

# The Eleven antenna feed for monopulse tracking and combining L-, C-, X- and Ku- satellite bands

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## INTRODUCTION

The Eleven feed, featured as a low-profile, logarithmic-periodic and ultra wideband antenna, has during the past few years been developed at Chalmers [1]-[5]. It is referred to as the Eleven feed because its basic geometry is two parallel folded dipoles half-wavelength apart, and it can be used over more than a decade bandwidth with 11dBi directivity by extending the basic configuration logarithmically. The Eleven feed can be used in both linear and dual polarizations, and its phase centre changes so little with frequency that the corresponding phase efficiency is better than -0.1dB at all frequencies. The 10dB semi-beam width is 50-60 degrees over the entire frequency band, and a reflector aperture efficiency of 66% or better can be achieved when the subtended angle towards the reflector is about 53 degrees. Therefore, it is suitable as feed for reflector antennas, in particular when they are primary-fed. The Eleven feed was developed on projects for California Institute of Technology (Caltech) as a feed for the reflectors of the US SKA proposal (Square Kilometer Array) [2].

The present paper describes the design of a model of the Eleven feed covering the satellite communication bands between 1 and 13 GHz, i.e. L-, C-, X- and Ku-band. The model is based on the experience of designing, fabricating and measuring several previous Eleven feeds at lower frequencies for radio telescopes such as Green Bank (WV, USA), RATAN (Russia) and GMRT (India) (Figure 1). The paper also describes how monopulse tracking can be implemented in the Eleven feed, which in its most general configuration can be regarded as a dual polarized antenna with 8 ports. By appropriate combination of these ports, patterns for the sum beam and monopulse tracking in two orthogonal planes can be generated for dual polarization. The monopulse tracking capability opens up interesting opportunities for using the Eleven antenna for satellite communications.

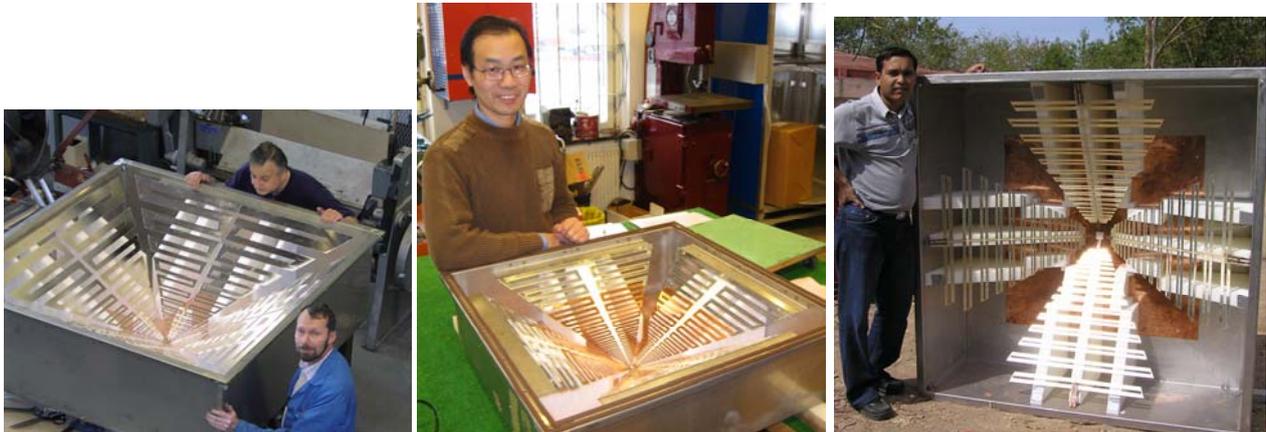


Figure 1. Three previous Eleven feed models developed for use in Green Bank radio telescope for 150 – 1700 MHz (left), in RATAN telescope for 500 – 3000 MHz (middle), and in Giant Meter Radio Telescope for 200 – 800 MHz (right).

## PERFORMANCE OF PREVIOUS ELEVEN FEED MODELS

Operational Eleven antennas have been designed and manufactured for use as a feed for the reflectors of three radio telescopes. All the three models are pictured in Figure 1. The model for the 42 m diameter radio telescope in Green Bank [3] was designed to operate between 150 MHz and 1.5 GHz, the model for the Giant Meter Radio Telescope (GMRT) in India between 200 and 800 MHz, and the model for the RATAN radio telescope between 500 MHz and 3 GHz. The input reflection coefficient  $S_{11}$  has been successively improved as shown in Figure 2. The antennas have

balanced feeding, so the measurements are done on the port of a 180 deg hybrid and the losses in the hybrid have been removed by appropriate calibration.

The Eleven antenna is designed by numerical simulation using a moment method program. The discrepancies between simulated and measured  $S_{11}$  in Figure 2 are mainly due to the difficulties in accurately including the central puck/feeding region in the simulations. Therefore, it is difficult to get smaller  $S_{11}$  than -10 dB.

The simulated radiation patterns are in very good agreement with the measurements, as can be seen from Figure 3. Therefore, the computed aperture efficiencies of the reflector are also quite accurate. These values when the feed is used in a reflector with 54 deg subtended angle are similar to the ones shown in Figure 5 for the recent 1-13 GHz model. The different subefficiencies are described in [2]. The beam width of the Eleven feed is fixed and almost independent of frequency. The beam width cannot be changed by modifying the geometry without destroying other performance parameters like symmetry of the beam and cross polar sidelobes.

The radiation efficiency due to losses in materials are shown in Figure 3 as well. The results have been measured in a reverberation chamber with an accuracy of about 0.5 dB RMS.

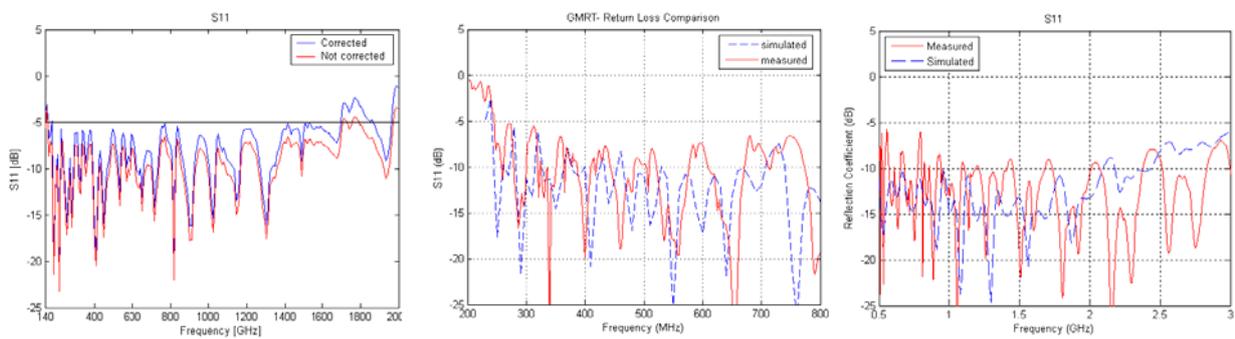


Figure 2 Simulated and measured reflection coefficients of Eleven feed for Green Bank, GMRT and RATAN radio telescopes, from left to right, respectively.

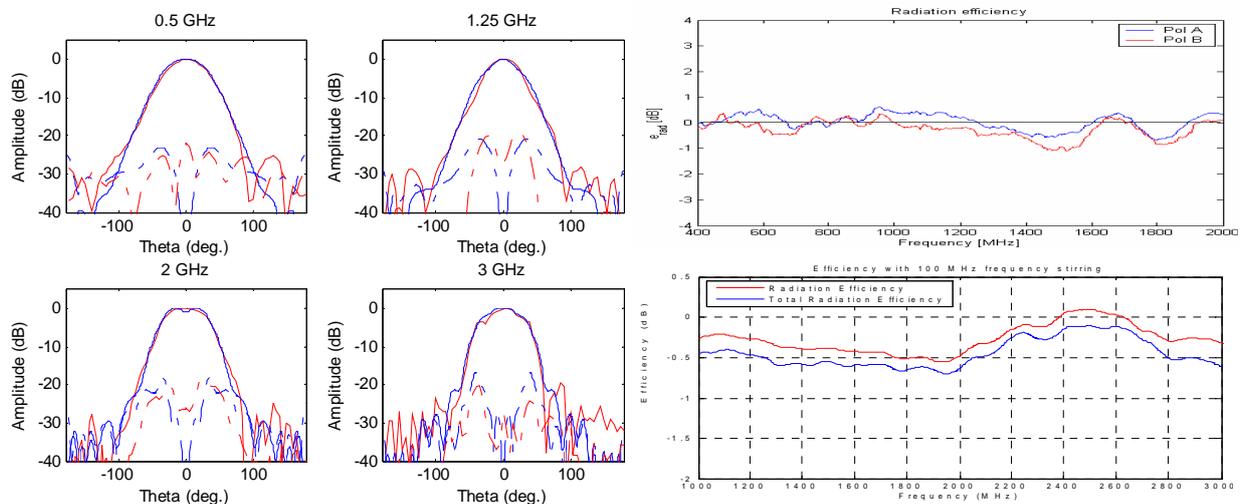


Figure 3. Left: Measured and simulated radiation patterns in 45 degree plane of Eleven feed for RATAN telescope at selected frequencies. Red lines are measured. Blue are simulated. Solid lines are co-polar patterns. Dashed lines are cross-polar patterns. Right: Measured radiation efficiencies for Green Bank (top) and RATAN (bottom) models by using reverberation chamber as explained in [7].

## ELEVEN FEED FOR 1-13 GHZ

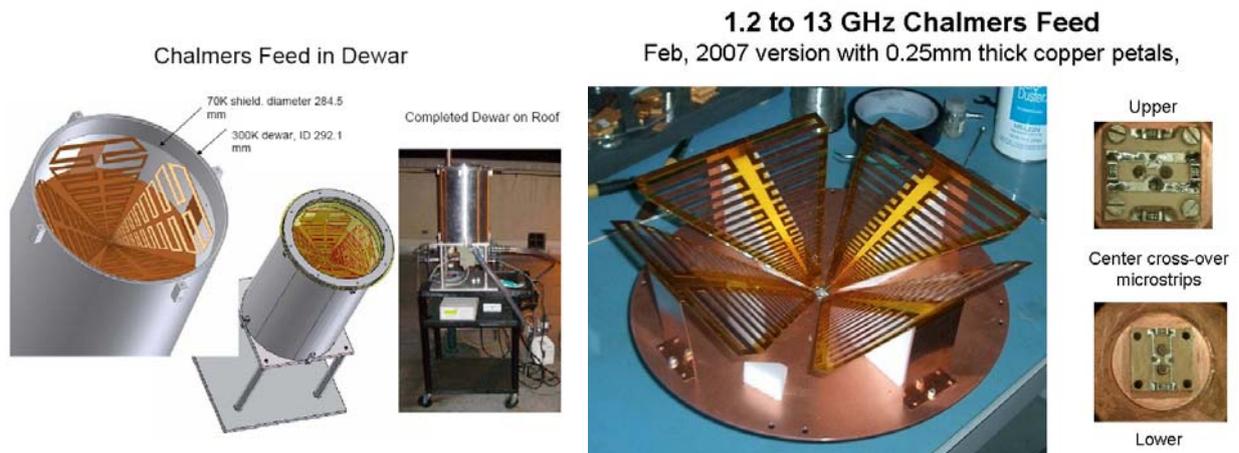


Figure 4. Drawing of Eleven antenna inside Dewar (left), and photo taken at Caltech of presently reported 1-13 GHz model (right) for dual polarization.

Recently a 1-13 GHz Eleven feed model has been developed together with Sander Weinreb at Caltech, see Figure 4. It is intended for use in a cooled metal container (Dewar) to minimize the noise temperature. This version is also of interest for satellite communications as it covers L-, C-, X- and most of Ku-band. The simulated  $S_{11}$  and aperture efficiencies when used in a reflector with 54 deg half subtended angle is shown in Figure 5. Measurements have not yet been performed.

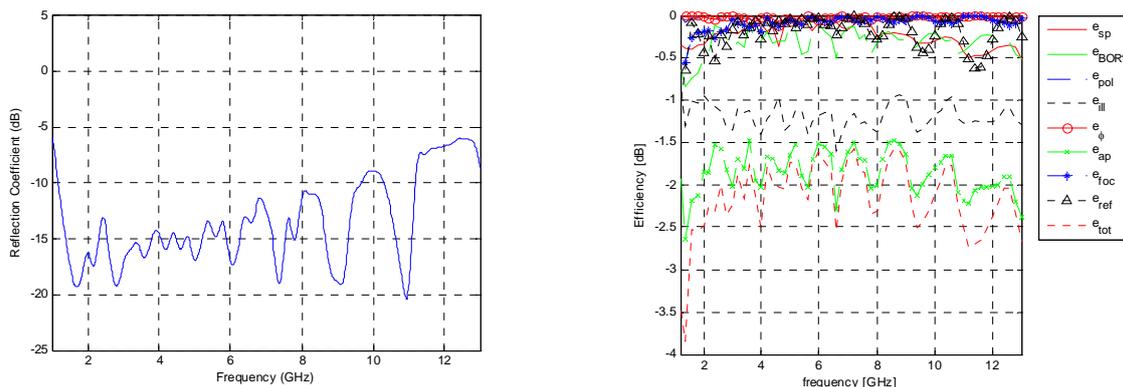


Figure 5 Simulated input reflection coefficient  $S_{11}$  (left) of 1-13 GHz Eleven feed, and aperture efficiencies when the 1-13 GHz Eleven antenna is used to feed a reflector with subtended half angle 54 deg. The subefficiencies are defined in [2].

## MONO-PULSE TRACKING WITH ELEVEN FEED

Mobile terminals for satellite communications must be provided with means for tracking the satellite. The Eleven antenna consists of two parallel dipoles (logarithmically extended), so it is possible to define four unbalanced coaxial ports for it. Thereby, it should be possible to perform monopulse tracking in two orthogonal planes for linear polarization. By using two orthogonal Eleven antennas, we get a total of eight unbalanced coaxial ports, and monopulse tracking in two orthogonal planes for any polarization will be possible. The principles of the feeding of the four ports to obtain the sum and difference patterns are shown in Table 1.

We have built a simple narrow band model of the Eleven antenna for operation at L-band (1.54 GHz) for measuring the tracking performance. The measured input  $S_{11}$  and radiation patterns for the sum excitation as well as the difference pattern excitations are shown in Figure 6. The results show that it is possible to match the Eleven antenna reasonably well for operation simultaneously in both sum and tracking patterns, and that the tracking patterns are as expected.

## CONCLUSION

The Eleven feed may have potential for use in satellite communication systems due to its wideband or multiband capability, as well as having the ability to provide monopulse tracking.

Table 2. Explanation of how the 4-port Eleven antenna needs to be fed to provide sum and difference ports for monopulse tracking. The difference patterns for vertical and horizontal plane tracking are marked with indices ver and hor, respectively.

Coaxial-cable Model	Numerical Model	Port definition	$\Sigma$ pattern excitation	$\Delta_{\text{ver}}$ pattern excitation	$\Delta_{\text{hor}}$ pattern excitation
		$\Sigma$ : A + B + C + D	$V_1 = +1$	$V_1 = +1$	$V_1 = +1$
		$\Delta_{\text{ver}}$ : A + C - (B + D)	$V_2 = -1$	$V_2 = +1$	$V_2 = -1$
		$\Delta_{\text{hor}}$ : A + B - (C + D)	$V_3 = +1$	$V_3 = +1$	$V_3 = -1$
			$V_4 = -1$	$V_4 = +1$	$V_4 = +1$

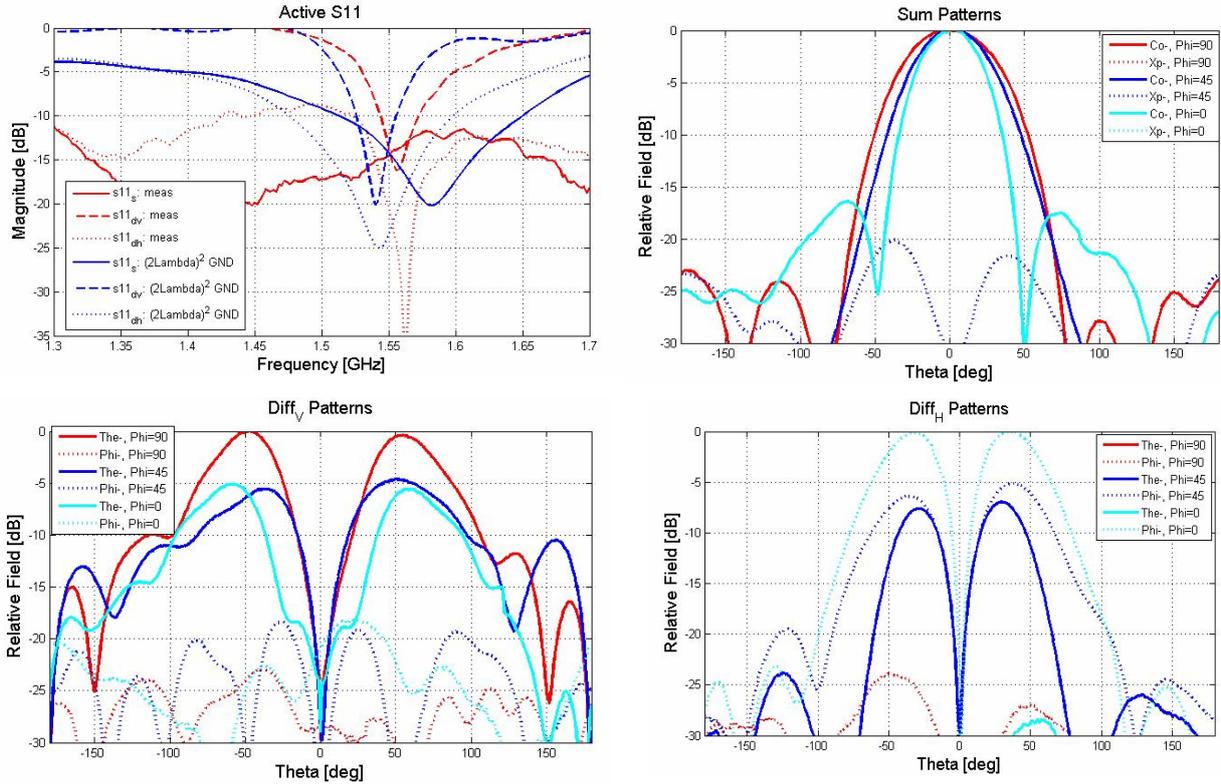


Figure 6. Measured S-parameters and radiation patterns of a test test of the Eleven antenna operating at L-band (1.56 GHz) for sum pattern and difference pattern excitations in the vertical and horizontal planes. The test model has only one folded dipole on each side of the center puck.

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