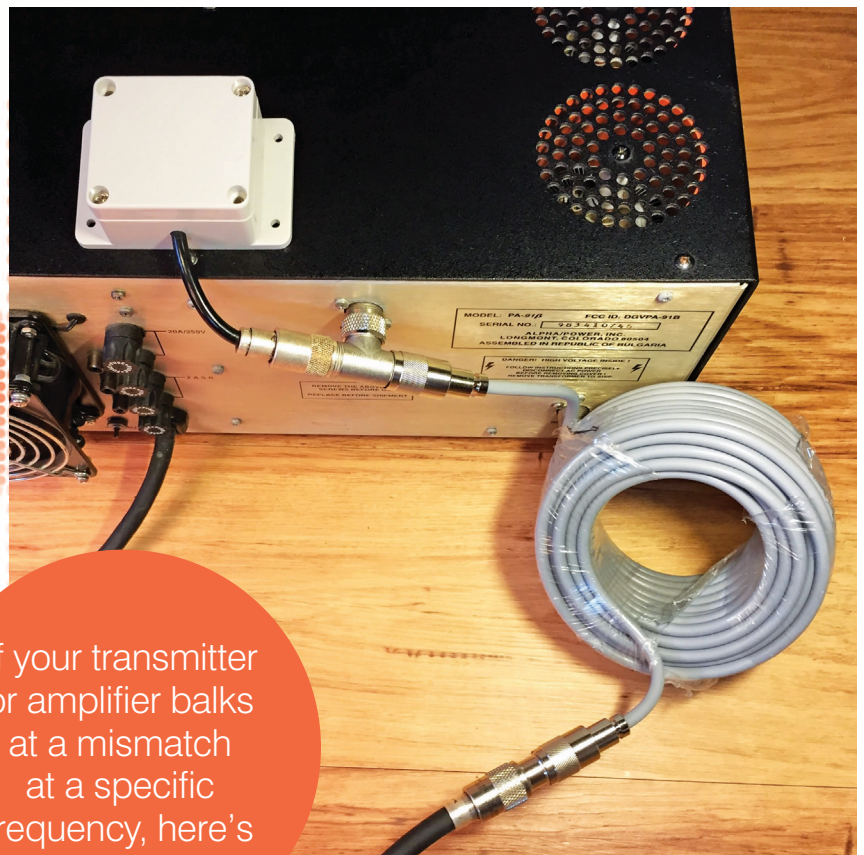


An SWR-Shifting T



If your transmitter or amplifier balks at a mismatch at a specific frequency, here's a simple fix.

The SWR-Shifting T at the station end of the transmission line.

Bill Conwell, K2PO

Any feed-line mismatch can be brought to a 1:1 SWR with a single shunt capacitor, provided its value and the location where it bridges the coaxial center and shield conductors is chosen correctly. This is because there are two locations at every half-wave along a mismatched feed line where the impedance is exactly $50\ \Omega$ in parallel with a reactive component. By extending or shortening the coax so that one of these locations is at the transmitter-end of the coax, a counter-reactive shunt component can be applied using a coaxial T connector (see the lead photo), thus bringing the SWR to 1:1. The shunt component can be unscrewed when desired to restore the antenna to its original tuning.

Using the Smith Chart

The Smith chart, invented by Phillip Smith, is a tool that enables us to determine the value of the necessary reactive component and its transmission line location to achieve a match — in my case, transforming a 4:1 SWR in the 80-meter RTTY band to 1:1.^{1,2}

To determine coax extension and shunt reactance with the Smith chart, we start by using an antenna analyzer to measure the impedance the feed line presents to the rig at the frequency of interest, and then *normalizing* it to plot on the Smith chart. Normalizing simply involves dividing the resistive and reactive parts of the measured impedance by the transmission-line impedance. The resistive axis of the Smith chart (see Figure 1) is the only straight line on the chart. Its normalized middle value is $1\ \Omega$. To the left side, the values approach $0\ \Omega$; to the right side, the values approach infinity. The reactive axis of the Smith chart is the outer perimeter. The normalized value at the top center is $1\ \Omega$ of inductive reactance, and the value at the bottom center is $1\ \Omega$ of capacitive reactance. As with the resistive axis, values to one side of the chart approach zero, and values to the other side approach infinity.

The $50\ \Omega$ coax from my very short, 80-meter coil-loaded rotatable dipole presented an impedance of $135 - j90\ \Omega$ to my rig at 3580 kHz (the “ $-j$ ” indicates a capacitive reactance). $135 - j90$ normalizes to $2.7 - j1.8$ and is plotted at point Z in Figure 1.

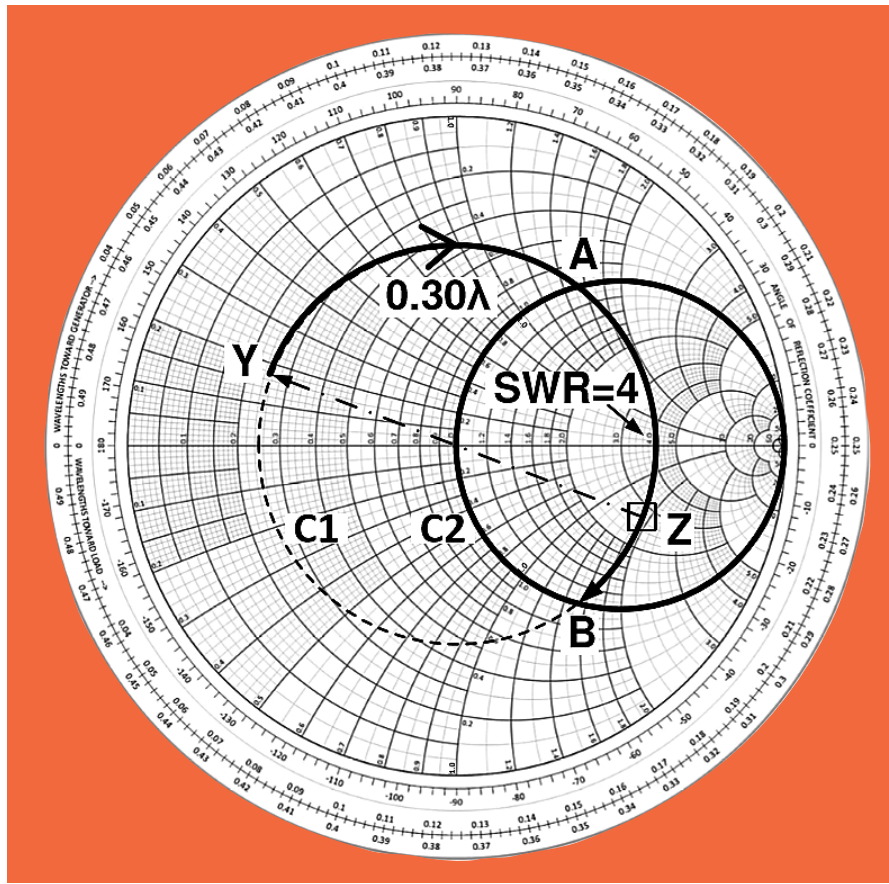


Figure 1 — A Smith chart showing the initial feed-line impedance, Z, and how to determine the value and location of a shunt reactance needed to achieve a 1:1 SWR.

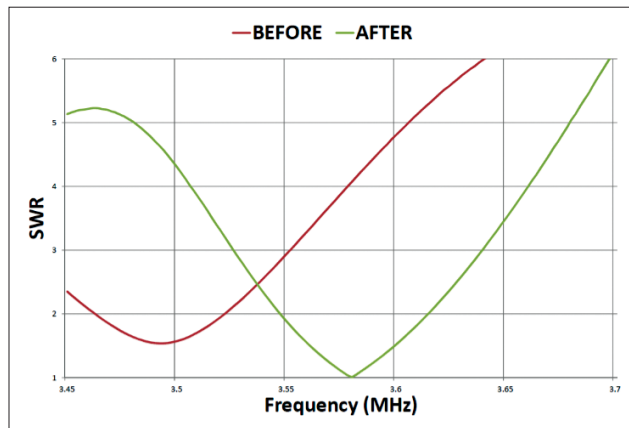


Figure 2 — SWR curves for the author's 80-meter antenna before and after connecting to the SWR-Shifting T.

Point Z establishes the radius of SWR circle C1, which is concentric with the center of the chart. The SWR circle traverses all the impedances along a half-wavelength of the coax (the impedances repeat every half-wave). The right-most value where circle

C1 crosses the straight, resistive axis indicates the SWR on the coax (4:1 in this case). We want to get from circle C1 to the center of the chart, which represents a perfect 1:1 SWR. I achieved this by extending the coax 0.30 wavelengths and using a shunt capacitor of 1,200 pF.

Finding the 1:1 SWR Value

The measured impedance is expressed as a *series* circuit — a resistance in series with a reactance. For a shunt component match, it's easiest to think in terms of a *parallel* circuit, which provides multiple pathways for current to flow. However, impedance calculations get intricate when dealing with parallel circuits. Consider two resistors, R_a and R_b . The series resistance is simply $R_a + R_b$, while the resistance of the two resistors in parallel is $1/[(1/R_a) + (1/R_b)]$. Adding the reactance complicates the parallel calculations even more.

Therefore, let's dive briefly into the inverted world of admittance.

Admittance is the reciprocal of impedance. To combine two circuit elements in parallel, we simply add their admittance values. We're back to the simplicity of $R_a + R_b$. To convert my starting normalized impedance of $2.7 - j1.8$ to admittance, we draw a line from the starting impedance at point Z, through the center of the chart, across to a point Y where it intersects the SWR circle C1 on the far side. The coordinates of intersection point Y are $0.25 + j0.17$, indicating, respectively, *conductance* and *susceptance* (the complement of reactance) — both measured in normalized *mos*, the reciprocal unit of ohms and a previous unit of measurement for electrical impedance. (Don't simply invert 2.7 and -1.8 separately.) Admittance point Y and impedance point Z represent the same original mismatch, just in different units.

As we move away from the mismatch on the Smith chart, we move along the SWR circle C1 in a clock-

wise direction. So, from the original mismatch expressed by its point Y admittance, we advance clockwise along circle C1 by adding feed line until we cross the *unity circle*, labeled C2. This unity circle is the set of all points where the normalized conductance and resistance are 1.0 — i.e., 50 Ω in real resistance terms. (This circle is among the curves pre-printed on the chart.) The SWR circle C1 and the unity circle C2 actually cross at both points A and B, each a shunt-matching opportunity.

The intersection point A, along the top half of the unity circle, is the point where an extended coax can be matched with a shunt inductor. We continue to the other point of intersection, B, along the bottom half of the unity circle, which is the point where extended coax can be matched with a shunt capacitor. Studying the chart coordinates, we find B has normalized admittance coordinates of 1 and -1.35 . If we shunt an admittance of $0 + j1.35$ at point B, the two admittances sum to $1 + j0$, and we end up at the center of the chart — a perfect match.

The needed length of coax extension is the length of the arc from point Y to point B. Using markings on the outer perimeter of the chart, we find this length to be about 0.30 wavelength. I used RG-8X coax with a velocity factor of 0.80. In this coax, a wavelength at 3.58 MHz is $(984 \times 0.80) / 3.58$, or 220 feet. Thus, the extension needed is 66 feet.

In the admittance world, measurements are normalized to a value of 0.02, the reciprocal of 50 Ω to which impedance is normalized. So, the normalized 1.35 value needed for a shunt match indicates a true susceptance of 0.027 mhos. To convert this value to a reactance, we take its reciprocal, and get 37 Ω. This is the value of capacitive reactance that needs to be placed in parallel with the end of the extended coax to achieve a 1:1 SWR.

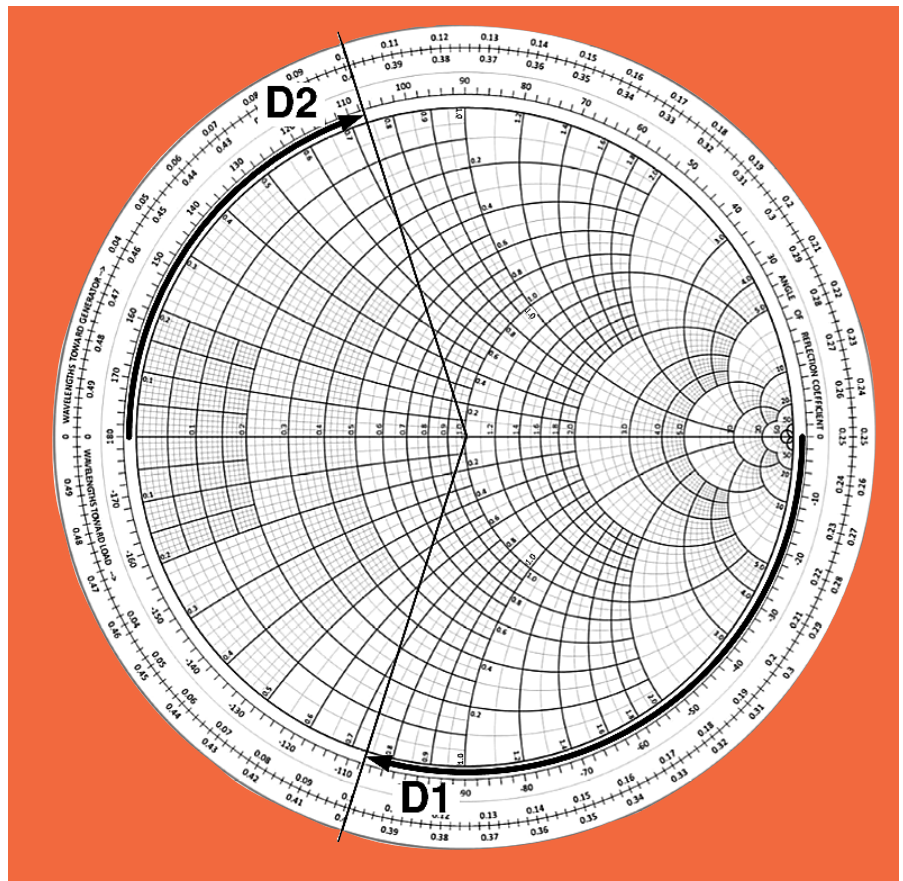


Figure 3 — A Smith chart showing how to determine the length of open-circuited coax (D1) serving as a 37 Ω capacitive reactance, or a short-circuited coax (D2) serving as a 37 Ω inductive reactance.

To convert a reactance of 37 Ω into picofarads, we use $C = 1,000,000 / 2\pi fX$, where f is the frequency in MHz (3.58), and X is the reactance in ohms (37). This formula indicates a needed capacitor value of 1,200 pF. Silver mica capacitors are well-suited for RF applications due to their low loss and stability.

Coax Length Variations

While most installations will use an added length of coax to put the reactive element at one of the circle-crossing points, it is equally possible to reach points A or B by putting the reactive element closer to the antenna (i.e., moving counterclockwise from point Y). You might have more feed line than you need to reach your rig, which you could shorten for this purpose. Or you could cut the existing coax short of the rig and insert the T and the reactive component at the cut location. In my case, instead of extending my coax 0.30 wavelength to apply a shunt capacitive reactance, I could have trimmed it by 0.20 wavelength and put the T there.

With the capacitor at a $50\ \Omega$ point as part of this matching process, the peak voltage is about 390 V at 1,500 W. A 1,000 V silver mica capacitor from Mouser or Digi-Key is less than \$5 and will work well. I mounted the capacitor in a plastic enclosure with a short length of coax and PL-259 to connect to the T, as shown in the lead photo. Figure 2 shows the unmatched and matched SWR curves.

While point B on the bottom half of the Smith chart in Figure 1 indicates where a *capacitor* can be shunted to bring the SWR to 1:1, point A on the top half indicates where an *inductor* can be shunted to bring the SWR to 1:1. Not coincidentally, the magnitude of reactance required is the same as in the capacitive case: $37\ \Omega$. The formula to compute the inductor value from reactance is L (microhenries) = $X / 2\pi f$, where X is the reactance, and f is the frequency in MHz.

The length of coax extension needed is the distance from point Y to point A, or 0.15 wavelength. I could also have achieved a 1:1 match by adding a 0.15-wavelength section of coax, using a T to shunt a $37\ \Omega$ inductive reactance (1.6 microhenries) at that point.

Using Coax as a Capacitor or Inductor

You can also use the Smith chart to find a length of open-circuited coax to use as a shunt matching capacitor. We want $37\ \Omega$ of capacitive reactance, which normalizes to 0.74 in $50\ \Omega$ coax. An open circuit has an impedance of infinite ohms of resistance, so we start at the far-right end of the straight axis in Figure 3. Proceed clockwise until we reach 0.74 on the perimeter reactance axis. That's a distance (D1) of about 0.15 electrical wavelength, or 33 feet in RG-8X, which would be connected to the T adapter in lieu of a 1,200 pF capacitor. Be sure to insulate the open end of the coax because high voltages can be present.

Conversely, a length of shorted coax can serve as a shunt inductor. A shorted coax starts as an impedance of zero ohms resistive, so we start at the far-left end of the straight axis. We proceed clockwise until we reach a normalized impedance of 0.74 on the top perimeter reactance scale. This is a distance (D2) of

about 0.10 wavelength, or 22 feet of shorted RG-8X, that can be connected to the T adapter at point A in lieu of a 1.6 microhenry coil.

Conclusion

The SWR-Shifting T described here can create a single frequency matching solution to deal with almost any mismatch. You can happily run your rig on 160 meters using your 40-meter dipole if you want. However, the efficiency of such a system would be poor, as the original mismatch persists on the other side of the reactive component, resulting in SWR-related feed line losses. But for tasks such as tuning a 160-meter or 80-meter antenna system to a different in-band frequency, this arrangement is hard to beat. And when you want to restore the antenna to its original resonance, simply unscrew and remove the shunt reactance. (You may wish to place a bare PL-259 in the unused T socket so the coax center conductor isn't so exposed.)

Some popular software tools capable of doing the calculations described in this article include Richard Dean Straw's, N6BV, *Transmission Line for Windows* (included with *The ARRL Handbook* and *The ARRL Antenna Book*), and Ward Harriman's, AE6TY, *SimSmith* program (www.ae6ty.com/Smith_Charts.html).

Notes

¹Smith, Philip, *Transmission Line Calculator*, Electronics, Vol. 12, No. 1, p. 29 – 31, Jan. 1939.

²Smith, Philip, *An Improved Transmission Line Calculator*, Electronics, Vol. 17, No. 1, p. 130, Jan. 1944.

For more on Philip Smith (1905 – 1987, licensed as 1ANB), see the IEEE oral history at https://ethw.org/Oral-History:Philip_H._Smith.

Bill Conwell, K2PO, got his Amateur Extra-class license as a teenager in Murray Hill, New Jersey. In 1976, he ordered Smith charts for a high school math project from Smith's company, and was surprised when Phil Smith, who turned out to live nearby, delivered them to his door. Bill went on to get an electrical engineering degree from Georgia Tech (where he did brief stints in antenna-related work for RCA and Radio Free Europe), and a law degree from Emory University. He now resides in Portland, Oregon, where he works as a patent attorney for Digimarc Corporation, dealing with data hiding technologies. You can contact Bill at bill@conwellpdx.com.

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