Circling the WRAPS

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The real purpose of this article is to describe a technique I used to make a ¼ wavelength delay-phasing line of non-standard impedance out of standard 50 Ω coax to circularly polarize a pair of ARROW antennas. However, this ultimate purpose is hidden inside a discussion of the mechanics of creating a circularly polarized array out of linearly polarized yagi antennas. Bare with me -- we will eventually get there.

I have received some very positive and inspirational feedback from the builders of the WRAPS portable satellite antenna rotator system that is described in January 2014 QST. The feedback first inspired the "tricked out WRAPS" which is a modification of the original design to handle two ARROW class antennas mounted on a horizontal boom. Next, the tricked out WRAPS inspired me to look into a polarity switching system to change between RHCP and LHCP by the flip of a switch. This idea was combined with a previous project I developed, the minimalist preamp, that was described a while back in the Nov/Dec 2012 Journal. The result is a polarity and frequency band agile antenna mounted preamp for portable satellite operations.

The basics of circular polarization. Antenna polarity switching has had some excellent coverage in many respected publications; this is going to be my stab at it. The basic concept, the physical arrangement and orientation of the antennas, and the requisite transformer and phasing lines have been very well documented, but the phasing line in particular requires a coax impedance that is non-standard, or is hard to come by through special orders of large quantities, or you just have to make do with what is available. My ultimate objective is to detail how to make a 100 Ω impedance ¼ wavelength phasing line for use in a circularly polarizing harness for ARROW class antennas mounted on the WRAPS rotator. First, where does the 100 Ω impedance ¼ wavelength phasing line fit into the big picture?

Figure 1 shows a pair of ARROWs set up for circular polarization operation. The 2-meter elements are mounted 45 degrees from the horizon and perpendicular to each other. This arrangement works well with the WRAPS rotator to keep the antenna elements clear of the supporting tripod. There is also one theory that the elements mounted 45 degrees from the horizon mitigates fading from ground reflections. This antenna arrangement is graphically illustrated in figure 2.

Figure 1.

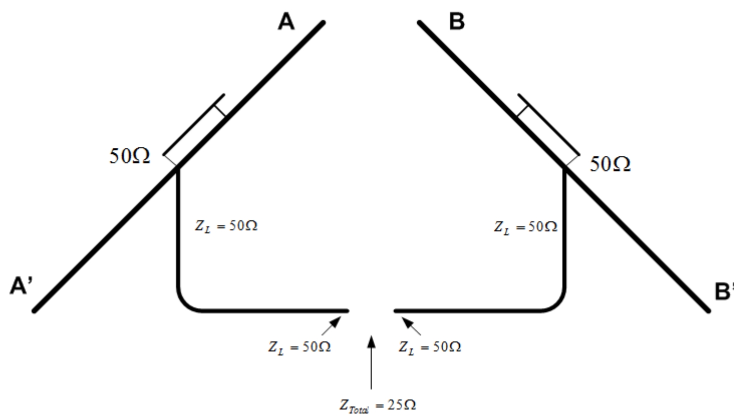

Figure 2.

Impedance transformation needed. If the two antennas are simply connected together with lengths of 50Ω coax, there would be a significant SWR issue. This arrangement is connecting two loads in parallel and the outcome of the two loads in parallel follows the familiar equation 1.

$$\boldsymbol{Z_{total}} = \frac{\boldsymbol{Z_1 Z_2}}{\boldsymbol{Z_1 + Z_2}} \qquad \text{equation 1.}$$

Two 50Ω lines connected in parallel result in 25Ω at the combined feed point. A more appropriate feed line system would be a power splitter made of two coax transformers that transform the 50Ω impedance of the antennas to a level that when combined in parallel result in 50Ω at the combined feed point. Figure 3 illustrates using two coax transformers made of odd multiples of ¼ wavelengths of RG-6, 75Ω cable TV coax (an excellent source of quality coax line).

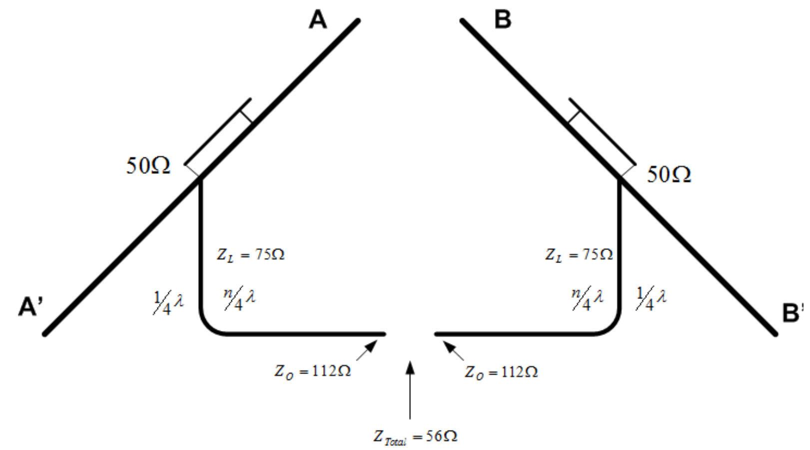

Figure 3.

A ¼ wavelength of coax transforms the input impedance to the coax according to equation 2. Equation 2 is transformed into a more useful form and is solved for the output impedance in equations 3 and 4. Z_L is the impedance of the coax line (75Ω), R_L is the impedance of the antenna (50Ω), and Z_o is the impedance at the output of the coax line.

$\boldsymbol{Z_L = \sqrt{Z_o R_L}}$	equation 2.
$\boldsymbol{Z_L^2 = Z_o R_L}$	equation 3.
$\boldsymbol{Z_o = \frac{Z_L^2}{R_L}}$	equation 4.

Referring back to equation 1, we need an impedance of 100Ω at the output of each feed line so that when connected in parallel, the result is 50Ω. Plugging 100Ω and 50Ω into equation 2, the calculated impedance of the coax transformer feed line is 70.7Ω. RG-6 coax at 75Ω is a convenient match. As a check, plugging 75Ω and 50Ω into equation 4, the output impedance of the transformer line is 112.5Ω. In turn, plugging 112.5Ω into equation 1 results in an impedance at the combined feed point of 56Ω…not prefect, but this impedance mismatch would result in an insertion SWR of 1.12:1. These two ¼ wavelength 75Ω feed line segments create an impedance transformer and power splitter that matches the 50Ω of the rig to the 50Ω impedances of the antennas. This however doesn't configure the pair of antennas for circular polarization. To accomplish this, a 90 degree (or ¼ wavelength) delay needs to be inserted into the system for one of the antennas.

<u>Creating circular polarization.</u> A ¼ wavelength delay can be easily created by inserting a ¼ electrical wavelength section of coax (with an impedance that matches the impedance of the antenna) as a delay or phasing line as illustrated in figure 4. The ¼ wavelength section of RG-8

Mini coax transfers the 50Ω of the antenna to the end of the phasing line while causing a ¼ wavelength (90 degree) delay of the signal received by antenna B relative to antenna A. The two transformer lines combine the signals from antennas A and B at the proper impedance to match the rig. The arrangement of figure 4 would create Left Hand Circular Polarization (LHCP), to create RHCP, the ¼ wavelength delay line would be moved over to antenna A. This configuration is not very practical for electro-mechanical switching between RHCP and LHCP during a pass to mitigate fades from polarity shifts.

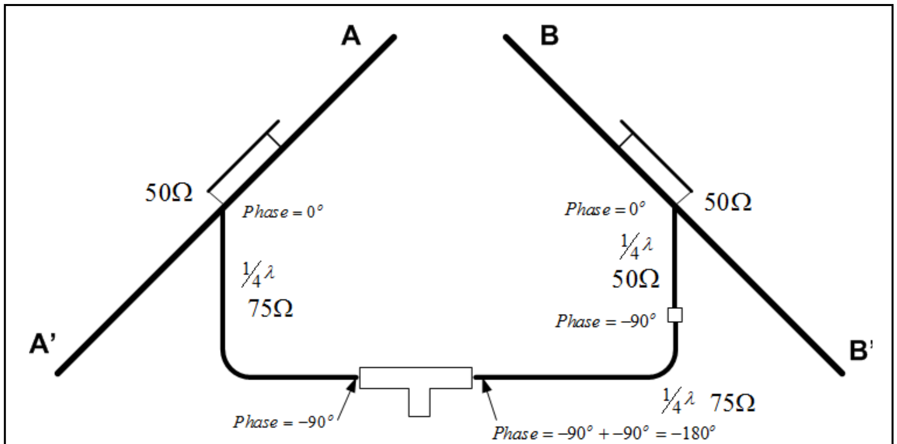

Figure 4.

Circular polarization another way. Figure 5 illustrates an alternate way to achieve circular polarization by inserting the ¼ wavelength delay line to the center of the interconnecting cable harness. To switch to the opposite polarization, the rig feed point is simply shifted to the other side of the ¼ wavelength delay line (figure 6). This configuration is more conducive to electro-mechanical switching; however, this arrangement is complicated because the impedance at the ends of the 75Ω transformer sections is approximately 100Ω and the delay line impedance needs to match that impedance. One hundred ohm coax is not a common coax, but short sections for phasing lines can be homebrewed out of standard coax.

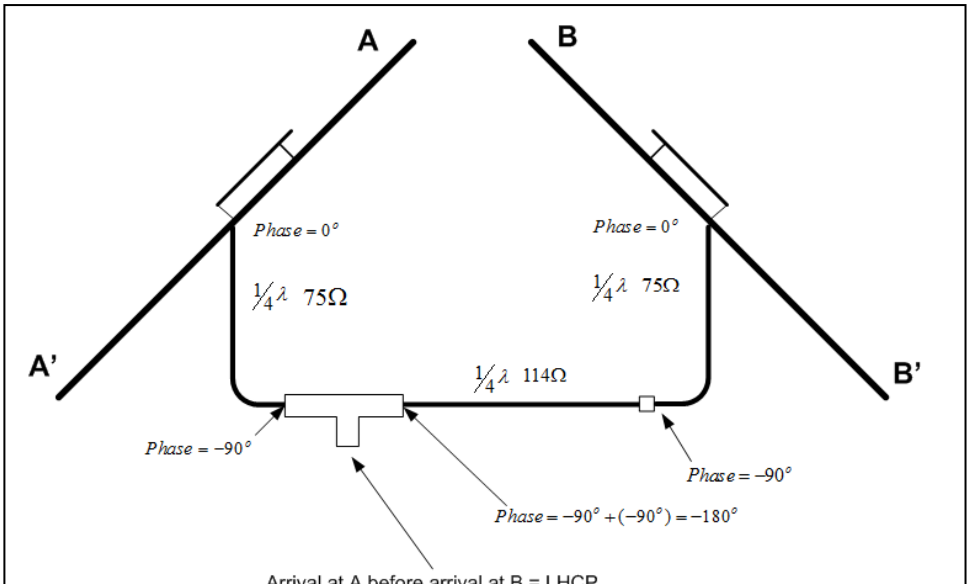

Figure 5.

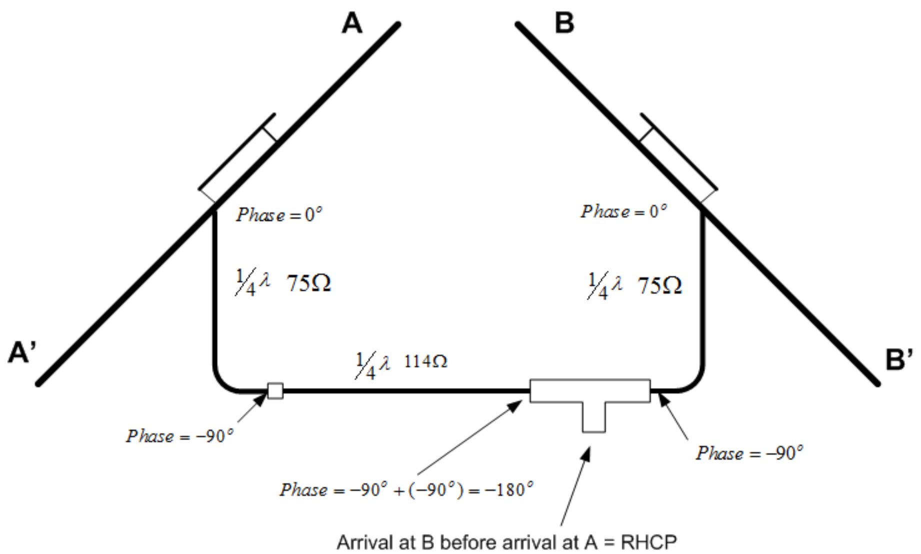

Figure 6.

Homebrew coax of non-standard impedance. The impedance of coax is dependent on three factors; the dielectric constant of the insulating material between the inner conductor and the outer shield, the diameter of the insulating material (the internal diameter of the outer shield braid), and the diameter of the center conductor (figure 7). The relationship between these coax characteristics are detailed in equation 5 (the cited web location has a nice coax impedance calculator to help play with the math). In this project, I modified lengths of RG-8 Mini Foam coax to create coax with an impedance of approximately 100Ω by replacing the center conductor with thinner, Cat-5 conductor wire.

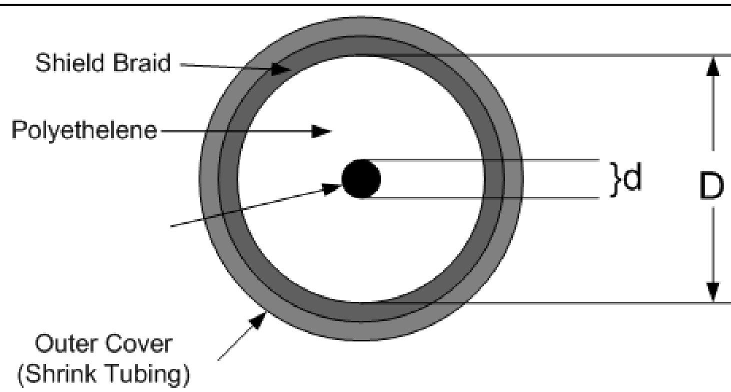

Figure 7.

These are the specifications for RG-8 Mini Foam cable:

- The insulation is foam polyethylene with a dielectric constant (E_r) of 1.16.
- The insulator diameter (D) is 0.157".

The diameter of one strand of a Cat-5 Cable (d) is 0.02 inches. Plugging these values into equation 5 results in an impedance for the modified coax of 114Ω. This is a pretty good match to the 112Ω output of the transformer lines. The problem is how to replace the center conductor of the RG-8 Mini coax?

$$Z_o = \frac{138 * \log\left(\frac{D}{d}\right)}{\sqrt{E_r}} \qquad \text{equation 5.}$$

From: http://www.microwaves101.com/encyclopedia/calcoax.cfm

The following is the process that I used to replace the center conductor of short lengths of RG-8 Mini coax to make the phasing lines (refer to figures 8 and 9).

1. Cut a section of RG-8 Mini cable that is slightly longer than what you estimate the electrical ¼ wavelength will be (I simply use the standard antenna wavelength formula. The actually velocity factor of your homebrew cable will be pretty good, so don't under estimate this length [i.e., the velocity factor is much better than 0.6]).
2. Carefully remove the outer covering of the RG-8 Mini coax using care not to score or cut the underlying braided shield.
3. Scrunch the braided shield like a Chinese Finger Trap so that the shield can be removed from the foam center insulator.
4. Using a knife to make sharp and clean edges, cut the foam insulating material into short sections so that the sections can be pulled off the center conductor (a little trial and error is appropriate, for me, lengths of about 5 inches seemed to work).
5. Strip the insulation off a length of one strand of a Cat-5 Cable conductor, the cable I had on hand had a solid conductor.
6. Slide the foam insulation sections over the new center conductor.
7. Using the appropriate size of shrink tubing, put a short section of shrink tubing over the joints in the foam insulation, heat to shrink.
8. Slide the braid shield over the form insulation and stretch out to the length of the modified cable.
9. Install a crimp BNC connector to one end of the modified cable; you are now ready to determine the electrical ¼ wavelength for the phasing line.

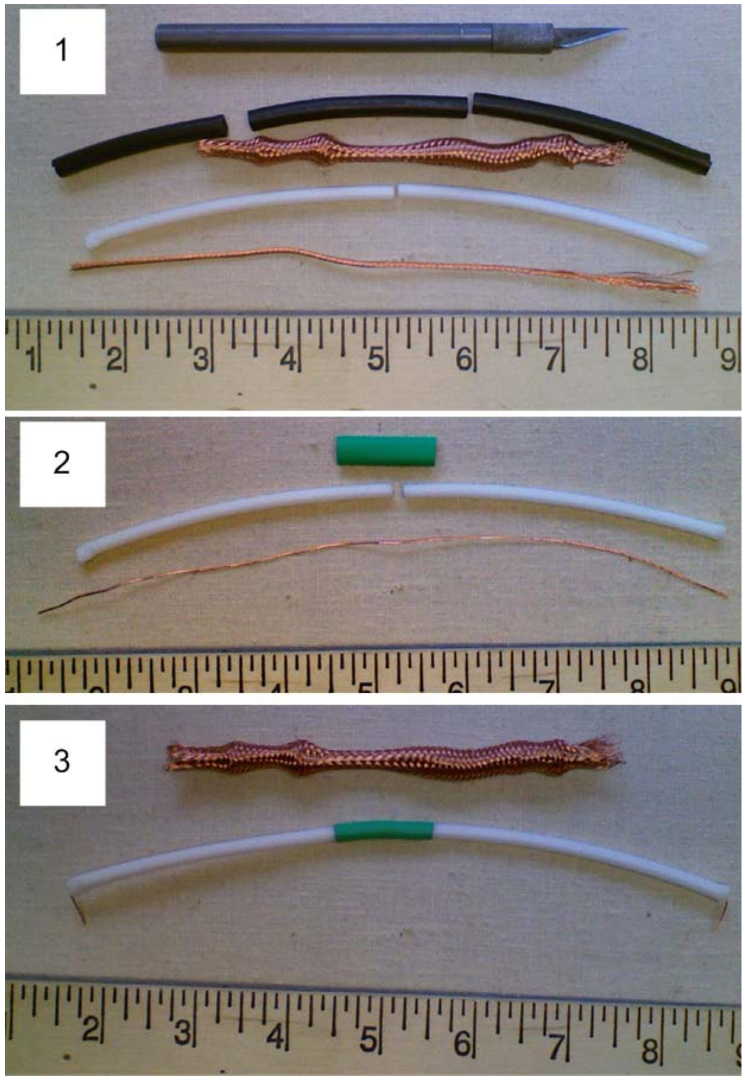

Figure 8.

Determining ¼ electrical wavelength. You will need an antenna analyzer (I have the MFJ model) or a SWR/watt meter to determine the electrical ¼ wavelength for the phasing line. If you are absolutely certain of the coax cable's velocity factor, you could probably apply that velocity factor to reduce the calculated length of a cable to the electrical length. In this case, the velocity factor of your homebrew cable is unknown so you will have to use the following procedure.

Make a jig with a mating coax connector for your analyzer or SWR meter (my meters needed a PL259), a 50Ω carbon resistor (small wattage would be fine), and a female BNC connector. Install the resistor in series with the connector center pins using as short of leads as practicable. Ground the outer shields of the connectors, the solder lug on the BNC connector works well. What this 50Ω terminating jig does is to allow any odd multiple of ¼ wavelength coax cable, open at the other end, regardless of the impedance, to resonate at 50Ω at the meter (jig) input.

Connect your homebrew 100Ω cable section to jig attached to the analyzer or the SWR meter. If you are using an SWR meter, you will need to attach a low power transmitter to the SWR meter to use as an RF source. Set the analyzer or rig to the frequency of interest (2-meters, I use 146MHz; 70CM, I use 436MHz). The SWR will read high. Incrementally trim off small sections of the homebrew coax, perhaps ½ inch at a time; as the SWR lowers toward 1:1, start trimming less, perhaps ¼ inch increments. When you reach very close to 1:1 SWR, trim one more short ¼ inch increment (to make up for the BNC connector to be installed later).

To complete the homebrew phasing line, install shrink tubing over ½ of the entire length of the cable snug up against the previously installed BNC, then shrink the tubing. Slip another section of shrink tubing over the other half of the cable, but do not shrink the tubing yet. Install the BNC connector. Just to be sure, double check the cable on your SWR setup, it should be close to 1:1 SWR. The final step is the cover the last half of the cable with the shrink tubing, heat to shrink, and you're done.

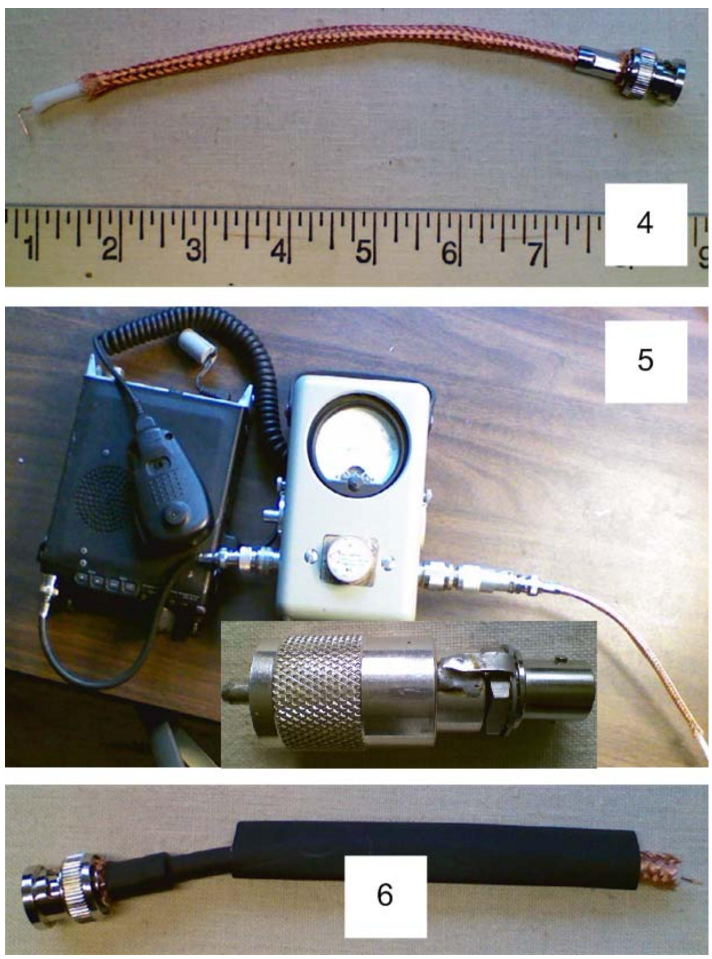

Figure 9.

Construct the two, odd multiples of ¼ electrical wavelength transformer lines out of RG-6, 75Ω cable (just straight RG-6, not modified). For my WRAPS system, I found that ¾ wavelength transformer lines are required for the 2-meter antennas, and 1¼ wavelength transformer lines are required for the 70 CM antennas to span the distance between the antennas. Install a couple of BNC "T" connectors between the transformers and the delay line. A pictorial representation of the completed antenna feed harness is illustrated in figure 10. To switch between RHCP and LHCP, simply move your rig feed point from one BNC "T" connector to the other.

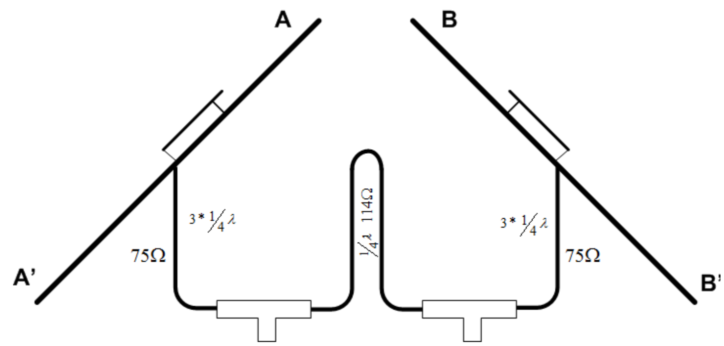

Figure 10.

Electro-mechanical polarity switching. The goal of this project however was to create an electro-mechanical way to make polarity changes. An RF appropriate SPDT, relay controlled switch will do the trick (Digi-key part number Z3288-ND). I included the polarity switching relay on a redesigned minimalist preamp PCB for this project, pictorially illustrated in figure 11. The PCB artwork for the modified board is shown in figure 12.

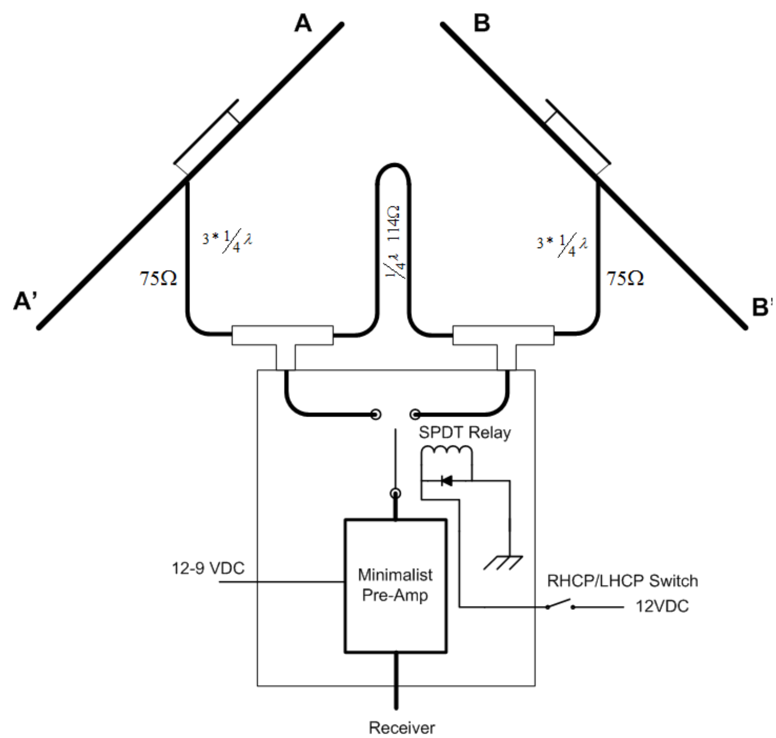

Figure 11.

Power for the preamp is supplied with one line, 12-VDC switched power for the polarity relay is supplied by another line. This system is NOT set up for polarity switching of the transmitter side of the station…NOT! (From my experience, there is far more need for polarity switching on the receive side. If there is polarity shifting at the satellite, I have found that I can usually "over-power" any attenuation due to polarity shifting by momentarily boosting my transmitter power, therefore I simply leave my transmit antennas fixed in RHCP mode.)

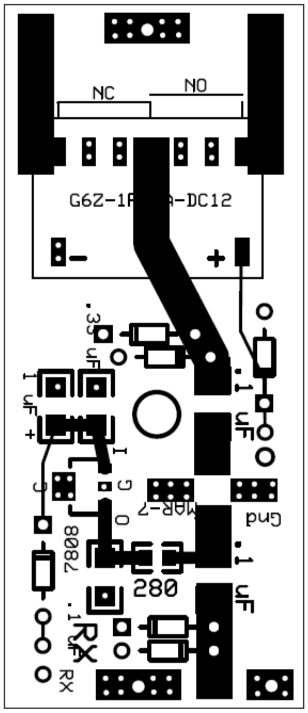

Figure 12.

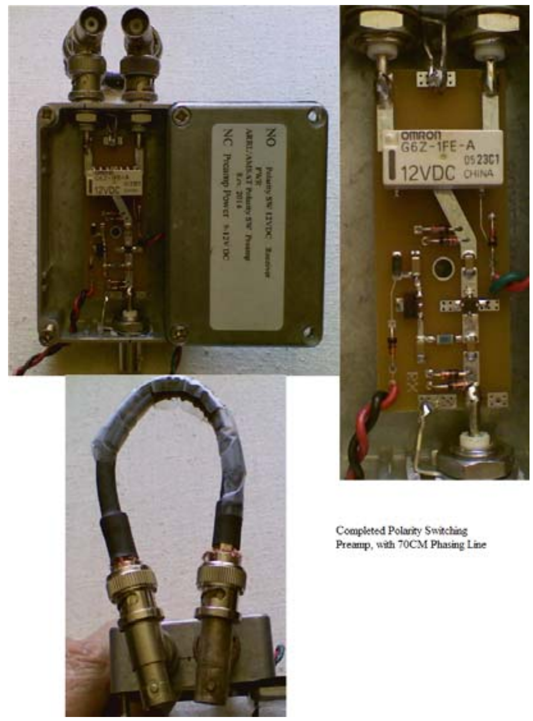

Figure 13.

Impedance matching on the PCB. The final technical topic I am going to address in this article is how to develop the appropriate PCB traces for routing the RF from the preamp to the SPDT relay contacts to minimize insertion loss. The paths traveled by the RF through the preamp and polarity switch should be treated as transmission lines, therefore these transmission line traces, or striplines, should exhibit 50Ω impedances. The impedance of a stripline trace depends on the dielectric constant of the PCB material, the distance between the trace on the top side of the board and the ground plain on the bottom side of the board, and the width of the trace. These parameters are illustrated in figure 14 and follow the equations 6 and 7. The dielectric constant for the PCB material is listed as 4.2 to 5, so I used a value of 4.6 for E_r in the calculations. The thickness of the PCB is 0.062 inches. You will notice that the value of E_{eff} is calculated in equation 6 and then used in equation 7; and both the value of W (the width of the stripline trace) and H (the thickness of the PCB) are used in both equations. This will require some iterative calculations to get to the desired value of W to give you the impedance Z_o of the trace that you want. I encourage you to go through the math exercise. It took me a couple of iterations, but I finally found a trace width W = 0.115 inches to give an impedance value close to 50Ω for the stripline RF traces I used in the board design.

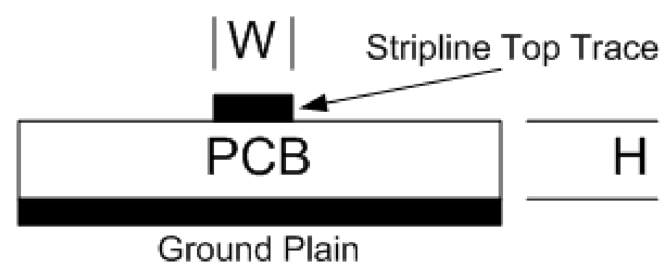

Figure 14.

$$E_{eff} = \frac{E_r+1}{2} + \frac{\frac{E_r-1}{2}}{\sqrt{1+12\left(\frac{H}{W}\right)}}$$ equation 6.

Equation 6 and 7 from: Semtech Application Note: AN1200.04

$$Z_o = \frac{\frac{120\pi}{\sqrt{E_{eff}}}}{\frac{W}{H}+1.393+0.667ln\left(\frac{W}{H}+1.444\right)}$$ equation 7.

Add a diplexer for a complete polarity agile station. If you use a dual band HT for your portable operations, you will need to insert a diplexer into the station configuration as illustrated in figure 15. (An excellent homebrew diplexer is described in Nov/Dec 2009 Journal.)

Operation. The minimalist preamp is broad-banded and covers both the 2-meter and 70 CM bands. I created a circular polarization harnesses for both bands with the BNC "T" connectors on each side of the phasing lines. If I am going to operate a satellite with a UHF uplink and a VHF downlink, I install the preamp on the VHF cable so that the antenna is RHCP when the polarity switching relay is at rest (non-energized) and I connect the transmitter to the BNC connector on the UHF cable for RHCP (visa versa for the UHF down, VHF up). Most of the time, the satellites are RHCP. I find that most of the polarity fades happen early (above AOS) and late (above LOS) in the pass. When a fade is detected, simply flip the polarity switch to energize or de-energize the relay, this action moves the ¼ wavelength delay line back and forth between the antennas and creates the RHCP/LHCP polarity shift. As I mentioned, I mitigate the polarity shifts on the uplink by manipulating the transmitting power to a level appropriate for respectful satellite operations.

Early in my satellite operation experience I used fixed RHCP and I simply accepted the fades. After I upgraded my station and included polarity switching, I could not believe what a difference it makes! By a simple flip of a switch, the signals would go from S-0 to S-9 in many cases; the difference is truly amazing.

I have become a firm proponent of antenna mounted preamps, and now, polarity switching. This relatively inexpensive modification to your portable station just might be the station upgrade you have been looking for to enhance your satellite operating experience. If you have questions or need additional information, please contact me at mspencer@arrl.org.

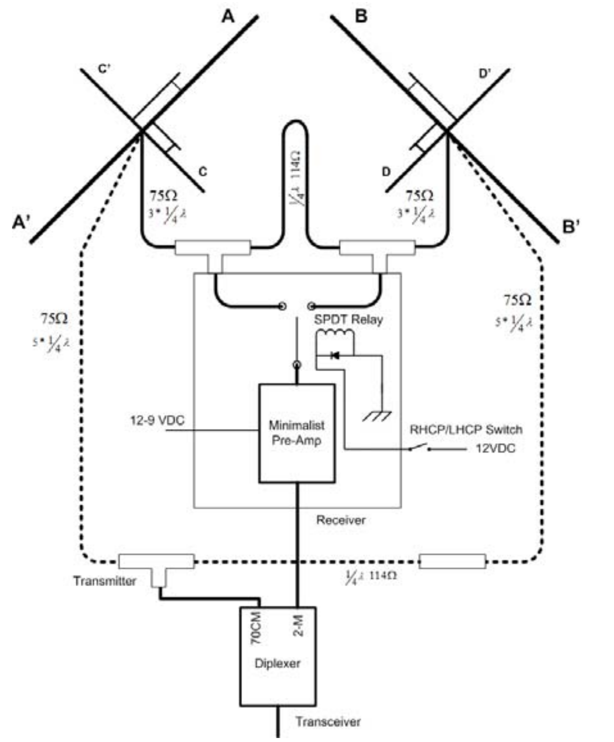

Figure 15.