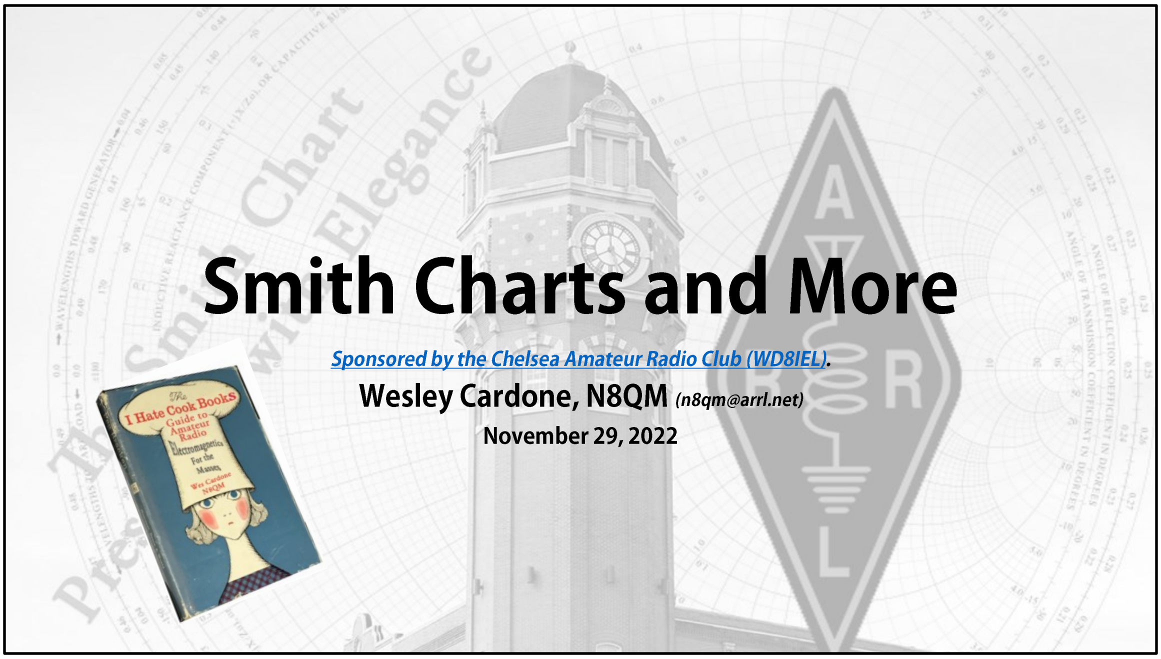


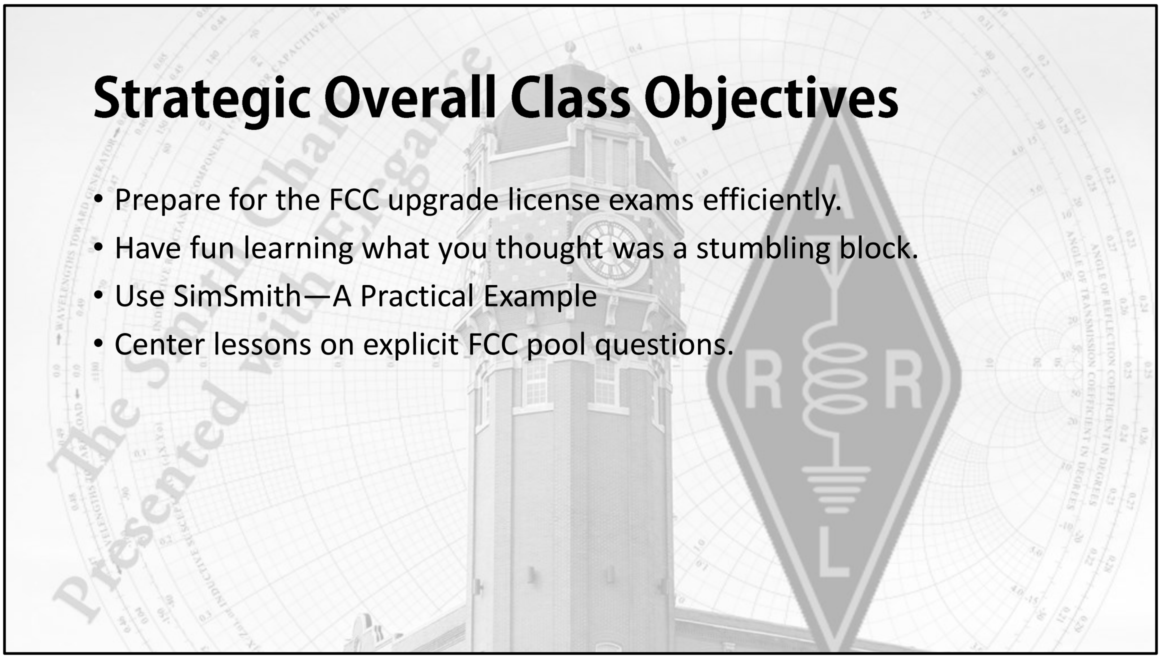
Smith Charts and More

Sponsored by the Chelsea Amateur Radio Club (WD8IEL).

Wesley Cardone, N8QM *(n8qm@arrl.net)*

November 29, 2022

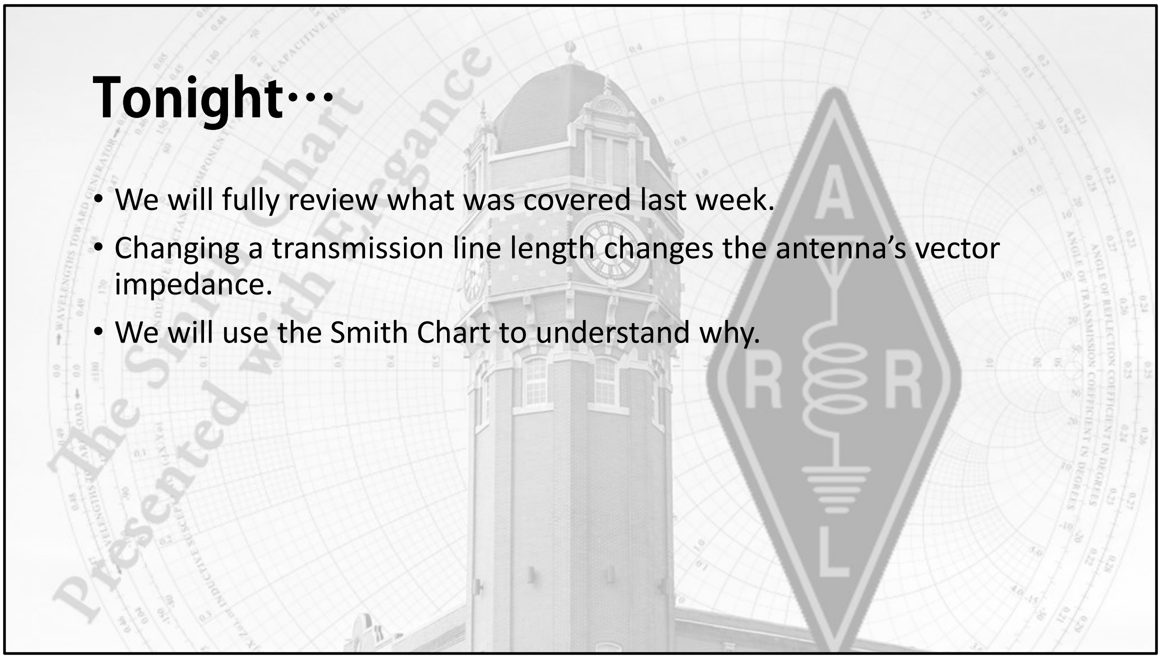
This is the Smith Charts ‘n More training (otherwise known as the I Hate Cookbooks Guide to Amateur Radio Electromagnetics) sponsored by the Chelsea Amateur Radio Club.



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.

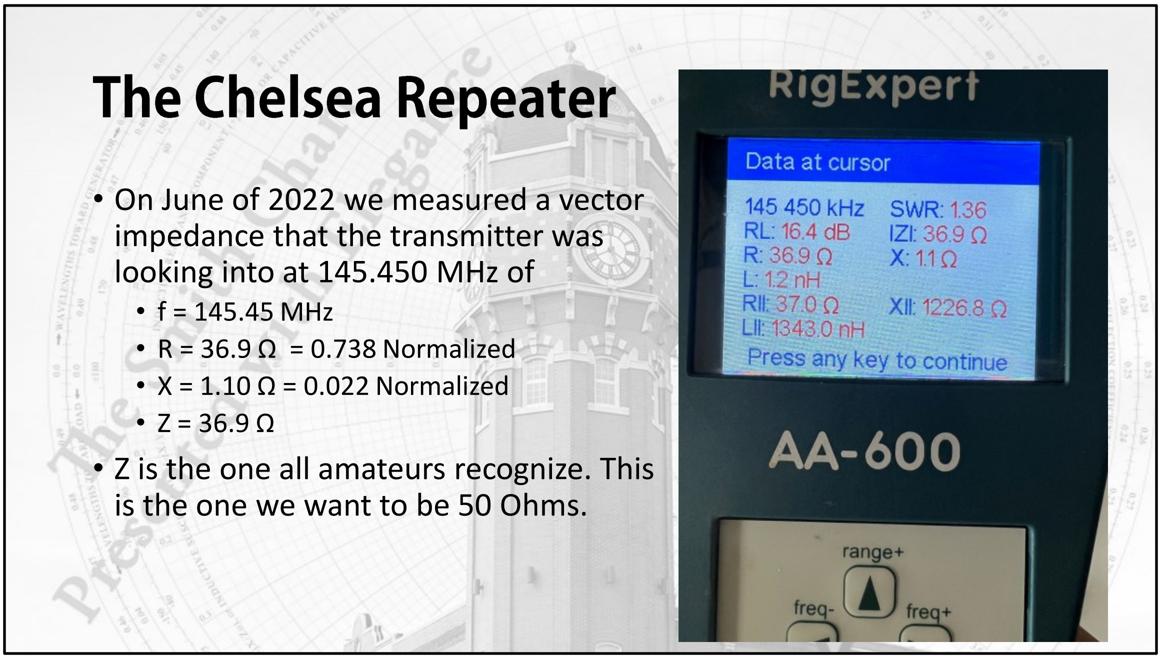
This class is aimed at addressing the electromagnetics of the FCC pool questions for upgrading an amateur radio license to both General and Extra classes. The study protocol is predicated upon you already knowing much of electromagnetics, but you just didn’t know that you knew. With the knowledge gained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



Tonight…

- We will fully review what was covered last week.
- Changing a transmission line length changes the antenna’s vector impedance.
- We will use the Smith Chart to understand why.

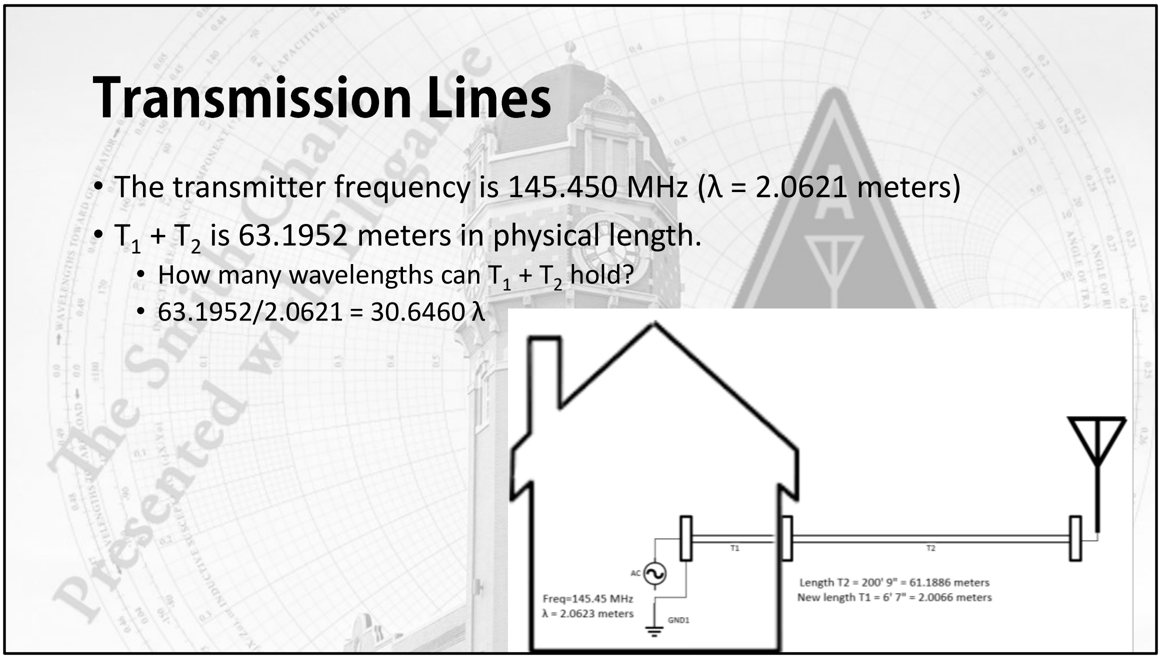
Many amateurs are not aware that changing the length of an antenna’s transmission line has a very great affect on that antenna’s vector impedance. There is one exception, however. If the antenna is already showing as a perfect 50 Ohms with a neutral reactance, changing the transmission line length has almost no effect on the vector impedance. We will show in this lesson what that is all about.



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 = 0.738 Normalized
  - X = 1.10 Ω = 0.022 Normalized
  - Z = 36.9 Ω
- Z is the one all amateurs recognize. This is the one we want to be 50 Ohms.

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. Last week we learned that a magnitude impedance, labeled as Z, is the heart and soul what a transmitter looks into. A vector impedance tells us the nature of what components are in any one measured Z.

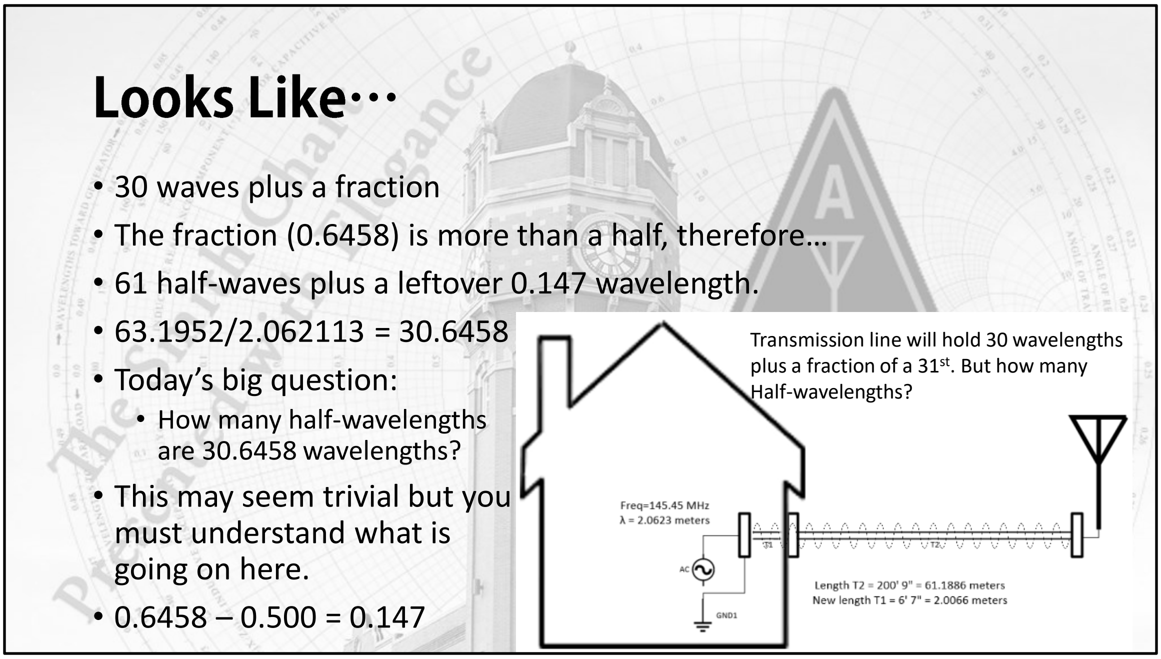


Transmission Lines

- The transmitter frequency is 145.450 MHz (λ = 2.0621 meters)
- $T_1 + T_2$ is 63.1952 meters in physical length.
  - How many wavelengths can $T_1 + T_2$ hold?
  - 63.1952/2.0621 = 30.6460 λ

It is now time to talk transmission lines. Let’s set up the Chelsea Repeater as if it were in somebody’s home. This will not be exact but more to create a realistic consideration. We have the operational frequency of 145.450 MHz assigned to us by the Michigan Coordination Committee. We would consider its downlink frequency of 144.850 MHz but that is only for receive, Transmit is the critical issue. In this discussion we will ignore velocity factor in order to simplify the discussion. I have shown the two transmission lines as separate entities but let’s talk as a whole.

The wavelength of 145.45 MHz is 2.062 meters and the sum-total of feedline wavelengths is a function of that. That sum-total length is 207 feet and 4 inches which is 63.1952 physical meters according to our tape measure. That means that the total path from transmitter to the antenna is 30.6460 wavelengths. Over 30 wavelengths of signal separate the antenna from the transmitter.

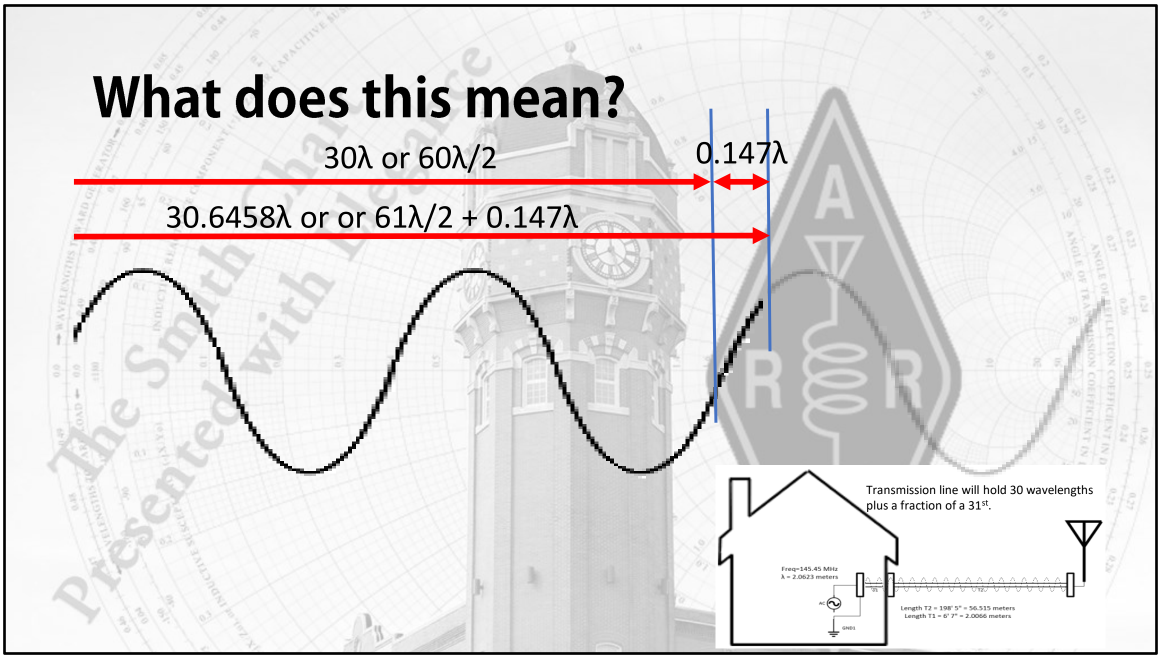


Looks Like…

- 30 waves plus a fraction
- The fraction (0.6458) is more than a half, therefore…
- 61 half-waves plus a leftover 0.147 wavelength.
- 63.1952/2.062113 = 30.6458
- Today's big question:
  - How many half-wavelengths are 30.6458 wavelengths?
- This may seem trivial but you must understand what is going on here.
- 0.6458 – 0.500 = 0.147

Transmission line will hold 30 wavelengths plus a fraction of a 31st. But how many Half-wavelengths?

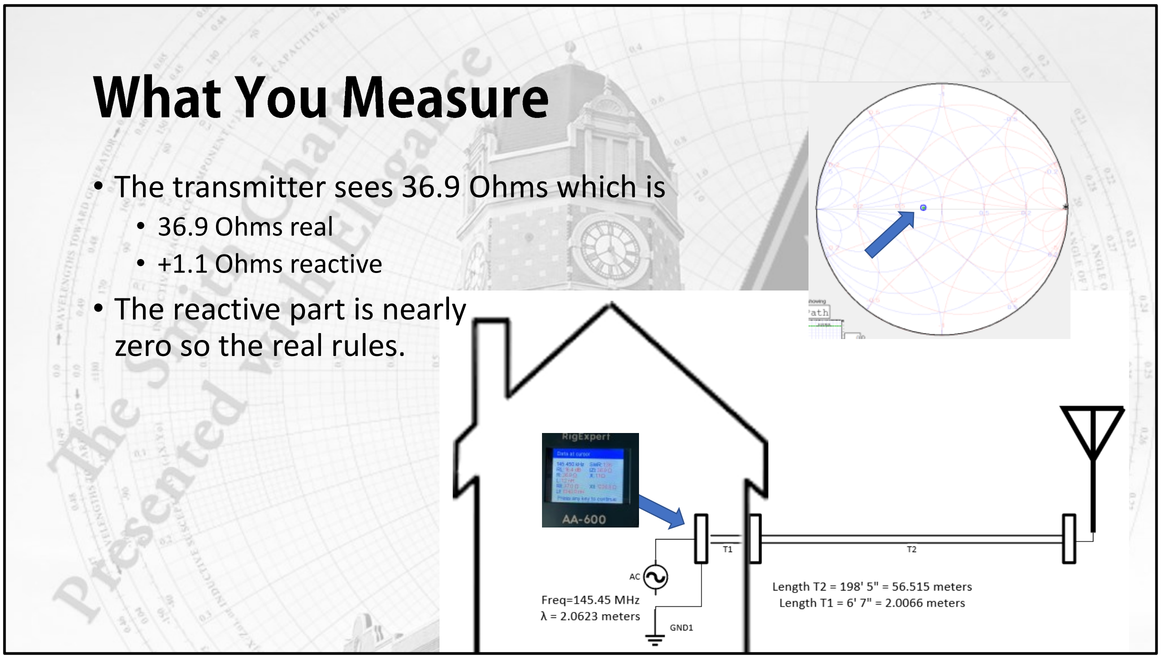
I don't have it to scale here but if I had done this to scale, you would be able to count 30 complete waves with about a third of the last one left over. But here's tonight's big question. How many **half-wavelengths** does 30.6458 wavelengths represent? To answer this, let's break it down into its components. Clearly, in 30 FULL wavelengths (did you get my operative word?) there are 60 half-wavelengths leaving a leftover of 0.6458 wavelengths. So, now the answer is a little bit more intuitive. We ask a second question which is, "How many half-wavelengths are in that leftover 0.6458 wavelength?" The answer is that there is ONE half-wavelength in 0.6458 wavelengths with still something leftover. What is the left-over portion? The answer is that there is a 0.147 wavelength leftover. Here it is folks. Drum roll please. All that we are interested in, all that makes any difference is that leftover 0.147 wavelength. We went through all that trouble only discard EVERYTHING but that pesky leftover fractional wavelength. **This is important, folks.** All those other wavelengths do **NOTHING** for our present concern. They might as well not be there except for adding a slight dB loss. But maybe I was not clear enough. Maybe we should look up the word "NOTHING" in the dictionary. There will be some signal attenuation but nothing that consumer instrumentation will be able to measure effectively.



What does this mean?

Transmission line will hold 30 wavelengths plus a fraction of a 31st.

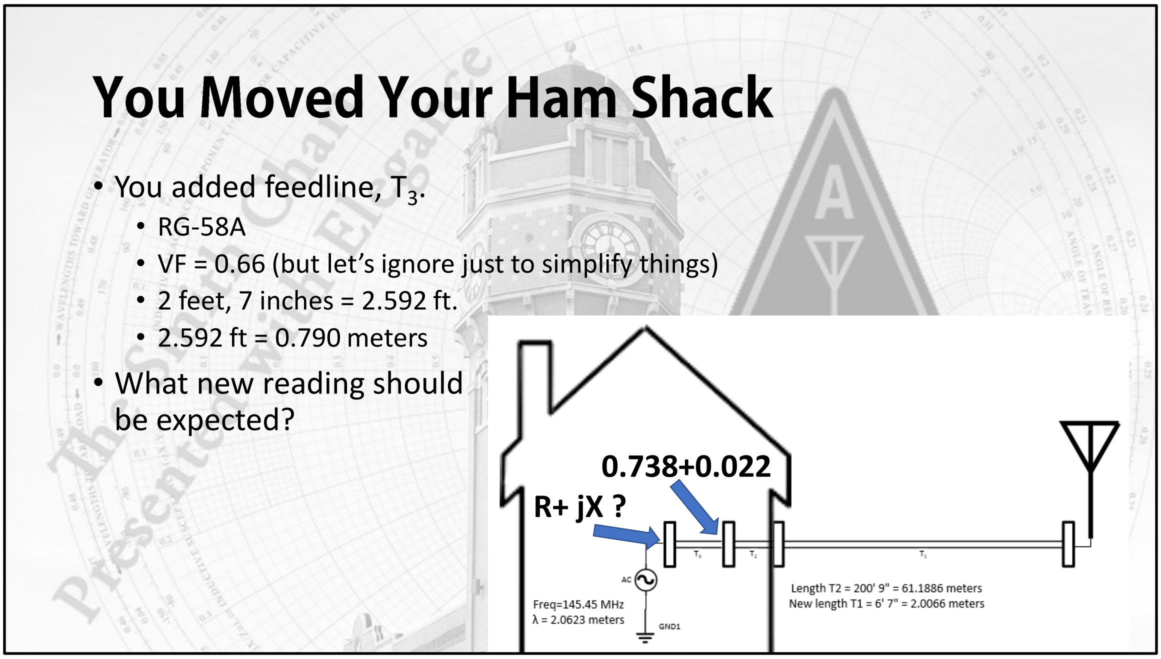
So, now is one of those times when we throw away the cookbook. I hate cookbooks and you will learn to hate cookbooks, too. The cookbook tells you that polarity doesn't count. But WHY does it not count? The distinction of half-waves is an important distinction to be aware of. Why? Because polarity does NOT count in these matters. Why does polarity NOT matter? Because this is energy which does what we define in physics as "work." These signals are active, they DO things. Nobody is DOING things **TO** them. If people were DOING things to these signals, then you could call it negative energy but people would understand you better if you called them "loads." Signals DO things to loads. Energy DOES things to loads. These signals have a polarity. But a PLUS polarized signal does the same work as a NEGATIVE polarized signal. Any load does not care which way it is being pushed. All that the load will know or care about is that somebody is giving them a potential difference. Thus, all that we care about are halfwaves. So, let's go over this again. Our ham shack has transmission line electrical length is 30.646 wavelengths. Within 30.646 wavelengths there exists 61 half-wavelengths and a fraction. If we were to convert this back to full wavelengths, 61 half-wavelengths are 30.5 full wavelengths. Are you getting confused yet? I hope not because this should be getting pretty clear by now. Half-wavelengths rule so we talk in half-wavelength units.



What You Measure

- The transmitter sees 36.9 Ohms which is
  - 36.9 Ohms real
  - +1.1 Ohms reactive
- The reactive part is nearly zero so the real rules.

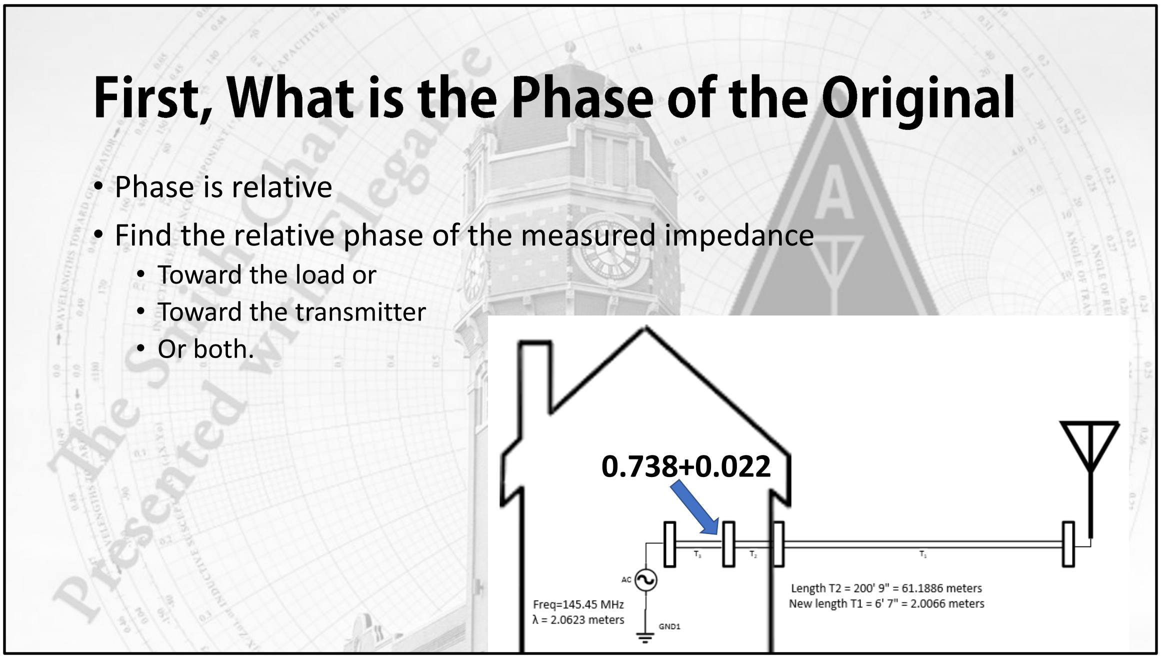
Here is what we are starting with. In the next slide we are moving our ham shack which means the transmission path for our signal will change.



You Moved Your Ham Shack

- You added feedline, T_3.
  - RG-58A
  - VF = 0.66 (but let’s ignore just to simplify things)
  - 2 feet, 7 inches = 2.592 ft.
  - 2.592 ft = 0.790 meters
- What new reading should be expected?

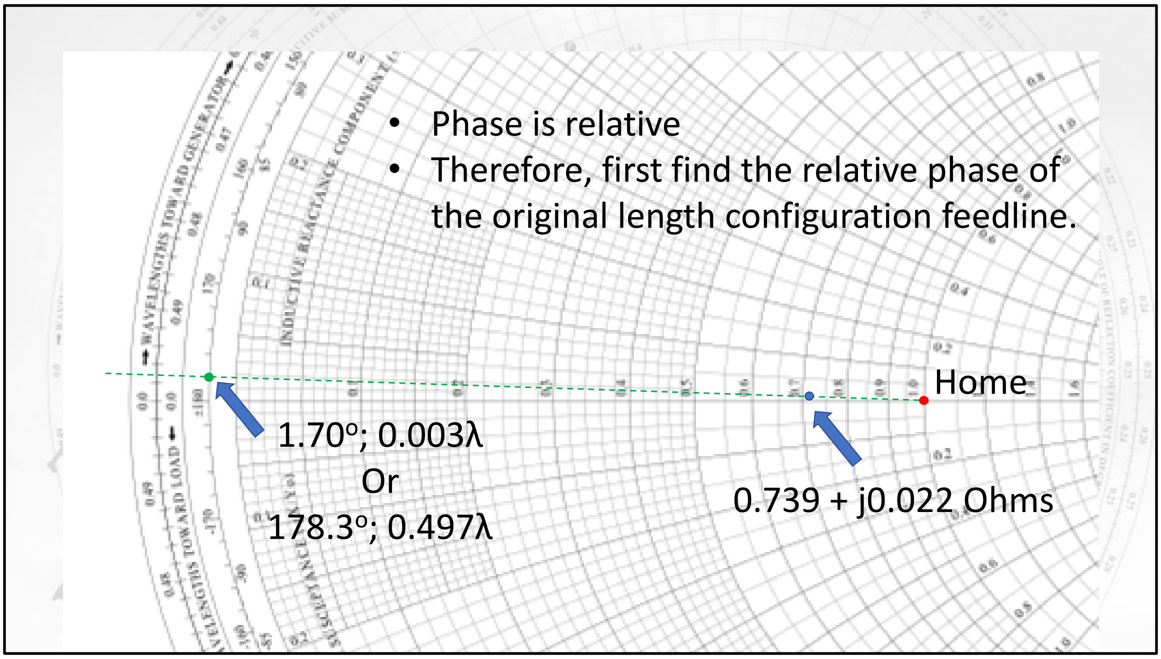
But now you decided that you had to move your ham shack and needed to add 2 ft and 7 inches of coax to your feedline which is 0.79 meters. To simplify the installation all you did was use a barrel connector so that you could simply splice into the existing feedline.



First, What is the Phase of the Original

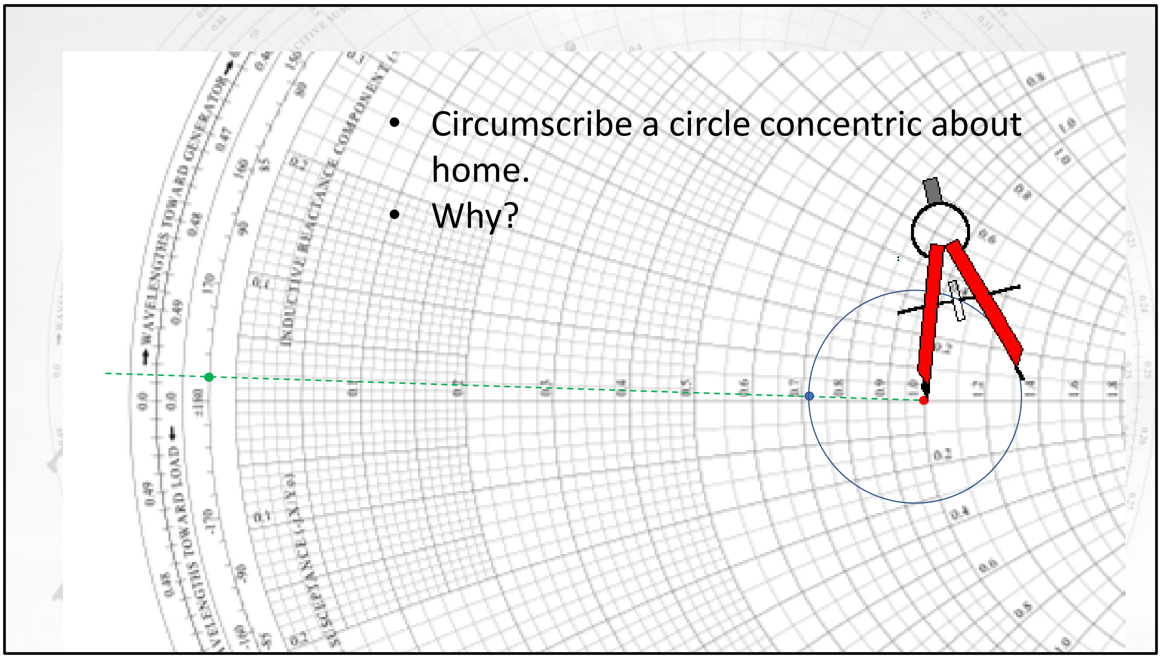
- Phase is relative
- Find the relative phase of the measured impedance
  - Toward the load or
  - Toward the transmitter
  - Or both.

The first order of business is to find the phase of the original configuration. Cable type and length are irrelevant because we already know the vector impedance at the original feed-point entrance. We could have done this before moving the ham shack but at that time there was no need for this information.



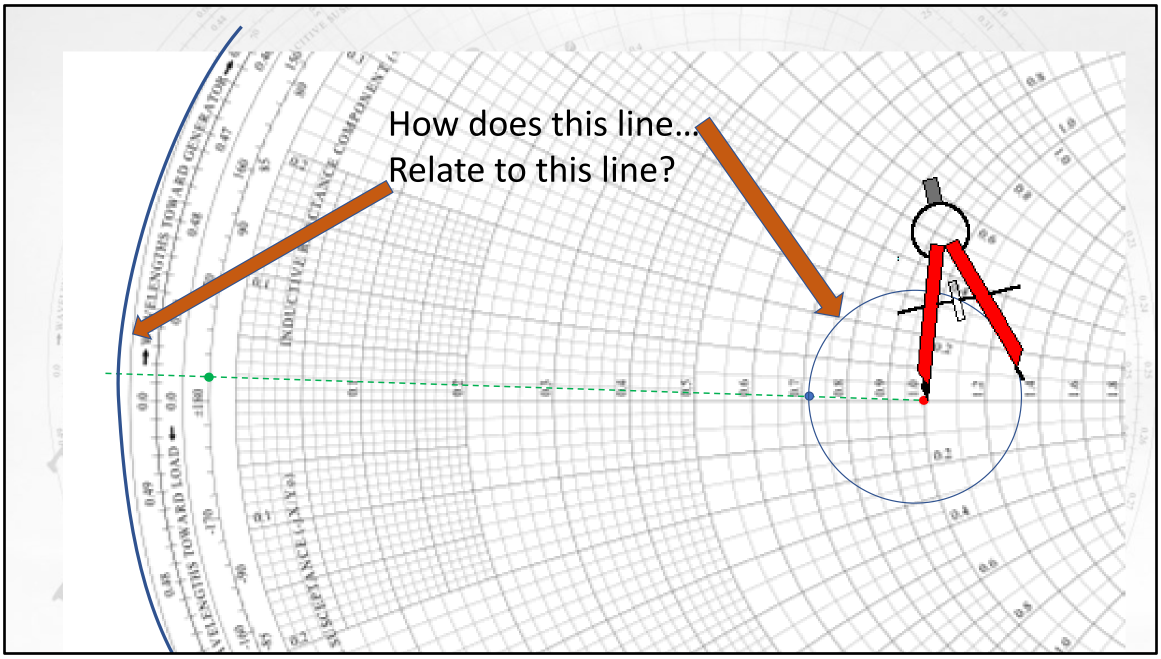
- Phase is relative
- Therefore, first find the relative phase of the original length configuration feedline.

Recall from earlier lessons that we lay down a straight-edge connecting the vector impedance with home-plate and extrapolate a line to the Smith Chart periphery where we can read the relative phase. The phase here is either 1.7 degrees (which is also 0.003 lambda) toward the load or 178.3 degrees (which is also 0.497 lambda) from the transmitter. It doesn't matter which one of the four that we use as long as when we take the difference that we use the same one. It might seem confusing that we have four figures that all same the same thing but that is why you are here. You want to be able to answer those pesky FCC pool questions with confidence. Remember, all this confusion is because of the relative nature of a phase reading. The phase alone means nothing. Phase is always in relation to something else temporal.



- Circumscribe a circle concentric about home.
- Why?

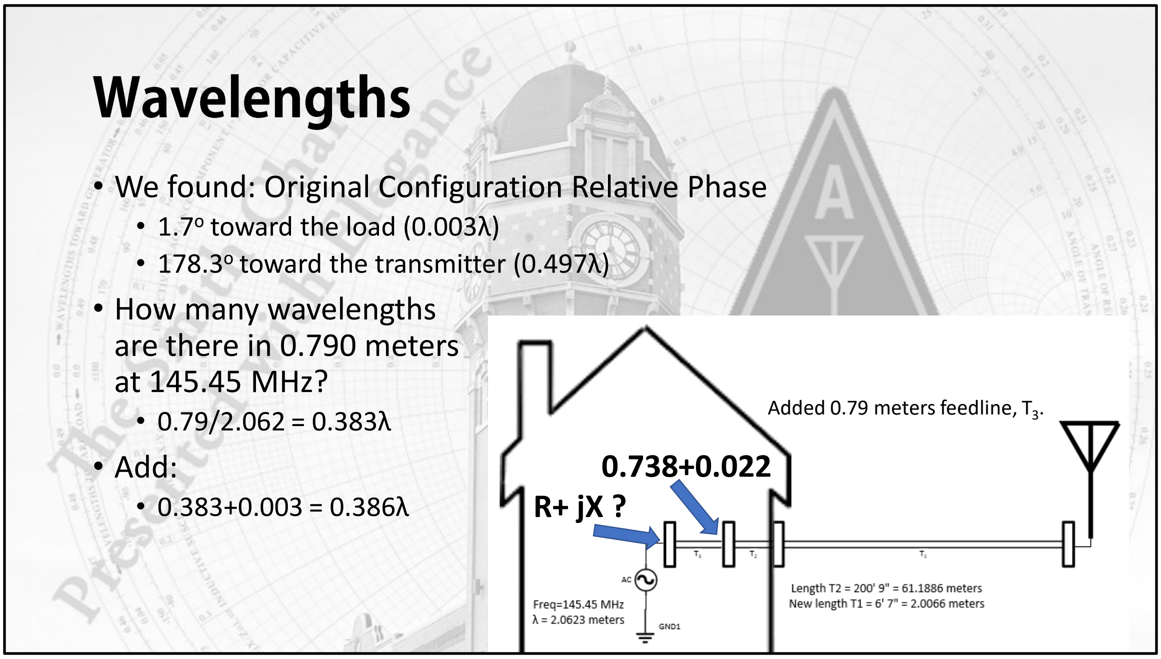
Recall in earlier lessons that we figuratively drew a circle around the vector impedance concentric with home-plate? What is the meaning of drawing a circle concentric about home? Maybe we can answer that with another question. See the next slide.



How does this line…

Relate to this line?

We know that the outer perimeter of the Smith Chart represents phase. Why not shrink down that circle? Can you get the same information from the shrunken circle as you could from the outer circle? In theory, yes. However, you obviously lose resolution but all the same information is there. All you are doing is simply shrinking the phase circle so that it superimposes over our vector impedance. You can now see what the meaning is of using a straight-edge to extrapolate from the home-vector impedance pair to the outer phase circle.



Wavelengths

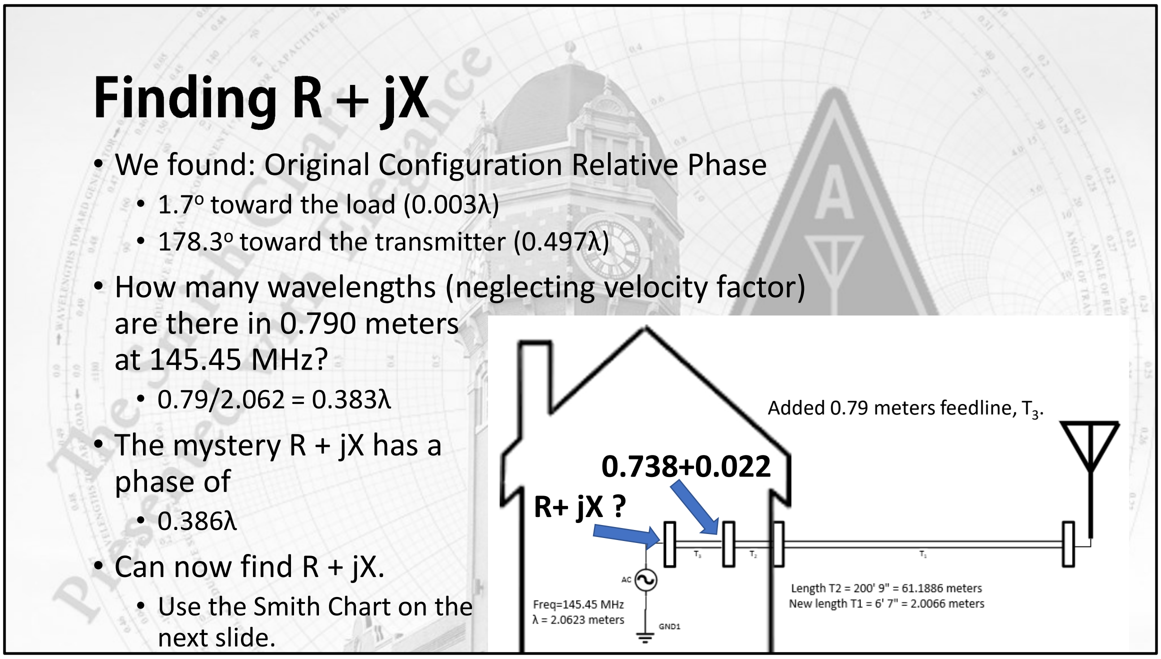
- We found: Original Configuration Relative Phase
  - 1.7^{o} toward the load (0.003λ)
  - 178.3^{o} toward the transmitter (0.497λ)
- How many wavelengths are there in 0.790 meters at 145.45 MHz?
  - 0.79/2.062 = 0.383λ
- Add:
  - 0.383+0.003 = 0.386λ

Added 0.79 meters feedline, T_3.

In a previous slide we found the relative phase for the original configuration. This was the phase from either the transmitter or from the load. The next task is to find out how many half-wavelengths the additional feedline represent. With that we will know the additional phase that the new feedline length change will add. Here is the important distinction to take home with you on all this "relative phase" mumbo-jumbo: All phase measurements are relative to something. The one that we have from the earlier slide is relative to either the transmitter or the antenna—its's your choice. Listen up folks: This new additional feedline length will be relative to the existing phase from the earlier slide.

So, now we need find out many half-wavelengths 0.79 meters represents for our allocated frequency of 145.45 MHz. Let's start with simplicity: how many full wavelengths fill fit in 0.79 meters? Divide 0.79 meters by the allocation frequency wavelength (2.062 meters) and we get a big fat zero full wavelengths. So, how many half-wavelengths? Our division came up with 0.383 which, of course, is ALSO zero half-wavelengths since 0.383 is less than 0.5. So, our fractional left-over wavelength is 0.383 lambda.

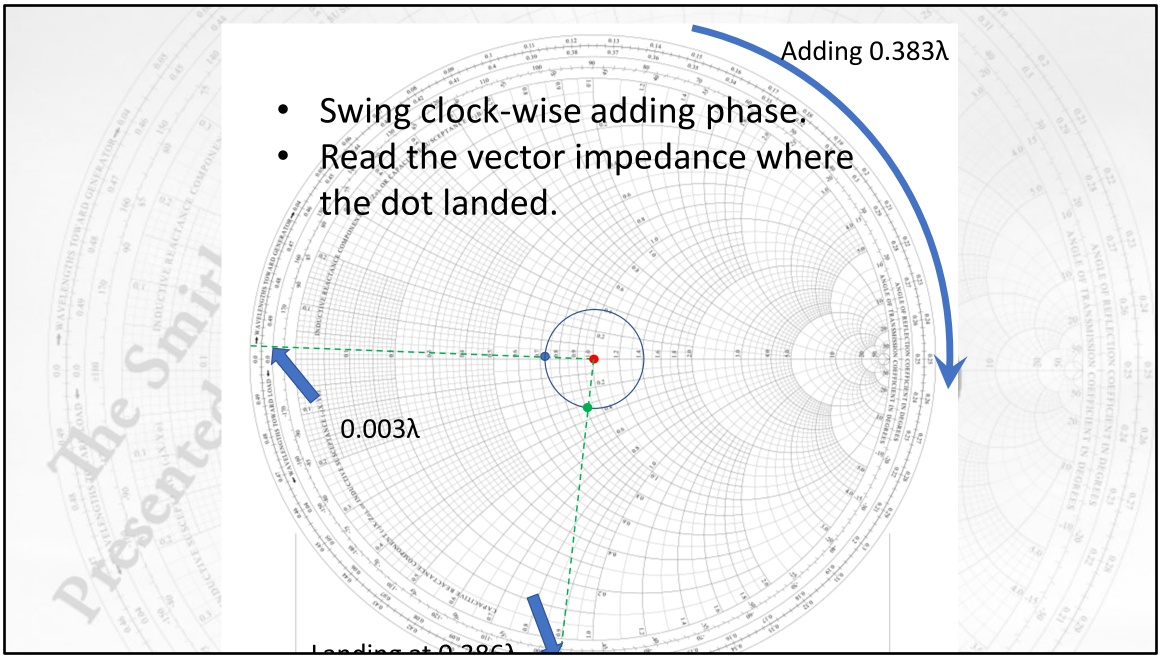
We have added feedline so we add this distance to the phase found in the earlier slide. That may sound confusing so let’s come up with some other words for this. The original configuration was a known distance in wavelengths from either the load or transmitter. We then added some feedline which added time for electrons to travel when we call “phase” to keep things simple. This new length of feedline has a relative phase at the allocated frequency which we simply add to the original relative phase. As far as when earlier phase figure to use, let’s use the one that will still leave us with less than half a wavelength when added. Therefore, our new relative phase is 0.383 plus 0.003 which is 0.386 lambda.



Finding R + jX

- We found: Original Configuration Relative Phase
  - 1.7^{o} toward the load (0.003λ)
  - 178.3^{o} toward the transmitter (0.497λ)
- How many wavelengths (neglecting velocity factor) are there in 0.790 meters at 145.45 MHz?
  - 0.79/2.062 = 0.383λ
- The mystery R + jX has a phase of
  - 0.386λ
- Can now find R + jX.
  - Use the Smith Chart on the next slide.

This new length of cable measures out using a tape measure at 0.79 meters. Putting our allocated frequency of 145.45 MHz through it, there is room for 0.383 electrical wavelengths of distance. With these pieces of the puzzle, we can now predict what the antenna analyzer will read when reading through this new section of feedline to the antenna.



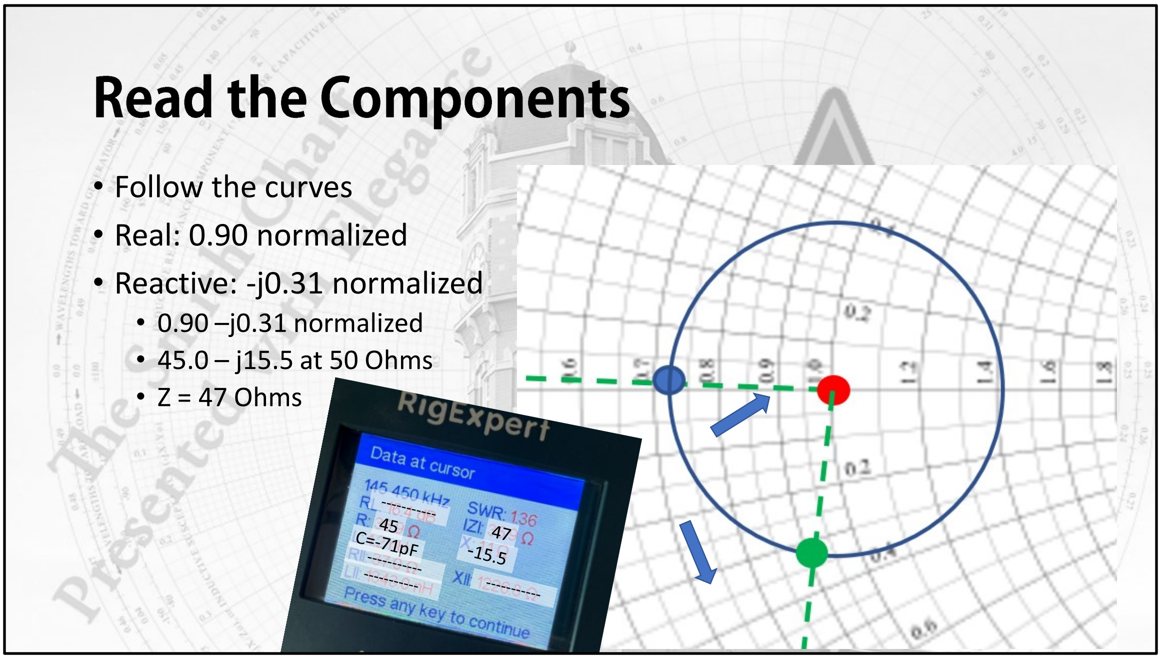
- Swing clock-wise adding phase.
- Read the vector impedance where the dot landed.

Adding 0.383λ

0.003λ

Landing at 0.386λ

Using the Smith Chart, we create a duplicate of the green dotted line and vector impedance dot with a pivot point at the same place as the other, home. We then swing this duplicate around clockwise. The starting location is superimposed over the original dotted line showing 0.003 wavelengths.



Read the Components

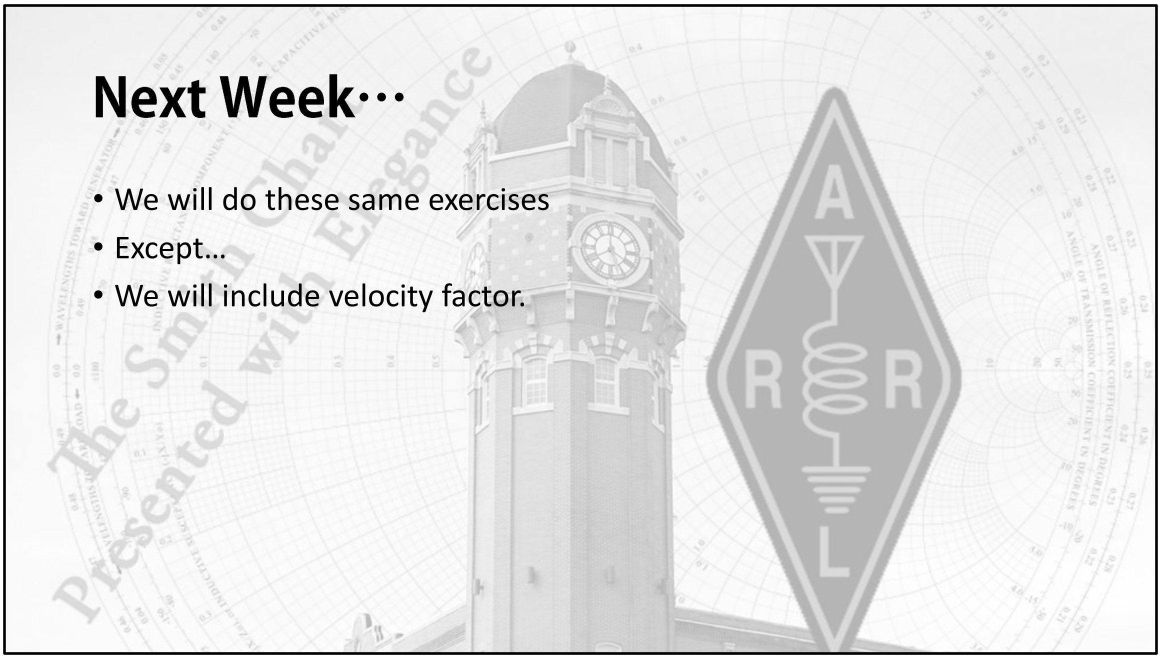
- Follow the curves
- Real: 0.90 normalized
- Reactive: -j0.31 normalized
  - 0.90 –j0.31 normalized
  - 45.0 – j15.5 at 50 Ohms
  - Z = 47 Ohms

RigExpert

Data at cursor

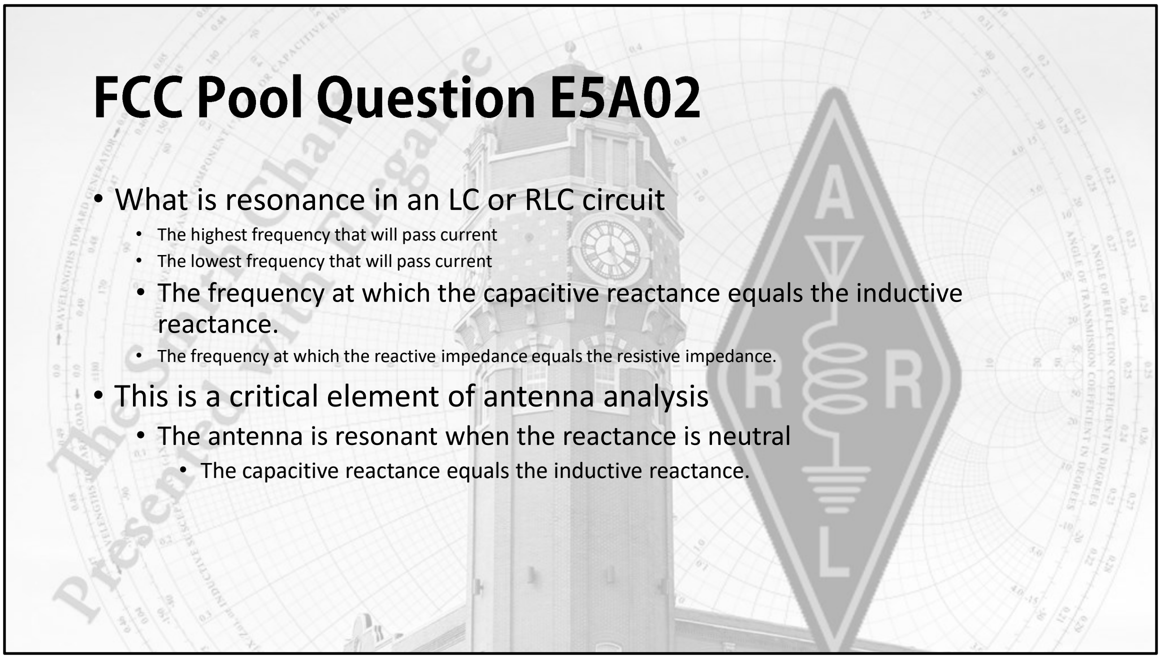
145 450 kHz
RL: ---------
R: 45 Ω
C=-71pF
RII: ---------
LII: ---------
SWR: 1.36
IZI: 47 Ω
X: -15.5
XII: ---------
Press any key to continue

We learn some interesting things from this exercise where we merely added feedline. The dotted lines in the graphic tells us that these values changed when taking the new reading but we are not prepared (or interested) in discussing them. First and foremost, the reactance changed from mildly inductive to much more capacitive. We went from 1.1 Ohms of inductive reactance to over 15 Ohms capacitive. But while the reactance increased radically, so did the resistance. The resistance changed from 36.9 Ohms to 45 Ohms. These two changes caused the magnitude of impedance to increase from 36.9 to 47 Ohms. We have not yet discussed extracting an SWR from the Smith Chart yet but if we had extracted the new SWR, we would have FOUND IT UNCHANGED! That's right. Adding or taking away feedline has no effect on the SWR other than from parasitics which likely are too small to be measured using consumer grade instrumentation. So, does this mean that the efficiency of our antenna has degraded or improved? Let's talk about it instead of having somebody tell you the answer. Since the antenna reactance has noticeably increased, the antenna will resonate less. This means less radiation owing to a degraded neutral reactance presence. But there is more to consider. The magnitude impedance has improved from 36.9 Ohms to 47 Ohms. We should consider this the same as 50 Ohms and call it right on the money. What does THIS mean to our efficiency. Your transmitter will like you since the impedances are matched between the transmitter and feedline input. This means better efficiency in getting power out. So on the one hand we have a loss of radiation efficiency and on the other hand a gain. So, who wins? The answer is in the SWR which has not changed. The answer is that nobody wins but neither does anybody lose.



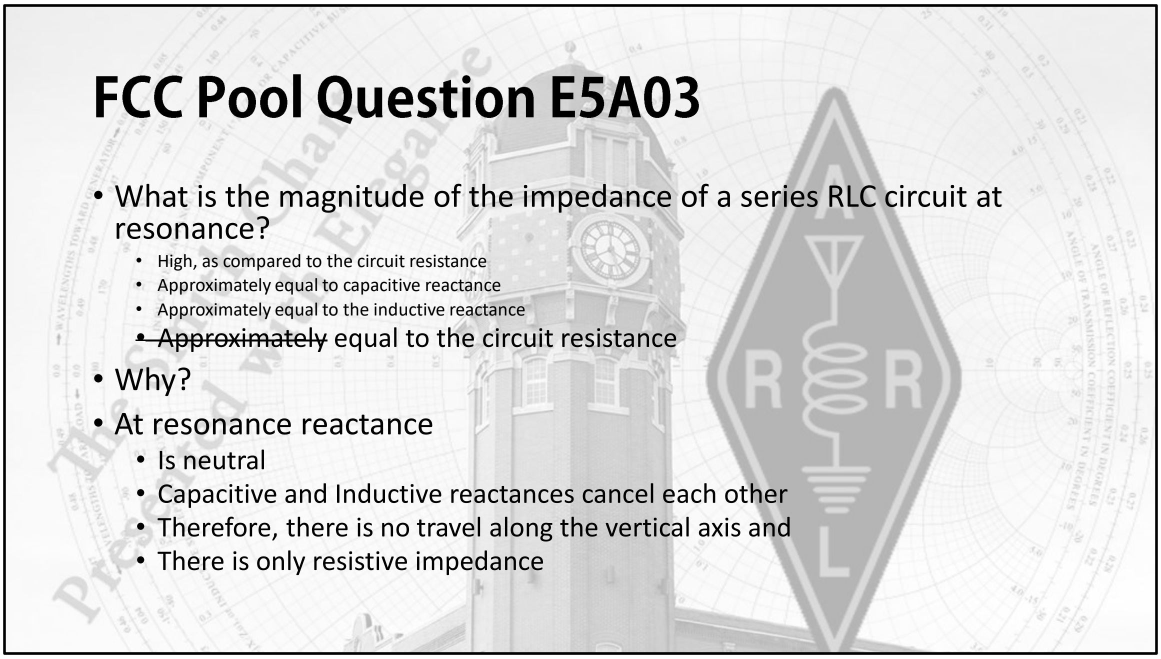
Next Week···

- We will do these same exercises
- Except…
- We will include velocity factor.



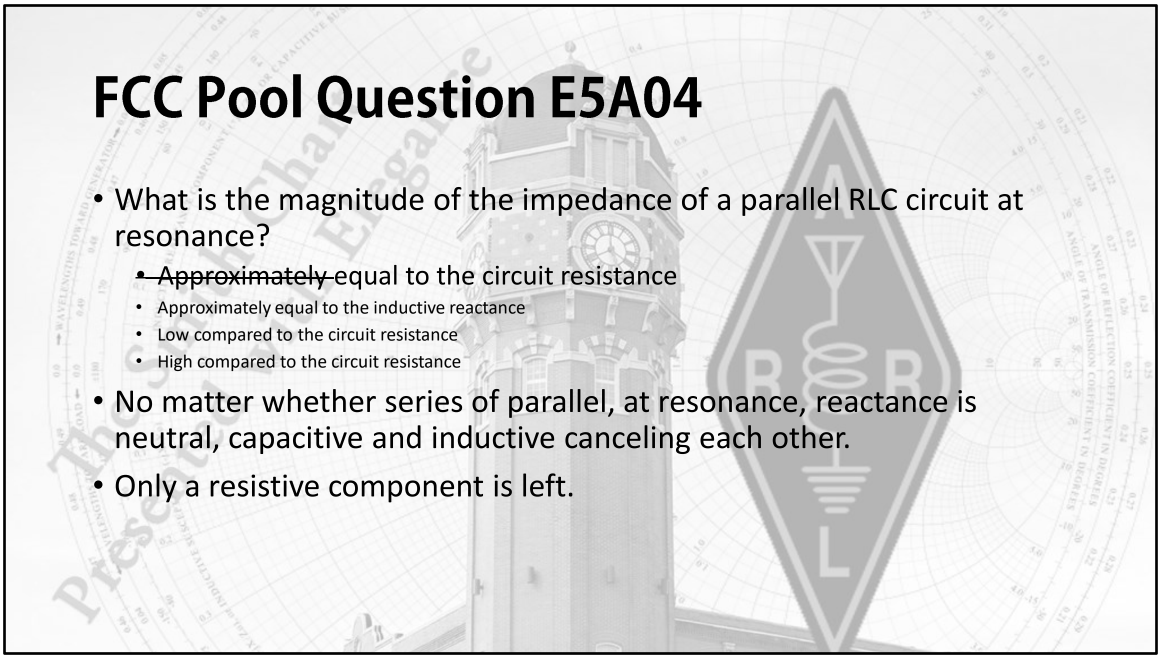
FCC Pool Question E5A02

- 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.



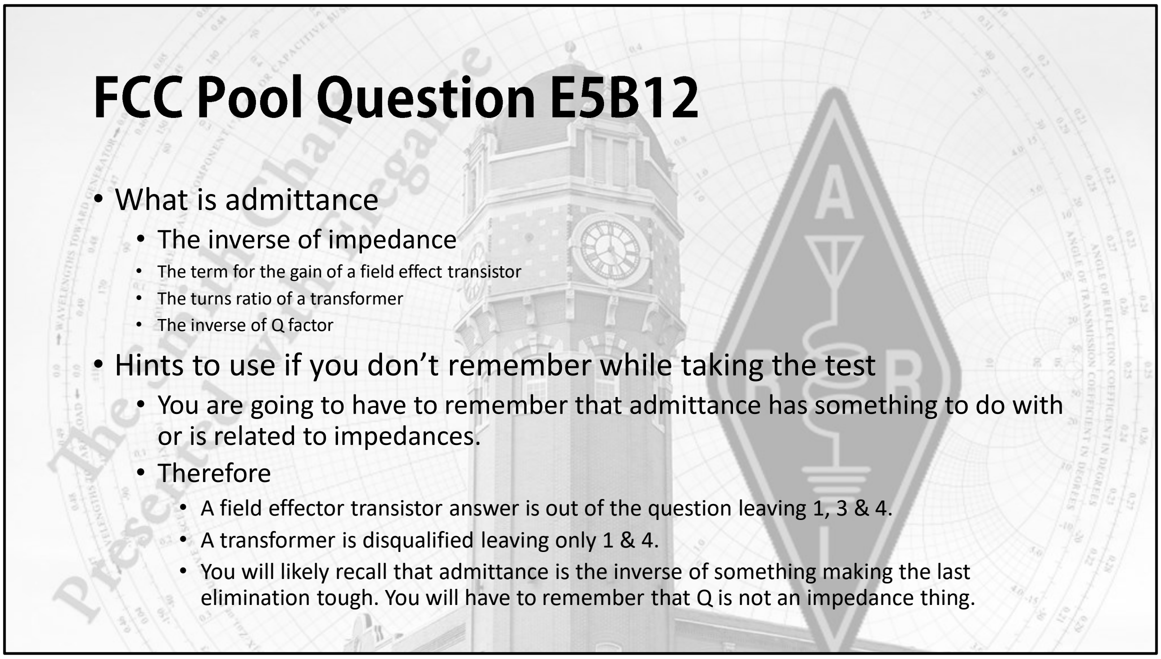
FCC Pool Question E5A03

- 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



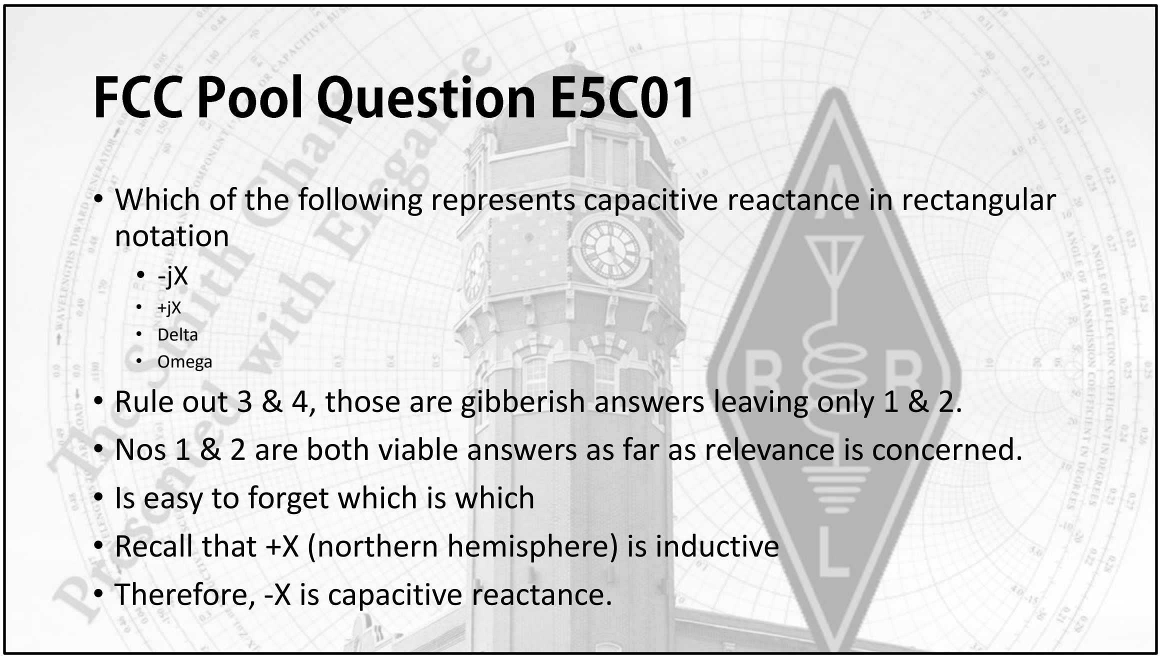
FCC Pool Question E5A04

- 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.



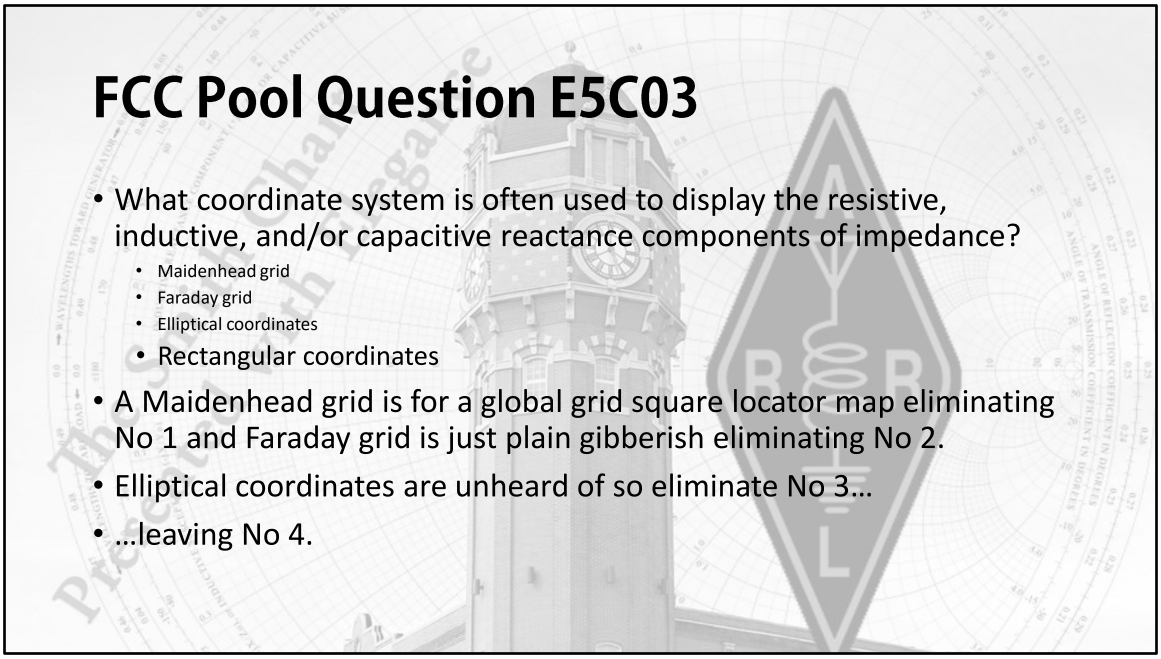
FCC Pool Question E5B12

- 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.



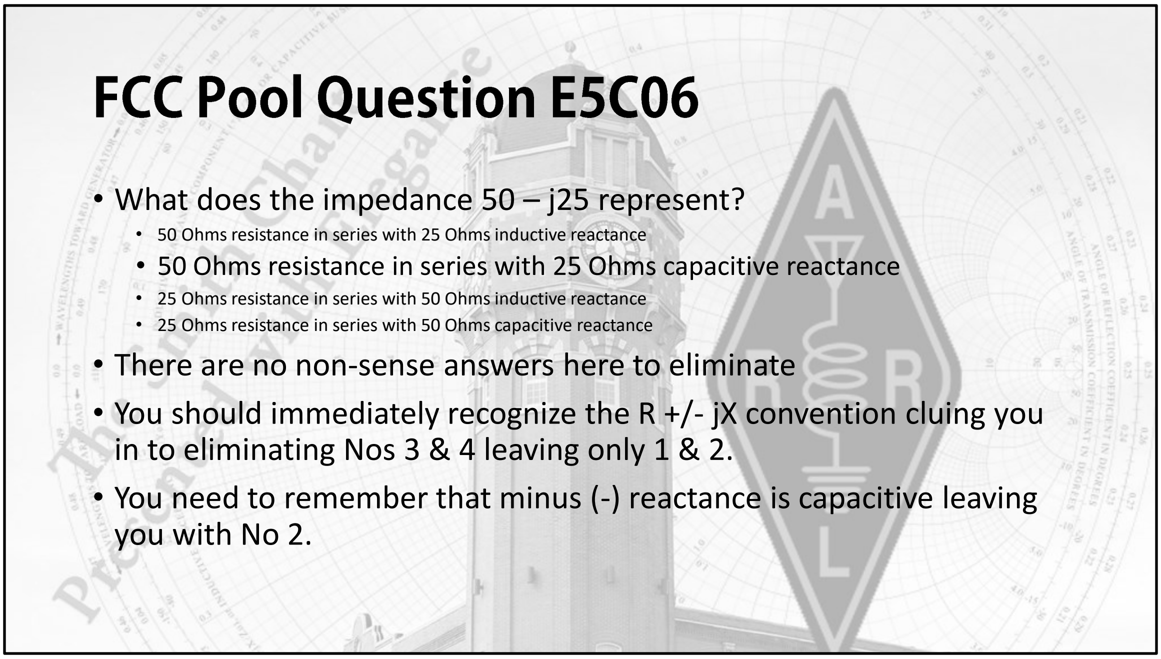
FCC Pool Question E5C01

- 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.



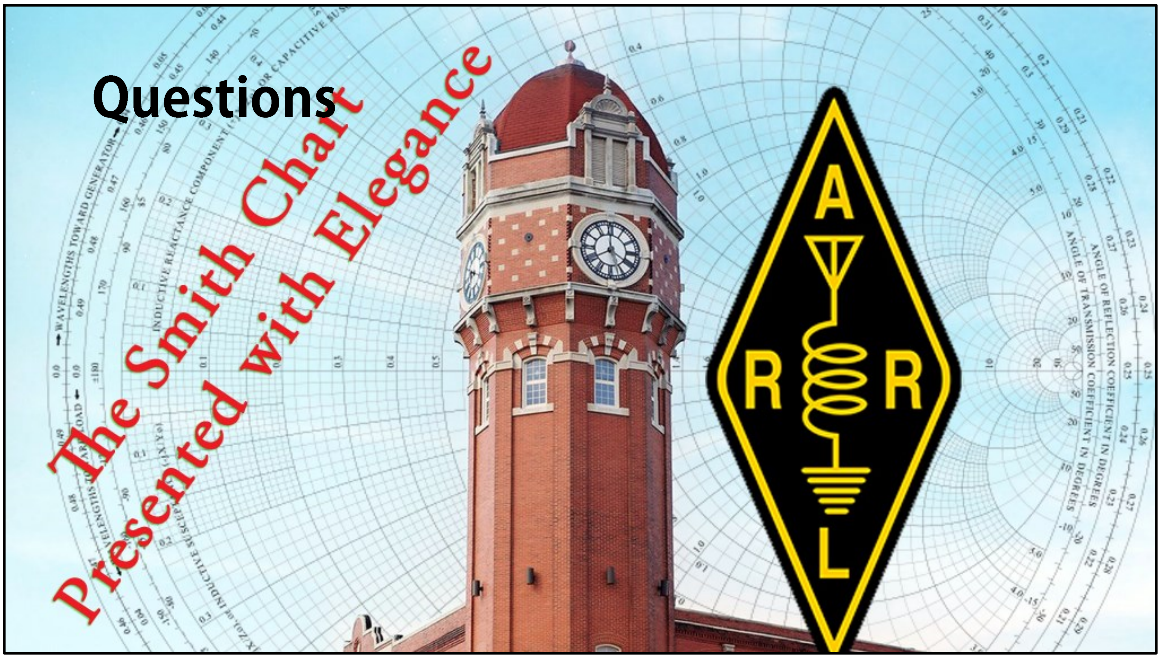
FCC Pool Question E5C03

- 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