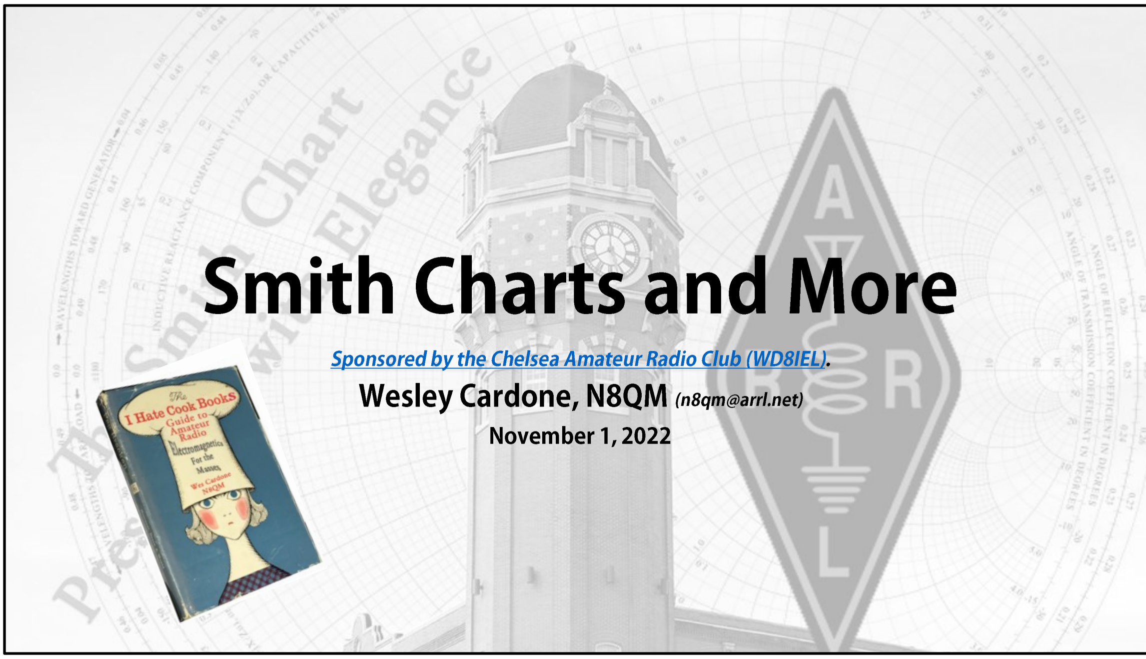
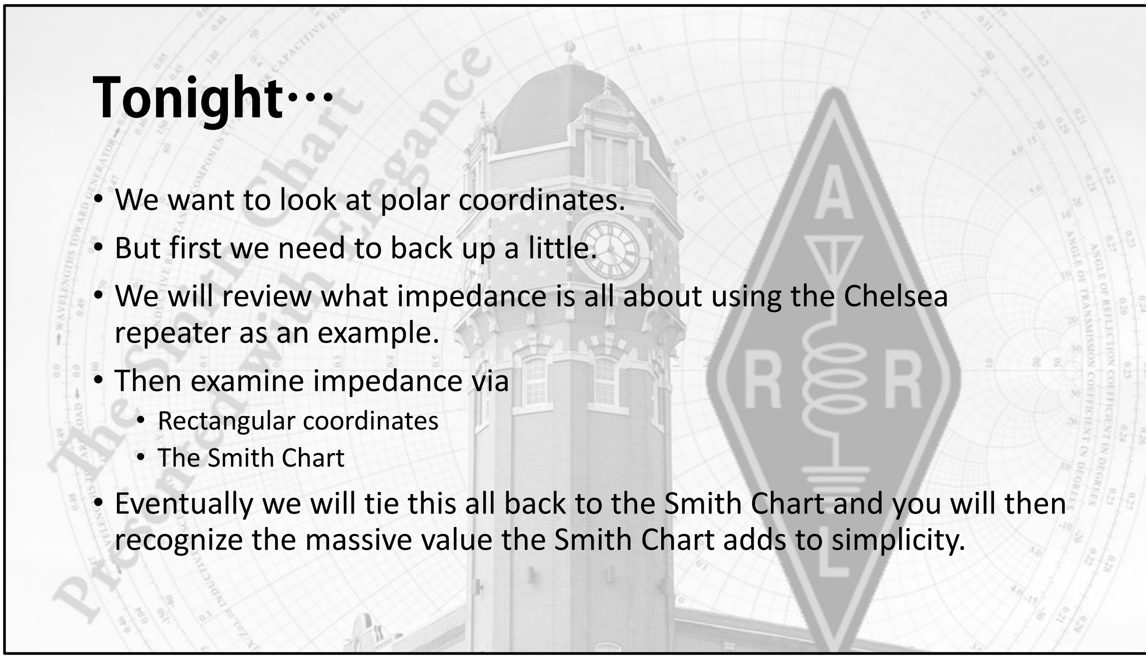


This is the Smith Charts ‘n More training (otherwise known as the I Hate Cookbooks Guide to Amateur Radio Electromagnetics) sponsored by the Chelsea Amateur Radio Club.

Strategic Overall Class Objectives

- Prepare for the FCC upgrade license exams efficiently.
- Have fun learning what you thought was a stumbling block.
- Use SimSmith—A Practical Example
- Center lessons on explicit FCC pool questions.

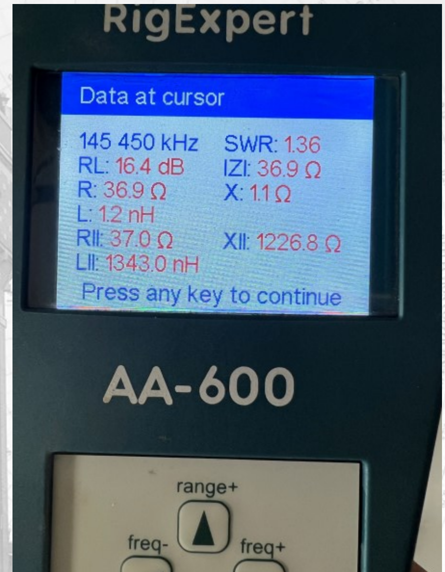
This class is aimed at addressing the electromagnetics of the FCC pool questions for upgrading an amateur radio license to both General and Extra classes. The study protocol is predicated upon you already knowing much of electromagnetics, but you just didn't know that you knew. With the knowledge gained in this series of classes you will be able to put Smith Charts to work for you.



Tonight, we want to prepare to examine polar coordinates. But before we can do that properly with understanding, we want to back up a little bit and look at a lot of things that we have looked at in the past so that we can eventually link everything together. We are going to use the Chelsea repeater as an example. Be warned, looking at these things may seem over whelming. When we eventually tie these things back to the Smith Chart you will then realize the beauty of the Smith Chart and how it simplifies things so much. But the road to that point is full of potholes.

The Chelsea Repeater

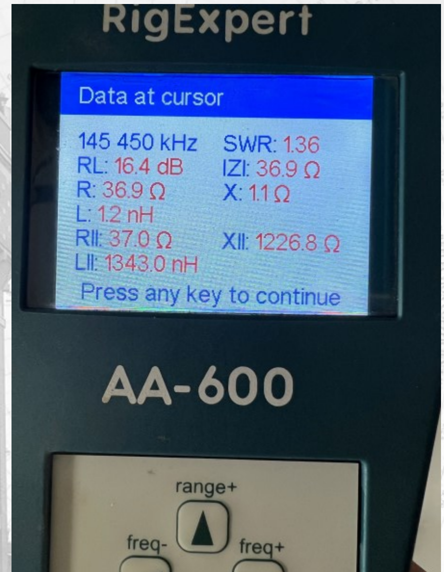
- On June of 2022 we measured a vector impedance that the transmitter was looking into at 145.450 MHz of
  - f = 145.45 MHz
  - R = 36.9 Ω
  - X = 1.10 Ω
  - Z = 36.9 Ω



Earlier in the year, Jim and I visited the Chelsea repeater located inside the Chelsea water tower on M-52 behind McDonalds. We took some measurements using the RigExpert model AA-600 antenna analyzer to determine what impedance the transmitter was looking into. In an ideal world we would like the transmitter to be looking into a 50 Ohm load (Z) because the transmitter was designed that way. What we found was that it was close showing a “magnitude impedance” (Z) of 36.9 Ohms. The word “magnitude” will be discussed later so, for the moment, don’t worry about not understanding it.

The Chelsea Repeater

- What do R, X and Z mean at f?
  - Frequency (f) = 145.450 MHz
  - Resistance (R) has no polarity and is independent of f.
  - Reactance (X) has a polarity
    - Minus (-) is CAPACITIVE reactance
    - Plus (+) is INDUCTIVE reactance-(+1.10 Ω)
  - X together with f defines a capacitance or inductance because X depends on f.
    - $\mathrm{L} = X/_{2\pi f} = {1.1\Omega}/_{2\,\pi\,145.45MHz} = 1.20nH$
  - Magnitude Impedance (Z) is

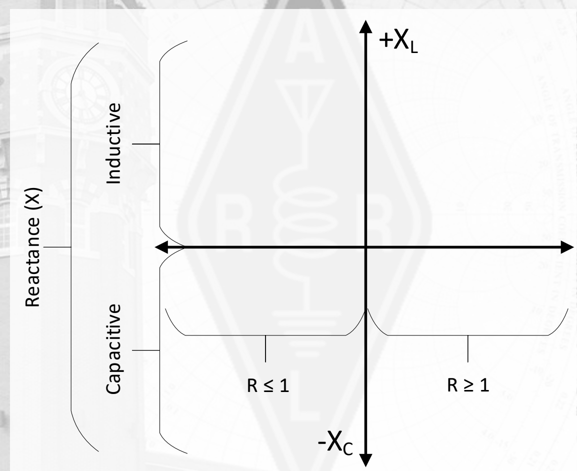


Resistance (R) does NOT have a polarity and is independent of frequency. Resistance always CONSUMES energy. Reactance (X), however, DOES have a polarity. But here's a key piece of knowledge to stick away in your bag of tricks. REACTANCE neither consumes nor generates energy. That is a KEY piece of information to tuck away in your quiver filled with all sorts of tricks. Reactance STORES energy but at the same time it has plus and minus values that tell us which one of two reactances that it is. Resistance is just simply resistance while reactance has two flavors: inductive and capacitive. "Inductive reactance" has a plus value while "capacitive reactance" has a minus value. Just knowing that the reactance is plus tells us it is INDUCTIVE. Knowing the frequency AND the reactance allows us to solve for the actual inductance which causes the reactance. As a convenience, the instrument tells us the inductance but if it only gave us the vector impedance, we could have solved for it by other means.

And then there is a MAGNITUDE of impedance (Z). Again, if we only knew the vector impedance (36.9, 1.10) we could solve for Z. Z is what the repeater transmitter cares about. The vector impedance tells us about the nature of Z so that we are better able to manipulate it with things like designing tuning stubs.

Impedance Represented Rectangular

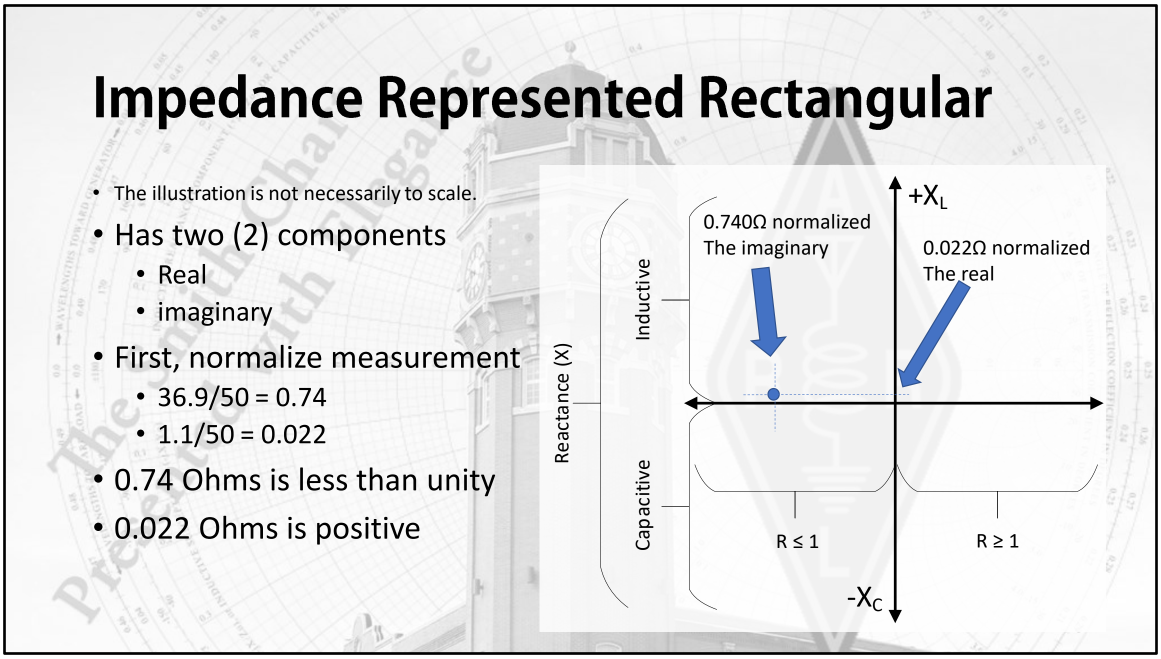
- Horizontal is Resistance
  - All values positive
  - To the right of X is greater than unity (i.e. 1.01, 10.345, etc.)
  - To the left of X is less than unity (i.e. 0.99, 0.12, etc.)
- Vertical is Reactance
  - Plus is inductive
  - Minus is capacitive
- Special Observation: Where is "home plate?"



So, what does all this RigExpert display mumbo-jumbo tell us? How can we represent it in a readable fashion to where we can do something with it? Look at the XY plot shown. The horizontal axis represents a normalized resistance. In the middle is unity or 1 Ohm. To the right of the vertical we have resistance greater than unity and to the left, less than unity.

The vertical axis represents reactance. There is a dichotomy much like we have for resistance where unity was at the fork in the road. With reactance, zero is at the fork in the road. Above the horizontal we have values greater than zero (inductive reactance) and be the horizontal we have values less than zero (capacitive reactance).

SPECIAL QUESTION: Recall with the Smith Chart we had "home plate." Is there a similar location with a "rectangular" perspective?



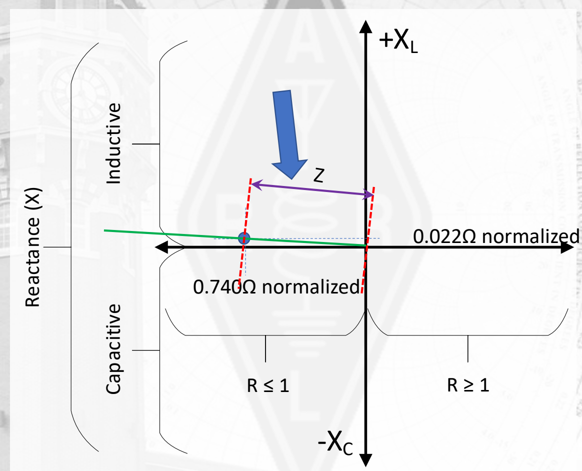
I apologize ahead of time for putting you through this but we are plotting these values normalized. It might seem easier if we were to plot them scaled to 50 Ohms but in the long-run you will benefit from understanding working with normalized values. Thus, we have converted our RigExpert instrument values to values normalized to 50 Ohms. Recall that home plate will show a 50 Ohm impedance as 1 Ohm normalized.

We first convert the RigExpert readings to normalized values of 0.74 and 0.022 Ohms. We then locate 0.74 Ohms on the horizontal. It is to the left of the vertical axis. We then locate 0.022 Ohms of reactance. Because if is greater than zero (a plus value), it goes above the horizontal axis, but just barely because it is almost zero.

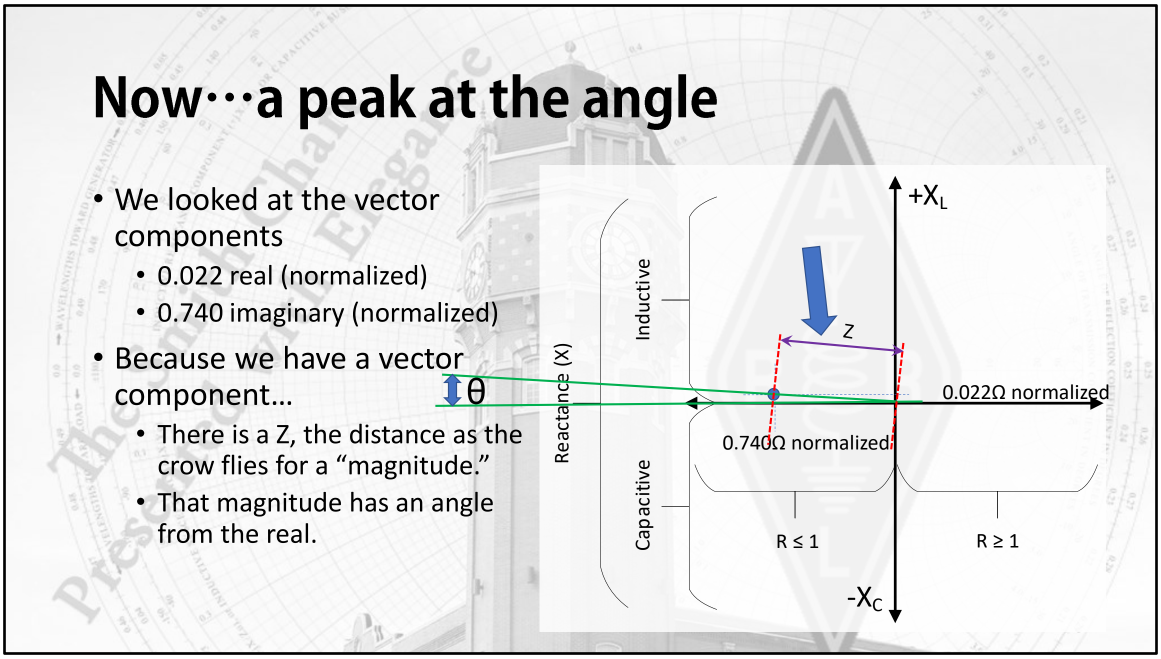
QUESTON: Why is it significant that the reactance is almost zero?
ANSWER: Because in an ideal world we want a zero-reactance telling us that our antenna is perfectly resonant.

Z—Magnitude Impedance

- The magnitude impedance (Z) is something like "…the distance as the crow flies."
- $Z = \sqrt{R^2 + X^2}$
- $Z = \sqrt{0.740^2 + 0.022^2}$
- $Z = 0.738\ Ohms$



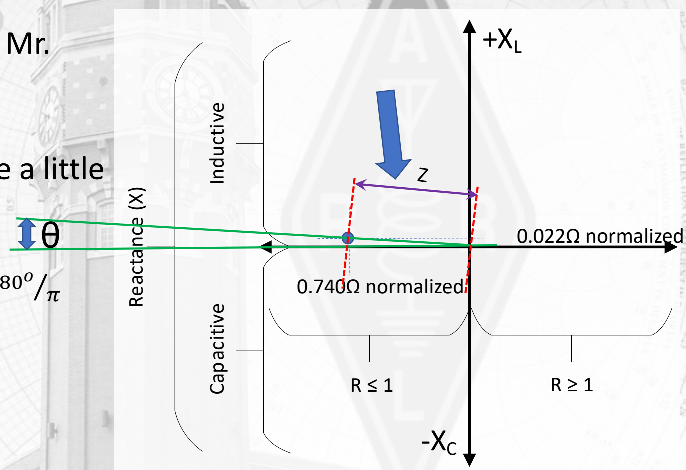
If there is 0.740 Ohms and 0.022 Ohms normalized, why is not the effective impedance simply 0.742 Ohms? It is because those impedances are not "going in the same direction." That's fancy talk for phase which we will discuss later. There is thing that we can call "…as the crow flies." This is an important concept to take home with you. Z has two components, each going in a different direction. One pulls at the other like a tail-wind on an airplane. Think of it as if were an airplane that had a goal of heading due-west (R headed toward zero) but there were strong winds coming up out of the south (X_L) blowing it off course. If there had been no cross-winds coming up out of the south, the airplane would have traveled a little bit further to the west. Z is the actual impedance experienced by the circuit owing to the net result of its two components, R and X.



If you have a vector impedance, there are some other ways to express this vector impedance. This vector impedance describes a "magnitude." This is what really counts. Think of Z as the working-stiff, the guy who matters. Last week we considered an airplane that was blown slightly off course by cross-winds. What the pilot is interested in is how far has he gone and how far off course is he. It's too difficult for the pilot to think in terms of a vector coordinate but is much more intuitive to think of an actual distance traveled and at what angle deviation it is from the plan. Thus, the purpose of a phase angle with our vector impedance is for simplification with some applications. In the next slide we will look at a complicated way to solve for the phase angle given the vector impedance but only just quickly because there is a simpler way.

The Hard Way…

- Invoke our good friend Mr. Pythagoras.
  - $Z = \sqrt{R^2 + X^2}$
- For the phase angle use a little of your old high school trig.
  - $\theta = \tan^{-1}\left(\frac{imag}{real}\right)_{rad} \; ^{180^o}/_{\pi}$
  - $\theta = 1.7^o$

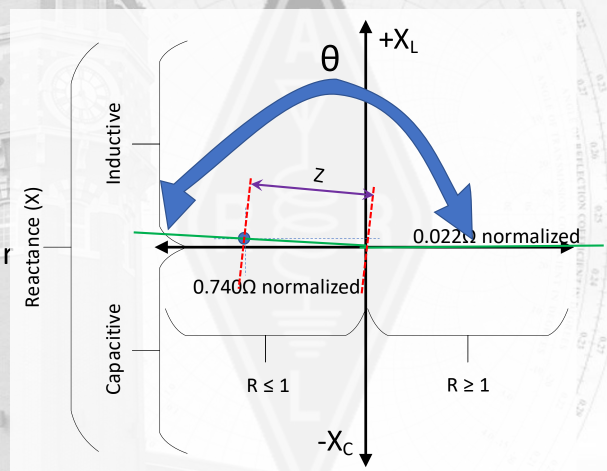


We invoke Pythagoras to get the length of the hypotenuse. Getting the phase angle means invoke a little trig but I am only showing this to that you will appreciate the beauty of the Smith Chart later on. So don't worry about memorizing this trig stuff.

But do you remember that with the Smith Chart there were two ways to express a phase angle depending on your perspective? There was so many degrees from the source or so many degrees from the load. But always, ALWAYS, the sum of those two is always 180°. What we are looking at here is the exact same thing. This is not just another related measurement but exactly what we looked at with phase angles in the Smith Chart. So, do you know that that means? It means that there is another angle here that I have not yet presented.

Another Way to say the same…

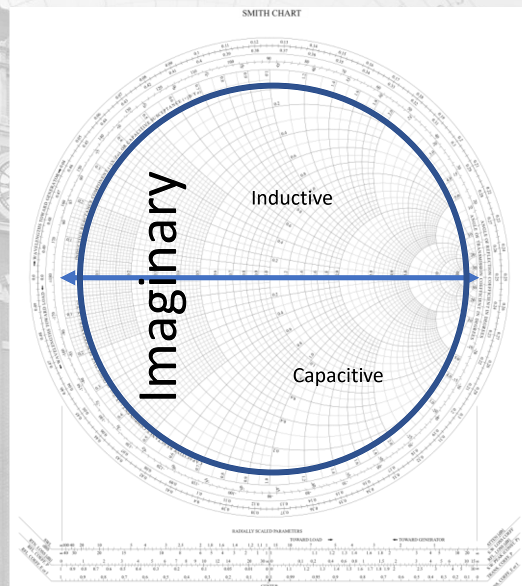
- Invoke our good friend Mr. Pythagoras doesn't change.
  - $Z = \sqrt{R^2 + X^2}$
- Let's skip the trig on this one.
- It gets even more complicated so I think the Smith Chart is our best bet.



There is another angle that says the same thing but just from a different perspective. But I have punished you enough on this crazy stuff. It is now time to review the Smith Chart.

Smith Chart Review

- Hemispherical Reactances
  - Inductive are in the northern hemisphere
  - Capacitive in the southern
- Points directly on the equator are real with zero value reactances.
- The circle
  - Where the circle appears is irrelevant in theory.
  - 360^{o} represents a half-wave



Let's review our friend the Smith Chart. Soon you are going to fall at the feet of the Smith Chart proclaiming its magnificence.

In the northern hemisphere are the inductive reactances. In the southern hemisphere are the capacitive reactances. In the middle at the equator the capacitive and inductive reactances cancel each other leaving only a real component of resistance.

I want you to understand the circle. The smith chart places the circle on the outer periphery of the Smith Chart because the information is more spread-out and easier to read. It is extremely important to recognize that the circle can be anywhere on the Smith Chart as long as its center is home-plate. The reason I say that this is important is because you will always be circumscribing circles on the Smith Chart with a compass whenever you use a paper version of the Smith Chart.


The Smith Chart
Presented with Elegance
A
R
R
L

FCC Pool Question E5A02

- What is resonance in an LC or RLC circuit
  - The highest frequency that will pass current
  - The lowest frequency that will pass current
  - The frequency at which the capacitive reactance equals the inductive reactance.
  - The frequency at which the reactive impedance equals the resistive impedance.
- This is a critical element of antenna analysis
  - The antenna is resonant when the reactance is neutral
    - The capacitive reactance equals the inductive reactance.

FCC Pool Question E5A03

- What is the magnitude of the impedance of a series RLC circuit at resonance?
  - High, as compared to the circuit resistance
  - Approximately equal to capacitive reactance
  - Approximately equal to the inductive reactance
  - ~~Approximately~~ equal to the circuit resistance
- Why?
- At resonance reactance
  - Is neutral
  - Capacitive and Inductive reactances cancel each other
  - Therefore, there is no travel along the vertical axis and
  - There is only resistive impedance

FCC Pool Question E5A04

- What is the magnitude of the impedance of a parallel RLC circuit at resonance?
  - ~~Approximately~~ equal to the circuit resistance
  - Approximately equal to the inductive reactance
  - Low compared to the circuit resistance
  - High compared to the circuit resistance
- No matter whether series of parallel, at resonance, reactance is neutral, capacitive and inductive canceling each other.
- Only a resistive component is left.

FCC Pool Question E5B12

- What is admittance
  - The inverse of impedance
  - The term for the gain of a field effect transistor
  - The turns ratio of a transformer
  - The inverse of Q factor
- Hints to use if you don't remember while taking the test
  - You are going to have to remember that admittance has something to do with or is related to impedances.
  - Therefore
    - A field effector transistor answer is out of the question leaving 1, 3 & 4.
    - A transformer is disqualified leaving only 1 & 4.
    - You will likely recall that admittance is the inverse of something making the last elimination tough. You will have to remember that Q is not an impedance thing.

FCC Pool Question E5C01

- Which of the following represents capacitive reactance in rectangular notation
  - -jX
  - +jX
  - Delta
  - Omega
- Rule out 3 & 4, those are gibberish answers leaving only 1 & 2.
- Nos 1 & 2 are both viable answers as far as relevance is concerned.
- Is easy to forget which is which
- Recall that +X (northern hemisphere) is inductive
- Therefore, -X is capacitive reactance.

FCC Pool Question E5C03

- What coordinate system is often used to display the resistive, inductive, and/or capacitive reactance components of impedance?
  - Maidenhead grid
  - Faraday grid
  - Elliptical coordinates
  - Rectangular coordinates
- A Maidenhead grid is for a global grid square locator map eliminating No 1 and Faraday grid is just plain gibberish eliminating No 2.
- Elliptical coordinates are unheard of so eliminate No 3…
- …leaving No 4.

FCC Pool Question E5C06

- What does the impedance 50 – j25 represent?
  - 50 Ohms resistance in series with 25 Ohms inductive reactance
  - 50 Ohms resistance in series with 25 Ohms capacitive reactance
  - 25 Ohms resistance in series with 50 Ohms inductive reactance
  - 25 Ohms resistance in series with 50 Ohms capacitive reactance
- There are no non-sense answers here to eliminate
- You should immediately recognize the R +/- jX convention cluing you in to eliminating Nos 3 & 4 leaving only 1 & 2.
- You need to remember that minus (-) reactance is capacitive leaving you with No 2.

Questions