10-4.1 Corrugated Rod (Cigar) BOR-MoM Analysis

The BOR-MoM code CHAMP (TICRA) can analyze the corrugated rod by feeding it from a circular waveguide using mode-matching and by using the BOR-MoM portion to compute its pattern. Figure 10-4.1.1 shows the model of a 5λ long corrugated rod. The uniform thickness corrugations are equally spaced along the rod with most corrugations the same diameter. We need to increase the diameter of the initial corrugations to transition from the waveguide to the rod so that P = 1.2. We taper the diameter of the last few corrugations to reduce end reflection. A reflected wave on the corrugated rod produces a second beam and increases the backlobe. The CHAMP model specifies every corrugation diameter as a variable so that we can use the optimization portion of CHAMP to improve performance. We support the rod by using two dielectric cylinders in the waveguide. The model specifies the lengths and spacing between the two dielectric cylinders as variables and enables an optimization of return loss, Figure 10-4.1.2.

Figure 10-4.1.1 5λ Long Corrugated Rod Fed by Circular Waveguide

The mode-matching waveguide ends a short axial distance from the rod which been tapered to a point. The model uses a distance of twice the waveguide wall thickness. The circular inner and outer surfaces of both dielectric supports are specified as metal. The model uses separate scatterers of the tapered rod, the rod between the dielectric spacers, the waveguide between the spacers, and the exterior of the waveguide feeder where “snap-to-aperture” has been turned off. The waveguide feeder will have significant outer wall currents due currents from the sum of inner waveguide wall currents flowing down the outside and a second component due to the backward wave radiation of the corrugated rod. You can see that the two dielectric spacers have different lengths determined by the optimization of return loss. These could be made equal but the return loss is not as good.

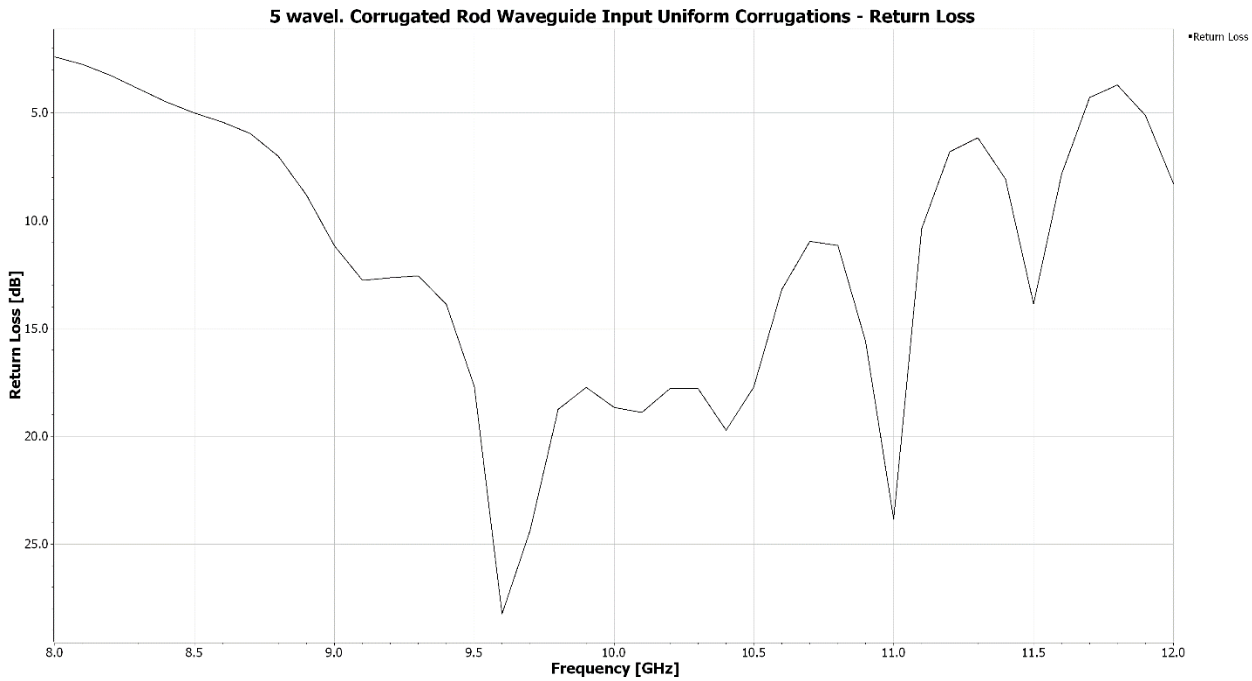

Figure 10-4.1.2 5λ Long Corrugated Rod Fed by Circular Waveguide optimized Return Loss

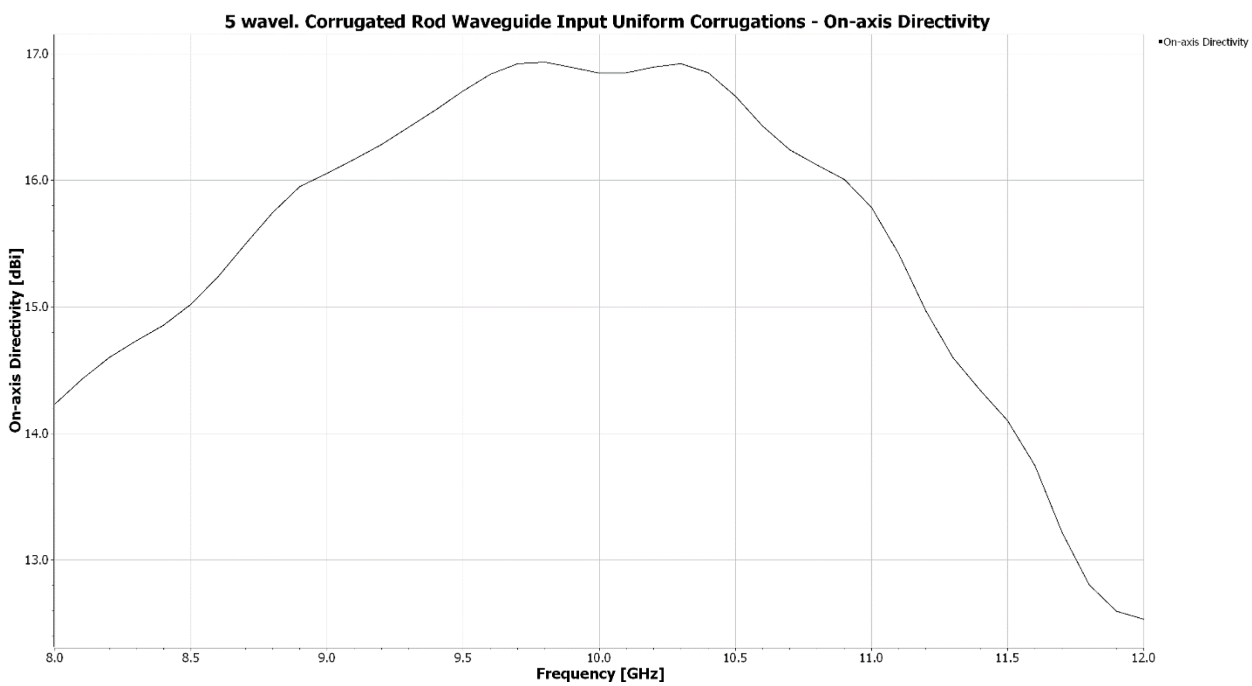

Figure 10-4.1.3 Directivity of 5λ Long Corrugated Rod Fed by Circular Waveguide

The center frequency directivity 16.8 dB matches the value given on Figure 10.2 within a few tenths of a dB for a uniformly fed traveling wave structure. We achieve a uniform distribution by making most of the corrugations the same diameter. Figure 10-4.1.4 of the pattern shows that the first sidelobes are similar to those given in Figure 10-16 of the uniform distribution dielectric rod. The front/back of 14 dB can be improved either by optimizing corrugation diameters or by adding structure on the feeding waveguide to block outer wall currents on the waveguide feeder.

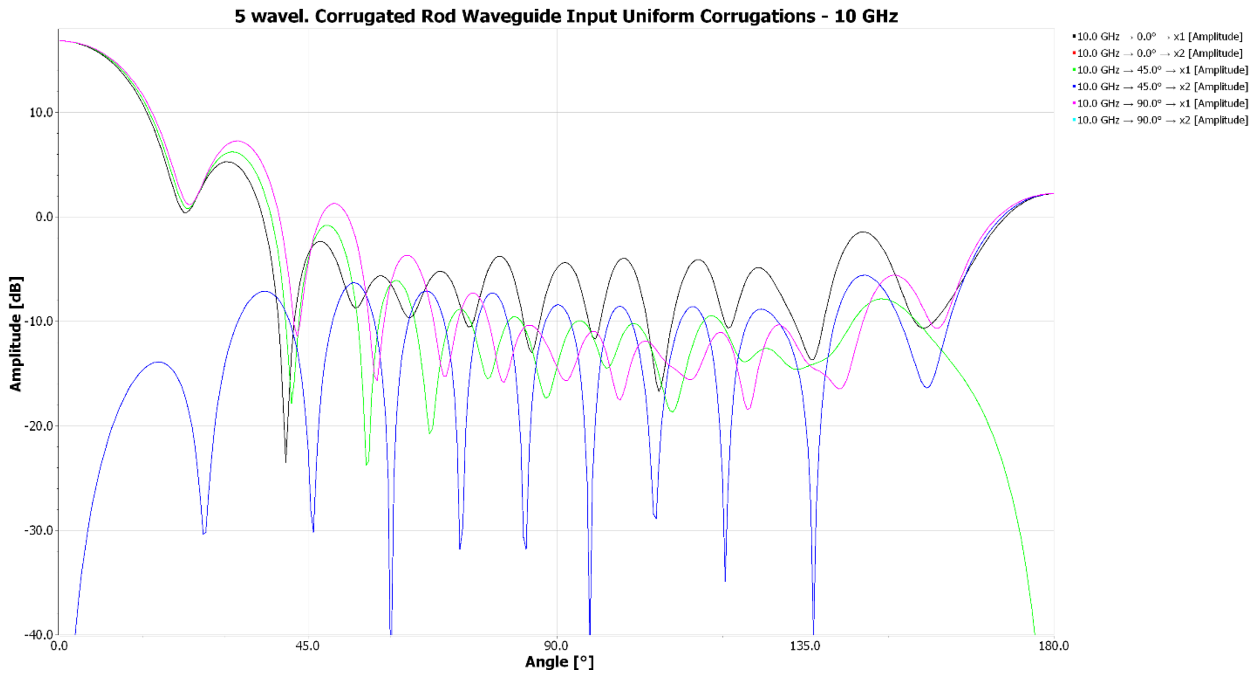

Figure 10-4.1.4 Center Frequency Pattern of 5λ Long Corrugated Rod Fed by Circular Waveguide

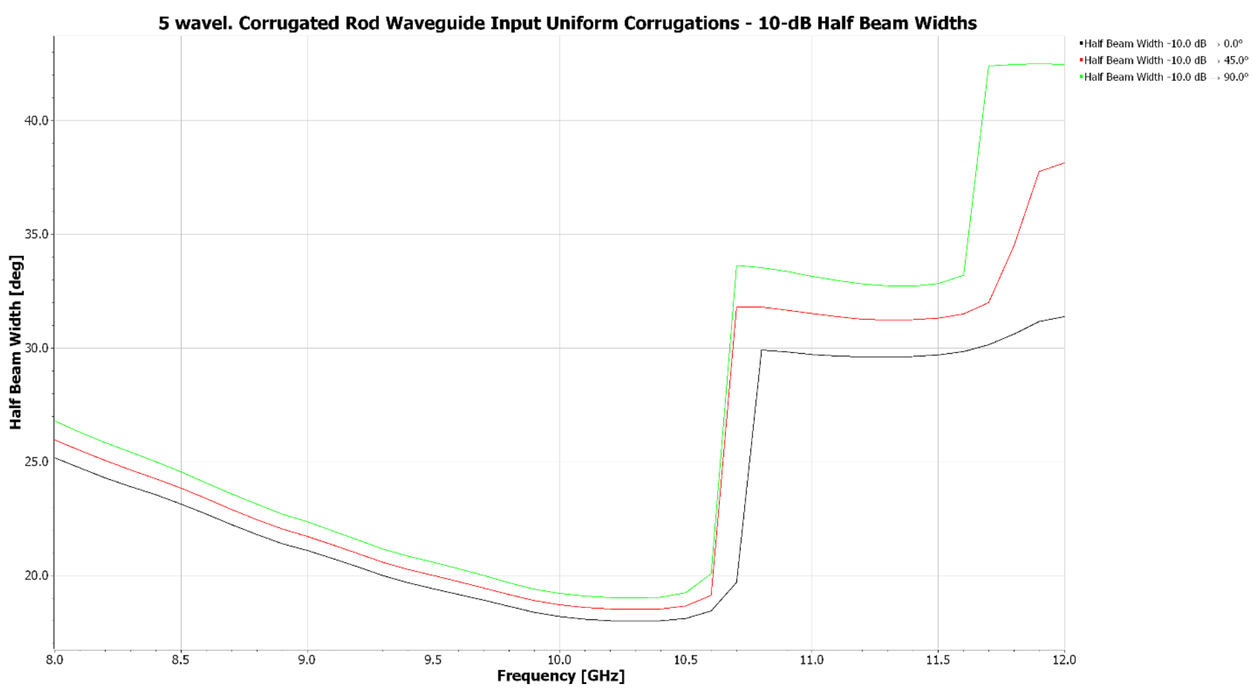

Figure 10-4.1.5 10-dB Half Beamwidth of 5λ Long Corrugated Rod Fed by Circular Waveguide

Figure 10-4.1.5 shows that the beamwidth decreases as frequency increases but has a discontinuity at about 10.7 GHz where the depth of the first null (dip) rises above 10-dB below the peak.

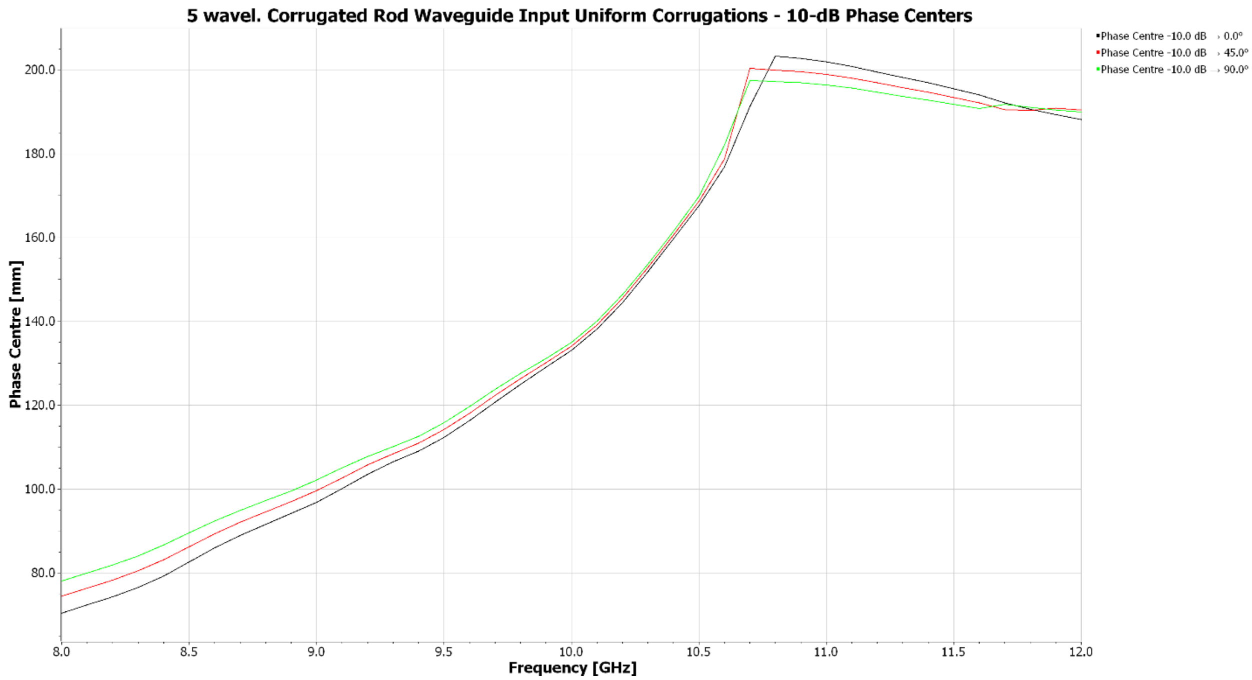

Figure 10-4.1.6 Phase Center using 10-dB beam of 5λ Long Corrugated Rod Fed by Circular Waveguide

CHAMP computes the location of phase center which we need if we use this antenna as a reflector feed. CHAMP measures the phase center distance from the mode-matching aperture. The equivalent model waveguide is located at about 40 mm. When we subtract 40 mm from the values on Figure 10-4.1.6, we compute the center frequency phase center as 95 mm along the 150 mm corrugated rod. By reading the half 10-dB beamwidth from Figure 10-4.1.5 (~19°) and by reading Scale 8-1, we would have a good feed for a reflector with an effective *f/D* = 1.5 (probably a dual reflector).

One method of reducing the backlobe is to use a small horn at the input to the corrugated rod, Figure 10-4.1.7. Figure 10-4.1.8 illustrates that the center frequency directivity increases by about 0.3 dB compared to the design without the small horn. A comparison of the sidelobes between the pattern with the small horn (Figure 10-4.1.9) and without (Figure 10-4.1.4) shows that sidelobes at angles greater than 60° are reduced by the small horn. Front/back has increased by about 7 dB to 21 dB. The beamwidth and phase center shows little change. Below we will illustrate a case where the cone has been greatly increased to decrease sidelobes based on reference [27].

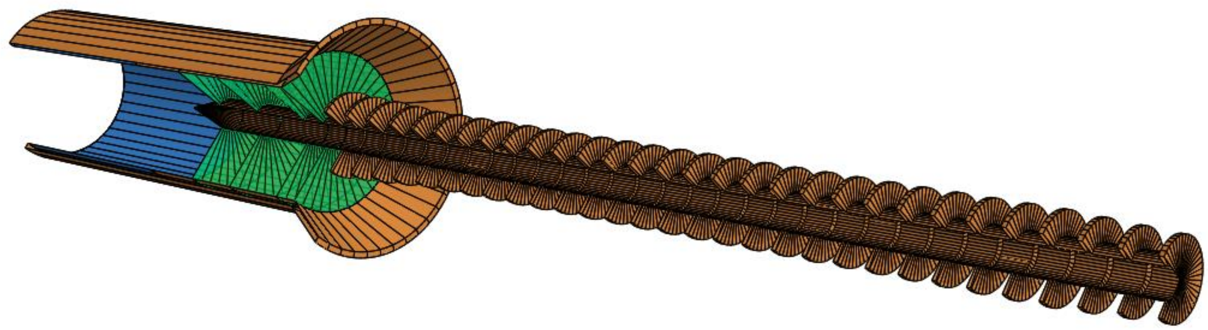

Figure 10-4.1.7 5λ Long Corrugated Rod Fed by Circular Waveguide with Small Horn

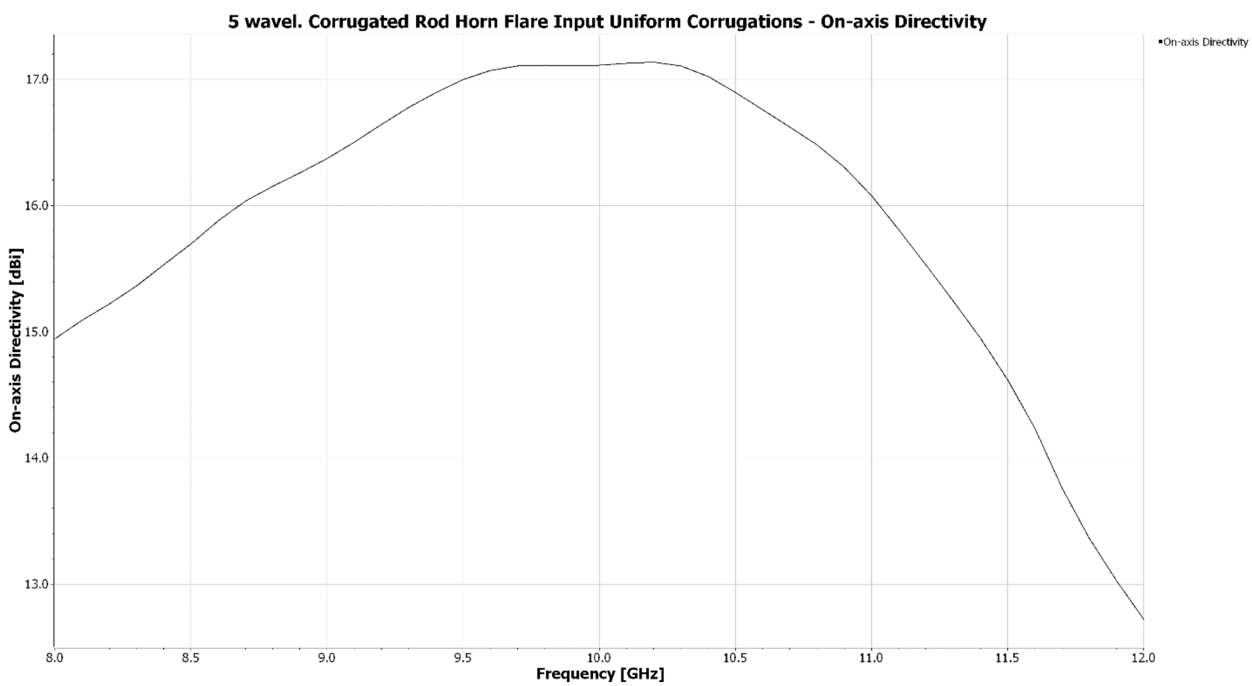

Figure 10-4.1.8 Directivity of 5λ Long Corrugated Rod Fed by Circular Waveguide with Small Horn

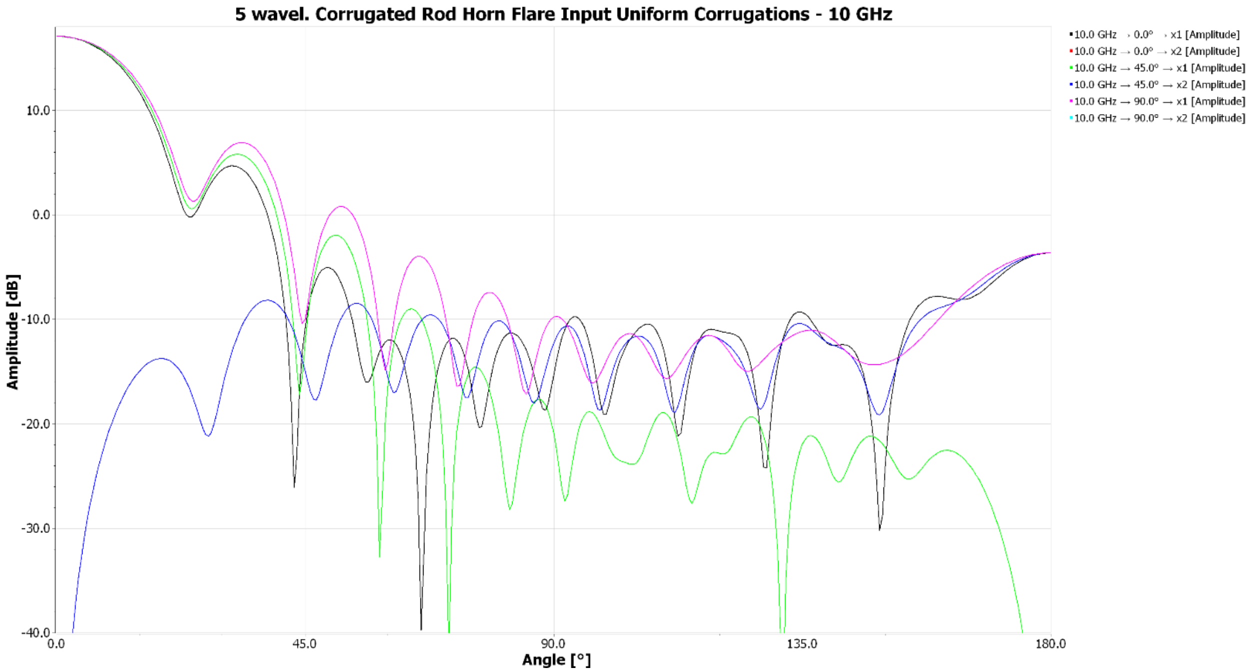

Figure 10-4.1.9 Center Frequency Pattern of 5λ Long Corrugated Rod Fed by Circular Waveguide with Small Horn

A second method of reducing the backlobe is to add a series of circular chokes on the feeding waveguide (Figure 10-4.1.10).

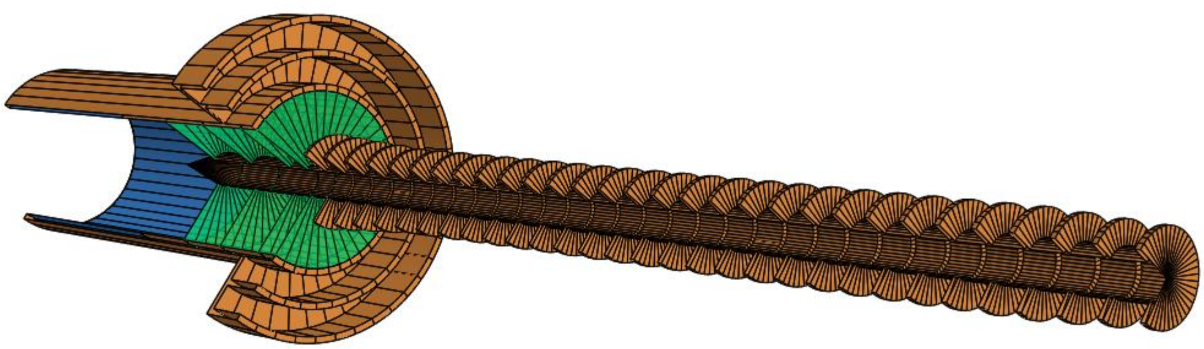

Figure 10-4.1.10 5λ Long Corrugated Rod Fed by Circular Waveguide with 2 Circular Chokes

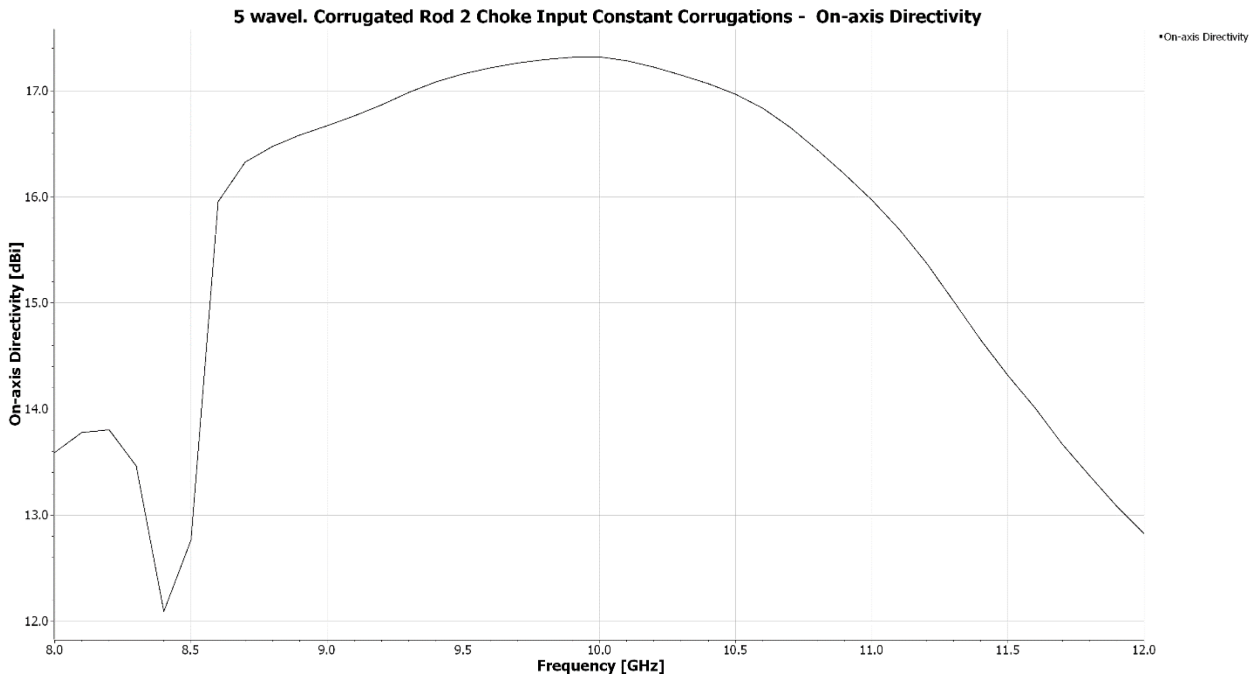

Figure 10-4.1.11 Directivity of 5λ Long Corrugated Rod Fed by Circular Waveguide with 2 Circular Chokes

The chokes increase the center frequency directivity by about 0.5 dB (Figure 10-4.1.11) compared to a design without the chokes (Figure 10-4.1.3).

Figure 10-4.1.12 Center Frequency of 5λ Long Corrugated Rod Fed by Circular Waveguide with 2 Circular Chokes

The 2 circular chokes reduce Front/Back by an additional 4 dB to 25 dB compared to using a small horn input feeder as well as all sidelobes beyond 60° of the design using a simple waveguide feed.

Uniform Taper Design

We can increase the beamwidth of the 5λ long corrugated rod antenna by applying a uniform taper from input to output as illustrated in Figure 10-16. Figure 10-4.1.13 illustrates this design, but it is hard to see the taper compared to Figure 10-4.1.10.

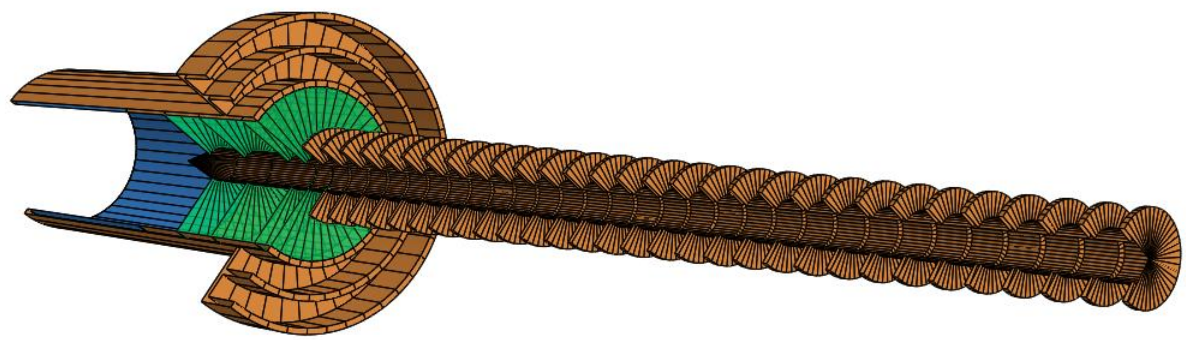

Figure 10-4.1.13 5λ Long Corrugated Rod with Uniform Tapered Corrugation Diameters from input to End Fed by Circular Waveguide with 2 Circular Chokes

Figure 10-4.1.14 gives the CHAMP analysis at the center frequency and shows that the first sidelobe (Figure 10-4.1.12) has been absorbed in the main beam due to the non-uniform phase of the wave propagating along the rod. The Front/Back has increased to about 30 dB but it is by chance and not by design. The widened beam reduces the center frequency directivity (Figure 10-4.1.15) by about 1 dB compared to the nearly uniform diameter corrugation design. The additional phase shift of the wave along the rod due to the larger diameter corrugations shifts the peak directivity to a lower frequency. The phase center also shifts about 30 mm further out along the rod.

CHAMP can produce a better design using its optimization section. Every corrugation diameter can be an optimization parameter and the program allows multiple optimization goals. This 5λ long design has 30 corrugations along the rod, plus choke depths and widths, and the internal parts as optimization variables. Including corrugation spacings as other variable adds little improvement and complicates manufacture. Below a 2λ design illustrates using CHAMP optimization by using corrugation diameters.

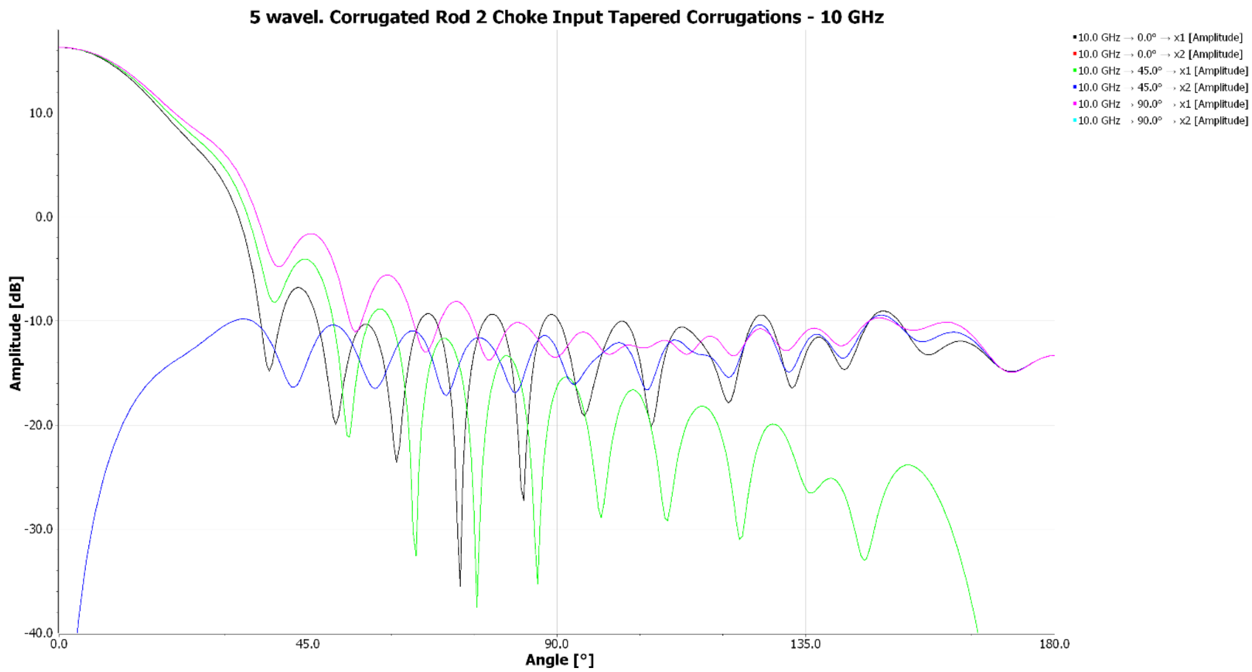

Figure 10-4.1.14 Center Frequency of 5λ Long Corrugated Rod with Uniform Tapered Corrugation Diameters from input to End Fed by Circular Waveguide with 2 Circular Chokes

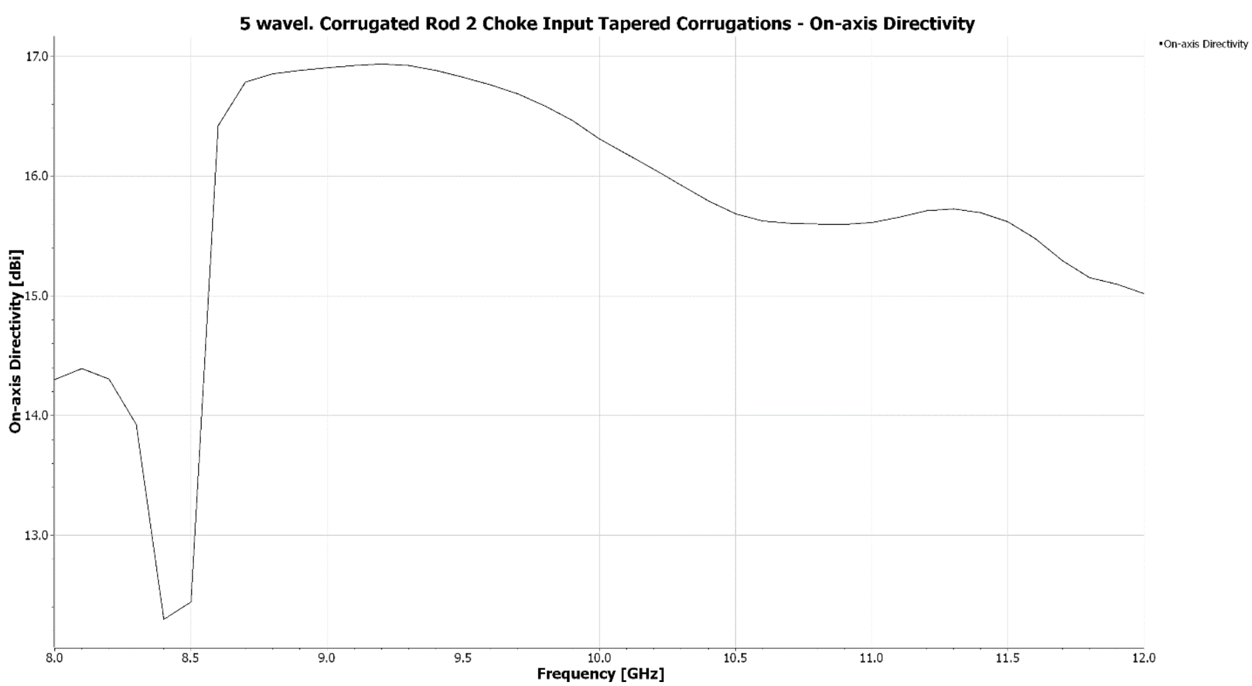

Figure 10-4.1.15 Directivity of 5λ Long Corrugated Rod with Uniform Tapered Corrugation Diameters from input to End Fed by Circular Waveguide with 2 Circular Chokes

Design including Large Cone [27]

Figure 10-4-1.16 illustrates a design with a 4λ long cone similar to the one given in [27]. The corrugated rod extends about 1λ beyond the cone.

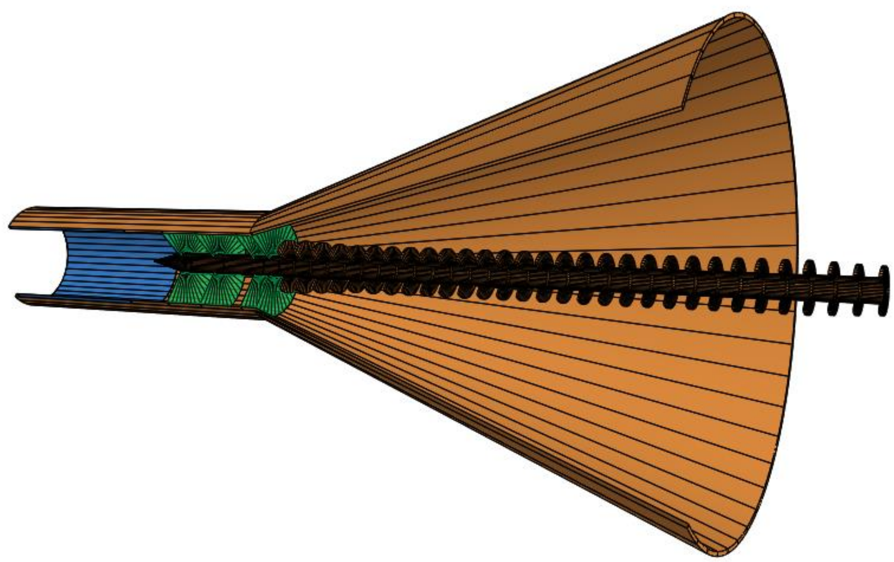

Figure 10-4.1.16 5λ Long Uniform Amplitude Corrugated Rod inside a 4λ Long 20° flare Cone

Figure 10-4.1.17 Center Frequency 5λ Long Uniform Amplitude Corrugated Rod inside a 4λ Long 20° flare Cone

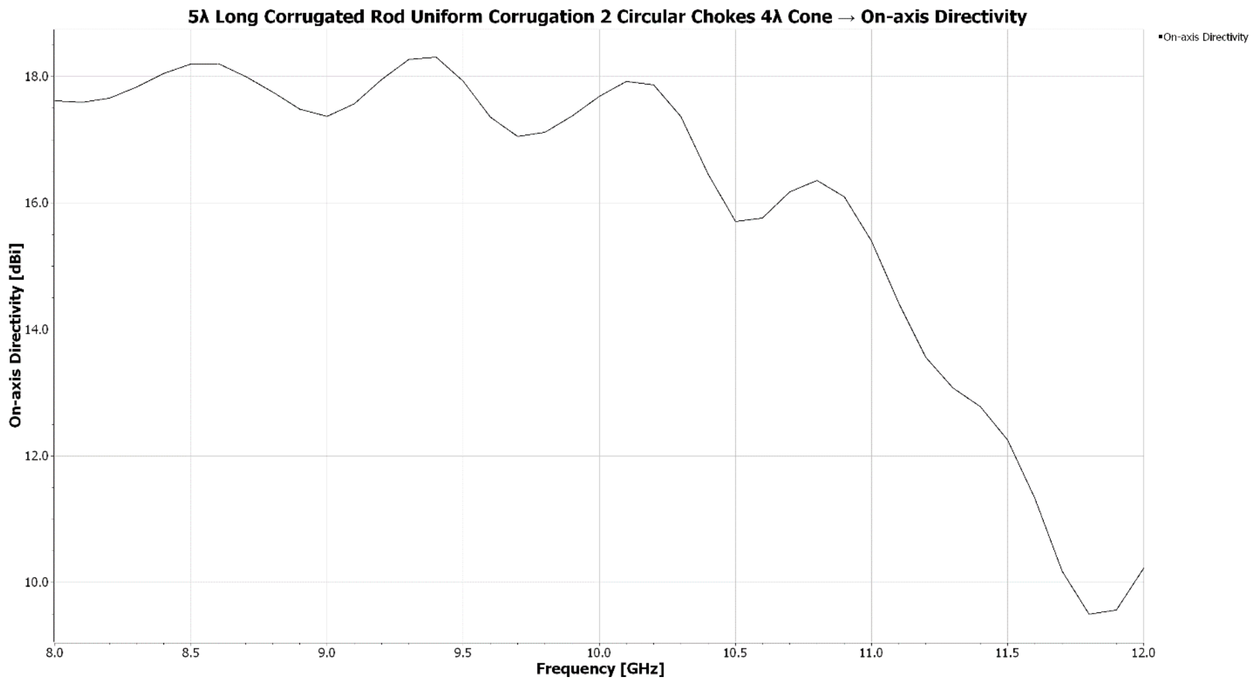

Figure 10-4.1.18 Directivity of 5λ Long Uniform Amplitude Corrugated Rod inside a 4λ Long 20° flare Cone

The cone increases the directivity a little to 17.7 dB. Near the center frequency the sidelobes are decreased and beyond 110° they are less than -30 dB.

2λ Long Corrugated Rod Antenna

Decreasing the length of the corrugated rod reduces directivity and increases the pattern beamwidth. CHAMP optimization improves both return loss and Front/Back by varying the last two and first corrugations, and the internal waveguide parts. Figure 10-4.1.19 shows the short rod fed from a simple waveguide.

Figure 10-4.1.1 5λ Long Corrugated Rod Fed by Circular Waveguide

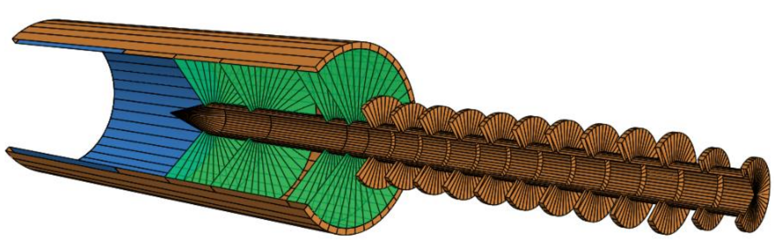

Figure 10-4.1.19 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide

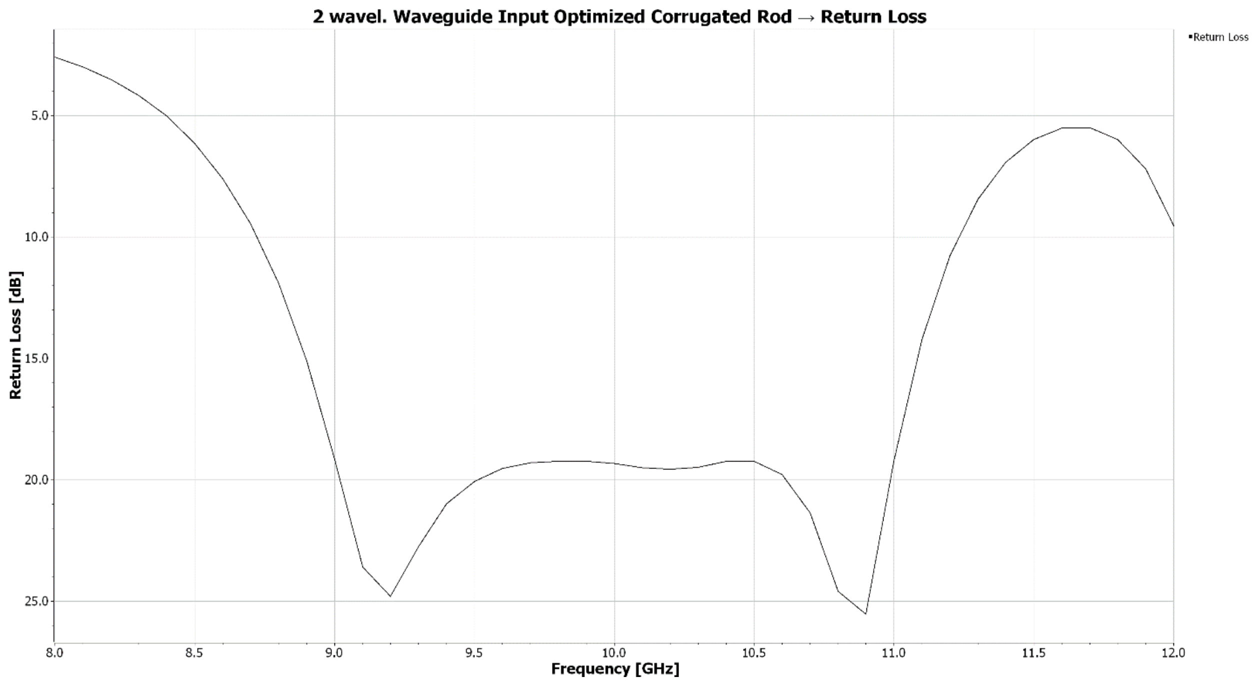

Figure 10-4.1.19 Return Loss of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide

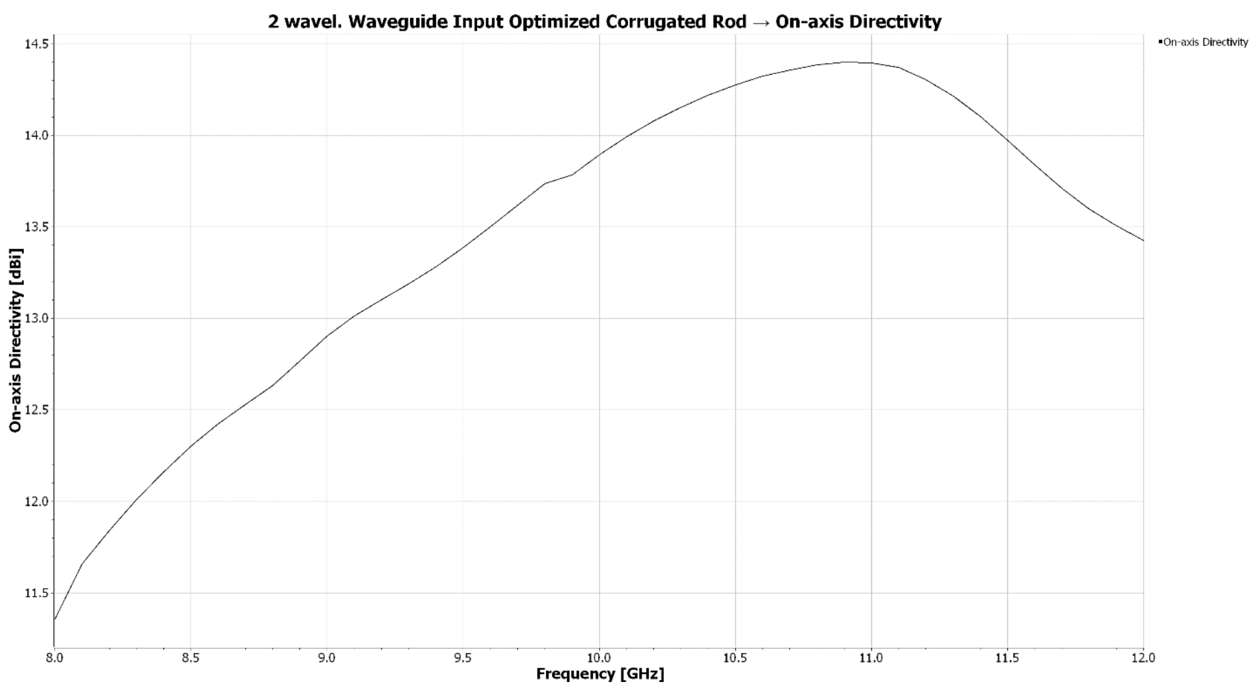

Figure 10-4.1.20 Directivity of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide

Directivity exceeds Figure 10-2 by a few 10^{ths} of a dB for a 2λ length antenna.

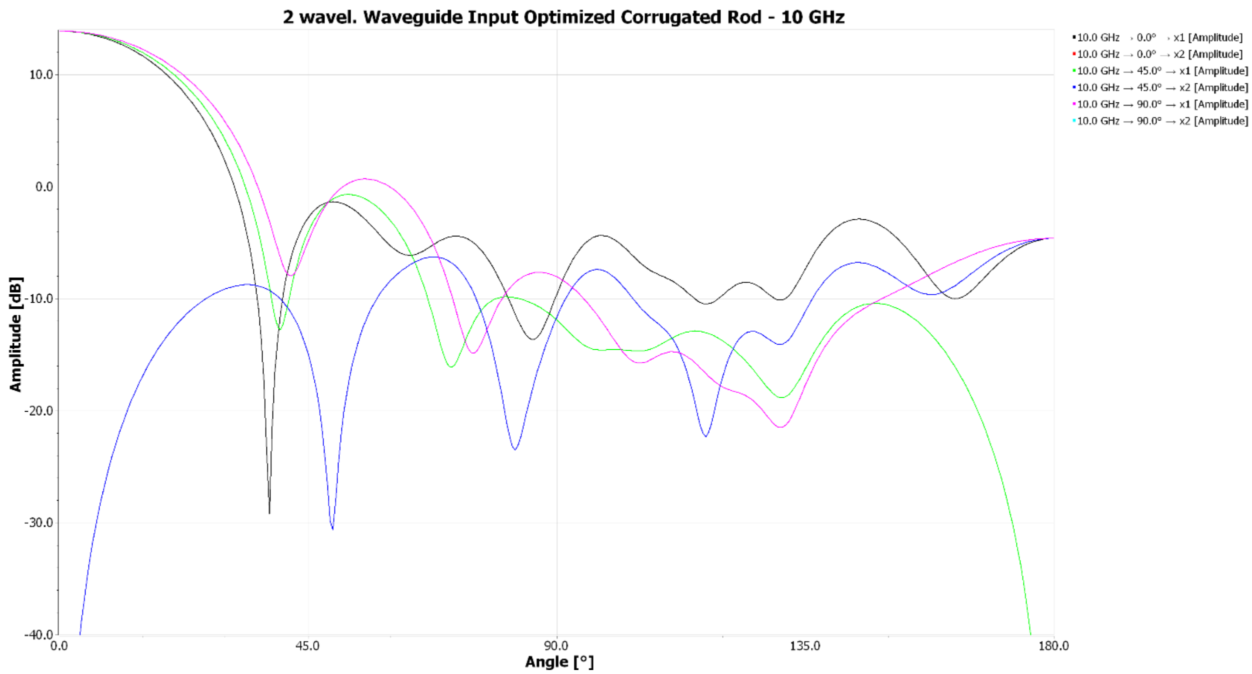

Figure 10-4.1.21 Center Frequency of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide

Optimization increased Front/Back by 4 dB, but only involved the diameters of the last 2 corrugations.

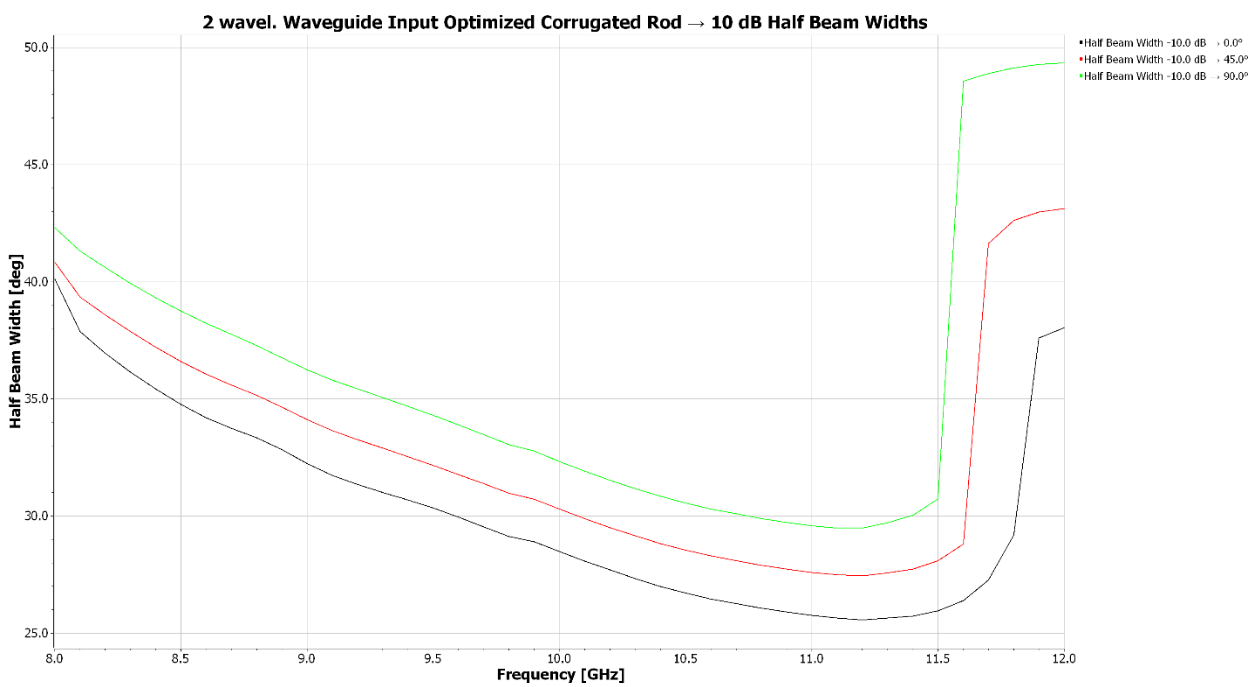

Figure 10-4.1.22 10-dB Half BW of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide

w

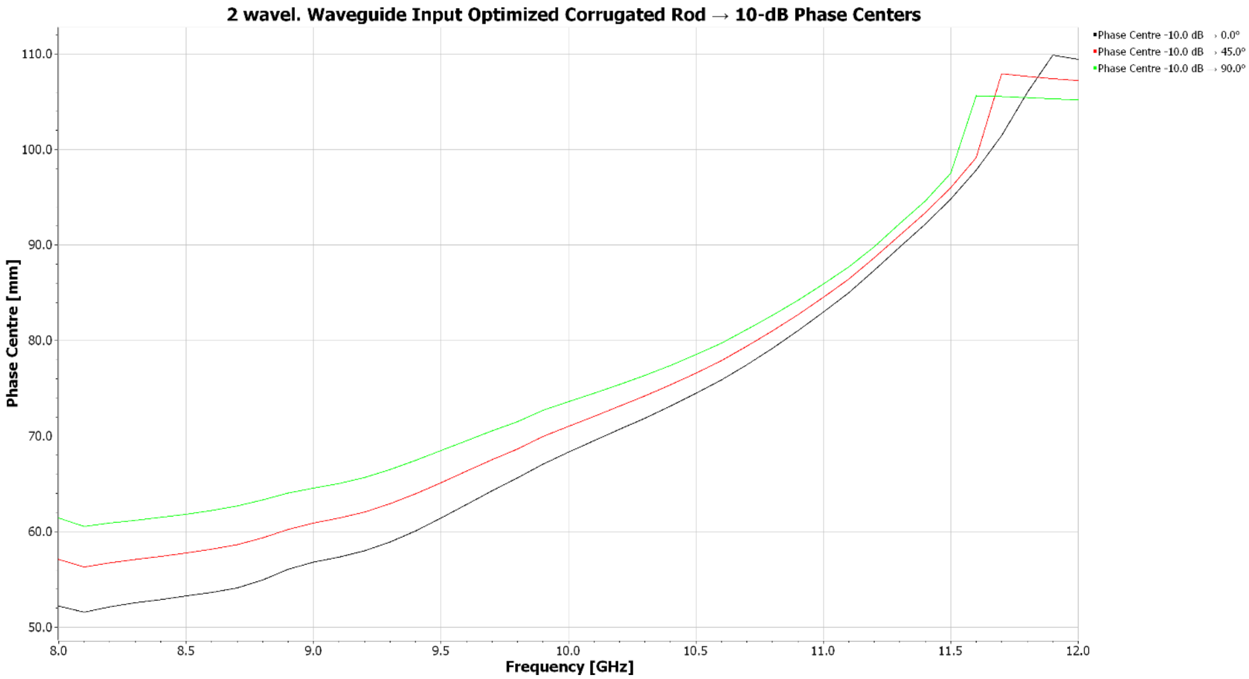

Figure 10-4.1.23 10-dB Half BW of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide

The phase center scale includes 43 mm of the internal waveguide parts which locates it 28 mm along the rod (~ halfway).

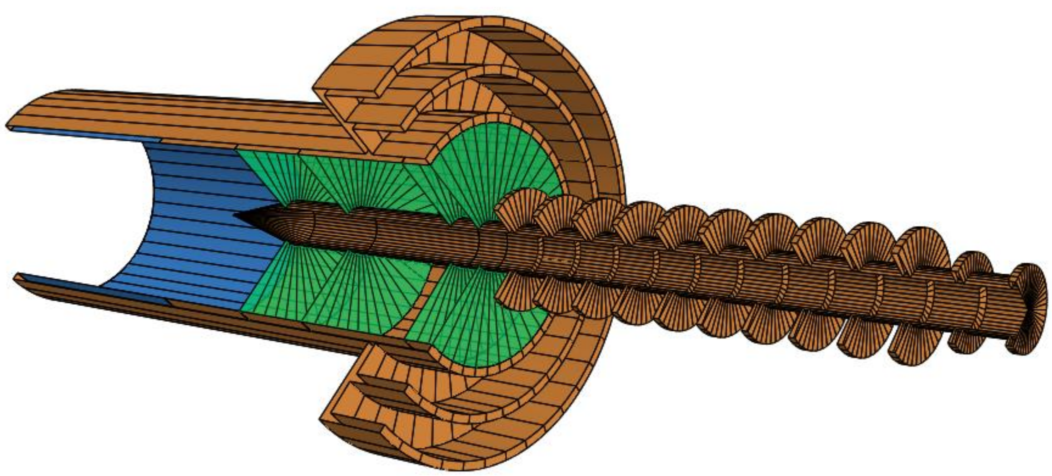

Figure 10-4.1.24 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide w/ 2 Chokes

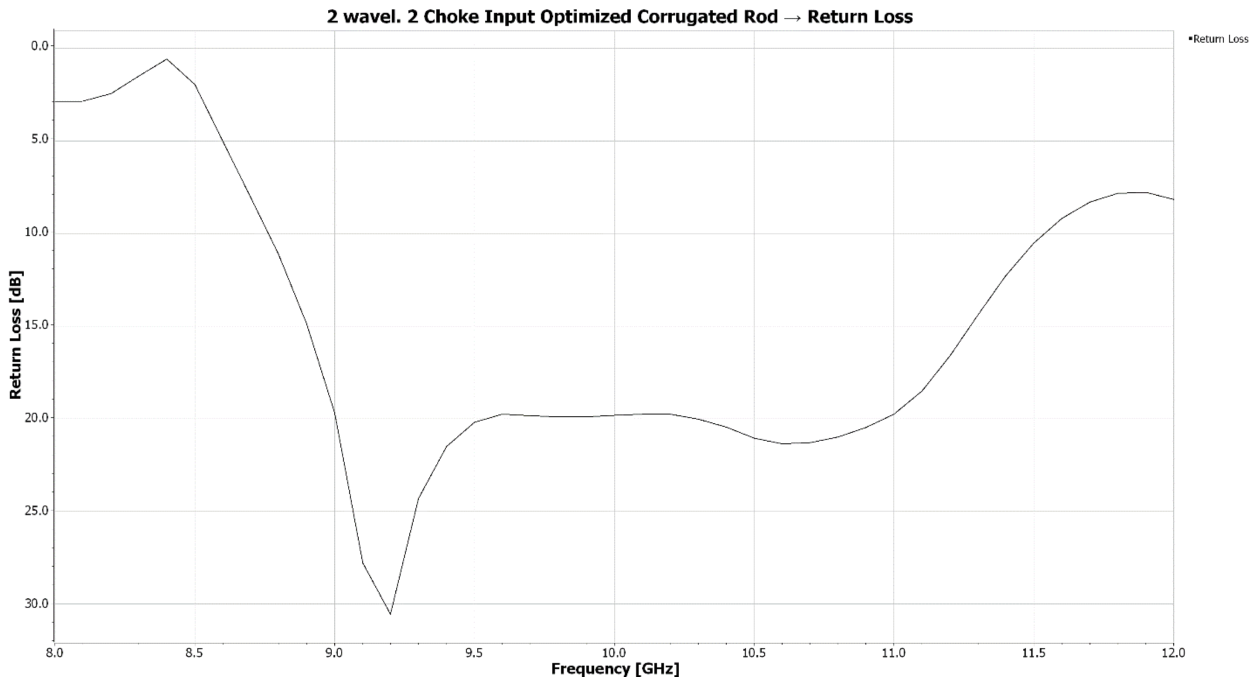

Figure 10-4.1.25 Return Loss of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide w/ 2 Chokes

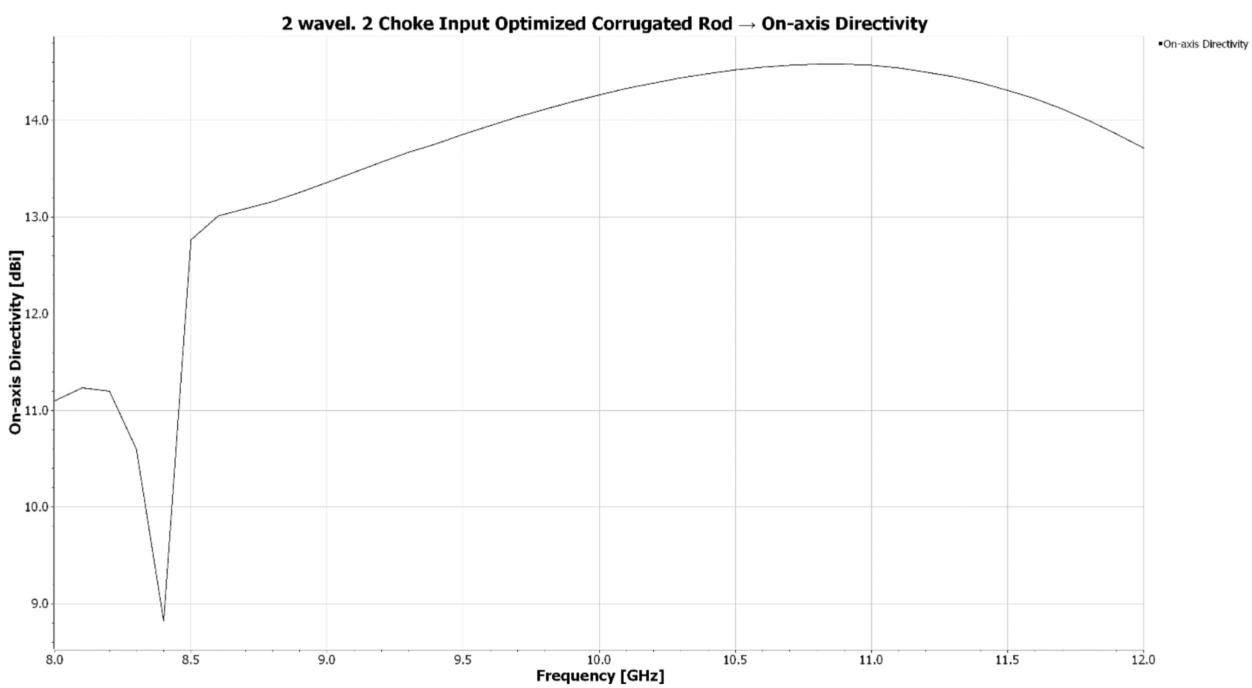

Figure 10-4.1.26 Directivity of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide w/ 2 Chokes

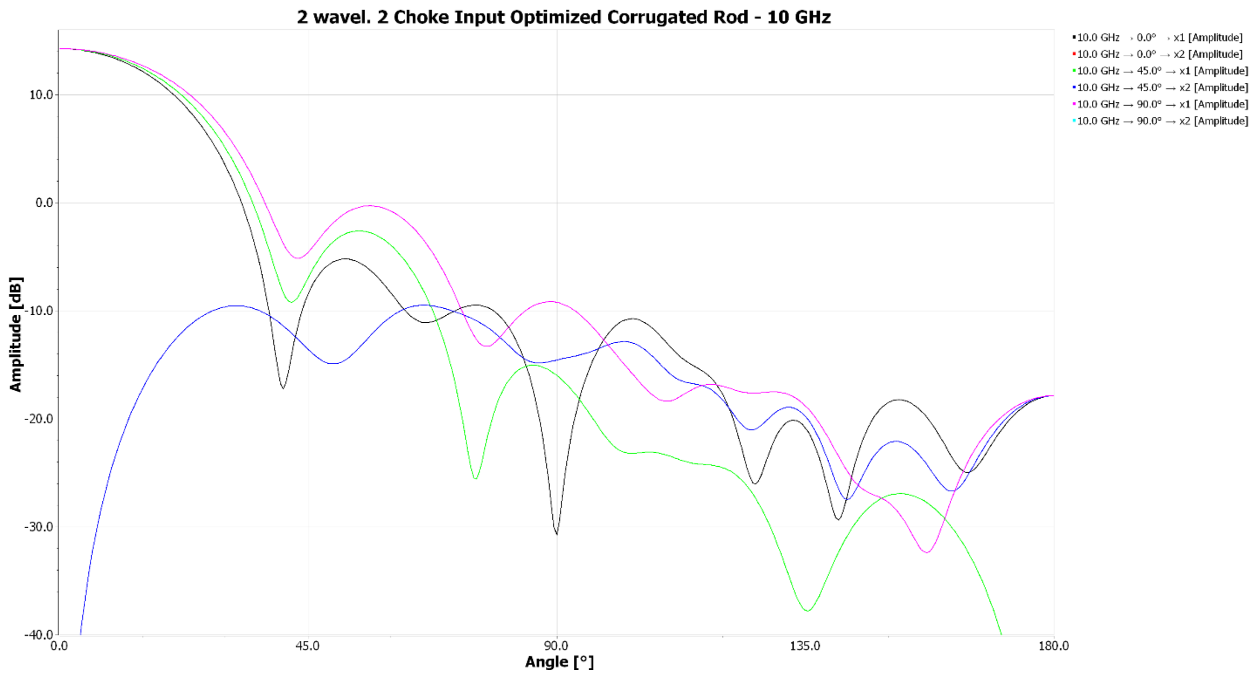

Figure 10-4.1.27 Center Frequency of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide w/ 2 Chokes

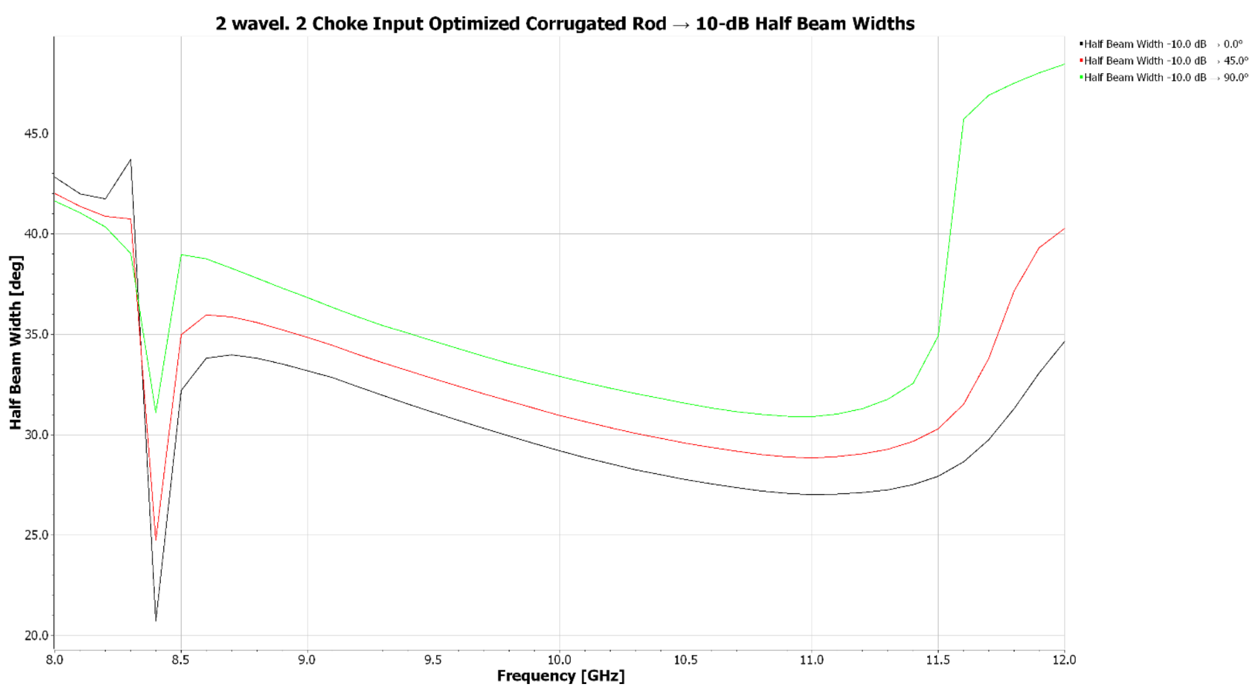

Figure 10-4.1.28 10-dB Half BW of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide w/ 2 Chokes

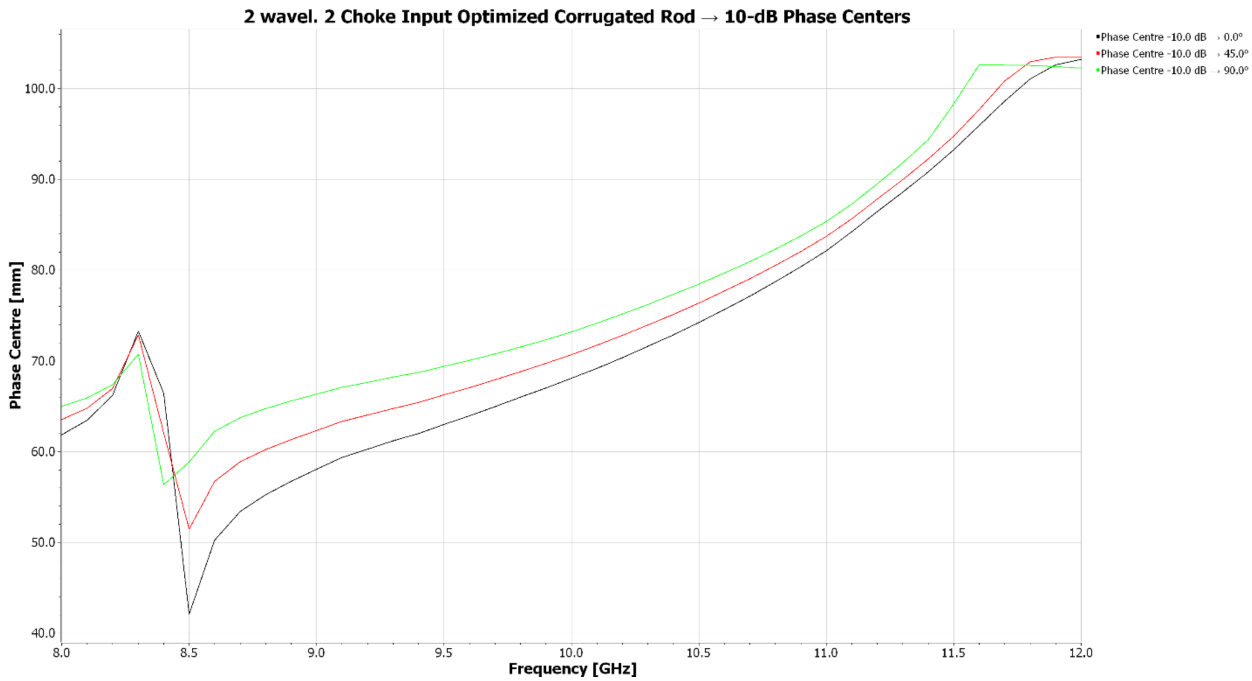

Figure 10-4.1.29 10-dB Phase Center of 2λ Long Optimized Corrugated Rod Fed by Circular Waveguide w/ 2 Chokes

12.2λ Long Corrugated Rod Antenna

•

Figure 10-4.1.30 12.2λ Long Uniform Amplitude Corrugated Rod w/ end tapers Fed by Circular Waveguide w/ 2 Chokes

Section 10-3.3 Yagi-Uda programs has an example of a 50-element dipole antenna whose axial length is approximately 12.2λ. We compare this to a corrugated rod the same length where corrugations are spaced λ/6. The corrugation diameters on both ends of the corrugated rod are tapered. The input end starts with P = 1.2 and the rod end has been tapered to reduce the reflected wave. The clean response of this antenna illustrates that the wave amplitude along the rod is nearly uniform with the proper progressive phase to form a beam peak at zero.

The frequency response of the return loss of the long antenna (Figure 10-4.1.31) matches the response of the 5λ-(Figure 10-4.1.2) and the 2λ-(Figure 10-4.1.19) antenna. This shows that the bandwidth is independent of length similar to the long Yagi-Uda dipole element antennas. Figure 10-4.1.32 of peak directivity demonstrates the increasing response over the frequency band. The directivity at 10-GHz (center frequency) matches the Figure 10-2 curve of a theoretical traveling-wave endfire antenna.

The center frequency pattern (Figure 10-4.1.33) has the expected 10 dB first sidelobe of a uniform distribution traveling wave for a phase distribution for peak gain. The long antenna produces a Front/Back of about 27 dB. The depth of chokes could be tuned using CHAMP optimization to reduce the Front/Back to a lower level, but this was not done. The 74 corrugations give plenty of variables (diameters) to produce a desired specified pattern through optimization, instead of peak gain using in this example to match section 10-3.3.

Phase center, Figure 10-4.1.35, 200 – 40 mm (horn aperture to start of corrugated rod) places near half way along the rod.

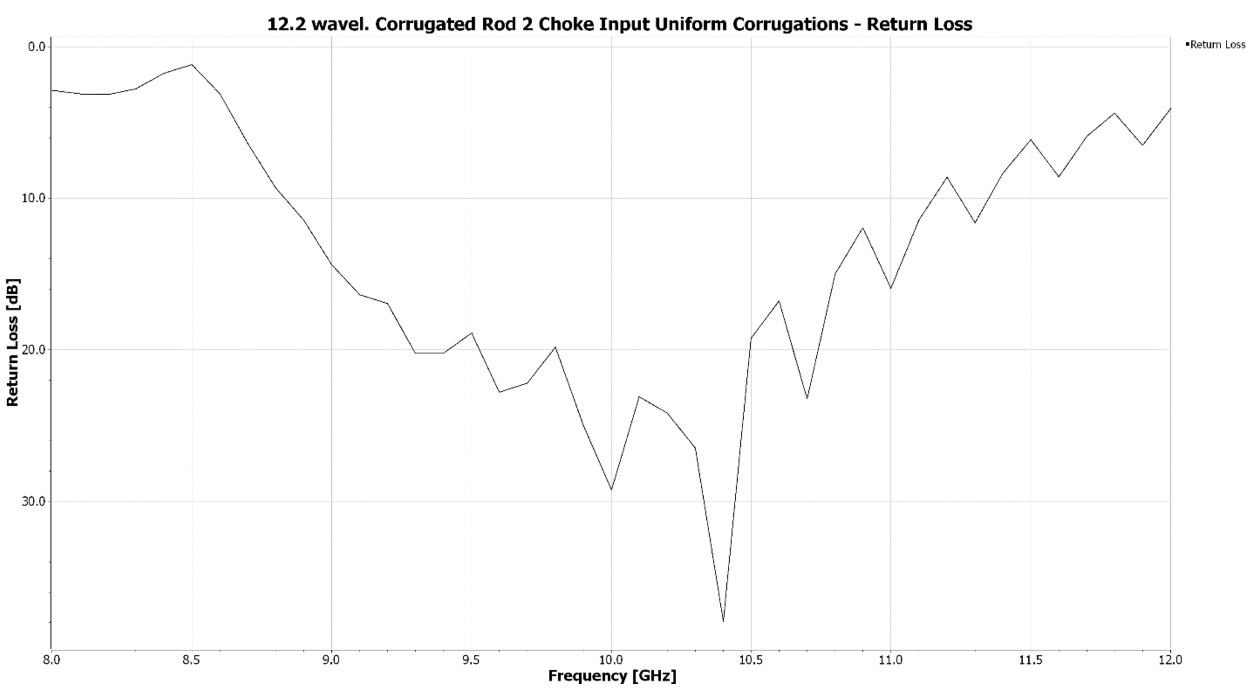

Figure 10-4.1.31 Return Loss of 12.2λ Long Uniform Amplitude Corrugated Rod w/ end tapers Fed by Circular Waveguide w/ 2 Chokes

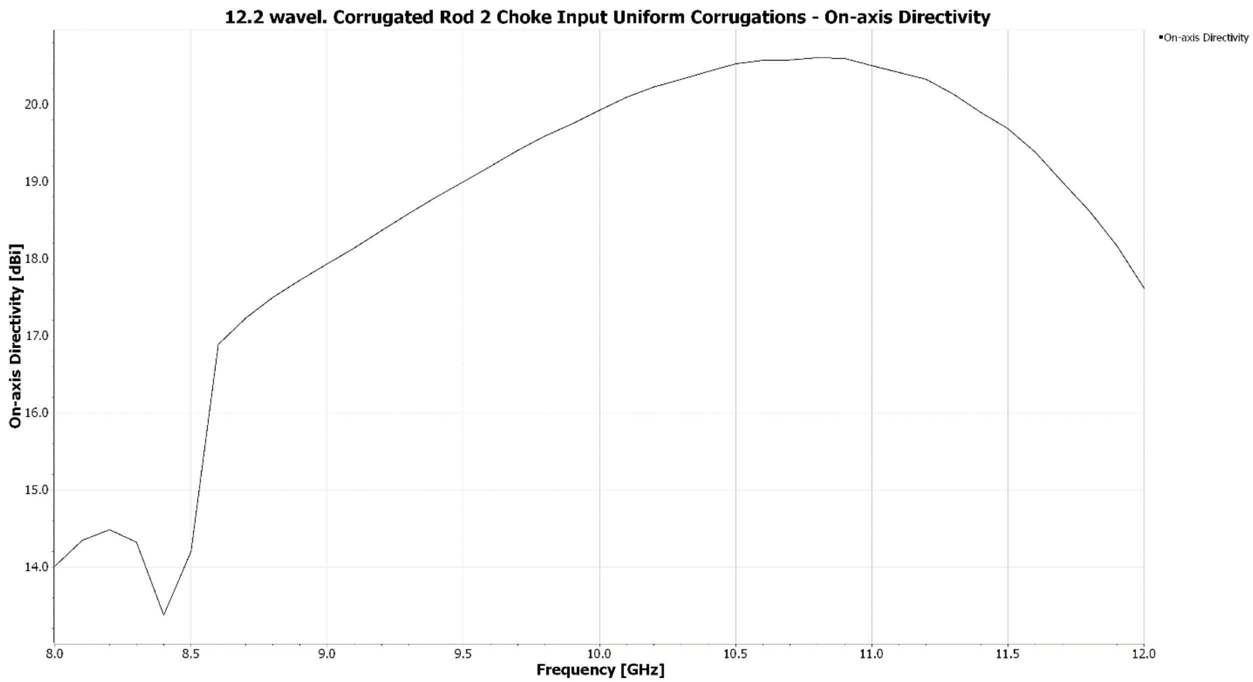

Figure 10-4.1.32 Directivity of 12.2λ Long Uniform Amplitude Corrugated Rod w/ end tapers Fed by Circular Waveguide w/ 2 Chokes

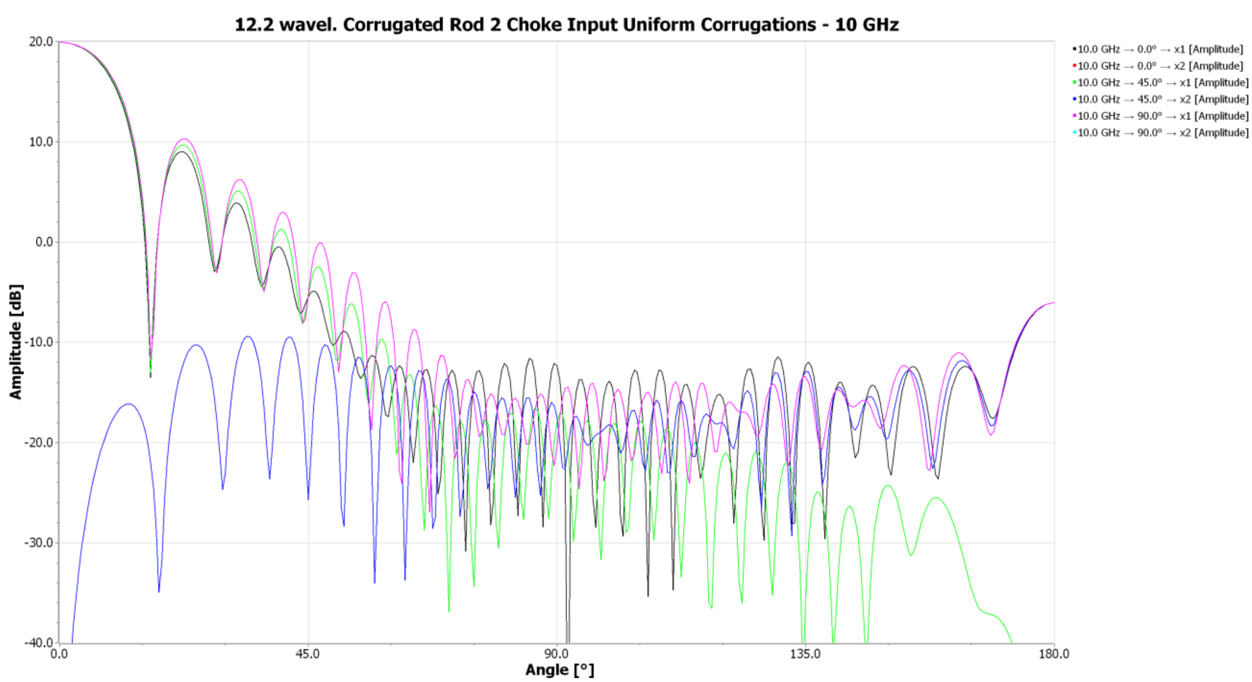

Figure 10-4.1.33 Center Frequency of 12.2λ Long Uniform Amplitude Corrugated Rod w/ end tapers Fed by Circular Waveguide w/ 2 Chokes

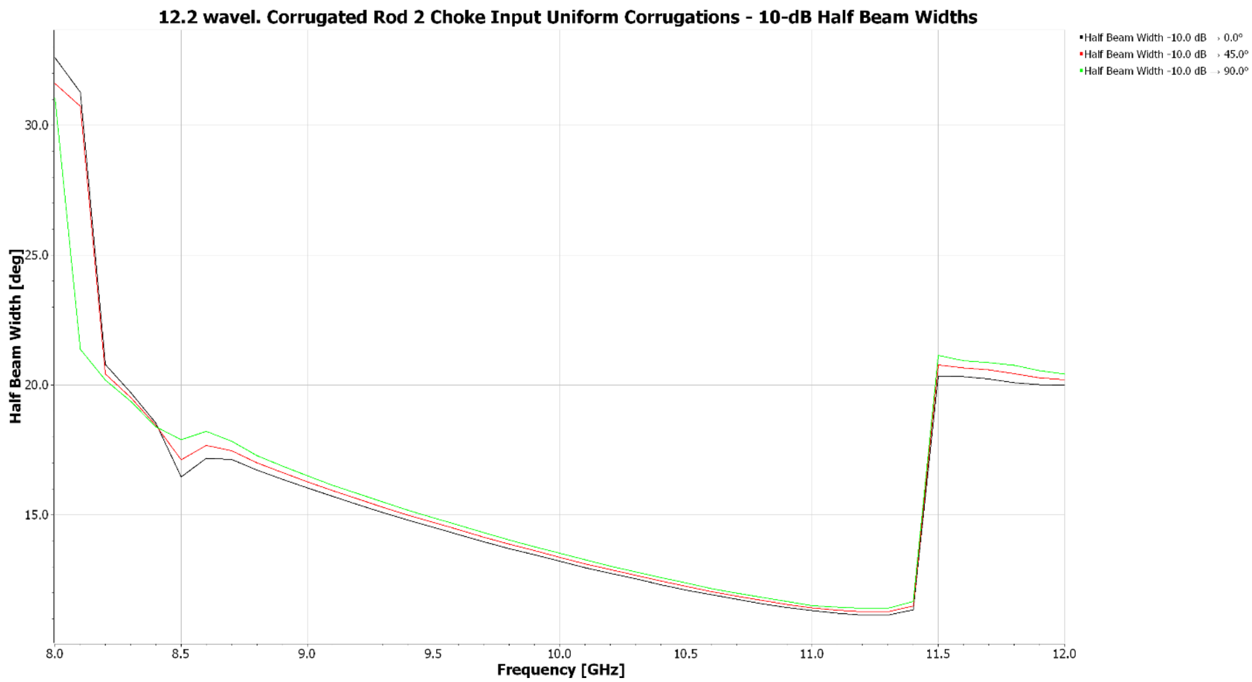

Figure 10-4.1.34 10-dB Half BW of 12.2λ Long Uniform Amplitude Corrugated Rod w/ end tapers Fed by Circular Waveguide w/ 2 Chokes

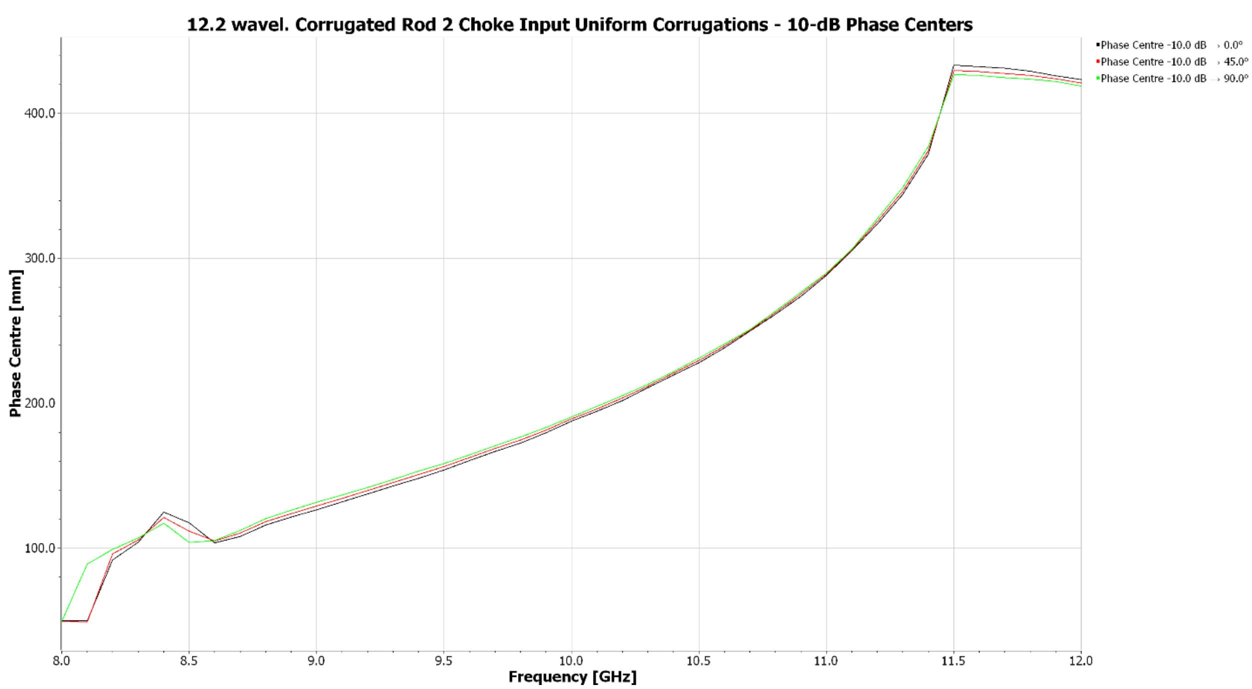

Figure 10-4.1.35 10-dB Phase Center of 12.2λ Long Uniform Amplitude Corrugated Rod w/ end tapers Fed by Circular Waveguide w/ 2 Chokes