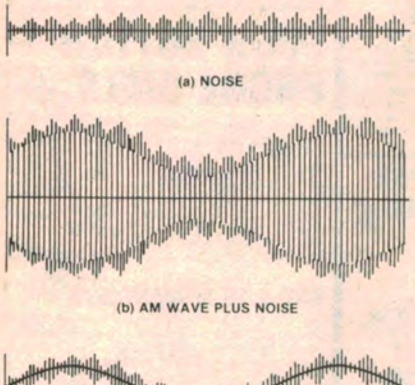
Frequency modula the basic concepts

Following on from last month's article on the fundamentals of amplitude modulation, this article explains frequency modulation, as used in commercial broadcasting, two-way communications and television sound transmissions. What is frequency modulation, and what advantages does it offer?

One of the greatest disadvantages in using amplitude modulation for the transmission of information is that the modulated signal has to compete with background electrical noise. Quite often, it is difficult to distinguish between the desired information signal and the undesired background electrical noise. The noise signal generally shows itself as an additional amplitude variation of the original signal as shown in Fig. 1.

Both the desired information signal and the undesired noise appear as amplitude variations, and any attempt to reduce or eliminate the noise will affect the information signal as well.



(a) NOISE

(b) AM WAVE PLUS NOISE

(c) SIGNAL

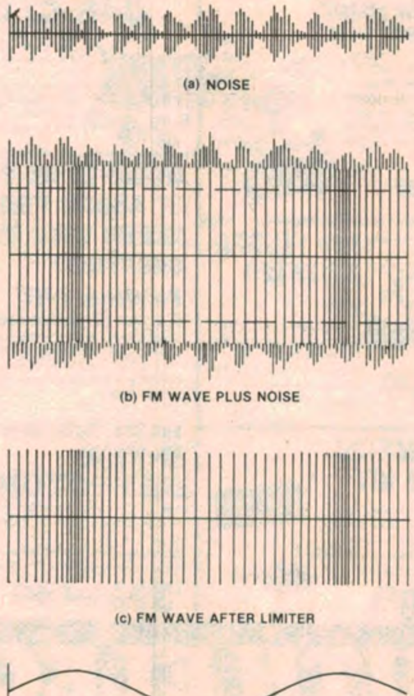
Fig. 1

Fig. 1, above, illustrates the effect of noise on an amplitude modulated signal. The noise appears as an additional variation in the amplitude of the signal and is reproduced by the receiver.

Fig. 2, at right, illustrates the effect of noise on a frequency modulated signal. Since the noise effects only the amplitude of the signal it can be eliminated.

The problem was studied by E. H. Armstrong in the 1930's and a reasonable solution was put forward. Instead of varying the amplitude of the carrier as is done in amplitude modulation, he placed the information on the carrier by varying the carrier frequency. That is, the frequency of the carrier is varied in keeping with the instantaneous amplitude of the modulation signal.

Fig. 2 shows the components of an FM signal and the effects of noise on it. Notice how at certain points the frequency has increased while at others it has decreased. The noise is shown at the top and bottom edge of Fig. 2b. The FM signal can now be put through a limiter in the receiving equipment which slices off the noise signal and leaves the FM signal as shown in Fig. 2c. We are able to do this in the case of FM, because it is the frequency variations we are interested in and not the amplitude variations as in AM. Figure 2d shows the modulation or information signal after it has been separated from the carrier.



(a) NOISE

(b) FM WAVE PLUS NOISE

(c) FM WAVE AFTER LIMITER

(d) SIGNAL

Fig. 2

Mathematical representation

Let us begin as we did in the case of amplitude modulation with a carrier wave, which we shall represent as follows.

$$Vc = A \text{ Sin } 2 f_c t$$

It is now required to vary the frequency f_c in keeping with the modulating signal, which is represented as follows.

$$Vm = B \text{ Sin } 2 f_m t$$

Using these two equations, it can be shown that the FM signal can be represented by an equation of the form

$$V_{FM} = [A \text{ Sin } 2\pi\, (f_c + \Delta f_c \text{Sin } 2\pi\, f_m t)\, t]$$

In this equation, f_c, which represents the frequency of the unmodulated carrier, is called the rest frequench. Δf_c is the maximum frequency change the car-

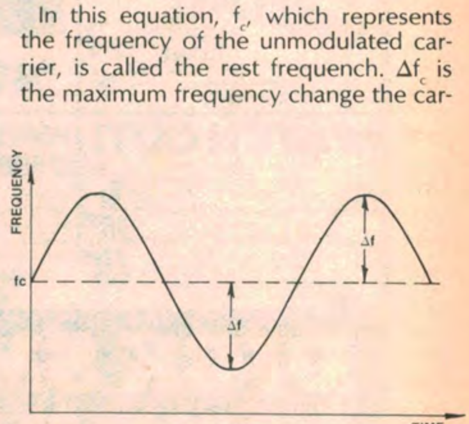


Fig. 3

Variation of carrier from rest frequency

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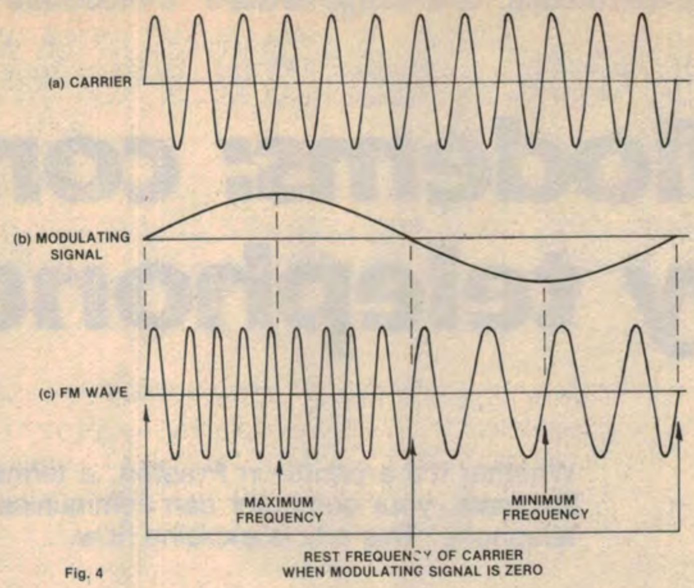

Fig. 4

A carrier frequency (a) modulated by signal (b) results in a frequency modulated waveform as shown in (c).

rier undergoes. The total frequency deviation from the lowest to the highest value is called the carrier swing. Fig. 3 shows the variation of carrier frequency from the rest frequency.

Modulation index

The frequency modulated wave is sometimes represented by an equation of the form

$$V_{FM} = A \operatorname{Sin} (2\pi f_c t + \frac{\Delta f_c}{f_m} \operatorname{Cos} 2\pi f_m t)$$

In this equation the quantity $\frac{\Delta f_c}{f_m}$ is called the modulation index and is normally designated by mf. In order that we do not lose the picture of the FM waveform in a lot of mathematical representation, Fig. 4 shows a carrier, frequency modulated by a sine wave.

Fig. 4a shows the unmodulated carrier. This is the rest frequency because no frequency modulation has taken place. Fig. 4b shows the modulating signal and Fig. 4c shows the resulting FM waveform. Notice that in Fig. 4c the frequency of the carrier increases in proportion to the amplitude of the modulating signal. That is, when the amplitude of the modulating signal reaches its maximum value so does the frequency of the carrier, and when the amplitude of the modulating signal reaches its minimum value the frequency of the carrier is at its minimum. This is what FM is all about.

Illustrative example

Let us illustrate the above ideas by working through a little problem. Suppose a 100MHz carrier signal is frequency modulated by a 4kHz audio tone, causing a frequency deviation of 25kHz. What are the highest and lowest frequencies that the modulated wave attains? Also find the carrier swing and the modulation index for this FM wave.

Frequency Deviation Δf = 25kHz.

Highest Frequency attained = $f_c + \Delta f_c$

= 100MHz + 25kHz = 100.025MHz.

Lowest Frequency attained = $f_c - \Delta f_c$

= 100MHz − 25kHz = 99.975MHz.

Carrier Swing = 2x Frequency Deviation

= 2 x 25kHz = 50kHz

Modulation Index mf $= \frac{\Delta f}{f_m} = \frac{25\text{kHz}}{4\text{kHz}}$

= 6.25

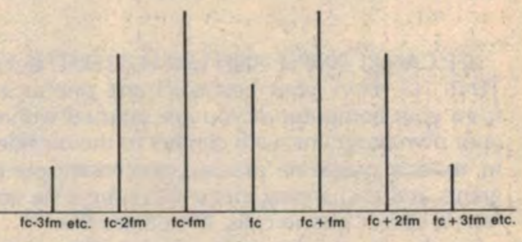

Fig. 5

A frequency modulated waveform consists of an infinite number of side-bands, although not all of them have enough power to be significant.

Frequency spectrum

Unlike an AM wave which consists of a carrier and an upper and lower side band, the FM wave consists of an infinite number of side bands as shown in Fig. 5.

Not all these side bands, however, have enough power to be significant. The amplitude distribution is clearly shown in Fig. 5.

Noise and modulation index

The modulation index of an FM system has a direct bearing on its ability to suppress noise. When the modulation index increases, the signal to noise ratio with respect to an AM system increases, for the same signal input to the AM receiver. The improvement in signal to noise voltage ratio is given by the formula

Improvement in dB =
4.75 + $20\log_{10}$ (Modulation Index)

As an example, suppose the maximum frequency deviation of a transmission is ±50kHz and the modulating frequency is 15kHz.

$$mf = \frac{\Delta f}{f_m} = \frac{50\text{kHz}}{15\text{kHz}} = 3.3$$

Therefore, the signal to noise voltage ratio improvement with respect to an AM system

$= 4.75 + 20\log_{10} (3.3)$
$= 15.2\text{dB}$

Using higher values of modulation index would increase the signal to noise ratio, but this would require an increase in bandwidth for the transmission of the FM signal. A compromise value of modulation index is normally used so that a significant improvement in signal to noise ratio takes place, without unduly increasing the bandwidth.