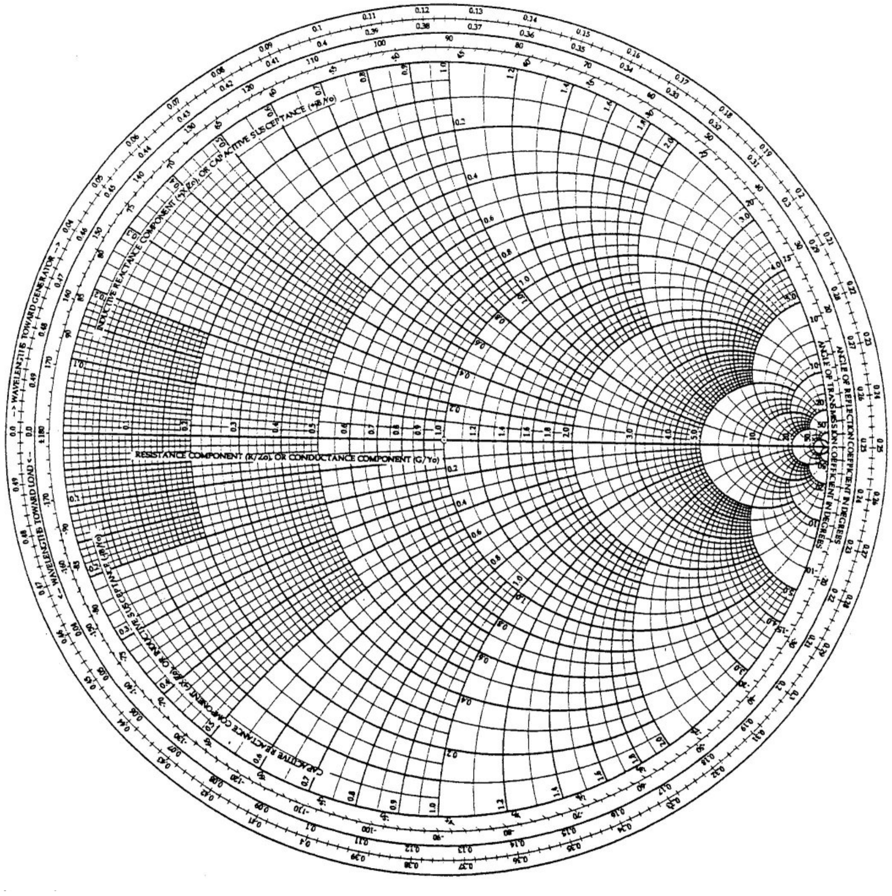
# A Discussion of Smith Chart Basics



## Somerset County Amateur Radio Club.

AC8SW

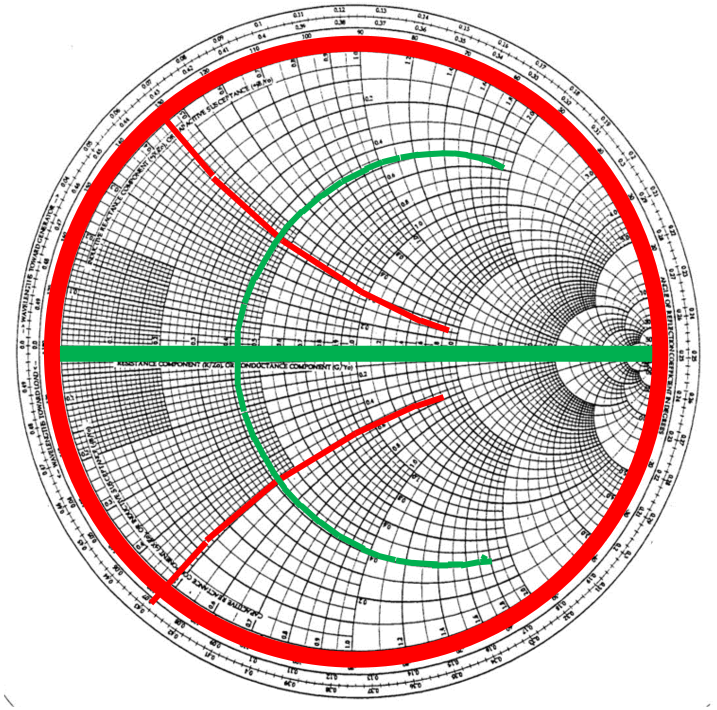
# Smith Chart Discussion Topics

- **Smith Chart Introduction and Overview**
- **Physical and Normalized Impedance**
- **Z-plane Connection to the Smith Chart**
- **Parts That Make Up a Smith Chart**
- **Amateur Extra Class Exam Smith Chart Questions**
- **Short-circuit Terminated 1/4 $\lambda$ Stubs**
- **Open-circuit Terminated 1/4 $\lambda$ Stubs**
- **Transmission Line Example**
- **Wrap-up**

# The Smith Chart - Overview

- **The Smith Chart (SC) is an impedance (R + Xj) grid for solving RF transmission line and impedance matching circuit problems. It was developed and published by Phillip Smith of Bell Labs in 1939.**

- **The SC, markup shown below, consists of a circle enclosing arcs of constant reactance (thin red) and circles of constant resistance (thin green), surrounded by a scale marked in fractional wavelengths and electrical degrees.**



**The circumference of the SC circle is the reactance axis (thick red). The resistance axis (thick green), the only straight line on the SC, divides the positive reactance (inductance) region from the negative reactance (capacitance) region**

**The resistance and reactance values plotted on the SC are normalized values; i.e., physical values divided by a ‘reference value’, usually 50 ohms for Amateur Radio use.**

# The Smith Chart - Overview

- **The SC contains every realizable impedance of the form R + Xj, where resistance R ranges from 0 to +infinity, reactance X from –infinity to +infinity, and j is $\sqrt{-1}$ .**

- **The SC can display impedances at multiple frequencies, as in antenna impedance vs. frequency, but it can only solve single frequency problems.**

- **If drawn to their full extent, all reactance arcs and all resistance circles would converge at the single infinity point of the SC, creating a density of lines that would render this region unusable. For this reason, arcs and circles are truncated to less than full extent. The optical effect of this truncation gives the SC grid its iconic appearance.**

- **The Smith Chart was a major electrical engineering tool for most of four decades, but its accuracy was always limited by artwork resolution. The SC has been displaced by digital computer software for commercial work, but still has utility for RF instrument displays, visualization of transmission line effects, and Amateur Radio impedance matching.**

# The Smith Chart - Normalized Impedance

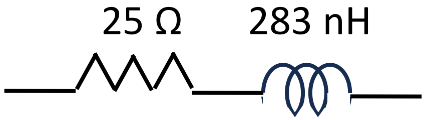
- **Physical Impedance Z = R + Xj**
  R = resistance, always ≥ 0
  X = reactance, positive for inductance, negative for capacitance

- **Smith Chart for a 50-ohm system**
  Z_norm = Z_phy / 50
  Z_phy = 50 * Z_norm

- **50 Ω system perfect match Z_phy = 50 + 0j ↔ Z_norm = 1 + 0j**

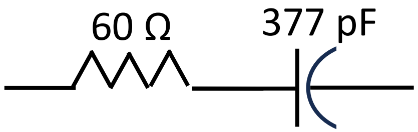
- **Examples impedances at 20m FT-8 14.074 MHz**

**A** ●



Z_phy = 25 + 25j ↔ Z_norm = 0.5 + 0.5j

**B** ●

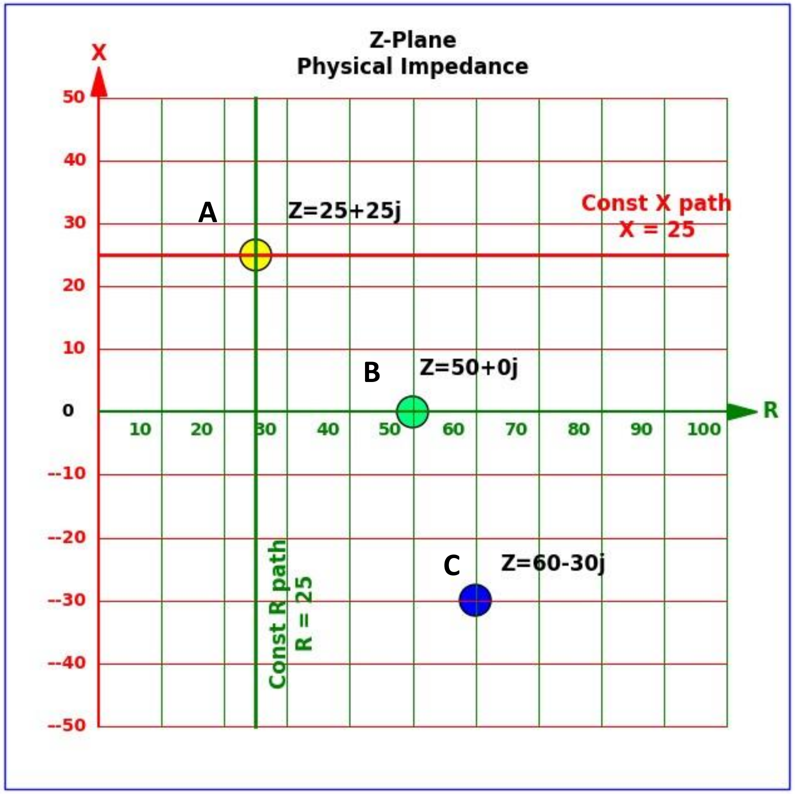


Z_phy = 60 - 30j ↔ Z_norm = 1.2 - 0.6j

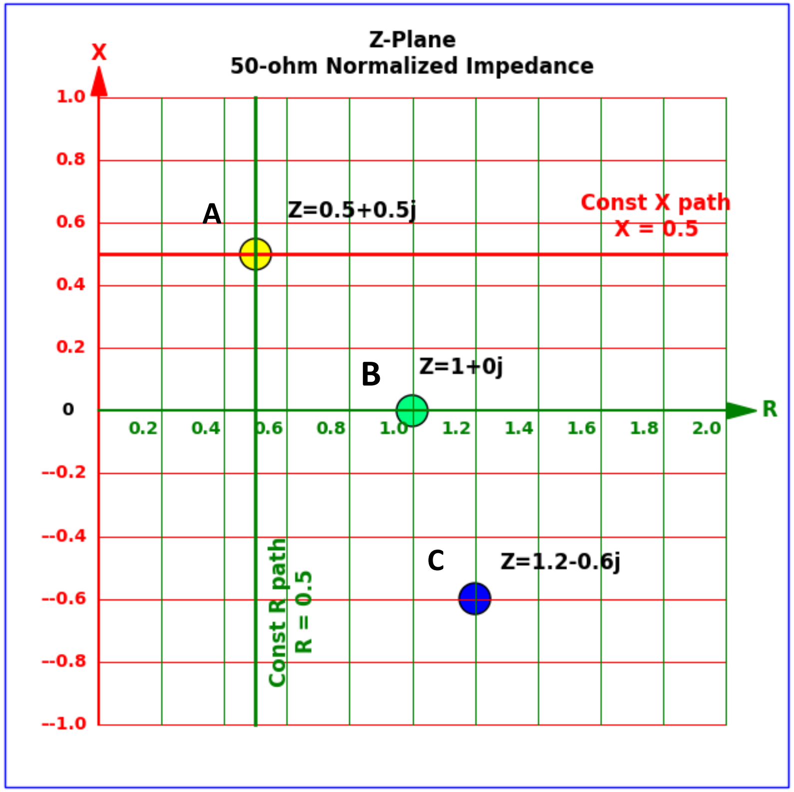
**C** ●

Z_phy = 50+ 0j ↔ Z_norm = 1 + 0j

# The Physical and 50-ohm Normalized Z-planes



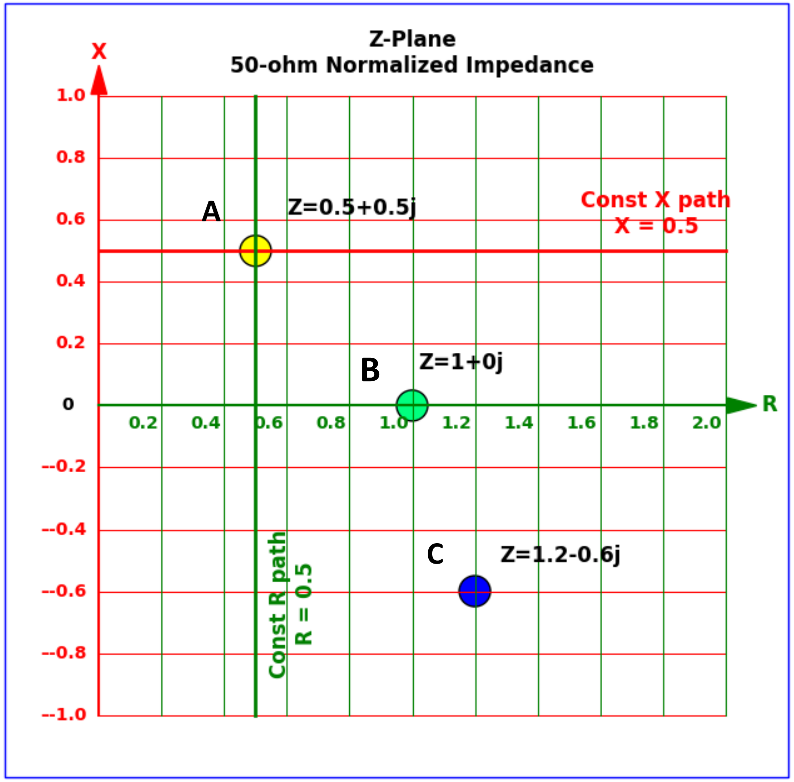
Z_norm = Z_phy / 50



Z_phy = Z_norm * 50

# The Smith Chart “squeezes” the infinite normalized Z-plane into a circle. This results in graphic distortion, but also a big gain in utility.

*Every impedance point in the Z-plane has a corresponding point in the Smith Chart*



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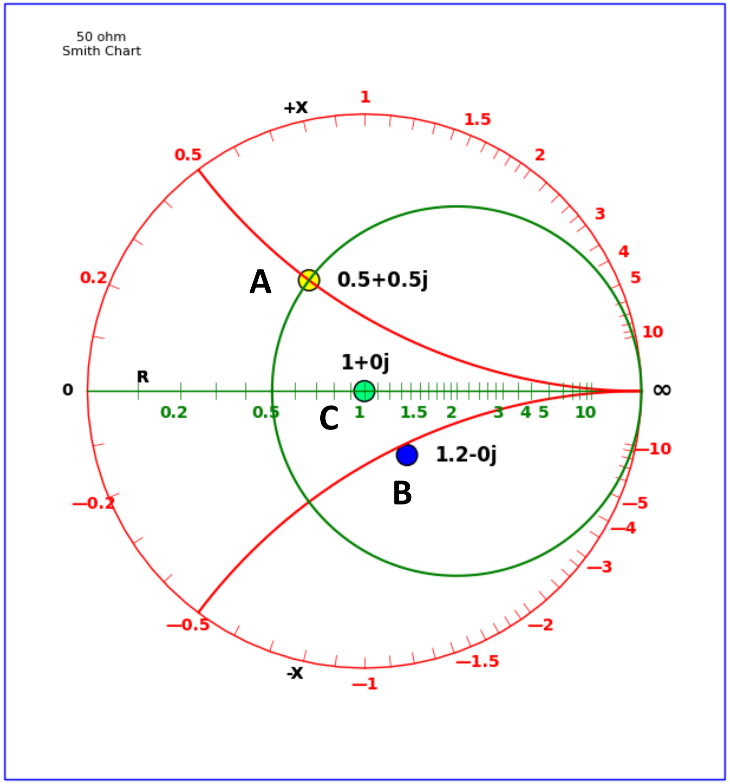
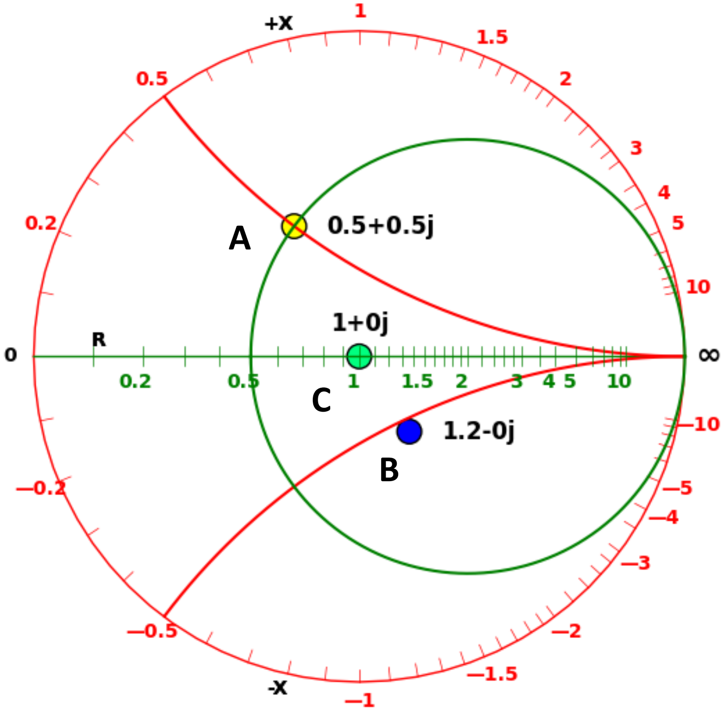


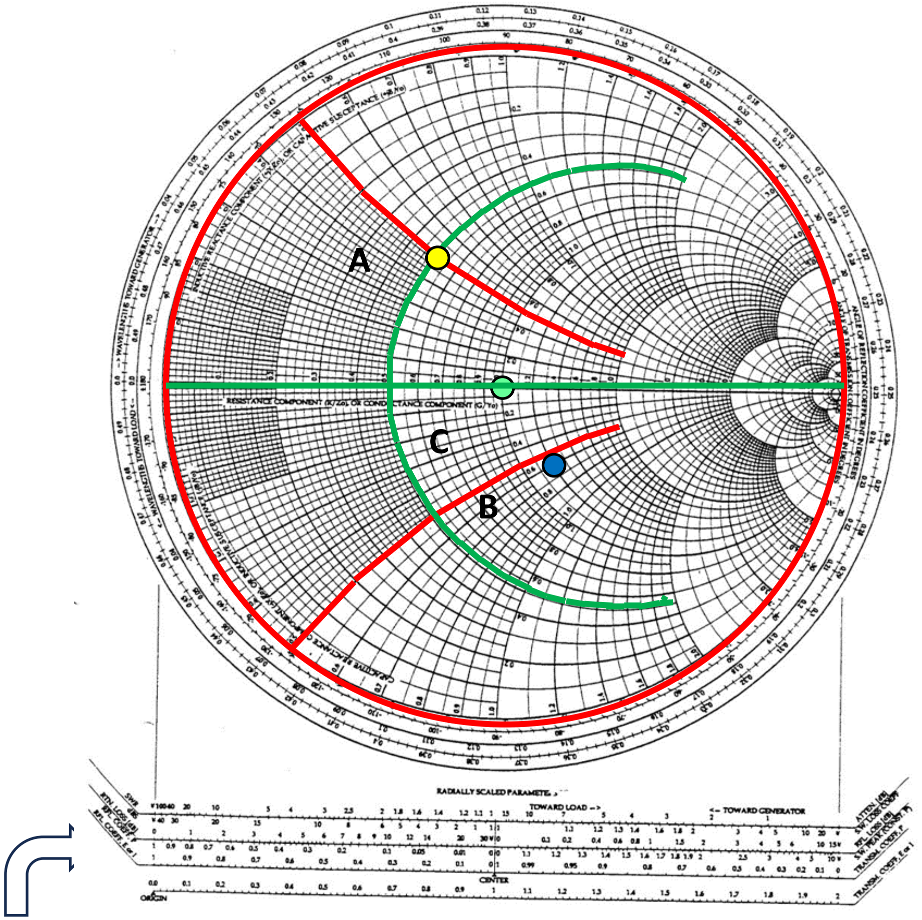
This is a tiny area of the Z-Plane. The entire plane extends to infinity and contains every possible impedance.

This simplified Smith Chart demonstrates all essential elements of a fully-developed version.

**The fully-developed Smith Chart has the same circles of constant resistance and arcs of constant reactance as this simple chart, just many more of them. The iconic grid pattern of the Smith Chart is the optical effect of circles and arcs being truncated for clarity.**



(Wavelength scale not shown)



**These scales are for reading SWR, Return Loss, Reflection Coefficient and a other characteristics. Except for SWR, I don’t use them and I am not qualified to discuss them. You can find information online.**

# 2020-2024 Extra Class
# FCC Element 4 Question Pool Syllabus, Effective July 1, 2020
## E9G The Smith chart

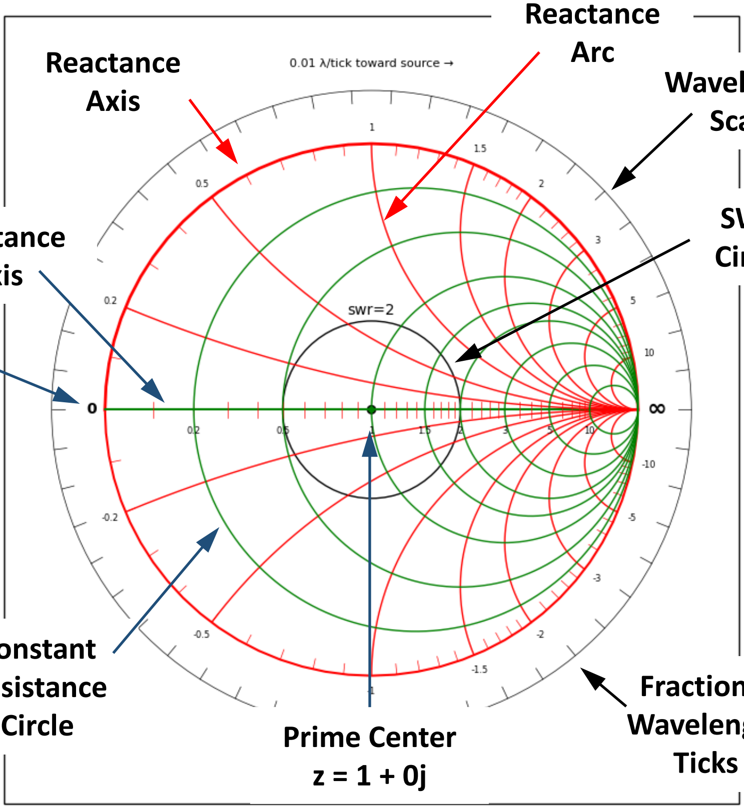
E9G01. Impedance along transmission lines can be calculated using a Smith chart.

E9G02. Resistance circles (green) and reactance arcs (red) are the type of coordinate system used in a Smith chart Resistance and reactance are both zero at the origin.

E9G03 Impedance and SWR values in transmission lines are often determined using a Smith chart. SWR is constant everywhere along an ideal lossless line.

E9G04 Resistance (green) and reactance (red) are the two families of circles and arcs that make up a Smith chart.

E9G05 Determining the length and position of an impedance matching stub are common uses for a Smith chart.



Reactance Axis

Constant Reactance Arc

Wavelength Scale

Resistance Axis

SWR Circle

Constant Resistance Circle

Prime Center z = 1 + 0j

Fractional Wavelength Ticks

E9G11 The wavelength scales (black) on a Smith chart are calibrated in fractions of transmission line electrical wavelength, so line velocity factor must be considered.

E9G10 The arcs (red) on a Smith chart represent points with constant reactance.

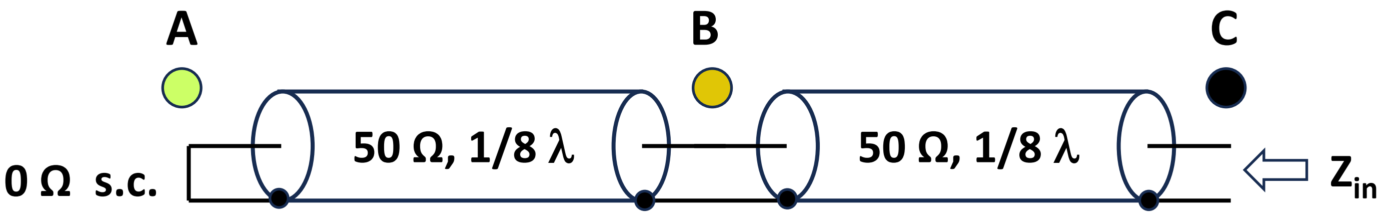
E9G09 The third family of circles is often added to a Smith chart are standing wave ratio circles (black).

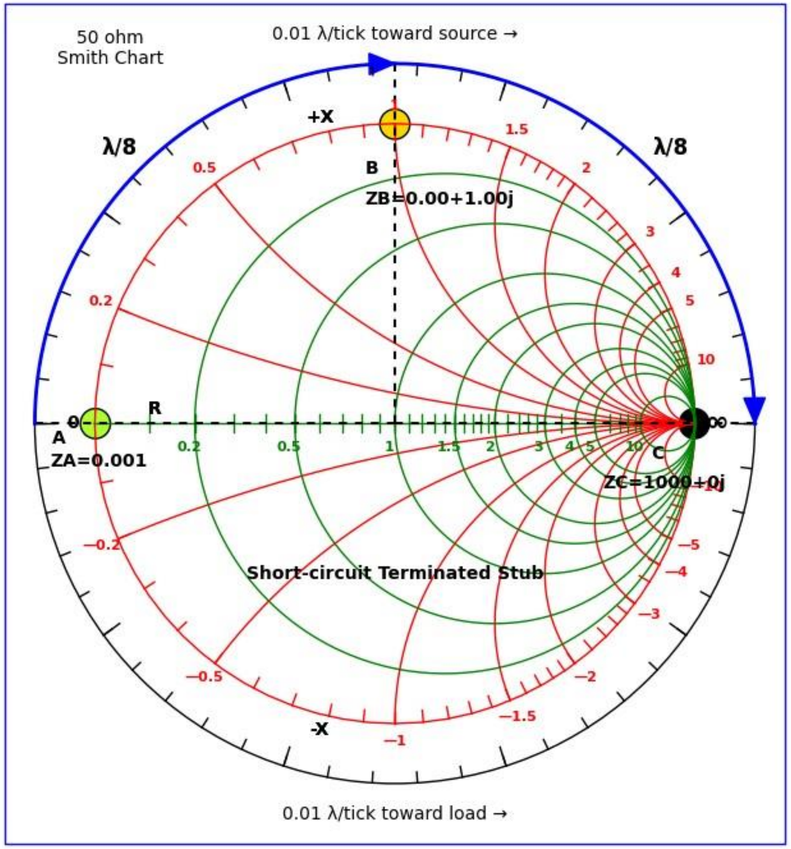
E9G07 The resistance axis (green) is the only straight line on a Smith Chart. Reactance is zero everywhere on this line.

E9G06 Reactance axis (red) is the name for the large outer circle on which the reactance arcs terminate. Resistance is zero everywhere on this circle.

E9G08 Impedance normalization reassigns impedance values with regard to the Smith Chart prime center. For a 50-ohm system, normalized impedance = physical impedance / 50.

# Short-circuit Terminated 1/4 λ Coax Stub





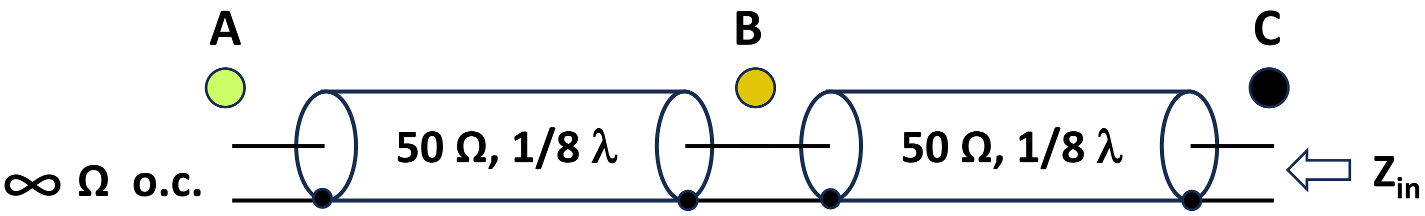
A coax stub ≤ 1/4 λ in length and terminated by a short-circuit (A) presents an inductive input impedance (Reactance X > 0).

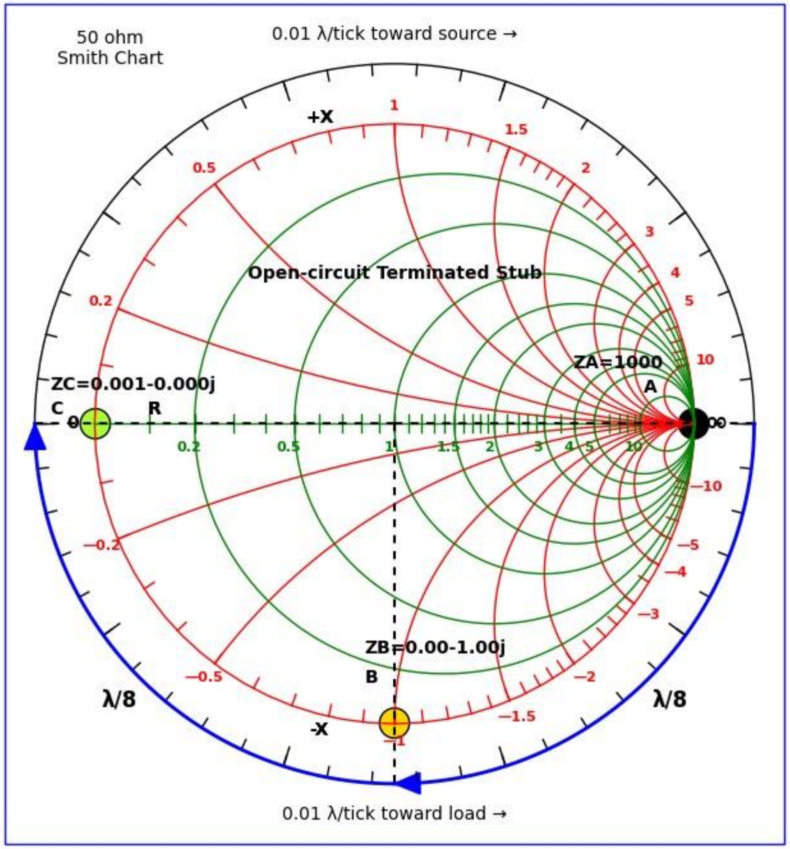
At the 1/8 λ point (B), the input Z_norm is 0+1j, Z_phy 0 + 50j Ω.

At the 1/4 λ point (C), the theoretical input impedance is infinite.

This is an example of 1/4 λ stub impedance transformation. A short-circuit at the load appears as an open-circuit at the input.

# Open-circuit Terminated 1/4 λ Coax Stub





**A coax stub ≤ 1/4 λ in length and terminated by an open-circuit (A) presents a capacitive input impedance. (Reactance < 0)**

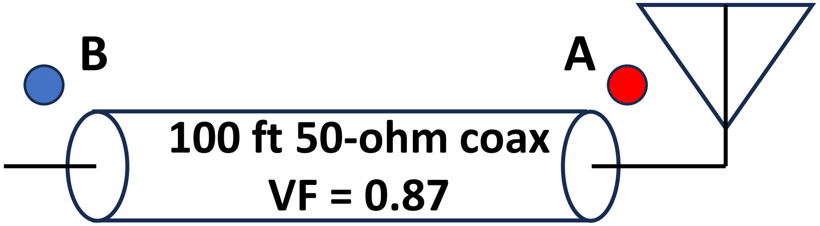
**At the 1/8 λ point (B), the input Z_norm is 0-1j, Z_phy 0 - 50j Ω.**

**At the 1/4 λ point (C), the theoretical input impedance is zero.**

**This is an example of 1/4 λ stub impedance transformation. An open-circuit at the load appears as a short-circuit at the input.**

# Smith Chart Transmission Line Example

At the shack
SWR = 3:1
ZB = ?



B

A

100 ft 50-ohm coax
VF = 0.87

ZA = 18.0 + 12.7j
(0.36 + 0.25j)
SWR = 3:1

An unmatched antenna at point A (red dot) has a physical impedance of Z = 18.0 + 12.7j  (0.36+0.25j normalized). At the 20m FT-8 frequency of 14.074 MHz., this creates SWR = 3:1.

The coax run to the shack is 100 ft of lossless 50-ohm coax, velocity factor = .87. At 14.074 MHz and VF = 0.87, the line’s electrical length is 1.644 wavelengths.

A lossless transmission line has constant SWR everywhere, so the SWR at the shack end of the coax is also 3:1.

The Smith Chart can be used to graphically determine ZB at the shack end of the coax. This is useful to design a 50-ohm matching circuit.

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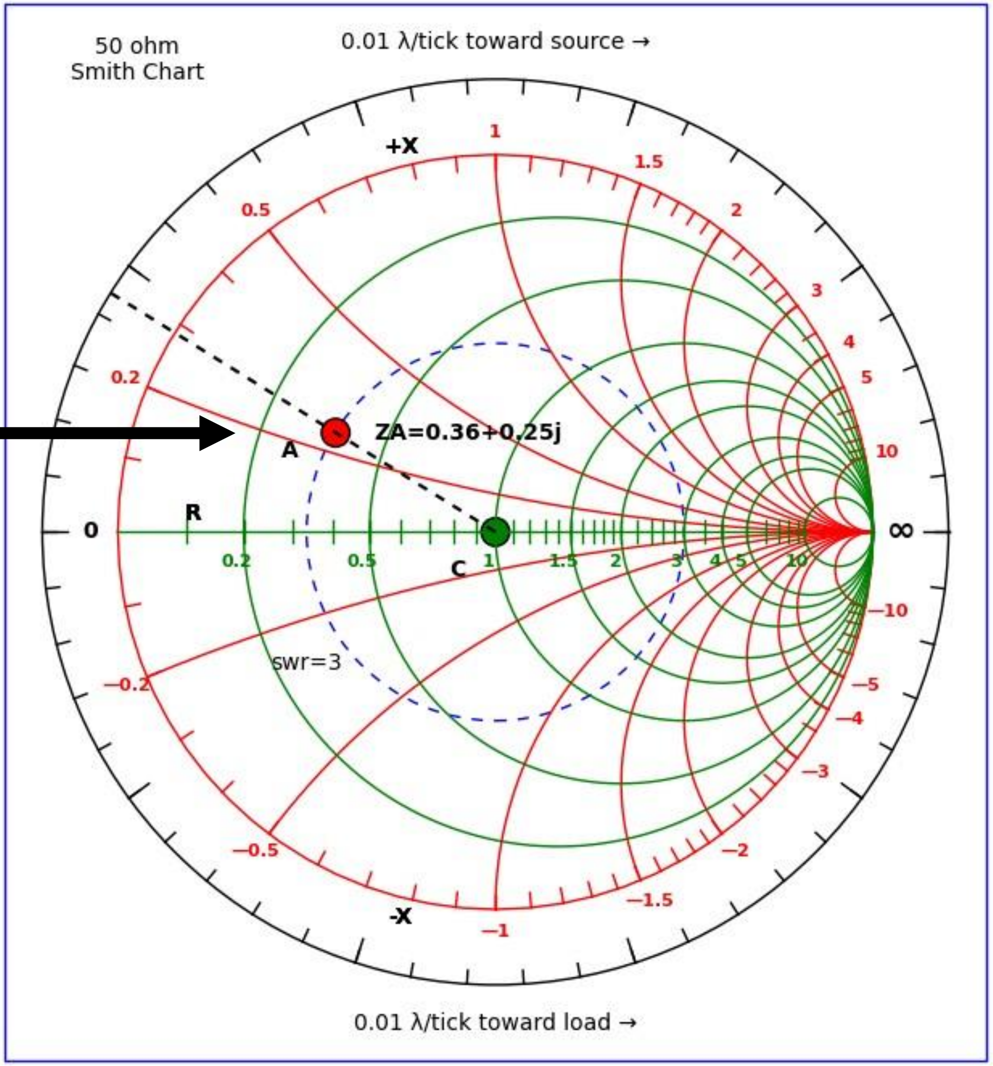
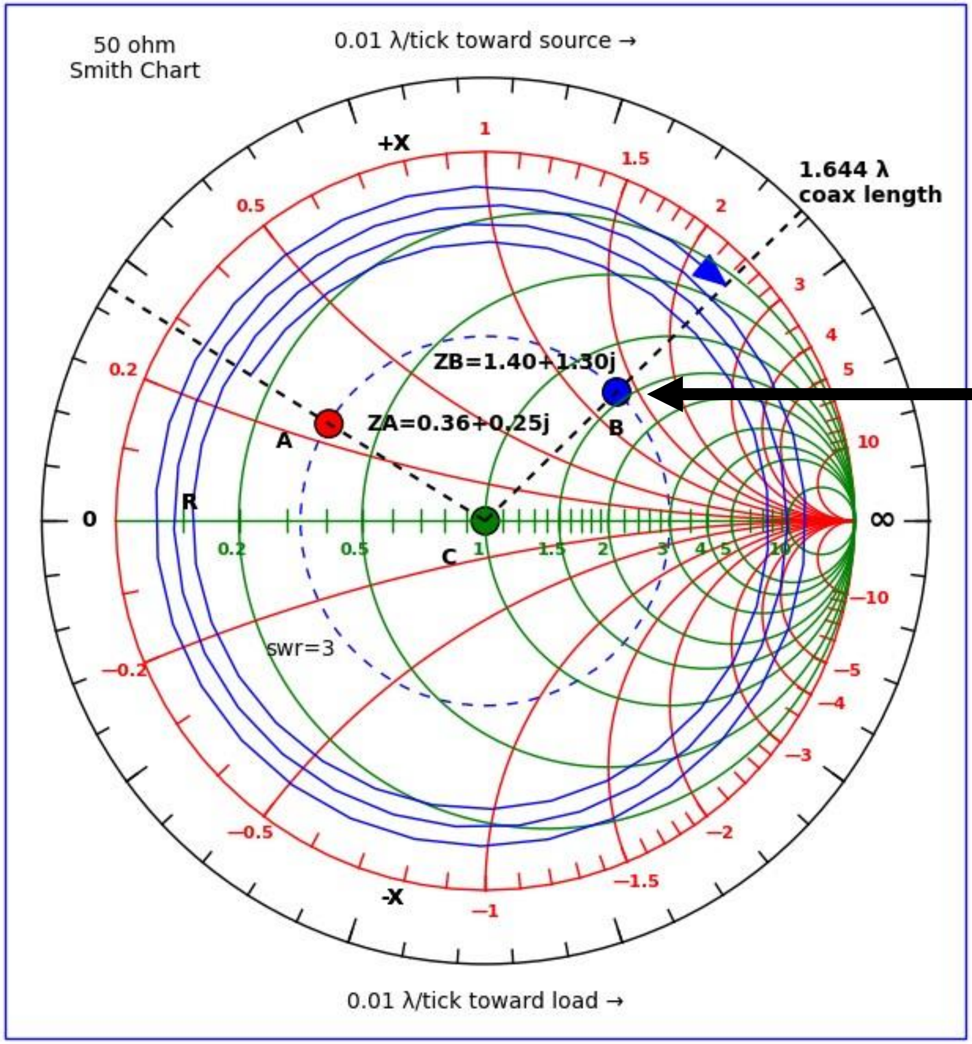
# Step 1 - Locate ZA on the Smith Chart

**ZA = 0.36+0.25j**
**at 14.074 MHz on**
**the SWR = 3:1 circle**



# Step 2 - Find ZB by rotating the ZA radial cw 1.644 λ (164.4 ticks) on the wavelength scale. ZB is located at the intersection of this new radial and the SWR = 3:1 circle.



**ZB = 1.40 + 1.30j**
**at 14.074 MHz which**
**equates to 70 + 65j**
**physical impedance**
**at the shack.**

# Smith Chart Discussion Wrap-up

- **The Smith Chart, named for its maker, Phillip Smith, was first published in 1932.**

- **The Smith Chart is a specialized grid for solving transmission line and impedance matching problems. The impedance values plotted on the Smith Chart are normalized; i.e. physical values divided by a reference value, usually 50-ohm for Amateur Radio work.**

- **The circular outer boundary of the Smith Chart is the Reactance Axis, positive X for inductance, negative X for capacitance. The equatorial straight line through the center is the Resistance Axis. A wavelength scale, graduated in fractional wavelengths, encircles the Smith Chart.**

- **The interior of the Smith Chart contains Arcs of Constant Reactance and Circles of Constant Resistance.**

- **Largely displaced by digital computer software, the Smith Chart is still used for RF instrument displays, visualization of transmission line effects, and Amateur Radio impedance matching.**