Demonstration of an X-Band Multilayer Yagi-Like Microstrip Patch Antenna With High Directivity and Large Bandwidth

James A. Nessel, Afroz Zaman, and Richard Q. Lee
Glenn Research Center, Cleveland, Ohio

Kevin Lambert
Analex Corporation, Brook Park, Ohio

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at 301–621–0134

- Telephone the NASA Access Help Desk at 301–621–0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/TM—2005-213554

Demonstration of an X-Band Multilayer
Yagi-Like Microstrip Patch Antenna With
High Directivity and Large Bandwidth

James A. Nessel, Afroz Zaman, and Richard Q. Lee
Glenn Research Center, Cleveland, Ohio

Kevin Lambert
Analex Corporation, Brook Park, Ohio

National Aeronautics and
Space Administration

Glenn Research Center

April 2005

Acknowledgments

Special thanks to Dr. Félix A. Miranda for all his helpful discussions and suggestions.

Demonstration of an X-Band Multilayer Yagi-Like Microstrip Patch Antenna With High Directivity and Large Bandwidth

James A. Nessel, Afroz Zaman, and Richard Q. Lee
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Kevin Lambert
Analex Corporation
Brook Park, Ohio 44142

Abstract

The feasibility of obtaining large bandwidth and high directivity from a multilayer Yagi-like microstrip patch antenna at 10 GHz is investigated. A measured 10-dB bandwidth of ~20 percent and directivity of ~11 dBi is demonstrated through the implementation of a vertically-stacked structure with three parasitic directors, above the driven patch, and a single reflector underneath the driven patch. Simulated and measured results are compared and show fairly close agreement. This antenna offers the advantages of large bandwidth, high directivity and symmetrical broadside patterns, and could be applicable to satellite as well as terrestrial communications.

Introduction

Despite many attractive features like low profile, low cost, and ease of solid state device integration, microstrip patch antennas are limited by their inherently narrow bandwidths and low directivity. Previous attempts to overcome these deficiencies have resulted in substantial success. Larger bandwidths have been achieved through clever use of shorting walls, shaped slots, and electromagnetically coupled patches, while higher directivities have been realized with parasitic patches or high permittivity substrates (refs. 1 to 3). However, most previous attempts were focused on the enhancement of either the bandwidth or directivity. Thus, it would be beneficial to simultaneously improve both of these parameters to increase the versatility of the patch antenna.

Planar Yagi arrays with patch antennas as driven and parasitic elements have been reported earlier (refs. 4 and 5). These antennas produce end-fire radiation and a four-element array of such antennas has been introduced for mobile satellite communications applications (ref. 5). In ground-to-space communications, however, an antenna with a broadside beam is required, and high directivity and large bandwidth are necessary to support high data rate communication. In this paper, a unique multilayer Yagi-like microstrip antenna is presented which simultaneously addresses these aforementioned requirements.

Antenna Design and Optimization

The antenna structure under examination is illustrated in figure 1. Verification that this structure is conceptually similar to a Yagi antenna was performed by varying the number of stacked directors and analyzing its radiation pattern at each increment. As more directors were added, the antenna's beamwidth narrowed, indicating higher directivity. Simulations performed using Zeland's IE3D electromagnetic simulator showed that maximum directivity was achieved with three directors and that further stacking had little effect on performance enhancement.

Dimensions

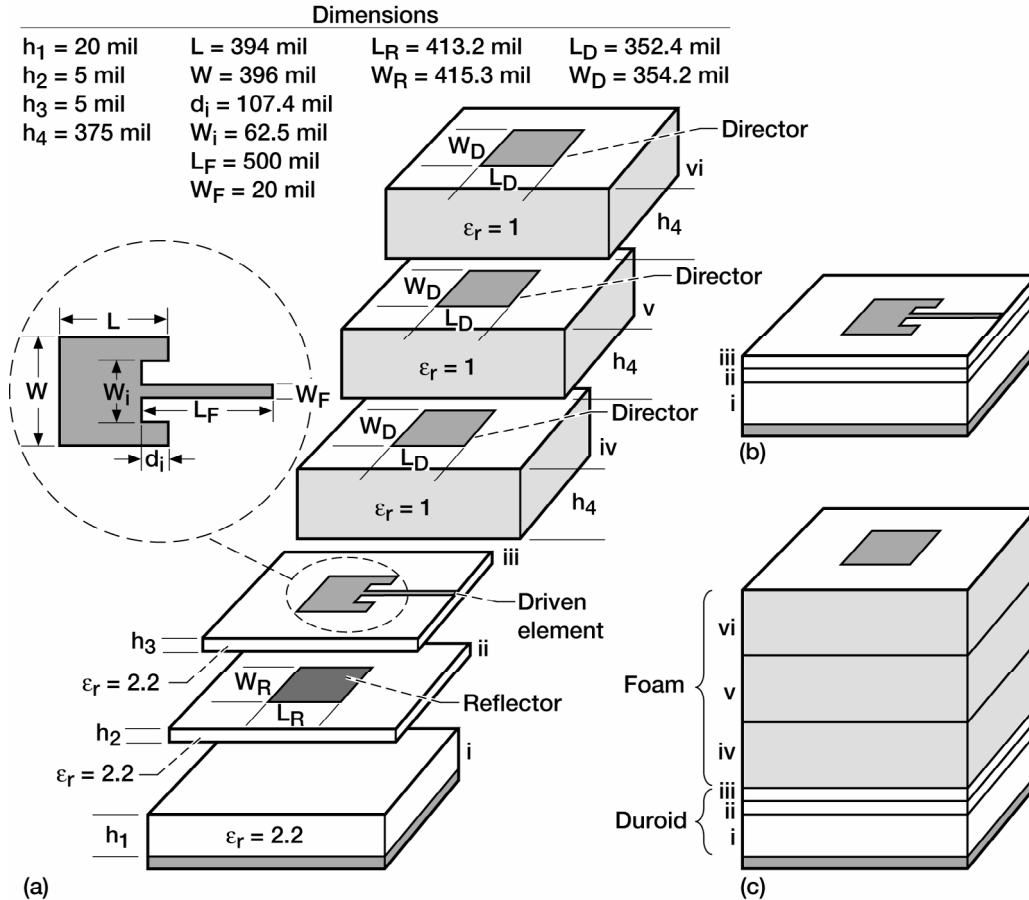|			
h_1 = 20 mil	L = 394 mil	L_R = 413.2 mil	L_D = 352.4 mil
h_2 = 5 mil	W = 396 mil	W_R = 415.3 mil	W_D = 354.2 mil
h_3 = 5 mil	d_i = 107.4 mil		
h_4 = 375 mil	W_i = 62.5 mil		
	L_F = 500 mil		
	W_F = 20 mil		

Figure 1.—Multilayer patch antenna and its assembly sequence. (a) Exploded 3D view showing the individual layers of the antenna. (b) Partially assembled antenna (without directors). (c) Complete assembled antenna (substrate and directors).

The directors' size and spacing of approximately 0.8A and 0.3λ_0, respectively, were baselined from previous designs (ref. 4), where A represents the area of the driven patch, and λ_0 is the free space wavelength. For a copper reflector, baseline size and spacing was determined to be 1.1A and 0.35λ_0, respectively (ref. 4). The investigation presented herein was performed, however, utilizing a lower conductivity material for the reflector (AgHT-8, $\sigma \approx 5 \times 10^4$ S/m). This material was chosen because it was readily available in our laboratory. The multilayer structure was optimized with IE3D based on the AgHT-8 material and 5 and 20 mil thick Duroid® substrates (ε_r = 2.2). From table 1, it can be observed that changing the conductivity of the reflector in the optimized design results in degradation of bandwidth and/or directivity.

TABLE 1.—IE3D SIMULATED REFLECTOR CONDUCTIVITY
EFFECTS ON ANTENNA PERFORMANCE

Conductivity (S/m)	Resonant Frequency (GHz)	10-dB BW	Directivity (dBi)
5×10^7	10.4	1.4%	12.4
5×10^6	10.3	1.9%	12
5×10^5	10.3	2.6%	12.2
1×10^5	10.2	8.1%	11.95
5×10^4	9.8	12.8%	11.8
2.5×10^4	9.9	11.6%	11.3
1×10^4	10	8.2%	11.6

Antenna Fabrication

The patch antenna was first patterned on a 5 mil thick Rogers Duroid® 5880 ($\varepsilon_r = 2.2$, ½ oz. copper) substrate. A second 5 mil layer was formed with a rectangular shape cut out and centered below the driven patch for reflector placement. Still a third 20 mil thick layer of the same material, with a ground plane, was placed underneath this reflector patch. The three layers were sandwiched together to form the partially assembled antenna structure (see fig. 1(b)) with total substrate thickness of 30 mils and mounted on a plastic fixture. Separation between the directors, also made from 5 mil thick Rogers Duroid® 5880, and the driven patch were accomplished with 3/8 inch foam spacers ($\varepsilon_r \approx 1$). Transparent adhesive was wrapped around the entire structure to keep the multiple layers together. A photograph of the fabricated multilayer patch antenna is shown in figure 2.

Simulated/Measured Results and Discussion

The simulated 10-dB bandwidth was found to be approximately 13 percent with an associated directivity of 11.8 dBi (see fig. 3).

The return loss of the fabricated design was measured using an Agilent 8510C Vector Network Analyzer, and the results are compared with simulation results as shown in figure 3. The measured 10-dB bandwidth was about 20 percent. Discrepancies between measurement and simulation are possibly attributable to slight differences in the actual physical properties of the lossy reflector as compared with those simulated on IE3D.

The antenna's radiation pattern was measured in NASA Glenn Research Center's Cylindrical Near Field Range Facility. Comparisons of the simulated and measured radiation pattern for the E-plane and H-plane cuts are shown in figures 4 and 5, respectively. Close agreement between the simulated and measured patterns is observed. The maximum directivity is calculated from equation (1), where $P(\theta)$ is the power radiated by the antenna, and is found to be 11.3 dBi, which agrees with the simulated value.

$$D = \frac{1}{\frac{1}{4\pi} \int\limits_{0}^{2\pi} \int\limits_{0}^{\pi/2} P(\theta) \sin(\theta) d\theta d\phi} \tag{1}$$
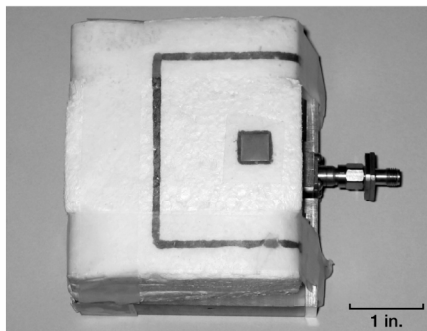

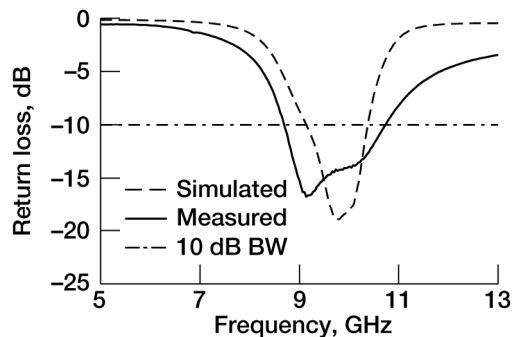Figure 2.—Photo of fabricated multilayer patch antenna.

Figure 3.—Comparison of measured and simulated return loss for multilayer patch antenna.
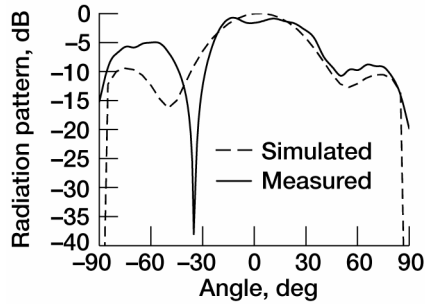
Figure 4.—Comparison between
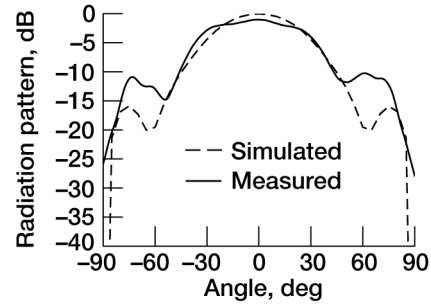measured and simulated far field
E-plane radiation pattern.

Figure 5.—Comparison between
measured and simulated far field
H-plane radiation pattern.

Conclusions

A directivity- as well as bandwidth-enhancement scheme, based on a vertically-stacked microstrip Yagi-like antenna is demonstrated. The antenna was analyzed via computer simulations and experimental measurements. Simulated as well as measured results show that this structure allows for high bandwidth while simultaneously maintaining a broadside beam of high directivity. Future work on this antenna will focus on design optimization for enhancement of these parameters. Application of this design concept to develop miniaturized antennas at S-band frequencies for surface-to-surface wireless lunar/mars communications is being investigated.

References

1. A.K. Shackelford, K.F. Lee, and K.M. Luk, "Design of Small-Size Wide-Bandwidth Microstrip-Patch Antennas," *IEEE Antennas and Propagation*, Vol. 45, No. 1, pp. 75–83, Feb. 2003.
2. R.Q. Lee and K.F. Lee, "Experimental Study of the Two-Layer Electromagnetically Coupled Rectangular Patch Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 38, No. 8, pp. 1298–1302, Aug. 1990.
3. S. Aditya, C.K. Sim, D. Wu, W.T. Chua, Z.X. Shen, and C.L. Law, "High-Gain 24-GHz CPW-fed Microstrip Patch Antennas on High-Permittivity Substrates," *Antennas and Wireless Propagation Letters*, Vol. 3, Iss. 3, pp. 30–33, 2004.
4. J. Huang, "Microstrip Yagi Array Antenna for Mobile Satellite Vehicle Application," *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 7, pp. 1024–1030, July 1991.
5. S.K. Padhi and M.E. Bialkowski, "Parametric Study of a Microstrip Yagi Antenna," Asia-Pacific Microwave Conference, pp. 715–718, Dec. 2000.

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 2005	Technical Memorandum

4. TITLE AND SUBTITLE

Demonstration of an X-Band Multilayer Yagi-Like Microstrip Patch Antenna With High Directivity and Large Bandwidth

5. FUNDING NUMBERS

WBS–22–612–30–81–04

6. AUTHOR(S)

James A. Nessel, Afroz Zaman, Richard Q. Lee, and Kevin Lambert

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–14994

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—2005-213554

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 32

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The feasibility of obtaining large bandwidth and high directivity from a multilayer Yagi-like microstrip patch antenna at 10 GHz is investigated. A measured 10-dB bandwidth of ~20 percent and directivity of ~11 dBi is demonstrated through the implementation of a vertically-stacked structure with three parasitic directors, above the driven patch, and a single reflector underneath the driven patch. Simulated and measured results are compared and show fairly close agreement. This antenna offers the advantages of large bandwidth, high directivity, and symmetrical broadside patterns, and could be applicable to satellite as well as terrestrial communications.

14. SUBJECT TERMS

Large bandwidth; High directivity; Microstrip antennas; Patch antennas; Multilayer structure

15. NUMBER OF PAGES

10

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	