Special Projects Office

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

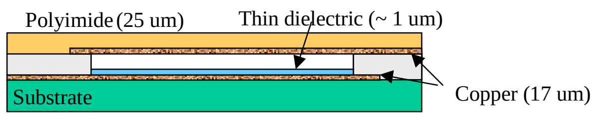
Closed Circuit / High Capacitance

  - 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

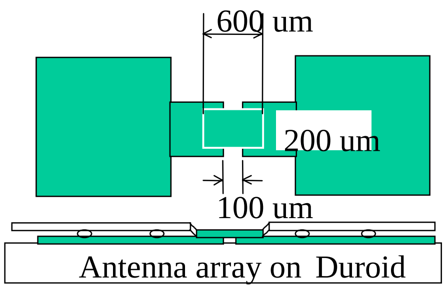
RF MEMS Switch Classification[1.)]

Special Projects Office

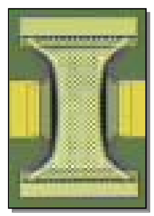
Signal Path:	**Capacitive; Contact**	Structure:	**Cantilever; Bridge; Membrane; Lever Arm; Rotary; Free Floating**
Actuation:	**Electrostatic; Electromagnetic; Thermal**	Topology:	**Series; Shunt; Combined**
Pull-Back:	**Spring; Active**	Throw:	**Single; Multiple**



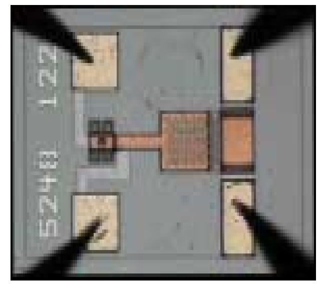
Ball Aerospace - polymer MEMS switch
(3/29/00 Design Review)



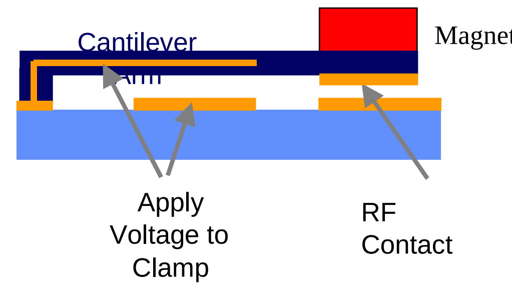
Univ. of Colorado - polymer MEMS switch
(3/28/00 Design Review)



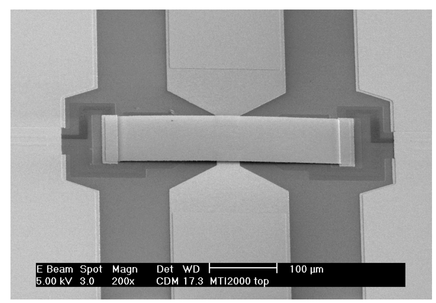
Raytheon bow-tie
MEMS switch
(2/1/00 Design Review)



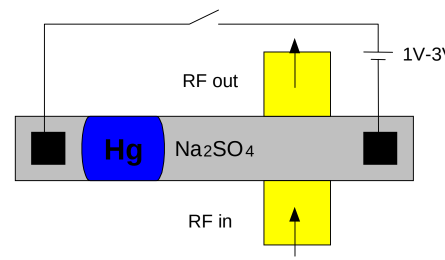
HRL - contact switch
(1/31/00 Design Review)



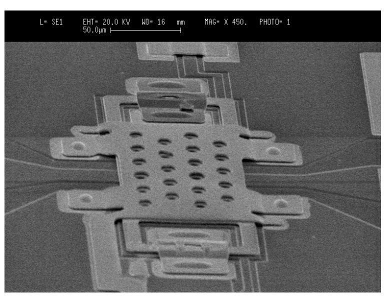
GTRI - contact switch
(Jan 00 Progress Report)



Univ. of Michigan (Rebeiz)
- microbridge switch
(5/10/00 Design Review)



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



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

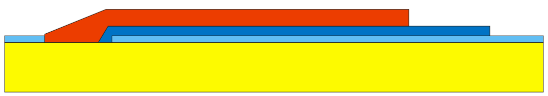
1.) RF MEMS Switches, R. Strawser et.al., Air Force Research Lab, Sept 12, 2000

Typical Fabrication Process [1]

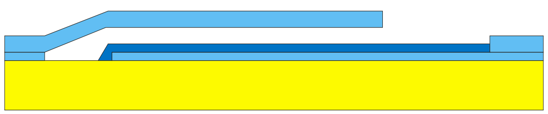
MEMS Switch Capacitively Coupled

Deposit and pattern bottom metal

Deposit and pattern dielectric

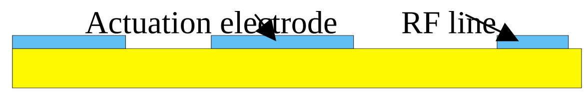


Deposit and pattern sacrificial layer



Deposit, pattern, and release top metal

MEMS Switch Metal Contact

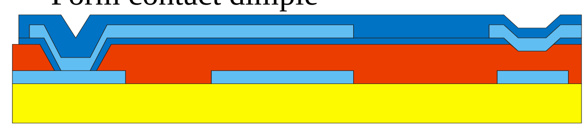


Deposit and pattern bottom metal

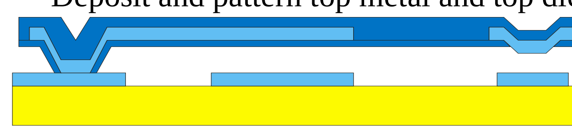
Deposit and pattern sacrificial layer

Deposit and pattern dielectric

Form contact dimple



Deposit and pattern top metal and top dielectric



Release switch

1 Schematics are from the Air Force Research Laboratory/ Aerospace Components Division

Why RF MEMS?

Special Projects Office

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

[1] Sanders **RECAP In-Process Review 2/00**
ADV in MEMS RF SYS 100600

MEMS RF Applications

Special Projects Office

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

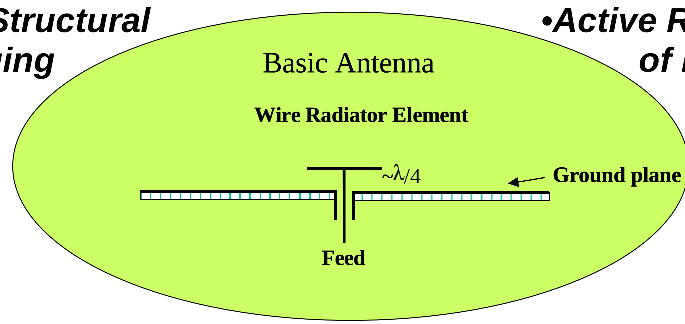
- **Overall Goals**
  - **Tailoring a radiation pattern dynamically**
    - **Greater than a Decade bandwidth coverage ; Geometric reconfiguration (horizon-to-horizon)**
    - **Adapt to frequency spectrum changes**

Reconfiguration For Optimized Performance

•Employ Variable radiating topology

•Composite Structural Packaging

•Active Reconfiguration of Elements



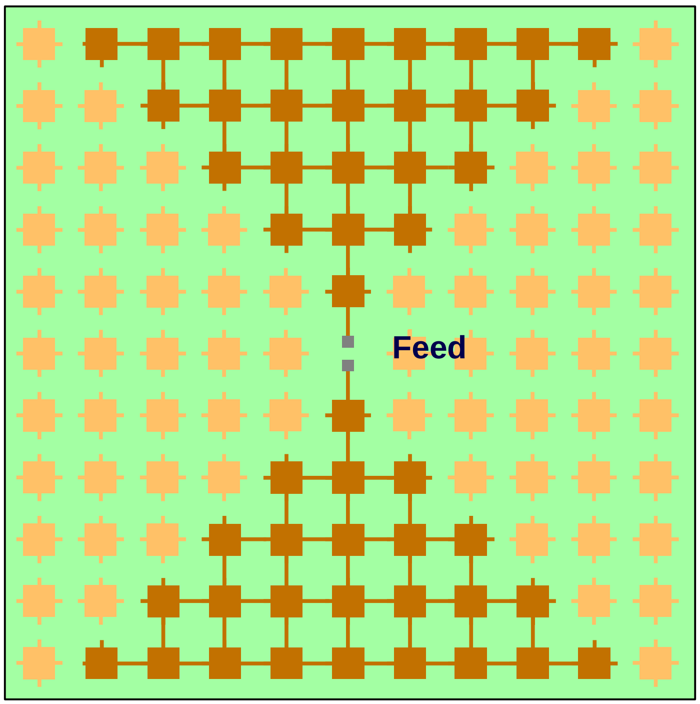
•Wide Band Feed Network

•Create a frequency independent multi layer ground plane

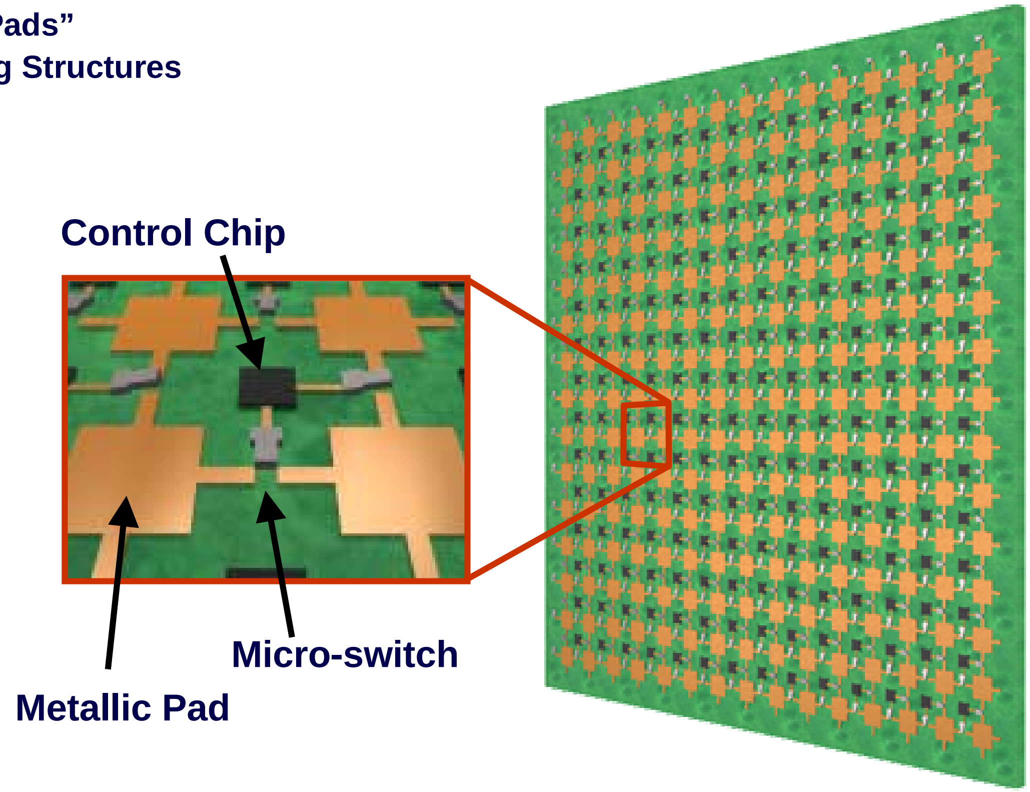
RF MEMS currently under investigation as a reconfiguration mechanism in each of these areas.

MEMS in a Variable Radiating Topology[1]

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



RECAP Element Anticipated Capability:

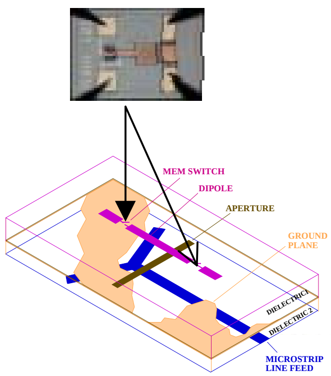
- **Allows Adaptive Optimization for Frequency Band**
- **Allows Steering of Pattern for Single Feed Aperture**
- **Lets User Adaptively Trade Bandwidth for Gain**

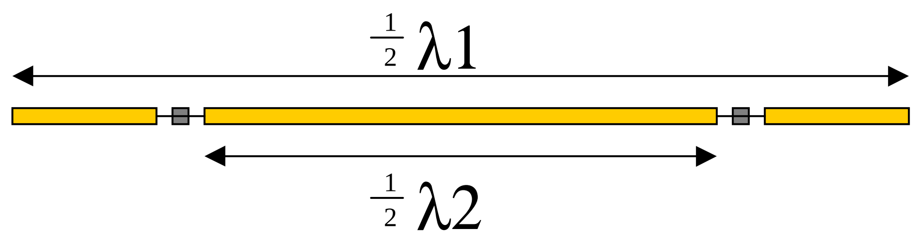
[1] GTRI DARPA RECAP Symposium 2000 - 8

Example of a Reconfigurable Antenna Element

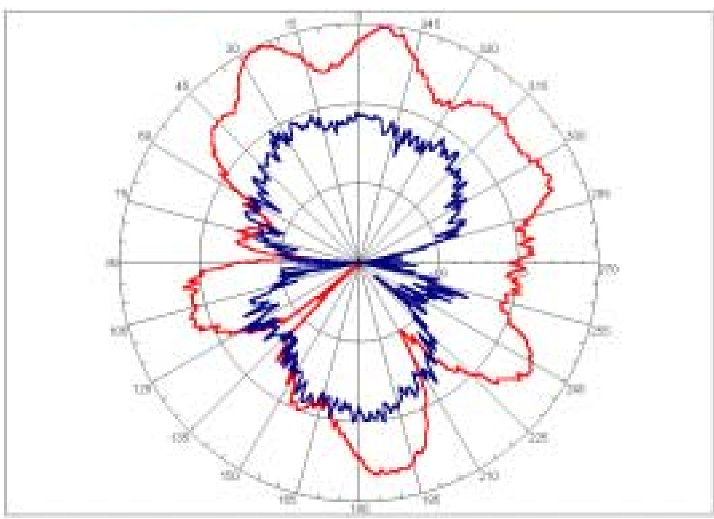
Special Projects Office

MEMS-SWITCHED DUAL-BAND DIPOLE ANTENNA[1]

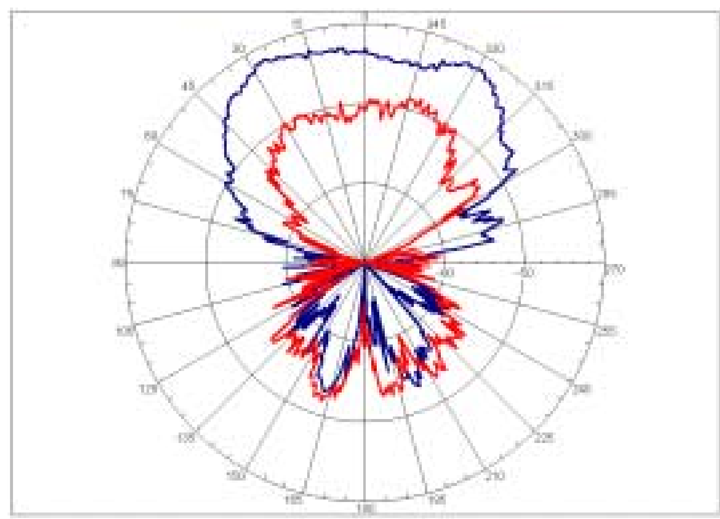




11 GHz



18 GHz



Switches Open

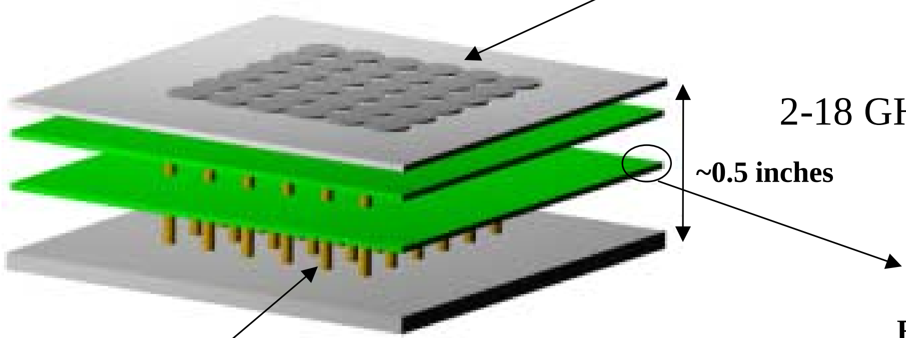
Switches Closed

[1] RECAP Quarterly Review 3/30/2000

MEMS in a Wideband Ground Plane

Special Projects Office

Spiral or Circle elements



2-18 GHz frequency range

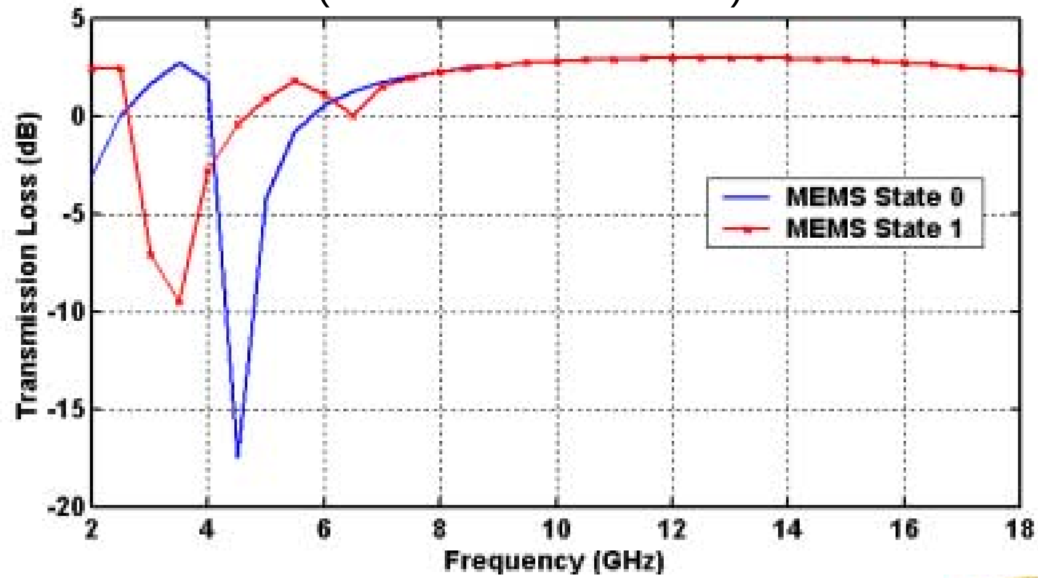
MEMS
FSS

Reconfigurable MEMS FSS

Baluns feed thru to elements

Fixed ground plane at base

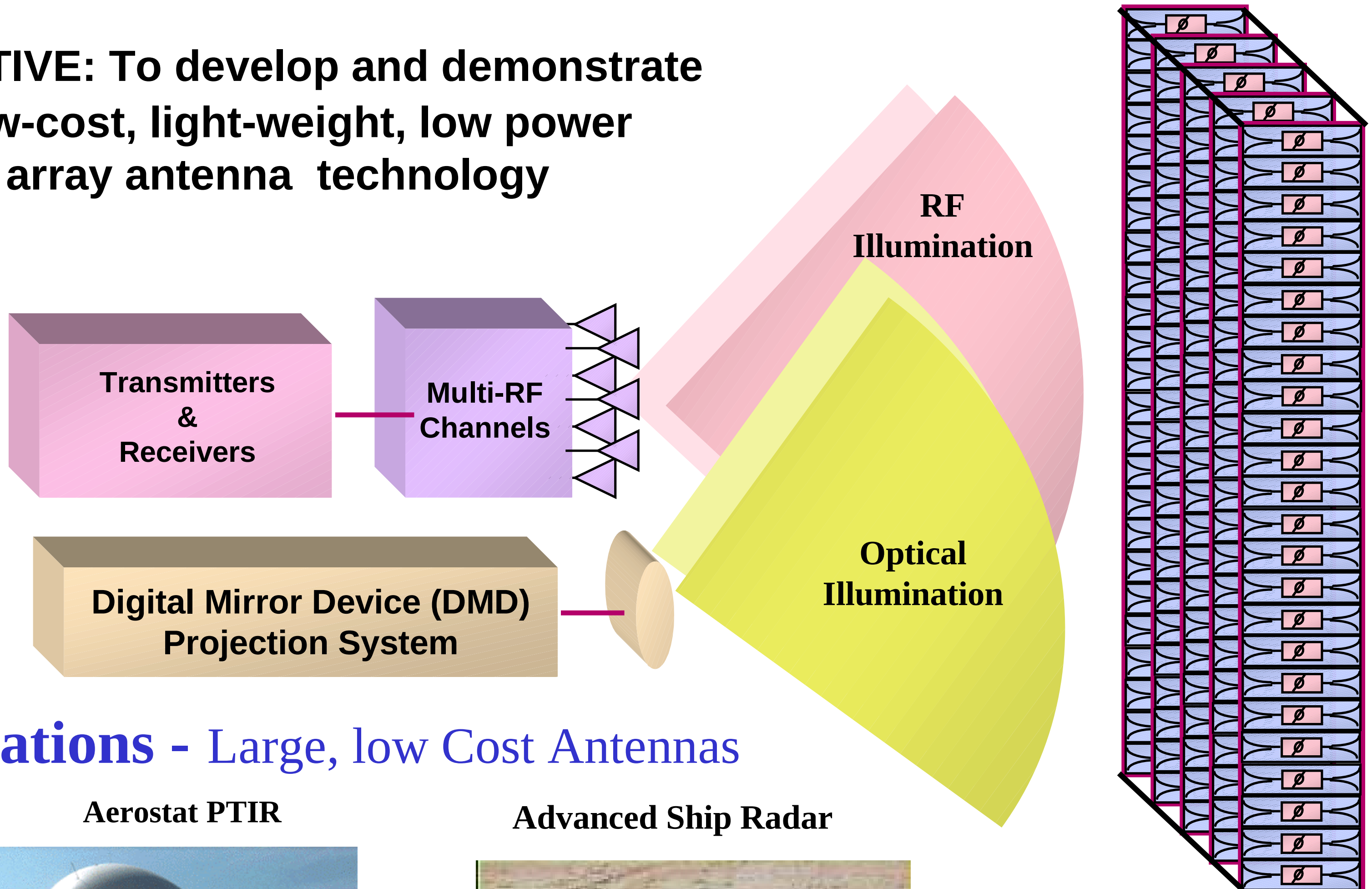
Predicted Boresight Gain Relative to Free Space (No Resistive Bias Film)



Ball Aerospace & Technologies Corp.
Advanced Antenna & Video Systems

MEM-Tenna Concept

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



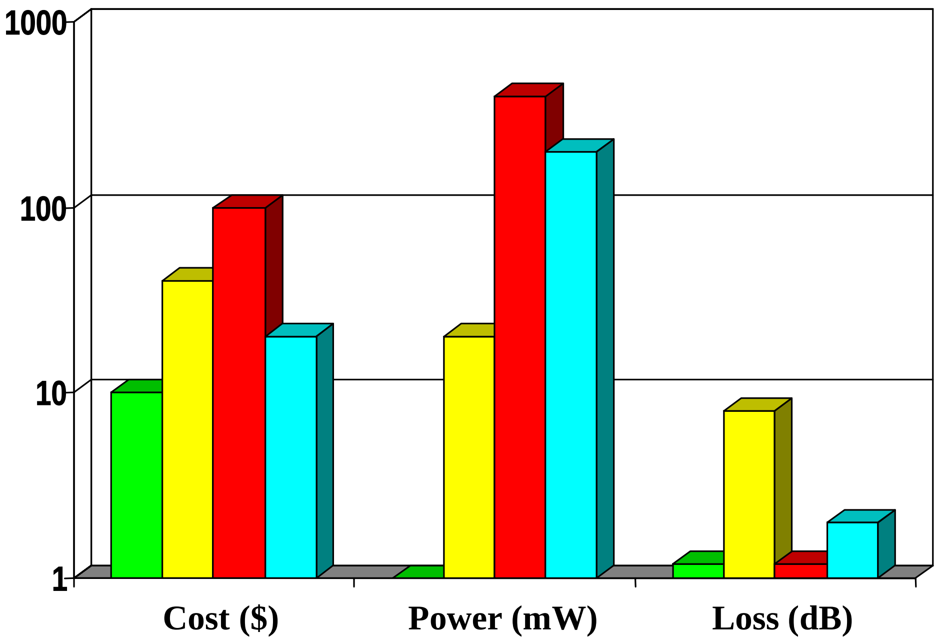
2-D MEM Lens

Applications - Large, low Cost Antennas

Aerostat PTIR

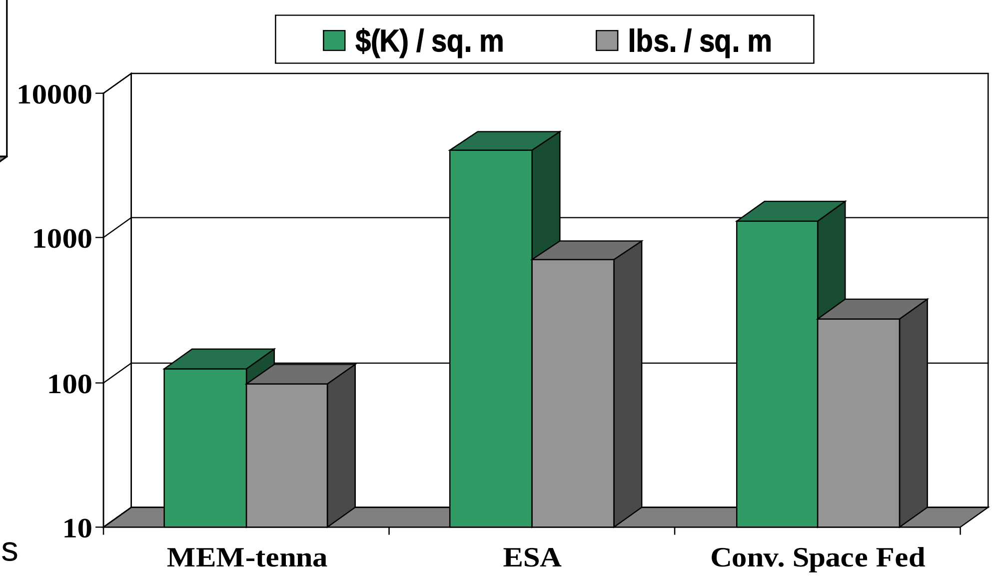
Advanced Ship Radar

MEMs - Enabling Technology



Phase Shifter Technology

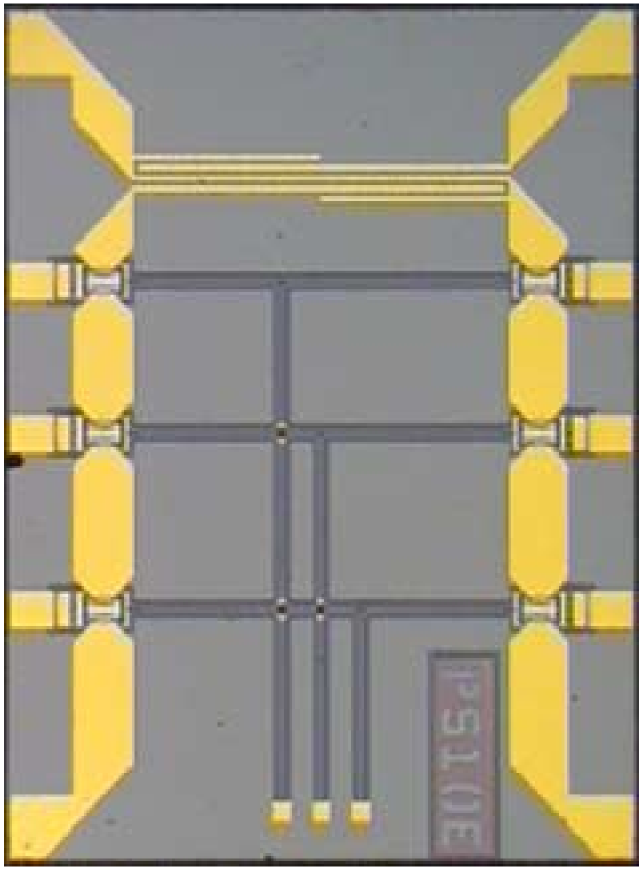
MEMS advantages lead to economies for large scale arrays



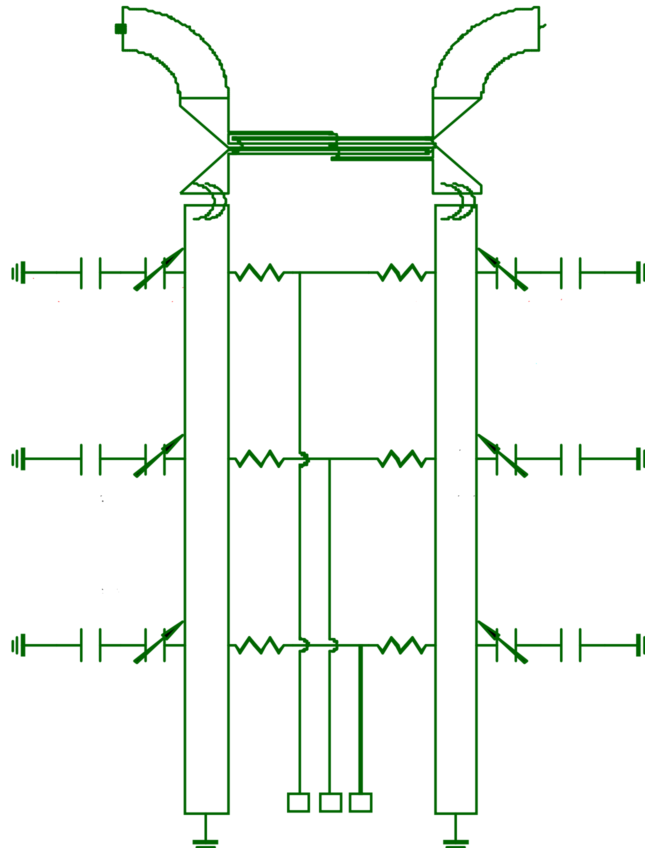
Space - fed lens eliminates cost of many T/R modules and weight of beamformer

Space - fed optical control reduces on-array wiring

X-Band Phase Shifter



Photograph

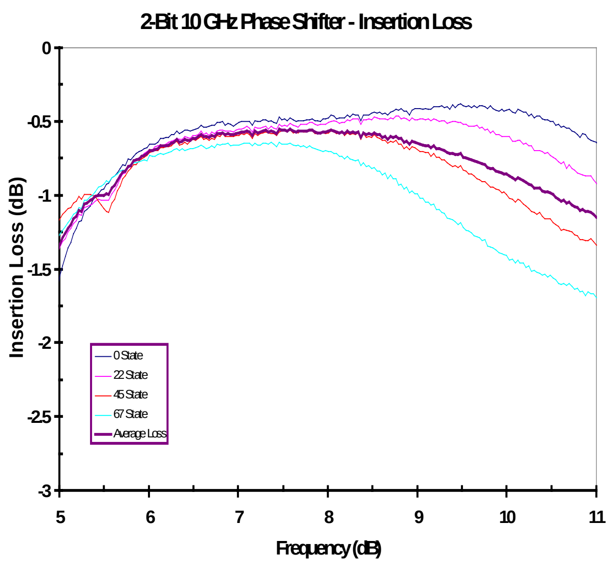


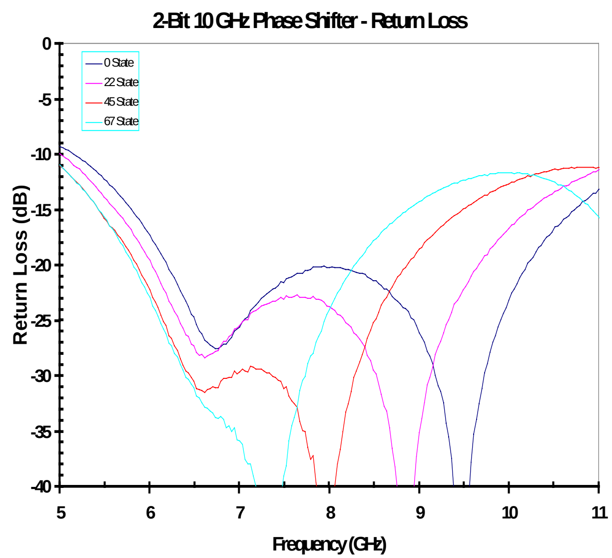
Schematic

2 bits of 4-bit phase shifter

Measured Characteristics

10 GHz 2-Bit (Small) PS Performance





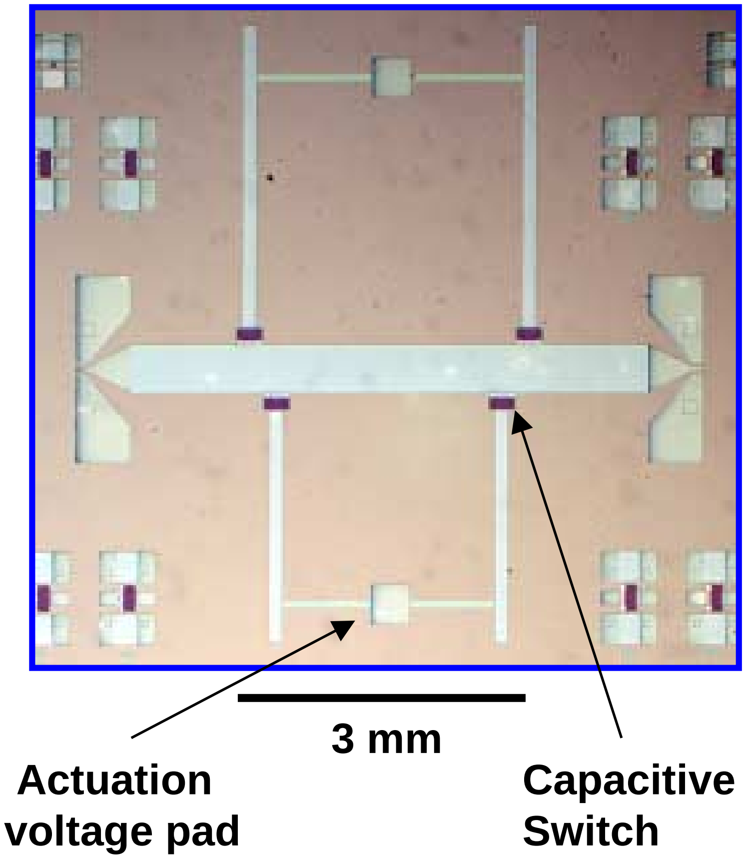
6.0 - 10.0 GHz
- Average insertion loss 0.55-0.9 dB (Arithmetic average of all 4 states)

5.5 - 11.0 GHz
- Return loss > 11 dB

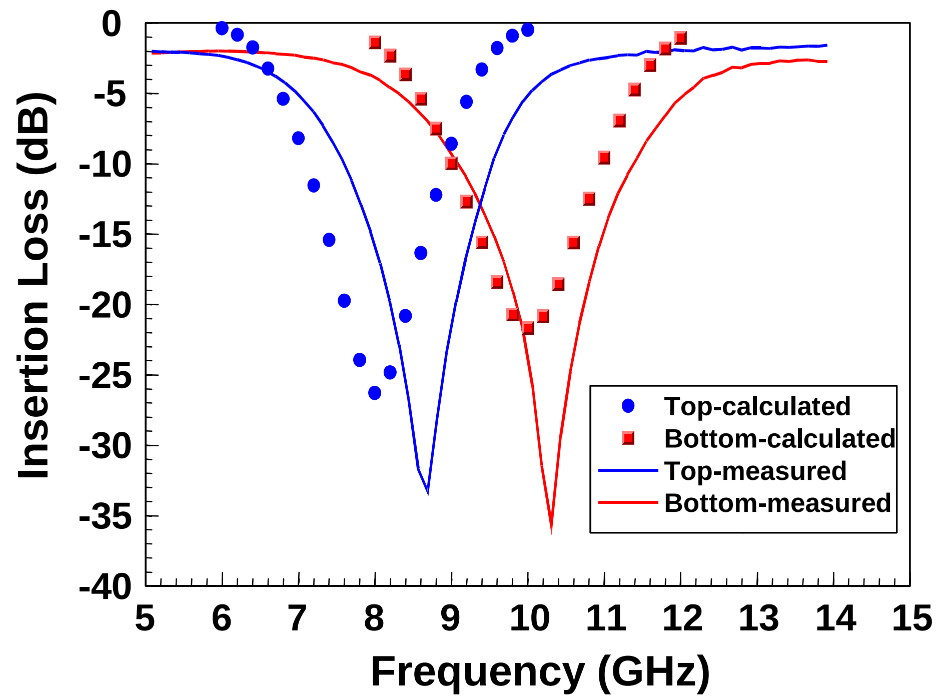
Individual RF Switches in Tunable Notch Filter Circuit[1]

Special Projects Office

Photo of Notch Filter Circuit



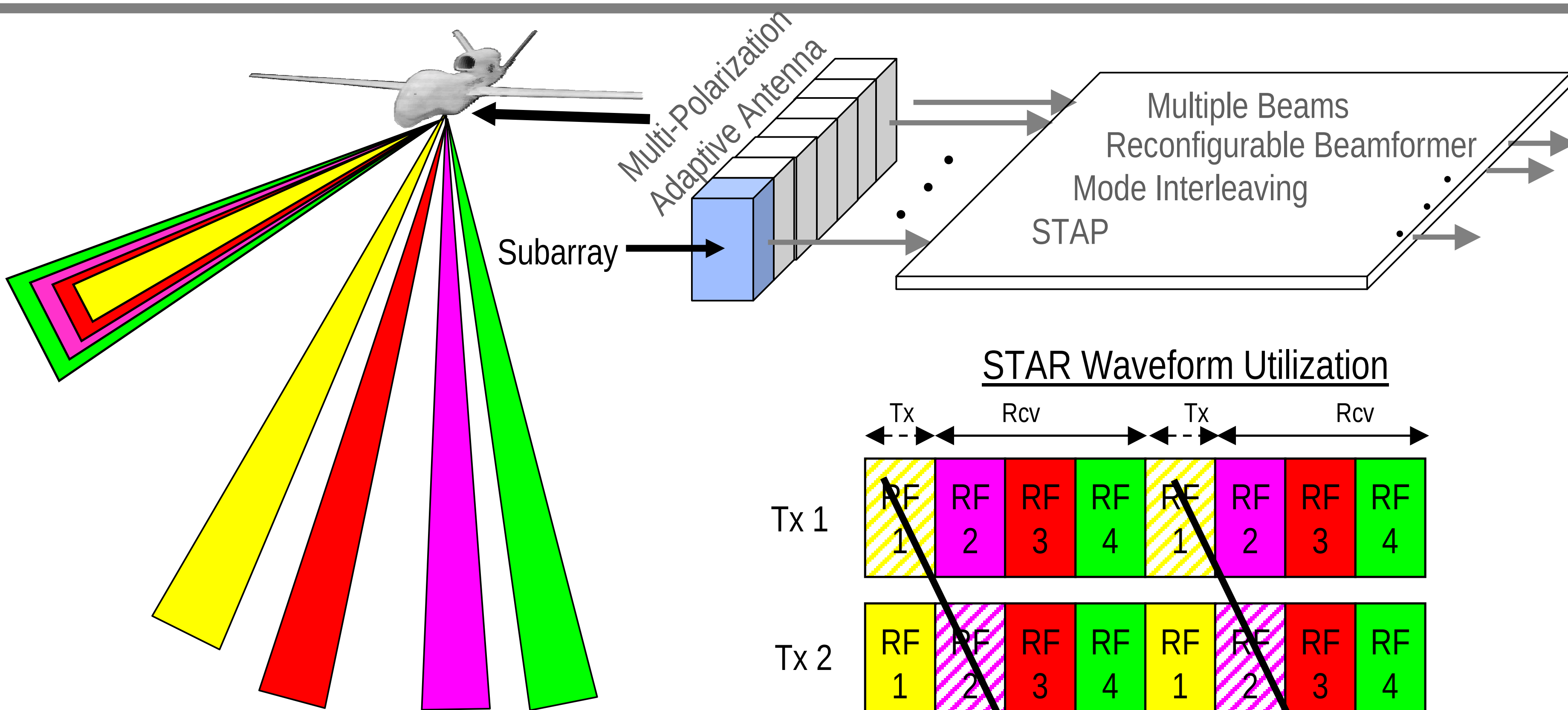
Measured and Calculated Results for Two State Notch Filter



[1] Develped by Licoln Lab for the RECAP progrm.

Advanced Multi-Mode Radar

Special Projects Office



STAR Waveform

PRI

RF 1	RF 2	RF 3	RF 4	RF 1	RF 2	RF 3	RF 4

STAR Waveform Utilization

	Tx	Rcv			Tx	Rcv		
Tx 1	RF 1	RF 2	RF 3	RF 4	RF 1	RF 2	RF 3	RF 4
Tx 2	RF 1	RF 2	RF 3	RF 4	RF 1	RF 2	RF 3	RF 4
Tx 3	RF 1	RF 2	RF 3	RF 4	RF 1	RF 2	RF 3	RF 4
Tx 4	RF 1	RF 2	RF 3	RF 4	RF 1	RF 2	RF 3	RF 4

Time

- 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