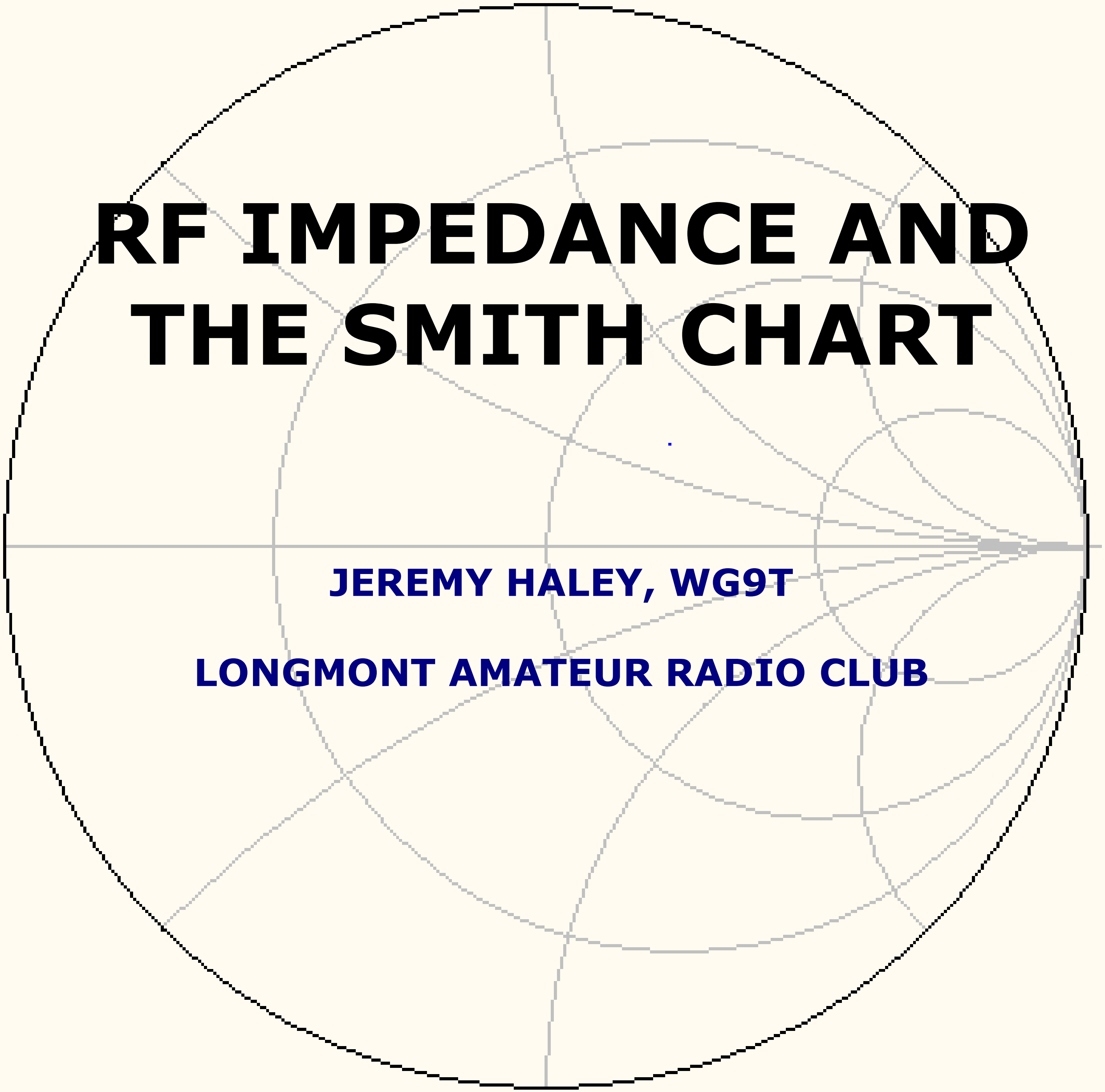


RF IMPEDANCE AND THE SMITH CHART

JEREMY HALEY, WG9T

LONGMONT AMATEUR RADIO CLUB

RESISTANCE, REACTANCE, AND IMPEDANCE

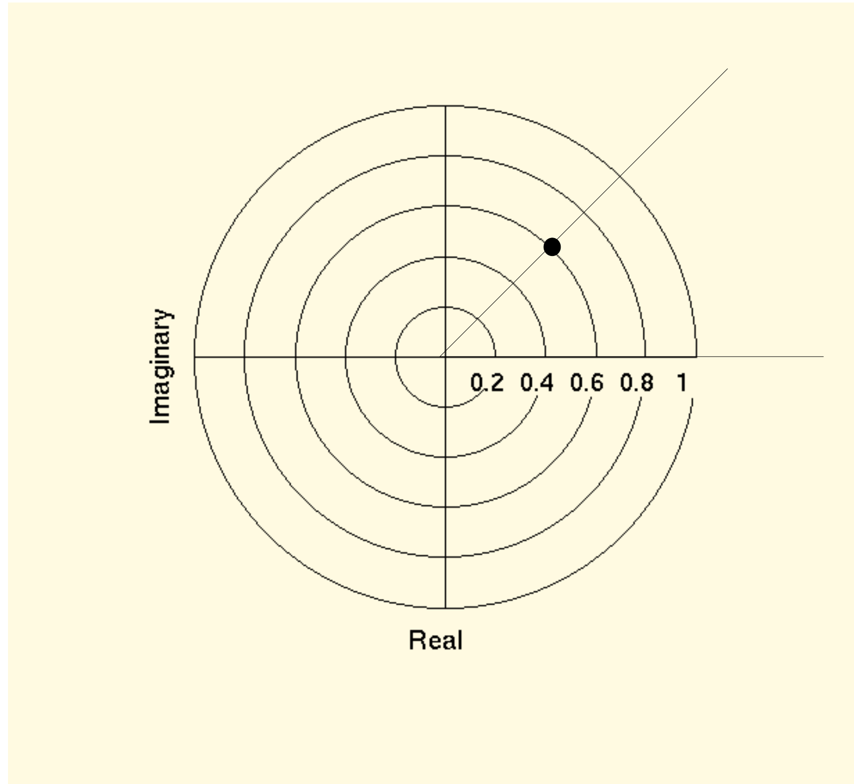
RESISTANCE Energy conversion to heat.

REACTANCE

Capacitance: Energy storage in electric field.
Inductance: Energy storage in magnetic field.

IMPEDANCE RESISTANCE + REACTANCE

POLAR PLOT OF REFLECTION COEFFICIENT



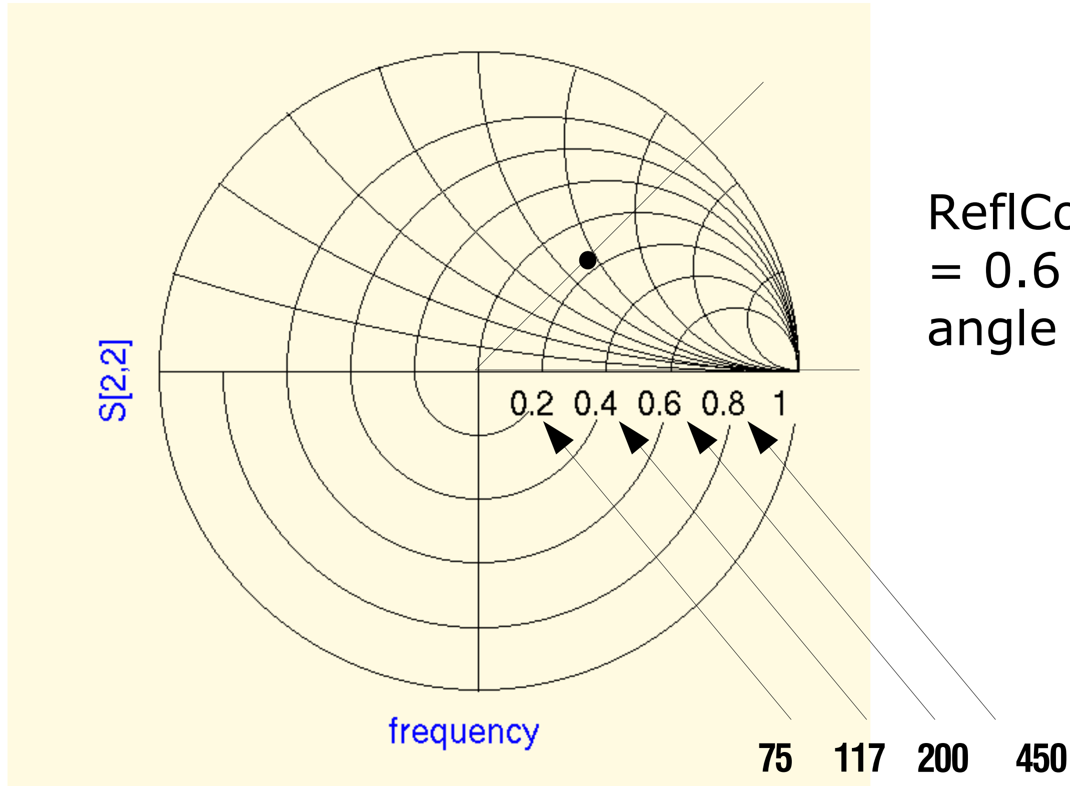
ReflCoeff.
= 0.6 magnitude,
angle 45 degrees.

Voltage Waves: forward and reflected relative to a fixed reference point (e.g. SWR meter in the shack).

Reflection Coefficient = (refl. voltage) / (fwd. voltage) [n.a.]

Voltages have amplitude [V] and phase angle [degrees].

OVERLAY IMPEDANCE COORDINATES



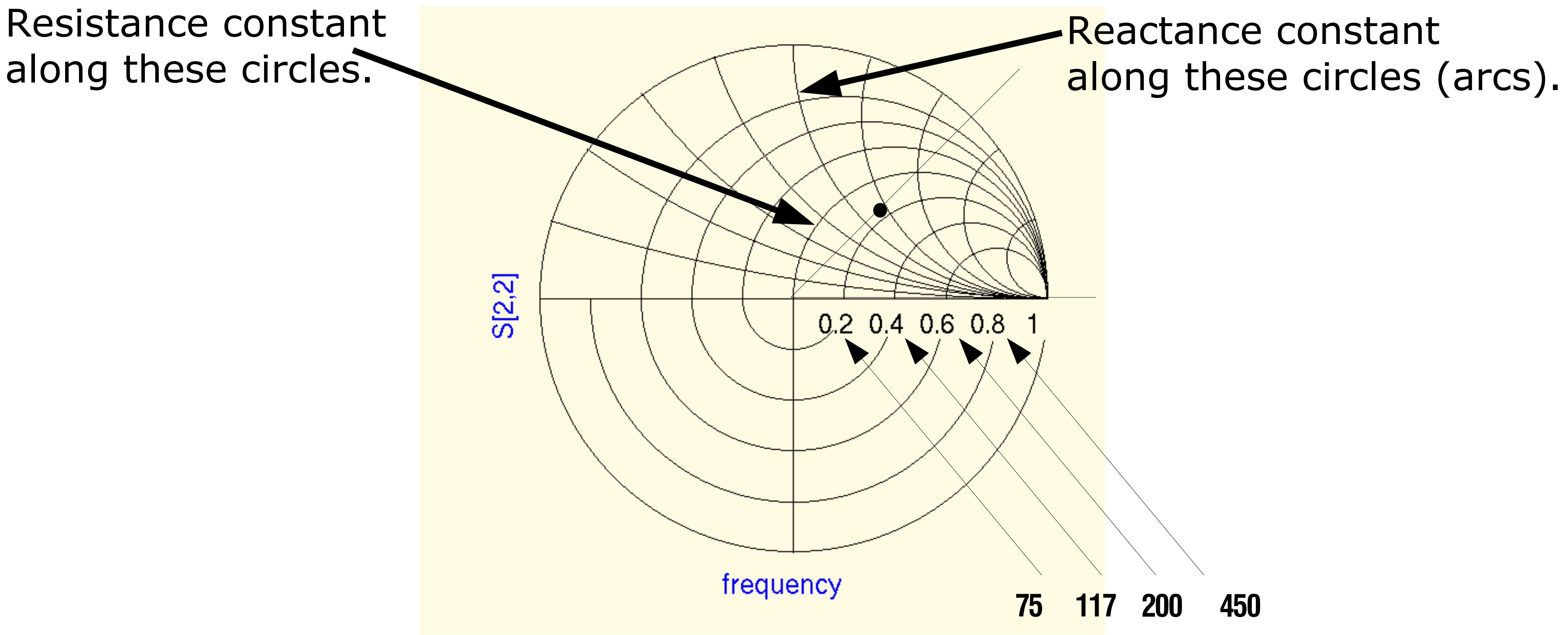
ReflCoeff.
= 0.6 magnitude,
angle 45 degrees.

Equation relates impedance to reflection coefficient.

Z = Zref*((1 + ReflCoeff.)/(1-ReflCoeff.)) [Ohm]

Reference impedance, Zref is typically 50 ohms.

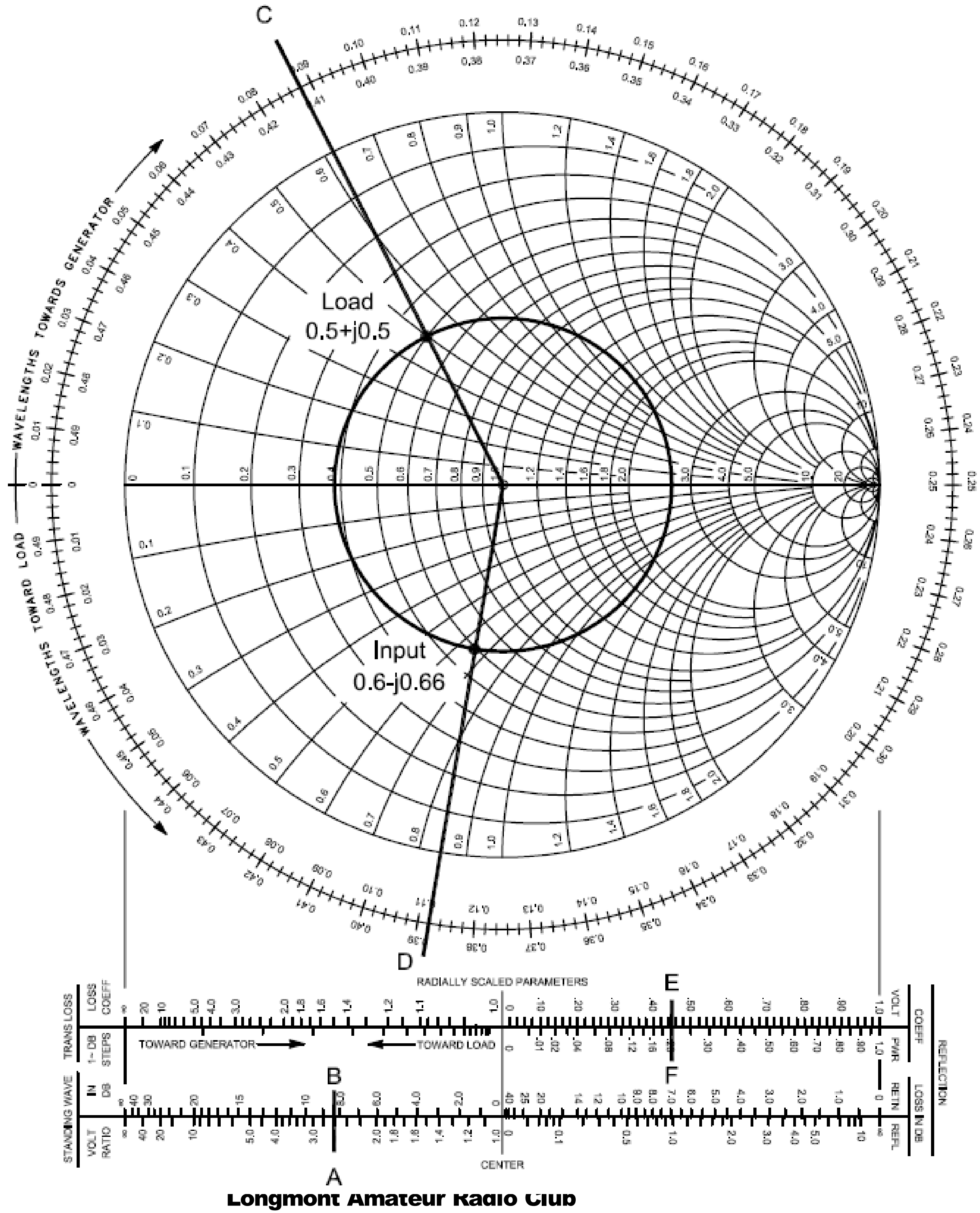
RESISTANCE & REACTANCE CIRCLES



Upper half of impedance map: inductive reactance and resistance.

Lower half of impedance map: capacitive reactance and resistance.

SMITH CHART FOR IMPEDANCE



NOTICE THAT IMPEDANCE IS NORMALIZED. 50 >>> 1

FROM EXAMPLE IN ARRL ANTENNA BOOK

COMPUTER TOOL ALTERNATIVE TO COMPASS AND STRAIGHTEDGE

Free open-source cross-platform software: Quite Universal Circuit Simulator "QUCS"

- http://qucs.sourceforge.net/
- DC circuit analysis
- AC circuit analysis
- RF circuit analysis (S-parameter simulation)

EXAMPLE CIRCUIT "A"

Example from ARRL Antenna Book, Chapter 28.

Antenna impedance is given as 25 + j 25 Ohm at some frequency.

The reactive portion +j25 Ohm indicates an inductive reactance.

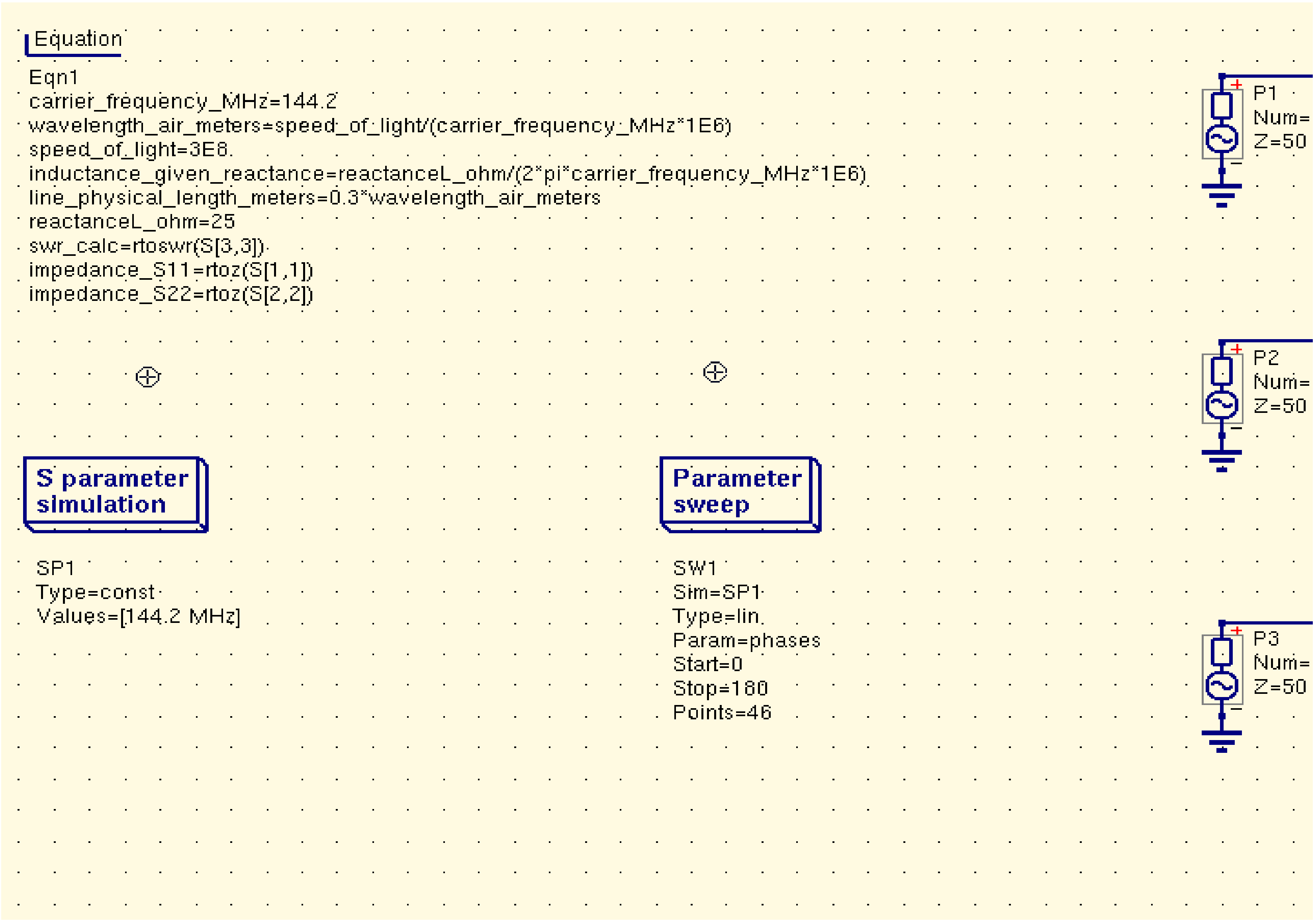
Assume the frequency is 144.200 MHz.

What is the impedance at the radio end of a 0.3 wavelength long low-loss cable?

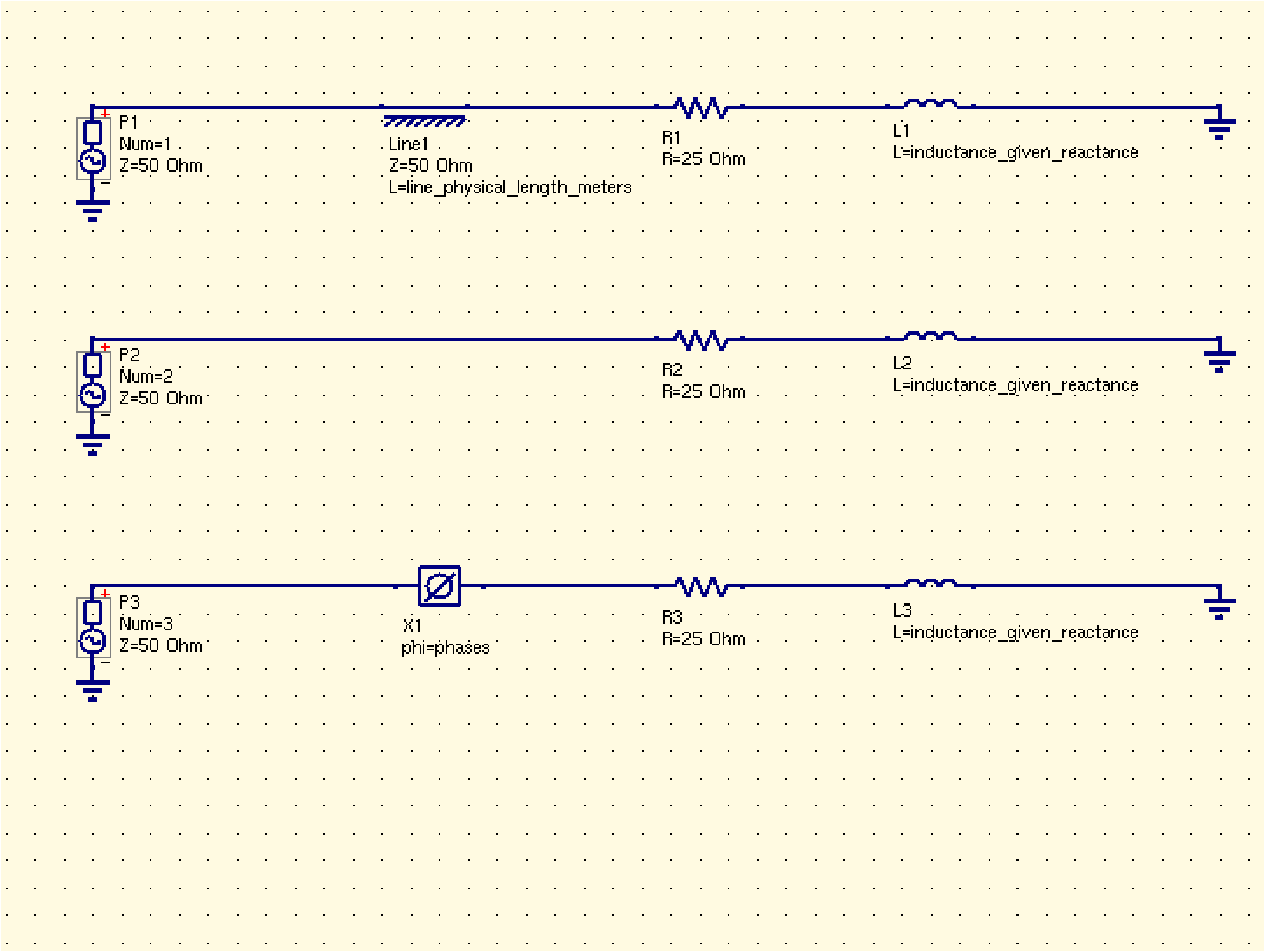
Assume the cable has a characteristic impedance (resistance) of 50 Ohms.

Simulate the circuit using the computer tool, and plot the result on the Smith Chart.

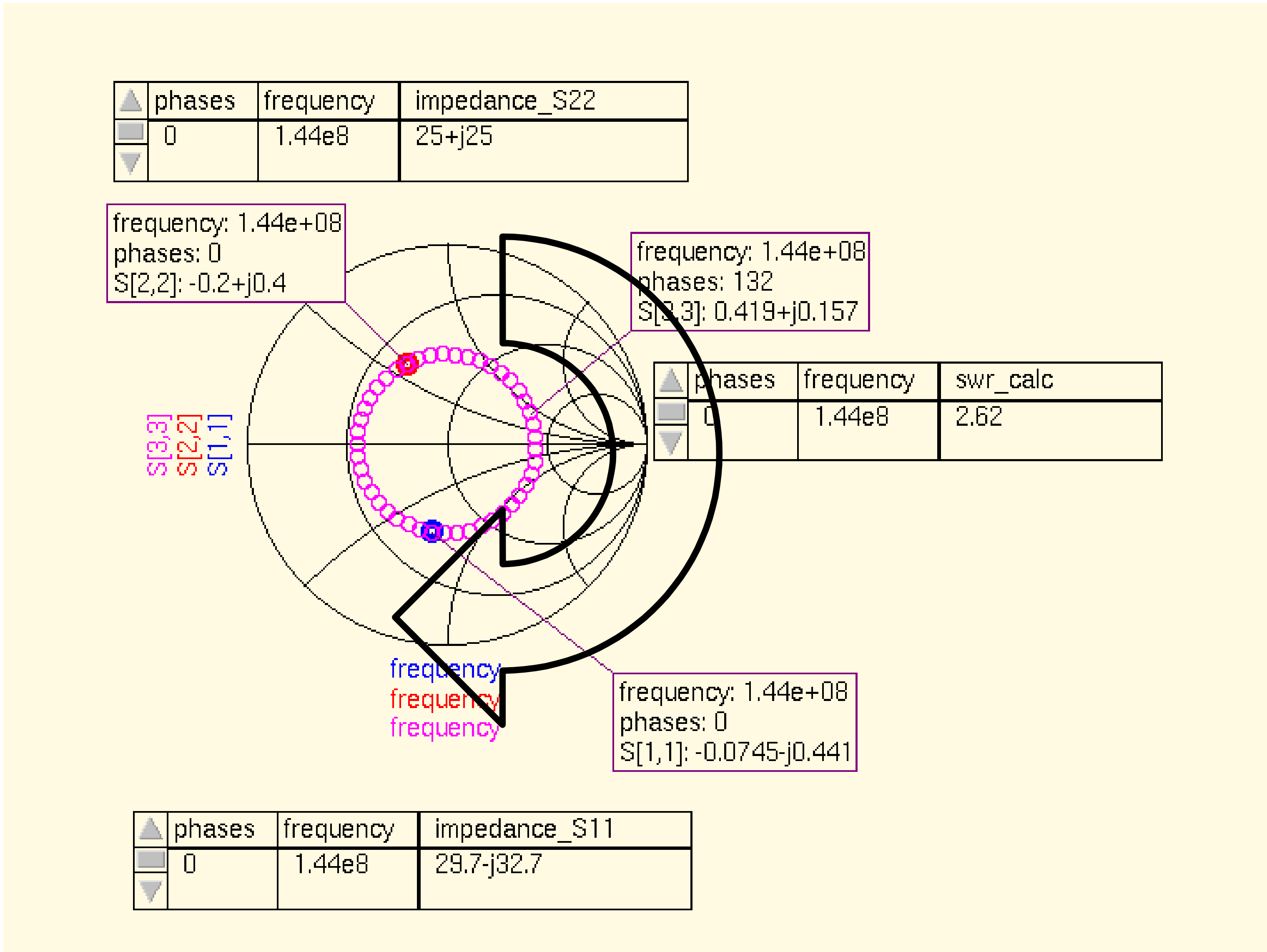
PC SIMULATION: CALCULATIONS AND DEFINITIONS



PC SIMULATION: SCHEMATIC



RESULTS: SMITH CHART PLOT



Rotation along 50 ohm line “Toward Generator (Radio)” 0.3 wavelengths.

EXAMPLE CIRCUIT "B"

Example from ARRL Antenna Book, Chapter 28.

Impedance measured at the radio end of a 2.35 wavelength long low-loss coaxial cable is 70 - j 25 Ohm at some frequency.

The reactive portion -j25 Ohm indicates a capacitive reactance.

Assume the frequency is 144.200 MHz.

What is the impedance at the antenna feedpoint?

Assume the cable has a characteristic impedance (resistance) of 50 Ohms.

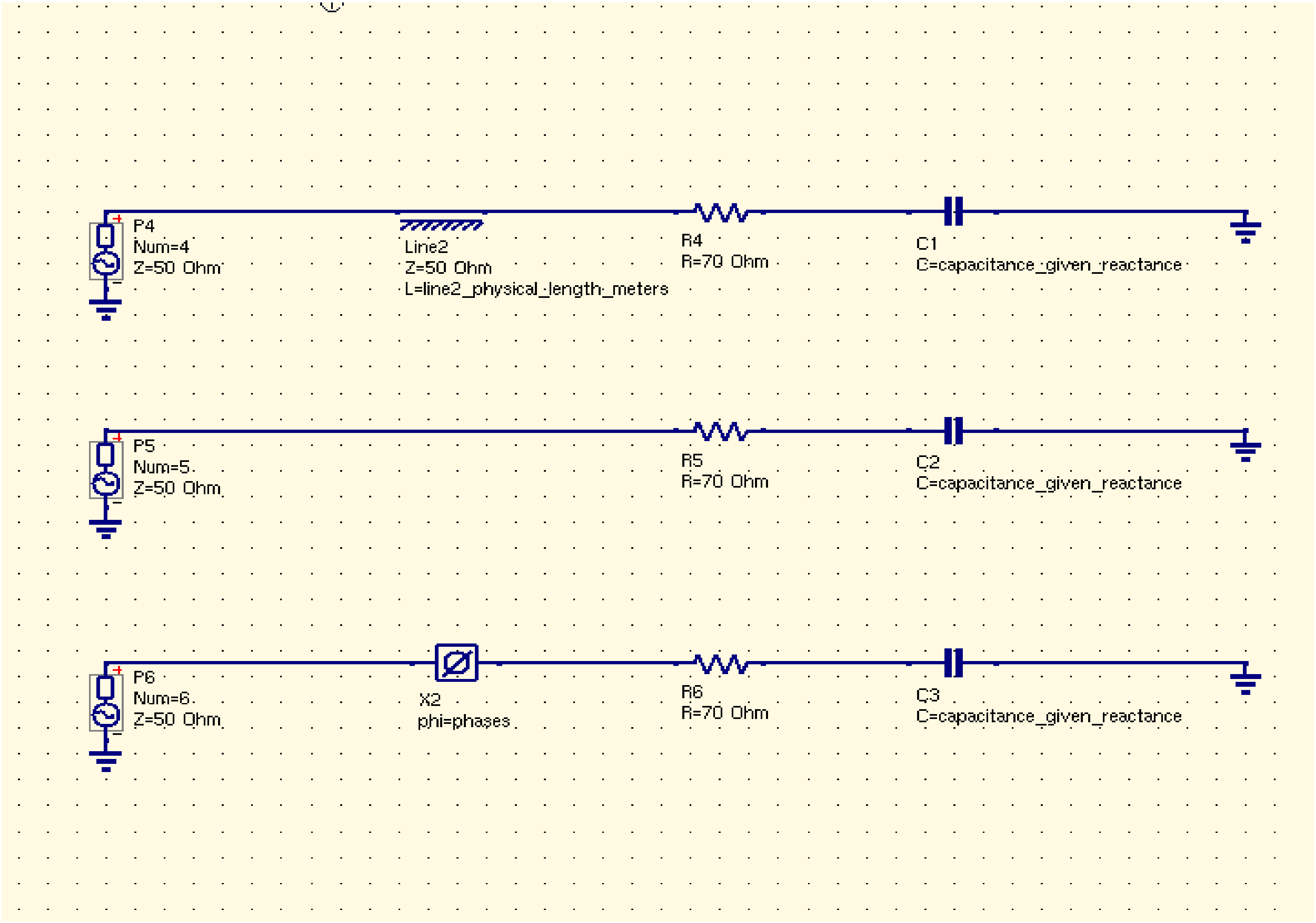
Simulate the circuit using the computer tool, and plot the result on the Smith Chart.

PC SIMULATION: CALCULATIONS AND DEFINITIONS

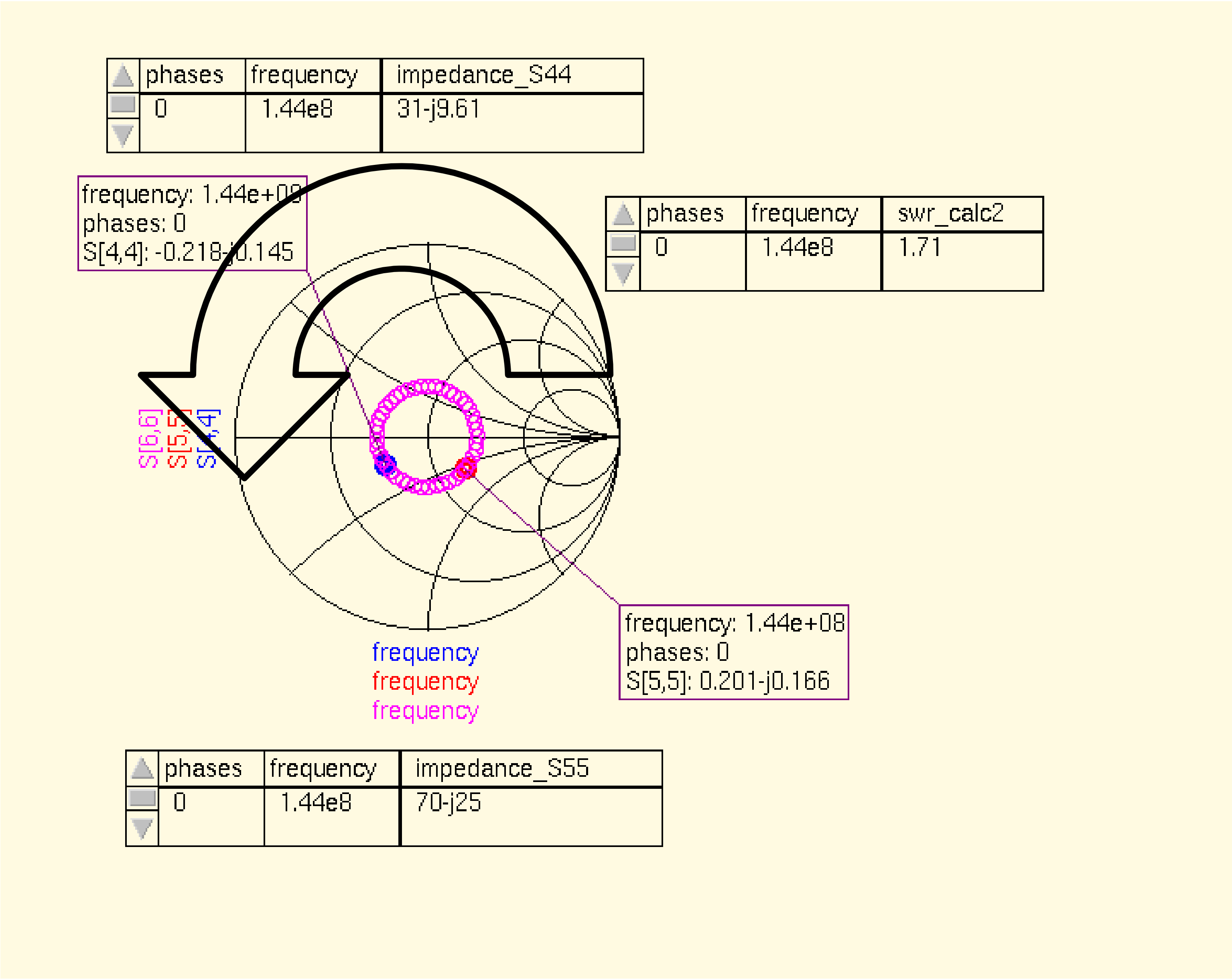
```
Equation
Eqn2
capacitance_given_reactance= 1/(2*pi*carrier_frequency_MHz*1E6*reactanceC_ohm)
line2_physical_length_meters=-2.35*wavelength_air_meters
reactanceC_ohm=25
swr_calc2=rtoswr(S[6,6])
impedance_S44=rtoz(S[4,4])
impedance_S55=rtoz(S[5,5])
```

Using the computer simulation, negative cable lengths are possible. The negative value allows rotation along the SWR circle in the opposite direction.

PC SIMULATION: SCHEMATIC



RESULTS: SMITH CHART PLOT



Rotation along 50 ohm line “Toward Load” 2.35 (4 times + 0.35)

EXAMPLE CIRCUIT “C”

An exact half-wavelength thin-wire dipole has been constructed from basic physics equations (instead of the more appropriate 468/f(MHz) design equation).

Impedance data versus frequency for this antenna is plotted in a textbook for antenna engineers by Stutzman & Thiele.

Antenna is designed for 7.110 MHz.

For the following frequencies what is the impedance at the antenna feedpoint? 7.110 MHz, 14.110 MHz , and 18.110 MHz?

Simulate the circuit using the computer tool, and plot the result on the Smith Chart.

Try to design a simple inductance-capacitance matching circuit to improve the SWR, and plot the performance.

PC SIMULATION: SCHEMATIC 7.11 MHz, 73 + j 30 Ohms

Equation

Eqn1
carrier1_frequency_MHz=7.110
wavelength_air_meters=speed_of_light/(carrier1_frequency_MHz*1E6)
speed_of_light=3E8
inductance1_given_reactance=reactance1L_ohm/(2*pi*carrier1_frequency_MHz*1E6)
line_physical_length_meters=0.0*wavelength_air_meters
reactance1L_ohm=30
swr_calc=rtoswr(S[3,3])
impedance_S11=rtoz(S[1,1])
impedance_S22=rtoz(S[2,2])

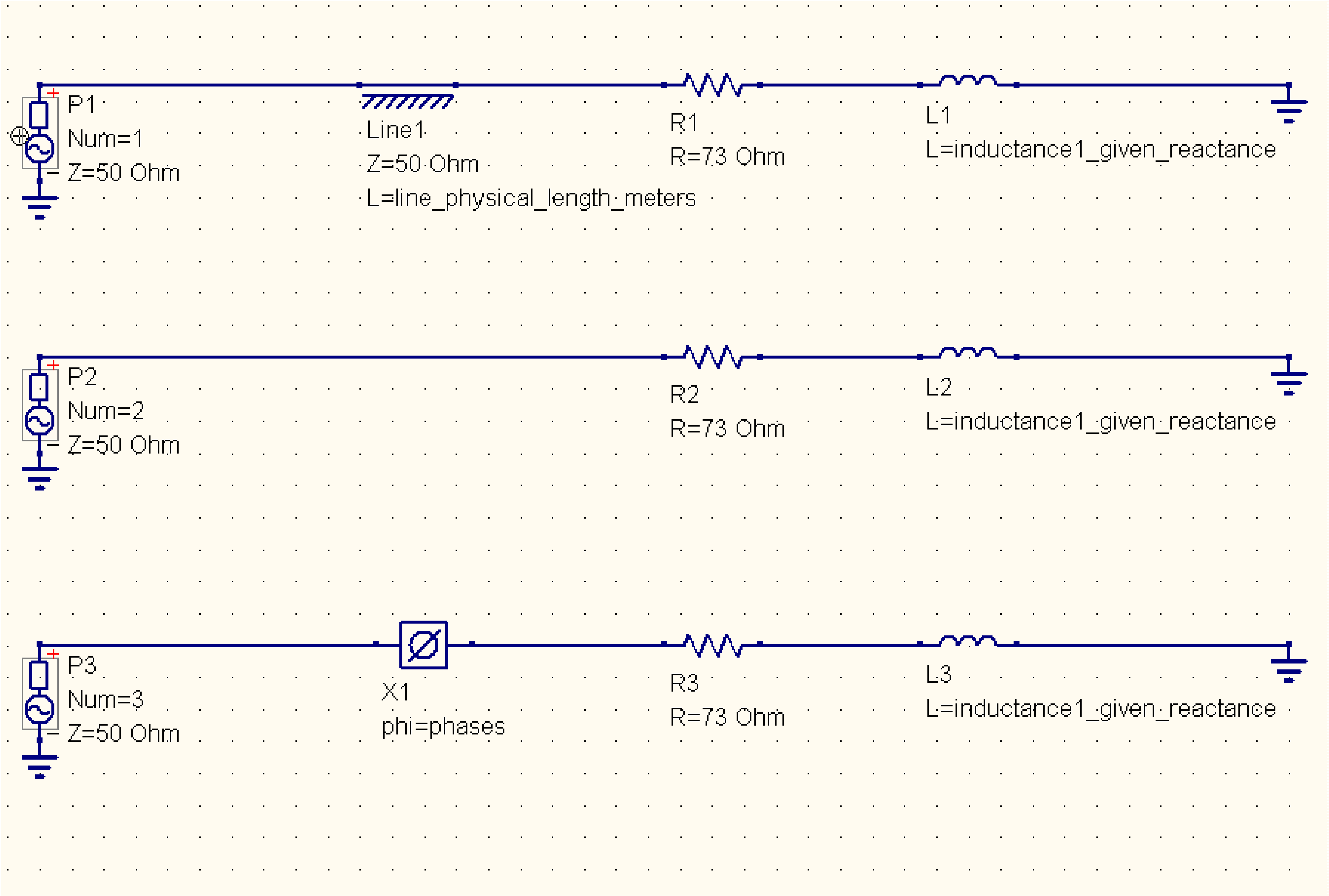
S parameter simulation

SP1
Type=const
Values=[7.11MHz]

Parameter sweep

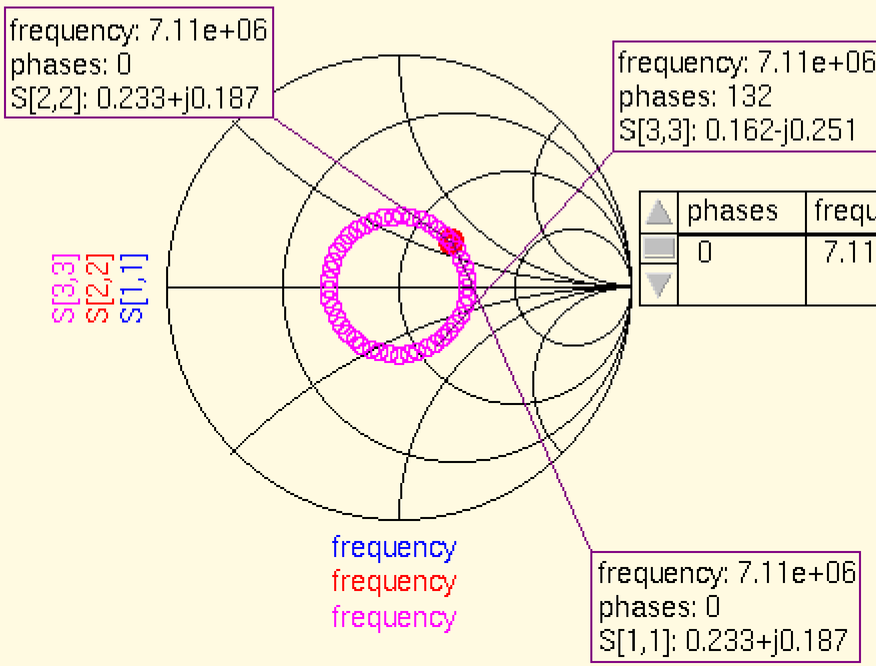
SW1
Sim=SP1
Type=lin
Param=phases
Start=0
Stop=180
Points=46

PC SIMULATION: SCHEMATIC 7.11 MHz, 73 + j 30 Ohms



RESULTS: SMITH CHART PLOT 7.11 MHz, 73 + j 30 Ohms

phases	frequency	impedance_S22
0	7.11e6	73+j30



phases	frequency	swr_calc
0	7.11e6	1.85

phases	frequency	impedance_S11
0	7.11e6	73+j30

PC SIMULATION: SCHEMATIC 14.110 MHz, 1700 – j 1500 Ohm

S parameter simulation

SP1
Type=const
Values=[14.11 MHz]

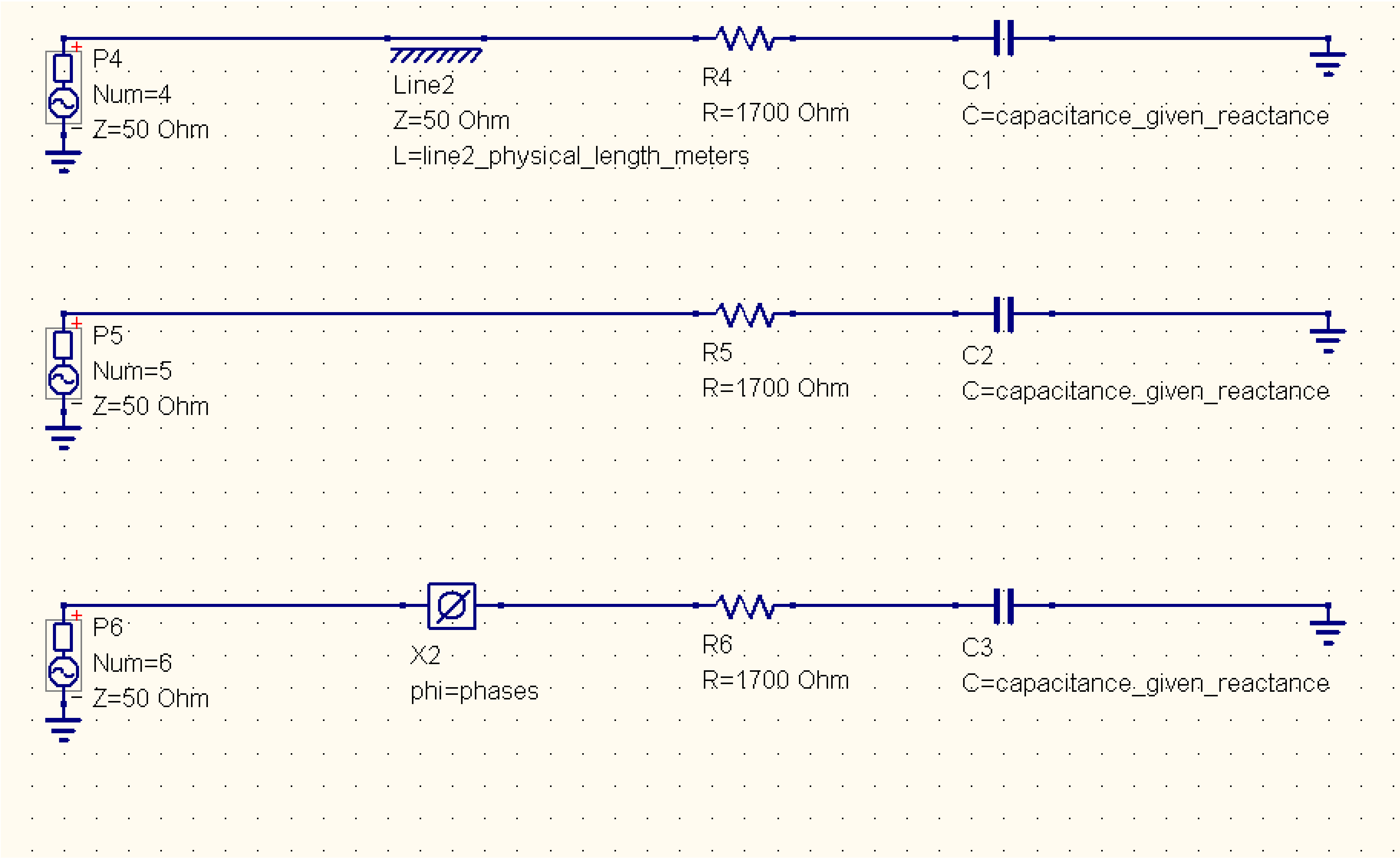
Parameter sweep

SW1
Sim=SP1
Type=lin
Param=phases
Start=0
Stop=180
Points=46

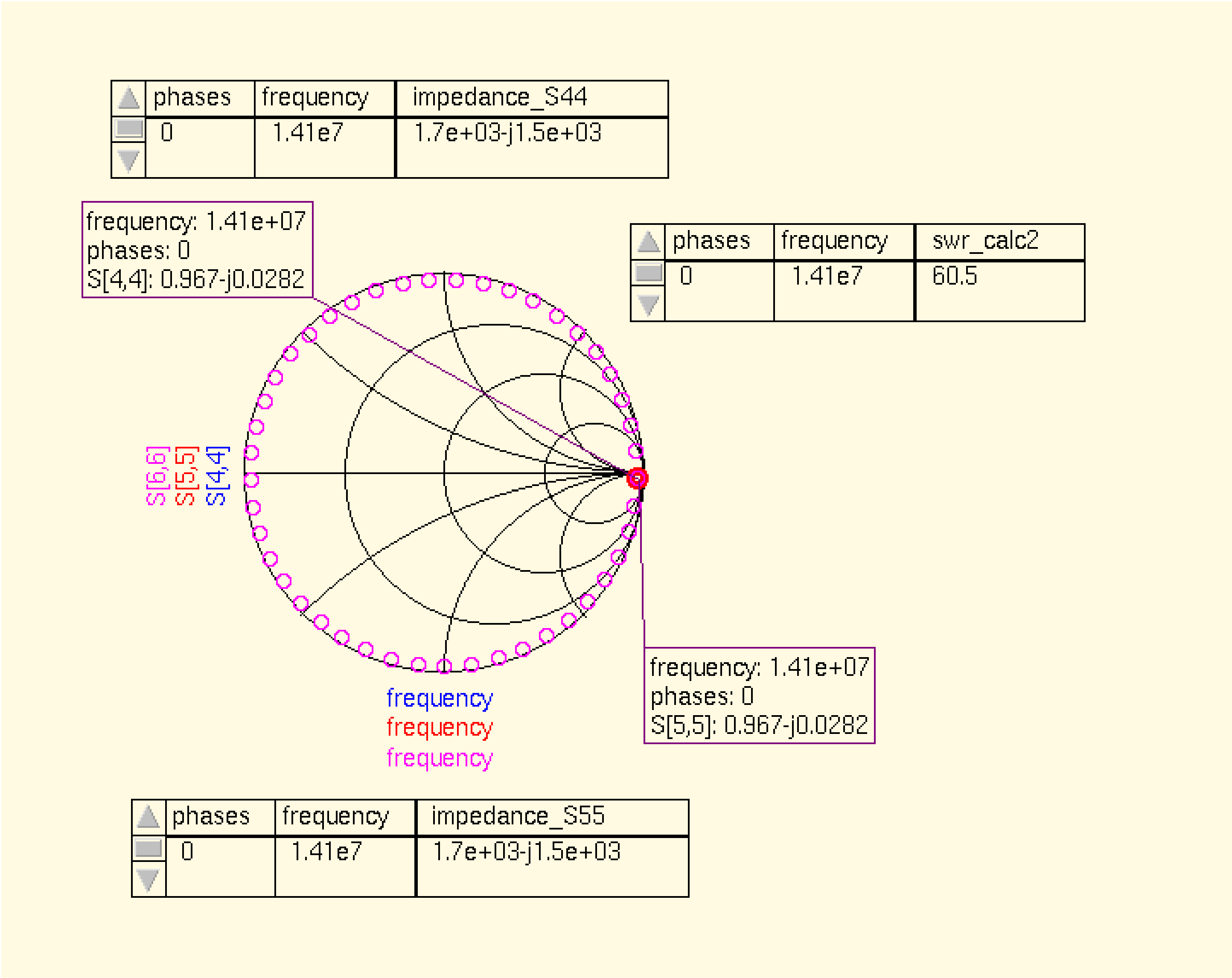
Equation

Eqn2
capacitance_given_reactance=1/(2*pi*carrier2_frequency_MHz*1E6*reactanceC_ohm)
carrier2_frequency_MHz=14.110
line2_physical_length_meters=0*wavelength_air_meters
reactanceC_ohm=1500
swr_calc2=rtoswr(S[6,6])
impedance_S44=rtoz(S[4,4])
impedance_S55=rtoz(S[5,5])

PC SIMULATION: SCHEMATIC 14.110 MHz, 1700 – j 1500 Ohm



RESULTS: SMITH CHART PLOT 14.110 MHz

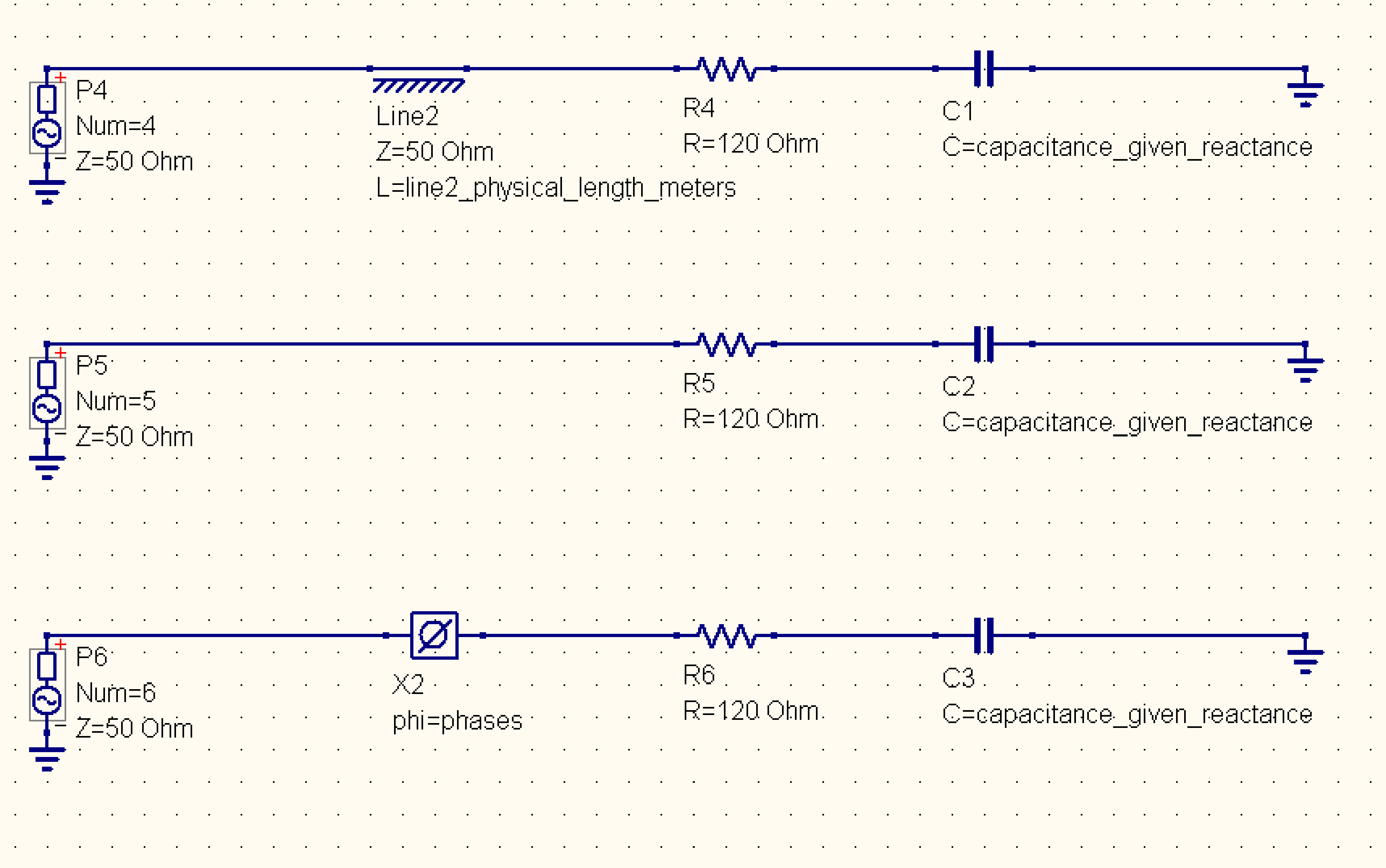


Matching this impedance to 50 ohms would be a challenge.
SWR 60:1

PC SIMULATION: SCHEMATIC 18.110 MHz, 120 – j 500 Ohms

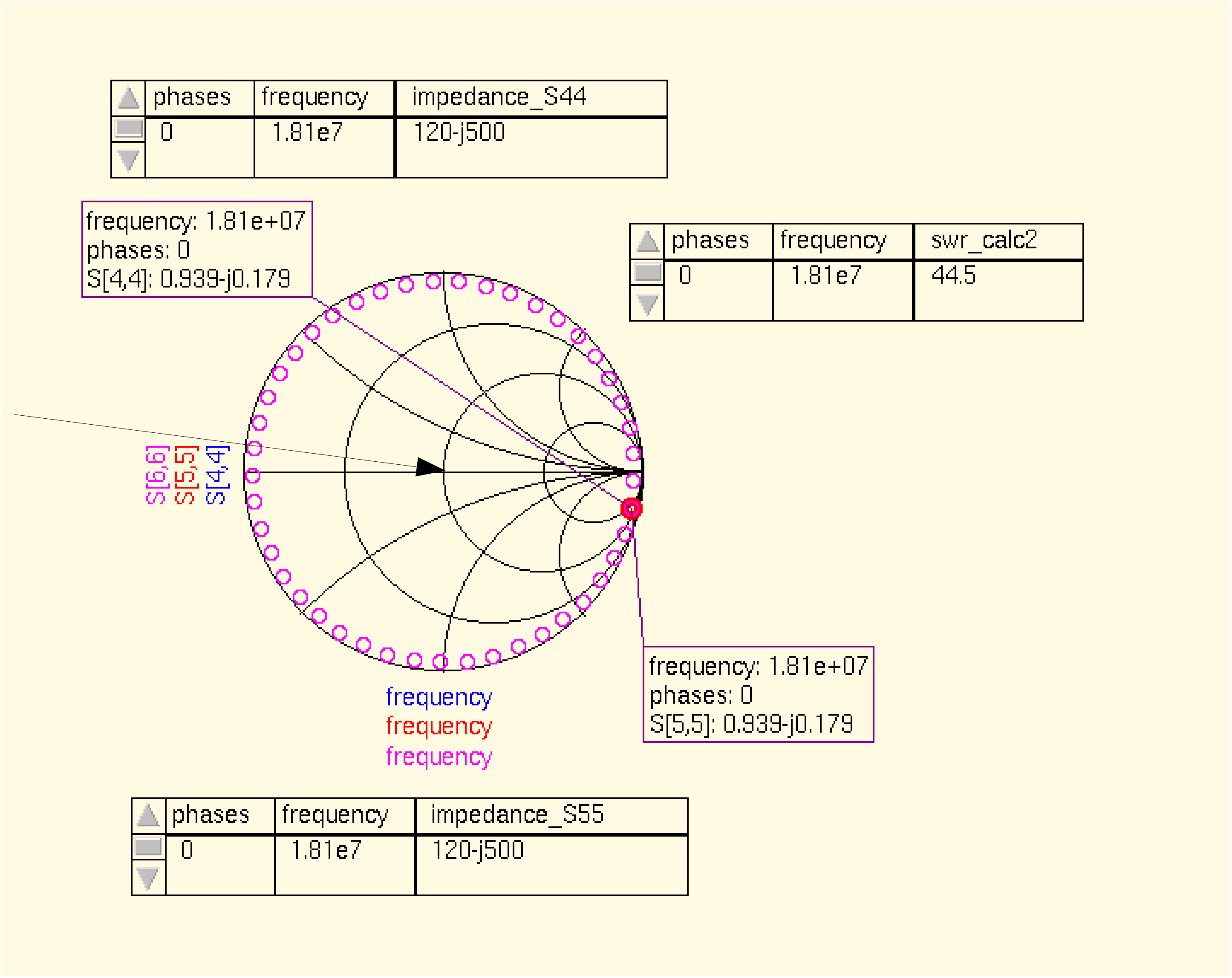
```
Equation
Eqn2
capacitance_given_reactance=1/(2*pi*carrier2_frequency_MHz*1E6*reactanceC_ohm)
carrier2_frequency_MHz=18.110
line2_physical_length_meters=0*wavelength_air_meters
reactanceC_ohm=500
swr_calc2=rtoswr(S[6,6])
impedance_S44=rtoz(S[4,4])
impedance_S55=rtoz(S[5,5])
```

PC SIMULATION: SCHEMATIC 18.110 MHz, 120 – j 500 Ohms



RESULTS: SMITH CHART PLOT 18.110 MHz

Need to match to here.



Matching this impedance to 50 ohms is not as severe as 14.11MHz. Here SWR 44:1. Try to design an L-C network.

PC SIMULATION: MATCHING NETWORK 18.110 MHz

S parameter simulation

SP1
Type=const
Values=[18.11 MHz]

Parameter sweep

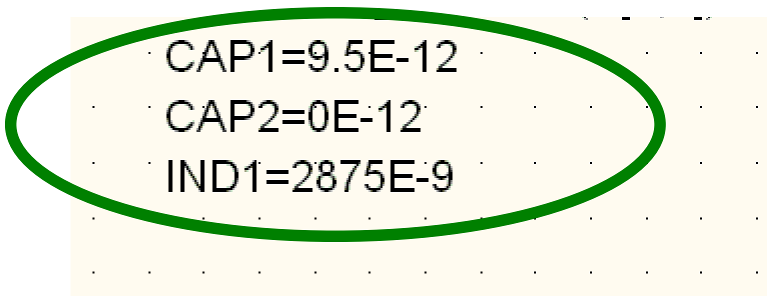
SW1
Sim=SP1
Type=lin
Param=phases
Start=0
Stop=180
Points=46

Equation

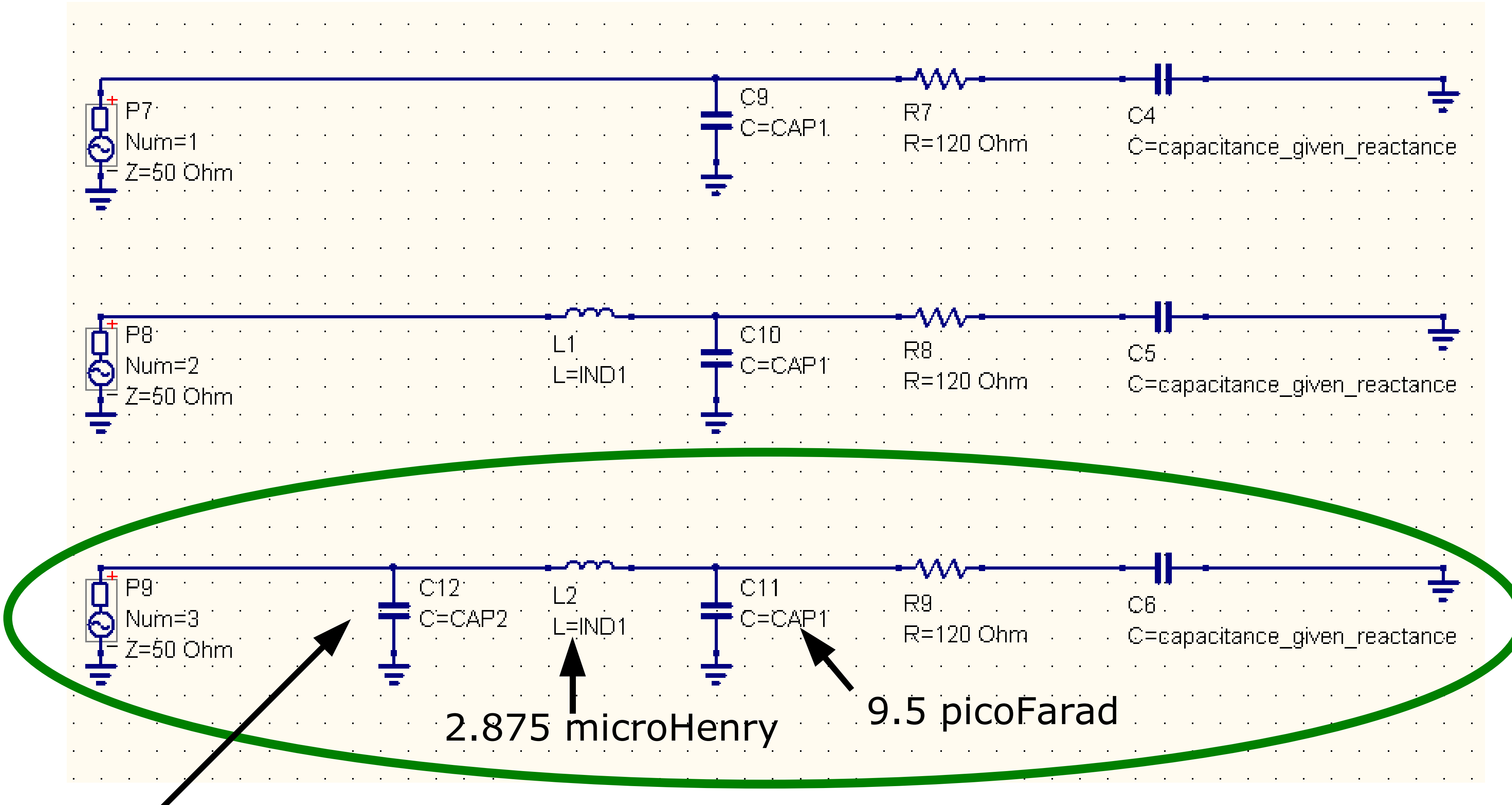
Eqn2
capacitance_given_reactance=1/(2*pi*carrier2_frequency_MHz*1E6*reactanceC_ohm)
carrier2_frequency_MHz=18.110
line2_physical_length_meters=0*wavelength_air_meters
reactanceC_ohm=500
swr_calc2=rtoswr(S[6,6])
impedance_S44=rtoz(S[4,4])
impedance_S55=rtoz(S[5,5])

PC SIMULATION: MATCHING NETWORK 18.110 MHz

Trial and error values of inductance and capacitance that produce a match for 18.110 MHz. Circuit shown on following page.

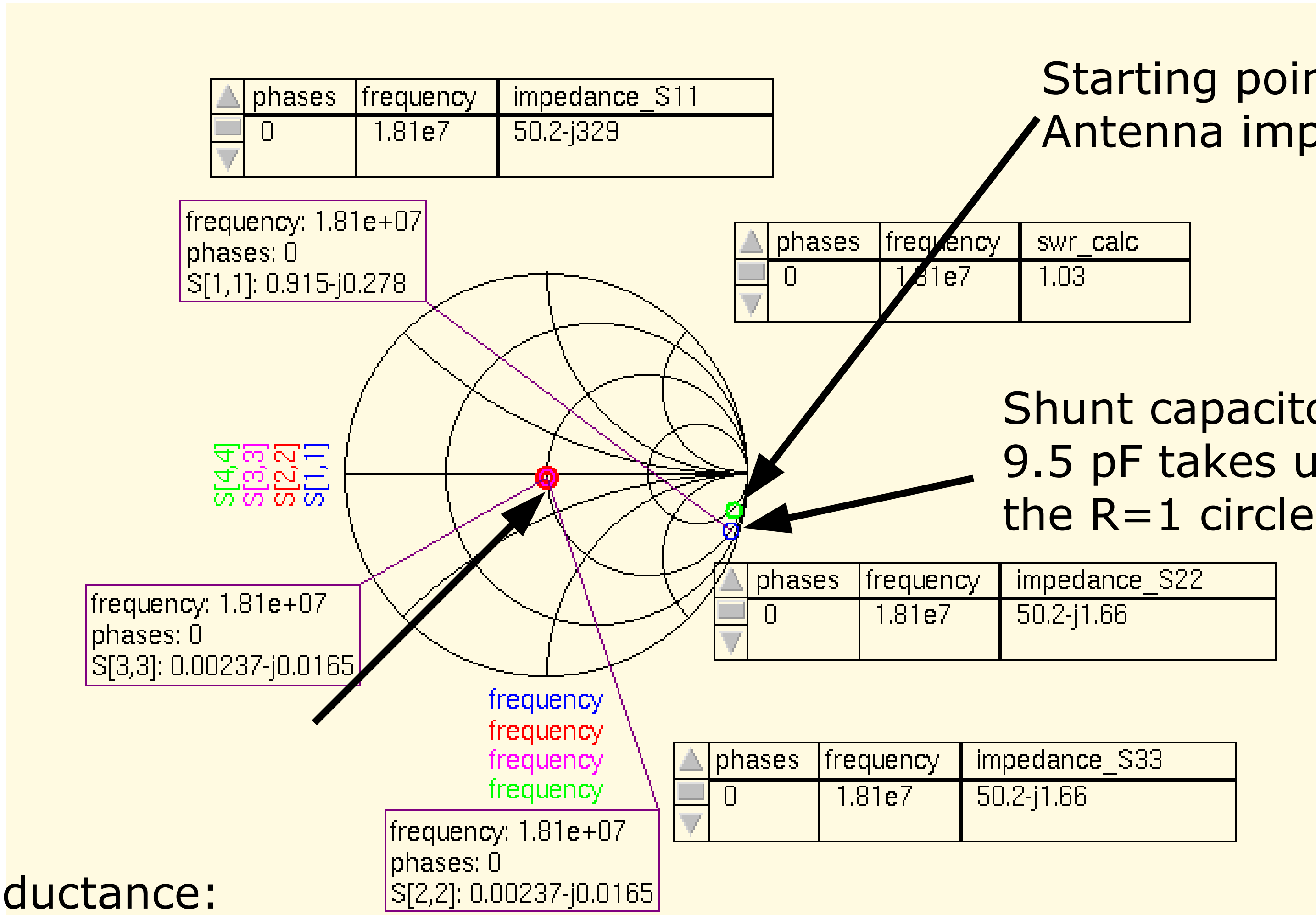


PC SIMULATION: MATCHING NETWORK 18.110 MHz



Zero picoFarad (in a real tuner, the radio-side variable capacitor is set to its minimum value)

RESULTS: SMITH CHART PLOT 18.110 MHz MATCHED



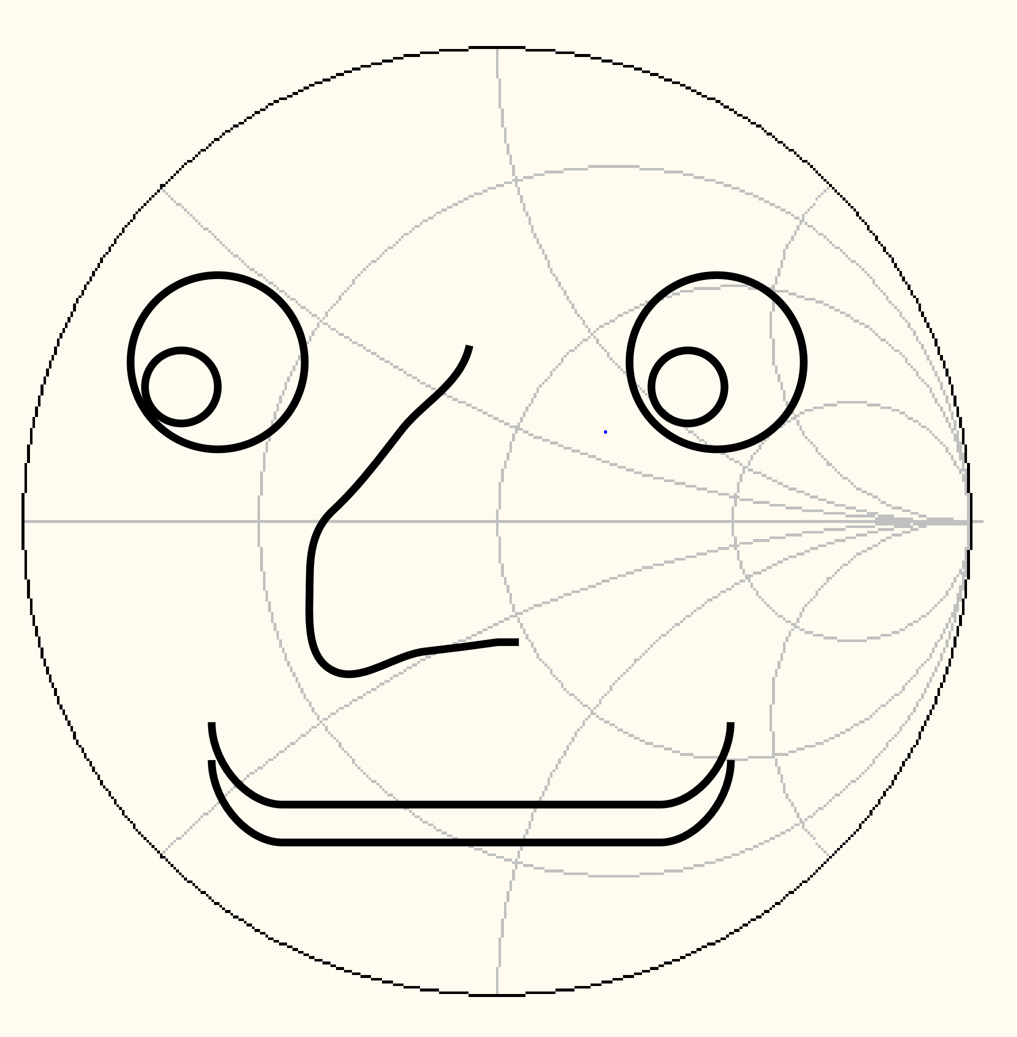
Starting point:
Antenna impedance.

Shunt capacitor:
9.5 pF takes us to the R=1 circle.

Series inductance:
2.875 μH takes us along the R=1 to the Z=1+j0 (X=0) chart center.

Z is normalized to the reference impedance 50 ohms.

Un-normalized impedance is 50 ohms.



THANKS!