Extra Class Reference Sheet - Tutorial

Overview

The Extra Class Reference sheet is a condensed summary of information needed for answering the Extra Class math questions. This tutorial will add background related to the definition of letters and how the formulas are used. Once this is understood, the short form Reference Sheet should be all you need.

Conventions

- Letters with subscripts (like "X_C") usually represent a unit plus additional information. In this case, X is the symbol for reactance, and X_C indicates we are specifically referring to Capacitive Reactance.
- An asterisk is commonly used to signify multiplication. This would be the same as the multiplication key on a calculator. Example: RC means *R* times *C*, which could be written *R*C.*
- In this tutorial, calculator key strokes will be shown with brackets. [5] means "press the number 5."
- Standard algebraic notation assumes letters in sequence are variables multiplied together. For example, $2\pi fL$ means $2 * \pi * f * L$.
- All unit values in the formulas (with one exception noted below), are in "base" units. For example, the base unit for Inductance is the Henry. Since tiny fractions of a Henry are normally used in electronics, we use scientific notation to enter these small values of Inductance for "L" in the $2\pi fL$ formula. For example, for a value of 253 µH, we need to enter the value into the formula in Henrys (the base unit). This would be $253 * 10^{-6}$ Henrys.

Notes on Calculator Modes

- Mode settings are required to get the specific results we teach in the course.
- We recommend three changes to default mode settings to support this course: ENG display, 2 Decimal Places, and Polar display (for complex numbers). See below for setting and confirming these settings.
- View the current mode settings: Press the [mode] key. Current settings will be highlighted.
- To set a mode value: Press the [mode] key. Use the navigator diamond to place a blinking cursor over the mode to be set. Set that mode value by pressing the [enter] key. After setting a mode, additional modes may be set by highlighting the next desired mode and pressing [enter] again. Press [clear] to exit the mode menu.
- Check to see that you have set the desired mode values by pressing the [mode] key. Press [clear] to exit.
- Mode menu values:

Line #	Default value (after a calculator reset)	Recommended setting
1	DEG	DEG (default)
2	NORM	**ENG** (displays scientific notation in multiples of 3)
3	FLOAT	**2** (display two decimal places)
4	REAL	$\boldsymbol{r\angle\theta}$ (sets complex number display to Polar)
5	DEC	DEC (default)
6	MATHPRINT	MATHPRINT (default)

Alphabet Soup (for formulas on the Extra Class Reference Sheet)

Identifier	Definition	Base Unit	Typical Values, Notes
C	Capacitance	Farads	pF, µF
E	Voltage	Volts	µV, mV, V, KV
f	Frequency	Hertz	kHz, MHz, GHz
f_r	Frequency of resonance	Hertz	kHz, MHz, GHz
Δf	Resonant Circuit Half-power Bandwidth	Hertz	kHz
I	Current	Amperes or Amps	µA, mA, A
L	Inductance	Henrys	mH, µH
N	Number of turns (coil)	Turns	Turns
P	Watts	Watt	µW, mW, W, KW
PF	Power factor	None	Between 0 and 1
VA	Apparent Power	VA	Used in AC circuits where part of the load may be reactive
P_{REAL}	Real Power (for AC circuits)	Watts	Power used to do real work, such as generate heat
Q	Quality factor of tuned circuit	None	
R	Resistance	Ohms	Ohms, Kilohms, Megohms
T_C	Time constant (=R*C)	Seconds	Seconds
X_C	Capacitive Reactance "Negative"	Ohms	Ohms, Kilohms, Megohms
X_L	Inductive Reactance "Positive"	Ohms	Ohms, Kilohms, Megohms
B	Susceptance: inverse of Reactance (X)	Siemens	Need to know definition and that phase angle reverses (see below); no exam calculations
Z	Impedance	Ohms	Ohms, Kilohms, Megohms
Y	Admittance: inverse of Impedance (Z)	Siemens	Need to know definition; no exam calculations
A_L	Inductance Index	Inductance per number of turns	See notes below for toroid winding formula

Radio Units

Prefix	Symbol	Power X 10^x	Value Examples
giga	G	9	Hertz, Watts
mega	M	6	Hertz, Ohms, Watts
kilo	K	3	Hertz, Ohms, Watts, Volts
(unit)		0	
milli	m	-3	Volts, Amps, Watts, Henrys
micro	µ	-6	Volts, Amps, Henrys, Farads
nano	n	-9	Farads
pico	p	-12	Farads

- Radio units are important because exam questions specify units such as pF (pico Farads) or MHz (Mega Hertz). To get the right answer to a problem, you must be able to recognize that 65 pF would be entered on a calculator as [6] [5] [EE] [(-)] [1] [2]. In this example, it is important to note that [(-)] is the gray Negation key to the left of the [enter] key, and not the silver subtraction key [-] to the right of the [9] key.
- Another way to say this is that you need to know the powers of ten for radio units. 65 pf is $65 * 10^{-12}$ Farads.
- Megahertz example for 3.5 MHz: this is $3.5 * 10^{6}$ Hertz and is entered on the calculator as [3] [.] [5] [EE] [6].

Time Constants

$$T_C = RC$$

- Interpretation: Time Constant (in Seconds) = Resistance (in ohms) * Capacitance (in Farads)
- One exam question requires this calculation: E5B04. The circuit described simplifies to a 440 microfarad capacitor in parallel with a 500 kilohm resistor. To solve for the Time Constant (in Seconds), the calculator key stokes for R*C are: [5] [0] [0] [EE] [3] [X] [4] [4] [0] [EE] [(-)] [6] [enter]. Answer = 220 Seconds.

1Tc = 63.2% charging

- Interpretation: For charging, one Time Constant (Tc) is defined as the amount of time, in seconds, it takes to charge a capacitor to 63.2% of the applied voltage in a series circuit consisting of a resistor and capacitor
- One exam question requires knowing this as a fact: E5B01
- There are no Time Constant calculations required on the exam

1Tc = 36.8% discharging

- Interpretation: For discharging, one Time Constant (Tc) is defined as the amount of time, in seconds, it takes to discharge a capacitor through a resistor to 36.8 % of the initial capacitor voltage
- One exam question requires knowing this as a fact: E5B02
- There are no Time Constant calculations required on the exam

Capacitive Reactance

$X_C = \frac{1}{2\pi f C}$ "Negative"

- Interpretation: Capacitive Reactance (in Ohms) = 1 divided by 2 * π *frequency (in Hertz) * Capacitance (in Farads)
- See the separate key stroke guide for Capacitive Reactance for an example of working this kind of problem.
- Three exam questions require this calculation: E5C14, E5C16, E5C17
- The word "Negative" on the Reference Sheet is a reminder that Capacitive Reactance is always shown with a negative value for the imaginary part (rectangular form) or a negative phase angle (polar form) when expressed as a complex number. Examples: 3-*j*4, or $5\angle -53°$

Inductive Reactance

$X_L = 2\pi f L$ "Positive"

- Interpretation: Inductive Reactance (in Ohms) = 2 * π *frequency (in Hertz) * Inductance (in Henrys)
- See the separate key stroke guide for Inductive Reactance for an example of working this kind of problem.
- Two exam questions require this calculation: E5C15, E5C17
- The word "Positive" on the Reference Sheet is a reminder that Inductive Reactance is always shown with a positive value for the imaginary part (rectangular form) or a positive phase angle (polar form) when expressed as a complex number. Examples: 3+*j*4, or $5\angle 53°$

Power Factor – calculating Real power

$P_{REAL\ (Watts)} = P_{APPARENT\ (VA)} * PF$

- Interpretation: Real Power (in watts) = the Apparent Power (in VA or Volts * Amps) times a Power Factor (PF)
- In DC circuits, Volts * Amps gives power directly in watts. This is **NOT** usually true in AC circuits because the voltage and current will be out of phase if there is inductive or capacitive reactance in the circuit, thus the need for Power Factor (PF) adjustment.
- The value of PF will be between 0 (pure reactance) and 1 (pure resistance)
- Four exam questions require this calculation: E5D12, E5D13, E5D17, E5D18

Power Factor – determining the PF

$PF = \cos\theta$

- Interpretation: The value of Power Factor (PF) is determined by the cosign (cos) of the phase angle (θ) of the complex impedance
- The exam questions are easy because the phase angle is given in the question
- To solve for the Power Factor (PF), the calculator entry is simply [cos] followed by the phase angle number given in the question, and [enter]
- Three exam questions require this calculation: E5D11, E5D15, E5D16,

Resonant Frequency

$f_r = \frac{1}{2\pi\sqrt{LC}}$

- Interpretation: The resonant frequency, or frequency of resonance (f_r) is determined by 1 divided by = 2 * π *the square root of: Inductance (L) in Henrys * Capacitance (C) in Farads
- See the separate Resonant key stroke guide for an example of working this kind of problem
- Two exam questions require this calculation: E5A14, E5A16

Quality Factor or Q

$$\textit{For resonant circuit:}\quad Q_{SERIES} = \frac{X}{R} \qquad or \qquad Q_{PARALLEL} = \frac{R}{X}$$

- Interpretation: The Quality Factor (Q) of a resonant circuit is determined by the Reactance (X), in ohms, and Resistance (R) in ohms per the formulas above.
- Since the Capacitive and Inductive Reactances are equal in a resonant circuit, either may be used in the formula (remember that resonance is defined as the frequency where Capacitive and Inductive Reactances are equal).
- There are no exam questions requiring the calculation of Q
- There are two exam questions asking for the formula for Q for the Series and Parallel circuit cases: E5A09, E5A10

Q and Resonant Circuit Half-power bandwidth

$$\textit{Half-power bandwidth} = \frac{f_r}{Q}$$

- Interpretation: The Half-power bandwidth, in Hz, = the frequency of resonance (f_r), in Hz, divided by the Quality factor (Q)
- Exam questions refer to half-power bandwidth. One of the exam problems asks for this value when the resonant frequency is 7.1 MHz and the Q is 150. On the calculator: [7] [.] [1] [EE] [6]   [÷]   [1] [5] [0]   [enter]. Should get 47.33E3 which is about 47.3 KHz.
- Two exam questions require this calculation: E5A11, E5A12

Toroid Winding Value – number of turns

$$\textbf{\textit{Powdered Iron:}}\ N = 100\sqrt{\frac{L_{(\mu H)}}{A_{L(\mu H/100\,turns)}}}$$

- Interpretation: The number of turns through a powdered iron toroid core = 100 * the square root of: the Inductance (L), in microhenries, divided by the Inductance Index, in microhenries per 100 turns.
- Note that **this is an exception to the rule stated earlier** that all unit values are in base units.
- This sounds complicated. However, the exam questions give us the exact values to use as part of the question, so no special conversions or exponent entries are needed. The calculator solution below illustrates.
- One exam questions requires this calculation: E6D01
- Question analysis:
  - The question: How many turns will be required to produce a 5-microhenry inductor using a powdered-iron toroidal core that has an inductance index (AL) value of 40 microhenries/100 turns?
  - Two helpful clues as to which formula to use. First it states that it is a powdered iron core, so that tells us to use the formula version of 100 times the square root. Second, the AL value is stated in terms of microhenries per 100 turns, which is also the standard unit for the 100 times the square root formula used for a Powdered Iron core.
- Calculator solution for number of turns required: [1] [0] [0]   [X]   [2nd] [] []. At this point the cursor will be blinking in the upper box. Enter [5] for L and then press the navigation diamond key down to move the cursor to the lower box – it will blink. Note the exception to the standard rule of entering the inductance in base units. This formula wants L *in microhenries*, so we just use 5. With the cursor now blinking in the bottom box, enter [4] [0]. The formula wants to see the value as microhenries per 100 turns, which is how the question gave it to us, which is why we only needed to enter 40. The calculator display should look like this: $100 * \sqrt{\frac{5}{40}}$
  Press [enter] and you should get 35.36E0, or about 35 Turns, which is the correct answer.

Ferrite Core: $N = 1000\sqrt{\frac{L_{(mH)}}{A_{L(mH/1000\ turns)}}}$

- Interpretation: The number of turns through a ferrite toroid core = 1000 * the square root of: the Inductance (L), in millihenries, divided by the Inductance Index, in millihenries per 1000 turns.
- Note that **this is an exception to the rule stated earlier** that all unit values are in base units.
- This sounds complicated. However, the exam questions give us the exact values to use as part of the question, so no special conversions or exponent entries are needed. The calculator solution below illustrates.
- One exam questions requires this calculation: E6D11
- Question analysis:
    - The question: How many turns will be required to produce a 1-mH inductor using a core that has an inductance index (AL) value of 523 millihenries/1000 turns?
    - This question does not state it is a Ferrite core, but we do get a clue for which formula to use. The AL value is stated in terms of millihenries per 1000 turns, which is the standard unit for the 1000 times the square root formula used for a Ferrite Core.
- Calculator solution for number of turns required: [1] [0] [0] [0] [X] [2nd] [] []. At this point the cursor will be blinking in the upper box. Enter [1] for L and then press the navigation diamond key down to move the cursor to the lower box – it will blink. Note the exception to the standard rule of entering the inductance in base units. This formula wants L in millihenries, so we just use 1. With the cursor now blinking in the bottom box, enter [5] [2] [3]. The formula wants to see the value as millihenries per 1000 turns, which is how the question gave it to us, which is why we only needed to enter 523. The calculator display should look like this:

  $1000 * \sqrt{\frac{1}{523}}$

  Press [enter] and you should get 43.73E0 or about 43 Turns, which is the correct answer.

Special Note for Number of Turns Questions: Given the exceptions to formula rules and the need to memorize two formulas for these kinds of questions, we could forgive you if you just memorized that the turns questions (if they appear on your exam) will be a value between 35 and 47.

Aids

Direct and Inverse Relationships

- There are test questions for Q and Half-power Bandwidth that ask if one increases, what will the other do. The formula is Half-power Bandwidth $= \frac{f_r}{Q}$.
- The key to answering this kind of question is to recognize that there is a direct relationship between half-power bandwidth and the value of the numerator (upper part) in the fraction. This means if f_r increases, half-power bandwidth will also increase, assuming Q stays the same – a direct relationship. Likewise if either gets smaller, so will the other.
- There is an inverse relationship between half-power bandwidth and Q. This is because Q is in the denominator (lower part) of the fraction. If Q gets **larger**, the half-power bandwidth will become **smaller** – an inverse relationship.
- Knowing the formula shows the relationship between the variables and will help answer exam questions about what happens to one value if another one gets larger or smaller.

$E_L I$ *the* $I_C E$ *man*

- This phrase helps show whether voltage or current leads or lags for a particular type of Reactance (inductive or capacitive)
- Observe the letter in the middle of $E_L I$ *and* $I_C E$. "L" is the symbol for inductance, so $E_L I$ is telling us something about relationships between E (voltage) and I (current) for inductive reactance.
- By looking at the letters in $E_L I$, we see that the letter E comes before the letter I. Thus, for an inductor, or inductive reactance, Voltage (E) will lead Current (I). For a pure inductor, voltage will lead current by 90 degrees. For a circuit where there is both resistance and inductive reactance, the voltage will still lead the current, but by an amount less than 90 degrees.
- Some exam questions ask the question a little differently by using the word lag rather than lead. By looking at the word $E_L I$, we can see that voltage leads the current, and also, current lags the voltage. If in doubt, write $E_L I$ on scratch paper and compare the order of the letters with what the question is asking (or what the answers are offering).
- Capacitive reactance is the reverse of inductive. For $I_C E$, the center letter is C identifying capacitive reactance. In this case, I (current) comes before E (voltage) in the word.
- So, for capacitive reactance, current leads voltage. This can also be stated as voltage lags current. Read the exam question and answers carefully.
- The phrase "$E_L I$ *the* $I_C E$ *man*" helps us remember $E_L I$ *and* $I_C E$. There is no significance to the words "the" and "man."
- There are three exam questions where $E_L I$ *the* $I_C E$ *man* will help you get the right answer: E5B07, E5B08, E5B11

$$\textbf{Impedance } (\boldsymbol{Z}) = \frac{1}{\textbf{Admittance } (\boldsymbol{Y})} \qquad \textbf{Reactance } (\boldsymbol{X}) = \frac{1}{\textbf{Susceptance } (\boldsymbol{B})}$$ **X to B phase angle reversal**

- These two formulas both show inverse/reciprocal relationships

- It is important to know Admittance (Y) is related to Impedance (X)
- One test question relates to Admittance: E5B12
- The exam does not ask you to calculate Admittance

- It is important to know Reactance (X) is related to Susceptance (B)
- It is important to know the **phase angle** of the reactance reverses when converting between Reactance and Susceptance. This means if the phase angle of the reactance was positive, the Susceptance will be negative, and vice versa.
- It is important to know the **magnitude** of the reactance becomes the reciprocal of reactance when stated as susceptance
- Four test questions relate to Susceptance: E5B03, E5B05, E5B06, E5B13
- There are no calculations for Susceptance on the exam – just facts about definitions and relationships to reactance