A Microstrip Patch-Fed Short Backfire Antenna for the Tracking and Data Relay Satellite System – Continuation (TDRSS-C) Multiple Access (MA) Array

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Introduction

Short Backfire Antennas (SBAs) are widely utilized for mobile satellite communications, tracking, telemetry, and wireless local area network (WLAN) applications due to their compact structure and excellent radiation characteristics [1-3]. Typically, these SBA's consist of an excitation element (*i.e.*, a half-wavelength dipole), a reflective bottom plane, a planar sub-reflector located above the "exciter", and an outer circular rim. This configuration is capable of achieving gains on the order of 13-15 dBi, but with relatively narrow bandwidths (~3%-5%), making it incompatible with the requirements of the next generation enhanced Tracking and Data Relay Satellite System-Continuation (TDRSS-C) Multiple Access (MA) array [1]. Several attempts have been made to enhance the bandwidth performance of the common dipole-fed SBA by employing various other feeding mechanisms (*e.g.*, waveguide, slot) with moderate success [4-5]. In this paper, a novel method of using a microstrip patch is employed for the first time to excite an SBA. The patch element is fed via two H-shaped slots electromagnetically coupled to a broadband hybrid coupler to maintain a wide bandwidth, as well as provide for dual circular polarization capabilities.

Antenna Requirements for TDRSS-C MA Array

TDRSS is a communication signal relay system developed by NASA that relays data to ground stations and tracks satellites in orbit, providing communication capabilities with assets such as the Space Transportation System (STS; commonly referred as the Space Shuttle) and International Space Station (ISS). The next generation TDRSS-C antenna concept will employ a Single Access (SA) S-band reflector antenna of reduced size (from 5 m to 3 m). To compensate for the reduction in gain resulting from the smaller aperture, beamforming between the SA reflector and an enhanced MA array will be performed. This imposes stricter requirements of the MA antenna elements composing the entire array. These requirements are summarized in Table I.

Table I – Multiple Access Antenna Element Requirements.

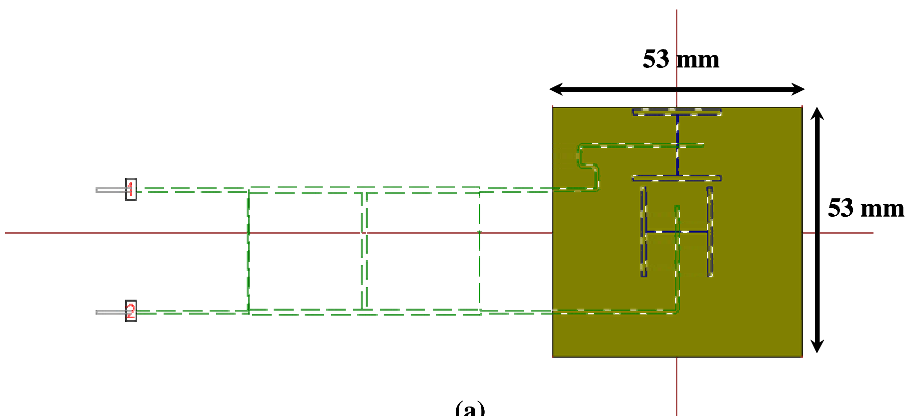
Antenna Element Characteristic	Requirement
Operating Frequency (Tx/Rx)	2.2875 GHz/2.1064 GHz
Bandwidth	> 100 MHz
Directivity (at boresight)	≥ 15.0 dBi
Polarization	LHCP[1] and RHCP[2] selectable
Axial Ratio	≤ 5.0 dB over ±20°
Isolation	≥ 15 dB
Return Loss	≤ 20 dB
Mounting Footprint (diameter)	< 13.5 in

[1]Left Hand Circular Polarization/[2]Right Hand Circular Polarization

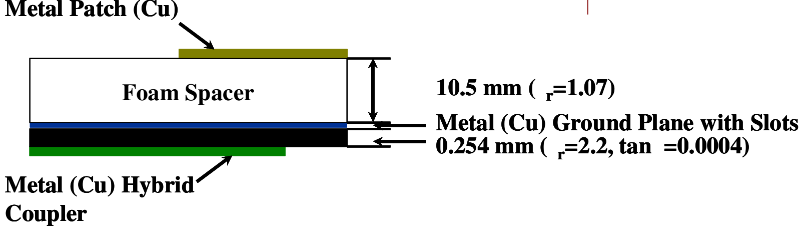
Excitation Structure Simulation and Measurement

The microstrip patch was chosen as a potential excitation structure for a short backfire antenna due to its simplicity, cost-effective fabrication, and low mass. Other prototypes developed by our group at the Glenn Research Center include the corrugated horn, helix, and a waveguide-excited SBA. The microstrip patch-excited SBA is superior over these other designs in its reduced size and mass while maintaining comparable performance. The excitation structure, itself, was designed and simulated on Zeland's IE3D electromagnetic simulator [6]. Figure 1 describes the layout of the microstrip patch. A square patch of 53 mm sits atop a foam spacer of height 10.5 mm (relative permittivity, ε_r, of 1.07). H-shaped slots are etched into a ground plane to improve bandwidth performance of the structure [7]. Likewise, a broadband hybrid coupler is implemented to create the necessary 90° phase shift between feeds and enable selectable left hand and right hand circular polarizations. The coupler and H-shaped slots were fabricated on the two sides of a sheet of 0.254 mm Duroid 5880® (ε_r = 2.2, ½ oz. copper).

The return loss and isolation (S_{11} and S_{21}, respectively) of the microstrip patch excitation structure were simulated in IE3D and measured on an Agilent 8510C Vector Network Analyzer (VNA). Return loss was measured as the reflected power from port 1, while isolation was measured as the amount of power coupled between ports 1 and 2 (as indicated in Figure 1a). A comparison between simulated and measured return losses and isolation is shown in Figure 2 and indicates good agreement over the operating bandwidth of 2.2 – 2.3 GHz. Discrepancies between measured and simulated data are most likely a result of misalignment of the patch and microstrip feed layers. From the measured return loss and isolation, it is observed that the feed network is efficiently transferring power to the radiating patch element over the 15-dB 100 MHz transmission bandwidth of the enhanced MA array element. In fact, a 15-dB bandwidth of 250 MHz (11%) was achieved.

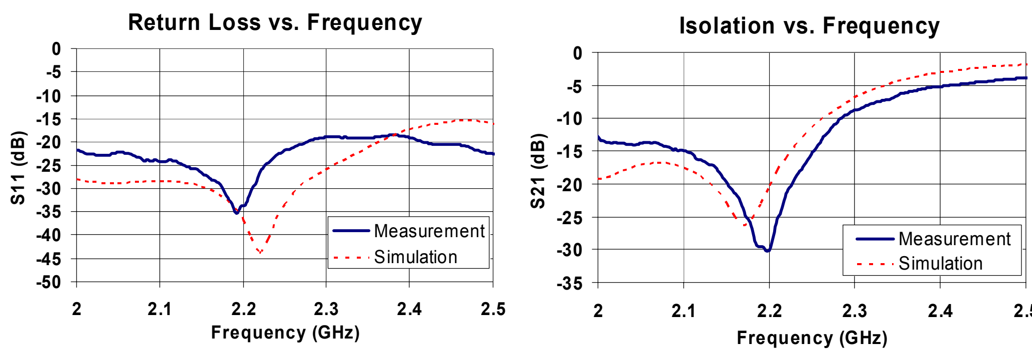


(a)



(b)

Figure 1 – (a) top view and (b) side view of aperture coupled microstrip patch excitation structure for the SBA.



(a) (b)

Figure 2 – (a) Return loss and (b) isolation of microstrip patch excitation structure.

Microstrip Patch-Fed SBA Simulation

The entire microstrip patch-fed SBA structure was simulated with Microwave Studio (MWS) [8] in the arrangement shown in Figure 3. The sub-reflector is 0.325λ in diameter and spaced approximately 0.45λ above the patch. The outer diameter of the rim is 2.05λ with a height of 1.4λ, where λ represents the free space wavelength at the transmitting center frequency of 2.2875 GHz. The input to the antenna consists of two coaxial ports, which allow for RHCP (Port 1) or LHCP (Port 2) operation depending on which port is excited.

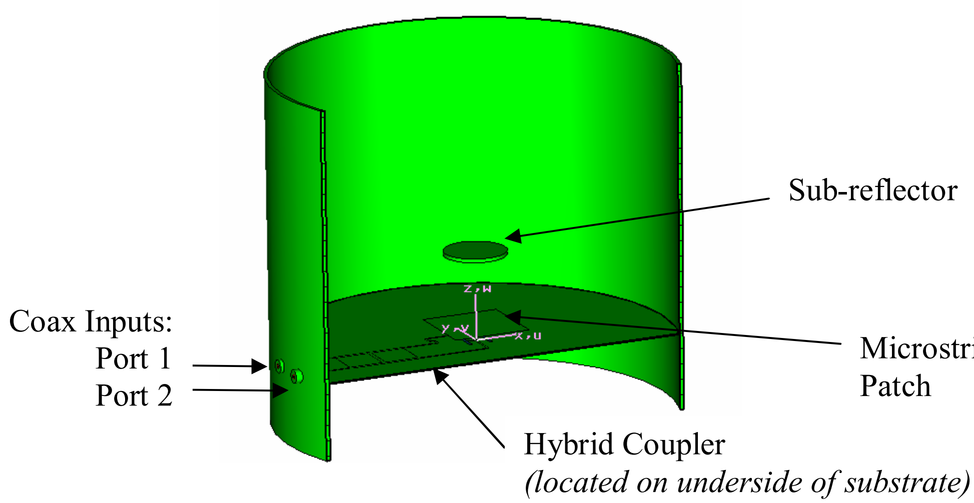


Figure 3 – Layout of Short Backfire Antenna excited by a microstrip patch, as developed in Microwave Studio. Pattern radiates in z-direction, as indicated by axes.

The simulated co-pol and cross-pol patterns of the short backfire antenna are shown in Figure 4. Both patterns were simulated with port 1 excited, inducing an RHCP co-pol element. As is evident, the microstrip-fed SBA just meets the 15.0 dBi boresight directivity requirement over the operating bandwidth. However, the cross-polarization component remains high at 2.30 GHz. Further optimization of the SBA geometry and the hybrid coupler will be necessary to reduce this effect.

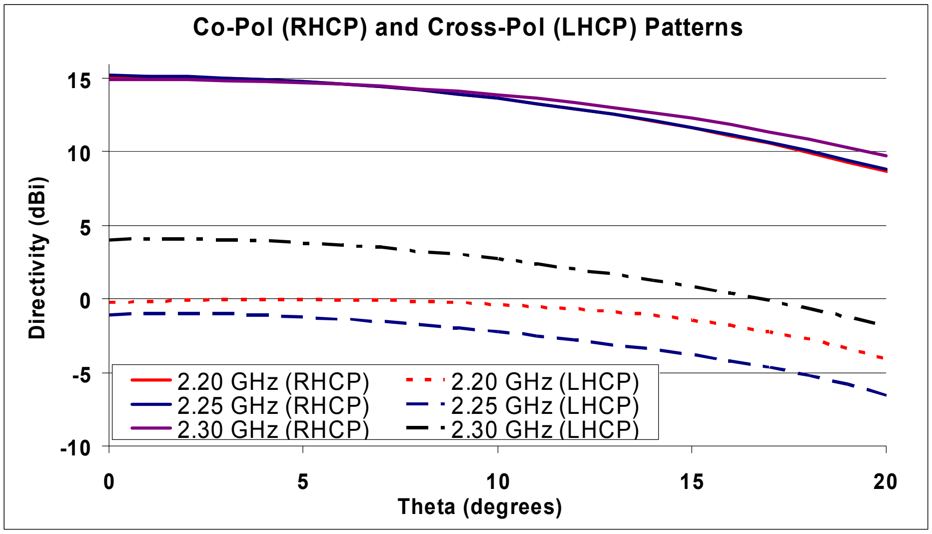


Figure 4 – Simulated cuts of the RHCP co-pol and LHCP cross-pol directivity at various frequencies over the 2.2–2.3 GHz band for when SBA is fed through Port 1.

Conclusions

A novel microstrip patch-fed short backfire antenna has been presented here for the first time as a candidate antenna element for the next generation TDRSS-C MA array. This design meets nearly all the specifications required for the enhanced MA array antenna element and promises to provide a lightweight low cost alternative over other designs presently being considered (*i.e.*, corrugated horn, helix, waveguide-fed SBA). Simulations performed using IE3D and MWS agree with measured data, thus far, and indicate an 11% 15-dB bandwidth and a maximum directivity of 15.2 dBi. Future work will involve further optimization of the radiation characteristics and the construction of the complete short backfire antenna structure to verify simulated results.

References:

[1] Y. Yamada, T. Takan, and N. Ishida, “Compact antenna equipment for maritime satellite communication systems,” Trans. IEICE, vol. 62-B, pp. 844-846, 1979.

[2] S. Yang, S.H. Tan, and J.S. Fu, “Short backfire antennas for wireless LAN applications at millimeter-waves,” in IEEE AP-S Int. Symp., vol. 3, pp.1260-1263, Jul. 2000.

[3] H.W. Ehrenspeck, “The backfire antenna, a new type of directional line source,” Proc. IRE, vol. 48, no. 1, pp. 109-110, Jan. 1960.

[4] R. Li, D. Thompson, M.M. Tentzeris, J. Laskar, and J. Papapolymerou, “Development of a Wide-Band Short Backfire Antenna Excited by an Unbalanced-Fed H-Shaped Slot,” IEEE Trans. on Antennas and Propagation, vol. 52, no. 2, pp. 662-671, Feb. 2005.

[5] A.A. Kishk and L. Shafai, “Gain optimization of short-backfire antenna with different excitation types,” IEEE AP-S Int. Symp., vol. 24, pp. 923-926, Jun. 1986.

[6] www.zeland.com

[7] S.Y. Ke, “Broadband proximity-coupled microstrip antennas with an H-shaped slot in the ground plane,” IEEE AP-S Int. Symp., vol. 2, pp. 530-533, Jun. 2002.

[8] www.cst.com