Narrowband Dielectric Patch Antennas

By Chris Fagas, WB2VVV

The halfwave by halfwave patch and the ground plane form a cavity in which there is an intense field. This field intensity is the reason why the lowest loss dielectrics must be used. The dielectric loss in the patch antenna is proportional to the loss tangent of the dielectric substrate. The Rogers Duroid 5880 I have used in all of my models uses a very low loss dielectric substrate. For comparison, substituting the new popular Rogers 4003 would slightly more than double the dielectric loss, while substituting standard glass epoxy FR4 would increase the dielectric loss by about eleven times. Another important factor is the dielectric constant, or relative permittivity, of the substrate. The higher the dielectric constant of the circuit board substrate, the smaller the patch's dimension will be. This is particularly important for the lower UHF bands, lest the patch will be too unwieldy, and also require a huge board if the dielectric constant is too low. On the other hand, greater cutting accuracy is required for higher dielectric constants, since being off a few mils is more significant. The following table shows the loss tangent and the dielectric constant of several popular circuit board materials:

Manufacturer	Product	Loss tangent @ 10 GHz	Relative Permittivity @ 10 GHz
Rogers	Duroid 5880	0.0009	2.2
Rogers	Duroid 5870	0.0012	2.33
Rogers	Duroid 6006	0.0019	6.0
Arlon	Epsilam-10	0.0020	10.2
Rogers	RO 4003	0.0020	3.38
Various	Glass Epoxy FR4	0.0100	4.4

In addition, the metalization should have very low resistivity and a thickness of about three times skin depth. Copper thickness on circuit boards is determined by copper weight. Copper weight is specified as the copper weight per square foot, and usually varies from 1/8 ounce to 2 ounces per square foot. This corresponds to a copper thickness of 4 um to 70 um, respectively. For the frequencies below, 1-2 ounce per square foot would be perfectly usable. The following is a table of several metals, note how low the resistivity of copper is:

Metal	Resistivity (ohms/m 10^{-8} @ 20 C)
Silver	1.62
Copper	1.72
Gold	2.44
Aluminum	2.62
Brass	3.90
Nickel	6.90
Platinum	10.50
Lead	21.90

Halfwave by Halfwave Patch Antennas on Roger Duroid 5880:

Band (MHz)	Patch "L"	Ground Plane "L"	50 ohm Feed Inset
432.1	9.089"	15.000"	3.108"
903.1	4.350"	8.000"	1.487"
1296.1	3.030"	5.250"	1.036"
2304.1	1.704"	3.250"	0.583"
3456.1	1.136"	2.250"	0.389"
5760.1	0.682"	1.250"	0.233"
10368.1	0.379"	0.750"	0.130"

These dimensions on Rogers Duroid 5880 support the following (field test adjusted) formula:

$$L = \frac{c}{2f\sqrt{\varepsilon_r}}$$

Where L = Patch Side Length;
f = Frequency in GHz;
ε_r = Dielectric Constant or Relative Permittivity of 2.2;
c = 11.650 for L in inches.

I built a series of 1296.1 MHz Halfwave by Halfwave Horizontal Polarization Patch Antennas and Range tested them with the following results:

Patch Antenna	Gain vs. Single Patch	Gain in dBi	Gain in dBd	Cross Polarization Null Depth
1. Single Patch	0 dB	+7.49 dBi	+5.35 dBd	-29 dB
2. Single Patch on a Multiband Patch Array (Large GP)	+0.75 dB	+8.24 dBi	+6.10 dBd	-21 dB
3. Dual Patch (rear mounted phasing harness)	+1.75 dB	+9.24 dBi	+7.10 dBd	-18 dB
4. Quad Patch (Microstrip Corporate Feed)	+5.8 dB	+13.29 dBi	+11.15 dBd	-11 dB
5. Quadrature Dual Feed CP Patch	-1.75 dB	+5.74 dBi	+3.60 dBd	-1.5 dB

It was interesting to see that the larger ground plane of antenna 2 resulted in a gain increase of 0.75 dB, as compared with antenna 1. This means that the ground plane dimension that I have used is a reasonable compromise that gives up a little gain for a more compact dimension.

Also, the traditional coaxial cable and power divider phasing harness of antenna 3 appears to be a little lossy. It's gain was only 1.75 dB better than the single patch, even though it had twice the antenna aperture. This is 1.25 dB off the theoretical 3 dB gain increase. I originally suspected that possibly my stacking distance was too close which might explain the somewhat low gain, and very clean pattern with very low level sidelobes. However, when I tested antenna 4, the quad patch using a microstrip corporate feed, the result was 5.8 dB better than the single patch, for four times the antenna aperture. This is only 0.2 dB off the theoretical 6 dB gain increase, which is very close, and it had exactly the same stacking distance. I am happy to add that the sidelobe performance was still excellent. Apparently, the microstrip corporate feed is just a very low loss way to feed a patch array.

While the microstrip corporate feed does appear to be a very low loss way to feed a patch array, it does make one slight compromise with respect to polarization. Because it has microstrip feeders running both vertically and horizontally and the microstrip feeders do indeed radiate, its polarization purity is not quite as high as the other linear polarization varieties I analyzed. This manifested itself as a relatively low cross polarization null on the test range. In most applications this will not be an important issue, and possibly over a heavily reflective propagation path it is even a slight advantage. However, this also means that it is a slightly less useful antenna for mitigating interference that is vertically polarized, if that is a goal.

In summary, the gain of these little antennas was proven at both the East Coast VHF Conference antenna range, and also on my antenna range. They are very practical and compact antennas for the high UHF bands!