ELEC 412 RF: Lecture 1

- Importance of RF circuit design
  - wireless communications (explosive growth of cell phones)
  - global positioning systems (GPS)
  - computer engineering (bus systems, CPU, peripherals exceeding 600 MHz)

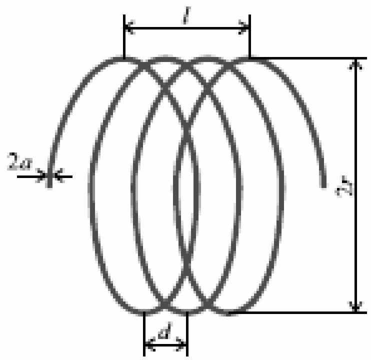
- **Why this course???**
  - lumped circuit representation no longer applies!

What do we mean by going from lumped to distributed theory?

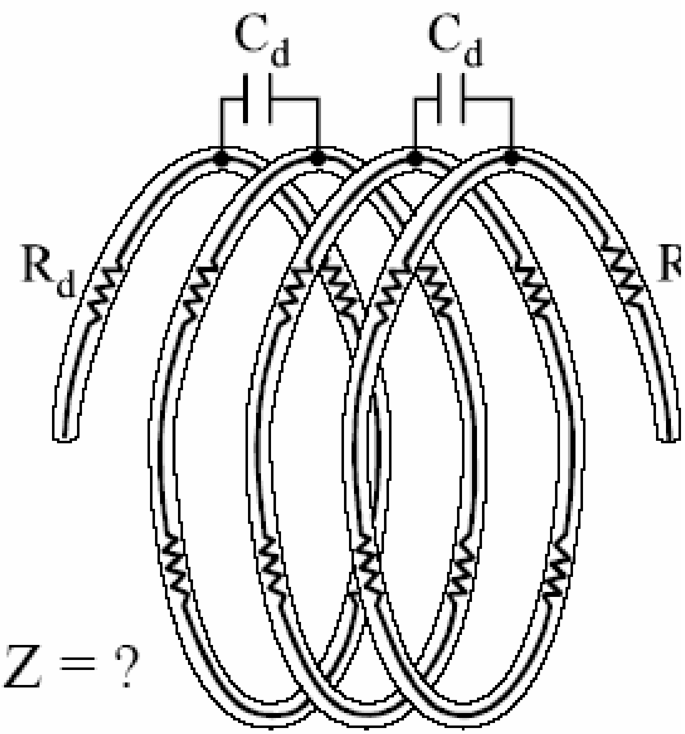
- Example: INDUCTOR

Low-frequency

(lumped)



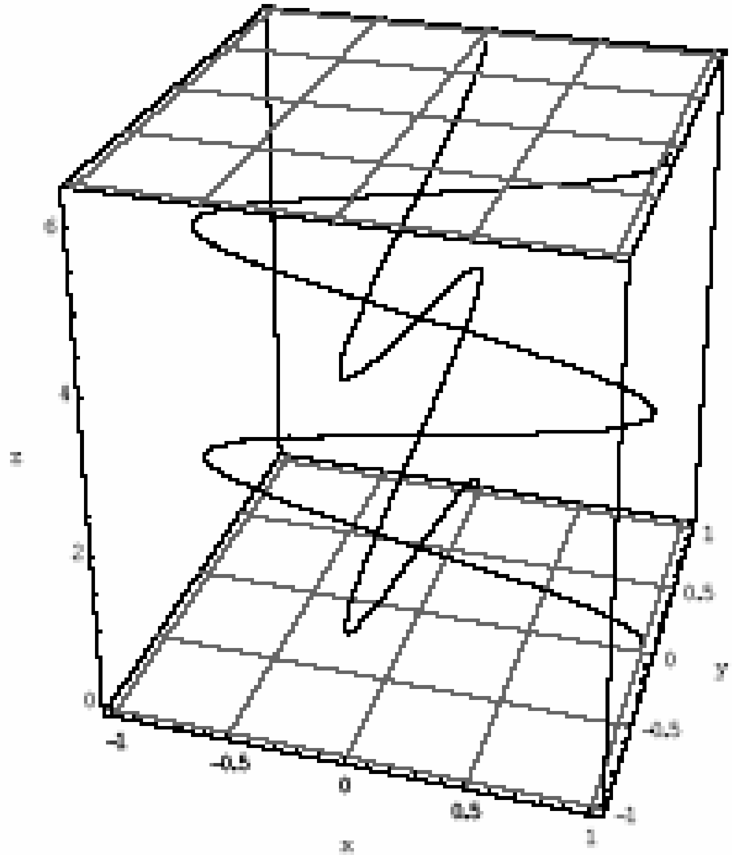
High-frequency



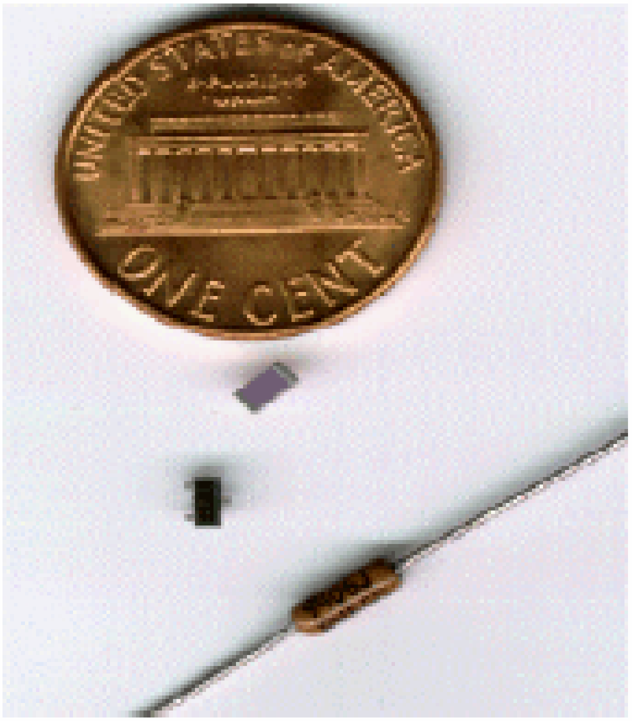
$$Z = R + j\omega L \longrightarrow Z = ?$$

Current and voltage vary spatially over the component size

E (or V) and H (or I) fields



Upper MHz to GHz range

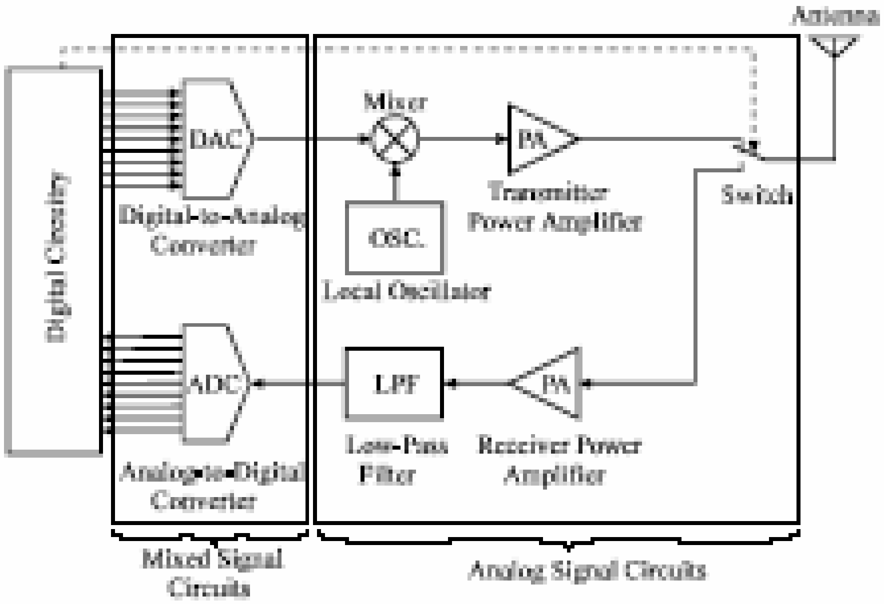


Frequency spectrum

- RadioFrequency (RF)
  - TV, wireless phones, GPS
  - 300 MHz … 3 GHz operational frequency
  - 1 m … 10 cm wavelength in **air**
- MicroWave (MW)
  - RADAR, remote sensing
  - 8 GHz … 40 GHz operational frequency
  - 3.75 cm …7.5 mm wavelength in **air**

Design Focus

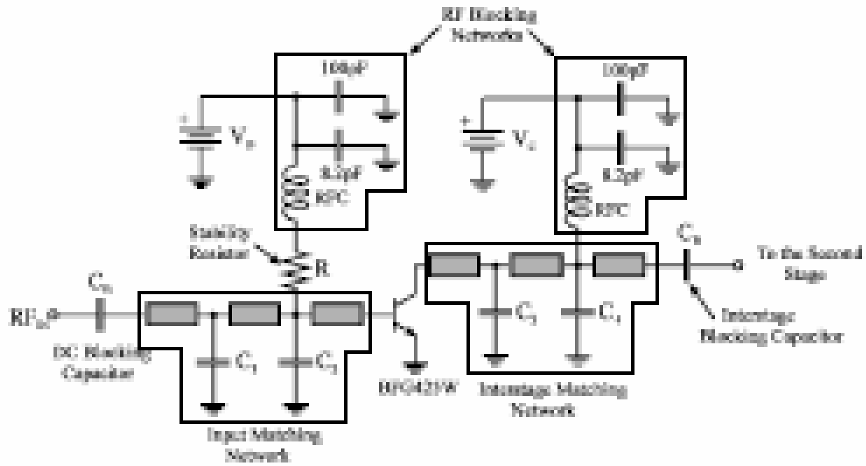
Cell phone transceiver circuit



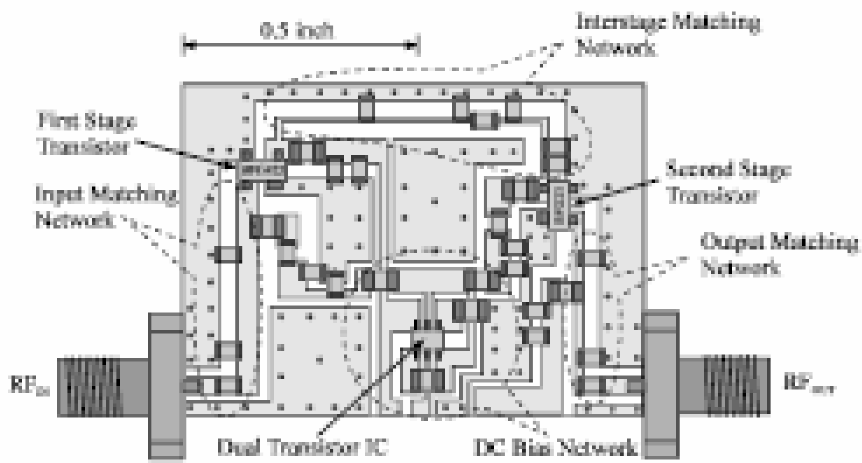
Typical frequency range:

- 950 MHz
- 1.9 GHz

Implementation



- matching networks
- BJT/FET active devices
- biasing circuits



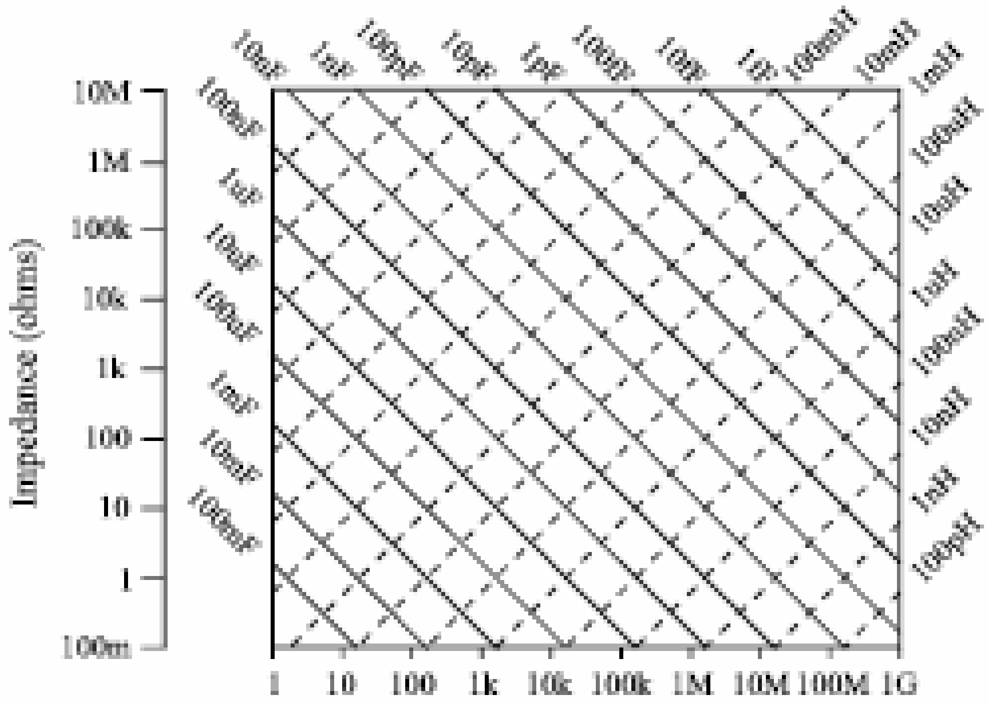
- printed circuit board
- mircostripline realization
- surface mount technology

RF Behavior of Passive Components

- Conventional circuit analysis
  - R is frequency independent
  - Ideal inductor: $X_L = j\omega L$
  - Ideal capacitor: $X_c = 1/\omega C$
- **Evaluation**
  - Impedance chart

Impedance Chart

(impedance of C & L vs frequency)

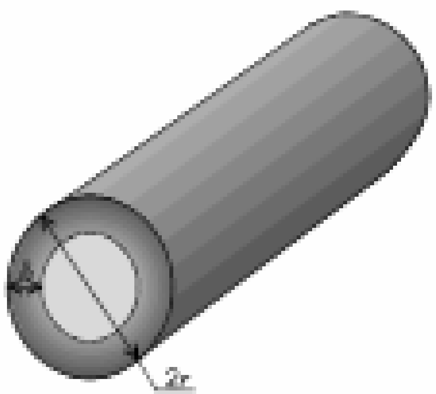


$Z_C = 1/(2\pi fC)$

$Z_L = 2\pi fL$

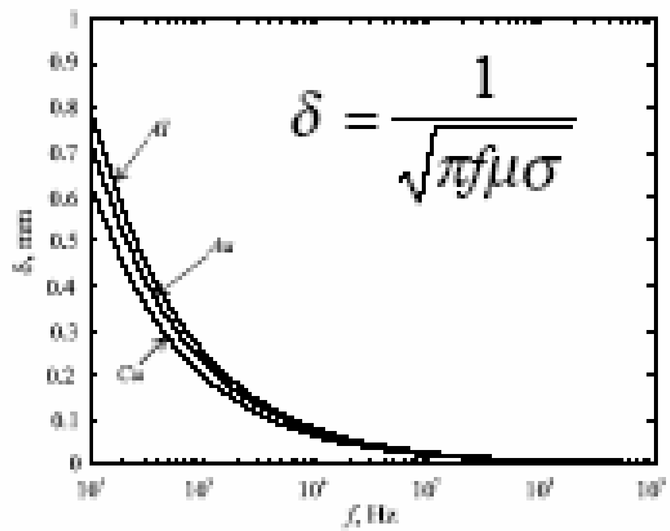
How does a wire behave at high frequency?

- Example: Resistor



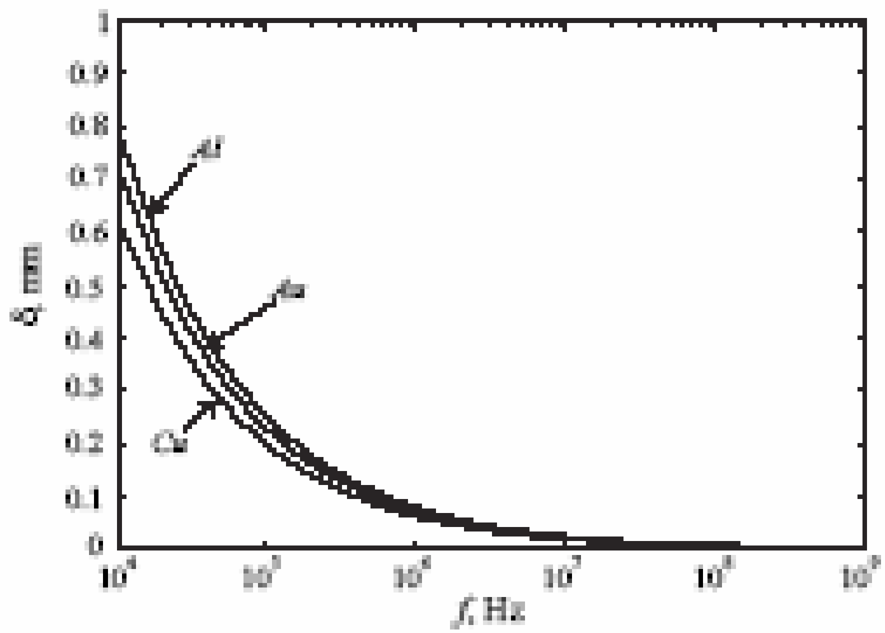
$$R_{DC} = \frac{l}{\pi a^2 \sigma}$$

$$R / R_{DC} = \frac{a}{2\delta} \qquad \omega L / R_{DC} = \frac{a}{2\delta}$$

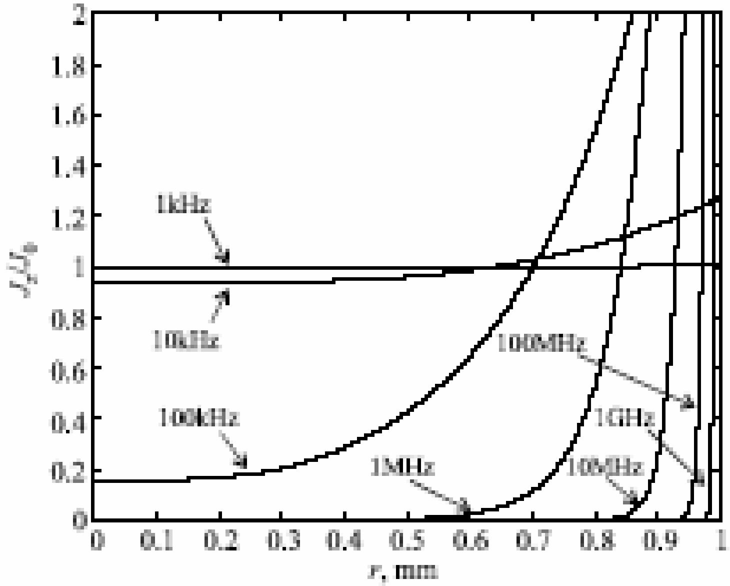


High frequency results in skin-effect whereby current flow is pushed to the outside

Skin Depth of Cu

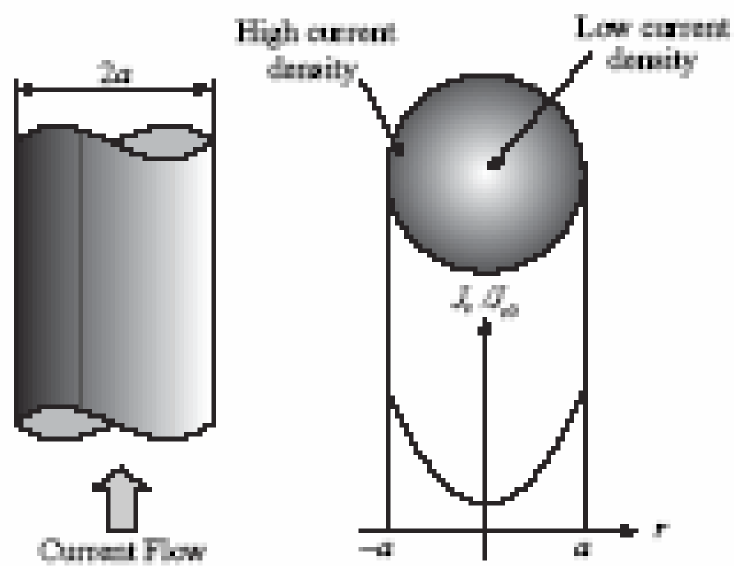


How exactly is the current distribution as a function of frequency?

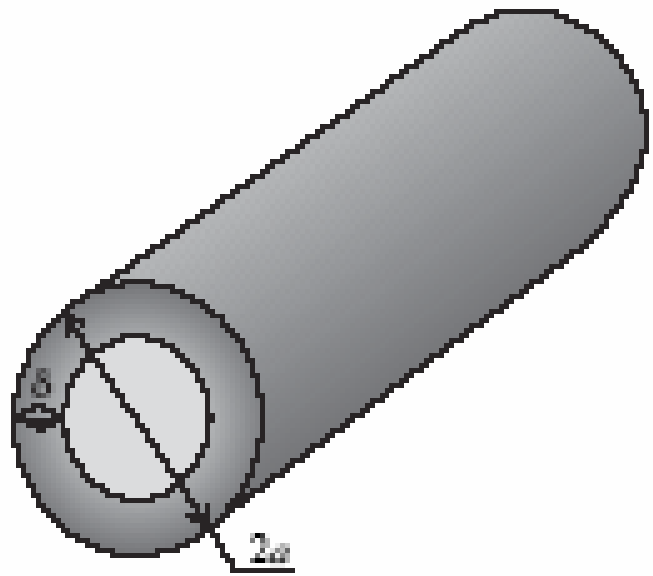


- Low frequency shows uniform current distribution
- medium to high frequency pushes current to the outside
- RF "sees" current completely restricted to surface

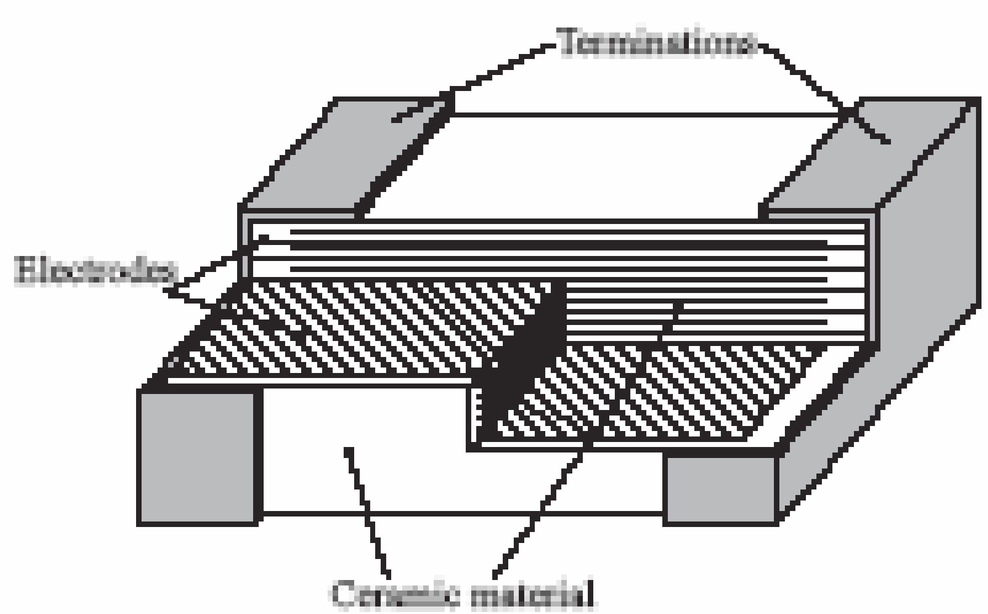
Schematic Crosssection AC Current Density Normalized to DC Current Density



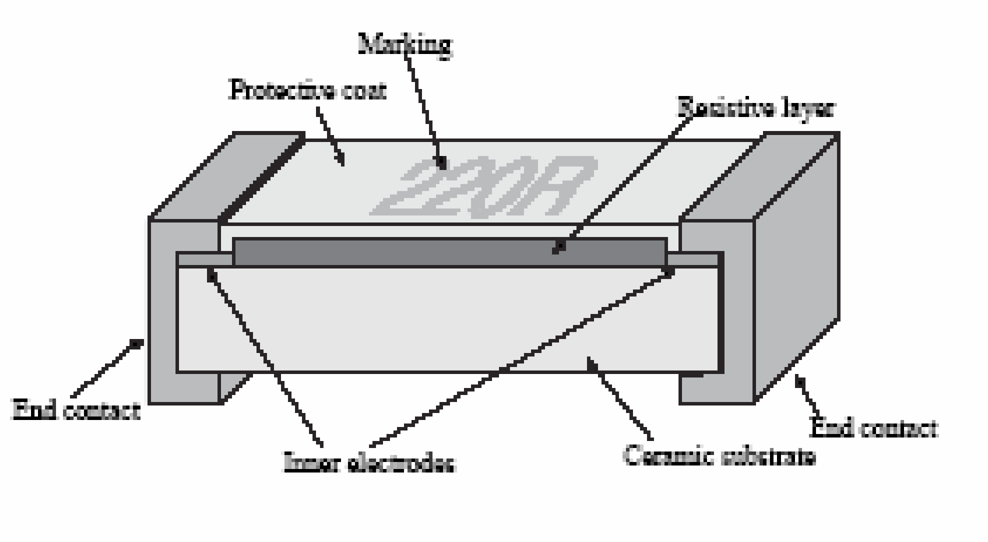
Skin Depth: Increased Resistance Over Crossection



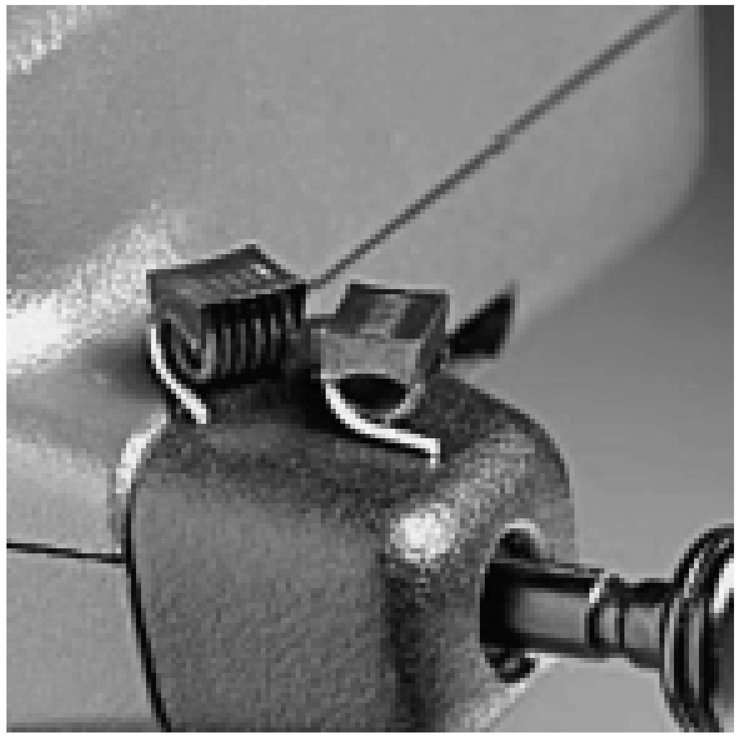
Multilayer Chip Cap Crossection



Crossection of Chip Resistor

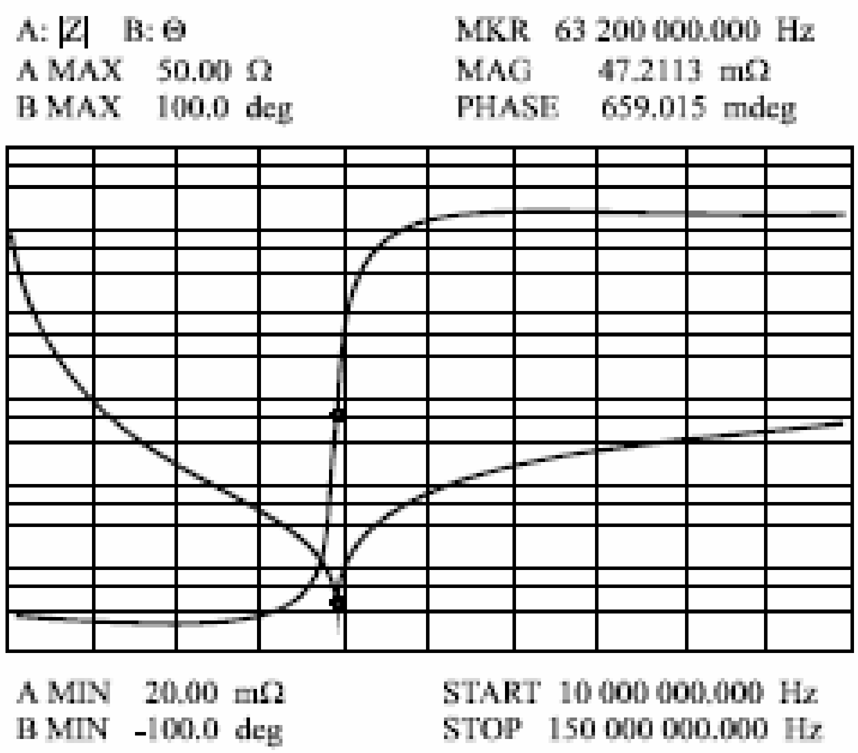


Air Core Inductor



Impedance Measurement Example

Capacitor going through resonance



Capacitor Characteristics

Equivalent Circuit Analysis