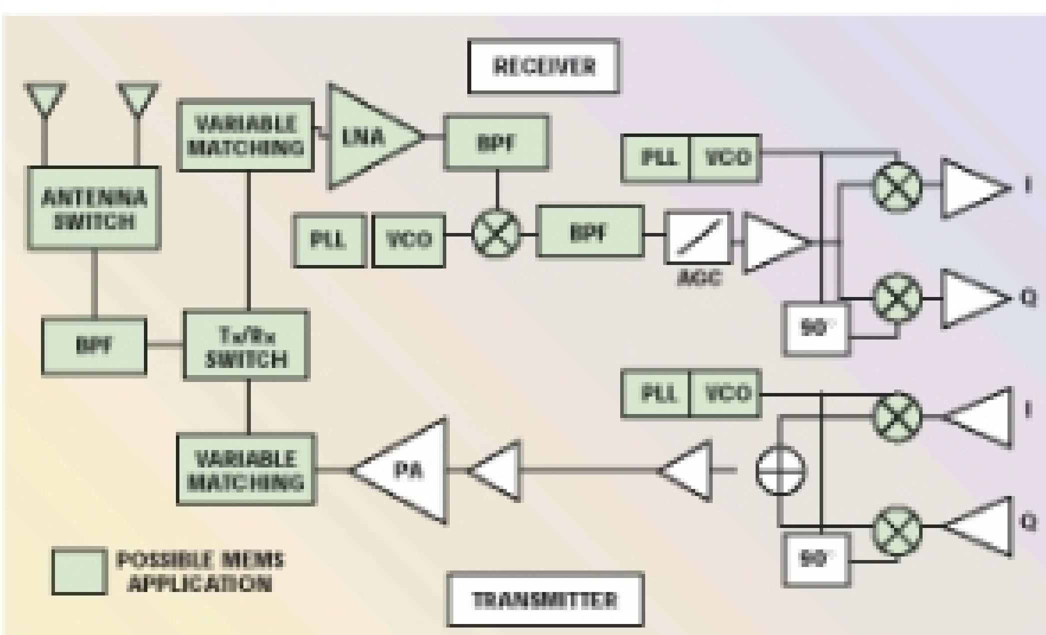
Lecture 13

- Agenda:
  - RF MEMS: Introduction

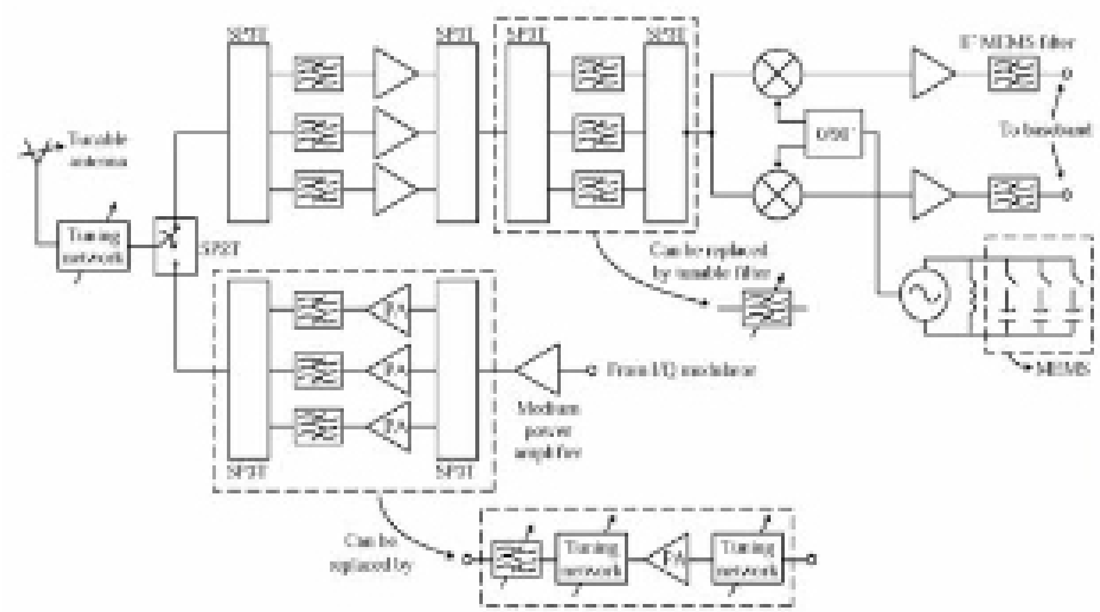
Wireless Communications

1G	2G	3G	4G
Analog (single-band)	Digital (dual-mode, dual-band)	Multimode, multiband	Multistandard + multiband
900 MHz	GSM (Global System for Mobile Communication)	UMTS (Universal Mobile Telecommunications System)	
Voice	Voice + data	Higher speed, improved voice/multimedia mobility, internet	GPS (globe positioning system), "messages in space"
Macro cell	Macro/micro/pico cell	~384kb/s to moving vehicles	>2Mb/s to moving vehicles

Simplified Transceiver Architecture



A 3-Band MEMS Wireless System



G. Rebeiz, RF MEMS: Theory, Design and Technology, John Wiley and Sons, Inc., 2003.

MEMS-Based Wireless Applications

High-Q Passives

- Inductors
- Varactors
- Transmission lines
- Switches
- Resonators

Circuits/Systems

- Oscillators
- Mixers
- Power amplifiers
- Phase shifters
- Filters
- Switch matrices
- Transceivers

RF MEMS Application Areas

RF MEMS Switches and Varactors

- Low loss and low power consumption (0.1 dB up to 120 GHz)
- High isolation (> 30 dB up to 100 GHz)
- Potential for low cost fabrication (no epi layers, no 0.15 um litho.)
- Very high Q possible with varactors (and large capacitance range)
- Very low intermodulation products (> 60 dBm)

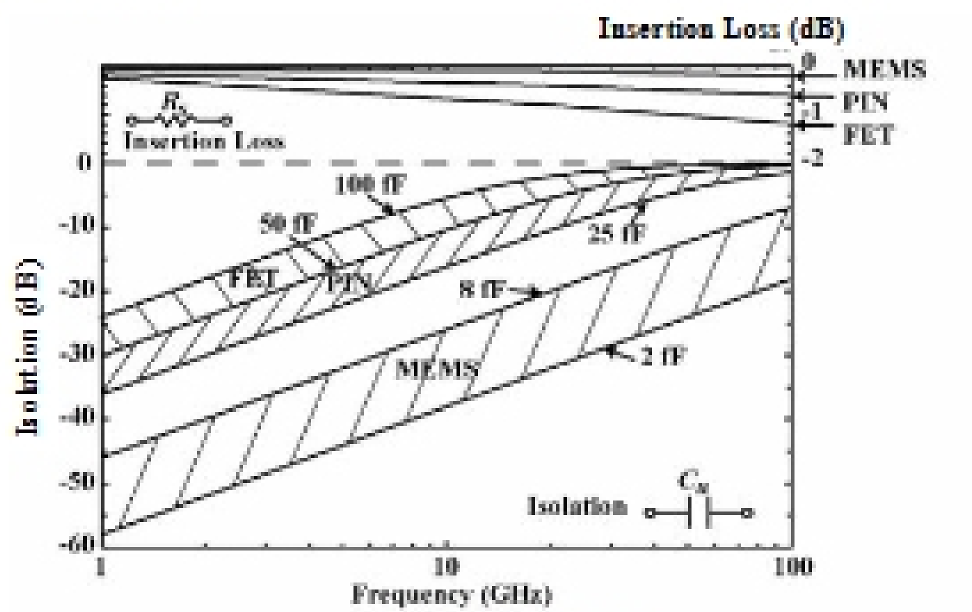
RF MEMS Inductors

- Very high Q possible (Q > 50 at 1-5 GHz)
- Built using MEMS processes but nothing moves (not tunable)

RF MEMS Filters

- Very small size possible (1000x reduction in size in element)
- Extremely high-Q (5,000 to 50,000)
- Compatible with CMOS and potential for low cost

Comparison of Different Switches



MEMS: MEMS switches
PIN: GaAs P-I-N Diodes
FET: GaAs Transistors

MEMS switches

- Good isolation
- Low insertion loss

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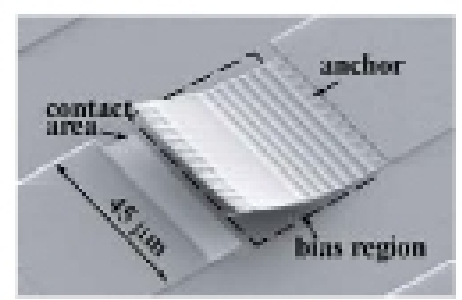
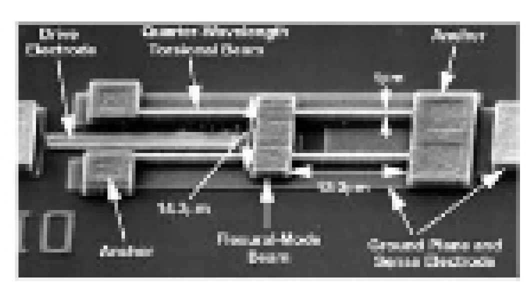
Example RF MEMS Devices

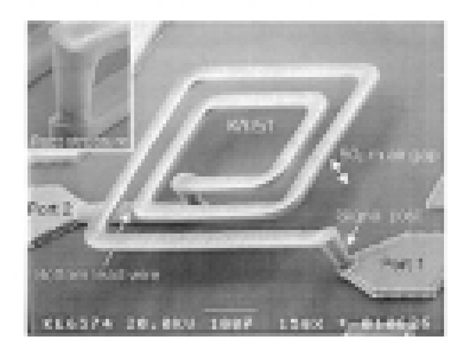


Capacitive Switch (Lincoln Lab)

Metal-contact Switch (Analog Devices)



MEMS Oscillator (U-Michigan)



MEMS Inductor (KAIST)

RF Basics

- ❑ Skin Effect
- ❑ Transmission Line (t-line)
- ❑ Microstrip Line
- ❑ Coplanar Waveguide Transmission Line (CPW)
- ❑ Smith Chart
- ❑ Quality Factor

Skin Depth

If a conductor with nonzero resistance is present in a propagating electromagnetic field, the field will penetrate the conductor. The penetration depth depends on the resistivity of the conductor and the frequency of the EM wave.

Skin Depth is defined as the distance at which the field is decayed to $e^{-1} = 36.8\%$ of its value at the air-conductor interface.

$$\delta = \frac{1}{\sqrt{\pi\mu}} \cdot \frac{1}{\sqrt{f\sigma}}$$

σ: conductivity of the conductor; μ: permeability of the medium; and f: signal frequency

Example:
σ(Al) = 37.2 MS/m; σ(Cu) = 58 MS/m;
Thus, at 2GHz, δ(Al)=1.85μm; δ(Cu)=1.47μm

Skin Depth

Surface resistivity (Ω per surface area)

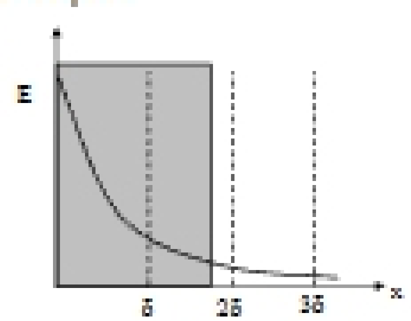
$$R_s = \frac{1}{\delta\sigma} = \sqrt{\frac{\pi\mu f}{\sigma}}$$

Energy Confinement

If the conductor is thin, some energy escapes.

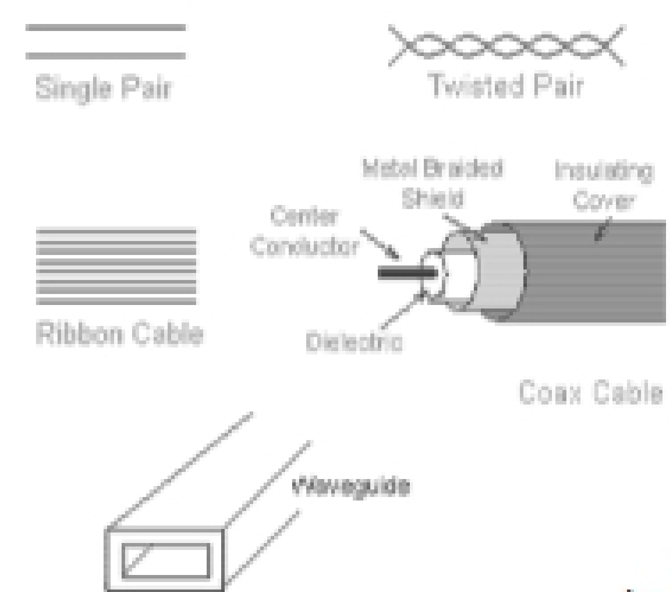
Conductor thickness Δ

Δ = δ → 36.8%
Δ = 2δ → 13.5%
Δ = 4δ → 1.8%



Transmission Line

A signal path connecting a source to a load



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