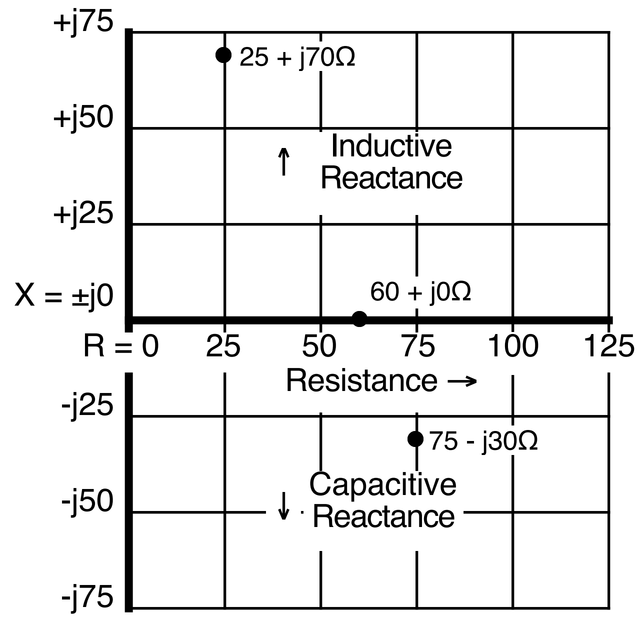
Bob's TechTalk #24
by Bob Eckweiler, AF6C

Impedance (Part IX of X)

The Smith Chart, an Overview:

Last month we discussed the RF Noise Bridge, a handy device for measuring impedance. But, if you're interested in the impedance at the antenna and make your measurements at the shack end of the feedline, you must calculate the impedance at the other end of the feedline. These calculations can be tedious unless you have a good programmable calculator or a computer with appropriate software handy. In 1939, way before computers were generally available, Philip H. Smith designed the **Smith Chart**, a graphic tool that allows an easy solution to the problem above, as well as many other feedline and matching problems.

A full discussion of the Smith Chart would overwhelm this newsletter for many months, so I will just try to introduce you to this tool and make its appearance a little less overwhelming. There are some fine articles that have been published on the using Smith Chart. Chapter 28 of the 18th edition of the *ARRL Antenna Handbook* is one. It is an update of the information that appeared in Chapter 3 of the 14th edition. I'm sure it can be found in many other editions too. It is, however, missing from some editions. Another good source is the long article in the November 1970 issue of *Ham Radio* by Jim Fisk–W1HR, (be sure to also read the comments in the December 1971 issue for some corrections by W2DU – the noted author of *Reflections II*.) This article was reprinted (in corrected form) in March 1978 issue of *Ham Radio*. The ARRL also has a two-part article from QST on their website (members only section).

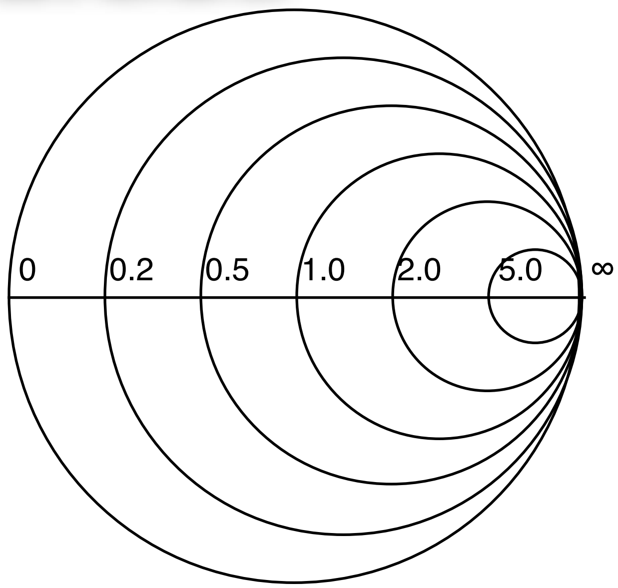


Impedance Graph (Z = R ± jX)
Figure 1

Figure one is a graph similar to the one in the March 2003 TechTalk article. It is a plot of impedance with resistance R on the horizontal axis and reactance jX on vertical axis. The vertical lines are lines of constant resistance and the horizontal lines are lines of constant reactance. To plot an impedance point such as 25 + j70Ω, locate 25 on the resistance axis; then move vertically along the line representing 25Ω resistance to where the +j70 line of constant reactance would be drawn from the vertical reactance axis.

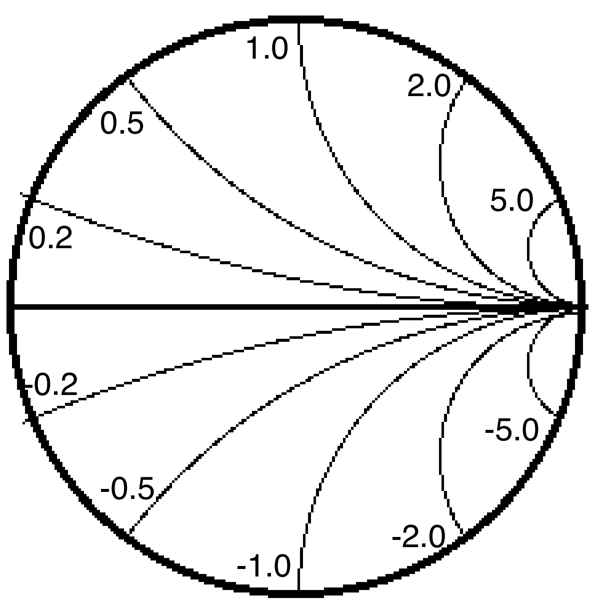
The Smith Chart also has a resistance and reactance axis. The resistance axis is the only straight line on the Smith Chart (this line is often called the **Axis of Reals**). The line is marked from zero on the left to infinity on the right. The midpoint of the line often has the value of one and represents the nominal impedance of the system.

Instead of vertical lines of constant resistance the Smith Chart has circles of constant resistance as shown in Figure two:

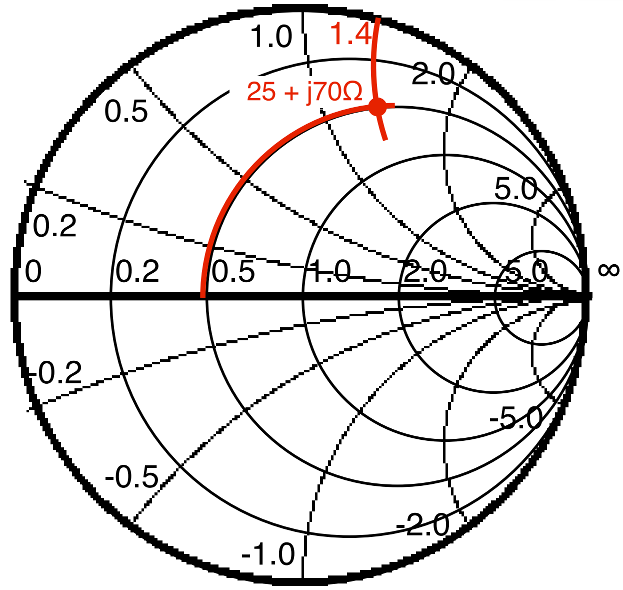


Circles of Constant Resistance
Figure 2

The reactance axis is the outside circle of the Smith Chart and its lines of constant reactance are segments of circles that meet the reactance axis as shown in Figure three. Notice that like the graph of Figure one, the reactance above the resistance axis is inductive (positive jX) and the reactance below is capacitive (negative jX).



Curves of Constant Reactance
Figure 3



Smith Chart - Combining Figs. 2 & 3 (with 25 + j70Ω plotted after being normalized to 0.5 + j1.4Ω)
Figure 4

Figure four shows a very basic Smith Chart that combines figures two and three. You may want to take a moment to download and print from the web a detailed Smith Chart. One is available at:

http://www.ife.ee.ch/~ichsc/smith_charts/smith2.pdf

Normalization:
The point directly in the center of the Smith Chart represents the nominal impedance of the system (feedline). Depending on which type of feedline we're using, this point can represent the nominal impedance of 50 ohm coax, 75 ohm coax, 600 ohm open-wire feed, etc. To make a specific chart for each feedline impedance would be impractical, so many Smith Charts are **normalized**. They are designed so that the center point represents 1 + j0 Ω. Before plotting your values on such a Smith Chart, you normalize all your data by dividing the resistance and reactance values by the nominal impedance. For example, say we are working with 50 ohm coax and want to plot 75 - j100Ω. We divide each part by 50

and plot 1.5 - j2Ω. Similarly, when reading from the chart you **denormalize** the data by multiplying both parts by 50. Let's plot 25 + j70Ω as we did on the previous chart. First we normalize for a 50 ohm system by dividing the resistance and the reactance terms by 50, getting: 0.5 + j1.4. Find 0.5 on the resistance axis and move up the circular line till you intercept where the 1.4 line would be on reactance axis (outside circle). This point is shown on Figure 4.

Distance in Wavelengths from Antenna	Impedance at this Point for loss less 72Ω coaxial cable
0	57.6 - j43.2
1/16	40.4 - j21.4
1/8	36.0 + j0.0
3/16	40.4 + j21.4
1/4	57.6 + j43.2
5/16	100.0 + j53.0
3/8	144 + j0.0
7/16	100.0 - j53.0
1/2	57.6 - j43.2

Table I: From *Bob's TechTalk #18*

In the June 2003 of TechTalk we listed the impedance at various places along a length of lossless 72 ohm coax in steps of one-eight wavelength from an antenna with a feedpoint impedance of 57.6 - j43.2 ohms (Which represents an SWR of 2.0:1). It is repeated in Table I, adding steps at one-sixteenth of a wavelength: Table II shows these impedances normalized to 50Ω.

Figure five shows these points plotted on our crude Smith Chart. Notice that the points form a circle with the same center as the chart, and fall in a clockwise direction. This circle is called an SWR circle. Its diameter represents the magnitude of the SWR. Notice also that the points form a complete revolution around the SWR circle. One revolution is equal to one-half wavelength – remember that the impedance repeats every half-wavelength along a length of lossless feedline.

Pt.	Impedance	Normalized Impedance
A	57.6 - j43.2	0.80 - j0.60
B	40.4 - j21.4	0.56 - j0.30
C	36.0 + j0.0	0.50 + j0.00
D	40.4 + j21.4	0.56 + j0.30
E	57.6 + j43.2	0.80 + j0.60
F	100.0 + j53.0	1.39 + j0.74
G	144.0 + j0.0	2.00 + j0.00
H	100.0 - j53.0	1.39 - j0.74
I	57.6 - j43.2	0.80 - j0.60

Table II: Normalized Impedance Points

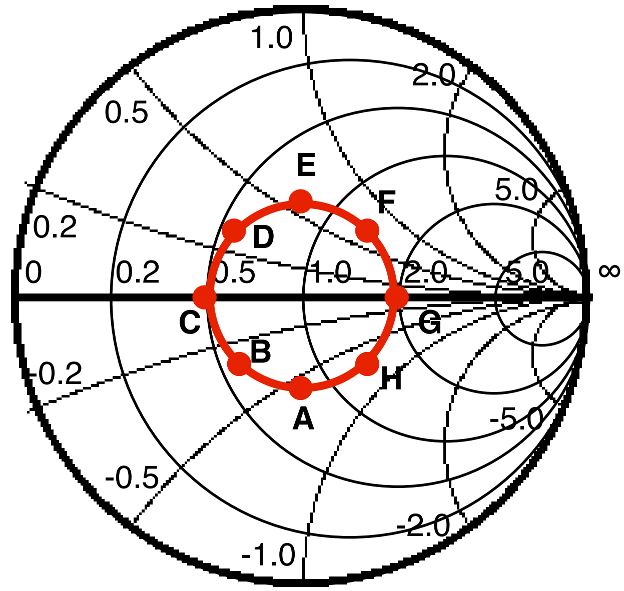


Figure 5 – Plot ot Table One: Constant SWR Circle Plot

A Smith chart has scales marked around its circumference (not shown). Two of interest are marked from zero to 0.50 wavelength for the complete circle. One is in the clockwise direction and is marked **Wavelengths Towards Generator**. The other is in the counterclockwise direction and is marked **Wave-**

lengths Towards Load. (Think of Transmitter as the generator and Antenna as the load).

Should the coax have losses, then the SWR circle would be a spiral of decreasing diameter towards the center of the chart. The higher the losses the steeper would be the inward spiral. This logically corresponds with the fact that, due to losses, the SWR appears lower when measured at the transmitter end than when measured at the antenna.

There are so many problems you can solve with a Smith Chart. Let's say your feedline is 2.33 wavelengths long (electrically - don't forget to correct for the coax's propagation velocity) at your favorite operating frequency. You measure the impedance at the shack end of your 50Ω coax as 45 - j10Ω (using your trusty noise bridge). You want to know if you have to lengthen or shorten your dipole to bring it to resonance. Since the impedance repeats (ignoring losses) every half wavelength you can subtract multiple half-wavelengths from the length of your feedline until it becomes less than a half-wavelength; you will end up with 0.33 wavelengths. Next, normalize and plot the measured point on the Smith Chart (0.9 - j0.2Ω). With a compass, draw an SWR circle through this point with the center of the chart as the center of the circle. Next draw a straight line from the center of the chart, through the plotted point and out to the scales at the circumference. Chose the "Wavelengths Towards Load" scale (The antenna is the Load) and read the scale: 0.096 wavelengths. Add to this the 0.33 wavelengths to get 0.426 wavelengths and find that value on the "Wavelengths Towards Load scale". Draw a line from this point to the center of the chart. Where this line intercepts the SWR circle you drew earlier read the normalized impedance at the antenna: 0.85 + j 0.16 (neglecting losses). You can denormalize this value to 42.5 + j 8.0Ω. Since the reactive term (j8.0) is positive, the antenna is inductive and needs to be shortened. We ignored losses in this example because it didn't affect our problem, however if you know your feedline loss, you can take it easily into account utilizing one of the auxiliary scales that are part of the Smith Chart. This is covered well in the sources listed earlier.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the December 2003 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.