RF MEMS Switches

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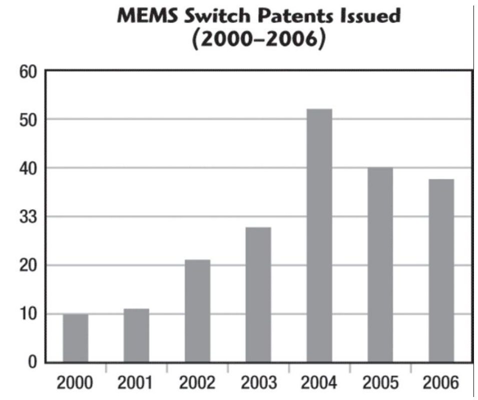
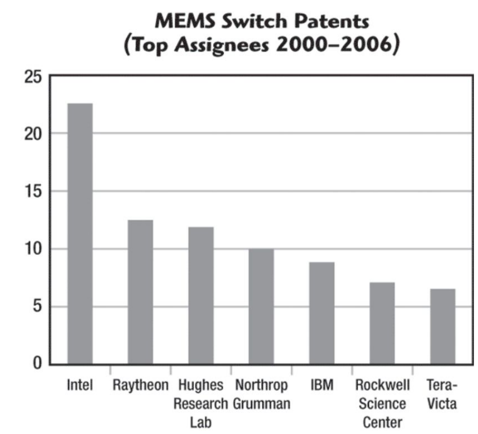
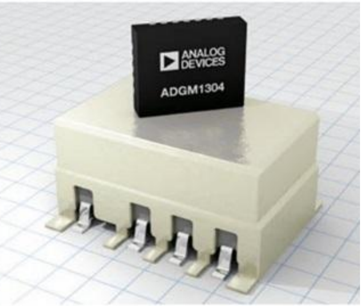
History and actual status

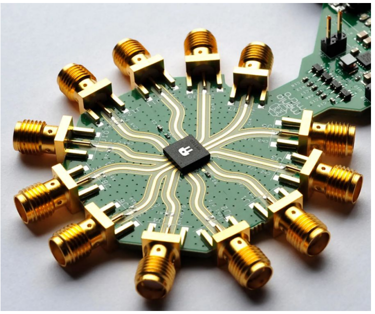
- **Discovery in the late 70's**
  - RF Switches were among the first studied MEMS (1979)
- **Pioneer researches in the 80's**
  - 1984: Electromechanical switch patent by Foxboro
- **Interest growth in the 90's**
  - First prototypes in the USA (DARPA, AirForce) and Europe (EUNE)
  - 1991: Hughes Research Lab (good perf but req. 100V)
  - 1994: Neuchâtel (LPCVD, 50V, but 10kOhm res)
  - 1995: TI, USA (electrostatic membrane switch)
  - 1999: Omron, JP (19V only, still very mature design)
  - IBM, ADI, Rockwell, MIT, Samsung, Intel…
  - Applications: multi-band, antenna & filter tuning, space communications.
- **Emergence and commercialization in the 2000's**
  - First MEMS switches were not reliable -> market opened to smaller companies and startups.
  - Radant MEMS, 2001
  - TeraVicta, 2005
- **Evolution and improvements 2010's-today**
  - New leaders: MenloMicro, Qorvo, ADI (generally available SP4T switches)
  - Current RF switches pave the path to "ideal switches"





https://www.microwavejournal.com/articles/4291-rf-mems-ready-for-prime-time





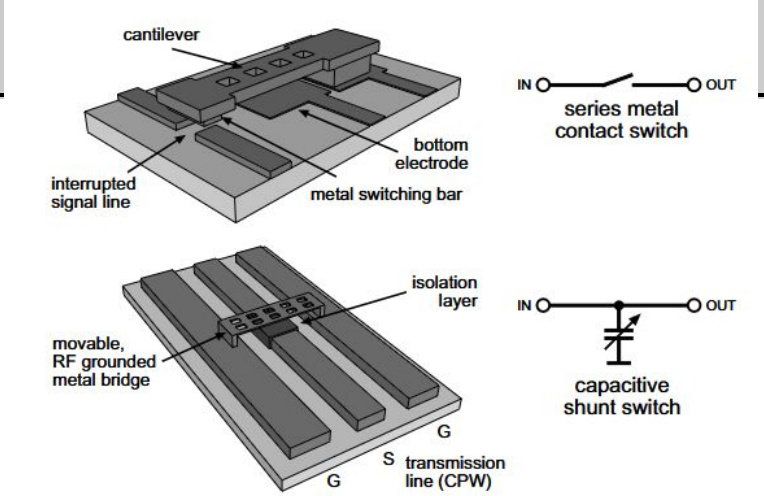
MEMS operation principle

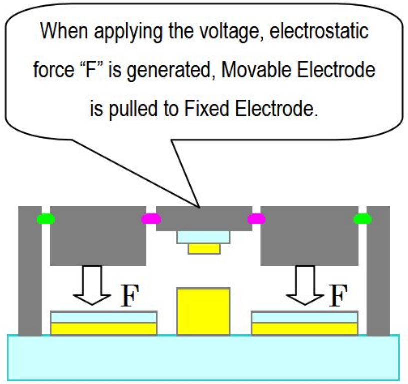
Classification

- Actuation method (electrostatic, electrothermal, magnetostatic, piezoelectric)
- Circuit (terminals, series, shunt)
- Configuration (cantilever, fixed beam)
- Contact interface (ohmic, capacitive)

Operation principle of some devices

- **Omron 2SMES-01**
    - Electrostatic SPDT, capacitive contact, shunt
    - 2 internal SPST chips bound together
    - Parallel plates capacitor generates an electrostatic force, closing the contact
- **ADI ADGM1304**
    - Electrostatic SP4T, ohmic cantilever, series
    - Force generated by Vgs.
        - Vgs > Vth -> ON
        - Vgs = 0 -> Stiffness resets the cantilever
- **MenloMicro MM5130**
    - Electrostatic SP4T, 3-terminal cantilevers
    - Voltage applied between Gate and Source
    - Independent gate control





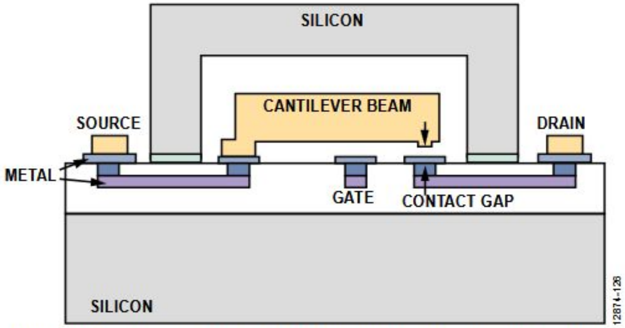


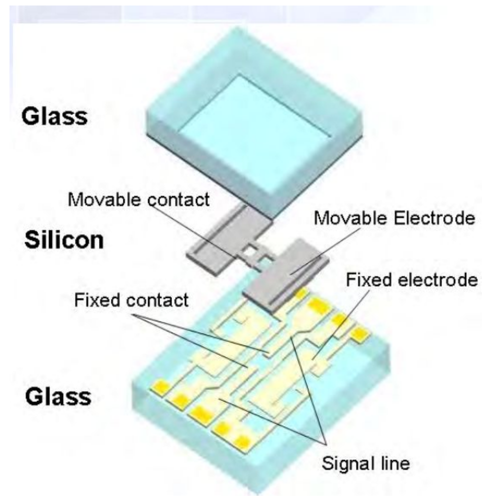
Figure 48. Cross Section of the MEMS Switch Design Showing the Cantilever Switch Beam (Not to Scale)

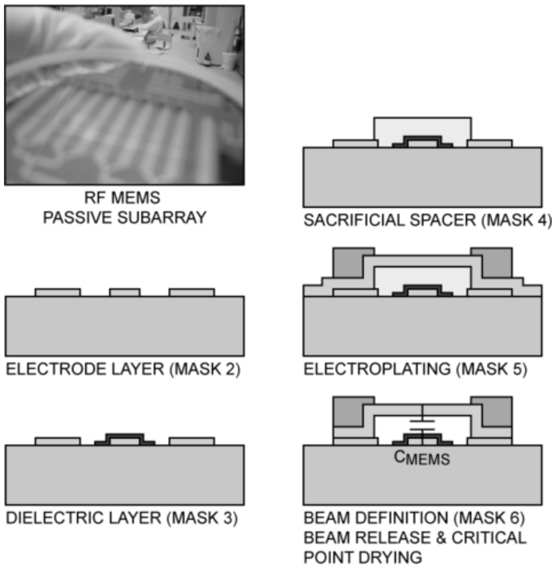
Main design and processes used in industry

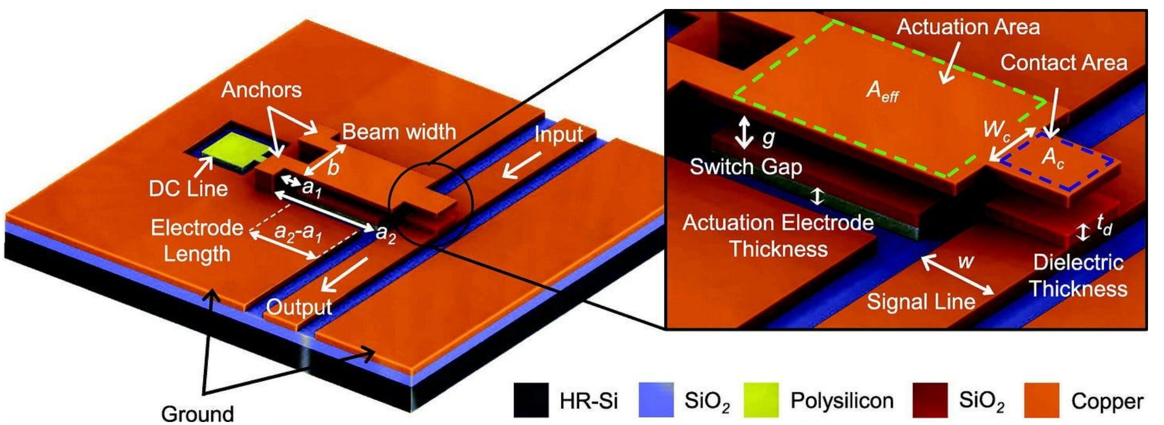
- **General aspects:**
  - Similar to CMOS microfabrication
  - Wide variety of wafers
  - Class 6-8 cleanroom
  - Photolitography, dry etching

- **Capacitive switches:**
  - 3-wafer and glass configuration
  - Bias line deposition
  - Electrodes deposition
  - Dielectric deposition
  - Sacrificial layer deposition
  - Electroplating

- **Ohmic switches**
  - More complex
  - Requires successive etching and lithography
  - The cantilever is fragile
  - More expensive







Characteristics

Typical MEMS-based RF switch characteristics

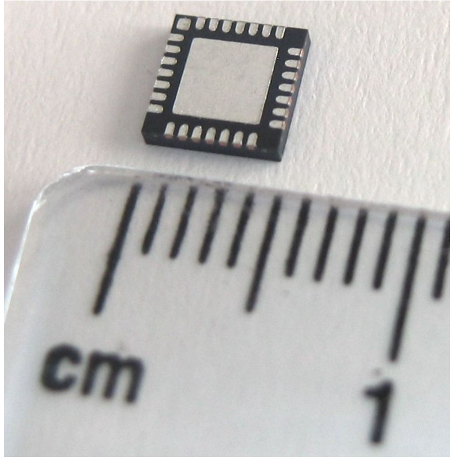
- **Operate from near DC to tens of GHz**, covering diverse RF and sensor-actuator needs.
- **Low insertion loss** (≈0.3–1 dB) ensures minimal signal attenuation in high-frequency chains.
- **High linearity** (IIP3 > +50 dBm) minimizes distortion for demanding communication systems.
- **Excellent isolation** (25–30 dB) prevents leakage and interference between signal paths.
- **Rated for up to billions of actuations** through reliable electrostatic drive mechanisms.
- **Microsecond-level switching times** enable rapid reconfiguration.
- **Ultra-low power consumption** suits battery or power-sensitive applications.
- **Broad operating temperature range** supports industrial and laboratory environments.

Note:
IIP3 = third-order intercept point. Linearity is quantified by the IP3, where distortion equals the fundamental signal, indicating the device's dynamic range.
Insertion loss = to any additional noise introduced into the RF path when a component is inserted

Packaging and systems integration

Packaging

- RF switch MEMS usually uses very compact packages that helps to minimize parasitic effects, boosting signal integrity and RF performance
- Robust packaging like QFN and LFCSP shields RF MEMS switches from moisture, ESD, and temperature variations, ensuring reliable performance.



QFN package, https://en.wikipedia.org/wiki/Flat_no-leads_package

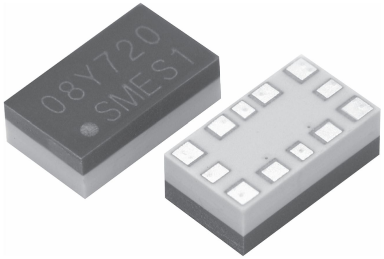
System integration

- RF interfaces use DC-blocking circuits and controlled impedance matched PCB traces for optimal 50 Ω matching, while integrated digital interfaces (SPI) simplify control and reduce external components.
- Adherence to recommended reflow profiles and moisture sensitivity level guidelines is crucial for reliable solder joints and preventing moisture-induced damage.

Typical products on the markets and their applications

Omron 2SMES-01 (MEMS SPDT)

- A very compact MEMS-based SPDT RF switch covering up to ~10 GHz, offering low insertion loss and high linearity.
    - Embedded applications (wifi/bluetooth switching in mobile robotics or IOT)



https://www.mouser.com/datasheet/2/307/2SMES-01_0911-15621.pdf

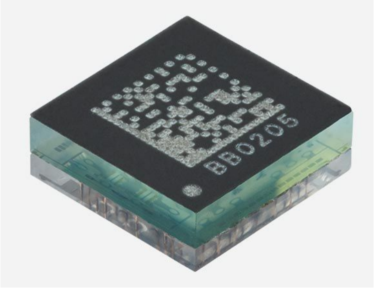
Analog Devices ADGM1304 (MEMS SP4T)

- A wideband (0 to 14 GHz) MEMS SP4T switch with excellent isolation, featuring an integrated driver and the possibility to disable the internal oscillator to reduce noise.
    - Noise sensitive application (lab equipment, RF device characterisation)

https://www.everythingrf.com/products/switches/analog-devices/613-29-adgm1304

Menlo Micro MM5130 (SP4T MEMS):

- Covers DC to 26 GHz with ~0.3 dB insertion loss.
- “Ideal Switch” Concept**:** Combines relay-like performance (low loss, high isolation) with semiconductor speed and longevity.
- High Power Handling**:** Up to 25 W continuous, supports billions of switching cycles.
    - High power, high number of channels (5G, phased array antenna)



https://menlomicro.com/images/general/MM5130_Datasheet.pdf

Note:
SPDT = Single Pole Double Throw
SP4T = Single Pole Four Throw

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Articles

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- Kumar, R. S. et al. (2018). Design and Analysis of RF MEMS Switches for High-Frequency Applications, Microsystems & Nanoengineering
- Oberhammer, J. (2004). Novel RF MEMS Switch and Packaging Concepts, KTH.
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- Omron, RF MEMS Switching: What You Need to Know https://www.mouser.com/pdfdocs/Omron_RFMEMSSwitch_Whitepaper_finalsm-3.pdf
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- Wikipedia, RF MEMS, , https://en.wikipedia.org/wiki/Radio-frequency_microelectromechanical_system
- A Brief History of RF Switch Technology, https://www.viksnewsletter.com/p/a-brief-history-of-rf-switch-technology
- IEEE, https://spectrum.ieee.org/how-rf-mems-tech-finally-delivered-the-ideal-switch
- MemsJournal, RF MEMS: A Brief History, https://www.memsjournal.com/2006/10/rf_mems_a_brief.html

Datasheets des composants :

- Omron 2SMES-01 (SPDT) : https://www.mouser.com/datasheet/2/307/2SMES-01_0911-15621.pdf
- Menlo Micro MM5130 (SP4T) : https://menlomicro.com/images/general/MM5130_Datasheet.pdf
- Analog Devices ADGM1304 (SP4T) : https://www.everythingrf.com/products/switches/analog-devices/613-29-adgm1304