NASA/TP—2007-214952

Design and Measurement of Self-Matched, Dual-Frequency Coplanar-Waveguide-Fed Slot Antennas

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December 2007

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Acknowledgments

We thank Elizabeth A. McQuaid and Nicholas C. Varaljay for their help with the fabrication of the antennas.

Level of Review: This material has been technically reviewed by an expert single reviewer.

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Summary

This report presents two new designs of dual-frequency, coplanar-waveguide-fed, double-folded slot antennas. An important advantage of these antennas is that, because they are self-matched to the feeding coplanar waveguide, they do not need an external matching circuit. This reduces the antenna size and simplifies its design. To verify the designs, the authors measured and compared the return loss and radiation patterns with those obtained using available commercial software with good agreement.

Introduction

Dual-frequency antennas are used in a variety of applications, including satellite communications, global positioning systems, synthetic aperture radar, and personal communications systems (refs. 1 to 3). Coplanar waveguide (CPW) feeds are attractive for microwave integrated circuits (MICs) and monolithic MIC applications because of their uniplanar structure, the ease of making shunt and series connections, and the wider degree of design freedom in comparison to microstrip.

For the designs described in this report, the CPW was used to feed two double-folded slot antennas of different lengths, resulting in dual-band operation. These folded slot antennas were chosen because they are conformal, have a low profile, and are easy to design.

One challenge in designing dual-band antennas is the need to match the antenna at both frequency bands. In a previous attempt, Omar and Antar (ref. 4) used seven matching stubs of different lengths to match both frequency bands. In the design work described in this report, the proposed antennas were self-matched at both frequency bands without an external matching circuit, which reduced the size of the antennas and considerably simplified the design procedure.

Two techniques were employed for self-matching. In design 1, the folded slot dipole was matched by increasing the number of slots from two for a regular folded dipole to *N*. This reduced the input impedance Z_{in} according to Babinet's principle as $Z_{in} = Z_{slot}/N_2$ (ref. 5), where *N* is the number of slots. Therefore, frequency bands were matched by increasing the number of slots in a folded slot antenna so that the input impedance approached that of the feed line.

In design 2, use was made of a published study (refs. 6 and 7) that showed that the impedance can be lowered by increasing the width of the slot arm that is farther from the feed. Hence, the width of one of the dipole arms was increased without changing any other dimension.

Design 1 Antenna on Alumina ($\varepsilon_r = 9.6$)

Design Procedure for the Design 1 Antenna

For the design 1 antenna, the chosen coplanar substrate was alumina with a thickness of 0.254 mm and a dielectric constant ε_r of 9.6. Figure 1 shows the geometry.

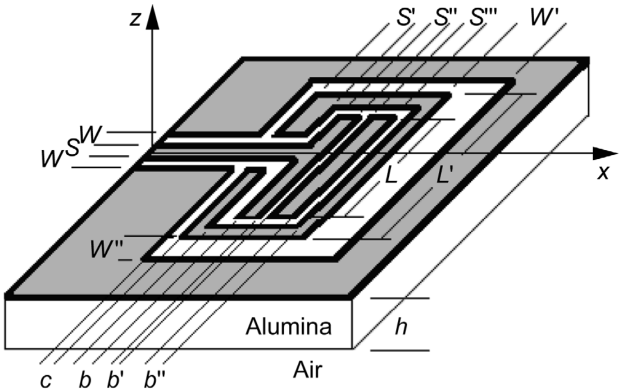

Figure 1.—Design 1 coplanar-waveguide-fed, dual-frequency slot antenna on alumina: W = 0.3 mm, S = 1.7 mm, S' = 0.1 mm, S'' = 0.3 mm, S''' = 0.1 mm, W' = 0.85 mm, c = 0.1 mm, b = b' = b'' = w'' = 0.1 mm, L = 11.26 mm, L' = 18.46 mm, h = 0.254 mm, and dielectric constant ε_r = 9.6.


Figure 2.—Experimental setup showing the transition from the coaxial connector to the coplanar waveguide feed.

The design procedure follows:

(1) The moment method simulator IE3D (Zeland Software, Inc.) was used to design the feed line to be a 50-Ω line on a 0.254-mm-thick alumina substrate. Hence, the slot width W was chosen to be 0.3 mm and the strip width S to be 1.7 mm. These dimensions were chosen to give a better transition between the coaxial connector and the CPW feed, as shown in figure 2.

(2) The outer folded slot dipole was a regular folded slot dipole with two slot arms, each having a length of approximately $\lambda_1/2$, where λ_1 is the guided wavelength of the CPW line at the lower resonant frequency f_1 of 5 GHz. From IE3D, λ_1 was 34.7 mm, hence the initial value of L' was 17.35 mm. The width of each slot was chosen to be 0.1 mm and could be slightly altered without affecting the design.

(3) The inner folded slot dipole was initially designed in the same way as for the outer loop using only two slot arms. Each arm had a length of approximately $\lambda_2/2$, where λ_2 is the guided wavelength of the CPW line at the upper resonant frequency f_2 of 7 GHz. From IE3D, λ_2 was 24.8 mm, hence the initial value of L was 12.4 mm. The width of each slot was also chosen to be 0.1 mm.

(4) At this stage, IE3D was used to carry out an initial simulation of the design. This showed that f_1 was 4.7 GHz, instead of 5 GHz, with a reflection coefficient $|S_{11}|$ of –3.54 dB; f_2 was 6.9 GHz with an $|S_{11}|$ of –5.18 dB.

(5) To obtain a better match at f_2, a third slot was added to the inner smaller folded dipole, as shown in figure 1, reducing $|S_{11}|$ at f_2 (6.76 GHz) from –5.18 to –14.24 dB. At f_1, $|S_{11}|$ worsened to –2.76 dB.

(6) To obtain a better match at f_1, the width W' of the outer slot of the larger folded dipole was increased in repeated steps, as shown in table I. From this table, W' was chosen to be 0.85 mm.

(7) Matching at both frequencies could be further improved by shifting the center slot arm of the smaller folded dipole away from the feed. Hence S'' was increased while S''' was decreased, as shown in figure 1. Taking S'' = 0.3 mm, and S''' = 0.1 mm gives $|S_{11}|$ = –26.39 dB at f_1 = 5.19 GHz, and $|S_{11}|$ = –37.79 dB at f_2 = 6.73 GHz.

(8) After a few repeated simulations using IE3D, we found that increasing L' to 18.46 mm and decreasing L to 11.26 mm resulted in more accurate resonant frequencies.

TABLE I.—EFFECT OF THE OUTER ARM WIDTH, W', ON THE REFLECTION COEFFICIENT, S_{11}, AND THE LOWER AND UPPER RESONANT FREQUENCIES, f_1 AND f_2

W', mm	f_1, GHz	S_{11} at f_1, dB	f_2, GHz	S_{11} at f_2, dB
0.1	4.63	–2.76	6.76	–14.24
0.3	4.8	–5.52	6.76	–42.22
0.5	4.98	–9.38	6.73	–39.08
0.7	5.08	–15.28	6.73	–19.91
0.85	5.19	–23.58	6.69	–16.05
1.0	5.22	–20.35	6.69	–14.26
1.2	5.29	–13.72	6.66	–11.99

Measured and Simulated Results for the Design 1 Antenna

The return loss was measured using the HP 8510 vector network analyzer (VNA) and HP 2.4 calibration standards. Figure 3 compares the measured and simulated results for the design 1 antenna on alumina. The return loss was obtained experimentally, using IE3D and the finite element simulator HFSS (Ansoft Corp.). The results are in very good agreement, verifying the design. The 10-dB bandwidth at both frequency bands was about 5 percent.

The copolarization and cross-polarization gain patterns of this antenna in the E-plane (x-z plane) and H-plane (y-z plane) were also measured and are shown in figures 4 and 5 for the

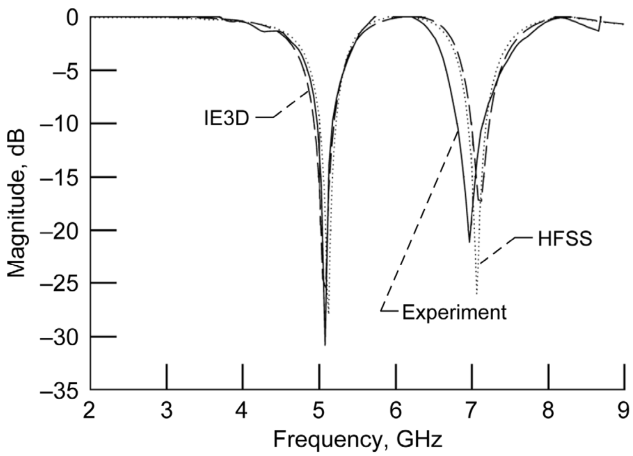

Figure 3.—Return loss of the design 1 dual-band antenna. Dimensions are shown in figure 1.

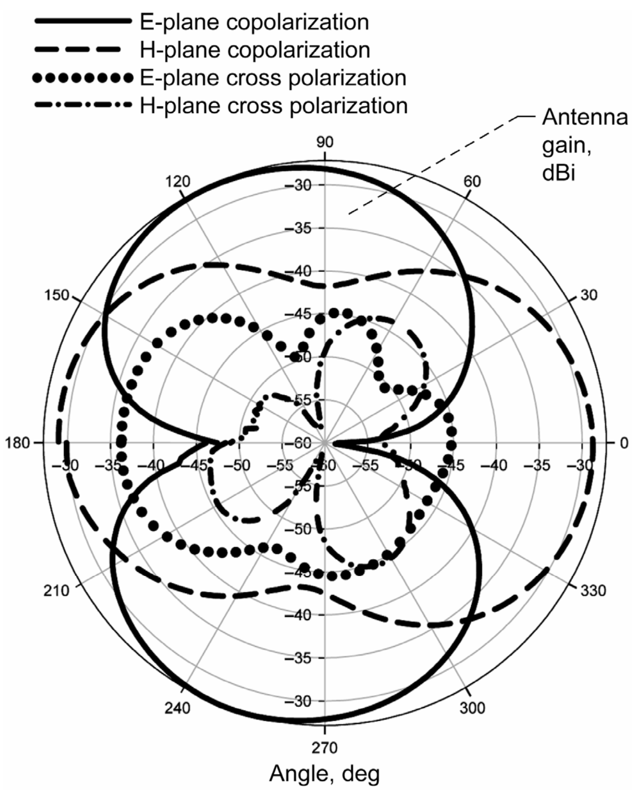

Figure 4.—Measured radiation pattern of the design 1 dual-band antenna at 5.0 GHz.

two measured center frequencies, 5.0 and 7.0 GHz, respectively. The antennas were measured in the far-field range in the Microwave Metrology Facility at the NASA Glenn Research Center. A 2- to –18-GHz broadband gain horn from Q-par Angus Ltd. (U.K.) was used to characterize the antenna gain patterns. These patterns show that the antenna possesses a linear polarization with a cross-polarization level that is more than 20 dBi (decibels isotropic) lower than the copolarization level. At 5.0 and 7.0 GHz, the antenna gain was about 3.5 dBi.

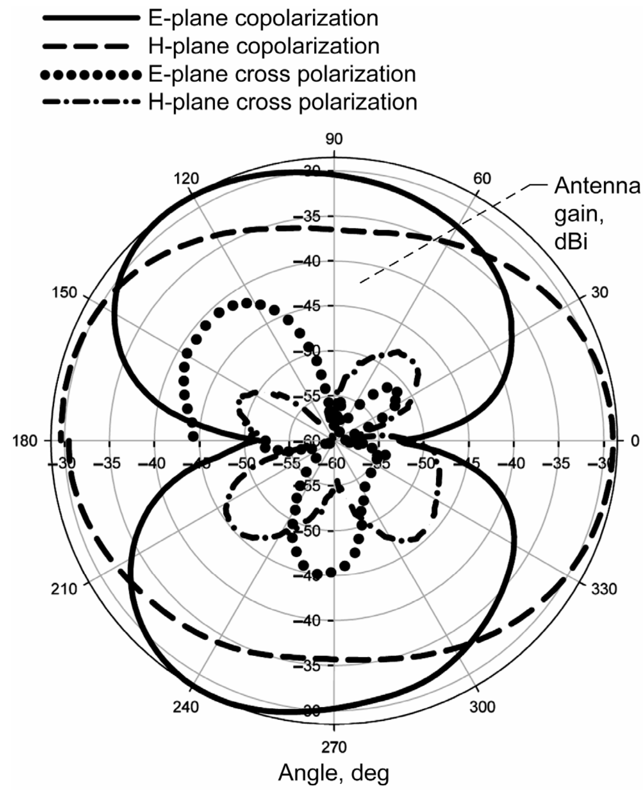

Figure 5.—Measured radiation pattern of the design 1 dual-band antenna at 7.0 GHz.

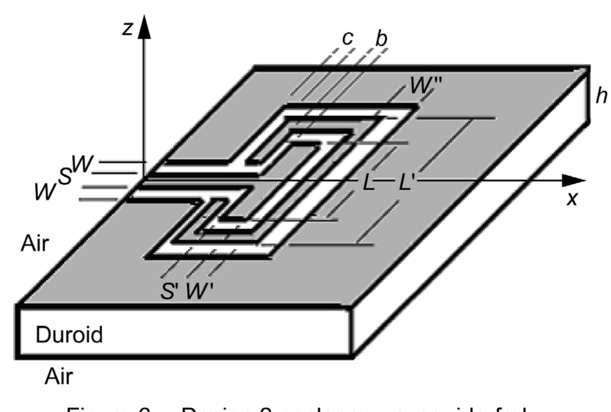

Figure 6.—Design 2 coplanar-waveguide-fed, dual-frequency slot antenna on Duroid: W = 0.3 mm, S = 1.7 mm, S' = 0.46 mm, W' = 0.35 mm, W'' = 1.36 mm, L = 16.7 mm, L' = 22.57 mm, c = b = 0.15 mm, dielectric constant ε_r = 2.2, and h = 3.175 mm.

Design 2 Antenna on Duroid (ε_r = 2.2)

Design Procedure for the Design 2 Antenna

For the design 2 antenna, the chosen coplanar substrate was Duroid with a thickness of 3.18 mm and ε_r of 2.2. Figure 6 shows the geometry of the design 2 antenna. The design

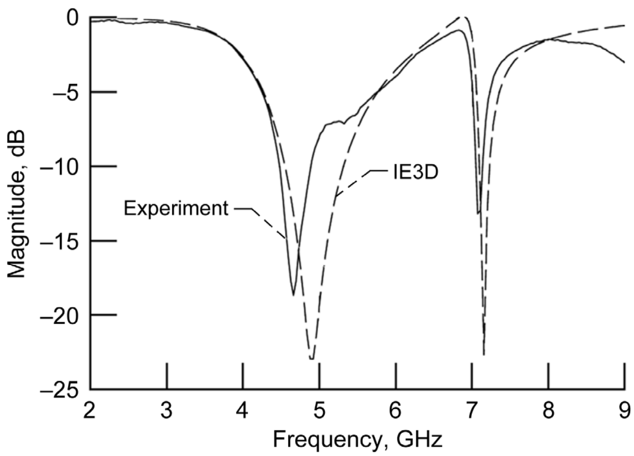

Figure 7.—Return loss of the design 2 dual-band antenna. Dimensions are shown in figure 6.

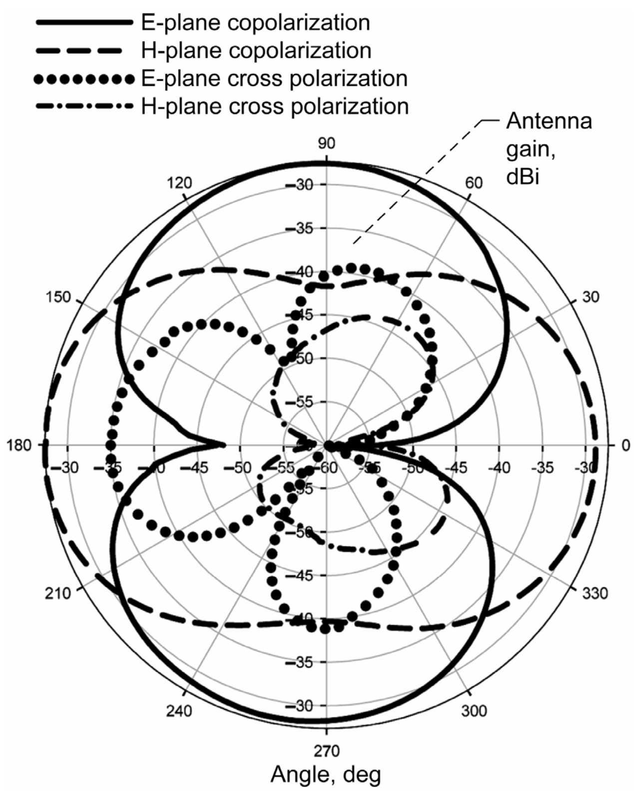

Figure 8.—Measured radiation pattern of the design 2 dual-band antenna at 7.0 GHz.

procedure was similar to that for design 1. The outer folded slot dipole is a regular folded slot dipole with two slot arms, each having a length *L*' of 22.57 mm and a width of 0.15 mm. This dipole resonates at 4.7 GHz and has an impedance of about 128 Ω. To match this antenna to the 70-Ω feeding CPW (*S* = 1.7 mm and *W* = 0.3 mm), the width of the external slot arm of the dipole *W*" was increased from 0.15 to 1.36 mm.

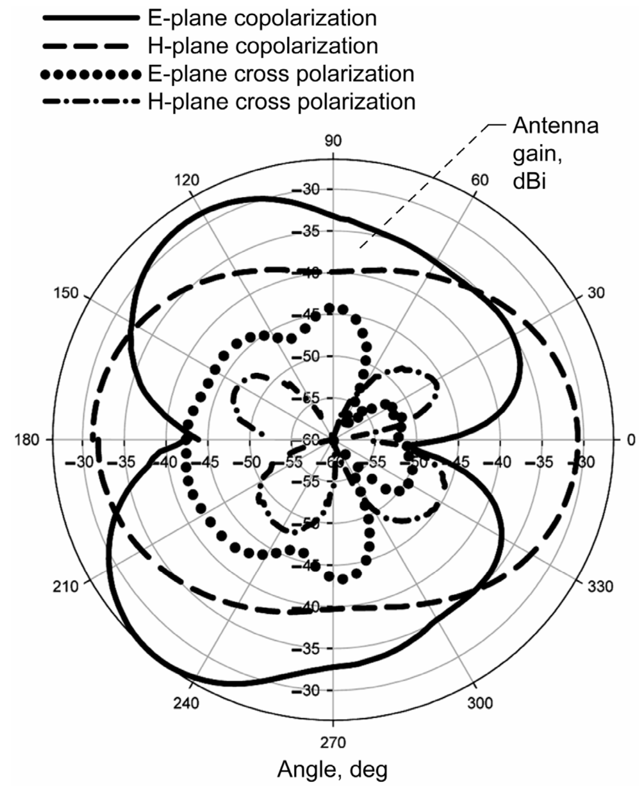

Figure 9.—Measured radiation pattern of the design 2 dual-band antenna at 7.1 GHz.

The difference between design 1 and 2 is that in the latter, the inner folded slot dipole consists of only two slot arms. Each arm has a length of 16.7 mm and a width of 0.15 mm. The width *W*' of the outer arm of the inner slot was increased from 0.15 to 0.35 mm for matching purposes. This dipole resonates at 7.1 GHz.

Measured and Simulated Results for the Design 2 Antenna

Figure 7 shows the measured and IE3D simulated return loss of the design 2 antenna on Duroid. The two resonances are at 4.7 and 7.1 GHz, with measured return losses of 20 and 15 dB, respectively. The 10-dB bandwidth at both frequency bands was about 4 percent.

The measured gain patterns of this antenna in the E-plane and H-plane are shown in figures 8 and 9 for the two center frequencies, 4.7 and 7.1 GHz, respectively. At both frequencies, the gain was about 4.5 dBi and the cross polarization was about 20 dBi less than the copolarization.

Conclusions

Two techniques for designing dual-band, coplanar-waveguide-fed, double-folded slot antennas that do not require an external matching circuit were demonstrated. Using more internal slots inside the antenna, shifting the position of these slots, or increasing the width of one of the slot arms achieved matching at both frequency bands without significantly affecting the shape of the radiation pattern.

Two different designs, on alumina and Duroid, were fabricated and measured. The experimental results were compared with those obtained using commercial full-wave simulators with very good agreement. A full design procedure has been provided.

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Glenn Research Center
National Aeronautics and Space Administration
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REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*
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4. TITLE AND SUBTITLE Design and Measurement of Self-Matched, Dual-Frequency Coplanar-Waveguide-Fed Slot Antennas					**5a. CONTRACT NUMBER**
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Omar, Amjad, A.; Scardelletti, Maximilian, C.; Hejazi, Zuhair, M.; Dib, Nihad					**5d. PROJECT NUMBER**
					5e. TASK NUMBER
					5f. WORK UNIT NUMBER WBS 953033.01.03.15
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-16181
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001					**10. SPONSORING/MONITORS ACRONYM(S)** NASA
					11. SPONSORING/MONITORING REPORT NUMBER NASA/TP-2007-214952
12. 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					
13. SUPPLEMENTARY NOTES Submitted to IEEE Antennas and Propagation Transactions.					
14. ABSTRACT This report presents two new designs of dual-frequency, coplanar-waveguide-fed, double-folded slot antennas. An important advantage of these antennas is that, because they are self-matched to the feeding coplanar waveguide, they do not need an external matching circuit. This reduces the antenna size and simplifies its design. To verify the designs, the authors measured and compared the return loss and radiation patterns with those obtained using available commercial software with good agreement.					
15. SUBJECT TERMS Dual-frequency slot antennas; Self impedance matching; Duroid; Alumina; Coplanar waveguide; Multiple band antennas					
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a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	11	**19b. TELEPHONE NUMBER** *(include area code)* 301-621-0390

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