Low Noise Phased-Array Feed With CMOS LNAs

Leonid Belostotski, Aaron J. Beaulieu, Tom Burgess, Bruce Veidt, and James W. Haslett

***Abstract*—Phased-array feeds are being developed for expansion of the field-of-view of parabolic reflector antennas. The University of Calgary (UCalgary) and the National Research Council (NRC) of Canada have recently demonstrated a low-noise phased-array feed for possible use in the Square Kilometre Array radio telescope. NRC has made noise measurements of such an array equipped with CMOS low-noise amplifiers (LNAs) designed by the University of Calgary. In the design range from 0.7 GHz to 1.5 GHz, array beam-referred noise measurements, using an ambient load as a hot load and the sky as a cold load, show array beam-referred noise temperatures as low as 20 K. This paper describes the phased-array feed.**

***Index Terms*—phased array, radio telescope, low noise amplifiers, Square Kilometre Array**

I. Introduction

PHASED-ARRAY feeds (PAFs) are being developed and deployed on reflector antennas to increase the field-of-view of radio telescopes. A PAF with low-noise receivers and a cluster of simultaneous beams produced by a digital beamformer will improve the survey speed of a telescope mapping large regions of the sky. The Advanced Focal Array Demonstrator (AFAD) is an experimental phased-array feed, which is designed by NRC and UCalgary and is intended to explore recent design techniques for such systems. Initial AFAD efforts focused on improving dissipative losses of antenna elements by removing as much dielectric as possible, thickening the antenna elements, and placing the low-noise amplifier (LNA) very close to the antenna feed point. This article reports the modifications made to the original version of AFAD [1] by using custom CMOS LNA ICs instead of Avago MGA16516 ICs [2]. The new CMOS LNAs were designed such that their reflection coefficient for minimum noise, Γ_{opt}, and their input reflection coefficient, S_{11}, were selected as close as possible to their optimum values that reduce the array beam-referred noise [3].

II. Element Design

AFAD is composed of 41 metallic Vivaldi elements arranged in a dual-polarization array as shown in Fig. 1(a). The design parameters are summarized in Fig. 1(b). The elements are 5 mm thick, sufficient to embed the LNA in the element very close to the feed point, as shown in Fig. 1(c). An analog beamformer combines 9 central co-polar elements to produce a single beam. All other elements have powered LNAs. These LNAs are terminated and form active cold loads [4], [5].

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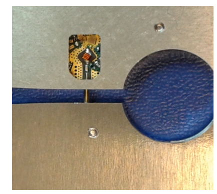
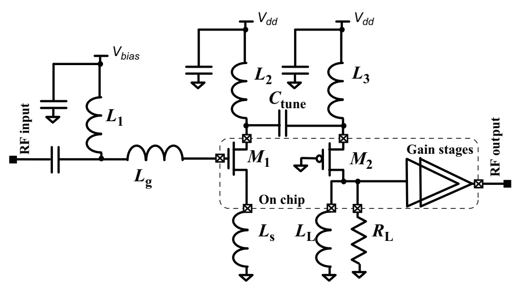
(a)

Frequency range	0.7–1.5 GHz
Element spacing	100 mm
Element thickness	5 mm
Taper length	113 mm
Slot width	3 mm
Overall length	158 mm
Number of elements	41

(b)



(c)

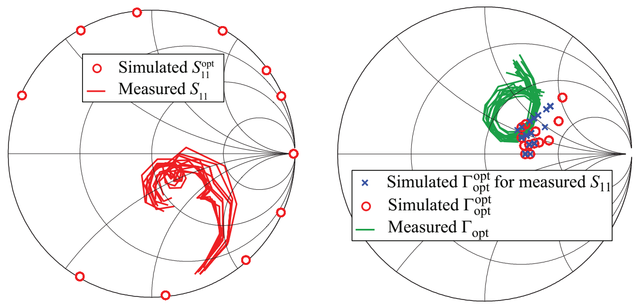


(d)

Fig. 1. (a) AFAD array. LNA components are on the underside of the green printed-circuit board. For ease of fabrication each element was milled in two pieces, which were then aligned with a dowel pin and secured with fasteners. (b) AFAD design parameters. (c) Coupling from the slotline to the LNA is accomplished by a pin that extends across the slot and is terminated in a grounded socket. (d) Representative circuit diagram of the folded-cascode LNA followed by the gain stages.

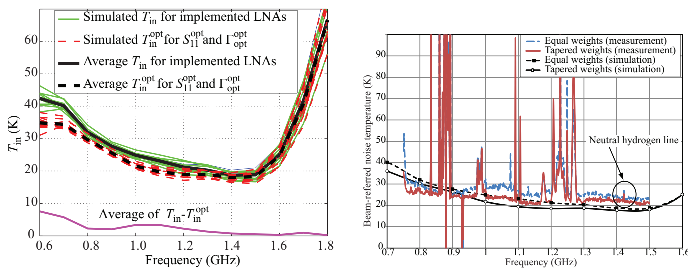
III. CMOS Receiver Design

The CMOS LNA, as the front-stage of the receiver, was implemented as a folded-cascode version of amplifiers that were developed over the last few years by the UCalgary team and were reported in [6]–[8]. The LNA was followed by gain stages, such as in [9]. During tests the receiver was configured to achieve power gain of 55 dB from from 0.7 to 1.5 GHz. A representative circuit diagram of the LNA is shown in Fig. 1(d). This LNA is selected due to the possibility of nearly independent tuning of the LNA S_{11} and Γ_{opt}. The tuning is primarily accomplished by selecting an appropriate size of the gate inductor L_g and the capacitor C_{tune} as explained in [10]. Both S_{11} and Γ_{opt} affect antenna array beam-referred noise temperature, T_{in}, as has been recently demonstrated in [3]. Having the ability to tune S_{11} and Γ_{opt} allowed their adjustment to match the antenna array, which was previously



(a) (b)

Fig. 2. Locations of measured Γ_{opt} and S_{11} and locations of simulated Γ_{opt}^{opt} and S_{11}^{opt} for 11 LNAs, 9 of which were installed on AFAD. Equal beamformer weights for the center 9 antenna elements were used.



(a) (b)

Fig. 3. (a) Mismatch penalty.(b) Noise temperature of the AFAD array with tapered- and equal-beamformer weights. Vertical displacements at 0.85–0.9, 0.93, 0.97–1.0, 11.9, and 1.15–1.3 GHz are radio-frequency interference. The spectral line for neutral hydrogen is visible at 1.42 GHz. Simulation results are also shown for comparison.

designed for another amplifier. As shown in [3], there are frequency dependent optimum S_{11}, S_{11}^{opt}, and an optimum Γ_{opt}, Γ_{opt}^{opt}, that reduce beam-referred noise temperature, T_{in}. However, S_{11}^{opt} is not practical as it is located on the edge of the Smith chart and exhibits significant frequency variation, as shown in Fig. 2(a). It was not possible to achieve such S_{11} with the LNA. Instead, S_{11} and Γ_{opt} were selected as a compromise between the best possible T_{in} and the practically realizable circuit.

The final locations of the measured Γ_{opt}, S_{11}, and the locations of the optimum Γ_{opt}^{opt} and optimum S_{11}^{opt} that optimize the noise of the array are shown for 11 LNAs built for AFAD in Figs. 2(a) and (b). As shown, it was possible to place Γ_{opt} in the vicinity of Γ_{opt}^{opt}. However, the penalty of a mismatch between S_{11} and S_{11}^{opt} was found to be relatively small as illustrated in Fig. 3(a).

IV. Array Noise Measurement

AFAD was tested in a Hot/Cold Test Facility (HCTF) consisting of a ground shield and a roll-off roof with downward-facing microwave absorber for hot-load measurements whereas the cold-load measurements were made with the roof moved to expose the array to cold sky. Measurements were made on 17 December 2014 at an ambient temperature of 0°C. The assumed cold sky temperature included the Cosmic Microwave Background, (2.7 K), atmospheric loss (2 K), and an estimate of galactic noise made using the Global Sky Model [11]. The array noise temperature was extracted using the standard Y-factor equation. Fig. 3(b) shows measured estimates of the array beam-referred noise temperature from 0.75 to 1.5 GHz along with the simulated noise temperature. Two different types of beamformer weights were applied during these measurements: uniform weighting of the central 9 antennas and a tapered weighting (0 dB weight for the center element, -3 dB weight for its horizontal and vertical neighbors, and -6 dB taper for the corner elements). Vertical spikes in both measured curves are due to radio-frequency interference. The Galactic Plane was overhead during measurements, and the neutral hydrogen line is clearly seen at 1.42 GHz. The measurement results demonstrate beam-referred noise temperatures averaging around 25 K and dipping to as low as 20 K. This closely matches the expected noise temperature predicted by the simulations, which were based on EM simulations of the array and measured LNA noise parameters.

V. Conclusions

NRC and UCalgary have developed a low-noise phased-array demonstrator using 65-nm CMOS LNAs. The phased array shows array beam-referred noise temperatures as low as 20 K and agrees well with the simulations.

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