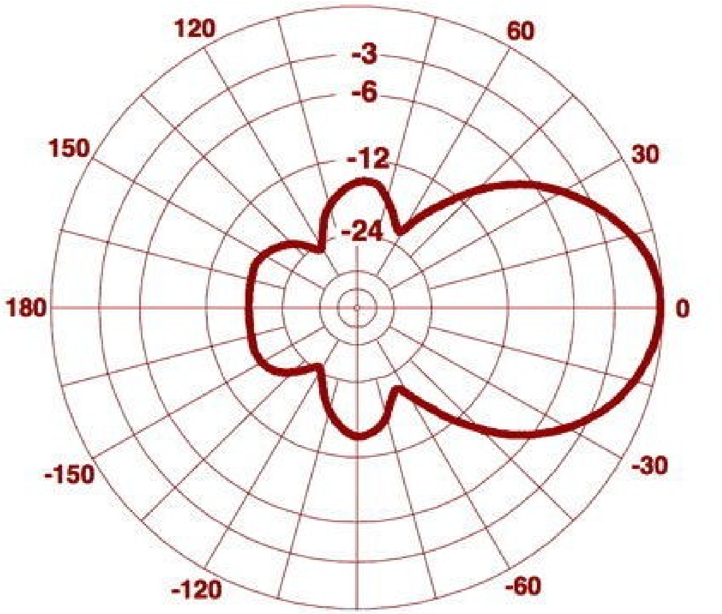
A No-Nonsense Amateur Radio Study Guide

Extra Class



License Study Guide

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The No-Nonsense, Extra Class License Study Guide

(for tests given after July 1, 2012)

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Table of Contents

Getting your Extra Class license

I got my Novice ticket way back in 1971. My first callsign was WN8KTZ. Back then, you had to upgrade to General Class within a year or lose your license. I upgraded about eight or nine months later. I upgraded to Advanced in 1979 when I was working for an electronics company in Santa Clara, CA.

This was at the prompting of my boss, who was also a General Class ham. He suggested that we take a day off, take the train up to the San Francisco FCC office and take the test. It was a beautiful day, we both passed the test, and just had a great time all the way around.

I didn't take the Extra Class test until 2006, almost 30 years later. At first, it was the 20 wpm code test that put me off. At that point, I wasn't getting on the air enough to get my speed up to 20 wpm. Later in life, I was afraid that I'd actually fail the written test. Besides, I had a good rejoinder whenever I was asked why I didn't have an Extra Class license. I used to joke that I wanted to be the last living Advanced Class licensee in the U.S.

After I started teaching amateur radio classes and writing license study guides, I decided it was high time to get the Extra. Besides, some of my students had already gotten their Extras, and I found it a bit embarassing to have a lower class of license than they had. So, in 2006, I decided it was time to study up and take the test.

I used the ARRL study guide. It did the job, and the test was actually a little easier than I'd anticipated. Even so, I got three wrong. I don't know that I'd have done any better if there had been a "No-Nonsense" study guide available for me to use. My guess is that it would not have. There are just so many things that you have to memorize that you're bound to forget something.

At first, I wasn't planning to produce an Extra Class study guide. There is a lot more material that you need to cover for the Extra Class when compared to the Technician Class and General Class that I knew that writing this study guide would take a long time. The material is a lot more complex, too, and that added to the amount of time it took me to write this book.

In the end, though, I knew that I would do it. Every week, I'd get emails from readers asking if or when a *No-Nonsense Extra Class License Study Guide* was going to be available, and I would have felt that my product lineup was incomplete without it.

How to use this manual

Simply read through the manual and take some practice tests. You will find the answers to questions in **bold**. Question designators, such as " (E5A07) " appear at the end of sentences. This is so you can refer to actual question in the question pool, if you would like to. You can take practice tests online at QRZ.Com, AA9PW.Com, and several other websites.

Good luck and have fun!

I hope that you find this study guide useful and that you'll upgrade to Extra. The Extra Class license gives you all privileges available to amateur radio operators. This means you get to learn even more about our great hobby.

If you have any comments, questions, compliments or complaints, I want to hear from you. E-mail me at cwgeek@kb6nu.com. My goal is to continually refine this study guide and to continually make it better.

73!

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E5: Electrical Principles

E5A - Resonance and Q: characteristics of resonant circuits; series and parallel resonance; Q; half-power bandwidth; phase relationships in reactive circuits

Resonance is one of the coolest things in electronics. Resonant circuits are what makes radio, as we know it, possible.

What is resonance? Well, a circuit is said to be resonant when the inductive reactance and capacitive reactance are equal to one another. That is to say, when

$$2\pi fL = 1/2\pi fC$$

where L is the inductance in henries and C is the capacitance in farads.

For a given L and a given C, this happens at only one frequency:

$$f = 1/2\pi\sqrt{(LC)}$$

This frequency is called the resonant frequency. Resonance in an electrical circuit is **the frequency at which the capacitive reactance equals the inductive reactance**.(E5A02)

Let's calculate a few resonant frequencies, using questions from the Extra question pool as examples:

The resonant frequency of a series RLC circuit if R is 22 ohms, L is 50 microhenrys and C is 40 picofarads is **3.56 MHz**. (E5A14)

$$f = 1/2\pi\sqrt{(LC)} = 1/(6.28 \text{ x } \sqrt{(50\text{x}10^{-6} \text{ x } 40\text{x}10^{-12})}) = 1/(2.8 \text{ x } 10^{-7}) = 3.56 \text{ MHz}$$

Notice that it really doesn't matter what the value of the resistance is. The resonant frequency would be the same is R = 220 ohms or 2.2 Mohms.

The resonant frequency of a series RLC circuit if R is 56 ohms, L is 40 microhenrys and C is 200 picofarads is **1.78 MHz**. (E5A15)

$$f = 1/2\pi\sqrt{(LC)} = 1/(6.28\text{x}\sqrt{(40\text{x}10^{-6} \text{ x } 200\text{x}10^{-12})}) = 1/(5.6\text{x}10^{-7}) = 1.78 \text{ MHz}$$

The resonant frequency of a parallel RLC circuit if R is 33 ohms, L is 50 microhenrys and C is 10 picofarads is **7.12 MHz**. (E5A16)

$$f = 1/2\pi\sqrt{(LC)} = 1/(6.28\text{x}\sqrt{(50\text{x}10^{-6} \text{ x } 10\text{x}10^{-12})}) = 1/(1.4\text{x}10^{-7}) = 7.12 \text{ MHz}$$

The resonant frequency of a parallel RLC circuit if R is 47 ohms, L is 25 microhenrys and C is 10 picofarads is **10.1 MHz**. (E5A17)

$$f = 1/2\pi\sqrt{(LC)} = 1/(6.28\text{x}\sqrt{(25\text{x}10^{-6} \text{ x } 10\text{x}10^{-12})}) = 1/(9.9\text{x}10^{-7}) = 10.1 \text{ MHz}$$

When an inductor and a capacitor are connected in series, the impedance of the series circuit at the resonant frequency is zero because the reactances are equal and opposite at that frequency. If there is a resistor in the circuit, that resistor alone contributes to the impedance. Therefore, the magnitude of the impedance of a series RLC circuit at resonance is **approximately equal to circuit resistance**. (E5A03)

The magnitude of the current at the input of a series RLC circuit is at **maximum** as the frequency goes through resonance. (E5A05) The reason for this is that neither the capacitor or inductor adds to the overall circuit impedance at the resonant frequency.

When the inductor and capacitor are connected in parallel, the impedances are again equal and opposite to one another at the resonant frequency, but because they are in parallel, the circuit is effectively an open circuit. Consequently, the magnitude of the impedance of a circuit with a resistor, an inductor and a capacitor all in parallel, at resonance, is **approximately equal to circuit resistance**. (E5A04)

Because a parallel LC circuit is effectively an open circuit at resonance, the magnitude of the current at the input of a parallel RLC circuit at resonance is at **minimum**. (E5A07) The magnitude of the circulating current within the components of a parallel LC circuit at resonance **is at a maximum**. (E5A06) **Resonance** can cause the voltage across reactances in series to be larger than the voltage applied to them. (E5A01)

Another consequence of the inductive and capacitive reactances canceling each other is that there is no phase shift at the resonant frequency. The phase relationship between the current through and the voltage across a series resonant circuit at resonance is that **the voltage and current are in phase**. (E5A08) The phase relationship between the current through and the voltage across a parallel resonant circuit at resonance is that **the voltage and current are in phase**. (E5A09)

Ideally, a series resonant circuit would have zero impedance at the resonant frequency and an infinite impedance at all others. A parallel resonant circuit would have an infinite impedance at the resonant frequency and be zero at all others.

Of course, in the real world, resonant circuits don't act this way. To describe how closely a circuit behaves like an ideal resonant circuit, we use the quality factor, or Q. Basically, the higher the Q, the more a resonant circuit behaves like an ideal resonant circuit.

A parameter of a resonant circuit that is related to Q is the half-power bandwidth. The half-power bandwidth is the bandwidth over which a series resonant circuit will pass half the power of the input signal and over which a parallel resonant circuit will reject half the power of an input signal.

We can use the Q of a circuit to calculate the half-power bandwidth:

$$BW = f/Q$$

Let's look at some examples:

The half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 1.8 MHz and a Q of 95 is **18.9 kHz**. (E5A10)

$$BW = f/Q = 1.8 \times 10^6/95 = 18.9 \times 10^3 = 18.9 \text{ kHz}$$

The half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 7.1 MHz and a Q of 150 is **47.3 kHz**. (E5A11)

$$BW = f/Q = 7.1 \times 10^6/150 = 47.3 \times 10^3 = 47.3 \text{ kHz}$$

What is the half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 3.7 MHz and a Q of 118 is **31.4 kHz**. (E5A12)

$$BW = f/Q = 3.5 \times 10^6/118 = 31.4 \times 10^3 = 31.4 \text{ kHz}$$

The half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 14.25 MHz and a Q of 187 is **76.2 kHz**. (E5A13)

$$BW = f/Q = 14.25 \times 10^6/187 = 76.2 \times 10^3 = 76.2 \text{ kHz}$$

E5B - Time constants and phase relationships: RLC time constants; definition; time constants in RL and RC circuits; phase angle between voltage and current; phase angles of series and parallel circuits

When you put a voltage across a capacitor, current will flow into the capacitor and the voltage across the capacitor will increase until the voltage across it reaches the value of the supply voltage. This is not a linear function. By that I mean that the voltage will increase quite rapidly at first, but the rate of increase will slow as time goes on.

To see how this works, let's consider the RC time constant. The time constant of an RC circuit is equal to the resistance in the circuit times the capacitance, or simply R x C. For example, the time constant of a circuit having two 220-microfarad capacitors and two 1-megohm resistors, all in parallel is **220 seconds**. (E5B04)

The equivalent resistance of two 1 MΩ resistors in parallel is 500 kΩ. The equivalent capacitance of two 220 μF capacitors in parallel is 440 μF. The time constant is $RxC = 440 \times 10^{-6} \times 500 \times 10^{3} =$ 220 s.

One time constant is the term for the time required for the capacitor in an RC circuit to be charged to 63.2% of the applied voltage. (E5B01) Similarly, **one time constant** is the term for the time it takes for a charged capacitor in an RC circuit to discharge to 36.8% of its initial voltage. (E5B02)

The capacitor in an RC circuit is discharged to **13.5%** of the starting voltage after two time constants. (E5B03) Similarly, a capacitor charges to 86.5% of the applied voltage after two time constants. After three time constants, a capacitor is charged up to 95% of the applied voltage or discharged to 5% of the starting voltage.

You can use these percentages to answer the questions about how much time it takes for a capacitor to discharge. The key is to figure out what percentage the voltage given is of the starting voltage. In one case, the starting voltage is 20 V and you must figure out how much time it will take for the capacitor to discharge to 7.36 V.

Well, 7.36 V just happens to be 36.8% of 20 V, so the time required will be one time constant. One time constant is R x C, or in this case $0.01 \times 10^{-6} \times 2 \times 10^{6}$, or .02 s. So, it takes **0.02 seconds** for an initial charge of 20 V DC to decrease to 7.36 V DC in a 0.01-microfarad capacitor when a 2-megohm resistor is connected across it. (E5B05)

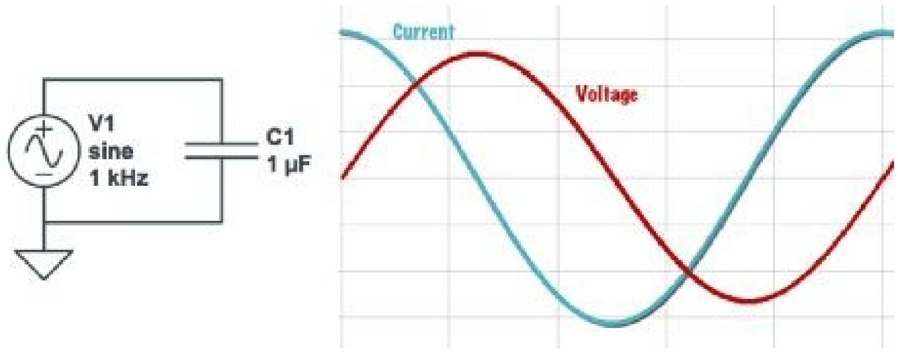
In the second case, the starting voltage is 800 V and you must calculate the time required for the voltage across the capacitor to drop to 294 V. Well, fortunately, 294 V / 800 V is again 36.8%, so the time required will be one time constant.

In this circuit, R = 1 MΩ and the capacitance 450 μF. $R \times C = 10^{6} \times 450 \times 10^{-6} = 450$ s. So, it takes **450 seconds** for an initial charge of 800 V DC to decrease to 294 V DC in a 450-microfarad capacitor when a 1-megohm resistor is connected across it. (E5B06)

In an AC circuit, with only resistors, the voltage and current are in phase. What that means is that the voltage and current change in lock step. When the voltage increases, the current increases. When the voltage decreases, the current decreases.

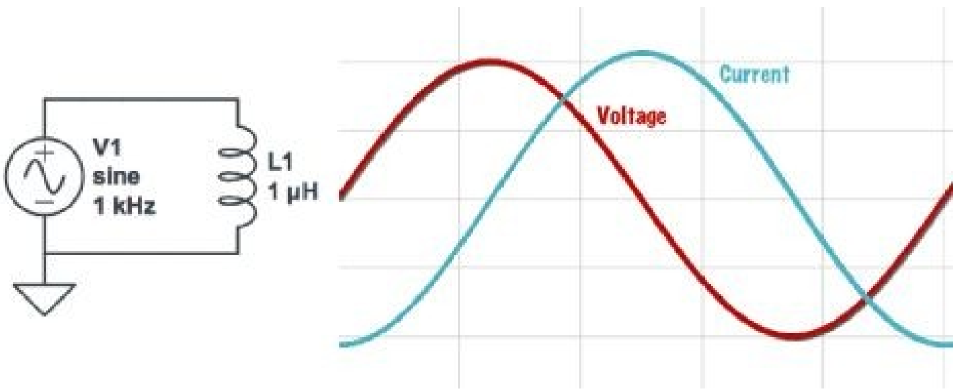
When there are capacitors and inductors in an AC circuit, however, the phase relationship between the voltage and current changes. Specifically, the relationship between the current through a capacitor and the voltage across a capacitor is that the **current leads voltage by 90 degrees**. (E5B09) We could also say that the voltage lags the current by 90 degrees. See figure below.

What that means is that the current through a capacitor increases and decreases before the voltage across a capacitor increases and decreases. We say that the current leads the voltage by 90 degrees because it starts increasing one-quarter of a cycle before the voltage starts increasing.

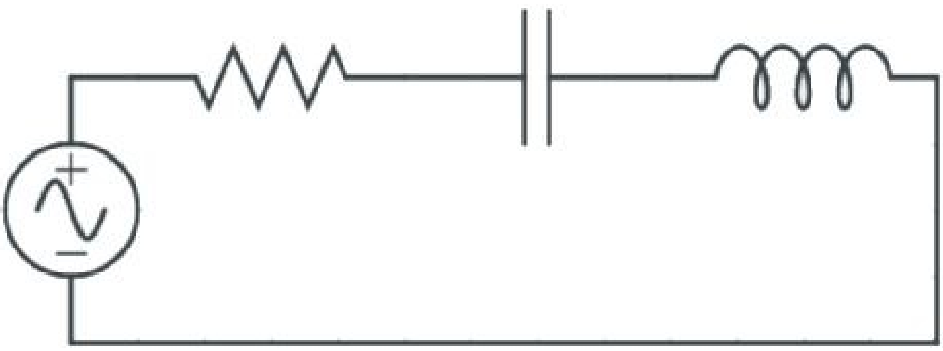


The relationship between the current through an inductor and the voltage across an inductor is that the **voltage leads current by 90 degrees**. (E5B10) We could also say that the current lags the voltage. See figure below.

What that means is that the voltage across an inductor increases and decreases before the current through the inductor increases and decreases. We say that the voltage leads the voltage by 90 degrees because it starts increasing one-quarter of a cycle before the current starts increasing.

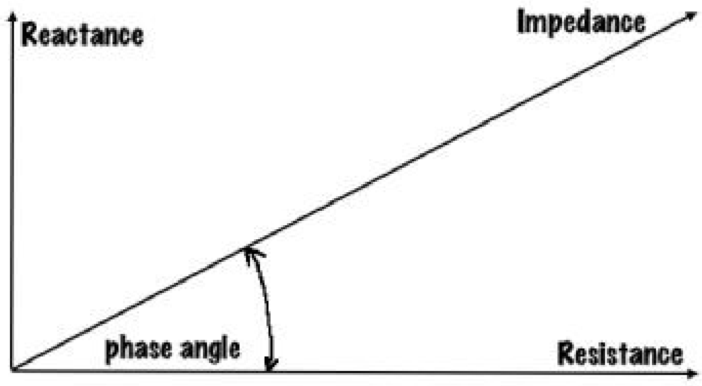


When there are resistors as well as a capacitor or inductor or both in a circuit, the relationship is a little more complicated. Let's look at what happens in the series RLC circuit shown below.



In this circuit, there is resistance, capacitive reactance, and inductive reactance. The reactances subtract from one another. If the capacitive reactance is greater than the inductive reactance, the net reactance will be capacitive. If the inductive reactance is greater than the capacitive reactance, the net reactance will be inductive.

The resistance and the reactance add to one another, but they add *vectorially*. The reason for this is that the reactance will be 90 degrees out of phase with the resistance. This is shown in the figure below.



The magnitude of the impedance, Z, will be equal to $\sqrt{(R^2 + X^2)}$ and the tangent of the phase angle will be equal to X/R. Let's see how this works in several examples.

If X_C is 500 ohms, R is 1 kilohm, and X_L is 250 ohms, the phase angle between the voltage across and the current through the series RLC circuit is **14.0 degrees with the voltage lagging the current**. (E5B07) Here's how to calculate that:

$X = X_C - X_L = 250\ \Omega$ (capacitive)

phase angle = $\tan^{-1}(250/1000) = 14$ degrees.

and because the reactance is capacitive, the voltage will lag the current.

If X_C is 100 ohms, R is 100 ohms, and X_L is 75 ohms, the phase angle between the voltage across and the current through the series RLC circuit is **14 degrees with the voltage lagging the current**. (E5B08) Here's the calculation:

$X = X_C - X_L = 25\ \Omega$ (capacitive)

phase angle = $\tan^{-1}(25/100) = 14$ degrees.

and because the reactance is capacitive, the voltage lags the current.

If X_C is 25 ohms, R is 100 ohms, and X_L is 50 ohms, the phase angle between the voltage across and the current through the series RLC circuit is **14 degrees with the voltage leading the current**. (E5B11) Here's the calculation:

$X = X_L - X_C = 25\ \Omega$ (inductive)

phase angle = $\tan^{-1}(25/100) = 14$ degrees.

and because the reactance is inductive, the voltage leads the current.

If X_C is 75 ohms, R is 100 ohms, and X_L is 50 ohms, the phase angle between the voltage across and the current through the series RLC circuit is **14 degrees with the voltage lagging the current**.

(E5B12) Here's the calculation:

$X = X_C - X_L = 25\ \Omega$ (capacitive)

phase angle = $\tan^{-1}(25/100) = 14$ degrees.

and because the reactance is capacitive, the voltage lags the current.

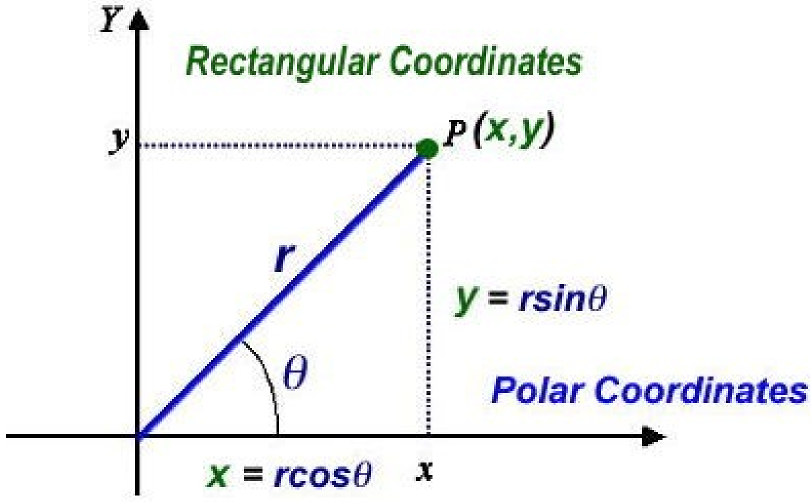
If X_C is 250 ohms, R is 1 kiloohm, and X_L is 500 ohms, the phase angle between the voltage across and the current through the series RLC circuit is **14 degrees with the voltage leading the current**. (E5B13) Here's the calculation:

$X = X_L - X_C = 250\ \Omega$ (inductive)

phase angle = $\tan^{-1}(250/1000) = 14$ degrees.

and because the reactance is inductive, the voltage leads the current.

E5C - Impedance plots and coordinate systems: plotting impedances in polar coordinates; rectangular coordinates



Most often when we plot values on a graph, we use the rectangular, or Cartesian, coordinate system. The two numbers that are used to define a point on a graph using rectangular coordinates are **the coordinate values along the horizontal and vertical axes**. (E5C11) In the graph above, point P is at x,y. **Rectangular coordinates** are often used to display the resistive, inductive, and/or capacitive reactance components of an impedance. (E5C13)

When thinking about how capacitive reactances, inductive reactances, and resistance combine, it's useful to think in terms of polar coordinates. **Polar coordinates** are often used to display the phase angle of a circuit containing resistance, inductive and/or capacitive reactance. (E5C14) In a polar-coordinate system, each point on the graph has two values, a magnitude (shown by *r* in the figure above) and an angle (shown by *θ* in the figure above).

When using rectangular coordinates to graph the impedance of a circuit, the vertical axis represents the **reactive component**. (E5C10) To figure out the impedance of a circuit, you first plot the inductive reactance on the positive y-axis and the capacitive reactance on the negative y-axis. The net reactance, X, will be the sum of the two reactances.

When using rectangular coordinates to graph the impedance of a circuit, the horizontal axis represents the **resistive component**. (E5C09) After you've computed the net reactance, you plot the resistance on the x-axis and compute the magnitude of the impedance, shown by *r* in the graph above. If you consider that r is the third side of a right triangle made up of the sides r, x, and y, r is equal to the square root of x^2 and y^2.

Let's take a look at an example. In polar coordinates, is the impedance of a network consisting of a 100-ohm-reactance inductor in series with a 100-ohm resistor is **141 ohms at an angle of 45 degrees**. (E5C01) In this example, x=100 and y=100, so

$$r = \sqrt{(X^2 + R^2)} = \sqrt{(100^2 + 100^2)} = \sqrt{(20000)} = 141 \text{ ohms.}$$

The cosine of the phase angle *θ* is equal to x/r, or 100/141, or .707. If you look up this value in a table of cosines, you'll find that the angle is 45 degrees.

Here's another thing to notice. When the value of the reactance is equal to the value of the resistance, the angle will be either 45 degrees or -45 degrees, depending on whether the net reactance is inductive or capacitive.

Now, let's look at an example with both inductive and capacitive reactance. In polar coordinates, the impedance of a network consisting of a 100-ohm-reactance inductor, a 100-ohm-reactance capacitor, and a 100-ohm resistor, all connected in series is **100 ohms at an angle of 0 degrees**. (E5C02) In this case, the inductive reactance and the capacitive reactance are the same, meaning that there is no net reactance. If you plot the impedance of a circuit using the rectangular coordinate system and find the impedance point falls on the right side of the graph on the horizontal axis, you know that the circuit impedance **is equivalent to a pure resistance**. (E5C12)

Here's an example with unequal inductive and capacitive reactances. In polar coordinates, the impedance of a network consisting of a 300-ohm-reactance capacitor, a 600-ohm-reactance inductor, and a 400-ohm resistor, all connected in series is **500 ohms at an angle of 37 degrees**. (E5C03) Here's how we got that result:

$$X = 600 - 300 = 300 \text{ ohms}$$

$$r = \sqrt{(X^2 + R^2)} = \sqrt{(300^2 + 400^2)} = \sqrt{(250000)} = 500 \text{ ohms}$$

$$\theta = \cos^{-1}(x/r) = \cos^{-1}(400/500) = 37 \text{ degrees}$$

Here are some more examples. I'll leave the solutions up to you:

- In polar coordinates, the impedance of a network consisting of a 400-ohm-reactance capacitor in series with a 300-ohm resistor is **500 ohms at an angle of -53.1 degrees**. (E5C04)
- In polar coordinates, the impedance of a network consisting of a 400-ohm-reactance inductor in parallel with a 300-ohm resistor is **240 ohms at an angle of 36.9 degrees**. (E5C05)
- In polar coordinates, the impedance of a network consisting of a 100-ohm-reactance capacitor in series with a 100-ohm resistor is **141 ohms at an angle of -45 degrees**. (E5C06)
- In polar coordinates, the impedance of a network comprised of a 100-ohm-reactance capacitor in parallel with a 100-ohm resistor is **71 ohms at an angle of -45 degrees**. (E5C07)
- In polar coordinates, what is the impedance of a network comprised of a 300-ohm-reactance inductor in series with a 400-ohm resistor is **500 ohms at an angle of 53 degrees**. (E5C08)
- In polar coordinates, the impedance of a series circuit consisting of a resistance of 4 ohms, an inductive reactance of 4 ohms, and a capacitive reactance of 1 ohm is **5 ohms at an angle of 37 degrees**. (E5C18)

Sometimes, we use what are calling "imaginary" numbers to represent reactance. An inductive reactance of 100 ohms would be denoted as j100 ohms. An capacitive reactance of 100 ohms would be denoted as -j100 ohms. The imaginary value *j* is plotted along the y-axis. Consequently, in polar coordinates, the impedance of a circuit of 100 -j100 ohms impedance is **141 ohms at an angle of -45 degrees**. (E5C15)

In rectangular coordinates, the impedance of a network consisting of a 10-microhenry inductor in series with a 40-ohm resistor at 500 MHz is **40 + j31,400**. (E5C22) The imaginary value is calculated using the formula for inductive reactance:

$$X = 2\pi fL = 2 \times 3.14 \times 500{,}000{,}000 \times .000010 = 31{,}400$$

Because this reactance is inductive, the imaginary value is positive.

Admittance is the inverse of impedance. So, in polar coordinates, the impedance of a circuit that has an admittance of 7.09 millisiemens at 45 degrees is **141 ohms at an angle of -45 degrees**. (E5C16) You calculate it this way:

$|Z| = 1/7.09x10^{-3} = 141$ ohms

The angle is the mirror image about the x axis:

$\theta = 0 - -45$ degrees = 45 degrees

The resistive value is then $|Z| \times \cos 45$ degrees = $141 \times 1 = 141$ ohms

Let's look at another example. In rectangular coordinates, the impedance of a circuit that has an admittance of 5 millisiemens at -30 degrees is **173 +j100 ohms**. (E5C17)

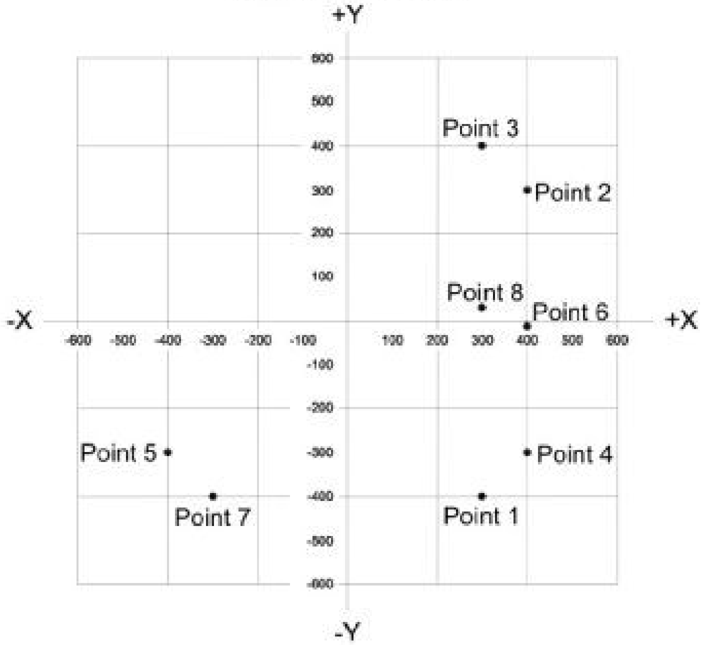
$|Z| = 1/5x10^{-3} = 200$ ohms

$\theta = 0 - -30$ degrees = 30 degrees

$R = |Z| \times \cos 30$ degrees = $200 \times .866 = 173$ ohms

X (the reactance part of the impedance) = $|Z| \times \sin 30$ degrees = $200 \times .5 = +j100$

Figure E5-2



Now, let's take a look at some actual circuits.

On Figure E5-2, the point that best represents the impedance of a series circuit consisting of a 400 ohm resistor and a 38 picofarad capacitor at 14 MHz is **Point 4**. (E5C19) Right off the bat, we know that the only choices are really Points 2, 4, and 6 because the resistance is 400 ohms. Next, we calculate the capacitive reactance:

$X_C = 1/2\pi fC = 1/(2 \times 3.14 \times 14x10^6 \times 38\times10^{-12}) \approx 300$ ohms

Because the reactance is capacitive, it's plotted as a negative value.

On Figure E5-2, the point that best represents the impedance of a series circuit consisting of a 300 ohm resistor and an 18 microhenry inductor at 3.505 MHz is **Point 3**. (E5C20) The resistance is 300 ohms and the reactance is:

$$X_L = 2\pi fL = 2 \times 3.14 \times 3.505x10^6 \times 18\times10^{-6}) \approx 400 \text{ ohms}$$

And, since the reactance is inductive, it's plotted as a postive value.

On Figure E5-2, the point that best represents the impedance of a series circuit consisting of a 300 ohm resistor and a 19 picofarad capacitor at 21.200 MHz is **Point 1**. (E5C21) The resistance is 300 ohms, and the reactance is:

$$X_C = 1/2\pi fC = 1/(2 \times 3.14 \times 21.2x10^6 \times 19\times10^{-12}) \approx 400 \text{ ohms}$$

Because the reactance is capacitive, it's plotted as a negative value.

On Figure E5-2, the point that best represents the impedance of a series circuit consisting of a 300-ohm resistor, a 0.64-microhenry inductor and an 85-picofarad capacitor at 29.400 MHz is **Point 8**. (E5C23) This problem is a little tougher because it has both capacitive and inductive reactance.

$$X_C = 1/2\pi fC = 1/(2 \times 3.14 \times 29.4x10^6 \times 85\times10^{-12}) \approx 63.7 \text{ ohms}$$

$$X_L = 2\pi fL = 2 \times 3.14 \times 29.4x10^6 \times 0.64\times10^{-6}) \approx 118.2 \text{ ohms}$$

$$X = X_L - X_C = 118.2 - 63.7 = 55.5 \text{ ohms}$$

Because the net reactance is inductive, it is plotted as a positive value, and because the resistance is 300 ohms, the answer is Point 8.

E5D - AC and RF energy in real circuits: electrostatic and electromagnetic fields; reactive power; power factor; coordinate systems; skin effect

AC circuits–and RF circuits are just a type of AC circuit–capacitors and inductors store and release energy as the voltages and currents change. Because of this calculating power and energy in an AC circuit is not as straightforward as it is for DC circuits.

For example, **a capacitor** is a device is used to store electrical energy in an electrostatic field. (E5D03) During the positive portion of an AC cycle, the capacitor stores energy in its electrostatic field, but during the negative portion of the cycle, it returns that energy to the circuit.

An inductor is a device used to store electrical energy in a magnetic field. **Electric current** creates a magnetic field. (E5D05) **The amount of current** determines the strength of a magnetic field around a conductor. (E5D07) The direction of the magnetic field oriented about a conductor in relation to the direction of electron flow runs **in a direction determined by the left-hand rule**. (E5D06)

A similar thing happens to the magnetic field created by the current flow through an inductor that happens to the electrostatic field in a capacitor. When the current flows in one direction, a magnetic field is created. When the current changes direction, the energy stored in that magnetic field gets returned to the circuit.

The type of energy stored in an electromagnetic or electrostatic field is **potential energy**. (E5D08) The unit that we use to measure the electrical energy stored in an electrostatic field is the **Joule**. (E5D04)

Reactive power

When talking about the power consumed by AC circuits, an important concept is *reactive power*. Reactive power is **wattless, nonproductive power**. (E5D14)

As noted above, during some portions of an AC cycle, inductors and capacitors will draw current and store energy, but during other portions of the cycle, it will return that energy to the circuit. So, what happens to reactive power in an AC circuit that has both ideal inductors and ideal capacitors is that **it is repeatedly exchanged between the associated magnetic and electric fields, but is not dissipated**. (E5D09) In other words, the net power dissipation is zero.

Of course, very few circuits contain only capacitors and inductors. In AC circuits where there is a resistance, that resistance will dissipate *real power*. For example, in a circuit consisting of a 100 ohm resistor in series with a 100 ohm inductive reactance drawing 1 ampere, the power consumed is **100 Watts**. (E5D13) ($P = I^2 \times R = 1A^2 \times 100$ ohms = 100 W.)

In an AC circuit with inductors and capacitors, the voltage is out of phase with the current. You determine the true power an AC circuit where the voltage and current are out of phase **by multiplying the apparent power times the power factor**. (E5D10) For example, if a circuit has a power factor of 0.71 and the apparent power is 500 VA, the watts consumed is **355 W**. (E5D18)

The power factor, or PF, is the cosine of phase angle between the voltage and current. For example, if an R-L circuit has a 60 degree phase angle between the voltage and the current, the power factor is the cosine of 60 degrees, or **0.5** (E5D11) The power factor of an RL circuit having a 45 degree phase angle between the voltage and the current is the cosine of 45 degrees, or **0.707**. (E5D15) The power factor of an RL circuit having a 30 degree phase angle between the voltage and the current is the cosine of 30 degrees, or **0.866**. (E5D16)

Let’s look at a few examples:

- If a circuit has a power factor of 0.2, and the input is 100-V AC at 4 amperes, the watts consumed is V × I × PF = 100V × 4A × 0.2 = **80 watts**. (E5D12)
- If a circuit has a power factor of 0.6 and the input is 200V AC at 5 amperes, the watts

consumed is V × I × PF = 200V × 5A × 0.6 = **600 watts**. (E5D17)

Skin Effect

Next, let's look at the phenomenon of skin effect. This phenomenon really has no connection at all to the previous discussion, but was thrown into this section for some reason.

At RF frequencies, the current in a conductor tends to flow near the surface of that conductor. This is the reason this phenomenon is called skin effect. The result of skin effect is that **as frequency increases, RF current flows in a thinner layer of the conductor, closer to the surface**. (E5D01)

Because the RF current flows in a smaller cross-sectional area of a conductor than a DC current, the RF current will experience more resistance than a DC current. In other words, the resistance of a conductor is different for RF currents than for direct currents **because of skin effect**. (E5D02)

E6: Circuit Components

E6A - Semiconductor materials and devices: semiconductor materials; germanium, silicon, P-type, N-type; transistor types: NPN, PNP, junction, field-effect transistors: enhancement mode; depletion mode; MOS; CMOS; N-channel; P-channel

While transistor theory is outside the scope of this study guide, I will attempt to at least give you a basic understanding of how transistors are put together and how they work. For more information, take a look at these two links:

- How Semiconductors Work (http://www.howstuffworks.com/diode.htm)
- P-type and N-type silicon (http://www.energyresearch.nl/energieopties/zonnecellen/achtergrond/techniek/p-en-n-type-silicium/)

Most transistors we use in amateur radio are made of silicon. Silicon is a semiconductor. That is to say, it's neither a conductor with a very low resistance, like copper, or an insulator with a very high resistance, like plastic or glass.

You can manipulate the electrical characteristics of silicon by adding slight amounts of impurities to a pure silicon crystal. When transistor manufacturers add an impurity that adds free electrons to the silicon crystal, it creates a crystal with a negative charge. We call that type of silicon N-type silicon. **N-type** is a semiconductor material that contains excess free electrons. (E6A02)

When you add other types of impurities to a pure silicon crystal, you can create a crystal with a positive charge. We call this type of material P-type semiconductor material. In N-type semiconductor material, the majority charge carriers are the **free electrons**. (E6A16) The majority charge carriers in P-type semiconductor material are called **holes**. (E6A03) **P-type** is the type of semiconductor material that contains an excess of holes in the outer shell of electrons. (E6A15)

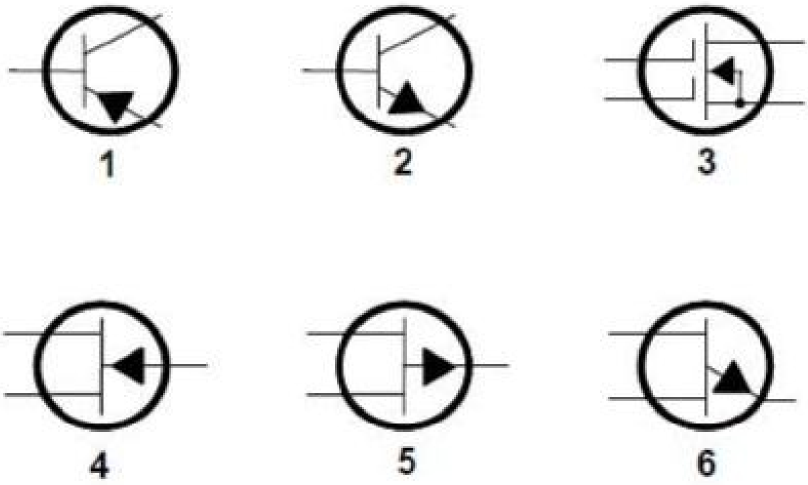
You can think of them as holes as spots in the crystal that accepts free electrons into. Because of that, the name given to an impurity atom that adds holes to a semiconductor crystal structure is call an **acceptor impurity**. (E6A04)

Silicon isn't the only semiconductor material used to make transistors. **At microwave frequencies**, gallium arsenide is used as a semiconductor material in preference to germanium or silicon. (E6A01)

Bipolar junction transistor characteristics

Perhaps the most popular type of transistor is the bipolar junction transistor (BJT). Bipolar junction transistors are three-terminal devices, called the emitter, base, and collector. In an NPN transistor, the emitter and collector are N-type material and the base is P-type material. In a PNP transistor, the emitter and collector are P-type, while the base is N-type. The base is sandwiched between the collector and emitter, so there is a diode junction between the base and the collector and the base and emitter.

Figure E6-1



Refer to Figure E6-1 above. In Figure E6-1, the schematic symbol for a PNP transistor is **#1**. (E6A07) #2 is the schematic symbol for an NPN transistor. The arrow in both symbols shows the direction of the current flow.

When the base-emitter diode is forward-biased, a current, called the base current will flow. If there is an appropriate voltage between the collector and emitter, this small base current will cause a much larger current to flow between the collector, through the base to the emitter. The amount of base current controls how much collector current flows. This is how transistors amplify signals.

The change in collector current with respect to base current is the beta of a bipolar junction transistor. (E6A06) This is also sometimes called the hfe, or current gain, of a transistor. **The change of collector current with respect to emitter current** is the alpha of a bipolar junction transistor. (E6A05)

Another important characteristic of a bipolar transistor is the alpha cutoff frequency. This is a measure of how high in frequency a transistor will operate. **Alpha cutoff frequency** is the frequency at which the grounded-base current gain of a transistor has decreased to 0.7 of the gain obtainable at 1 kHz. (E6A08)

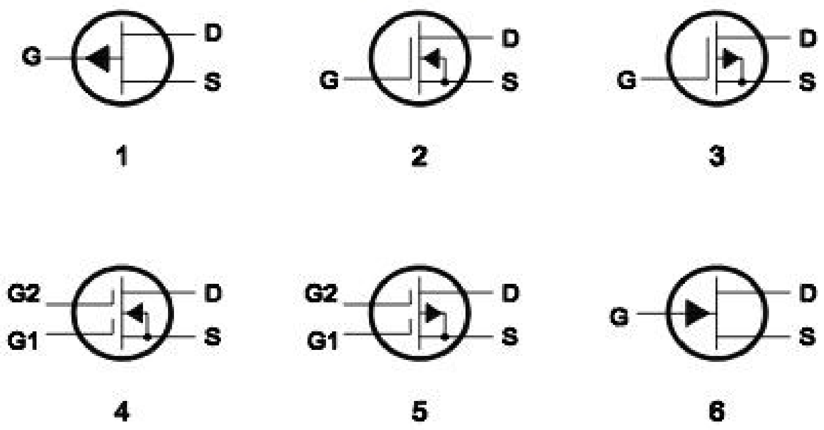
Field Effect Transistors

A field-effect transistor (FET) is a device that uses an electric field to control current flow through the device. Like the bipolar transistor, a FET normally has three terminals. The names of the three terminals of a field-effect transistor are **gate, drain, source**. (E6A17)

FETs are normally made with a technology called Complementary Metal-Oxide Semiconductor, or CMOS. The initials CMOS stand for **Complementary Metal-Oxide Semiconductor**. (E6A13) FETs made with CMOS technology are sometimes call MOSFETs.

In Figure E6-2 (below), schematic symbol **1** is the symbol for a P-channel junction FET. (E6A11) In Figure E6-2 (below), schematic symbol **4** is the symbol for an N-channel dual-gate MOSFET. (E6A10)

Figure E6-2



One characteristic of the MOSFET is that they have a high input impedance. This makes them more attractive for use in many test equipment applications than bipolar transistors. How does DC input impedance at the gate of a field-effect transistor compare with the DC input impedance of a bipolar transistor? **An FET has high input impedance; a bipolar transistor has low input impedance**. (E6A14)

One disadvantage of using MOSFETs is that they are very sensitive to electrostatic discharge (ESD). Sometimes, they are damaged by static discharges so low that you never even see the spark or feel the shock. **To reduce the chance of the gate insulation being punctured by static discharges or excessive voltages** many MOSFET devices have internally connected Zener diodes on the gates. (E6A12)

Most FETs are enhancement-mode devices. When using an enhancement-mode FET, you must apply a voltage to the gate to get current to flow from source to drain. Some FETs are, however, depletion mode devices. A depletion-mode FET is **an FET that exhibits a current flow between source and drain when no gate voltage is applied**. (E6A09)

E6B - Semiconductor diodes

Diodes are the simplest semiconductor devices. In their simplest form, they have two terminals and conduct current in only one direction, from the cathode to the anode. By manipulating the characteristics of the semiconductor material, manufacturers can make diodes useful in a wide variety of applications.

Take, for example, the Zener diode. The most useful characteristic of a Zener diode is **a constant voltage drop under conditions of varying current**. (E6B01) This makes it useful in voltage regulator circuits.

Another example is the varactor diode. The **varactor diode** is a semiconductor device designed for use as a voltage-controlled capacitor. (E6B04) Varactor diodes are often used in tuning circuits.

A PIN diode is a semiconductor device that operates as a variable resistor at RF and microwave frequencies. One common use for PIN diodes is **as an RF switch**. (E6B12)The characteristic of a PIN diode that makes it useful as an RF switch or attenuator is **a large region of intrinsic material**. (E6B05) **The forward DC bias current** is used to control the attenuation of RF signals by a PIN diode. (E6B11)

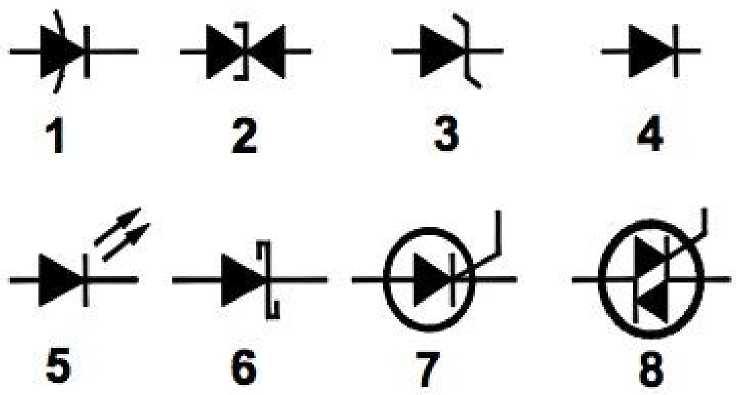
Two types of diodes used in RF circuits are the tunnel diode and hot-carrier diode. The **tunnel** diode is a special type of diode is capable of both amplification and oscillation. (E6B03) Tunnel diodes are capable of operating well into the microwave region. A hot-carrier diode is commonly used **as a VHF / UHF mixer or detector**. (E6B06)

Metal-semiconductor junction is a term that describes a type of semiconductor diode. (E6B08) A Schottky diode is an example of a metal-semiconductor diode. An important characteristic of a Schottky diode as compared to an ordinary silicon diode when used as a power supply rectifier is that it has **less forward voltage drop**. (E6B02) This characteristic also makes them useful in digital logic circuits. The lower forward voltage drop allows the digital ICs to switch faster.

Another type of diode is the point-contact diode. A common use for point-contact diodes is **as an RF detector**. (E6B09)

In Figure E6-3 (below), **5** is the schematic symbol for a light-emitting diode. (E6B10) **Forward bias** is required for an LED to emit light. (E6B13)

Figure E6-3



No matter what kind of diode you are using, it’s very important to not exceed the forward current specification. Doing so, will cause it to fail. **Excessive junction temperature** is the failure mechanism when a junction diode fails due to excessive current. (E6B07)

E6C - Integrated circuits: TTL digital integrated circuits; CMOS digital integrated circuits; gates

Integrated circuits (ICs) are now an integral part (pun intended) of amateur radio electronics. The two main technologies used to manufacture IC are transistor-transistor logic, or TTL, and complementary metal-oxide semiconductor, or CMOS.

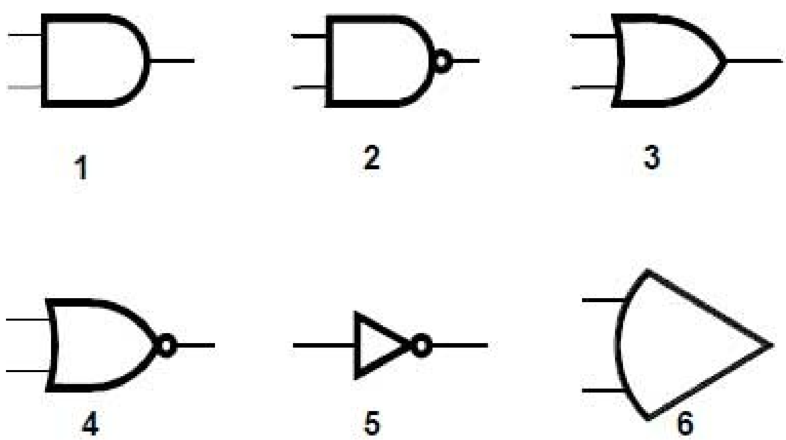
CMOS is arguably the most common type of digital IC. An advantage of CMOS logic devices over TTL devices is that the have **lower power consumption**. (E6C05) CMOS digital integrated circuits also have high immunity to noise on the input signal or power supply because **the input switching threshold is about one-half the power supply voltage**. (E6C06)

TTL is the other common digital logic IC technology. **5 volts** is the recommended power supply voltage for TTL series integrated circuits. (E6C01) The inputs of a TTL device assume **a logic-high state** if they are left open. (E6C02)

BiCMOS logic is **an integrated circuit logic family using both bipolar and CMOS transistors**. (E6C12) An advantage of BiCMOS logic is that **it has the high input impedance of CMOS and the low output impedance of bipolar transistors**. (E6C13)

Tri-state logic devices are **logic devices with 0, 1, and high impedance output states**. (E6C03) These devices can be made with either TTL or CMOS technology. The primary advantage of tri-state logic is the **ability to connect many device outputs to a common bus**. (EC604) When a device's outputs are in the high-impedance state, they act as if they are disconnected.

Figure E6-5



When working with digital ICs, it is important to recognize the various symbols for the different types of logic gates. In Figure E6-5, **1** is the schematic symbol for an AND gate. (E6C07) In Figure E6-5, **2** is the schematic symbol for a NAND gate. (E6C08) In Figure E6-5, **3** is the schematic symbol for an OR gate. (E6C09) In Figure E6-5, **4** is the schematic symbol for a NOR gate. (E6C10) In Figure E6-5, **5** is the schematic symbol for the NOT operation (inverter). (E6C11)

E6D Optical devices and toroids: cathode-ray tube devices; charge-coupled devices (CCDs); liquid crystal displays (LCDs) Toroids: permeability; core material; selecting; winding

Cathode-ray tubes (CRTs) used to the be most common type of display. They were not only used in television sets, but also computer terminals. They have an electron gun which shoots electrons onto a screen which then glows where the electron hits the screen. By sweeping this "beam" both horizontally and vertically, you can display an image on the screen.

To sweep the beam across the CRT, you deflect it by passing it though a set of plates. Varying the voltage will change the angle at which the beam is deflected. **Electrostatic** deflection is the type of CRT deflection that is better when high-frequency waveforms are to be displayed on the screen. (E6D13)

To accelerate the electron towards the screen, you apply a relatively high anode voltage to it. The higher the voltage, the brighter the CRT will glow. You don't want to make that voltage too high, however. Exceeding **the anode voltage** specification can cause a cathode ray tube (CRT) to generate X-rays. (E6D02)

A spot on the CRT screen will glow even after the beam moves onto another spot. Cathode ray tube (CRT) persistence is **the length of time the image remains on the screen after the beam is turned off**. (E6D01) This characteristic is useful in many different applications.

A more modern type of display is the liquid-crystal display. A liquid-crystal display (LCD) is **a display using a crystalline liquid which, in conjunction with polarizing filters, becomes opaque when voltage is applied**. (E6D05) The principle advantage of liquid-crystal display (LCD) devices over other types of display devices is that **they consume less power**. (E6D15)

Unlike the CRT or LCD display, which transform electrical signals into an image, a charge-coupled device is used to transform an image into electrical signals. A charge-coupled device (CCD) **samples an analog signal and passes it in stages from the input to the output**. (E6D03) One of the things a charge-coupled device (CCD) does in a modern video camera is that **it stores photogenerated charges as signals corresponding to pixels**. (E6D04)One thing that is *NOT* true of a charge-coupled device (CCD) is that **it is commonly used as an analog-to-digital converter**. (E6D14)

Toroids

Toroidal inductors are very popular these days. A primary advantage of using a toroidal core instead of a solenoidal core in an inductor is that **toroidal cores confine most of the magnetic field within the core material**. (E6D10)

Another reason for their popularity is the frequency range over which you can use them. The usable frequency range of inductors that use toroidal cores, assuming a correct selection of core material for the frequency being used is **from less than 20 Hz to approximately 300 MHz**. (E6D07) **Ferrite beads** are commonly used as VHF and UHF parasitic suppressors at the input and output terminals of transistorized HF amplifiers. (E6D09)

An important characteristic of a toroid core is its permeability. **Permeability** is the core material property that determines the inductance of a toroidal inductor. (E6D06)

One important reason for using powdered-iron toroids rather than ferrite toroids in an inductor is that **powdered-iron toroids generally maintain their characteristics at higher currents**. (E6D08) One reason for using ferrite toroids rather than powdered-iron toroids in an inductor is that **ferrite toroids generally require fewer turns to produce a given inductance value**. (E6D16)

To calculate the inductance of a ferrite-core toroid, we need the inductance index of the core material. The formula that we use to calculate the inductance of a ferrite-core toroid inductor is:

$$L = A_L \times N^2/1,000,000$$

where L = inductance in microhenries, A_L = inductance index in µH per 1000 turns, and N = number of turns

We can solve for N to get the following formula:

$$N = 1000 \text{ x } \sqrt{(L/A_L)}$$

Using that equation, we see that **43 turns** will be required to produce a 1-mH inductor using a ferrite toroidal core that has an inductance index (A L) value of 523 millihenrys/1000 turns. (E6D11)

$$N = 1000 \text{ x } \sqrt{(1/523)} = 1000 \text{ x } .0437 = 43.7 \text{ turns}$$

The formula for calculating the inductance of a powdered-iron core toroid inductor is:

$$L = A_L \times N^2/10,000$$

where L = inductance in microhenries, A_L = inductance index in µH per 1000 turns, and N = number of turns

We can solve for N to get the following formula:

$$N = 100 \text{ x } \sqrt{(L/A_L)}$$

Using that equation, **35 turns** turns will be required to produce a 5-microhenry inductor using a powdered-iron toroidal core that has an inductance index (A L) value of 40 microhenrys/100 turns. (E6D12)

$$N = 1000 \text{ x } \sqrt{(5/40)} = 100 \text{ x } .353 = 35.3 \text{ turns}$$

E6E Piezoelectric crystals and MMICs: quartz crystal oscillators and crystal filters); monolithic amplifiers

Piezoelectric crystals are used in several amateur radio applications. They are called piezoelectric crystals because they rely on the piezoelectric effect, which is the **physical deformation of a crystal by the application of a voltage**. (E6E03)

Perhaps the most common use for a piezoelectric crystal is as the frequency-controlling component in an oscillator circuit. To ensure that a crystal oscillator provides the frequency specified by the crystal manufacturer, you must **provide the crystal with a specified parallel capacitance**. (E6E09)

Piezoelectric crystals are also used in crystal filters. A crystal lattice filter is a filter with narrow bandwidth and steep skirts made using quartz crystals. (E6E01) **The relative frequencies of the individual crystals** is the factor that has the greatest effect in helping determine the bandwidth and response shape of a crystal ladder filter. (E6E02) A "Jones filter" is **a variable bandwidth crystal lattice filter** used as part of a HF receiver IF stage. (E6E12)

Monolithic microwave ICs (MMICs)

Monolithic microwave integrated circuits, or MMICs, are ICs that are made to perform various functions at high frequencies. **Gallium nitride** is the material that is likely to provide the highest frequency of operation when used in MMICs. (E6E11)

The characteristics of the MMIC that make it a popular choice for VHF through microwave circuits are **controlled gain, low noise figure, and constant input and output impedance over the specified frequency range**. (E6E06) For example, a low-noise UHF preamplifier might have a typical noise figure value of **2 dB**. (E6E05) **50 ohms** is the most common input and output impedance of circuits that use MMICs. (E6E04)

To achieve these specifications, great care is taken in building and using an MMIC. For example, **microstrip construction** is typically used to construct a MMIC-based microwave amplifier. (E6E07) The power-supply voltage is normally furnished to the most common type of monolithic microwave integrated circuit (MMIC) **through a resistor and/or RF choke connected to the amplifier output lead**. (E6E08)

E6F: Optical components and power systems: photoconductive principles and effects, photovoltaic systems, optical couplers, optical sensors, and optoisolators

The photovoltaic effect is **the conversion of light to electrical energy**. (E6F04) In a device called a photovoltaic cell, **electrons** absorb the energy from light falling on a photovoltaic cell. (E6F12) The electrons then become free electrons.

The most common type of photovoltaic cell used for electrical power generation is **silicon**. (E6F10) The approximate open-circuit voltage produced by a fully-illuminated silicon photovoltaic cell is **0.5 V**. (E6F11) The efficiency of a photovoltaic cell is **the relative fraction of light that is converted to current**. (E6F09)

Photoconductivity is a similar phenomenon. Photoconductivity is **the increased conductivity of an illuminated semiconductor**. (E6F01) The conductivity of a photoconductive material **increases** when light shines on it. (E6F02) **A crystalline semiconductor** is the material that is affected the most by photoconductivity. (E6F06)

A device that uses the phenomenon of photoconductivity is the optoisolator. The most common configuration of an optoisolator or optocoupler is **an LED and a phototransistor**. (E6F03) Optoisolators are often used in conjunction with solid state circuits when switching 120 VAC because **optoisolators provide a very high degree of electrical isolation between a control circuit and the circuit being switched**. (E6F08)

A similar device is the solid-state relay. A solid state relay is **a device that uses semiconductor devices to implement the functions of an electromechanical relay**. (E6F07)

Optical shaft encoders are another device that rely on photoconductivity. An optical shaft encoder is **a device which detects rotation of a control by interrupting a light source with a patterned wheel**. (E6F05) Optical shaft encoders are used to detect when an operator turns a knob on an amateur radio transceiver.

E7: Practical Circuits

E7A - Digital circuits: digital circuit principles and logic circuits: classes of logic elements; positive and negative logic; frequency dividers; truth tables

Digital circuits are used for a variety of functions in modern amateur radio equipment. Unlike analog circuits, the output voltage of an ideal digital circuit can only be one of two values. One of these voltages—normally a positive voltage—represents a digital 1. The other value—normally near 0 V—represents a digital 0.

This type of logic is generally called positive logic. **Positive Logic** is the name for logic which represents a logic "1" as a high voltage. (E7A11) The logic may be reversed, though. That is to say that a high voltage may represent a logic 0. **Negative logic** is the name for logic which represents a logic "0" as a high voltage. (E7A12)

The microcomputers that control today's transceivers, for example, are very complex digital circuits. These complex digital circuits are made by combining many smaller building blocks called logic gates. These gates perform basic digital logic functions.

One of the most basic digital circuits in the NAND gate. The logical operation that a NAND gate performs is that **it produces a logic "0" at its output only when all inputs are logic "1."** (E7A07)

This logical operation can be described by a truth table. A truth table is **a list of inputs and corresponding outputs for a digital device**. (E7A10) Table E7-1 shows a truth table that describes the operation of a two-input NAND gate. A and B are the two inputs; Q is the output.

2-INPUT NAND		
A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

Table E7-1

Other types of gates perform different logical functions. The logical operation that an OR gate performs is that **it produces a logic "1" at its output if any or all inputs are logic "1."** (E7A08) Table E7-2 shows a truth table that describes the logical operation of an OR gate.

2-INPUT OR		
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

Table E7-2

The logical operation that is performed by a two-input exclusive NOR gate is that **it produces a logic "0" at its output if any single input is a logic "1."** (E7A09) Table E7-3 shows a truth table that describes the logical operation of an OR gate.

2-INPUT XNOR		
A	B	Q
0	0	1
0	1	0
1	0	0
1	1	1

Table E7-3

Flip-flops are circuits that are made from combinations of logic gates. The output of a flip-flop is not entirely dependent on its inputs; it is also dependent on the current value of its output.

As an example, let's look at the SR or RS flip-flop. An SR or RS flip-flop is **a set/reset flip-flop whose output is low when R is high and S is low, high when S is high and R is low, and unchanged when both inputs are low**. (E7A13) So, once set to a particular value, the output will not change when both inputs are set to low.

Some flip-flops are clocked. That is to say that they only change states when a clock signal input changes states. A D flip-flop is an example of this type of flip-flop. A D flip-flop is **a flip-flop whose output takes on the state of the D input when the clock signal transitions from low to high**. (E7A15) A JK flip-flop is **a flip-flop similar to an RS except that it toggles when both J and K are high**. (E7A14)

Another type of flip-flop is the T flip-flop. The T flip-flop is so called because for each transition from low to high on the flip-flop's T input, the output "toggles" from 0 to 1 if the output was already at 0, and from 1 to 0 if the output was already at 1. **Two** output level changes are obtained for every two trigger pulses applied to the input of a T flip-flop circuit. (E7A02) See figure E7-2 below.

As you can see in figure E7-2, **a flip-flop** can divide the frequency of a pulse train by 2. (E7A03) Consequently, **2** flip-flops are required to divide a signal frequency by 4. (E7A04)

A flip-flop is a bistable circuit. (E7A01) What that means is that its output is stable in either state.

An **astable multivibrator** is a circuit that continuously alternates between two states without an external clock. (E7A05) In other words, it is an oscillator.

A monostable circuit is one that is stable in one state but not the other. One characteristic of a monostable multivibrator is that **it switches momentarily to the opposite binary state and then returns, after a set time, to its original state**.(E7A06) A trigger pulse causes the monostable vibrator to switch to the unstable state, and it stays in that state for a set period, no matter how long the trigger pulse.

E7B - Amplifiers class of operation; vacuum tube and solid-state circuits; distortion and intermodulation; spurious and parasitic suppression; microwave amplifiers

There are several classifications of amplifiers, based on their mode of operation. In a class A amplifier is always conducting current. That means that the bias of a Class A common emitter amplifier would normally be set **approximately half-way between saturation and cutoff** on the load line. (E7B04)

In a class B amplifer, there are normally two transistors operating in a “push-pull” configuration. One transistor turns on during the positive half of a cycle, while the other turns on during the negative half. **Push-pull** amplifiers reduce or eliminate even-order harmonics. (E7B06)

A Class AB amplifier operates over **more than 180 degrees but less than 360 degrees** of a signal cycle. (E7B01) Class B and Class AB amplifiers are more efficient than Class A amplifiers.

A Class D amplifier is **a type of amplifier that uses switching technology to achieve high efficiency**. (E7B02) The output of a class D amplifier circuit includes **a low-pass filter to remove switching signal components**. (E7B03)

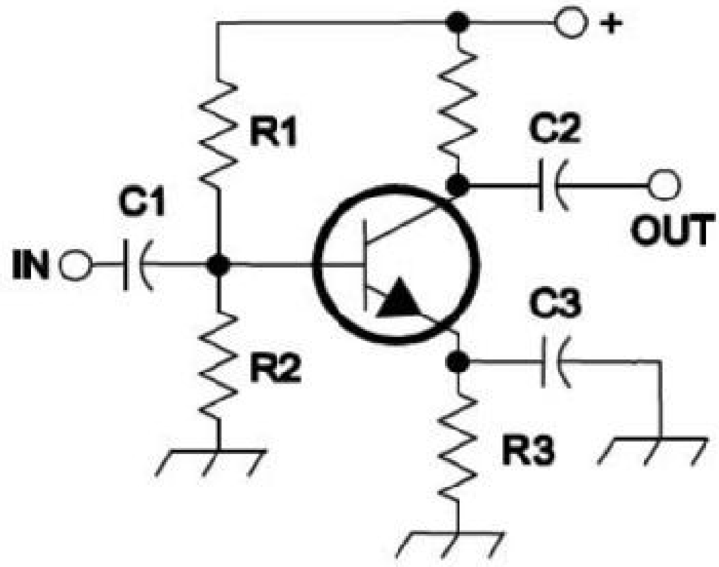
Amplifiers are used in many different applications, but one application that is especially important, at least as far as signal quality goes, is RF power amplification. RF power amplifiers may emit harmonics or spurious signals, that may cause harmful interference.

One thing that can be done to prevent unwanted oscillations in an RF power amplifier is to **install parasitic suppressors and/or neutralize the stage**. (E7B05) An RF power amplifier be neutralized **by feeding a 180-degree out-of-phase portion of the output back to the input**. (E7B08) Another thing one can do to reduce unwanted emissions is to use a push-pull amplifier. **Signal distortion and excessive bandwidth** is a likely result when a Class C amplifier is used to amplify a single-sideband phone signal. (E7B07)

Most modern transceivers use transistors in their final amplifiers, and the output impedance is 50 ohms over a wide frequency range. A **field effect transistor** is generally best suited for UHF or microwave power amplifier applications. (E7B21)

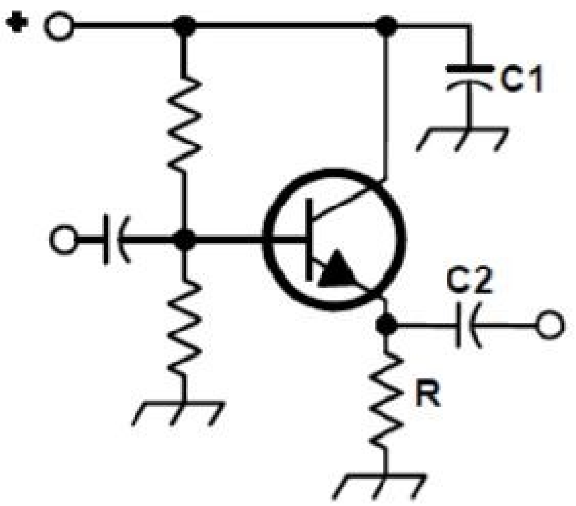
Many high-power amplifiers, however, still use vacuum tubes. These amplifiers require that the operator tune the output circuit. **The tuning capacitor is adjusted for minimum plate current, while the loading capacitor is adjusted for maximum permissible plate current** is how the loading and tuning capacitors are to be adjusted when tuning a vacuum tube RF power amplifier that employs a pi-network output circuit. (E7B09)

Figure E7-1



The type of circuit shown in Figure E7-1 is a **common emitter amplifier**. (E7B12) In Figure E7-1, the purpose of R1 and R2 is to provide **fixed bias**. (E7B10) In Figure E7-1, the purpose of R3 is to provide **self bias**. (E7B11)

Figure E7-2



In Figure E7-2, the purpose of R is to provide **emitter load**. (E7B13) In Figure E7-2, the purpose of C2 is to provide **output coupling**. (E7B14)

Thermal runaway is one problem that can occur if a transistor amplifier is not designed correctly. What happens is that when the ambient temperature increases, the leakage current of the transistor increases, causing an increase in the collector-to-emitter current. This increases the power dissipation, further increasing the junction temperature, which increases yet again the leakage current. One way to prevent thermal runaway in a bipolar transistor amplifier is to **use a resistor in series with the emitter**. (E7B15)

RF power amplifers often generate unwanted signals via a process called intermodulation. Strong signals external to the transmitter combine with the signal being generated, causing sometimes unexpected and unwanted emissions. The effect of intermodulation products in a linear power amplifier is the **transmission of spurious signals**. (E7B16) Third-order intermodulation distortion products are of particular concern in linear power amplifiers **because they are relatively close in frequency to the desired signal**. (E7B17)

One type of amplifer that is often used as a power amplifier is the *grounded-grid amplifier*. Grounded-grid amplifiers are relatively easy to build, and they are very stable in operation. One characteristic of a grounded-grid amplifier is **low input impedance**. (E7B18)

Finally, there are several questions on special-application amplifiers. A klystron is **a VHF, UHF, or microwave vacuum tube that uses velocity modulation**. (E7B19) A parametric amplifier is **a low-noise VHF or UHF amplifier relying on varying reactance for amplification**. (E7B20)

E7C - Filters and matching networks: types of networks; types of filters; filter applications; filter characteristics; impedance matching; DSP filtering

Because the impedance of inductors and capacitors vary with frequency, we often make filters out of them. One of the most common is the T-network filter, so called because it looks like the letter T. An example is shown in figure E7C-1.

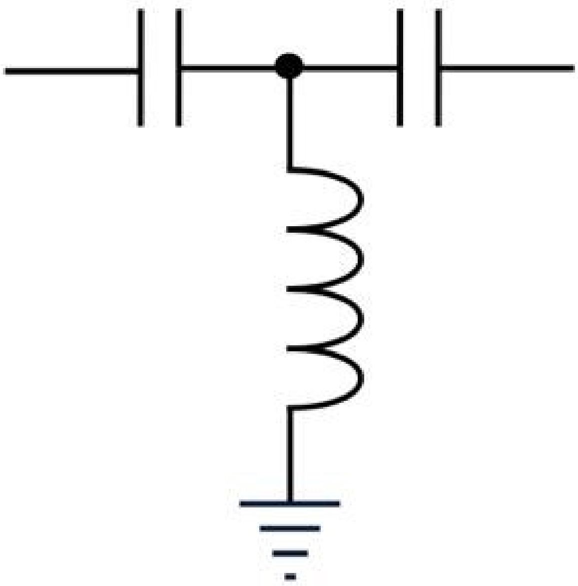


Figure E7C-1. T-network filter

This particular filter has the characteristic of being a high-pass filter. That is to say it will pass frequencies above a certain frequency, called the cutoff frequency, and block frequencies below that frequency. A T-network with series capacitors and a parallel shunt inductor has the property of it being **a high-pass filter**. (E7C02) The reason the circuit acts this way is that as the frequency of a signal increases, capacitive reactance decreases and inductive reactance increases, meaning that lower-frequency signals are more likely to be shunted to ground.

A circuit containing capacitors and inductors can also form a low-pass filter. A low-pass filter is a circuit that passes frequencies below the cutoff frequency and blocks frequencies above it.

The circuit shown in figure E7C-2 is called a pi filter because it looks like the Greek letter π. The capacitors and inductors of a low-pass filter Pi-network are arranged such that **a capacitor is connected between the input and ground, another capacitor is connected between the output and ground, and an inductor is connected between input and output**. (E7C01) The reason the circuit acts this way is that as the frequency of a signal increases, capacitive reactance decreases and inductive reactance increases, meaning that higher-frequency signals are more likely to be shunted to ground.

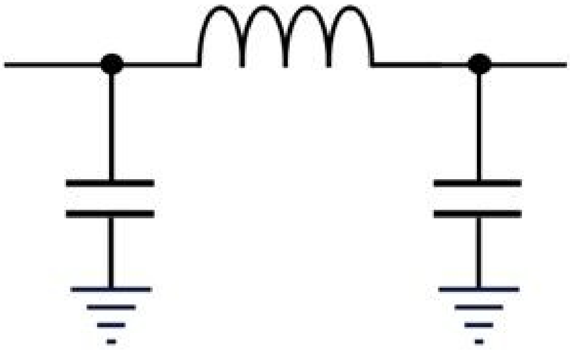


Figure E7C-2. Pi-network filter

Pi networks can also be used to match the output impedance of one circuit to the input impedance of another or the output impedance of a transmitter to the input impedance of an antenna. An impedance-matching circuit transforms a complex impedance to a resistive impedance because **it cancels the reactive part of the impedance and changes the resistive part to a desired value**. (E7C04) One advantage of a Pi matching network over an L matching network consisting of a single inductor and a single capacitor is that **the Q of Pi networks can be varied depending on the component values chosen**. (E7C13)

A Pi network with an additional series inductor on the output describes a Pi-L network used for matching a vacuum-tube final amplifier to a 50-ohm unbalanced output. (E7C12) One advantage a Pi-L-network has over a Pi-network for impedance matching between the final amplifier of a vacuum-tube transmitter and an antenna is that it has **greater harmonic suppression**. (E7C03)

Different types of filters have different characteristics. For example, a **Chebyshev filter** is a filter type described as having ripple in the passband and a sharp cutoff. (E7C05) On the other hand, the distinguishing features of an elliptical filter are **extremely sharp cutoff with one or more notches in the stop band**. (E7C06)

Filters have both amplitude and phase-response characteristics. In some applications, both are important. **Digital** modes, for example, are most affected by non-linear phase response in a receiver IF filter. (E7C14)

The Chebyshev filter was named for Pafnuty Chebyshev, whose mathematical work led to the development of these filters. Sometimes filters are named for their circuit topoology. **Pi** is the common name for a filter network which is equivalent to two L networks connected back-to-back with the inductors in series and the capacitors in shunt at the input and output. (E7C11) When you look at the circuit diagram for a filter of this type, you'll see that it looks like the Greek letter pi.

Often, you'll choose a filter type for a particular application. For example, to attenuate an interfering carrier signal while receiving an SSB transmission, you would use **a notch filter**. (E7C07)

Today, many of these filters are implemented using digital signal processing. The kind of digital signal processing audio filter might be used to remove unwanted noise from a received SSB signal is **an adaptive filter**. (E7C08) The type of digital signal processing filter might be used to generate an SSB signal is **a Hilbert-transform filter**. (E7C09)

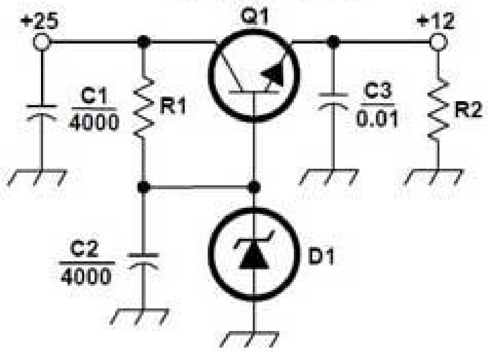
Some filters are used almost exclusively in a particular application. **A cavity filter**, for example, would be the best choice for use in a 2 meter repeater duplexer. (E7C10)

E7D - Power supplies and voltage regulators

One characteristic of a linear electronic voltage regulator is **the conduction of a control element is varied to maintain a constant output voltage**. (E7D01) This would be Q1 in the circuit in Figure E3-7 below. The device typically used as a stable reference voltage in a linear voltage regulator is **a Zener diode**. (E7D03)

A series regulator is the type of linear voltage regulator that usually makes the most efficient use of the primary power source. (E7D04) **A shunt regulator** is the type of linear voltage regulator that places a constant load on the unregulated voltage source. (E7D05)

Figure E7- 3



The circuit shown in Figure E7-3 is a **linear voltage regulator**. (E7D08) This is a series voltage regulator. D1 in the circuit shown in Figure E7-3 **provides a voltage reference**. (E7D13) Q1 in the circuit shown in Figure E7-3 **increases the current-handling capability of the regulator**. (E7D06)

C1 in the circuit shown in Figure E7-3 **filters the supply voltage**. (E7D09) C2 in the circuit shown in Figure E7-3 **bypasses hum around D1**. (E7D07) C3 in the circuit shown in Figure E7-3 **prevents self-oscillation**. (E7D10)

R1 in the circuit shown in Figure E7-3 **supplies current to D1**. (E7D11) R2 in the circuit shown in Figure E7-3 **provides a constant minimum load for Q1**. (E7D12)

Switching power supplies

Nowadays, you are as likely to find a switching power supply in an amateur radio station as you are a linear power supply. Switching power supplies use a much different method of regulating the output voltage than a linear supply. Perhaps the biggest advantage of the switching supply is that it doesn't use a transformer. This makes the switching power supply less expensive and lighter than a linear power supply with the same output rating. One characteristic of a switching electronic voltage regulator is **the control device's duty cycle is controlled to produce a constant average output voltage**. (E7D02)

The disadvantage is that the circuitry is more complicated. In a way, this is an advantage for you, the person studying to pass the Extra Class test. Because the circuitry is more complicated, the questions would be more complicated. So, there is only one question on the test about switching power supplies.

High-voltage power supplies

Most HF transceivers and VHF/UHF transceivers operate at a relatively low voltage. This is normally around 12 - 15 VDC. Some devices, such as older tube equipment and linear amplifiers need higher voltages to operate. These power supplies are quite different than the low-voltage linear and switching supplies describe above.

One difference is that the unregulated supplies used in tube equipment often have what's called a bleeder resistor. One purpose of a "bleeder" resistor in a conventional (unregulated) power supply is

to improve output voltage regulation. (E7D14)

High-voltage supplies may also have a step-start circuit. The purpose of a "step-start" circuit in a high-voltage power supply is **to allow the filter capacitors to charge gradually**. (E7D15)

The primary reason that a high-frequency inverter type high-voltage power supply can be both less expensive and lighter in weight than a conventional power supply is that **the high frequency inverter design uses much smaller transformers and filter components for an equivalent power output**. (E7D17)

When several electrolytic filter capacitors are connected in series to increase the operating voltage of a power supply filter circuit, resistors should be connected across each capacitor:

- To equalize, as much as possible, the voltage drop across each capacitor
- To provide a safety bleeder to discharge the capacitors when the supply is off
- To provide a minimum load current to reduce voltage excursions at light loads

All of these choices are correct. (E7D16)

E7E - Modulation and demodulation: reactance, phase and balanced modulators; detectors; mixer stages; DSP modulation and demodulation; software defined radio systems

Modulation is the process of adding some kind of information, including voice and digital information, to a carrier signal. The most common types of modulation that we use in amateur radio are amplitude modulation (AM) and frequency modulation (FM). Single-sideband, or SSB, is a form of amplitude modulation.

To frequency modulate a carrier, a transmitter will sometimes use a modulator that varies the phase of the signal. This is sometimes called phase modulation (PM). One way to generate FM phone emissions is to use **a reactance modulator on the oscillator**. (E7E01) The function of a reactance modulator is **to produce PM signals by using an electrically variable inductance or capacitance**. (E7E02) An analog phase modulator functions **by varying the tuning of an amplifier tank circuit to produce PM signals**. (E7E03)

To boost the higher audio frequencies, **a pre-emphasis network** is often added to an FM transmitter. (E7E05) **For compatibility with transmitters using phase modulation,** de-emphasis is commonly used in FM communications receivers. (E7E06)

Amplitude modulation and single-sideband signals are produced using mixer circuits. The carrier frequency and the baseband signals are input to the mixer circuit which produces an amplitude modulated output. The term *baseband* in radio communications refers to **the frequency components present in the modulating signal**. (E7E07) The principal frequencies that appear at the output of a mixer circuit are **the two input frequencies along with their sum and difference frequencies**. (E7E08)

When using a mixer, you must take care not to use too high of a signal at the inputs. **Spurious mixer products are generated** when an excessive amount of signal energy reaches a mixer circuit. (E7E09)

Single sideband is most often used for phone transmission on the HF bands and for weak-signal operation on the VHF and UHF bands. One way a single-sideband phone signal can be generated is **by using a balanced modulator followed by a filter**. (E7E04) A balanced modulator is a type of mixer. The output of a balanced modulator, however, does not contain the carrier frequency, only the two sidebands.

Modern transceivers use digital signal processing to generate SSB signals. **The quadrature method** describes a common means of generating an SSB signal when using digital signal processing. (E7E13)

At the receiving station, a modulated signal has to be demodulated. Amplitude modulated signals are often demodulated using a diode detector circuit. A diode detector functions **by rectification and filtering of RF signals**. (E7E10)

For demodulating SSB signals, you want something a little more sophisticated. A **product detector** is a type of detector that is well suited for demodulating SSB signals. (E7E11) A product detector is actually a frequency mixer. It takes the product of the modulated signal and a local oscillator, hence the name. In an FM receiver, **the circuit for detecting FM signals** is a frequency discriminator. (E7E12)

Some modern receivers demodulate a signal entirely in software. These receivers are called software-defined receivers. When referring to a software defined receiver, direct conversion means **incoming RF is mixed to “baseband” for analog-to-digital conversion and subsequent processing**. (E7E14)

E7F - Frequency markers and counters: frequency divider circuits; frequency marker generators; frequency counters

To measure the frequency of a signal, you use an instrument called a *frequency counter*. The purpose of a frequency counter is **to provide a digital representation of the frequency of a signal**. (E7F09) A frequency counter **counts the number of input pulses occurring within a specific period of time**. (E7F08)

To accurately measure high-frequency signals digitally, you need a highly stable and accurate frequency source, called the time base. The time base provides an accurate and repeatable time period, over which you count the number of pulses of the test signal. **The accuracy of the time base** determines the accuracy of a frequency counter. (E7F07)

An alternate method of determining frequency, other than by directly counting input pulses that is used by some counters is **period measurement plus mathematical computation**. (E7F10) An advantage of a period-measuring frequency counter over a direct-count type is that **it provides improved resolution of low-frequency signals within a comparable time period**. (E7F11)

You also need an accurate and stable time base to generate and receive microwave signals. **All of these choices are correct** when talking about techniques for providing high stability oscillators needed for microwave transmission and reception: (E7F05)

- Use a GPS signal reference
- Use a rubidium stabilized reference oscillator
- Use a temperature-controlled high Q dielectric resonator

If you want to measure a signal whose frequency is higher than the maximum frequency of your counter, you might use a prescaler. The purpose of a prescaler circuit is to **divide a higher frequency signal so a low-frequency counter can display the input frequency**. (E7F01) **A prescaler** would, for example, be used to reduce a signal’s frequency by a factor of ten. (E7F02)

You might use a decade counter digital IC in a prescaler circuit. The function of a decade counter digital IC is to **produce one output pulse for every ten input pulses**. (E7F03)

In some cases, you might use a flip-flop. **Two flip-flops** must be added to a 100-kHz crystal-controlled marker generator so as to provide markers at 50 and 25 kHz. (E7F04) The purpose of a marker generator is **to provide a means of calibrating a receiver's frequency settings**. (E7F06) You mostly find marker generators in older, analog receivers.

E7G - Active filters and op-amps: active audio filters; characteristics; basic circuit design; operational amplifiers

An integrated circuit operational amplifier is **a high-gain, direct-coupled differential amplifier with very high input and very low output impedance**. (E7G12) They are very versatile components. They can be used used to build amplifiers, filter circuits, and many other types of circuits that do analog signal processing.

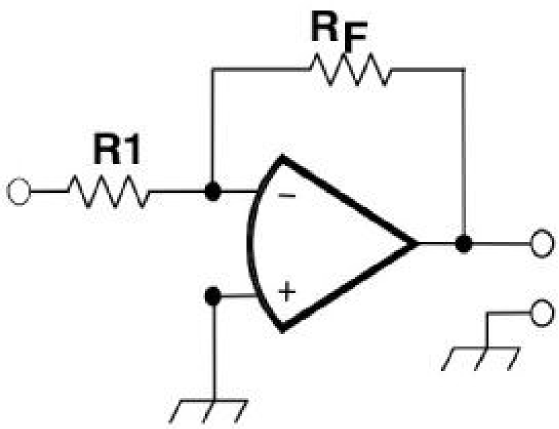
Because they are active components--that is to say that they amplify--filters made with op amps are called active filters. The most appropriate use of an op-amp active filter is **as an audio filter in a receiver**. (E7G06). An advantage of using an op-amp instead of LC elements in an audio filter is that **op-amps exhibit gain rather than insertion loss**. (E7G03)

The values of capacitors and resistors external to the op-amp primarily determine the gain and frequency characteristics of an op-amp RC active filter. (E7G01) The type of capacitor best suited for use in high-stability op-amp RC active filter circuits is **polystyrene**. (E7G04) Polystyrene capacitors are used in applications where very low distortion is required.

Ringing in a filter may cause **undesired oscillations to be added to the desired signal**. (E7G02) One way to prevent unwanted ringing and audio instability in a multi-section op-amp RC audio filter circuit is to **restrict both gain and Q**. (E7G05)

Calculating the gain of an op amp circuit is relatively straightforward. The gain is simply R_F/R_{in}. In figure E7-4 below, $R_{in} = R_1$. Therefore, the magnitude of voltage gain that can be expected from the circuit in Figure E7-4 when R1 is 10 ohms and RF is 470 ohms is 470/10, or **47**. (E7G07) The absolute voltage gain that can be expected from the circuit in Figure E7-4 when R1 is 1800 ohms and RF is 68 kilohms is 68,000/1,800, or **38**. (E7G10) The absolute voltage gain that can be expected from the circuit in Figure E7-4 when R1 is 3300 ohms and RF is 47 kilohms is 47,000/3,300, or **14**. (E7G11)

Figure E7-4



-2.3 volts will be the output voltage of the circuit shown in Figure E7-4 if R1 is 1000 ohms, RF is 10,000 ohms, and 0.23 volts dc is applied to the input. (E7G09) The gain of the circuit will be 10,000/1,000 or 10, and the output voltage will be equal to the input voltage times the gain. 0.23 V x 10 = 2.3 V, but since the input voltage is being applied to the negative input, the output voltage will be negative.

Two characteristics that make op amps desirable components is their input impedance and output impedance. The typical input impedance of an integrated circuit op-amp is **very high**. (E7G14) This feature makes them useful in measurement applications. The typical output impedance of an integrated circuit op-amp is **very low**. (E7G15)

The gain of an ideal operational amplifier **does not vary with frequency. (**E7G08**)** Most op amps aren't ideal, though. While some modern op amps can be used at high frequencies, many of the older ones can't be used at frequencies above a couple of MHz.

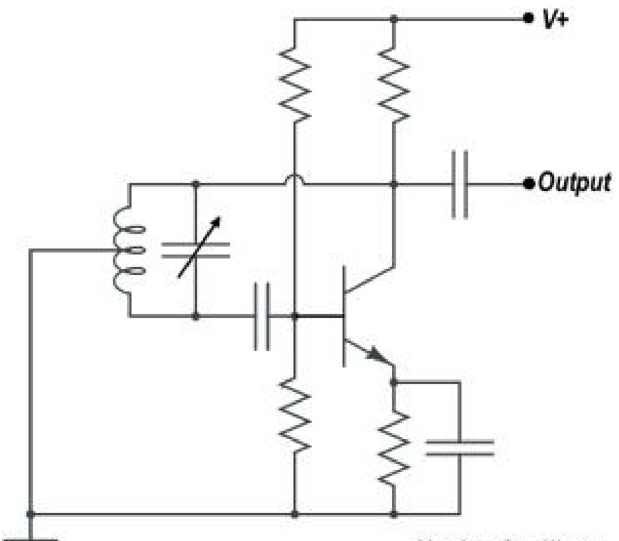
Ideally, with no input signal, there should be no voltage difference between the two input terminals. Since no electronic component is ideal, there will be a voltage between these two terminals. We call this the input offset voltage. Put another way, the op-amp input-offset voltage is **the differential input voltage needed to bring the open-loop output voltage to zero**. (E7G13)

E7H - Oscillators and signal sources: types of oscillators; synthesizers and phase-locked loops; direct digital synthesizers

Oscillator circuits are one of the basic building blocks of amateur radio equipment. Oscillator circuits are not only used to generate the signals we transmit. They are also an integral part of receivers, such as the superheterodyne receiver.

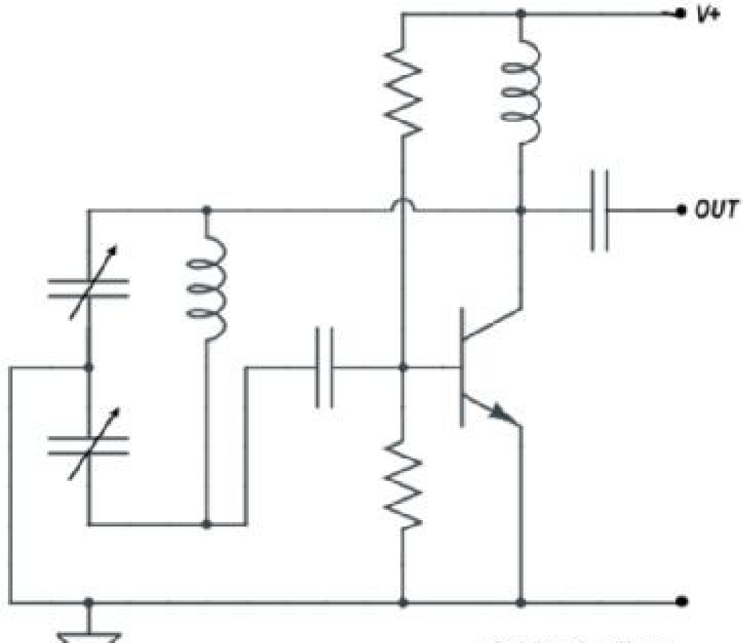
You can think of an oscillator as an amplifier with a tuned circuit at the input. This tuned circuit might be an LC circuit or a crystal. The values of the components in the tuned circuit determine the output frequency of the oscillator. There are three types of oscillator circuits commonly used in Amateur Radio equipment - **Colpitts, Hartley and Pierce**. (E7H01) **Colpitts and Hartley** oscillator circuits are commonly used in VFOs. (E7H06)

For a circuit to oscillate, **it must have positive feedback with a gain greater than 1**. (E7H02) In a Hartley oscillator, positive feedback is supplied **through a tapped coil**. (E7H03)



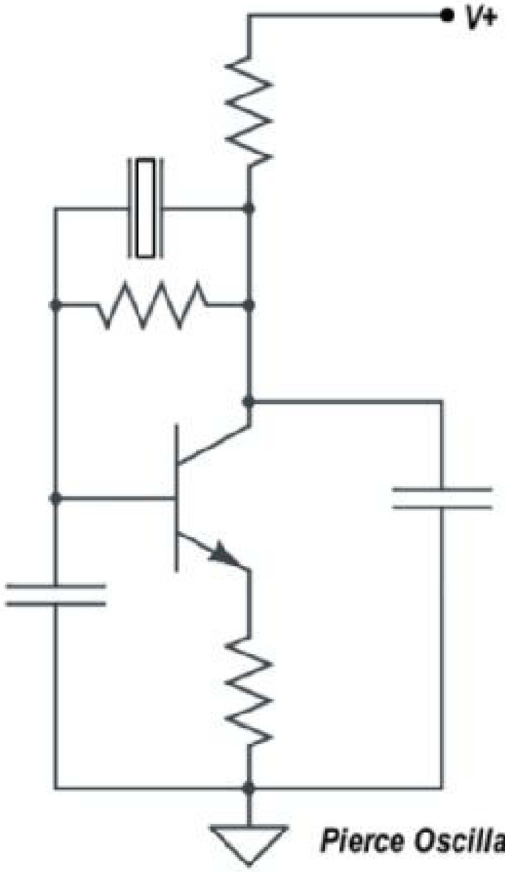
Hartley Oscillator

In a Colpitts oscillator, positive feedback is supplied **through a capacitive divider**. (E7H04)



Colpitts Oscillator

In a Pierce oscillator, positive feedback is supplied **through a quartz crystal**. (E7H05) See schematics below.



Pierce Oscillator

In addition to these basic oscillators, there are a couple of other oscillator types that you have to know about for the Extra Class test. A magnetron oscillator is **a UHF or microwave oscillator consisting of a diode vacuum tube with a specially shaped anode, surrounded by an external magnet**. (E7H07) A Gunn diode oscillator is **an oscillator based on the negative resistance**

properties of properly-doped semiconductors. (E7H08)

Digital frequency synthesizers

Most modern amateur radio transceivers use digital frequency synthesizers instead of analog oscillators to generate RF signals. One reason for this is that they are much more stable than analog oscillators. The two main types of digital frequency synthesizers are the direct digital synthesizer and the phase-locked loop synthesizer.

A direct digital synthesizer is the type of frequency synthesizer circuit that uses a phase accumulator, lookup table, digital to analog converter and a low-pass anti-alias filter. (E7H09) The **phase accumulator** is a principal component of a direct digital synthesizer (DDS). (E7H12) The information is contained in the lookup table of a direct digital frequency synthesizer is **the amplitude values that represent a sine-wave output**. (E7H10)

Both the direct digital synthesizer and the phase-locked loop synthesizer have issues with spectral purity. The major spectral impurity components of direct digital synthesizers are **spurious signals at discrete frequencies**. (E7H11)

For a more detailed explanation of how direct digital synthesizers work, see the electric druid's Synth DIY page.

Another type of frequency synthesizer that's popular are those that use a phase-locked loop. A phase-locked loop circuit is **an electronic servo loop consisting of a phase detector, a low-pass filter, a voltage-controlled oscillator, and a stable reference oscillator**. (E7H14)

A phase-locked loop is often used as part of a variable frequency synthesizer for receivers and transmitters because **it makes it possible for a VFO to have the same degree of frequency stability as a crystal oscillator**. (E7H17) **Frequency synthesis, FM demodulation** are two functions that can be performed by a phase-locked loop. (E7H15)

An important specification for phase-locked loop circuits is the short-term stability of the reference oscillator. The short-term stability of the reference oscillator is important in the design of a phase locked loop (PLL) frequency synthesizer because **any phase variations in the reference oscillator signal will produce phase noise in the synthesizer output**. (E7H16) **Phase noise** is the major spectral impurity components of phase-locked loop synthesizers. (E7H18)

Another important specification is capture range. The capture range of a phase-locked loop circuit is **the frequency range over which the circuit can lock**. (E7H13)

E8: Signals and Emissions

E8A - AC waveforms: sine, square, sawtooth and irregular waveforms; AC measurements; average and PEP of RF signals; pulse and digital signal waveforms

We use all different kinds of waveforms in amateur radio. It is, therefore, important to know about the different types of waveforms and how to measure their parameters. One of the most important parameters of a waveform is its period. The period of a wave is **the time required to complete one cycle**. (E8A08) The frequency is the inverse of the period. For example, if the period of a wave is 1 msec, or .001 s, the frequency of that wave is 1 / .001s, or 1000 Hz.

Another parameter that we need to know about a waveform is it root mean square, or RMS, value. The root-mean-square value of an AC voltage is **the DC voltage causing the same amount of heating in a resistor as the corresponding RMS AC voltage**. (E8A04) Because of this, the most accurate way of measuring the RMS voltage of a complex waveform would be **measuring the heating effect in a known resistor**. (E8A05)

If the waveform is regular, it's relatively easy to calculate the RMS value. In the case of a sine wave, the RMS value is 0.707 times the peak value. You use the RMS voltage value to calculate the power of a wave.

The type of waveform produced by human speech is, however, **irregular**. (E8A09), and **the characteristics of the modulating signal** determine the PEP-to-average power ratio of a single-sideband phone signal. (E8A07) This makes calculating or measuring the average power more difficult.

If you know the peak envelope power (PEP), though, you can make a pretty good guess at the average power. The approximate ratio of PEP-to-average power in a typical single-sideband phone signal is **2.5 to 1**. (E8A06) Put another way, the average power of an SSB signal is about 40% of the peak power.

It used to be that all the waveforms we used in amateur radio were analog waveforms, but digital waveforms may be even more important than analog waveforms. An advantage of using digital signals instead of analog signals to convey the same information is that **digital signals can be regenerated multiple times without error**. (E8A13) **All of these choices are correct** when talking about the types of information that can be conveyed using digital waveforms (E8A12):

- Human speech
- Video signals
- Data

Perhaps the most common digital wave form is the square wave. An ideal square wave alternates regularly and instantaneously between two different values. An interesting fact is that **a square wave** is the type of wave that is made up of a sine wave plus all of its odd harmonics. (E8A01)

Another type of wave used in amateur radio is the sawtooth wave. **A sawtooth wave** is the type of wave that has a rise time significantly faster than its fall time (or vice versa). (E8A02) The type of wave made up of sine waves of a given fundamental frequency plus all its harmonics is **a sawtooth wave**. (E8A03)

Digital data transmission is one use for a pulse modulated signal. (E8A11) **Narrow bursts of energy separated by periods of no signal** is a distinguishing characteristic of a pulse waveform. (E8A10) The waveform of a stream of digital data bits would look like **a series of pulses with varying patterns** on a conventional oscilloscope. (E8A15)

To make use of digital techniques in amateur radio, such as digital signal processing or DSP, we must convert analog signals to digital signals and vice-versa. **Sequential sampling** is one of the methods commonly used to convert analog signals to digital signals. (E8A14) When converting an analog signal to digital values, an analog to digital converter measures, or samples, the value of the analog signal at different points, and converts that measurement to a numeric value. Those numbers are then input to a processor or directly into memory.

E8B - Modulation and demodulation: modulation methods; modulation index and deviation ratio; pulse modulation; frequency and time division multiplexing

In FM modulation, the two primary parameters of interest are *deviation ratio* and *modulation index*. Deviation ratio is **the ratio of the maximum carrier frequency deviation to the highest audio modulating frequency**. (E8B09) The deviation ratio of an FM-phone signal having a maximum frequency swing of plus-or-minus 5 kHz when the maximum modulation frequency is 3 kHz is **1.67**. (E8B05)The deviation ratio of an FM-phone signal having a maximum frequency swing of plus or minus 7.5 kHz when the maximum modulation frequency is 3.5 kHz is **2.14**. (E8B06)

The term for the ratio between the frequency deviation of an RF carrier wave, and the modulating frequency of its corresponding FM-phone signal is **modulation index**. (E8B01) The modulation index is equal to the ratio of the frequency deviation to the modulating frequency. The modulation index of a phase-modulated emission **does not depend on the RF carrier frequency**. (E8B02)

The modulation index of an FM-phone signal having a maximum frequency deviation of 3000 Hz either side of the carrier frequency, when the modulating frequency is 1000 Hz is **3**. (E8B03) The modulation index of an FM-phone signal having a maximum carrier deviation of plus or minus 6 kHz when modulated with a 2-kHz modulating frequency is **3**. (E8B04)

Some amateur radio communications are pulse-width modulated. That is to say that the information being sent is proportional to the time the carrier is on. When using a pulse-width modulation system, the transmitter's peak power greater than its average power because **the signal duty cycle is less than 100%**. (E8B07)

Some signals are pulse-position modulated. That is to say, what is significant is when the pulse occurs. **The time at which each pulse occurs** is the parameter that the modulating signal varies in a pulse-position modulation system. (E8B08)

Frequency division multiplexing is one method that can be used to combine several separate analog information streams into a single analog radio frequency signal. (E8B10) When a system uses frequency division multiplexing, **two or more information streams are merged into a "baseband," which then modulates the transmitter**. (E8B11)

When a system uses digital time division multiplexing, **two or more signals are arranged to share discrete time slots of a data transmission**. (E8B12)

E8C - Digital signals: digital communications modes; CW; information rate vs. bandwidth; spread-spectrum communications; modulation methods

Morse Code is arguably the original digital mode. **Morse code** is a digital code consists of elements having unequal length. (E8C01) One advantage of using Morse Code is that it is very narrow bandwidth. The bandwidth necessary for a 13-WPM international Morse code transmission is **approximately 52 Hz**. (E8C05)

The next oldest digital mode is radioteletype, or RTTY. RTTY uses a five-bit code called Baudot. Most modern digital devices these days use ASCII, which is a 7-bit or 8-bit code. Some of the differences between the Baudot digital code and ASCII are that **Baudot uses five data bits per character, ASCII uses seven or eight; Baudot uses two characters as shift codes, ASCII has no shift code**. (E8C02) One advantage of using the ASCII code for data communications is that **it is possible to transmit both upper and lower case text**. (E8C03)

The reason that some ASCII transmissions have only seven bits, while others use eight bits is that the eighth bit is a parity bit. The advantage of including a parity bit with an ASCII character stream is that **some types of errors can be detected**. (E8C12)

The bandwidth needed for ASCII digital transmissions increases as the data rate increases. The bandwidth necessary for a 170-hertz shift, 300-baud ASCII transmission is **0.5 kHz**. (E8C06) The bandwidth necessary for a 4800-Hz frequency shift, 9600-baud ASCII FM transmission is **15.36 kHz**. (E8C07)

PSK has become a very popular digital mode. One reason for this is that it occupies a very narrow bandwidth - only 31 Hz. One technique used to minimize the bandwidth requirements of a PSK31 signal is the **use of sinusoidal data pulses**. (E8C04)

An up-and-coming digital mode is JT-65, named after its inventor, Nobel Prize winner and amateur radio operator, Joe Taylor, K1JT. It uses 65 different tones spread over a bandwidth of 175 Hz. One advantage of using JT-65 coding is **the ability to decode signals which have a very low signal to noise ratio**. (E8C13)

Spread-spectrum communication is a wide-bandwidth communications system in which the transmitted carrier frequency varies according to some predetermined sequence. (E8C08) **Direct sequence** is a spread-spectrum communications technique uses a high speed binary bit stream to shift the phase of an RF carrier. (E8C11) **Frequency hopping** is a spread-spectrum communications technique that alters the center frequency of a conventional carrier many times per second in accordance with a pseudo-random list of channels. (E8C10) **Spread-spectrum** techniques causes a digital signal to appear as wide-band noise to a conventional receiver. (E8C09)

E8D - Waveforms: measurement, peak-to-peak, RMS, average; Electromagnetic Waves: definition, characteristics, polarization

An electromagnetic wave is **a wave consisting of an electric field and a magnetic field oscillating at right angles to each other**. (E8D07) **Changing electric and magnetic fields propagate the energy** is a phrase that best describes electromagnetic waves traveling in free space. (E8D08)

The polarization of an electromagnetic wave is related to the orientation of the wave's electric field. If, for example, the electric field is oriented vertically, we say that the electromagnetic wave is vertically polarized. **Waves with a rotating electric field** are called circularly polarized electromagnetic waves.(E8D09)

Peak-to-peak voltage is the easiest voltage amplitude parameter to measure when viewing a pure sine wave signal on an analog oscilloscope. (E8D01) The relationship between the peak-to-peak voltage and the peak voltage amplitude of a symmetrical waveform is **2:1**. (E8D02) **Peak voltage** is a valuable input-amplitude parameter for evaluating the signal-handling capability of a Class A amplifier.(E8D03)

For sinusoidal voltages, the peak voltage is 1.414 times the RMS voltage, and the peak-to-peak voltage is 2.828 times the RMS voltage. The peak voltage of a sinusoidal waveform would be **48 volts** if an RMS-reading voltmeter reads 34 volts. (E8D12) If an RMS-reading AC voltmeter reads 65 volts on a sinusoidal waveform, the peak-to-peak voltage is **184 volts**. (E8D05)

120V AC is a typical value for the RMS voltage at a standard U.S. household electrical power outlet. (E8D15) **170 volts** is a typical value for the peak voltage at a standard U.S. household electrical outlet. (E8D13) **340 volts** is a typical value for the peak-to-peak voltage at a standard U.S. household electrical outlet. (E8D14) **120V AC** is the RMS value of a 340-volt peak-to-peak pure sine wave. (E8D16)

The peak envelope power of a radio signal is equal to $V^2_{peak}/2 \times 1/R$. Consequently, the PEP output of a transmitter that develops a peak voltage of 30 volts into a 50-ohm load is **9 watts**. (E8D04)

$V_{peak} = 30$ V, $V^2_{peak} = 900$ V^2

PEP = 900 / 2 x 50 = 9 W.

The average power of a radio signal is equal to V^2_{RMS}/R. The average power dissipated by a 50-ohm resistive load during one complete RF cycle having a peak voltage of 35 volts is **12.2 watts**. (E8D11)

$V^2_{RMS} = 35$ V / 1.414 = 24.75V

$V^2_{RMS} = 612$ V^2

$P_{avg} = 612$ V^2 / 50 = 12.2 W.

Radio amateurs most often specify the output power of a single-sideband transmitter as peak envelope power and use a peak-reading wattmeter. The advantage of using a peak-reading wattmeter to monitor the output of a SSB phone transmitter is that **it gives a more accurate display of the PEP output when modulation is present**. (E8D06) **A peak-reading wattmeter** should be used to monitor the output signal of a voice-modulated single-sideband transmitter to ensure you do not exceed the maximum allowable power. (E8D10)

E9: Antennas and Transmission Lines

E9A Isotropic and gain antennas: definitions; uses; radiation patterns; Basic antenna parameters: radiation resistance and reactance, gain, beamwidth, efficiency

Antenna gain is one of the most misunderstood topics in amateur radio. There are several reasons for this, including:

- Antennas don't really have gain in the same way that an amplifier has gain. When you use a linear amplifier, you get more power out than you put in. Since transmitting antennas are passive devices, there's no way to get more power out than you put in.
- It's not easy to measure antenna gain. There is no antenna gain meter that you can simply hook up to an antenna to measure its gain.

So, what is antenna gain? According to question E9A08, antenna gain is **the ratio relating the radiated signal strength of an antenna in the direction of maximum radiation to that of a reference antenna**. What this means is that when you talk about antenna gain, you have to know what kind of antenna you're comparing it to.

When talking about antenna gain, antenna engineers often refer to the "isotropic antenna." An isotropic antenna is **a theoretical antenna used as a reference for antenna gain**. (E9A01) An **isotropic antenna** is an antenna that has no gain in any direction. (E9A03) That is to say it radiates the power input to it equally well in all directions.

Let's take a look at a practical example. I often say that the 1/2-wavelength dipole antenna is the most basic amateur radio antenna. Well, the dipole actually has some gain over isotropic antenna. The reason for this is that it is directional. The signal strength transmitted broadside to the antenna will be greater than the signal strength transmitted off the ends of the antenna.

The gain of a 1/2-wavelength dipole in free space have compared to an isotropic antenna is **2.15 dB**. (E9A02) Sometimes, you'll see this value as 2.15 dBi, where dBi denotes that an isotropic antenna is being used for this comparison.

Since the isotropic antenna is a theoretical antenna, some think it's better to compare an antenna to a dipole antenna. An antenna will have a gain **3.85 dB** compared to a 1/2-wavelength dipole when it has 6 dB gain over an isotropic antenna. (E9A13) You obtain this value by simply subtracting 2.15 dB from the 6 dB figure:

Gain over a dipole = gain over an isotropic antenna - 2.15 dB = 6 dBi - 2.15 dBi = 3.85 dBd

Sometimes, the gain over a dipole is denoted as dBd.

Similarly, an antenna has a gain of **9.85 dB** compared to a 1/2-wavelength dipole when it has 12 dB gain over an isotropic antenna. (E9A14):

Gain over a dipole = gain over an isotropic antenna - 2.15 dB = 12 dBi - 2.15 dBi = 9.85 dBd

Feedpoint impedance, antenna efficiency, frequency range

One of the most basic antenna parameters is the feedpoint impedance. Why would one need to know the feed point impedance of an antenna? **To match impedances in order to minimize standing wave ratio on the transmission line**. (E9A04) The reason that it's important to minimize the standing wave ratio, or SWR, is that if you're using coaxial cables, minimizing the SWR will also help you minimize losses. If you minimize losses, you'll radiate more signal.

Many factors may affect the feed point impedance of an antenna, including **antenna height, conductor length/diameter ratio and location of nearby conductive objects**. E9A05 For example, we say that the feedpoint impedance of a half-wavelength, dipole antenna is 72 Ω, but that's only really true if the antenna is in free space. When it's closer to the ground than a quarter wavelength, then the impedance will be different. That's why you have to tune the antenna when you install it.

Another antenna parameter that's frequently discussed is radiation resistance. The radiation resistance of an antenna is **the value of a resistance that would dissipate the same amount of power as that radiated from an antenna**. (E9A15) **Radiation resistance plus ohmic resistance** is included in the total resistance of an antenna system. (E9A06)

If you know the radiation resistance and the ohmic resistance of an antenna, you can calculate its efficiency. You calculate antenna efficiency with the formula **(radiation resistance / total resistance) x 100%**. (E9A10)

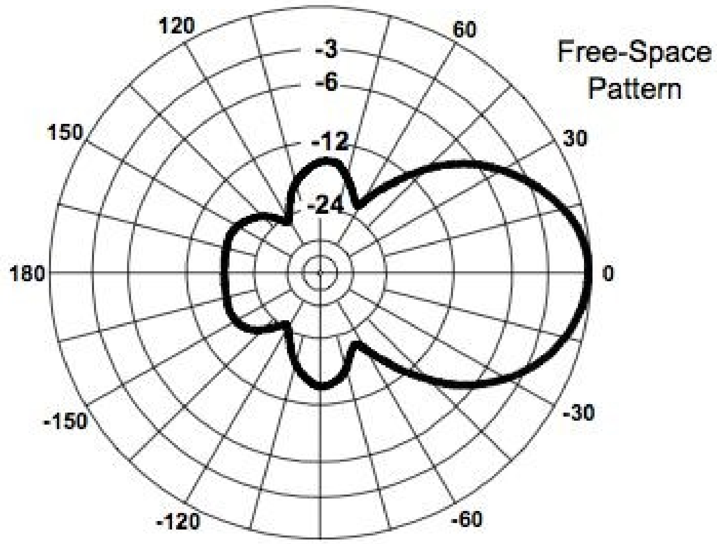
Vertical antennas are sometimes criticized as being inefficient antennas. **Soil conductivity** is one factor that determines ground losses for a ground-mounted vertical antenna operating in the 3-30 MHz range. (E9A12) If soil conductivity is poor, ohmic resistance will be high. One way to improve the efficiency of a ground-mounted quarter-wave vertical antenna is to **install a good radial system**. (E9A11)

The frequency range over which an antenna satisfies a performance requirement is called antenna bandwidth. (E9A09) Normally, the performance requirement is an SWR of 2:1 or less. In fact, you'll sometimes hear this parameter referred to as the 2:1 SWR bandwidth.

Finally, this section has a question that really doesn't fit in here about folded dipoles. A folded dipole antenna is **a dipole constructed from one wavelength of wire forming a very thin loop**. (E9A07)

E9B - Antenna patterns: E and H plane patterns; gain as a function of pattern; antenna design (computer modeling of antennas); Yagi antennas

Figure E9-1



Many amateurs use directional antennas because they are said to have "gain." When this term is used, what it means is that a directional antenna will output more power in a particular direction than an antenna that is not directional. This only makes sense; You can't get more power out of an antenna than you put in. Assuming each is driven by the same amount of power, the total amount of radiation emitted by a directional gain antenna compared with the total amount of radiation emitted from an isotropic antenna **is the same**. (E9B07)

To evaluate the performance of directional antennas, manufacturers will measure the field strength at various points in a circle around the antenna and plot those field strengths, creating a chart called the antenna radiation pattern. Figure E9-1 is a typical antenna radiation pattern.

The antenna radiation pattern shows the relative strength of the signal generated by an antenna in its "far field." The far-field of an antenna is **the region where the shape of the antenna pattern is independent of distance**. (E9B12)

From the antenna radiation pattern, we can tell a bunch of things about the antenna. One of them is beamwidth. Beamwidth is a measure of the width of the main lobe of the radiation pattern. To determine the approximate beamwidth in a given plane of a directional antenna, **note the two points where the signal strength of the antenna is 3 dB less than maximum and compute the angular difference**. (E9B08) In the antenna radiation pattern shown in Figure E9-1, **50 degrees** is the 3-dB beamwidth. (E9B01)

Another parameter that's important for a directional antenna is the front-to-back ratio. In a sense, this is a measure of how directional an antenna really is. The higher this ratio, the more directional the antenna. In the antenna radiation pattern shown in Figure E9-1, **18 dB** is the front-to-back ratio. (E9B02)

A similar parameter is the front-to-side ratio. In the antenna radiation pattern shown in Figure E9-1, the front-to-side ratio is **14 dB**. (E9B03)

When reviewing an antenna radiation pattern, you need to remember that the field strength measurements were taken at a particular frequency. When a directional antenna is operated at different frequencies within the band for which it was designed, **the gain may change depending on frequency**. (E9B04)

Many different design factors affect these antenna parameters. For example, if the boom of a Yagi antenna is lengthened and the elements are properly retuned, what usually occurs is that **the gain increases**. (E9B06) Gain isn't everything, however. What usually occurs if a Yagi antenna is designed solely for maximum forward gain is that **the front-to-back ratio decreases**. (E9B05)

To help design antennas, many amateurs use antenna modeling programs. **All of these choices are correct** when talking about the information obtained by submitting the details of a proposed new antenna to a modeling program (E9B14):

- SWR vs. frequency charts
- Polar plots of the far-field elevation and azimuth patterns
- Antenna gain

The type of computer program technique commonly used for modeling antennas is **method of moments**. (E9B09) The principle behind a method of moments analysis is that **a wire is modeled as a series of segments, each having a uniform value of current**. (E9B10)

The more segments your simulation uses, the more accurate the results. The problem with using too many segments, though, is that the program will take a very long time to run. You don't want to use too few segments, though. A disadvantage of decreasing the number of wire segments in an antenna model below the guideline of 10 segments per half-wavelength is that **the computed feed point impedance may be incorrect**. (E9B11)

The abbreviation NEC stands for **Numerical Electromagnetics Code** when applied to antenna modeling programs. (E9B13) This is different from the more common definition of NEC, which is the National Electrical Code.

E9C - Wire and phased vertical antennas: beverage antennas; rhombic antennas; elevation above real ground; ground effects as related to polarization; take-off angles

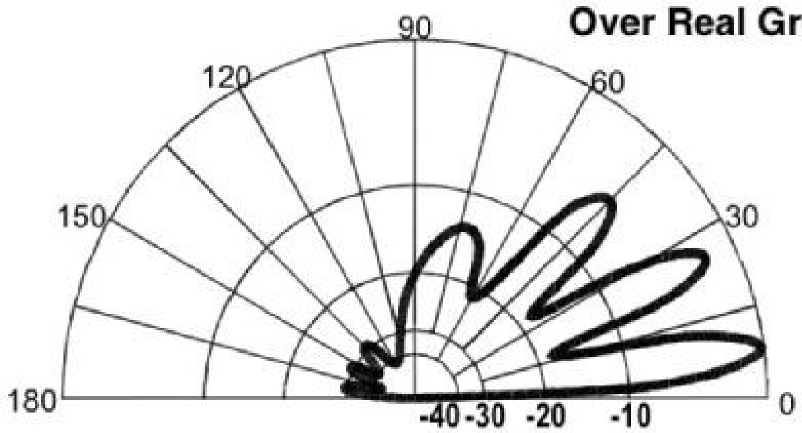
There are many ways to put up antennas that are directional. Yagis are directional antennas, but they require a structure, such as a tower, to get them high in the air. One way to get directionality without a tower is to use phased vertical arrays.

In general, the phased vertical array consists of two or more quarter-wave vertical antennas. The radiation pattern that the array will have depends on how you feed the vertical antennas.

So, for example, the radiation pattern of two 1/4-wavelength vertical antennas spaced 1/2-wavelength apart and fed 180 degrees out of phase is **a figure-8 oriented along the axis of the array**. (E9C01) The radiation pattern of two 1/4-wavelength vertical antennas spaced 1/4-wavelength apart and fed 90 degrees out of phase is **a cardioid**. (E9C02) The radiation pattern of two 1/4-wavelength vertical antennas spaced 1/2-wavelength apart and fed in phase is **a Figure-8 broadside to the axis of the array**. (E9C03)

A rhombic antenna is often used for receiving on the HF bands. A basic unterminated rhombic antenna is described as **bidirectional; four-sides, each side one or more wavelengths long; open at the end opposite the transmission line connection**. (E9C04) The disadvantages of a terminated rhombic antenna for the HF bands is that **the antenna requires a large physical area and 4 separate supports**. (E9C05) Putting a terminating resistor on a rhombic antenna **changes the radiation pattern from bidirectional to unidirectional**. (E9C06)

Figure E9-2



The type of antenna pattern over real ground that is shown in Figure E9-2 is an **elevation** pattern. (E9C07) The elevation angle of peak response in the antenna radiation pattern shown in Figure E9-2 is **7.5 degrees**. (E9C08) The front-to-back ratio of the radiation pattern shown in Figure E9-2 is **28 dB**. (E9C09) **4** elevation lobes appear in the forward direction of the antenna radiation pattern shown in Figure E9-2. (E9C10)

How and where you install an antenna affects its radiation pattern. For example, the far-field elevation pattern of a vertically polarized antenna is affected when it is mounted over seawater versus rocky ground. What happens is that **the low-angle radiation increases**. (E9C11) The main effect of placing a vertical antenna over an imperfect ground is that **it reduces low-angle radiation**. (E9C13) When constructing a Beverage antenna, remember that **it should be one or more wavelengths long** to achieve good performance at the desired frequency. (E9C12)

E9D - Directional antennas: gain; satellite antennas; antenna beamwidth; stacking antennas; antenna efficiency; traps; folded dipoles; shortened and mobile antennas; grounding

This section consists of a miscellaneous selection of antenna questions. We'll start with some questions about grounding, then talk a little bit about vertical antennas, then mobile antennas, and finally directional antennas.

Much has been written about station grounding. One thing's for sure. A station's safety ground is not adequate as an RF ground. The reason for this is that conductors present different impedances at different frequencies.

A wide flat copper strap is the type of conductor that would be best for minimizing losses in a station's RF ground system. (E9D14) The main reason for this is that RF tends to be conducted near the surface of a conductor. The more surface area there is, the lower the impedance to ground.

To minimize inductance, it's best to keep the RF ground connection as short as possible. **An electrically-short connection to 3 or 4 interconnected ground rods driven into the Earth** would provide the best RF ground for your station. (E9D15)

For many amateurs, their first antenna is a trapped vertical antenna. Mine was a Hy-Gain 14AVQ. One advantage of using a trapped antenna is that **it may be used for multiband operation**. (E9D12) Another big advantage is that it doesn't require a lot of space when compared to a dipole antenna.

A disadvantage of using a multiband trapped antenna is that **it might radiate harmonics**. (E9D07) For example, if your 40m transmissions have high harmonic content on 20m, and the multiband vertical is also resonant on 20m, it will radiate those harmonics.

Another disadvantage is that they are generally shorter than 1/4 wavelength. The bandwidth of an antenna **is decreased** as it is shortened through the use of loading coils. (E9D08) Not only do they have a smaller bandwidth, but loaded verticals are also less efficient than full, quarter-wavelength verticals. One way to lessen this disadvantage is to use top loading. An advantage of using top loading in a shortened HF vertical antenna is **improved radiation efficiency**. (E9D09)

Mobile antennas are almost always shorter than a quarter wavelength. What happens to the feed point impedance at the base of a fixed-length HF mobile antenna as the frequency of operation is lowered is that **the radiation resistance decreases and the capacitive reactance increases**. (E9D13) To transform this impedance to 50 ohms, they use a loading coil. The function of a loading coil as used with an HF mobile antenna is **to cancel capacitive reactance**. (E9D11)

Because short verticals, such as those used in mobile installations are inherently inefficient, you should do whatever you can to make them as efficient as possible. An HF mobile antenna loading coil should have a high ratio of reactance to resistance **to minimize losses**. (E9D06)

The ratio of reactance to resistance is called Q. A high-Q loading coil should be placed **near the center of the vertical radiator** to minimize losses in a shortened vertical antenna. (E9D05)

An antenna that used to be very popular when TV antennas used 300-ohm feedline is the folded dipole. The reason for this is that that approximate feed point impedance at the center of a two-wire folded dipole antenna is **300 ohms**. (E9D10) Amateurs would use the 300-ohm feedline for both the antenna elements and the feedline, and then use a balun or some other matching device to match the 300 ohm impedance to the transmitter output impedance.

Finally, there are four miscellaneous questions about directional antennas. The first is about how beamwidth and antenna gain are related. The beamwidth of an antenna **decreases** as the gain is increased. (E9D03) This is intuitively obvious. An antenna does not amplify a signal but instead focuses the power. So, when we say that the gain is increased, what we're really saying is that we're focusing the power into a smaller beam.

On the VHF and UHF bands, Yagi antennas are operated either horizontally for weak-signal work and vertically for FM operations. In some cases, however circular polarization is desirable. You can use linearly polarized Yagi antennas to produce circular polarization if you **arrange two Yagis perpendicular to each other with the driven elements at the same point on the boom and feed them 90 degrees out of phase**. (E9D02) The disadvantage to this approach is, obviously, that you need two antennas, instead of just one to achieve circular polarization.

For satellite operation, some hams have antenna systems that can tilt up and down as well as rotate. This is so the antenna can point directly at the satellite as it passes overhead. It is desirable for a ground-mounted satellite communications antenna system to be able to move in both azimuth and elevation **in order to track the satellite as it orbits the Earth**. (E9D04)

Parabolic antennas are often used at microwave frequencies to direct a signal in a particular direction. One thing to keep in mind is that **gain increases by 6 dB** if you are using an ideal parabolic dish antenna when the operating frequency is doubled. (E9D01) Also keep in mind that, as pointed out earlier, the beamwidth is narrower as well.

E9E - Matching: matching antennas to feed lines; power dividers

For many types of antennas, matching the impedance of the antenna to the impedance of the feedline, normally coax, is essential. Mismatched lines create high SWR and, consequently, feedline losses. **An SWR greater than 1:1** is characteristic of a mismatched transmission line. (E9E08)

When a feedline and antenna are mismatched, some of the power you are trying to transmit will be reflected back down the feedline. The ratio of the amplitude of the reflected wave to the amplitude of the wave you are trying to send is called the *reflection ratio*, and it is mathematically related to SWR. **Reflection coefficient** is the term that best describes the interactions at the load end of a mismatched transmission line. (E9E07)

To match the impedance of the feedline to the impedance of the antenna, we use a variety of different techniques. **The delta matching system** matches a high-impedance transmission line to a lower impedance antenna by connecting the line to the driven element in two places spaced a fraction of a wavelength each side of element center. (E9E01)

The gamma match is the name of an antenna matching system that matches an unbalanced feed line to an antenna by feeding the driven element both at the center of the element and at a fraction of a wavelength to one side of center. (E9E02) The purpose of the series capacitor in a gamma-type antenna matching network is **to cancel the inductive reactance of the matching network**. (E9E04)The **gamma match** is an effective method of connecting a 50-ohm coaxial cable feed line to a grounded tower so it can be used as a vertical antenna. (E9E09)

The stub match is the name of the matching system that uses a section of transmission line connected in parallel with the feed line at or near the feed point. (E9E03) What the stub does is to add reactance at the feed point. By varying the length of the stub, you can change the reactance that the stub provides to whatever value is needed. An effective way of matching a feed line to a VHF or UHF antenna when the impedances of both the antenna and feed line are unknown is to **use the universal stub matching technique**. (E9E11)

Inserting a 1/4-wavelength piece of 75-ohm coaxial cable transmission line in series between the antenna terminals and the 50-ohm feed cable is an effective way to match an antenna with a 100-ohm feed point impedance to a 50-ohm coaxial cable feed line. (E9E10) Note that this will only work on one band as the length of 75-ohm coax you use will only be 1/4 of a wavelength on one band.

Many directly-fed Yagi antennas have feedpoint impedances of approximately 20 to 25 ohms. One technique often use to match these antennas to 50-ohm coaxial cable is the hairpin match. To use a hairpin matching system to tune the driven element of a 3-element Yagi, **the driven element reactance must be capacitive**. (E9E05) The equivalent lumped-constant network for a hairpin matching system on a 3-element Yagi is an **L network**. (E9E06)

Some beam antennas use multiple driven elements in order to make them multi-band antennas. The primary purpose of a phasing line when used with an antenna having multiple driven elements is that **it ensures that each driven element operates in concert with the others to create the desired antenna pattern**. (E9E12)

I'm not sure that Wilkinson dividers are used much in antenna systems, or why this question is in the section on feedline matching, but here it is. The purpose of a Wilkinson divider is that **it divides power equally among multiple loads while preventing changes in one load from disturbing power flow to the others**. (E9E13)

E9F - Transmission lines: characteristics of open and shorted feed lines; 1/8 wavelength; 1/4 wavelength; 1/2 wavelength; feed lines: coax versus open-wire; velocity factor; electrical length; coaxial cable dielectrics; velocity factor

The physical length of a coaxial cable transmission line is shorter than its electrical length because **electrical signals move more slowly in a coaxial cable than in air**. (E9F03) The term we use to quantify the difference in how fast a wave travels in air versus how fast it travels in a feedline is *velocity factor*.

The velocity factor of a transmission line is **the velocity of the wave in the transmission line divided by the velocity of light in a vacuum**. (E9F01) Put another way, **velocity factor** is the term for the ratio of the actual speed at which a signal travels through a transmission line to the speed of light in a vacuum. (E9F08) **The dielectric materials used in the line** determines the velocity factor of a transmission line. (E9F02)

The typical velocity factor for a coaxial cable with solid polyethylene dielectric is **0.66**. (E9F04) That makes the approximate physical length of a solid polyethylene dielectric coaxial transmission line that is electrically one-quarter wavelength long at 14.1 MHz about **3.5 meters**. (E9F05)The approximate physical length of a solid polyethylene dielectric coaxial transmission line that is electrically one-quarter wavelength long at 7.2 MHz is **6.9 meters**. (E9F09)

The velocity factor of air-insulated, parallel conductor transmission lines is a lot closer to 1 than the velocity factor for coaxial cable. The approximate physical length of an air-insulated, parallel conductor transmission line that is electrically one-half wavelength long at 14.10 MHz is **10 meters**. (E9F06)

While having a higher velocity factor is not really such a big advantage, open-wire or ladder line feedlines do have other advantages. For example, ladder line has **lower loss** than small-diameter coaxial cable such as RG-58 at 50 MHz. (E9F07)

Sometimes we use various lengths of coax to match an antenna system or to filter out frequencies. A 1/8-wavelength transmission line presents **an inductive reactance** to a generator when the line is shorted at the far end. (E9F10) A 1/8-wavelength transmission line presents **a capacitive reactance** to a generator when the line is open at the far end.

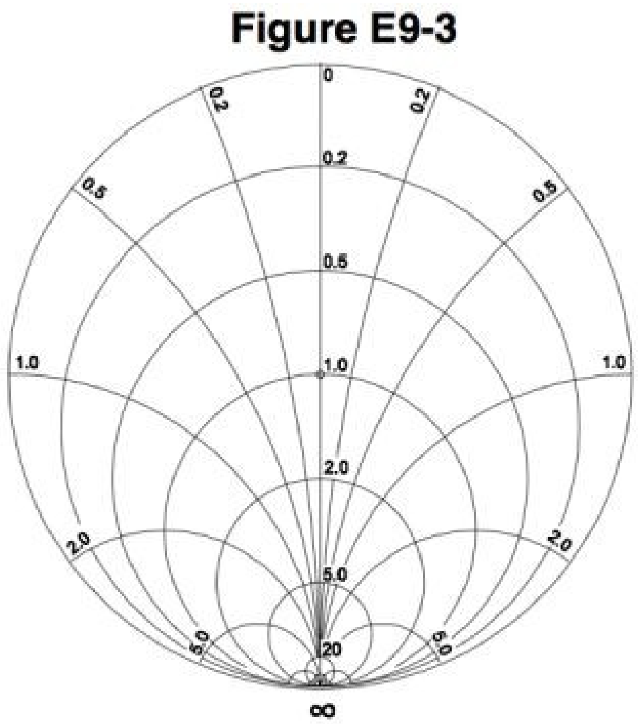
A 1/4-wavelength transmission line presents **a very low impedance** to a generator when the line is open at the far end. (E9F12) A 1/4-wavelength transmission line presents a **very high impedance** to a generator when the line is shorted at the far end. (E9F13)

A 1/2-wavelength transmission line presents a **very low impedance** to a generator when the line is shorted at the far end. (E9F14) A 1/2-wavelength transmission line presents a **very high impedance** to a generator when the line is open at the far end. (E9F15)

All of these choices are correct when talking about significant differences between foam-dielectric coaxial cable and solid-dielectric cable, assuming all other parameters are the same (E9F16):

- Reduced safe operating voltage limits
- Reduced losses per unit of length
- Higher velocity factor

E9G - The Smith chart



A **Smith chart** is shown in Figure E9-3 above. (E9G05) It is a chart designed to solve transmission line problems graphically. While a complete discussion of the theory behind the Smith Chart is outside the scope of this study guide, a good discussion of the Smith Chart can be found on the ARRL website (http://www.arrl.org/files/file/Antenna%20Book%20Supplemental%20Files/22nd%20Edition/Smith%20Chart%20Supplement%20-%20Corrected%20Jan%202012.pdf).

The coordinate system is used in a Smith chart is comprised of **resistance circles and reactance arcs**. (E9G02) **Resistance and reactance** are the two families of circles and arcs that make up a Smith chart. (E9G04)

The resistance axis is the only straight line shown on the Smith chart shown in Figure E9-3. (E9G07) Points on this axis are pure resistances. In practice, you want to position the chart so that 0 ohms is at the far left, while infinity is at the far right.

The arcs on a Smith chart represent **points with constant reactance**. (E9G10) On the Smith chart, shown in Figure E9-3, the name for the large outer circle on which the reactance arcs terminate is the **reactance axis**. (E9G06) Points on the reactance axis have a resistance of 0 ohms. When oriented so that the resistance axis is horizontal, positive reactances are plotted above the resistance axis and negative reactances below.

The process of normalization with regard to a Smith chart refers to **reassigning impedance values with regard to the prime center**. (E9G08) The prime center is the point marked 1.0 on the resistance axis. If you're working with a 50 ohm transmission line, you'd normally divide the impedances by 50, meaning that a 50 ohm resistance would then be plotted on the resistance axis at the point marked 1.0. A reactance of 50 + j100 would be plotted on the resistance circle going through the prime center where it intersects the reactance arc marked 2.0.

Impedance along transmission lines can be calculated using a Smith chart. (E9G01) **Impedance and SWR values in transmission lines** are often determined using a Smith chart. (E9G03) **Standing-wave ratio circles** are often added to a Smith chart during the process of solving problems. (E9G09)

The wavelength scales on a Smith chart calibrated **in fractions of transmission line electrical wavelength**. (E9G11) These are useful when trying to determine how long transmission lines must be when used to match a load to a transmitter.

E9H - Effective radiated power; system gains and losses; radio direction finding antennas

Effective radiated power is a widely misunderstood concept. **Effective radiated power** is the term that describes station output, including the transmitter, antenna and everything in between, when considering transmitter power and system gains and losses. (E9H04)

The effective radiated power, or ERP, is always given with respect to a certain direction. Let's think about this for a second. If your transmitter has an output of 100 W, the maximum power that the antenna can radiate is also 100 W. Transmitting antennas are, after all, passive devices. You can't get more power out of them that you put into them. In reality, the total power output will be even less than 100 W because you will have losses in the feedline.

An antenna can, however, concentrate the power in a certain direction. The power being radiated in that direction will be more than the power radiated in that direction by a reference antenna, usually a dipole or an isotropic antenna, which is an antenna that radiates equally in all directions.

When an antenna concentrates power in a certain direction, we say that it has gain in that direction, and we specify the amount of gain in dB. If the reference antenna is an isotropic antenna, then the unit of gain is dBi. If the reference antenna is a dipole, then the unit of gain is dBd.

With that in mind, let's take a look at an example. In this example, a repeater station has 150 watts transmitter power output, there is a 2-dB feed line loss, 2.2-dB duplexer loss, and the antenna has 7-dBd gain. To calculate the system gain (or loss), you add the gains and losses, so

$$\text{Gain} = 7 \text{ dBd} - 2 \text{ dB} - 2.2 \text{ dB} = +2.8 \text{ dB}$$

Now, if you recall, 3 dB is close to a gain of 2, as shown in the table below, so in this example, to calculate the effective radiated power, you multiply the transmitter's output power by a factor slightly less than two. This makes the effective radiated power slightly less than 150 W x 2, or 300 W. The closest answer to 300 W is **286 W**. (E9H01)

dB	Gain	Loss
3	x2	x1/2
6	x4	x1/4
10	x10	x1/10

Let's look at another example. The effective radiated power relative to a dipole of a repeater station with 200 watts transmitter power output, 4-dB feed line loss, 3.2-dB duplexer loss, 0.8-dB circulator loss and 10-dBd antenna gain is **317** watts. (E9H02) In this example, the gain is equal to 10 dB - 8 dB in lossses or a net gain of 2 dB. That's equivalent to a ratio of 1.585:1. The ERP is then 200 W x 1.585 = 317 W.

Now, lets look at an example using an isotropic antenna as the reference antenna. The effective isotropic radiated power of a repeater station with 200 watts transmitter power output, 2-dB feed line loss, 2.8-dB duplexer loss, 1.2-dB circulator loss and 7-dBi antenna gain is **252 watts**. (E9H03) In this example, the gain is equal to 7 dB - 2 dB - 2.8 dB - 1.2 dB = 1 dB. That's equivalent to a ratio of 1.26:1, so the ERP is 200 W x 1.26 = 252 W.

Direction finding

Direction finding is an activity that's both fun and useful. One of the ways that it's useful is to hunt down noise sources. It can also be used to hunt down stations causing harmful interference.

A variety of directional antennas are used in direction finding, including the shielded loop antenna. A receiving loop antenna consists of **one or more turns of wire wound in the shape of a large open coil**. (E9H09) The output voltage of a multi-turn receiving loop antenna be increased **by increasing either the number of wire turns in the loop or the area of the loop structure or both**. (E9H10)

An advantage of using a shielded loop antenna for direction finding is that **it is electro-statically balanced against ground, giving better nulls**. (E9H12) The main drawback of a wire-loop antenna for direction finding is that **it has a bidirectional pattern**. (E9H05)

Sometimes a sense antenna is used with a direction finding antenna. The function of a sense antenna is that **it modifies the pattern of a DF antenna array to provide a null in one direction**. (E9H08)

Another way to obtain a null in only one direction is to build an antenna array with a cardioid pattern. One way to do this is to build an array with two dipoles fed in quadrature. **A very sharp single null** is a characteristic of a cardioid-pattern antenna is useful for direction finding. (E9H11)

Another accessory that is often used in direction finding is an attenuator. It is advisable to use an RF attenuator on a receiver being used for direction finding because **it prevents receiver overload which could make it difficult to determine peaks or nulls**. (E9H07)

If more than one operator can be mobilized for a direction-finding operation, they could use the triangulation method for finding a noise source or the source of a radio signal. When using the triangulation method of direction finding, **antenna headings from several different receiving locations are used to locate the signal source**. (E9H06)

E3: Radio Wave Propagation

E3A - Propagation and technique: Earth-Moon-Earth communications (EME), meteor scatter

One of the more exotic things that amateur radios do is earth-moon-earth (EME) communication, sometimes called “moon bounce.” As this name implies, radio amateurs actually bounce their signals off the moon. This is the ultimate DX. The approximate maximum separation measured along the surface of the Earth between two stations communicating by Moon bounce is **12,000 miles, as long as both can “see” the Moon.** (E3A01)

Because the signal travels such a long way, you need to do everything you can to avoid signal loss. So, for example, scheduling EME contacts **when the Moon is at perigee** will generally result in the least path loss. (E3A03) Perigee is the point at which the Moon is the closest to Earth.

Because the signals are so weak, it’s also important to use equipment with very low noise, so that the signals don’t fall below the noise level. That being the case, the type of receiving system that is desirable for EME communications is **equipment with very low noise figures.** (E3A04)

EME communications can take place on both the 2m band and the 440 MHz band. The frequency range that you would normally tune to find EME signals in the 2 meter band is **144.000 - 144.100 MHz**. (E3A06) The frequency range that you would normally tune to find EME signals in the 70 cm band is **432.000 - 432.100 MHz.** (E3A07)

As you can imagine, there are not many operators working moon bounce. You don’t just get on and call CQ—generally you set up a schedule with another operator to contact one another via moon bounce. At the appointed time, the operators take turns transmitting, while the other listens. **Time synchronous transmissions with each station alternating** describes a method of establishing EME contacts. (E3A05)

One interesting phenomenon is libration fading. Libration fading of an Earth-Moon-Earth signal is **a fluttery, irregular fading**. (E3A02) This fading is caused by the irregular surface of the Moon, and the peaks can last for up to two seconds on the 2m band. These peaks can actually help operators make contacts when they would otherwise be impossible.

Meteor scatter

Another interesting communication method is meteor scatter propagation.

Meteor scatter propagation is possible because when a meteor strikes the Earth's atmosphere, a cylindrical region of free electrons is formed at **the E layer** of the ionosphere. (E3A08) **28 - 148 MHz** is the frequency range that is well suited for meteor-scatter communications. (E3A09)

Unfortunately, these ionization trails are relatively short-lived, so to communicate via meteor scatter, you need to either be able to detect when these paths are available or be transmitting when the paths are available. **All of these choices are correct** when talking about good techniques for making meteor-scatter contacts (E3A10):

- 15 second timed transmission sequences with stations alternating based on location
- Use of high speed CW or digital modes
- Short transmission with rapidly repeated call signs and signal reports

E3B - Propagation and technique: trans-equatorial, long path, gray-line; multi-path propagation

There are a number of interesting types of propagation that occurs on the HF bands. They include *transequatorial* propagation, *long-path* propagation, and *gray-line* propagation.

Transequatorial propagation is **propagation between two mid-latitude points at approximately the same distance north and south of the magnetic equator**. (E3B01) The approximate maximum range for signals using transequatorial propagation is **5000 miles**. (E3B02) The best time of day for transequatorial propagation is **afternoon or early evening**. (E3B03)

Long-path propagation is the type of propagation that occurs when the longer of the two direct paths between stations is better for communications than the shorter path. The type of propagation that is probably occurring if an HF beam antenna must be pointed in a direction 180 degrees away from a station to receive the strongest signals is **long-path**. (E3B04) **160 to 10 meters** are the amateur bands that typically support long-path propagation. (E3B05) **20 meters** is the amateur band that most frequently provides long-path propagation. (E3B06)

Gray-line propagation can be described as **long distance communications at twilight on frequencies less than 15 MHz**. (E3B11) **Gray-line** is the type of HF propagation is probably occurring if radio signals travel along the terminator between daylight and darkness. (E3B08) Gray-line propagation is most likely to occur **at sunrise and sunset**. (E3B09) Gray-line propagation occurs because, **at twilight, D-layer absorption drops while E-layer and F-layer propagation remain strong**. (E3B10)

Another interesting propagation phenomenon is echoes. While not strictly a type of propagation, echoes are the result of propagation conditions. **Receipt of a signal by more than one path** is one condition that could account for hearing an echo on the received signal of a distant station. (E3B07)

E3C - Propagation and technique: Aurora propagation, selective fading; radio-path horizon; take-off angle over flat or sloping terrain; effects of ground on propagation; less common propagation modes

One of the most interesting propagation phenomena is Aurora propagation. To make use of this phenomenon, radio amateurs actually bounce their signals off of the Aurora Borealis, also known as the "Northern Lights." **All of these choices are correct** when talking about effects Aurora activity has on radio communications (E3C01):

- SSB signals are raspy
- Signals propagating through the Aurora are fluttery
- CW signals appear to be modulated by white noise

The cause of Aurora activity is **the interaction of charged particles from the Sun with the Earth's magnetic field and the ionosphere**. (E3C02) Aurora activity occurs **in the E-region** of the ionosphere. (E3C03) **CW** is the emission mode that is best for Aurora propagation. (E3C04) From the contiguous 48 states, an antenna should be pointed **North** to take maximum advantage of aurora propagation. (E3C11)

Normally, we think of the ionosphere as a mirror, reflecting HF signals back to Earth at the same angle at which the signal hits the ionosphere. While this is normally the case, sometimes the ionosphere does not get refracted sufficiently to return directly to Earth, but instead travels for some distance in the F2 layer before finally being returned. The name of the high-angle wave in HF propagation that travels for some distance within the F2 region is called the **Pedersen ray**. (E3C08)

While we say that VHF/UHF communication is "line of sight," the distance that a VHF/UHF radio wave will travel is slightly longer than the line-of-sight distance. We call this distance the "radio horizon" or "radio-path horizon." The VHF/UHF radio-path horizon distance exceeds the geometric horizon **by approximately 15% of the distance**. (E3C06) The radio-path horizon distance exceeds the geometric horizon because of **downward bending due to density variations in the atmosphere**. (E3C14)

Another phenomenon that sometimes makes VHF signals travel beyond the line of sight is tropospheric ducting. **Tropospheric ducting** is usually responsible for causing VHF signals to propagate for hundreds of miles. (E3C09)

One of the most frustrating propagation phenomena is selective fading. Selective fading is **partial cancellation of some frequencies within the received pass band**. (E3C05) It is frustrating because it sometimes makes portions of an otherwise perfectly readable signal unreadable.

Amateur radio operators may sometimes use ground-wave propagation to communicate. One important thing to know about this type of propagation is that the maximum distance of ground-wave propagation **decreases** when the signal frequency is increased. (E3C12) **Vertical** polarization is the best type of polarization for ground-wave propagation. (E3C13) So, if you really want to make a contact via ground wave, use a vertical antenna on the 160m band.

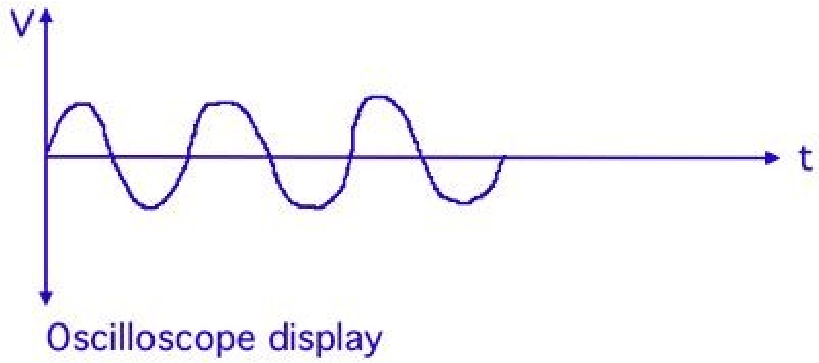
To take advantage of some of these phenomena, or to just make your antenna work better, you should know how antenna's performance changes with changes in its design or installation. For example, the radiation pattern of a horizontally polarized 3-element beam antenna varies as the height above ground changes. What happens is the **the main lobe takeoff angle decreases with increasing height**. (E3C07)

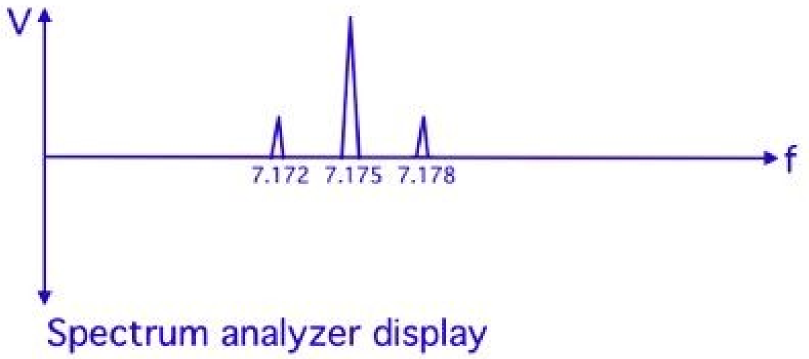
The performance of a horizontally polarized antenna mounted on the side of a hill will be different from the performance of same antenna mounted on flat ground. Specifically, **the main lobe takeoff angle decreases in the downhill direction**. (E3C10)

E4: Amateur Practices

E4A - Test equipment: analog and digital instruments; spectrum and network analyzers, antenna analyzers; oscilloscopes; testing transistors; RF measurements

Two instruments that amateur radio operators frequently use when experimenting or when debugging equipment are the oscilloscope and the spectrum analyzer. How does a spectrum analyzer differ from an oscilloscope? **A spectrum analyzer displays signals in the frequency domain; an oscilloscope displays signals in the time domain**. (E4A01) What this means is that an oscilloscope will show you have the amplitude of a signal changes with time, while a spectrum analyzer shows you how the amplitude of a signal changes with frequency. The drawing below shows typical displays from an oscilloscope and a spectrum analyzer.





Because the spectrum analyzer shows how the amplitude of a signal changes with frequency, **amplitude** is the parameter a spectrum analyzer would display on the vertical axis. (E4A03) **Frequency** is the parameter a spectrum analyzer would display on the horizontal axis. (E4A02)

Spectrum analyzers are very useful for troubleshooting problems. For example, **a spectrum analyzer** is used to display spurious signals from a radio transmitter. (E4A04) **A spectrum analyzer** is also used to display intermodulation distortion products in an SSB transmission. (E4A05) The reason for this is that in both of these cases we are looking for signals that are being erroneously generated.

Whenever frequency is an important part of the measurement, you want to use a spectrum analyzer, if one is available. **All of these choices are correct** when talking about parameters than can be determined with a spectrum analyzer (E4A06):

- The degree of isolation between the input and output ports of a 2 meter duplexer
- Whether a crystal is operating on its fundamental or overtone frequency

- The spectral output of a transmitter

Because spectrum analyzers are sensitive instruments, you need to be cautious when using them. For example, an important precaution to follow when connecting a spectrum analyzer to a transmitter output is to **attenuate the transmitter output going to the spectrum analyzer**. (E4A12) Not doing so could damage the spectrum analyzer because its input circuits are not designed to handle high power.

Despite all this talk about spectrum analyzers, the oscilloscope is actually the more versatile instrument, and will be more useful than the spectrum analyzer for most radio amateurs. For example, the **oscilloscope** is the instrument used for detailed analysis of digital signals. (E4A11) You can make a number of digital-signal measurements with a scope, including rise time and fall time, as well as analyze how two or more digital signals change in time with regard to one another.

Antenna analyzers

One of the instruments that I think every amateur radio operator should have (or at least have access to) is the antenna analyzer. Antenna analyzers are versatile instruments that allow amateur radio operators to easily make antenna measurements, as well as other impedance measurements. They can even be used as low power RF signal generators.

An antenna analyzer is the instrument that would be best for measuring the SWR of a beam antenna. (E4A08) Actually, it's the best instrument for measuring the SWR of any kind of antenna. That's what they're made for! When measuring antenna resonance and feed point impedance with a portable antenna analyzer, **connect the antenna feed line directly to the analyzer's connector.** (E4B11)

An advantage of using an antenna analyzer compared to an SWR bridge to measure antenna SWR is that **antenna analyzers do not need an external RF source**. (E4A07) What this means is that you don't need to connect your transmitter to the antenna to tune it. This is because they have an internal RF signal generator.

Other measurements

One of the reasons we need to make measurements is to ensure that the signals we transmit are the best quality signals that we can transmit. For example, intermodulation distortion is a problem that can occur when operating a phase-shift keying mode, such as PSK31.

Fortunately, it's relatively easy to measure this parameter. In fact, you don't even need a separate instrument to do this. A good method for measuring the intermodulation distortion of your own PSK signal is to **transmit into a dummy load, receive the signal on a second receiver, and feed the audio into the sound card of a computer running an appropriate PSK program**. (E4A09)

For other measurements, we can simply use the multimeter. For example, to establish that a silicon NPN junction transistor is biased on, **measure base-to-emitter voltage with a voltmeter; it should be approximately 0.6 to 0.7 volts**. (E4A10) This is the voltage drop across the diode formed by the base-emitter junction.

E4B - Measurement techniques: Instrument accuracy and performance limitations; probes; techniques to minimize errors; measurement of Q; instrument calibration

One thing about test instruments is that you need to take the readings with a grain of salt. By that, I mean that chances are that the instrument reading is not exactly the value of the parameter you're measuring. The reason for this is that no instrument is 100% accurate.

Let's consider frequency counters. Frequency counters are useful instruments for measuring the output frequency of amateur radio transceivers. While a number of different factors can affect the accuracy of an instrument, **time base accuracy** is the factor that most affects the accuracy of a frequency counter. (E4B01) The time base accuracy of most inexpensive frequency counters is about 1 part per million, or 1 ppm.

Now, let's see how that affects the accuracy of a frequency measurement. If a frequency counter with a specified accuracy of +/- 1.0 ppm reads 146,520,000 Hz, **146.52 Hz** is the most the actual frequency being measured could differ from the reading. (E4B03) Practically, what this means is that while the frequency counter reads 146,520,000 Hz, or 146.52 MHz, the actual frequency of the signal might be as low as 146.519853 Mhz or as high as 146.520147 MHz.

More accurate—and therefore more expensive—frequency counters might have a specified accuracy of .1 ppm. If a frequency counter with a specified accuracy of +/- 0.1 ppm reads 146,520,000 Hz, **14.652 Hz** is the most the actual frequency being measured could differ from the reading. (E4B04) This is very accurate for amateur radio work.

Very inexpensive frequency counters might have an accuracy of only 10 ppm. If a frequency counter with a specified accuracy of +/- 10 ppm reads 146,520,000 Hz, **1465.20 Hz** is the most the actual frequency being measured could differ from the reading. (E4B05) This might be adequate for amateur radio work, but as you can see, the difference between the frequency counter's reading and the signal's actual frequency can be up to ten times as much as with the frequency counter with a 1 ppm accuracy.

In the previous section, we talked about using oscilloscopes to make measurements. One of the factors that affects the accuracy of oscilloscope measurements is the probe being used. You not only have to use a good probe, but you have to know how to use it properly.

Oscilloscope probes

When making measurements at RF frequencies, it's important to connect the probe's ground connection as close to the location of the measurement as possible. **Keeping the signal ground connection of the probe as short as possible** is good practice when using an oscilloscope probe. (E4B07) Keeping this connection as short as possible reduces the inductance of the connection, which in turn, makes the measurement more accurate.

Good quality passive oscilloscope probes have an adjustable capacitor in them that needs to be adjusted so that the probe capacitive reactance is at least nine times the scope input capacitive reactance. When this capacitor is adjusted properly, we say that the probe is properly compensated, and the scope will display the waveform with as little distortion as possible.

How is the compensation of an oscilloscope probe typically adjusted? **A square wave is displayed and the probe is adjusted until the horizontal portions of the displayed wave are as nearly flat as possible**. (E4B13) High-quality oscilloscopes will have a special square-wave output specifically for the purpose of compensating probes.

Voltmeters

Probably the most common test instrument in an amateur radio station is a voltmeter. The voltmeter may be part of a digital multimeter (DMM) or volt-ohm meter (VOM). DMMs have the advantage of high input impedance, and **high impedance input** is a characteristic of a good DC voltmeter. (E4B08) The higher the input impedance, the less effect the meter will have on the measurement.

The quality of a VOM is given by the VOM's sensitivity expressed in ohms per volt. **The full scale reading of the voltmeter multiplied by its ohms per volt rating will provide the input impedance of the voltmeter.** (E4B12) A higher ohms per volt rating means that it will have a higher input impedance than a meter with a lower ohms per volt rating.

RF measurements

Directional power meters and RF ammeters are two instruments that you can use to make antenna measurements. With a directional power meter, you could measure the forward power and reflected power and then figure out how much power is being delivered to the load and calculate the SWR of the antenna system. For example, **75 watts** is the power is being absorbed by the load when a directional power meter connected between a transmitter and a terminating load reads 100 watts forward power and 25 watts reflected power. (E4B06)

With an RF ammeter, you measure the RF current flowing in the antenna system. If the current reading on an RF ammeter placed in series with the antenna feed line of a transmitter increases as the transmitter is tuned to resonance it means **there is more power going into the antenna**. (E4B09)

There are a number of instruments that you can use to measure the impedance of a circuit. An antenna analyzer is one. Some sort of bridge circuit is another. An advantage of using a bridge circuit to measure impedance is that **the measurement is based on obtaining a signal null, which can be done very precisely**. (E4B02)

That's the principle behind the dip meter. You adjust the meter's controls so that the reading "dips" to a minimum value. The controls then indicate the resonant frequency. When using a dip meter, don't couple it too tightly to the circuit under test. **A less accurate reading results** if a dip meter is too tightly coupled to a tuned circuit being checked. (E4B14)

For some experiments, you'll want to know not only the resonant frequency of a circuit but also the *quality factor*, or Q, of the circuit. **The bandwidth of the circuit's frequency response** can be used as a relative measurement of the Q for a series-tuned circuit. (E4B15)

Finally, a method to measure intermodulation distortion in an SSB transmitter is to **modulate the transmitter with two non-harmonically related audio frequencies and observe the RF output with a spectrum analyzer**. (E4B10) The instrument we use to do this is called, oddly enough, a two-tone generator. Typically, these generators provide tones of 700 Hz and 1,900 Hz simultaneously.

E4C - Receiver performance characteristics: phase noise; capture effect; noise floor; image rejection; MDS; signal-to-noise-ratio; selectivity

In the past, sensitivity was one of the most important receiver performance specifications. Today, instead of sensitivity, we speak of a receiver's minimum discernible signal, or MDS. The MDS of a receiver is **the minimum discernible signal**. (E4C07) This is the weakest signal that a receiver will detect.

One parameter that affects receiver sensitivity is the *noise figure*. The noise figure of a receiver is **the ratio in dB of the noise generated by the receiver compared to the theoretical minimum noise**. (E4C04) Lowering the noise figure of a receiver **would improve weak signal sensitivity**. (E4C08)

A related specification is the noise floor. When we say that the noise floor of a receiver has a value of -174 dBm/Hz, it is referring to **the theoretical noise at the input of a perfect receiver at room temperature**. (E4C05) If a CW receiver with the AGC off has an equivalent input noise power density of -174 dBm/Hz, the level of an unmodulated carrier input to this receiver would have to be **-148 dBm** to yield an audio output SNR of 0 dB in a 400 Hz noise bandwidth. (E4C06)

A receiver's *selectivity* is the result of a lot of things, including the filters a receiver has. **300 Hz** is a desirable amount of selectivity for an amateur RTTY HF receiver. (E4C10)**2.4 kHz** is a desirable amount of selectivity for an amateur SSB phone receiver.(E4C11)

In addition to a 300 Hz filter and a 2.4 kHz filter, high-end receivers also have filters called *roofing filters*. A narrow-band roofing filter affects receiver performance because **it improves dynamic range by attenuating strong signals near the receive frequency**. (E4C13)

Back in the day, when superheterodyne receivers had intermediate frequencies, or IFs, in the 400 - 500 kHz range, image rejection was a problem. If there was a strong signal present on a frequency about two times the IF away from the frequency your receiver was tuned to, you might hear that signal. Accordingly, **15.210 MHz** is a frequency on which a station might be transmitting if is generating a spurious image signal in a receiver tuned to 14.300 MHz and which uses a 455 kHz IF frequency. (E4C14)

One solution to this problem is to select an IF higher in frequency. One good reason for selecting a high frequency for the design of the IF in a conventional HF or VHF communications receiver is that it is **easier for front-end circuitry to eliminate image responses**. (E4C09) **A front-end filter or pre-selector** of a receiver can also be effective in eliminating image signal interference. (E4C02)

Another way to get rid of image signals is to use a narrow IF filter. An undesirable effect of using too wide a filter bandwidth in the IF section of a receiver is that **undesired signals may be heard**. (E4C12)

Because most modern transceivers use digital techniques to generate a local oscillator signal to tune a receiver, synthesizer phase noise might be a problem. An effect of excessive phase noise in the local oscillator section of a receiver is that **it can cause strong signals on nearby frequencies to interfere with reception of weak signals**. (E4C01)

Finally, here are two miscellaneous questions on receiver performance characteristics. **Atmospheric noise** is the primary source of noise that can be heard from an HF receiver with an antenna connected. (E4C15) **Capture effect** is the term for the blocking of one FM phone signal by another, stronger FM phone signal. (E4C03)

E4D - Receiver performance characteristics: blocking dynamic range; intermodulation and cross-modulation interference; 3rd order intercept; desensitization; preselection

One of the most commonly mentioned HF receiver specifications is *blocking dynamic range.* The blocking dynamic range of a receiver is **the difference in dB between the noise floor and the level of an incoming signal which will cause 1 dB of gain compression**. (E4D01) **Cross-modulation of the desired signal and desensitization from strong adjacent signals** are two problems caused by poor dynamic range in a communications receiver. (E4D02)

Another specification commonly bandied about is *third-order intercept level.* A third-order intercept level of 40 dBm with respect to receiver performance means **a pair of 40 dBm signals will theoretically generate a third-order intermodulation product with the same level as the input signals**. (E4D10) Compared to other products, third-order intermodulation products created within a receiver are of particular interest because **the third-order product of two signals which are in the band of interest is also likely to be within the band**. (E4D11)

The term for the reduction in receiver sensitivity caused by a strong signal near the received frequency is **desensitization**. (E4D12) **Strong adjacent-channel signals** can cause receiver desensitization. (E4D13) One way to reduce the likelihood of receiver desensitization is to **decrease the RF bandwidth of the receiver**. (E4D14)

A preselector might help in some cases. The purpose of the preselector in a communications receiver is **to increase rejection of unwanted signals**. (E4D09)

When operating a repeater, one thing that can occur is *intermodulation interference,* or simply *intermod.* **Intermodulation interference** is the term for unwanted signals generated by the mixing of two or more signals. (E4D06) **Nonlinear circuits or devices** cause intermodulation in an electronic circuit. (E4D08)

Intermodulation interference between two repeaters occurs **when the repeaters are in close proximity and the signals mix in the final amplifier of one or both transmitters**. (E4D03) The transmitter frequencies would cause an intermodulation-product signal in a receiver tuned to 146.70 MHz when a nearby station transmits on 146.52 MHz are **146.34 MHz and 146.61 MHz**. (E4D05) We get this in the following way:

2 x 146.52 MHz - 146.34 MHz = 146.70 MHz and

2 x 146.61 MHz - 146.52 MHz = 146.70 MHz

A properly terminated circulator at the output of the transmitter may reduce or eliminate intermodulation interference in a repeater caused by another transmitter operating in close proximity. (E4D04) The circulator reduces intermodulation distortion because it helps to reduce the amount of energy from nearby transmitters that might get into a repeater’s final amplifier.

Cross modulation is a form of intermodulation. Cross modulation occurs when a very strong signal combines with a weaker signal and actually modulates the weaker signal. The most significant effect of an off-frequency signal when it is causing cross-modulation interference to a desired signal is that **the off-frequency unwanted signal is heard in addition to the desired signal**. (E4D07)

E4E - Noise suppression: system noise; electrical appliance noise; line noise; locating noise sources; DSP noise reduction; noise blankers

Noise is often a real problem for radio amateurs. Fortunately, by understanding how noise is generated and how to reduce or eliminate it, noise can be tamed.

Atmospheric noise is naturally-occurring noise. **Thunderstorms** are a major cause of atmospheric static. (E4E06) There's not much you can do to eliminate, but you can often use a receiver's noise blanker to help you copy signals better. **Signals which appear across a wide bandwidth** (like atmospheric noise) are the types of signals that a receiver noise blanker might be able to remove from desired signals. (E4E03) **Ignition noise** is one type of receiver noise that can often be reduced by use of a receiver noise blanker. (E4E01)

One undesirable effect that can occur when using an IF noise blanker is that **nearby signals may appear to be excessively wide even if they meet emission standards**. (E4E09)

Many modern receivers now use digital signal processing (DSP) filters to eliminate noise. **All of these choices are correct** when talking about types of receiver noise can often be reduced with a DSP noise filter (E4E02):

- Broadband white noise
- Ignition noise
- Power line noise

One disadvantage of using some types of automatic DSP notch-filters when attempting to copy CW signals is that **the DSP filter can remove the desired signal at the same time as it removes interfering signals**. (E4E12)

While filters can be very effective at reducing noise, it is often better to figure out what is generating the noise and taking steps to reduce or eliminate the amount of noise generated in the first place. For example, one way you can determine if line noise interference is being generated within your home is **by turning off the AC power line main circuit breaker and listening on a battery operated radio**. (E4E07) If by doing this you determine that an electric motor is a problem, noise from an electric motor can be suppressed **by installing a brute-force AC-line filter in series with the motor leads**. (E4E05)

All of these choices are correct when it comes to the cause of a loud roaring or buzzing AC line interference that comes and goes at intervals (E4E13):

- Arcing contacts in a thermostatically controlled device
- A defective doorbell or doorbell transformer inside a nearby residence
- A malfunctioning illuminated advertising display

Sometimes your own equipment may be the cause of received noise. **A common-mode signal at the frequency of the radio transmitter** is sometimes picked up by electrical wiring near a radio antenna. (E4E08)

The main source of noise in an automobile is the alternator. Conducted and radiated noise caused by an automobile alternator be suppressed **by connecting the radio's power leads directly to the battery and by installing coaxial capacitors in line with the alternator leads**. (E4E04)

Personal computer and other digital devices can also generate noise. One type of electrical interference that might be caused by the operation of a nearby personal computer is **the appearance of unstable modulated or unmodulated signals at specific frequencies**. (E4E14) **All of these choices are correct** when talking about common characteristics of interference caused by a touch controlled electrical device (with an internal microprocessor) (E4E10):

- The interfering signal sounds like AC hum on an AM receiver or a carrier modulated by 60

Hz hum on a SSB or CW receiver

- The interfering signal may drift slowly across the HF spectrum
- The interfering signal can be several kHz in width and usually repeats at regular intervals across a HF band

Noise can even be generated by the most unlikely things. For example, it is mostly likely that **nearby corroded metal joints are mixing and re-radiating the broadcast signals** if you are hearing combinations of local AM broadcast signals within one or more of the MF or HF ham bands. (E4E11)

E2: Operating Procedures

E2A - Amateur radio in space: amateur satellites; orbital mechanics; frequencies and modes; satellite hardware; satellite operations

Working the satellites is a very popular amateur radio activity. There's even an organization dedicated to launching and operating amateur radio satellites - AMSAT (www.amsat.org).

Perhaps the most important thing you need to know when trying to communicate via satellite is where the satellites are. One way to predict the location of a satellite at a given time is **by calculations using the Keplerian elements for the specified satellite**. (E2A12)

Amateur radio satellites are not in a geostationary orbit. That is to say they are constantly changing position in relationship to a point on the Earth. The type of satellite appears to stay in one position in the sky is **geostationary**. (E2A13)

When determining where a satellite is, you might want to know its orbital period. The orbital period of an Earth satellite is **the time it takes for a satellite to complete one revolution around the Earth**.(E2A03)

It's also important to know the direction in which it is travelling. The direction of an ascending pass for an amateur satellite is **from south to north**. (E2A01) The direction of a descending pass for an amateur satellite is **from north to south**. (E2A02)

Next, you need to know what mode the satellite is in. The term mode as applied to an amateur radio satellite means **the satellite's uplink and downlink frequency bands**. (E2A04)

We use a combination of letters to denote the mode. The letters in a satellite's mode designator specify **the uplink and downlink frequency ranges**. (E2A05) If it were operating in mode U/V, a satellite's receive signals would be in the **435-438 MHz** band. (E2A06) U stands for UHF, V for VHF. With regard to satellite communications, the terms L band and S band specify **the 23 centimeter and 13 centimeter bands**. (E2A09)

Satellites repeat signals using transponders. Transponders are similar to repeaters, except that they receive signals across a band of frequencies and repeat them across another band of frequencies. The most common type of transponder is the linear transponder. **All of these choices are correct** when talking about the types of signals can be relayed through a linear transponder (E2A07):

- FM and CW
- SSB and SSTV
- PSK and Packet

One thing to keep in mind is to keep your transmitter power to the minimum needed to hit the satellite. Effective radiated power to a satellite which uses a linear transponder should be limited **to avoid reducing the downlink power to all other users**. (E2A08)

There are quite a few interesting phenomena that result from the fact that satellites rotate while they are orbiting. One reason the received signal from an amateur satellite may exhibit a rapidly repeating fading effect is because **the satellite is spinning**. (E2A10) To mitigate the effects of this of fading, you might use a circularly polarized antenna. **A circularly polarized antenna is the** type of antenna that can be used to minimize the effects of spin modulation and Faraday rotation. (E2A11)

E2B- Television practices: fast scan television standards and techniques; slow scan television standards and techniques

Although we are called "radio" amateurs, we can also send and receive television signals. There are several ways that amateurs communicate by television. Perhaps the two most popular ways are standard fast-scan television and slow-scan television (SSTV).

The video standard used by North American Fast Scan ATV stations is called **NTSC**.(E2B16) The NTSC, or National Television Systems Committee, is the body that set standards for the analog television system that was used in the U.S. and many other parts of the world. After nearly 70 years of using the analog NTSC system, U.S. broadcasters switched over to a digital broadcasting system on June 12, 2009.

A fast-scan (NTSC) television frame has **525** horizontal lines (E2B02), and a new frame is transmitted **30** times per second in a fast-scan (NTSC) television system. (E2B01) NTSC systems use an interlaced scanning pattern. An interlaced scanning pattern is generated in a fast-scan (NTSC) television system **by scanning odd numbered lines in one field and even numbered ones in the next**. (E2B03)

In order for the scanning beam to only show the picture, a technique called blanking is used. Blanking in a video signal is **turning off the scanning beam while it is traveling from right to left or from bottom to top**. (E2B04)

NTSC signals are amplitude modulated (AM) signals, but use a technique called vestigial sideband modulation. Vestigial sideband modulation is **amplitude modulation in which one complete sideband and a portion of the other are transmitted**. (E2B06) The reason that NTSC TV uses vestigial modulation is to conserve bandwidth. Even using this technique, an NTSC signal is 6 MHz wide. One advantage of using vestigial sideband for standard fast- scan TV transmissions is that **vestigial sideband reduces bandwidth while allowing for simple video detector circuitry**. (E2B05)

Amateurs can transmit color TV as well as black-and-white TV. The name of the signal component that carries color information in NTSC video is **chroma**. (E2B07)

There are a number of different ways to transmit audio with an NTSC signal. The following are common methods of transmitting accompanying audio with amateur fast-scan television:

- Frequency-modulated sub-carrier
- A separate VHF or UHF audio link
- Frequency modulation of the video carrier

All of these choices are correct. (E2B08)

Because of the bandwidth requirements, amateurs can only transmit fast-scan TV above 440 MHz. FM ATV transmissions, for example, are likely to be found on **1255 MHz**. (E2B18) In fact, one special operating frequency restriction imposed on slow scan TV transmissions is that **they are restricted to phone band segments and their bandwidth can be no greater than that of a voice signal of the same modulation type**. (E2B19) The approximate bandwidth of a slow-scan TV signal is **3 kHz**. (E2B17)

SSTV images are typically transmitted on the HF bands by **varying tone frequencies representing the video are transmitted using single sideband**. (E2B12) The **tone frequency** of an amateur slow-scan television signal encodes the brightness of the picture. (E2B14)

128 or 256 lines are commonly used in each frame on an amateur slow-scan color television picture. (E2B13) **Specific tone frequencies** signal SSTV receiving equipment to begin a new picture line. (E2B15)

There are a number of different SSTV modes. The function of the Vertical Interval Signaling (VIS) code transmitted as part of an SSTV transmission is **to identify the SSTV mode being used**. (E2B11)

Digital Radio Mondiale is one way to send and receive SSTV signals. **No other hardware is needed**, other than a receiver with SSB capability and a suitable computer, is needed to decode SSTV using Digital Radio Mondiale (DRM). (E2B09) Just like any SSTV transmission, **3 KHz** is an acceptable bandwidth for Digital Radio Mondiale (DRM) based voice or SSTV digital transmissions made on the HF amateur bands. (E2B10)

E2C - Operating methods: contest and DX operating; spread-spectrum transmissions; selecting an operating frequency

Contesting is one of the most popular activities in amateur radio. While the rules differ from contest to contest, in general, the goal is to make as many contacts as possible in a given time period.

To enter a contest and be considered for awards, you must submit a log of your contacts. The contest organizers will check the log to make sure that you actually made the contacts that you claim. To make this easier to do, most contest organizers now request that you send in a digital file that lists your contacts in the Cabrillo format. The Cabrillo format is **a standard for submission of electronic contest logs**. (E2C07)

In contest operating, **operators are permitted to make contacts even if they do not submit a log**. (E2C01) If you do not submit a log, you obviously cannot win a contest, but there are several reasons why you still might choose to participate in a contest. For example, for big DX contests, some amateurs travel to locations where amateur radio operation is infrequent. Making contact with those stations during a contest gives you an opportunity to add countries to your total.

Another reason is that it will give you a good idea of the capabilities of your station. If, for example, during a contest, you need to call repeatedly before a DX station replies, it might mean that you should improve your antenna system.

There are some operating practices that are either prohibited or highly discouraged. On the HF bands, for example, operating on the "WARC bands," is normally prohibited. Therefore, **30 meters** is one band on which amateur radio contesting is generally excluded. (E2C03). The other "WARC bands" are 17 meters and 25 meters.

Another prohibited practice is "self-spotting." Self-spotting is **the generally prohibited practice of posting one's own call sign and frequency on a call sign spotting network**. (E2C02) The reason this is prohibited is that doing so would give you an advantage over other operators.

During a VHF/UHF contest, you would expect to find the highest level of activity **in the weak signal segment of the band, with most of the activity near the calling frequency**. (E2C06) VHF/UHF contesters stay away those portions of the band that are normally reserved for FM operation. That being the case, **146.52 MHz** is one of the frequencies on which an amateur radio contest contact is generally discouraged. (E2C04) 146.52 MHz is the national FM simplex calling frequency.

Operating DX

The function of a DX QSL Manager is **to handle the receiving and sending of confirmation cards for a DX station**. (E2C05)

Sending your full call sign once or twice is the way you should generally identify your station when attempting to contact a DX station working a pileup or in a contest. (E2C11)

One thing that might help to restore contact when DX signals become too weak to copy across an entire HF band a few hours after sunset is to **switch to a lower frequency HF band**. (E2C12)

All of these choices are correct as reasons why might a DX station state that they are listening on another frequency (E2C10):

- Because the DX station may be transmitting on a frequency that is prohibited to some responding stations
- To separate the calling stations from the DX station
- To reduce interference, thereby improving operating efficiency

Received spread-spectrum signals are resistant to interference because **signals not using the spectrum-spreading algorithm are suppressed in the receiver**. (EC208)

The spread-spectrum technique of frequency hopping works by **the frequency of the transmitted signal is changed very rapidly according to a particular sequence also used by the receiving station**. (E2C09)

E2D - Operating methods: VHF and UHF digital modes; APRS

One of the most commonly misunderstood concepts in digital communications is the baud. A baud is not equal to a bit per second, except for very simple systems. Rather, the definition of baud is **the number of data symbols transmitted per second**. (E2D02) A data symbol may represent multiple bits.

The baud rate is a measure of how fast a digital communications system can transmit data. Under clear communications conditions, **300-baud packet** is the digital communication mode that has the fastest data throughput. (E2D09)

In the past ten years or so, we've had an explosion of digital modes become available. JT65 is one example. **JT65** is a digital mode especially useful for EME communications. (E2D03) JT65 improves EME communications because **it can decode signals many dB below the noise floor using FEC**.(E2D12) **FSK441** is a digital mode especially designed for use for meteor scatter signals. (E2D01)

One of the most popular digital modes is the Automatic Packet Reporting System, or APRS. **AX.25** is the digital protocol used by APRS. AX.25 is more commonly known as packet radio. (E2D07) **Unnumbered Information** is the type of packet frame used to transmit APRS beacon data. (E2D08)

APRS stations can be used to help support a public service communications activity. **An APRS station with a GPS unit can automatically transmit information to show a mobile station's position during the event.** (E2D10) **Latitude and longitude** are used by the APRS network to communicate your location. (E2D11) **144.39 MHz** is a commonly used 2-meter APRS frequency. (E2D06)

Amateurs that enjoy satellite communications also use digital modes. For example, **store-and-forward** is a technique normally used by low Earth orbiting digital satellites to relay messages around the world. (E2D05) The purpose of digital store-and-forward functions on an Amateur Radio satellite is **to store digital messages in the satellite for later download by other stations**. (E2D04)

E2E - Operating methods: operating HF digital modes; error correction

Perhaps the most popular digital mode these days is PSK31. PSK stands for “phase shift keying.” One of its main advantages is that it had a very narrow bandwidth—only 31 Hz. In fact, **PSK31** is the digital communications mode that has the narrowest bandwidth. (E2E10)

One of the ways is achieves this narrow bandwidth is that uses variable length coding. That is to say, characters have different numbers of bits, depending on how frequently they appear in normal text. **PSK31** is an HF digital mode that uses variable-length coding for bandwidth efficiency. (E2E09)

Another type of modulation commonly used on the HF bands is frequency-shift keying, or FSK. RTTY, for example uses FSK modulation. **FSK** is a type of modulation that is common for data emissions below 30 MHz. (E2E01) One type of FSK modulation is MFSK16. The typical bandwidth of a properly modulated MFSK16 signal is **316 Hz**. (E2E07)

Amateur transceivers use two different methods to modulate a signal using FSK: direct FSK and audio FSK. The difference between direct FSK and audio FSK is that **direct FSK applies the data signal to the transmitter VFO**. (E2E11) When using audio FSK, audio, typically from a computer sound card, is used to shift the frequency of the transmitted signal.

To tune an FSK signal, one often uses a *crossed-ellipse display.* You have properly tuned a signal when one of the ellipses is as vertical as possible, and the other is as horizontal as possible. When one of the ellipses in an FSK crossed-ellipse display suddenly disappears, **selective fading has occurred**. (E2E04)

PACTOR is one digital mode that uses FSK. It also uses the ARQ protocol to detect errors. Because of this, **PACTOR** is an HF digital mode that can be used to transfer binary files. (E2E08) How does ARQ accomplish error correction? **If errors are detected, a retransmission is requested**. (E2E05)

Another way to detect and correct errors in a data transmission is *forward error correction*. The letters FEC mean **Forward Error Correction** when talking about digital operation. (E2E02) Forward Error Correction is implemented **by transmitting extra data that may be used to detect and correct transmission errors**. (E2E03)

No matter what type of modulation you use, data transmission over an HF radio link is very slow. **300 baud** is the most common data rate used for HF packet communications. (E2E06) In fact, due to bandwidth limitations, 300 baud is the maximum data rate.

Many of the digital modes were designed to allow keyboard-to-keyboard operation. That is to say, that operators can type messages back and forth to one another, almost as if they were having a conversation using SSB. **Winlink**, however, does not support keyboard-to-keyboard operation. (E2E12)

E0: Safety

E0A Safety: amateur radio safety practices; RF radiation hazards; hazardous materials

No matter what amateur radio activities you engage in, I hope that you will engage in them safely. Every year, we lose amateur radio operators because of injuries they sustained while putting up antennas or doing things that could be dangerous.

Perhaps the most common danger is from RF exposure. The dangers from RF exposure differ from those posed by exposure to radioactive materials. What, if any, are the differences between the radiation produced by radioactive materials and the electromagnetic energy radiated by an antenna? **Radioactive materials emit ionizing radiation, while RF signals have less energy and can only cause heating**. (E0A01)

The amount of heating is proportional to the specific absorption rate (SAR). SAR measures **the rate at which RF energy is absorbed by the body**. (E0A08) In general, the SAR increases as the frequency increases. **Localized heating of the body from RF exposure in excess of the MPE limits** is an injury that can result from using high-power UHF or microwave transmitters. (E0A11) One of the potential hazards of using microwaves in the amateur radio bands is that **the high gain antennas commonly used can result in high exposure levels**. (E0A05)

The FCC, as you might expect, has a lot to say about RF exposure. They have set limits on the field strengths that humans may be exposed to. These limits are called maximum permissible exposure, or MPE.

The MPEs for the electric field and magnetic field of an electromagnetic wave differ. **All of these choices are correct** as to why there are separate electric (E) and magnetic (H) field MPE limits (E0A06):

- The body reacts to electromagnetic radiation from both the E and H fields
- Ground reflections and scattering make the field impedance vary with location
- E field and H field radiation intensity peaks can occur at different locations

One way to make sure that the field strengths that your transmissions expose you and others to is to measure the absolute field strengths. Unfortunately, this is not easy to do. The equipment used to measure field strength is very expensive and difficult to use. An alternative is to use software that calculates field strength. **Using an antenna modeling program to calculate field strength at accessible locations** would be a practical way to estimate whether the RF fields produced by an amateur radio station are within permissible MPE limits. (E0A03)

Remember to include your neighbors when evaluating RF exposure levels. In some cases, your antennas may actually be closer to your neighbors' houses than they are to your house. When evaluating RF exposure levels from your station at a neighbor's home, you must **make sure signals from your station are less than the uncontrolled MPE limits**. (E0A02)

Typically, amateur repeater stations are located in places where there are transmitters for other radio services, such as cell phone and pager services. These sites should be regularly evaluated so that RF field strengths don't exceed the MPE limits. When evaluating a site with multiple transmitters operating at the same time, the operators and licensees of **each transmitter that produces 5% or more of its MPE exposure limit at accessible locations** are responsible for mitigating over-exposure situations. (E0A04)

RF exposure is not the only danger posed by an amateur radio station. For example, in emergency situations, you may want to use a gasoline-powered generator. One of the dangers posed by a gas-powered generator is that its exhaust contains carbon monoxide. Dangerous levels of carbon monoxide from an emergency generator can be detected **only with a carbon monoxide detector**.

(E0A07)

Some of the materials used in electronics pose a danger to amateur radio operators. They are used because they have some desirable electrical property, but may be dangerous if used improperly. For example, **beryllium oxide** is an insulating material commonly used as a thermal conductor for some types of electronic devices that is extremely toxic if broken or crushed and the particles are accidentally inhaled. (E0A09) **Polychlorinated biphenyls**, or PCBs, is a material found in some electronic components, such as high-voltage capacitors and transformers, that is considered toxic. (E0A10)

E1: Commission's Rules

E1A Operating Standards: frequency privileges; emission standards; automatic message forwarding; frequency sharing; stations aboard ships or aircraft

When using a transceiver that displays the carrier frequency of phone signals, the highest frequency at which a properly adjusted USB emission will be totally within the band is **3 kHz below the upper band edge**. (E1A01) So, with your transceiver displaying the carrier frequency of phone signals, you hear a DX station's CQ on 14.349 MHz USB. Is it legal to return the call using upper sideband on the same frequency? **No, the sidebands will extend beyond the band edge. (**E1A03)

The reason for this is that the USB signal extends from the carrier frequency, which is the frequency that the transceiver is displaying, up 3 kHz. When you set the transceiver to 14.349 kHz, the upper sideband will extend up to 14.352 MHz, and because the amateur radio band stops at 14.350 MHz, some of the transmission will fall outside the band.

A similar thing happens, but in reverse, when you operate lower sideband, or LSB. When using a transceiver that displays the carrier frequency of phone signals,the lowest frequency at which a properly adjusted LSB emission will be totally within the band is **3 kHz above the lower band edge**. (E1A02) With your transceiver displaying the carrier frequency of phone signals, you hear a DX station calling CQ on 3.601 MHz LSB. Is it legal to return the call using lower sideband on the same frequency? **No, my sidebands will extend beyond the edge of the phone band segment**. (E1A04)

The lower sideband will extend down 3 kHz from the carrier frequency. So, when your transceiver is set to 3.601 Mhz, your signal will extend down to 3.598 MHz, which is outside the phone band.

This is also a consideration when operating CW because a CW signal occupies a finite bandwidth. With your transceiver displaying the carrier frequency of CW signals, if you hear a DX station's CQ on 3.500 MHz, it is not legal to return the call using CW on the same frequency because **the sidebands from the CW signal will be out of the band**. (E1A12)

The 60 m band is one of the oddest amateur radio bands. One of the reasons for this is that the **60 meter band** is the only amateur band where transmission on specific channels rather than a range of frequencies is permitted. (E1A07) Also, the rules for operation on the 60 meter band state that **operation is restricted to specific emission types and specific channels**. (E1A06)

The rules for power output are also a bit arcane. The maximum power output permitted on the 60 meter band is **100 watts PEP effective radiated power relative to the gain of a half-wave dipole**. (E1A05) The rules are written this way to minimize interference between amateur radio operators, who are secondary users of this band, and the primary users, which are primarily government radio stations.

Some amateur radio systems automatically forward messages for other amateur radio stations. Winlink is one such system. There is always a question of who is responsible when an automatically-controlled station forwards a message that violates FCC rules.

If a station in a message forwarding system inadvertently forwards a message that is in violation of FCC rules, **the control operator of the originating station** is primarily accountable for the rules violation, (E1A08) This is very similar to the situation where a repeater is used to send messages that violate FCC rules.

The first action you should take if your digital message forwarding station inadvertently forwards a communication that violates FCC rules is to **discontinue forwarding the communication as soon as you become aware of it**. (E1A09) This is also similar to what a repeater control operator should do if a repeater user is violating FCC rules.

Operating an amateur radio station on a ship or an airplane can be a lot of fun, but there are some rules that govern this operation. For example, if an amateur station is installed aboard a ship or aircraft, **its operation must be approved by the master of the ship or the pilot in command of the aircraft** before the station is operated. (E1A10) **Any FCC-issued amateur license or a reciprocal permit for an alien amateur licensee** is required when operating an amateur station aboard a US-registered vessel in international waters. (E1A11)

Even when operating from a ship, there must be a control operator. **Any person holding an FCC-issued amateur license or who is authorized for alien reciprocal operation** must be in physical control of the station apparatus of an amateur station aboard any vessel or craft that is documented or registered in the United States. (E1A13)

E1B - Station restrictions and special operations: restrictions on station location; general operating restrictions; spurious emissions, control operator reimbursement; antenna structure restrictions; RACES operations

Part 97 places many different restrictions on how amateurs can use their stations and specifies technical standards that amateur radio station must meet. For example, some rules set standards for spurious emissions A spurious emission is **an emission outside its necessary bandwidth that can be reduced or eliminated without affecting the information transmitted**. (E1B01) The rules also state that permitted mean power of any spurious emission relative to the mean power of the fundamental emission from a station transmitter or external RF amplifier must be **at least 43 dB below** for transmitters or amplifiers installed after January 1, 2003, and transmitting on a frequency below 30 MHZ is. (E1B11)

There are also restrictions on erecting antennas. One factor that might cause the physical location of an amateur station apparatus or antenna structure to be restricted is if **the location is of environmental importance or significant in American history, architecture, or culture**. (E1B02) If you are installing an amateur station antenna at a site at or near a public use airport, **you may have to notify the Federal Aviation Administration and register it with the FCC as required by Part 17 of FCC rules**. (E1B06)

The 60m band is one band that has a lot of weird restrictions not found on other ham bands. For example, the maximum bandwidth for a data emission on 60 meters is **2.8 kHz**. (E1B05) The carrier frequency of a CW signal must be set **at the center frequency of the channel** to comply with FCC rules for 60 meter operation. (E1B07)

Because RACES operation is quasi-governmental, there are some rules about RACES operations. **Any FCC-licensed amateur station certified by the responsible civil defense organization for the area served** may be operated in RACES. (E1B09) **All amateur service frequencies authorized to the control operator** are authorized to an amateur station participating in RACES. (E1B10)

Finally, there are some questions about random rules in this section:

- The distance at which an amateur station must protect an FCC monitoring facility from harmful interference is **1 mile**. (E1B03)
- **An Environmental Assessment must be submitted to the FCC** must be done before placing an amateur station within an officially designated wilderness area or wildlife preserve, or an area listed in the National Register of Historical Places. (E1B04)
- **The amateur station must avoid transmitting during certain hours on frequencies that cause the interference** if its signal causes interference to domestic broadcast reception, assuming that the receiver(s) involved are of good engineering design. (E1B08)
- The highest modulation index permitted at the highest modulation frequency for angle modulation is **1.0**. (E1B12)

E1C - Station Control: Definitions and restrictions pertaining to local, automatic and remote control operation; control operator responsibilities for remote and automatically controlled stations

An important concept in the rules governing amateur radio is the concept of station control and the control operator. The *control operator* is the licensed radio amateur who is responsible for the transmissions of a station, and the location of that operator is called the *control point*. There are three ways that a control operator can control a station: local control, remote control, or automatic control.

Local control means **direct manipulation of the transmitter by a control operator**. (E1C07) So, when you were sitting in front of your radio, you are using local control.

A remotely controlled station is **a station controlled indirectly through a control link**. (E1C01) **A control operator must be present at the control point** is the true statement about remotely controlled amateur stations. (E1C06) This is, of course, true for local control as well. **3 minutes** is the maximum permissible duration of a remotely controlled station's transmissions if its control link malfunctions. (E1C08)

Automatic control of a station means **the use of devices and procedures for control so that the control operator does not have to be present at a control point**. (E1C02) The control operator responsibilities of a station under automatic control differs from one under local control. **Under automatic control the control operator is not required to be present at the control point**. (E1C03)

Most repeaters are operated with automatic control. **Only auxiliary, repeater or space stations** are the types of amateur stations that may automatically retransmit the radio signals of other amateur stations. (E1C10) **29.500 - 29.700 MHz** is the frequency band available for an automatically-controlled repeater operating below 30 MHz. (E1C09) No repeaters are allowed on any other HF band.

An automatically controlled station may retransmit third party communications **only when transmitting RTTY or data emissions**. (E1C04) An automatically controlled station may **never** originate third party communications. (E1C05)

E1D - Amateur Satellite service: definitions and purpose; license requirements for space stations; available frequencies and bands; telecommand and telemetry operations; restrictions and special provisions; notification requirements

The amateur satellite service is **a radio communications service using amateur radio stations on satellites**. (E1D02) In the amateur satellite service, the satellites are called space stations and are remotely controlled by telecommands.

Only 40m, 20m, 17m, 15m, 12m and 10m are the amateur service HF bands have frequencies authorized to space stations. (E1D07) **2 meters** is the only VHF amateur service band that has frequencies available for space stations. (E1D08)

One special provision that a space station must incorporate in order to comply with space station requirements is that **the space station must be capable of terminating transmissions by telecommand when directed by the FCC**. (E1D06) A telecommand station in the amateur satellite service is **an amateur station that transmits communications to initiate, modify or terminate functions of a space station**. (E1D03)

An amateur station eligible to be a telecommand stations is **any amateur station so designated by the space station licensee, subject to the privileges of the class of operator license held by the control operator**. (E1D10) **All classes** of licensees are authorized to be the control operator of a space station. (E1D05)

Another important concept in the amateur satellite service is the Earth station. An Earth station in the amateur satellite service is **an amateur station within 50 km of the Earth's surface intended for communications with amateur stations by means of objects in space**. (E1D04) **Any amateur station, subject to the privileges of the class of operator license held by the control operator** is eligible to operate as an Earth station. (E1D11)

To obtain information about the operation of the space station itself, many space stations send telemetry. Telemetry is defined as **one-way transmission of measurements at a distance from the measuring instrument**. (E1D01)

E1E - Volunteer examiner program: definitions; qualifications; preparation and administration of exams; accreditation; question pools; documentation requirements

The Volunteer Examiner program started in the early 1980s, and has been a boon for amateur radio. Exam sessions are now more accessible than when tests were given by the FCC, meaning that it is much easier to obtain an amateur radio license, and that more people can now enjoy our hobby.

As the name implies, volunteer examiners (VEs) are volunteers. They may not accept any payment for administering tests. They may, however, be reimbursed for some expenses. **Preparing, processing, administering and coordinating an examination for an amateur radio license** are the types of out-of-pocket expenses that Part 97 rules state that VEs and VECs may be reimbursed. (E1E14)

The organizations that are responsible for accrediting and administering the exams are called Volunteer Examiner Coordinators (VECs). A Volunteer Examiner Coordinator is **an organization that has entered into an agreement with the FCC to coordinate amateur operator license examinations**. (E1E03) There are currently 14 VECs in the U.S. **The procedure by which a VEC confirms that the VE applicant meets FCC requirements to serve as an examiner** is the phrase that describes the Volunteer Examiner accreditation process. (E1E04)

The National Conference of Volunteer Examiner Coordinators (NCVEC) is a group made up from representatives of the 14 VECs. The NCVEC is responsible for maintaining the question pools for the three examinations. The questions for all written US amateur license examinations are listed **in a question pool maintained by all the VECs**. (E1E02)

The rules and procedures for administering the tests are written so that everything is on the up and up. For example, **3** is the minimum number of qualified VEs required to administer an Element 4 amateur operator license examination. (E1E01) **Each administering VE** is responsible for the proper conduct and necessary supervision during an amateur operator license examination session. (E1E06) Having several VEs, and making them all responsible, leaves very little room for cheating.

VEs are not to show any favoritism. To minimize the chance of this happening, a VE may not administer an examination to **relatives of the VE as listed in the FCC rules**. (E1E08)

The penalty for a VE who fraudulently administers or certifies an examination can be **revocation of the VE's amateur station license grant and the suspension of the VE's amateur operator license grant**. (E1E09)

Before administering a test, the VEs instruct the candidates of the rules. For example, the candidates are not allowed to consult any books during the test. They may use a calculator, but only if they can demonstrate to a VE that all of the calculator's memories have been cleared. If a candidate fails to comply with the examiner's instructions during an amateur operator license examination, a VE should **immediately terminate the candidate's examination**. (E1E07)

After the test, three VEs must correct each test sheet. This minimizes the chance for making a scoring mistake. On amateur operator license examinations, there is a **minimum passing score of 74%**. (E1E05) If an examinee scores a passing grade on all examination elements needed for an upgrade or new license, **three VEs must certify that the examinee is qualified for the license grant and that they have complied with the administering VE requirements**. (E1E11)

After the administration of a successful examination for an amateur operator license, the VEs **must submit the application document to the coordinating VEC according to the coordinating VEC instructions**. (E1E10) If the examinee does not pass the exam, the VE team must **return the application document to the examinee**. (E1E12)

From time to time, a licensee may be asked to re-take a test. The consequences of failing to appear for re-administration of an examination when so directed by the FCC are that **the licensee's license**

will be cancelled. (E1E13)

E1F - Miscellaneous rules: external RF power amplifiers; national quiet zone; business communications; compensated communications; spread spectrum; auxiliary stations; reciprocal operating privileges; IARP and CEPT licenses; third party communications with foreign countries; special temporary authority

As the name of this section implies, it contains a hodgepodge of questions covering sometimes obscure rules. About the only way to get these right is to memorize the answers.

The use of spread-spectrum techniques is a topic that comes up from time to time. Many amateurs feel that the rules are too restrictive. For example, **10 W** is the maximum transmitter power for an amateur station transmitting spread spectrum communications. (E1F10) **Only on amateur frequencies above 222 MHz** are spread spectrum transmissions permitted. (E1F01)

All of these choices are correct when talking about the conditions that apply when transmitting spread spectrum emission: (E1F09)

- A station transmitting SS emission must not cause harmful interference to other stations employing other authorized emissions.
- The transmitting station must be in an area regulated by the FCC or in a country that permits SS emissions.
- The transmission must not be used to obscure the meaning of any communication.

The rules governing the use of external amplifiers is also somewhat controversial. A dealer may sell an external RF power amplifier capable of operation below 144 MHz if it has not been granted FCC certification if **it was purchased in used condition from an amateur operator and is sold to another amateur operator for use at that operator's station**. (E1F03) One of the standards that must be met by an external RF power amplifier if it is to qualify for a grant of FCC certification is that **it must satisfy the FCC's spurious emission standards when operated at the lesser of 1500 watts, or its full output power**. (E1F11)

There are some rules that spell out restrictions based on where a station is located. For example, amateur radio stations may not operate in the National Radio Quiet Zone. The National Radio Quiet Zone is **an area surrounding the National Radio Astronomy Observatory**. (E1F06) The NRAO is located in Green Bank, West Virginia.

There is also a regulation that protects Canadian Land/Mobile operations near the US/Canadian border from interference. Amateur stations may not transmit in the **420 - 430 MHz** frequency segment if they are located in the contiguous 48 states and north of Line A. (E1F05) **A line roughly parallel to and south of the US-Canadian border** describes "Line A." (E1F04) There is a corresponding "Line B" parallel to and north of the U.S./Canadian border.

As you might expect, there are some questions about not making any money from operating an amateur radio station. **Communications transmitted for hire or material compensation, except as otherwise provided in the rules** are prohibited. (E1F08) An amateur station may send a message to a business only **when neither the amateur nor his or her employer has a pecuniary interest in the communications**. (E1F07)

This next question is a bit of a trick question. 97.201 states that **only Technician, General, Advanced or Amateur Extra Class operators** may be the control operator of an auxiliary station. (E1F12) It's a trick question because there are also holders of Novice Class licenses even though no new Novice licenses have been issued for many years, and the number of Novice Class licensees dwindles every year.

Communications incidental to the purpose of the amateur service and remarks of a personal nature are the types of communications may be transmitted to amateur stations in foreign countries. (E1F13)

The FCC might issue a "Special Temporary Authority" (STA) to an amateur station **to provide for experimental amateur communications**. (E1F14)

The **CEPT agreement** allows an FCC-licensed US citizen to operate in many European countries, and alien amateurs from many European countries to operate in the US. (E1F02)

About the Author

I have been a ham radio operator since 1971 and a radio enthusiast as long as I can remember. In addition to being an active CW operator on the HF bands:

- I blog about amateur radio at KB6NU.Com, one of the leading amateur radio blogs on the Internet.
- I am the author of the No-Nonsense Technician Class License Study Guide and the No-Nonsense General Class License Study Guide. These study guides are available as a free PDF file, in e-book format, and even in a traditional print version. See http://www.kb6nu.com/tech-manual for more information.
- I am the author of *21 Things to Do With your Amateur Radio License*, an e-book for those who have been recently licensed or just getting back into the hobby. You can find it on Amazon or Barnes&Noble.
- I send out a monthly column to more than 300 amateur radio clubs in North America for publication in their newsletters.
- I am the station manager for WA2HOM (http://www.wa2hom.org), the amateur radio station at the Ann Arbor Hands-On Museum (http://www.aahom.org).
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You can contact me by sending e-mail to cwgeek@kb6nu.com. If you have comments or question about any of the stuff in this book, I hope you will do so.

73!

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