Technical Article

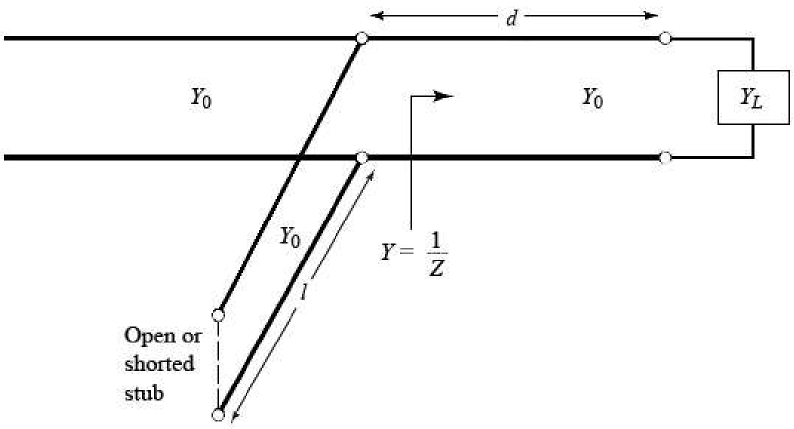
Learn Stub Tuning with a Smith Chart

October 09, 2015 by Benjamin Crabtree

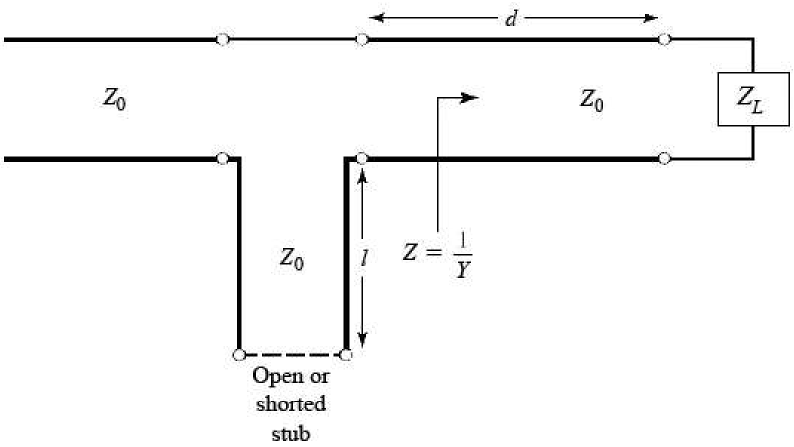
Overview of stub tuning examples using the Smith chart to match RF lines to various loads. Having the ability to design these matching circuits on the fly can be very handy if you ever find yourself working in the RF field both because it can be faster than calculation, as well as being a great tool for visualizing what is going on.

Learn the secrets to becoming a stub tuning wizard.

In RF engineering, it is critical to have a waveguide line matched to its load; this minimizes signal loss, maximizes power handling, and ultimately will give the best performance out of any given RF circuit. This can be accomplished using a variety of different methods and components, each suited towards specific applications. This of course leads to the inevitable and age-old dilemma of the engineer where we will have to balance the best possible solution with the cheapest possible implementation. Stub tuning is one method that satisfies both of these criteria; stub tuning is simply the process of adding a length of transmission line to the existing length in either series, shunt, open circuit, or short circuit configuration to match the line to the load. This occurs by placing a specific length of stub a specific distance away from the load. The image below depicts the basic layout of stub tuners from Pozar's Microwave Design:



(a)



(b)

Stub tuners are simple to implement and cheap to manufacture: they only require more of the same material used to make the transmission line. Because of this, one of the primary places an engineer will encounter stub tuners is in printed circuit boards using microstrip-line waveguides. The stub can simply be fabricated onto the PCB along with the rest of the circuit. The goal that stubs are designed to accomplish is to cancel out the reactive component of the load to be matched, thus they will only work at a specific frequency. Special stub circuits can help increase this otherwise narrow bandwidth which we will discuss later on.

Design

The design specifications for stub tuners can be found analytically, but an engineer has a tool at his disposal that can be used to solve these problems much faster: the Smith chart. For the purposes of this article we will assume that the reader is already familiar with using a Smith chart and the focus of this article will be the application of the Smith chart to stub tuning. That being said, we will take a look at each of the stub tuning configurations using sample problems; solved using the Smith chart.

Shunt Stub Tuning

Say we have a 75Ω line but our load is 100+j80Ω; we will need to add a stub to match these lines, adding a length of transmission line to cancel out the reactive j80 from the unmatched load.

Series Stub

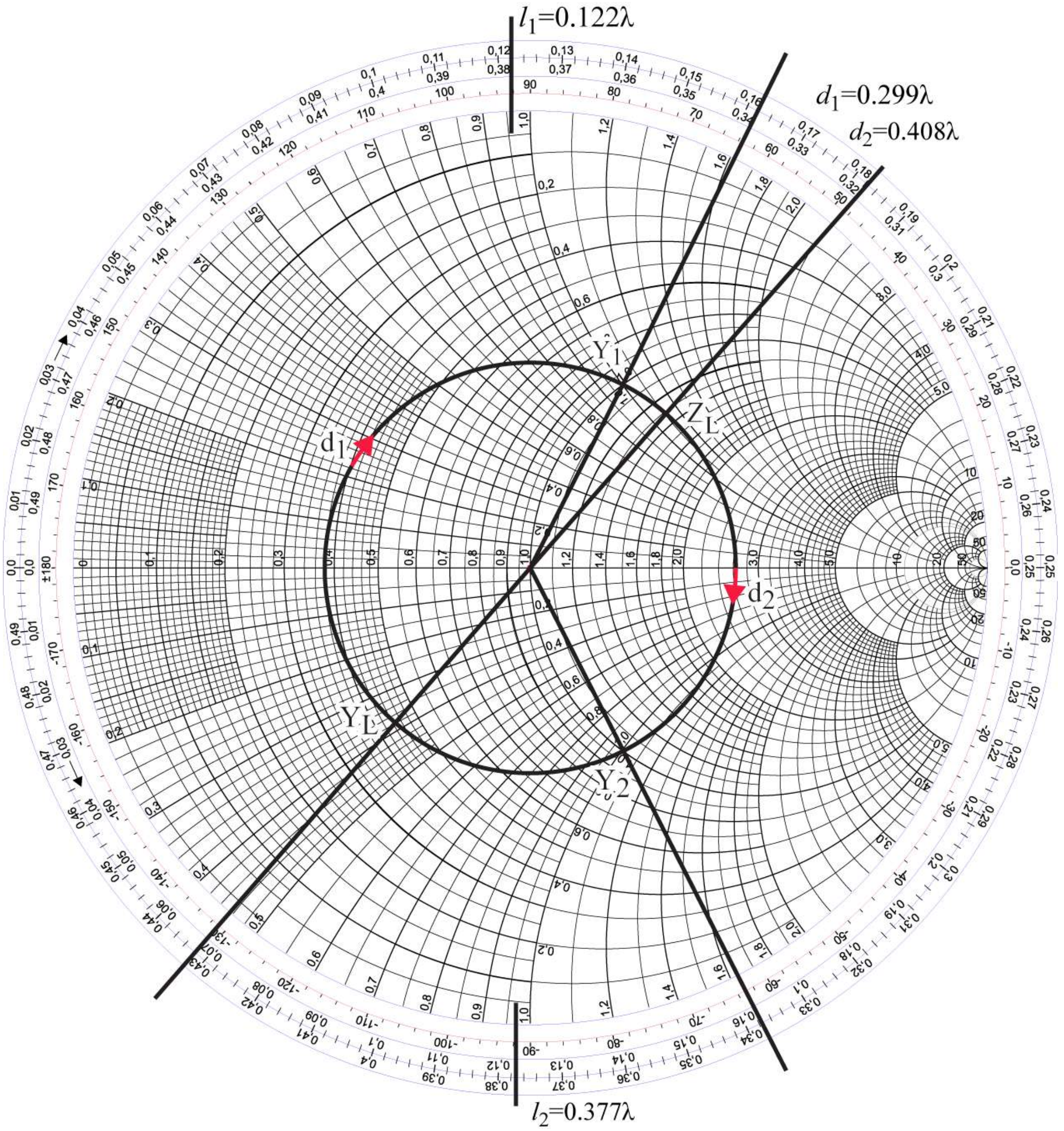
Shunt stubs are by far the most common arrangement, so we will look at these first. Like the name implies, a shunt stub of some unknown length will be placed in parallel with the transmission line at some point near the load, the parameters of which we will generate using a Smith chart.

Open Circuit:

Begin by normalizing the impedance parameters:

$$\frac{100 + j80\Omega}{75\Omega} = 1.333 + j1.067$$

Plot this zL on the Smith chart and use a compass to create an SWR circle. This circle will intersect with the *1+jb* circle at two points. For shunt stubs we will use the Smith chart as an admittance chart, so mark the inductive reactance component (upper side) y1 and the capacitive reactance component (lower side) as y2. Use a ruler to draw a line from zL through the center of the circle to the far edge of the chart; the intersection point with the SWR circle should be marked yL for the admittance component we will need to cancel out the inductive reactance. Draw line from the center through y1 and y2 outward to the edge of the chart. The arc between yL and y1 (wavelength toward generator- WTG) is d1, our first solution for the distance from the load to the stub. On the chart below I measured 0.229λ.



The second solution, d2, is measured from yL to y2 WTG. I measured 0.408λ as shown on the chart. To get the possible lengths of our stub we will look at the reactive axis of y1 and y2. Follow this point on the reactive axis as it curves outward toward the edge of the chart and draw a line normal (perpendicular) to the edge of the chart. This point for y1 is *L1*, and likewise for y2 and *L2*; measuring these lengths is easy, start from the short circuit edge and simply read the WTG scale at *L1* and *L2*. I measure *L1* to be 0.122λ and *L2* to be 0.377λ

You may be asking, why two solutions? In actuality, it's not just two solutions, but infinite solutions, with more found every time you go around the chart and hit those length marks. As a general rule, the shortest d and *L* pair will have the best bandwidth as it will be the least sensitive to frequency variation, but this is not always the case. The only way to be sure is to simulate it or verify experimentally. Now that we have our Smith chart solution, let's take a look at how close we are:

Using analytical equations for this circuit we get:

$$t = \frac{X_L + -\sqrt{R_L[(Z_0 - R_L)^2 + X_L^2]/Z_0}}{R_L - Z_0}$$

$$t = \frac{80 + -\sqrt{100[(75 - 100)^2 + 80^2]/75}}{100 - 75} = 7.071\,or\;-.671$$

so the possible stub positions are:

$$d_1 = \frac{\lambda}{2\pi}\tan^{-1} t = 0.2276\lambda$$

$$d_2 = \frac{\lambda}{2\pi}(\pi + \tan^{-1} t) = 0.4059\lambda$$

and the stub susceptances we need are:

$$B = \frac{R_L^2 t - (Z_0 - X_L t)(X_L + Z_0 t)}{Z_0[R_L^2 + (X_L + Z_0 t)^2]} = +/-0.0129$$

Scroll to continue with content

finally giving us our lengths of:

$$l_1 = \frac{-\lambda}{2\pi}\tan^{-1}(B_1 Z_0) = 0.3776\lambda$$

$$l_2 = \frac{-\lambda}{2\pi}\tan^{-1}(B_2 Z_0) = 0.1224\lambda$$

This tells us that the solutions obtained from the Smith chart are very close and that it saved us from having to go through all that math to get an answer we can work with to design our circuit.

Short circuit:

If we want to get the values for a short circuit stub, we have already done all the work on the smith chart; we just need to read it from the open circuit side. Doing so you should simply get $L1 = 0.128\lambda$ and $L2 = 0.373\lambda$.

Series Stubs

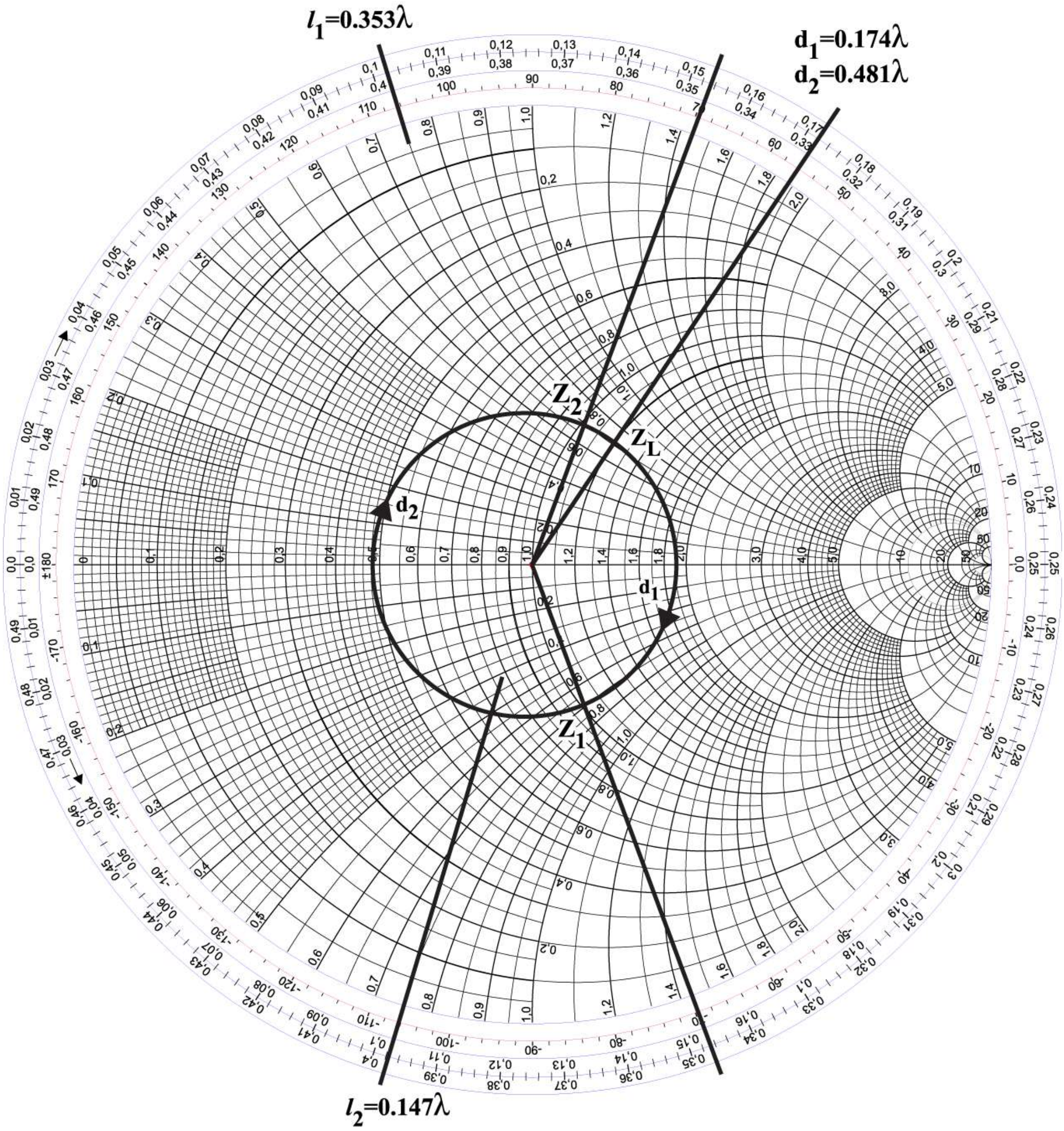
In this example we will be matching a 75Ω line to a load that has an impedance of 90+j60Ω.

Open Circuit:

Beginning with open circuit stubs again we must first normalize the impedance parameters:

$$\frac{90 + j60\Omega}{75\Omega} = 1.2 + j0.8$$

With these in hand, the process is almost identical to the shunt stub Smith chart, only this time we are treating the chart as an impedance chart. This makes life a little simpler as we do not have to use admittance parameters. Label the points on the chart like shown below and measure d1 from zL to z1 and d2 from zL to z2 to get d1 = 0.174λ and d2 = 0.481λ. Here's where things get a little different from the shunt stub: to measure open circuit stub length, measure the wavelength on the WTG scale starting from the open circuit side of the chart. Doing so you will get *L1* = 0.353λ and *L2* = 0.147λ



Short Circuit

This time to get the short circuit length we read from the short circuit side of the Smith chart, giving *L1* = 0.103λ and *L2* = 0.397λ. This tells us that the required short circuit stub length are either a quarter wavelength longer or shorter than that of the open circuit stubs. It is important to consider these differences when designing a stub so that you can achieve either large bandwidth or a narrow low loss bandwidth as your design requires.

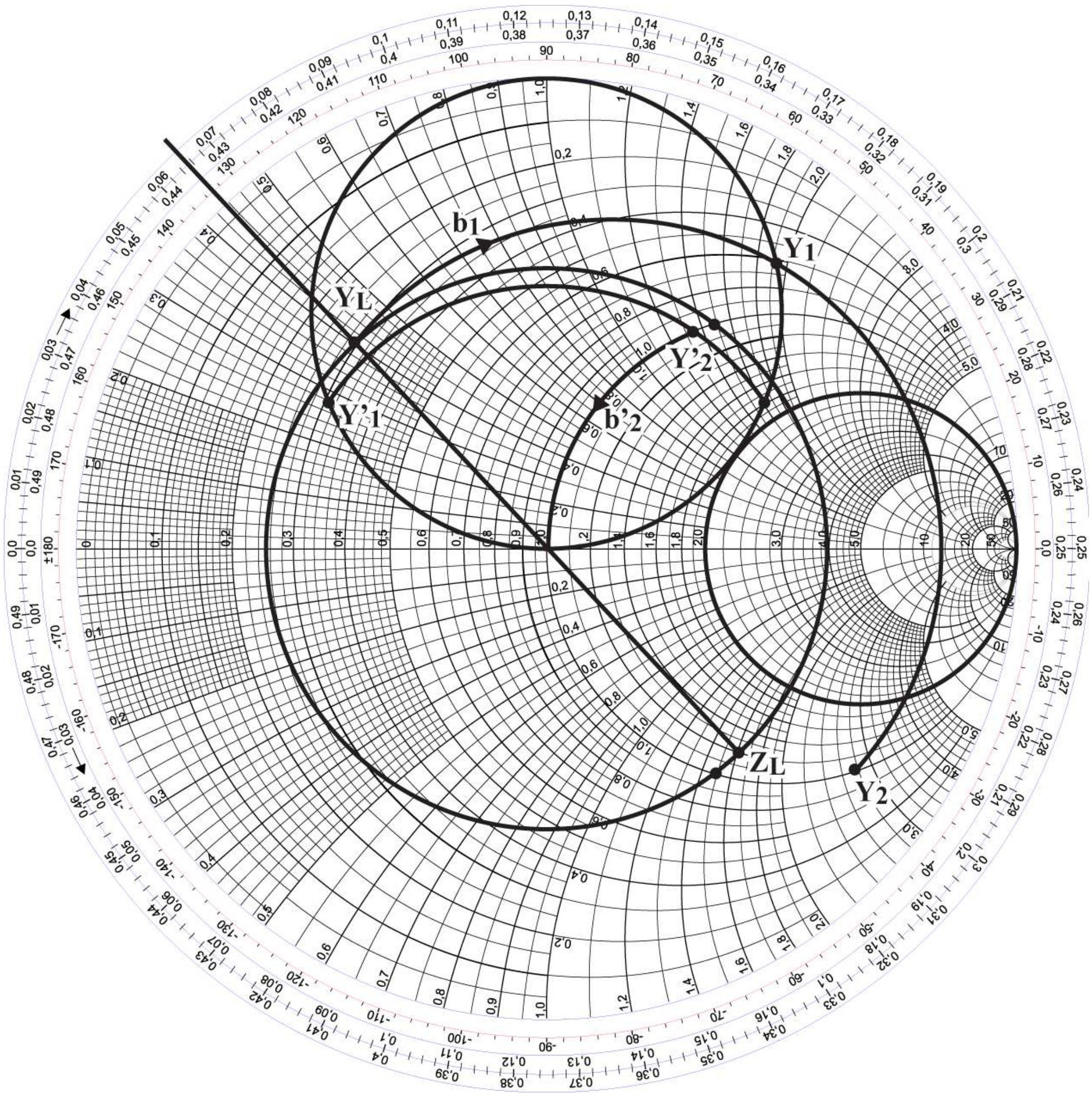
Double Stub Tuning

Single stub tuners have the ability to match any load impedance that has a positive real component, but they require placement at a specific distance from the load to maintain matching. When working with a fixed frequency this is not an issue, however if multiple frequencies must be supported, designing a double stub tuner may be desirable. A double stub tuner uses two stubs at fixed locations and has the advantage of being able to place the first stub at an arbitrary distance from the load.

Let take a look at an example where we wish to match a 50Ω line to a load of 60-j80Ω and have the stubs placed λ/8 apart; as usual we will begin by normalizing our impedance:

$$\frac{60 + j80\Omega}{50\Omega} = 1.2 + j1.6$$

Plot this point, draw the SWR circle and a line from zL across the center point to the other side of the SWR circle as we did in the first problem to get our normalized admittance parameters. Now we are going to rotate the entire 1+jb circle WTL by λ/8 wavelengths. This is our new 1+jb circle and we will draw the y intersections just as we would have on the old 1+jb circle. This leads us to our first susceptance which can be either of the two values b1 = 1.314 or b'1 = -0.114. From the y1 intersection, we will now rotate λ/8 wavelengths WTG until we intersect the old 1+jb circle, giving us our y2, and similarly rotate from y'1 λ/8 wavelengths WTG to intersect the old 1+jb circle giving us y'2; so y2 = 1-j3.38 and y'2 = 1+j1.38. Finally rotating back to the origin via the original 1+jb circle gives us b2 = 3.38 and b'2 = -1.38. Thus the lengths needed for the two solutions are *L1* = 0.146λ, *L2* = 0.204λ or *L'1* = 0.482λ, *L'2* = 0.35λ.



Note that because the solutions must lie along the 1+jb circles, there is a circular zone for R/Z_0 >2 where the rotated circle does not cross. This is known as the *forbidden zone* (cue thunder and lightning). The forbidden zone represents the part of the chart for which there is not match. This means that unlike the single stub tuners, double stub tuning cannot match every load.

Having the ability to design these matching circuits on the fly can be very handy if you ever find yourself working in the RF field both because it can be faster than calculation, as well as being a great tool for visualizing what is going on. Often times the greatest hurdle in learning complex topics is not so much that it is too difficult, but that the mind needs a way of picturing the solution.

Load more comments
