Recent Development of Printed Reflectarrays at JPL[⊕]

J. Huang, R. Hodges, M. Zawadzki, S. Rengarajan
C. Han[*] and K. Chang[*]

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109, USA

[*]Department of Electrical Engineering
Texas A&M University
College Station, Texas, USA

Abstract -- At the Jet Propulsion Laboratory (JPL), three different reflectarray technologies have recently been developed for NASA's future deep-space and Earth remote sensing missions. One is a 3-meter Ka-band inflatable reflectarray with 200,000 elements printed on a 0.13mm-thick membrane. It is currently known as the electrically largest reflectarray. The second development is a reflectarray having a rectangular aperture intended for the NASA/JPL's Wide Swath Ocean Altimeter (WSOA) radar application. The required rectangular aperture of 2.0m x 0.5m consists of five flat sub-panels that are connected together to form a deployable flat reflectarray. The third development is a dual-band reflectarray, where the two bands are widely separated, such as the X and Ka-bands. It uses an offset feed with an aperture diameter of 0.5m. The dual-band capability is achieved by using a multi-layer technique where the X-band annular ring elements are placed above the Ka-band ring elements and serve as a frequency selective surface to allow the Ka-band signal to pass through.

Introduction -- The concept of reflectarray antenna has been around for several decades [1]. However, the low-profile printed microstrip reflectarray is a fairly new concept [2,3,4]. It combines some of the best features of microstrip array antenna technology and the traditional parabolic reflector antenna. The printed reflectarray can be designed to have very high gain with relatively good efficiency, as well as to have its main beam tilted/scanned to large angles from its broadside direction. One significant advantage of the printed reflectarray is that, when a large aperture (e.g. 10-meter size) spacecraft antenna requires a deployment mechanism, the flat structure of the reflectarray will allow a much simpler and reliable folding or inflation mechanism than the curved surface of a parabolic reflector. The flat reflecting surface of the reflectarray also lends itself to flush mounting onto an existing flat structure without adding significant amount of mass and volume to the overall system structure. The reflectarray, being in the form of a printed microstrip antenna with thousands or more elements, can be fabricated with a simple and low-cost etching process. With all the above capabilities [5], there is one distinct disadvantage associated with the reflectarray antenna. This is its inherent narrow bandwidth due to different path lengths or the so-called differential spatial phase delays [6] from the feed to the reflecting elements, and the resonant nature of the patch elements. This narrow bandwidth generally cannot extend much beyond ten percent depending on its element design, aperture size, focal length, etc. One proposed technique to achieve a good bandwidth is to use piecewise-flat but globally-curved aperture [7]. Dual-band capability with multi-layer structure is also currently being developed [8] for the reflectarray to function at two widely separated frequencies, such as X and Ka-bands.

Description of Recent Developments -- One earlier reflectarray development was a Ka-band circularly polarized inflatable reflectarray [9] with a three-meter diameter aperture developed for NASA's future spacecraft communication antenna application. As shown in Fig. 1, the antenna uses a torus-shaped inflatable tube to support and tension a three-meter thin membrane reflectarray surface (mechanical structure developed by ILC Dover, Inc.). This circularly polarized reflectarray, having approximately 200 thousand elements using variable angular rotation technique [6,10], is considered electrically the largest reflectarray ever built. A close-up view of the variable rotation elements is shown in Fig. 2. In a

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reflectarray, having a "natural" flat surface, allows the inflatable structure to more easily maintain the required surface tolerance (0.2 mm rms in this case) than a "non-natureal" parabolic surface, especially for long space flights. This inflatable antenna was later improved with rigidizable inflatable tubes [11] in order to survive the hazardous space environment, such as bombardment by space debris and strenuous thermal effects. This reflectarray achieved an aperture efficiency of 30% with room for improvement and excellent far-field pattern shape with average sidelobe and cross-pol levels below –40 dB as shown in Fig. 3.

A second development that is worth mentioning is a reflectarray having a rectangular aperture intended for the NASA/JPL's Wide Swath Ocean Altimeter (WSOA) radar application. This reflectarray uses variable-size patches [4] as elements. The required rectangular aperture, as shown in Fig. 4a, consists of five flat sub-apertures that are connected together to form a piecewise-planar parabolic reflectarray [7]. The curving of the long dimension of the rectangular surface is to minimize the incident angles from the feed to the end elements and, thus, to optimize the radiation efficiency for all elements, as well as to achieve a robust bandwidth. The advantage of using a reflectarray with flat sub-apertures is that it allows mechanical folding of the flat panels into a compact structure for spacecraft launch-vehicle stowage. Test data indicates that this reflectarray is functioning properly and some minor improvements need to be carried out in the future. In addition to the curved aperture, WSOA has also investigated a flat rectangular aperture as shown in Fig. 4b. This reflectarray, using variable-size patches, is offset-fed by a set of linear arrays to form a set of fan beams with dual-linear polarizations. An interesting discovery here was that this flat reflectarray unit has much better scan performance (by offsetting the feed) than the parabolic unit.

A third important development is a dual-frequency reflectarray, where the two frequencies are widely separated, such as the X and Ka bands. The developed prototype antenna, shown in Fig. 5, is circularly polarized and uses variably-rotated annular rings [8]. It was developed by the Texas A&M University for JPL/NASA's future space communication application. This antenna, with an offset feed and a diameter of 0.5 meter, uses a multi-layer technique where the X-band annular rings are placed above the Ka-band rings and serve as a frequency selective surface to let the Ka-band signal to pass through. The measured results indicate that there is very little impact on the X-band performance due to the presence of the Ka-band elements. The measured radiation patterns of the X and Ka-band reflectarray are shown in Figs. 6 and 7, respectively. Excellent pattern behaviors are demonstrated. The measured Ka-band gain of the dual-band antenna is about 1.0 dB lower than the Ka-band-alone antenna. The Ka-band-alone reflectarray has a measured aperture efficiency of 50%, while the dual-frequency dual-layer antenna has a Ka-band efficiency of about 40%. In other words, the X-band annular rings did impact somewhat the Ka-band performance. Efforts need to be carried out in the future to minimize this impact.

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Figure 1. 3m Ka-band inflatable reflectarray.

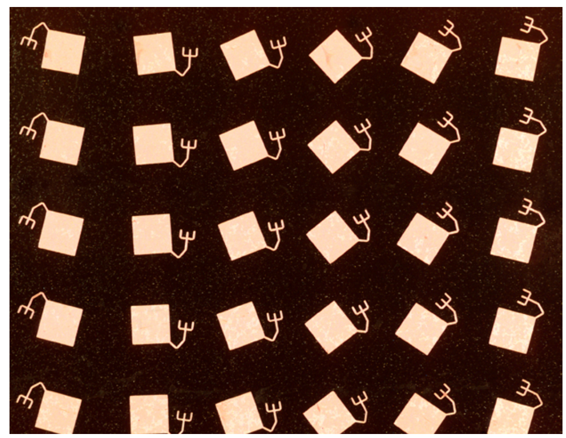

Figure 2. Patches on inflatable membrane with variable-angle rotated elements

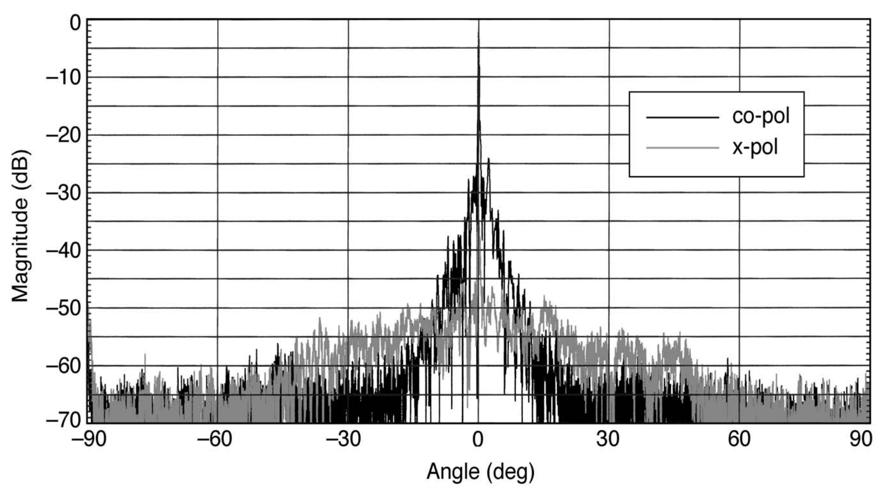

Figure 3. Measured radiation pattern of the 3m inflatable reflectarray showing low sidelobe and low cross-pol levels.

(a)

(b)

Figure 4. Deployable rectangular reflectarrays with a piecewise-flat globally-curved aperture shown on the left and a complete flat aperture shown on the right.

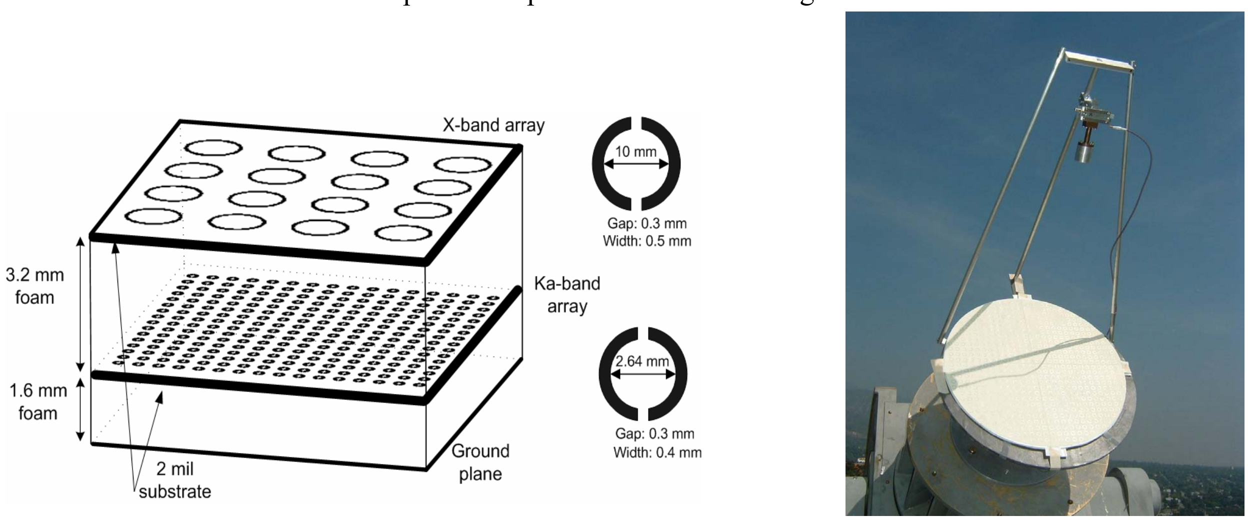

Figure 5. X/Ka dual-band reflectarray using multi-layer structure with annular ring elements.

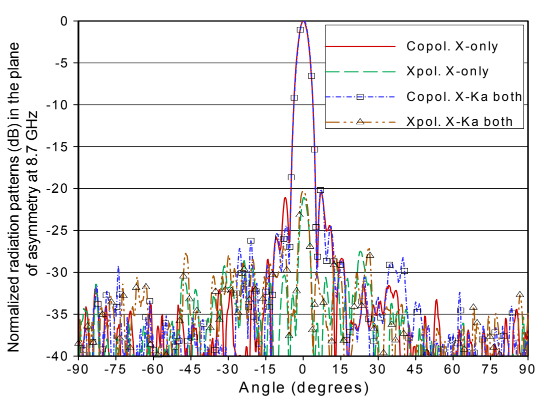

Figure 6. Measured X-band pattern of the X/Ka dual-band reflectarray.

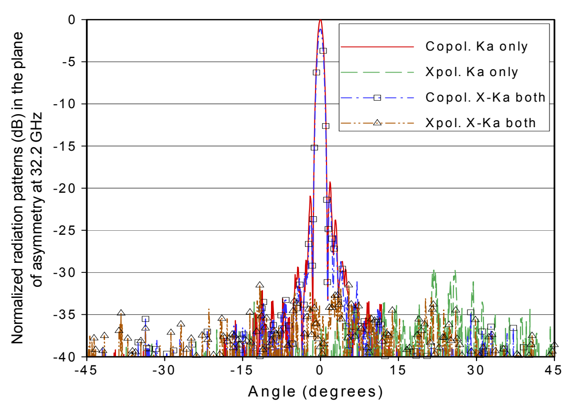

Figure 7. Measured Ka-band pattern of the X/Ka dual-band reflectarray.