EASY(ER) ELECTRICAL PRINCIPLES FOR EXTRA CLASS HAM LICENSE

2012 - 2016

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FOREWORD

Taking an exam in order to get a ham license is quite stressful ordeal as it comes. To make things worse most people get extremely confused when dealing with calculations required. This guide will help you understand how to come to the answer as simply as possible and without calculator (which you will inevitably forget at home).

In order to make things easier to remember physics here is extremely simplified and takes full advantage of rounding numbers and moving decimal point around to get us into a ballpark of an answer. It is what engineers around the world do when they refer to "back of the envelope" calculations.

These simplifications work with Extra Class exam expiring on June 30, 2016. Most shortcuts will still apply for new exam but be warned that there might be some deviations.

Only Electrical Principles part of an exam is covered here and you will need to use other resources too. I recommend No-Nonsense Study Guides by KB6NU and do check for free classes at nearby Ham club. Ham radio is all about community – there is no reason to pass through all this alone.

SUBELEMENT E5 - ELECTRICAL PRINCIPLES

COMPONENTS AND RESONANCE

There are only three components that you need to understand here.

Resistor is a component that **resists flow of electrical current** and its property of resistance is expressed in units of **Ohm**. Voltage and current are buddies and they go together through this one.

In AC circuit we also need to know of impedance. Simplified, this is an opposition circuit presents to a current. It is, again extremely simplified, an form of resistance.

Capacitor is a component that resists signals at low frequencies but passes whatever comes at high frequency. Increase in current will always come before any voltage increase. I simply remember that **capacitor loves high frequencies** (as it passes them) **and current** (as it leads).

Inductor is a component that resists signals at high frequencies but passes whatever comes at low frequency. For it increase in voltage will always come before the current increase. It is essentially quite the opposite of how capacitor behaves. That is, **inductor loves low frequencies and voltage**.

Resonance is what happens when **inductive reactance is equal to capacitive reactance**. While there is a formula to calculate frequency at which this happens (and we will use it a bit further) only thing of importance here is that inductor and capacitor sort of “cancel” one another.

These three components can be arranged either in series or parallel to one another. **If they are serial, at resonance input current is at maximum while circulating current will be at its minimum.**

Same components arranged in **parallel** will have input current at minimum while in resonance. At same time circulating current will be at its maximum – exactly the **opposite of serial arrangement**. Just remember series circuit behavior and you’ll be fine.

E5A01

What can cause the voltage across reactances in series to be larger than the voltage applied to them?

- **A. Resonance**
- B. Capacitance
- C. Conductance
- D. Resistance

This is kind of an odd ball – just remember it.

E5A02

What is resonance in an electrical circuit?

A. The highest frequency that will pass current
B. The lowest frequency that will pass current
C. The frequency at which the capacitive reactance equals the inductive reactance
D. The frequency at which the reactive impedance equals the resistive impedance

This comes directly out of definition for resonance and it is one of things you need to remember.

E5A03

What is the magnitude of the impedance of a series RLC circuit at resonance?

A. High, as compared to the circuit resistance
B. Approximately equal to capacitive reactance
C. Approximately equal to inductive reactance
D. Approximately equal to circuit resistance

RLC circuit is just a fancy name for something that consist of resistor (R), inductor (L), and capacitor (C). In this particular question they are arranged in series.

As we can think of resonance as capacitor and inductor “canceling” one another, only thing left over is actual resistor and its impedance (opposition to current).

E5A04

What is the magnitude of the impedance of a circuit with a resistor, an inductor and a capacitor all in parallel, at resonance?

A. Approximately equal to circuit resistance
B. Approximately equal to inductive reactance
C. Low, as compared to the circuit resistance
D. Approximately equal to capacitive reactance

Again, as in previous question, key word here is resonance. As capacitor and inductor “cancel” each other, only thing left over is resistor and its resistance.

E5A05

What is the magnitude of the current at the input of a series RLC circuit as the frequency goes through resonance?

A. Minimum
B. Maximum
C. R/L
D. L/R

If RLC are connected in series their input will be at maximum at resonance frequency. At same time circulating current will be at minimum.

E5A06

What is the magnitude of the circulating current within the components of a parallel LC circuit at resonance?

A. It is at a minimum
B. It is at a maximum
C. It equals 1 divided by the quantity 2 times Pi, multiplied by the square root of inductance L multiplied by capacitance C
D. It equals 2 multiplied by Pi, multiplied by frequency "F", multiplied by inductance "L"

Circulating current is always opposite of input current. As parallel RLC circuit in resonance has input current in minimum, correct answer here is maximum current.

E5A07

What is the magnitude of the current at the input of a parallel RLC circuit at resonance?

A. Minimum
B. Maximum
C. R/L
D. L/R

Input of parallel RLC circuit at resonance has exactly the opposite of behavior of serial circuit at resonance. As serial circuit has its input at maximum at resonance, here answer is minimum.

E5A08

What is the phase relationship between the current through and the voltage across a series resonant circuit at resonance?

A. The voltage leads the current by 90 degrees
B. The current leads the voltage by 90 degrees
C. The voltage and current are in phase
D. The voltage and current are 180 degrees out of phase

Resistor is as boring and passive as it gets. Voltage and current are buddies and in phase.

E5A09

What is the phase relationship between the current through and the voltage across a parallel resonant circuit at resonance?

A. The voltage leads the current by 90 degrees
B. The current leads the voltage by 90 degrees
C. The voltage and current are in phase
D. The voltage and current are 180 degrees out of phase

This is again case of boring resistor. Since at resonant frequency capacitor and inductor “cancel” each other only component doing anything is resistor. And resistor is boring and does nothing leaving voltage and current in phase.

HALF-POWER BANDWIDTH

There is only a single formula you have to know for any half-power bandwidth. **BW = f / Q**. So, to get any half-bandwidth figure just divide frequency with Q. Questions are written in such manner that only understanding of formula with a lot of rounding is enough for correct result.

And calculator is not necessary for this – if in doubt just round. E.g. If frequency is 7.1 MHz and Q is 150, just abuse the heck out of metric system and move decimal place around at will. That is, result will start with same number if you divide 71 (instead of 7.1) with 15 (instead of 150). In this example result will start with a number slightly less than 5. This would be close to select 47.3 kHz as an answer (remember, move decimal places at will in both question and answer).

Do notice that we can completely ignore units in this case and there is a good reason for this. Those preparing questions want to see it you understand the principle, not whether you can do basic algebra. When you need this formula in real life, you will have a calculator next to you and you can do it properly.

E5A10

What is the half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 1.8 MHz and a Q of 95?

A. 18.9 kHz
B. 1.89 kHz
C. 94.5 kHz
D. 9.45 kHz

Here we move decimal place a bit and we calculate 18 (1.8 MHz) divided by 1 (95 is close to 100 that can be used as 1 after moving decimal point). This gives us number 18 as an prefix. Unfortunately there are two answers fitting this – both 18.9 kHz and 1.89 kHz. At this point you might check how many zeroes you had to remove by rounding Q to 100 and simply moving decimal point of 1.8 Mhz twice to 0.018 Mhz which converts nicely to 18 kHz pointing us toward correct answer.

Other simplification that could help here is that 1.89 kHz is simply too low of a figure. You should expect number in tens when speaking of half-power bandwidth.

E5A11

What is the half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 7.1 MHz and a Q of 150?

A. 157.8 Hz
B. 315.6 Hz
C. 47.3 kHz
D. 23.67 kHz

BW = 7.1 MHz / 150 = ~71 / ~15 = ~5. Value 157.8 Hz and 23.67 Hz can be rounded to 2, 315.6 Hz can be rounded to 3, and only remaining is 47.3 Hz (rounded to 5) which is our correct answer.

If we had 4.72 kHz as one of answers here, we would just use same decimal point counting trick as in previous one. 150 is worth two decimal points (to be left with only one decimal digit) and for 7.1 MHz that would mean moving it to 0.071 Mhz which is in tens of kHz range.

E5A12

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?

A. 436.6 kHz
B. 218.3 kHz
C. 31.4 kHz
D. 15.7 kHz

Here we can divide 37 (3.7 MHz) by 12 (118) which results in slightly over 3. Only one matching that calculation is 31.5 kHz.

E5A13

What is the half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 14.25 MHz and a Q of 187?

A. 38.1 kHz
B. 76.2 kHz
C. 1.332 kHz
D. 2.665 kHz

Again we cheat and divide 14 (14.25 MHz) by 2 (187). This gives us 7 which brings us to correct value of 76.2 kHz.

RESONANT FREQUENCY

Formula for resonant frequency is

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

In human words, it is inverse of 6.28 (or just 6) times square root of inductance and capacitance. For square root I find it easier to remember squares. That is, if I have to do square root of 150, it is handy to remember 12 squared is 144 and that is reasonably close. So square root for 150 is slightly above 12.

You can also get a square root of each component before multiplying them together. If we had L = 15 and C = 10 (as in previous case), we could say that square root of 15 is slightly less than 4 and square root of 10 is slightly higher than 3. Both of those multiplied together give us ball park value of 12. Do notice that doing this will increase your error so single square root is preferred.

If you want to play with decimal points when calculating squares, do remember that you need to move decimal point in increments of two. That is, square root will start with same numbers for 1230, 123000, and 1.23.

For inverse I just add zeros to 1 until I am happy. If I have to calculate 1 / 12.34 I will add two zeroes up to make it 100 / 12.34 and then I will forget anything after decimal point for lower number making it 100 / 12. Result is slightly higher than 8 and that is usually sufficient to select correct answer.

And resistance you see in questions when resonant frequency is needed you can safely and completely ignore.

E5A14

What is the resonant frequency of a series RLC circuit if R is 22 ohms, L is 50 microhenrys and C is 40 picofarads?

A. 44.72 MHz
B. 22.36 MHz
C. 3.56 MHz
D. 1.78 MHz

This we calculate as 1 / (6 x √(50x40)). Calculating for square root of 2000 is not trivial but we can multiply few numbers on side paper and see it is slightly less than 45 (as 45x45 is 2025). Multiply that with 6 and we get 270. Inverse of that can be seen as 100 / 27. And that is a bit higher than 3. One answer that is starting with something slightly above 3 is 3.56 MHz.

E5A15

What is the resonant frequency of a series RLC circuit if R is 56 ohms, L is 40 microhenrys and C is 200 picofarads?

A. 3.76 MHz
B. 1.78 MHz
C. 11.18 MHz
D. 22.36 MHz

This can be simplified as 1 / (6 x √(40x200)). As 40x200 is difficult to calculate and we can move decimal points in pairs when speaking about roots we can further simply this by making it 1 / (6 x √(40x2)). Finding square root of 80 will be something slightly lower than 9. Which gives us 54 to inverse.

Adding some zeros makes 100 / 54 slightly less than 2. Numbers fitting this are 1.78 MHz and 11.18 MHz. However, as our result is just slightly below 2, 1.78 MHz seems as a reasonable figure.

E5A16

What is the resonant frequency of a parallel RLC circuit if R is 33 ohms, L is 50 microhenrys and C is 10 picofarads?

A. 23.5 MHz
B. 23.5 kHz
C. 7.12 kHz
D. 7.12 MHz

Our simplification is 1 / (6 x √(50x10)). First we calculate square root of 500. For this we can take move decimal points and make it a square root of 5 which is slightly over 2. Calculating 6 times 2 gives us 12 (although we might as well call it 13 as we rounded down both 2π and square root). Inverse of 12 can be calculated as 100 divided by 12 (or 13) which gives 8 (or 7).

Unfortunately two results fit this criteria. Both 7.12 kHz and 7.12 MHz are in this ballpark. While calculating values (or tracking all decimal place movements) is one solution we don't need it here – we can be sure any result in this exam will be in MHz range – not in kHz.

E5A17

What is the resonant frequency of a parallel RLC circuit if R is 47 ohms, L is 25 microhenrys and C is 10 picofarads?

- **A. 10.1 MHz**
- B. 63.2 MHz
- C. 10.1 kHz
- D. 63.2 kHz

Simplified this becomes 1 / (6 x √(25x10)). Square root for 250 is slightly less than 16 (as 16x16 is 256) so we need to have inverse of 96 (6 x 16). To get inverse of 100 (approximated again) we need to calculate 100 / 100 which is essentially 1.

Again we have two values in the ball park – 10.1 MHz and 10.1 kHz. As for last question, MHz range is one we are searching for.

TIME CONSTANT

Time constant for an RC circuit is calculated by simple **multiplication of resistance and capacitance values** (thus its name – RC).

If you start with capacitor at 0 volts, its voltage will raise to 63.2% (**or 2/3rd**) within that **single time constant** value. If you start discharging capacitor it will fall to 36.8% (or **1/3rd** – exactly the same as in previous situation) of its value within same time.

If we wait twice as long (**two time constants**) we are going to either raise to **7/8th** or fall to **1/8th** of voltage.

E5B01

What is the term for the time required for the capacitor in an RC circuit to be charged to 63.2% of the applied voltage?

- A. An exponential rate of one
- **B. One time constant**
- C. One exponential period
- D. A time factor of one

Time to get voltage on the capacitor up to (approximately) 2/3rd of target is one time constant.

E5B02

What 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?

A. One discharge period
B. An exponential discharge rate of one
C. A discharge factor of one
D. One time constant

Time to get voltage on the capacitor 2/3rd down (or to 1/3rd) is one time constant.

E5B03

The capacitor in an RC circuit is discharged to what percentage of the starting voltage after two time constants?

A. 86.5%
B. 63.2%
C. 36.8%
D. 13.5%

After two time constants we are going to be at 1/8th of starting value.

E5B04

What is the time constant of a circuit having two 220-microfarad capacitors and two 1-megohm resistors, all in parallel?

A. 55 seconds
B. 110 seconds
C. 440 seconds
D. 220 seconds

Time constant is calculated by multiplying capacitance and resistance values. Two 220 μF capacitors in parallel are still 220 μF. And same goes for two 1 MΩ resistors – value is still 1 MΩ. As before we simply ignore units and calculate 220 x 1 which gives us correct answer of 220 seconds.

E5B05

How long does it take 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?

- **A. 0.02 seconds**
- B. 0.04 seconds
- C. 20 seconds
- D. 40 seconds

Looking at decrease of voltage on capacitor we can see it is close to $1/3^{rd}$ of initial value which gives us indicator we're looking at one time constant. Multiplication of 2 MΩ with 0.01 µF gives us 0.02 which is correct answer (notice that Mega and micro unit prefixes conveniently cancel one another).

Do notice that we could also calculate this by moving decimal places around and have result of 2. This gives us choice between 0.02 and 20 seconds. Here we need to have previous knowledge of what appropriate value would be. Since capacitance value is on lower side, chance is that result would be too so 0.02 fits better.

E5B06

How long does it take 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?

- A. 4.50 seconds
- B. 9 seconds
- **C. 450 seconds**
- D. 900 seconds

Result of 800 divided by 290 is again around $1/3^{rd}$ and we are looking into one time constant. Simple multiplication of 450 by 1 gives us 450 and that is our answer. As in previous question, Mega and micro prefixes conveniently cancel one another.

PHASE RELATIONSHIPS

In any RLC circuit we will have **reactance due to an inductor (X_L) and reactance due capacitor (X_C)**. Whichever is higher determines which characteristic is more pronounced. For example, if X_C is 500 Ω and X_L is 300 Ω, this is pretty much same as if X_C was to be 200 Ω and we ignore X_L altogether.

For this we need to remember capacitors love current and inductors love voltage and we will know whether voltage or current leads when angle is needed. To get exact phase angle we can use formula

$$\text{phase angle} = \tan^{-1}(X / R)$$

where X is difference between XC and XL. However, you don't need to remember it for this exam – phase angle is always **14°**.

E5B07

What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 500 ohms, R is 1 kilohm, and XL is 250 ohms?

A. 68.2 degrees with the voltage leading the current
B. 14.0 degrees with the voltage leading the current
C. 14.0 degrees with the voltage lagging the current
D. 68.2 degrees with the voltage lagging the current

In this case we can see that we essentially have XC = 250 Ω (XC – XL) due to XC being higher. As capacitors “love” current, we know that current leads. Other way to say current leads is that voltage lags and there are two such answers. Our crystal ball tells us angle is 14° so we know correct answer is 14.0 degrees with the voltage lagging the current.

E5B08

What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 100 ohms, R is 100 ohms, and XL is 75 ohms?

A. 14 degrees with the voltage lagging the current
B. 14 degrees with the voltage leading the current
C. 76 degrees with the voltage leading the current
D. 76 degrees with the voltage lagging the current

In this case we can see that XC is higher and thus combined reactance will be 25 Ω (100 Ω - 75 Ω) but with pronounced capacitor reactance so we might as well treat it as if XC was 25 Ω and XL was 0 Ω. So basically we only have capacitor reactance to deal with.

As capacitors “love” current, we know that current will lead. Another way of saying that is that voltage lags. And that leaves us with a single answer that satisfies both that and our magic 14° rule.

E5B09

What is the relationship between the current through a capacitor and the voltage across a capacitor?

A. Voltage and current are in phase
B. Voltage and current are 180 degrees out of phase
C. Voltage leads current by 90 degrees
D. Current leads voltage by 90 degrees

Capacitors love current. So current leads.

E5B10

What is the relationship between the current through an inductor and the voltage across an inductor?

A. **Voltage leads current by 90 degrees**
B. Current leads voltage by 90 degrees
C. Voltage and current are 180 degrees out of phase
D. Voltage and current are in phase

Inductors are exactly opposite of capacitor. They simple adore voltage. So voltage leads here.

E5B11

What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 25 ohms, R is 100 ohms, and XL is 50 ohms?

A. 14 degrees with the voltage lagging the current
B. **14 degrees with the voltage leading the current**
C. 76 degrees with the voltage lagging the current
D. 76 degrees with the voltage leading the current

As XL is bigger than XC, we know we only deal with inductor reactance XL = 25 Ω. As inductors love voltage, simply select answer stating magical 14 degrees with the voltage leading the current.

E5B12

What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 75 ohms, R is 100 ohms, and XL is 50 ohms?

A. 76 degrees with the voltage lagging the current
B. 14 degrees with the voltage leading the current
C. **14 degrees with the voltage lagging the current**
D. 76 degrees with the voltage leading the current

Capacitor reactance will be XC = 25 Ω (75 Ω - 50 Ω). This brings us suitable to fact that capacitors are madly in love with current and they'll do anything to make voltage lag.

E5B13

What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 250 ohms, R is 1 kilohm, and XL is 500 ohms?

A. 81.47 degrees with the voltage lagging the current
B. 81.47 degrees with the voltage leading the current
C. 14.04 degrees with the voltage lagging the current
D. **14.04 degrees with the voltage leading the current**

With reactance XL being 250 Ω (500 Ω - 250 Ω) we know that rule of love between inductors and voltage applies. So voltage leads the current.