Septum Feeds – Tolerances and Sensitivity

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Last year, we visited DJ3FI in Germany. Hubert showed me some of the lovely things he has made, including septum feeds. One thing he asked was about my analysis of septum feeds – how critical are the dimensions? Too often, I see hams obsessing over dimensions which are not critical, and sometimes compromising the important ones. If we know which dimensions are critical, we could concentrate on those and also better make use of readily available materials.

There is also a bit of mythology floating around the web about these and other feeds. For instance, sometime recently on one of the reflectors, someone asked about a six degree error in phasing; he was told it would be fatal. Since most phase errors involve sine and cosine functions, this seemed counterintuitive.

Since good measurements on CP feeds are difficult, and measuring sensitivity of dimensions would require making many feeds, I started to analyze sensitivity of two popular septum feeds, the OK1DFC square septum[1] and the N2UO circular septum[2]. I found that most of the dimensions are quite forgiving, but one dimensions is surprisingly sensitive and deserves careful attention.

I hope this will also partly repay Hubert for his kind hospitality.

Septum Feed Simulation

Before doing a lot of computer simulation and analysis, we would like some assurance that the results are meaningful. Hubert, DJ3FI, provided me with a septum feed he made for 10.368 GHz according to the OK1DFC design. Glenn Robb, KS4VA, was kind enough to measure the antenna patterns on his commercial antenna range at Research Triangle Compliance Engineering[3]. Figure 1 shows the measured and calculated antenna patterns – the heavy green line from computer simulation using Ansoft **HFSS** software[4] is very close to the measured patterns in the forward 180 degrees, showing that the illumination of the parabolic reflector is accurate.

Sensitivity Analysis

For problems with a closed form solution, sensitivity analysis can be done rigorously, with nice differential equations. For a septum feed horn, however, there are several parameters to be considerer: efficiency, circularity, and isolation. VSWR is not considered since it is not strictly part of the antenna; it may be adjusted independent of antenna performance.

My approach to sensitivity is more direct: perturb each dimension independently and look at the resulting antenna performance and other parameters. Then sensitivity is the percent change in result divided by the percent perturbation. We might expect different sensitivities for the different output parameters.

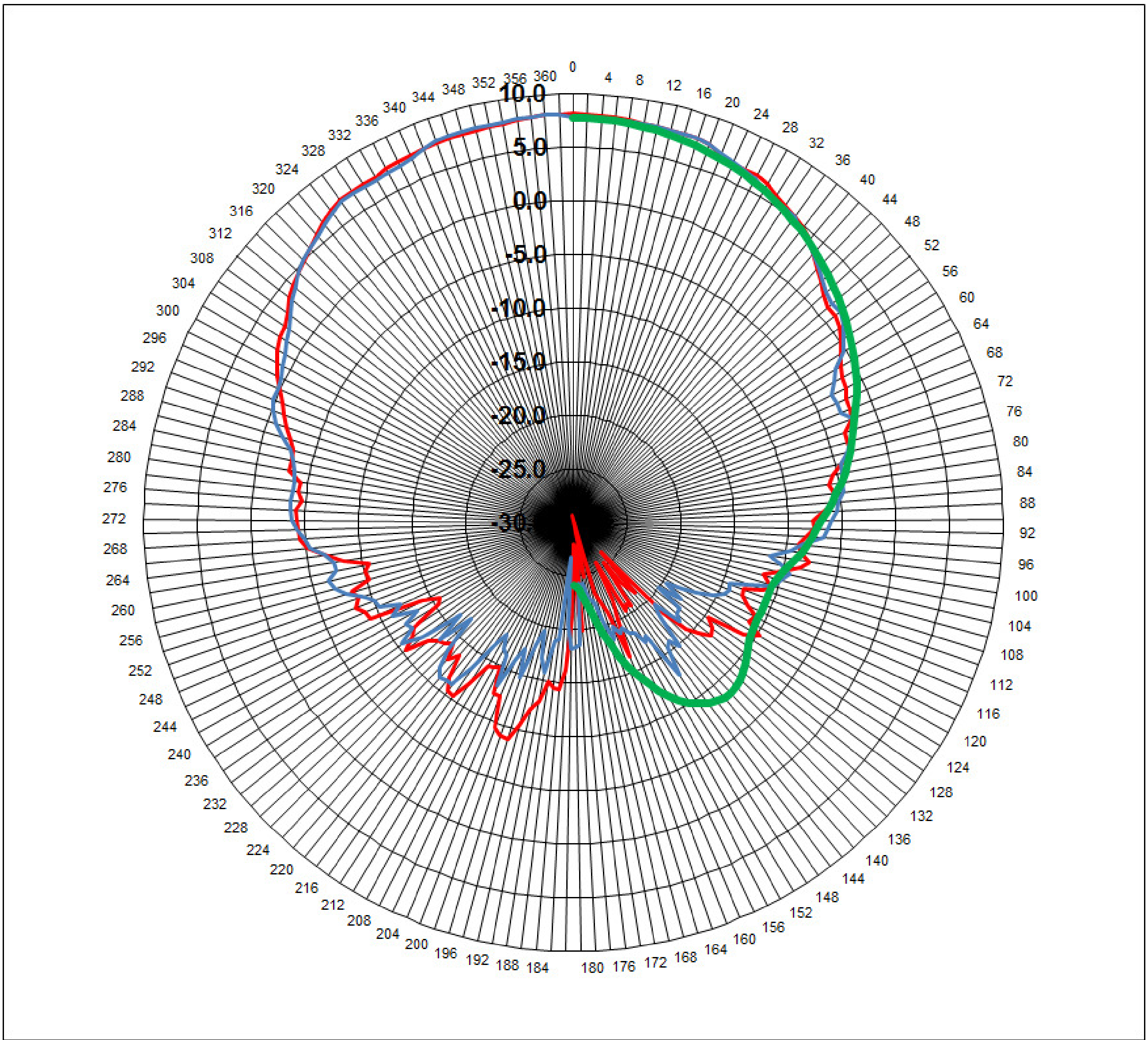

Figure 1- Measured and simulated radiation patterns for OK1DFC septum feed at 10.368 GHz

Each septum dimension was perturbed by 5 percent, one at a time. At 1296 MHz, the smallest perturbation is thus roughly 1 mm, a pretty reasonable tolerance for home construction. The frequency was also varied plus and minus 5 percent for each variation – this is equivalent to changing the diameter or square dimension by five percent, allowing use of available round or square tubing. The assumption is that all dimensions would be scaled to the actual tubing size rather than trying to find a complete new set of dimensions.

The septum thickness was varied over a much wider range, from half of the specified value to six times the specified value. This could allow for more freedom in materials and construction techniques – a thick septum could be drilled, tapped, and bolted in place, or a thin one could be soldered. At higher frequencies, a reasonable metal thickness could be used.

Results for all the variations were recorded: antenna patterns, axial ratio, polarization ratio, and isolation between ports. Dish efficiency was then calculated from the antenna patterns. VSWR was not considered – the analysis uses direct waveguide excitation, while most practical implementations use probe excitation, and the VSWR is a function of the probe dimensions. Waveguide excitation removes the probe as a variable.

Sensitivity Results

The first, and most important, finding is that none of the septum changes in either feed have a significant effect on antenna performance – calculated efficiency only changes by less than one percent. This means that precision machining is not necessary; even at 10 GHz, careful amateur work can hold a reasonable tolerance.

The antenna performance does change slightly with frequency, or equivalently, feed diameter. As we might expect, the feed pattern is a function of feed diameter, so that larger diameters produce a narrower illumination favoring larger ***f*/D**. For the five percent change in frequency or diameter, the change in optimum ***f*/D** is small. Adding a choke to the septum feed will allow fine tuning for the reflector ***f*/D** as well as improving the dish efficiency. Since the septum dimensions do not affect antenna performance, we may assume that previous results[5] for choke dimensions are not changed with variations in septum dimensions.

The septum thickness is particularly insensitive – changing thickness by a factor of ten or more, from 0.5mm to 6mm at 1296 MHz, has very little effect on antenna performance.

The septum dimensions did have an effect on circular polarization, which is rarely circular – it is nearly always elliptical. Our measure for CP is the axial ratio, the voltage ratio of the largest dimension of the polarization ellipse to the smallest dimension. For perfect circular polarization, the ratio is unity, or 0 dB. For pure linear polarization, the ratio is infinite. An alternate measure of circularity, the polarization ratio, is easily calculated from axial ratio.

Axial Ratio and Phasing Error

Before we look at the septum results, it is instructive to consider the effect of imperfect circular polarization on antenna performance.

Good circular polarization requires two components 90 degrees out of phase. The phasing can be provided by phasing lines, a 90 degree hybrid, or a polarizer such as the septum. Errors in phasing result in elliptical polarization, with a maximum and minimum field determined by the amount of phase error. The ratio between maximum and minimum is called the axial ratio, usually expressed in dB.

A good analysis of phasing error was provided by OM6AA[6]. He showed that the loss due to phasing error is modest and depends on the ellipticity of the antennas on both ends, and how well the transmitted polarity aligns at the receiving end. If one end has perfect CP, then the loss is constant. But if the other end also has ellipticity, then the loss can be very small, if the polarities align, or larger, if they are mismatched. The loss calculation comes from Milligan[7].

I calculated axial ratios for a common feedhorn, the Super-VE4MA horn, with a range of phase errors in the excitation. Then I calculated the loss to ideal CP, and the maximum loss for an EME echo, which obviously has similar polarization error in both directions. These are shown in Figure 2. Clearly modest phasing errors, up to about 10º, cause almost no polarization loss even though a 10º error causes an axial ratio of about 1.5 dB. Experimental verification of this is provided by the OK1DFC Septum Feed – my simulations[5] showed that the polarization error produced by the recommended dimensions is about 11º, yet it has been widely used for successful EME operation.

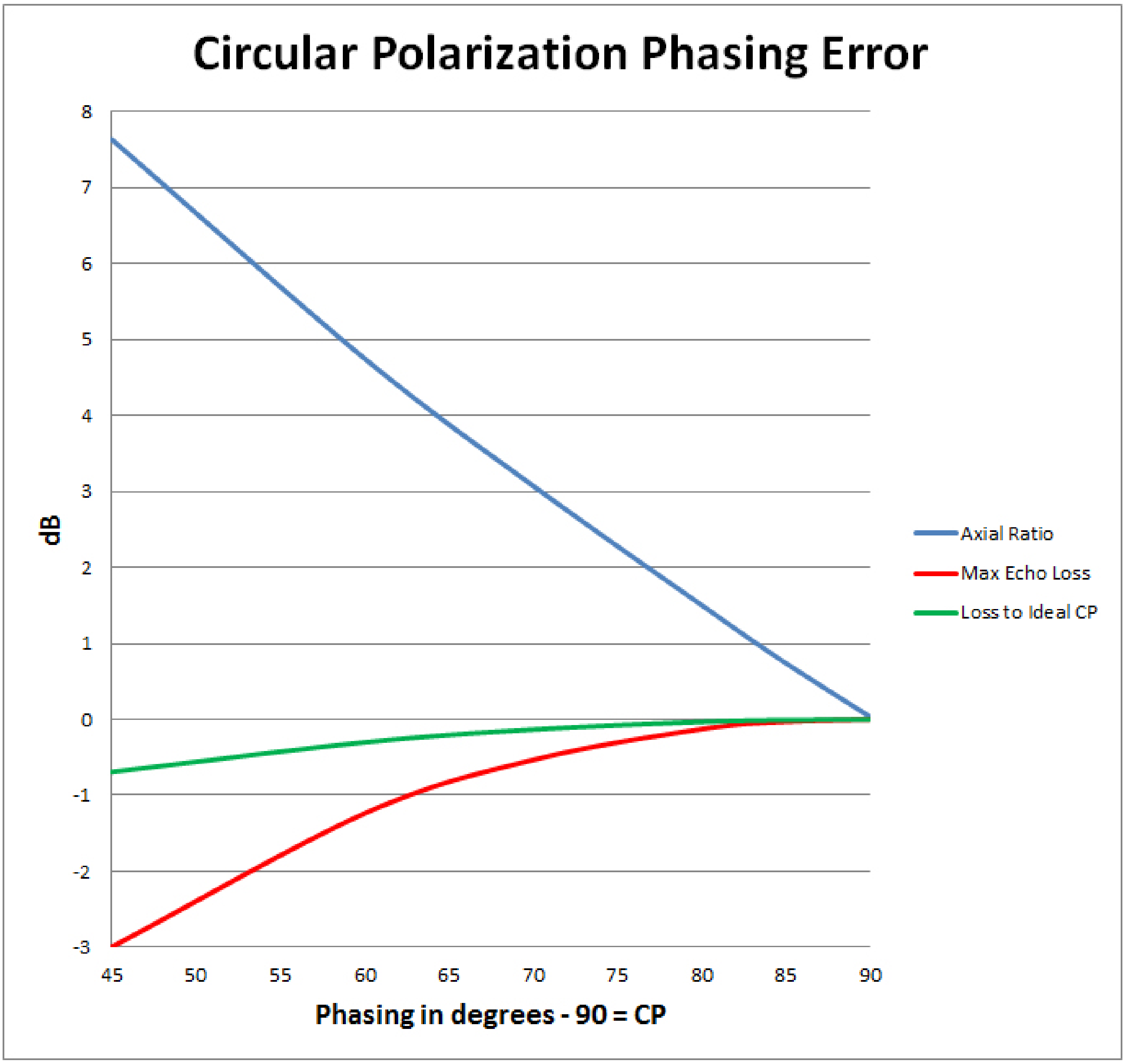

Figure 2- Circular Polarization Phasing Error and Resultant Losses

OK1DFC Septum Polarizer Axial Ratio Sensitivity

Varying the septum polarizer dimensions for the OK1DFC square septum feed did have an effect on the circular polarization – some showed quite high sensitivities. For instance, a 5% change in a tooth dimension changes the axial ratio by a sizable amount, but it is from 1.5 dB to 0.5 dB, not significant in terms of antenna circular polarization performance. None of the septum dimension variations made a large enough change to impact antenna performance.

The effect of increasing each tooth dimension individually by 5% is shown in Figure 3. Some of them do provide a significant improvement in axial ratio, but remember that the difference in loss is still very small. Teeth are numbered from the back: LN1 is the length of tooth number 1, the largest one, and HT1 is the height of that tooth.

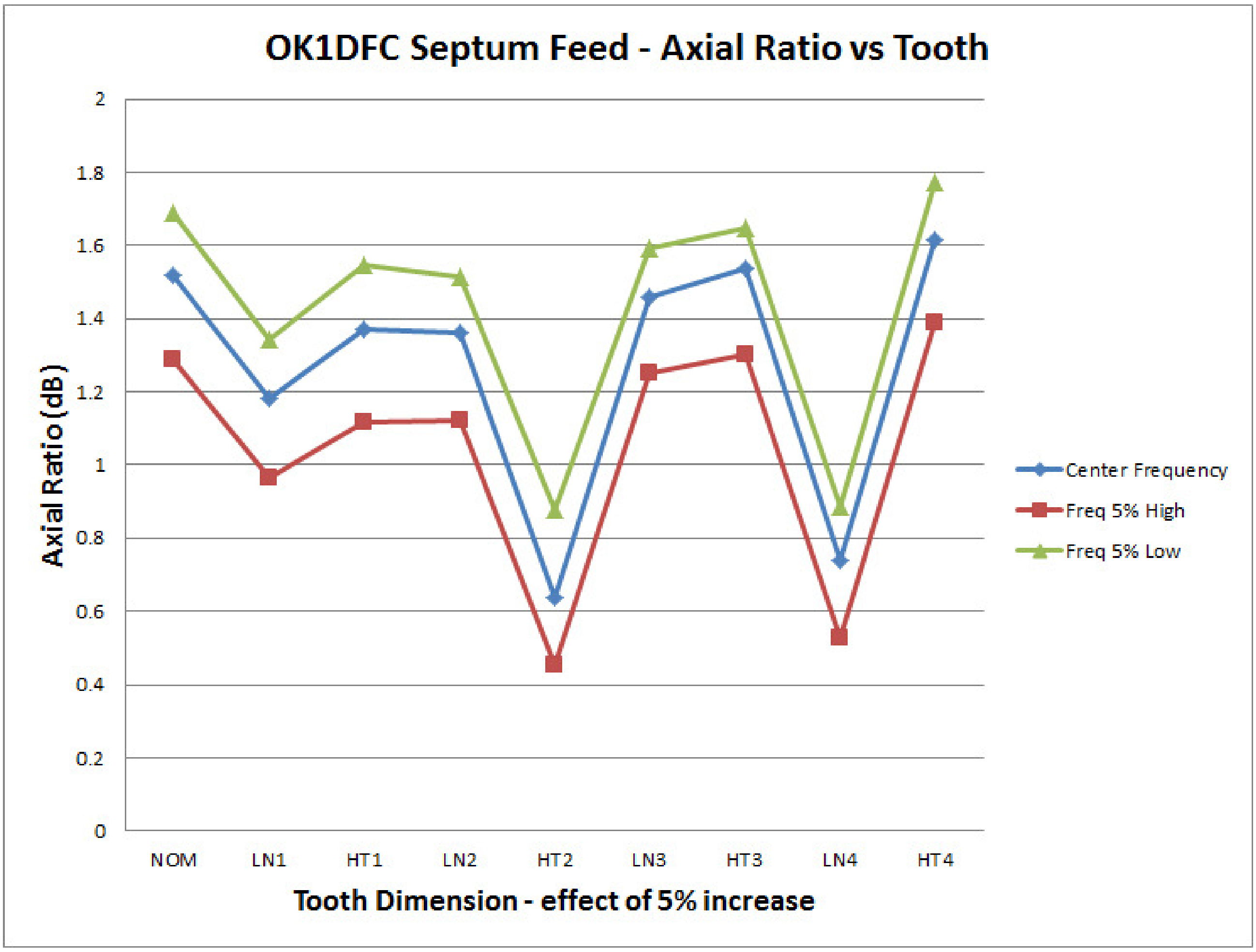

Figure 3- OK1DFC Septum Feed Tooth Sensitivity

The effect of septum thickness is even less sensitive, as shown in Figure 4. The septum thickness can be varied over a wide range with little effect, though thicker seems to be slightly better. The range shown is roughly 0.5 mm to 6 mm at 1296 MHz.

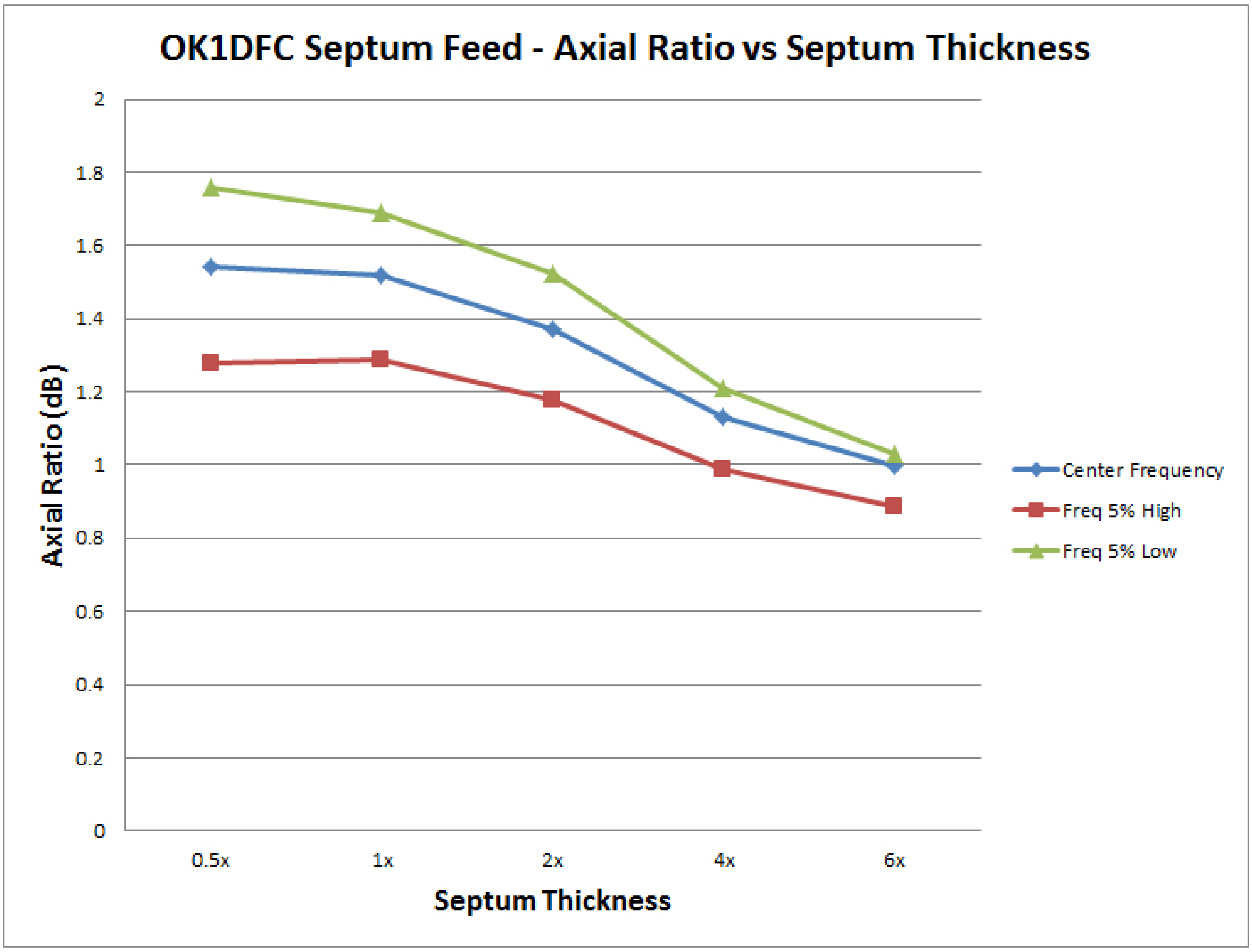

Figure 4 - OK1DFC Septum Feed Sensitivity to septum thickness

But what about improvements? Many of the changes can improve one parameter, but always to the detriment of another parameter, such as isolation. The published dimensions seem to be a good compromise; many others are probably possible, but they are all compromises. I did try changing three of the most promising dimensions simultaneously, and ended up with no real improvement.

Some improvement is provided by increasing frequency slightly. This is equivalent to reducing the size of the square guide, and scaling all the dimensions proportionally. But the difference is small, even in the other direction, so scaling to available tubing seems like a good tradeoff.

N2UO Septum Polarizer Axial Ratio Sensitivity

Varying the septum polarizer tooth dimensions for the N2UO cylindrical septum feed by 5% also resulted in sizable changes in the axial ratio, shown in Figure 5 but none that result in significant polarization loss. Teeth are again numbered from the back, so that number 1 is the largest tooth.

For this feed, a slight improvement is found by lowering the frequency, equivalent to increasing the diameter.

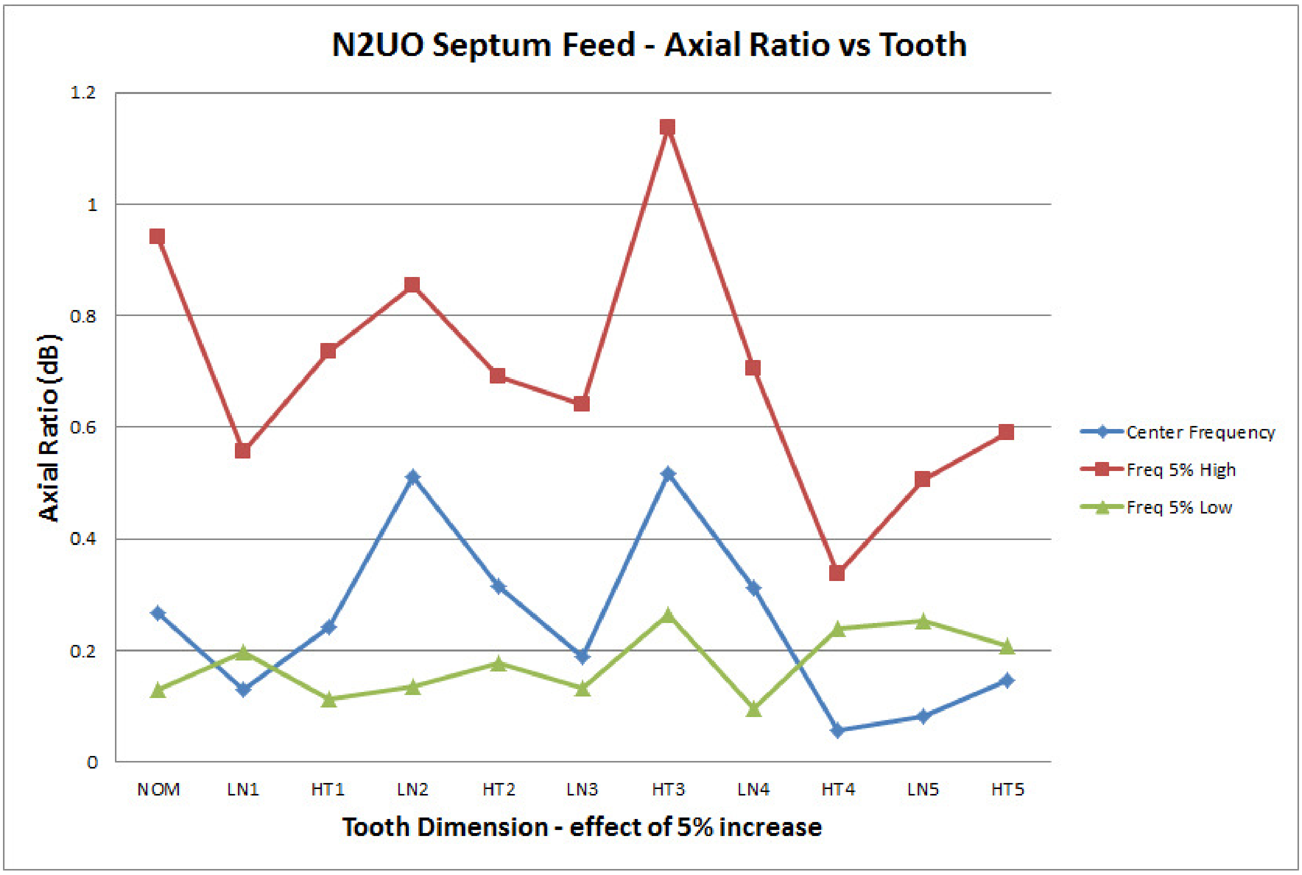

Figure 5 – N2UO Septum Feed tooth dimension sensitivity

The septum thickness in the N2UO feed is also very forgiving, with little effect on axial ratio over a side range of thickness.

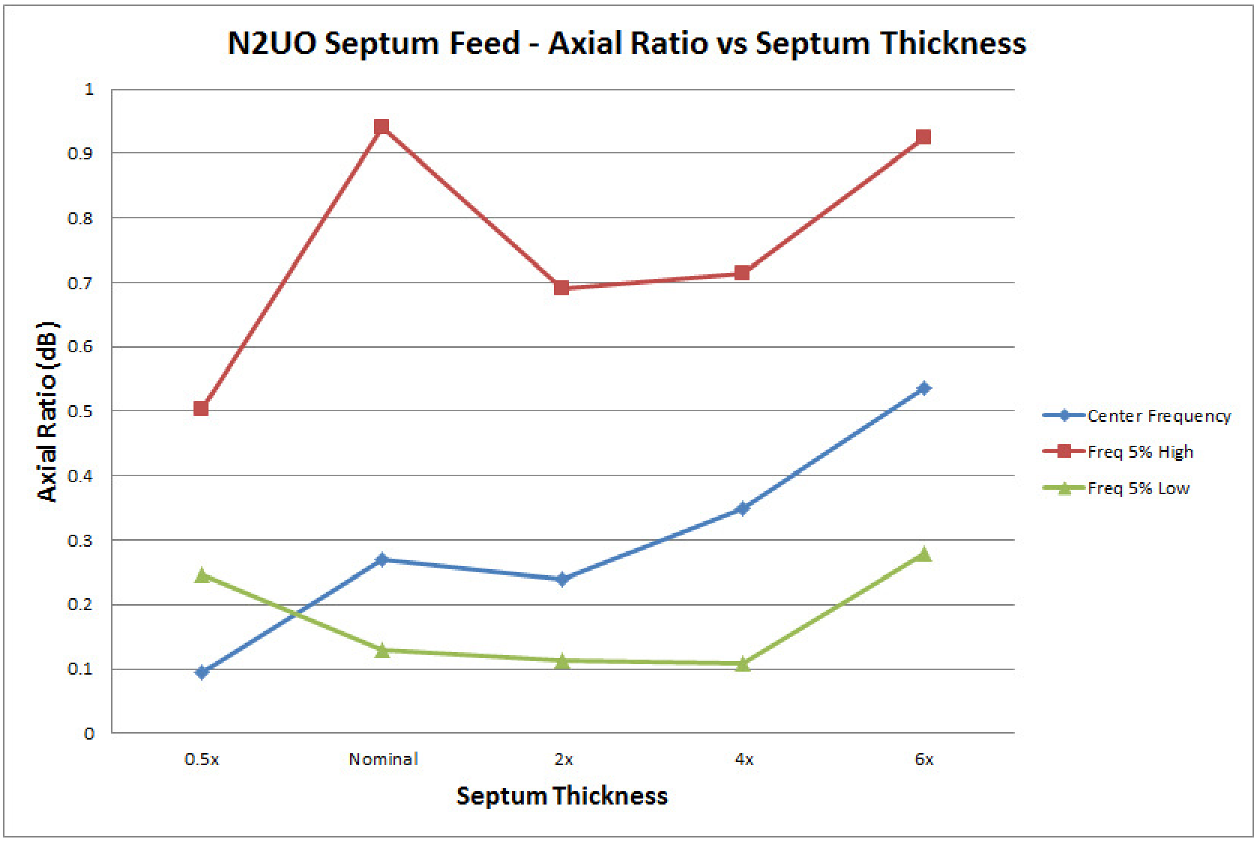

Figure 6 – N2UO Septum Feed Sensitivity to septum thickness

Both septum feeds showed improvement with frequency change, so I tried a wider frequency range, ±10%. In Figure 7, both feeds show good axial ratio over this frequency range, but significant degradation in isolation as the frequency is lowered. However, the antenna performance in Figure 8 is pretty constant over the range.

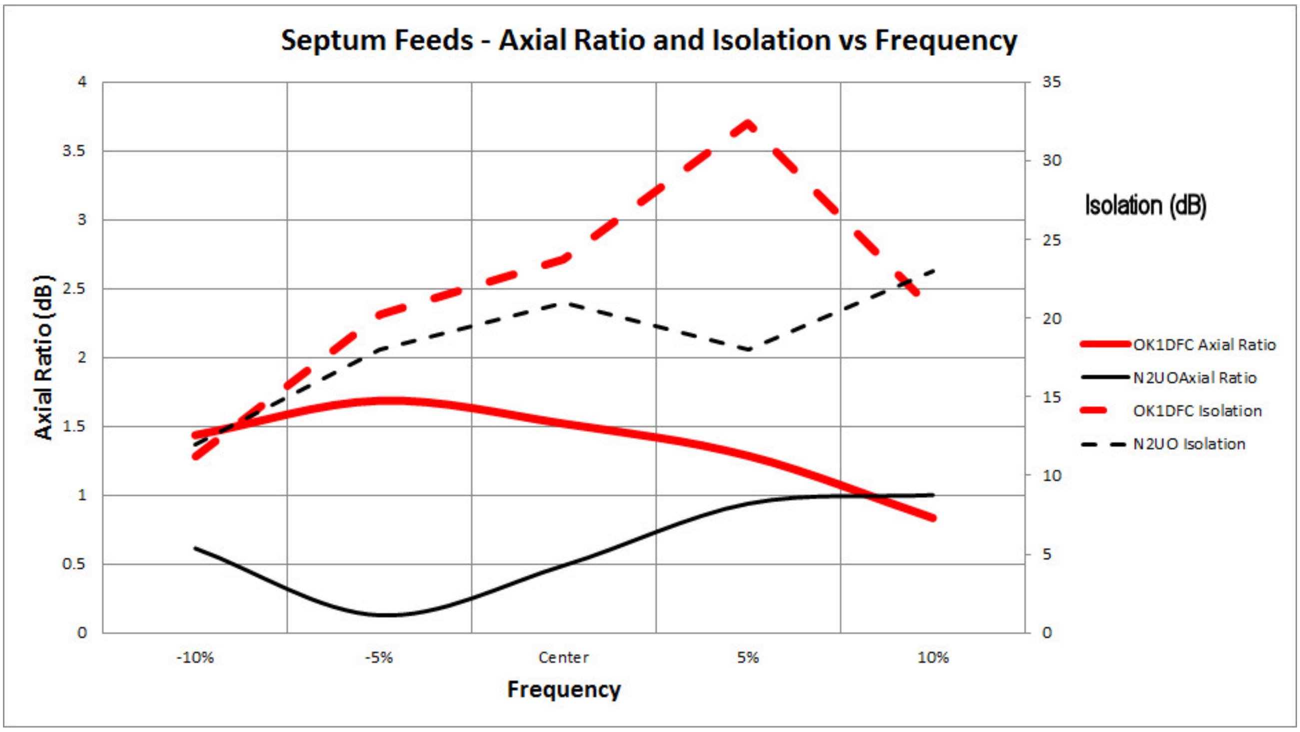

Figure 7 – Axial Ratio and Isolation over frequency range

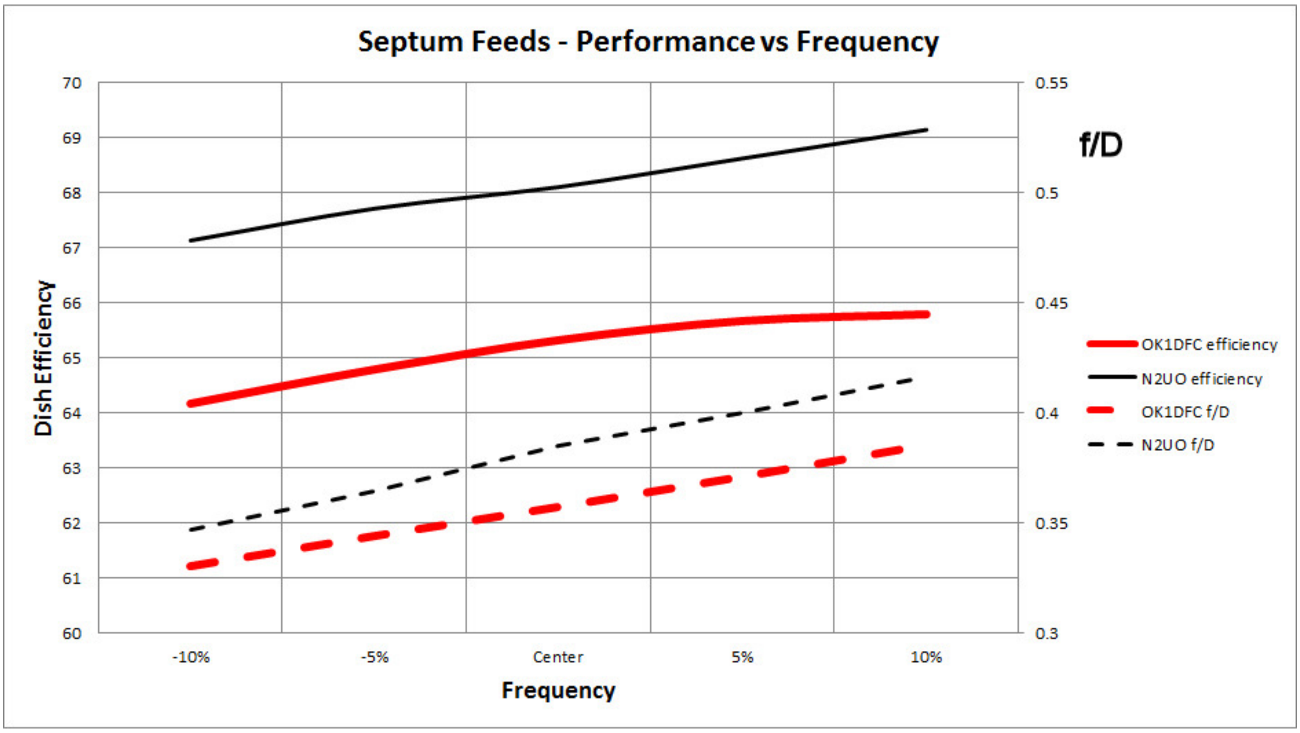

Figure 8 - Septum Feed antenna performance vs frequency

Critical Dimensions

In waveguide, guide wavelength is a function of the H dimension (wide dimension in rectangular waveguide), and the velocity of propagation varies with guide wavelength. With circular polarization, the field is rotating; if the guide is not symmetrical, velocity will vary with rotation and the circularity of the polarization will be affected. One way to make a circular polarizer is to squeeze a section of cylindrical waveguide into an elliptical shape.

The sensitivity to waveguide asymmetry was tested by varying the dimension, both square and round, perpendicular to the septum, with the septum dimensions held constant. For both versions, a 5% change in dimensions made a huge difference – the circular polarization was completely upset, and calculated dish efficiency was reduced. Clearly, this is very sensitive dimension, so smaller increments were tried. The results are plotted in Figure 9 for the OK1DFC feed and Figure 10 for the N2UO feed; the waveguide must be within about 1% of square or cylindrical to maintain full antenna performance.

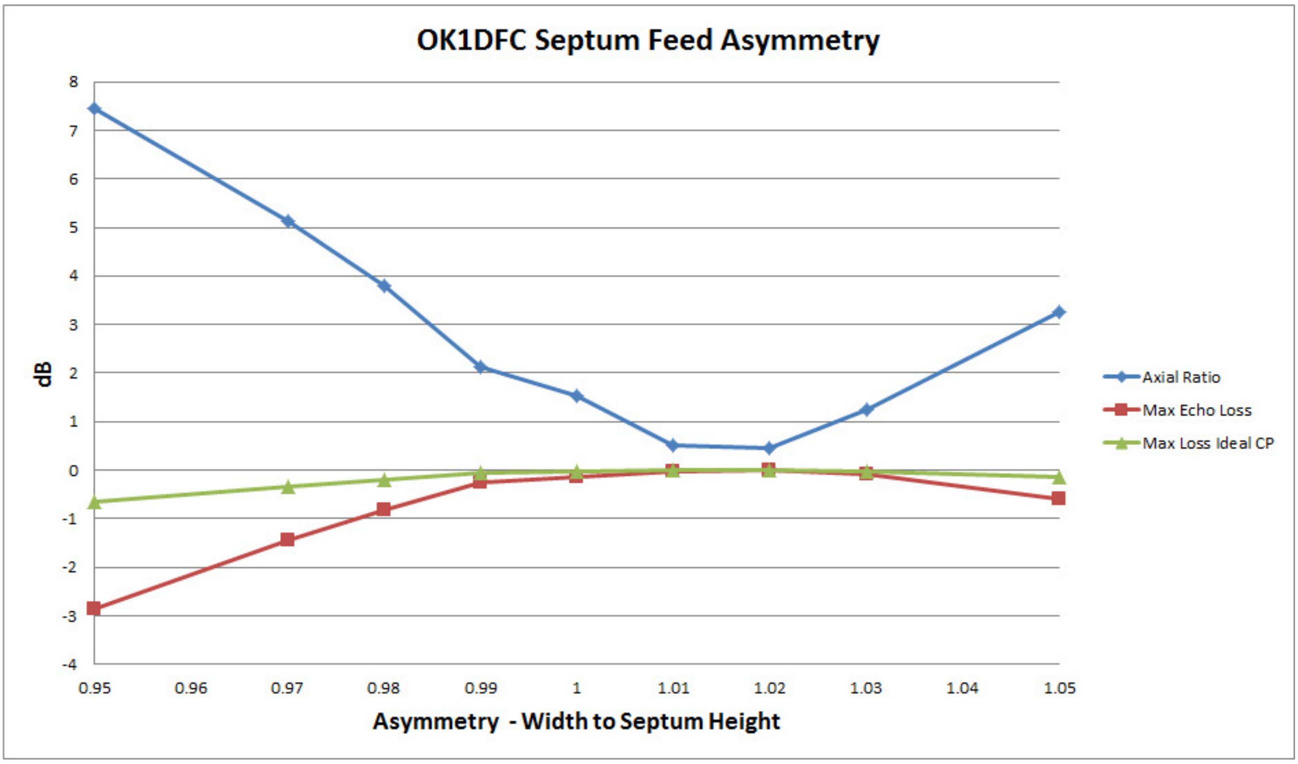

Figure 9 – Effect of asymmetry on OK1DFC septum feed

Note that the OK1DFC square septum is actually better when the perpendicular dimension is 1 to 2% larger than the septum height. One method of construction inserts the septum between two identical halves, which may produce the optimum asymmetry by accident. Note that the phase error produced by asymmetry is a function of waveguide length, which makes the length of the horn another variable – for symmetrical square or cylindrical horns, length should not matter.

Asymmetry also affects antenna performance, as shown in Figure 11. There is a decrease in dish efficiency in addition to any polarization loss.

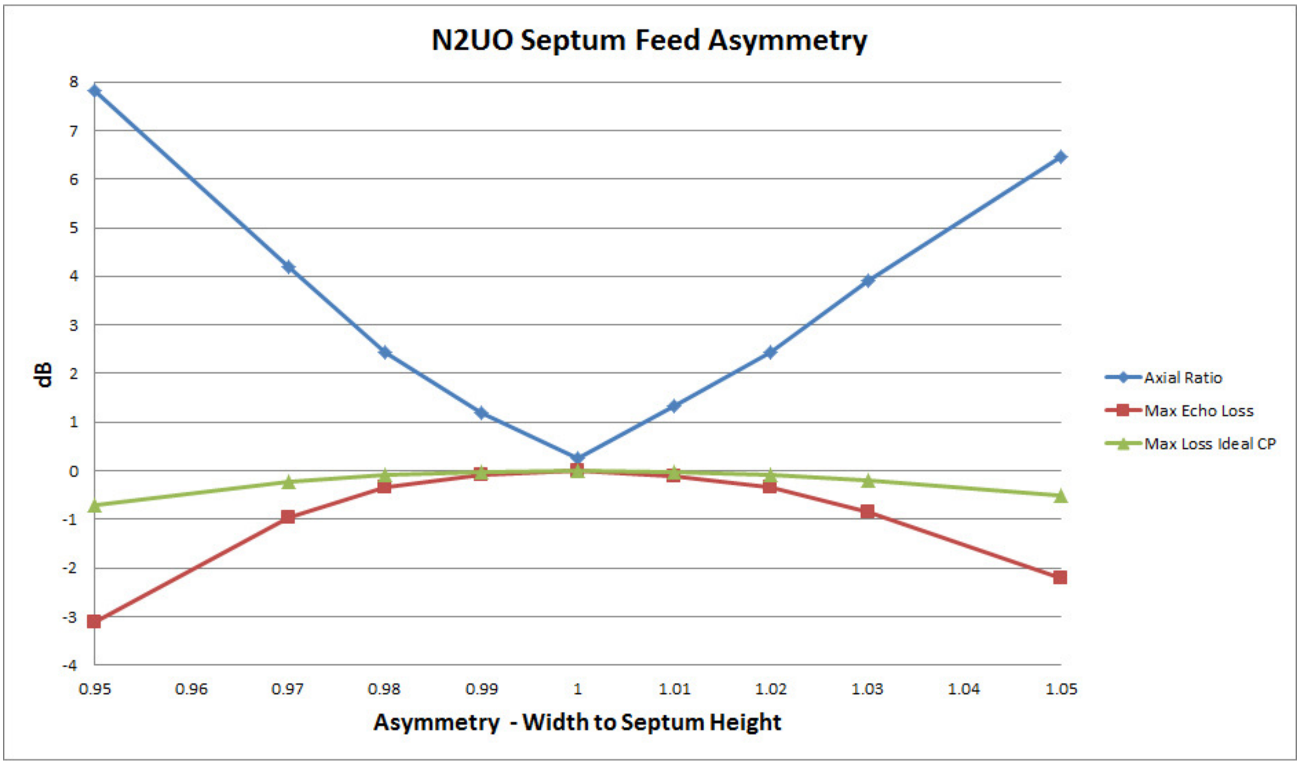

Figure 10 – Effect of asymmetry on OK1DFC septum feed

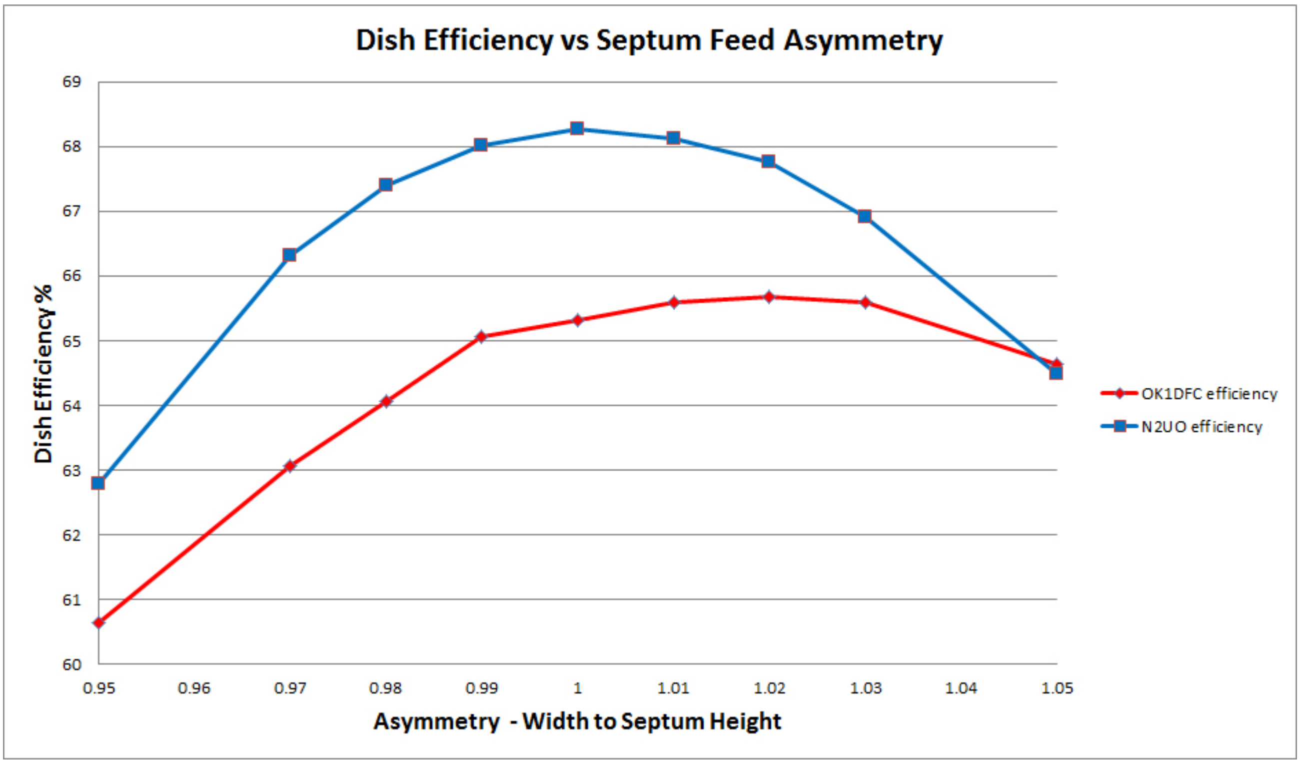

Figure 11 – Effect of septum feed asymmetry on dish antenna performance

Septum Centering

If symmetry is important, what about centering of the septum? Perhaps surprisingly, this does not seem to be critical – moving the septum off center by up to three septum thickness makes almost no difference. At five septum thicknesses off center, the axial ratio starts to degrade.

Septum Contact

Another common recommendation is the need for good contact between the septum and the waveguide walls. While I expected this to be true, I wanted to see how critical it was. To test, I added some arbitrary small gaps in the septum, so that there were only a few points of contact. The most critical area was along the bottom of the septum – with only two or three contact points, circular polarization was upset, with axial ratios of 7 dB for two points and 3.4 dB for three points. Calculated dish efficiency also suffered. With four points of contact, the axial ratio was better than with full contact; however, this is probably dependent on the contact points chosen – I did not experiment further.

The top of the septum is somewhat more forgiving. Two points of contact provide reasonable performance, and even with no contact at all, the axial ratio is about 2 dB. However, one point of contact is worse than none.

My conclusion is that good contact is required along the bottom and top for predictable results. For constructions requiring bolting aluminum pieces together, maximize the number of bolts.

The back of the septum is less critical. From work with waveguide-to-coax transitions, I learned that even a modest amount of metal provides a reasonably good backshort. Having a single point of contact to the septum or even no contact does not affect the performance markedly, except for isolation.

Choke Contact

Adding a choke to a septum feed has been shown to improve performance. One recommendation is that good contact to the choke is important. Simulation with a small gap showed a definite degradation of performance. However, making the back of the choke ¼ λ thick provides a virtual short circuit and performs as well as perfect contact. This could make a good adjustable choke for the higher bands. A tubular collar, ¼ λ, insulated with a thin dielectic would work as well for the lower bands.

Summary

For these septum feeds, the septum dimensions are not critical and amateur construction tolerances should suffice. Minor variations to accommodate available materials are also acceptable. The critical dimension is the symmetry of the square or cylindrical waveguide, which must be within about 1%. There is no reason to believe that other septum designs are any less tolerant, and some newer ones by RA3AQ and OM6AA may provide slightly better performance. So go ahead and build one.

The most important thing for any antenna is to get it on the air.

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