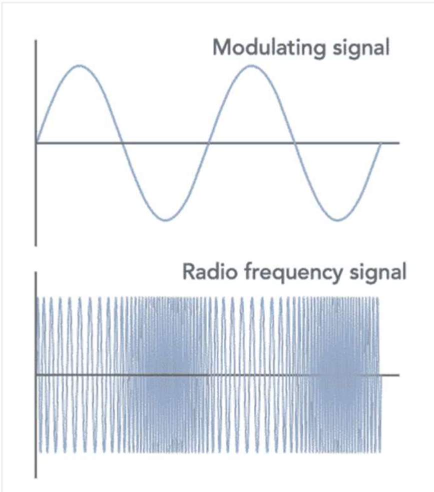
While changing the amplitude of a radio signal is the most obvious method to modulate it, it is by no means the only way. It is also possible to change the frequency of a signal to give frequency modulation or FM. Frequency modulation is widely used on frequencies above 30 MHz, and it is particularly well known for its use for VHF FM broadcasting.

Although it may not be quite as straightforward as amplitude modulation, nevertheless frequency modulation, FM, offers some distinct advantages. It is able to provide near interference free reception, and it was for this reason that it was adopted for the VHF sound broadcasts. These transmissions could offer high fidelity audio, and for this reason, frequency modulation is far more popular than the older transmissions on the long, medium and short-wave bands.

In addition to its widespread use for high quality audio broadcasts, FM is also used for a variety of two-way radio communication systems. Whether for fixed or mobile radio communication systems, or for use in portable applications, FM is widely used at VHF and above.

What is frequency modulation, FM?

To generate a frequency modulated signal, the frequency of the radio carrier is changed in line with the amplitude of the incoming audio signal.



Frequency Modulation, FM

When the audio signal is modulated onto the radio frequency carrier, the new radio frequency signal moves up and down in frequency. The amount by which the signal moves up and down is important. It is known as the deviation and is normally quoted as the number of kilohertz deviation. As an example, the signal may have a deviation of plus and minus 3 kHz, i.e. ±3 kHz. In this case the carrier is made to move up and down by 3 kHz.

Broadcast stations in the VHF portion of the frequency spectrum between 88.5 and 108 MHz use large values of deviation, typically ±75 kHz. This is known as wide-band FM (WBFM). These signals are capable of supporting high quality transmissions, but occupy a large amount of bandwidth. Usually 200 kHz is allowed for each wide-band FM transmission. For communications purposes less bandwidth is used. Narrow band FM (NBFM) often uses deviation figures of around ±3 kHz.

It is narrow band FM that is typically used for two-way radio communication applications. Having a narrower band, it is not able to provide the high quality of the wideband transmissions, but this is not needed for applications such as mobile radio communication.

Frequency demodulation

As with any form of modulation, it is necessary to be able to successfully demodulate it and recover the original signal. The FM demodulator may be called a variety of names including FM demodulator, FM detector or an FM discriminator.

There are a number of different types of FM demodulator, but all of them enable the frequency variations of the incoming signal to be converted into amplitude variations on the output. These are typically fed into an audio amplifier, or possibly a digital interface if data is being passed over the system.

FM modulators

There is a variety of different methods that can be used to generate frequency modulated signals.

- ***Varactor diode oscillator:*** This method simply requires the use of a varactor diode placed within the tuned circuit of an oscillator circuit. It is even possible to use a varactor diode within a crystal oscillator circuit. Typically, when crystal oscillators are used the signal needs to be multiplied in frequency, and only narrow band FM is attainable.
- ***Phase locked loop:*** Phase locked loops provide an excellent method of generating frequency modulation. It is often necessary to manage the constraints within the loop carefully but once done it provides and excellent solution.

Frequency modulation advantages & disadvantages

As with any form of modulation there are several advantages and disadvantages to its use. These need to be considered before making any decision or choice about its use:

Advantages of frequency modulation, FM:

- ***Resilience to noise:*** One particular advantage of frequency modulation is its resilience to signal level variations. The modulation is carried only as variations in frequency. This means that any signal level variations will not affect the audio output, provided that the signal does not fall to a level where the receiver cannot cope. As a result, this makes FM ideal for mobile radio communication applications including more general two-way radio communication or portable applications where signal levels are likely to vary considerably. The other advantage of FM is its resilience to noise and interference. It is for this reason that FM is used for high quality broadcast transmissions.
- ***Easy to apply modulation at a low power stage of the transmitter:*** Another advantage of frequency modulation is associated with the transmitters. It is possible to apply the modulation to a low power stage of the transmitter, and it is not necessary to use a linear form of amplification to increase the power level of the signal to its final value.
- ***It is possible to use efficient RF amplifiers with frequency modulated signals:*** It is possible to use non-linear RF amplifiers to amplify FM signals in a transmitter and these are more efficient than the linear ones required for signals with any amplitude variations (e.g. AM and SSB). This means that for a given power output, less battery power is required and this makes the use of FM more viable for portable two-way radio applications.

Disadvantages of frequency modulation, FM:

- ***FM has poorer spectral efficiency than some other modulation formats:*** Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission than frequency shift keying, a form of frequency modulation. As a result, most data transmission system use PSK and QAM.
- ***Requires more complicated demodulator:*** One of the minor disadvantages of frequency modulation is that the demodulator is a little more complicated, and hence slightly more expensive than the very simple diode detectors used for AM. However, this is much less of an issue these days because many radio integrated circuits incorporate a built-in frequency demodulator.

- ***Some other modes have higher data spectral efficiency:*** Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission that frequency shift keying, a form of frequency modulation. As a result, most data transmission system use PSK and QAM.
- ***Sidebands extend to infinity either side:*** The sidebands for an FM transmission theoretically extend out to infinity. They are normally significant for wideband frequency modulation transmissions, although small for narrow band FM. To limit the bandwidth of the transmission, filters are often used, and these introduce some distortion of the signal. Normally this is not too much of an issue although care has to be taken to include these filters for wideband FM and to ensure they are properly designed.

Single Sideband Modulation, SSB

Single sideband, SSB, modulation is used in many voice applications. It is used for HF communications, but forms have been used for analogue TV broadcasting.

Single sideband modulation is widely used in the HF portion, or short-wave portion of the radio spectrum for two-way radio communication. There are many users of single sideband modulation. Many users requiring two-way radio communication will use single sideband and they range from marine applications, generally HF point to point transmissions, military as well as radio amateurs or radio hams.

Single sideband modulation or SSB is derived from amplitude modulation (AM) and SSB modulation overcomes a number of the disadvantages of AM.

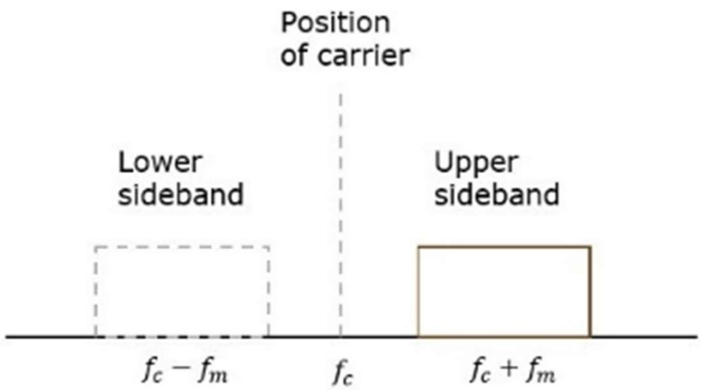
Single sideband modulation is normally used for voice transmission, but technically it can be used for many other applications where two-way radio communication using analogue signals is required.

As a result of its widespread use there are many items of radio communication equipment designed to use single sideband radio including: SSB receiver, SSB transmitter and SSB transceiver equipment.

What is single sideband modulation?

In the previous chapters, we have discussed DSBSC modulation and demodulation. The DSBSC modulated signal has two sidebands. Since, the two sidebands carry the same information, there is no need to transmit both sidebands. We can eliminate one sideband.

The process of suppressing one of the sidebands along with the carrier and transmitting a single sideband is called as **Single Sideband Suppressed Carrier** system or simply **SSBSC**. It is plotted as shown in the following figure.



Carrier and a sideband are suppressed and a single sideband is allowed for transmission

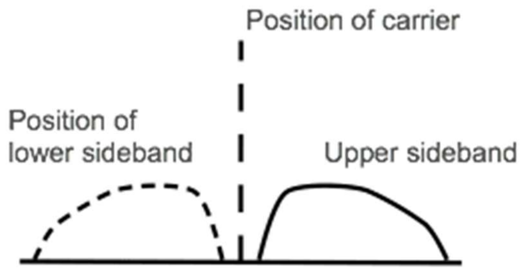
In the above figure, the carrier and the lower sideband are suppressed. Hence, the upper sideband is used for transmission. Similarly, we can suppress the carrier and the upper sideband while transmitting the lower sideband.

This SSBSC system, which transmits a single sideband has high power, as the power allotted for both the carrier and the other sideband is utilized in transmitting this Single Sideband.

Single sideband, SSB modulation is basically a derivative of amplitude modulation, AM. By removing some of the components of the ordinary AM signal it is possible to significantly improve its efficiency.

It is possible to see how an AM signal can be improved by looking at the spectrum of the signal. When a steady state carrier is modulated with an audio signal, for example a tone of 1 kHz, then two smaller signals are seen at frequencies 1 kHz above and below the main carrier.

If the steady state tones are replaced with audio like that encountered with speech of music, these comprise many different frequencies and an audio spectrum with frequencies over a band of frequencies is seen. When modulated onto the carrier, these spectra are seen above and below the carrier.



It can be seen that if the top frequency that is modulated onto the carrier is 6 kHz, then the top spectra will extend to 6 kHz above and below the signal. In other words, the bandwidth occupied by the AM signal is twice the maximum frequency of the signal that is used to modulated the carrier, i.e. it is twice the bandwidth of the audio signal to be carried.

Amplitude modulation is very inefficient from two points. The first is that it occupies twice the bandwidth of the maximum audio frequency, and the second is that it is inefficient in terms of the power used. The carrier is a steady state signal and in itself carries no information, only providing a reference for the demodulation process. Single sideband modulation improves the efficiency of the transmission by removing some unnecessary elements. In the first instance, the carrier is removed - it can be re-introduced in the receiver, and secondly one sideband is removed - both sidebands are mirror images of one another and the carry the same information. This leaves only one sideband - hence the name Single Sideband / SSB.

SSB receiver

While signals that use single sideband, modulation are more efficient for two-way radio communication and more effective than ordinary AM, they do require an increased level of complexity in the receiver. As SSB modulation has the carrier removed, this needs to be re-introduced in the receiver to be able to reconstitute the original audio. This is achieved using an internal oscillator called a Beat Frequency Oscillator (BFO) or Carrier Insertion Oscillator (CIO). This generates a carrier signal that can be mixed with the incoming SSB signal, thereby enabling the required audio to be recovered in the detector.

Typically, the SSB detector itself uses a mixer circuit to combine the SSB modulation and the BFO signals. This circuit is often called a product detector because (like any RF mixer) the output is the product of the two inputs.

It is necessary to introduce the carrier using the BFO / CIO on the same frequency relative to the SSB signal as the original carrier. Any deviation from this will cause the pitch of the recovered audio to change. Whilst errors of up to about 100 Hz are acceptable for communications applications including amateur radio, if music is to be transmitted the carrier must be reintroduced on exactly the correct frequency. This can be accomplished by transmitting a small amount of carrier, and using circuitry in the receiver to lock onto this.

Single sideband power measurement

It is often necessary to define the output power of a single sideband transmitter or single sideband transmission. For example, it is necessary to know the power of a transmitter used for two-way radio communication to enable its effectiveness to be judged for particular applications.

Power measurement for an SSB signal is not as easy as it is for many other types of transmission because the actual output power is dependent upon the level of the modulating signal. To overcome this a measure known as the peak envelope power (PEP) is used. This takes the power of the RF envelope of the transmission and uses the peak level of the signal at any instant and it includes any components that may be present. Obviously, this includes the sideband being used, but it also includes any residual carrier that may be transmitted.

The level of the peak envelope power may be stated in Watts, or nowadays figures quoted in dBW or dBm may be used. These are simply the power levels relative to 1 Watt or 1 milliwatt respectively. As an example, a signal of 10 watts peak envelope power is 10 dB above a 1-Watt signal and therefore it has a power of 10 dBW. Similar logic can be used to determine powers in dBm.

Single sideband modulation variants

There are many variants of single sideband modulation that are used, and there are several different abbreviations for them. These are explained below.

- ***LSB:*** This stands for Lower Sideband. This form of single sideband modulation is formed when the lower sideband only of the original signal is transmitted. Typically, this is used by radio amateurs or radio hams on their allocations below 9 MHz.
- ***USB:*** This stands for Upper Sideband. This form of single sideband modulation is formed when the upper sideband only of the original signal is transmitted. Typically, this form of SSB modulation is used by professional users on all frequencies and by radio amateurs or radio hams on their allocations above 9 MHz.
- ***DSB:*** This is Double Sideband and it is a form of modulation where an AM signal is taken and the carrier is removed to leave the two sidebands. Although easy to generate, it does not give any improvements in spectrum efficiency and it is also not particularly easy to resolve. Accordingly, it is rarely used.
- ***SSB SC:*** This stands for Single Sideband Suppressed Carrier. It is the form of SSB modulation where the carrier is removed completely as opposed to SSB reduced carrier where some of the carrier is left.
- ***VSB:*** This stands for Vestigial Sideband. It is a form is signal where one sideband is completely present, and the other sideband that has been only partly cut off or suppressed. It is widely used for analogue television transmissions. It comes in useful because the baseband video signal is wide (typically 6 MHz). To transmit this using AM would require a bandwidth of 12 MHz. To reduce the amount of spectrum used, one sideband is transmitted fully, whereas only the lower frequencies of the other are transmitted. The high frequencies can be later enhanced using filters.

- ***SSB reduced carrier:*** In this form of SSB modulation one sideband is present along with a small amount of the carrier. For some applications, a small amount of carrier is kept. This may be used to provide a reference signal for accurate demodulation.

SSB advantages

Single sideband modulation is often compared to AM, of which it is a derivative. It has several advantages for two-way radio communication that more than outweigh the additional complexity required in the SSB receiver and SSB transmitter required for its reception and transmission.

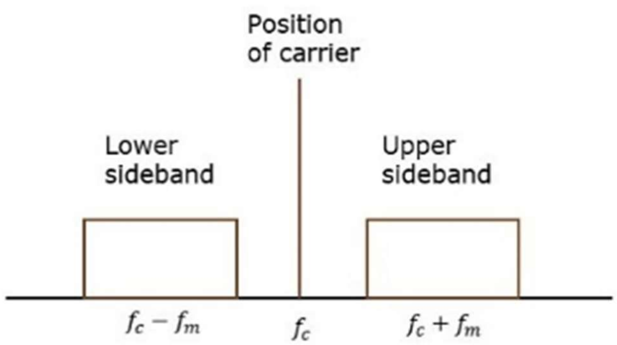
1. As the carrier is not transmitted, this enables a 50% reduction in transmitter power level for the same level of information carrying signal. [NB for an AM transmission using 100% modulation, half of the power is used in the carrier and a total of half the power in the two sideband - each sideband has a quarter of the power.]
2. As only one sideband is transmitted there is a further reduction in transmitter power.
3. As only one sideband is transmitted the receiver bandwidth can be reduced by half. This improves the signal to noise ratio by a factor of two, i.e. 3 dB, because the narrower bandwidth used will allow through less noise and interference.

DOUBLE SIDE BAND TRANSMISSION

The transmission of a modulated carrier wave accompanied by both of the sidebands resulting from modulation; the upper sideband corresponds to the sum of the carrier and modulation frequencies, whereas the lower sideband corresponds to the difference between the carrier and modulation frequencies.

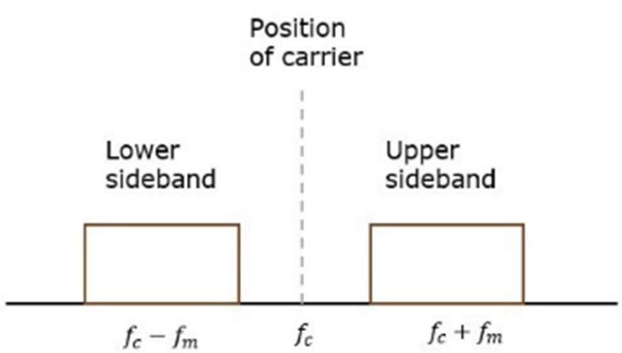
In the process of Amplitude Modulation, the modulated wave consists of the carrier wave and two sidebands. The modulated wave has the information only in the sidebands. **Sideband** is nothing but a band of frequencies, containing power, which are the lower and higher frequencies of the carrier frequency.

The transmission of a signal, which contains a carrier along with two sidebands can be termed as **Double Sideband Full Carrier** system or simply **DSBFC**. It is plotted as shown in the following figure.



However, such a transmission is inefficient. Because, two-thirds of the power is being wasted in the carrier, which carries no information.

If this carrier is suppressed and the saved power is distributed to the two sidebands, then such a process is called as **Double Sideband Suppressed Carrier** system or simply **DSBSC**. It is plotted as shown in the following figure.



Carrier is suppressed and sidebands
are allowed for transmission

Advantages of DSB-SC modulation

1. It provides 100% modulation efficiency.
2. Due to suppression of carrier, it consumes less power.
3. It provides a larger bandwidth.

Disadvantages of DSB-SC modulation

1. It involves a complex detection process.
2. Using this technique, it is sometimes difficult to recover the signal at the receiver.
3. It is an expensive technique when it comes to demodulation of the signal.

Applications of DSB-SC modulation

1. During the transmission of binary data, DSB-SC system is used in phase shift keying methods.
2. In order to transmit 2 channel stereo signals, DSB signals are used in Television and FM broadcasting.

DSB-SC technique allows us to have a transmission that reduces overall power consumption rate, thereby ensuring a stronger signal at the output.

SIGNAL TO NOISE RATIO

Defined as the ratio of signal power to the noise power, often expressed in Decibels. A ration of more than 1:1 indicates more signal than nose.

SNR Calculation Complicated
If the Units of Signal and Noise are in Voltages:

10* log (Signal Voltage/Noise Voltage) = SNR in Decibels

If the Units of Signal and Noise are in Power:

20*log (Signal Voltage/Noise Voltage) = SNR in Decibels

SNR Calculation Simple
If the Signal and Noise measurements are already in dB form, simply subtract the noise figure from the Signal figure

SNR= Noise Figure – Signal Figure

NOISE CLASSIFICATION

Thermal Noise (Johnson Nyquist noise)
Is unavoidable and generated by random thermal motion of charge carriers (usually electrons) inside an electrical conductor, which happens regardless of any applied voltage.

Shot Noise
Shot noise in electrical devices results from unavoidable random statistical fluctuations of the electrical current when charge carriers (such as electrons) traverse a gap. If electrons flow across a barrier, then they have discrete arrival times. Those discrete arrivals exhibit shot noises.

Flicker Noise
Is also known as the 1/f noise, is a signal/process with a frequency spectrum that falls off steadily into the higher frequencies with a pink spectrum. It occurs in almost all devices and results from a variety of effects.

Burst Noise
It consists of sudden stop like transitions between two or more discrete voltage or current levels, as high as hundreds of microvolts at random and unpredictable times. Each shift in offset voltage or current lasts for several milliseconds. It is also known as *popcorn noise* for the popping or cracking sounds it produces in audio circuits.

Time Transit Noise
If the time taken by the electrons to travel from the emitter to the collector in a transistor becomes comparable to the period of the signal being amplified, that is, at frequencies above VHF and beyond, the transit time effect takes place and noise input impedance of the transistor decreases. From the frequency at which this effect becomes significant, it increases with frequency and quickly dominates other sources of noise.