Advances in MEMs for RF Technology

2000 AOC Radar and EW Conference
Session 2: Technology Developments & Impact on Radar/ESM

25 October 2000

Mr. Vince Sieracki
Naval Air Systems Command
MEMS
(Micro ElectroMechanical Systems)

• Outgrowth of “Micromachining”
  – Creation of unique physical structures through the use of sacrificial layers resulted in miniature mechanical structures on a substrate (often Silicon)

• MEM Switch in RF Applications

  Open Circuit / Low Capacitance

  Closed Circuit / High Capacitance

  – Acts as RF Switch Or Capacitor (100:1 ratios)
  – Loss dominated by conductor loss
  – Controlled By Static DC Voltage (10 nJ switching energy)
  – Low cost processing (~ 5 mask layers)
  – High Cutoff Frequency
  – Minimum intermodulation distortion
RF MEMS Switch Classification

- **Signal Path:** Capacitive; Contact
- **Actuation:** Electrostatic; Electromagnetic; Thermal
- **Pull-Back:** Spring; Active
- **Structure:** Cantilever; Bridge; Membrane; Lever Arm; Rotary; Free Floating
- **Topology:** Series; Shunt; Combined
- **Throw:** Single; Multiple

1. **Signal Path:** Capacitive; Contact
2. **Actuation:** Electrostatic; Electromagnetic; Thermal
3. **Pull-Back:** Spring; Active
4. **Structure:** Cantilever; Bridge; Membrane; Lever Arm; Rotary; Free Floating
5. **Topology:** Series; Shunt; Combined
6. **Throw:** Single; Multiple

---

- **Polyimide (25 um)**
- **Thin dielectric (~ 1 um)**
- **Copper (17 um)**

- **Ball Aerospace - polymer MEMS switch**
  - (3/29/00 Design Review)

- **Univ. of Colorado - polymer MEMS switch**
  - (3/28/00 Design Review)

- **Raytheon bow-tie MEMS switch**
  - (2/1/00 Design Review)

- **HRL - contact switch**
  - (1/31/00 Design Review)

- **GTRI - contact switch**
  - (Jan 00 Progress Report)

- **Univ. of Illinois - floating beam switch**
  - (4/11/00 Design Review)

- **UCLA - liquid metal switch**
  - (3/30/00 Design Review)

---

1. **RF MEMS Switches, R. Strawser et.al., Air Force Research Lab, Sept 12, 2000**

ADV in MEMS RF SYS 100600
MEMS Switch Capacitively Coupled

1 Schematics are from the Air Force Research Laboratory/ Aerospace Components Division
# Why RF MEMS?

<table>
<thead>
<tr>
<th>Switch Type</th>
<th>Insertion Loss</th>
<th>Isolation</th>
<th>Power Consumption</th>
<th>DC Voltage</th>
<th>Speed</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIN/SCHOTTKY</td>
<td>~.15 dB</td>
<td>45 dB</td>
<td>1-5 mW per device</td>
<td>1-10 V</td>
<td>1-5 ns</td>
<td>Narrow/Wide</td>
</tr>
<tr>
<td>GaAs FETs</td>
<td>1-2 dB</td>
<td>~20 dB</td>
<td>1-5 mW per device</td>
<td>1-10 V</td>
<td>2-10 ns</td>
<td>Narrow/Wide</td>
</tr>
<tr>
<td>HBT/PIN</td>
<td>0.82 dB</td>
<td>25 dB</td>
<td>1-5 mW per device</td>
<td>1-10 V</td>
<td>1-5 ns</td>
<td>Narrow/Wide</td>
</tr>
<tr>
<td>Best FET</td>
<td>0.5 dB</td>
<td>70 dB</td>
<td>5 mW</td>
<td>3.5 V</td>
<td>2 ns</td>
<td>Narrow/Wide</td>
</tr>
<tr>
<td>MEMS – Sergio Shunt</td>
<td>0.06 dB @ 20 GHz</td>
<td>30 dB</td>
<td>~1μW</td>
<td>12-14 V</td>
<td>&gt; 30 μs</td>
<td>Wide (1-40 GHz)</td>
</tr>
<tr>
<td>MEMS – Scott/Jeremy(Shunt)</td>
<td>0.3 dB @ 30 GHz</td>
<td>50-60 dB</td>
<td>~1μW</td>
<td>~20 V</td>
<td>&gt; 30 μs</td>
<td>Moderate (10-40 GHz)</td>
</tr>
</tbody>
</table>

1 Sanders RECAP In-Process Review 2/00
ADV in MEMS RF SYS 100600
Advantages of RF MEMS
- High performance, low bias power consumption
- Potential low cost manufacturing into a variety of substrates

Limitations of RF MEMS
- Slower switching speed
- Potential lifetime limitations

Applications
- Reconfigurable Apertures
- Elements
- Ground planes
- Array feeds/architecture
- Phase shifters
- Filters

DARPA/SPO is attempting to exploit these MEMS device/component capabilities in RF SYSTEMS through the following programs: RECAP; MEM-Tenna; Global Eye-STAR.
Reconfigurable Aperture Program

RECAP

• Overall Goals
  • Tailoring a radiation pattern dynamically
    - Greater than a Decade bandwidth coverage;
      Geometric reconfiguration (horizon-to-horizon)
    - Adapt to frequency spectrum changes

Reconfiguration For Optimized Performance

• Employ Variable radiating topology

• Composite Structural Packaging

• Active Reconfiguration of Elements

• Wide Band Feed Network

• Create a frequency independent multi layer ground plane

RF MEMS currently under investigation as a reconfiguration mechanism in each of these areas.
GTRI Concept is the Adaptive Design of Element
From the Connections Between Conducting “Pads”
(Pads are Not Patch Antennas, But Simple Conducting Structures

Connected Pads
Forming
a Bow-tie Pattern

Control Chip
Micro-switch
Metallic Pad

RECAP Element Anticipated Capability:
• Allows Adaptive Optimization for Frequency Band
• Allows Steering of Pattern for Single Feed Aperture
• Lets User Adaptively Trade Bandwidth for Gain

1 GTRI DARPA RECAP Symposium 2000 - 8
Example of a Reconfigurable Antenna Element

MEMS-SWITCHED DUAL-BAND DIPOLE ANTENNA

11 GHz 18 GHz

Switches Open
Switches Closed

1 RECAP Quarterly Review 3/30/2000
ADV in MEMS RF SYS 100600
MEMS in a Wideband Ground Plane

Spiral or Circle elements

2-18 GHz frequency range

~0.5 inches

Baluns feed thru to elements

Fixed ground plane at base

Reconfigurable MEMS FSS

Predicted Boresight Gain Relative to Free Space
(No Resistive Bias Film)

Transmission Loss (dB)

Frequency (GHz)

Ball Aerospace & Technologies Corp.
Advanced Antenna & Video Systems

Presented at DARPA RECAP Workshop 3 October 2000

ADV in MEMS RF SYS 100600
MEM-Tenna Concept

- **OBJECTIVE:** To develop and demonstrate ultra low-cost, light-weight, low power phased array antenna technology

**Applications** - Large, low Cost Antennas

- Aerostat PTIR
- Advanced Ship Radar

2-D MEM Lens
MEMs - Enabling Technology

MEMS advantages lead to economies for large scale arrays

Space-fed lens eliminates cost of many T/R modules and weight of beamformer
Space-fed optical control reduces on-array wiring

Phase Shifter Technology

Cost ($), Power (mW), Loss (dB)

MEMS, GaAs MIMIC, Ferrite, Diode

Space-fed ESA Conv. Space Fed

$(K) / sq. m, lbs. / sq. m
X-Band Phase Shifter

Photograph

Schematic

2 bits of 4-bit phase shifter
10 GHz 2-Bit (Small) PS Performance

- 6.0 - 10.0 GHz
  - Average insertion loss 0.55-0.9 dB (Arithmetic average of all 4 states)

- 5.5 - 11.0 GHz
  - Return loss > 11 dB
Individual RF Switches in Tunable Notch Filter Circuit

Photo of Notch Filter Circuit

Measured and Calculated Results for Two State Notch Filter

-40 -35 -30 -25 -20 -15 -10 -5 0
Insertion Loss (dB)

5 6 7 8 9 10 11 12 13 14 15
Frequency (GHz)

Top-calculated
Bottom-calculated
Top-measured
Bottom-measured

1 Developed by Lincoln Lab for the RECAP program.

ADV in MEMS RF SYS 100600
Advanced Multi-Mode Radar

STAR Waveform Utilization

STAR Waveform

Subarray

Multiple Beams
Reconfigurable Beamformer
Mode Interleaving
STAP

Multi-Polarization
Adaptive Antenna
Required RF MEMS Technology Activities

- Process Development
  - Reproducibility, Yield, cost, performance, complexity
- Reliability
  - mechanical longevity
  - stiction issues
- Environmental Packaging
  - Low cost
  - very low loss

• Transition from development to program insertions
Summary

• Advances in RF MEMS provide exciting opportunities to inject dramatic device/component advances into RF SYSTEMS

• Early results show technological feasibility of applications in antennas, phase shifters, and filters

• Additional technology development required before transitioning to programs