A Single-Layer Tri-Band Reflectarray Antenna Design

Fan Yang(1), Yanghyo Kim(1), John Huang(2), and Atef Elsherbeni(1)
(1) Electrical Engineering Dept., The University of Mississippi, University, MS 38677
(2) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
fyang@olemiss.edu, yhkim@olemiss.edu, john.huang@jpl.nasa.gov, atef@olemiss.edu

Introduction

NASA’s Earth remote sensing program and deep-space exploration program have increasing demands for high gain and large aperture antennas. The conventional high gain antennas, such as parabolic reflectors, are generally bulky in size and large in mass due to the curved reflecting surfaces. Recently, inflatable planar reflectarray has been proposed, which has numerous advantages such as light weight, small stowage volume, and enhanced reliability [1-2]. However, the bandwidth performance of a reflectarray is limited due to the narrow bandwidth of microstrip antenna element and the differential spatial phase delay in a large aperture.

Multi-layer stack structure has been used to improve the bandwidth performance. For example, a stack-patch element was proposed in [3] to broaden the reflectarray bandwidth, and a dual-band reflectarray on a two-layer structure with two different-size rings and variable angular rotations was successfully demonstrated in [4]. This paper, with analysis results, proposes a single-layer reflectarray design that effectively uses the reflecting surface area to realize tri-band (C/X/Ka) operation. The single-layer design is easy to fabricate, and it can be combined with multi-layer technique to further enhance the number of frequencies that a reflectarray can cover.

Antenna Geometry and Design

The geometry of the tri-band reflectarray design is sketched in Fig. 1. It consists of three different types of elements: split circular ring for Ka band operation, split square loop for C band operation, and cross-dipole element for X band operation. All three types of elements are mounted on a 62 mil thick RT/Duroid 5870 substrate ($\varepsilon_r=2.33$). The tri-band reflectarray is analyzed using Ansoft Designer. Periodic boundary conditions are placed around a single unit to model an infinite array environment.

A. Ka band element design. A split ring with a vertical bar [5] is designed to reflect the right-hand circularly polarized (RHCP) wave with the same polarization state at 32 GHz. Figure 2a shows the unit geometry, and its dimensions are provided in the caption. The element spacing is $0.5 \lambda_0$, where $\lambda_0$ is the free space wavelength. Figure 2b presents the magnitude of reflected wave for
a RHCP incident wave. At 32 GHz, the cross-polarization (LHCP) is 36 dB lower than the co-polarization (RHCP). Since the substrate thickness is around 0.17 $\lambda_0$, the element will provide a relatively broad operating bandwidth. In order to realize a planar wavefront and generate a focused beam, the angular rotation technique [6] is used to compensate the spatial phase delay.

**B. C band element design.** A split square loop is designed to reflect the RHCP wave with the same polarization state at 7.1 GHz. The element spacing is four times of the element spacing at Ka band. The geometry is sketched in Fig. 3a and the simulated field magnitudes are depicted in Fig. 3b. Since the substrate thickness is around 0.037 $\lambda_0$, the operational bandwidth is relatively narrow.

The previous angular rotation technique cannot be used here because the rotation of square rings will collide with the split ring elements. To solve this problem, an alternative approach is to move the position of slots along the perimeter of the square loop. The slot position can be identified by an equivalent rotation angle $\Phi$, as labeled in Fig. 3a. It is observed that when the slot position is moved along the perimeter of the square loop, the resonant frequency of the structure will shift. To maintain the same operating frequency at 7.1 GHz, the slot width needs to be adjusted, as illustrated in Fig. 4a. When $\Phi = 45^\circ$, slots locate at the corners of the square loop and their width is reduced to 2.19 mm. Figure 4b shows the phase variation versus the rotation angle. When the rotation angle changes from -90$^\circ$ to 90$^\circ$, the phase difference varies from -180$^\circ$ to 180$^\circ$, which can be used to compensate the spatial phase delay required in a reflectarray. It is worthwhile to point out that the phase variation is no longer a linear function of the rotation angle as in the previous angular rotation technique for the circular ring element.

**C. X band element design.** A cross dipole is designed to operate at 8.4 GHz, which has the same element spacing as the square loop but shifts half periodicity in space. In contrast to the previous two designs, this cross dipole reflects the incident CP wave with the opposite polarization state, namely, from LHCP to RHCP. This design will help to avoid the coupling effect between two close frequencies (7.1 GHz and 8.4 GHz). Figure 5a shows the geometry of the cross dipole element. To compensate for the spatial phase delay, the X band element uses variable size method [7]. The length of the cross dipole is adjusted to obtain the required reflection phase. As shown in Fig. 5b, as the dipole length is increased from 10 mm to 15 mm, the reflection phase decreases from 143$^\circ$ to -202$^\circ$.

**Conclusions**

This paper presents a single-layer tri-band reflectarray. Circular ring, square loop, and cross dipole are designed to operate at 7.1 GHz, 8.4 GHz, and 32 GHz, respectively, and they are assembled on the same reflecting surface. A reflectarray prototype will be fabricated and the measured results will be presented in the symposium.
References

Fig. 1: Geometry of a single-layer tri-band reflectarray design.

Fig. 2. Ka band element: (a) geometry, (b) magnitudes of reflected fields. $P_1 = 4.6875$ mm, $g_1 = 0.4$ mm, $r_0 = 1.6$ mm, $r_1 = 1.2$ mm, $L_1 = 2.23$ mm, $w_1 = 0.4$ mm.
Fig. 3. C band element: (a) geometry, (b) magnitudes of reflected fields. $P_2 = 18.75$ mm, $a_o = 9.775$ mm, $a_i = 8.975$ mm, $g_2 = 3.155$ mm.

Fig. 4. Angular rotation technique for the square loop element at 7.1 GHz: (a) slot width and (b) phase difference.

Fig. 5. X band element: (a) geometry and (b) reflection phase versus the element length $L_3$ at 8.4 GHz. $P_3 = 18.75$ mm, $w_3 = 0.4$ mm.