Lecture-1

Date: 05.08.2014

- Motivation
- Why this course?
- Differentiating factor between low and high frequency circuits
- Transmission Line (Intro.)

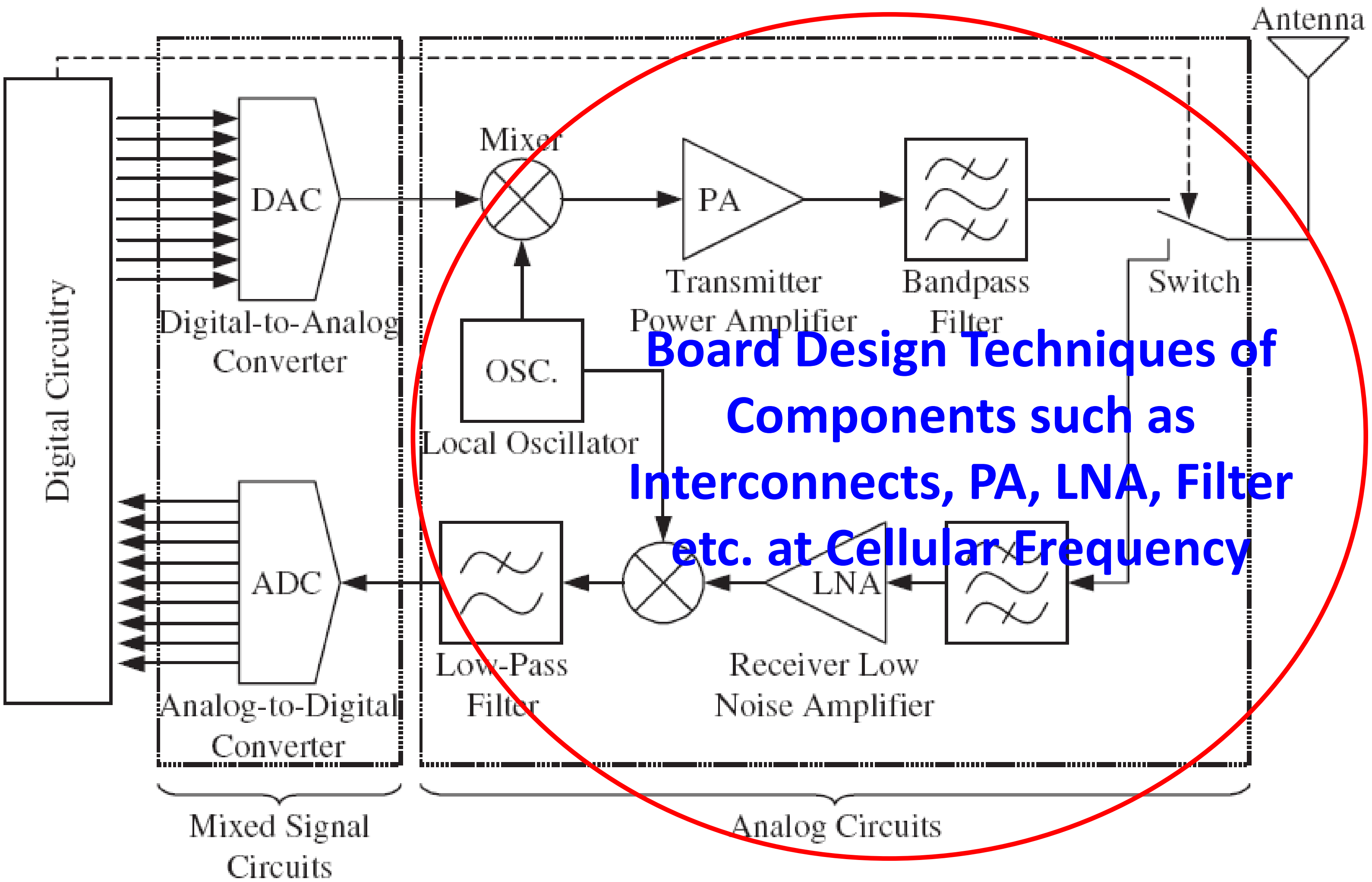
Motivation

- Importance of RF Circuit Design
  - Wireless/Wirebased Communication Circuits → multi-band and multi-standard transceivers
  - Global Positioning System (GPS)
  - Increased clock speeds in ASICs/SoCs

- Why this course
  - Lumped no more applicable!
  - Solution? → **distributed!!!**

Motivation (contd.)

Design Focus in this Course



Motivation (contd.)

Frequency Spectrum

	100 Hz
ELF	10 kHZ
VLF	100 kHz
LF	1 MHz
MF (MW)	3 MHz
HF (SW)	30 MHz
VHF	300 MHz
UHF	1 GHz
SHF	30 GHz
EHF	300 GHz
IR	

300 MHz – 3 GHz

Radio Frequency
- TV
- Wireless Phones
- GPS

8 GHz to 40 GHz

Microwave Frequency
- Radar
- Remote Sensing

Why this course?

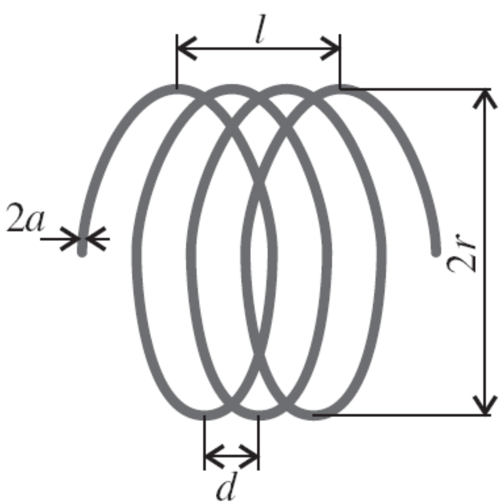
- Lumped components (wires, resistors, capacitors, inductors, connectors etc.) behave differently at low and high frequencies.
- Why?
    - current and voltage vary spatially over the component size
    - Leads to the concept of distributed components!

The KCL and KVL are no more applicable

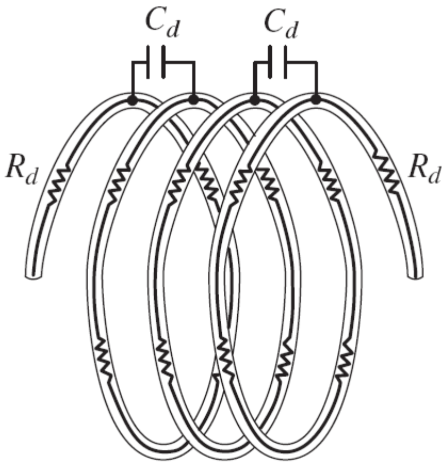
Why this course?

- What do we mean by distributed?
  - Example – Inductor

Low Frequency (Lumped)



High Frequency (Distributed)



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

$$Z = ?$$

RF Behavior of Passive Components

- Why do inductors, capacitors, and resistors behave differently at Radio Frequency?
- What is skin effect?
- Equivalent Circuit Model?

RF Behavior of Passive Components (contd.)

For conventional AC circuit analysis:

- R is considered frequency independent
- Ideal Inductor (L) possesses an impedance $(X_L = j\omega L)$
- Ideal capacitor (C) possesses an impedance $\left(X_C = {}^{1}/_{j\omega C}\right)$

Capacitor behaves as open circuit at DC and low frequency **whereas** an Inductor behaves as short circuit at DC and low frequencies

RF Behavior of Resistors

At low frequency:

- Resistances, inductances, and capacitances are formed by wires, coils, and plates etc.
- Even a single wire or a copper line on a PCB possesses resistance and inductance.
- this cylindrical copper conductor has a DC resistance:

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

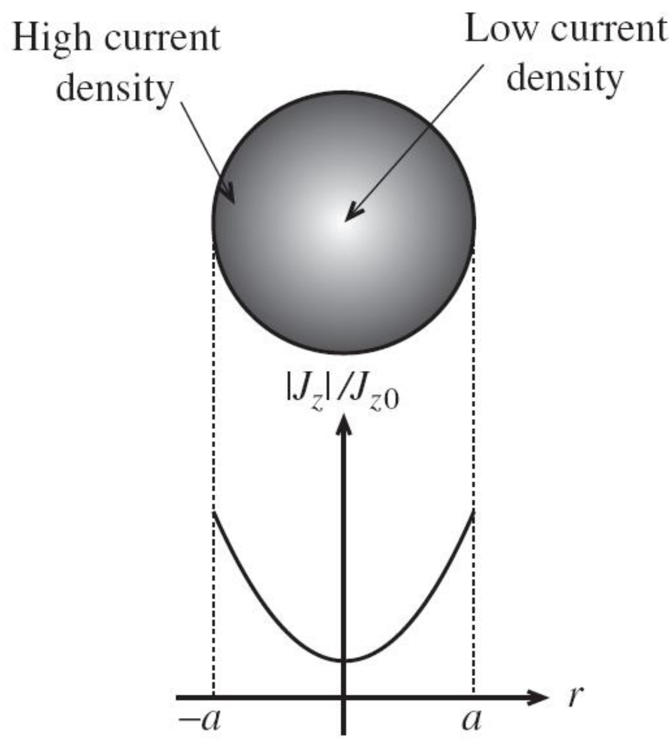
Length of cylinder

Radius of cylinder

conductivity

RF Behavior of Resistors (contd.)

- At DC, current flows uniformly distributed over the entire conductor cross-sectional area.
- At AC, the alternating charge carrier flow establishes a magnetic field that induces an electric field (Faraday's Law) whose associated current density opposes the initial current flow → this effect is very strong at the center (r=0) where the impedance is substantially increased → as a result the current flow resides at the outer periphery with the increasing frequency.



DC Current Density: $J_{z0} = \dfrac{I}{\pi a^2}$

→ **Skin Effect**

RF Behavior of Resistors (contd.)

- The current density at AC is given by:

$$J_z = \frac{pI}{2\pi a j\sqrt{r}} \exp\left(-(1+j)\frac{a-r}{\delta}\right)$$

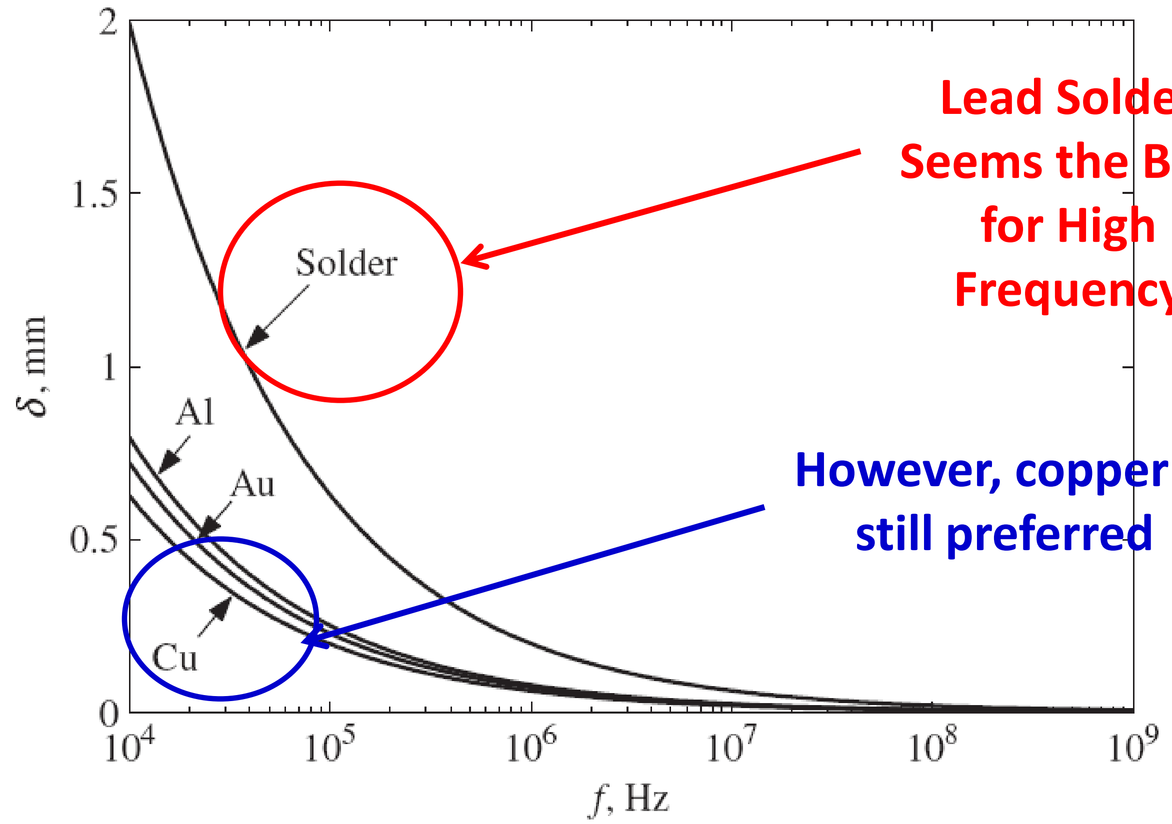
$$p^2 = -j\omega\mu\sigma_{cond}$$

$$\delta = \frac{1}{\sqrt{\pi f \mu\sigma_{cond}}}$$

Skin Depth

- J_z drops with decrease in r (proximity to the center)
- δ decreases with increase in frequency (skin depth from periphery reduces with increased frequency) → means the path for current conduction remains nearer to the periphery (skin effect) → means, current density towards center decreases with increase in frequency and increase in conductivity

RF Behavior of Resistors (contd.)

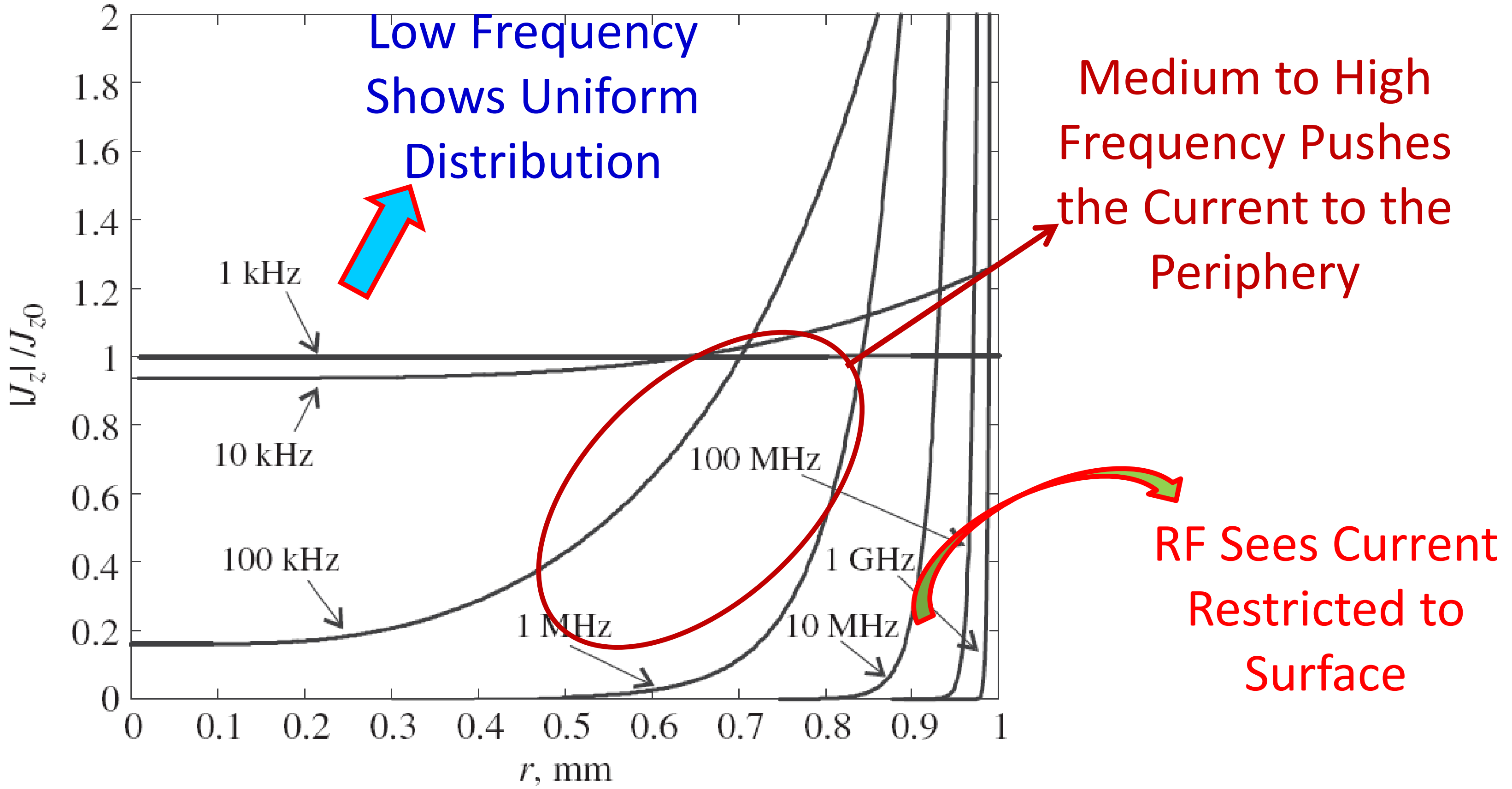


Lead Solder Seems the Best for High Frequency

However, copper is still preferred

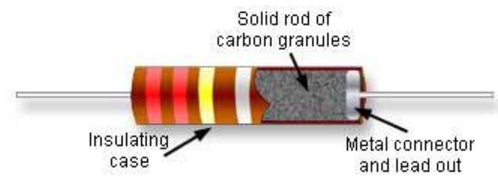
RF Behavior of Resistors (contd.)

Frequency sweep: For a fixed wire radius of $a = 1mm$, the plot $|J_z|/|J_{z0}|$ as a function of depth r:



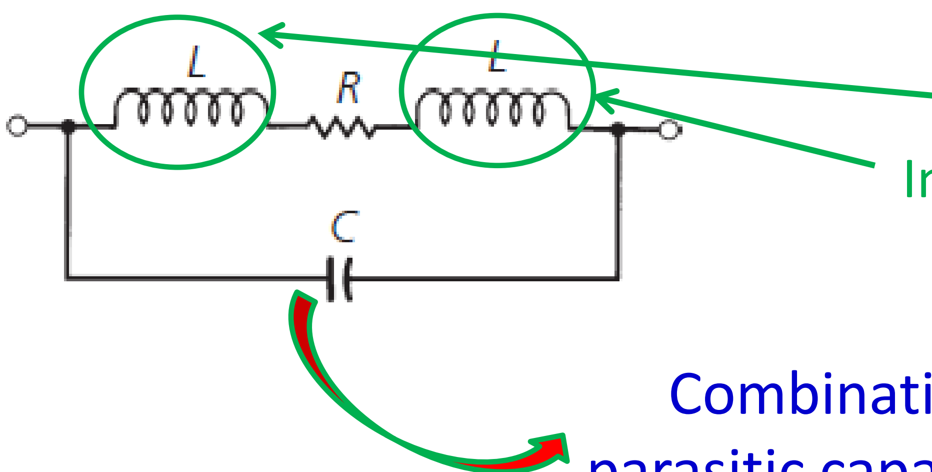
Resistors at High Frequencies

1. Carbon-composition resistors:



- Consists of densely packed dielectric particulates or carbon granules.
- **Between each pair of carbon granules is very small parasitic capacitor.**
- These parasitics, in aggregate, are significant → **primarily responsible for notoriously poor performance at high frequencies.**

Equivalent Ckt Model:

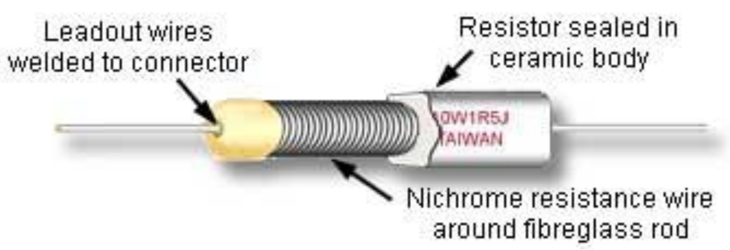


Lead
Inductance

Combination of
parasitic capacitances

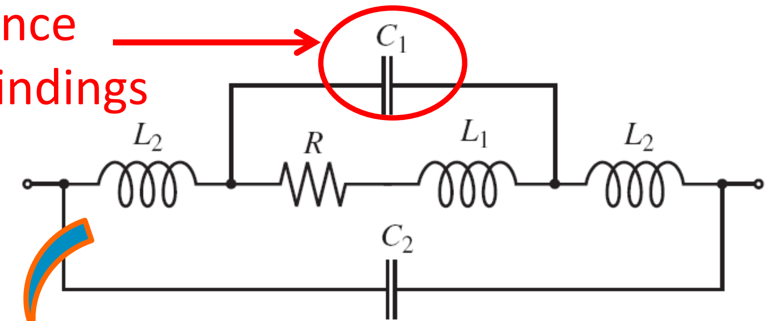
Resistors at High Frequencies (contd.)

2. Wire-wound Resistors:



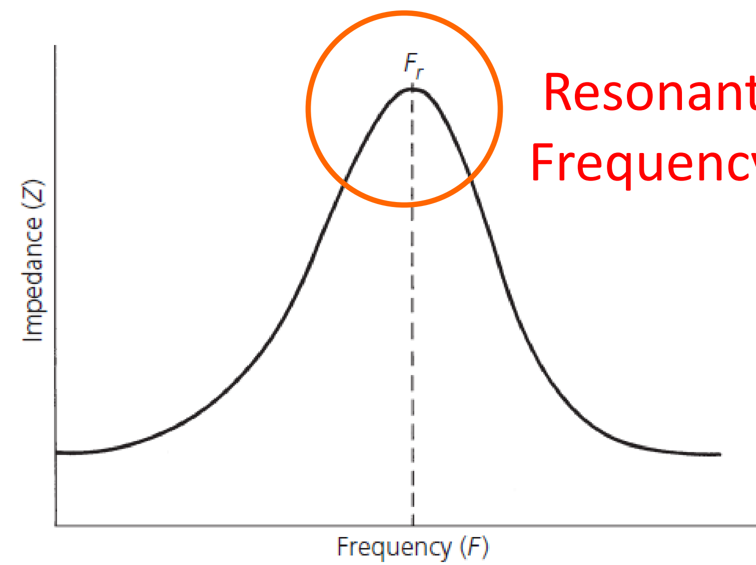
Equivalent Ckt Model:

Capacitance between Windings



L_2: lead inductance
L_1: inductance of resistive wires
C_2: Interlead Capacitance

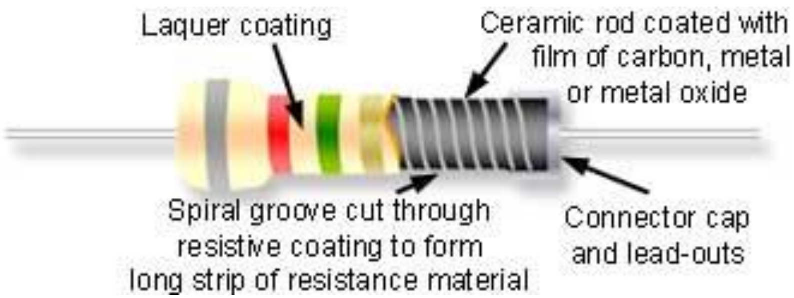
- Exhibit widely varying impedances over various frequencies.
- The inductor L is much larger here as compared to carbon-composition resistor.
- These resistors look like inductors → impedances will increase with increase in frequency.
- At some frequency F_r, the inductance will resonate with shunt capacitance → leads to decrease in impedance.



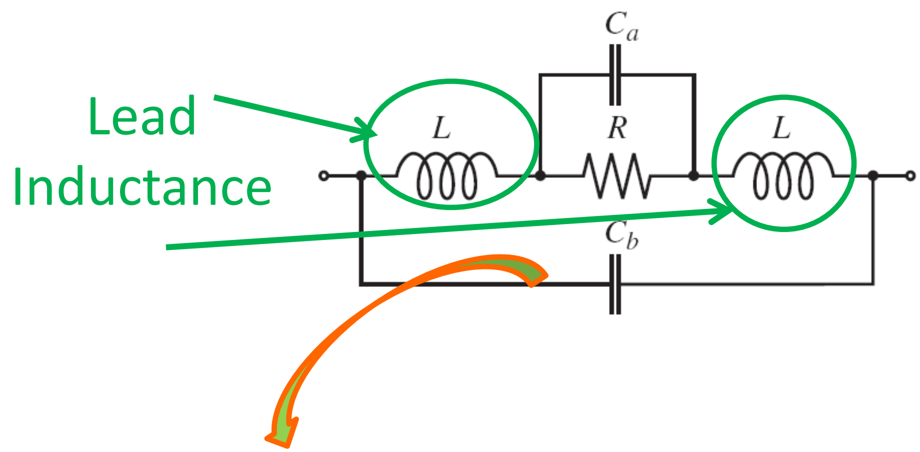
Resonant Frequency

Resistors at High Frequencies (contd.)

3. Metal-film Resistors:



Equivalent Ckt Model:



C_a models charge separation effects and C_b models interlead capacitance

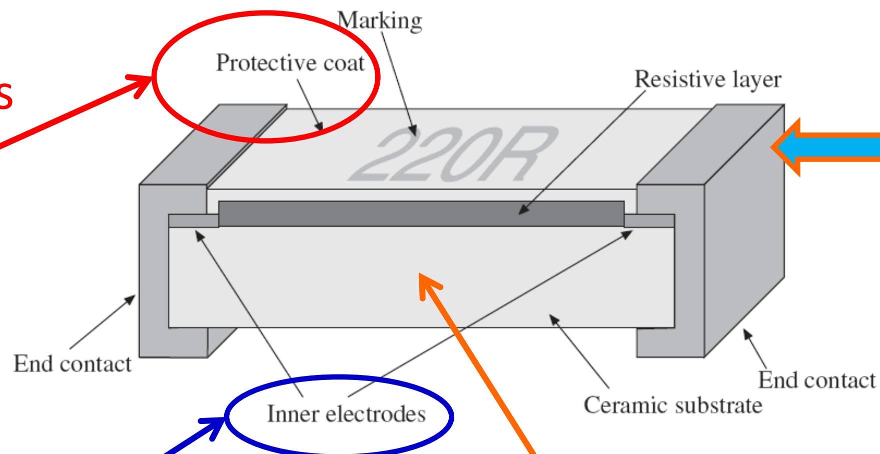
- Seems to exhibit very good characteristics over frequency.
- Values of L and C are much smaller as compared to wire-wound and carbon-composition resistors.
- It works well up to 10 MHz → useful up to 100 MHz

Resistors at High Frequencies (contd.)

3. Thin-film Chip Resistors:

- The idea is to eliminate or reduce the stray capacitances associated with the resistors
- Good enough up to 2 GHz.

Protective coat prevents variations from any environmental interferences



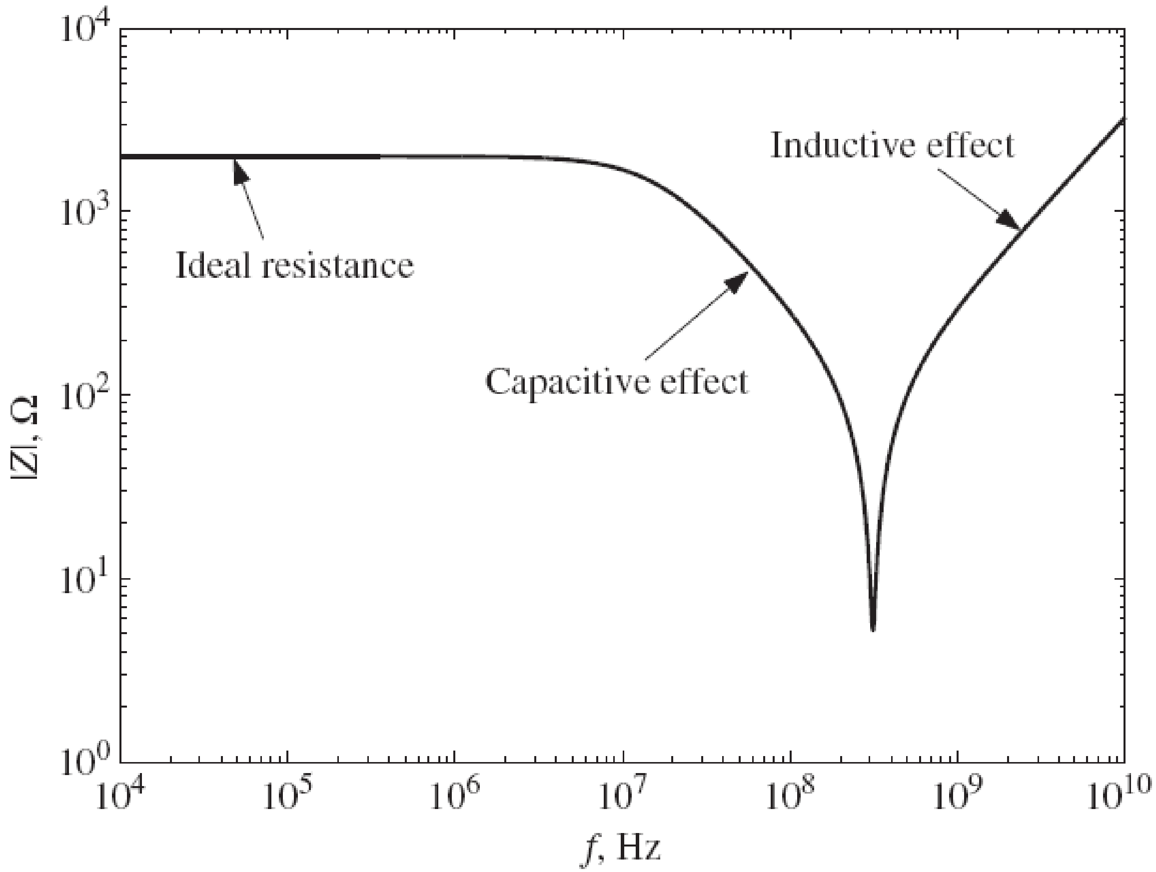
The end contacts are required for soldering purposes

These electrodes are inserted after trimming the resistive layer to the desired value

A metal film (usually nichrome) layer is deposited on this ceramic substrate → this layer works as resistor

Resistors at High Frequencies (contd.)

What is the reason for following behavior of a 2000Ω thin-film resistor?



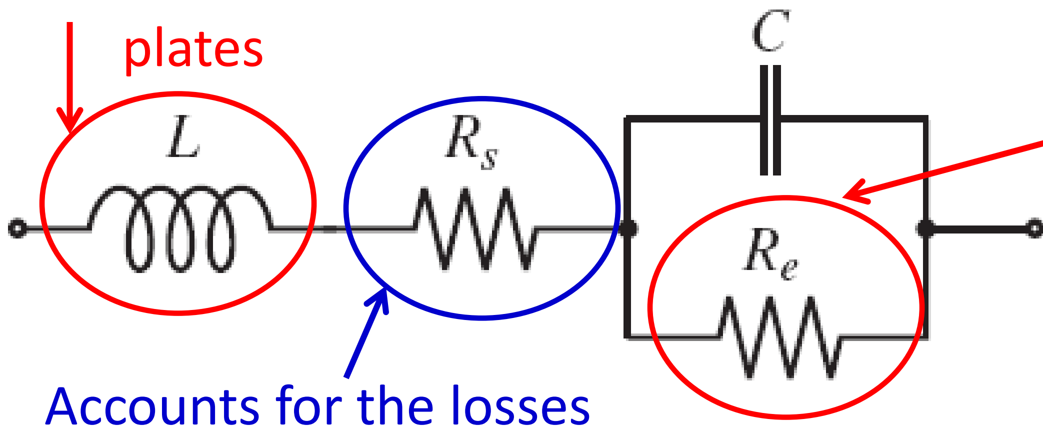
HW # 0

Demonstrate using either ADS or MATLAB

Capacitors at High Frequencies

Equivalent Circuit Representation of a Capacitor → for a parallel-plate

Inductance of the leads and plates



Represents Insulation Resistance

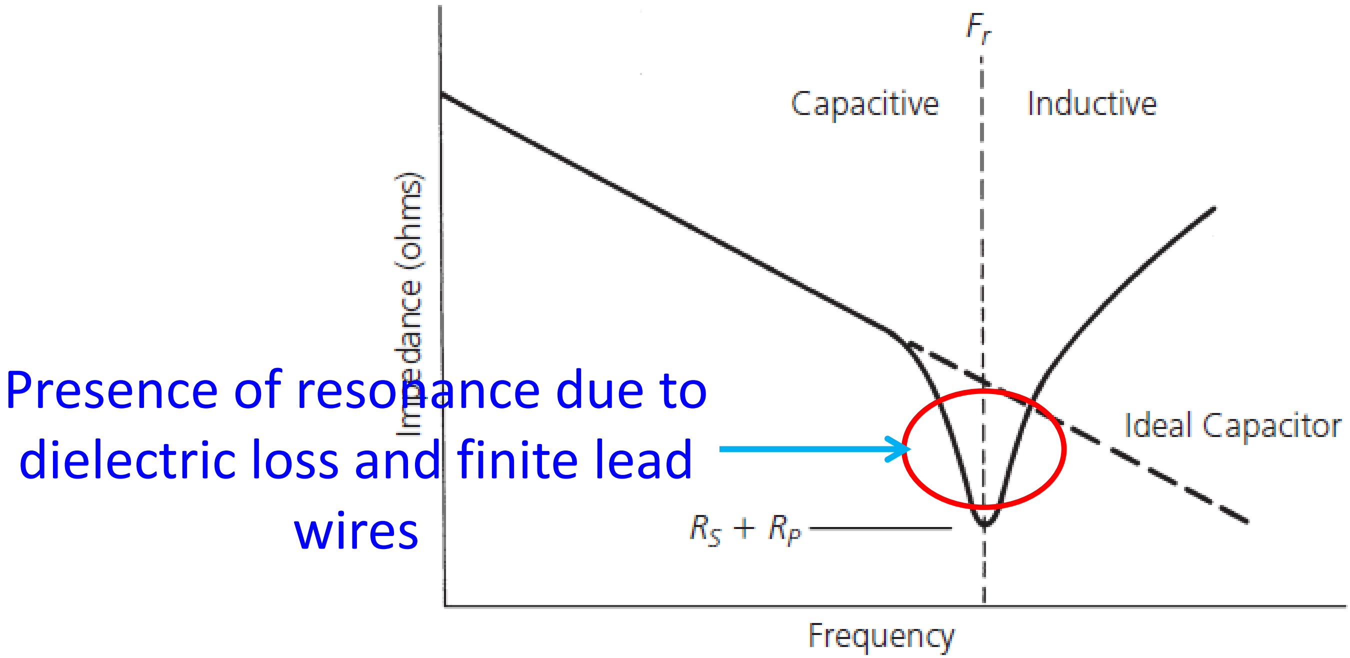
Accounts for the losses in the leads

$$C = \frac{\varepsilon A}{d} = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

At high frequency, the dielectric become lossy i.e., there is conduction current through it

Then impedance of capacitor becomes a parallel combination of C and conductance G_e

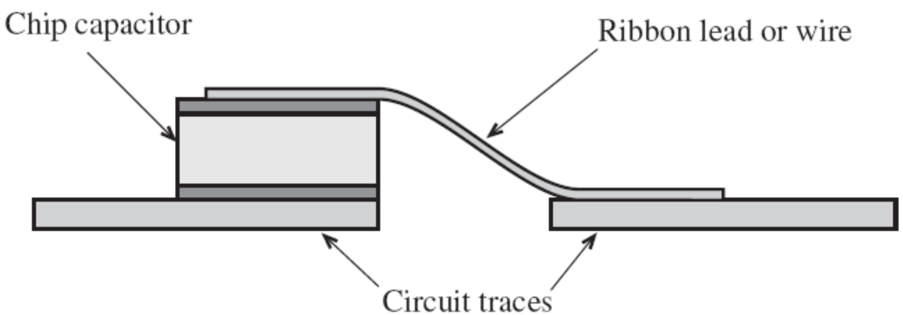
Capacitors at High Frequencies (contd.)



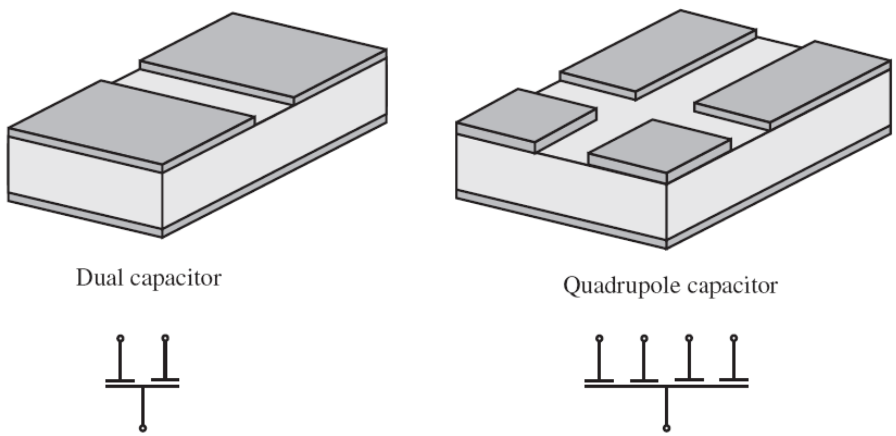
- Above F_r, the capacitor behaves as an inductor.
- In general, larger-value capacitors tend to exhibit more internal inductance than smaller-value capacitors.
- Therefore, it may happen that a $0.1\mu F$ may not be as a good as a $300pF$ capacitor in a bypass application at $250\ MHz$.
- The issue is due to significance of lead inductances at higher frequencies.

Capacitors at High Frequencies (contd.)

Chip Capacitors

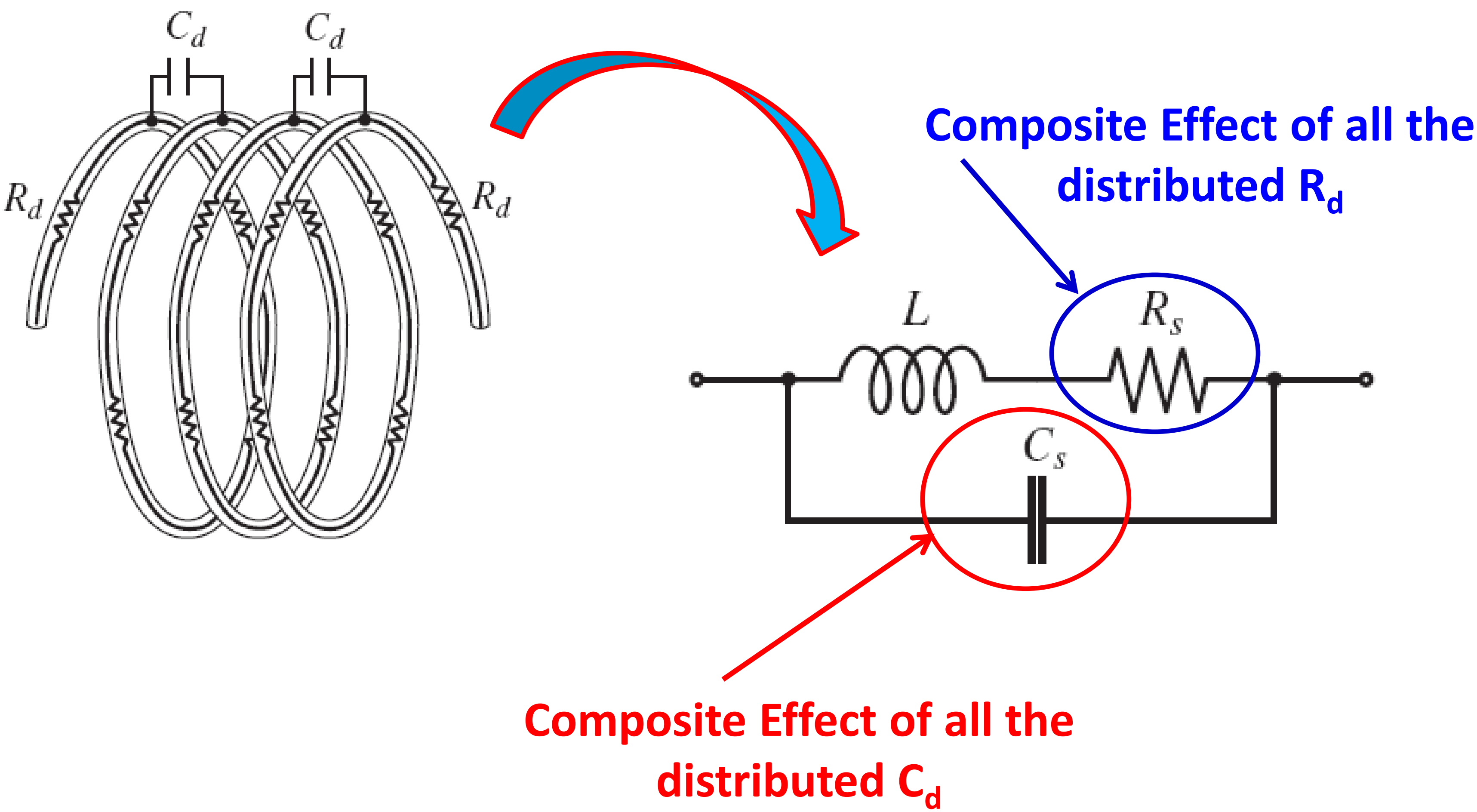


Cross-section of a single-plate capacitor connected to the board

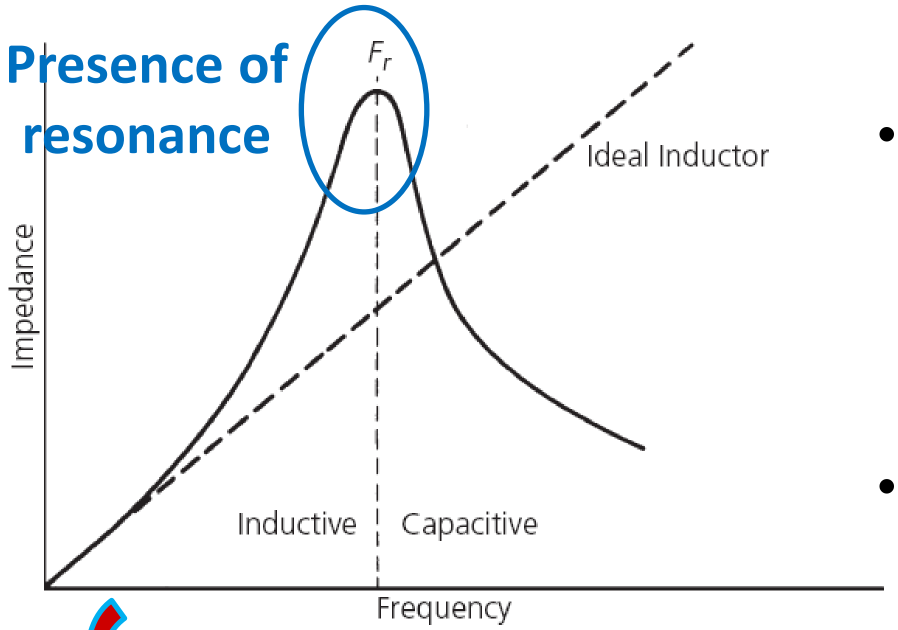


Inductors at High Frequencies

Equivalent Circuit Representation of an Inductor → coil type



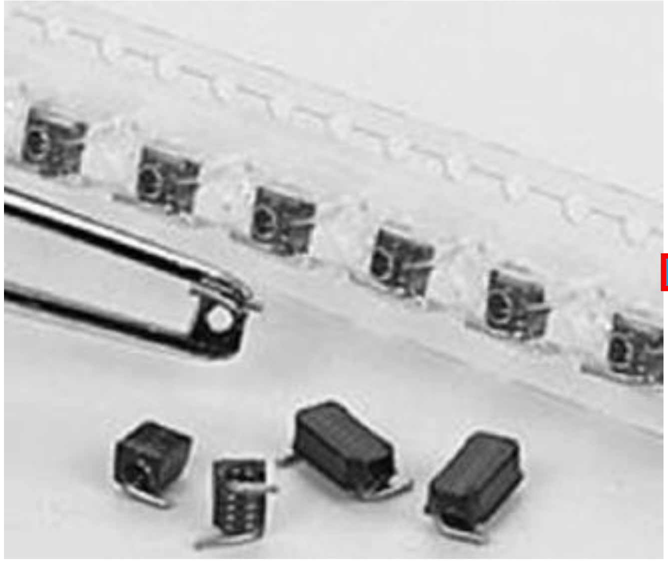
Inductors at High Frequencies (contd.)



- Initially the reactance of inductor follows the ideal but soon departs from it and increases rapidly until it reaches a peak at the inductor's resonant frequency (F_r). **Why?**
- Above F_r, the inductor starts to behave as a capacitor.

Implement this in MATLAB or ADS → **HW#0**

Chip Inductors



Surface mounted inductors still come as wire-wound coil →these are comparable in size to the resistors and capacitors