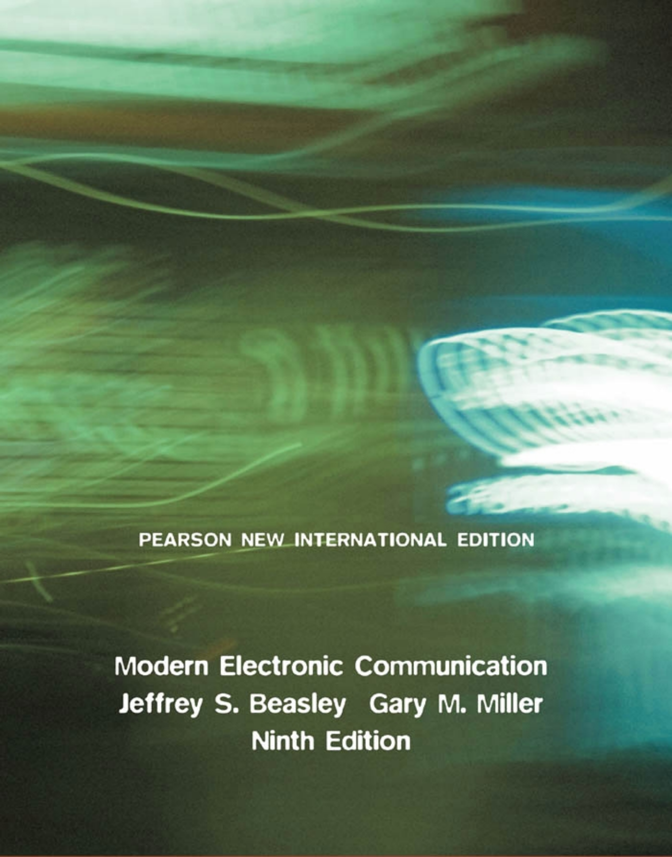

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Modern Electronic Communication

Jeffrey S. Beasley   Gary M. Miller

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Example 5

An FM signal, 2000 sin($2\pi \times 10^8 t + 2 \sin \pi \times 10^4 t$), is applied to a 50-Ω antenna. Determine
(a) The carrier frequency.
(b) The transmitted power.
(c) m_f.
(d) f_i.
(e) BW (by two methods).
(f) Power in the largest and smallest sidebands predicted by Table 2.

Solution

(a) By inspection of the FM equation, $f_c = (2\pi \times 10^8)/2\pi = 10^8 = 100$ MHz.
(b) The peak voltage is 2000 V. Thus,

$$P = \frac{(2000/\sqrt{2})^2}{50\ \Omega} = 40\text{ kW}$$

(c) By inspection of the FM equation, we have

$$m_f = 2 \tag{3}$$

(d) The intelligence frequency, f_i, is derived from the $\sin \pi\, 10^4 t$ term [Equation (3)]. Thus,

$$f_i = \frac{\pi \times 10^4}{2\pi} = 5\text{ kHz}$$

(e)

$$m_f = \frac{\delta}{f_i} \tag{4}$$

$$2 = \frac{\delta}{5\text{ kHz}}$$

$$\delta = 10\text{ kHz}$$

From Table 2 with $m_f = 2$, significant sidebands exist to J_4 (4×5 kHz $= 20$ kHz). Thus, BW $= 2 \times 20$ kHz $= 40$ kHz. Using Carson's rule yields

$$\begin{aligned} \text{BW} &\simeq 2(\delta_{\max} + f_{i\max}) \\ &= 2(10\text{ kHz} + 5\text{ kHz}) = 30\text{ kHz} \end{aligned} \tag{7}$$

(f) From Table 2, J_1 is the largest sideband at 0.58 times the unmodulated carrier amplitude.

$$p = \frac{(0.58 \times 2000/\sqrt{2})^2}{50\ \Omega} = 13.5\text{ kW}$$

or 2×13.5 kW $= 27$ kW for the two sidebands at ±5 kHz from the carrier. The smallest sideband, J_4, is 0.03 times the carrier or $(0.03 \times 2000/\sqrt{2})^2/50\ \Omega = 36$ W.

Zero-Carrier Amplitude

Figure 4 shows the FM frequency spectrum for various levels of modulation while keeping the modulation frequency constant. The relative amplitude of all components is obtained from Table 2. Notice from the table that between $m_f = 2$ and

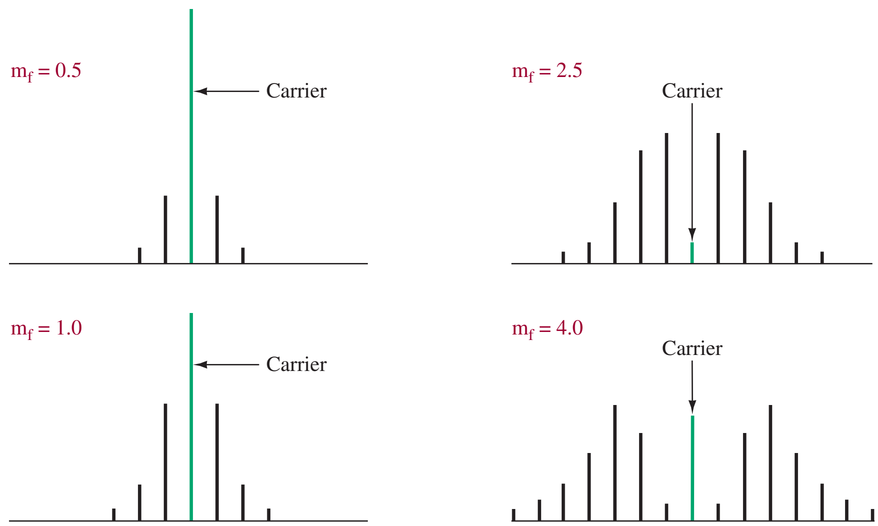


FIGURE 4 Frequency spectrum for FM (constant modulating frequency, variable deviation).

$m_f = 2.5$, the carrier goes from a plus to a minus value. The minus sign simply indicates a phase reversal, but when $m_f = 2.4$, the carrier component has zero amplitude and all the energy is contained in the side frequencies. This also occurs when $m_f = 5.5$, 8.65, and between 10 and 12, and 12 and 15.

The zero-carrier condition suggests a convenient means of determining the deviation produced in an FM modulator. A carrier is modulated by a single sine wave at a known frequency. The modulating signal's amplitude is varied while observing the generated FM on a spectrum analyzer. At the point where the carrier amplitude goes to zero, the modulation index, m_f, is determined based on the number of sidebands displayed. If four or five sidebands appear on both sides of the nulled carrier, you can assume that $m_f = 2.4$. The deviation, δ, is then equal to $2.4 \times f_i$. The modulating signal could be increased in amplitude, and the next carrier null should be at $m_f = 5.5$. A check on modulator linearity is thereby possible because the frequency deviation should be directly proportional to the modulating signal's amplitude.

Broadcast FM

Standard broadcast FM uses a 200-kHz bandwidth for each station. This is a very large allocation when one considers that one FM station has a bandwidth that could contain many standard AM stations. Broadcast FM, however, allows for a true high-fidelity modulating signal up to 15 kHz and offers superior noise performance (see Section 4).

Guard Bands
25-kHz bands at each end of a broadcast FM channel to help minimize interference with adjacent stations

Figure 5 shows the FCC allocation for commercial FM stations. The maximum allowed deviation around the carrier is ± 75 kHz, and 25-kHz **guard bands** at the upper and lower ends are also provided. The carrier is required to maintain a ± 2-kHz stability. Recall that an infinite number of side frequencies are generated during frequency modulation, but their amplitude gradually decreases as you move

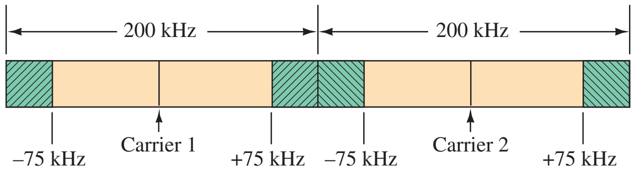


FIGURE 5 Commercial FM bandwidth allocations for two adjacent stations.

away from the carrier. In other words, the significant side frequencies exist up to ±75 kHz around the carrier, and the guard bands ensure that adjacent channel interference will not be a problem.

Since full deviation (δ) is 75 kHz, that is 100 percent modulation. By definition, 100 percent modulation in FM is when the deviation is the full permissible amount. Recall that the modulation index, m_f, is

$$m_f = \frac{\delta}{f_i} \tag{4}$$

so that the actual modulation index at 100 percent modulation varies inversely with the intelligence frequency, f_i. This is in contrast with AM, where full or 100 percent modulation means a modulation index of 1 regardless of intelligence frequency.

Another way to describe the modulation index is by **deviation ratio (DR).** Deviation ratio equals the result of dividing the maximum possible frequency deviation by the maximum input frequency, as shown in Equation (8).

Deviation Ratio (DR)
maximum possible frequency deviation over the maximum input frequency

$$\text{DR} = \frac{\text{maximum possible frequency deviation}}{\text{maximum input frequency}} = \frac{f_{\text{dev(max)}}}{f_{i\text{(max)}}} \tag{8}$$

Deviation ratio is a commonly used term in both television and FM broadcasting. For example, broadcast FM radio permits a maximum carrier frequency deviation, $f_{\text{dev(max)}}$, of ±75 kHz and a maximum audio input frequency, $f_{i\text{(max)}}$ of 15 kHz. Therefore, for broadcast FM radio, the deviation ratio (DR) is

$$\text{DR (broadcast FM radio)} = \frac{75\text{ kHz}}{15\text{ kHz}} = 5$$

and for broadcast television (NTSC format), the maximum frequency deviation of the aural carrier, $f_{\text{dev(max)}}$ is ±25 kHz with a maximum audio input frequency, $f_{i\text{(max)}}$, of 15 kHz. Therefore, for broadcast TV (NTSC format), the deviation ratio (DR) is

$$\text{DR (TV NTSC)} = \frac{25\text{ kHz}}{15\text{ kHz}} = 1.67$$

FM systems that have a deviation ratio greater than or equal to 1 (DR $\geq$ 1) are considered to be **wideband** systems, whereas FM systems that have a deviation ratio less than 1 (DR $<$ 1) are considered to be narrowband FM systems.

Wideband FM
a system where the deviation ratio is ≥ 1

Narrowband FM

Narrowband FM FM signals used for voice transmissions such as public service communication systems

Frequency modulation is also widely used in communication (i.e., not to entertain) systems such as those used by police, aircraft, taxicabs, weather service, and private industry networks. These applications are often voice transmissions, which means that intelligence frequency maximums of 3 kHz are the norm. These are **narrowband FM** systems because Federal Communications Commission (FCC) bandwidth allocations of 10 to 30 kHz are provided. Narrowband FM (NBFM) systems operate with a modulation index of 0.5 to 1.0. A glance at the Bessel functions in Table 2 shows that at these index values, only the first set (J_1) of side frequencies has a significant amplitude; the second (J_2) and third (J_3) lose amplitude quickly. Thus, we see that NBFM has a bandwidth no wider than an AM signal.

Example 6

(a) Determine the permissible range in maximum modulation index for commercial FM that has 30-Hz to 15-kHz modulating frequencies.
(b) Repeat for a narrowband system that allows a maximum deviation of 1-kHz and 100-Hz to 2-kHz modulating frequencies.
(c) Determine the deviation ratio for the system in part (b).

Solution

(a) The maximum deviation in broadcast FM is 75 kHz.

$$m_f = \frac{\delta}{f_i} \tag{4}$$

$$= \frac{75\text{ kHz}}{30\text{ Hz}} = 2500$$

For $f_i = 15$ kHz:

$$m_f = \frac{75\text{ kHz}}{15\text{ kHz}} = 5$$

(b)

$$m_f = \frac{\delta}{f_i} = \frac{1\text{ kHz}}{100\text{ Hz}} = 10$$

For $f_i = 2$ kHz:

$$m_f = \frac{1\text{ kHz}}{2\text{ kHz}} = 0.5$$

(c)

$$\text{DR} = \frac{f_{\text{dev(max)}}}{f_{i(\text{max})}} = \frac{1\text{ kHz}}{2\text{ kHz}} = 0.5 \tag{8}$$

Example 7

Determine the relative total power of the carrier and side frequencies when $m_f = 0.25$ for a 10-kW FM transmitter.

Solution

For $m_f = 0.25$, the carrier is equal to 0.98 times its unmodulated amplitude and the only significant sideband is J_1, with a relative amplitude of 0.12 (from Table 2). Therefore, because power is proportional to the voltage squared, the carrier power is

$$(0.98)^2 \times 10 \text{ kW} = 9.604 \text{ kW}$$

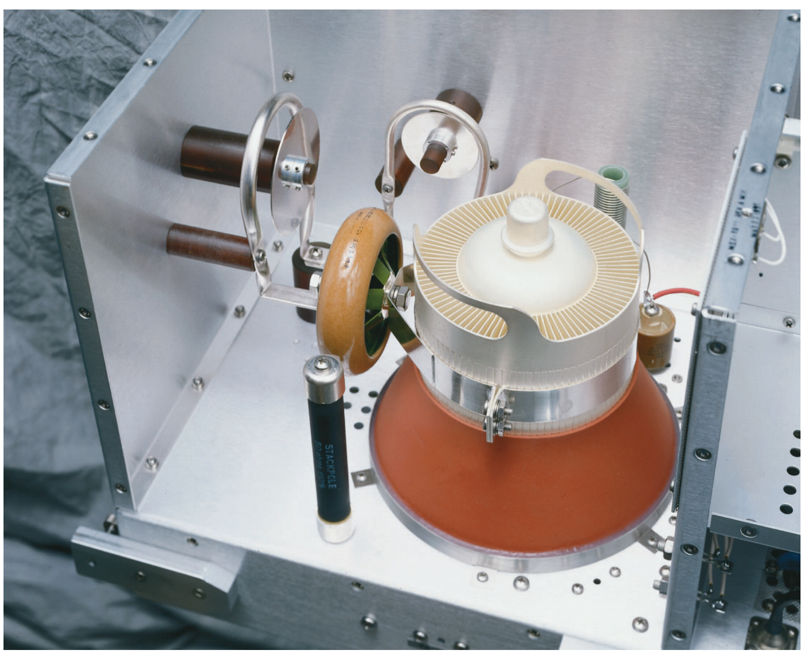
and the power of each sideband is

$$(0.12)^2 \times 10 \text{ kW} = 144 \text{ W}$$

The total power is

$$\begin{aligned} 9604 \text{ W} + 144 \text{ W} + 144 \text{ W} &= 9.892 \text{ kW} \\ &\cong 10 \text{ kW} \end{aligned}$$

The result of Example 7 is predictable. In FM, the transmitted waveform never varies in amplitude, just frequency. Therefore, the total transmitted power must remain constant regardless of the level of modulation. It is thus seen that whatever energy is contained in the side frequencies has been obtained from the carrier. No additional energy is added during the modulation process. The carrier in FM is not redundant as in AM because its (the carrier's) amplitude is dependent on the intelligence signal.



The final power stage of a 20-kW amplifier uses a tube as the active element. (Courtesy of ETO, Inc.—An ASTEX Company.)

4 Noise Suppression

The most important advantage of FM over AM is the superior noise characteristics. You are probably aware that static noise is rarely heard on FM, although it is quite common in AM reception. You may be able to guess a reason for this improvement. The addition of noise to a received signal causes a change in its amplitude. Since the amplitude changes in AM contain the intelligence, any attempt to get rid of the noise adversely affects the received signal. However, in FM, the intelligence is *not* carried by amplitude changes but instead by frequency changes. The spikes of external noise picked up during transmission are clipped off by a **limiter** circuit and/or through the use of detector circuits that are insensitive to amplitude changes.

Limiter
stage in an FM receiver that removes any amplitude variations of the received FM signal before it reaches the discriminator

Figure 6(a) shows the noise removal action of an FM limiter circuit, while in Figure 6(b) the noise spike feeds right through to the speaker in an AM system. The advantage for FM is clearly evident; in fact, you may think that the limiter removes all the effects of this noise spike. While it is possible to clip the noise spike off, it still causes an undesired phase shift and thus frequency shift of the FM signal, and this frequency shift *cannot* be removed.

The noise signal frequency will be close to the frequency of the desired FM signal due to the selective effect of the tuned circuits in a receiver. In other words, if you are tuned to an FM station at 96 MHz, the receiver's selectivity provides gain only for frequencies near 96 MHz. The noise that will affect this reception must, therefore, also be around 96 MHz because all other frequencies will be greatly attenuated. The effect of adding the desired *and* noise signals will give a resultant signal with a different phase angle than the desired FM signal alone. Therefore, the noise signal, even though it is clipped off in amplitude, will cause phase modulation (PM), which indirectly causes undesired FM. The amount of frequency deviation (FM) caused by PM is

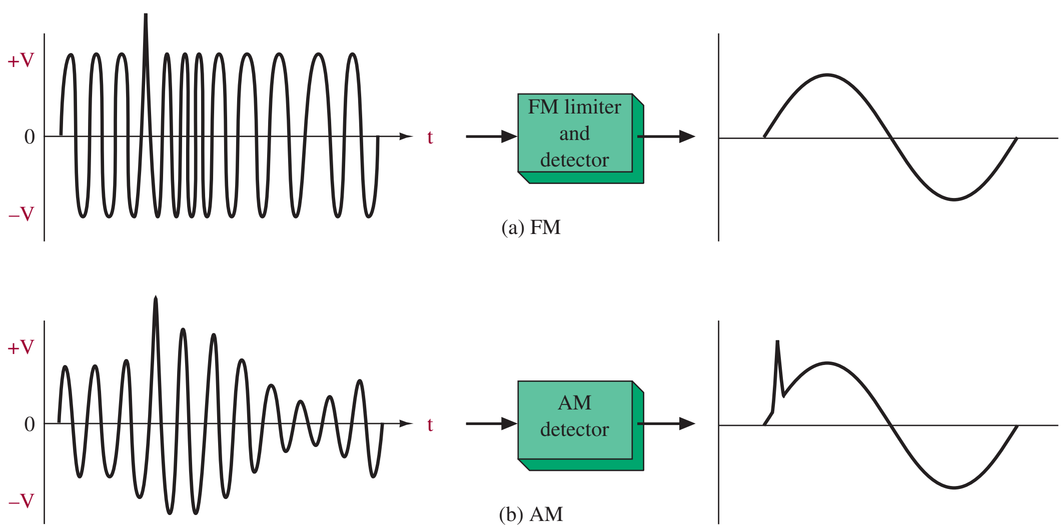


FIGURE 6 FM, AM noise comparison.