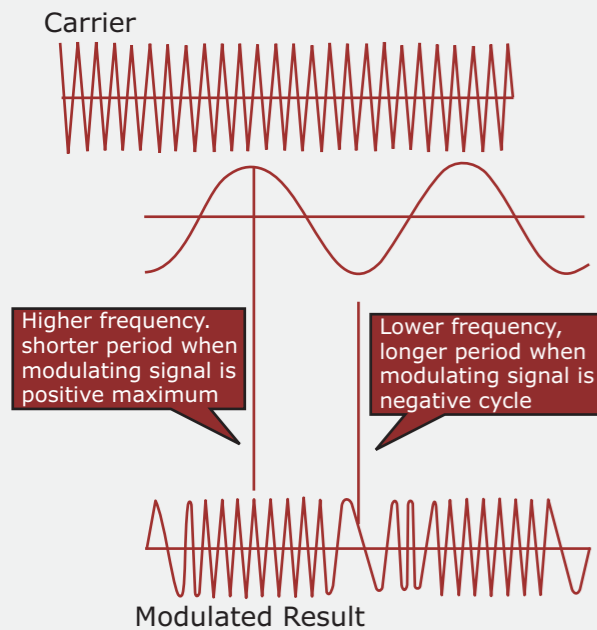## History of Frequency Modulation

Edwin Armstrong is most commonly known for inventing frequency-modulated of FM improved the audio signal of ration by controlling the noise static caused by electrical equipment and the earth's atmosphere. However, Edwin Armstrong should be know for inventing three key innovations; regeneration, superheterodyning and frequency modulation.

What is Frequency Modulation ?

Frequency modulation (FM) is the method of conveying information over a carrier wave by varying its frequency and keeping amplitude constant.
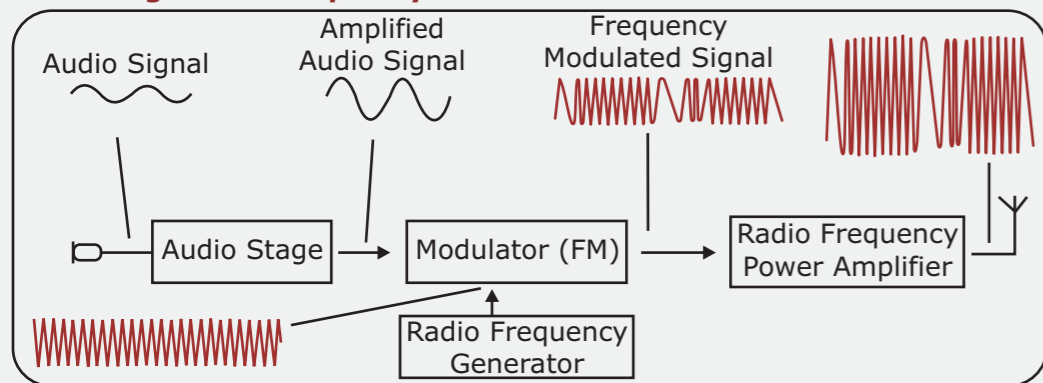
Edwin Howard Armstrong

Concept of Frequency Modulation

Carrier

Higher frequency. shorter period when modulating signal is positive maximum

Lower frequency, longer period when modulating signal is negative cycle

Modulated Result

Features of FM Signals

! Modulation is carried only as variations in frequency. That is, any signal level variations will not affect the audio output.
! FM wave is not affected to noise and interference. So FM is used for high quality broadcast transmissions.
! 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.
! For FM transmission, it is possible to use non-linear RF amplifiers to amplify FM signals in a transmitter. This is more efficient than the linear RF amplifier. Therefore, for a given power output, less battery power is required.

Block Diagram of Frequency Modulation

Audio Signal → Amplified Audio Signal → Frequency Modulated Signal

Audio Stage → Modulator (FM) → Radio Frequency Power Amplifier

Radio Frequency Generator

Advantages of Frequency Modulation:

Resilient to noise: Reduction is noise. As most noise is amplitude based, this can be removed by running the signal through a limiter so that only frequency variations appear. This is provided that the signal level is sufficiently high to allow the signal to be limited. Resilient to signal strength variations: It makes FM ideal for use in mobile applications where signal levels constantly vary. This is provided that the signal level is sufficiently high to allow the signal to be limited.
Does not require linear amplifiers in the Transmitter: As only frequency changes are required to be carried. Enables greater efficiency than many other modes.
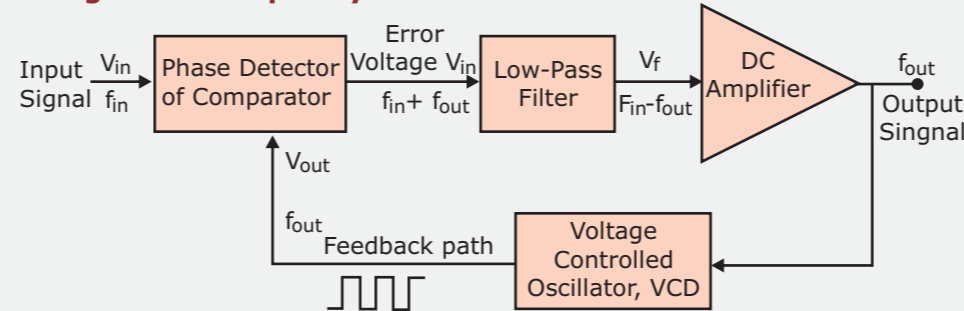
Disadvantages of Frequency Modulation

Requires more complicated demodulator and hence slightly more expensive than the very simple diode detectors used for AM. Also requiring a tuned circuit adds cost.
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.
Sidebands extend to infinity either side: The sidebands for an FM transmission theoretically extend out to infinity. To limit the bandwidth of the transmission, filters are used, and these introduce some distortion of the signal.

Block Diagram of Frequency Demodulation

Input Signal V_{in} f_{in} → Phase Detector of Comparator → Error Voltage V_{in} $f_{in}+f_{out}$ → Low-Pass Filter $F_{in}-f_{out}$ → V_f → DC Amplifier → f_{out} Output Singnal

V_{out}
f_{out} Feedback path → Voltage Controlled Oscillator, VCD

The PLL detector used PLL technology to demodulate FM signals. The diagram below shows a simple PLL detector. The phase of the FM input and the VCO output. Frequency deviation of the carrier results in phase difference between the two and the phase detector sends and error voltage to the low pass filter. The filtered error signal is used to change the VCO output frequency in order to reduce the phase error. The output of the low pass filter has an amplitude that is proportional to the deviation of the FM input, so it is actually a replica of the original modulating signal. FM is converted directly to audio.

1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.1
2nd 3nd 4th 5th 6th 7th 8th 9th 10th 11th 12th
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
m_C

FM Modulation Index

The modulation index is equal to the ratio of the frequency deviation to the modulating frequency. The modulation index will very according to the frequency that is modulating the transmitted carrier and the amount of deviation. However when designing a system it is important to know the maximum permissible values. This is given by the deviation ration and is obtained by inserting the maximum values into the formula for the modulation index. D=(Max deviation frequency)/(Max modulation frequency) for a VHF FM sound broadcast transmitter the maximum deviation is 75 KHz and the maximum modulation frequency is 15kHz giving a deviation ration of 5.
Frequency modulation Bassel functions & sidebands. Any signal that is modulated produces sidebands. In the case of an amplitude modulated signal they are easy to determine, but for frequency modulation the situation is not quite as straightforward. They are dependent upon the not only the deviation, but also the level of deviation, i.e. The modulation index M. The total spectrum is an infinite series fo discrete spectral components expressed by a complex formula using Bessel functions of the first kind.
The total spectrum can be seen to consist of the carrier plus an infinite number of sidebands spreading out on either side of the carrier at integral multiples of the modulating frequency. The relative levels of the sidebands can be obtained by referring to a table of Bessel functions. It can be seen from the image below that the relative levels rise and fall according to the different values of modulating index.

Relative Levels of Carrier and Sidebands for a Frequency Modulated Signal

For small values of modulation index, when using narrow-band FM, FM signal consists of the carrier and the two sidebands spaced at the modulation frequency either side of the carrier. This looks to be the same as an AM signal but the difference is that the lower sidebands is out of phase by 180 degrees. As the modulation index increases it is found that other sidebands at twice the modulation frequency start to appear. As the index is increased further other sidebands can also be seen.

V_C f_m M 0.5
1
2
4

Spectra of an FM signal with differing levels of modulation index
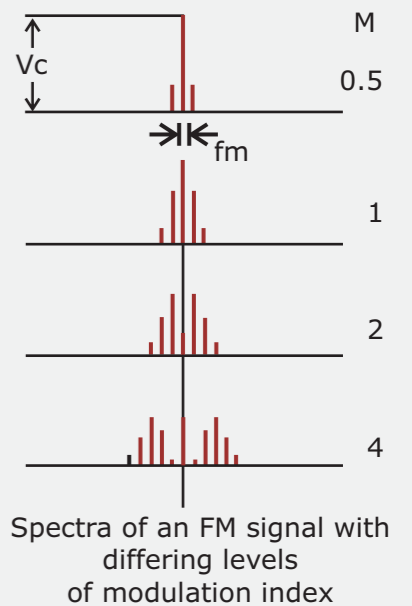
Bandwidth of a Frequency Modulated Signal

Interference and does not introduce any undue distortion of the signal. In other words for a VHF FM broadcast station this must be $(2 \times 75) + 15$KHz, i.e. 175KHz. In view of this a total fo 200 KHz is usually allowed, enabling stations to have a small guard band and their center frequencies on integral numbers of 100 Khz. A rule of thumb, often termed Carson's Rule states that 98% of the signal power is contained within a band width equal to the deviation frequency, plus the modulation frequency doubled, i.e.:

$$BT = 2 (\Delta f + fm)$$

The bandwidth of a frequency modulated signal varies with both deviation and modulating frequency. Increasing modulating frequency reduces modulation index - it reduces the numbers of sidebands with significant amplitude and hence the bandwidth.
Increasing modulating frequency increases the frequency separation between sidebands. The frequency modulation bandwidth increases with modulation frequency but it is not directly proportional to it. Frequency modulation bandwidth is of importance as it is with any other from of signal. With band occupancy growing, and pressure on spectrum space it is necessary to ensure the bandwidth of a frequency modulated signal falls within its specified allowance. Any undue signal spread outside this is likely to cause interference to other users.

Expressions for the frequency modulated signal:

Expressions for the frequency modulated signal:

$v_{out} = E_{rt} [\omega_c t + M_t \sin\omega_m t]$

$v_{out} = E_{rt} \begin{cases} J_o(M_t)\cos\omega_c t + J_1(M_t)[\cos(\omega_c + \omega_m)t - \cos(\omega_c - \omega_m)t] \\ + J_2(M_t)[\cos(\omega_c + 2\omega_m)t + \cos(\omega_c - 2\omega_m)t] \\ + J_3(M_t)[\cos(\omega_c + 3\omega_m)t - \cos(\omega_c - 3\omega_m)t] + \cdots \end{cases}$

Even for sinusoidal modulation the number of side frequency pairs is theoretically infinite. The $J_n(M_t)$ functions are Bessel functions. Amplitudes are in peak volts.

Instantaneous frequency

$f_i = f_c + \Delta f \cos \omega_m t$ Hz

f_i is the instantaneous frequency [Hz]
f_c is the carrier frequency [Hz]
Δf is the frequency deviation [Hz]
ω_m is the modulating signal frequency or message signal [rad/s]

Modulation index
The ratio of the frequency deviation to the modulating signal frequency.

$M_t = \frac{\Delta f}{f_m}$

Minimum bandwidth required | $BW_{min} = 2nf_m$ | where n = M_t + 1 rounded to the next integer