Measurements of a 1 to 13 GHz Model of a Dual Polarized Low-profile Log-periodic Feed for US-SKA

Rikard Olsson[1], Per-Simon Kildal[2] and Sander Weinreb[3]
[1,2]Chalmers University of Technology, Göteborg, Sweden
[3]California Institute of Technology, Pasadena, California

[1]E-mail: rikard.olsson@elmagn.chalmers.se
[2]E-mail: simon@elmagn.chalmers.se
[3]E-mail: sweinreb@caltech.edu

Abstract

We present measured results for a dual polarized 1 to 13 GHz laboratory model of a feed for use in reflector antennas. The main goals of the laboratory model were achieved: it provides dual polarization and can provide more than a decade bandwidth. The aperture efficiency in a primary fed reflector system is greater than 56% over the entire band, and the input reflection coefficient of the feed is better than -5.5 dB. The results agree well with computed values.

I. INTRODUCTION

The Square Kilometer Array (SKA) [1] has been proposed as a major new instrument in radio astronomy. As the name indicates the radio telescope will have a staggering total aperture area of about 1 square kilometer. This huge radio telescope will provide two orders of magnitude increase in sensitivity compared to existing radio telescopes. In order to achieve this large total area, a large array of small antennas has been proposed to reduce total cost and to allow phased-array imaging of the entire beam area of the small antenna. There are many different suggestions for antenna elements, ranging from a few tens of very large single reflectors to very large numbers of small, fixed antennas with near-hemispherical field of view. The US proposal, for which the present feed has been designed, makes use of an array of 4550 symmetric parabolic reflectors with 16 m diameter. The feed described in the present paper will be placed in such a way that the subtended half angle towards the sub reflector is 53 deg. One of the advantages with the US proposal is that it makes use of reflector antennas, representing a well known and well understood technology which has been used in radio astronomy during several decades. The system is very wide band; the goal is to cover 100 MHz to 25 GHz. In order to cover this much bandwidth with a minimum number of receivers on each of the 4550 elements very wideband feeds and receivers are required; three decade-bandwidth feeds are sufficient to cover a range which would require eight octave-bandwidth feeds. In this paper we describe initial experimental results on a decade-plus bandwidth feed which can be scaled to any frequency range.

Traditionally end-fire style log-periodic dipole arrays [2] have been used in ultra wide band antenna design to achieve medium gain antennas for use in both antenna measurements and EMC (ElectroMagnetic Compatability) studies. Log-periodic antennas are not common as reflector feeds because the phase center varies strongly with frequency [3]. The phase center variation can be reduced to acceptable levels, such as e.g. in the log-periodic feed for the Allen Telescope Array (ATA) [4]. However, the ATA feed is large and there are significant losses due to phase center variation [5]. During the last year we have been developing a log-periodic folded dipole feed first described in [6] which has no phase center variation and constant beam width over a decade bandwidth. In the present paper we present measured results for the first decade bandwidth dual-polarized laboratory model of this feed.

To characterize the feed performance we use the aperture efficiency of a rotationally symmetric Cassagrain antenna when the effects of center blockage and subreflector diffraction are

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neglected. It includes losses due to spill-over, higher order φ-variation in the radiation pattern, cross-polarization, non-uniform aperture distribution and phase errors [7, section 8.4]. The work presented in this paper was supported by California Institute of Technology and Cornell University under a contract with ASTRON in connection with the US SKA proposal. The present feed is protected by the patent application in [8].

II .DESCRIPTION OF FEED

The experimental feed model presented in this paper has been designed to cover 1 to 13 GHz and to be used for dual linear polarization. To achieve this, the lowest geometrical frequency of the feed was chosen to be 1 GHz and the highest geometrical frequency to be 15.6 GHz. The lowest (highest) geometrical frequency corresponds to the frequency at which the longest (shortest) dipole spacing corresponds to 0.5 wavelengths. Figure shows 1 a photograph of the feed described in the present memo with key dimensions indicated. The dimensions of the dipoles such as length L, separation D, height above ground plane h, and strip width, are scaled with frequency to provide the log-periodic shape. The scaling factor k is 1.1161. The described feed contains no balun, but it is intended to be integrated with an active 180 deg balun and low noise receiver. The reported measurements have been done with a broadband commercial 180 deg hybrid power divider [9] replacing the balun. Each of the two parallel strip lines are fed by a separate coaxial cable. Each coaxial cable is, on the back side of the ground plane, connected to the commercial 180 deg hybrid. All measurements are corrected for the loss and reflection coefficients of the hybrid. The inset in figure 2 shows a sketch of the exciting structure.

The effect of the finite ground plane is included in the numerical analysis of the feed. However, to save time the dielectric support has been neglected in the calculations.

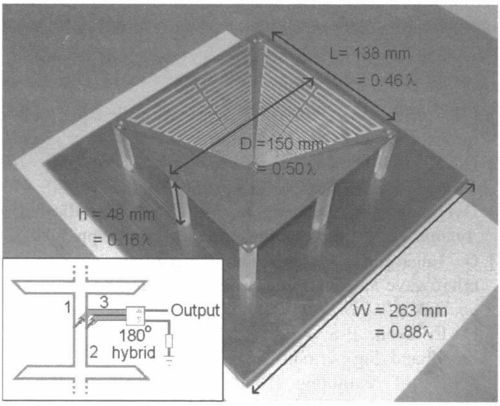

Fig 1. Photograph of the Manufactured 1 to 13 GHz lab model with key dimensions indicated. The largest of dimensions are given in mm. These sizes are also given in terms of the lowest geometrical frequency. The inset shows the central part of the feed and illustrates how each of the two transmission lines (1 and 2) are fed by a separate coaxial line (3) and connected to the hybrid on the back side of the ground plane.

III. RESULTS

In table 1 we see a summary of measured and calculated efficiencies when the feed is used in a reflector of 53 deg subtended half angle. We see that there is fairly good agreement at least in terms of average levels with somewhat greater variation from the average than calculated. In figure 2 we see the computed and measured far-field pattern in the 45 degree plane at 6 different frequencies. In order to quantify the difference in computed and measured patterns we show the corresponding aperture efficiency as a function of frequency in figure 3. As shown in figure 4 the measured reflection efficiency below 6 GHz are better than computed; above 6 GHz the variations are predicted though with some discrepancy in frequency structure. The reflection efficiency is better than -1.45 dB at all frequencies corresponding to an input reflection coefficient better than -5.5 dB. It should be noted that at frequencies as low as 100 MHz the figure of merit of a radio astronomy antenna, area divided by system temperature, is not reduced by feed reflections because the sky noise is much higher than receiver noise. Furthermore at higher frequencies, remotely controlled tuners can be used to correct for small reflections without significant loss.

TABLE I
SUMMARY OF MEASURED AND CALCULATED SUB EFFICIENCIES FROM 1 TO 13 GHZ

Cause of efficiency	BEST CALCULATED [DB]	BEST MEASURED [DB]	WORST CALCULATED [DB]	WORST MEASURED [DB]
Spill-over, e_{sp}	-0.20	-0.20	-0.76	-1.37
Illumination, e_{ill}	-0.43	-0.31	-1.13	-1.25
Polarization, e_{pol}	-0.00	-0.08	-0.18	-0.54
Phase, e_{ϕ}	-0.00	N/A	-0.22	N/A
Aperture, e_{ap}	**-1.15**	**-1.03**	**-2.25**	**-2.54**
Reflections, e_{refl}	-0.06	-0.02	-1.44	-1.45
Total, e_{tot}	**-1.29**	**-1.25**	**-3.05**	**-3.39**

IV. CONCLUSION

A 1 to 13 GHz feed has been designed and manufactured for use in dual linear polarization. The measured results agree well with the computed and the aperture efficiency is better than -2.54 dB over the entire band. Also, the reflection efficiency is well predicted and better than -1.45 dB at all frequencies. Work is ongoing to improve impedance matching.

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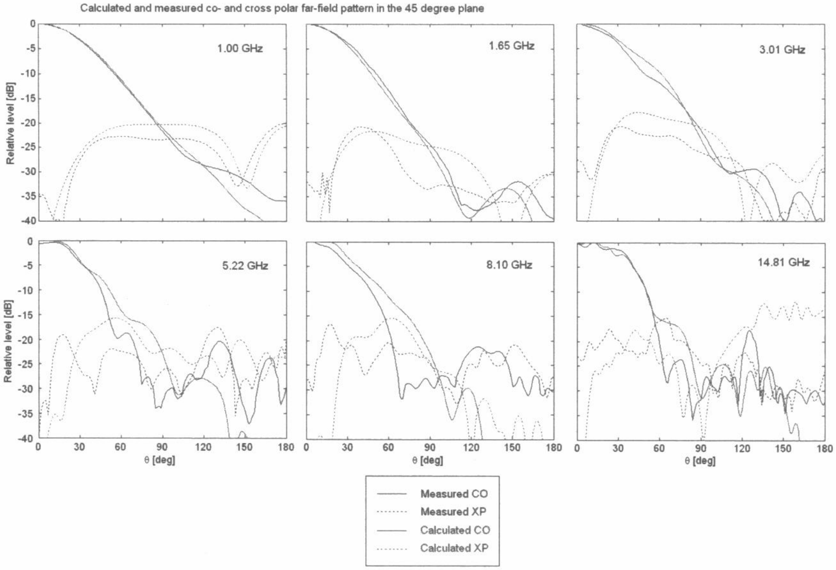
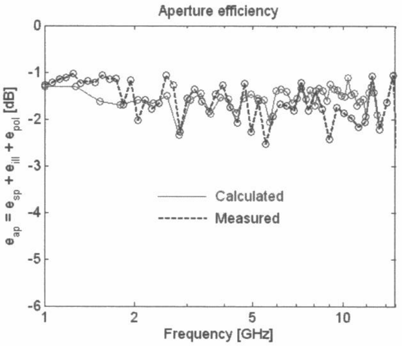


Fig. 2. Calculated and Measured Co- and cross-polar 45 degree plane relative far-field patterns at 6 different frequencies.



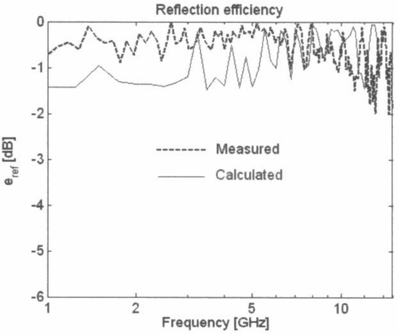


Fig. 3. Measured and calculated aperture efficiency for 53 degree subtended half angle.

Fig. 4. Calculated and measured reflection efficiency. The effects of the cables and hybrid have been removed by appropriate calibration.