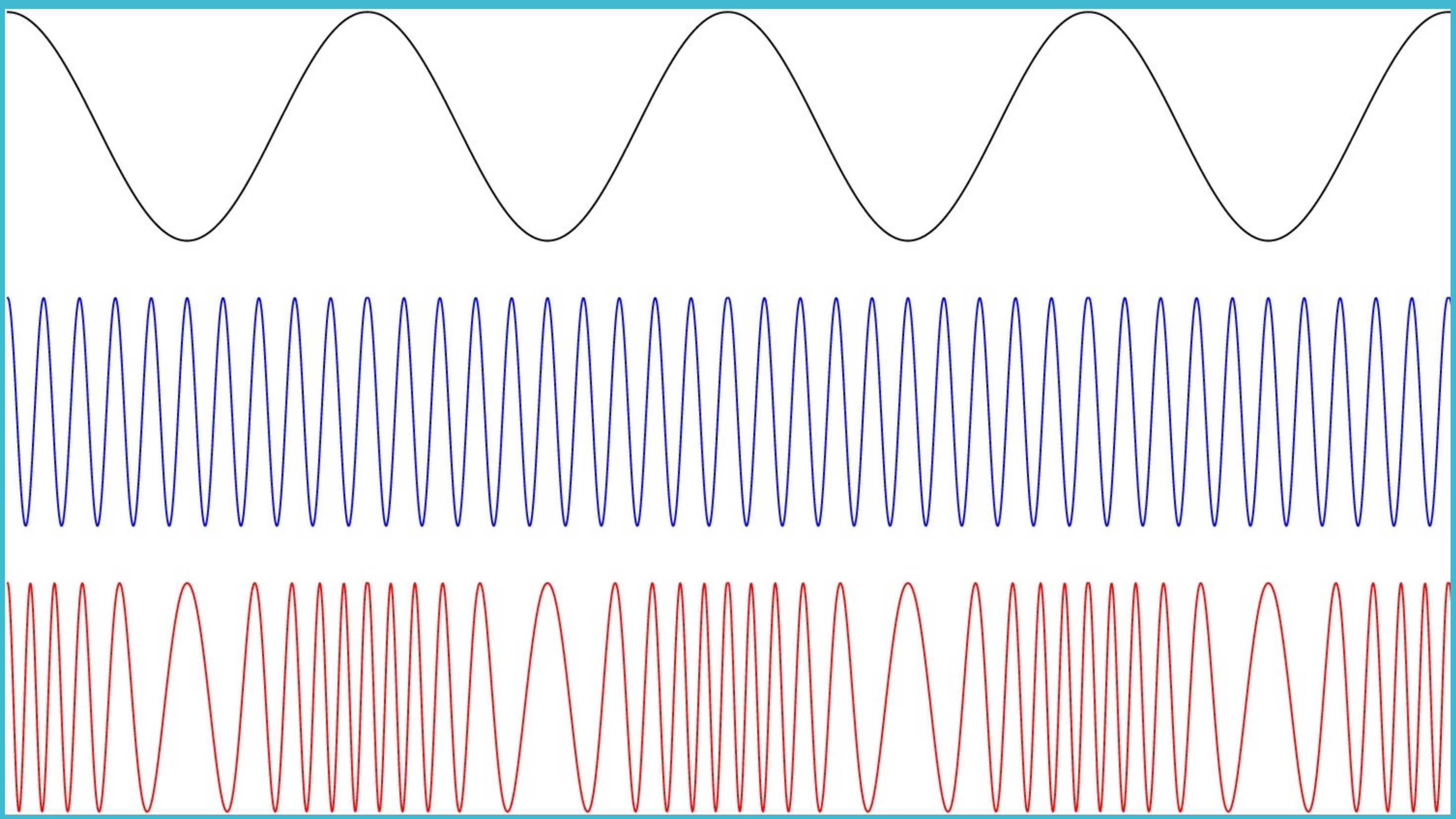

Marwadi University

Department of Information and Communication Technology

Unit no: 2

Unit title: Angle Modulation

Subject name: Analog and Digital Communication

Subject code: 01CT0404

Marwadi University

Department of Information and Communication Technology

Outline

- Concept of instantaneous frequency and phase modulation
- Sinusoidal FM and its time domain representation
- Spectral components of angle modulated signals
- Power in sinusoidal FM and modulation index,
- Carson's rule
- Multitone wideband FM
- Generation of Wideband FM from Narrow band FM
- Generation of WBFM by Armstrong method.

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- In angle modulation, the information signal may be used to vary the carrier frequency, giving rise to *frequency modulation,* or it may be used to vary the angle of phase lead or lag, giving rise to *phase modulation*.
- Since both frequency and phase are parameters of the carrier angle, which is a function of time, the general term *angle modulation* covers both.
- Frequency and phaseproperties modulation have some very similar properties, but also some marked differences.

Credit: Electronic Communication by Roddy and Coolen

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- Compared to amplitude modulation, frequency modulation has certain advantages. Mainly, the signal to- noise ratio can be increased without increasing transmitted power (but at the expense of an increase in frequency bandwidth required)
- Certain forms of interference at the receiver are more easily suppressed; and the modulation process can take place at a low-level power stage in the transmitter
- Thus avoiding the need for large amounts of modulating power.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

The modulating signal $e_m(t)$ is used to vary the carrier frequency. For example, $e_m(t)$ may be applied as a voltage to a voltage-dependent capacitor, which in turn controls the frequency of an oscillator. (Some modulating circuits are described in Section 10.12). In a well-designed modulator the *change* in carrier frequency will be proportional to the modulating voltage and thus can be represented as $ke_m(t)$, where k is a constant known as the *frequency deviation constant*. The units for k are clearly *hertz/volt* or Hz/V. The instantaneous carrier frequency is therefore equal to

$$f_i(t) = f_c + ke_m(t) \tag{10.2.1}$$

where f_c is the unmodulated carrier frequency.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

EXAMPLE 10.2.1

Sketch the instantaneous frequency–time curve for a 90-MHz carrier wave frequency modulated by a 1-kHz square wave that has zero dc component and peak-to-peak voltage of 20 V. The frequency deviation constant is 9 kHz/V.

SOLUTION The peak-to-peak frequency deviation is $20 \times 9 = 180$ kHz, and this is spaced symmetrically about the unmodulated carrier of 100 MHz. The resulting frequency–time curve is shown in Fig. 10.2.1.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

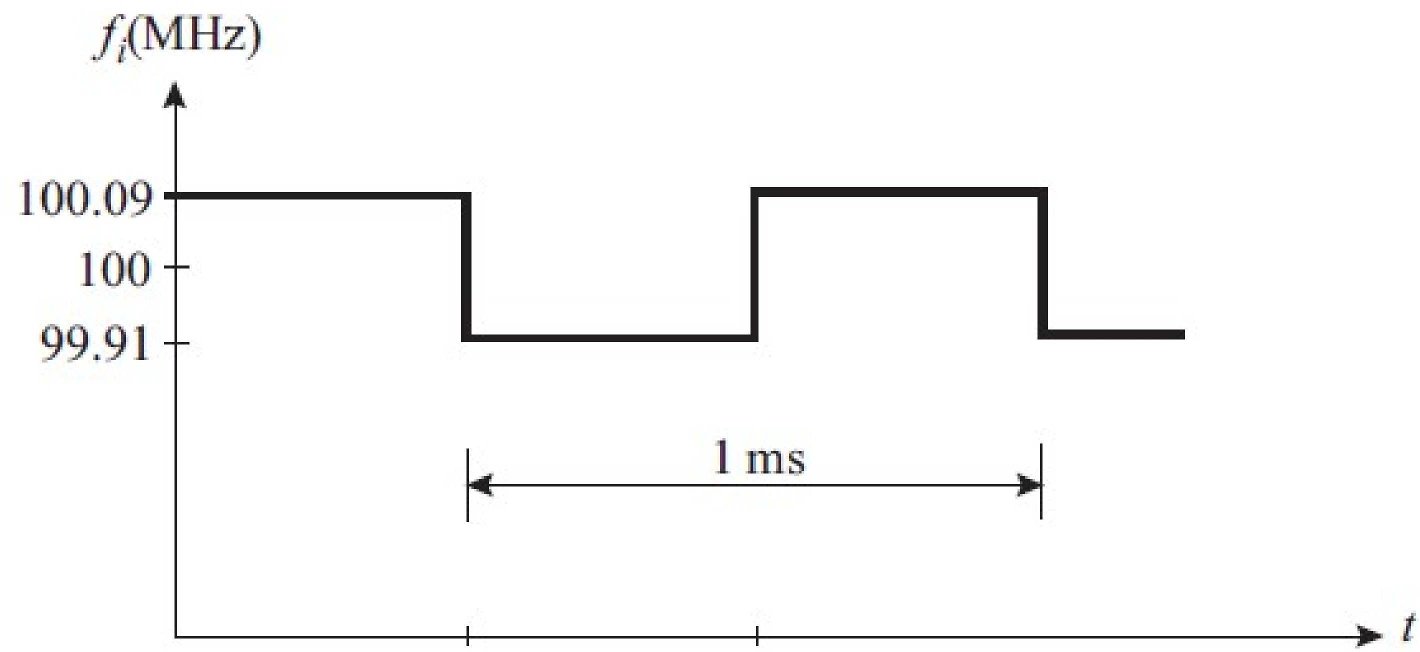


Figure 10.2.1 Instantaneous frequency–time curve for Example 10.2.1.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

As noted previously, the instantaneous frequency may be expressed as $f_i(t) = f_c + ke_m(t)$, and the corresponding instantaneous angular velocity is $\omega_i(t) = 2\pi f_i(t)$, The generation of the modulated carrier can be represented graphically by means of a rotating phasor as shown in Fig. 10.2.2 (a).

The phasor, of constant length $E_{c\ \max}$, rotates in a counterclockwise direction at an angular velocity $\omega_i(t) = 2\pi f_i(t)$. The angle turned through in time t is shown as $\theta(t)$, where for convenience the positive x-axis is used as the reference axis. The angle $\theta(t)$ is found by noting that the angular velocity is the time rate of change of angle, or

$$\frac{d\theta(t)}{dt} = \omega_i(t) \tag{10.2.2}$$

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

and hence

$$\theta(t) = \int_0^t \omega_i(t)\,dt$$

$$= \int_0^t 2\pi(f_c + ke_m(t))\,dt$$

$$= 2\pi f_c t + 2\pi k \int_0^t e_m(t)\,dt \tag{10.2.3}$$

Thus the modulating signal is contained in the angle, in this rather indirect way. Note that the expression for the modulated angle could not have been obtained by simply substituting f_i for f_c in the sine-wave function $E_{c\,\max}\sin(2\pi f_c t)$, the reason being that this is derived on the basis of a constant frequency, which is not valid for frequency modulation. By setting $e_m(t) = 0$, the unmodulated angle is seen in Fig 10.2.2 (b) to be simply $\theta(t) = 2\pi f_c t$.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

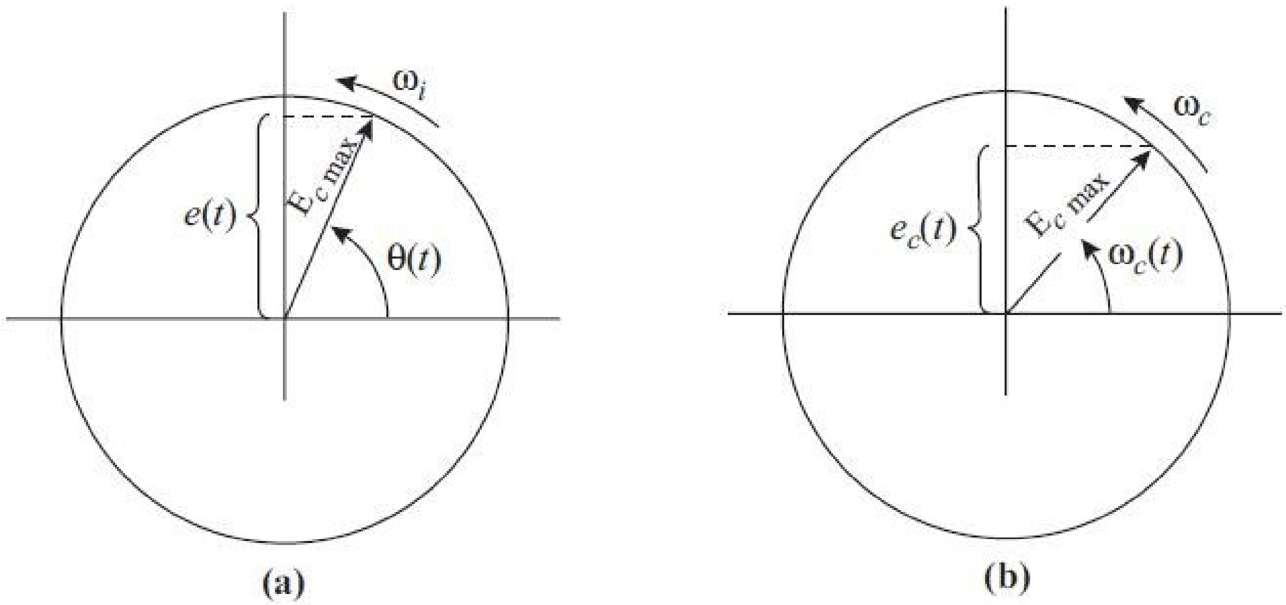


Figure 10.2.2 Rotating phasor representation of a carrier of amplitude $E_{c\ \max}$ rotating (a) at instantaneous angluar velocity $\omega_i(t)$ and (b) at constant angular velocity ω_c.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

EXAMPLE 10.2.2

Sketch $\theta(t)$ as a function of time for a 100-MHz carrier wave frequency modulated by a 1-kHz square wave that has zero dc component and peak-to-peak voltage of 20 V. The frequency deviation constant is 9 kHz/V.

SOLUTION The peak-to-peak frequency deviation is $20 \times 9 = 180$ kHz, and this is symmetrical about the unmodulated carrier of 100 MHz. Thus $\Delta f = \pm 90$kHz about the carrier, where the plus sign is used for the positive half-cycles and the negative sign for the negative half-cycles of the modulating waveform. Over the positive half-cycles the integral term gives $+\Delta f \cdot t$, and over the negative half-cycles $-\Delta f \cdot t$. Thus the angle is given by $\theta(t) = 2\pi(f_c \pm \Delta f)t$, where the plus sign applies to positive half-cycles and the negative sign to negative half-cycles. The waveforms are sketched in Fig. 10.2.3.

Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

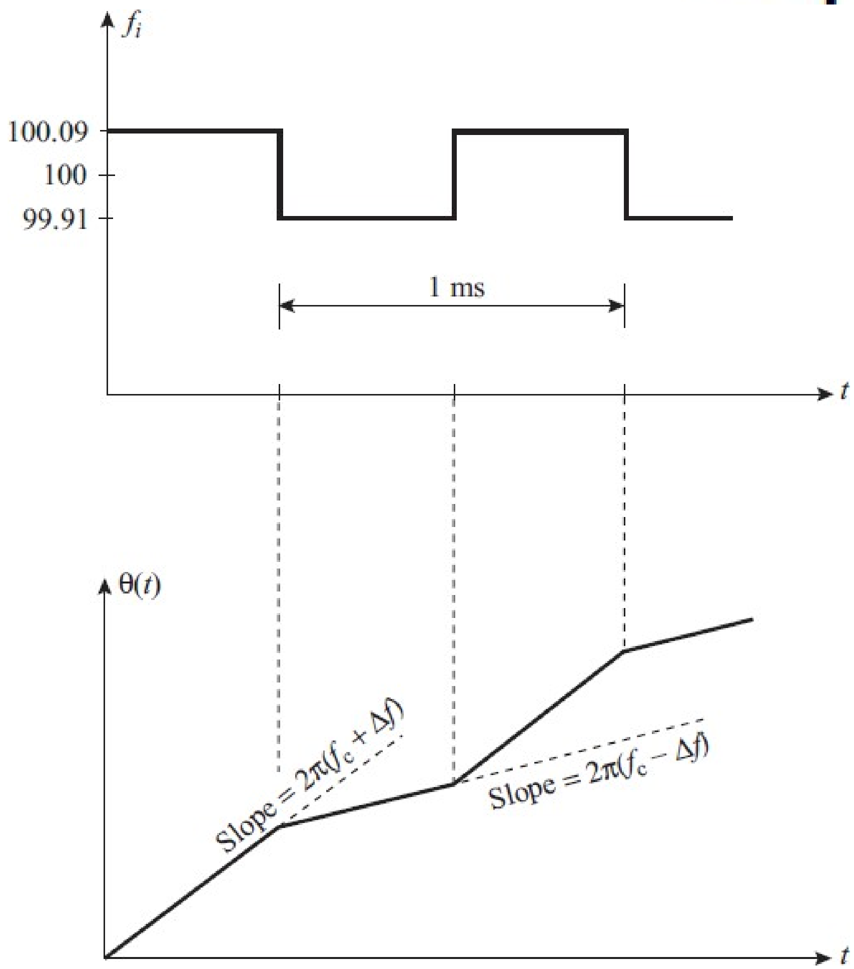


Figure 10.2.3 Solution to Example 10.2.2

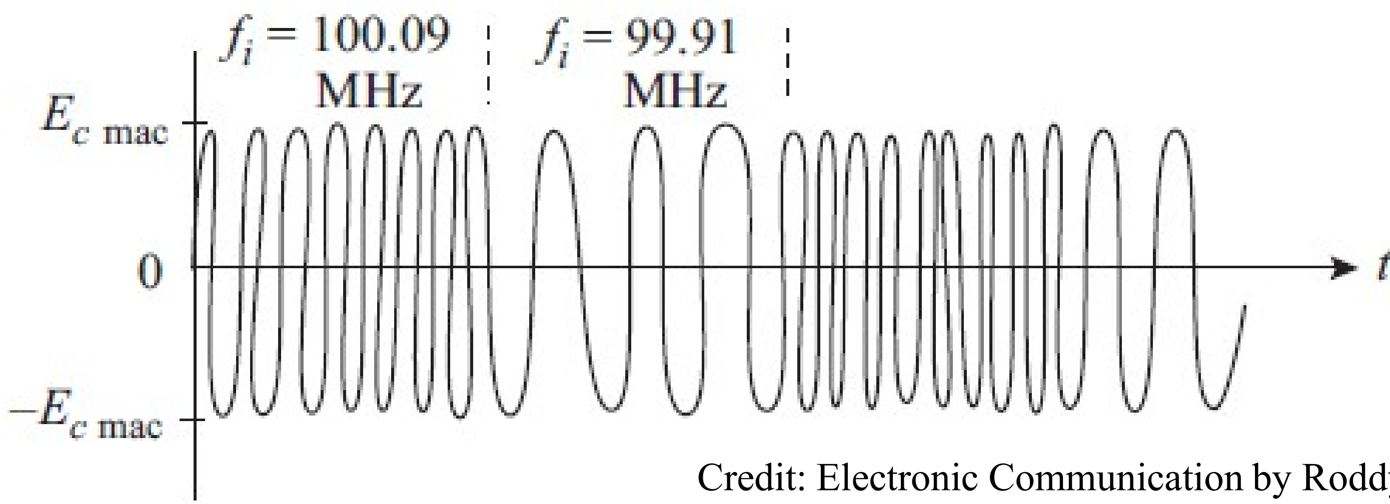
Credit: Electronic Communication by Roddy and Coolen

Frequency Modulation

The cosine function representing the carrier wave is given by the projection of the phasor on the x-axis and is seen to be

$$e_c = E_{c\,\max} \cos \theta(t) \tag{10.2.4}$$

Thus, in the unmodulated case, this reduces to the sinewave $E_{c\,\max} \cos 2\pi f_c t$, while for the modulated case, the full expression for $\theta(t)$, including the integral term, must be used. For the square-wave modulation in the previous example, the modulated carrier would appear as sketched in Fig. 10.2.4.



Credit: Electronic Communication by Roddy and Coolen

Sinusoidal FM

Many important characteristics of FM can be found from an analysis of sinusoidal modulation. For sinusoidal modulation, $e_m(t) = E_{m\,\max} \cos 2\pi f_m t$ and hence

$$\begin{aligned} f_i(t) &= f_c + k e_m(t) \\ &= f_c + k E_{m\,\max} \cos 2\pi f_m t \\ &= f_c + \Delta f \cos 2\pi f_m t \end{aligned} \tag{10.3.1}$$

Credit: Electronic Communication by Roddy and Coolen

Sinusoidal FM

where the peak *frequency deviation* Δf is proportional to the peak modulating signal and is

$$\Delta f = kE_{m\,\max} \tag{10.3.2}$$

The instantaneous frequency as a function of time is sketched in Fig. 10.3.1.

The expression for the sinusoidally modulated carrier therefore become

$$\begin{aligned} e(t) &= E_{c\,\max}\cos\theta(t) \\ &= E_{c\,\max}\cos\left(2\pi f_c t + 2\pi\Delta f\int_0^t \cos 2\pi f_m t\,dt\right) \\ &= E_{c\,\max}\cos\left(2\pi f_c t + \frac{\Delta f}{f_m}\sin 2\pi f_m t\right) \end{aligned} \tag{10.3.3}$$

Credit: Electronic Communication by Roddy and Coolen

Sinusoidal FM

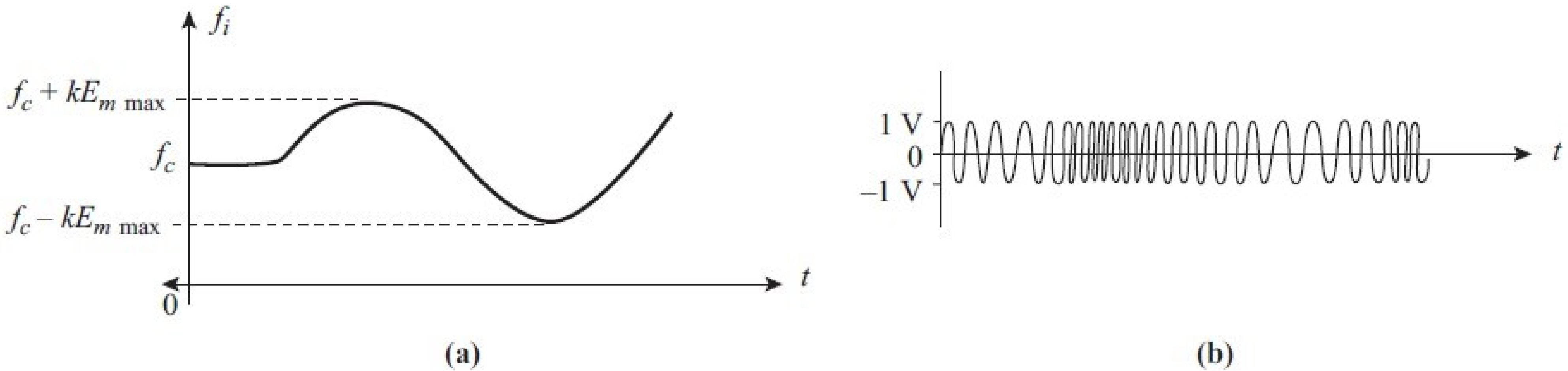


Figure 10.3.1 Instantaneous frequency–time curve for a sinusoidally frequency modulated wave.

Credit: Electronic Communication by Roddy and Coolen

Sinusoidal FM

The modulation index for FM, usually denoted by β, is defined as

$$\beta = \frac{\Delta f}{f_m} \tag{10.3.4}$$

and hence the equation for the sinusoidally modulated wave becomes

$$e(t) = E_{c\,\max} \cos(2\pi f_c t + \beta \sin 2\pi f_m t) \tag{10.3.5}$$

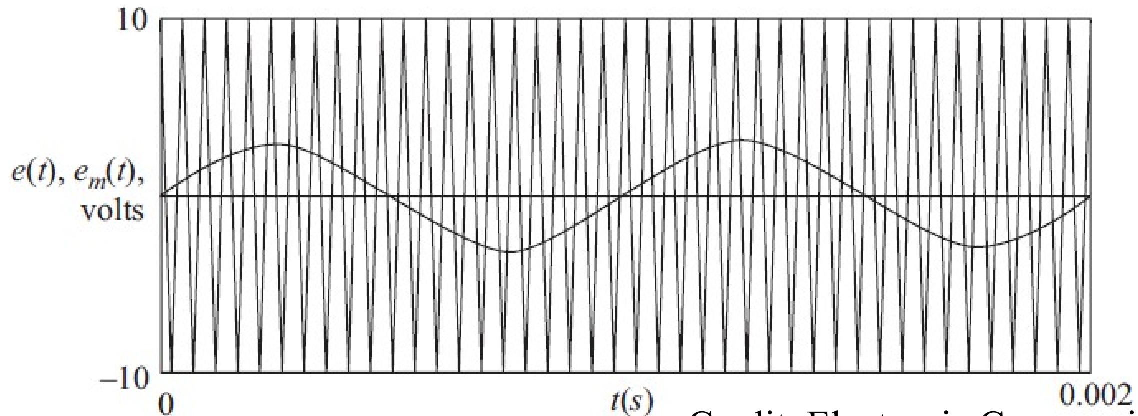
Credit: Electronic Communication by Roddy and Coolen

Sinusoidal FM

EXAMPLE 10.3.1

Determine the modulation index, and plot the sinusoidal FM wave for which $E_{c\ max} = 10$ V, $E_{m\ max} = 3$ V, $k = 2000$ Hz/V, $f_m = 1$ kHz, and $f_c = 20$ kHz. On the same set of axes, plot the modulating function. The plot should extend over two cycles of the modulating function.

SOLUTION The peak deviation is $\Delta f = 2000 \times 3 = 6000$ Hz. The modulation index is $\beta = 6$ kHz/1 kHz $= 6$. The functions to be plotted are $e_m(t) = 3 \cos 2\pi 10^3 t$ and $e(t) = 10 \cos(4\pi 10^4 t + 6 \sin 2\pi 10^3 t)$ over a range $0 \le t \le 2$ ms. The graphs, obtained using Mathcad, are shown in Fig. 10.3.2.



Credit: Electronic Communication by Roddy and Coolen

Figure 10.3.2 Solution to Example 10.3.1.

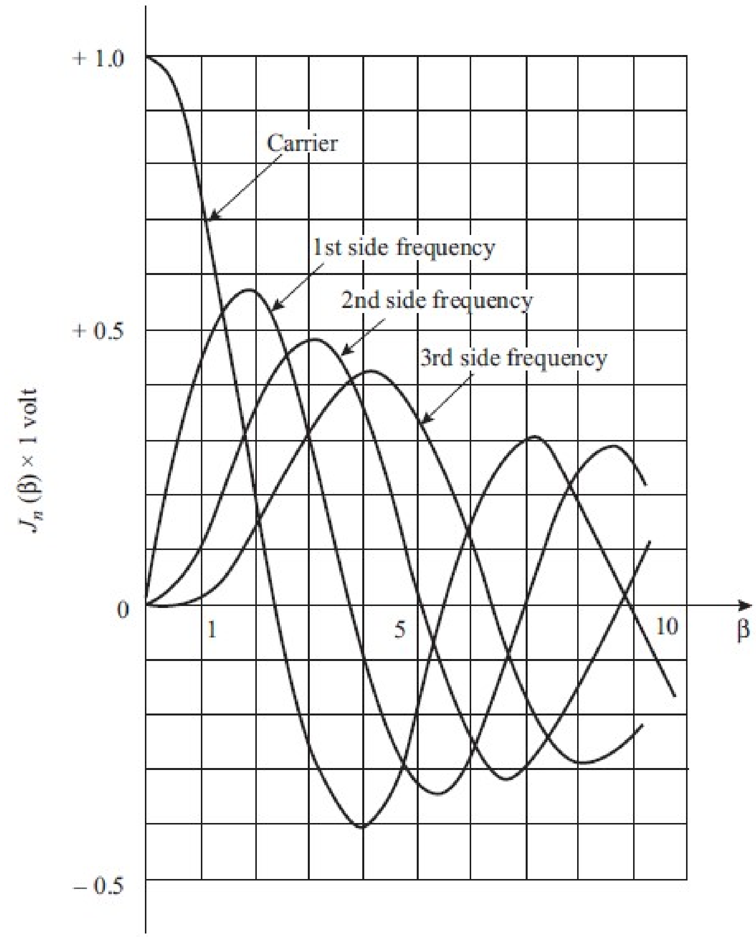
Frequency Spectrum for Sinusoidal FM

$$e(t) = E_{c\,\max} \cos(2\pi f_c t + \beta \sin 2\pi f_m t) \tag{10.3.5}$$

Equation (10.3.5) may be analyzed by Fourier methods in order to obtain the spectrum. The actual analysis is quite involved and only the results will be presented here. The trigonometric series contains a carrier term $J_0(\beta)E_{c\,\max} \cos \omega_c t$, a first pair of side frequencies $J_1(\beta)E_{c\,\max} \cos (\omega_c \pm \omega_m)t$, a second pair of side frequencies $J_2(\beta)E_{c\,\max} \cos (\omega_c \pm 2\omega_m)t$, a third pair of side frequencies $J_3(\beta)E_{c\,\max} \cos (\omega_c \pm 3\omega_m)t$, and so on. The amplitude coefficients $J_n(\beta)$ are known as *Bessel functions of the first kind of order n*. Values for these functions are available in both tabular and graphical form and are also available as built-in functions in programs for calculators and computers (such as Mathcad). From the point of view of applications here, the Bessel function gives the amplitude of the carrier ($n = 0$) and side frequencies ($n = 1, 2, 3, \ldots$). Some values are shown in Table 10.4.1, where for convenience $E_{c\,\max}$ is set equal to unity. The graphs of the carrier and the first three side frequencies are shown in Fig. 10.4.1 for values of β up to 10.

Credit: Electronic Communication by Roddy and Coolen

Frequency Spectrum for Sinusoidal FM



Credit: Electronic Communication by Roddy and Coolen

Figure 10.4.1 Graphs of the carrier amplitude and the first three side frequencies for a sinusoidally frequency modulated carrier (Ec_{max} = 1V).

Frequency Spectrum for Sinusoidal FM

Table 10.4.1 Bessel Functions for a Sinusoidally Frequency-modulated Carrier of Unmodulated Amplitude, 1.0 V (Amplitude Moduli Less than $|0.01|$ not shown.)

		Side Frequencies											
Modulation Index β	*Carrier* J_0	*1st* J_1	*2nd* J_2	*3rd* J_3	*4th* J_4	*5th* J_5	*6th* J_6	*7th* J_7	*8th* J_8	*9th* J_9	*10th* J_{10}	*11th* J_{11}	*12th* J_{12}
0.25	0.98	0.12	0.01										
0.5	0.94	0.24	0.03										
1.0	0.77	0.44	0.11	0.02									
1.5	0.51	0.56	0.23	0.06	0.01								
2.0	0.22	0.58	0.35	0.13	0.03	0.01							
2.4	0	0.52	0.43	0.20	0.06								
3.0	−0.26	0.34	0.49	0.31	0.13	0.04	0.01						
4.0	−0.40	−0.07	0.36	0.43	0.28	0.13	0.05	0.02					
5.0	−0.18	−0.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02	0.01			
5.5	0	−0.34	−0.12	0.26	0.40	0.32	0.19	0.09	0.03	0.01			
6.0	0.15	−0.28	−0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02	0.01		
7.0	0.30	0	−0.30	−0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02	0.01	
8.0	0.17	0.23	−0.11	−0.29	−0.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03	0.01
8.65	0	0.27	0.06	−0.24	−0.23	0.03	0.26	0.34	0.28	0.18	0.10	0.05	0.02

Credit: Electronic Communication by Roddy and Coolen

Frequency Spectrum for Sinusoidal FM

As an example of the use of Table 10.4.1, it can be seen that, for β = 0.05, the spectral components are

Carrier (f_c)	$J_0(0.5) = 0.94$
First-order side frequencies ($f_c \pm f_m$)	$J_1(0.5) = 0.24$
Second-order side frequencies ($f_c \pm 2f_m$)	$J_2(0.5) = 0.03$

The fact that the spectrum component at the carrier frequency decreases in amplitude does *not* mean that the carrier wave is amplitude modulated. The carrier wave is the sum of all the components in the spectrum, and these add up to give a constant amplitude carrier as shown in Fig. 10.3.2. The distinction is that the modulated carrier is not a sine wave, whereas the spectrum component at carrier frequency is. (All spectrum components are either sine or cosine waves.) It will be noted from Table 10.4.1 that amplitudes can be negative in some instances. It will also be seen that for certain values of β (2.4, 5.5, 8.65, and higher values not shown), the carrier amplitude goes to zero. This serves to emphasize the point that it is the sinusoidal component of the spectrum at carrier frequency, *not* the modulated carrier, that goes to zero and that varies from positive to negative peak (1 V in this case) as the frequency varies.

Credit: Electronic Communication by Roddy and Coolen

Frequency Spectrum for Sinusoidal FM

The spectra for various values of β are shown in Fig. 10.4.2(a), (b), and (c). In each case the spectral lines are spaced by f_m, and the bandwidth occupied by the spectrum is seen to be

$$B_{FM} = 2nf_m \tag{10.4.1}$$

where n is the highest order of side frequency for which the amplitude is significant. From Table 10.4.1 it can be seen that, where the order of side frequency is greater than $(\beta + 1)$, the amplitude is 5% or less of unmodulated carrier amplitude. Using this as a guide for bandwidth requirements, Eq. (10.4.1) can be written as

$$B_{FM} = 2(\beta + 1)f_m \tag{10.4.2}$$

or, substituting for β from Eq. (10.3.4)

$$B_{FM} = 2(\Delta f + f_m) \tag{10.4.3}$$

Credit: Electronic Communication by Roddy and Coolen

Frequency Spectrum for Sinusoidal FM

To illustrate the significance of this, three examples will be considered:

1. $\Delta f = 75$ kHz, $f_m = 0.1$ kHz

$$B_{\text{FM}} = 2(75 + 0.1)$$
$$= 150 \text{ kHz}$$

2. $\Delta f = 75$ kHz, $f_m = 1.0$ kHz

$$B_{\text{FM}} = 2(75 + 1)$$
$$= 152 \text{ kHz}$$

3. $\Delta f = 75$ kHz, $f_m = 10$ kHz

$$B_{\text{FM}} = 2(75 + 10)$$
$$= 170 \text{ kHz}$$

Thus, although the modulating frequency changes from 0.1 to 9 kHz, or by a factor of 100 : 1, the bandwidth occupied by the spectrum alters very little, from 150 to 170 kHz. These examples illustrate why frequency modulation is sometimes referred to as a constant-bandwidth system.

Credit: Electronic Communication by Roddy and Coolen

Spectrum for Sinusoidal FM

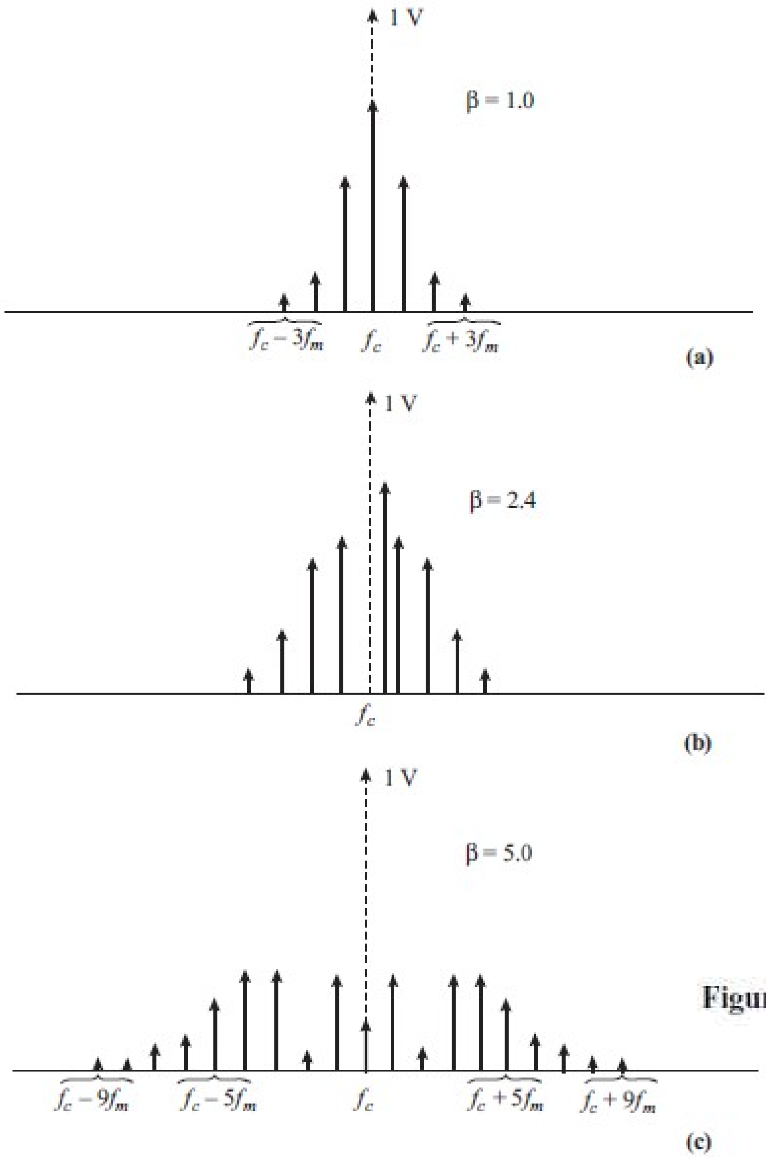


Figure 10.4.2 Spectra for sinusoidal FM with (a) $\beta = 1.0$, (b) $\beta = 2.4$ (note missing carrier), and (c) $\beta = 5.0$.

Credit: Electronic Communication by Roddy and Coolen

Average Power in Sinusoidal FM

The peak voltages of the spectrum components are given by $E_{n\ \max} = J_n(\beta)E_{c\ \max}$. Since the rms values denoted by E_n and E_c are proportional to the peak values, these are also related as

$$E_n = J_n(\beta)E_c \tag{10.5.1}$$

For a fixed load resistance R the average power of any one spectral component is $P_n = E_n^2/\mathrm{R}$. The total average power is the sum of all such components. Noting that there is only one carrier component and a pair of components for each side frequency, the total average power is

$$P_T = P_o + 2(P_1 + P_2 + \cdots) \tag{10.5.2}$$

In terms of the rms voltages this becomes

$$P_T = \frac{E_o^2}{R} + \frac{2}{R}(E_1^2 + E_2^2 + \cdots) \tag{10.5.3}$$

Credit: Electronic Communication by Roddy and Coolen

Average Power in Sinusoidal FM

In terms of the unmodulated carrier and the Bessel function coefficients, this is

$$
\begin{aligned}
P_T &= \frac{E_c^2 J_o^2(\beta)}{R} + \frac{2E_c^2}{R}(J_1^2(\beta) + J_2^2(\beta) + \cdots) \\
&= \frac{E_c^2}{R}[J_o^2(\beta) + 2(J_1^2(\beta) + J_2^2(\beta) + \cdots)] \\
&= P_c[J_o^2(\beta) + 2(J_1^2(\beta) + J_2^2(\beta) + \cdots)] \qquad (10.5.4)
\end{aligned}
$$

Here, the unmodulated power is $P_c = E_c^2/R$. A property of the Bessel functions is that the sum $[J_o^2(\beta) + 2(J_1^2(\beta) + J_2^2(\beta) + \cdots)] = 1$, so the total average power is equal to the unmodulated carrier power. This result might have been expected because the amplitude of the wave remains constant whether or not it is modulated. In effect, when modulation is applied, the total power that was originally in the carrier is redistributed between all the components of the spectrum. As previously pointed out, at certain values of β the carrier component goes to zero, which means that in these instances the power is carried by the side frequencies only.

Credit: Electronic Communication by Roddy and Coolen

Average Power in Sinusoidal FM

EXAMPLE 10.5.1

A 15−W unmodulated carrier is frequency modulated with a sinusoidal signal such that the peak frequency deviation is 6 kHz. The frequency of the modulating signal is 1 kHz. Calculate the average power output by summing the powers for all the side-frequency components.

SOLUTION The total average power output P is 15 W modulated. To check that this is also the value obtained from the sum of the squares of the Bessel functions, from Eq. (10.3.4) we have

$$\beta = \frac{\Delta f}{f_m} = \frac{6}{1} = 6$$

Credit: Electronic Communication by Roddy and Coolen

Average Power in Sinusoidal FM

The Bessel function values for $\beta = 6$ are read from Table 10.4.1 and substituted in Eq. (10.5.4) to give

$$P_T = 15[0.15^2 + 2(0.28^2 + 0.24^2 + 0.11^2 + 0.36^2 + 0.36^2 + 0.25^2 + 0.13^2 + 0.06^2 + 0.02^2 + 0.01^2)]$$

$$= 15(1.00)$$

$$= 15 \text{ W}$$

It follows that, since the average power does not change with frequency modulation, the rms voltage and current will also remain constant, at their respective unmodulated values.

Credit: Electronic Communication by Roddy and Coolen

Non-sinusoidal Modulation: Deviation Ratio

In the frequency-modulation process, intermodulation products are formed; that is, beat frequencies occur between the various side frequencies when the modulation signal is other than sinusoidal or cosinusoidal. It is a matter of experience, however, that the bandwidth requirements are determined by the maximum frequency deviation and maximum modulation frequency present in the modulating wave. The ratio of maximum deviation to maximum frequency component is termed the *deviation ratio*, which is defined as

$$D = \frac{\Delta F}{F_m} \tag{10.6.1}$$

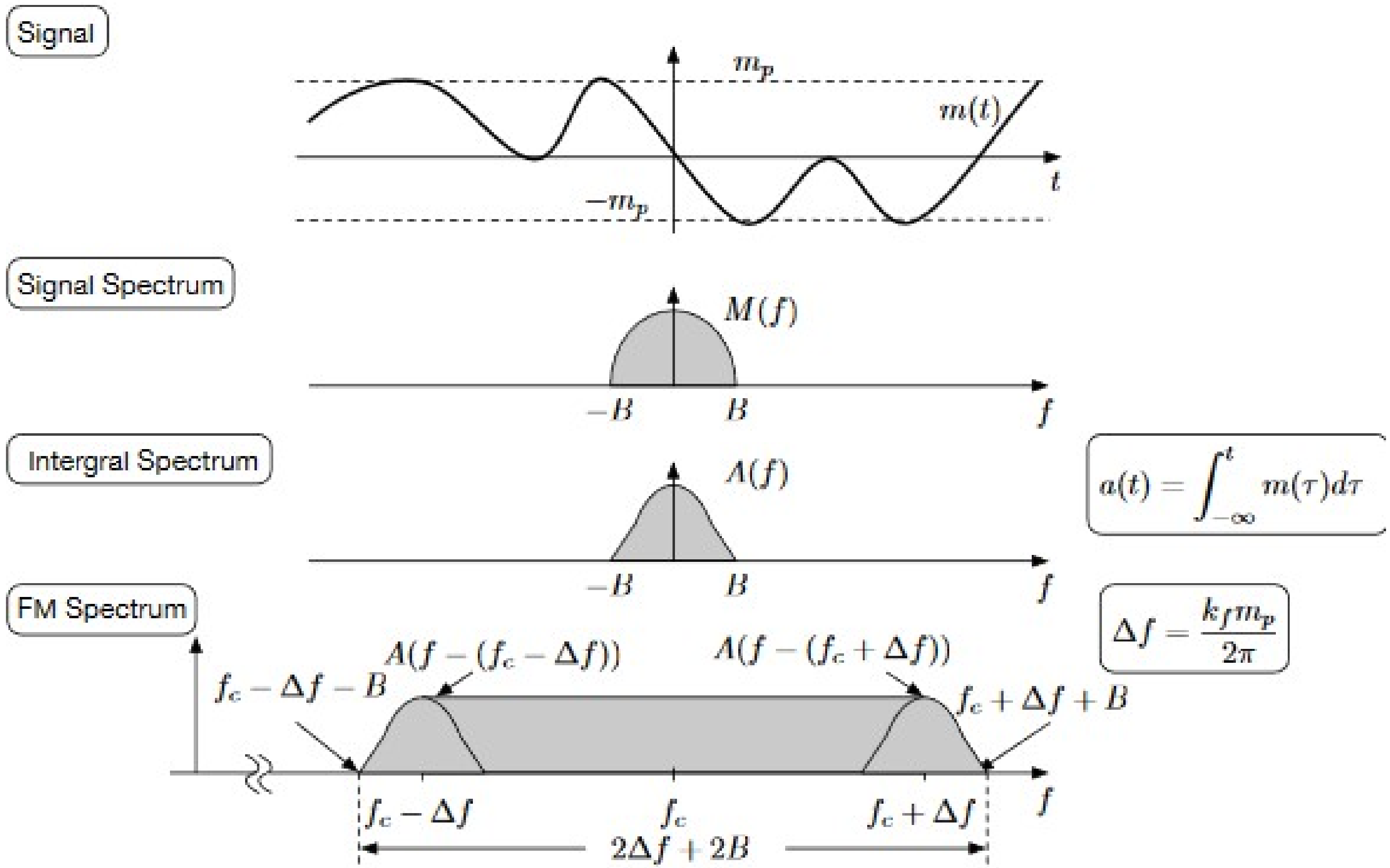
where ΔF is the maximum frequency deviation and F_m is the highest frequency component in the modulating signal. The bandwidth is then given by Eq. (10.4.2) on substituting D for β, with the same limitations on accuracy, as

$$\begin{aligned} B_{\max} &= 2(D + 1)F_m \\ &= 2(\Delta F + F_m) \end{aligned} \tag{10.6.2}$$

This is known as *Carson's rule*.

Credit: Electronic Communication by Roddy and Coolen

Carson's Rule in One Figure



Credit: https://web.stanford.edu

Non-sinusoidal Modulation: Deviation Ratio

EXAMPLE 10.6.1

Canadian regulations state that for FM broadcast the maximum deviation allowed is 75 kHz and the maximum modulation frequency allowed is 15 kHz. Calculate the maximum bandwidth requirements.

SOLUTION Using Eq. (10.6.2),

$$\begin{aligned} B_{\max} &= 2(\Delta F + F_m) \\ &= 2(75 + 15) \\ &= 180 \text{ kHz} \end{aligned}$$

Examination of Table 10.4.1 shows that side frequencies of 1% amplitude extend up to the ninth side-frequency pair, so Carson's rule underestimates the bandwidth required. For D equal to 5 or greater, a better estimate is given by $B_{\max} = 2(D + 2)F_m$. In this example, this would result in a maximum bandwidth requirement of 210 kHz. The economic constraints on commercial equipment limit the bandwidth capabilities of receivers to about 200 kHz.

Credit: Electronic Communication by Roddy and Coolen

Phase Modulation

Referring once again to the expression for an unmodulated carrier, this is

$$e_c(t) = E_{c\,\max} \cos(\omega_c t + \phi_c) \tag{10.8.1}$$

The phase angle ϕ_c is arbitrary and is included in the general case to show that the reference line for the rotating phasor of Fig. 10.2.2 is arbitrary. Figure 10.8.1(a) shows the situation for $\phi_c = 25°$.

When phase modulation is applied, it has the effect of moving the reference line (circuits for phase modulation are described in Section 10.12), as shown in Fig. 10.8.1(b). Mathematically, the phase modulation may be written as

$$\phi(t) = \phi_c + Ke_m(t) \tag{10.8.2}$$

where K is the *phase deviation constant*, analogous to the frequency deviation constant k introduced for frequency modulation. It will be seen that K must have units of radians per volt when ϕ_c is measured in radians. The constant phase angle ϕ_c has no effect on the modulation process, and this term can be dropped without loss of generality. Thus the equation for the phase modulated wave becomes

$$e(t) = E_{c\,\max} \cos(\omega_c t + Ke_m(t)) \tag{10.8.3}$$

Credit: Electronic Communication by Roddy and Coolen

Phase Modulation

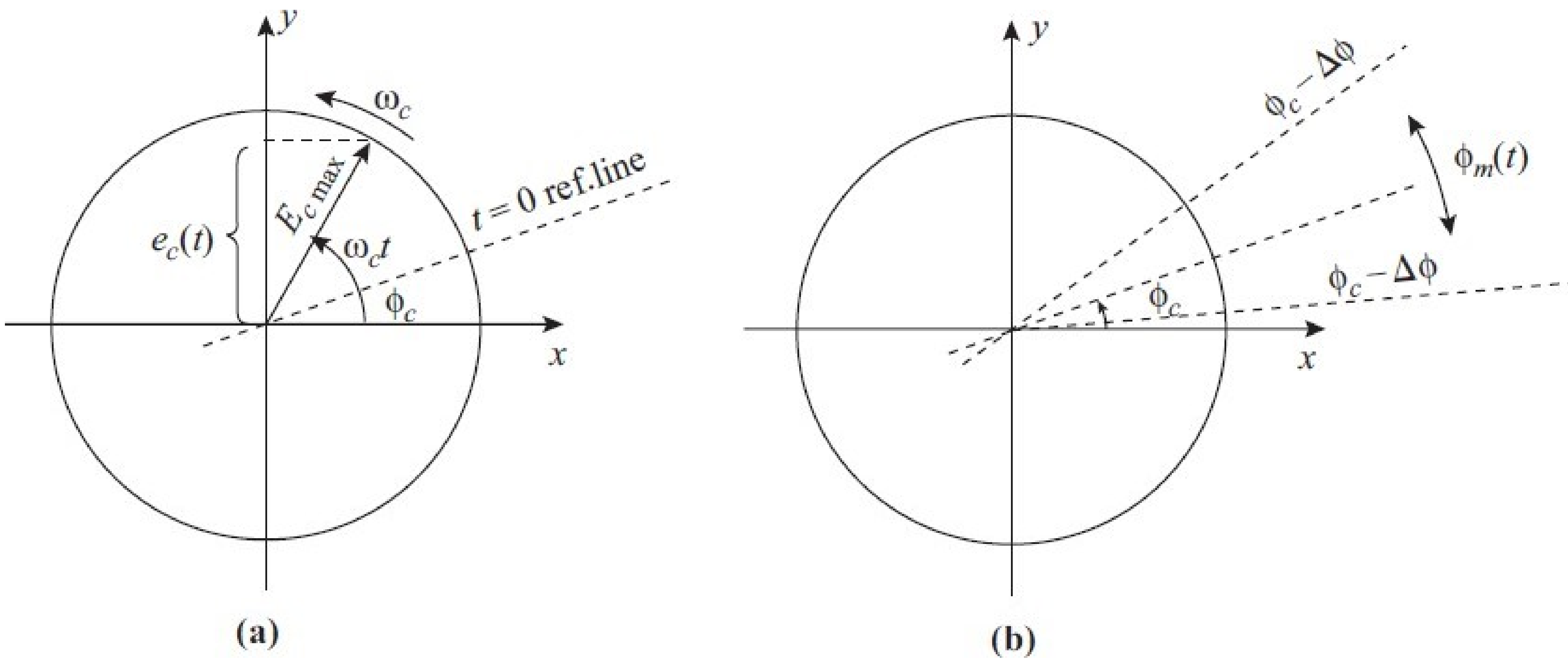


Figure 10.8.1 (a) Rotating phasor representation of a carrier of amplitude $E_{c\,\max}$ and phase lead $\phi_c = 25°$. (b) Effect of applying phase modulation.

Credit: Electronic Communication by Roddy and Coolen

Phase Modulation

EXAMPLE 10.8.1

A modulating signal given by $e_m(t) = 3 \cos (2\pi 10^3 t - 90°)$ volts is used to phase modulate a carrier for which $E_{c\ max} = 10$ V and $f_c = 20$ kHz. The phase deviation constant is $K = 2$ rad/V. Plot the modulated waveform over two cycles of the modulating function.

SOLUTION The phase modulation function is

$$\begin{aligned}\phi_m(t) &= Ke_m(t)\\ &= 2 \times 3 \cos(2\pi 10^3 t - 90°)\\ &= 60 \sin 2\pi 10^3 t\end{aligned}$$

Hence the modulated wave function is

$$e(t) = 10 \cos(4\pi 10^4 t + 6 \sin 2\pi 10^3 t)$$

This is identical to the modulated wave in Example 10.3.1 and hence the .graph of Fig. 10.3.2 applies.

Credit: Electronic Communication by Roddy and Coolen

Equivalence between PM and FM

It is seen that for phase modulation the angular term is given by

$$\theta(t) = \omega_c t + K e_m(t) \tag{10.9.1}$$

Now, the corresponding instantaneous frequency in general is obtained from

$$f_i(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} \tag{10.9.2}$$

Hence the equivalent instantaneous frequency for phase modulation is, on differentiating Eq. (10.9.1),

$$f_{iPM}(t) = f_c + \frac{K}{2\pi}\frac{de_m(t)}{dt} \tag{10.9.3}$$

The importance of this equation is that it shows how phase modulation may be used to produce frequency modulation. The differentiation is nullified by passing the modulating signal through an integrator before it is applied to the phase modulator, as shown in Fig. 10.9.1. The time constant of the modulator is shown as τ, so the actual voltage applied to the phase modulator is

$$v_m(t) = \frac{1}{\tau}\int_0^t e_m(t)\, dt \tag{10.9.4}$$

Credit: Electronic Communication by Roddy and Coolen

Sinusoidal Phase Modulation

For sinusoidal modulation, $e_m(t) = E_{m\,\max} \sin 2\pi f_m t$, and hence

$$\begin{aligned} Ke_m(t) &= KE_{m\,\max} \sin 2\pi f_m t \\ &= \Delta\phi \sin 2\pi f_m t \end{aligned} \tag{10.10.1}$$

where the *peak phase deviation* $\Delta\phi$ is proportional to the peak modulating signal and is

$$\Delta\phi = KE_{m\,\max} \tag{10.10.2}$$

The sine expression is used for the modulation signal rather than the cosine expression, because this brings out more clearly the equivalence in the spectra for FM and PM, as will be shortly shown. The equation for sinusoidal PM is therefore

$$e(t) = E_{c\,\max} \cos(\omega_c t + \Delta\phi \sin \omega_m t) \tag{10.10.3}$$

Credit: Electronic Communication by Roddy and Coolen

Equivalence between PM and FM

The equivalent frequency modulation is then

$$f_{i\mathrm{PM}}(t) = f_c + \frac{K}{2\pi}\frac{dv_m(t)}{dt}$$
$$= f_c + \frac{K}{2\pi\tau}e_m(t) \qquad (10.9.5)$$

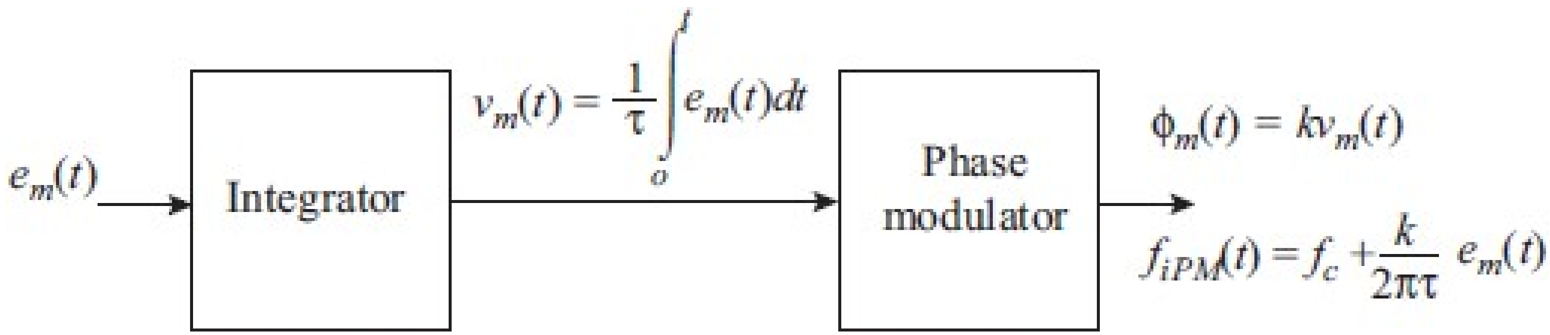


Figure 10.9.1 How FM may be obtained from PM.

Credit: Electronic Communication by Roddy and Coolen

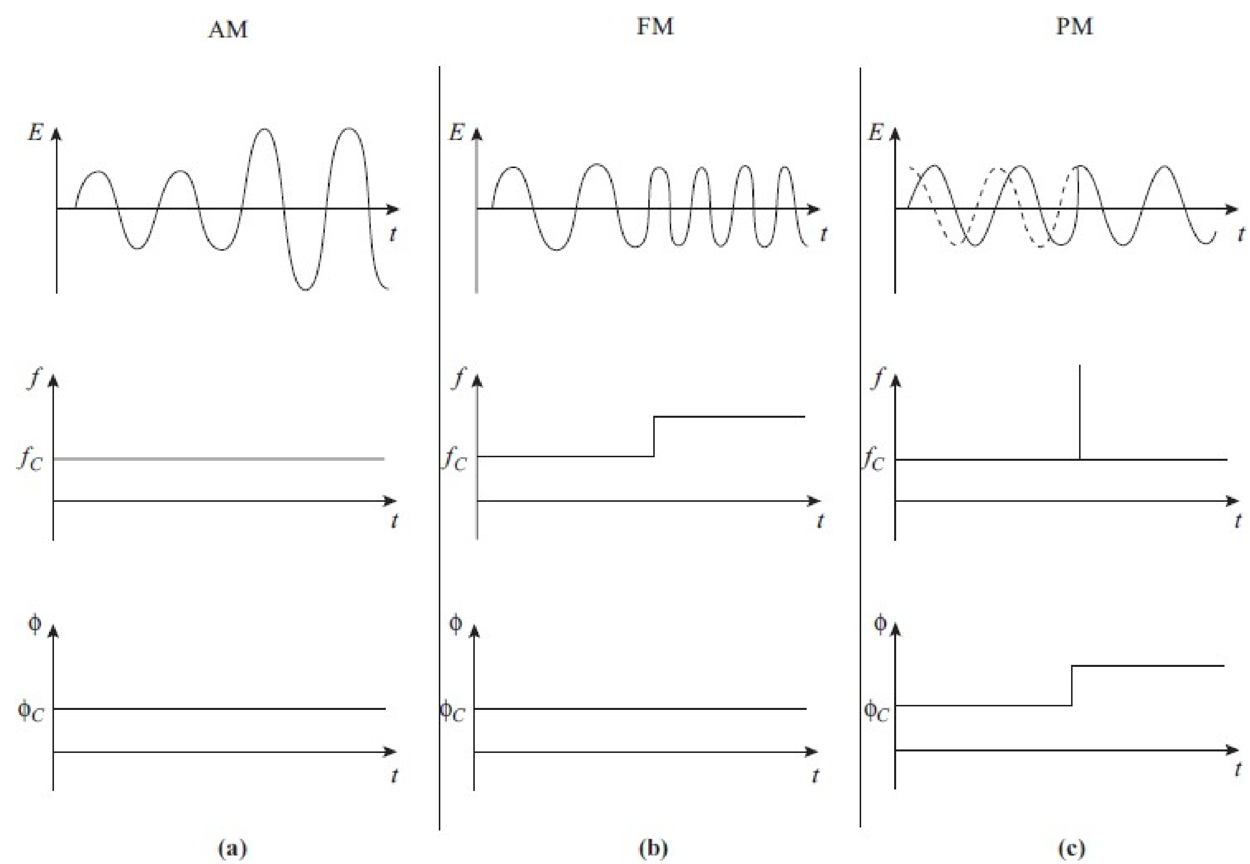


Figure 10.9.2 Modulating with a step waveform: (a) AM, (b) FM, (c) PM.

Credit: Electronic Communication by Roddy and Coolen

S.No.	FM	AM
1.	Amplitude of FM wave is constant. It is independent of the modulation index.	Amplitude of AM wave will change with the modulating voltage.
2.	Hence, transmitted power remains constant. It is independent of m_f.	Transmitted power is dependent on the modulation index.
3.	All the transmitted power is useful.	Carrier power and one sideband power are useless.
4.	FM receivers are immune to noise.	AM receivers are not immune to noise.
5.	It is possible to decrease noise further by increasing deviation.	This feature is absent in AM.
6.	Bandwidth = $2[\Delta f + f_m]$. The bandwidth depends on modulation index.	BW = 2 f_m. It is not dependent on the modulation index.
7.	BW is large. Hence, wide channel is required.	BW is much less than FM.

NBFM and WBFM

S.No.	Parameter/Characteristics	Wideband FM	Narrowband FM
1.	Modulation index	Greater than 1	Less than or slightly greater than 1
2.	Maximum deviation	75 kHz	5 kHz
3.	Range of modulating frequency	30 Hz to 15 kHz	30 Hz to 3 kHz
4.	Maximum modulation index	5 to 2500	Slightly greater than 1
5.	Bandwidth	Large about 15 times higher than BW of narrowband FM	Small. Approximately same as that of AM
6.	Applications	Entertainment broad-casting (can be used for high quality music transmission)	FM mobile communication like police wireless, ambulance etc. (This is used for speech trans-mission)
7.	Pre-emphasis and De-emphasis	Needed	Needed

In the case of amplitude modulation (Fig. 10.9.2[a]), the amplitude follows the step change, while the frequency and phase remain constant with time. The amplitude change could be observed, for example on an oscilloscope. With frequency modulation, shown in Fig. 10.9.2(b), the amplitude and phase remain constant while the frequency follows the step change. Again, this change could be observed, for example on a frequency counter.

With phase modulation, the amplitude remains constant while the phase angle follows the step change with time, as shown in Fig. 10.9.2(c). The phase change is measured with reference to what the phase angle would have been with no modulation applied. After the step change in phase, the sinusoidal carrier appears as though it is a continuation of the dashed curve shown on the amplitude–time graph of Fig. 10.9.2(c). Also, from the amplitude–time graph it is seen that the frequency of the wave before the step change is the same as after the step change. However, at the step change in phase, the abrupt displacement of the waveform on the time axis makes it appear as though the frequency undergoes an abrupt change. This is shown by the spike in the frequency–time graph in Fig. 10.9.2(c). A phase meter could be used to measure the change in phase, but this requires the reference waveform and is not as direct as the measurement of amplitude or frequency. The spike change in frequency could be measured directly on a frequency counter. In principle, the apparent change of frequency with phase modulation will occur even where the source frequency of the carrier is held constant, for example by using a crystal oscillator. In practice, it proves to be more difficult to achieve large frequency swings using phase modulation.

Credit: Electronic Communication by Roddy and Coolen

Sinusoidal Phase Modulation

This is identical to Eq. (10.3.5) with $\Delta\phi = \beta$, and therefore the trigonometric expansion will be similar to that for sinusoidal FM, containing a carrier term, and side frequencies at $f_c \pm nf_m$. The amplitudes are also given in terms of Bessel functions of the first kind, $J_n(\Delta\phi)$. In this case the argument is the peak phase deviation $\Delta\phi$, rather than the frequency modulation index β. It follows therefore that the magnitude and extent of the spectrum components for the PM wave will be the same as for the FM wave for which $\Delta\phi$ is numerically equal to β. It also follows that the power relationships developed in Section 10.5 for sinusoidal FM apply to the equivalent sinusoidal PM case.

For analog modulating signals, phase modulation is used chiefly as a stage in the generation of frequency modulation; as previously described. It should be noted that the demodulators in analog FM receivers (even the phase discriminators described in Section 10.14) interpret the received signal as frequency modulation, real or equivalent. The effect this has on the reception of a phase modulated carrier is illustrated in Problem 10.17.

With sinusoidal phase modulation, application of Eq. (10.9.3) gives the equivalent frequency modulation as

$$\begin{aligned} f_{i\,eq}(t) &= f_c + \Delta\phi f_m \cos\omega_m t \\ &= f_c + \Delta f_{eq} \cos\omega_m t \end{aligned} \tag{10.10.4}$$

The equivalent peak deviation is seen to be

$$\Delta f_{eq} = \Delta\phi \cdot f_m \tag{10.10.5}$$

The other major area of application for phase modulation lies in the digital modulation of carriers.

Credit: Electronic Communication by Roddy and Coolen

Comparison of Wideband and Narrowband FM

By convention, *wideband FM* has been defined as that in which the modulation index normally exceeds unity. This is the type so far discussed. Since the maximum permissible deviation is 75 kHz and modulating frequencies range from 30 Hz to 15 kHz, the maximum modulation index ranges from 5 to 2500. (The maximum permissible deviation for the sound accompanying TV transmissions is 25 kHz in the United States NTSC system and 50 kHz in the PAL system used in Europe and Australia. Both are wideband systems.) The modulation index in narrowband FM is near unity, since the maximum modulating frequency there is usually 3 kHz, and the maximum deviation is typically 5 kHz.

Credit: Electronic Communication System by Kennedy and Davis

Comparison of Wideband and Narrowband FM

The proper bandwidth to use in an FM system depends on the application. With a large deviation; noise will be better suppressed (as will other interference), but care must be taken to- ensure that impulse noise peaks do not become excessive. On the other hand, the wideband system will occupy up to 15 times the bandwidth of the narrowband system. These considerations have resulted in wideband systems being used in entertainment broadcasting, while narrowband systems are employed for communications.

Credit: Electronic Communication System by Kennedy and Davis

Comparison of Wideband and Narrowband FM

Thus narrowband FM is used by the so-called *FM mobile* communications services. These include police, ambulances, taxicabs, radio-controlled appliance repair services, short-range VHF ship-to-shore services and the Australian "Flying Doctor“ service. The higher audio frequencies are attenuated, as indeed they are in most carrier (long-distance) telephone systems, but the resulting speech quality is still perfectly adequate. Maximum deviations of 5 to 10 kHz are permitted, and the channel space is not much greater than for AM broadcasting, i.e., of the order of 15 to 30 kHz Narrowband systems with even lower maximum deviations are envisaged. Pre-emphasis and de-emphasis are used, as indeed they are with all FM transmissions.

Credit: Electronic Communication System by Kennedy and Davis

Narrowband FM

Following are the features of Narrowband FM.

- This frequency modulation has a small bandwidth when compared to wideband FM.
- The modulation index β is small, i.e., less than 1.
- Its spectrum consists of the carrier, the upper sideband and the lower sideband.
- This is used in mobile communications such as police wireless, ambulances, taxicabs, etc.

Wideband FM

Following are the features of Wideband FM.

- This frequency modulation has infinite bandwidth.
- The modulation index β is large, i.e., higher than 1.
- Its spectrum consists of a carrier and infinite number of sidebands, which are located around it.
- This is used in entertainment, broadcasting applications such as FM radio, TV, etc.

Credit: https://www.tutorialspoint.com

Stereophonic FM Multiplex System

Stereo FM transmission is a modulation system in which sufficient information is sent to the receiver to enable it to reproduce original stereo material. It became commercially available in 1961, several years after commercial monaural transmissions. Like color TV (which of course came after monochrome TV), it suffers from the disadvantage of having been made more complicated than it needed to be, to ensure that it would be compatible with the existing system. Thus, in stereo FM, it is not possible to have a two-channel system with a *left* channel and a *right* channel transmitted simultaneously and independently, because a monaural system would not receive all the information in an acceptable form.

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

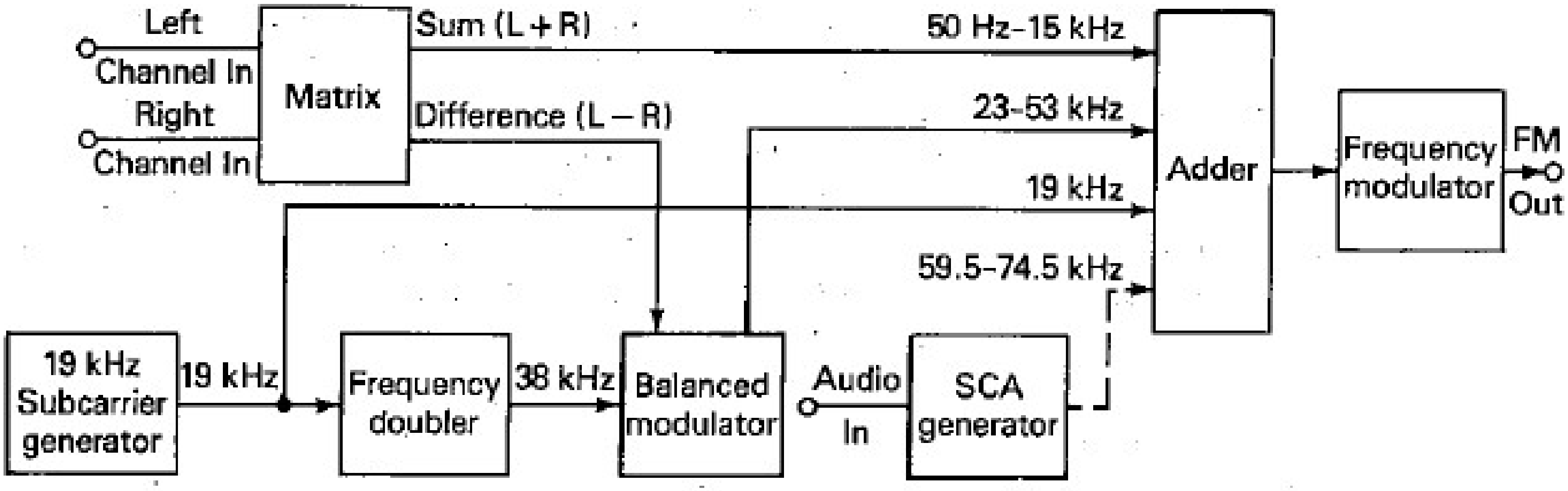


FIGURE 5-9 **Stereo FM multiplex generator with optional SCA.**

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

As shown in the block diagram of Figure 5-9, the two channels in the FM stereo multiplex system are passed through a matrix which produces two outputs. The sum *(L + R)* modulates the carrier in the same manner as the signal in a monaural transmission, and this is the signal which is demodulated and reproduced by a mono receiver tuned to a stereo transmission. The other output of the matrix is the difference signal *(L - R).* After demodulation in a stereo receiver, *(L* - R) will be added to *(L + R)* to produce the left channel, while the difference between the two signals will produce the right channel. What happens, in essence, is that the difference signal is shifted in frequency from the 50- to 15,000-Hz range (which it would otherwise co-occupy with the sum signal) to a higher frequency.

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

Such signal "stacking" is known as *multiplexing,* hence the name of the system. In this case, as in other multiplexing, a form of single sideband suppressed carrier (SSBSC) is used, with the signals to be multiplexed upbeing modulated onto a subcarrier at a high audio or supersonic frequency. However, -there is a snag here, which makes this form of multiplexing different from the more common ones. The problem is that the lowest audio frequency is 50 Hz, much lower than the normal minimum of 300 Hz encountered in communications voice channels. This makes it difficult to suppress the unwanted sideband. without affecting the wanted one; pilot carrier extraction in the receiver is equally difficult. Some form of carrier must be transmitted, to ensure that the receiver has a stable reference frequency for demodulation; otherwise, distortion of the difference signal will result.

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

The two problems are solved in similar ways. In the first place, the difference signal is applied to a balanced modulator (as it would be in any multiplexing system) which suppresses the carrier. Both sidebands are then used as modulating signals and duly transmitted, whereas normally one might expect one of them to be removed prior to transmission. Since the subcarrier frequency is 38 kHz, the sidebands produced by the difference signal occupy the frequency range from 23 to 53 kHz. It is seen that they do not interfere with the sum signal, which occupies the range of 50 Hz to 15 kHz.

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

The reason that the 38-kHz subcarrier is generated by a 19-kHz oscillator whose frequency is then doubled may now be explained. Indeed, this is the trick used to avoid the difficulty of having to extract the pilot carrier from among the close sideband frequencies in the receiver. As shown in the block diagram (Figure 5-9), the output of the 19-kHz subcarrier generator is added to the sum and difference signals in the output adder preceding the modulator. In the receiver; the frequency of the 19-kHz signal is doubled, and it can then be reinserted as the carrier for the difference signal. It should be noted that the subcarrier is inserted at a level of 10 percent, which is both adequate and not so large as to take undue power from the sum and difference signals (or to cause overmodulation). The frequency of 19 kHz fits neatly into the space between the top of the sum signal and the bottom of the difference signal. It is far enough from each of them so that no difficulty is encountered in the receiver.

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

The FM stereo multiplex system described here is the one used in the United States, and is in accordance with the standards established by the Federal Communications Commission (FCC) in 1961. Stereo FM has by now spread to broadcasting in most other parts of the world, where the systems in use are either identical or quite similar to the above. A Subsidiary Communications Authorization (SCA) signal may also be transmitted in the U.S. stereo multiplex system. It is the remaining signal feeding in to the output adder. It is shown dashed in the diagram because it is not always present (See Figure 5-10). Some stations provide SCA as a second, medium quality transmission, used as background music in stores, restaurants and other similar settings.

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

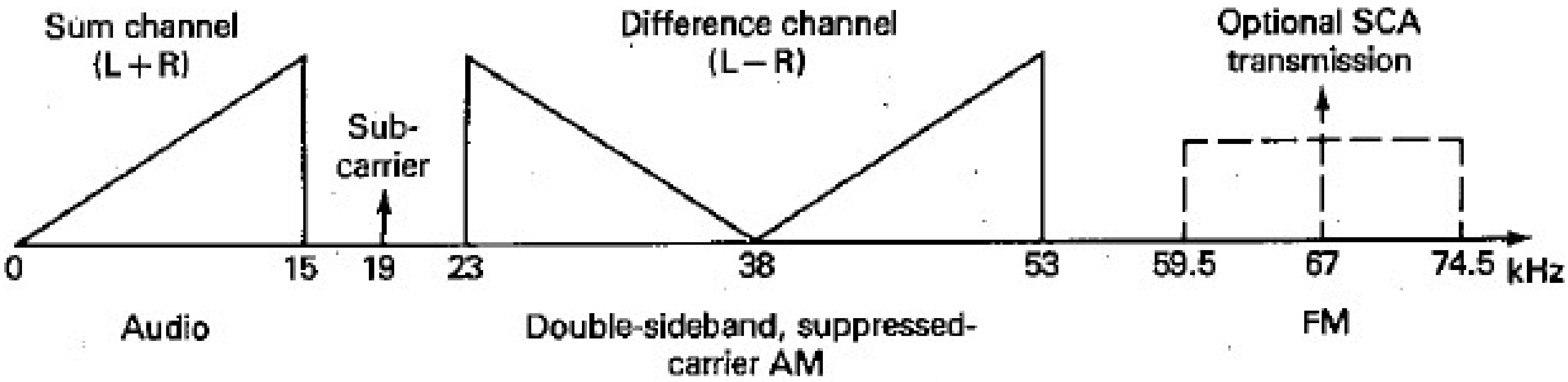


FIGURE 5-10 Spectrum of stereo FM multiplex modulating signal (with optional SCA).

Credit: Electronic Communication System by Kennedy and Davis

Stereophonic FM Multiplex System

SCA uses a subcarrier at 67 kHz, modulated to a depth of ±7.5 kHz by the audio signal. Frequency modulation is used. The frequency band thus occupied ranges from 59.5 to 74.5 kHz and fits sufficiently above the difference signal as not to interfere with it. The overall frequency allocation within the modulating signal of an FM stereo multiplex transmission with SCA is shown in Figure 5-10. The amplitude of the sum and difference signals must be reduced (generally by 10 percent) in the presence of SCA; otherwise, overmodulation of the main carrier could result.

Credit: Electronic Communication System by Kennedy and Davis

GENERATION OF FREQUENCY MODULATION

The prime requirement of a frequency modulation system is a variable output frequency, with the variation proportional to the instantaneous amplitude of the modulating voltage. The subsidiary requirements are that the unmodulated frequency should be constant, and the deviation independent of the modulating frequency. If the system does not produce these characteristics, corrections can be introduced during the modulation process.

Credit: Electronic Communication System by Kennedy and Davis

FM Generation Methods

One method of FM generation suggests itself immediately. If either the capacitance or inductance of an *LC* oscillator tank is varied, frequency modulation of some form will result. If this variation can be made directly proportional to the voltage supplied by the modulation circuits, true FM will be obtained.

Credit: Electronic Communication System by Kennedy and Davis

FM Generation Methods

There are several controllable electrical and electronic phenomena which provide a variation of capacitance as a result of a voltage change. There are also some in which an inductance may be similarly varied. Generally, if such a system is used, a voltage-variable reactance is placed across the tank, and the tank is tuned so that (in the absence of modulation) the oscillating frequency is equal to the desired carrier frequency. The capacitance (or inductance) of the variable element is changed with the modulating voltage, increasing (or decreasing) as the modulating voltage increases positively, and going the other way when the modulation becomes negative. The larger the departure of the modulating voltage from zero, the larger the reactance variation and therefore the frequency variation. When the modulating voltage is zero, the variable reactance will have its average value. Thus, at the carrier frequency, the oscillator inductance is tuned by its own (fixed) capacitance in parallel with the average reactance of the variable element.

Credit: Electronic Communication System by Kennedy and Davis

FM Generation Methods

There are a number of devices whose reactance can be varied by the application of voltage. The three-terminal ones include the reactance field-effect transistor (FET), the bipolar transistor and the tube. Each of them is a normal device which has been biased so as to exhibit the desired property. By far the most common of the two-terminal devices is the varactor diode. Methods of generating that do not depend on varying the frequency of an oscillator will be discussed under the heading "Indirect Method." A prior generation of phase modulation is involved.

Credit: Electronic Communication System by Kennedy and Davis

Direct Methods

Of the various· methods of providing a voltage-variable reactance which can be connected across the tank circuit of an oscillator, the most common are the reactance modulator and the varactor diode.

Credit: Electronic Communication System by Kennedy and Davis

Basic reactance modulator

Provided that certain simple conditions are met, the impedance *z,* as seen at the input terminals *A-A* of Figure 5-11, is. almost entirely reactive. The circuit shown is the basic circuit of a FET reactance modulator, which behaves as a three-terminal reactance that may be connected across the tank circuit of the oscillator to be frequency-modulated. It can be made inductive or capacitive by a simple component change. The value of this reactance is proportional to the transconductance of the device, which can be made to depend on the gate bias and its variations. Note that an FET is used in the explanation here for simplicity only. Identical reasoning would apply top. bipolar transistor or a vacuum tube, or indeed to any other amplifying device.

Credit: Electronic Communication System by Kennedy and Davis

Basic reactance modulator

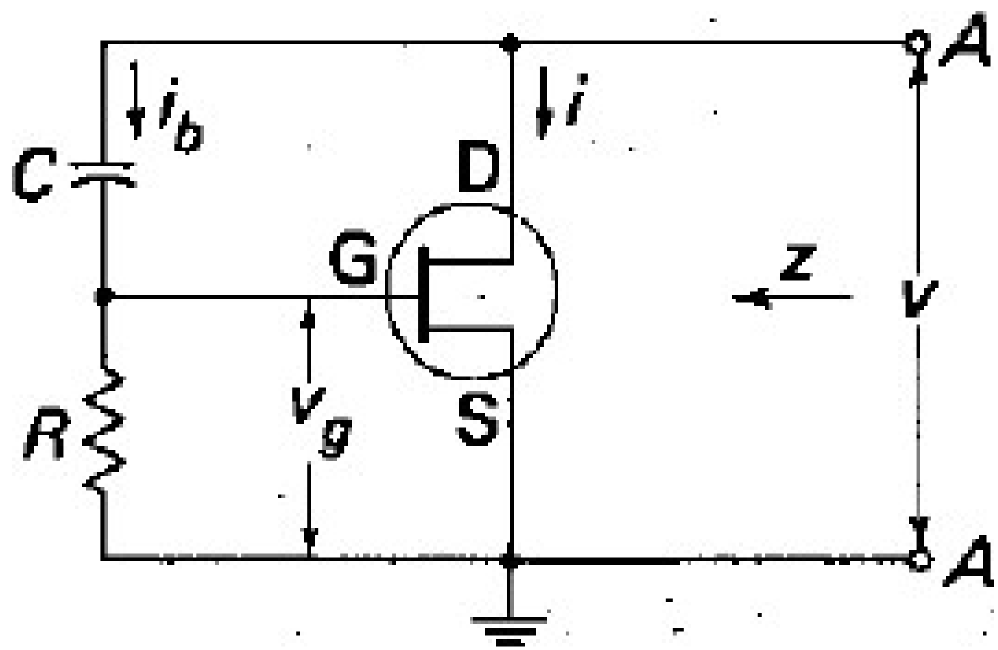


FIGURE 5-11 Basic reactance modulator.

Credit: Electronic Communication System by Kennedy and Davis

Theory of reactance modulators

In order to determine z; a voltage v is applied to the terminals *A-A* between which the impedance is to be measured, and the resulting current i is calculated. The applied voltage is then divided by this current, giving the impedance seen when looking into the terminals. In order for this impedance to be a pure reactance (it is capacitive here), two requirements must be fulfilled. The first is that the bias network current i_b must be negligible compared to the drain current. The impedance of the bias network must be large enough to be ignored .. The second requirement is that the drain-to-gate impedance (X_c here) must (be greater than the gate to- source impedance *(R* in this case), preferably by more than 5: I. The following analysis may then be applied:

Credit: Electronic Communication System by Kennedy and Davis

Basic reactance modulator

$$v_g = i_b R = \frac{Rv}{R - jX_C} \tag{5-15}$$

The FET drain current is

$$i = g_m v_g = \frac{g_m R v}{R - jX_C} \tag{5-16}$$

Therefore, the impedance seen at the terminals A–A is

$$z = \frac{v}{i} = v \div \frac{g_m R v}{R - jX_C} = \frac{R - jX_C}{g_m R} = \frac{1}{g_m}\left(1 - \frac{jX_C}{R}\right) \tag{5-17}$$

If $X_C \gg R$ in Equation (5-17), the equation will reduce to

$$z = -j\,\frac{X_C}{g_m R} \tag{5-18}$$

This impedance is quite clearly a capacitive reactance, which may be written as

$$X_{\text{eq}} = \frac{X_C}{g_m R} = \frac{1}{2\pi f g_m RC} = \frac{1}{2\pi f C_{\text{eq}}} \tag{5-19}$$

From Equation (5-19) it is seen that under such conditions the input impedance of the device at A–A is a pure reactance and is given by

$$C_{\text{eq}} = g_m RC \tag{5-20}$$

Credit: Electronic Communication System by Kennedy and Davis

Basic reactance modulator

The following should be noted from Equation (5-20):

1.This equivalent capacitance depends on the device transconductance and can therefore be varied with bias voltage.

2.The capacitance can be originally adjusted to any value, within reason, by varying the components R and C.

3. The expression $g_m RC$ has the correct dimensions of capacitance; R, measured in ohms, and K_m, measured in siemens(s) : Cancel each other's dimensions, leaving C as required.

4.It was stated earlier that the gate-to-drain impedance must be much larger than the gate-to-source impedance. This is illustrated by Equation (5-17). If X_c/R had not been much greater than unity, z would have had a resistive component as well.

Credit: Electronic Communication System by Kennedy and Davis

Basic reactance modulator

If R is not much less than X_C (in the particular reactance modulator treated), the gate voltage will no longer be exactly 90° out of phase with the applied voltage v, nor will the drain current i. Thus, the input impedance will no longer be purely reactive. As shown in Equation (5-17), the resistive component for this particular FET reactance modulator will be $1/g_m$. This component contains g_m, it will vary with the applied modulating voltage. This variable resistance (like the variable reactance) will appear directly across the tank circuit of the master oscillator, varying its Q and therefore its output voltage. A certain amount of amplitude modulation will be created. This applies to all the forms of reactance modultor. If the situation is unavoidable, the oscillator being modulated must be followed by an amplitude limiter.

Credit: Electronic Communication System by Kennedy and Davis

Basic reactance modulator

The gate-to-drain impedance is, in practice, made five to ten times the gate-to source impedance. Let $Xc = nR$ (at the carrier frequency) in the capacitive RC reactance FET so far discussed. Then

$$X_C = \frac{1}{\omega C} = nR$$

$$C = \frac{1}{\omega nR} = \frac{1}{2\pi fnR} \tag{5-21}$$

Substituting Equation (5-21) into (5-20) gives

$$C_{eq} = g_m RC = \frac{g_m R}{2\pi fnR}$$

$$C_{eq} = \frac{g_m}{2\pi fn} \tag{5-22}$$

Equation (5-22) is a very useful formula. In practical situations the frequency of operation and the ratio of X_C to R are the usual starting data from which other calculations are made.

Credit: Electronic Communication System by Kennedy and Davis

Types of reactance modulators

There are four different arrangements of the reactance modulator (including the one initially discussed) which will yield useful results. Their data are shown in Table 5-3, together with their respective prerequisites and output reactance formulas. The general prerequisite for all of them is that drain current must be much greater than bias network current. It is seen that two of the arrangements give a capacitive "reactance, and the other two give an inductive reactance.

TABLE 5-3

NAME	Z_{gd}	Z_{gs}	CONDITION	REACTANCE FORMULA
RC capacitive	C	R	$X_C \gg R$	$C_{eq} = g_m RC$
RC inductive	R	C	$R \gg X_C$	$L_{eq} = \frac{RC}{g_m}$
RL inductive	L	R	$X_L \gg R$	$L_{eq} = \frac{L}{g_m R}$
RL capacitive	R	L	$R \gg X_L$	$C_{eq} = \frac{g_m L}{R}$

Credit: Electronic Communication System by Kennedy and Davis

Reactance modulator

In the reactance modulator shown in Figure 5-12, an *RC* capacitive transistor reactance modulator, quite a common one in use, operates on the tank circuit of a Clapp-Gouriet oscillator. Provided that the correct component values are employed, any reactance modulator may be connected across the tank circuit of any *LC* oscillator (not crystal) with one provision: The oscillator used must not be one that requires two tuned circuits for its operation, such as the tuned-base-tuned-collector oscillator. The Hartley and Colpitts (or Clapp-Gouriet) oscillators are most commonly used, and each should be isolated with a buffer. Note the RF chokes in the circuit shown, they are used to isolate various points of the circuit for alternating current while still providing a dc path.

Credit: Electronic Communication System by Kennedy and Davis

Transistor reactance modulator

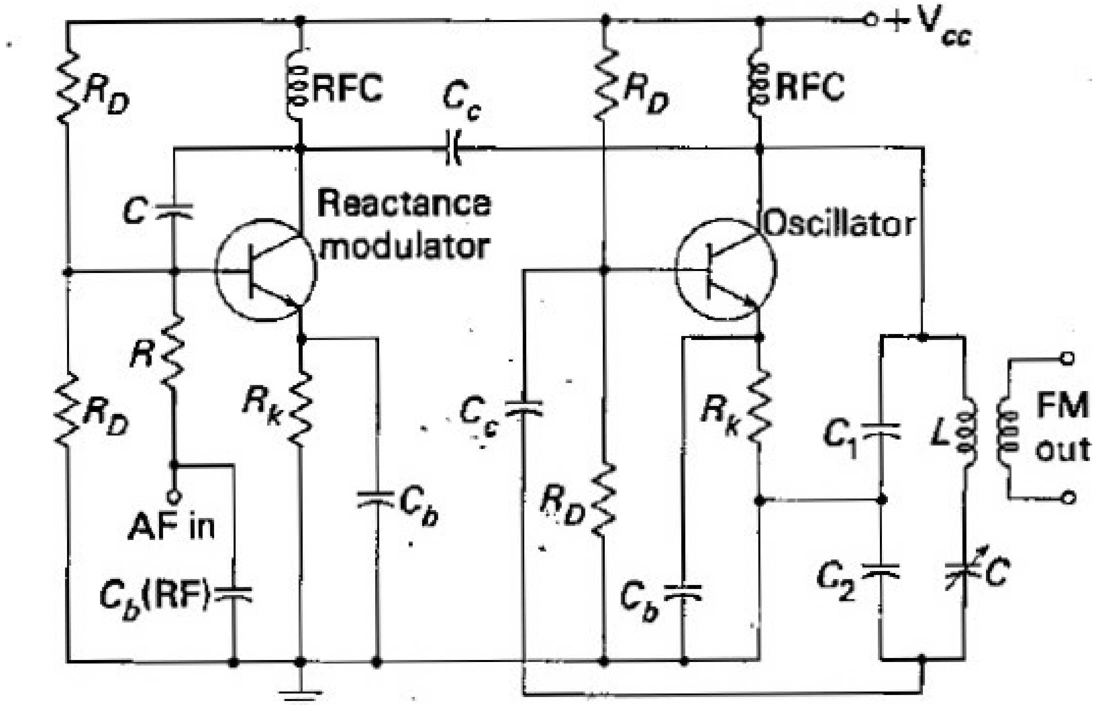


FIGURE 5-12 Transistor reactance modulator.

Credit: Electronic Communication System by Kennedy and Davis

Varactor Diode modulator

A varactor diode is a semiconductor diode whose junction capacitance varies linearly with the applied voltage when the diode is reverse biased. It may also be used to produce frequency modulation. Varactor -diodes are certainly employed frequently, together with a reactance modulator, to provide automatic frequency correction for an FM transmitter. The circuit of Figure 5-13 shows such a modulator. It is seen that the diode has been back-biased to provide the junction capacitance effect, and since this bias is varied by the modulating voltage which is in series with it, the junction capacitance will also vary, causing the oscillator frequency to change accordingly. Although this is the simplest reactance modulator circuit, it does have the disadvantage of using a two-terminal device; its applications are somewhat limited. However, it is often used for automatic frequency control and remote tuning.

Credit: Electronic Communication System by Kennedy and Davis

Varactor Diode modulator

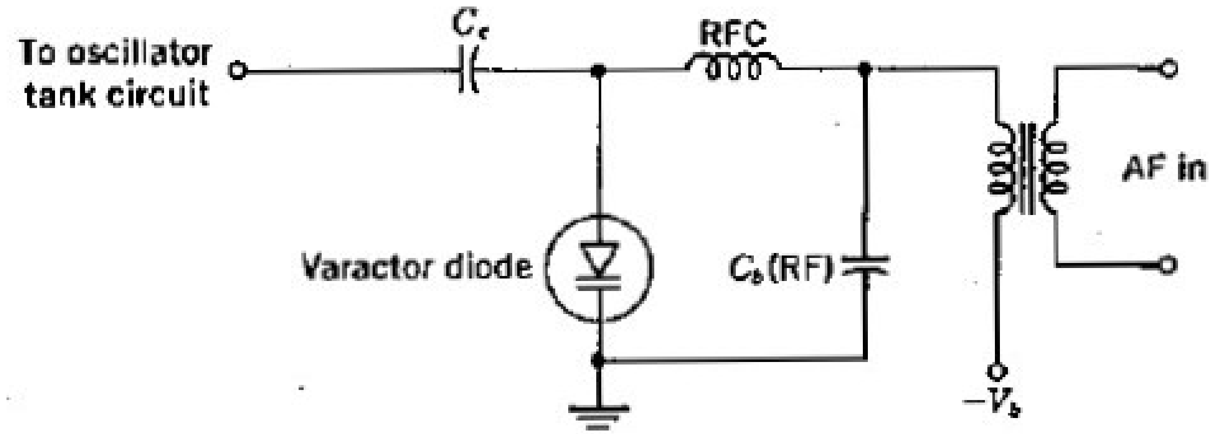


FIGURE 5-13 Varactor diode modulator.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

Although the oscillator on which a reactance modulator operates cannot be crystal controlled, it must nevertheless have the stability of a crystal oscillator if it is to be part of a commercial transmitter. This suggests that frequency stabilization of the reactance, modulator is required, and since this is very similar to an automatic frequency control system, AFC will also be considered. The block diagram of a typical system is shown in Figure 5-14.

Credit: Electronic Communication System by Kennedy and Davis

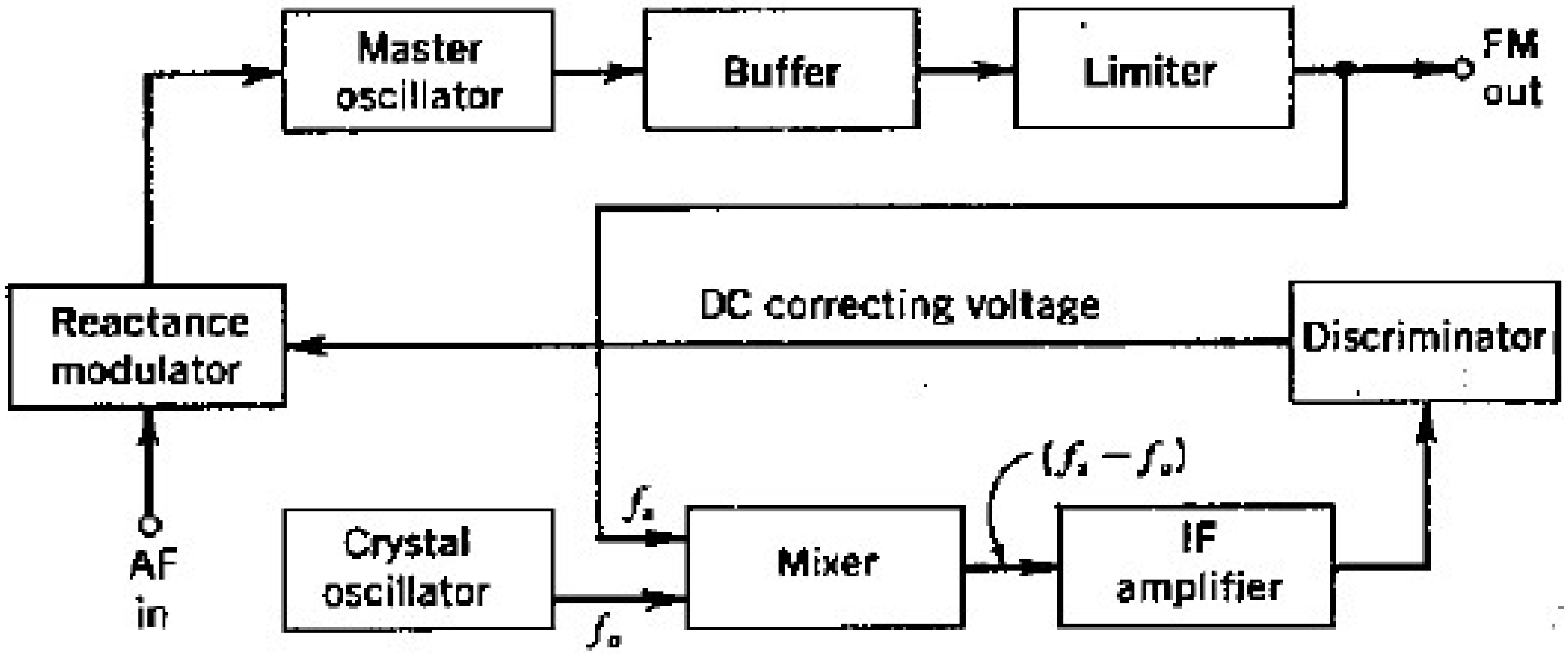


FIGURE 5-14 A typical transmitter AFC system.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

As can be seen, the reactance modulator operates on the tank circuit of an *LC* oscillator. It is isolated by a buffer, whose output goes through an amplitude limiter to power amplification by class *C* amplifiers (not shown). A fraction of the output is taken from the limiter and fed to a mixer, which also receives the signal from a crystal oscillator. The resulting difference signal, which has a frequency usually about one twentieth of the master oscillator frequency, is amplified and fed to a phase discriminator. The output of the discriminator is connected to the reactance modulator and provides a dc voltage to correct automatically any drift in the average frequency of the master oscillator.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

Operation: The time constant of the diode load of the discriminator is quite large, in the order of 100 milliseconds (100 ms). Hence the discriminator will react to slow changes in the incoming frequency but not to normal frequency changes due to frequency modulation (since they are too fast). Note also that the discriminator must be connected to give a positive output if the input frequency is higher than the discriminator tuned frequency, and a negative output if it is lower.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

Consider what happens when the frequency of the master oscillator drifts high. A higher frequency will eventually be fed to the mixer, and since the output of the crystal oscillator may be considered as stable, a somewhat higher frequency will also be fed to the phase discriminator. Since the discriminator is tuned to the correct frequency difference which should exist between the two oscillators, and its input frequency is now somewhat higher, the output of the discriminator will be a positive dc voltage. This voltage is fed in series with the input of the reactance modulator and therefore increases its transconductance. The output capacitance of the reactance modulator is given by $C_{eq} = g_m RC$, and it is, of course, increased, therefore lowering the oscillator's center frequency. The frequency rise which caused all this activity has been corrected. When the master oscillator drifts low, a negative correcting voltage is obtained from this circuit, and the frequency of the oscillator is increased correspondingly.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

This correcting dc voltage may instead be fed to a varactor diode connected across the oscillator tank and be used for AFC only. Alternatively, a system of amplifying the dc voltage and feeding it to a servomotor which is connected to a trimmer capacitor in the oscillator circuit may be used. The setting of the capacitor plates is then altered by the motor and in turn corrects the frequency.

Credit: Electronic Communication System by Kennedy and Davis

Reasons for mixing If it were possible to stabilize the oscillator frequency directly instead of first mixing it with the output of a crystal oscillator, the circuit would be much simpler but the performance would suffer. It must be realized that the stability of the whole circuit depends on the stability of the discriminator. If its frequency drifts, the output frequency of the whole system must drift equally. The discriminator is a passive network and can therefore be expected to be somewhat more stable than the master oscillator, by a factor of perhaps 3: 1 at most. A well-designed *LC* oscillator could be expected. to drift by about 5 parts in 10,000 at most, or about 2.5 kHz at 5 MHz, so that direct stabilization would improve this only to about 800 Hz at best.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

When the discriminator is tuned to a frequency that is only one-twentieth of the master oscillator frequency, then (although its percentage frequency drift may still be the same) the actual drift in hertz is one-twentieth of the previous ·figure, or 40 Hz in this case. The master oscillator will thus be held to within approximately 40 Hz of its 5-MHz nominal frequency. The improvement over direct stabilization is therefore in direct proportion to the reduction in center frequency of the discriminator, or twentyfold here.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

Unfortunately, it is not possible to make the frequency reduction much greater than 20: I, although the frequency stability would undoubtedly be improved even further. The reason for this is a practical one. The bandwidth of the discriminator's curve could then become insufficient (see Section 6-4.3) to encompass the maximum possible frequency drift of the master oscillator, so that stabilization could be lost. There is a cure for this also. If the frequency of the output of the mixer is divided, the frequency drift will be divided with it. The discrimination can now be tuned to this divided frequency, and stability can be improved without theoretical limit.

Credit: Electronic Communication System by Kennedy and Davis

Stabilized Reactance Modulator-AFC

Although the previous discussion is concerned directly with the stabilization of the center frequency of an FM transmitter, it applies equally to the frequency stabilization of any oscillator which cannot be crystal-controlled. The only difference in such an AFC system is that now no modulation is fed to the reactance modulator, and the discriminator load time constant may now be faster. It is also most likely that a varactor diode would then be used for AFC.

Credit: Electronic Communication System by Kennedy and Davis

Indirect Method

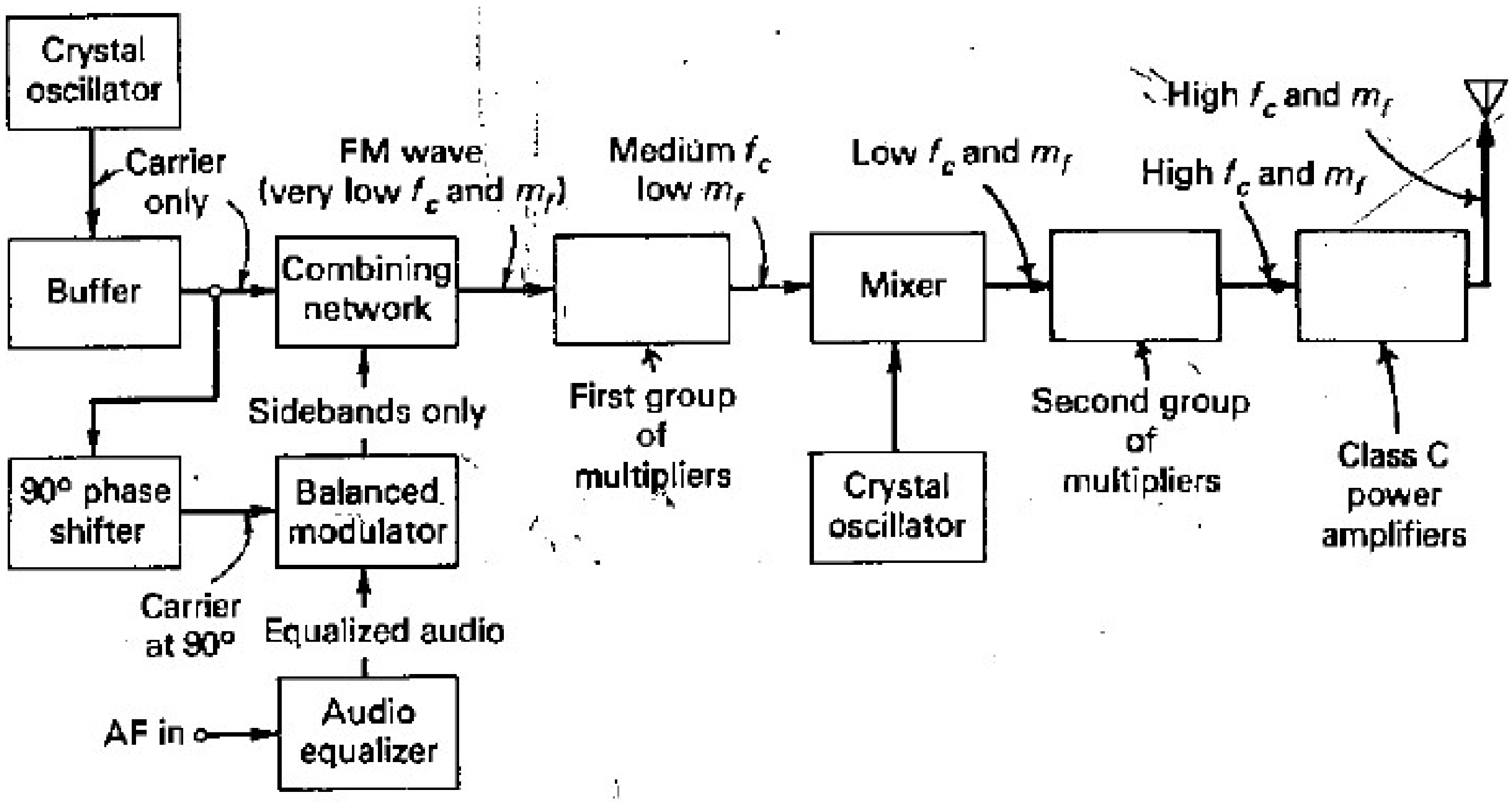


FIGURE 5-15 Block diagram of the Armstrong frequency-modulation system.

Credit: Electronic Communication System by Kennedy and Davis

Indirect Method

Because a crystal oscillator cannot be successfully frequency-modulated, the direct modulators have the disadvantage of being based on an LC oscillator which is not stable enough for communications or broadcast purposes. In turn, this requires stabilization of the reactance modulator with attendant circuit complexity. It is possible, however, to generate FM through phase modulation, where a crystal oscillator can be used. Since this method is often used in practice, it will now be described. It is called the *Armstrong system* after its inventor, and it historically precedes the reactance modulator.

Credit: Electronic Communication System by Kennedy and Davis

Indirect Method

The most convenient operating frequency for the crystal oscillator and phase modulator is in the vicinity of 1 MHz. Since transmitting frequencies are normally much higher than this, frequency multiplication must be used, and so multipliers are shown in the block diagram of Figure 5-15.

Credit: Electronic Communication System by Kennedy and Davis

Indirect Method

The block diagram of an Armstrong system is shown in Figure 5-15. The system terminates at the output of the combining network; the remaining blocks are included to show how wideband FM might be obtained. The effect of mixing on an FM signal is to change the center frequency only, whereas the effect of frequency multiplication is to multiply center frequency and deviation equally.

Credit: Electronic Communication System by Kennedy and Davis

Indirect Method

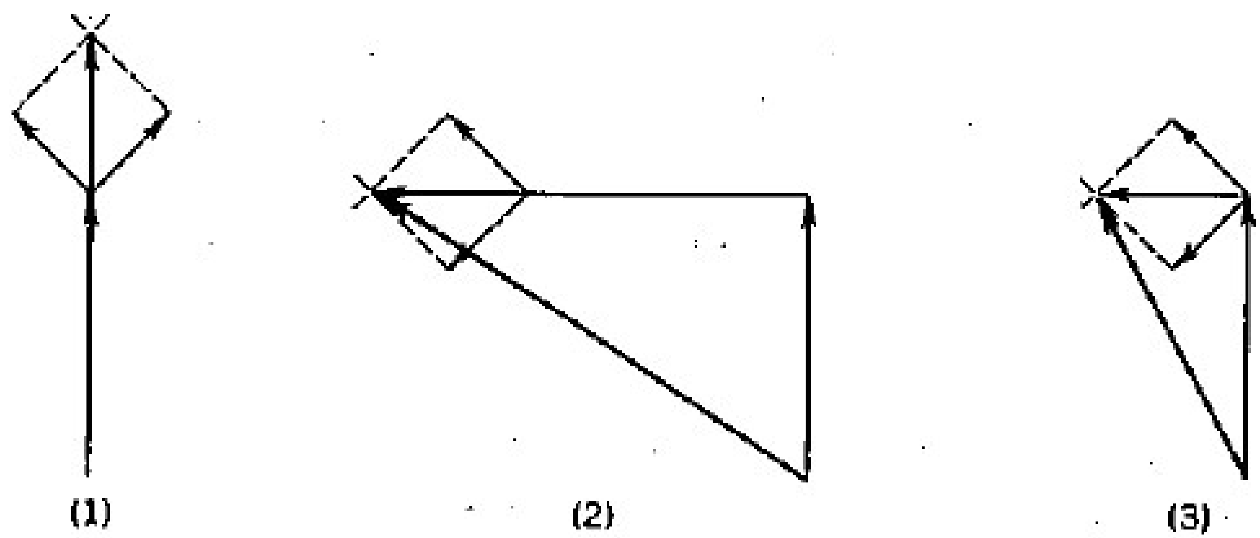


FIGURE 5-16 Phase-modulation vector diagrams.

Credit: Electronic Communication System by Kennedy and Davis