Vivaldi Antenna Arrays for SKA

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Abstract

In this paper we present several broad band arrays of tapered slot antennas for use in a new generation phased array telescope. In specific, a four element linearly polarized 3-12 GHz array, a 3 element 0.8-2.5 GHz coupled array and a four element dual polarized 0.8-2.5 GHz array are discussed. Integration with LNAs and coupling between elements is examined.

I. INTRODUCTION

For the new generation of radio telescopes, one proposed architecture is a phased array known as the Square Kilometer Array (SKA)[1]. This antenna will be built using broadband subarrays with one decade of bandwidth. In addition, the subarrays must have a broad beam to allow a large scan angle. The cost of an element is also an important consideration for SKA since the total number of subarrays is on the order of a million. Our design for a subarray calls for a multi-element active antenna array, with different elements operating in different frequency ranges and arrayed in a fractal layout. The elements presented in this paper are exponentially tapered slot antennas, or Vivaldi antennas [2]. For radio astronomy, two orthogonal polarizations need to be received simultaneously. Therefore we also present results on a dual polarized array. Low noise is an other parameter critical to radio astronomy applications, and in this paper we present an LNA integrated with a Vivaldi antenna.

II. LINEAR POLARIZED PASSIVE VIVALDI ELEMENTS IN SUBARRAYS

In theory, the bandwidth of a Vivaldi antenna is infinite. In practice, the feed in general determines the high frequency limit, and the aperture size the low frequency limit. We examined several different substrates and frequency ranges: (A) a four element linear 3-12 GHz subarray on a Comclad substrate;(B) a 3 element 0.8-2.5 GHz linear polarized subarray on a Poly-Carbonate substrate;(C) a dual polarized Poly-Carbonate 0.8-2.5 GHz subarray.

One of the main bandwidth limitations of a Vivaldi antenna is the microstrip-to-slotline transition. There are several papers that propose to solve this problem using either a broadband balun, or an alternate type of feed [3] [4]. One solution is to use a transition from a microstrip line to a printed twin line, or two-sided slotline transition, as proposed in [5]. The printed-twinline fed antenna has the added benefit of not requiring a high dielectric constant sub-

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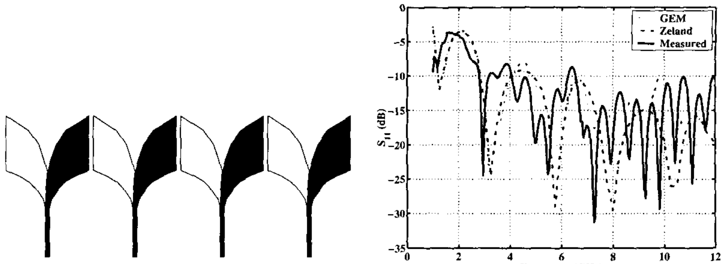
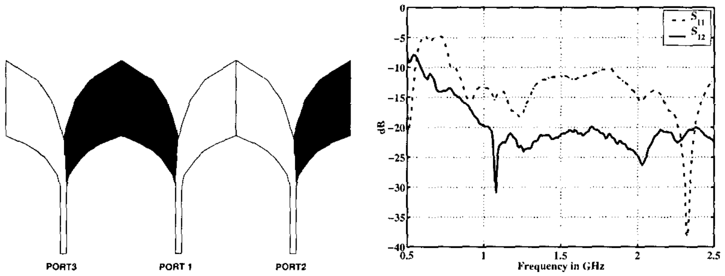


(a) (b)

Fig. 1. (a) Sketch of linear subarray A. (b) Modeled and measured insertion loss of array A.



(a) (b)

Fig. 2. (a) Sketch of array B. (b) Insertion loss of array B.

strate as is needed in the case of a slotline-fed Vivaldi. In array A, Fig.1a, the right and left radiating elements are on opposite sides of the substrate. The element is fed using a microstrip to printed-twinline exponentially tapered balun. The substrate is a 1.57 mm thick Comclad with $\varepsilon_r = 3.6$. Each element is 6.5 cm wide, and the element spacing is 7.0 cm. A four element array was simulated, built, and tested. Two full wave method of moment (MoM) simulators were used: Zeland's IE3D (subdomain basis MoM); GEM (large domain basis function MoM, in-house developed tool) [6]. The simulated and measured insertion loss is shown in Fig.1. The standing wave at the higher frequency is possibly due to the type of calibration of the Network analyzer which did not calibrate the coax to twin line transition. The 2:1 VSWR bandwidth of the antenna is from 3 to 12 GHz. The element size at the lowest frequency of operation is $0.65\,\lambda_o$ which would lead to grating lobes at larger scan angles. An array of small elements, however could lead to high coupling between elements, and a higher cost for combining (feed) networks.

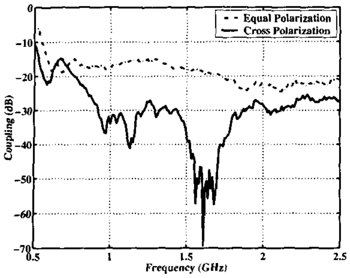


Fig. 3. Measured coupling of dual-pol Vivaldi antenna array C.

One of the goals of our research is to design a broadband element where the size of the antenna is $0.5\,\lambda_o$ at the lowest frequency of operation. One solution is to increase the coupling between the elements at the lower frequencies in order to improve the bandwidth. This can be accomplished by minimizing the space between the array elements, or by physically connecting them. In array B, the antennas are physically connected by connecting the right "ear" of one Vivaldi to the left "ear" of its neighbor. The connection can be either a short, capacitor or inductor, since only noiseless reactive elements are of interest. It was found that the simplest method, a short worked best, as shown in Fig.2. The measured insertion loss and coupling between two of the elements of the antenna is shown in Fig.2b. The lowest operating frequency of the antenna is 0.8 GHz. The size of the antenna is $0.4\,\lambda_o$ at the lowest frequency.

III. DUAL POLARIZATION

In a dual polarized version of this antenna, each array element is attached to the other elements as shown in Fig.3a. One connected element has the same polarization, and the other two are of an orthoginal polorization. The measured coupling between two elements is shown in Fig.3b. The insertion loss of the dual polarized antenna is the same as that of the linearly polarized array. It can be seen from Fig.??b that the coupling between two nearest co-polarized elements is below 15dB, while the coupling between the two nearest cross polarized elements is below 25dB over the entire range of operation.

IV. ACTIVE TAPERED SLOT ANTENNA ARRAYS

In order to reduce or even eliminate the noise associated with loss in the feed line, a Low Noise Amplifier (LNA) can be integrated as close to the feed point as possible. Integration of an amplifier with an antenna also usually has effects on the gain and bandwidth. Here we present results obtained by integrating an HP MGA-82563 LNA into one element of array A. The LNA has a specified noise figure of 2.4 and a gain of 10.7 dB at 4 GHz. This LNA

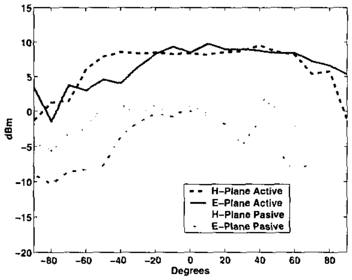


Fig. 4. Measured active and passive element radiation patters of array A. at 4.0 GHz.

has a single bias which makes it straightforward to integrate with the antenna. The measured radiation patterns for one element of array A with and without LNA are shown in Fig.4. At boresight, the LNA is contributing 8.0 dB of gain and it can also be seen that the beam broadens with the LNA. Both of these effects are an advantage for the SKA element.

V. CONCLUSION

In summary we present several small arrays of Vivaldi antennas that appear to be suitable elements for a broadband phased array telescope: a demonstrated fractional bandwidth or 4:1; low coupling in co-polarized and cross-polarized elements; broad beam width of over 100° as compared to other broadband antennas (e.g. log-periodics); and convenient integration with LNAs. The low coupling between elements that was acheived will be critical for the overall noise performance of the array. Another important goal of our research is to produce antennas at a low cost. The material cost of the Poly-Carbonate antenna is less than $3.00 for a three element 800 MHz array, excluding connectors. Since the antenna does not use a stripline structure, the fabrication costs are also reduced.

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