A multi-layer circularly polarized microstrip patch antenna with proximity coupling and increased gain

Mark Zawadzki

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Introduction

There is currently interest at NASA and the Jet Propulsion Laboratory in developing an antenna system at Ka-band for use in future deep-space missions. For an equivalent 3-meter aperture, switching to Ka-band not only means a 6dB improvement in gain over the current X-band systems in use today, but it also implies an increase in the data rate for transmitting scientific data back to Earth. One significant drawback of the Ka-band antenna is that its narrow beam (≈0.2°) may point far enough away from the Earth as the spacecraft wobbles slightly during flight to cause unacceptable degradation of the signal. This wobble, which can be as much as 1°, is not an issue at X-band because the beam is broad enough to provide adequate coverage regardless of the wobble. One way to solve this problem is to impose tighter flight control requirements on the attitude control system (ACS) of the spacecraft, but this leads to greater fuel consumption. Another possibility, the one considered here, is to use positioning data from the ACS to steer the beam back to Earth. This requires that the antenna be capable of vernier scanning adjustments to the main beam. An antenna configuration that accomplishes this is the near-field dual-reflector system shown in Fig. 1a. By placing the subreflector in the near-field of a phased array feed, limited scanning in the far-field of the main reflector can be effected. Computer simulations determined that the array spacing had to be a relatively large 1.2λ for satisfactory performance with a minimum number of elements, 21 in this case (see Fig. 1b). In order to overcome potential grating lobe problems, the element had to be fairly directive. The element developed for this purpose was a multi-layered microstrip antenna with relatively large spacing between layers to increase the effective aperture size and element gain (similar to a Yagi).

Stacking layers of microstrip patches to improve gain is not a new concept. Previous work[1, 2] reported a gain of 10.6dB for a three-layer linearly polarized stack. Circular polarization (CP) using a two-layer stack was also reported.[3] In this work, an effort was made to optimize the gain for a three-layer CP stack, which resulted in a measured CP gain of 12.2dB. Additionally, all of the previous work used a coaxial probe to feed the element while the element considered here uses proximity coupling by microstrip lines as the feeding mechanism. The element was designed using commercial software and was fabricated at the scaled frequency of 2.56GHz to facilitate testing and tuning of the antenna. The stacked element was then included in a 21-element array at 2.56GHz. Presented below is a description of the single stacked element, and measured and calculated results at 2.56GHz. Also included are measured results for the array, and calculated results of a stacked element for the required frequency-scaled version at 32GHz.

Antenna Description

The three-layer antenna is shown in isometric view in Fig. 2a. A photograph of the fabricated antenna is given in Fig. 2b. The antenna consists of four layers of PTFE substrate ($\varepsilon_r = 2.2$) and two thick layers of foam with a low dielectric constant ($\varepsilon_r = 1.08$). The total height of the antenna is approximately 1λ. The feed line is etched on the lowest PTFE substrate and is proximity coupled to the driven patch element located on the next PTFE layer above. The foam substrates support two additional PTFE substrates with parasitic microstrip patches, which are electromagnetically coupled to the driven element. The use of proximity coupling by a microstrip line assisted mainly in matching to the high input impedance of the three-layer configuration; however, it also likely contributed to improving the bandwidth slightly by allowing the driven patch to exist on a thicker substrate than the feed lines. The wider coupling lines underneath the driven patch helped fine-tune the impedance match to the antenna.

Results

The return loss and Smith chart plots are shown in Fig. 3, and the CP patterns are given in Fig. 4. The results were generally very good with a measured CP gain of about 12.2dB and on-axis axial ratio of 0.4dB. In tuning the antenna, it was also discovered that the gain could be improved by about 2dB if metal walls were placed around the antenna at a distance of about 1λ away from the patch edges, bringing the total gain to over 14dB. The main limitation of the antenna, as discovered in prior work [1, 2], is reduced bandwidth. While the measured bandwidth here was approximately an 80% improvement over previous work [1], it is still relatively low at 1.8%. Another consideration in the performance is the relatively high cross-polarized radiation at ±60° off broadside.

The three-layer element was then used in a 21-element array (Figs. 1b and 5b). The results for one cut are given in Fig. 5a, and include one scan of approximately 11°. The measured CP gain and on-axis axial ratio of the array were 24dB and 0.7dB, respectively. The efficiency was approximately 75%. An interesting computational result was discovered during the simulation of a 3 x 3 array using the element. At a 1λ inter-element spacing, the calculated active-element pattern produced a sharp null at broadside, while yielding an acceptable active pattern at a spacing of 1.2λ. In the 21-element test array, with 1.2λ spacing the highest coupling level measured between elements was -23dB.

Since the system is planned for Ka-band, the element was scaled to 32GHz and simulated using the same commercial software. The results are given in Fig. 6 and verify that the design is scalable when compared with the S-band results. However, conductor and dielectric losses will obviously increase at 32GHz, as will fabrication errors due to much tighter tolerances.

Conclusions

A three-layer circularly polarized microstrip antenna using proximity coupling and exhibiting increased gain at 2.56GHz has been presented. While the bandwidth has been increased over previous work, it is still relatively low, which limits applications of the antenna to those requiring smaller bandwidths. The stacked element was also applied in a 21-element array. Further work will involve scaling the 2.56GHz design to the planned operating frequency of 32GHz.

Acknowledgements

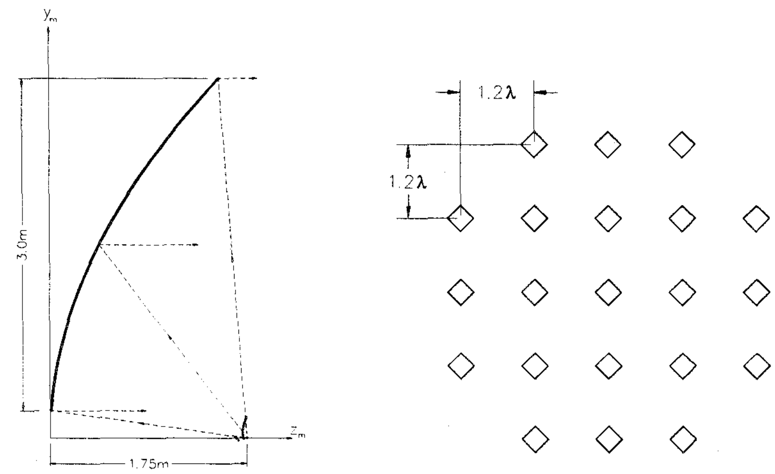
The author would like to thank John Huang for his helpful discussions and contributions. The research in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

[1] R. Q. Lee and K. F. Lee, "Gain enhancement of microstrip antennas with overlaying parasitic directors", Electronics Letters, vol. 24, pp. 656-658, May 1988.

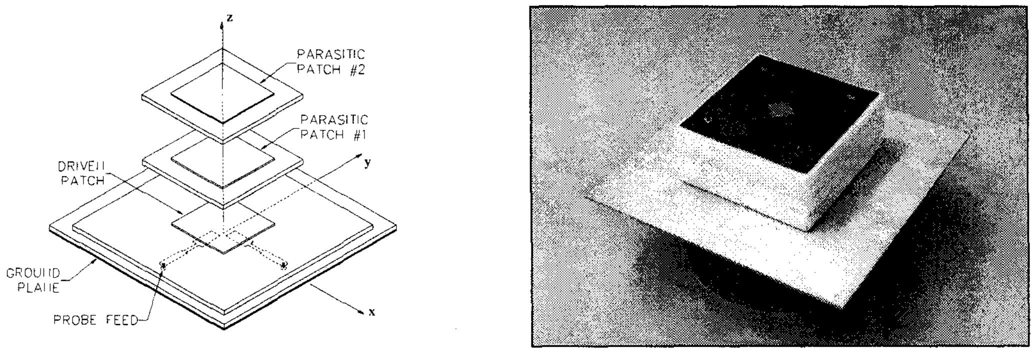
[2] R. Q. Lee, K. F. Lee, and J. Bobinchak, "Characteristics of a two-layer electromagnetically-coupled rectangular patch antenna", Electronics Letters, vol. 23, pp. 1070-1072, Sept. 1987.

[3] R. Q. Lee, T. Talty and K. F. Lee, "Circular polarisation characteristics of stacked microstrip antennas", Electronics Letters, vol. 26, pp. 2109-2110, Dec. 1990.



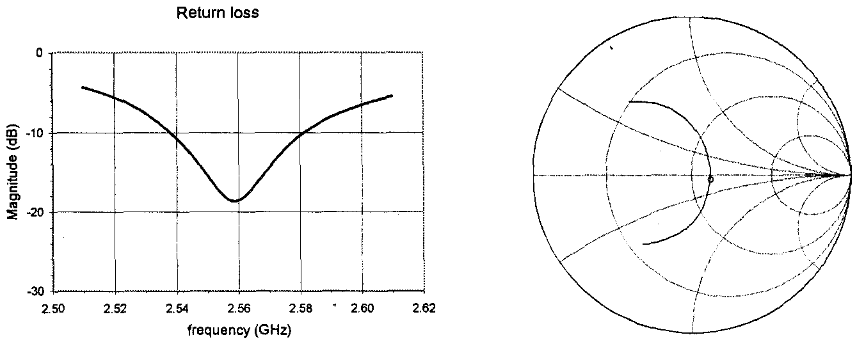
(a) (b)

Figure 1. (a) Offset near-field dual-reflector antenna.
(b) Phased array feed geometry.



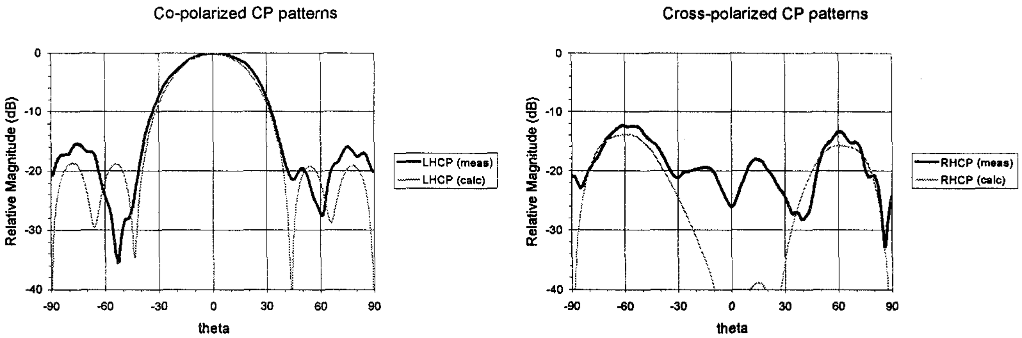
(a) (b)

Figure 2. A three-layer circularly polarized antenna
with proximity coupling



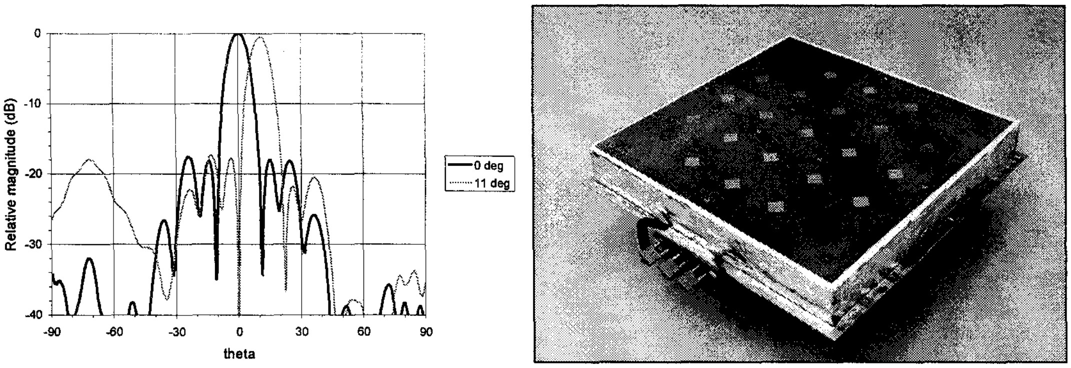
(a) (b)

Figure 3. Measured return loss and Smith chart
for each polarization at 2.56GHz



(a) (b)

Figure 4. Measured and calculated CP patterns for single-element at 2.56GHz



(a) (b)

Figure 5. 21-element CP array at 2.56GHz. (a) Measured CP patterns. (b) Photograph

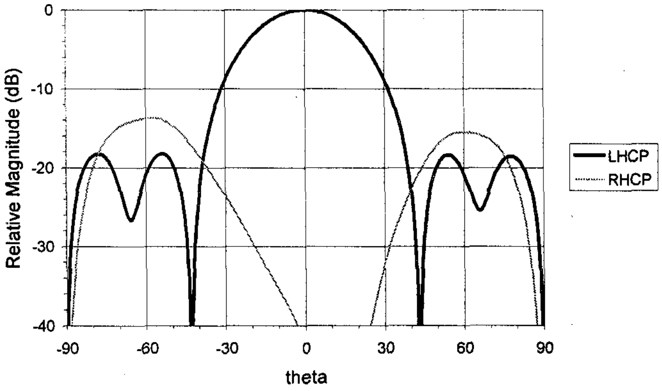


Figure 6. Calculated CP patterns for single element at 32GHz