Chapter 4: AM Transmitters

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.

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, study the block diagram first.*

After studying a block diagram, a professional 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. Gaining an understanding of these circuits is critical for this reason.

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. 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.

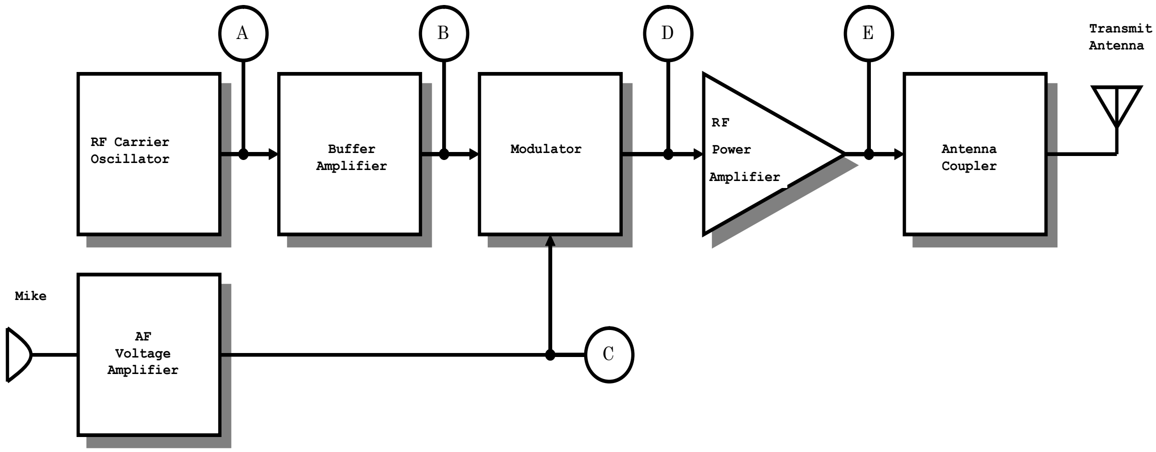

Figure 4-1: Low Level AM Transmitter Block Diagram

There are two signal paths in the transmitter, audio frequency (AF) and radio frequency (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. It has a constant *input impedance* (resistance). Therefore, the it 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 this stage 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 for Oscillator Stage

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 Stage

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, it 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. But 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 (2nd harmonic), 3000 kHz (3rd 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

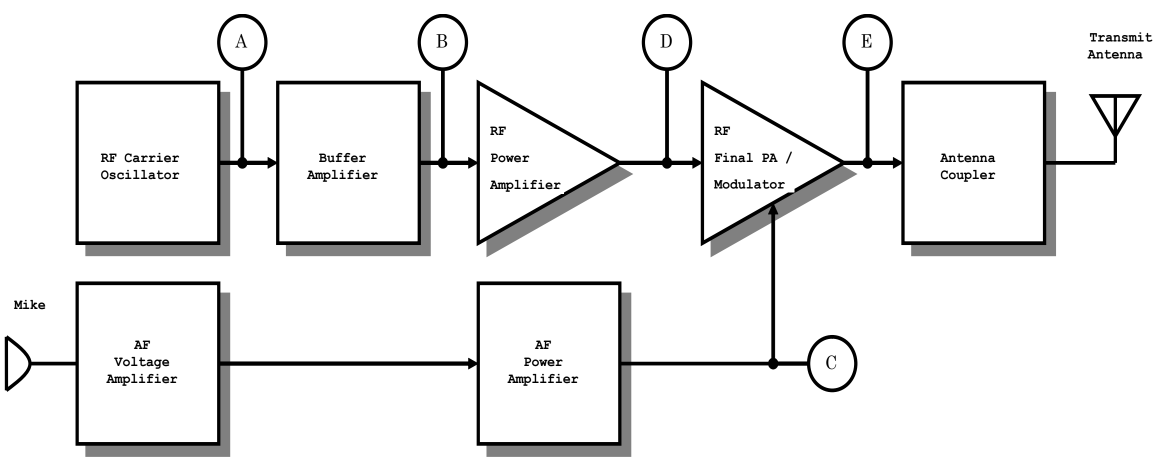

Figure 4-2: A High-Level AM Transmitter

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.

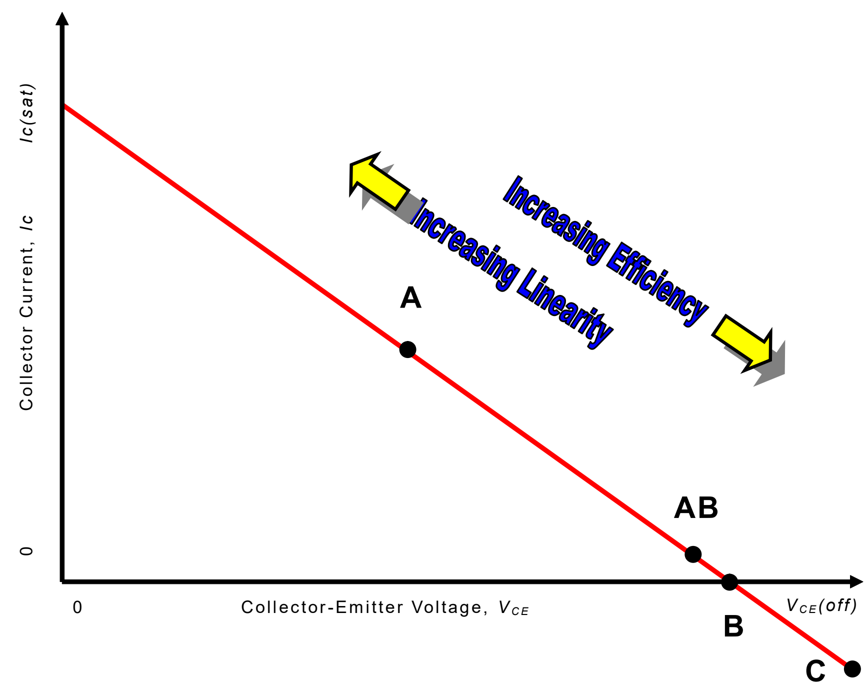

Figure 4-3: The Q Point of Various Amplifier Classes

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) $$\xi \mid \frac{P_{out4RF}}{P_{in4DC}}$$

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:

$$\xi \mid \frac{P_{out4RF}}{P_{in4DC}} \mid \frac{18W}{36W} \mid \underline{\underline{50\%}}$$

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.

Example 4-1

Calculate the DC efficiency of an AM transmitter with the following ratings: *Pout* = 4 W into 50 Ohm load, while drawing 1A from a 12V supply.

Solution:
We need Equation (4-1) and Ohm's law. The input power is given indirectly in the specifications, since P = VI = (12V)(1A) = 12 Watts. With this information in hand, we can calculate efficiency:

$$\xi = \frac{P_{out-RF}}{P_{in-DC}} = \frac{4W}{12W} = \underline{\underline{33.3\%}}$$

Section Checkpoint

4-1 What are the two main types of AM transmitters?
4-2 How can a low-level transmitter be identified?
4-3 What signal appears at test point C in Figure 4-1?
4-4 Why do transmitters use a *buffer amplifier?*
4-5 What is done with the power supply to oscillators in radio transmitters, and why?
4-6 The power amplifiers in a low-level transmitter will be in class ___ or class ___.
4-7 List two functions of an *antenna coupler*.
4-8 What are the advantages of a high-level transmitter?
4-9 The final power amplifier in a high-level transmitter operates in class ___.

4-2 Oscillator Theory

Oscillators are a key ingredient in both radio transmitters and receivers. An *oscillator* is a circuit that converts DC power supply energy into an AC output signal. Since the frequency of the oscillator in a transmitter determines the carrier frequency, it is important that the frequency produced be very stable and steady.

How Oscillators Work

Everyone has heard a public address system howl and whistle when the performer's microphone has been placed too close to a speaker. The microphone picks up a bit of the sound from the loudspeaker, which is again amplified by the PA system. The sound re-enters the microphone again, resulting in *oscillation* as the sound makes repeated trips through the loop. We would say that *positive feedback* has occurred. This is an example of an undesired oscillation. It illustrates that for an oscillator to work, two things are needed, *power gain* and *positive feedback*.

Any linear oscillator can be broken into two parts, the *gain* and *feedback* blocks, as shown in Figure 4-4.

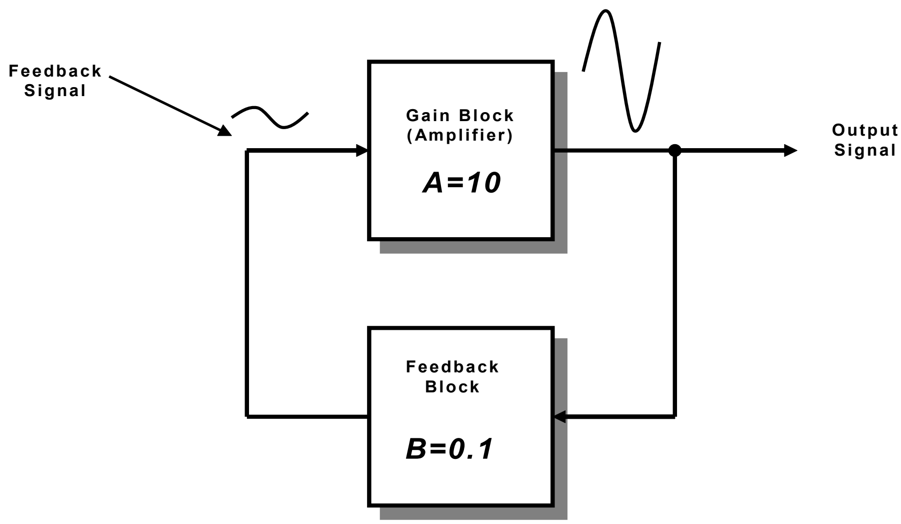

Figure 4-4: The Block Diagram of an Oscillator

An electronic oscillator has a carefully controlled gain and feedback. In Figure 4-4 a small sine wave signal is entering the amplifier. At the output of the amplifier the sine wave has increased in size. Some of this is used as the output signal. The rest enters the feedback block where it is reduced in size in preparation for another trip around the circuit.

A little arithmetic can reveal some very interesting things about how the oscillator of Figure 4-4 will behave. For example, suppose that the feedback signal (at the input of the amplifier) is 100 mV, and that the amplifier voltage gain *A* is 10. What will the output voltage be?

Did you calculate about *1 volt* ? That's right -- *Vout = (Vin)(A) = (100 mV)(10 V/V) = 1 volt*. This 1-volt signal must then pass back into the feedback portion. Suppose now that the feedback block has a gain of 1/10 (0.1). What is the resulting output *feedback signal* voltage?

That's strange -- the feedback network has reduced the signal back to 100 mV. We've recreated a signal just like the one that originally entered the amplifier! This new signal will enter the amplifier, be amplified again to 1 volt, and be again reduced to 100 mV for the next trip around the block. The action will repeat again and again. *The circuit produces steady oscillations!*

The conditions for getting steady oscillations are tricky to maintain. Let's again put 100 mV into the amplifier, but reduce its voltage gain to 9 (it was originally 10). The output voltage now becomes *900 mV* -- hmm, smaller than before! The 900 mV signal now flows through the feedback network, with its gain of 1/10. The resulting feedback signal is now ... *90 mV*. Something seems odd -- *the feedback signal has shrunk from 100 mV to 90 mV*. Do you see what is happening? Follow the signal around the loop another time. The 90 mV "new" feedback signal is amplified times 9 again at the amplifier, giving an output signal of *810 mV* (hmm, it was bigger last time around!), and after passing through the feedback loop again, becomes *81 mV*. *The oscillations are dying out because there isn't enough gain around the loop to sustain them!* The output signal will look like Figure 4-5.

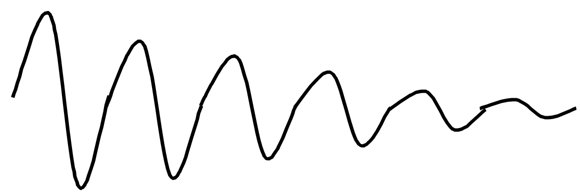

Figure 4-5: The output with gain reduced

Let's try a third case. Let's adjust the amplifier gain to *11*, and again insert a 100 mV signal into its input. The amplifier output becomes 11 times 100 mV, or 1.1 V (bigger than before). The 1.1 volt signal passes into the feedback block, where it is again multiplied by 1/10, giving a feedback signal of (1.1V/10), or *110 mV* (at least we're not dying out here!) Can you see what this case will do? The signals will grow … and grow … until something *limits* their growth (no, you don't need to run away from this circuit!) That *something* is the power supply voltage. The amplifier can only produce an output voltage less than or equal to the power supply voltage; therefore, the output signal of the circuit will now look like Figure 4-6.

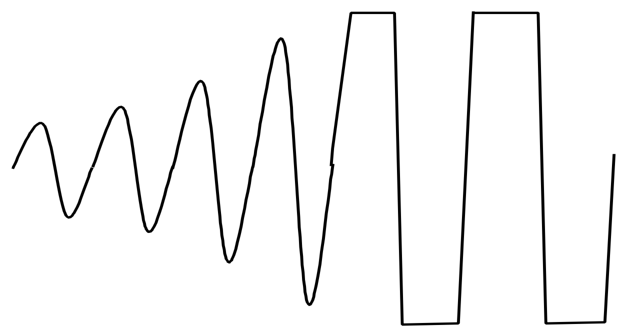

Figure 4-6: The loop gain is too large!

The *loop gain* of an oscillator is the product of the *amplifier gain A* and the *feedback* gain *B*. For the first case we got steady oscillation. The loop gain AB was (10)(0.1) or *1*.

In the second case, the oscillations soon died away, because there was insufficient loop gain. *A* was 9, and *B* was 0.1; the loop gain AB was (9)(0.1) or *0.9*. This isn't promising as an oscillator!

In the third case, the circuit went bonkers. In fact, the output rapidly became a *square wave* as the amplifier output voltage reached the limits of the power supply voltage. Calculating the loop gain for this third case, we get AB = (11)(0.1) = *1.1*. Although this circuit continues oscillating, the waveform is distorted. A square wave isn't useful as a carrier signal, since it contains more than one frequency (remember harmonics?)

These observations lead to what is known as the *Barkhausen criteria for oscillators*. Don't worry too much about number crunching these. They are presented only to give a better idea about what makes oscillators work. A technician troubleshooting a "dead" oscillator needs to know what to look for. The Barkhausen criteria give the technician a way of understanding what features in a circuit cause it to oscillate. The criteria are as follows:

Barkhausen Criteria

1. If the loop gain AB < 1, the circuit will *not* oscillate.
2. If the loop gain AB = 1 , the circuit will oscillate if it is doing so already. (If it is not oscillating, it will *not* start doing so with AB = 1).
3. For an oscillator to *start*, the loop gain AB *must be greater than 1*. (AB > 1 ensures oscillator starting.)

The designers of oscillators have quite a problem on their hands, because a successful oscillator must start reliably (AB > 1), but must also produce nice clean sine waves (AB = 1). These are seemingly contradictory conditions. Most RF oscillators rely on the nonlinearity of the active device (usually a transistor) to roll off the loop gain once the oscillator has started. When the oscillator is first powered up (and is producing little signal), the loop gain AB is designed to be more than 1, which causes the amplitude of the sine wave oscillations to rapidly increase. As the amplitude gets larger, the gain of the active device folds back, reducing the loop gain AB to unity (1), thus providing a stable output amplitude.

Positive Feedback is Required

Not only must an oscillator have sufficient loop gain to run, it must also receive *positive feedback*. Positive feedback means that the signal from the feedback block is *in phase* with the original input signal to the amplifier.

For this to be true, the sum of all the phase shifts around the loop must be 0∀, 360∀, or some exact multiple of 360 degrees. Figure 4-7 illustrates this point.

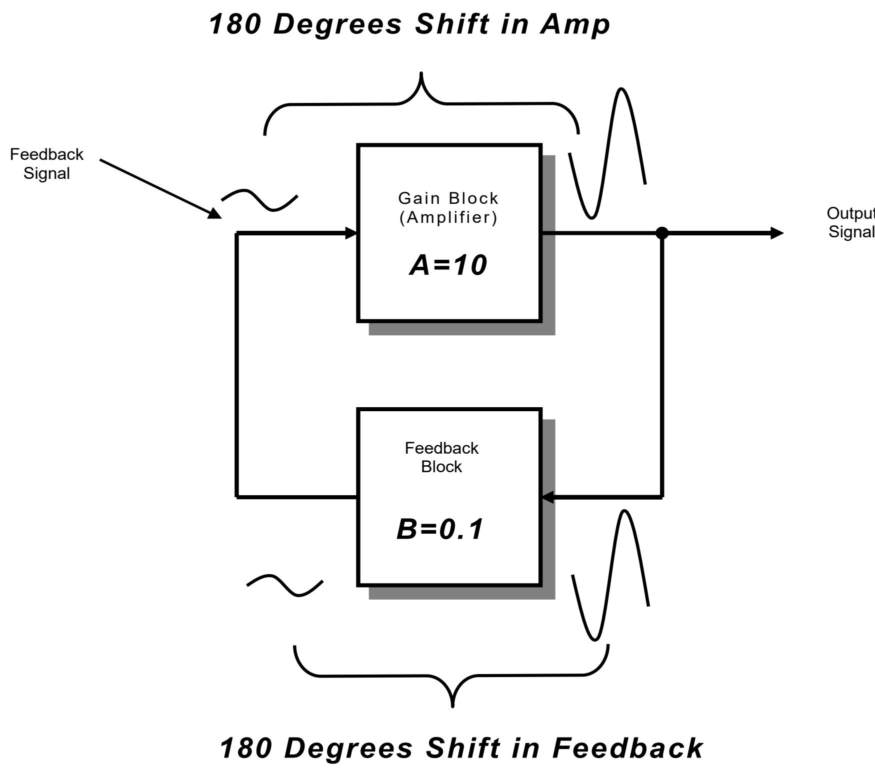

Figure 4-7: An oscillator with included phase shifts

In Figure 4-7, the amplifier provides a voltage gain of 10, but also inverts the signal by 180 degrees. *If the signal were fed back in this form, it would cancel at the amplifier's input, causing the oscillation to stop!*

The feedback network in Figure 4-7 corrects the "problem" by inserting its own 180 degree phase shift. Since (180 + 180) = 360, the feedback signal at the input of the amplifier remains *in phase* and the circuit receives *positive feedback*, which allows it to oscillate.

When we look at oscillator circuits, portions of the circuit can contribute phase shift. For example, a common-emitter transistor amplifier produces a 180-degree phase shift. Therefore, if this type of amplifier is being used in an oscillator, the feedback network must also produce a 180 degree phase shift to ensure that positive feedback will take place.

Section Checkpoint

4-10 What is the purpose of an oscillator circuit?
4-11 An oscillator can be divided into two parts. What are these parts?
4-12 What is meant by the term *loop gain* when referring to oscillators?
4-13 For an oscillator to continue running, what must the loop gain *AB* be equal to?
4-14 What loop gain *AB* is required for an oscillator to start?
4-15 For an oscillator to run, what type of feedback is needed?
4-16 What loop phase shifts provide positive feedback?

4-3 Three Oscillators

There are three basic oscillator configurations used in transmitters. These are the *Armstrong*, *Hartley*, and *Colpitts* circuits. These circuits are named after their inventors. Many other circuits are derived from these three. Let's take a look at the *Armstrong* circuit first.

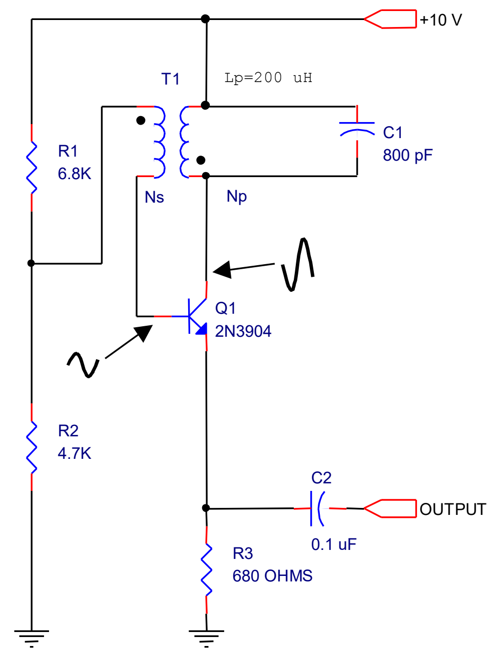

Figure 4-8: An Armstrong Oscillator

DC Circuit Analysis

Although it might not look like it initially, transistor Q1 in Figure 4-8 is biased using a *voltage divider*. The divider is built from R1 and R2. Why isn't the junction of R1 and R2 connected directly to the base? Good question.

A common trick in RF circuitry is to use a coupling coil or transformer winding to pass the DC bias voltage (along with the intended AC signal). Doing it this way eliminates a coupling capacitor. The voltage travels from the junction of R1 and R2 through the left-hand winding of T1, and down into the base of Q1.

The winding of T1 has *no* effect on the DC voltage for all practical purposes. Inductors are short-circuits to DC (there is usually a small DC resistance due to the wire itself). Therefore, it's just as if R1 and R2 were directly connected to the base.

TIP: When doing a DC circuit analysis, don't forget to short inductors, and open capacitors!

Resistor R3 sets the DC emitter current for Q1. You may be disturbed to learn that there is no collector resistor. No collector resistor is needed! The collector of Q1 gets its DC bias through the right-hand winding of T1. *The collector DC voltage will be equal to the power supply voltage.* Again, this is *very* typical of RF circuitry. Using an inductor (or transformer winding) to complete a DC bias path eliminates a coupling capacitor, and in this case, also eliminates a resistor.

Example 4-2

What should the voltages *Vb*, *Ve*, and *Vc* read in the circuit of Figure 4-8?

Solution:
The circuit of Figure 4-8 is voltage divider biased, so again, Ohm's law (and a little transistor theory) comes to the rescue. We're assuming a DC beta of 100 or more for the transistor so that we can ignore base loading effects.

$$Vb = Vcc\left(\frac{R2}{R1 + R2}\right) = 10V\left(\frac{4.7K}{4.7K + 6.8K}\right) = \underline{\underline{4.09\,V}}$$

Since this is an *NPN* transistor, the emitter voltage is lower (more negative) than the base voltage:

$$Ve = Vb - Vbe = 4.09V - 0.7V = \underline{\underline{3.39\,V}}$$

Finally, the collector is "shorted" to the power supply rail by the primary of T1, so we get:

$$Vc = Vcc = \underline{\underline{10\,V}}$$

Oscillator AC Circuit Analysis

In performing an AC circuit analysis of an oscillator, a technician normally looks for three things:

- What provides the gain?
- Where is the feedback?
- What controls the frequency of the oscillator?

You're probably not overly surprised that the transistor Q1 provides the voltage gain in this circuit. The feedback signal is sent into the base. Q1 acts as a *common emitter* amplifier and thus provides a 180 degree phase shift on the signal as it amplifies it. At the collector of Q1, the signal appears larger, but also *out of phase*.

Where does the signal go after it leaves the collector of Q1? There's only one place the signal can go, and that is into the right hand side of T1, the oscillator transformer *primary* winding. The purpose of T1 is to control the amount of feedback. In this circuit, T1 *steps down* the AC voltage by a prescribed amount. The feedback voltage emerges on the *left* side of T1 and is coupled into the base of Q1, completing the feedback path.

Recall that Q1 introduces a 180 degree phase shift into the signal. Unless that is corrected somewhere else in the loop, the circuit will not oscillate! In a transformer, it's easy to get a 180 degree phase shift by *reversing one set of winding connections*. The *phasing dots* that appear at the upper left and lower right of T1 specify that *one* winding's connections are flipped upside down. In this way, the proper loop phase shift is obtained.

The frequency of this oscillator is controlled by a bandpass filter. A bandpass filter can pass only frequencies within its bandwidth; it rejects frequencies that are above or below its resonant frequency. The bandpass filter is formed by capacitor C1 and the inductance of the primary of T1. The transformer does double-duty in this circuit; it not only controls the amount of feedback, but it also acts as part of a bandpass filter.

How does the bandpass filter *really* control the frequency of oscillation? Remember that two things are required for an oscillator to run. These are *gain* and *positive feedback*. Anything that removes the positive feedback will stop the oscillator. The bandpass filter formed by C1 and T1 is in the feedback path. Therefore, any frequency that cannot get through this filter *can't* be a feedback signal. The circuit can only oscillate at or near the resonant frequency of C1 and T1, which is a LC resonant circuit.

TIP: Most oscillators have a bandpass filter that controls oscillation frequency, and it is commonly an LC circuit (or equivalent, like a quartz crystal, as we'll soon see.)

Example 4-3

What is the frequency of oscillation for the Armstrong oscillator of Figure 4-8?

Solution:
To calculate the frequency of oscillation, identify the components in the *bandpass filter*. In this circuit, C1 and the primary of T1 form a parallel-resonant circuit. This is the bandpass filter.
On the schematic diagram, the equivalent inductance of the primary winding of T1 is given as <u>200μH</u>, and the value of C1 is given as 800 pF. (Note that manufacturers usually don't give winding inductances on schematics!)
From electronic fundamentals, we know that the frequency of resonance is given by:

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(200\mu H)(800\,pF)}} = \underline{\underline{397.9\,kHz}}$$

The Armstrong oscillator is one of the earliest-developed electronic oscillators. *It is usually identified as using a transformer within the feedback loop*. The primary limitation of an Armstrong oscillator is its *maximum operating frequency*. Above about 2 MHz, the Armstrong oscillator tends to become unstable because at high radio frequencies, the transformer begins to operate in a non-ideal manner. Other circuits are used when higher frequencies are required. These circuits eliminate the coupling transformer.

The Hartley Oscillator

Figure 4-9 shows a *Hartley* oscillator. It is simpler than the Armstrong oscillator because the coupling transformer has been eliminated. A Hartley oscillator can be made workable up to 30 MHz or so. A Hartley oscillator is usually identified by a *tapped inductor*, which is L1 in this case.

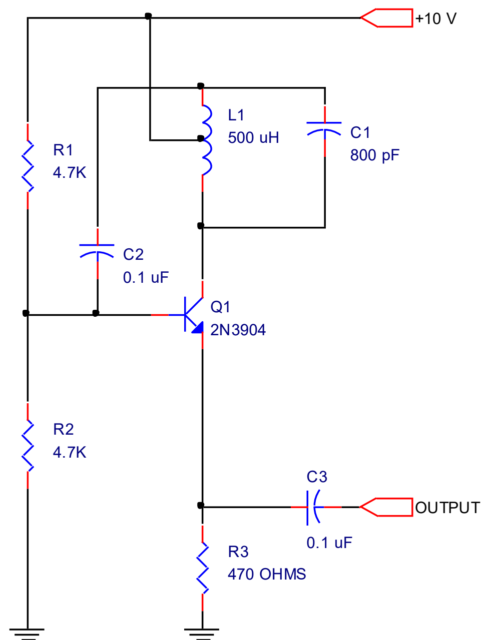

Figure 4-9: The Hartley oscillator

Hartley DC Analysis

The DC analysis of the Hartley oscillator is very similar to that of the Armstrong unit. Again, voltage divider biasing is used, with R1 and R2 setting the base bias voltage of Q1. R3 sets the emitter current, and again, there's no collector resistor. The inductor L1 "shorts" the collector of Q1 to the positive (Vcc) power supply, so the full power supply voltage (10V) appears at the collector.

Hartley AC Analysis

The circuit of Figure 4-9 is again using a common-emitter amplifier. AC signal flows into the base, and the transistor causes a 180 degree phase shift to appear (as well as providing a voltage gain.) The enlarged signal exits the collector of the transistor and moves up into the bottom of inductor L1.

Since a 180 degree phase shift has occurred in the amplifier, there *must* be another 180 degree phase shift somewhere in the loop. This one is hidden in L1's wiring. See the center tap of L1? It goes to *Vcc*.

The power supply of an electronic circuit is normally an AC ground. In AC analysis, DC sources are replaced with a short. Therefore, the center tap of L1 is at *ground* potential as far as AC is concerned!

This doesn't really answer the phase shift question. Look at Figure 4-10.