

Steerable Space Fed Lens Array for Low-Cost Adaptive Ground Station Applications

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Introduction

The Space Fed Lens Array (SFLA) is an alternative to a phased array antenna that replaces large numbers of expensive solid-state phase shifters with a single spatial feed network. SFLA can be used for multi-beam application where multiple independent beams can be generated simultaneously with a single antenna aperture [1]. Unlike phased array antennas where feed loss increases with array size, feed loss in a lens array with more than 50 elements is nearly independent of the number of elements, a desirable feature for large apertures. In addition, SFLA has lower cost as compared to a phased array at the expense of total volume and complete beam continuity. For ground station applications, both of these tradeoff parameters are not important and can thus be exploited in order to lower the cost of the ground station. In this paper, we report the development and demonstration of a 952-element beam-steerable SFLA intended for use as a low cost ground station for communicating and tracking of a low Earth orbiting satellite. The dynamic beam steering is achieved through switching to different feed-positions of the SFLA via a beam controller.

Theory and Design

The basic SFLA scanning architecture is shown in Figure 1 (a) for the case of receiving mode only. The SFLA consists of three antenna arrays: the receiving-side array, the feed-side array, and the array of feed elements. The pairs of antenna elements on the two former arrays are connected through appropriate true-time delay lines. The receiving-side array determines the beamwidth as in standard antenna array theory. The multiple beams are obtained with multiple *spatial* feeds. When a plane wave is incident from some direction (azimuth and elevation), the receive array antennas sample the wave-front at approximately the Nyquist criterion depending on the antenna element radiation pattern. Each sample is then appropriately time-delayed and re-radiated by a second array of antennas, focusing the power onto the focal surface. The field is now sampled on the focal surface so that each feed antenna element preferentially receives incoming waves from a single direction. The SFLA can be implemented using standard printed-circuit board technology and can incorporate power amplifiers for transmit mode or low-noise amplifiers (LNAs) for receive mode. The polarization can be chosen to be different on the two sides of the array for isolation purposes and also for design simplicity. The LNAs can also be placed after the feed antennas, since the spatial feed does not contribute resistive loss.

SFLA Geometry

NASA GRC, in collaboration with the University of Colorado, Boulder, has developed a 952-element SFLA for ground station applications to communicate with low Earth orbiting satellites. This is a low cost approach using multiple relatively small SFLAs to replace a 10-11 meter reflector and to achieve beam scanning non-mechanically. Figure 1(b) shows the switching connection of the 36-beam network for the 952-element SFLA. The switching to each beam position is accomplished using one 1:4 and four 1:8 GaAs MMIC non-reflective switches (Hittite). The output signal was amplified with a GaAs PHEMT MMIC low noise amplifier (Hittite) which has a frequency range of 2.0-20.0 GHz. The 952-element prototype SFLA was designed to operate at 8.386 GHz with circular polarization on the receiving side and linear polarization on the feed side. The elements in the array are patch antennas, and there are 2 dielectric substrates with metallized via holes interconnecting corresponding antenna elements of the two arrays. Figure 2 shows the layout of the antenna elements for the radiating and feed sides as well as the interconnect between different layers. For the 952-element SFLA, the feed array located along a focal arc has 32 feed elements with each feed to receive a directional beam from different beam directions. Scanning in this architecture is accomplished by switching between independent beams through a beam-controller, thus eliminating a need for microwave phase shifters. The switches do not need to be high-speed as the pass of a satellite allows many seconds per beam. The finished 952-element SFLA is shown in Figure 3. The feed-array and electronic circuits were shielded in a metallic enclosure to minimize electromagnetic interference.

Results and Discussions

The SFLA was characterized using GRC's planar Near-Field Antenna Facility [2]. Figure 4 shows the radiation patterns along the scan plane for different beam positions. The scan loss was found to have approximately a $\cos(\theta)$ dependence with scan angle, θ . For the prototype demonstration, the beam was scanned only in one plane (elevation), while scanning in the other plane (azimuth) was accomplished mechanically. In general, to track the satellite, scanning in the elevation plane is sufficient if the satellite does not drift too far away from its orbital plane, but a 2-D scan can be accomplished with a 2-D feed array over the focal plane. Our results demonstrate the feasibility of the SFLA for the aforementioned application.

Conclusion

A 952-element SFLA has been developed, and its feasibility for ground station applications has been demonstrated through establishing a link with a low Earth orbiting communication satellite. The success of this work could have potential impact on future ground network designs based on using multiple smaller low-cost SFLA to replace large conventional reflectors of 10-11 meter in size.

Reference

[1] Richard Q. Lee, S. Romisch and Z. Popovic, "Multi-beam phased array antennas", Proceedings of the 2002 Antenna Applications Symposium, pp.18-27.

[2] K. Lambert, G. Anzic, R. Zakrajsek and A. Zaman, "An overview of the antenna measurement facilities at the NASA Glenn Research Center", NASA/TM 2002-211883.

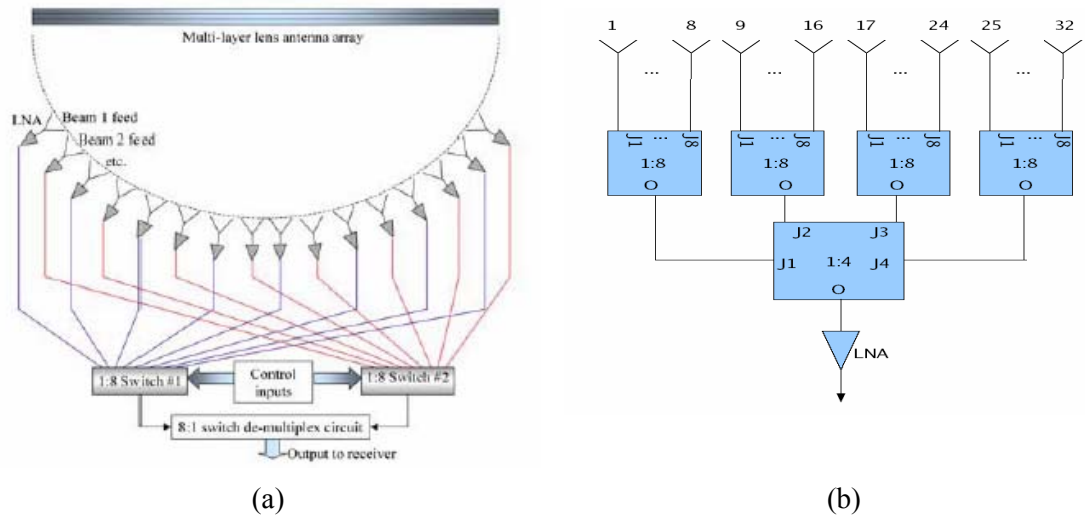


Fig. 1 Schematic of (a) a SFLA and feed switching connections for a 16-beam feed network, and (b) switching connections for a 32-beam feed network for the 952-element SFLA.

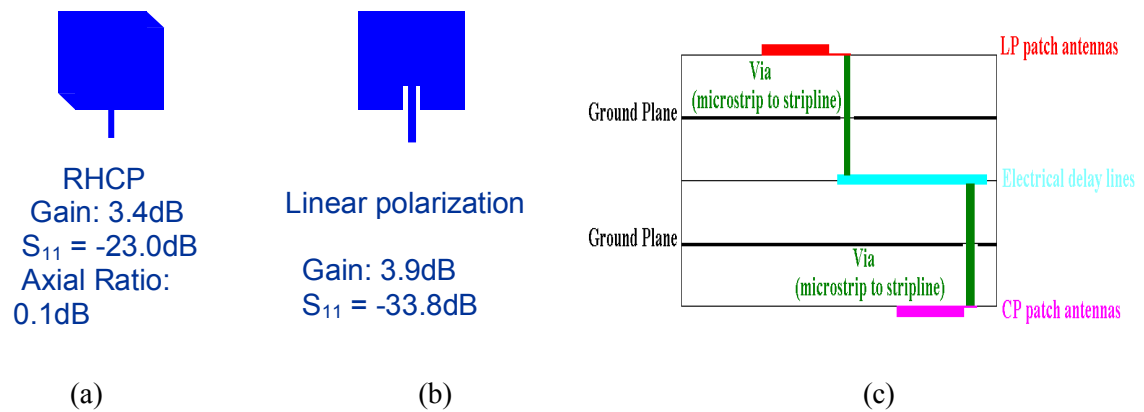
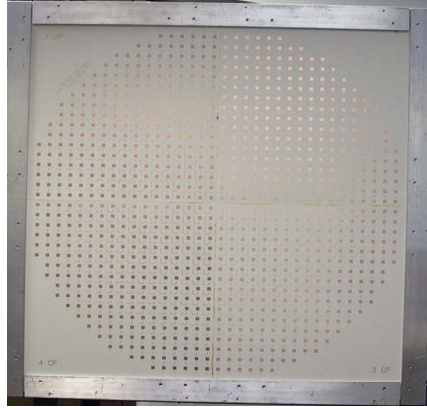


Fig. 2 Schematics for (a) RHCP antenna element for the receiving-side array, (b) LP antenna element for the feed-side array of the SFLA, and (c) interconnect between different layers



(a)



(b)

Fig. 3 Photos of a 952-element SFLA: (a) receiving-side array, and (b) feed-side array, and the array feed-elements and switching network

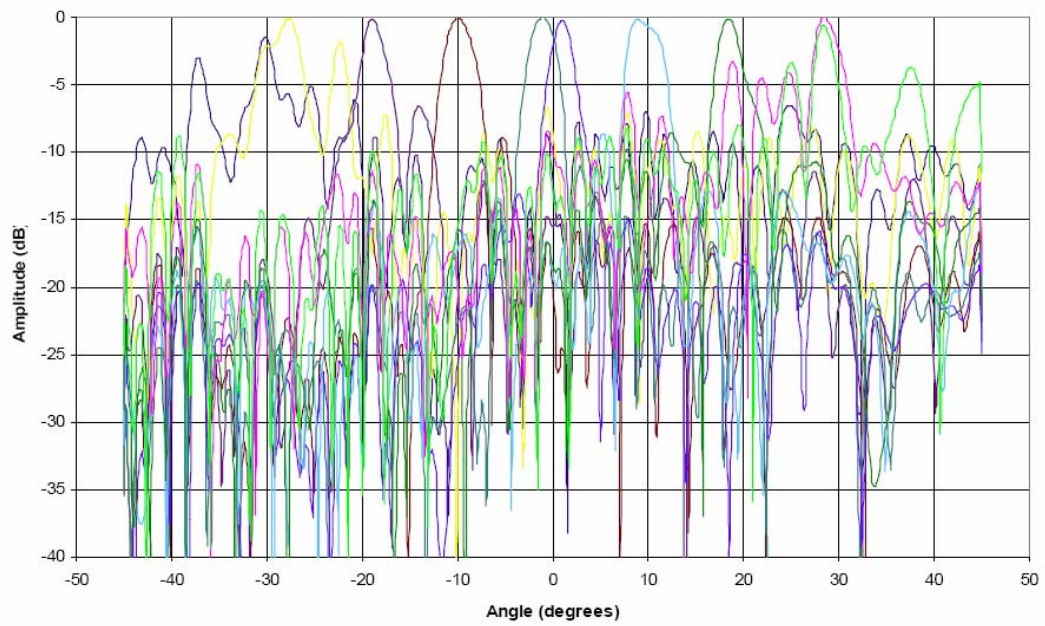


Fig. 4 Measured radiation patterns along the scan plane for various beam positions.