Wideband Array for C, X, and Ku-Band Applications with 5.3:1 Bandwidth

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***Abstract*—Planar arrays that exploit strong intentional coupling between elements have allowed for very wide bandwidths in low-profile configurations. However, such designs also require complex impedance matching networks that must also be very compact. For many space applications, typically occurring at C-, X-, Ku-, and most recently at Ka-band, such designs require specialized and expensive fabrication techniques. To address this issue, a novel ultra-wideband array is presented, using a simplified feed network to reduce fabrication cost. The array operates from 3.5–18.5 GHz with VSWR<2.4 at broadside, and is of very low profile, having a total height of λ/10 at the lowest frequency of operation. Validation is provided using a 64-element prototype array, fabricated using common Printed Circuit Board (PCB) technology. The low size, weight, and cost of this array make it attractive for space-borne applications.**

I. Introduction & Background

Ultra wideband (UWB) and beam forming arrays for multifunctional apertures [1] have received strong interest in recent years. As is well known, satellite communication has largely been accomplished using reflector antennas [2]–[3]. However, such antennas are inherently bulky, and rely on mechanical steering. Lower weight, size, and cost arrays can support several existing and upcoming satellite applications spread throughout the C–Ku bands, including: Fixed Satellite Service (3.7–4.2 GHz, 11.5–11.7 GHz), Tracking Data and Relay services (13.7/14.9 GHz), the Deep Space Network (7.2/8.45 GHz), and various radar bands (7–11.2 GHz) [4].

This paper is focused on developing thin and low-cost phased arrays for space-based applications. Indeed, phased arrays offer an attractive alternative, enabling fixed and conformal implementation, while forming highly agile beams. Already, arrays of tapered slots and ferrite backed arrays have demonstrated excellent bandwidth and scanning capability, but remain bulky and heavy. Targeting this deficiency, numerous low-profile, UWB phased arrays have been proposed. Amongst these is a class of arrays stemming from Munk's Current Sheet Array [5], achieving up to 7.3:1 bandwidth [6]–[7]. These arrays integrate an electrically small, balanced-to-unbalanced transformer within the volume of the array. This circuit is critical to providing a differential and impedance matched feed to the array elements. But because it must work across a 10:1 range of impedances, its adaptation to C-band and above (i.e. >4 GHz) introduces fabrication challenges, due to the required geometrical tolerances (<20 μm).

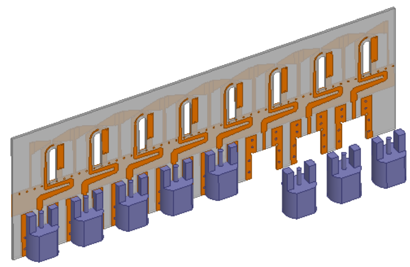

Fig. 1: Linear array of the proposed UWB feed structure. The tightly coupled elements are seen as the "shade" on the reverse of the substrate. The front shows one side of the feed balun and the SMP coaxial connectors (array ground-plane not shown).

II. Design & Simulation

We present several modifications to the feed and array designs of [6], embodied in the design of an UWB array operating from the S-band up to the Ku-band, with significantly reduced fabrication constraints. This array is depicted in Fig. 1.

The requisite 20–200Ω range of impedances within the balun is accomplished through the design of a hybrid stripline and microstrip structure. As depicted in Fig. 1, microstrip transmission lines are used as they enable wider traces for a given characteristic impedance, by reducing capacitance with respect to the return trace. In this way, the high-Z_0 input to the balun (as microstrip) can be made wider while the low-Z_0 stub (as stripline) can be made narrower. Crowding within the unit cell is further reduced by eliminating the rectangular, quarter-wavelength (λ/4) spacing introduced in [5]. However, this exacerbates the impedance matching challenge in the feed network. Therefore, matching is addressed with a continuous linear taper applied to the input trace with an additional length, approximately one wavelength at the high frequency, meandered beneath the ground-plane. Further, as λ/2 spacing in coupled arrays can introduce undesired modes when scanning, metallized posts are added between elements to push theses resonance out of the band.

The developed array model was verified through full-wave simulations carried out in Ansoft HFSS and measurements. The active VSWR at broadside and at ±45°, in both cardinal planes, is given in Fig. 2. We observe that the array maintains an impedance matching from 3.5–18.5 GHz (a 5.3:1 range) with

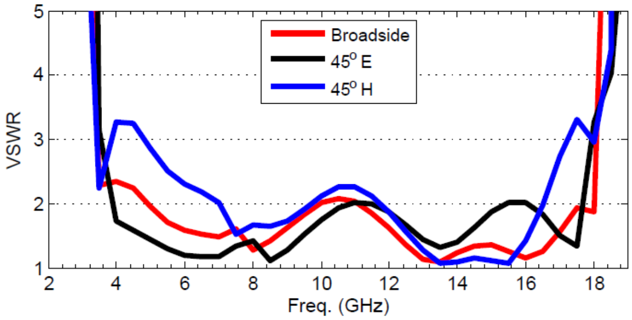

Fig. 2: Active array VSWR, showing operation from 3.5–18.5 GHz.

VSWR<2.4 at broadside. Scanning to ±45° in the E- and H-planes is achieved with VSWR<3.2.

III. Fabrication

The design utilizes four metalization layers on a Rogers Durroid 5880 substrate (ϵ_r=2.2, 5 mil thick) with a Polyflon bond layer (ϵ_r=2.2, 4 mil thickness). Including copper layers, the substrate has a total thickness of 0.4 mm. Each board is 12 mm (λ_{low}/10) tall above the coax port and 65 mm long. The smallest required tolerance in this design is 0.178 mm. When scaled to equivelant frequencies, this is a factor of 8 increase inminimum tolerance as compared to [6]. Accordingly, and unlike previous work, the described array can be fabricated using common Printed Circuit Board (PCB) technology.

An 8×8 array prototype was fabricated, comprised of eight PCBs. Each PCB contains a linear array of eight elements, as shown in Fig. 3. The PCBs are inserted through the ground-plane and a polyethalene superstrate was attached. 3D printed spacers (97% air by volume, $\epsilon_r \simeq 1$) are inserted between each row of elements, to support the superstrate and increase rigidity. The array elements are fed using coaxial, subminiature push-on (SMP) connectors.

The array's operation was verified through measurements conducted in the NASA Glenn Research Center far-field range. The measured broadside co- and cross-polarized gains are shown in Fig. 4. We observe that the measured gain tracks the theoretical directivity, and that the cross polarization is <-20dB across most of the band.

IV. Conclusions

Low-profile, UWB arrays are attractive for enabling multifunctional apertures. This is particularly true of space borne applications, where size and weight reduction without sacrificing performance, are paramount. However, low-profile UWB arrays require complex feeding networks, which cannot be easily fabricated when scaled to the frequencies of interest for the NASA Space Network.

In this paper, we presented a simplified 3.5-18.5 GHz array design with a factor of 8 increase in the minimum required fabrication tolerance. This allows for array fabrication using low-cost PCB technology. The design was verified through fabrication and measurement of an 8×8 prototype array. The

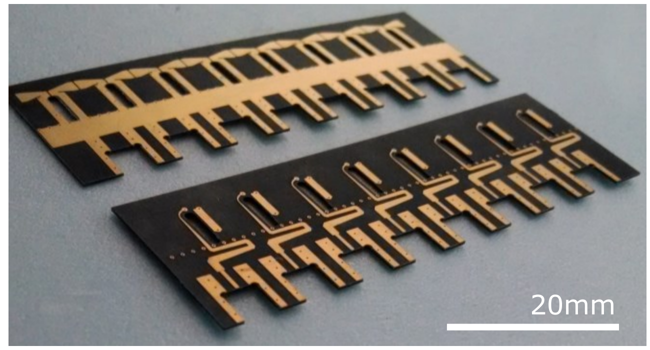

Fig. 3: Photograph of front (top right) and back (bottom left) of fabricated antenna boards prior to soldering of coaxial connectors.

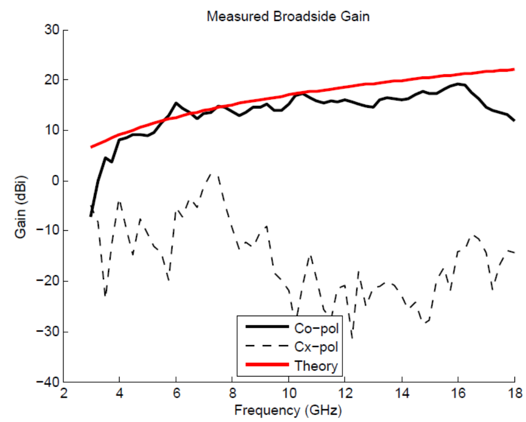

Fig. 4: Measured broadside co- and cross-polarized array gain. The 8x8 array is 65mm long per side.

small size and weight of the array, paired with UWB operation across the C, X, and Ku bands, makes this array highly suitable for numerous satellite applications.

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