CURSOS DE VERANO 08
DE LAS UNIVERSIDADES NAVARRAS

THE FUTURE OF THE ANTENNA TECHNOLOGY
IN THE COMMUNICATIONS AND OBSERVATION SYSTEMS
8, 9, 10, 11 y 12 de septiembre

historia.arte.cine.ciencias sociales.empresa.mitos y leyendas.marketing.tecnología.economía.ciencias políticas.sociología.desarrollo.comunicación.psicología

MEMs, FET and PIN RF Switching Devices and Circuits for Reconfigurable Antennas

Juraj Bartolic
University of Zagreb (Croatia)

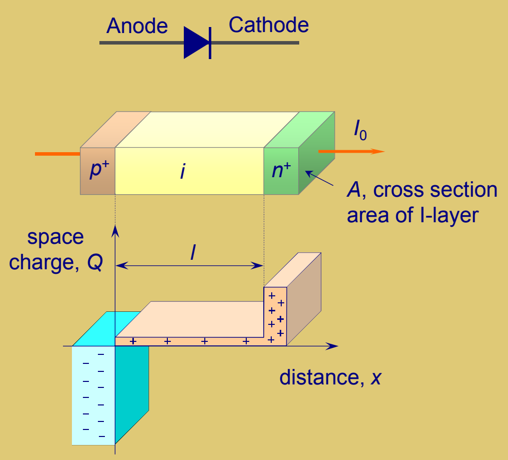
upna Universidad Pública de Navarra Nafarroako Unibertsitate Publikoa

Part 1: MEMS, FET AND PIN RF SWITCHING DEVICES AND CIRCUITS

Outline

- Semiconductor switching devices
  Basic properties of PIN diode and FETs in RF switching applications
  - Comparison of semiconductor switches
- MEMS as RF Switches
  - What are MEMS?
  - Why RF MEMS?
  - Advantages over conventional technologies
  - MEMS resistive and capacitive switches
  - MEMS modelling
  - MEMS applications and conclusions

PIN diode



PIN diode

Typical values of PIN diode parameters

	width, l [cm]	area, A [cm^2]
layer p^+	0.76×10^{-3}	2.0×10^{-3}
layer i	7.6×10^{-3}	3.12×10^{-3}
layer n^+	10.2×10^{-3}	4.5×10^{-3}
metallisation	0.127×10^{-3}	4.5×10^{-3}
heat sink	10.2×10^{-2}	12.9×10^{-3}

PIN diode

Resistance of the intrinsic layer

$$R_i = \frac{l^2}{2\mu_{ap} I_0 \tau_r}$$

where:

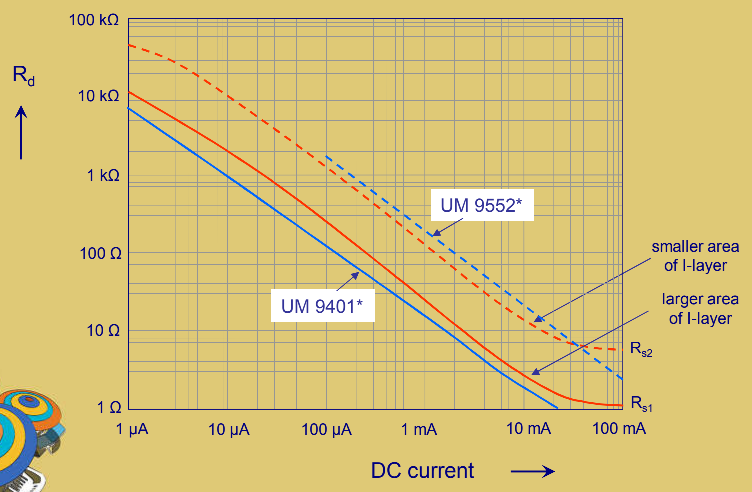
$$\mu_{ap} = \frac{2\mu_e \mu_h}{\mu_e + \mu_h}$$ ambipolar mobility

l = chip length
A= chip area
τ_r = life time of recombined carriers

For silicon diodes with μ_e=1350 cm^2/(Vs) and μ_h=400 cm^2/(Vs) the ambipolar mobility μ_{am} equals 620 cm^2/(Vs)

PIN diode

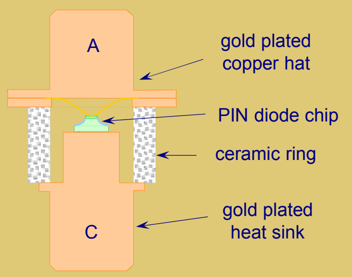
Microwave resistance of a typical PIN diode

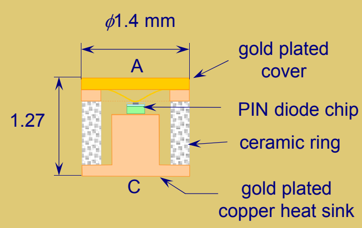


*Unitrode Semiconductor Products Division

PIN diode

Typical packages

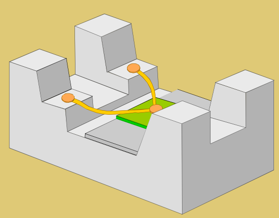




microwave packages

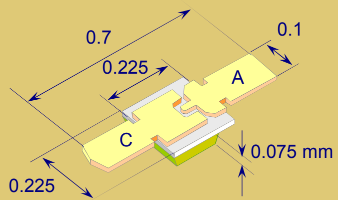
PIN diode

Typical packages



LID package

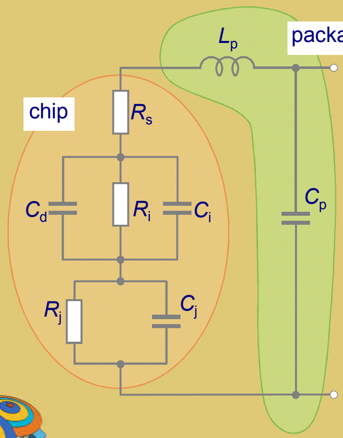
lidless inverted device

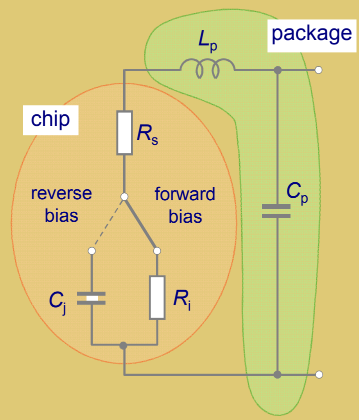


beam-lead package

PIN diode

Equivalent circuits:

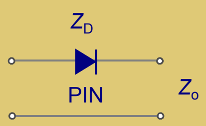




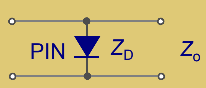
PIN switches

Series and shunt switch attenuation
(general formulas)

$$A = 20\log\left|\frac{2Z_0}{2Z_0 + Z_D}\right|$$ (series switch)



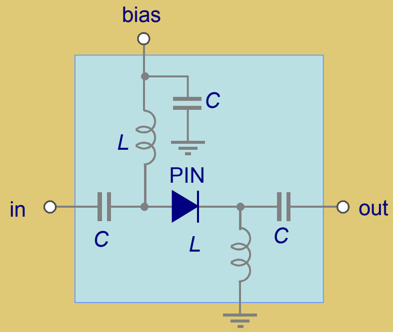
$$A = 20\log\left|\frac{2Z_D}{2Z_0 + Z_D}\right|$$ (shunt switch)



where Z_D is the total impedance of the PIN diode

PIN switches

Series SPST switch



$$\text{Isolation} \approx 10 \log\left[1 + \frac{1}{(4\pi f C_r Z_0)^2}\right] \text{ dB}$$

$$\text{Insertion Loss} = 20 \log\left(1 + \frac{R_s + R_i}{2Z_0}\right) \text{ dB}$$

Power dissipated in the diode:

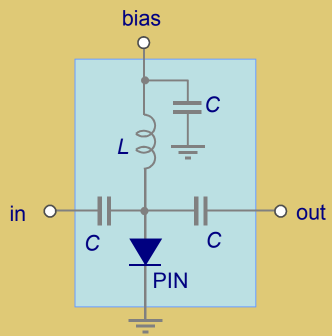
$$P_{dis} \approx \frac{2R_s Z_0}{(2Z_0 + R_s)^2} P_{av} \approx \frac{R_s}{2(Z_0 + R_s)} P_{av}$$

where P_{av} is the maximum available power:

$$P_{av} = \frac{|V_G|^2}{4Z_0}$$

PIN switches

Shunt SPST switch



$$\text{Insertion Loss} \approx 10 \log\left[1 + \frac{1}{(\pi f C_i Z_0)^2}\right] \text{ dB}$$

$$\text{Isolation} \approx 20 \log\left(1 + \frac{Z_0}{2R_s}\right) \text{ dB}$$

Power dissipation:

forward bias

$$P_{dis} \approx \frac{4R_s Z_0}{(Z_0 + 2R_s)^2} P_{av}$$

reverse bias

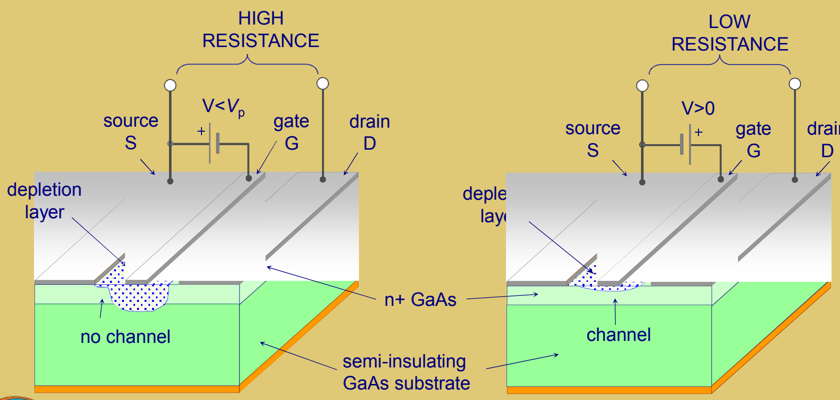
$$P_{dis} \approx \frac{Z_0}{R_j} P_{av}$$

where P_{av} is the maximum available power:

$$P_{av} = \frac{|V_G|^2}{4Z_0}$$

FET switches

Basic principle

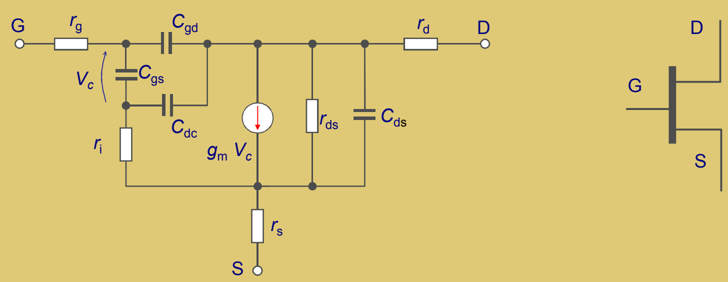


High channel resistance – OFF state

Low channel resistance – ON state

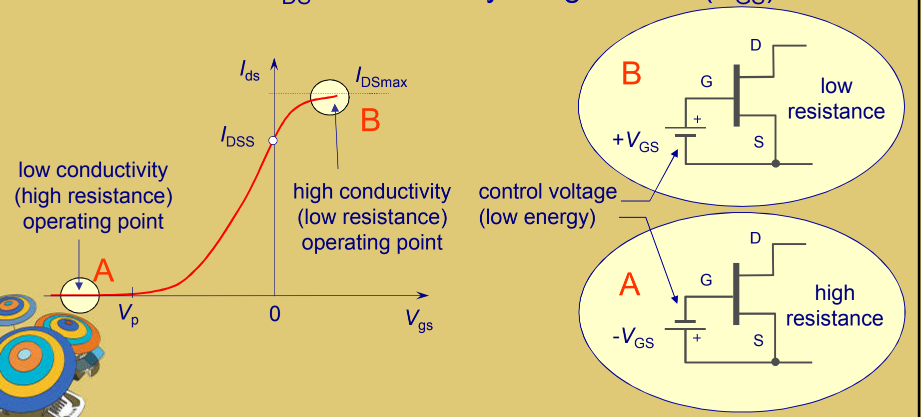
FET switches

MESFET equivalent circuit and symbol



FET switches

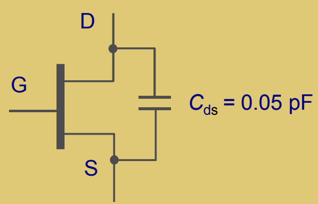
- **FET transfer characteristic**: I_{DS} driven by V_{GS} for given V_{DS} located in the saturation region
- Resistance r_{DS} controlled by the gate bias (V_{GS})



FET switches

- **Isolation** in FET switches degrades at higher frequencies due to the effect of drain-to-source capacitance (C_{ds})
- ***Example***: drain-to-source impedance = 320 Ω at 10 GHz resulting in an isolation of 10.5 dB between drain and source, with additional degradation at higher frequencies

OFF state



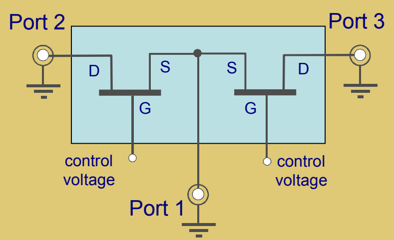
FET switches

- Gate voltage switches the FET from a small resistive device (r_{dsON}) to a small capacitive device (C_{dsOFF})
- Intended to operate passively (no gain)
- Typical V_{ds}=0 V (easy to bias)
- Like PIN diodes, the FET switch can be configured in series with transmission line (drain and source act as input or output and vice versa), or shunt with the grounded source

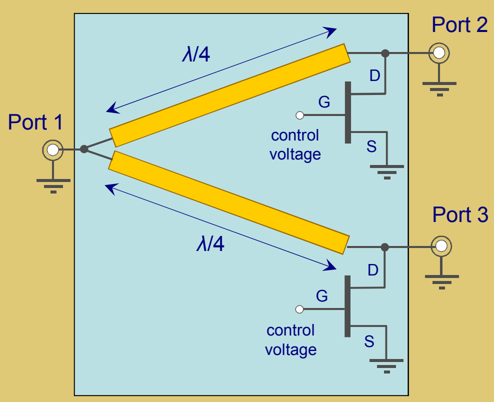
FET switches

Different designs

Series SPDT* switch



Shunt SPDT switch



Combine series and shunt switches for better performances

*Single Pole Double-Throw

Main performance specifications for RF switches

- Frequency bandwidth (highest and lowest frequency)
- Switching speed (speed of moving to 90% ON or 90% OFF)
- Linearity (pollution of adjacent channels)
- Power handling (RF)
- Power consumption (DC)
- Insertion loss
- Isolation (vital in measurement systems)
- SWR (matching)
- Expected lifetime (big consideration for MEMS switches)
- Driver requirements: DC current / DC voltage, negative polarity

Figure of Merit (FoM) of RF switches

- Rates the switching characteristics of different switch devices
- Figure of Merit = $1/(2\pi C_{OFF} R_{ON})$
- Higher FoM yields greater bandwidth
- Rule of thumb: FoM/100 yields the highest operating frequency
- FoM of PIN diode >> FoM of FET (Why? Lower OFF-state capacitance for a given ON-resistance)

Figure of Merit (FoM) of RF switches

- PIN diode: $C_{OFF} \approx 50$ fF, $R_{OFF} \approx 3\ \Omega$ @ 5 mA and 1.7 Ω at 20 mA
  - FoM ≈ 1900 GHz
- MESFET switch: $C_{OFF} \approx 400$ fF, $R_{OFF} \approx 1.5\ \Omega$ @ 5 mA
  - FoM ≈ 265 GHz

✓ MESFET switches work well up to about 26 GHz
✓ PHEMT switches work well up to about 40 GHz
✓ PIN diodes work well up to 180 GHz

RF switch modelling

- Use simple models when applicable: resistor in the ON-state (low resistance) and capacitance (low) in the OFF-state
- Electromagnetic simulators can integrate circuit models
  → only valid in a transmission line environment
- OFF-capacitance of a PIN diode is a function of reverse voltage
- More negative voltage yields less capacitance
- Ground inductance and bond-wire inductance should be accounted for
- At X-band frequencies and above, more complex models should be employed:
  → distributed properties of switch devices
  → transmission-line properties of the device due to its physical area

RF switches comparison

- PIN diode switches have lower losses in comparison to FET switches
- Switching speed higher for GaAs FET (< 10 ns)
- FET switches are better for MMIC applications
- PIN diode switches work from tenths of MHz to over 100 GHz (but not at DC)
- FETs can switch from DC to mm-wave frequencies
- FETs: gate terminal decoupled from source and drain
  - No bias tee and blocking capacitors are needed to separate DC bias from RF signal
- PIN diodes: bias tees and blocking capacitors limit usable bandwidth in the UWB applications
- FETs require only a DC voltage for switching, instead of strong DC current
  - Essentially zero DC power consumption, compared to 10 mA (min) to turn on PIN diode
  - Huge advantage in phase array applications with thousands of switch devices needed to control the phase and amplitude of T/R modules

Limitations of semiconductor switches

☺

- Fast, commercially available, low cost, and ruggedness

☹

- Frequency bandwidth upper limits: degradation of insertion loss and isolation at signal frequencies above few GHz
- Breakdown of linearity: adjacent channel power violations when operating at high RF power levels in addition to noise problems

What are MEMS?

- MEMS are Micro Electro-Mechanical Systems
- MEMS typically have both electrical and mechanical components
- As microelectronics has shown, size doesn't necessarily matter
- First MEMS Publication :
  → H.C. Nathanson, et al., *The Resonant Gate Transistor*, IEEE Trans. Electron Devices, March 1967, vol. 14, no. 3, pp 117-133
- Pressure sensors were the first MEMS products
  → Si diaphragms and diffused piezo-resistors
- Surface μ-machined accelerometers and flow sensors

Why RF MEMS?

- Miniaturization with no loss of functionality
- Integration to form a monolithic system
- Improved reproducibility, reliability and accuracy
- Exploitation of new physics domains
- Low power
- Fast actuation techniques
- Improved selectivity and sensitivity

Why RF MEMS?

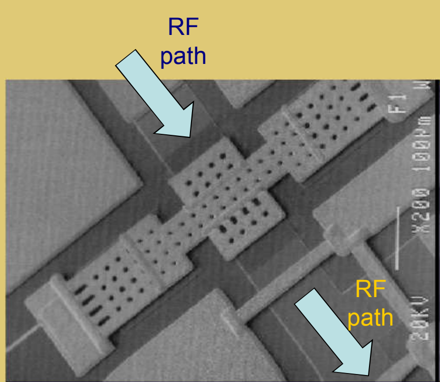
Switch type	Properties					
	Insertion loss	Isolation	Power consumpt.	DC voltage	Speed	Bandwidth
PIN / Schottky	≈0.15 dB	45 dB	1-5 mW	1-10 V	1-5 ns	narrow / wide
GaAs Fetes	1-2 dB	≈ 20 dB	1-5 mW	1-10 V	2-20 ns	narrow / wide
HBT / PIN	0.82 dB	25 dB	1-5 mW	1-10 V	1-5 ns	narrow / wide
Best FET	0.5 dB	70 dB	5 mW	3.5 V	2 ns	narrow / wide
MEMS	0.06	40-60 dB	≈1 μW	10-20 V	> 30 μs	wide (1-40 GHz)

Advantages over conventional technologies (PIN diodes, JFET, MESFET….)

- High RF performance (up to mm-waves)
- Near-zero power consumption
- Volume production →low cost
- Miniaturization

Open issues

- Reliability
- Switching speed
- Power handling



RF MEMS

Advantages

Advantages of using MEMS switches over solid state switches (i.e. PIN diodes, MESFETs):

- Can be designed for any frequency (other only good up to a few GHz)
- Can be fabricated on wafer (other require soldering)
- Much less power consumption
- Excellent RF isolation

RF MEMS

Disadvantages

- Relatively new technology (10 years old versus 50 years old)
- More complicated
- Packaging is large and expensive
- Slow switch time (microseconds instead of nanoseconds)
- Reliability (best switches reported only good for 100B cycles)

Main issues

Manufacturing

- Outgrowth of “Micromachining”

  Creation of unique physical structures through the use of sacrificial layers resulted in miniature mechanical structures on a substrate (often Silicon)

  Open circuit / low capacitance dielectric layer

  Closed circuit / high capacitance

- MEM switch in RF applications
  - 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**

Basics of MEMS RF switches (1)

- MEMS: miniature device or an array of devices combining electrical and mechanical components and fabricated with surface micromachining

- Surface micromachining: deposition and lithographic pattering of various thin films, usually on Si substrates

- Interaction of elastic membranes with static electric fields causes membrane deflection → DC voltage controlled switch

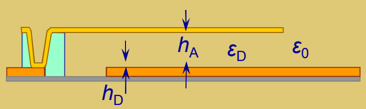
Basics of MEMS RF switches (2)

- Advantage of electromechanical relays
  - ultra-low loss high isolation and high linearity
- Advantage of solid state switches
  - significant size, power consumption, and cost advantages of high volume wafer manufacturability
- Packaging
  - freestanding mechanical structures must be protected and free of contamination during both the manufacturing process and the life time of the component
  - layout and materials in the package have a large effect on MEMS performance
- Most common being resistive series switches and capacitive shunt switches

MEMS resistive switches

Cantilever

switch UP (OFF state)



$$C_{OFF} = \frac{\varepsilon_0 A}{h_A}$$

switch DOWN (ON state)

$$R_{ON} = \frac{\rho_c}{A}$$

where A is the area of the contact

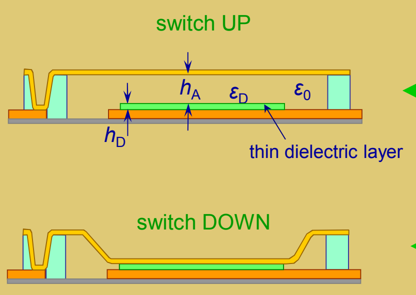
Typical values:

h_A = 2 μm
ρ_c= 10^{-8} Ωcm^2
$R_{ON}C_{OFF} < 10^{-17}$ s

$$\text{Figure of merit} = R_{ON}C_{OFF} = \frac{\varepsilon_0 \rho_c}{h_A}$$

MEMS capacitive switches

Bridge



$$C_{OFF} = \frac{1}{\frac{h_D}{\varepsilon_D A} + \frac{h_A}{\varepsilon_0 A}}$$

where A is the area of the dielectric layer

$$C_{ON} = \frac{\varepsilon_D A}{h_D}$$

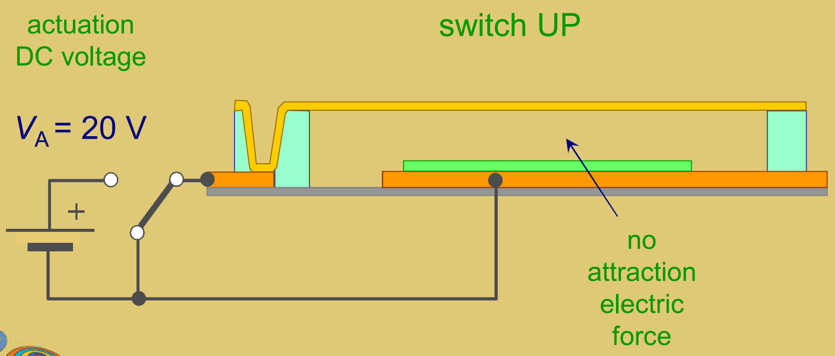
Typical values:

h_A = 2 μm
h_D = 100 nm
$\varepsilon_D = 7.5\ \varepsilon_0$

$$\text{Figure of merit} = \frac{C_{ON}}{C_{OFF}} = 1 + \frac{h_A \varepsilon_D}{h_D \varepsilon_0} > 100$$

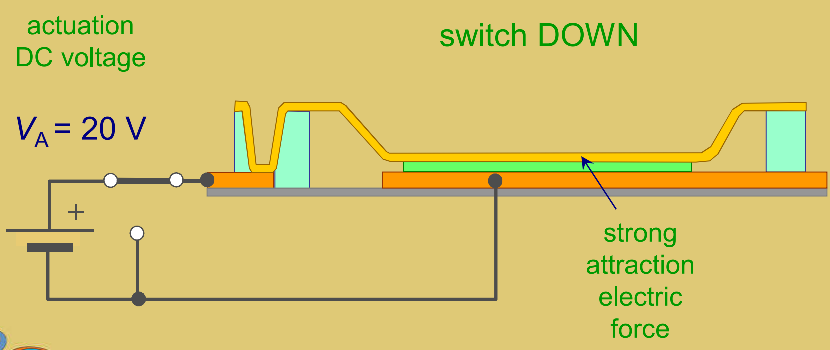
MEMS capacitive switches

Bridge



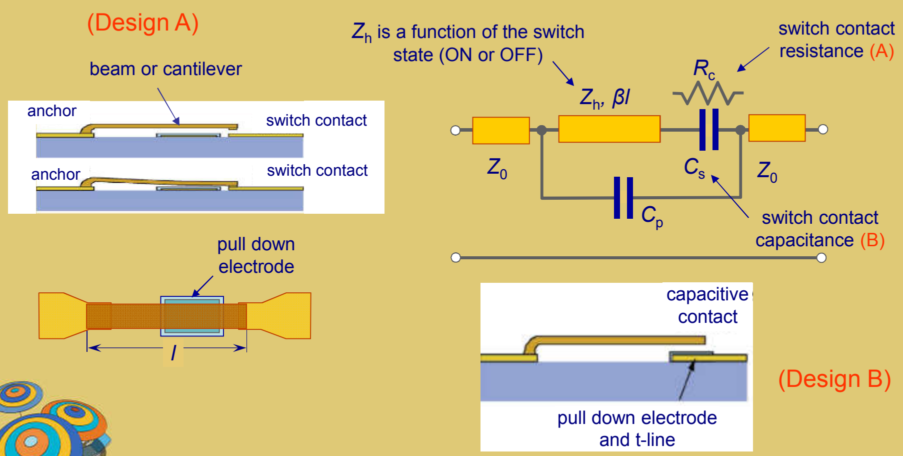
MEMS capacitive switches

Bridge



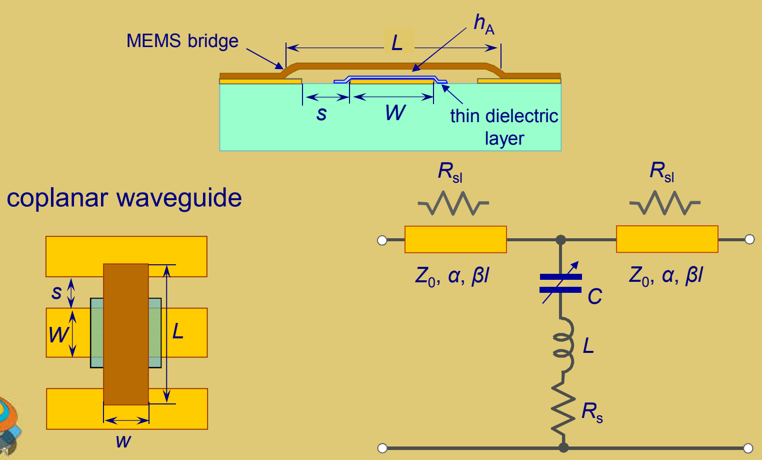
MEMS

RF MEMS modelling



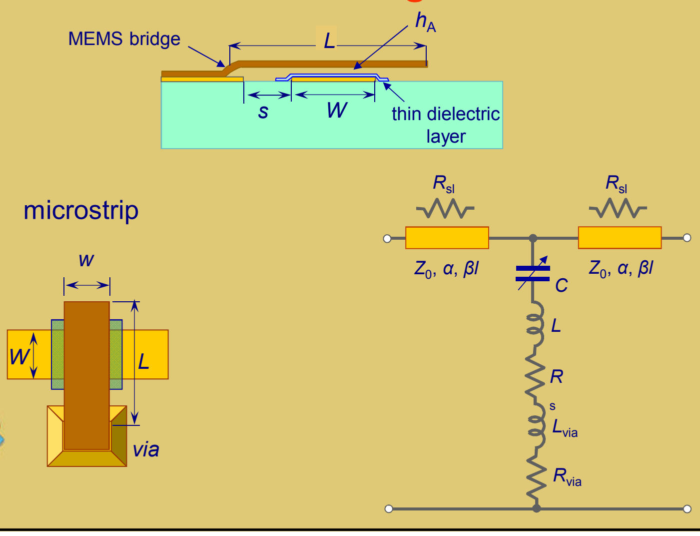
MEMS

Modelling

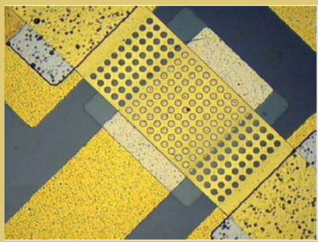


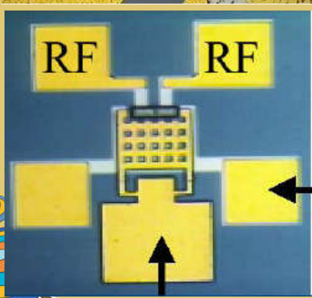
RF MEMS

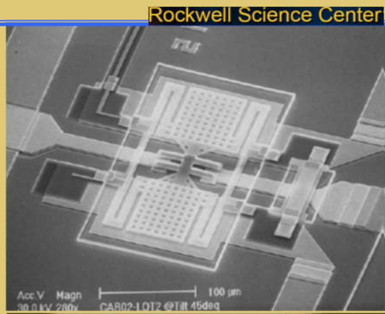
Modelling

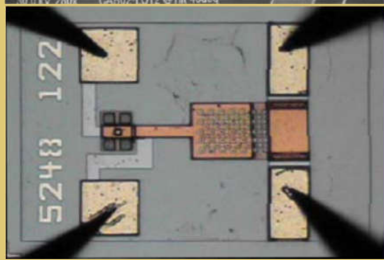


RF MEMS

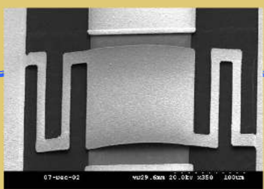


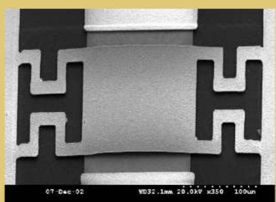


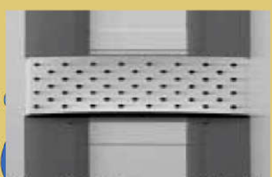




RF MEMS

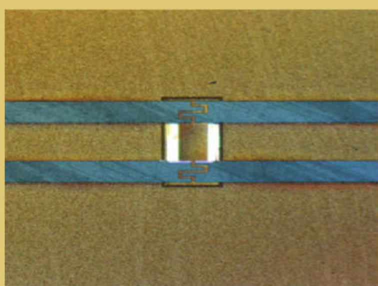


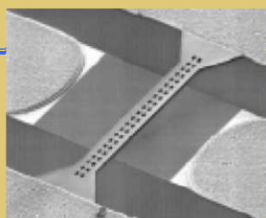


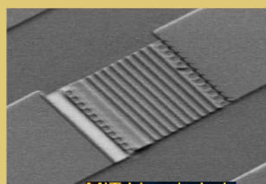


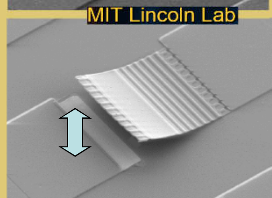
High lifetime (repeatability) of the switch on nano-scale level !!

Million cycles





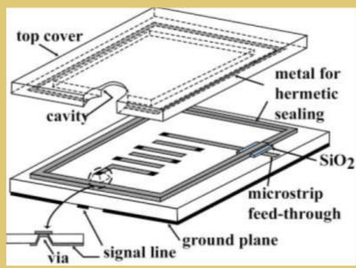




RF MEMS

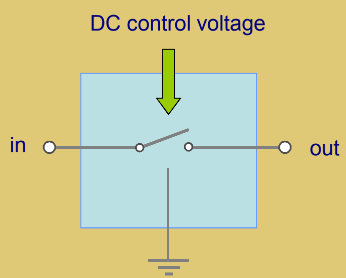
Packaging Considerations in MEMS Circuits

- Wafer level packaging will result in lowest cost for MEMS switches
- Packaging gas has a large effect on reliability
- Hermetic sealing is essential since MEMS switches are sensitive to humidity
- For high performance, low quantities, packaging can be done using standard techniques.
- The highest cost will have the package in single MEMS switches. This is not the case in phase shifters or filters, or high isolation switch networks



MEMS and PIN switches

RF MEMS switch circuit

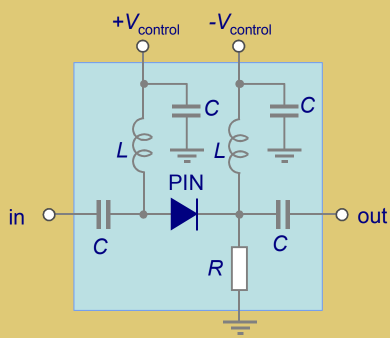


0.0025 sq inch

one polarity

< 1 nW

PIN diode switch circuit



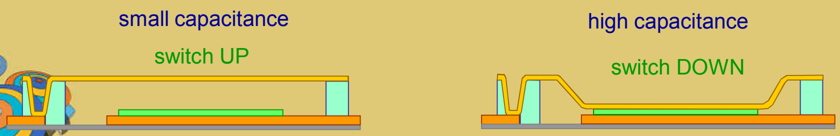
0.25 sq inch

two polarities: + and -

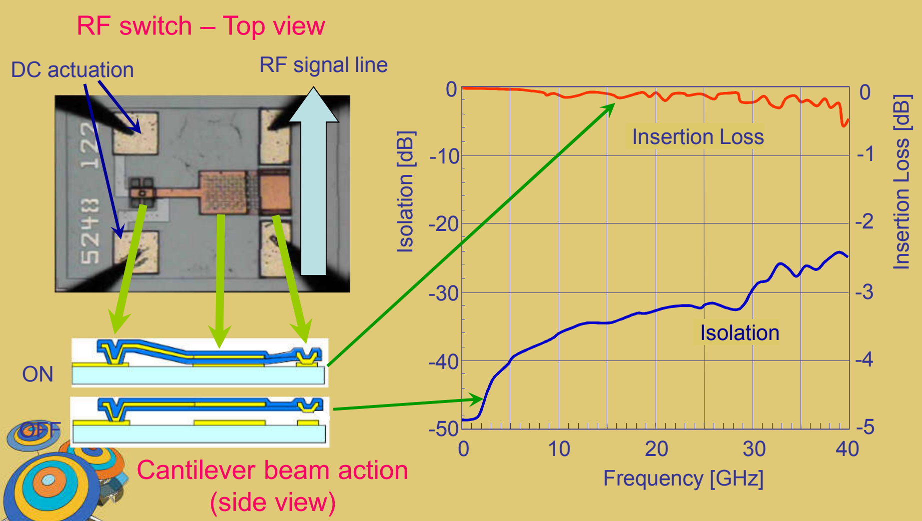
≈ 300 mW

Capacitive shunt SPST

- Metallic membrane shaped like a bridge the central (underpass) conductor
- Connects both ground electrodes
- DC voltage applied between the central conductor (or separate pull-down electrodes) and the membrane
  → Membrane attracted to the central conductor
- Underpass conductor covered by a thin dielectric layer
  → No sticking of the electrodes
- DOWN increased capacitance

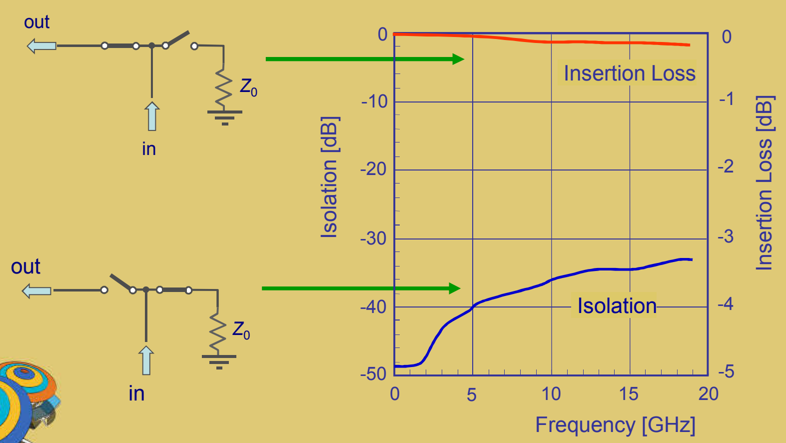


Microwave components with MEMS switches

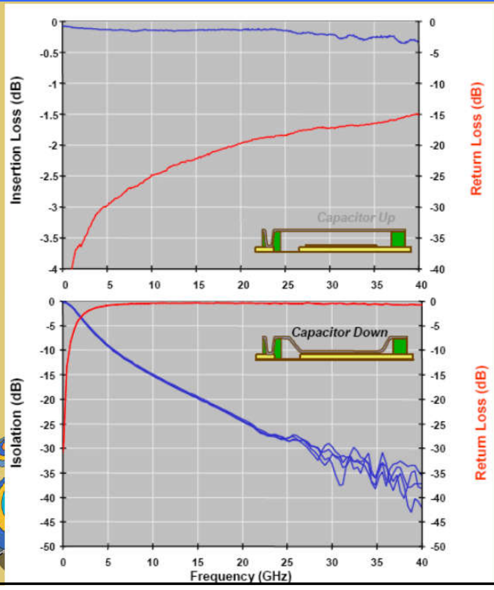


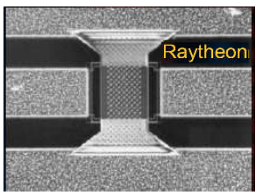
Microwave components with MEMS switches

Single-pole double-throw switch

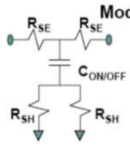


Microwave components with MEMS switches





Insertion Loss @ 40 GHz	<0.07	dB
Isolation @ 40 GHz	>35	dB



Model Values		
Rs	0.11	Ohms
Rsh	0.2	Ohms
Coff	0.03-0.045	pF
Con	3.4	pF
Ron	0.25	Ohms
Capacitance Ratio	70-110	
Cutoff Frequency	18,000	GHz
Switching Speed	< 10	µs
Intercept Point	> +66	dBm
Switching Voltage	30-50	volts
Size	280 × 170	µm

RF MEMS applications

- **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**
  - Ground planes
  - Elements
  - Array feeds/architecture
- **Phase shifters**
- **Filters**

Conclusions

- The main question now is reliability and packaging
- Reliability is currently high
- Failure mechanisms are:
  - Resistive failure in DC-contact switches (metallurgy, contact forces)
  - Sticking due to humidity and/or charging of the dielectric (capacitive switches)
  - Sticking due to metal-to-metal contacts (contact physics)
  - Micro-welding due to large currents
- To combat failures, industry is doing the following:
  - Packaging in inert atmosphere such as nitrogen and/or hermetic sealing
  - Large voltage and large spring constant structures
  - Development of better metal contacts
  - Designs with no contact between the pull-down electrode and the bottom metal (not applicable for current capacitive switches)

Conclusions

- Today, most MEMS switches are being developed for phase shifters and defence applications
- Tomorrow, most MEMS switches will be developed for wireless applications and low-power applications:
  - Single-Pole Multiple-Throw Switches
  - Switched filter banks for portable and base stations (receive)
  - Switched attenuators for high dynamic range receivers and instrumentation
  - Tunable filters (high-Q varactors)
  - Tunable networks for wideband applications (switched capacitors, medium Q needed)
- There are currently no high power (100 mW to 10 W) MEMS switches.
- There are currently no services or foundries for RF MEMS switches.

Part 2: Reconfigurable antenna

Contents

Introduction

- **Why reconfigurability?**

Increasing demand of bandwidth and service quality.
Antenna reconfigurability offers:

- Electronic beam steering
- Multibeam capability
- Optimized coverage
- Increased number of channels
- Robustness with respect to element failure
- Robustness with respect to interference

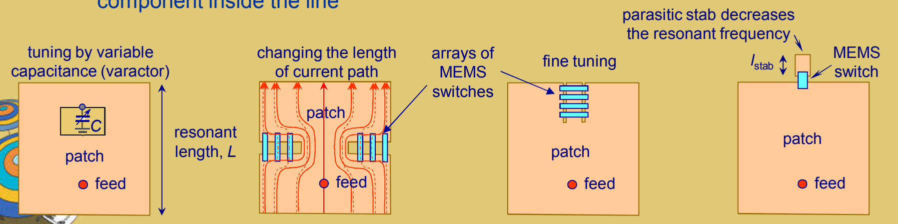
Main issues

- Indoor and urban environments: fading effects caused by multipath phenomena + depolarization.
- Objective: design simple (single port and compact) antennas providing different channels (patterns, polarisations) to multiply the channels and fight the fading/depolarisation effects.
- More generally, improve the communication in multi-terminal applications.
- How?
  - By altering a basic antenna with parasitics and switch the parasitics to modify the radiation characteristics
  - By multiplying the feeds (one feed per pattern/polarisation) and switch to either feed.

Reconfigurable antennas

Principle of operation

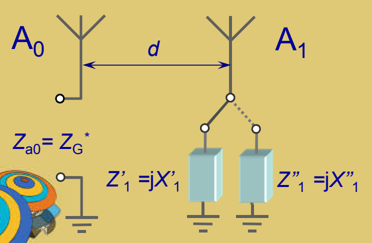
- Main idea: create a continues (variable capacitor) or discrete (switch) alternation of the resonant lengths, either by modifying the current paths, the propagation constants or by loading the antenna
- Effective influence on the resonance:
  - Solution 1: components located in a strategic position inside the antenna, i.e., a position where its parasitic influence on the electromagnetic field is remarkable
  - Solution 2: loading the antenna by an external line and inserting a switchable component inside the line



Reconfigurable antennas

Basic concept

- Antenna system consist of:
  - An active element, A_0 (permanently connected to the receiver)
  - *N* parasitic elements, A_1 , A_2… A_N (strongly coupled to the active element)
- Parasitic elements with switchable terminating impedances
- Different switch settings result in different far-field patterns



A simple example with only one parasitic element:

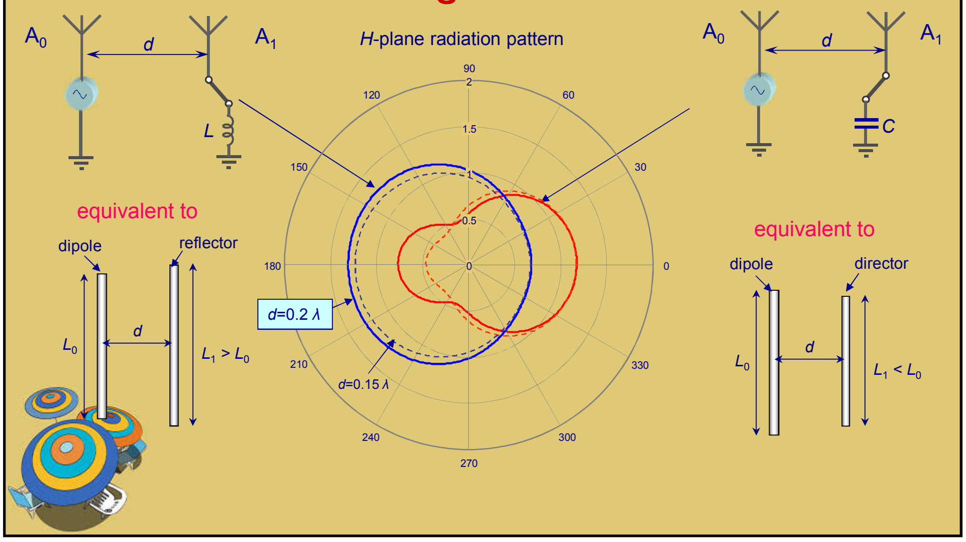
X'_1 = inductive reactance (reflector)

X''_1 = capacitive reactance (director)

All metallic parts have the same geometry. By changing the character of the termination one can effectively change the role of the passive structure from the director to the reflector, and vice versa

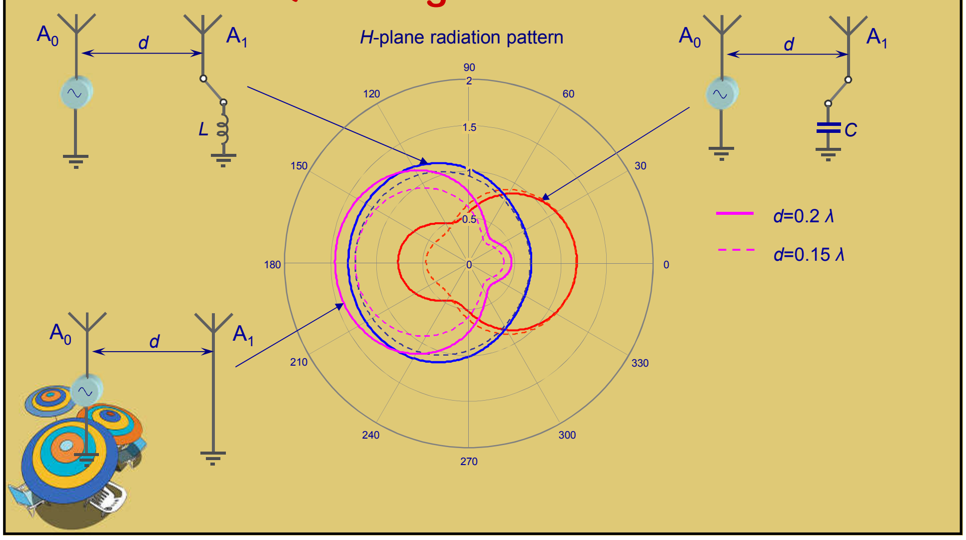
Reconfigurable antennas

Quasi Yagi-Uda antenna



Reconfigurable antennas

Quasi Yagi-Uda antenna

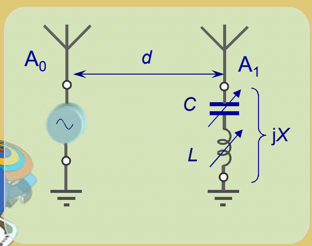


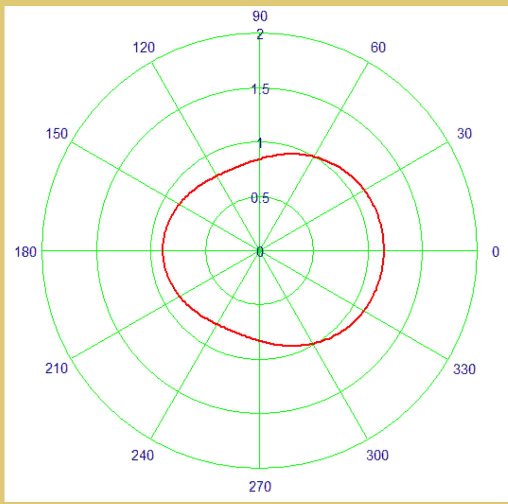
Reconfigurable antennas

Quasi Yagi-Uda antenna

***H*-plane radiation pattern** of a simple Yagi-antenna system consisting of an "active" radiator A_0 and a "passive" radiator A_1 which is loaded by a pure reactive (imaginary) impedance.

Loading reactance *X*, at the Antenna 1 terminals, is changing from negative to positive values





Reconfigurable antennas

Competition with passive multiband antennas

- Tunable antennas:
  - Added complexity (bias circuit, soldering points,…) and cost (active components…)
  - Losses in active components
- Multiband passive antennas:
  - Often narrow bandwidths for one or several bands ⤇ sensitive to fabrication tolerances or electromagnetic perturbations (human body) ⤇ tuning properties increase the effective bandwidth
  - Receive unwanted signals and/or added noise from the other bands when a given band/standard is selected ⤇ filtering circuits BUT intrinsic filtering is performed in tunable antennas
  - Can hardly be small, efficient and have good radiation properties (polarisation purity, stable radiation pattern) in all bands simultaneously

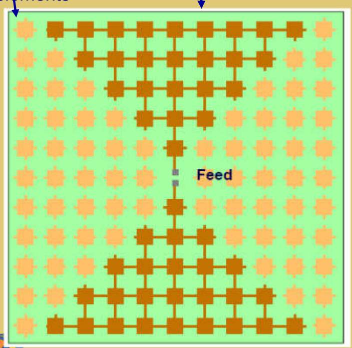
Reconfigurable antennas

Source: DARPA

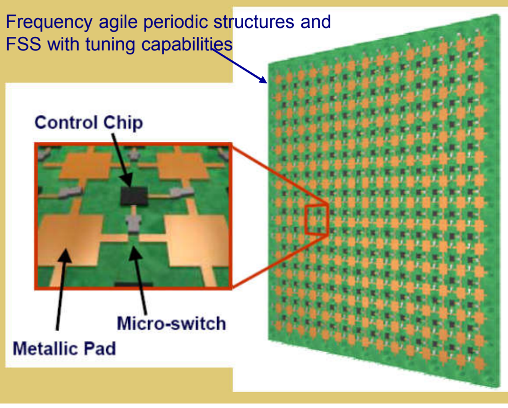
Reconfigurable aperture

"passive" elements

"active" elements



Frequency agile periodic structures and FSS with tuning capabilities



Connected pads forming a bow-tie metallisation pattern. Almost any shape of the active metallic part of the antenna can be readily realised

- Allows adaptive optimisation for frequency band
- Allows steering of pattern for single feed aperture
- Lets user adaptively trade bandwidth for gain

Reconfigurable Aperture

- Overall Goals
- Tailoring a radiation pattern dynamically
  - Greater than a decade bandwidth coverage
  - Geometric reconfiguration
- Adapt to frequency spectrum changes

Reconfiguration for optimized performance

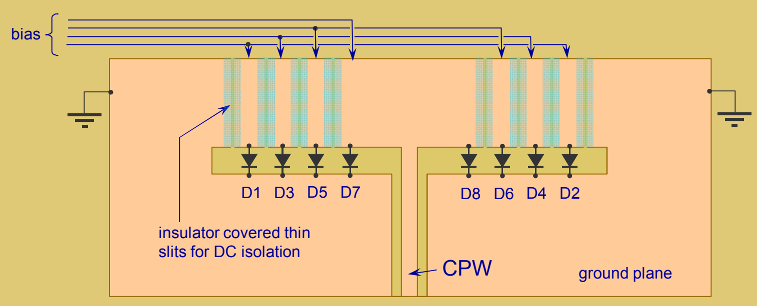
Frequency reconfiguration

- Resonant antenna which impedance features can be modified by tuning the electrical properties of a component integrated inside the antenna volume
- Continuous (varactor, ferrite, biased silicon substrate…) or discrete (MEMS, PIN diodes, FET,…) tuning or changing of the resonant frequency
- Frequency tuning must be obtained with a good return loss and efficiency performances over the tuning range

Frequency reconfiguration

- Multi-frequency applications:
  - Two or more types of standards (GSM + DCS1800, WiFi + Bluetooth)
  - Different frequencies for transmission and reception
- Fine resonance adjustment when de-tuning occurs
  - De-tuning results from the hand or body influence (RFID tags, mobile phones, …)
  - Associated with some feedback to realise self-reacting antennas

Switchable CPW-fed slot antenna

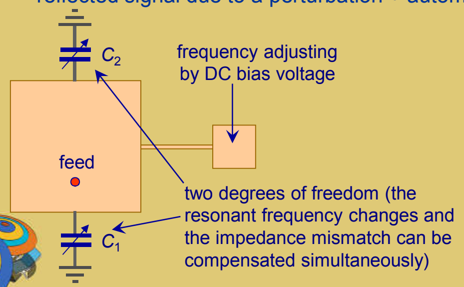


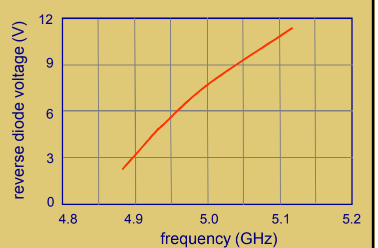
The radiating slot of 500 μm is selected so that a beam-lead diode (total length 800 μm) can easily be soldered

The impedance of a radiating slot at its series resistance frequency weakly depends on its length / width ratio

Self-adjusting microstrip antenna

- Microstrip antenna loaded by two varactor diodes
- Well matched at the nominal operating frequency 5.0 GHz (no environment perturbation) for a correct reverse DC voltage applied to the varactors
- Perturbation effect:
  - Detuning of resonance → shift of the resonant frequency
  - Self-adjusting of the resonant frequency: comparison of the incoming signal with the reflected signal due to a perturbation + automatic feedback





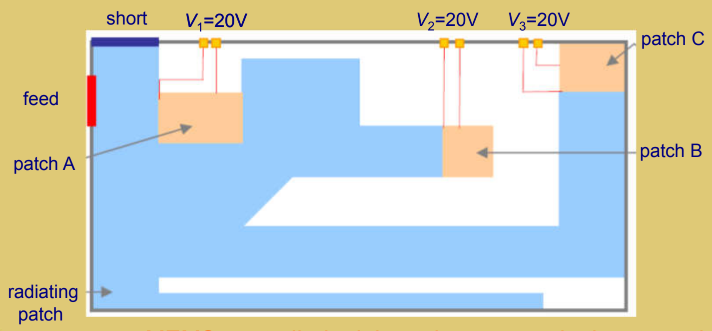
Source: Y. Turki, R. Staraj: *Self-adjusting microstrip antenna*, Electronics Letters, Vol. 35, No. 2, 21 Jan. 1999, pp. 106-107.

Reconfigurable PIFA

Penta-band antenna

GSM900, GPS1575, GSM1800, PCS1900, MTS2100

V_1, V_2, and V_3 are actuating voltages



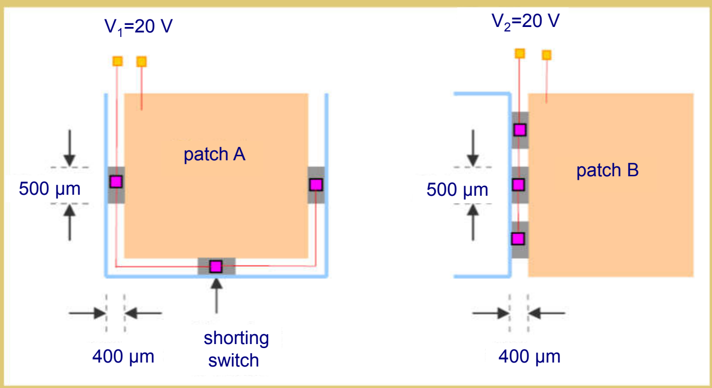
MEMS-controlled mini-patches are put in the strategic points inside the radiating structure to optimize multi-band operation

Source: B. Yıldırım, B. Çetiner, Q. Xu: *Reconfigurable Planar Inverted-F Antenna for Mobile Phones*, 2007 AP-S Symposium, Hawaii

Reconfigurable PIFA

Penta-band antenna

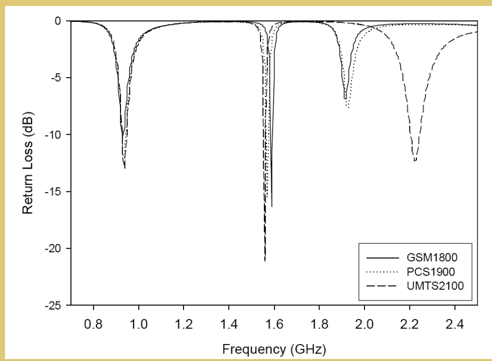
GSM900, GPS1575, GSM1800, PCS1900, MTS2100



Source: B. Yıldırım, B. Çetiner, Q. Xu: *Reconfigurable Planar Inverted-F Antenna for Mobile Phones*, 2007 AP-S Symposium, Hawaii

Reconfigurable PIFA

Results

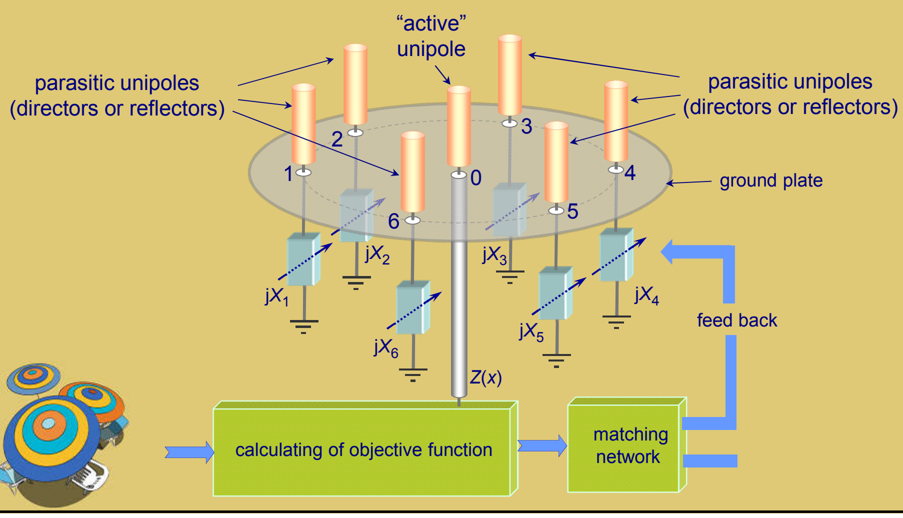


Switch Status	Active Bands		
$\bar{A}B\bar{C}$	GSM 900	GPS 1575	GSM 1800
ABC	GSM 900	GPS 1575	PCS 1900
$A\bar{B}C$	GSM 900	GPS 1575	UMTS 2100

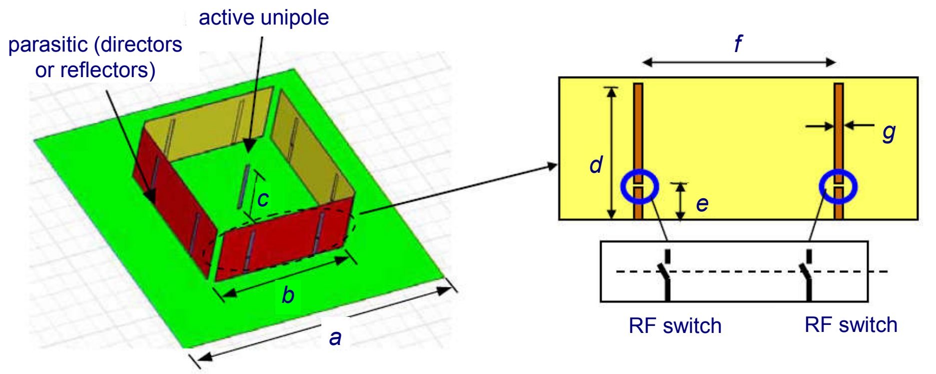
Source: B. Yıldırım, B. Çetiner, Q. Xu: *Reconfigurable Planar Inverted-F Antenna for Mobile Phones*, 2007 AP-S Symposium, Hawaii

Electronically steerable parasitic unipole array

Radiation pattern reconfiguration



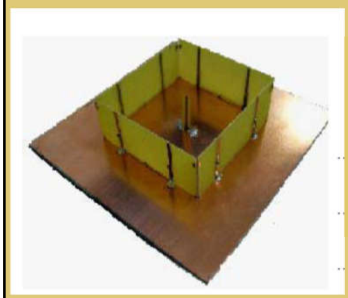
Electronically controlled multi-beam antenna with switched parasitic elements

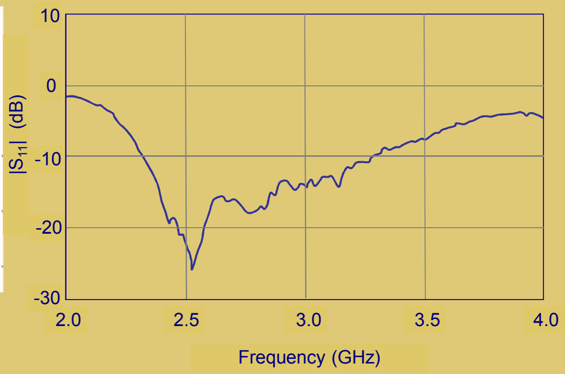


Source: Jia-Cheng Ke, Ching-Wei Ling and Shyh-Jong Chung: *Implementation of a Multi-Beam Switched Parasitic Antenna for Wireless Applications*, 2007 AP-S Symposium, Hawaii

Electronically controlled multi-beam antenna with switched parasitic elements

Return loss

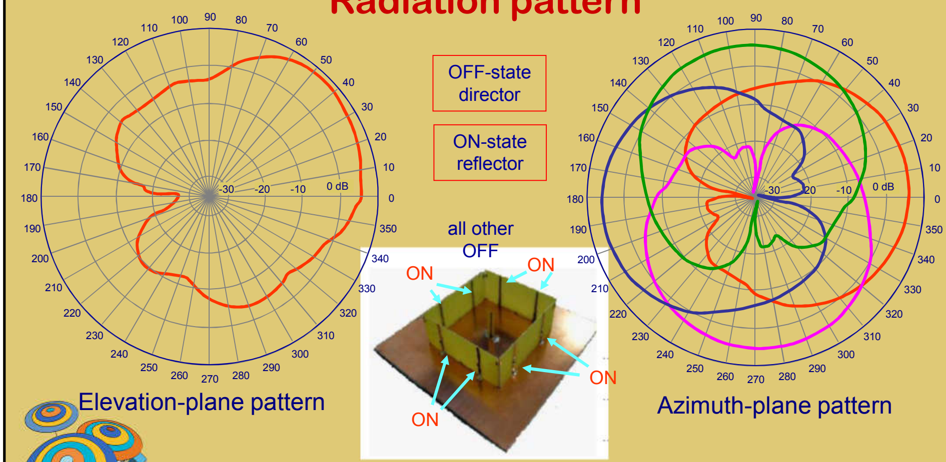




Source: Jia-Cheng Ke, Ching-Wei Ling and Shyh-Jong Chung: *Implementation of a Multi-Beam Switched Parasitic Antenna for Wireless Applications*, 2007 AP-S Symposium, Hawaii

Electronically controlled multi-beam antenna with switched parasitic elements

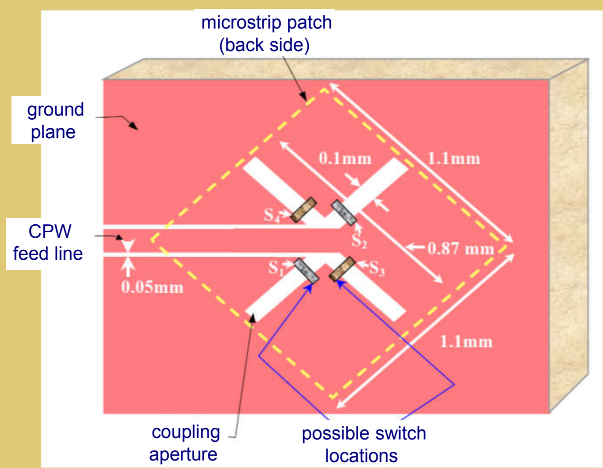
Radiation pattern



Source: Jia-Cheng Ke, Ching-Wei Ling and Shyh-Jong Chung: *Implementation of a Multi-Beam Switched Parasitic Antenna for Wireless Applications*, 2007 AP-S Symposium, Hawaii

Reconfigurable polarisation

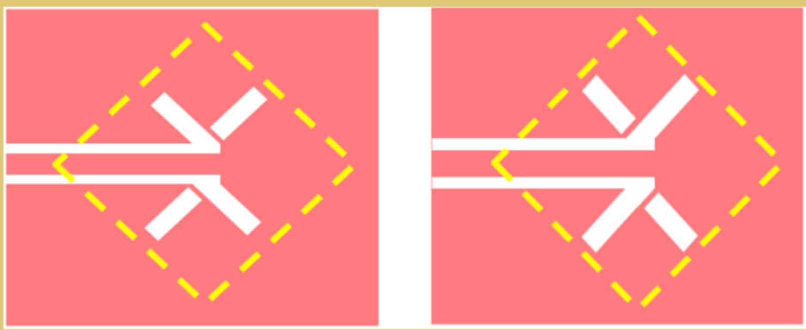
Antenna topology



Source: K.Hettak, G.Y. Delisle, G.Morin and M.Stubbs: *A Novel Reconfigurable Single-feed CPW Coupled Patch Antenna Topology with Switchable Polarization*, 2007 AP-S Symposium, Hawaii

Reconfigurable polarisation

Switch status



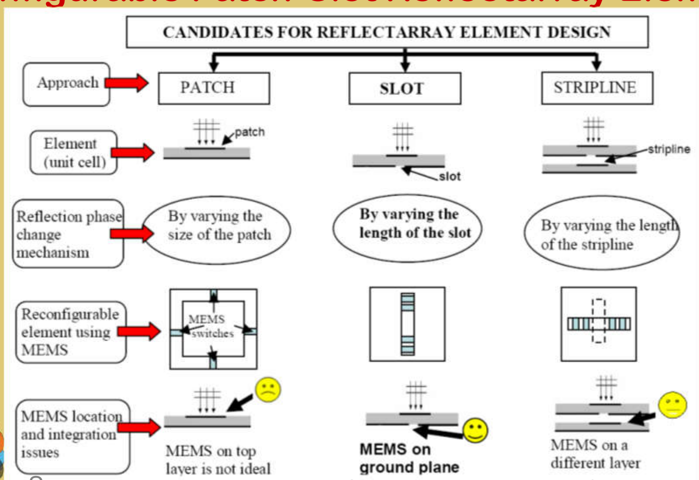
S_1 and S_2 are ON, S_3 and S_4 are OFF

S_1 and S_2 are OFF, S_3 and S_4 are ON

Source: K.Hettak, G.Y. Delisle, G.Morin and M.Stubbs: *A Novel Reconfigurable Single-feed CPW Coupled Patch Antenna Topology with Switchable Polarization*, 2007 AP-S Symposium, Hawaii

Reconfigurable reflectarrays

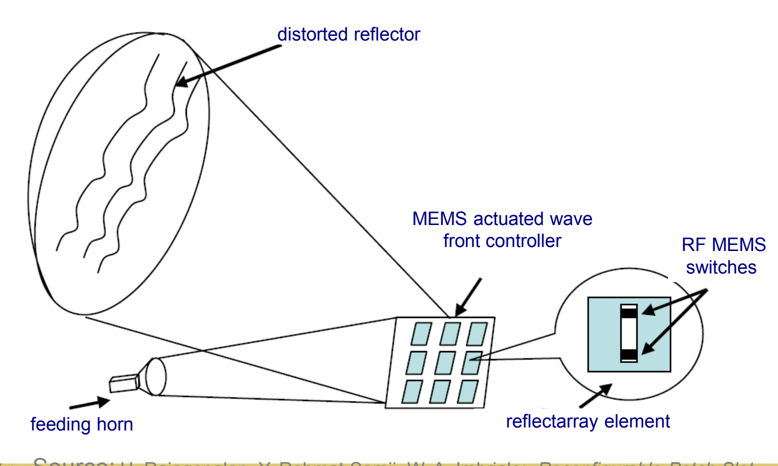
Reconfigurable Patch-Slot Reflectarray Elements



Source: H. Rajagopalan, Y. Rahmat-Samii, W. A. Imbriale: *Reconfigurable Patch-Slot Reflectarray Elements using RF MEMS Switches: A Subreflector Wavefront Controller*, 2007 AP-S Symposium, Hawaii

Reconfigurable reflectarrays

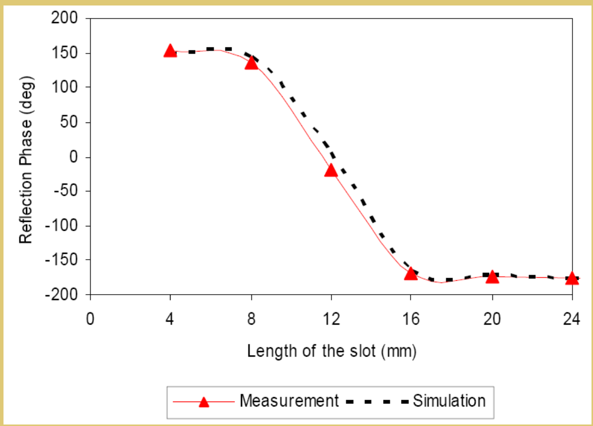
Concept



Source: H. Rajagopalan, Y. Rahmat-Samii, W. A. Imbriale: *Reconfigurable Patch-Slot Reflectarray Elements using RF MEMS Switches: A Subreflector Wavefront Controller*, 2007 AP-S Symposium, Hawaii

Reconfigurable reflectarrays

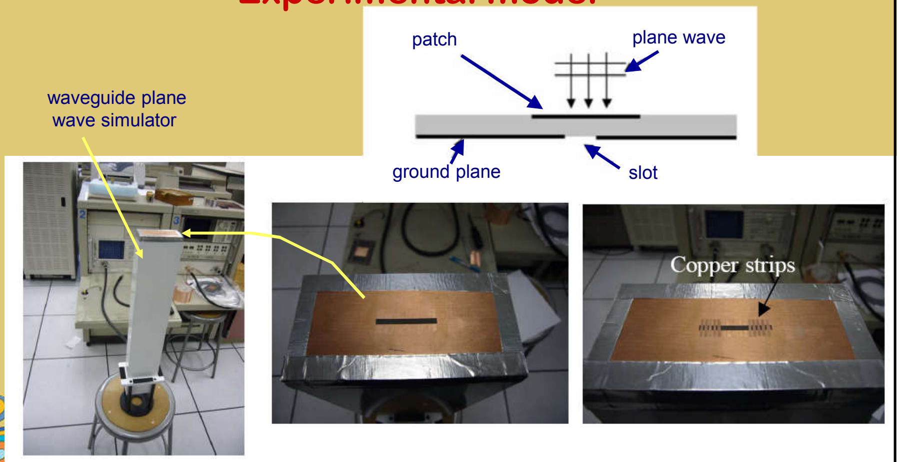
Results



Source: H. Rajagopalan, Y. Rahmat-Samii, W. A. Imbriale: *Reconfigurable Patch-Slot Reflectarray Elements using RF MEMS Switches: A Subreflector Wavefront Controller*, 2007 AP-S Symposium, Hawaii

Reconfigurable reflectarrays

Experimental model



Source: H. Rajagopalan, Y. Rahmat-Samii, W. A. Imbriale: *Reconfigurable Patch-Slot Reflectarray Elements using RF MEMS Switches: A Subreflector Wavefront Controller*, 2007 AP-S Symposium, Hawaii

Conclusions

- Reconfigurable antennas respond to the increasing demand for bandwidth and service quality
- Advanced synthesis methods allow for sophisticated functional capabilities: beam steering, beam shaping, null placing
- MEMS technology allows for practical implementation of such capabilities through various tunable devices (Phase shifters, power combiners, directional couplers…)
- MEMS-reconfigurable reflectarrays are a promising candidate for such applications
- Convergence of various competences: microelectronics, materials, electromagnetics, microwave circuits, signal processing