

Cryogenic Integration of the 2–14 GHz Eleven Feed in a Wideband Receiver for VLBI2010

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Abstract

The next generation VLBI systems require the design of a wideband receiver covering the 2–14 GHz range, necessitating a wideband feed. Presented here are the 2009 development of a cryogenic 2–14 GHz Eleven feed for reflector radio telescope antennas, including its integration into a cryogenic receiver. The Eleven feed is designed for dual linear polarization and consists of four log-periodic folded dipole arrays. Each pair of arrays is fed by a differential two-wire transmission line connected either to balun or a differential LNA. The present configuration has been measured in many configurations, at various independent labs — corresponding simulations have been done. The results show (across the band) a high polarization efficiency for the feed, with a nearly constant beam width, a reflection coefficient below –10dB, and a constant phase center. Electrical parameters under cryogenic conditions and measured receiver noise temperatures are presented.

1. Introduction

New systems, such as the Square Kilometre Array (SKA) and VLBI2010, are planned to continuously cover a very wide frequency range, with very low noise performance and high receiving efficiency [1, 2, 3]. For example the SKA is planned to have anywhere between 1500 and 3000 reflectors, equipped with wideband, low-noise receivers (1–10 GHz, 35 K and an A/T of $5000 \text{ m}^2/K$ [4]).

The goal of VLBI2010 is highest-precision geodetic and astrometric results, defined as precision of 1 mm in the space domain, which corresponds to only 3 picoseconds in the time domain and can be achieved with extending the bandwidth to about 5:1. Furthermore, the technical realization of a VLBI observing system introduces another characterizing quantity: the signal-to-noise-ratio (SNR), which finally decides whether or not an observation is successful out of the correlation process. Therefore, the implementation of receivers with lower system noise temperature and feeds with higher efficiency is desirable—to allow shorter scans per unit time and better geometrical solutions. Current receivers for geodetic VLBI operate in an octave band, using optimized corrugated horn feeds, with cryo-cooled LNAs, covering a few hundred MHz in S and X band. In some cases, separate horns are used to switch between different bands, and a manual replacement of waveguides is required. Newly developed feeds like log-periodic antennas developed for the Alan Telescope Array (ATA) [5], the ETS Lindgren quadridge horn [6], and the Quasi-Self-Complimentary antenna [7], although covering enough broadband, do not meet all the required

specifications (e.g., polarization purity, beam width, and phase center location). In contrast to these, the Eleven feed shows good polarization characteristics and has a constant beam width and phase center and very wide frequency bandwidth [8]. All these characteristics are required for high performance radio astronomical applications. This view was supported by a recent international workshop on geodetic VLBI [9]. Experiments with the Eleven feed for single dish applications are taking place in America, India, China, and South Africa. Interest has been shown from Japan as well as from the international SKA office. The purpose of the present paper is to document the latest developments and present the recent measurement results of a coolable Eleven feed for VLBI2010 and SKA.

2. Feed Design

The Eleven feed is a decade-bandwidth log-periodic dual-dipole feed, developed at Chalmers University of Technology (Chalmers) beginning in 2005, originally proposed by P.-S. Kildal, and presented in [13]. The current realization operates across 2–14 GHz, within cryogenic systems. As seen in Figure 1, the feed is four petals above a ground plane, fed with four twin lead lines at each petal base. Depending on the application, it can be connected to the receiver backend in multiple ways, using either passive baluns and co-axial amplifiers or differential amplifiers. Five 2–14 GHz Eleven feeds based on the present design have been manufactured, and they either have been or will be tested at different places. The design is proven to have good features for the application in radio telescopes, such as nearly constant beamwidth with about 11 dBi directivity and fixed phase center location over the entire decade bandwidth (or more). It has also a low profile and simple geometry. Further details of the electrical design and measured results can be found in [8].

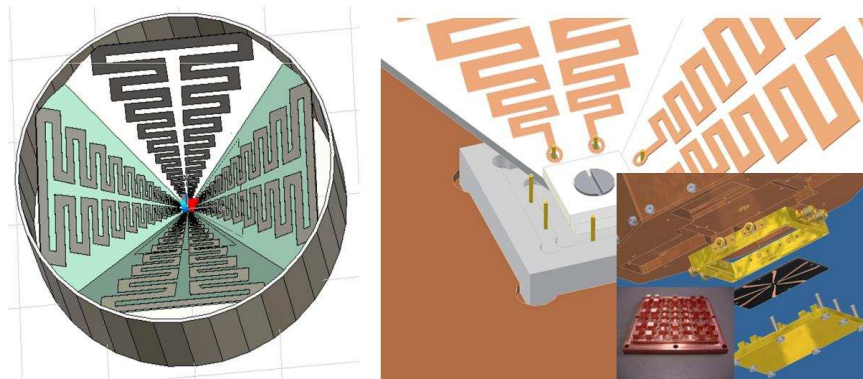


Figure 1. Front and back view of the Eleven feed. The picture on the left shows the front view of the Eleven Feed. The picture on the right shows the assembly of the center puck with the twin lead line. The insert shows a CAD-model of the descrambling board with four coaxial outputs per polarization.

3. Receiver Integration

Extremely low noise system performance requires cooling of both the cryogenic LNAs and the preceding lossy components. Even the feed has ohmic losses, and thus its integration into the cryostat improves system performance. An additional advantage of the feed integration is that we

can simplify the connection of the LNA and feeding network. Therefore, size and cryogenic coolability play important roles in the design of decade-bandwidth feeds for VLBI2010 and SKA radio telescopes. There are several issues that have to be considered in designing a feed for cryogenic integration: the microwave substrate should have well-matched thermal expansion coefficients for the copper and the dielectric; to follow the lob-periodic scaling, the dielectric thickness should change along the petal, and the petals should be well-attached thermally to the 20 K stage to allow effective cooling.

A very important component of the receiver chain is the LNA. The recent advance in GaAs and InP based low-noise cryogenic amplifiers allows the achievement of noise temperatures of less than 5 K for devices operated at 12 K physical temperature. Traditionally the ultra low-noise amplifiers were built using InP. The excellent low-noise characteristics are presented in a number of publications, for example [10] and [11]. Even though they demonstrate exceptional performance, the bandwidth of these amplifiers is usually limited to 2:1 since it is difficult to maintain optimal noise matching and stability over wider bandwidths. Recently the Caltech group led by Sander Weinreb has introduced several alternative designs of wideband LNAs with noise temperatures less than 5 K over 0.3–4 GHz and 1–10 GHz range [12]. Initial tests presented here used available LNAs with commercial GaAs transistors [14] — four such amplifiers were integrated with the feed for the first lab tests. The LNAs have 25 dB gain and noise temperature of 5K for the 4–8 GHz band. The amplifiers were connected directly to the descrambling board at the back side of the ground plane. The outputs were fed to the inputs of two 180 degree hybrids, and their differential outputs were combined in the power divider, all installed at the 70 K stage of the cryostat thus providing single polarization 50 ohm output.

The cryogenic integration takes advantage of the CTI 1020 cryogenic compressor and relatively large vacuum chamber available from an old receiver. The Eleven feed is installed on the 20K stage of the receiver. To decrease the infrared radiation, we have used Multi Insulation Layer (MIL) structure made of layers of Teflon separated by wedding veil [15]. Such MILs are installed in front of the antenna at 20 K and 70 K staged. The window on the cryostat is made from 0.35 mm thick Mylar and has diameter of 280 mm [15].

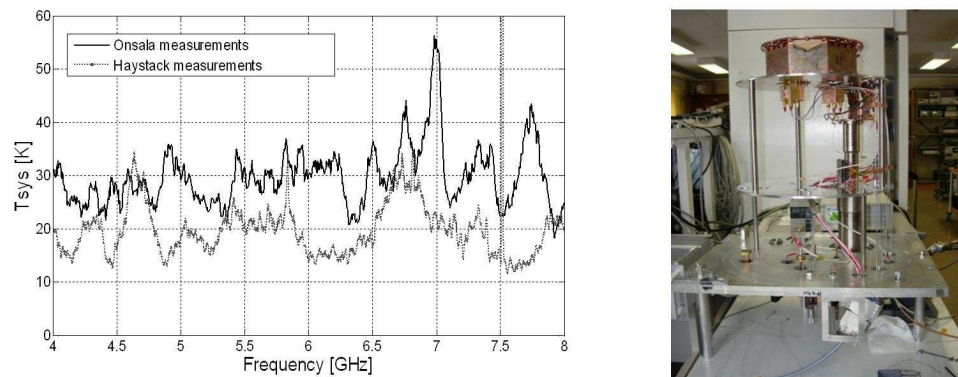


Figure 2. The measured reflection coefficient at room and cryogenic temperatures (left). The cryostat used for the measurements (right).

4. Measurement Results

The reflection coefficient of the Eleven feed was verified with numerous measurements. The results for room and cryogenic temperatures, along with simulations, are shown in Figure 3. The measurements were done using a 4-port Vector Network Analyser (VNA). The feeding network, hybrids, and power combiner were connected outside the cryostat. The small differences between the S11 at cryogenic and ambient temperatures confirms that neither the petals nor the twin lead line deform much, but rather the differences are due to changes in dielectrical permittivity.

The system noise temperature performance was measured using the common Y-factor approach. A microwave absorber was used for the hot load, and sky for the cold. The temperature of the hot load was measured using a temperature sensor, and the sky radiometric temperature was estimated using data available from the aeronomy station at Onsala Space Observatory (OSO).

The measured result is shown in Figure 3. The system noise temperature performance averaged across the band is 28 K. Plotted alongside are the corresponding results (for the 4-8 GHz band) from tests performed at the Haystack Observatory with the Eleven feed integrated into a cryostat with 2-12 GHz LNA from Caltech [16].

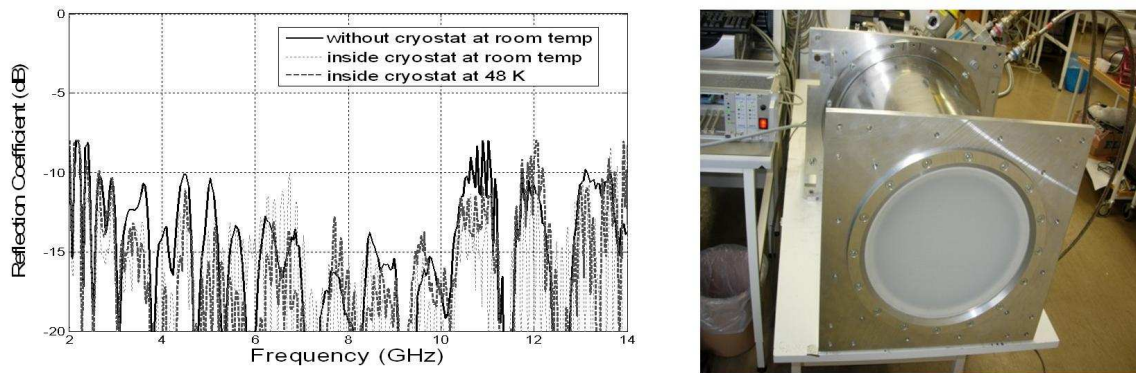


Figure 3. Preliminary results: measured system noise temperature of Eleven feed in cryostat at 28 K physical temperature (left picture) and Eleven feed prototype mounted in the test cryostat with 4-8 GHz cryogenic LNAs.

5. Conclusions and Future Work

This paper reports the first measurement results obtained with an Eleven feed integrated with LNAs and at cryogenic temperature. Even though the experiments at OSO were made with existing LNAs not optimal to achieve end-to-end optimal performance, we can claim that we have achieved good results in terms of low system noise temperature.

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