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

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October 2002

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

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ABSTRACT

The paper presents a novel on-wafer, antenna far field pattern measurement technique for microelectro-mechanical 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.

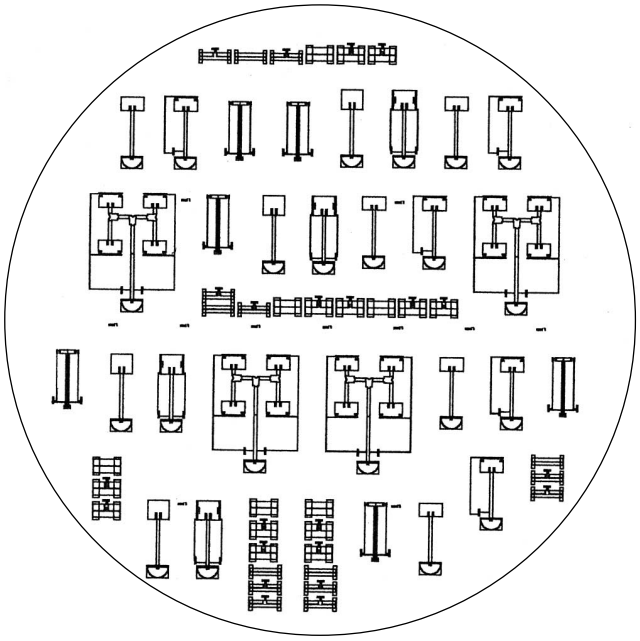

Figure 1(a).—Patch Antennas With Integrated MEMS Actuator for Frequency Reconfiguation On a 3 Inch Diameter High Resistivity Silicon Wafer.

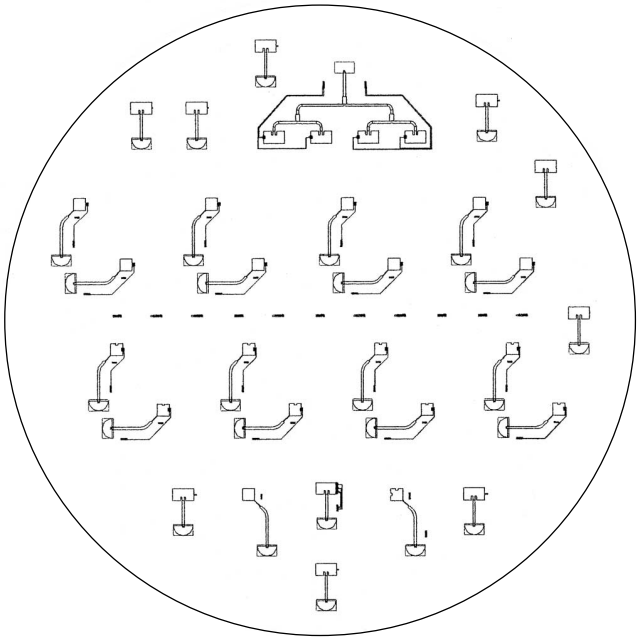

Figure 1(b).—Patch Antennas With Integrated MEMS Actuator for Polarization Reconfiguation On a 3 Inch Diameter High Resistivity Silicon Wafer.

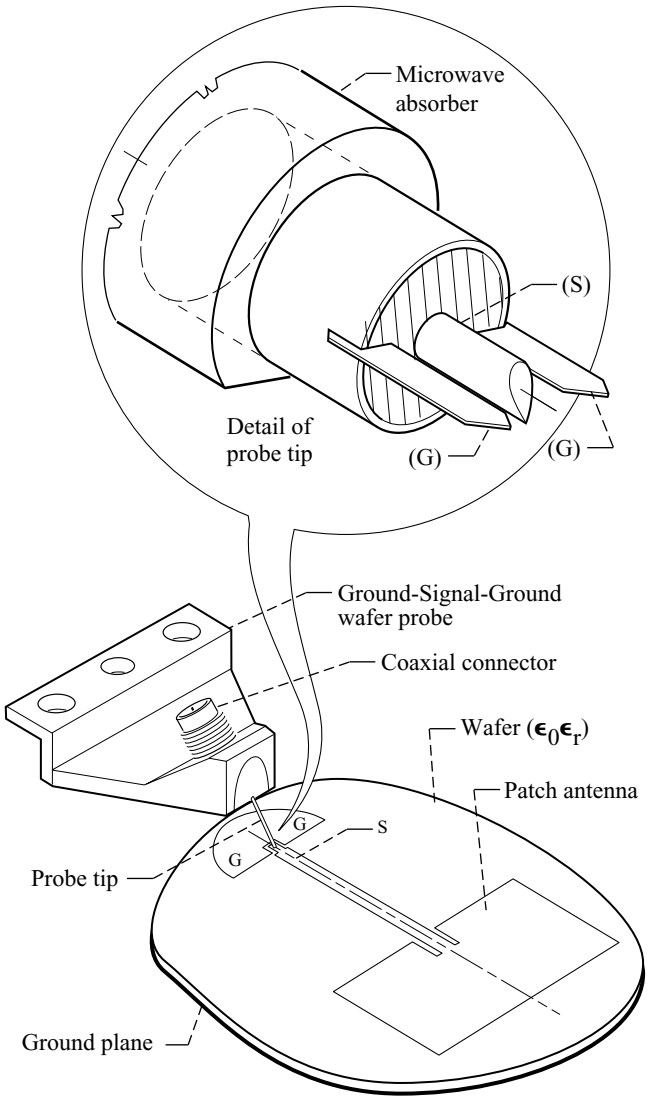

Figure 2.—Schematic Illustrating the Experimental Setup for Measuring the Return Loss of a Patch Antenna.

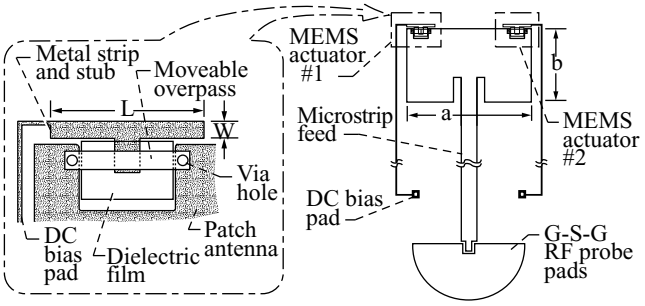

Figure 3(a).—Frequency Reconfigurable Patch Antenna Element With Two Independent MEMS Actuators, L = 580 µm, W = 50 µm, a = 2600 µm, b = 1500 µm.

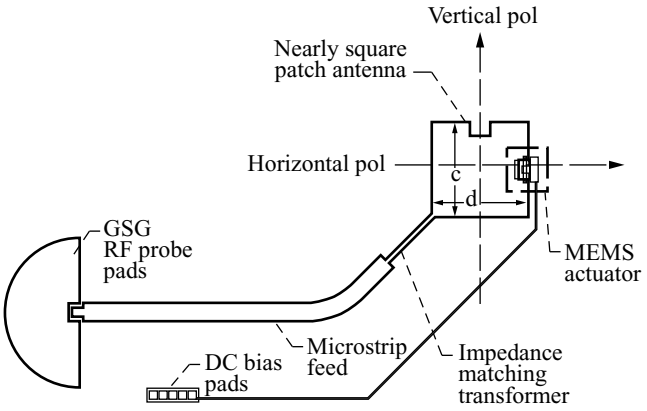

Figure 3(b).—Polarization Reconfigurable Patch Antenna Element With Integrated MEMS Actuator, c = 1500 µm and d = 1492 µm.

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

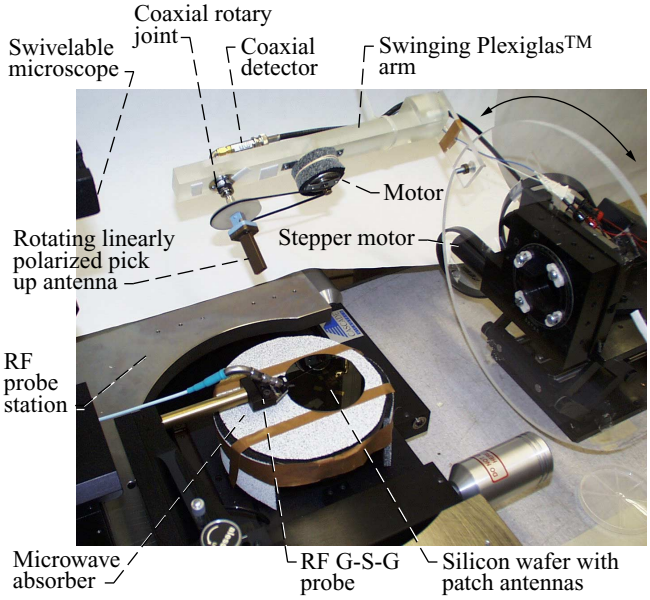

Figure 4.—Computer Controlled On-Wafer CP Radiation Pattern Measurement Set-Up Using a Rotating Linearly Polarized Pick-Up Antenna for MEMS Actuator Based Patch Antennas. (Surrounding Microwave Absorber Panels Have Been Removed).

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.

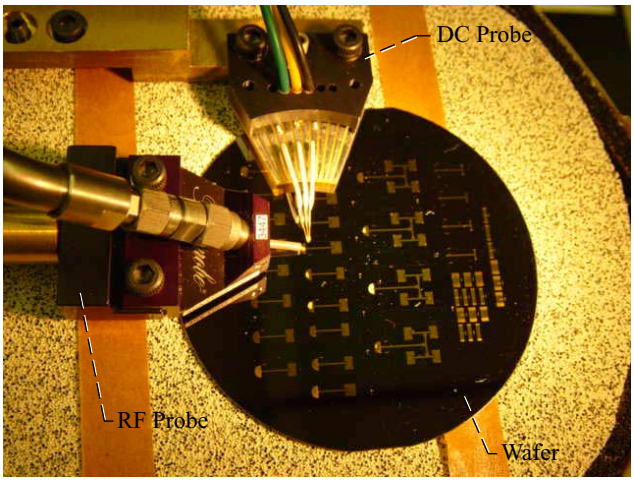

Figure 5.—Close-up of the Measurement Set-Up.

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.

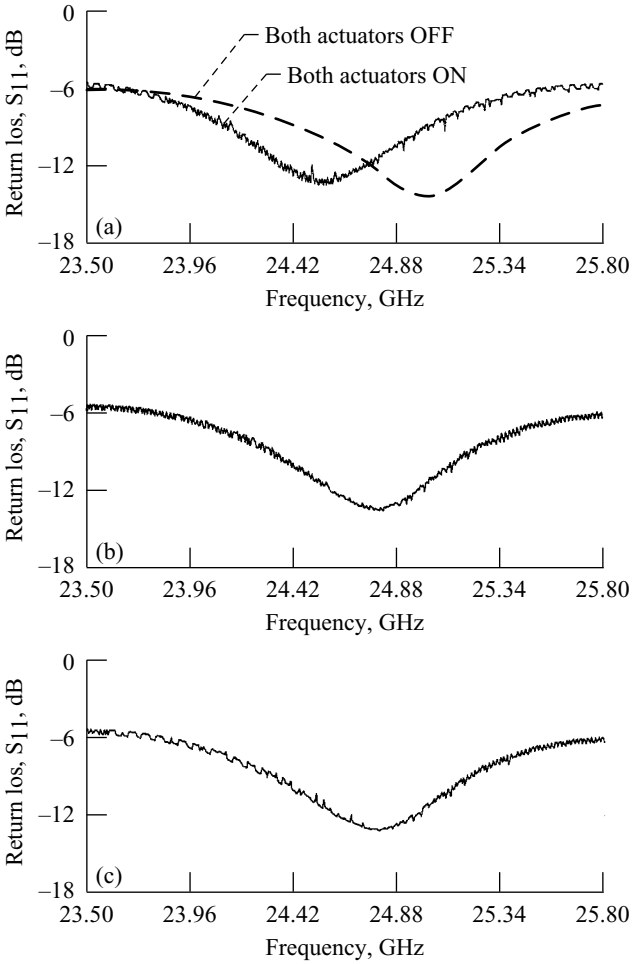

Figure 6.—Measured Return Loss Demonstrating Frequency Reconfigurability. (a) Both Actuators Are Either in the OFF State or ON State. (b) Actuator #1 is ON and Actuator #2 is OFF. (c) Actuator #1 is OFF and Actuator #2 is ON.

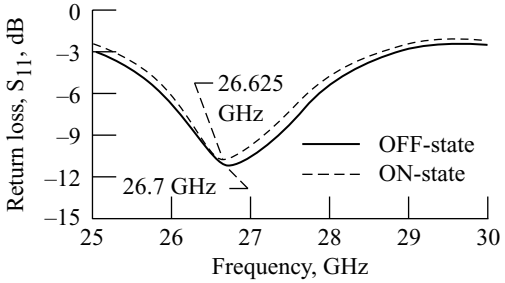

Figure 7.—Measured Return Loss of Nearly Square Patch Antenna.

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.

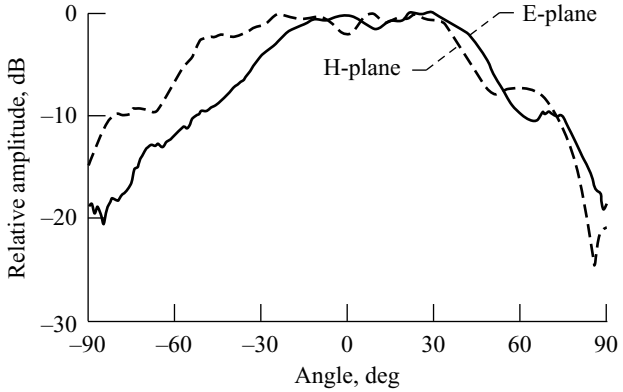

Figure 8.—Measured E and H-plane Radiation Patterns of The Frequency Reconfigurable Patch Antenna.

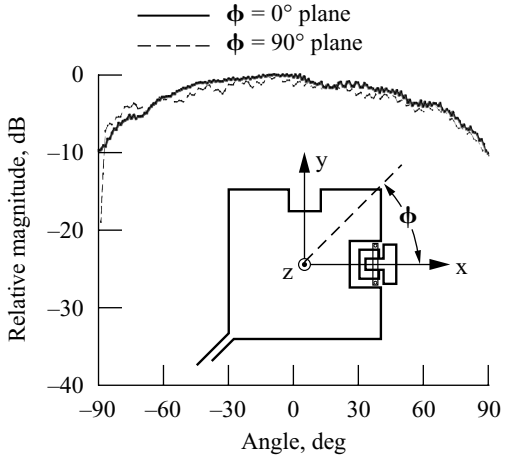

Figure 9.—Measured Circularly Polarized Radiation Patterns of Nearly Square Patch Antenna.

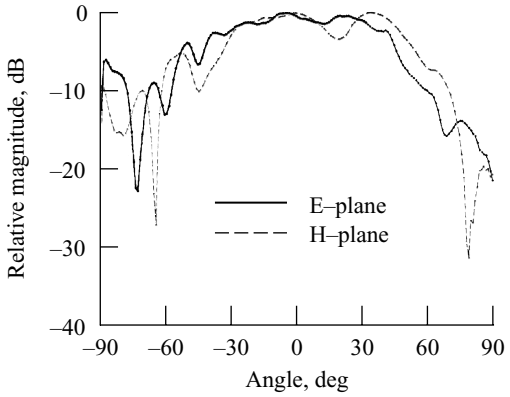

Figure 10.—Measured Linearly Polarized Radiation Patterns for Vertical Polarization of Nearly Square Patch Antenna.

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.

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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

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