What is Impedance Matching?

Impedance matching is the act of tuning the complex/real/imaginary input (and/or output) impedance to minimize reflection and/or to achieve maximum power transfer (under conjugate matching conditions).

To break down this concept further, let's take another grossly oversimplified example as we've done many times throughout this book. Say I have a lightbulb, a black box, and a battery. The battery has an output of 5W and the lightbulb requires 5W to operate. Say I hook up the 5W battery to the 5W light bulb without the black box, but it barely turns on because it's only getting 1W. What gives?

In terms of RF, the 5W battery represents the generator, the 5W light bulb represents an arbitrary load, and the wires represent the transmission line from the generator to the load. This outcome represents the basic effect of a mismatched transmission line where not all of the available power from the generator is utilized for the load due to voltage and current wave reflections on the line. Now, let's say we add this black box to the previous scenario. I hook up this magical black box and all of a sudden, I've got 5W of power to my 5W light bulb! In this scenario, the circuit is now matched to the load and the maximum power from the generator is being utilized. How? The impedance of the generator (battery) is matched to the impedance of the load (the lightbulb) via some arbitrary impedance matching transformer (the black box). There is little to no reflection coming back towards the generator. More power can reach the lightbulb!

This box can contain many things, but at its core, the box is a collection of inductance, capacitance, resistance, and reactance cleverly arranged to create the necessary impedance transformation. In this chapter, we will be reviewing different impedance matching techniques to match the source (generator) and load impedance via distributed elements, open stubs, short stubs, and quarter wave transformers. There are many more techniques to impedance match a circuit, but these are the ones the reader should nail before mastering other techniques.

The Smith Chart

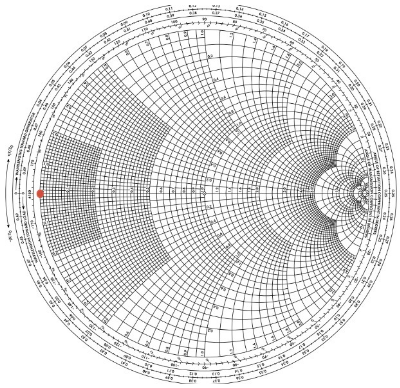
The Smith Chart has been the most dominant tool for microwave engineers since 1939 thanks to Phillip Smith - an engineer at Bell Laboratories studying transmission lines for AM broadcasting. Since analytical impedance matching can be time-consuming and complicated, Philip Smith wanted to create a visual tool for RF engineers to use to quickly solve impedance matching circuits related to signal reflection on transmission lines via a visual representation of complex impedances. Needless to say, RF Engineers owe a lot to Philip Smith as the Smith Chart is an extraordinarily powerful tool for design and network analysis.

Important Smith Chart Areas and Basic Plots

The Smith Chart can be pretty daunting at first glance. There's a lot of circles, a lot of lines, and a lot of numbers.

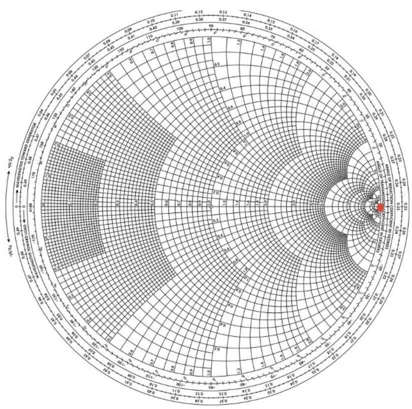
Remember the special cases for the load impedance described in Chapter 2? The load impedance short, open, and load are important areas to know on the Smith Chart.

A pure short is located on the very far middle left of the Smith Chart at $z = 0$



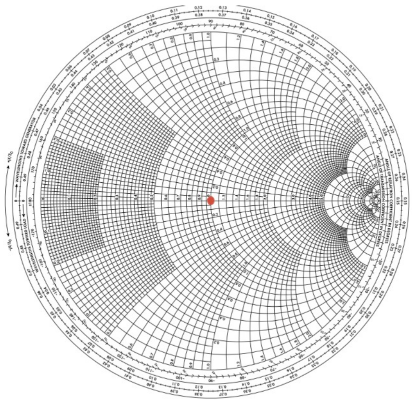
Short Circuit Location

A pure open is located on the very far middle right of the Smith Chart at z = ∞



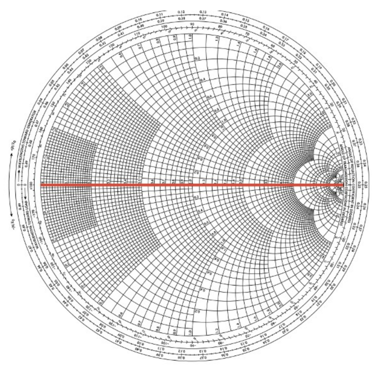
Open Circuit Location

A pure impedance match is located right in the middle of the smith chart at z = 1



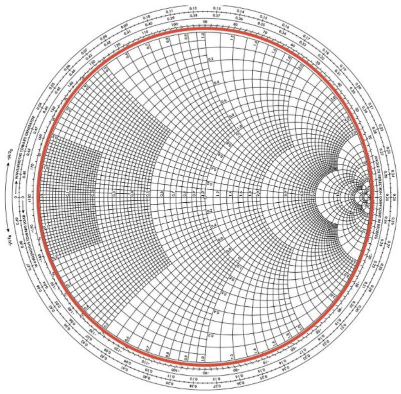
Perfect Match Location

For plotting complex impedances on the Smith Chart, it's important to first understand the real and imaginary axis/circles on the Impedance Smith Chart. The PURELY real axis runs horizontal right across the middle of the Smith Chart:



Purely Real Axis

The imaginary axis circles around the Smith Chart.



Purely Imaginary Axis

If the impedance is purely real, the impedance point will be located on the horizontal axis. If the impedance is purely imaginary, it will be located on the perimeter of the Smith Chart. If the impedance is complex, meaning there is a real AND imaginary component, the impedance point will be located somewhere in between.

The bottom half of the Smith Chart represents a capacitive impedance and the upper half of the Smith Chart represents an inductive impedance. Depending on where the normalized impedance is on the Smith Chart, you will either need to add inductance or capacitance to the circuit to obtain a perfect match. For example, if the normalized impedance is located on the bottom half of the Smith Chart (capacitive), you will need to add inductance to the circuit - going upwards towards the purely real axis. If the normalized impedance is located on the upper half of the Smith Chart (inductive), you will need to add capacitance to the circuit - going downwards towards the purely real axis.

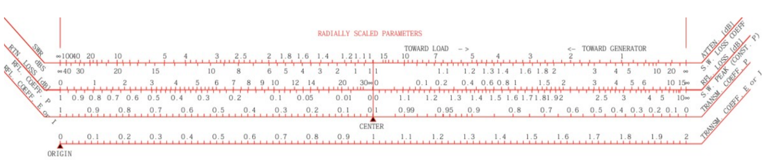
Speaking of design, it's very important to know *which way* to orient a stub - either putting the stub with the wavelength facing towards the generator (source) or putting the stub with the wavelength towards the load. For wavelength towards load, the orientation is counterclockwise and for wavelength towards generator, the orientation is clockwise around the Smith Chart (following the wavelength-towards-generator convention used in this chart). Since the Smith Chart is a polar plot, it's also possible to locate the phase of either the reflection or transmission coefficient by using the "Angle of Reflection Coefficient in Degrees" or by using the "Angle of Transmission Coefficient in Degrees" axis.

It's also important to note the wavelength increments in relation to the "Wavelength Towards Generator" and "Wavelength Towards Load":

- 0.5λ is one full rotation around the Smith Chart.
- 0.25λ is half a rotation around the Smith Chart.
- 0.125λ is a quarter rotation around the Smith Chart

Since stubs (like open and short stubs) utilize admittance, it's also important to understand the normalized admittance Smith Chart (which is really just an inverted Smith Chart). Sometimes, the two charts are overlaid to minimize the use of using two different charts. When starting out in design, I would recommend utilizing the impedance Smith Chart to first plot the normalized impedance coordinate and then utilize the overlaid normalized impedance and admittance coordinate Smith Chart to tune the stub.

At the very bottom of most Smith Charts, there are the SWR, dBs, Return Loss, Reflection Coefficient magnitude, attenuation, and Transmission Coefficient lines.



3.1 Basic Smith Chart Plotting and Information

So, how exactly do we utilize this chart? The first step to utilizing the Smith Chart is to highlight important areas. So far, we've highlighted the open, short, and load points as well as where the purely real axis, purely imaginary axis, constant resistance, and constant admittance circles lie. We also are now familiar with our wavelength orientations, wavelength towards generator and wavelength towards load. The second step in utilizing the Smith Chart is to practice plotting normalized impedances. We will get to designing stub networks shortly, but if you walk before you can run with the Smith Chart, you are likely going to fall on your face and make some big mistakes along the way. I am a prime example of this. When I was studying undergrad at WNEU as a Junior, I had a design project I had to complete in my Electromagnetic Fields and Waves class. Instead of practicing plotting on the Smith Chart, I went straight into designing the circuit outlined in the design project. Needless to say, my RF simulation failed dramatically and I was up until 4AM staring blankly at the 15 plus Smith Charts and simulation wondering where I:

1. Went wrong with my life
2. Why my design wasn't working

Turns out, I messed up from the start, because I wasn't plotting normalized impedance correctly. I then practiced my plotting skills and everything fell into place shortly afterwards. Practice plotting before you design.