A Cassegrain Offset-Fed Dual-Band Reflectarray

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Abstract – An X/Ka dual-band microstrip reflectarray with circular polarization (CP) has been constructed using thin membranes and Cassegrain offset-fed configuration. It is believed that this is the first Cassegrain reflectarray ever been developed. This antenna has a 75-cm-diameter aperture and uses metallic subreflector and angular-rotated annular ring elements. It achieved a measured -3dB-gain bandwidth of 700 MHz at X-band and 1.5 GHz at Ka-band, as well as a CP bandwidth (3dB axial ratio) of more than 700 MHz at X-band and more than 2 GHz at Ka-band. The measured peak efficiencies are 49.8% at X-band and 48.2% at Ka-band.

Introduction – With the advancement of space exploration, there is an increasing demand for larger aperture antennas with very small masses and launch volumes. As one of the solutions, deployable antenna technology using inflatable structures and thin membranes [1,2] has recently being investigated, particularly, the technology of inflatable flat reflectarray [3]. It is believed that for a very large aperture in space, the flat thin membrane surface of a reflectarray is much more reliable and more easily maintains its required surface tolerance than a curved parabolic thin-membrane surface. A recent development [4] has demonstrated that a 0.2mm rms surface tolerance (1/50th of a wavelength) was achieved on a 3-meter Ka-band inflatable reflectarray. The reflectarray approach, however, suffers from limited bandwidth (typically < 10%). A dual-band technology has to be developed for the reflectarray to meet the multi-band requirement of, for example, X-band uplink and Ka-band downlink. Under contract to JPL, Texas A&M University has carried out a series of developments to demonstrate the dual-band capability of the reflectarray. First, a 0.5m center-fed X/Ka dual-band reflectarray using two-layer thin membranes was successfully developed [5]. This reflectarray used annular ring elements [6] with the angular rotation technique [7] to achieve the required phase delays for circular polarization. A subsequent development using similar technologies for an offset-fed configuration [8] was also successfully demonstrated. Finally, this paper reports the development of a Cassegrain offset-fed X/Ka dual-band reflectarray with a 0.75m diameter. For very large apertures (> 3m), Cassegrain offset-fed configuration, in addition to minimizing the feed blockage, would allow the feed and its associated electronics to be located close to the spacecraft for easier thermal control, in particular, when minimization of RF loss in the feed cable is in consideration. This Cassegrain dual-band technology developed here is currently being implemented onto a 3m reflectarray with inflatable structures and is planned for application to an 8m inflatable reflectarray in the near future.

Antenna description and performance – The photo of the 0.75m Cassegrain offset-fed X/Ka dual-band reflectarray is shown in Fig. 1 with its two-layer thin membrane configuration depicted in Fig. 2. The reflectarray elements are etched on commercial Rogers R/flex 3000 liquid crystalline polymer (LCP) thin membrane material with $\varepsilon_r = 2.9$. The thickness of the membrane is 0.0508mm (2mil) for both layers. Low-density foams are used between the thin membrane layers for mechanical support. For in-space application with inflatable structures, the foam spacers will be replaced by empty spaces. The dimensions of the annular ring elements are shown in Fig. 2. All ring elements in each frequency band are identical except with different rotation angles designed to compensate for the different path-length phase delays. The effective focal length of the Cassegrain system is 48 cm. With the diameter of the reflectarray being 75 cm, the f/D ratio is 0.64. The subreflector's aperture is elliptically shaped with a major axis equal to 15 cm and a minor axis of 8.4 cm. The main beam of the reflectarray is designed to tilt at an angle of 27° from the broadside direction. The reflectarray elements for both bands are designed to have half-wavelength spacings. In order to effectively illuminate the subreflector and to minimize the development effort, both X and Ka-band feeds are made of microstrip arrays with each having 4x4 elements. In actual space application, a dual-band feed horn could be used.

The measured two-principal-plane far-field patterns at the X-band frequency of 8.4 GHz are shown in Fig. 3, while that for the Ka-band frequency of 31.8 GHz are given in Fig. 4. It can be seen that the patterns are well behaved with relatively low cross-pol and sidelobe levels, in particular for the Ka-band results. The measured axial ratio versus the X-band frequency range of 8.0 GHz to 8.7 GHz is shown in Fig. 5, while that for the Ka-band range from 31 GHz to 33 GHz is shown in Fig. 6. The measured aperture efficiency versus the same X-band frequency range is given in Fig. 7, while that for the Ka-band frequency range is shown in Fig. 8. All measurements were made at one time with both X and Ka-band layers present and at another time with only either a single X-band layer or a single Ka-band layer present. In doing so, the effect of one layer on the other layer can be determined. The measured gain at 8.4 GHz with only the X-band layer present is 33.25 dB and is 33.36 dB with both Ka-band and X-band layers present. The measured gain at 31.8 GHz with only the Ka-band layer present is 45.95 dB and is 44.73 dB with the X-band layer present on top of the X-band layer. From all above measured results, several observations can be made. First, the presence of the Ka-band layer below the X-band layer did not impact the X-band performance significantly, while the presence of the X-band layer on top of the Ka-band layer did reduce the aperture efficiency (as blockage) of the Ka-band performance by about 1 dB. Second, the reflectarray in general shows better performance (efficiency, sidelobe & cross-pol levels) at ka-band than at the X-band. This is because, due to a design oversight, the X-band feed array is in the near-field region of the subreflector and has too large a size relative to the subreflector size, which resulted in high spillover and high edge diffraction on the subreflector. A 3x3 array, instead of the 4x4 size, may be more appropriate for the X-band feed. A 3rd observation is that this reflectarray has a relatively wide bandwidth. It achieved a -3dB-gain bandwidth of 8.3% at X-band and about 5% at Ka-band. The CP bandwidth is extremely wide; more than 8% at X-band and is significantly wider than 6% at Ka-band. This relatively wide bandwidth performance is because the reflectarray has a large f/D ratio of 0.64 and uses relatively thick foam substrates at both X and Ka-bands. Using angular rotation technique also lends itself to good CP bandwidth because the cross-pol radiations from all elements are diffused instead of added coherently in the far-field.

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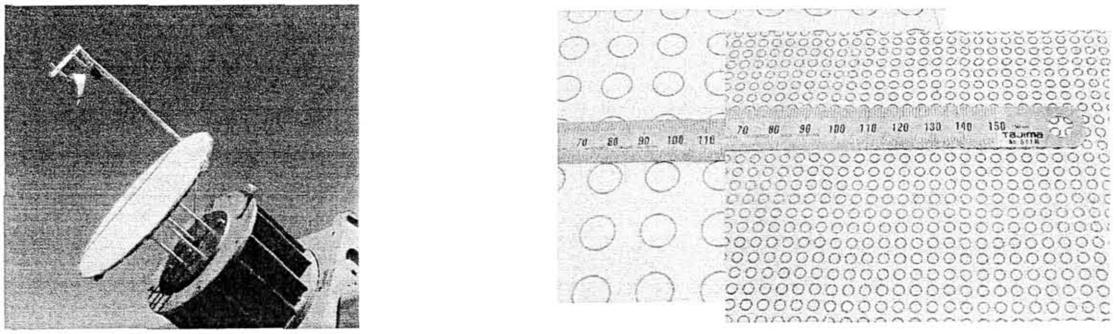

Figure 1. Photos of the Cassegrain reflectarray, right photo shows the ring elements on the thin membranes

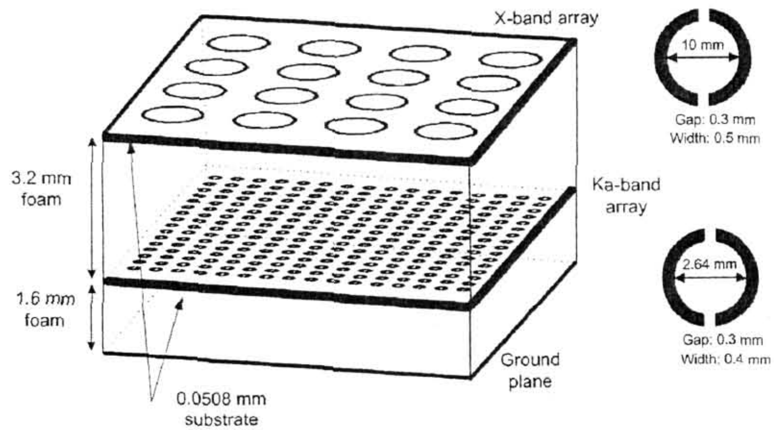

Figure 2. Two-layer thin-membrane configuration

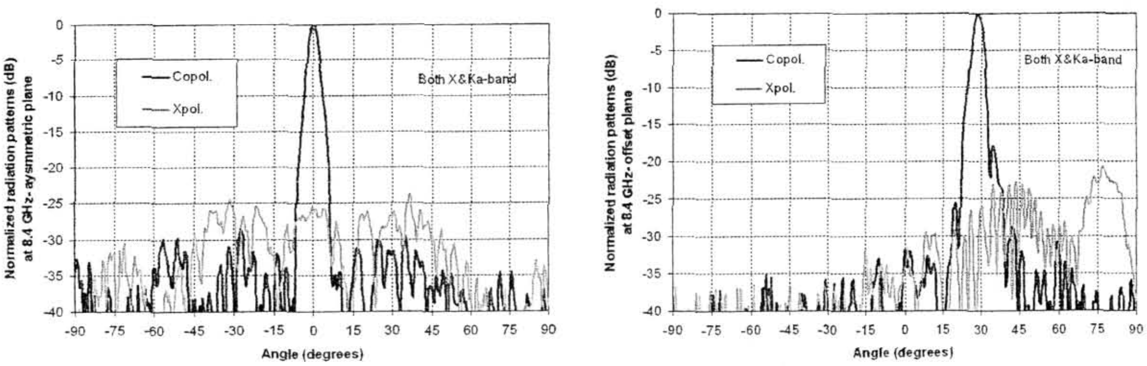

Figure 3. Measured X-band two-principal-plane patterns

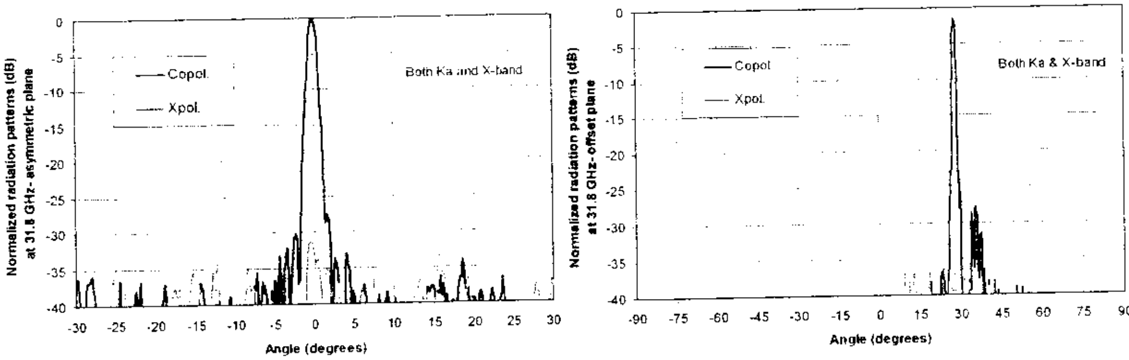

Figure 4. Measured Ka-band two-principal-plane patterns

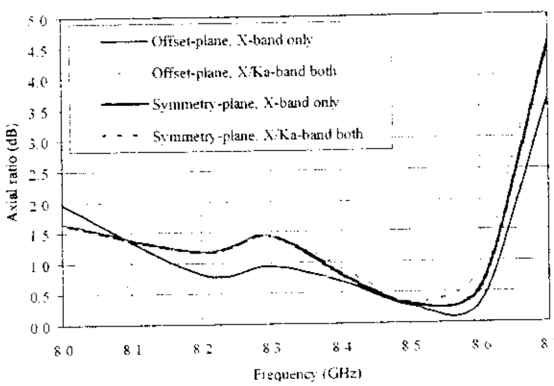

Figure 5. Measured axial ratio vs. X-band frequencies

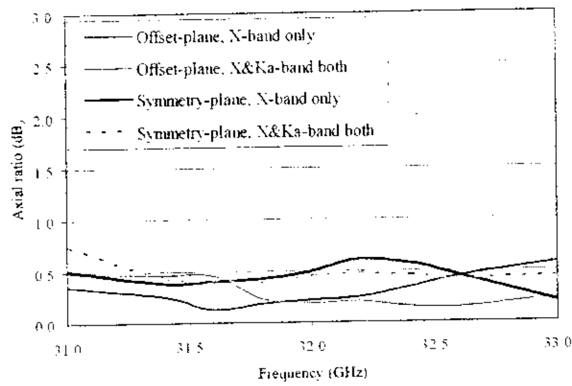

Figure 6. Measured axial ratio vs. Ka-band frequencies

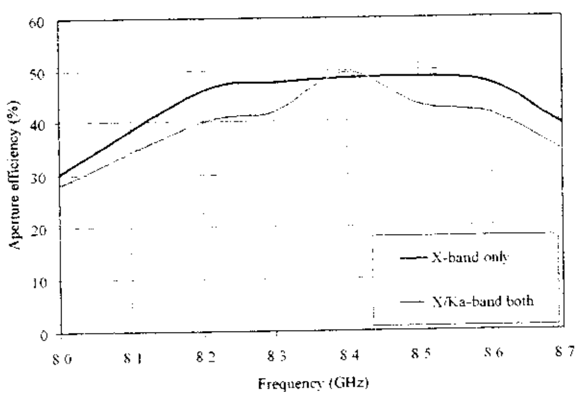

Figure 7. Measured efficiency vs. X-band frequencies.

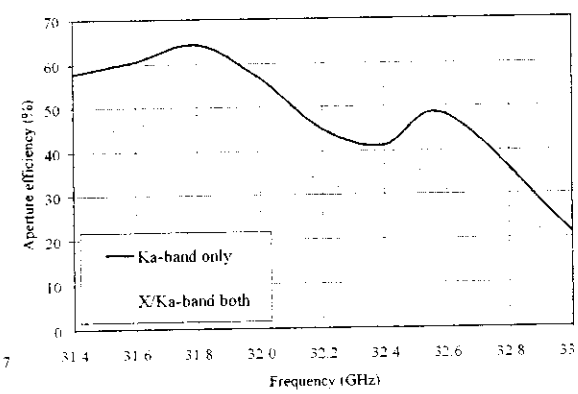

Figure 8. Measured efficiency vs. Ka-band frequencies.