Amateur Radio General Class License Study Guide

week 1

Element 5: Electrical Principles

October 3, 2023

Question pool sections: G5

Concepts covered:

G5A – Reactance; inductance; capacitance; impedance; impedance transformation; resonance

G5B – The decibel; current and voltage dividers; electrical power calculations; sine wave root-mean-square (RMS) values; PEP calculations

G5C – Resistors, capacitors, and inductors in series and parallel; transformers

Corresponding pages of ARRL *General Class license manual*:
4-1 through 4-8, 4-14 through 4-25

<u>Element 5: Electrical Principles</u>

<u>Basic electronics</u>: Before digging into some more advanced electrical principles, let's review some of the concepts covered on the Technician class exam.

Electrons can be made to flow through an electrically conductive material (a conductor) by applying an electromotive force or EMF. This is the “push” that makes the electrons move along. The basic unit of electromotive force (EMF) is the volt. EMF, also known as electrical potential, is abbreviated as “**E**” in equations.

The resulting flow of electrons in a conductor is known as **current**. The more electrons flowing through a conductor, the higher the current. Electrical **current** is measured in **amperes**, most often called “amps”. In equations, current is abbreviated as “**I**”. Current that flows in only one direction is known as “direct current” or DC.

The property of a material which resists the flow of electrons is known as electrical resistance. The basic unit of electrical **resistance** is the **ohm**. Resistance is abbreviated as “**R**” in equations. Pure resistance opposes the flow of all types of current, direct, alternating or RF.

The power in your home, however, is most likely “alternating current”, or AC, which is current that flows in one direction, then reverses and flows in the opposite direction. The number of times per second that an alternating current makes a complete cycle is known as the **frequency**. The basic unit of **frequency** is the **Hertz**. Radio signals are a type of alternating current, but at much higher frequencies than household current. The abbreviation **“RF”** refers to radio frequency energy of all types.

The opposition to AC current flow in a circuit (similar to resistance in a DC circuit) is known as **impedance**. The basic unit of **impedance** is the **ohm**, same as resistance. More on this later.

The current (flow) in an electrical circuit decreases as the voltage (pressure) decreases or as the resistance increases. This relationship, which can be written as I (current) = E (voltage)/R (resistance), is known as **“Ohm’s law”**. This equation shows that the current will increase if the voltage is increased, or if the resistance is decreased.

Power is the term that describes the rate at which electrical energy is being used. The basic unit of **electrical power** is the **watt**. Watts are easily calculated in DC circuits. The power “P” in watts is equal to the current “I“ in amps, times the EMF “E” in volts, or P = I x E. Changes in power levels are expressed in decibels or dB. Each *+3 dB change represents a doubling of power*, while a -3 dB change reflects a halving of power. Only two questions reference dB and power changes. As noted above, a *factor of two increase in power equals a +3 dB change*. A *-1 dB change is equivalent to a 20.6% loss* of power. The ARRL guide provides a much more in-depth discussion of dB calculations on pages 4-2, 4-3, and 4-5..

DC power calculations

Let's see how these concepts are incorporated into the General class exam. Three questions involve power calculations in DC circuits with two requiring application of Ohm's law.

- E = 12 V and I = 0.2 A, P = ?
- E = 400 V and R = 800 Ω, P = ?
- I = 7 mA, and R = 1250 Ω, P = ?

AC power calculations

Power calculations become a bit more complex in AC circuits. While the same formulas apply, how do you deal with a voltage that is constantly changing, either increasing or decreasing? One way is to reference conditions at the peak voltage, or peak to peak (2X the peak voltage). In order to calculate "average" conditions for a sine wave, the "root mean square" or ***RMS*** is used. $V_{RMS} = 0.707 \times V_{PK}$. Since the peak voltage is only half of the full cycle voltage swing, *RMS of a peak-to-peak voltage is* $V_{RMS} = 0.707 \times (V_{P\text{-}P}/2)$. Given the RMS voltage of a sine wave signal, the peak-to-peak voltage may be calculated as $V_{P\text{-}P} = 2 \times 1.414 \times V_{RMS}$.

Now let's apply this concept to power calculations with AC signals. *The power dissipated in a resistor at a given DC voltage is matched by an equal AC RMS voltage. The average power of one full RF cycle at the peak of the signal's envelope is known at the peak envelope power or **PEP**.* This value may be calculated if you know the load impedance in ohms (R) and the RMS voltage. PEP (in watts) = V_{RMS}^2/R. This can be rewritten as $V_{RMS} = \sqrt{PEP \times R}$ If provided with the peak-to-peak voltage, first convert it to RMS using the formula $V_{RMS} = 0.707 \times (V_{P\text{-}P}/2)$.

The *PEP is equal to the <u>average</u> power of* signals with no amplitude modulation applied. This includes <u>*unmodulated*</u> *AM signals*, as well as CW and FM signals. Another way to state this is *the ratio of PEP to average power for an unmodulated carrier is 1.0*.

Impedance and Reactance

Just as power calculations become more complex in AC circuits, so does the response of some electrical components. As noted before, the opposition to AC current flow in a circuit is known as ***impedance*** *and is defined the ratio of voltage to current.* If this looks familiar, resistance, also measured in ohms, is the ratio of voltage to current in a DC circuit. The *inverse of impedance is known as admittance.*

Some of the components that were discussed in the previous section respond differently to AC. While capacitors block the flow of DC and inductors allow DC to pass, things change with AC. Both devices oppose the flow of AC, with the degree depending on the frequency. This *opposition to flow of alternating current in a capacitor or inductor is known as reactance designed as "X" in formulas and is measured in ohms. The reactance in an inductor increases as frequency increases, while capacitive reactance decreases with increasing frequency*.

When an inductor and capacitor are connected in an "LC" circuit (series or parallel), magic happens. *Resonance occurs when the capacitive reactance* X_c *and the inductive reactance* X_L are equal and *cancel each othe*r. When this happens in *a <u>series</u> LC circuit, <u>resonance</u> causes the <u>impedance to be very low</u>*.

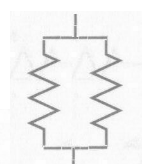
Transformers
Transformers are essentially two inductors with overlapping magnetic fields, condition known as “mutual inductance”. Transformers are unique to AC circuits, and may be used to “transform” AC voltage or impedance, up or down.

The increase (or decrease) in voltage or impedance from the primary to secondary side of a transformer is proportional to the ratio of primary to secondary windings. *The voltage that appears across the secondary winding of a transformer with an AC voltage applied to the primary (due to mutual inductance)* is equal to the primary voltage multiplied ratio of secondary to primary windings. So if 10 VAC is applied to the primary side of a 1:4 step-up transformer, 40 volts will appear across the secondary. Since transformers do not create power, the power must be equal on the primary and secondary sides. This means that the *current on the primary side of a voltage step-up transformer is higher than the current flowing through the secondary, which is why larger size wire is usually used for the primary*.

Transformers don't “know” which winding is the primary and which is the secondary, so they will still function if hooked up “backwards”. So *if an input signal is applied to the secondary of a 4:1 voltage step down transformer, the output voltage will equal the input voltage multiplied by 4*. This demonstrates that it's all about the winding ratio. *A transformer with a 500-turn primary and a 1500 turn secondary (1:3) will produce 360 VAC on the secondary when 120 VAC is applied to the primary*.

Things are a little different when transforming impedance. Turns ratio = $N_p / N_S = \sqrt{Zp/Zs}$
So *to match a 600-ohm feed point impedance to a 50-ohm coaxial cable (600/50 = 12) requires* $\sqrt{12}$ *= 3.5 to 1 turns ratio. Transformers are not the only devices can be used for impedance matching at radio frequencies. A Pi-network or length of transmission line* may also be used.

Connecting like components in series or parallel
The final concept in this section is calculating the effective value of like components when connected in series (end to end) or parallel (side by side)

series   parallel

We'll begin with resistors, as we can apply Ohm's law to explain the calculations*. When resistors are connected in parallel, the total current is equal to the sum of the current through each resistor*. An example is a circuit with 10 V applied across a 10Ω, 20Ω, and 50Ω resistors in parallel. Using Ohm's law, the current through each resistor is as follows:

10Ω = 10/10 = 1.0 A
20Ω = 10/20 = 0.5 A
50Ω = 10/50 = 0.2 A

This yields a total current of 1.7 A. Using Ohm's law again, you can calculate the effective resistance of the three parallel resistors. E = 10V, I = 1.7 A R = E/I = 10/1.7 = 5.9Ω

Note that the <u>total resistance</u> is **less** than any of the individual resistors in the circuit.

While you could use this approach to calculate the effective resistance the following formulas may be used:

If it's only two resistors in parallel: $R_{EQU} = (R_1 \times R_2)/(R_1 + R_2)$
A 100Ω and a 200Ω resistor in parallel $R_{EQU} = (100 \times 200)/(100+200) = 20000/300 = 66.6\Omega$

For three resistors in parallel $R_{EQU} = 1/(1/R_1 + 1/R_2 + 1/R_3)$
For 10Ω, 20Ω, and 50Ω resistors in parallel:
$R_{EQU} = 1/(1/10 + 1/20 + 1/50) = 1/(0.1 + 0.05 + 0.02) = 1/0.17 = 5.9\Omega$

Calculations for resistors in series is much simpler, as the resistance is additive. For 10Ω, 20Ω, and 50Ω resistors in <u>series</u>, $R_{EQU} = R_1 + R_2 + R_3 = 10 + 20 + 50 = 80\Omega$

The same formulas that apply to resistors also apply to inductors. *A 20 mH inductor in series with a 50 mH inductor = 20 + 50 = 70 mH. The inductance of three 10 mH inductors in parallel = 1/(1/10 + 1/10 + 1/10) = 1/(0.1 + 0.1 + 0.1) = 1/ 0.3 = 3.3 mH*. *If you need to <u>increase inductance</u> in a circuit, <u>add</u> another inductor <u>in series</u>.*

Capacitors are just the opposite, additive when connected in parallel, and reduced when connected in series. *The equivalent capacitance of two 5 nF and one 750 pF capacitors connected in parallel is* $C_{EQU} = C_1 + C_2 + C_3 = 5 + 5 + 0.75 =$ *10.750 nF. If you need to <u>increase capacitance</u> in a circuit, <u>add</u> a capacitor <u>in parallel</u>.*

Use the same formulas used for parallel resistors or inductors to calculate the effective capacitance to capacitors in series. Two capacitors in series: $C_{EQU} = (C_1 \times C_2)/(C_1 + C_2)$
A 20 μF capacitor in series with a 50 μF capacitor $C_{EQU} = (20 \times 50)/(20+50) = 1000/70 =$ 14.8 *μF.*

Three 100 μF capacitors in series $C_{EQU} = 1/(1/C_1 + 1/C_2 + 1/C_3)$
$C_{EQU} = 1/(1/100 + 1/100 + 1/100) = 1/(0.003) =$ *33.3 μF*