DEVELOPMENT OF RF MEMS SYSTEMS

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Outline

• What are RF MEMS?
• Basic Receiver Architecture
• Roles and advantages of RF MEMS Devices
• RF MEMS Devices and Applications
• RF Switches
• RF Resonators
• Integrated Process Flows
• Challenges
• Summary
What are RF MEMS?

- MEMS – Micro Electro Mechanical Systems
- RF – Radio Frequency applications

- Ohmic switch and relays – DC switching
- Capacitive switch – Tunable RF Circuits
- Capacitive relay – Matching networks
- Mechanical resonator – Band pass filters
- Bulk acoustical resonator – Local Oscillators

Basic Receiver Architecture

- Superheterodyne receiver
  Uses **frequency mixing** or **heterodyning** to convert a received signal to a fixed **intermediate frequency**, which can be more conveniently processed than the original radio carrier frequency.

**Diagram**

- **RF Amplifier**
- **Mixer**
- **Filter**
- **IF Amplifier**
- **Demodulator or detector**

**Bandpass filter** \( f_{IF} = f_{LO} - f_d \)

\( f_{IF} \) is constant

**Local Oscillator**

- **Mixing of incoming** \( f_d \) and local \( f_{LO} \)
- Results in \( f_{LO} - f_d, f_{LO} + f_d, f_d, f_{LO} \) and harmonics.

- \( f_{LO} \) tracks incoming \( f_d \) so that \( f_{IF} \) is always the same

**IF**
- 455 kHz for AM radio
- 10.7 MHz for broadcast FM receivers,
- 38.9 MHz (Europe) or 45 MHz (US) for television
- 70 MHz for satellite and terrestrial microwave equipment.

RF Tuning, Mixers and Band-Pass Filter Circuits

- Band-pass Filters
- Non-linearity Mixers
- Sampling mixers

RF Amplifier → Mixer → Filter → IF Amplifier → Demodulator Audio Amplifier

Local Oscillator

Tuned RF amplifier, 550-1000 KHz, tuned to 1490 KHz
Station at 1490 KHz
Station at 2400 KHz

Tuned LO 1005 - 2045 KHz, tuned to 1945 KHz

http://en.wikipedia.org/wiki/Superheterodyne_receiver
Passive RF Components

Typical passive devices:
• LC Resonators
• Bulky/large inductors and capacitors
• **Low Q** (low frequency selectivity, lossy – Energy loss)

Passive Devices with high Q’s:
• Ceramic RF Filters
• SAW RF Filter – surface acoustic wave filter
• Quartz Crystal
• Off chip inductors
Disadvantages – Off chip, large, expensive

RF MEMS:
• Variable capacitors and switches
• Mechanically resonating structures
Advantages: **high Q**, inexpensive, small and potentially integrated

http://mems.sandia.gov/about/rf-mems.html
RF MEMS Switches, switched capacitors and varactors

- Ohmic switch and relays
- Tunable RF Circuits
- Matching networks

- Deflecting cantilever or fixed-fixed beam
- Electrostatic, electrothermal, magnetostatic or piezoelectric
- Lateral or vertical
- Series or shunt
- Capacitive or ohmic

RF Switches

a) Capacitive shunt, fixed-fixed beam
b) Ohmic series cantilever beam

Ohmic RF MEMS Switches

http://www.radantmems.com

Vibrating RF MEMS Resonators

- Filters and resonators
- Vibrating beam, comb, disc or ring which is sufficiently isolated from the surroundings in order to obtain a high $Q_m$.
- Actuation mechanism
  - Electrostatic, piezoelectric, thermal
- Suspension
  - Fixed-fixed, free-free, stem
- Vibrating geometry
  - Beam, comb, disc, ring
- Vibration mode
  - Bulk (extensional), elliptical (wine glass), flexural, radial contour, torsional

Types by vibration mode

- Vibration mode
  - Bulk (extensional), elliptical (wine glass), flexural, radial contour, torsional
  - Higher order vibration modes cannot also be used.

Co-fabrication of Electrostatic MEMS Switches and Resonators

- Three poly layers (electrode, resonators and anchor structures)
- Conformal sacrificial layer for the formation of small gap <100nm
- High Conductivity layer for low resistance switch
- 6 mask layers

Isolated conductive material

- <100nm gap
- 1um Poly
- 3500 Å Si$_3$N$_4$
- 2 um SiO$_2$
Tunable Filters

Co-fabrication of switches and resonators
RF MEMS Challenges

• Bandwidth, insertion loss and isolation:
  ✓ High $R_{\text{ON}}C_{\text{OFF}}$ or low $C_{\text{ON}}/C_{\text{OFF}}$
• Power handling:
  ✓ Electromigration (JRMS) and dielectric breakdown (VRMS) limits.
• Reliability:
  ✓ Temperature drift
  ✓ Dielectric charging
  ✓ Humidity-induced stiction
  ✓ Fatigue
  ✓ Contact degradation
  ✓ Creep
RF MEMS Challenges

• **Temperature drift**


**Fig. 1:** Plots of fractional frequency change versus temperature comparing AT-cut quartz crystals at various angles [6] with polysilicon μmechanical resonators.

• **Solutions:**
  - Temp compensation
  - Passive → SiO2 coating to cope with young’s modulus temp dependence, degenerated doping and geometry changes
  - Active → Micro-oven to control temp, bias compensation and phase locking.
RF MEMS Challenges

- **Dielectric charging**
  
  R.W. Herfst, “Characterization of dielectric charging in RF MEMS capacitive switches”, Semiconductor Components, University of Twente.

- **Solutions:**
  - Reduce dc bias, use ac bias,
  - Avoid hard contact (dimples, holes)
  - Non-dielectric switches
RF MEMS Challenges

- **Humidity-induced stiction**

- **Solutions:**
  - Supercritical drying (liquid CO2 at critical point)
  - Dry etching
  - Hydrophobic coatings
  - Recoverable

RF MEMS Challenges

- Contact degradation

Solutions:
- Reduce bias current
- Avoid hard contact (dimples, holes)
- Vacuum encapsulation
- Degradation resistant materials

Conclusion

• RF MEMS applications
  o Band selective receivers

• RF MEMS fabrication
  o Co-fabrication of switches and resonators

• RF MEMS challenges
  o Fabrication, materials and reliability
Appendix
RF MEMS Devices/applications

- RF MEMS switches, switched **capacitors** and **varactors**
  - Ohmic switch and relays
  - Capacitive switch – Tunable RF Circuits
  - Capacitive relay – Matching networks

- Vibrating RF MEMS resonators
  - Band pass filters
  - Mixers
  - Reference oscillators

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Resonator Modeling

- Flexural mode fixed-fixed beam
- Modeled by two capacitors in series.
- Most resonators can be modeled this way