Chapter 4 Objectives

At the conclusion of this chapter, the reader will be able to:

- Draw a block diagram of a high or low-level AM transmitter, giving typical signals at each point in the circuit.
- Discuss the relative advantages and disadvantages of high and low-level AM transmitters.
- Identify an RF oscillator configuration, pointing out the components that control its frequency.
- Describe the physical construction of a quartz crystal.
- Calculate the series and parallel resonant frequencies of a quartz crystal, given manufacturer's data.
- Identify the resonance modes of a quartz crystal in typical RF oscillator circuits.
- Describe the operating characteristics of an RF amplifier circuit, given its schematic diagram.
- Explain the operation of modulator circuits.
- Identify the functional blocks (amplifiers, oscillators, etc) in a schematic diagram.
- List measurement procedures used with AM transmitters.
- Develop a plan for troubleshooting a transmitter.

Chapter 4: AM Transmitters

In chapter 3, we studied the theory of amplitude modulation, but we never actually built an AM transmitter. To construct a working transmitter (or receiver), a knowledge of RF circuit principles is necessary. A complete transmitter consists of many different *stages* and hundreds of electronic components.

When beginning technicians see the schematic diagram of a "real" electronic system for the first time, they're overwhelmed. A schematic contains much valuable information; but to the novice, it's a swirling mass of resistors, capacitors, coils, transistors, and IC chips, all connected in a massive web of wires! *How can anyone understand this?*

All electronic systems, no matter how complex, are built from functional *blocks or stages*. A *block diagram* shows how the pieces are connected to work together. *To understand an electronic system, a technician first reads the block diagram.*

After studying a block diagram, a tech has a good idea of how an electronic device works. However, a block diagram usually doesn't have enough information for in-depth troubleshooting and analysis. For detailed work, a schematic diagram is a must.

There's no magic in electronics. Engineers design systems by using combinations of basic circuits. In RF electronics, there are only four fundamental types of circuits: *amplifiers, oscillators, mixers, and switches.* Once a technician learns to recognize these circuits, he or she can begin to rapidly and accurately interpret the information on schematic diagrams.

A final note: The RF circuit techniques described in this chapter are used in *receivers* as well. Understanding them will be very helpful when studying receivers.

4-1 Low and High Level Transmitters

There are two approaches to generating an AM signal. These are known as *low* and *high level* modulation. They're easy to identify: A low level AM transmitter performs the process of modulation near the *beginning* of the transmitter. A high level transmitter performs the modulation step *last,* at the last or "final" amplifier stage in the transmitter.

Each method has advantages and disadvantages, and both are in common use.

Low Level AM Transmitter

Figure 4-1 shows the block diagram of a low-level AM transmitter. It's very similar to the AM transmitter we studied in chapter 1.

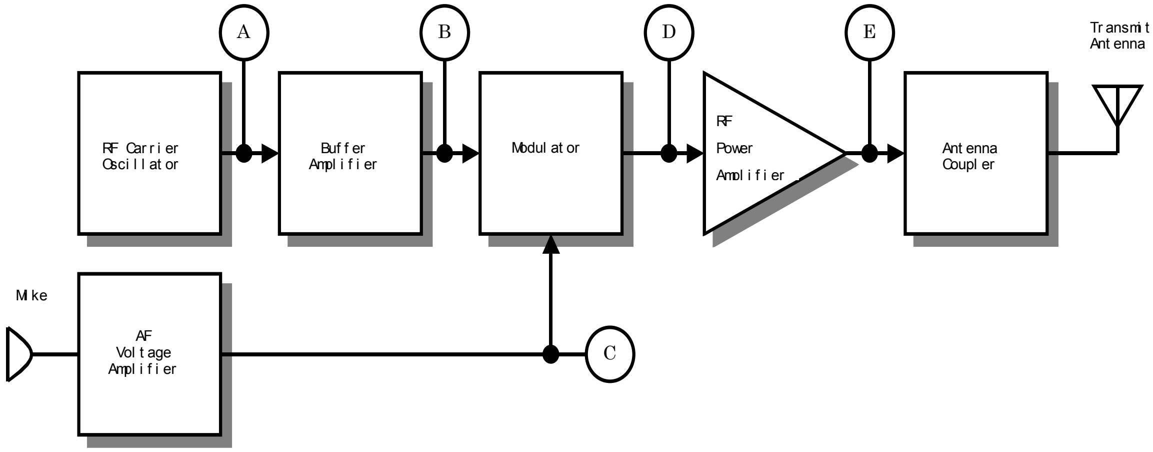

Figure 4-1: Low Level AM Transmitter Block Diagram

There are two signal paths in the transmitter, AF and RF. The RF signal is created in the *RF carrier oscillator*. At test point "A" the oscillator's output signal is present. The output of the carrier oscillator is a fairly small AC voltage, perhaps 200 to 400 mV RMS.

The oscillator is a critical stage in any transmitter. It must produce an accurate and steady frequency. You might recall that every radio station is assigned a different carrier frequency. The dial (or display) of a receiver displays the carrier frequency. If the oscillator drifts off frequency, the receiver will be unable to receive the transmitted signal without being readjusted. Worse yet, if the oscillator drifts onto the frequency being used by *another* radio station, interference will occur. This is hardly desirable!

Two circuit techniques are commonly used to stabilize the oscillator, *buffering* and *voltage regulation*.

Buffer Amplifier

You might have guessed that the *buffer amplifier* has something to do with buffering or protecting the oscillator. It does! An oscillator is a little like an engine (with the speed of the engine being similar to the oscillator's frequency). If the load on the engine is increased (the engine is asked to do more work), the engine will respond by slowing down. An oscillator acts in a very similar fashion. If the *current* drawn from the oscillator's output is increased or decreased, the oscillator may speed up or slow down slightly. We would say that its frequency has been *pulled*.

The *buffer amplifier* is a relatively low-gain amplifier that follows the oscillator. The buffer amplifier has a constant *input impedance* (resistance). Therefore, the buffer amplifier always draws the same amount of current from the oscillator. This helps to prevent "pulling" of the oscillator frequency.

The buffer amplifier is needed because of what's happening "downstream" of the oscillator. Right after the buffer amplifier is the *modulator*. Because the modulator is a nonlinear amplifier, it may not have a constant input resistance -- especially when information is passing into it. But since there is a buffer amplifier between the oscillator and modulator, the oscillator sees a steady load resistance, regardless of what the modulator stage is doing.

Voltage Regulation

An oscillator can also be pulled off frequency if its power supply voltage isn't held constant. In most transmitters, the supply voltage to the oscillator is *regulated* at a constant value. The regulated voltage value is often between 5 and 9 volts; zener diodes and three-terminal regulator ICs are commonly used voltage regulators.

Voltage regulation is especially important when a transmitter is being powered by batteries or an automobile's electrical system. As a battery discharges, its terminal voltage falls. The DC supply voltage in a car can be anywhere between 12 and 16 volts, depending on engine RPM and other electrical load conditions within the vehicle.

Modulator

The stabilized RF carrier signal feeds one input of the *modulator* stage. The modulator is a variable-gain (nonlinear) amplifier. To work, it must have an RF carrier signal and an AF information signal. In a low-level transmitter, the power levels are *low* in the oscillator, buffer, and modulator stages; typically, the modulator output is around 10 mW (700 mV RMS into 50 ohms) or less.

AF Voltage Amplifier

In order for the modulator to function, it needs an information signal. A microphone is one way of developing the intelligence signal; however, a microphone only produces a few millivolts of signal. This simply isn't enough to operate the modulator, so a *voltage* amplifier is used to boost the microphone's signal. The signal level at the output of the AF voltage amplifier is usually at least 1 volt RMS; it is highly dependent upon the transmitter's design. Notice that the AF amplifier in the transmitter is only providing a *voltage* gain, and not necessarily a *current* gain for the microphone's signal. The power levels are quite small at the output of this amplifier; a few mW at best.

RF Power Amplifier

At test point D the modulator has created an AM signal by impressing the information signal from test point C onto the stabilized carrier signal from test point B at the buffer amplifier output. This signal (test point D) is a complete AM signal, but has only a few milliwatts of power.

The RF power amplifier is normally built with several stages. These stages increase both the *voltage* and *current* of the AM signal. We say that *power amplification* occurs when a circuit provides a current gain.

In order to accurately amplify the tiny AM signal from the modulator, the RF power amplifier stages must be *linear*. You might recall that amplifiers are divided up into "classes," according to the *conduction angle* of the active device within. Class A and class B amplifiers are considered to be linear amplifiers, so the RF power amplifier stages will normally be constructed using one or both of these type of amplifiers. Therefore, the signal at test point E looks just like that of test point D; it's just much bigger in voltage and current.

Antenna Coupler

The antenna coupler is usually part of the last or *final* RF power amplifier, and as such, is not really a separate active stage. It performs no amplification, and has no active devices! It performs two important jobs: Impedance matching and filtering.

For an RF power amplifier to function correctly, it must be supplied with a load resistance equal to that for which it was designed. This may be nearly any value. 50 ohms would be an optimal value, since most antennas and transmission lines are 50 ohms. What if the RF power amplifier needs to see 25 Ohms? Then we must somehow *transform* the antenna impedance from 50 Ohms down to 25 Ohms. Are you thinking *transformer*? If so, great -- because that's one way of doing the job. A transformer can step an impedance up (higher voltage) or down (lower voltage). Special transformers are used at radio frequencies. Transformers aren't the only circuits used for impedance matching. LC resonant circuits can also be used in many different forms to do the job.

There's nothing mysterious about impedance matching. The antenna coupler does the same thing for the RF final power amplifier that the gears in a car's transmission do for the engine. To climb a steep hill, a lower gear must be chosen in order to get maximum mechanical power transfer from the engine to the wheels. Too high a gear will stall the motor -- think of it as a mechanical impedance mismatch! The engine speed is *stepped down* to help the car climb the hill.

The antenna coupler also acts as a *low-pass filter*. This filtering reduces the amplitude of *harmonic energies* that may be present in the power amplifier's output. (All amplifiers generate *harmonic distortion*, even "linear" ones.) For example, the transmitter may be tuned to operate on 1000 kHz. Because of small nonlinearities in the amplifiers of the transmitter, the transmitter will also produce *harmonic energies* on 2000 kHz (2^{nd} harmonic), 3000 kHz (3^{rd} harmonic), and so on. Because a low-pass filter passes the fundamental frequency (1000 kHz) and rejects the harmonics, we say that *harmonic attenuation* has taken place. (The word *attenuate* means “to weaken.”)

High Level AM Transmitter

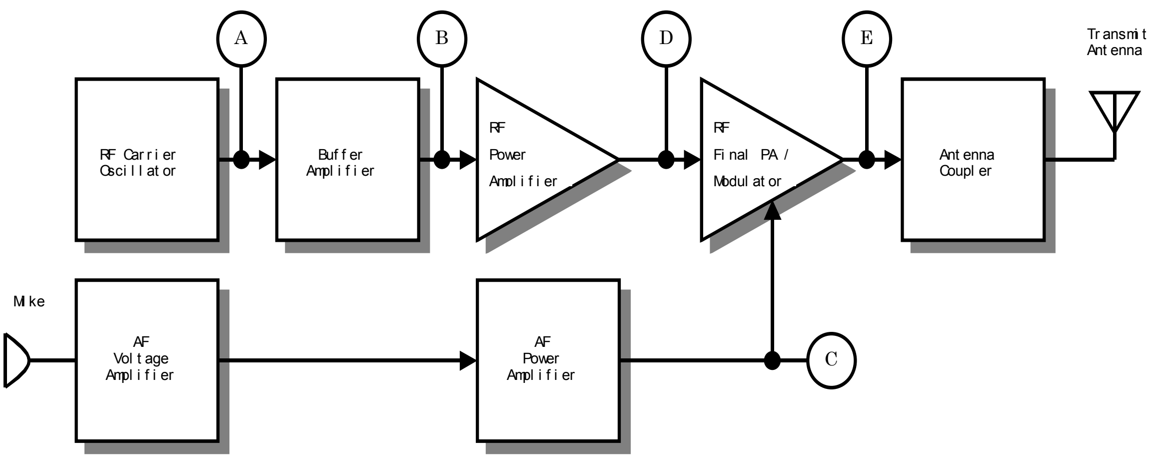

Figure 4-2: A High-Level AM Transmitter

The high-level transmitter of Figure 4-2 is very similar to the low-level unit. The RF section begins just like the low-level transmitter; there is an oscillator and buffer amplifier.

The difference in the high level transmitter is *where* the modulation takes place. Instead of adding modulation immediately after buffering, this type of transmitter amplifies the *unmodulated* RF carrier signal first. Thus, the signals at points A, B, and D in Figure 4-2 all look like unmodulated RF carrier waves. The only difference is that they become bigger in voltage and current as they approach test point D.

The modulation process in a high-level transmitter takes place in the last or *final* power amplifier. Because of this, an additional audio amplifier section is needed. In order to modulate an amplifier that is running at power levels of several watts (or more), comparable power levels of information are required. Thus, an *audio power amplifier* is required.

The final power amplifier does double-duty in a high-level transmitter. First, it provides power gain for the RF carrier signal, just like the RF power amplifier did in the low-level transmitter.

In addition to providing power gain, the final PA also performs the task of *modulation*. If you've guessed that the RF power amplifier operates in a *nonlinear class,* you're right! Classes A and B are considered linear amplifier classes. *The final power amplifier in a high-level transmitter usually operates in class C, which is a highly nonlinear amplifier class.*

Figure 4-3 shows the relative location of the quiescent operating point ("Q point") for several different classes of amplifier. Note that as we move away from class A operation, efficiency increases, but distortion (caused by nonlinearity) also increases!

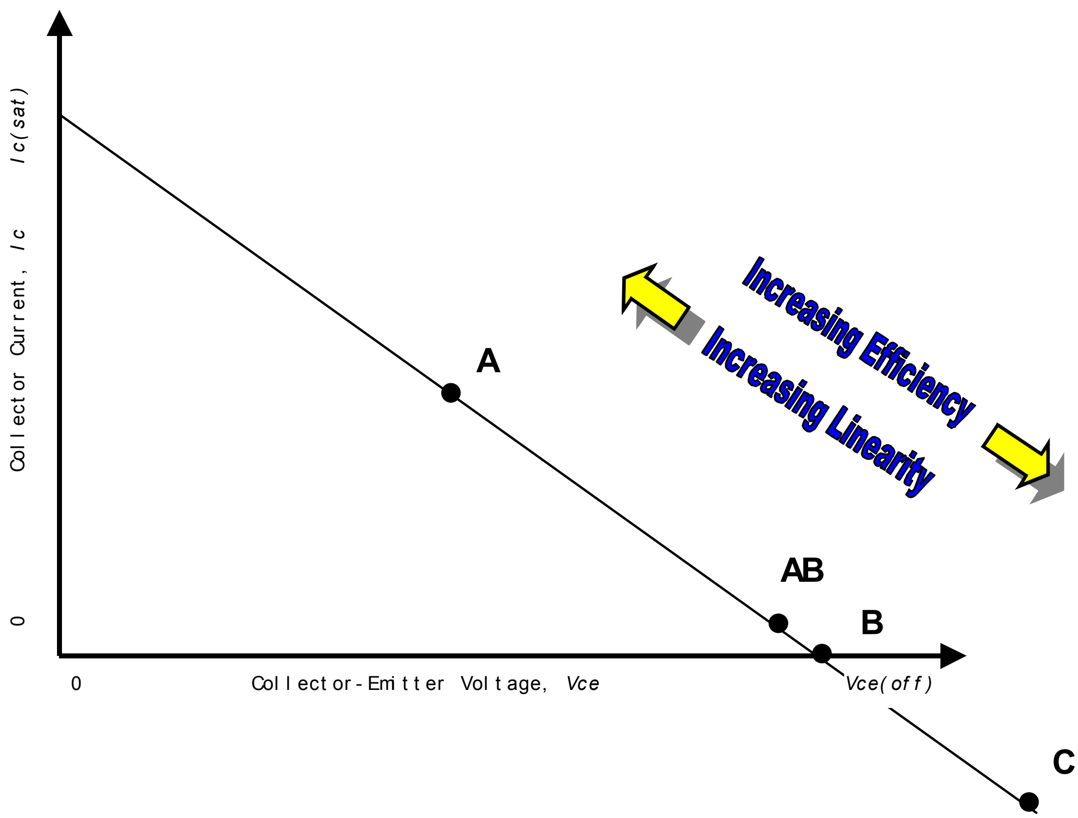

Figure 4-3: The Q Point of Various Amplifier Classes

Low and High Level Transmitter Efficiency

You might wonder why two different approaches are used to build AM transmitters, when the results of both methods are essentially the same (a modulated AM carrier wave is sent to the antenna circuit).

The answer to this question lies in examining the relative cost, flexibility, and DC efficiency of both approaches. The *DC efficiency* of a transmitter can be defined as follows:

4-1 $$\eta = \frac{P_{out-RF}}{P_{in-DC}}$$

For example, suppose that a certain transmitter requires 36 W of power from its DC power supply, and produces 18W of RF at the antenna connector. The efficiency of the transmitter will be:

$$\eta = \frac{P_{out-RF}}{P_{in-DC}} = \frac{18W}{36W} = \underline{\underline{50\%}}$$

This transmitter converts 50% of the battery power to useful RF energy at the antenna, and 50% is converted to *heat* (and lost.)

Naturally, we'd like all of our electronic devices to be as efficient as possible, especially in certain cases. Suppose that a transmitter is operated from battery power - as in a walkie-talkie, or aircraft ELT (emergency locator transmitter). We would want to get maximum life from the batteries, and we would use the most efficient approach possible.

Broadcasting uses tremendous amounts of electricity, due to the high power levels. It makes good economic sense to use the most efficient transmitter layout available.

Overall, the high-level transmitter sports better DC efficiency than the low-level approach, and is normally the first choice in battery-operated AM transmitters, and commercial AM broadcast. This is because the high-level transmitter is able to use class C RF power amplifiers, which are more efficient than the class A or B RF amplifiers required for a low-level transmitter.

A high-level transmitter still requires a linear power amplifier, but it is an *audio frequency (AF)* type. It is much easier to build efficient linear amplifiers for audio than it is for RF, so *the high-level approach wins in efficiency contests.*

If efficiency is so important, then why use a low-level approach at all, since it uses "wasteful" linear RF power amplification techniques? This is a very good question. The high-level approach performs its modulation at the very last stage. At such high power levels, the only practical method of modulation is AM -- in other words, *it's just about impossible to achieve FM or PM in a high-level transmitter. The high-level transmitter can only produce AM.*

A low-level transmitter can generate any type of modulation; all that must be done is to switch *modulator* circuits. Since the power amplifiers are of linear type in a low-level transmitter, they can amplify AM, FM, or PM signals. *The low-level method is very flexible; when a transmitter must produce several different types of modulation, this is the method that is generally used.*

A Summary of Low-Level and High Level Characteristics:

Low Level Transmitters...

(+) Can produce any kind of modulation; AM, FM, or PM.

(-) Require linear RF power amplifiers, which reduces DC efficiency and increases production costs.

High Level Transmitters...

(+) Have better DC efficiency than low-level transmitters, and are very well suited for battery operation.

(-) Are restricted to generating AM modulation only.