OPTIMIZATION OF PRIME-FOCUS CIRCULAR WAVEGUIDE FEED WITH SEPTUM POLARIZATION TRANSFORMER FOR 1.296 GHZ EME STATION

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ABSTRACT

We describe the reduction of polarization losses and other optimizations in the design of a septum polarizer antenna feed configured in a circular waveguide. The goal is to improve the overall efficiency of a parabolic dish antenna system which will be used for EME (Earth-Moon-Earth) microwave communication.

1. INTRODUCTION

EME, “Earth-Moon-Earth” or “Moon Bounced,” communication systems use the Moon as a passive microwave reflector. The Moon reflects only 7 % of incident RF energy and this combined with additional negative factors causes substantial signal loss, making EME the most technically demanding discipline in amateur radio microwave communications. For example, on the 23 cm / 1296 MHz band, an attenuation of up to 272.5 dB must be overcome to be able to detect one’s own Moon-reflected signal. In addition to space and reflection losses, the signal is also affected by Faraday`s rotation and Moon libration. The Faraday phenomenon causes rotation of the polarization vector of electromagnetic waves passing through the ionosphere. These factors introduce additional signal attenuation by causing fading and polarization mismatch losses. To avoid polarization mismatch losses, circular polarization is used on the 23, 13, and 6 cm microwave bands allocated for amateur radio service. Since reflection of circular polarized signals changes the sense of polarization, EME antennas must be able to work with both LHC and RHC, left- and right-hand circular, polarization.

Successful EME communication requires high-gain antennas of 30dBi or more, high-power amplifiers of up to 1.5kw and low-noise preamplifiers with noise figures below 0.4 dB.

2. ANTENNAS FOR EME COMMUNICATION

The above considerations dictate the following requirements for EME antennas:

1. High gain
2. Low noise
3. RHC- and LHC-polarization capability with good axial ratio
4. Able to handle high power, up to 1.5 kW
5. Easy mechanical construction
6. Easy to aim and track the motion of the Moon
7. Low cost

Presently, most EME stations use parabolic reflector antennas which can be easily obtained previously-used from liquidations of obsolete radio-relay links. Another source is dishes intended for TVRO use.

The main design effort is to achieve high efficiency in a parabolic antenna configuration taking all factors into account. Since the radiated power of an amateur radio station is limited by antenna dimensions and input power, each tenth of a dB loss may arbitrate to determine whether or not successful contact can be achieved. Amateur radio antenna designers usually cannot change the properties of parabolic reflectors, so the design emphasis is placed on the feed and its associated parameters.

3. FEED DESIGN

To achieve good parabolic antenna efficiency, the following four main, independent, efficiency components must be addressed in formulating the antenna design goals [1]:

1. Illumination efficiency
2. Spillover efficiency
3. Phase efficiency
4. Crosspolarization efficiency

There are many additional negative factors which lower antenna efficiency i.e. VSWR, struts and feed blockage, material losses, shape deformation, etc. that must also be considered.

Waveguide feeds that produce circular polarization generally consist of three interfuse sections:

A. Waveguide excitation section - coaxial to waveguide transition
B. Polarization transformer
C. Radiation section

Frequently, a circular waveguide feed excited by two orthogonal probes whose applied signals are 90 degrees out of phase is used. The 90 degree phase shift is produced by a “power hybrid divider” that must handle high power levels; thus, it is very difficult to manufacture and introduces unwanted attenuation in the 0.1 to 0.2 dB range as well.

Another popular septum polarization transformer feed employing a waveguide with square cross-section is frequently used [2]. The mismatch between the waveguide’s square shape and the inherently circular form of the electromagnetic field originating behind the septum introduces unwanted side lobes. Crosspolarization losses, which may be reduced somewhat by optimization of the septum transformer and choke designs, also contribute to the degradation in overall efficiency of this configuration.

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

Our feed is designed for the 23cm band with center frequency at 1296 MHz. See layout in Fig. 1.

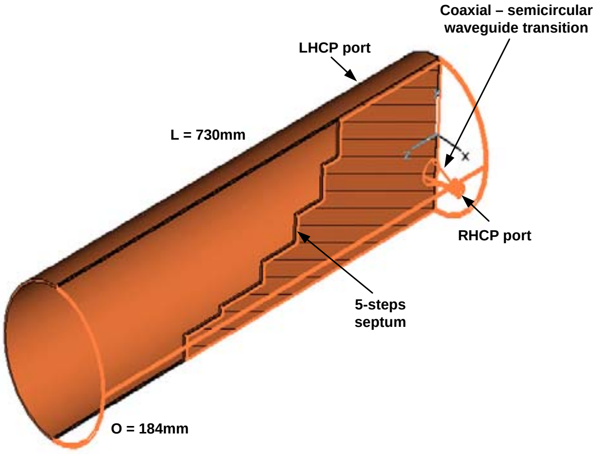

Figure 1. Proposed septum feed layout

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 5-step septum in a circular waveguide using the Mician Microwave Wizard (MMW) [3]. This software utilizes fast modal matching techniques [4], [5].

2. Design and adjustment of the coaxial-semicircular waveguide transition together with the septum by using the full-wave FIT method implemented in CST Microwave Studio (CST MWS) [6].

Simulations in MMW (see Fig. 2) were intended to achieve the maximum possible separation between the radiated LHC and RHC components by adjusting all parameters of the 5-step septum. The best separation obtained was about 50dB.

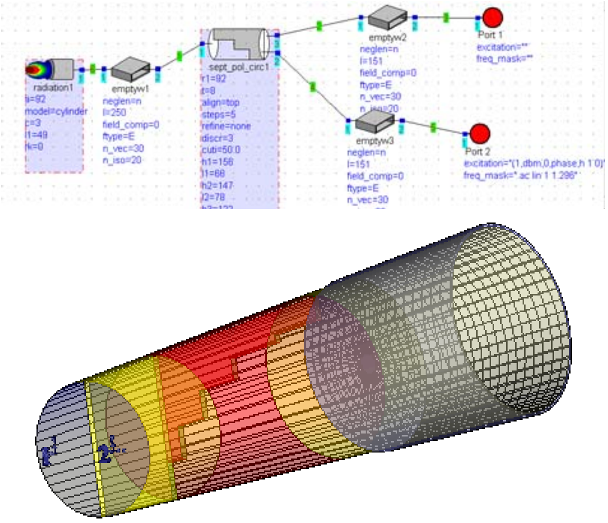

Figure 2. Simplified feed model for MMW analyses

Once the optimum dimensions of the 5-step septum were determined, the entire feed was simulated using CST MWS applied to the model in Fig. 2. Electrical excitation of the waveguide was chosen because of its simplicity. Two probes with conical shapes (see Fig. 3) were employed to match the waveguide structure to the input coaxial line. 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. Outer diameter *rc* was fixed at *rc*=30mm and parameters *lc* and *z* were varied. The best results were obtained with *lc*=39mm and *z*=64mm.

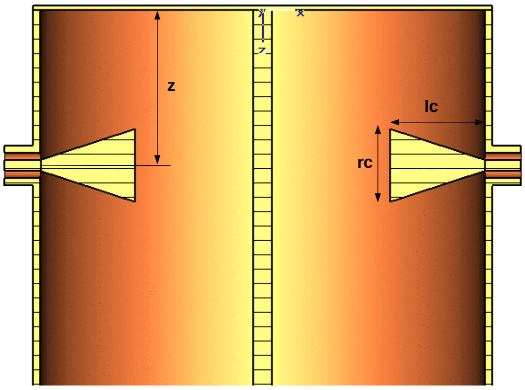

Figure 3. Detailed sectional view of the cone transition

4. PERFORMANCE SIMULATION

Very fine computational meshing (2.4E6 cells) was required. One simulation cycle took about 18 hours on a PC equipped with two 2GHz AMD Opteron µ-processors. Very good radiation properties were obtained. Separation between LHC and RHC polarizations at the main lobe direction is 40dB;

moreover, the pattern exhibits excellent rotational symmetry (circularity). See Fig. 4, 5 and 6. In Fig. 4 and 5, the 3D pattern is placed at the phase center for clearness.

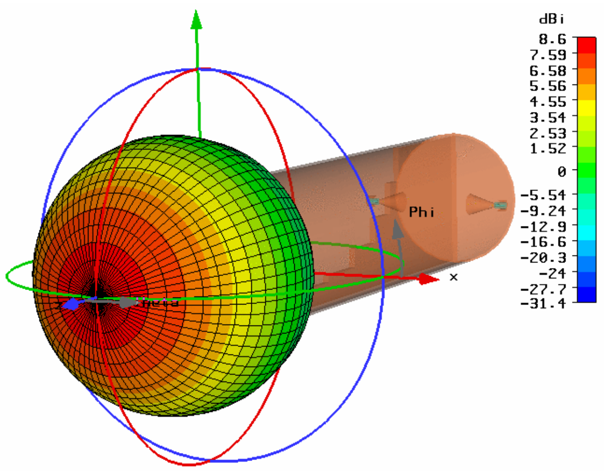

Figure 4. 3D directivity pattern @ 1296 MHz with LHC port excited, LHC component shown. Pattern is normalized to maximum directivity D_{max}=8.61dBi

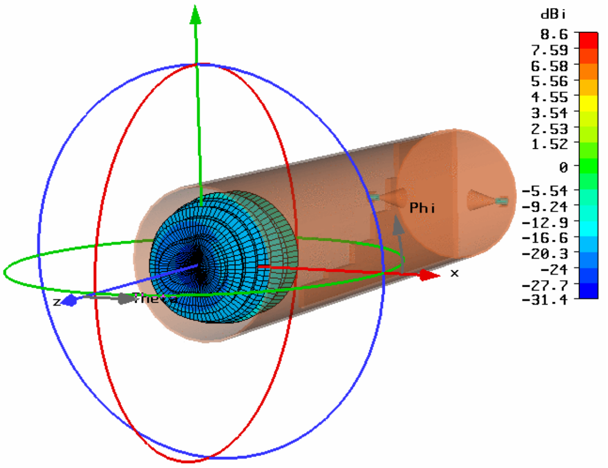

Figure 5. 3D directivity pattern @ 1296 MHz with LHC port excited, RHC component shown. Pattern is normalized to maximum directivity of the RHC component (D_{max}=8.61dBi)

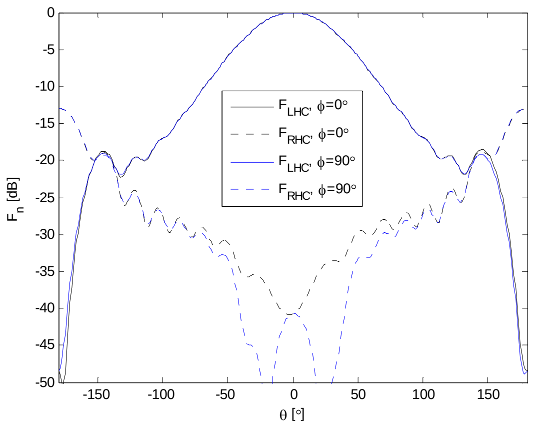

Figure 6. Normalized LHC and RHC patterns @ 1296 MHz for two perpendicular cuts, Φ=0° and Φ=90°

The axial ratio does not exceed -1dB within the range of $-50° < \theta < +50°$. See Fig. 7.

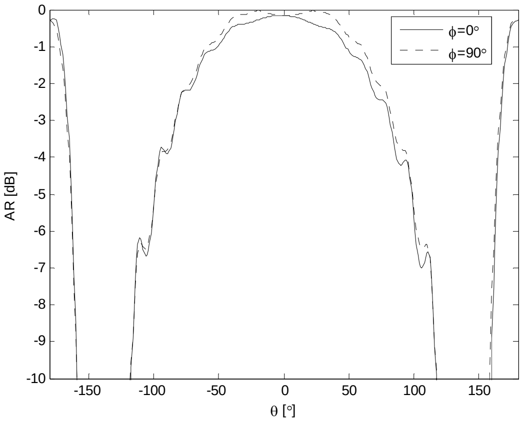

Figure 7. Axial ratio @ 1296 MHz for two perpendicular cuts, Φ=0° and Φ=90°

Using the calculated 3D radiation pattern, polarization efficiency has been evaluated using the following equation (consider the LHC port being active):

$$\eta_{POL} = \frac{P_{LHC}}{P_{LHC} + P_{RHC}}, \qquad (1)$$

where ***P*** is radiated power calculated by integrating the farfield pattern over the sphere. Evaluation of the proposed septum feed gives η_{POL} = 97.68%; thus, only 2.32% of the input power is lost by being radiated as unwanted polarization.

To determine the polarization efficiency of the septum polarizer transformer only, a circular waveguide without a septum was simulated. Excitation at a port in a waveguide model without septum, but having the same dimensions as the previous model, was simulated using CST MWS. The port was excited simultaneously by two orthogonal modes with 90° phase shift at 1296 MHz. Thus, ideal circular polarization was simulated for the waveguide without septum. Polarization efficiency was again calculated using equation (1) and in this case gave the same result (η_{POL} = 97.68%) as the model with the septum polarizer present. From this we conclude that one can expect the efficiency of the designed septum polarization transformer to be near 100%. The 2.32% loss in polarization efficiency is therefore attributed to unbalanced surface currents originating on the open side of the waveguide. This phenomenon is in conformity with the observation that radiation of the unwanted polarization is dominant in the backward direction.

Further improvements in polarization efficiency may be realized with the use of a choke; however, choke design is beyond the scope of this article.

To investigate maximum input power, |E|, 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. 8). The most critical area was found to be at the vertex of the cone, with intensity ~ 8kV/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.

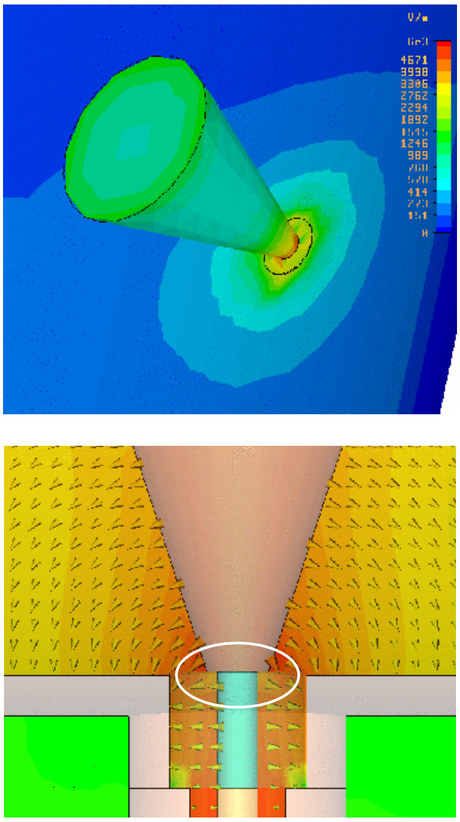

Figure 8. Intensity of electric field with 1W input power

5. ACTUAL MEASURED PERFORMANCE

Finally, the feed design described in this paper has been fabricated using duralumin and S-parameters have been measured in an anechoic chamber with an Agilent Technologies E8364A network analyzer. Excellent agreement between CST MWS simulations and actual measurements has been observed (see Fig. 9). We must note that the input coaxial connector has been slightly simplified for the simulated model; this may explain the slight deviations in measured S_{11} from the simulated values. However, in the 23cm band, measured matching is S_{11}=-35dB (VSWR=1.00063) and isolation S_{21} = -26.5 dB. Frequency bandwidth for S_{11} < -30dB is 11%.

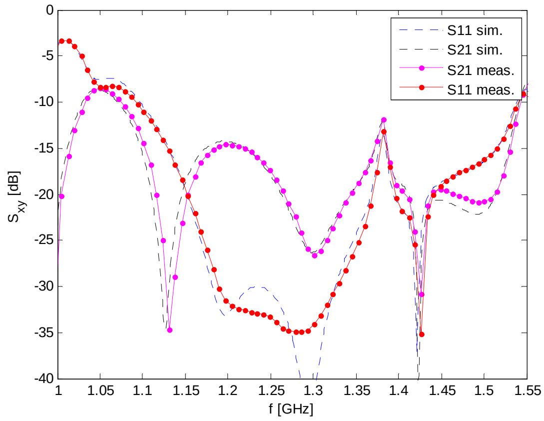

Figure 9. Simulated and measured S-parameters

Main parameters of the designed feed are shown in Tab.1.

Summary (with respect to center frequency 1296 MHz)

Return Loss	-35dB (VSWR = 1.00063)
Isolation between ports	26.5dB
LHC/RHC separation	40dB at the main lobe direction
Polarization efficiency	97.7 %
Directivity	8.61 dBi
Relative bandwidth (S_{11}<-30dB)	11%

Table 1. Summary of the designed feed parameters

6. CONCLUSIONS

The circular waveguide feed with septum polarization transformer exhibits excellent performance parameters. Very good circularity without adjustment and operation without requiring a hybrid power divider is achieved. The feed operates with very high polarization efficiency, which may be further improved by adding a choke. Very good isolation and impedance matching were also realized. An improved version of this feed that includes a choke is currently being developed by the authors.

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