

Prime-focus circular waveguide feed with septum polarization transformer

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Introduction

Dish antenna feeds employing septum polarization transformers, which transform linear polarization to circular polarization (CP), have now successfully proliferated throughout the EME community after facing some initial skepticism. Their success is due, in part, to promotion of the septum feed configuration in publications by Zdenek Samek, OK1DFC, [1] and Paul Wade, W1GHZ, [2] who performed a detailed computer analysis of the same.

Despite several advantages, such as ease of assembly, minimal adjustments, and no 90 degree power splitter requirements, septum polarizer feeds employing waveguides having a square cross-section typically cause some degradation in the dish antenna's overall efficiency. This is the result of two different phenomena. Mismatch between the waveguide's square shape and the inherently circular form of electromagnetic field propagating through the waveguide introduces unwanted side lobes. As previously documented [3], these lobes contain parasitic crosspolarized radiation radiated at the expense of desirable radiation causing "crosspolarization losses." Also, the form of the electromagnetic field emanating from a square cross-section waveguide's aperture will introduce some "illumination losses." These resulting crosspolarization and illumination losses may be reduced by configuring the septum transformer based feed with a waveguide having *circular* cross-section.

Feed optimization and analyses for general improvements in dish antenna efficiency have been described by Paolo Antoniazzi, IW2ACD and Marco Arecco, IK2WAQ in [4].

The focus of this article is to describe the design of a circular cross-section, prime-focus, feed waveguide with septum polarization transformer with the goal of improving the overall antenna efficiency of circular polarization dish antenna systems.

1. Dish Antenna Gain

The Gain of a dish antenna is given by:

$$G = \frac{\pi^2 D^2}{\lambda^2} \eta \quad (\text{ratio}) \quad (1)$$

where D is dish diameter, λ is wavelength, and η is total efficiency.

Efficiency consists of many individual components [5,6]; consequently, total efficiency is a function of their product. For circular polarization the total efficiency, η , is given by:

$$\eta = \eta_{\text{ill}} \times \eta_{\text{so}} \times \eta_{\text{pe}} \times \eta_{\text{xp}} \times \eta_{\text{pol}} \times \eta_{\text{bl}} \times \eta_{\text{im}} \times \eta_{\text{isol}} \times \eta_{\text{ohm}} \times \eta_{\text{pos}} \times \eta_{\text{rgeom}} \times \eta_{\text{req}} \times \eta_{\text{rest}} \quad (2)$$

where

- η_{ill} = illumination efficiency
- η_{so} = spillover efficiency
- η_{pe} = phase efficiency
- η_{xp} = crosspolarization efficiency
- η_{pol} = circular polarization efficiency
- η_{bl} = aperture blockage efficiency
- η_{im} = impedance match efficiency
- η_{isol} = efficiency given by port to port isolation
- η_{ohm} = efficiency given by material conductivity
- η_{pos} = efficiency given by primary feed position error
- η_{rgeom} = efficiency given by quality of reflector's geometrical shape
- η_{req} = efficiency given by electric quality of reflector's surface
- η_{rest} = others factors.

Note that the above efficiency factors are not entirely independent of one another. Under some circumstances it is possible that some interdependency exists; for example, crosspolarization efficiency may at times be included in circular polarization efficiency.

Polarization efficiency and crosspolarization efficiency have been discussed in our previous article [3]. Here we address input-impedance mismatch loss (S_{11}, S_{22}) and the loss caused by port-to-port isolation (S_{12}, S_{21}). Dependencies of dish antenna system losses caused by input impedance mismatch and port-to-port isolation are plotted in Fig. 1.

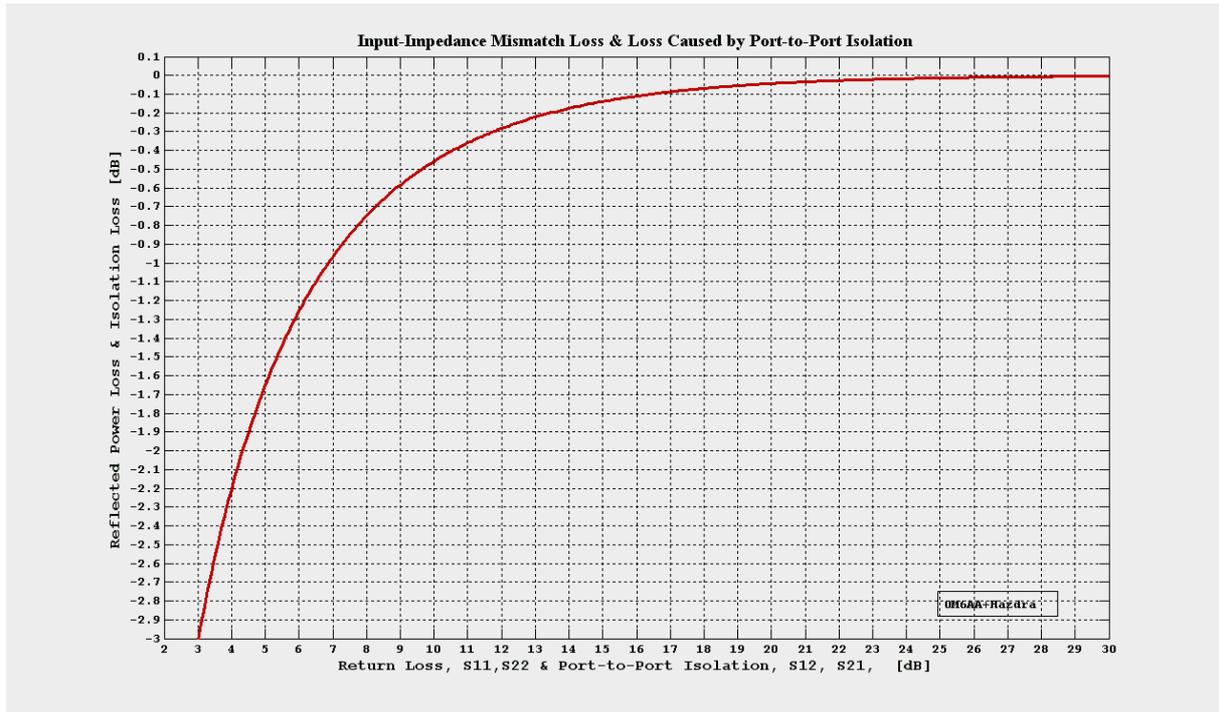


Fig. 1

For a brief orientation on input impedance match and port-to-port isolation, see the relationship between return loss and VSWR in the plot of Fig. 2. Also, Fig. 3 shows the relationship between unwanted power impressed upon the R_X port and port-to-port isolation when the T_X port is excited by 1 kW.

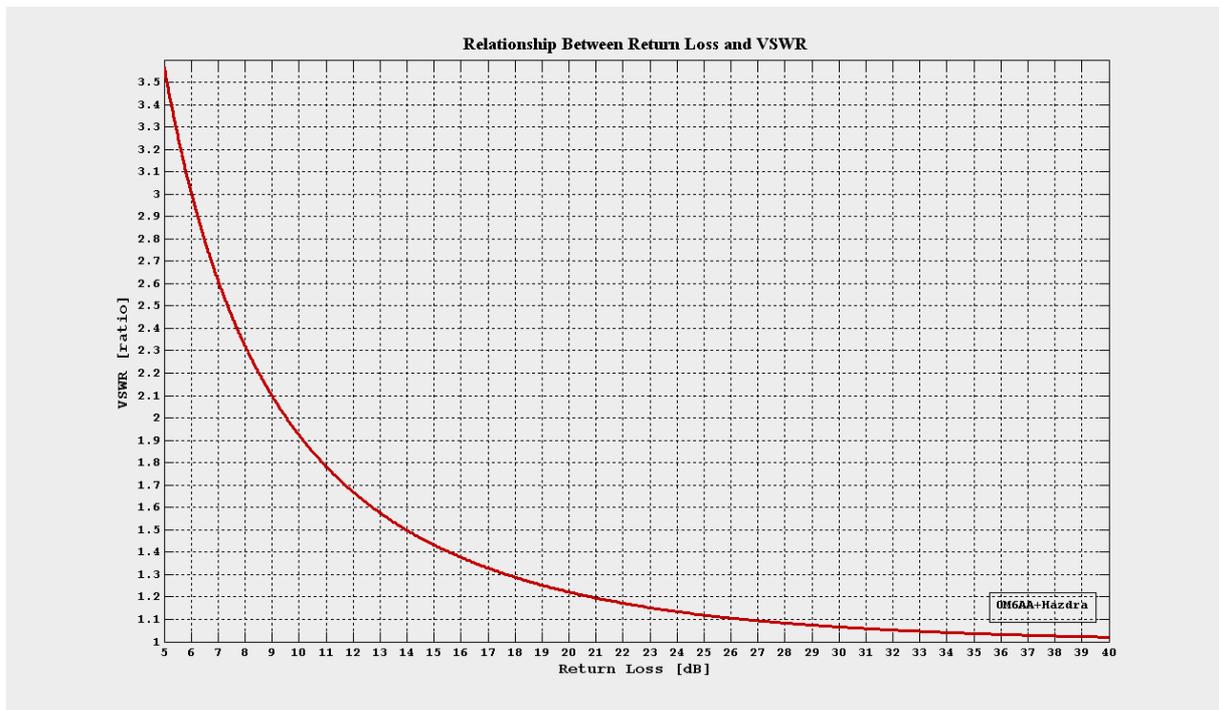


Fig. 2

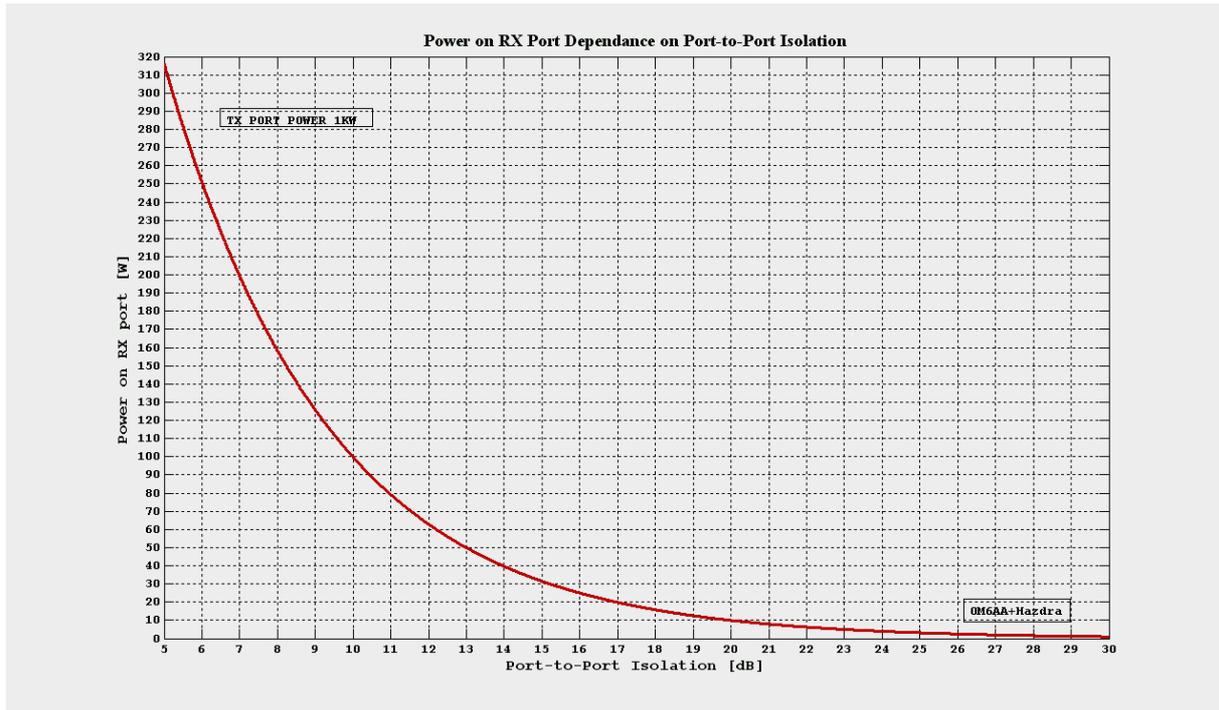


Fig. 3

Example

Determine polarization, input impedance match and port-to-port isolation losses of a parabolic dish antenna assembly equipped with a feed having an axial ratio of 2 dB, return loss of 20 dB (VSWR = 1.22) and port-to-port isolation of 14 dB.

From [3], the polarization loss of an antenna with axial ratio of 2 dB, receiving a pure CP signal is 0.06 dB. As read from the nomograph, the reflected power loss is 0.04 dB and isolation loss is 0.18 dB. The sum of these losses is $0.06 \text{ dB} + 0.04 \text{ dB} + 0.18 \text{ dB} = 0.28 \text{ dB}$.

2. Feed Design

Requirements for an efficient feed design for circular polarization ensue from the factors in equation (2), above:

1. Good illumination, spillover and phase efficiency
2. Very good circularity over the entire feed subtended angle with low crosspolarization losses
3. Good impedance match
4. High isolation between RHCP and LHCP ports
5. Low aperture blockage
6. Good wideband parameters (13 cm band)

The above feed-related requirements can be satisfied by using a septum polarization transformer feed configured in a waveguide having circular cross section.

Because the structure is quite complex, to perform a full-wave optimization directly, we divided its design into two somewhat independent steps:

1. Design of the septum in a circular waveguide using the Mician Microwave Wizard (MMW) [7]. This software utilizes fast modal matching techniques [8], [9].
2. Design and adjustment of the coaxial-semicircular waveguide transition together with the septum by using the full-wave Finite Integration Method with Perfect Boundary Approximation technique in CST Microwave Studio (CST MWS) [10].

Our first design attempt was to scale the dimensions of the four-step septum from the feed designed by J. Kysela, OK1AHH, and Franta, OK1CA, [11], matching it to a 0.8λ diameter right-circular cylindrical, waveguide. In this configuration, main beam circularity of about 1.8 dB was achieved. The next step was to perform hundreds of computations with MMW software to find the best dimensions for the septum transformer steps. To find optimum performance, i.e. good separation between LHC and RHC components with reasonable S_{11} , S_{22} and S_{21} parameters, the step dimensions must be calculated for the actual overall septum and waveguide dimensions that will be used. This repetitive exercise enhanced our appreciation for the high-speed computation capabilities of this modern software. A 1.4 GHz Pentium IV μ P-equipped notebook computer averaged 6 minutes to perform one feed computation. We obtained the best results with a five-step septum.

After the optimum dimensions of the 5-step septum were determined, the entire feed was simulated using CST MWS applied to the model in Fig. 4. This Rolls Royce-category software attains very good accuracy, but unfortunately at a Rolls Royce price. The high precision is additionally paid for with computation time. One simulation cycle took about 18 hours on a PC equipped with two 2 GHz AMD Opteron μ P's.

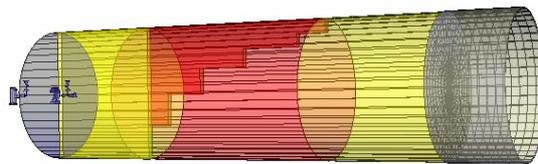


Fig. 4 Model optimized by MMW software

Electrical excitation of the waveguide was chosen because of its simplicity. Two probes with conical shapes (see Fig. 5) were employed to match the waveguide structure to their associated coaxial lines. Because of the structure's symmetry ($S_{11}=S_{22}$, $S_{12}=S_{21}$), simulation of only one port was necessary. The optimization strategy used was to determine the probe parameters leading to the best matching and isolation between ports.

To date, feeds for 23 cm and 13 cm have been solved. For higher frequencies, very tight physical tolerances must be held. For 10 GHz, tolerances better than 0.1 mm are expected. This will probably be the technological limit of septum polarization transformer-based feeds for amateur radio utilization.

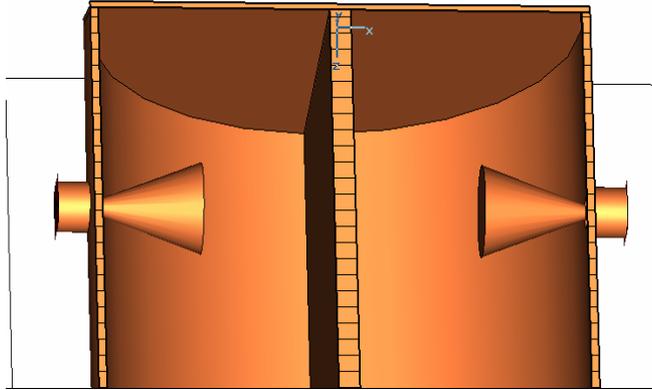


Fig. 5 Detail of coaxial-waveguide transition

3. 23 cm Feed Design

To achieve good illumination for most common dish antennas ($0.35 < f/D < 0.40$), a waveguide with inside diameter (ID) of 0.8λ should be used. [Note: For deeper dishes, a feed having a smaller ID should be used and a new septum optimization must be performed.]

To fabricate the $ID = 0.8\lambda$ waveguide, a “Dural” cylindrical tube with $ID = 184$ mm is used. See Fig. 6. The tube material thickness is 3 mm and the septum transformer is made



Fig. 6 Dural tube with probes and septum

from 8mm thick “Dural” plate. An 8mm thickness was chosen for ease of fitting and

mounting the septum in the waveguide tube with M3-size screws. The distance from the last septum step transition to the closed end of the waveguide was designed to excite a good form

of the fundamental semicircular waveguide mode and to achieve low VSWR on the probe. The distance from the waveguide aperture to the front edge of the septum was made as short as possible to retain good polarization and radiation parameters. The probes are made of “Dural” and have a conical shape to increase bandwidth and improve the impedance match. As verified in our previous project [12], a wide-band coaxial to waveguide transition is less sensitive to detuning caused by the choke, dish, or moisture. Computed feed radiation patterns and axial ratio appear in Fig’s. 7 through 9. In fabricating the feed, Computer Numerically Controlled (CNC) machining technology was used. Feeds for test and measuring purposes were fabricated by Milan, OM1ATT [13].

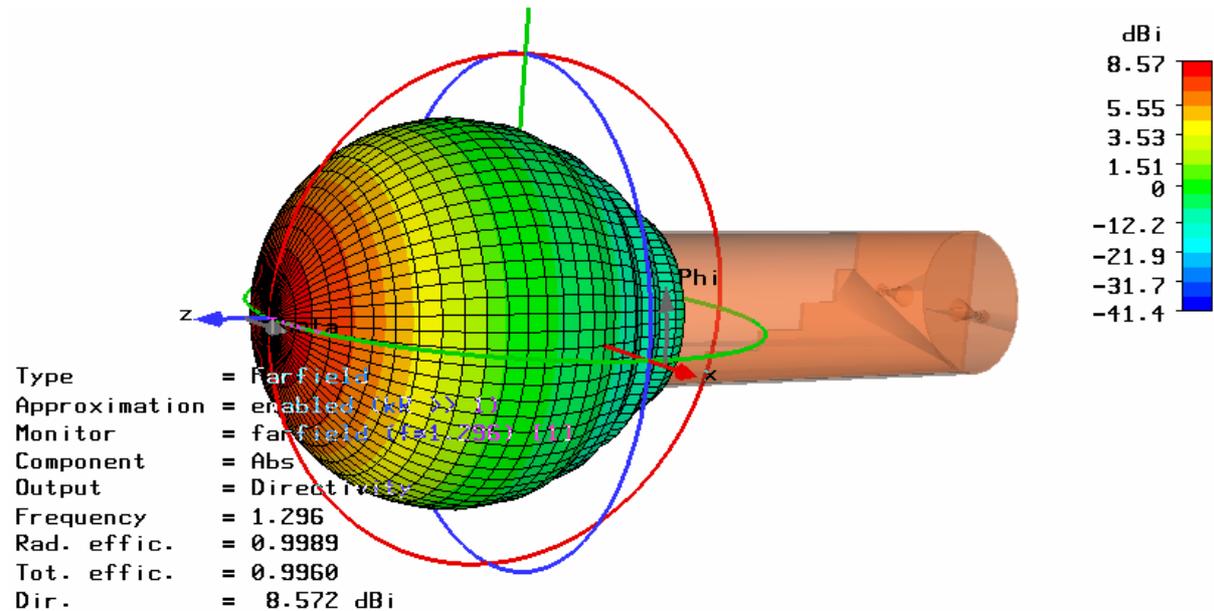


Fig. 7 3D Directivity radiation pattern

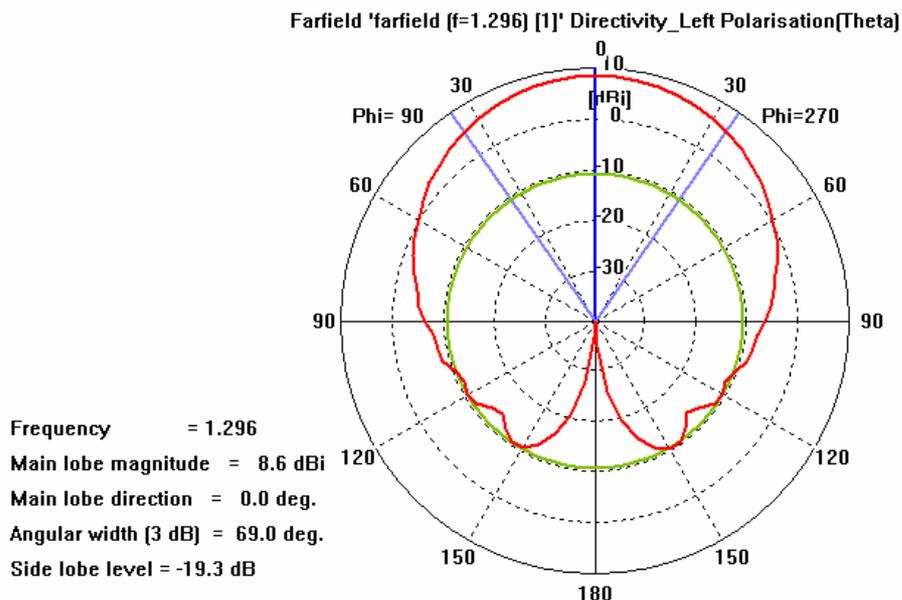


Fig. 8 2D Polar radiation pattern

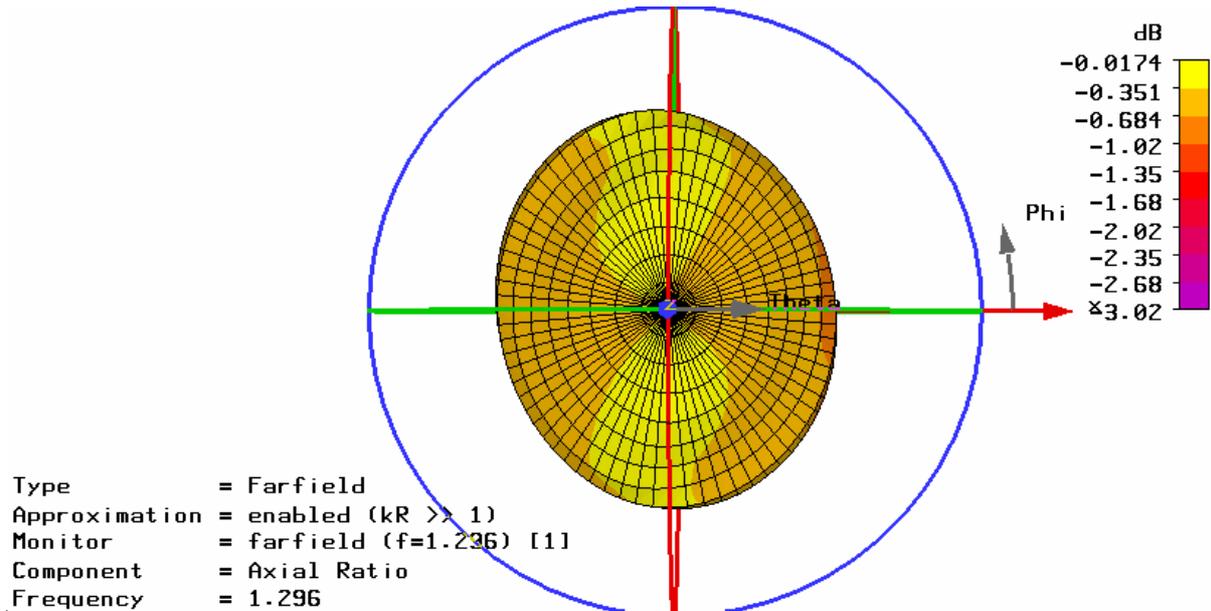


Fig. 9 Axial ratio

4. Power Capability

To investigate maximum input power, P , for no arcing, the electric field intensity was calculated and mapped on a 3-D model of the conical probe area. “Hot spots,” with the highest electrical field intensity, were located (see Fig.10). The most critical area was found to be at the vertex of the cone, with intensity $\sim 8\text{kV/m}$ (relative to 1W input power). Taking into account the separation of nearby conductors (2.75mm), the maximum possible peak power limited by arcing is approximately 100kW. Of course in the real world, maximum power is limited by the coaxial connectors and waveguide conductivity.

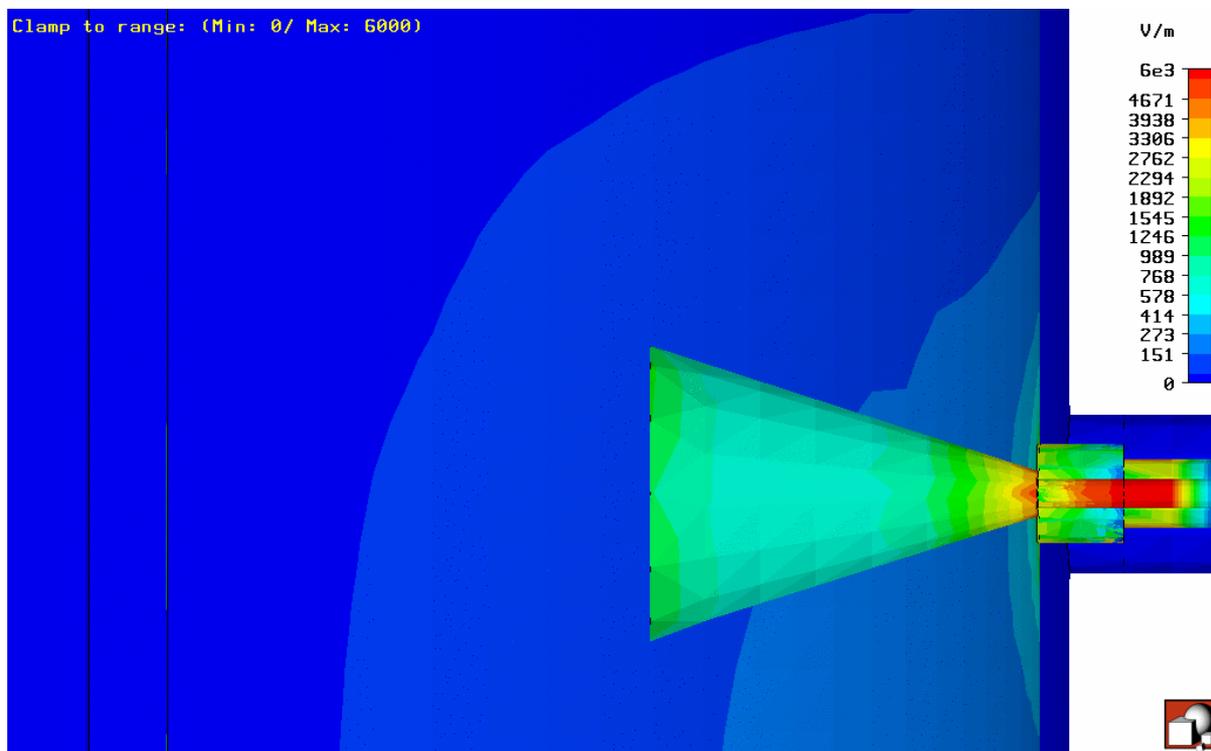


Fig. 10 E-field intensity

5. 13 cm Feed Design

The main goal of this design was to achieve good performance parameters for the frequency range of 2304 to 2424 MHz; i.e. for US, EU and JA bands. This range covers frequencies for satellite allocation as well. For the waveguide, a cylindrical tube with an ID of 100mm (0.79λ @ 2363 MHz) was chosen. From the 23 cm feed design, it was apparent that to achieve acceptable wideband parameters of VSWR (S_{11} , S_{22}), axial ratio, and especially port-to-port isolation (S_{21}), various performance tradeoffs had to be allowed to arrive at a “best compromise” between these parameters. Having carefully determined the tradeoffs, we found that very good overall performance parameters had been attained. Axial ratio for frequencies 2304, 2363 and 2424 MHz, isolation between ports, and impedance match appear in Fig. 11. The probes of this feed were also designed to be of conical shape, but with a smaller taper to facilitate assembly. To accelerate procurement, assembly of these feeds was entrusted to Eddy, ON7UN and his team Walter, ON4BCB, and Marc, ON5OT, who had previous experience with a similar project. Feeds produced by them (see Fig.12) were delivered to Prague for measurements and testing in an anechoic chamber.

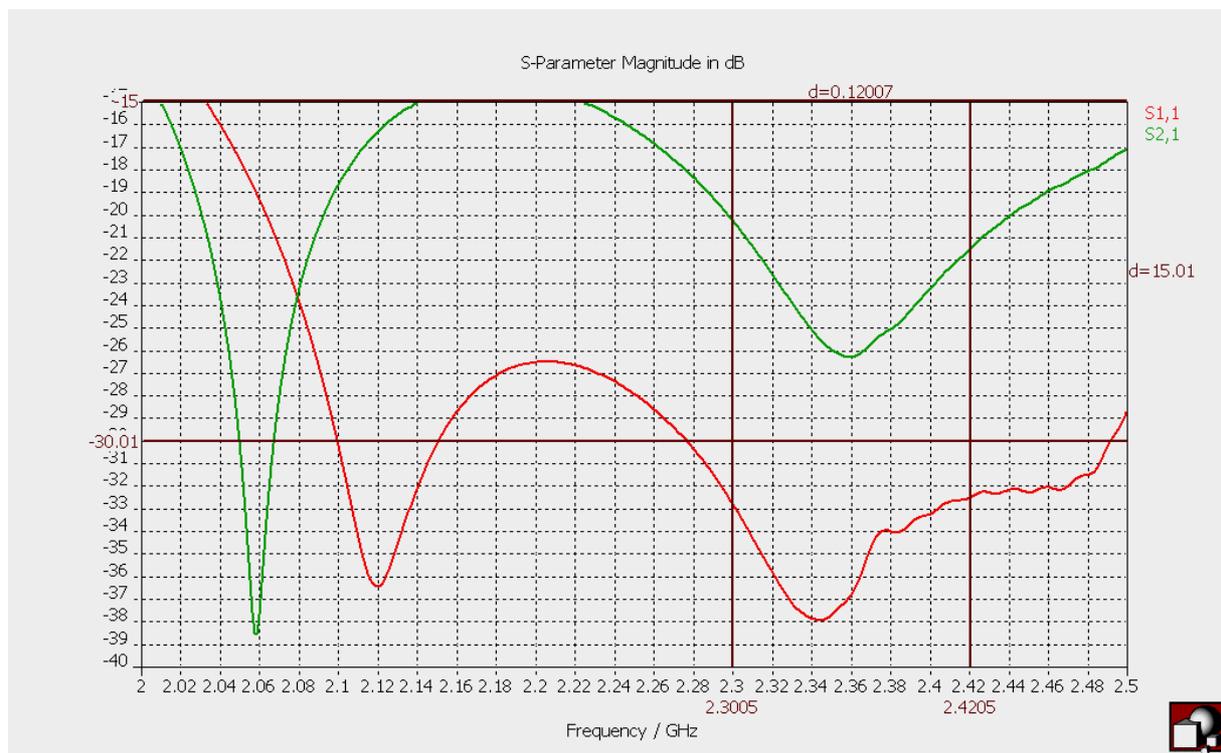


Fig. 11 13 cm Feed, computed S parameters



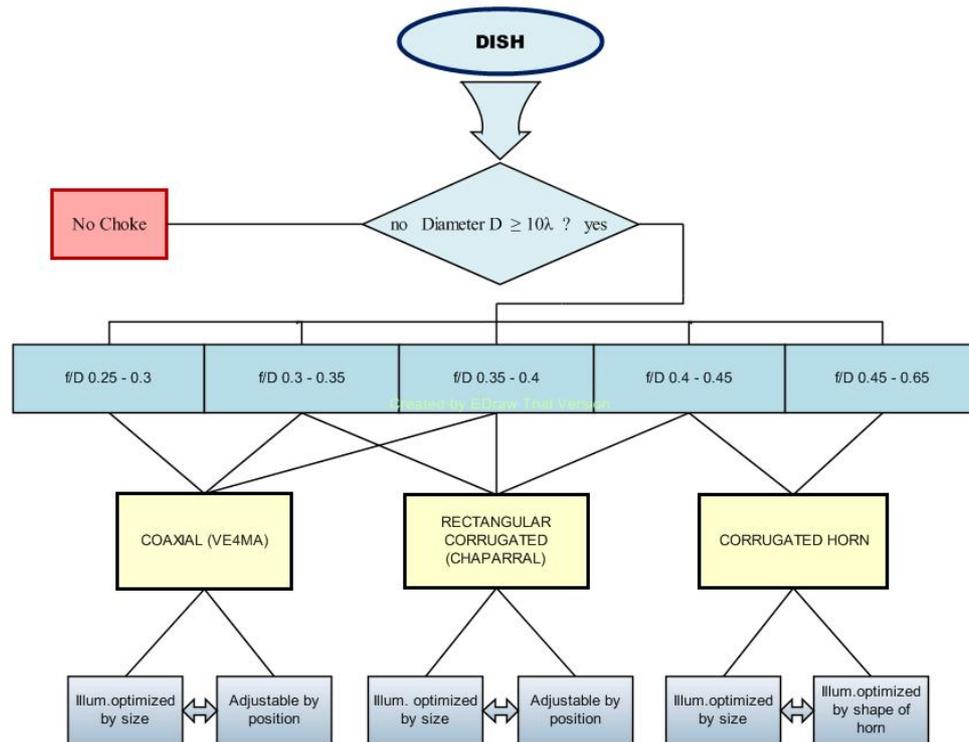
Fig. 12 Feeds produced by ON7UN's team

6. Chokes

A “choke” is used in conjunction with a dish antenna feed to reshape the radiation pattern to focus more energy from the feed toward the dish’s aperture. A choke takes the form of a cylindrical ring or rings that surround the feed waveguide. The use of a choke increases the dish antenna’s efficiency but may also introduce problems that are subtle and technically complex, meriting independent analyses. Here we briefly describe the selection of a proper choke for a given dish diameter and f/D ratio as relates to our designed feed. A flow diagram for quick selection of an appropriate choke appears in Fig. 13. Chokes for deep dishes was reported on by Kim [14] and reprinted [5]. Modification of these chokes has been recently described by Wade, W1GHZ, and Henderson [15].

Radiation patterns of feeds used in conjunction with dish reflectors may be optimized for maximum transmission gain with a -10 dB edge taper, or optimum receiving noise parameters i.e. G/T ratio. Some dish antenna assemblies for radio astronomy allow a -15 dB edge taper [16]. Apparently, compromise is unavoidable. Most dish antennas for EME have about a -13 dB edge taper.

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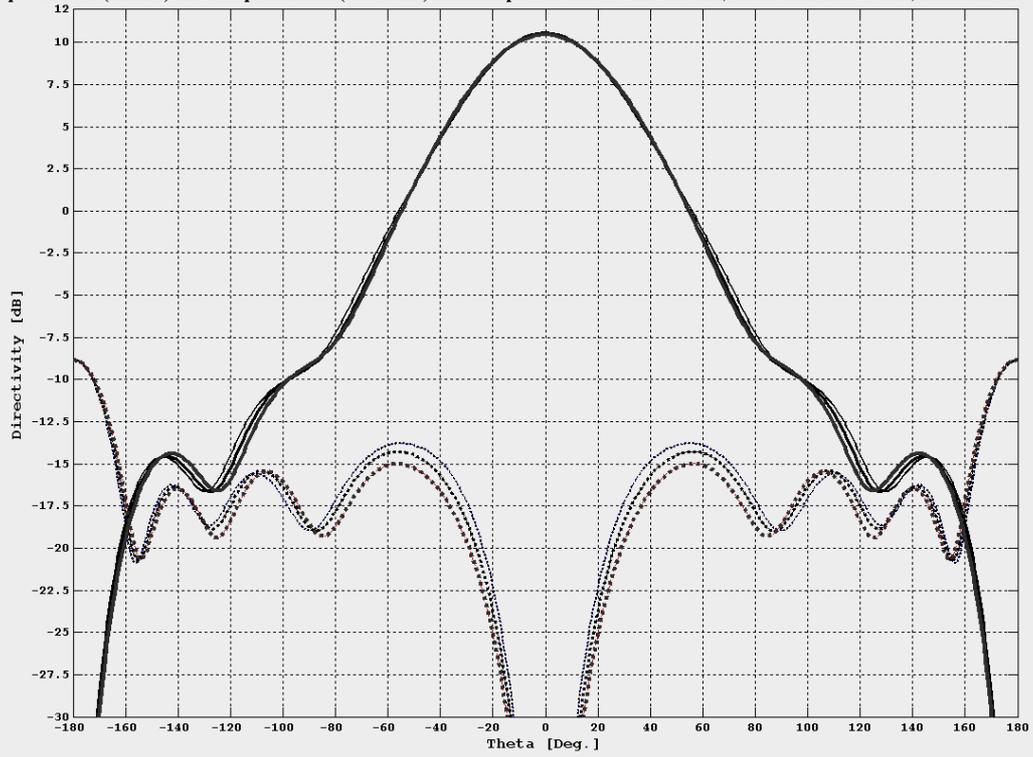


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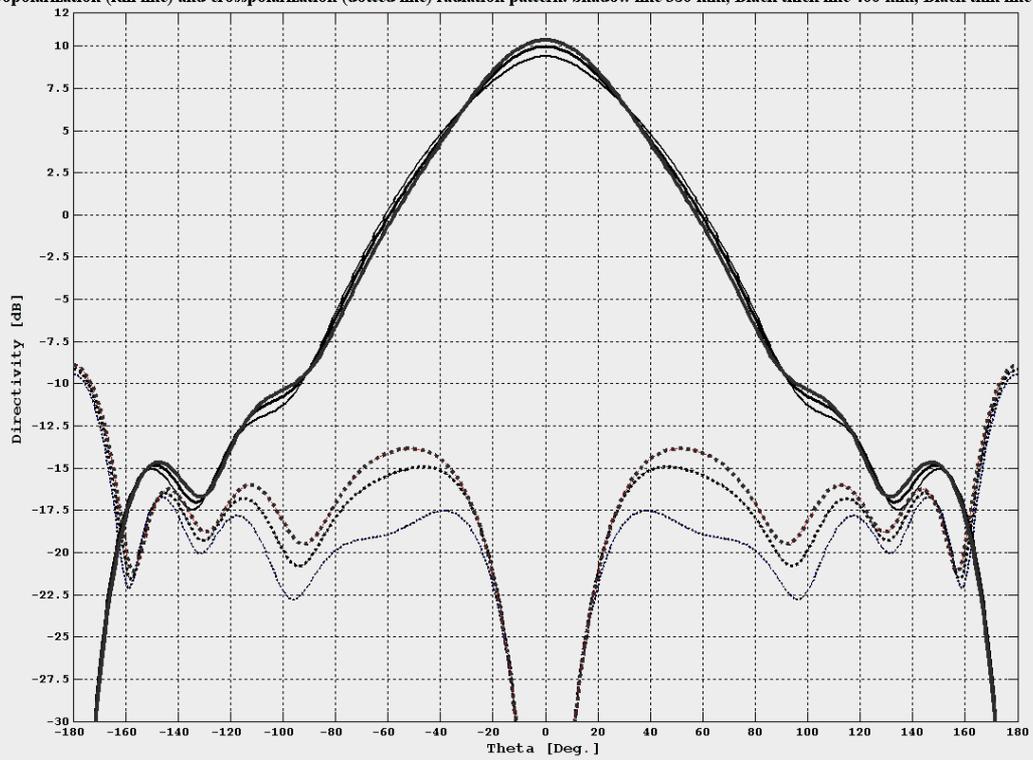
Fig. 13 Flown diagram for choke selection

We have performed many calculations for various types of chokes. For example, Fig. 14 shows co- and crosspolarization radiation patterns for Kim's choke. Choke calculations with dimensions for 23 cm have been solved to find the optimum taper for our dish with 0.36 f/D ratio. Calculation was performed from 380 to 600 mm of the choke's outer diameter. It is apparent from the diagrams that a diameter about 500 mm seems to be best. Another optimization may be accomplished by changing the choke position (distance X) with respect to the waveguide's aperture. The resulting calculated radiation pattern is then imported to FEKO software [17] to re-calculate the final dish antenna radiation pattern. This complicated process is both tedious and painstaking.

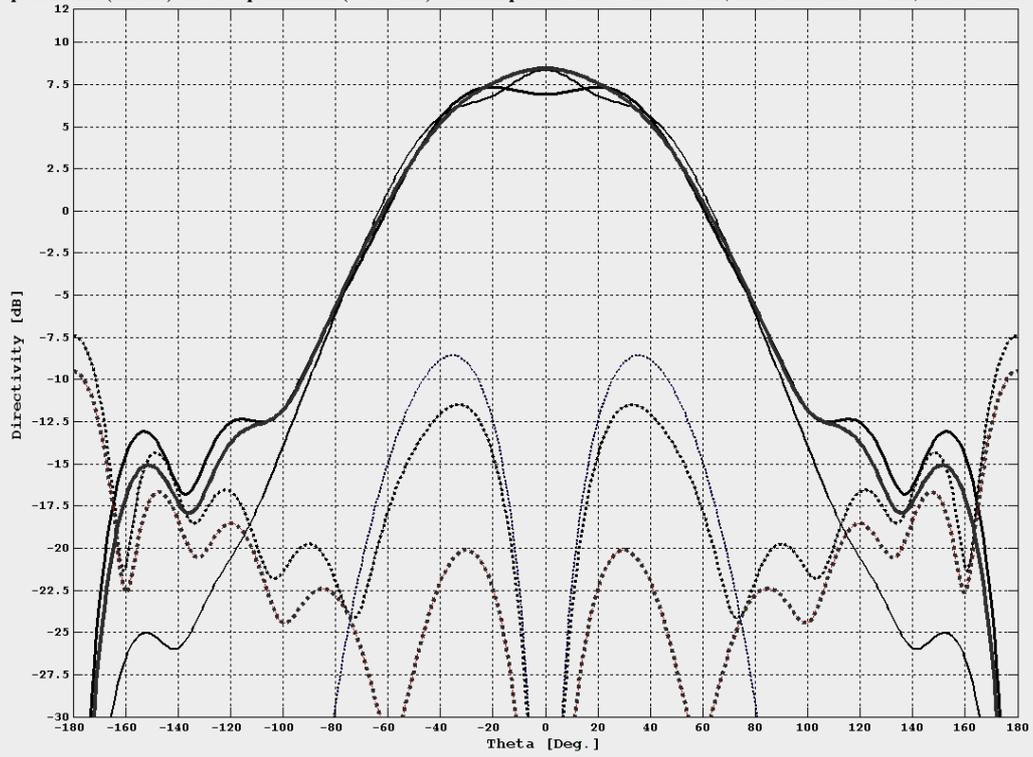
Copolarization (full line) and crosspolarization (dotted line) radiation pattern. Shadow line 320 mm, Black thick line 340 mm, Black thin line 360 mm.



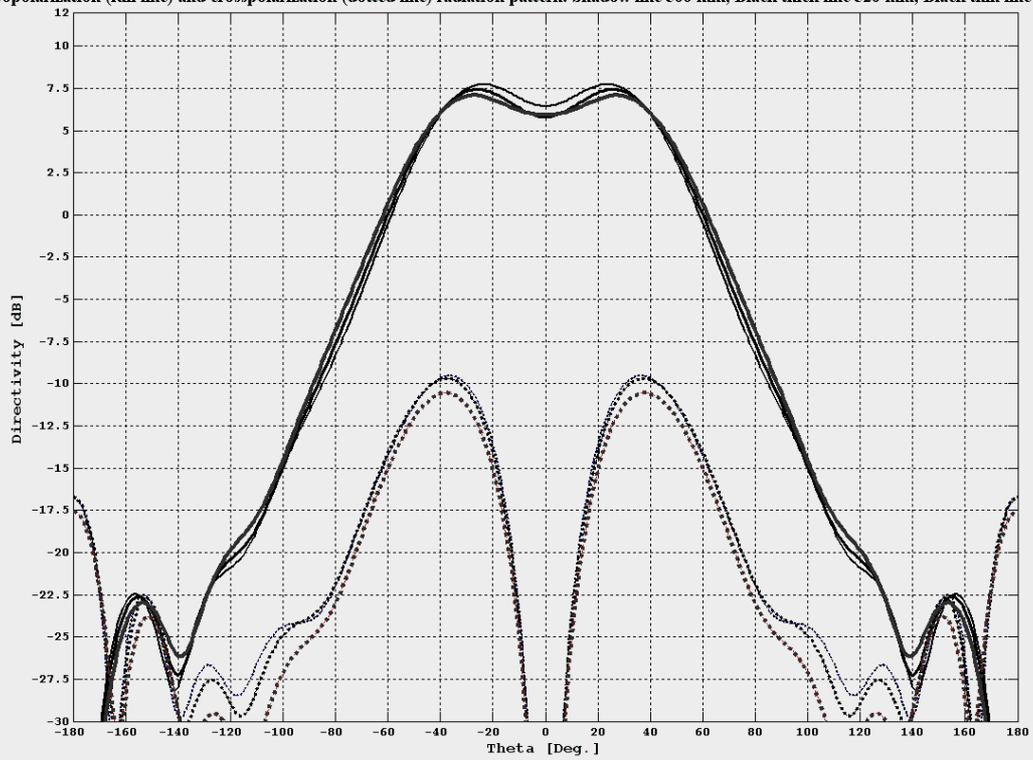
Copolarization (full line) and crosspolarization (dotted line) radiation pattern. Shadow line 380 mm, Black thick line 400 mm, Black thin line 420 mm.



Copolarization (full line) and crosspolarization (dotted line) radiation pattern. Shadow line 440 mm, Black thick line 460 mm, Black thin line 480 mm.



Copolarization (full line) and crosspolarization (dotted line) radiation pattern. Shadow line 500 mm, Black thick line 520 mm, Black thin line 540 mm.



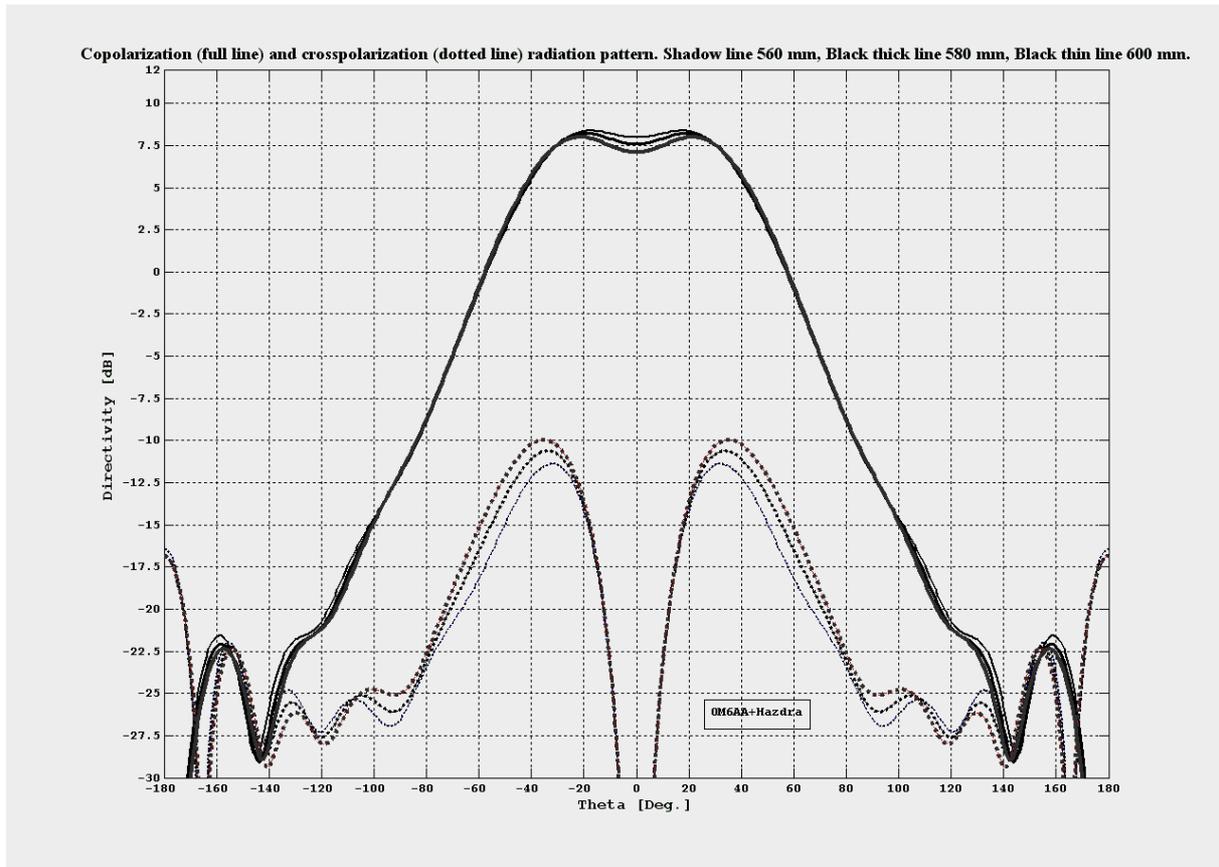


Fig. 14 Kim's choke optimization

Since chokes for deep dishes have previously been described [5,14,15], we decided to document a choke suitable for shallow dishes ($f/D = 0.5$) here, which is compatible with our designed feed. Choke dimension are shown in Fig. 15. Calculated 3D and 2D radiation patterns appear in Fig. 16. Fig. 17 shows 3D and 2D radiation patterns for a dish with diameter of 20λ . As we can see, directivity is 34.7 dB and the dish antenna assembly operates at 75 % efficiency. Side lobes are suppressed below 29 dB.

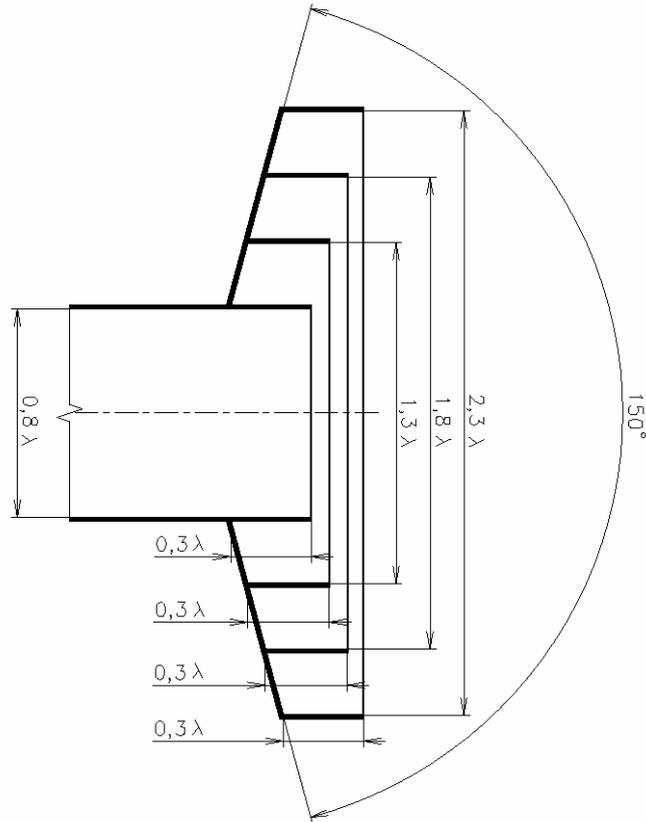
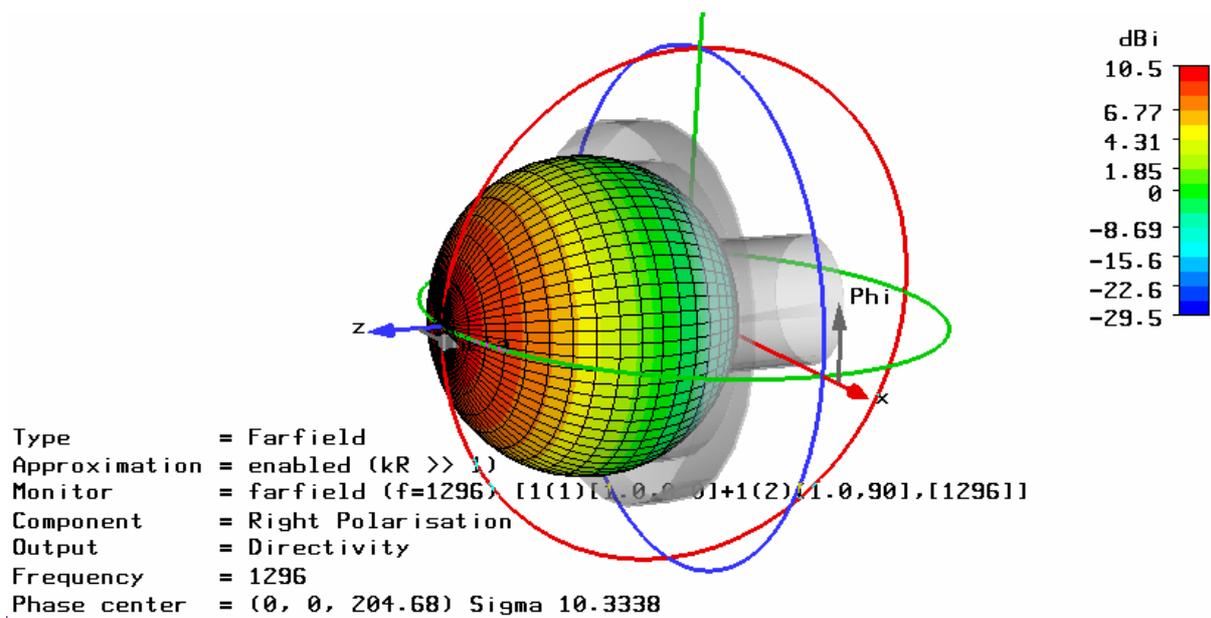


Fig. 15 Choke for shallow dishes



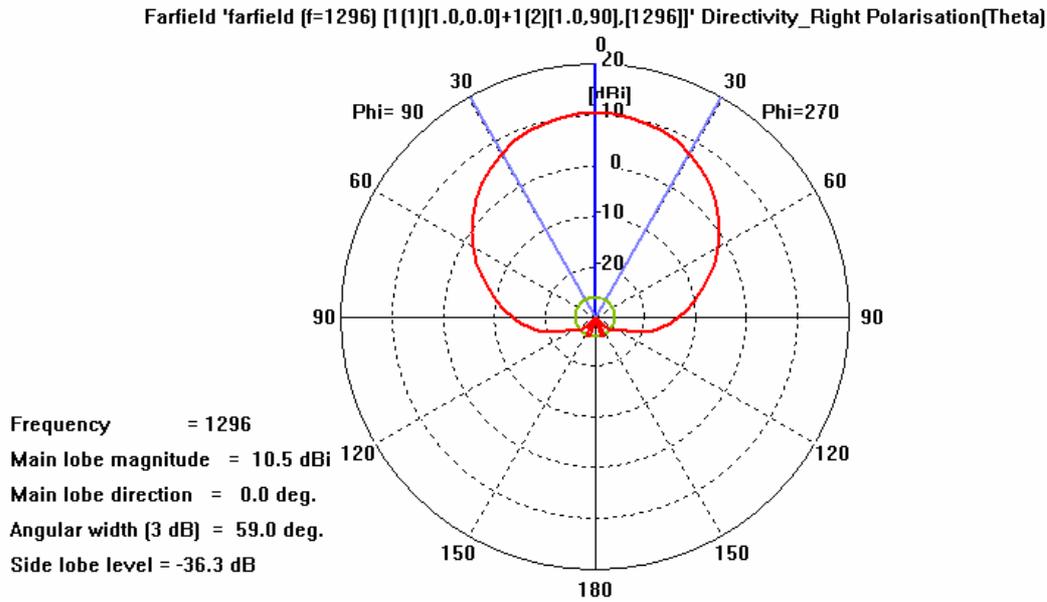


Fig. 16 3D Directivity radiation pattern (above), 2D polar pattern (below)

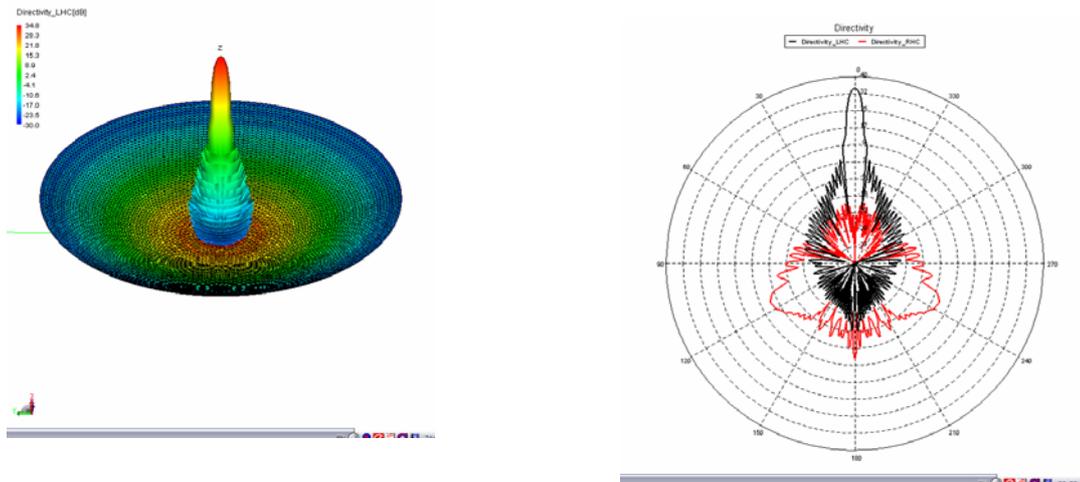


Fig. 17 3D Radiation pattern for dish with $f/D = 0.5$, $D = 20\lambda$ (left), 2 D Polar radiation pattern (right)

The physical connection between waveguide and choke is very important. It should insure the integrity of the positional alignment and function as a low inductance electrical connection over the entire perimeter. Poor connections degrade circularity, see Fig. 18. For our 23 cm feed design, a stainless steel spring placed in the flange recess is used. See Fig. 19. According to Walter, ON4BCB, to avoid possible corrosion between the stainless steel spring and the Dural choke and feed, a copper-based grease should be applied to these areas. Additionally, because of its conductive properties, the grease also helps to ensure a low impedance connection.

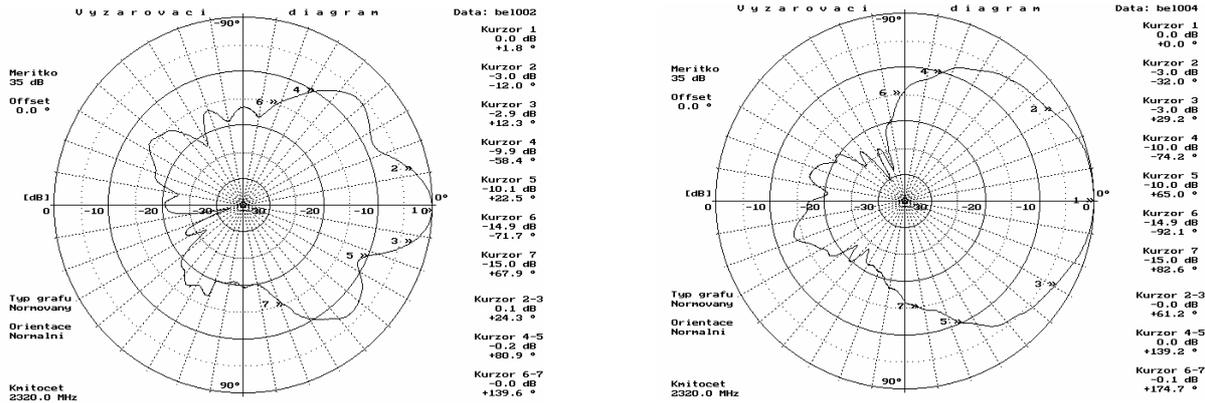


Fig. 18 Radiation pattern of a feed with improper connection between feed body and choke. Azimuth-left, elevation plane-right. (Circular polarization should exhibit a similar pattern.) Axial ratio degradation attributed to this choke exceeds 1.2 dB

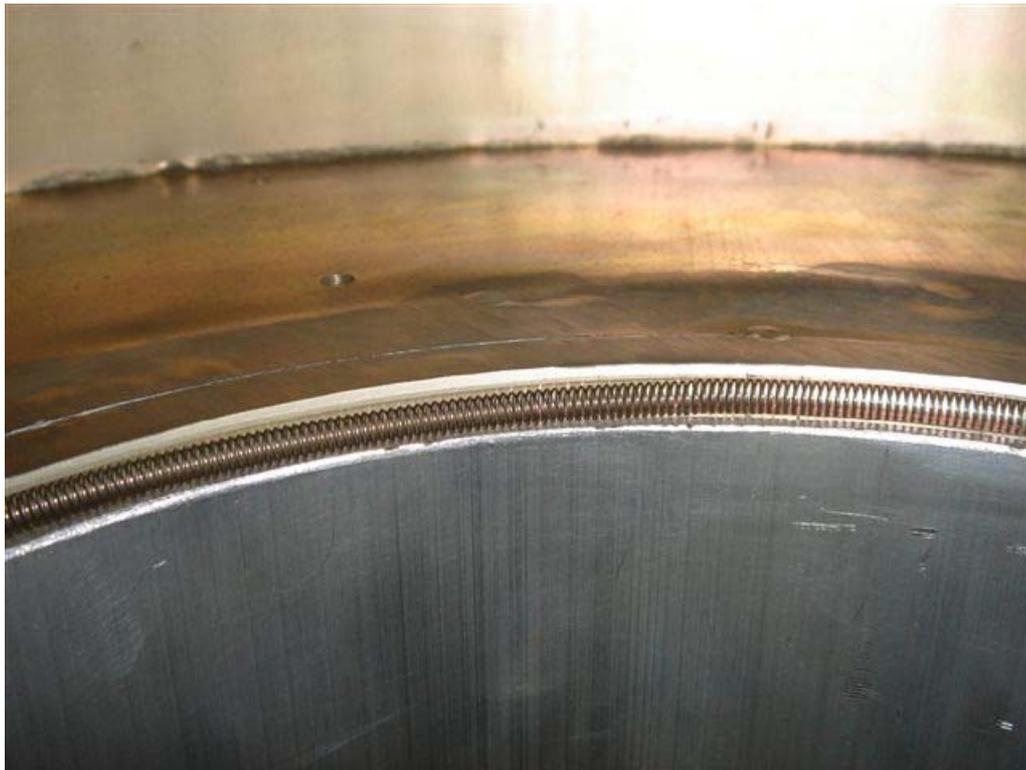


Fig. 19 Stainless steel spring connection

7. Actual Measured Performance

Feed measurements were performed in two different anechoic chambers. The 23 cm band feed was tested in an anechoic chamber at Czech Technical University (CTU) in Prague. S-parameters, co- and crosspolarization radiation patterns, and the polarization pattern without a choke were measured at CTU. The 23 cm feed equipped with a choke and 13 cm feeds with

and without a choke were tested in an anechoic chamber at ERA Pardubice Company (Czech Republic) [18]. Some of the impedance matching and port-to-port isolation measurements were performed by Franta, OK1CA.

7.1 S_{21} Parameters and Impedance Match (S_{11} , S_{22}) at R_X and T_X Ports

a/ 23 cm

The 23 cm measurements were performed using an Agilent Technologies E8364 network analyzer. Computed and measured results are shown in Fig. 20. Excellent agreement between CST MWS simulations and the actual measurements were observed. Differences between the computed and measured parameters S_{11} (S_{22}) below 30 dB are attributed to the use of coaxial N-style connectors. As verified by Eddy, ON7UN, utilization of higher quality connectors leads to nearly total agreement between computed and measured parameters. (An S_{11} better than 40 dB was reported by Eddy).

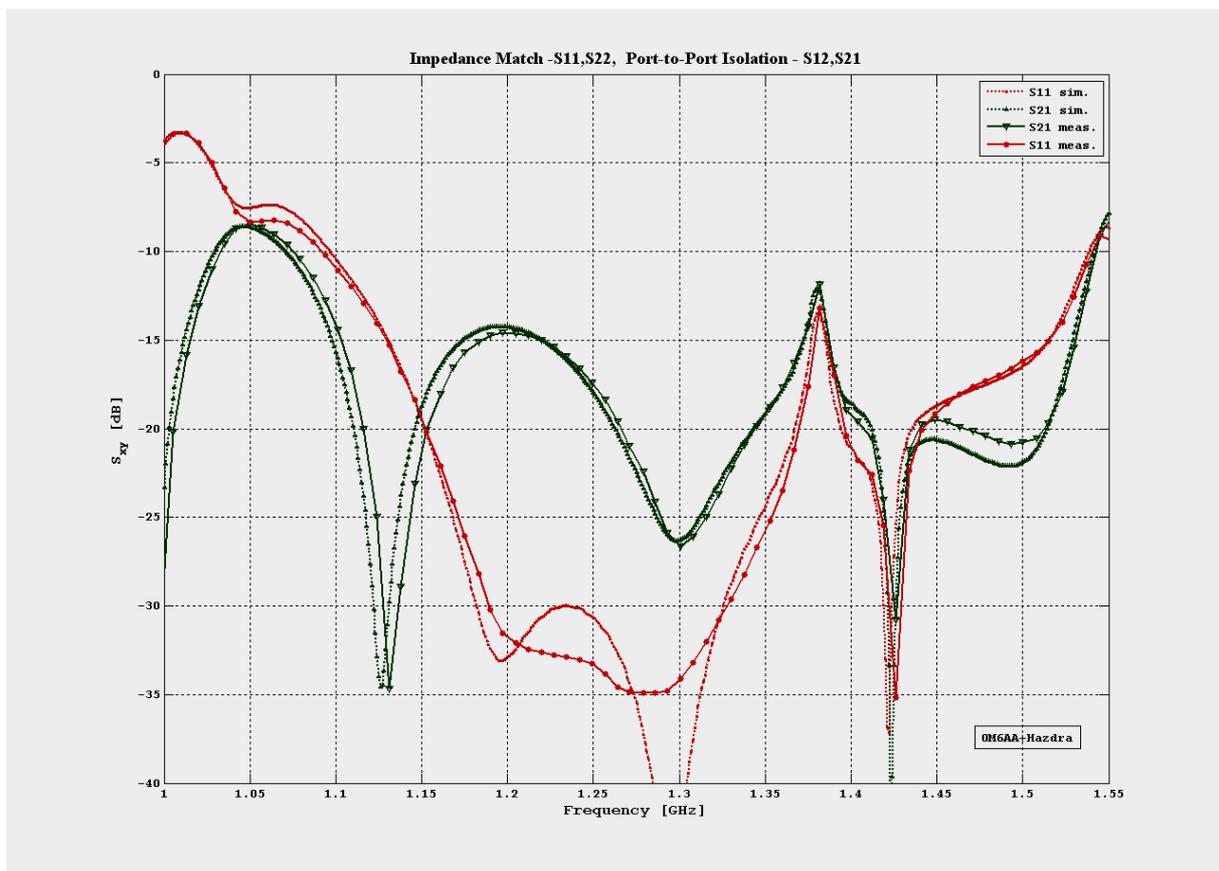


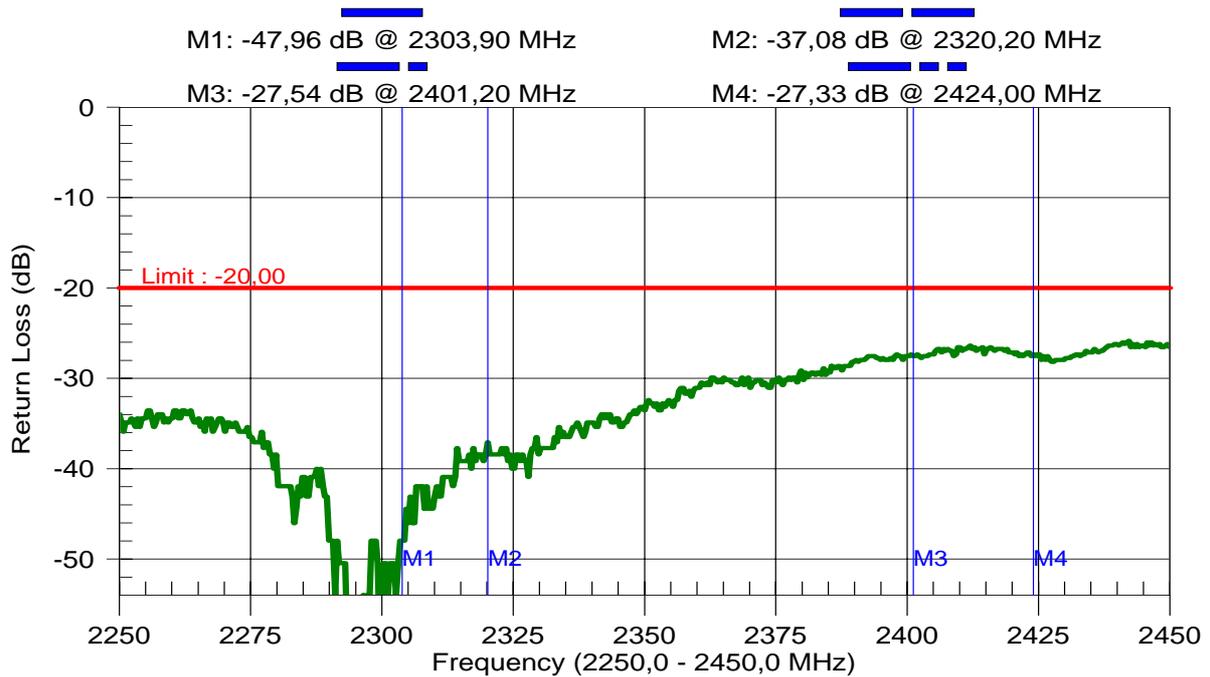
Fig. 20 23 cm Feed, computed and measured S parameters

b/13 cm

13 cm band measurements were performed by Franta, OK1CA, using an ANRITSU S331 Site Master analyzer. Results are displayed in Fig's.21 and 22.

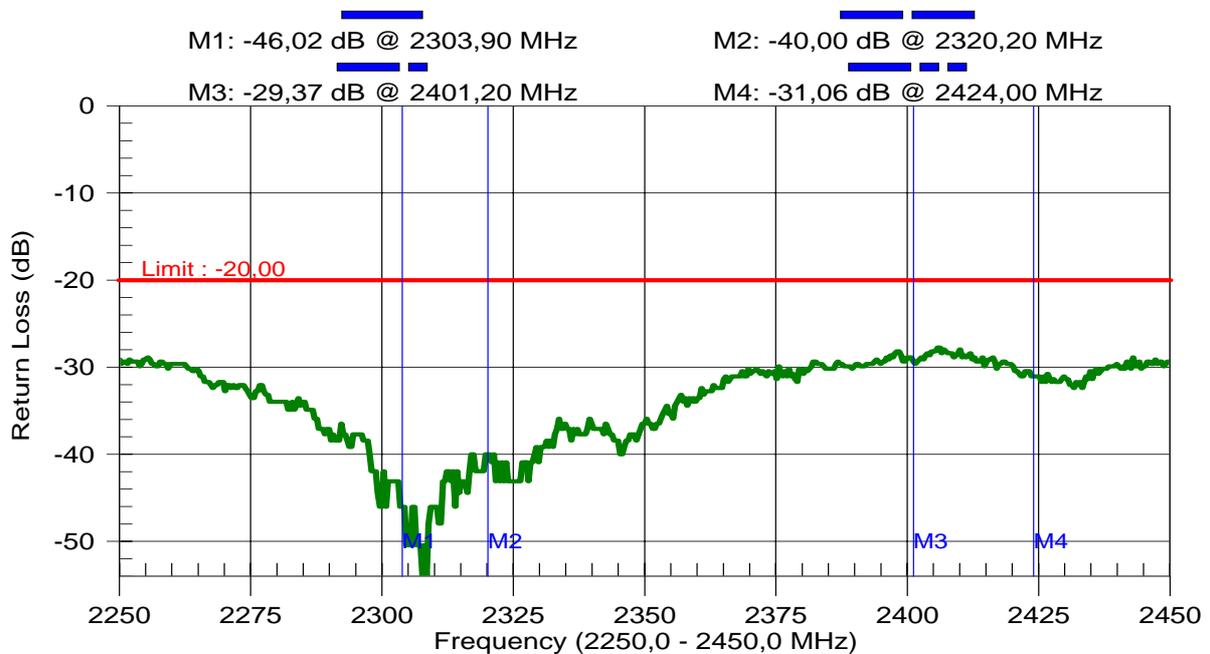
CP feed, 5 stepped septum polarizer (OM6AA and Hazdra design)

Port LHCP, N female



CP feed, 5 stepped septum polarizer (OM6AA and Hazdra design)

Port RHCP, N female



7.2 Radiation Patterns with and without a Choke

Two feeds were available for these measurement for both bands. This enabled measurements of copolarization and crosspolarization patterns directly.

a/23 cm

Radiation patterns are shown in Fig. 23. The relatively low separation between boresight co- and crosspolarization was caused by depolarization on wall panels of the anechoic chamber. To achieve more accurate circularity results, additional polarization pattern measurements were performed.

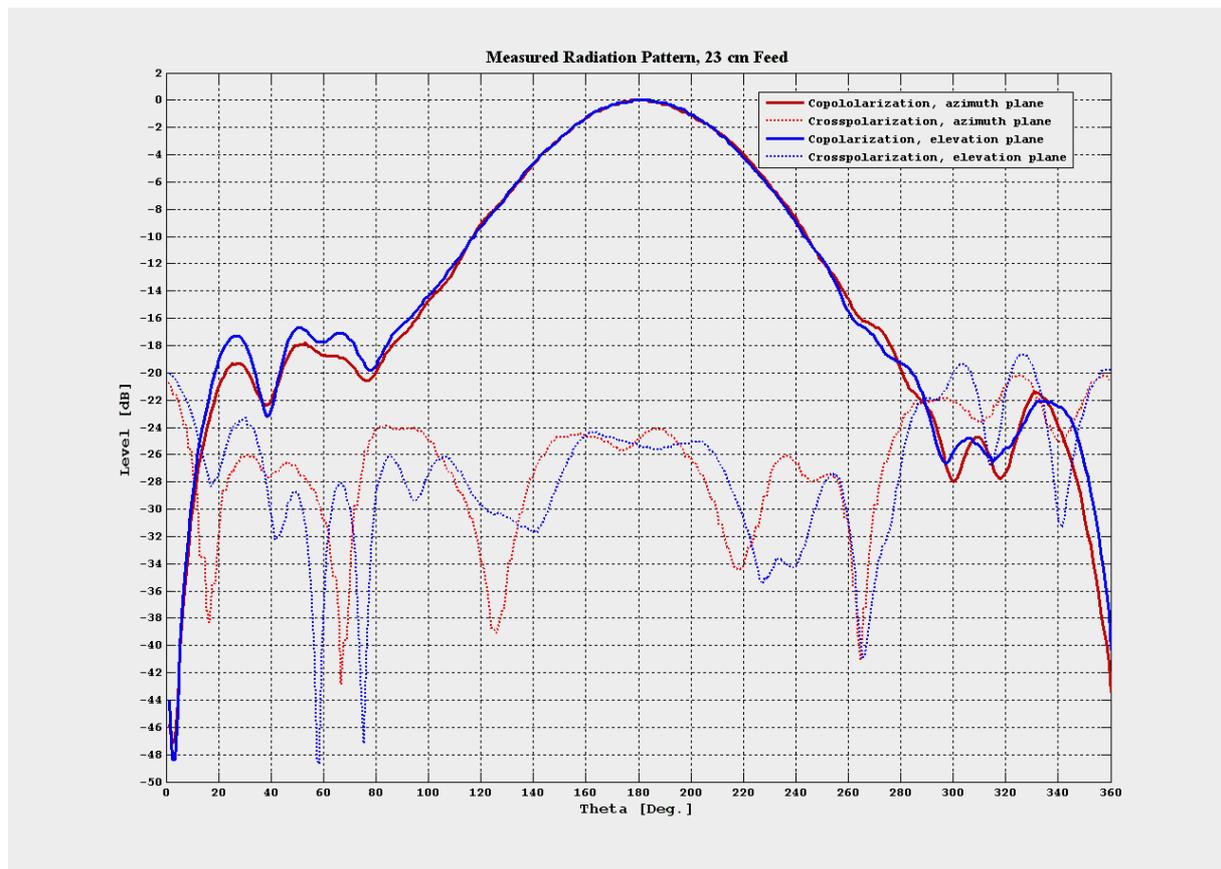


Fig. 23 Radiation pattern of 23 cm feed

b/13 cm

Radiation patterns for frequencies 2300, 2363 and 2424 MHz are shown in Fig's. 24 through 26.

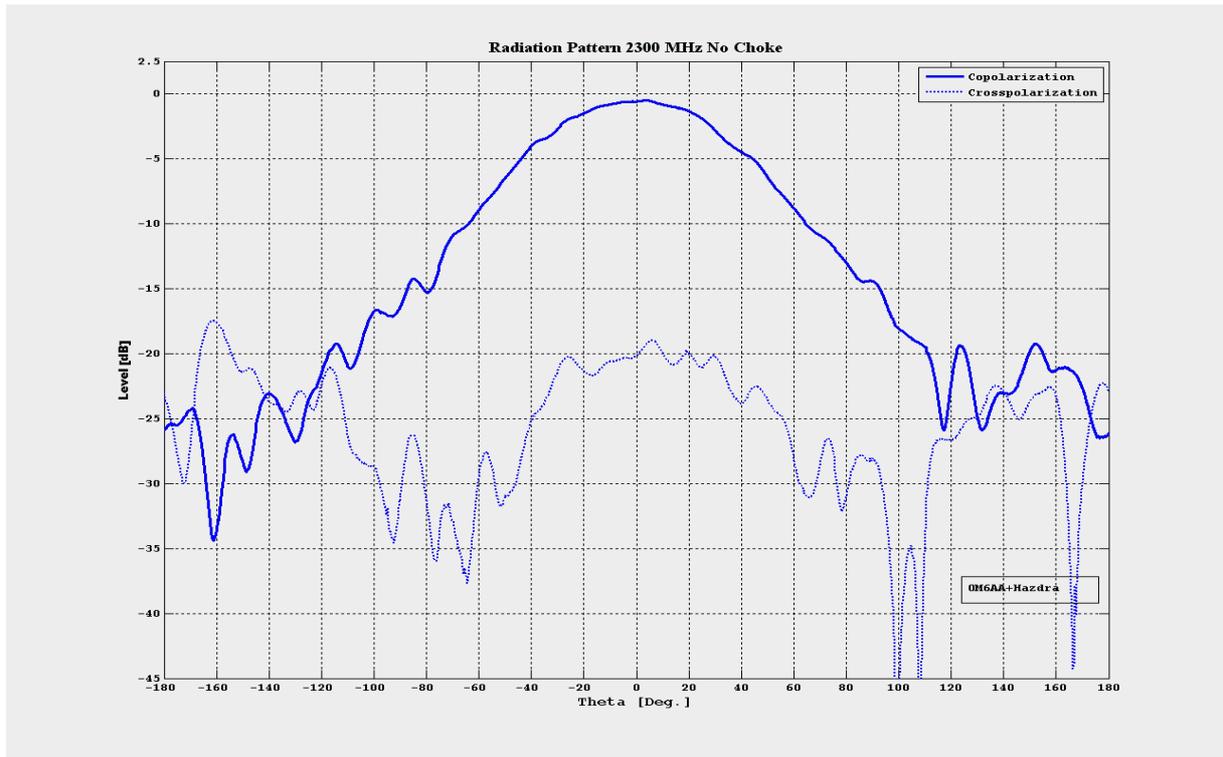


Fig. 24 Radiation pattern 2300 MHz

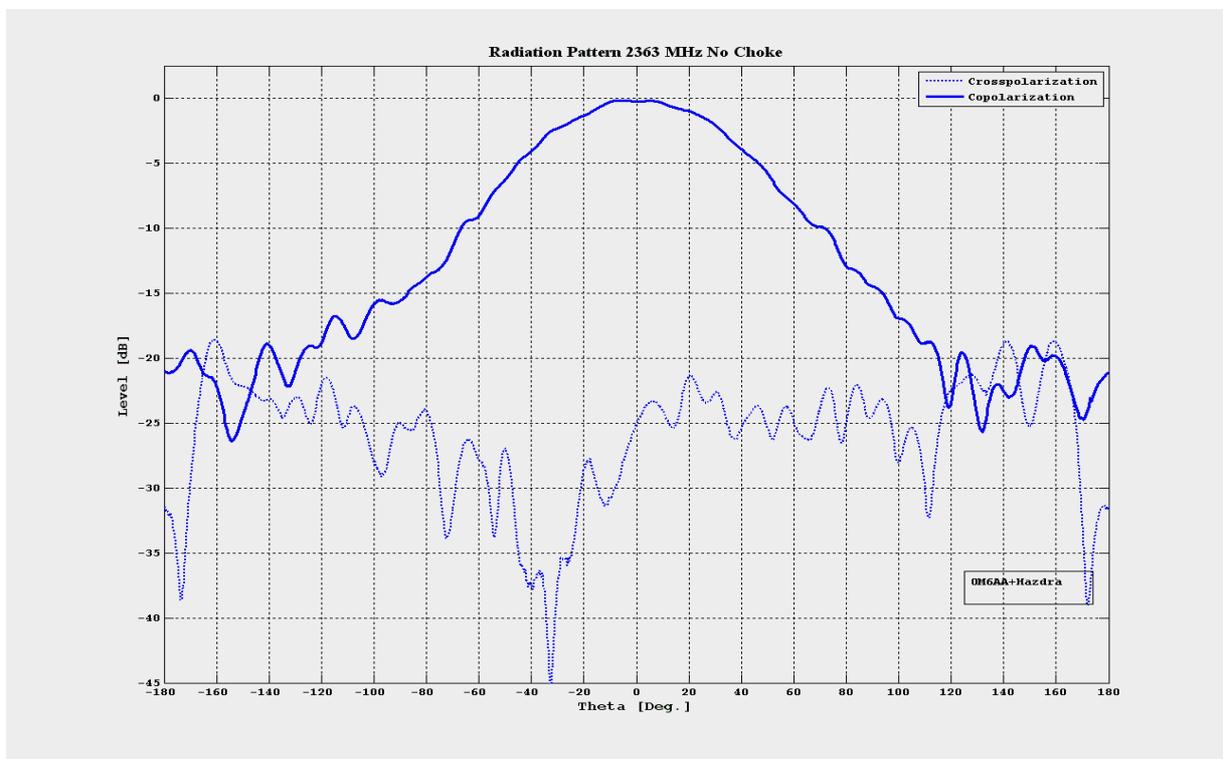


Fig. 25 Radiation pattern 2363 MHz

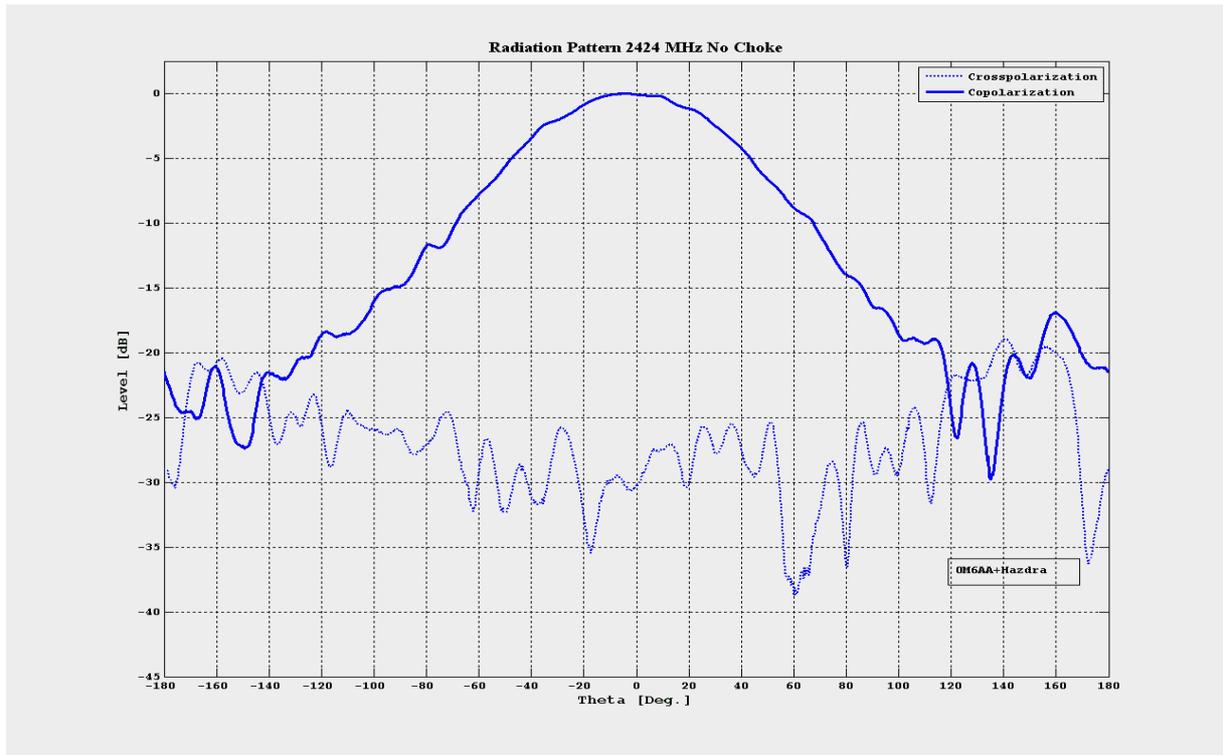


Fig. 26 Radiation pattern 2424 MHz

c/Radiation pattern with choke

Radiation patterns for two types of chokes are displayed in Fig. 27. To enhance visual comparison, polar graphs were used.

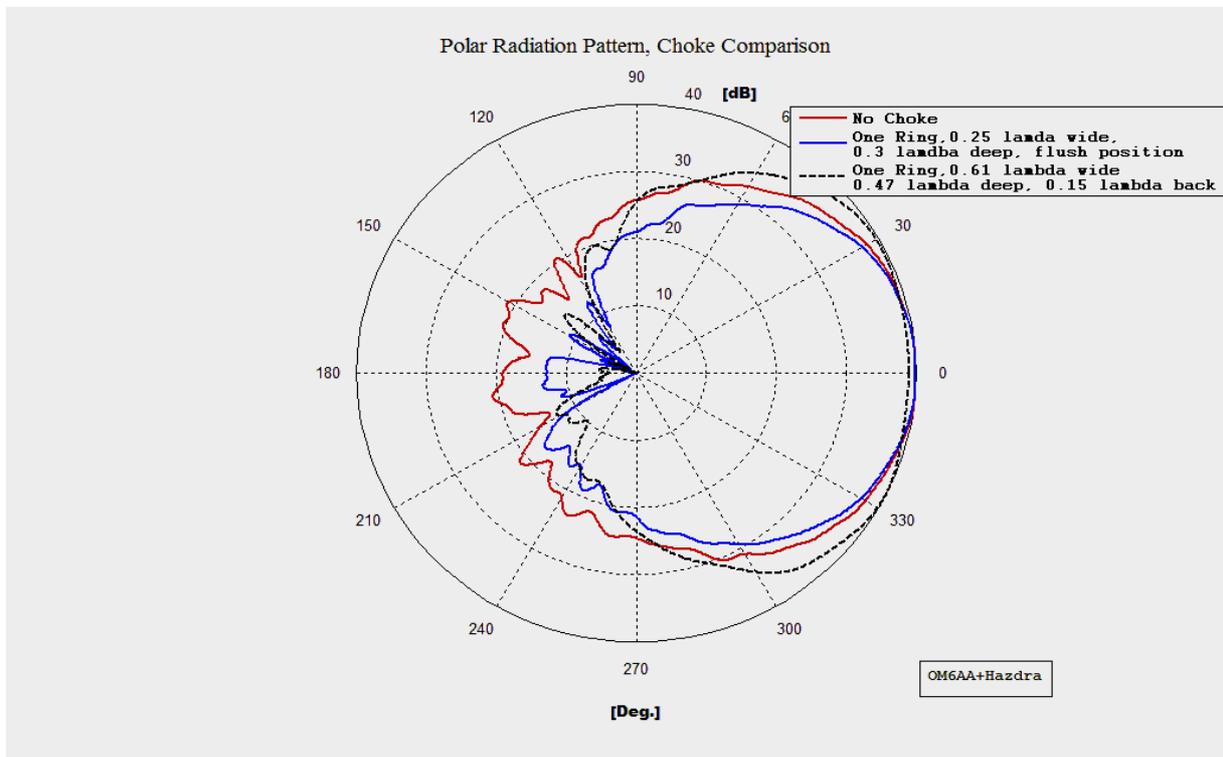


Fig 27 Radiation pattern with various chokes

7.3 Axial Ratio

a/23 cm

To obtain important circularity data, the polarization pattern was measured. The measurement configuration is shown in Fig. 28 and the polarization pattern in Fig. 29. From these data, an axial ratio of better than 0.2 dB for boresight transmission was calculated. The feed equipped with a choke, 0.61λ wide, 0.47λ deep, with distance $X = 0.15\lambda$, has a boresight transmission axial ratio of 0.6 dB.

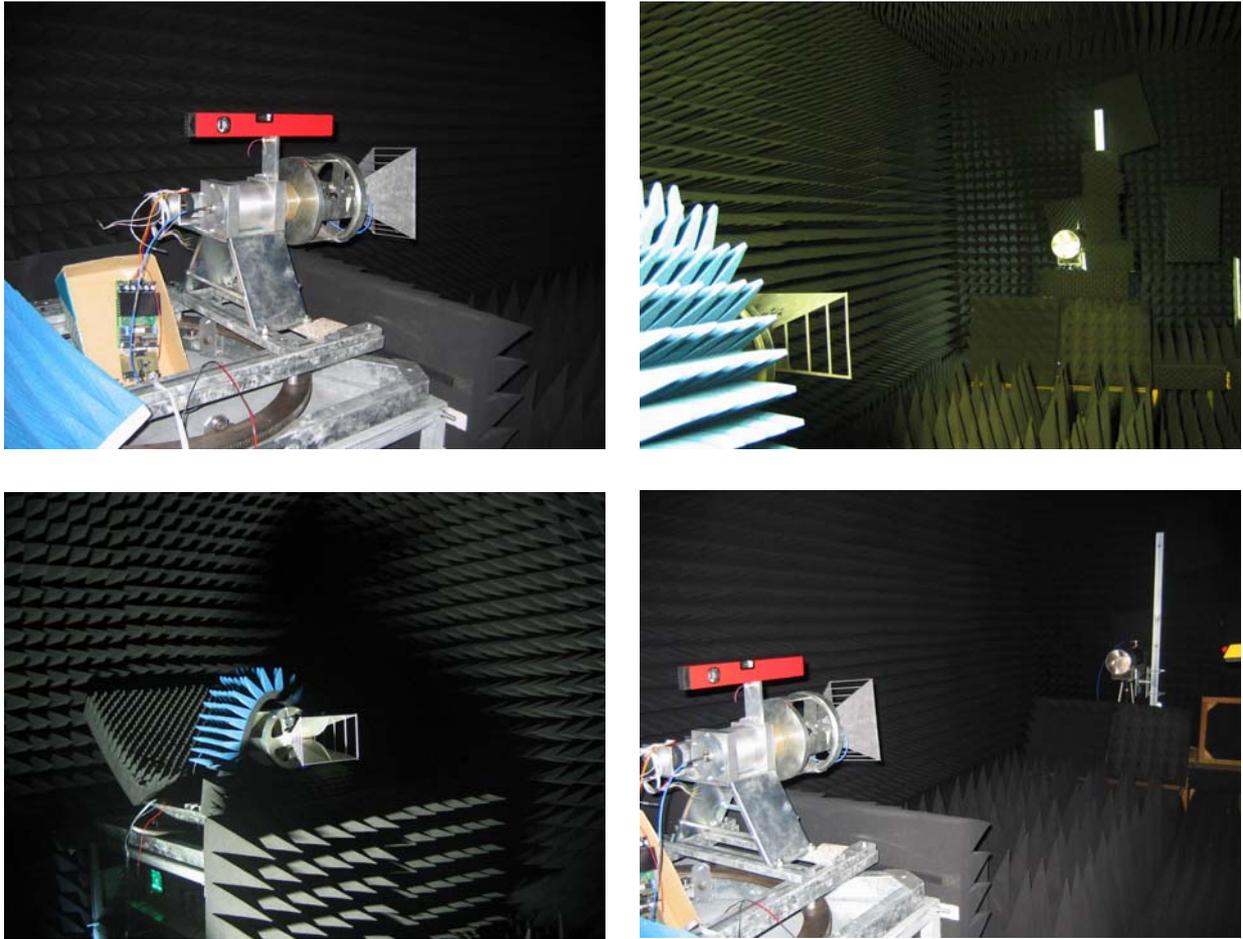


Fig. 28 Axial ratio measurement

b/13 cm

An axial ratio for the frequency interval 2300 to 2424 MHz was measured. The axial ratio is better than 0.5 dB throughout the entire interval. No diagram of this measurement is available.

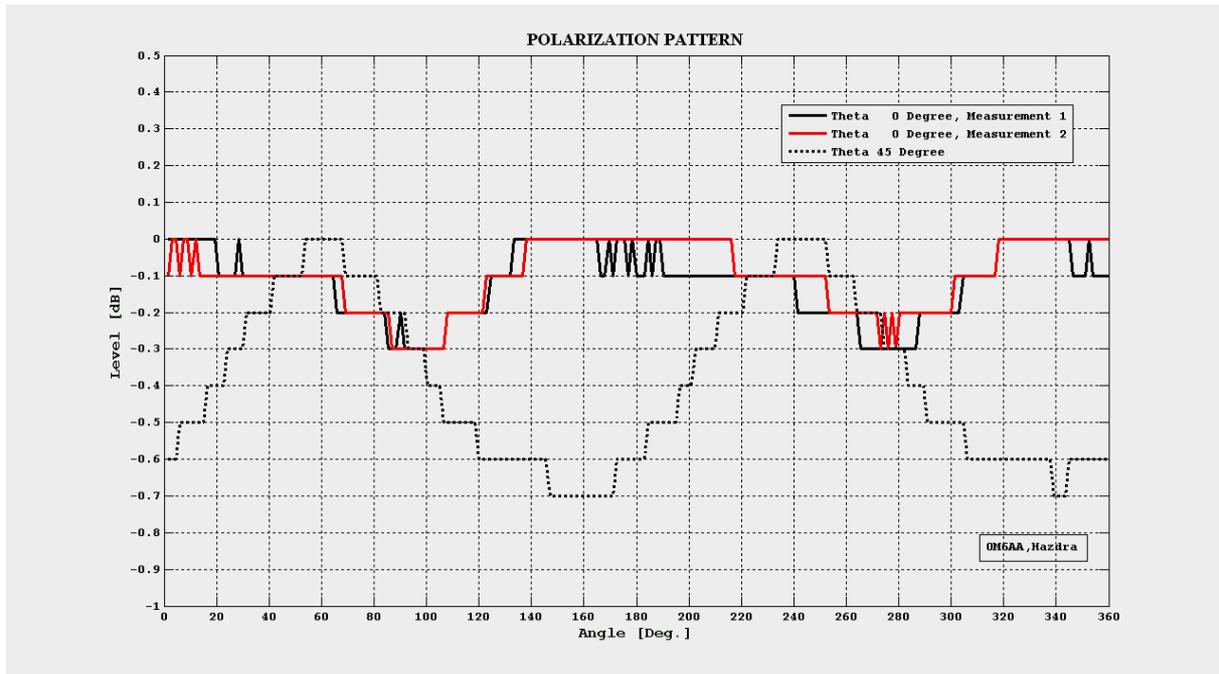


Fig. 29 Polarization pattern

7.4 Isolation Between Ports (S_{21})

a/23 cm

See Fig. 20

b/13 cm

Frequency dependence of port-to-port isolation is shown in Fig.30. Also displayed in this figure is the port-to-port isolation of a 0.7λ diameter waveguide feed with a 4-step septum polarizer recently published by Paul, W1GHZ, and Tommy, WD5AGO [15]. We obtained this feed for our measurements courtesy of Walter, ON4BCB. Measurements were performed by Franta, OK1CA. An Agilent E 4432B Signal Generator and Agilent HP 8593E Spectrum Analyzer were used.

7.5 Phase Center Position

Phase center positions were measured for 23 and 13 cm feeds without chokes and a 23 cm feed equipped with a $0.61\lambda \times 0.47\lambda$ choke positioned 0.15λ back from the waveguide aperture. In all cases, the phase center position was located at the center of the aperture ± 2 cm.

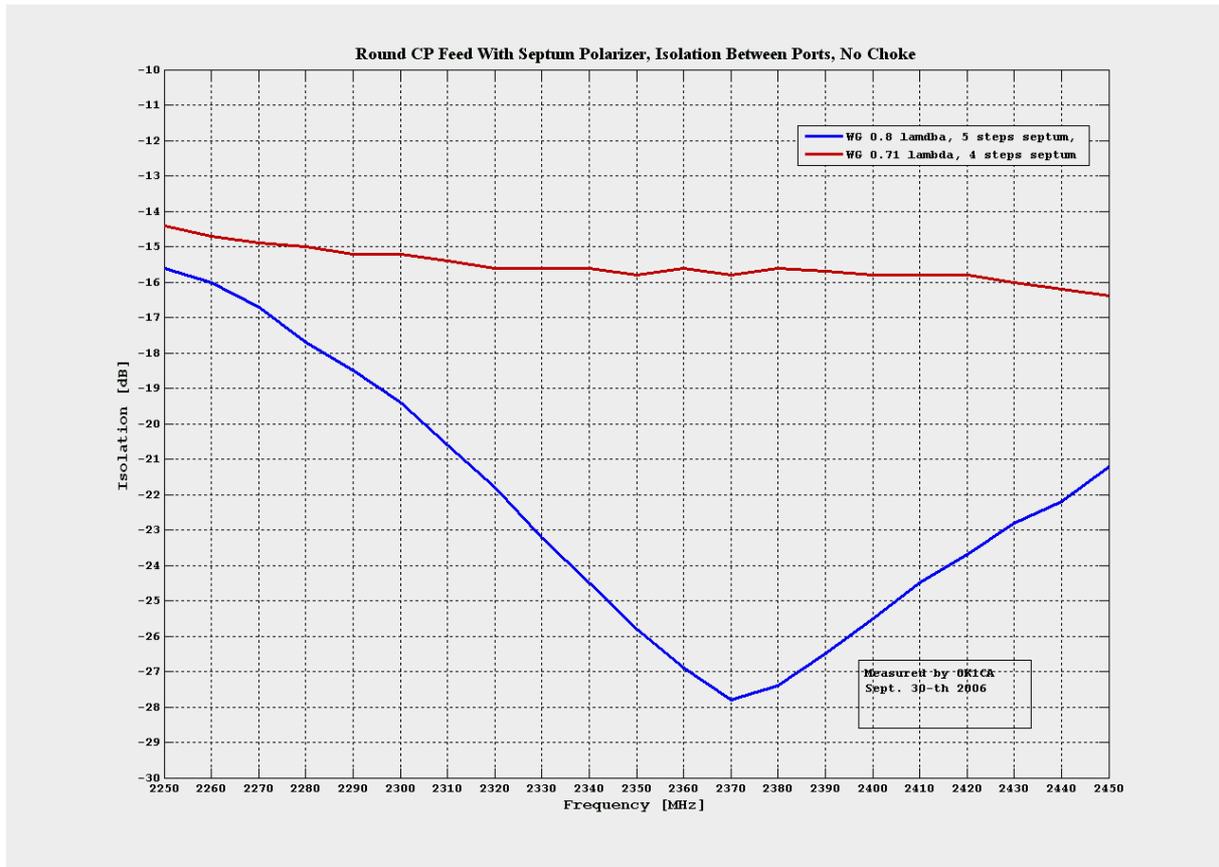


Fig. 30 13 cm feed port-to-port isolation

8. Feed Comparison

8.1 Square feed with septum polarizer

In our previous project [12] we documented the performance of a square cross-section septum polarizer-equipped feed. Having this baseline data permits the comparison of efficiencies of several feeds installed in various dish antenna assemblies. FEKO software was used to compute the dish antenna efficiencies. The diagram of Fig. 31 validates the excellent correlation of computed data to measured data. From the figure it is apparent that the feed with circular cross-section without a choke improved the 20λ diameter dish antenna ($f/D = 0.4$) efficiency by nearly 6 %. Additional improvement in efficiency is possible with a properly designed choke.

8.2 Circular feed with 4 step septum polarizer

As described above, we had the opportunity to measure the feed designed by Paul, W1GHZ, and Tommy, WD5AGO. The circularity of this feed is quite good, below 1 dB, in the frequency range of 2304 to 2424 MHz; however, a significant problem with this design is its low port-to-port isolation, which does not exceed 16 dB. See Fig.30.

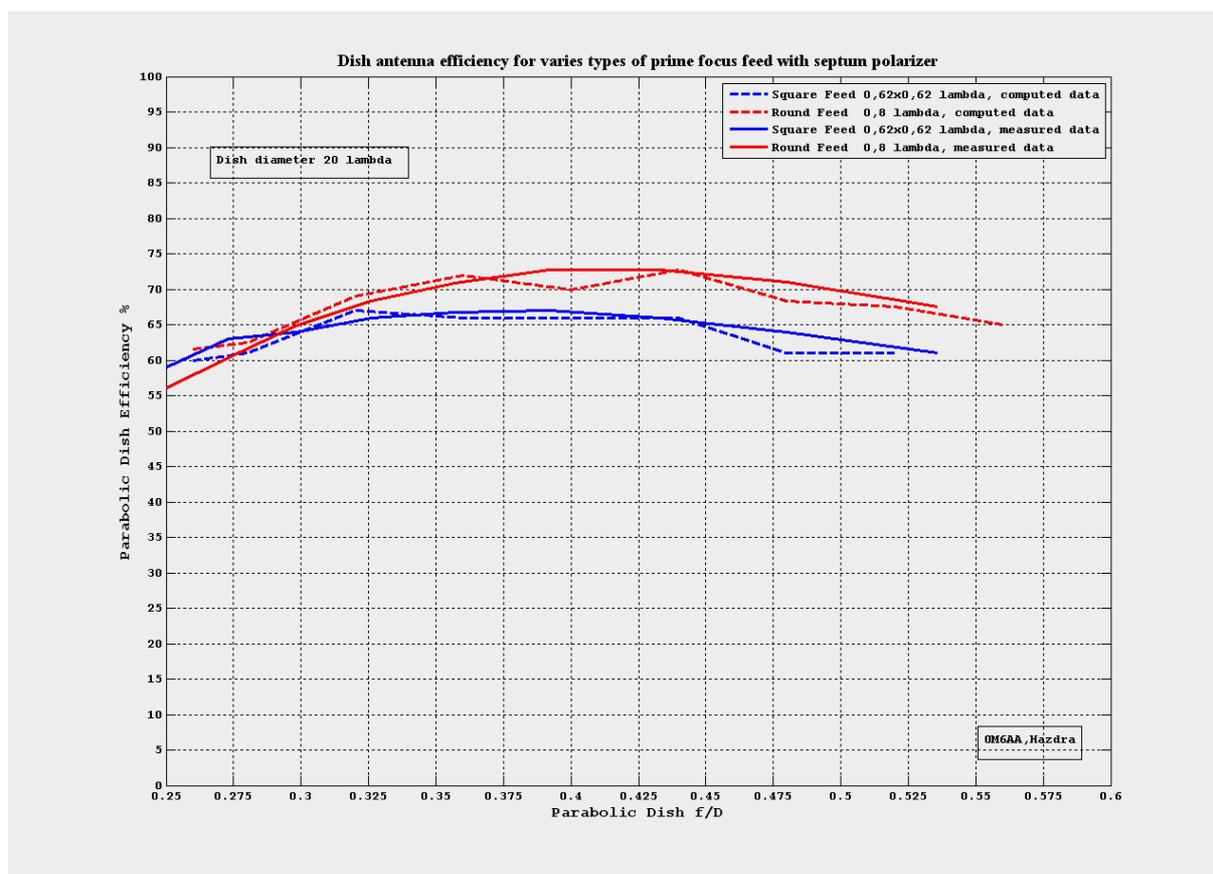


Fig. 31 Feed comparison

8.3 Practical results

As discussed in our previous article [3], an antenna system for circular polarization may be optimized using sun noise measurements after an inspection of its polarization pattern, when its polarization properties are known. Since polarization measurements had been previously completed, we were very impatiently waiting for the opportunity to do a practical test of the feed in a dish antenna assembly.

The first test of a dish antenna assembly using our described feed was performed by Franta, OK1CA. He used our feed design with scaled dimensions in his 10 m dish antenna assembly ($f/D=0.26$, 2300 MHz, intended for reception of research satellites). See Fig. 32. Compared to the square cross section feed with septum polarizer without a choke, he achieved a 1.2 dB higher level of sun noise with an optimized choke. Since Franta's antenna is very deep, it was not possible to unambiguously determine this incremental gain distribution. Because of this, Franta is planning future measurements with a shallow dish.

Eddy, ON7UN, tested the feed equipped with a choke on the 23 cm band in his 6.2 m dish ($f/D = 0.4$). Compared to his previous VE4MA style feed, he achieved a 1.4 dB improvement in sun noise measurement. See Fig.33.

Another improvement in sun noise measurement compared to a VE4MA style feed was reported by Walter, ON4BCB. See Fig.34.



Fig. 32 OK1CA `s feed for 2300 MHz



Fig. 33a ON7UN`s feed for 1296 MHz



Fig 33b ON7UN's feed and sun noise measurement



Fig.34 ON4BCB's feed for 1296 MHz

Summary and Conclusion

We have successfully designed, assembled, simulated and tested several septum transformer-based dish antenna feeds configured in circular cross-section waveguides that operate in the 13 cm (EME and ham satellite bands) and 23 cm bands. The feeds are able to handle very high power, limited only by the Tx port connectors, and operate without a hybrid power divider.

The feeds were assembled and tested without any special mechanical or electrical “tuning” adjustments for better performance. We found that they achieve very good circularity, isolation, and impedance matching and operate with very high polarization efficiency, which may be further improved by adding a choke.

Performance parameters were measured by both computer simulation and actual physical tests with near-perfect agreement between computed and actual results. We found that the cylindrical waveguide feed with septum polarization transformer exhibits excellent performance in all important areas.

Ready-made feeds and chokes are available at ATTPLUS Ltd. [13].

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References

- [1] Samek, Zdenek-OK1DFC; “*Feed for Parabolic Dish with circular Polarization.*” CD ROM for 10-th International EME Conference 2002 in Prague.
- [2] Wade, Paul-W1GHZ; “*Analysis of the OK1DFC Septum Feed*” DUBUS, 1/2003
- [3] Galuscak, Rastislav-OM6AA; Hazdra, Pavel; “*Circular Polarization and Polarization Losses*” DUBUS, 4/2006
- [4] Antoniazzi, Paolo-IW2ACD; Arecco, Marco-IK2WAQ; “*Chaparral Style 10 GHz Feed Simulation*” DUBUS, 2/2005
- [5] Olver, A.D., Clarricoats, P.J.B., Kishk, AA. and Shafaz, L.; “*Microwave Horns and Feed*” IEE Press, Electromagnetic Wave Series Vol. 39 1994.
- [6] Bui-Hai; “*ANTENNES MICRO-ONDES*“ 08/01/1999 MASSON
- [7] Mician GmbH web site: www.mician.com
- [8] Balaji, U., Vahldieck, R.: “*Field Theory Based S-parameter Analysis of Circular Ridged Waveguide Discontinuities*“ IEEE XPLORE
- [9] Bornemann, J., Amari, S., Uher, J., Vahldieck, R.: “*Fast and Efficient Mode-Matching Analysis of Ridged Circular Waveguide Polarizers*“, IEEE XPLORE
- [10] Computer Simulation Technology web site: www.cst.de
- [11] Strihavka, Frantisek-OK1CA; “*Septum Feed History in Czech Republic*” DUBUS 4/2004
- [12] Galuscak, Rastislav- OM6AA; “*Septum Feed Revisited*” DUBUS 4/2004
- [13] ATTPLUS Ltd. Web site: www.attplus.cz
- [14] KIM, C., Rhoden, W.: “*Radiation pattern analysis of coaxial cavity feed horn*” IEEE APS, international symposium, Philadelphia, 1986, vol. 1, pp. 95-98
- [15] Wade, Paul-W1GHZ; Henderson, Tommy-WD5AGO; “*High-Efficiency Feedhorns for Prime-focus Dishes,*” paper for EME conference in Wurzburg, 2006
- [16] Granet, C.; Zhang, H. Z.; Forsyth, A. R.; Graves, G. R.; Doherty, P.; Greene, K. J.; James, G. L.; Sykes, P.; Bird, T. S.; Sinclair, M. W.; Moorey, G. G., and Manchester, R. N. “*The designing, manufacturing, and testing of a dual-band feed system for the Parkes radio telescope.*“ IEEE Antennas & Propagation Magazine. 2005; 47(3):13-19.

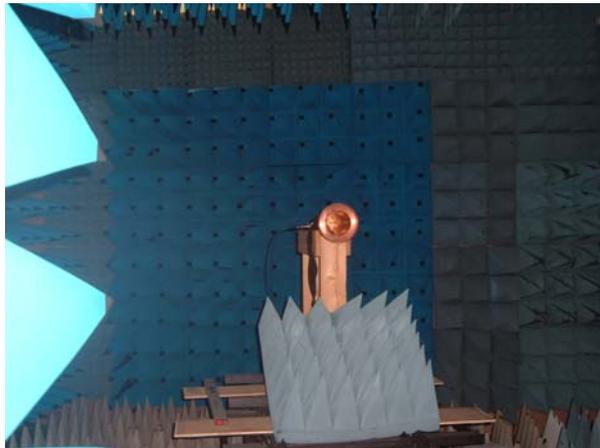
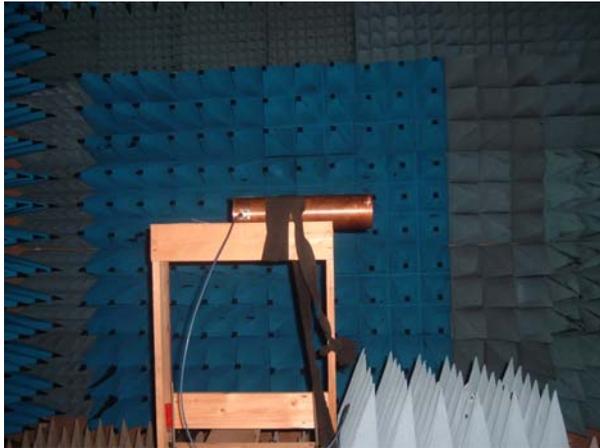
[17] FEKO, EM Software & Systems-S.A. (Pty) Ltd, website: www.feko.info

[18] ERA Pardubice, website: www.era.cz

Appendix I.

Pictures taken during feed measurement in ERA Pardubice.

Head of the anechoic chamber, Mr. Krcmar (above), Vita, OKITIG (below)



Appendix II.

Pictures taken during feeds measurement in anechoic chamber of Czech Technical University in Prague

Head of the university's anechoic chamber Mr. Bartik (left), OM6AA (right)

