Abstract

The presentation will first of all address the advantages of RF MEMS circuits in antenna applications and also the need for electronically reconfigurable antennas. Next, discuss some of the recent examples of RF MEMS based reconfigurable microstrip antennas. Finally, conclude the talk with a summary of MEMS antenna performance.

RF MEMS Based Reconfigurable Antennas

by

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Invited Lecture

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Outline

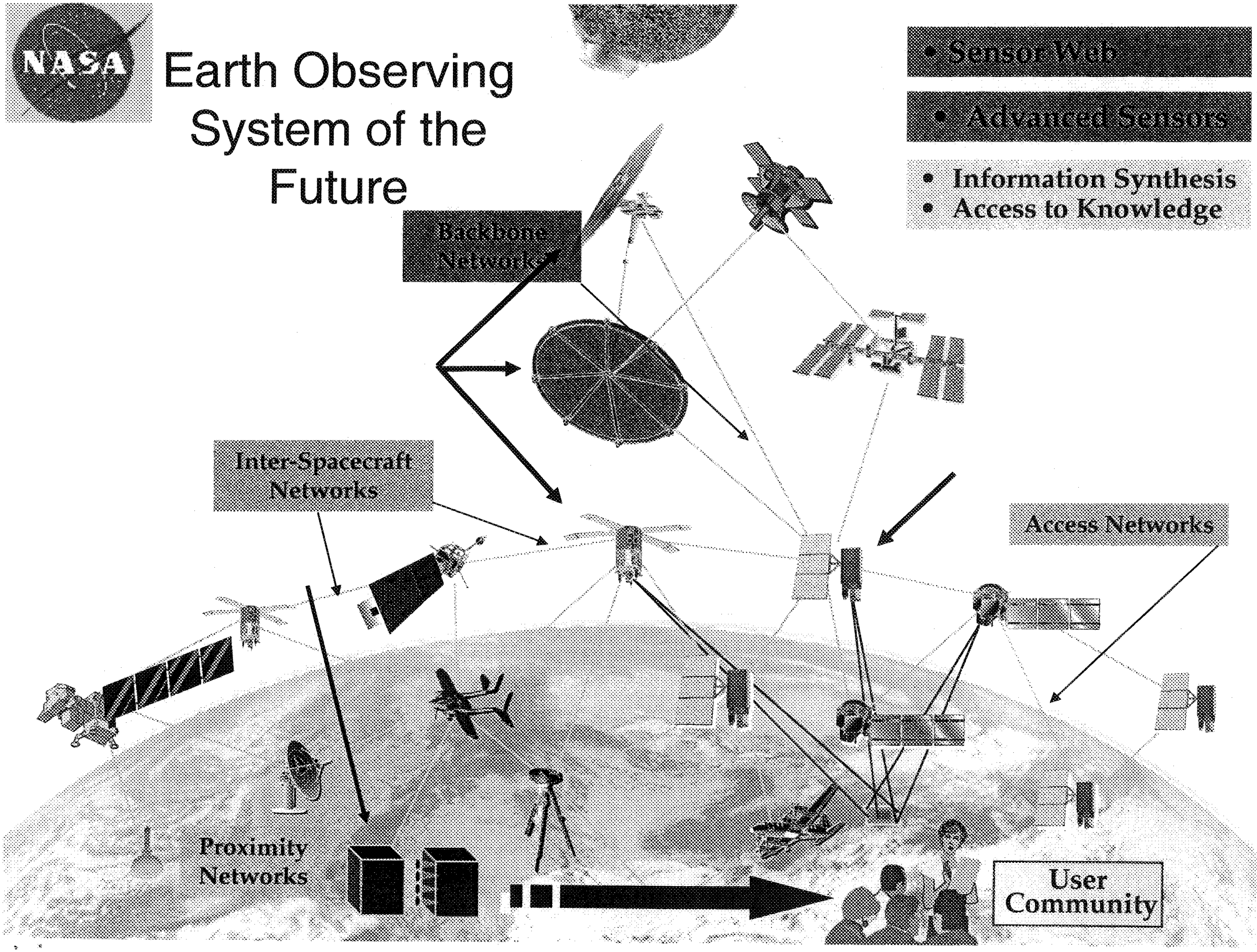
- Introduction
- Examples of MEMS Based Reconfigurable Microstrip Antennas
- Characterization Methodology
- MEMS Antenna Performance Summary
- Conclusions

Introduction

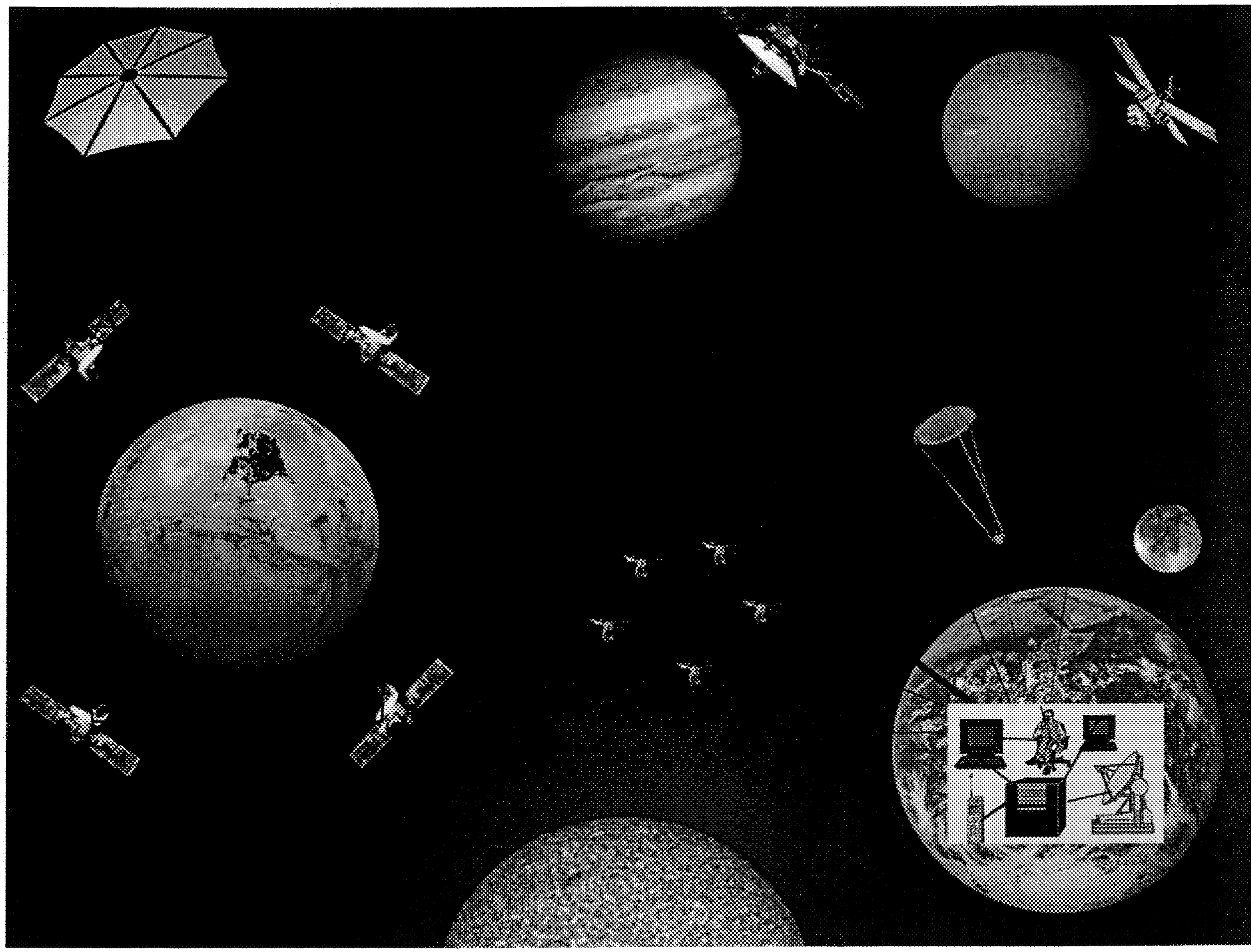
- **The Need for Electronically Reconfigurable Antennas**
  - **Earth observing systems of the future**
  - **Exploration of the solar system**

Earth Observing System of the Future

- Sensor Web
- Advanced Sensors
- Information Synthesis
- Access to Knowledge



Exploration of the Solar System



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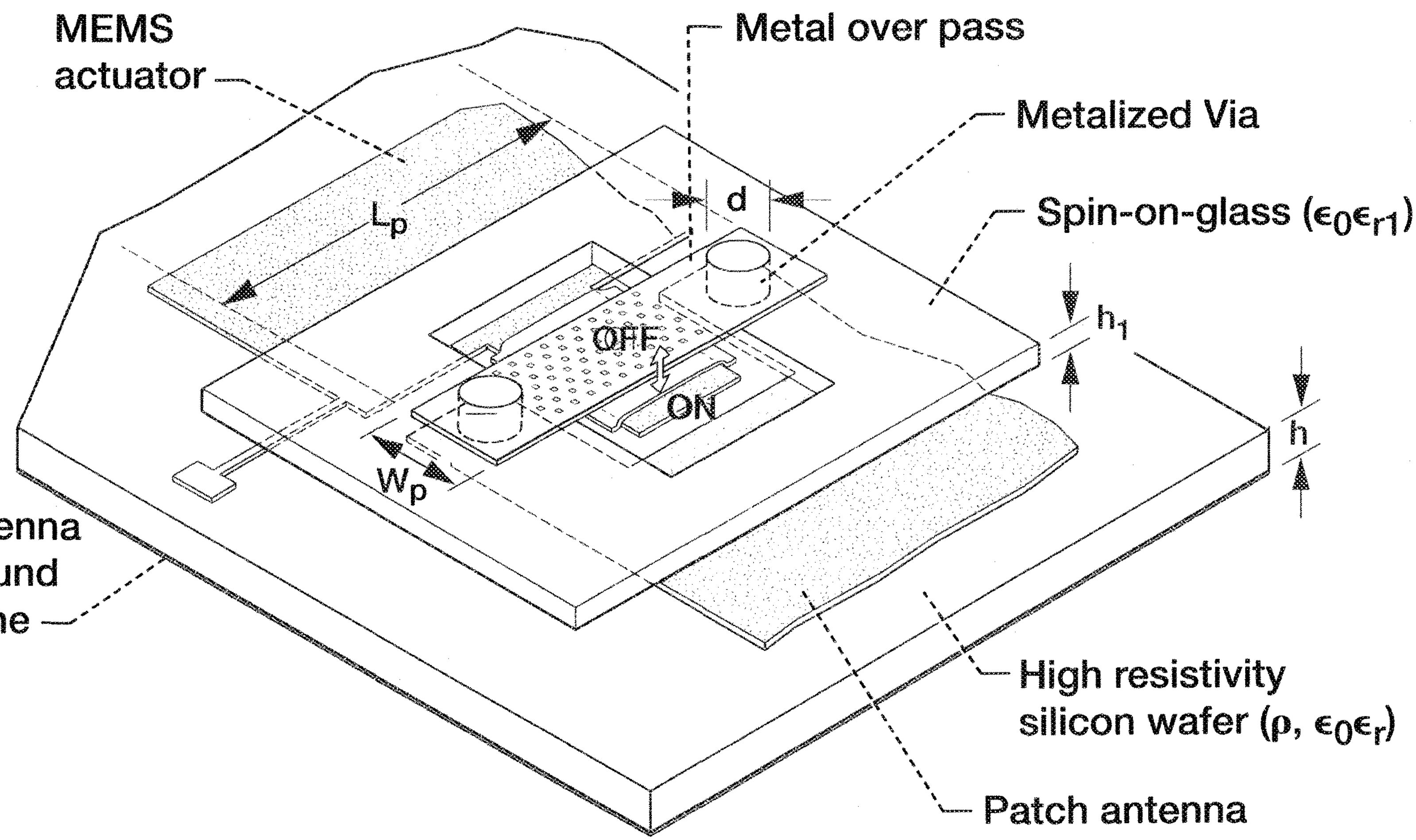
Introduction (Continued)

- **How This is Accomplished?**
  - **RF MEMS actuators**
    - **Construction**
    - **Principle of operation**
    - **Advantages**

Schematic of a MEMS Actuator Integrated With a Patch Antenna Element



Introduction (Continued)

- **Advantages**
  - **Low insertion loss - higher figure-of-merit**
  - **Consume insignificant amount of power - higher efficiency**
  - **Higher linearity- lower signal distortion**
  - **Potential to dynamically reconfigure - frequency, polarization and radiation pattern**

Examples of Reconfigurable Microstrip Antennas

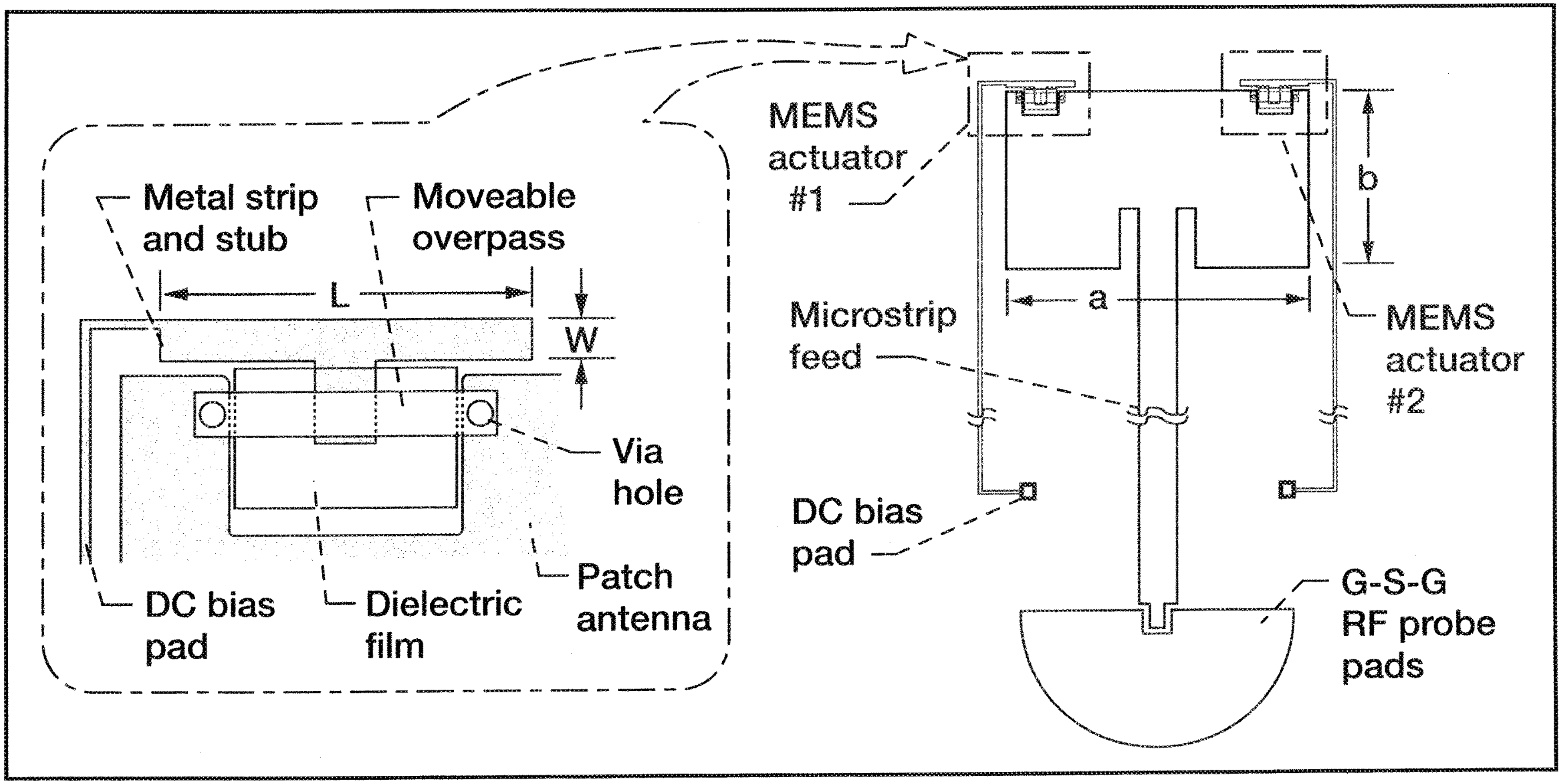
- Frequency Reconfiguration
  - Rectangular patch
  - Rectangular slot-ring
  - Rectangular patch surrounded by 2-D microswitch array
- Polarization Reconfiguration
  - Nearly square patch
- Dual Band Operation
  - Switched fragmented aperture consisting of square patches
- Beam Switching
  - Flared-notch reflectarray

Examples of Reconfigurable Microstrip Antennas

- **Beam Steering**
  - Patch on a 1-D torsion hinged substrate
  - Patch array (2x2) on a 2-D torsion hinged substrate
- **Dynamic Beam Shaping & Steering**
  - Polysilicon Vee antenna with scratch drive microactuators, sidebars and rotation hinges
- **Spatial Diversity**
  - Two element diversity antennas on PCB substrate

Frequency Reconfigurable Patch Antenna Element With Two Independent MEMS Actuators

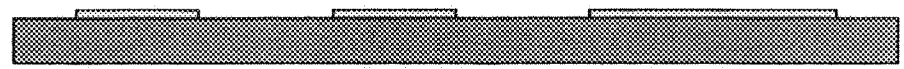
$L = 580\ \mu m$, $W = 50\ \mu m$, $a = 2600\ \mu m$, $b = 1500\ \mu m$



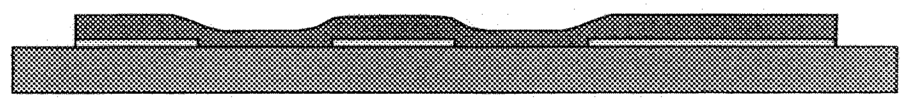
Simons, R.N.; Donghoon Chun; Katehi, L.P.B. : 2001 IEEE MTT-S Inter. Microwave Symp. Dig., Vol: 1, Page(s): 215 -218

MEMS Fabrication Process

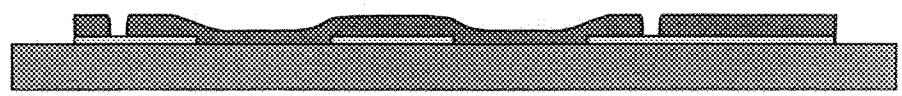
Step 1 Deposit Patch Antenna Conductors



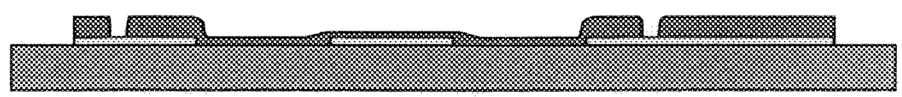
Step 2 Spin Coat Spin-on-Glass (SOG)



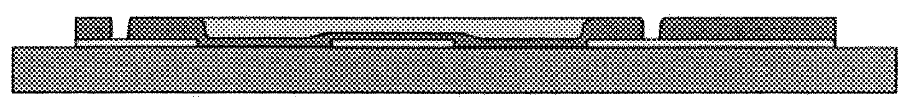
Step 3 Photoresist and Pattern for Via Holes



Step 4 Photoresist and Plasma Etch the SOG to Form the Insulating Layer

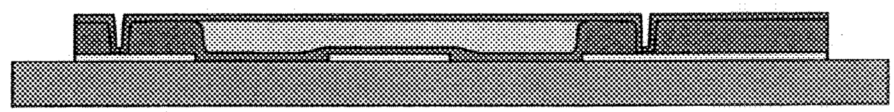


Step 5 Back Fill Opening with Photoresist to Form the Sacrificial layer

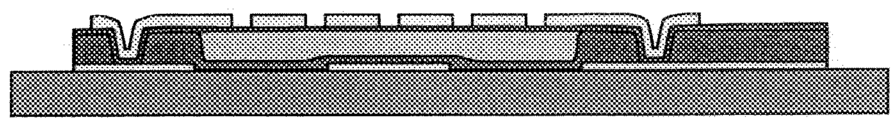


MEMS Fabrication Process (Continued)

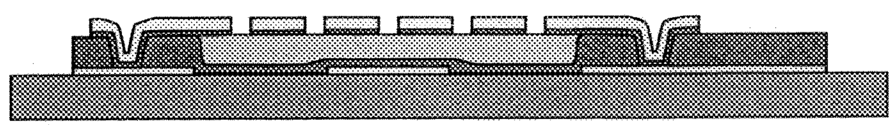
Step 6 Sequentially Evaporate Chromium/Gold to Protect Sacrificial layer



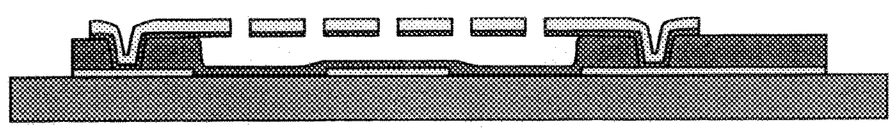
Step 7 Photoresist and Pattern for Liftoff of Metal for Overpass.
Sequentially Evaporate Chromium/Gold/Chromium and do Liftoff



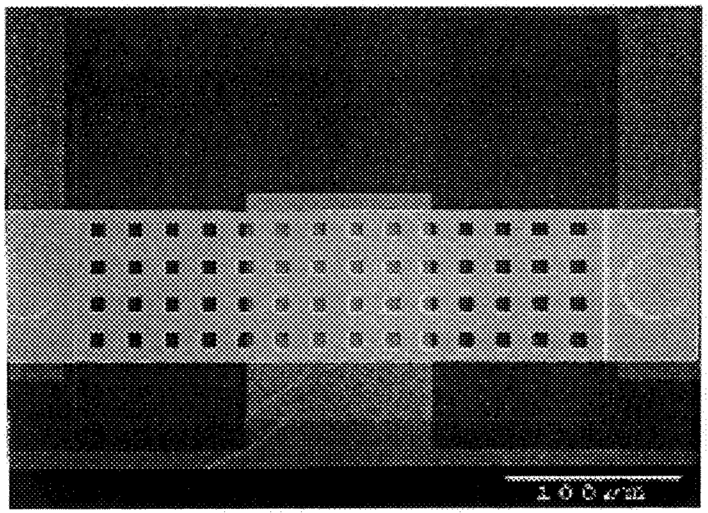
Step 8 Dip in Gold Etchant followed by Chrome Etchant to Remove the Protective Metal



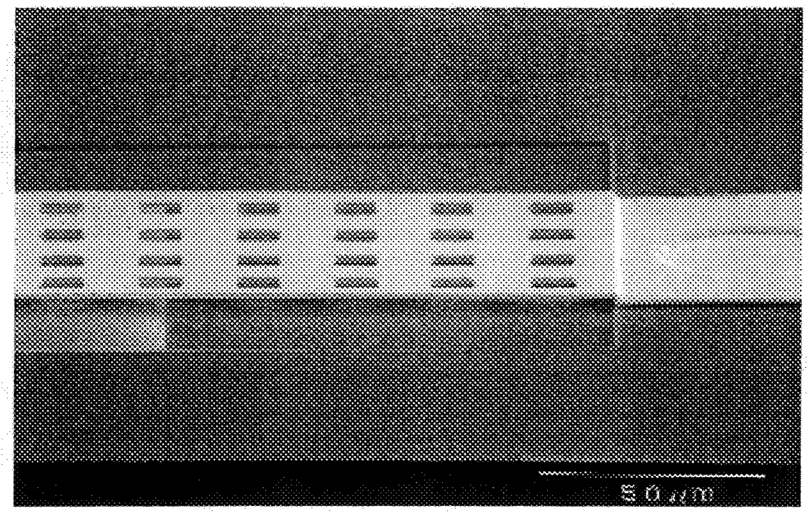
Step 9 Sacrificial Layer is removed resulting in Fully Released Metal Membrane



Photomicrograph of a MEMS Actuator

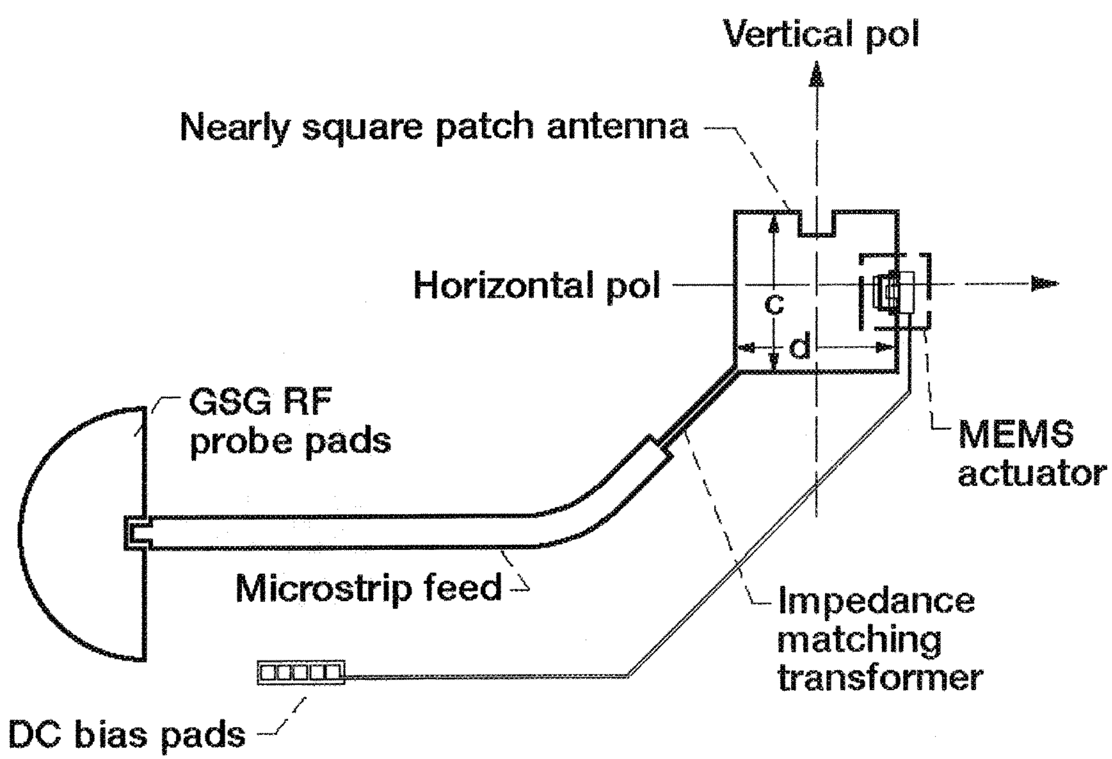


Top view



Side view

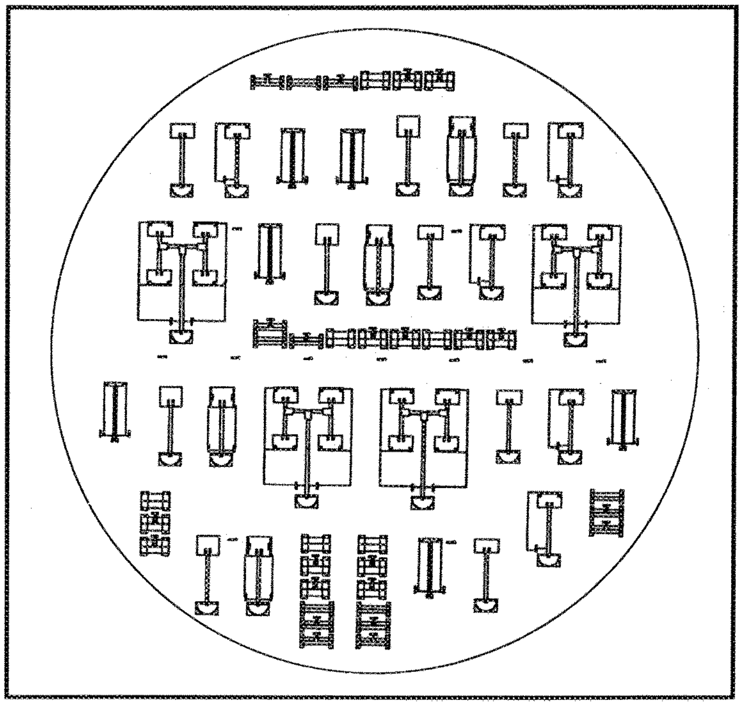
Polarization Reconfigurable Patch Antenna Element With Integrated MEMS Actuator



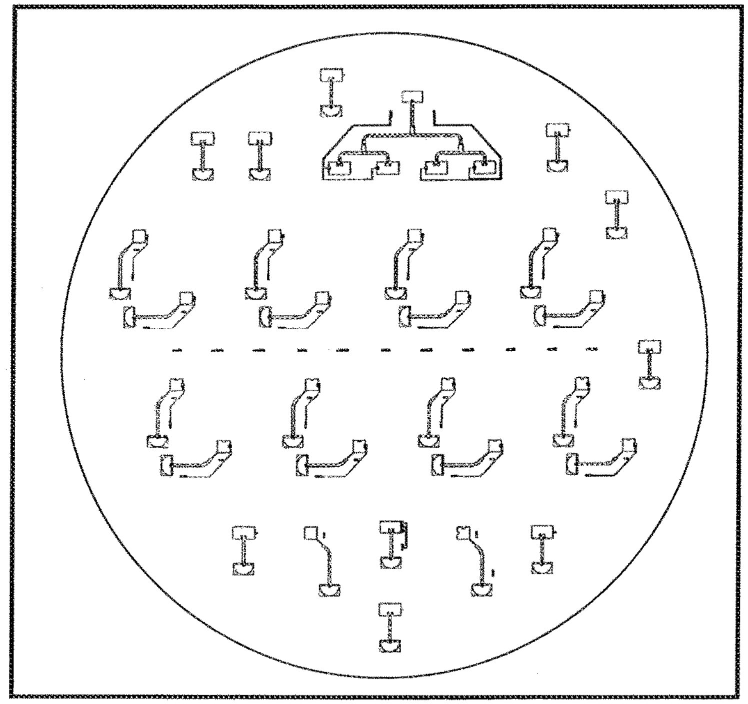
c = 1500 μm and d = 1492 μm

Simons, R.N.; Donghoon Chun; Katehi, L.P.B.; 2002 IEEE Antennas and Propagation Society Inter. Symp., Vol: 2, Page(s): 6 -9

Patch Antennas With Integrated MEMS Actuator on 3-in. Diameter High Resistivity Silicon Wafer

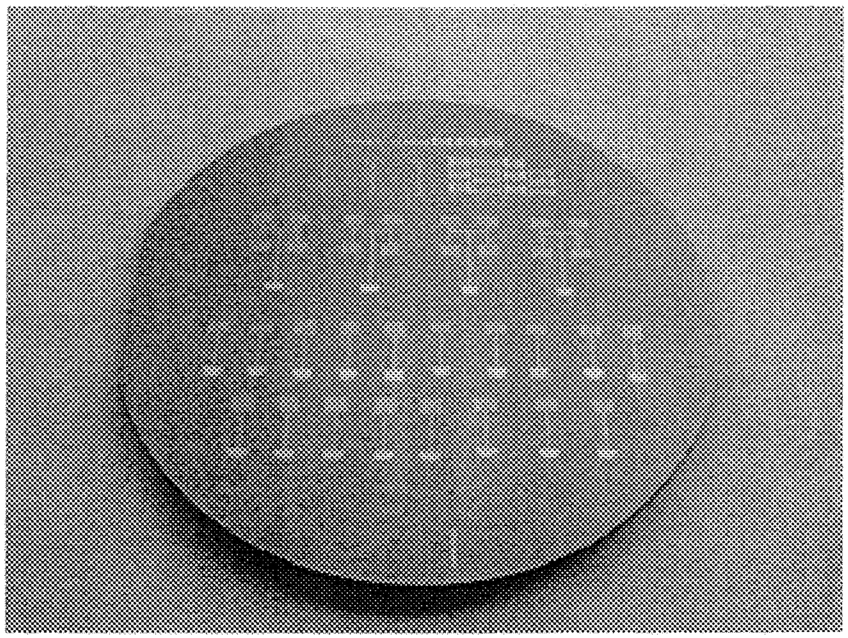


For Frequency Reconfiguration

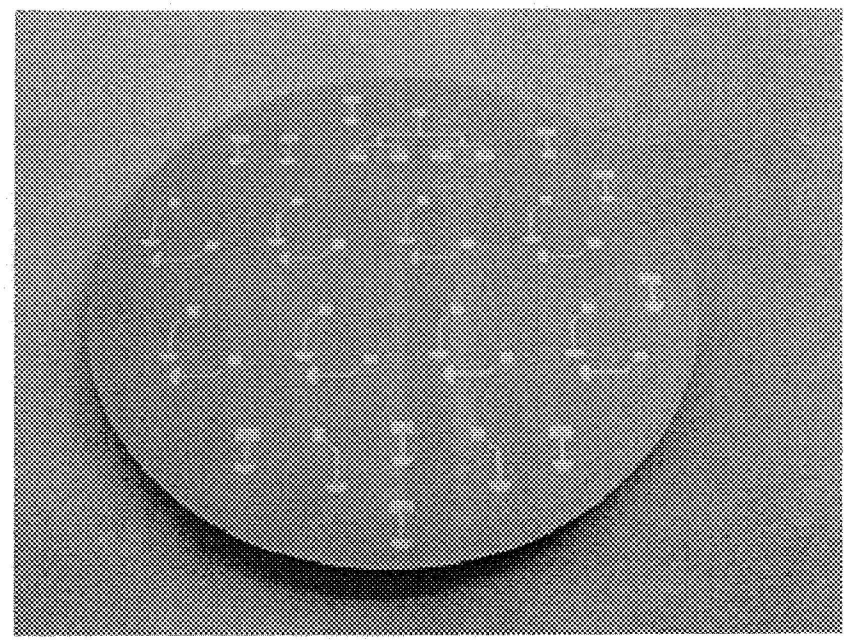


For Polarization Reconfiguration

Patch Antennas With Integrated MEMS Actuator on 3-in. Diameter High Resistivity Silicon Wafer

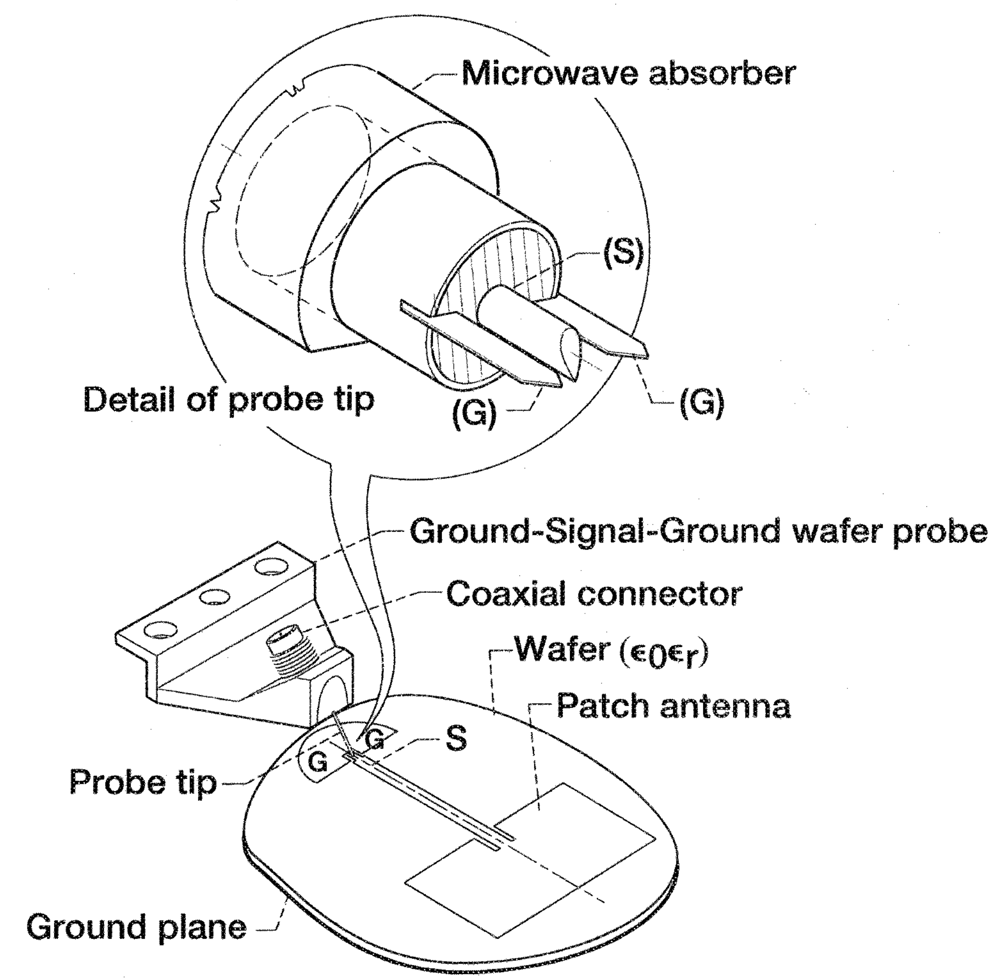


For Frequency Reconfiguration

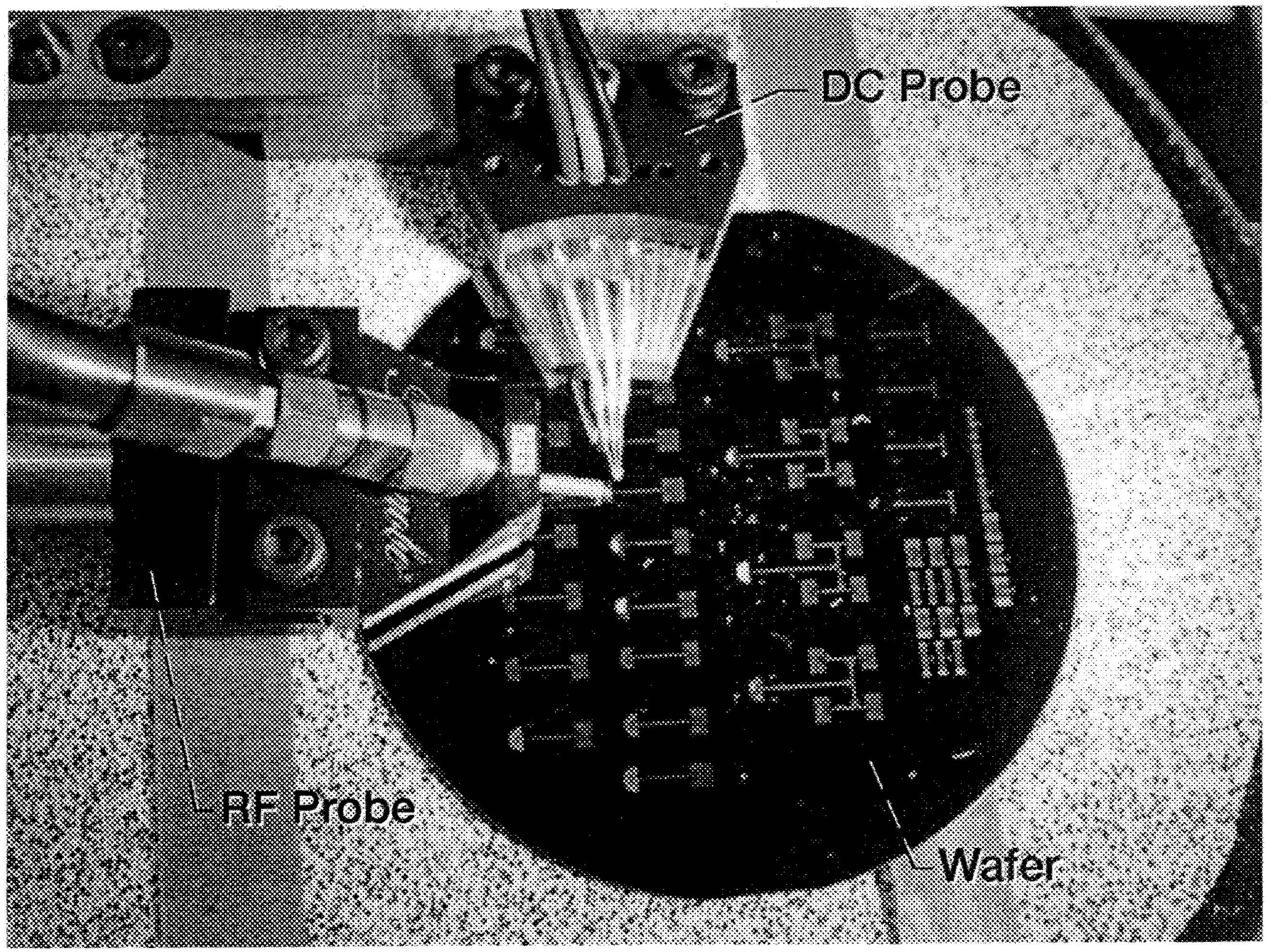


For Polarization Reconfiguration

Schematic Illustrating the Experimental Setup for Measuring the Return Loss of a Patch Antenna



Close-Up of the Measurement Set-Up Showing the RF and DC Probes Contacting the Circuit

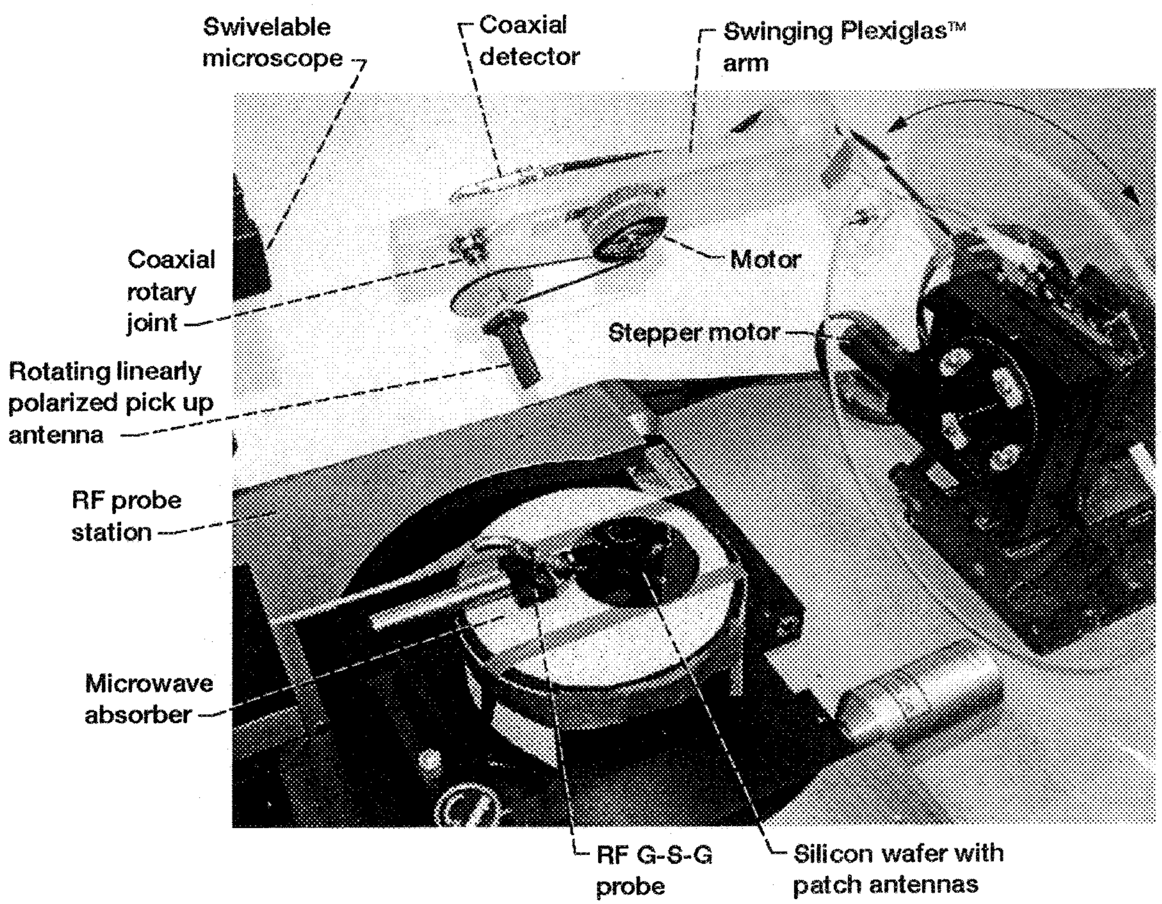


Measurement Methodology

- On-wafer characterization technique
  - Coplanar waveguide (CPW) ground-signal-ground (G-S-G) probe
  - RF probe station
  - Integration of a CPW-to-microstrip transition
  - Impedance standard substrate
- Advantages
  - Eliminates the need to saw the wafer into smaller individual patch antennas - minimizes loss due to breakage and enhances yield
  - Eliminates the need for custom-built test fixtures - reducing development time, complexity, and cost
  - In production environment - extremely fast and inexpensive when automated for repeated measurements

Computer Controlled On-Wafer CP Radiation Pattern Measurement Set-up Using a Rotating Linearly Polarized Pick-Up Antenna for MEMS Actuator Based Patch Antennas

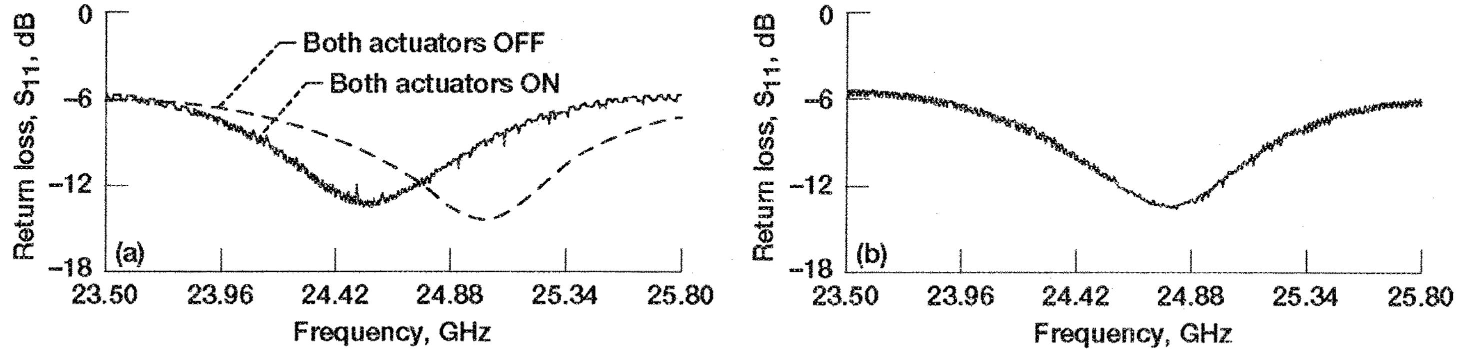
(Surrounding Microwave Absorber Panels Have Been Removed)



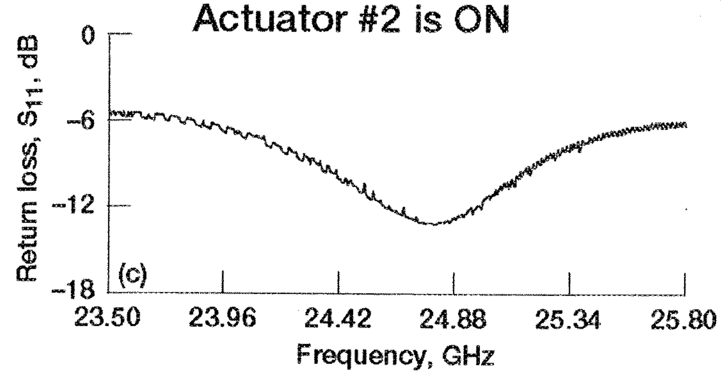
Measured Return Loss Demonstrating Frequency Reconfigurability When the MEMS Actuators are Biased Independently

(a) Both Actuators are Either in the OFF State or ON State

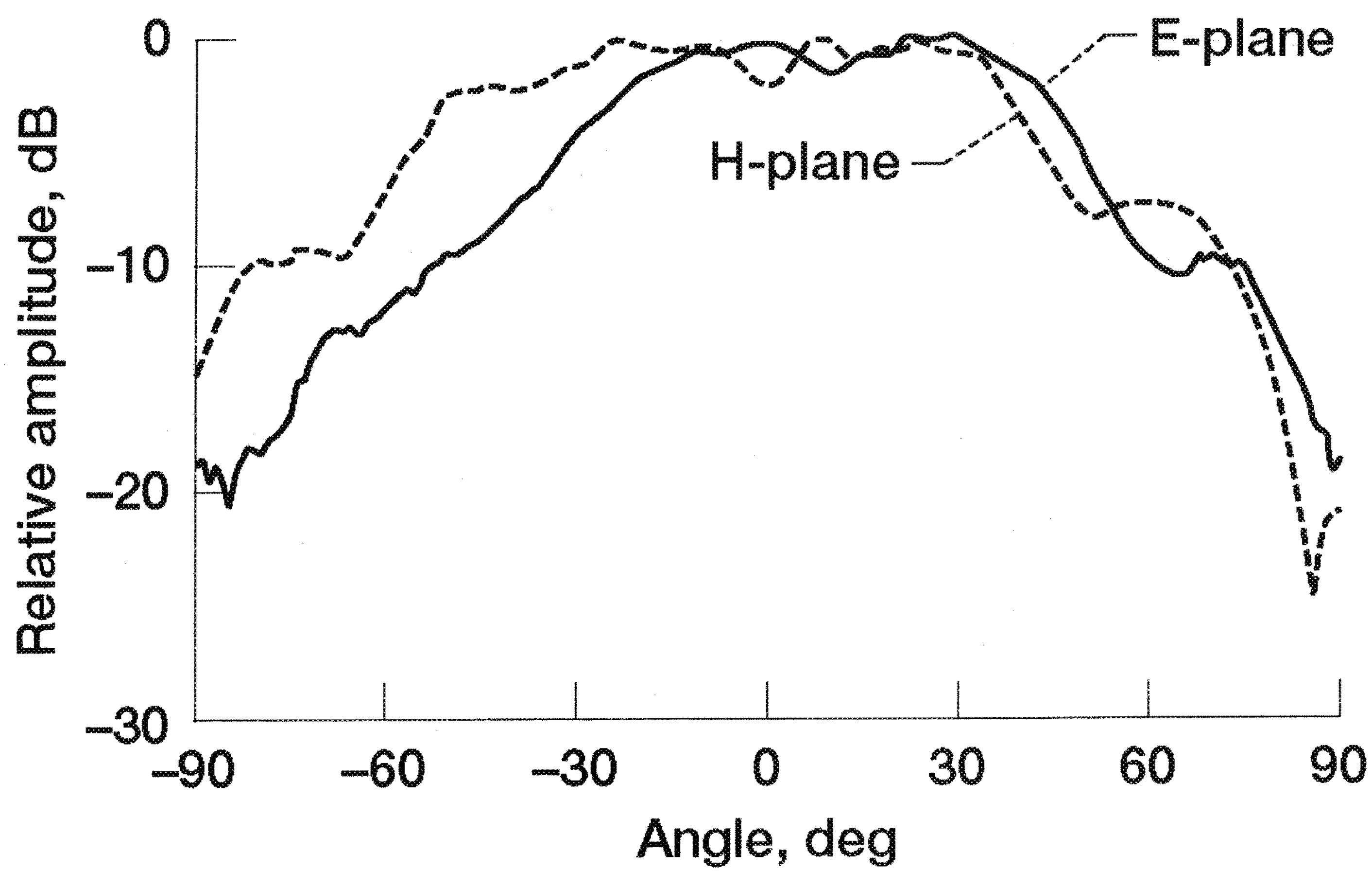
(b) Actuator #1 is ON and Actuator #2 is OFF



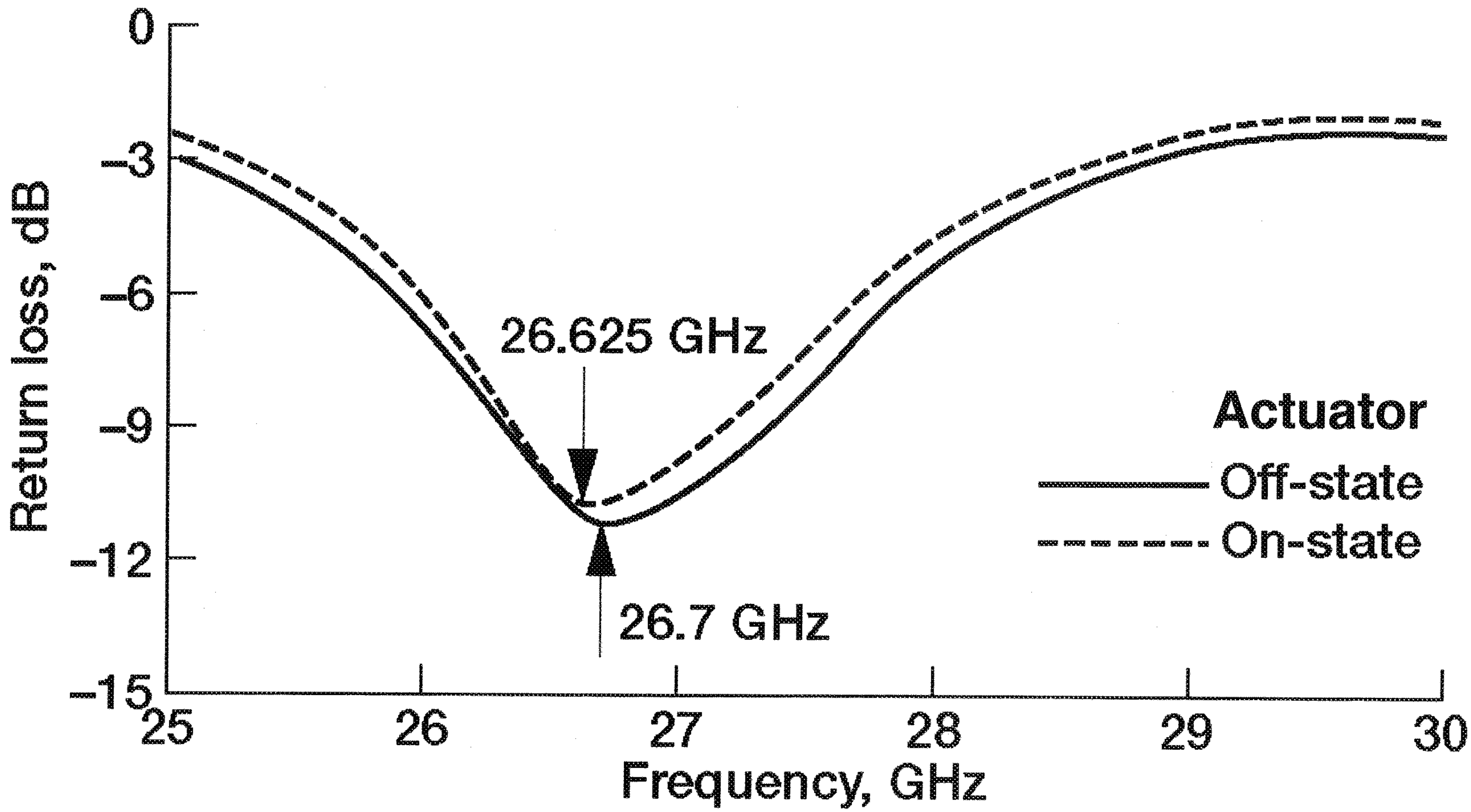
(c) Actuator #1 is OFF and Actuator #2 is ON



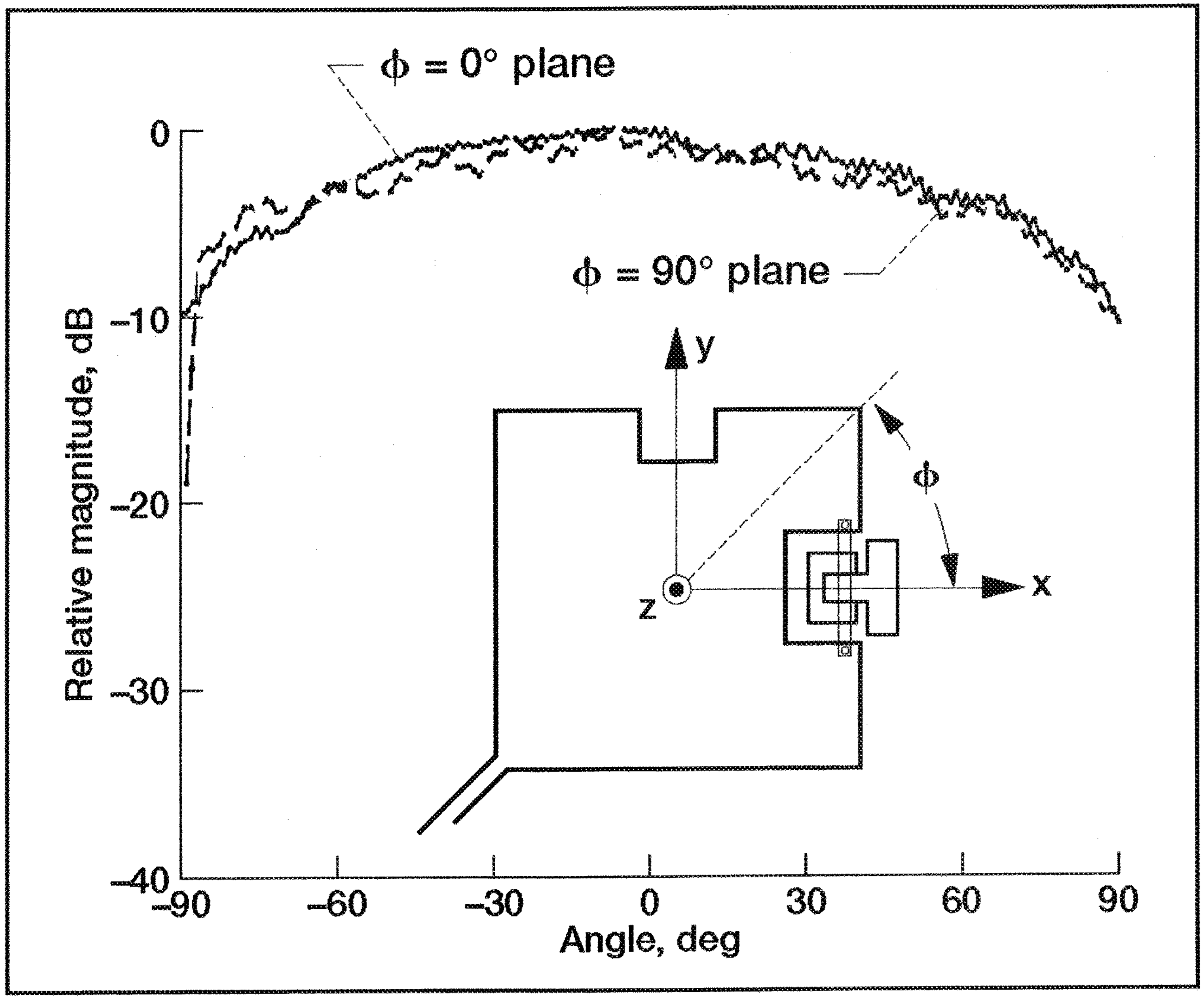
Measured E and H-Plane Radiation Patterns of the Patch Antenna



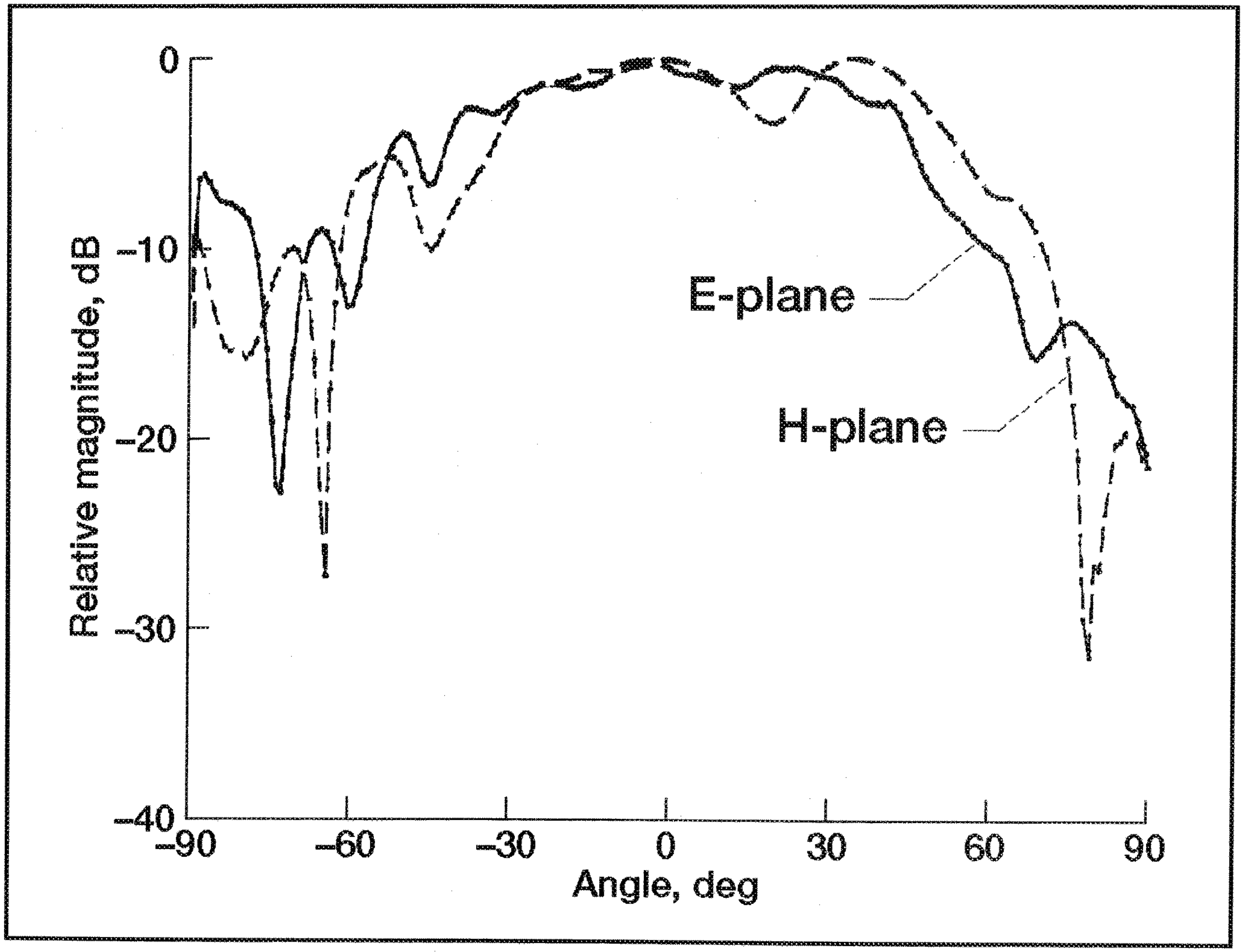
Measured Return Loss for Polarization Reconfigurable Patch Antenna



Measured Circularly Polarized Radiation Patterns



Measured Linearly Polarized Radiation Patterns for Vertical Polarization



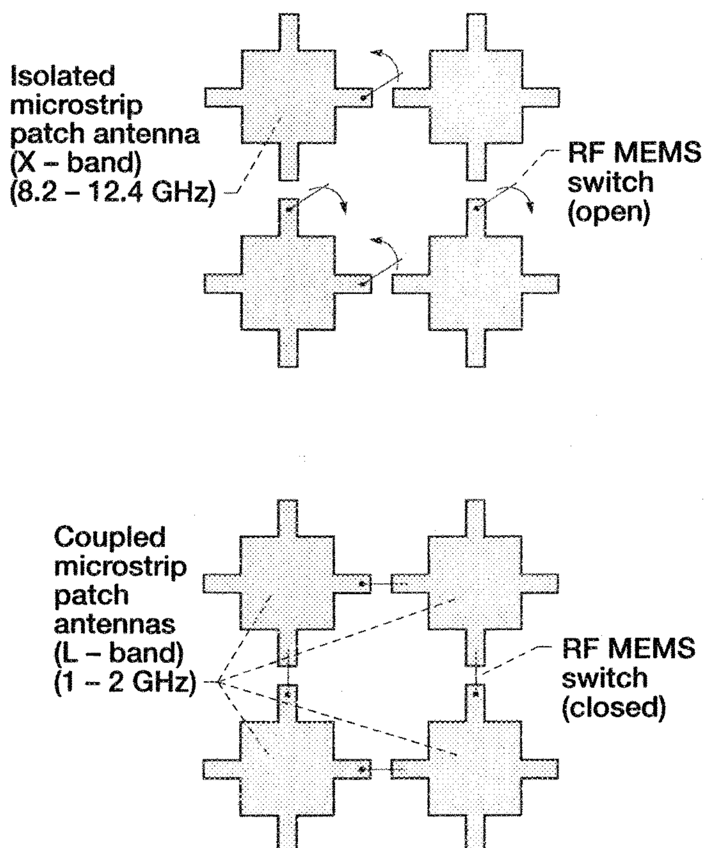
MEMS Antenna Performance Summary

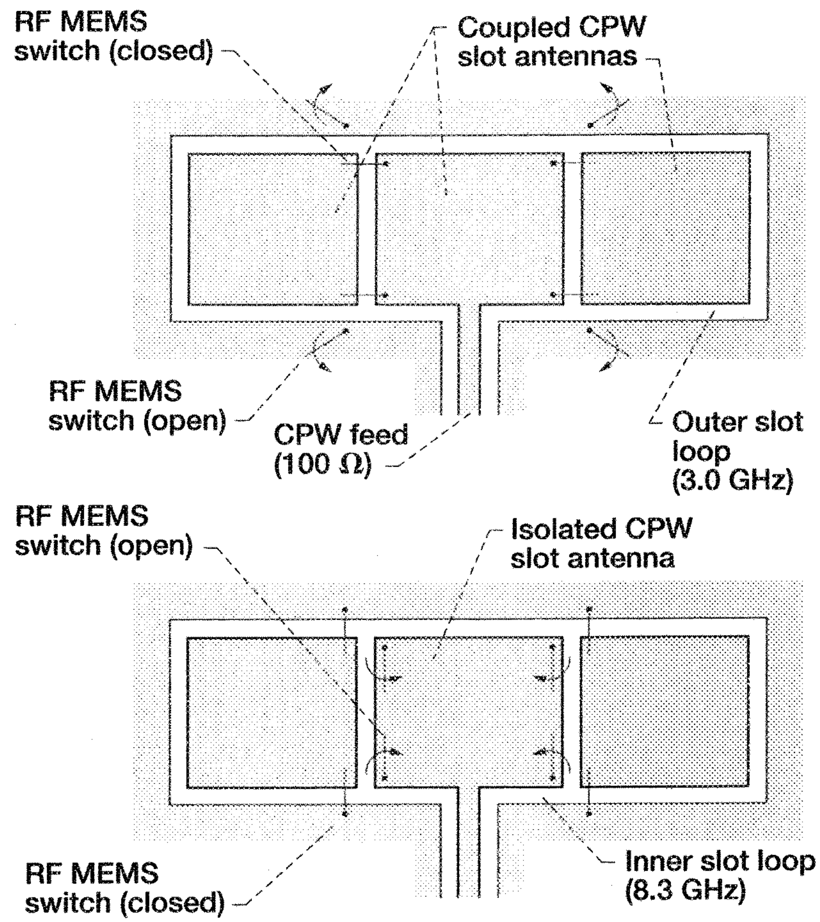
Electronically Reconfigurable Antenna Type	RF MEMS Characteristics that are Exploited	Antenna is Capable of Reconfiguring	Antenna Features & Benefits
Switched Fragmented Aperture	RF MEMS have low Insertion loss and high Isolation over a wide frequency band	Band of operation	• Dual band operation (L- & X-Band) • Both bands share a common aperture which results in antenna size reduction
Rectangular slot-ring		Frequency	• 3.0 GHz & 8.3 GHz • Bi-directional pattern
Flared-Notch Reflectarray	True tine delay phase shifters realized using RF MEMS switches	Beam direction	• End fire radiation • Simple construction • Wide band operation (DC to 40 .0 GHz)
Patch on a torsion hinged substrate	Substrate rotation realized through electro static force	Beam direction	• 1-D mechanical beam steering • mm-wave (60 GHz) • Scan angle $\pm$ 10 ° (@ 80V) • Simple & low cost
Vee antenna with scratch drive actuators, sidebars & rotation hinges	Nanometer step size movement realized through voltage pulsed scratch actuators	Beam direction & beam shape	• 1-D beam steering & beam shaping • Low cost

MEMS Antenna Performance Summary

Electronically Reconfigurable Antenna Type	RF MEMS Characteristics that are Exploited	Antenna is Capable of Reconfiguring	Antenna Features & Benefits
Patch with 2-D microswitch array Rectangular slot-ring	Microswitch array physically changes the patch dimensions	Frequency	• 10 GHz & 20 GHz • Eliminates the need for multiple antennas • Lowers cost • Enhances reliability
Patch array (2x2) on a torsion hinged substrate	Substrate rotation realized through magnetic force	Beam direction	• mm-wave operation (60 GHz) • 2-D mechanical beam steering • Scan angle ±20° • Constant gain in most of the beam direction • Beam focusing in the near-field space by rotation the individual antenna elements • Simple & low cost
Diversity antennas on PCB substrate	RF MEMS are used to switch between antennas	Spatial diversity	• 6.15 GHz • Diversity technique enhances receiver performance while mitigating multipath effects

Switched Patch/Slot-Ring Reconfigurable Apertures





Applications:

- Communications/synthetic aperture radar

W. H. Weedon et al., 2001 IEEE AP-S Inter. Symp. Dig., Vol. III, pp. 654-657

K. C. Gupta, 2000 IEEE AP-S Inter. Symp. Dig., Vol. I, p. 326

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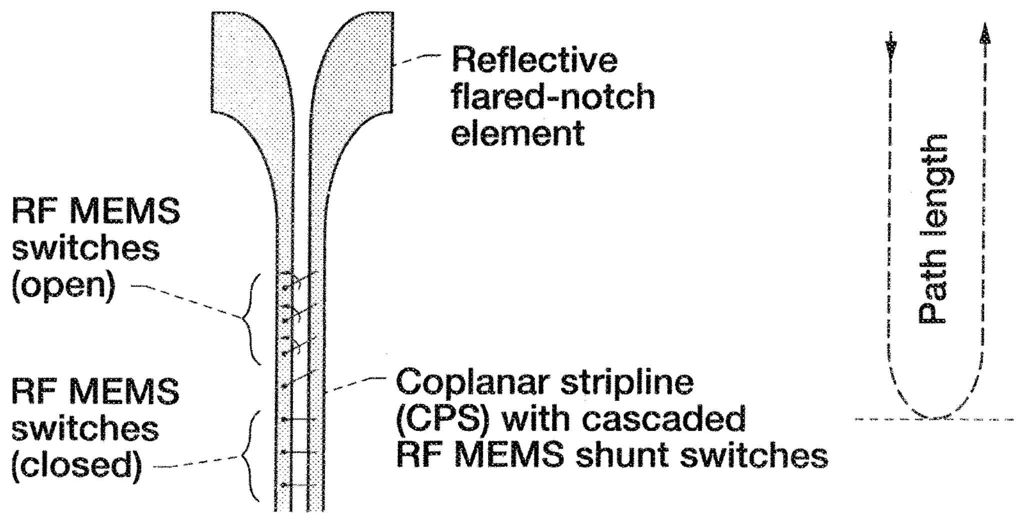
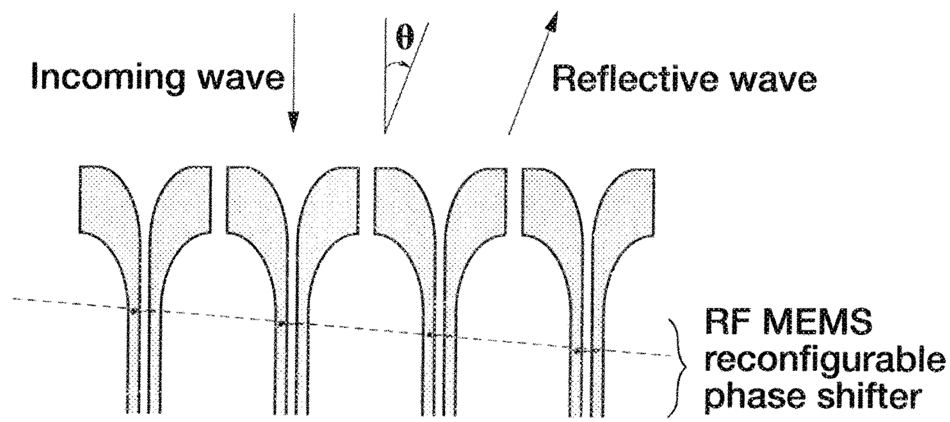
True-Time Delay Beam Switching





Features:

- Broadband operation (up to 40 GHz)
- Simple design

J. H. Schaffner, et al., 2001 IEEE AP-S Inter. Symp. Dig., Vol. III, pp. 658-661

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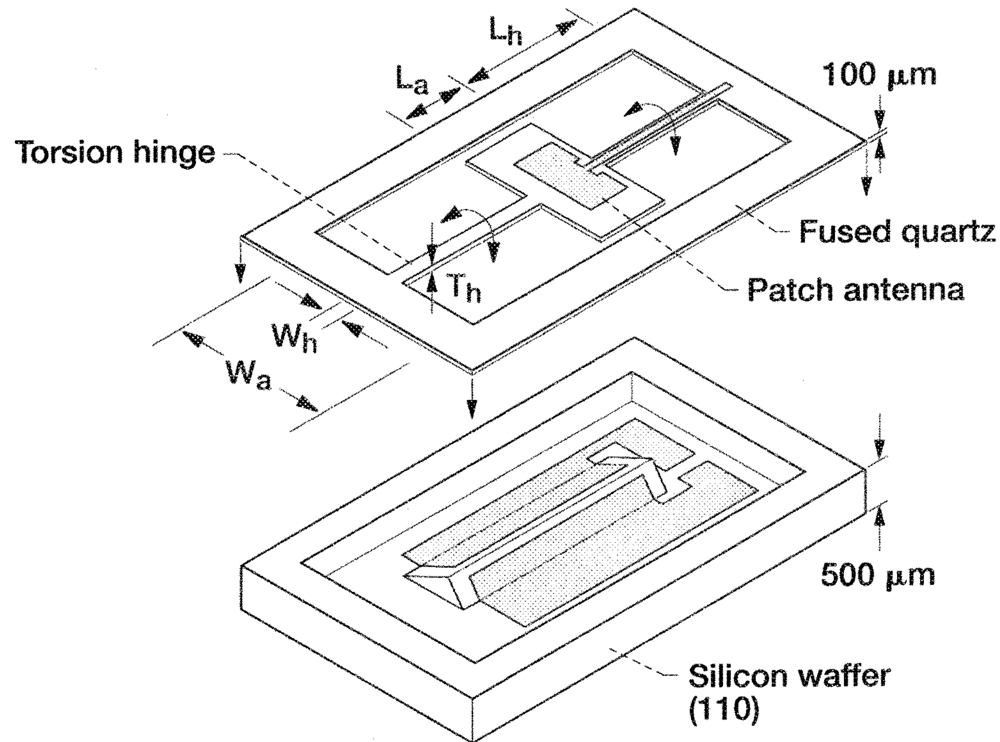
Electrostatic Spatial Scanning



- L_a = 1 mm, W_a = 2 mm
- L_h = 2 mm, W_h = 10 μm, T_h = 4 μm
- Deflexion = ± 10°, Patch: 1750 × 1170 μm
- Actuation voltage = 80 V
- frequency ≈ 60 GHz

D. Chauvel, et al., Proc. IEEE 10th Annual Inter. Workshop on Micro Electro Mechanical Systems, pp. 84-89, Jan. 1997

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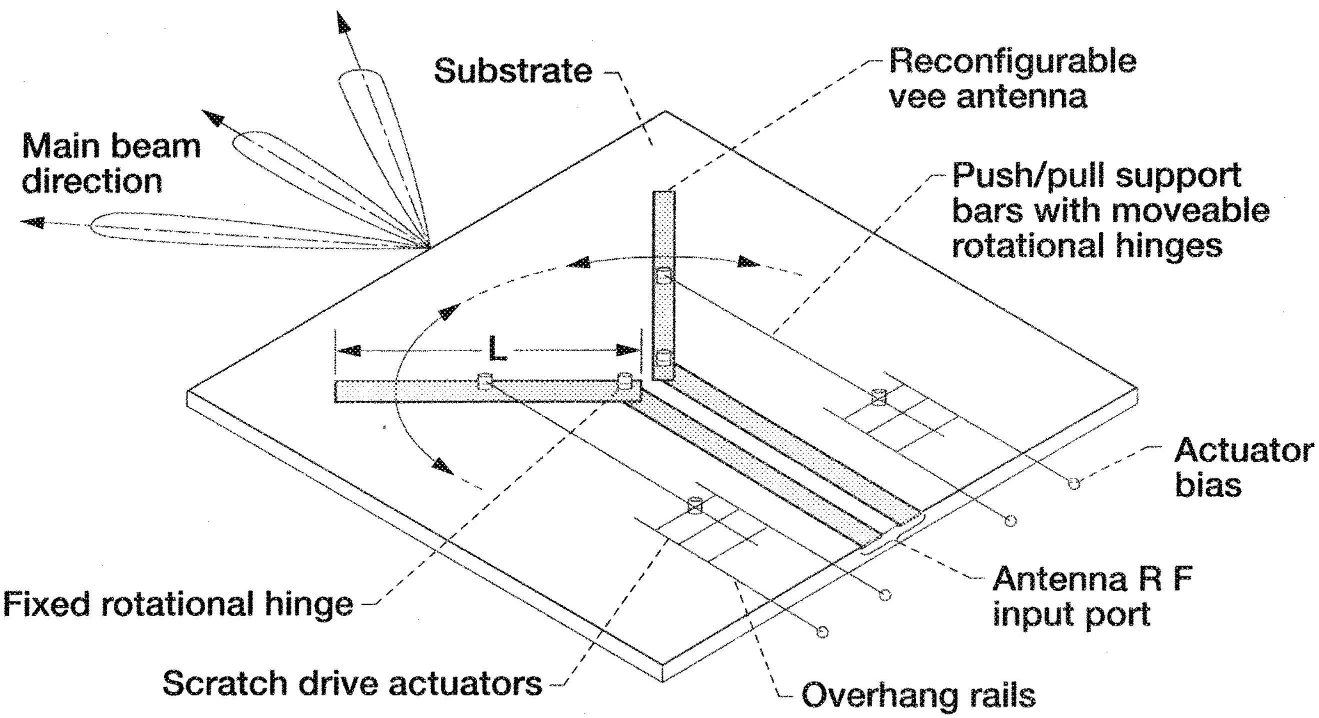
Dynamically Reconfiguring Beam Shape and Direction



- Frequency = 17.5 GHz
- $L = 1.5\ \lambda_0$
- Scratch drive movement per bias pulse $\approx$ 20 nm
- Voltage = 70 to 120 V

J. – C. Chiao et al., 1999 IEEE MTT-S Inter. Microwave Symp. Dig., Vol. IV, pp. 1515-1518

CD-03-82462