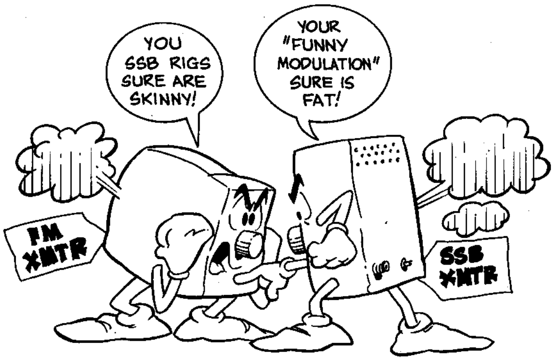
• *First Steps In Radio*

Understanding FM Transmitters



Part 17: Odds are, you'll operate VHF or UHF FM someday, so why not learn how frequency modulation works.

By Doug DeMaw,* W1FB

FM stands for *frequency modulation.* Its cousin is *phase modulation,* or PM. Either method of modulation will permit reception of the transmitted energy by an FM receiver. This month, we'll concentrate on FM and PM transmitters. FM receivers will be addressed in a later installment of this series.

Creating an FM Signal

Two ingredients are necessary to generate an FM radio signal. First, we must have a *carrier* frequency. Second, we need some AF (audio frequency) energy to modulate the carrier. If we allow the audio frequency signal to vary the frequency of the carrier, we'll have an FM signal.

Assume that you're examining the transmitter carrier, as displayed on an oscilloscope (Fig. 1A). Next, suppose a steady audio tone, such as 1 kHz, is generated. It will also appear as a sine wave (Fig. 1B). Note that A and B are on vastly different frequencies, as shown in the illustration. When the 1-kHz audio frequency is applied to the RF carrier, we find a waveform such as that in Fig. 1C.

What is happening here? When the audio energy is applied to the RF carrier, the carrier frequency increases (goes higher in frequency) during half of the audio cycle (positive), and it decreases (shifts lower in frequency) during the negative half of the audio cycle. The RF cycles occupy less time (higher frequency) during the positive period of the modulating cycle, and occupy more time during the negative cycle.

Deviation is the term used for a shift in the RF carrier frequency. Deviation is proportional to the amplitude of our modulating signal; that is, the lower the audio level, the smaller the amount of deviation (frequency swing). Conversely, the higher the audio level, the greater the deviation.

Unlike AM transmitter output, the output from an FM transmitter does not change amplitude during modulation. Rather, the carrier frequency of the FM transmitter swings above and below some center carrier frequency during modulation, but the carrier amplitude remains the same.

Phase Modulation (PM)

The major difference between FM and PM is the method of creating the deviation. Frequency modulation takes place in an oscillator stage. Phase modulation occurs after the oscillator. See Fig. 2.

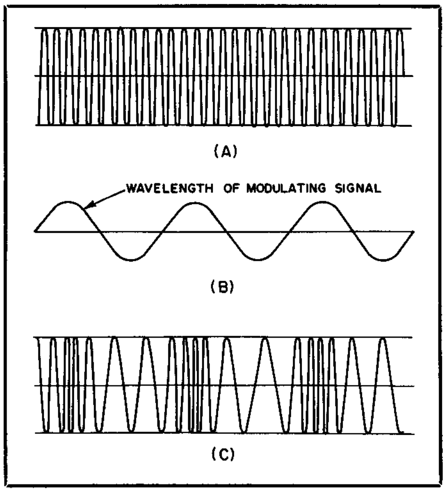


Fig. 1 — A graphic representation of FM (and PM). The unmodulated carrier is illustrated at A. The audio-frequency waveform is shown at B. When the modulating energy at B is applied to the RF energy at A, we obtain the display shown at C. (See text).

Another difference is how the frequency of the modulating signal affects the deviation. In FM, the deviation does not change if you change the modulation frequency, assuming the signal level is the same. In PM, on the other hand, the deviation increases with modulating frequency with the signal level held constant.

FM Sidebands

FM signals usually occupy a much wider bandwidth than do AM or SSB signals. Commercial FM stations have peak deviation of 75 kHz, while most amateur and commercial land-mobile FM stations use 5-kHz deviation. These extremes represent wide-band and narrow-band FM, respectively. A peak deviation of 15 kHz was the standard many years ago, but it was abandoned in favor of 5-kHz peak deviation to conserve frequency spectrum in the crowded commercial and amateur bands. In amplitude modulation, there is one set of sidebands, one above, the other below, the carrier frequency. In FM and PM, there can be one, three, five or more sets of sidebands.

The number of sideband pairs that occur during FM or PM operation depends on the ratio between the audio modulating frequency and the carrier-frequency deviation. That ratio is called the *modulation index.* Expressed mathematically:

$$\chi = \frac{D}{m} = \phi \qquad \text{(Eq. 1)}$$

where

χ = modulation index
D = peak deviation (half the difference between the maximum and minimum values of the instantaneous frequency
m = modulation frequency in hertz
ϕ = phase deviation in radians (a

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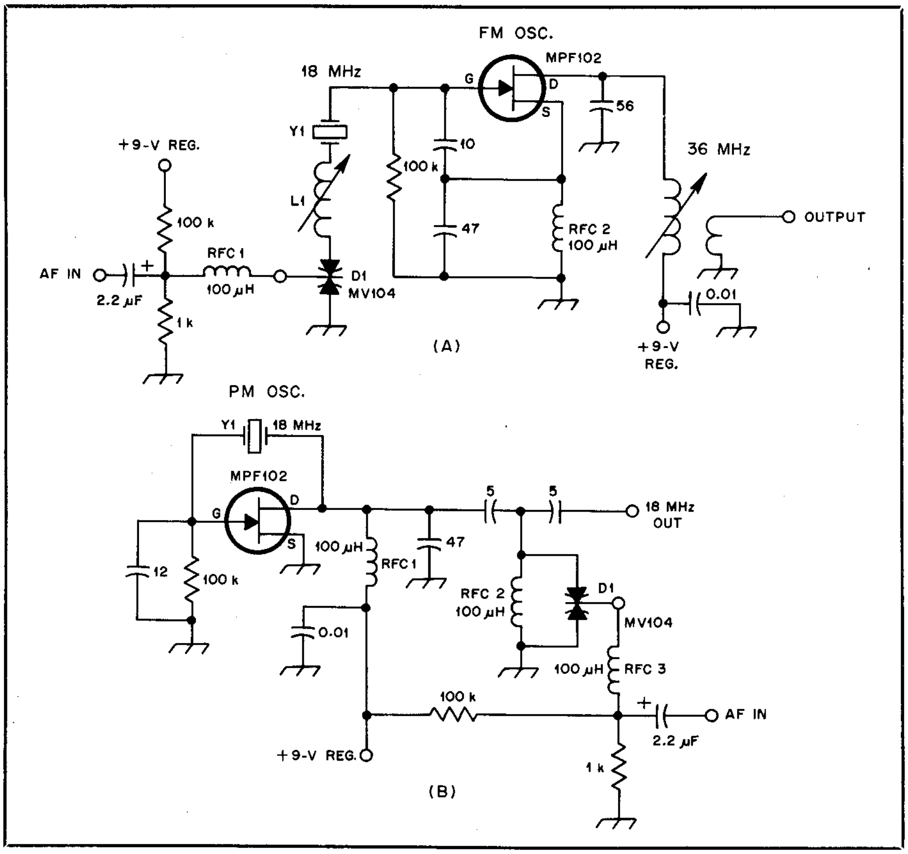

Fig. 2 — Examples of oscillators used for FM and PM generators in a crystal-controlled system. At A, the internal capacitance of D1 changes in accordance with the audio voltage impressed upon it. This change in capacitance causes the crystal frequency to shift above and below the frequency for which it is cut, thereby causing FM. The circuit at B shows how we might generate a PM signal. When audio energy is applied to D1, the phase of the oscillator signal is shifted instantaneously, which results in a frequency shift above and below the frequency of Y1.

radian = $180/\pi$ or approximately 57.3 degrees)

Therefore, if our maximum deviation were 5 kHz (5000 Hz) either side of the center carrier frequency, and the modulating frequency were 1000 Hz, we would obtain the following for the modulation index:

$$\chi = \frac{5000}{1000} = 5 \qquad \text{(Eq. 2)}$$

In the case of PM (with constant amplitude into the modulator), the modulation index is constant, irrespective of modulating frequency. In other words, if a 1-kHz tone causes a 500-Hz deviation, a 2-kHz tone of the same amplitude causes a 1-kHz carrier deviation. In an FM (or PM) system, the ratio of the *maximum* carrier-frequency deviation and the *highest* modulating frequency is called the *deviation ratio.*

The bandwidth of an FM signal depends on the amplitude of the sidebands farthest from the carrier frequency. For a complex waveform such as voice modulation, a good rule of thumb is that the bandwidth is twice the deviation, plus twice the highest modulating audio frequency. Thus, an FM transmitter with 5-kHz deviation modulated by a voice with an upper limit of 3 kHz will have a bandwidth of approximately 16 kHz.

Audio for FM Modulators

To obtain maximum effectiveness from our FM signal, we must ensure that ample audio is available. The average audio level may be increased by means of clipping. This will give the FM signal more apparent volume at the receiver. A simple circuit for creating a clipped and filtered modulating voltage is shown in Fig. 3. Q1 amplifies the audio energy from the microphone. This amplified audio is passed to the speech *clipper* (D1, D2), where the positive and negative peaks of the audio sine wave are squared or clipped. R1 sets the amount of clipping. The clipped audio would cause distortion if it were applied directly to the modulator, so we must filter it first. C1, C2 and R2 of Fig. 3 serve as a simple filter that restores the audio waveform to a sine-wave shape.

Some audio power is lost in the filtering process, so we have added Q2 for the purpose of building up the audio level to a sufficient value for modulating the transmitter. The deviation (frequency swing) of the transmitter signal is determined

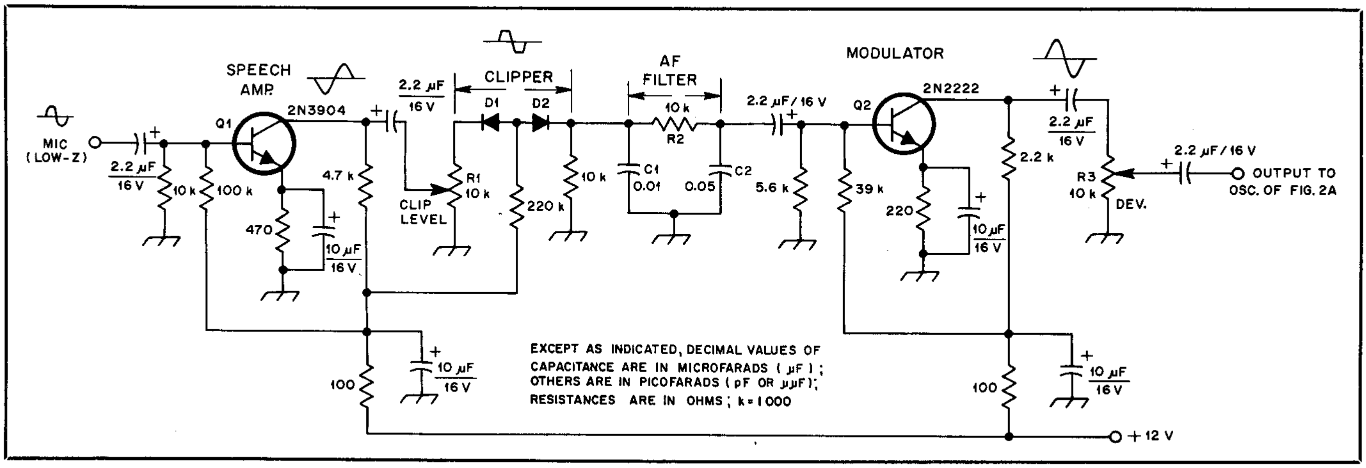

Fig. 3 — Circuit for a simple audio channel that might be used in an FM transmitter. Observe the changes in wave shape as the signal passes through the circuit. Note also the changes in audio signal amplitude. A detailed description of how this circuit operates is given in the text.

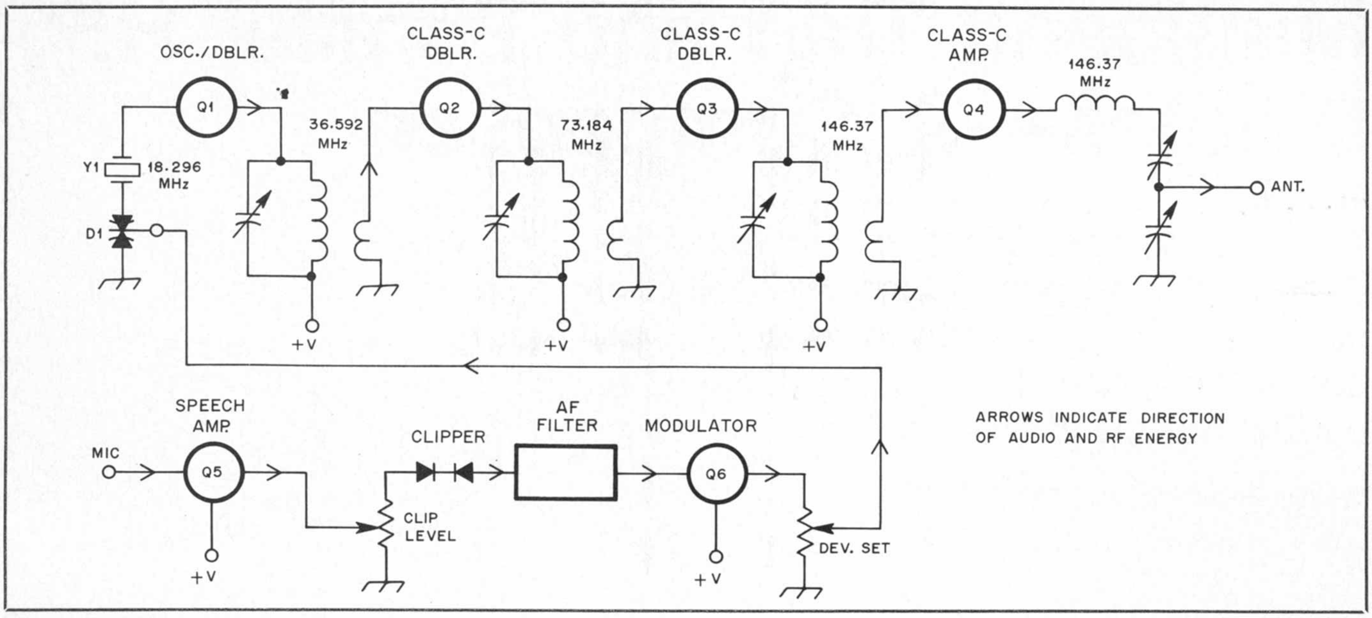

Fig. 4 — Hybrid block diagram of a composite FM transmitter. The frequency of Y1 is multiplied by a factor of eight as the various doubler stages amplify the signal. Similarly, the deviation at Y1 is increased by a factor of eight during the multiplication process. Class-C stages are used throughout the transmitter RF section.

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by the setting of R3.

Composite FM Transmitter

How do all the circuits we have discussed fit together? We can consider a typical setup for an amateur FM transmitter, as shown in Fig. 4. This diagram shows the direction of flow (arrows) for the audio and radio frequencies. Consider Q1 the oscillator of Fig. 2A. Q5 and Q6 represent the circuit in Fig. 3. You can see that the oscillator also functions as a frequency doubler. This frequency-doubling action also increases the deviation by a factor of two. The deviation is also doubled in the Q2 and Q3 stages. In this circuit example, the deviation is increased from Q1 to Q4 by a factor of eight. Therefore, in order to have, say, a 5-kHz deviation at 146.37 MHz, we would need only 0.625 kHz of deviation at 18.269 MHz. It is easy to shift the frequency of Y1 that small amount when using D1 as a voltage-variable-capacitor (VVC) diode. The audio energy impressed on D1 causes its internal capacitance to change during the audio cycle, thereby causing the transmitter to swing above and below the carrier frequency.

Use of FM or PM results in perhaps the simplest type of voice transmitter. Very few parts are necessary compared to an SSB transmitter, and we can use class-C transmitter stages without worrying about distortion of the transmitter signal. (Class-A or class-B linear amplifiers are required for SSB transmitters, and their design is somewhat more complicated, to say nothing of the additional components needed.)

Wrap-Up

The aspects of frequency and phase modulation covered in this installment are those you'll be most likely to encounter when taking your amateur license tests. To be fully prepared for exam day, be sure to obtain a copy of the appropriate *ARRL License Manual*. Also, a great deal more about FM circuits and operation can be found in the League publications, *Understanding Amateur Radio* and *FM and Repeaters for the Radio Amateur.*

Glossary

carrier — the RF output from a transmitter, without modulation. It contains no signal information.
clipper — a circuit that limits the peaks of a waveform by clipping or squaring the otherwise rounded positive and negative peaks of a sine wave.
deviation — the amount of frequency swing above and below the FM transmitter carrier frequency when modulating voltage is applied to the low-level RF energy.
FM — frequency modulation.
modulator — a circuit designed to add information to a carrier.
modulation index — pertains to an FM or PM transmitter. The ratio between carrier-frequency deviation (in hertz) and modulating frequency (also in hertz).
PM — phase modulation.
sidebands — bands of frequencies that appear above and below, but close to, the carrier frequency during modulation.
VVC diode — voltage-variable-capacitor diode. The diode internal capacitance changes as the voltage applied to the diode is varied. Sometimes called a *varactor* diode.

Strays

I would like to get in touch with . . .

☐ anyone with a service manual for an Ohio Scientific Color Monitor, Model DC13 PF 5. Richard Neiswonger, WA6AGL, 6052 Ocaso Ave., Buena Park, CA 90620.

☐ anyone who has troubleshooting data on the Heath SB-102 transceiver. Bruce Chadbourne, KD2CZ, 304 Riverglen Rd., Liverpool, NY 13090.

☐ anyone with a circuit diagram for an RIT control on a Swan HF-700S transceiver. Paul Schweikert, W8KND, 560 Stanley Rd., Akron, OH 44312.