NASA/TM—2002-211816

Novel On-Wafer Radiation Pattern Measurement Technique for MEMS Actuator Based Reconfigurable Patch Antennas

Rainee N. Simons
Glenn Research Center, Cleveland, Ohio

October 2002

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—2002-211816

Novel On-Wafer Radiation Pattern Measurement Technique for MEMS Actuator Based Reconfigurable Patch Antennas

Rainee N. Simons
Glenn Research Center, Cleveland, Ohio

Prepared for the
24th Annual Antenna Measurement Techniques Association Meeting and Symposium
cosponsored by the Aeroflex Lintek Corporation and Mission Research Corporation
Cleveland, Ohio, November 3–8, 2002

National Aeronautics and
Space Administration

Glenn Research Center

October 2002

Acknowledgments

This work was funded under the NASA CICT TASK entitled "MEMS Actuator-Based Antenna Technology" under Code R.

This report contains preliminary findings, subject to revision as analysis proceeds.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

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

NOVEL ON-WAFER RADIATION PATTERN MEASUREMENT TECHNIQUE FOR MEMS ACTUATOR BASED RECONFIGURABLE PATCH ANTENNAS

Rainee N. Simons
National Aeronautics and Space Administration
Glenn Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Phone: 216–433–3462, Fax: 216–433–8705
E-mail: Rainee.N.Simons@grc.nasa.gov

ABSTRACT

The paper presents a novel on-wafer, antenna far field pattern measurement technique for microelectromechanical systems (MEMS) based reconfigurable patch antennas. The measurement technique significantly reduces the time and the cost associated with the characterization of printed antennas, fabricated on a semiconductor wafer or dielectric substrate. To measure the radiation patterns, the RF probe station is modified to accommodate an open-ended rectangular waveguide as the rotating linearly polarized sampling antenna. The open-ended waveguide is attached through a coaxial rotary joint to a Plexiglas™ arm and is driven along an arc by a stepper motor. Thus, the spinning open-ended waveguide can sample the relative field intensity of the patch as a function of the angle from bore sight. The experimental results include the measured linearly polarized and circularly polarized radiation patterns for MEMS-based frequency reconfigurable rectangular and polarization reconfigurable nearly square patch antennas, respectively.

1. Introduction

Microelectromechanical systems (MEMS) based actuators have emerged as a viable alternative to solid state control devices in microwave circuits. The MEMS actuators offer several advantages [1]. First, significant reduction in insertion loss, which results in higher figure-of-merit. Second, they consume insignificant amount of power during operation, which results in higher efficiency. Third, they exhibit higher linearity and as a result lower signal distortion when compared to semiconductor devices. Last, MEMS actuators have the potential to dynamically reconfigure the frequency, polarization, and radiation pattern of antennas thus providing total reconfigurability. These advantages have been the motivation to integrate MEMS switches/actuators with planar antennas for beam steering and frequency/polarization reconfiguration. Typical examples of MEMS based antennas are reported in references [1–9]. In these examples, the antennas and arrays are fabricated on a semiconductor wafer, such as high resistivity silicon, semi-insulating GaAs or a dielectric substrate, such as alumina or fused quartz, using conventional photolithography techniques. One of the challenges faced with the characterization of MEMS based antennas on semiconductor wafers is the need for a fast and inexpensive technique to measure the radiation patterns without having to saw the wafer. Measurement techniques reported in the literature [10–12] are more suited for conventional printed antennas.

In this paper, we demonstrate a novel on-wafer, antenna far field pattern measurement technique for MEMS-based reconfigurable patch antennas fabricated on a high resistivity silicon wafer. This technique requires a coplanar waveguide (CPW) ground-signal-ground (G-S-G) microwave probe (Picoprobe Model 40 A, pitch 250 μm), a RF wafer probe station (Cascade Model 42), and an automatic network analyzer/microwave receiver. The advantages of this technique are (1) it eliminates the need to saw the wafer into smaller individual patch antenna for characterization, minimizing loss due breakage and enhancing yield, and (2) it eliminates the need for custom-built test fixtures with special launchers/transitions, reducing the complexity, development time, and cost. In a production environment, this technique is extremely fast and inexpensive when automated for repeated measurements.

2. Patch Antennas with Integrated MEMS Actuators

Figures 1(a) and (b) are wafer maps illustrating patch antennas on a 3-in. diameter high resistivity silicon wafer (ε_r = 11.7) with integrated MEMS actuator for frequency and polarization reconfiguration, respectively. In these circuits a microstrip line of characteristic impedance equal to 50 Ω excites the patch antennas. The length of this line is kept small to minimize feed losses. The microstrip feed is terminated at the opposite end in a microstrip-to-CPW transition for on-wafer characterization using CPW RF probes, as illustrated in figure 2. The transition makes use of a radial stub to provide a virtual RF short circuit between the ground contacts of the CPW RF wafer probe and the substrate ground plane [13]. A typical frequency reconfigurable and polarization reconfigurable patch antennas with integrated MEMS actuator are illustrated in figures 3 (a) and (b), respectively. The design and fabrication of these antennas are described in references [3] and [4], respectively. Briefly, the frequency reconfigurable patch antenna operates at its normal frequency as determined by the dimension b when the actuator is in the OFF-state. In the ON-state, the excess capacitance provided by the actuator tunes the patch to a lower operating frequency thus providing frequency reconfiguration.

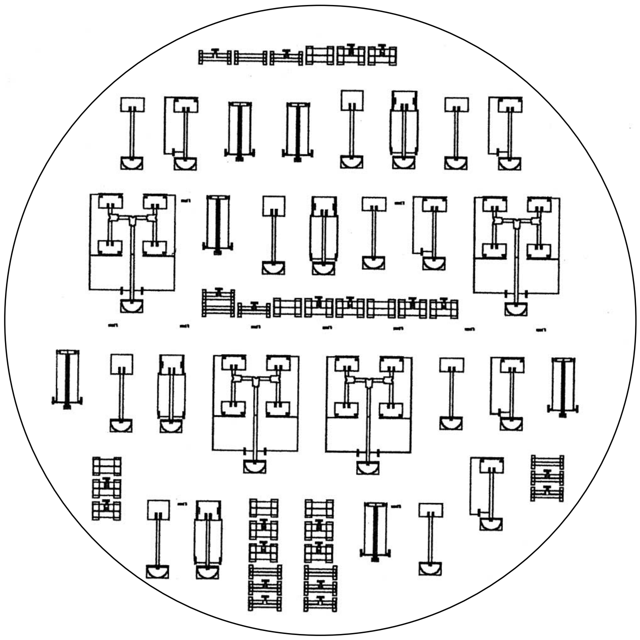

Figure 1(a).—Patch Antennas With Integrated MEMS Actuator for Frequency Reconfiguation On a 3 Inch Diameter High Resistivity Silicon Wafer.

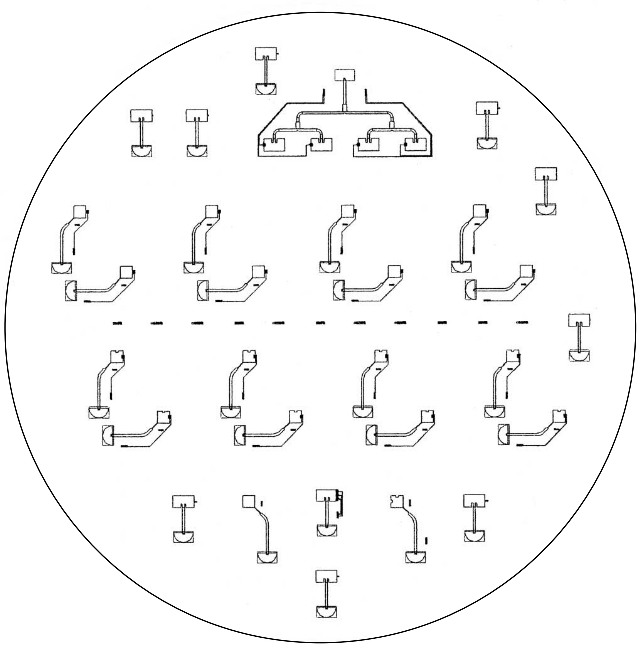

Figure 1(b).—Patch Antennas With Integrated MEMS Actuator for Polarization Reconfiguation On a 3 Inch Diameter High Resistivity Silicon Wafer.

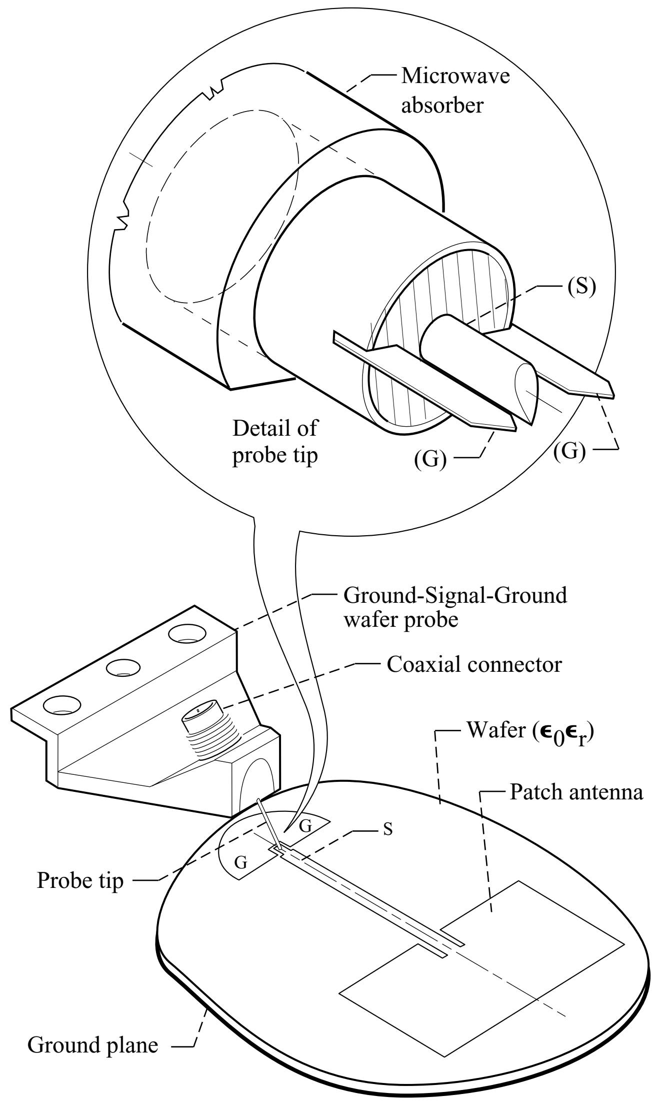

Figure 2.—Schematic Illustrating the Experimental Setup for Measuring the Return Loss of a Patch Antenna.

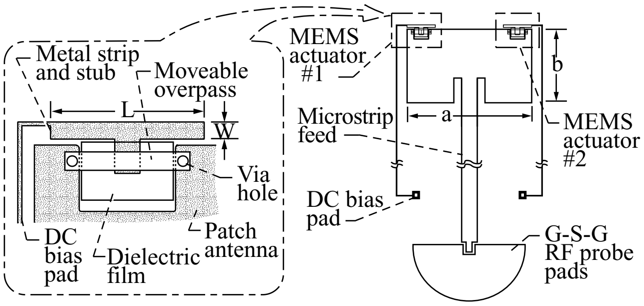

Figure 3(a).—Frequency Reconfigurable Patch Antenna Element With Two Independent MEMS Actuators, L = 580 µm, W = 50 µm, a = 2600 µm, b = 1500 µm.

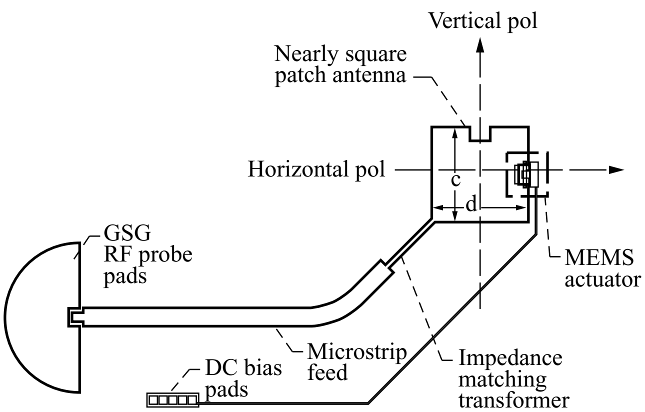

Figure 3(b).—Polarization Reconfigurable Patch Antenna Element With Integrated MEMS Actuator, c = 1500 µm and d = 1492 µm.

In the case of polarization reconfigurable patch antenna, the nearly square patch with notches is designed to support two degenerate orthogonal modes when excited at a corner. When the MEMS actuator is in the OFF-state, the perturbation of the modes is negligible and hence the patch radiates a circularly polarized (CP) wave. In the ON-state, the excess capacitance perturbs the phase relation between the modes causing the patch to radiate dual linearly polarized (LP) waves.

3. Measurement Methodology

3.1 Return Loss

The CPW G-S-G RF probes are calibrated to the tips using an automatic network analyzer (ANA) (HP 8510C) and a short circuit, open circuit, and a matched load as standards. The probe manufacturer provides, on an impedance standard substrate (ISS) and on a disc, the calibration standards and the software necessary to carry out the calibration. The calibration corrects for the errors, the losses as well as the parasitics associated with the experimental set-up, which includes the CPW RF probes. The calibrated

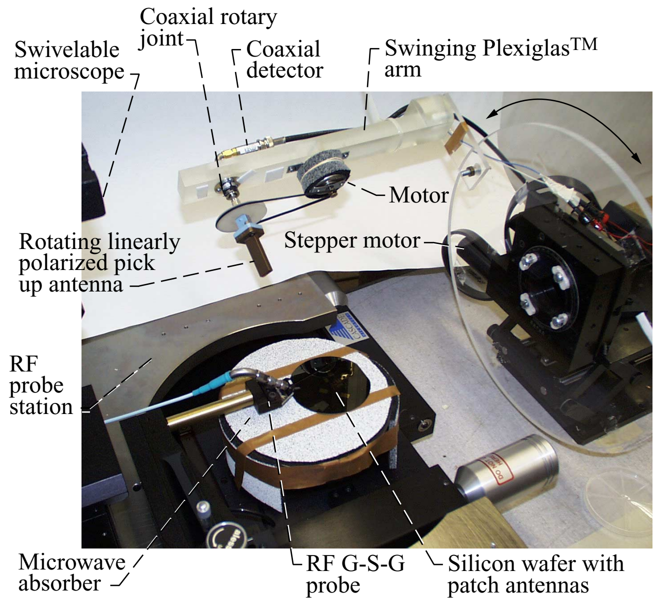

Figure 4.—Computer Controlled On-Wafer CP Radiation Pattern Measurement Set-Up Using a Rotating Linearly Polarized Pick-Up Antenna for MEMS Actuator Based Patch Antennas. (Surrounding Microwave Absorber Panels Have Been Removed).

probe is then made to contact the circuit under test as shown in figure 2. Thus, the intrinsic return loss of the antenna is displayed on the ANA and can be recorded. In addition, the feed losses as well as the input impedance of the antenna can be de-embedded as demonstrated in references [14,15].

3.2 Radiation Pattern

To measure the radiation patterns, the RF probe station is modified to accommodate an open-ended rectangular waveguide (e.g., WR–42) as the rotating linearly polarized sampling antenna. The open-ended waveguide is attached to a custom-built Plexiglas™ fixture. The fixture arm is positioned along a virtual arc, extending from –90° to +90° in increments of few degrees, by a stepper motor. Simultaneously, a miniature DC motor attached to the Plexiglas™ arm spins the open-ended waveguide. The spinning open-ended waveguide samples the relative field intensity of the circularly polarized radiation from the patch as a function of the angle from bore sight. The signals picked up by the waveguide are coupled to a detector through a coaxial rotary joint. The experimental setup is illustrated in figure 4. Figure 5 presents a close-up of the experimental set-up showing the CPW RF and the DC probes for exciting the patch and biasing the MEMS actuator.

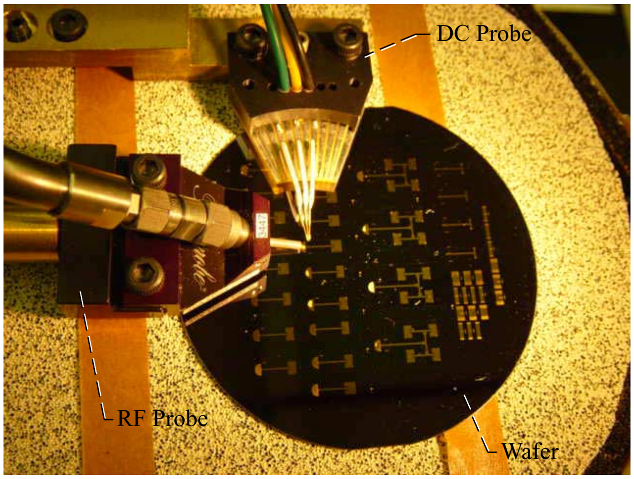

Figure 5.—Close-up of the Measurement Set-Up.

4. Measured Return Loss Characteristics

4.1 Frequency Reconfigurable Patch

The measured return loss for the two states of the actuators are shown in figures 6(a)–(c). When both the actuators are in the OFF-state, the patch resonates at its nominal operating frequency of about 25.0 GHz as shown in figure 6(a). The –10.0 dB return loss bandwidth of the patch is about 3.3 percent. When actuator #1 is in ON-state and actuator #2 is in the OFF-state, the resonant frequency (f_r) shifts to about 24.8 GHz as shown in figure 6(b). Similarly, when actuator #1 is in the OFF-state and actuator #2 is in the ON-state, the f_r shifts to 24.8 GHz. This result is expected since the two actuators are identical in construction. The step change of 200 MHz in the f_r for both cases is about 0.8 percent of the patch nominal operating frequency. Finally, when both actuators are in the ON-state, the f_r is 24.6 GHz as shown in figure 6(a). The shift is twice as much as the case when a single actuator is turned ON. Furthermore, at resonance the magnitudes of the return loss are almost equal for the two states, implying minimum loss of sensitivity. Thus for this configuration, the patch antenna can be dynamically reconfigured to operate at different bands, separated by a few hundred MHz, by digitally addressing either or both actuators. This is a desirable feature in mobile wireless systems to enhance capacity as well as combat multipath fading.

4.2 Polarization Reconfigurable Patch

The measured return loss for the OFF-state of the actuator is shown in figure 7. The patch is well matched to the 50Ω feed line and resonates at a frequency of 26.7 GHz. In the OFF-state the patch radiates a circularly polarized wave. The measured return loss for the ON-state of the actuator is also shown in figure 7. In the ON-state also the patch is also well matched to the 50Ω feed line and resonates at a frequency of 26.625 GHz. The change in the resonance frequency for the two states is considered to be small. In the ON-state, the patch radiates dual linearly polarized waves.

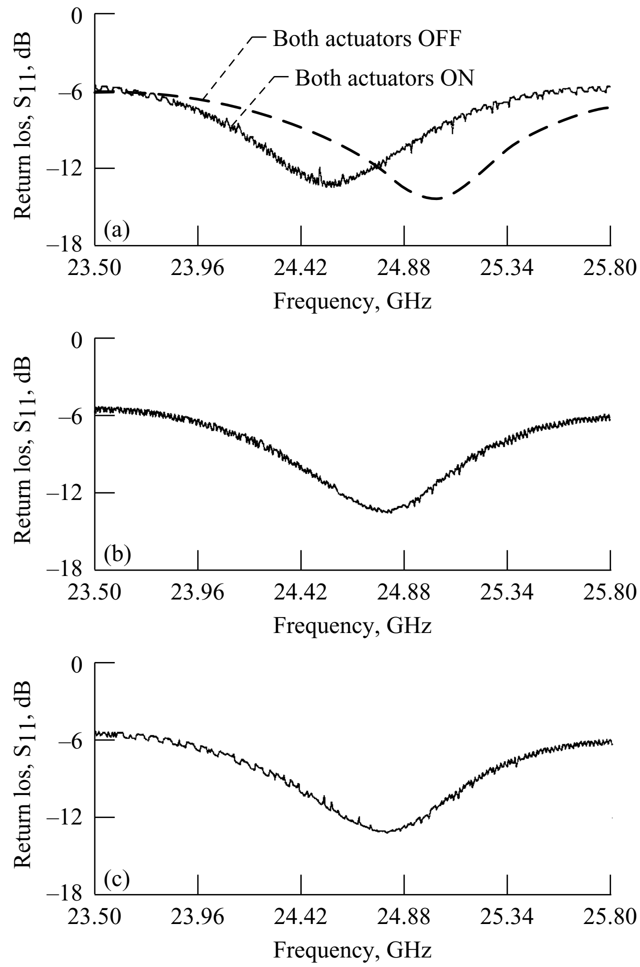

Figure 6.—Measured Return Loss Demonstrating Frequency Reconfigurability. (a) Both Actuators Are Either in the OFF State or ON State. (b) Actuator #1 is ON and Actuator #2 is OFF. (c) Actuator #1 is OFF and Actuator #2 is ON.

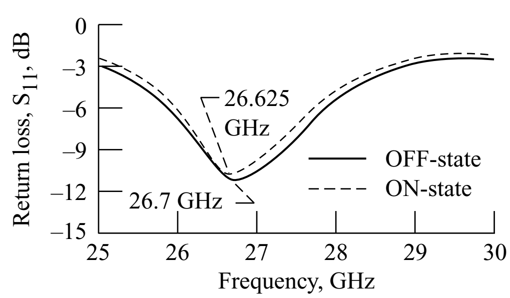

Figure 7.—Measured Return Loss of Nearly Square Patch Antenna.

5. Measured Radiation Patterns

5.1 Frequency Reconfigurable Patch

The measured E- and H-plane radiation patterns are shown in figure 8.

5.2 Polarization Reconfigurable Patch

In the OFF-state, the patch radiates a circularly polarized wave. The measured radiation patterns along the two orthogonal planes are shown in figure 9. The measured axial ratio at boresight is about 2.0 dB. In the ON-state, the patch radiates dual linearly polarized waves. The measured E- and H-plane radiation patterns for the vertical polarization are shown in figure 10. Similar radiation patterns are observed for the horizontal polarization.

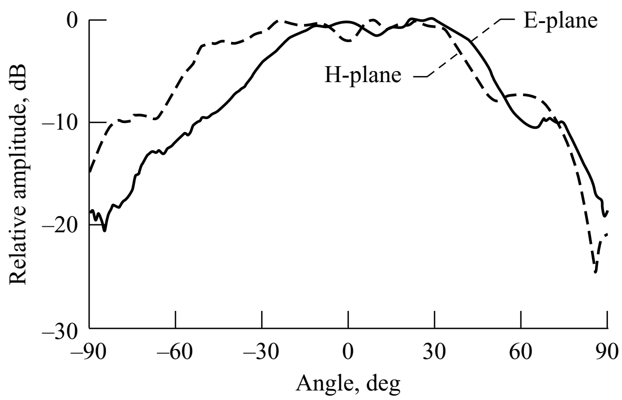

Figure 8.—Measured E and H-plane Radiation Patterns of The Frequency Reconfigurable Patch Antenna.

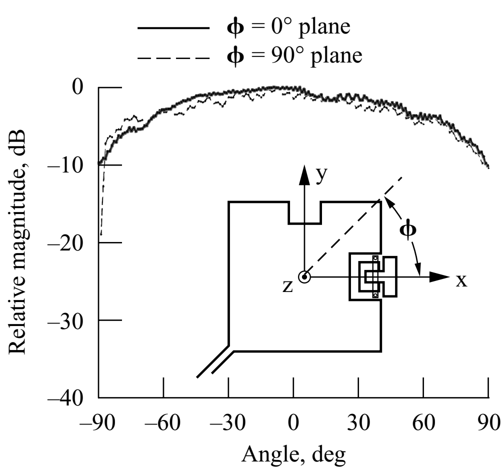

Figure 9.—Measured Circularly Polarized Radiation Patterns of Nearly Square Patch Antenna.

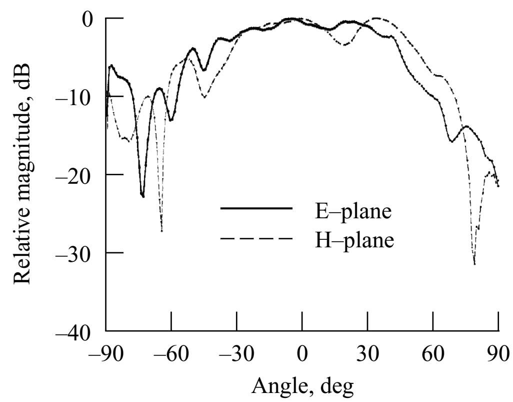

Figure 10.—Measured Linearly Polarized Radiation Patterns for Vertical Polarization of Nearly Square Patch Antenna.

6. Sources of Measurement Errors

One of the major sources of error is the reflection of the signal radiated from the patch antenna by the probe station positioners and fixtures. This causes distortion in the measured radiation patterns. This problem can be reduced with the use of high quality microwave absorbing material covering the probe station metal surfaces. A second source of error is due to misalignment of the patch antenna and the sampling antenna. The wafer with the patch antennas can be horizontally aligned and the open-ended waveguide sampling antenna can be vertically aligned using a precision level and a plumb bob, respectively. In addition, the angular alignment of the wafer can be done optically with the help of a microscope. Last, the errors associated with the CPW G-S-G RF probes can be calibrated out as discussed in section 3.1.

7. Conclusions and Future Directions

A novel fast and inexpensive on-wafer far field radiation pattern measurement technique for characterizing patch antennas with integrated MEMS actuators is demonstrated. This technique eliminates the need to saw the wafer into smaller individual patch antennas, thus minimizing loss due breakage and enhancing yield. In addition, eliminates the need for custom-built test fixtures with special launcher/transition, thus reducing the complexity, development time, and cost.

We plan to extend this effort to the measurement of gain and cross-polarization. The gain can be determined by the reflection method [16]. The cross-polarization can be measured using a circularly polarized sampling antenna whose sense of polarization is known.

8. REFERENCES

[1] J.K. Smith, “Reconfigurable Aperture Program (RECAP) –MEMS Revolutionary Impact on RF Systems,” Notes of the Workshop “RF MEMS for Antenna Applications,” 2000 IEEE Ant. and Prop. Inter. Symp., Salt Lake City, UT, July 16, 2000.

[2] R.N. Simons, D. Chun, and L.P.B. Katehi, “Microelectromechanical Systems (MEMS) Actuators for Antenna Reconfigurability,” 2001 IEEE MTT-S Inter. Microwave Symp. Dig., Vol. 1, pp. 215–218, Phoenix, AZ, May 20–25, 2001.

[3] R.N. Simons, D. Chun, and L.P.B. Katehi, “Reconfigurable Array Antenna Using Microelectromechanical Systems (MEMS) Actuators,” 2001 IEEE Ant. and Prop. Inter. Symp. Dig., Vol. 3, pp. 674–677, Boston, MA, July 8–13, 2001.

[4] R.N. Simons, D. Chun, and L.P.B. Katehi, “Polarization Reconfigurable Patch Antenna Using Microelectromechanical Systems (MEMS) Actuators,” 2002 IEEE Ant. and Prop. Inter. Symp. Dig., Vol. 2, pp. 6–9, San Antonio, TX, June 16–21, 2002.

[5] J.H. Schaffner, D.F. Sievenpiper, R.Y. Loo, J.J. Lee, and S.W. Livingston, “A Wideband Beam Switching Antenna Using RF MEMS Switches,” 2001 IEEE Ant. and Prop. Inter. Symp. Dig., Vol. 3, pp. 658–661, Boston, MA, July 8–13, 2001.

[6] C.-W. Baek, S. Song, C. Cheon, Y.-K. Kim, and Y. Kwon, “2-D Mechanical Beam Steering Antenna Fabricated Using MEMS Technology,” 2001 IEEE MTT-S Inter. Microwave Symp. Dig., Vol. 1, pp. 211–214, Phoenix, AZ, May 20–25, 2001.

[7] C. Bozler, et al., “MEMS Microswitch Arrays for Reconfigurable Distributed Microwave Components,” 2000 IEEE Ant. and Prop. Inter. Symp., Dig., Vol. 2, pp. 587–591, Salt Lake City, UT, July 16–21, 2000.

[8] J.-C. Chiao, Y. Fu, I.M. Chio, M. DeLisio, and L.-Y. Lin, “MEMS Reconfigurable Vee Antenna,” 1999 IEEE MTT-S Inter. Microwave Symp. Dig., Vol. 4, pp. 1515–1518, Anaheim, CA, June 13–19, 1999.

[9] D. Chauvel, N. Haese, P.-A. Rolland, D. Collard, and H. Fujita, “A Micro-Machined Microwave Antenna Integrated with its Electrostatic Spatial Scanning,” Proc. IEEE Tenth Annual Inter. Workshop on Micro Electro Mechanical Systems (MEMS 97), pp. 84–89, Nagoya, Japan, Jan. 26–30, 1997.

[10] J.S. Hollis, T.J. Lyon, and L. Clayton, Jr., (Editors), Microwave Antenna Measurements, Scientific-Atlanta, Inc., Second Edition, Atlanta, GA, Chap. 10, 1970.

[11] Y.T. Lo and S.W. Lee, (Editors), Antenna Handbook, Theory, Applications, and Design, Van Nostrand Reinhold Company, Inc., New York, NY, Chap. 32, pp. 49–64, 1988.

[12] R.C. Johnson, (Editor), Antenna Engineering Handbook, Third Edition, McGraw-Hill, Inc., New York, NY, Chap. 23, pp. 1–33, 1993.

[13] D.F. Williams and T.H. Miers, “A Coplanar Probe to Microstrip Transition,” IEEE Trans. Microwave Theory Tech., Vol. 36, No. 7, pp. 1219–1223, July 1988.

[14] R.N. Simons and R.Q. Lee, “On-Wafer Characterization of Millimeter-Wave Antennas for Wireless Applications,” IEEE Trans. Microwave Theory Tech., Vol. 47, No. 1, pp. 92–96, Jan. 1999.

[15] A.J. Zaman, R.Q. Lee, and R.N. Simons, “A New Design Approach for a Patch Antenna with a Notch Feed,” Microwave and Optical Technology Lett., Vol. 23, No. 4, pp. 236–238, Nov. 1999.

[16] S. Silver, (Editor), Microwave Antenna Theory and Design, Peter Peregrinus Ltd., London, UK, Sec. 15·20, 1984.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2002	Technical Memorandum

4. TITLE AND SUBTITLE

Novel On-Wafer Radiation Pattern Measurement Technique for MEMS Actuator Based Reconfigurable Patch Antennas

5. FUNDING NUMBERS

WU–755–08–0B–00

6. AUTHOR(S)

Rainee N. Simons

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–13508

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—2002-211816

11. SUPPLEMENTARY NOTES

Prepared for the 24th Annual Antenna Measurement Techniques Association Meeting and Symposium cosponsored by the Aeroflex Lintek Corporation and Mission Research Corporation, Cleveland, Ohio, November 3–8, 2002. Responsible person, Rainee N. Simons, organization code 5620, 216–433–3462.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 33 Distribution: Nonstandard

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 paper presents a novel on-wafer, antenna far field pattern measurement technique for microelectromechanical systems (MEMS) based reconfigurable patch antennas. The measurement technique significantly reduces the time and the cost associated with the characterization of printed antennas, fabricated on a semiconductor wafer or dielectric substrate. To measure the radiation patterns, the RF probe station is modified to accommodate an open-ended rectangular waveguide as the rotating linearly polarized sampling antenna. The open-ended waveguide is attached through a coaxial rotary joint to a Plexiglas™ arm and is driven along an arc by a stepper motor. Thus, the spinning open-ended waveguide can sample the relative field intensity of the patch as a function of the angle from bore sight. The experimental results include the measured linearly polarized and circularly polarized radiation patterns for MEMS-based frequency reconfigurable rectangular and polarization reconfigurable nearly square patch antennas, respectively.

14. SUBJECT TERMS

Antenna measurements; Microelectromechanical systems; MEMS; Automated on-wafer measurements; Instrumentation; Coplanar waveguide; Microstrip; Radiation pattern; Circular polarization; Dual linear polarization; Patch antenna; Semiconductor antenna

15. NUMBER OF PAGES

12

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	