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Development of a Compact Eleven Feed Cryostat for the Patriot 12-m Antenna System

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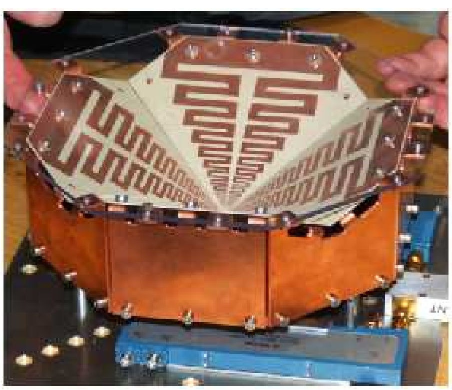
Abstract

The Eleven antenna has constant beam width, constant phase center location, and low spillover over a decade bandwidth. Therefore, it can feed a reflector for high aperture efficiency (also called feed efficiency). It is equally important that the feed efficiency and its subefficiencies not be degraded significantly by installing the feed in a cryostat. The MIT Haystack Observatory, with guidance from Onsala Space Observatory and Chalmers University, has been working to integrate the Eleven antenna into a compact cryostat suitable for the Patriot 12-m antenna. Since the analysis of the feed efficiencies in this presentation is purely computational, we first demonstrate the validity of the computed results by comparing them to measurements. Subsequently, we analyze the dependence of the cryostat size on the feed efficiencies, and, lastly, the Patriot 12-m subreflector is incorporated into the computational model to assess the overall broadband efficiency of the antenna system.



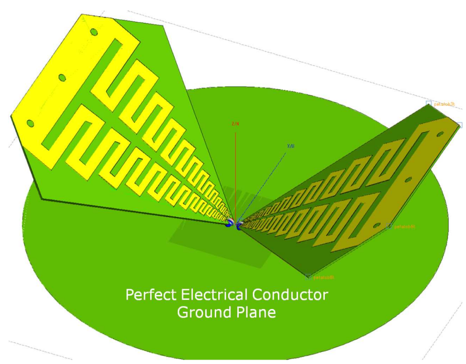


Figure 1. a) 2-14 GHz cryogenic Eleven antenna; b) geometric representation of the Eleven antenna used for computations.

1. Validation of Computational Results

Computational electromagnetic analysis of the Eleven antenna was performed using the commercial software suite FEKO. To give credence to the computations, a freespace model of the Eleven antenna was first constructed to compare the computational results against their measured counterparts. These results refer to the feed efficiencies, which are calculated from the antenna radiation patterns as described in [1]. Figure 1a displays a photo image of the 2-14 GHz Eleven antenna, the radiation pattern of which was measured in an anechoic chamber at the Technical University of Denmark [2] [5]. Figure 1b displays the corresponding FEKO geometric representation used to model the electromagnetic behavior of the antenna in Figure 1a.

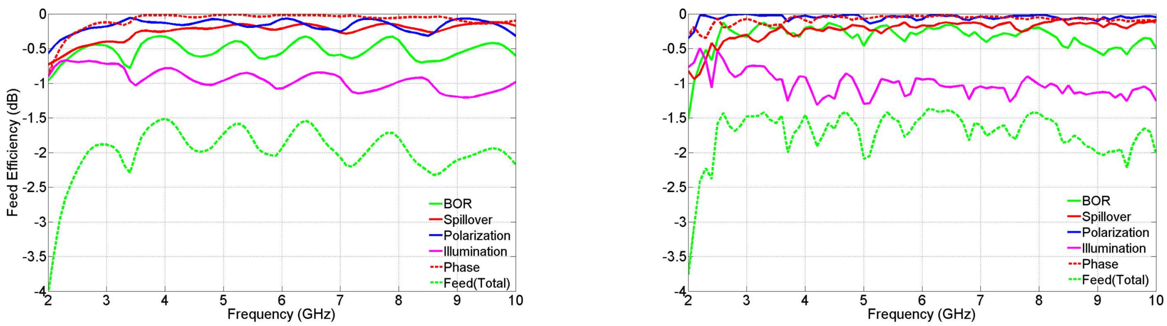


Figure 2. a) Eleven antenna feed efficiencies based on FEKO model; b) Eleven antenna feed efficiencies based on measurements.

In order to make the model computationally tractable, many of the components comprising the physical antenna were not modeled in FEKO as they do not contribute significantly to the feed efficiencies. Furthermore, we only model a single polarization (one pair of petals) as the two polarizations are rotationally symmetric. The feed efficiencies calculated from the measured and computed radiation patterns are shown in Figures 2a and 2b, respectively. These calculations were performed assuming a full-width primary reflector capture angle of 120 degrees. Comparison of these two plots provides faith in the computed radiation patterns which are used to calculate the feed efficiencies specific to the 12-m Patriot antenna system.

2. Feed Efficiency Dependence on Cryostat Size

In the interest of minimizing feed blockage and weight, it is desirable to make the cryostat as small as possible. However, if the cryostat is too small, the electromagnetic fields near the aperture of the antenna will be choked, and the feed efficiencies will be degraded. This trade-off has been analyzed by means of a computational model in FEKO. The feed model shown in Figure 1b was modified in order to study the dependence of the cryostat walls on the feed efficiencies; the modified geometric representation is shown in Figure 3.

Since the primary phenomenon expected to degrade the feed efficiencies is choking of the electromagnetic fields near the top of the feed, only the top most portion of the cryostat walls were modeled. Defining the problem in this way also has the advantage of minimizing the size of the computational problem to be solved. As indicated in Figure 3, the feed efficiencies were examined as a function of the cryostat wall length ‘L’ and the cryostat radius ‘R’. In this examination, the feed efficiencies were calculated from 2-10 GHz for each L,R pair and these quantities were subtracted from their corresponding freespace counterpart. The average of this difference over 2-10 GHz is referred to as the efficiency degradation and describes the feed efficiency losses relative to those shown in Figure 2a. The efficiency degradation data form a rectangular grid in L and R, and this data was interpolated to generate the efficiency degradation map shown in Figure 4.

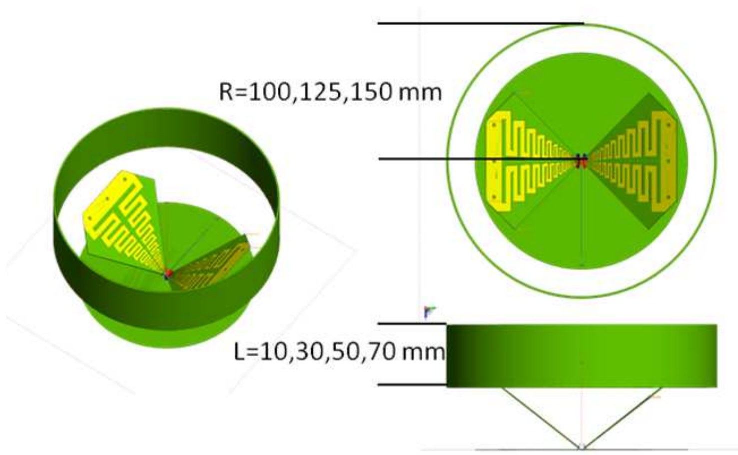


Figure 3. Geometric model used to study feed efficiency dependence on the cryostat size.

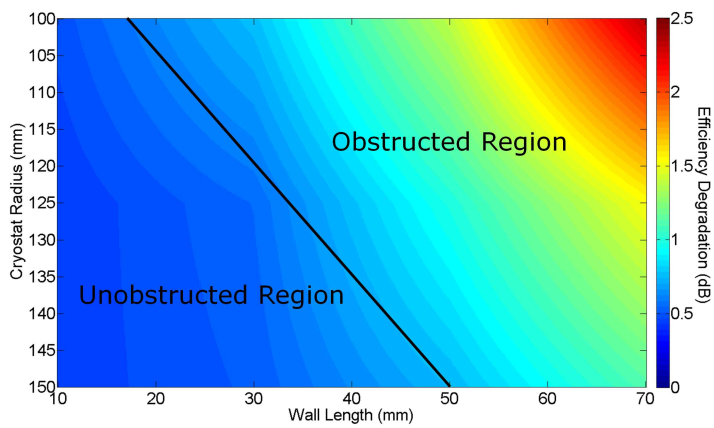


Figure 4. Feed efficiency dependence on cryostat size. The obstructed region is that in which the cylinder radius and length are such that the opening angle of the feed is obstructed by the cylinder in the geometrical optics sense. The efficiency degradation increases from bottom left to top right.

3. Feed Efficiencies on the Patriot 12-m Antenna

The Patriot 12-m antenna (Figure 6) is a dual-shaped reflector system which is one of the two new antenna systems being incorporated for use in the VLBI2010 network, the other being the VertexRSI design. Currently, a Patriot 12-m antenna is being installed at the Goddard Geophysical Astronomical Observatory (GGAO) in Greenbelt Maryland, USA. This antenna will be retrofit with an Eleven feed to provide broadband capability for VLBI2010 observations. As such, the feed efficiencies incorporating the 12-m subreflector have been calculated for future sensitivity estimates. The radiation pattern of the Patriot subreflector under illumination by the Eleven antenna was simulated in FEKO, and Figure 5 displays the feed efficiencies calculated from these patterns based on the 150 degree full-width capture angle of the primary reflector. Because the subreflector is shaped, as a single reflector it does not possess a well-defined focal point. This being the case, the subreflector was assumed to not degrade the phase sub-efficiency of the feed pattern in order to avoid application of a phase correction needed to compensate for the surface shaping.

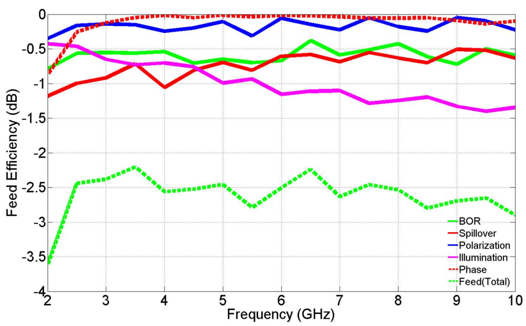


Figure 5. Feed efficiencies on the Patriot 12-m antenna system simulated with the Eleven antenna's freespace radiation pattern.

Figure 6. Patriot 12-m antenna system (photo courtesy of Jim Lovell, University of Tasmania).

4. Conclusions

- The feed efficiencies based on the calculated radiation patterns computed from the FEKO Eleven antenna model (Figure 1b) demonstrate good agreement with the feed efficiencies obtained from measurements of the antenna's (Figure 1a) radiation patterns.
- The feed efficiencies of the Eleven antenna are degraded when the Eleven antenna is placed in a cryostat that is too confining. Figure 4 exhibits the dependence between the cryostat size and the efficiency degradations.
- The frequency averaged efficiency is expected to be 55% when the Eleven antenna is used to feed the Patriot 12-m antenna system; this is 5% greater than the VLBI2010 specification [3].
- The feed efficiencies were derived assuming that the subreflector does not degrade the freespace phase sub-efficiency.
- The feed efficiencies were derived under the assumption of no blockage, but the subreflector shaping mitigates this efficiency loss.

References

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