Passive Devices

Last updated 3/12/19

Passive Devices

- We are used to using passive devices in our discrete designs
  - Resistor values from a few Ohms to 100s of MΩ
  - Capacitor values from 100s of pF to 100s of uF
  - Inductor values from mH to H
- Integrated versions of these devices are limited to much smaller values due to area considerations
  - In fact – Inductors are avoided wherever possible

Passive Devices

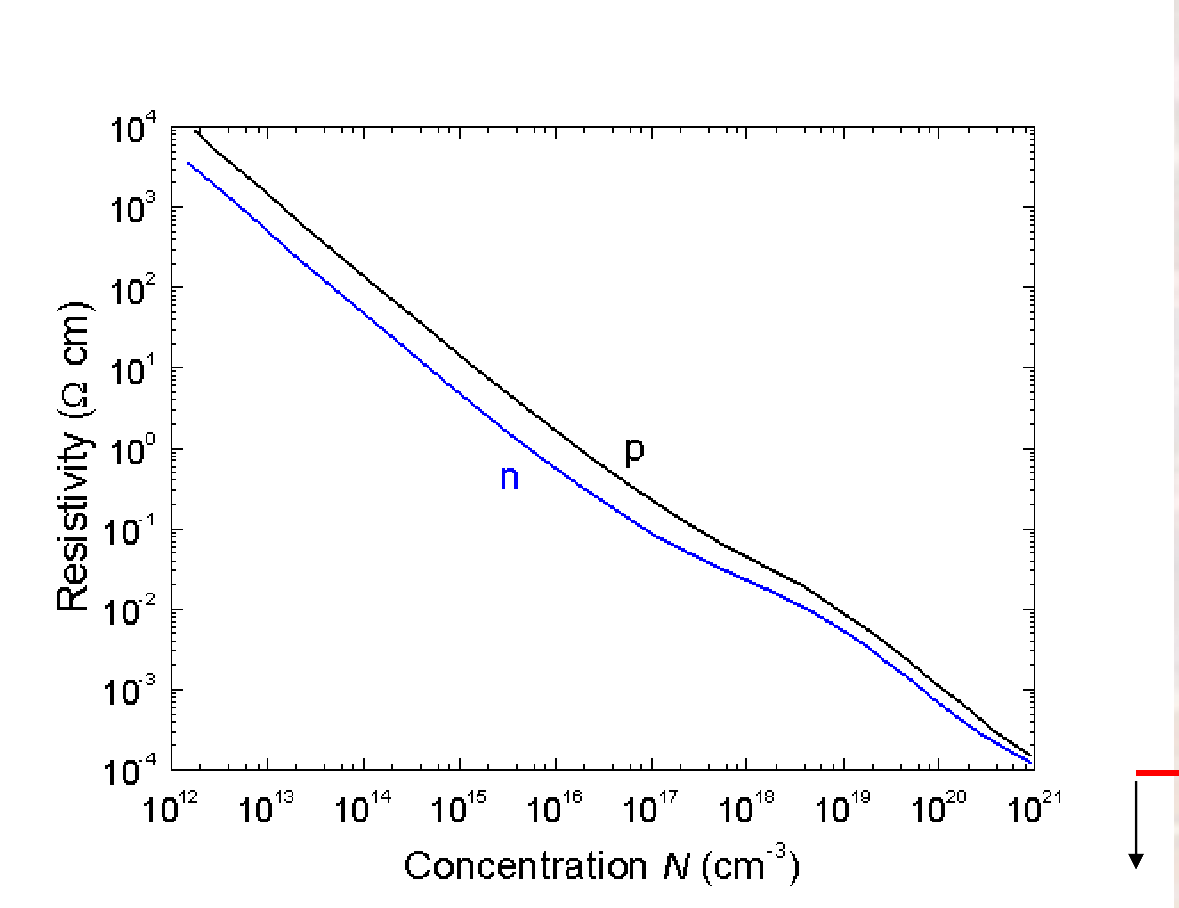
- Integrated Circuit Resistors

  - Conductance – conductivity of a 3 dimensional material
    - Symbol: σ
    - Measured in 1/Ohm-m
    - Measure of how easy/hard it is to free electrons from the material
      - Copper 5.96x10^7/Ω-m
      - Gold 4.10x10^7/Ω-m
      - Aluminum 3.77x10^7/Ω-m

  - Resistivity – inverse of conductance
    - Symbol: ρ
    - Measured in Ohm-m (or often Ω-cm)

Passive Devices

- Integrated Circuit Resistors
  - Resistivity of doped silicon

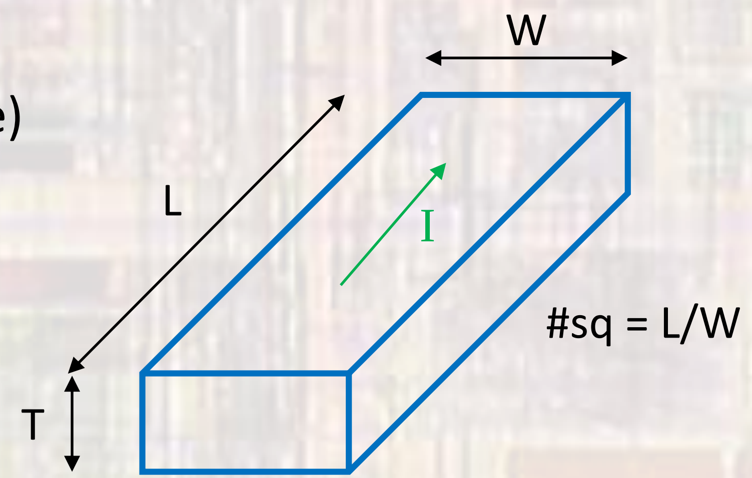


Metals

(1 to 3)x10^{-6}Ω-cm

Passive Devices

- Integrated Circuit Resistors
  - During manufacturing the thickness of the resistive material is fixed
  - Designer can change the width and length
  - Sheet resistance
    - Resistivity / Thickness (ρ/T)
    - $R_{\square}$
    - Measured in Ω/□ (Ohms/square)
  - Resistance
    - $R = \frac{L}{W} R_{\square}$



Passive Devices

- Integrated Circuit Resistors
  - Consider a bulk P-type resistor in a 20nm process technology
    - T = 1um
    - ρ = 5x10^{-2} Ω-cm (1x10^{18} doping)

      → $R_{□}$ = 500Ω/□

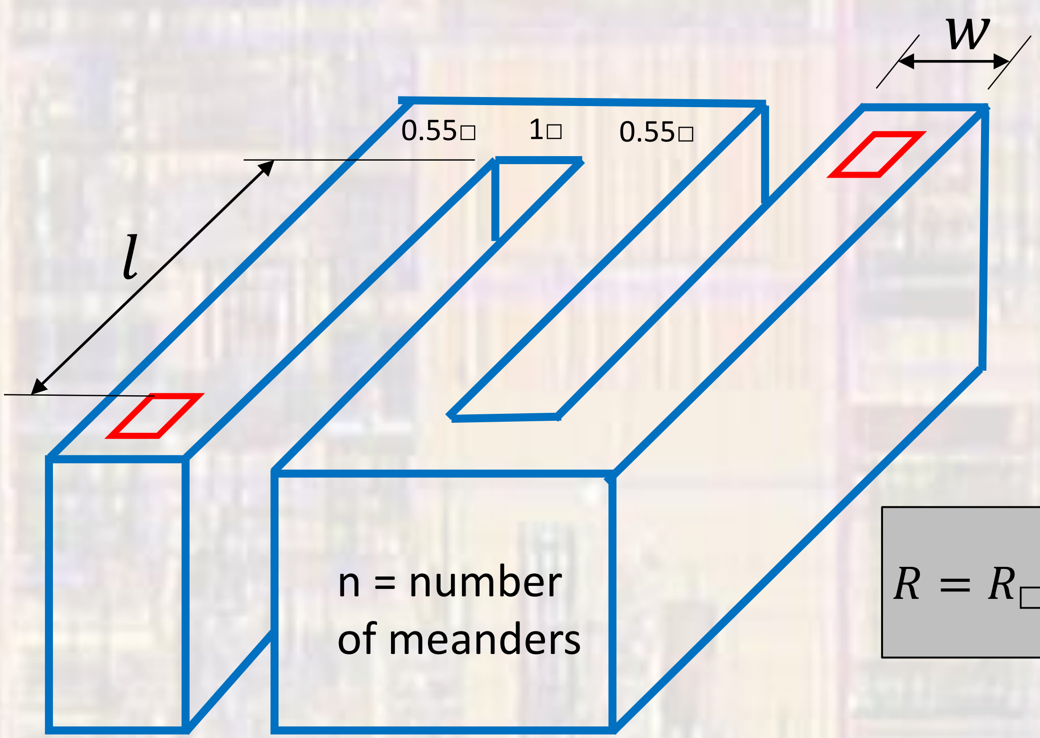
  - If the resistor width is 80nm, how long would a 10KΩ resistor be

#□'s = 10KΩ / 500Ω/□ = 20□'s

$$L = 10K\Omega \times \frac{1\square}{500\Omega} \times \frac{80nm}{1\square} = 1.6x10^{2}nm$$

Passive Devices

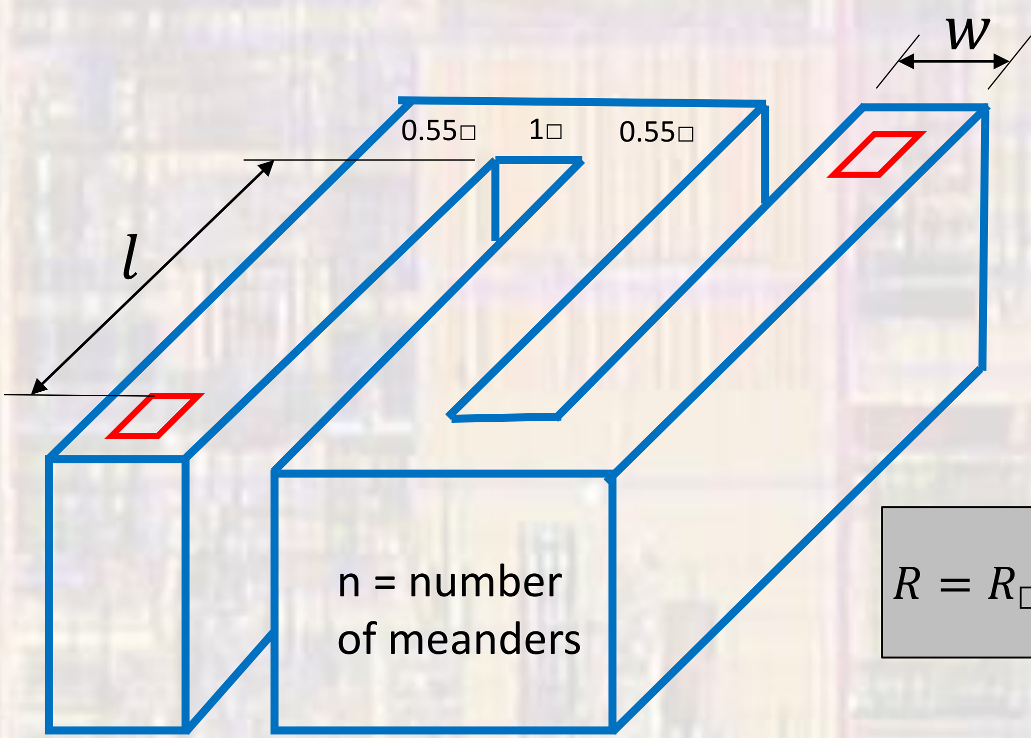
- Integrated Circuit Resistors
  - Meandering resistor
  - Corners = 0.55□
  - Measure from contact to contact



$$R = R_{\square} \times \left(\left(\frac{l}{w} \times n \right) + (1.1 \times (n-1)) \right)$$

Passive Devices

- Integrated Circuit Resistors
  - Meandering resistor
  - Assume a ½ pitch = W = 20nm
  - Create an equation for the area of a resistor in terms of l and w

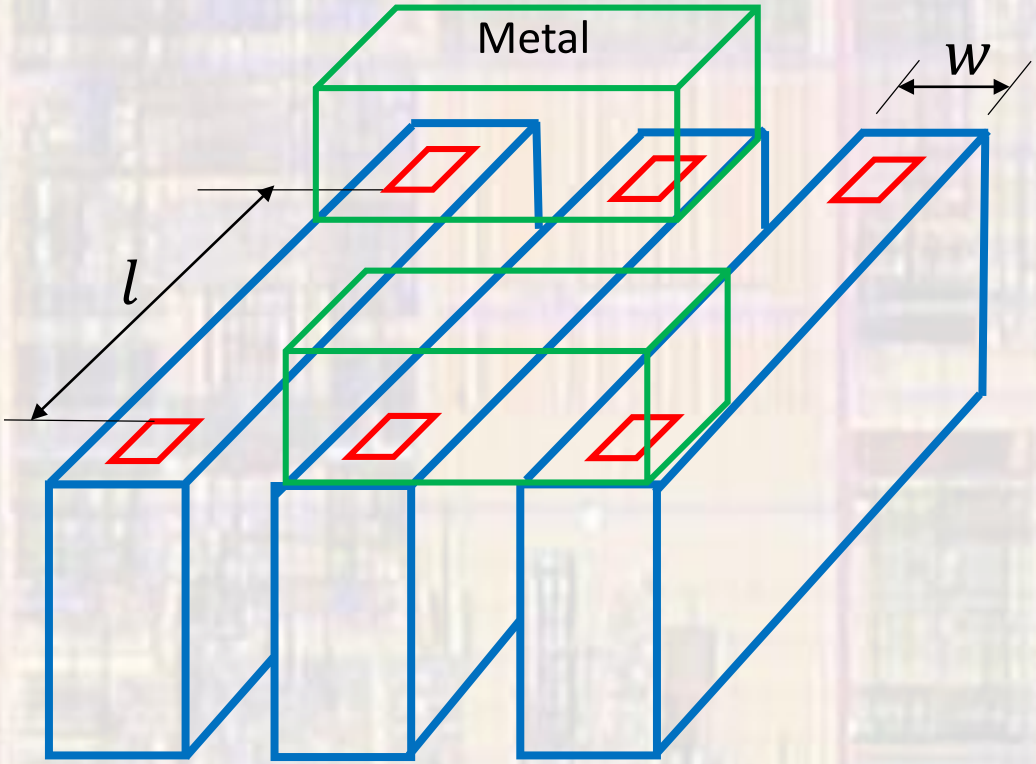


A=

$$R = R_{\square} \times \left(\left(\frac{l}{w} \times n\right) + (1.1 \times (n-1))\right)$$

Passive Devices

- Integrated Circuit Resistors
  - Meandering resistor

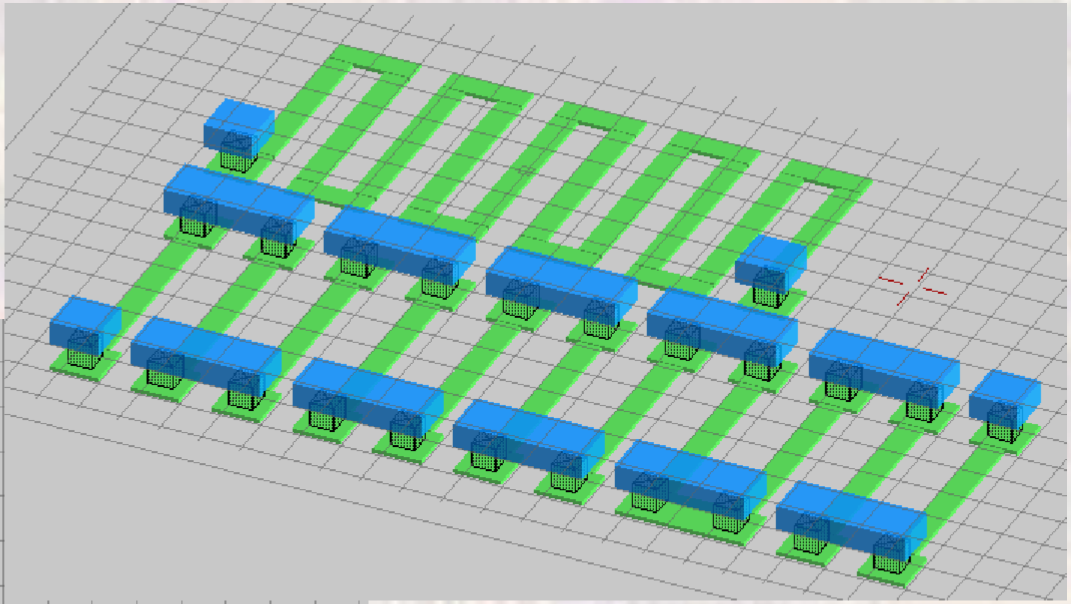


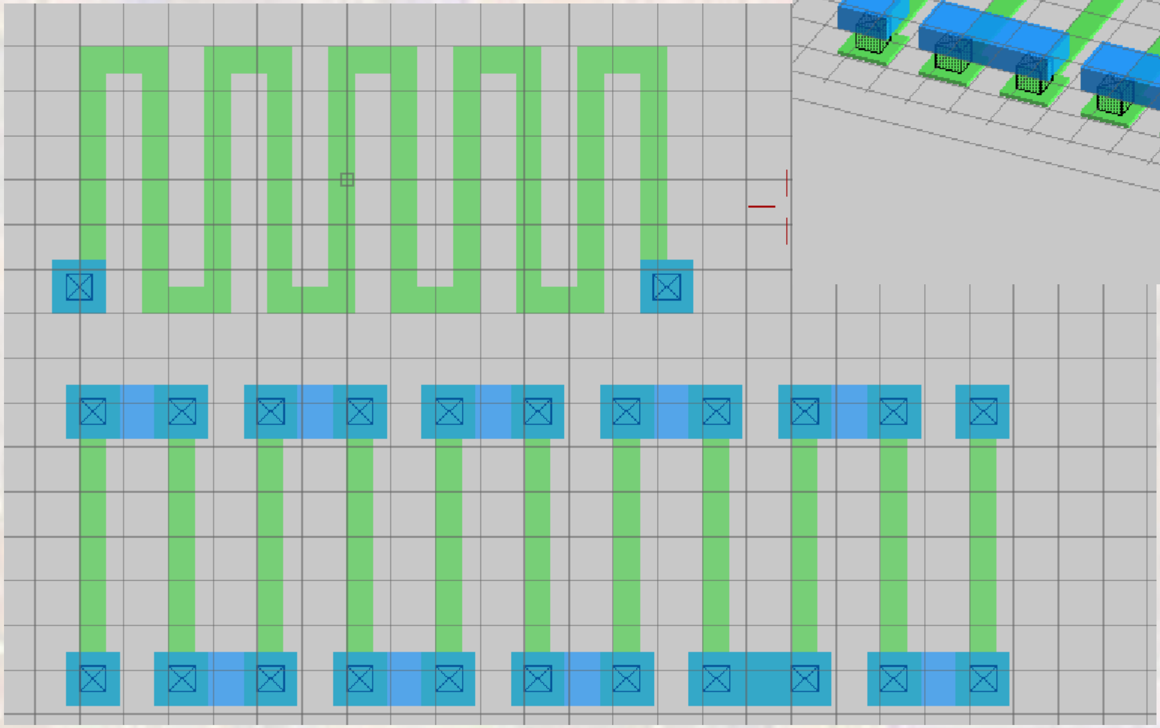
n = number of meanders

$$R = R_{\square} \times \left(\left(\frac{l}{w} \times n\right)\right)$$

Passive Devices

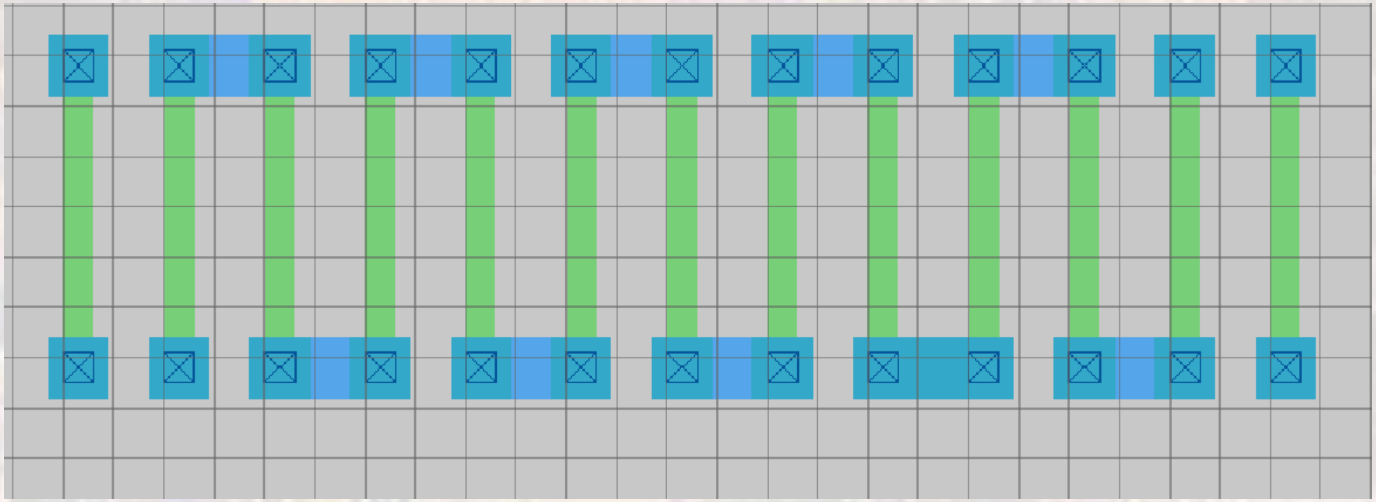
- Integrated Circuit Resistors
  - Meandering resistor
  - N-diff





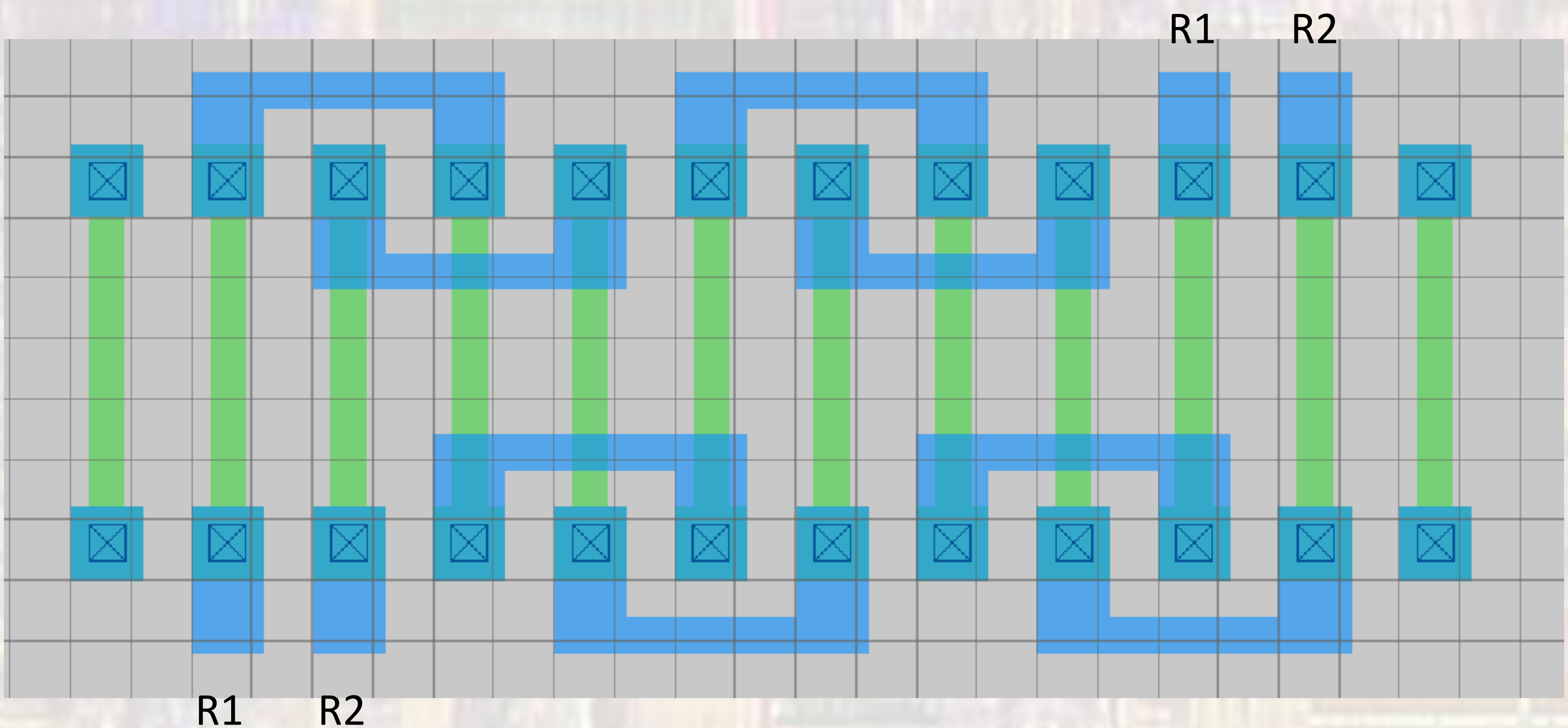
Passive Devices

- Integrated Circuit Resistors
  - For most types of resistors we can add extra legs at the end
    - Help make sure all parts of the resistor see the same lithography and process condition



Passive Devices

- Integrated Circuit Resistors
  - When we need 2 matched resistors (analog circuits), they can be inter-digitated

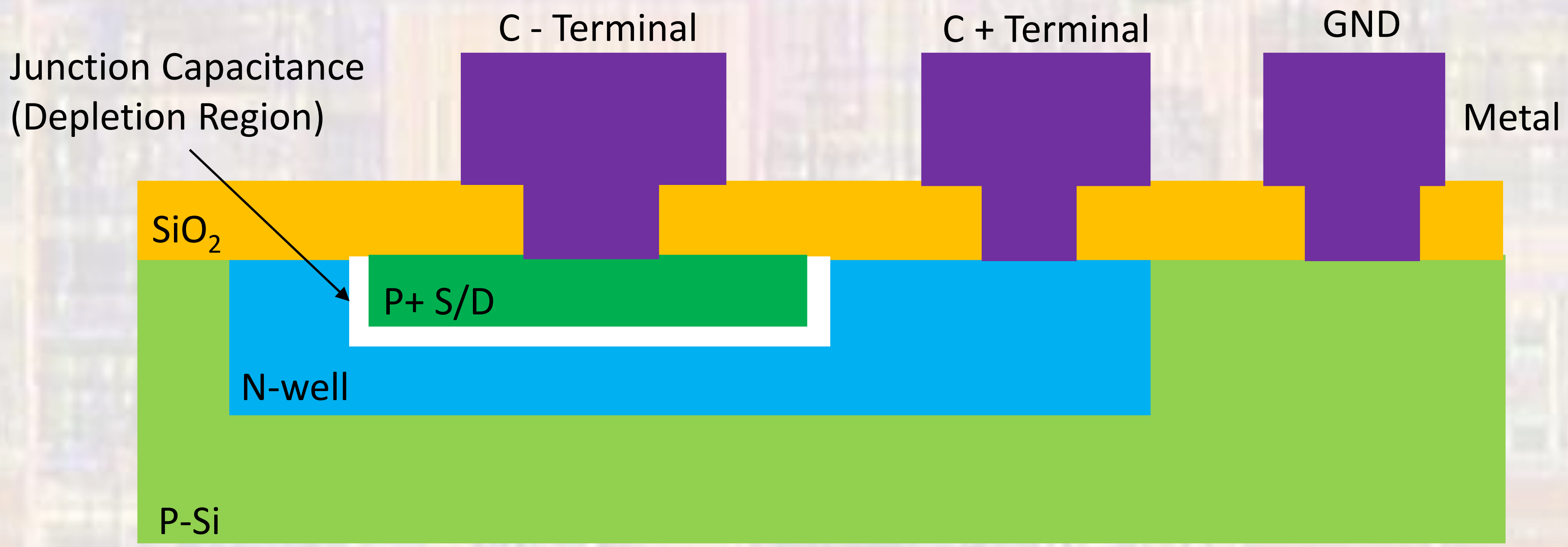


Passive Devices

- Integrated Circuit Capacitors
  - Three types of integrated capacitors
    - Diffusion (depletion capacitance)
    - Multiple layer
    - Vertical

Passive Devices

- Integrated Circuit Capacitors
  - Diffusion Capacitor
    - Relies on the depletion capacitance of a diode junction
    - Voltage variable



Passive Devices

- Integrated Circuit Capacitors
  - Diffusion Capacitor
    - Relies on the depletion capacitance of a diode junction
    - Voltage variable

Depletion region widths-

$$x_n = \left(\frac{2\varepsilon_{si}(\phi_o - v_D)N_A}{qN_D(N_A+N_D)}\right)^m$$

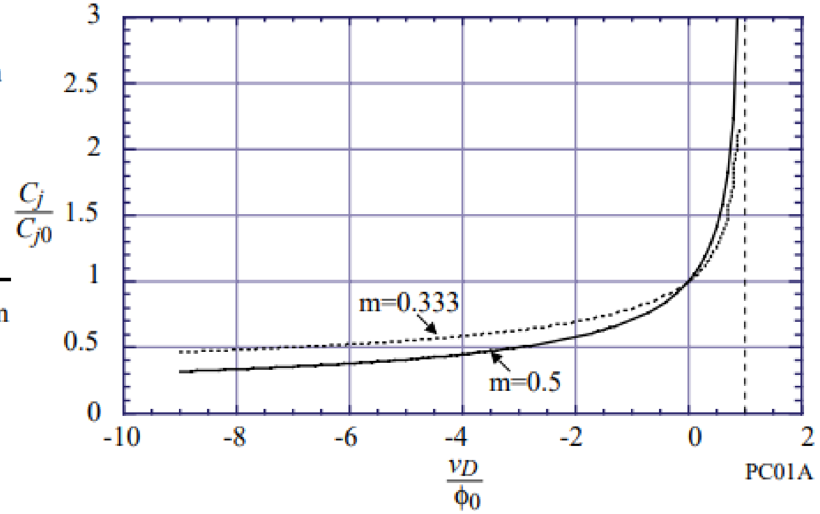
$$x_p = \left(\frac{2\varepsilon_{si}(\phi_o - v_D)N_D}{qN_D(N_A+N_D)}\right)^m$$

$$x \propto \left(\frac{1}{N}\right)^m$$

Depletion capacitance-

$$C_j = A\left(\frac{\varepsilon_{si} q N_A N_D}{2(N_A+N_D)}\right)^m \frac{1}{(\phi_o - v_D)^m} = \frac{C_{j0}}{\left(1 - \frac{v_D}{\phi_o}\right)^m}$$

where $0.33 \le m \le 0.5$. (Note that $m = MJ$)



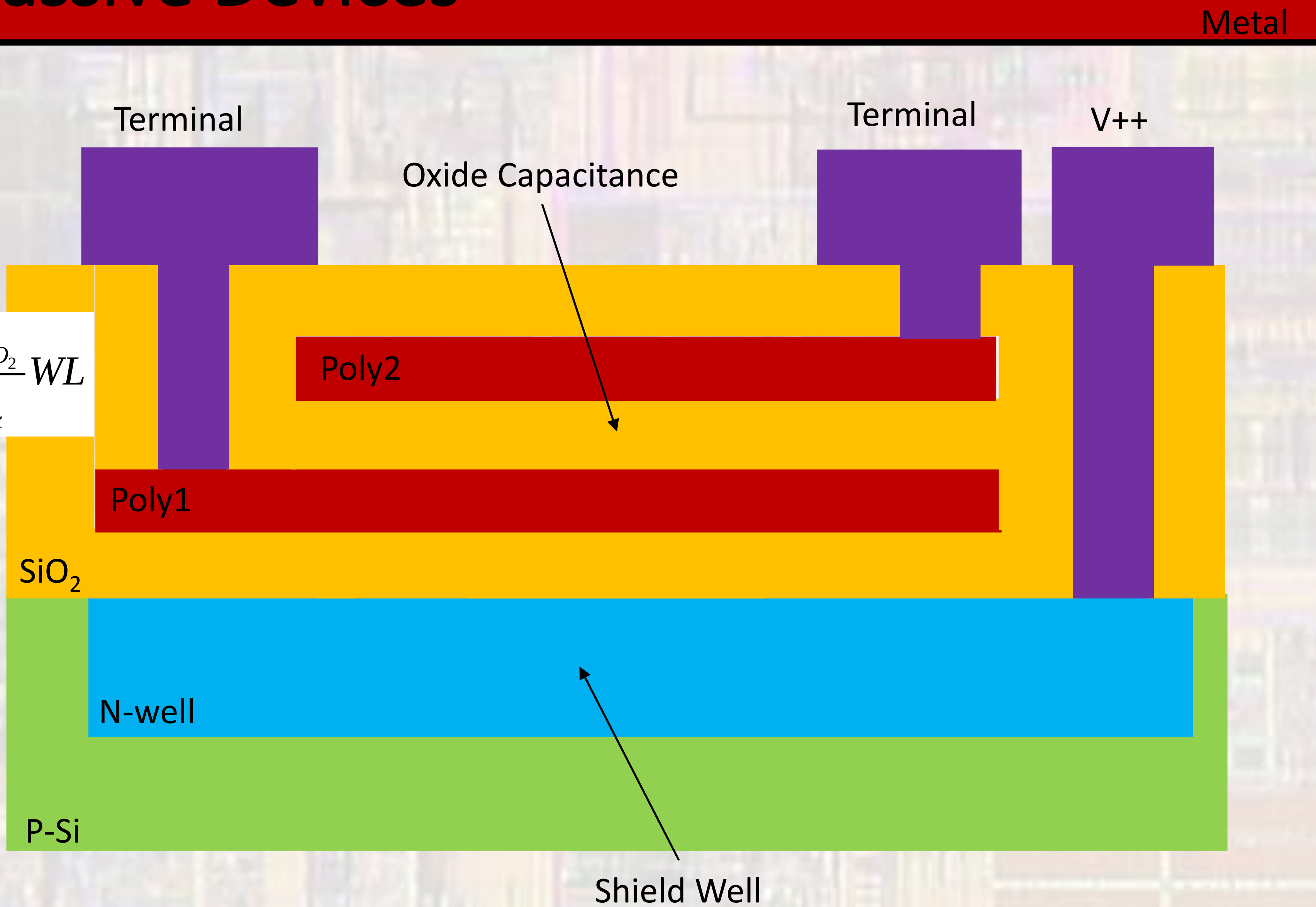
src: Allen and Connolly - 2000

Passive Devices

- Integrated Circuit Capacitors
  - Multi-layer Capacitor
    - Analog processes include a second polysilicon layer with a fixed oxide thickness
      - Poly2 – oxide – poly1 capacitor
      - Reasonable absolute capacitance
      - Very good capacitor matching
    - Digital processes can sandwich multiple metal layers to form a capacitor
      - M1 – oxide – M2 – oxide –M3 …
      - Oxide thickness is not well controlled → high C variation

Passive Devices

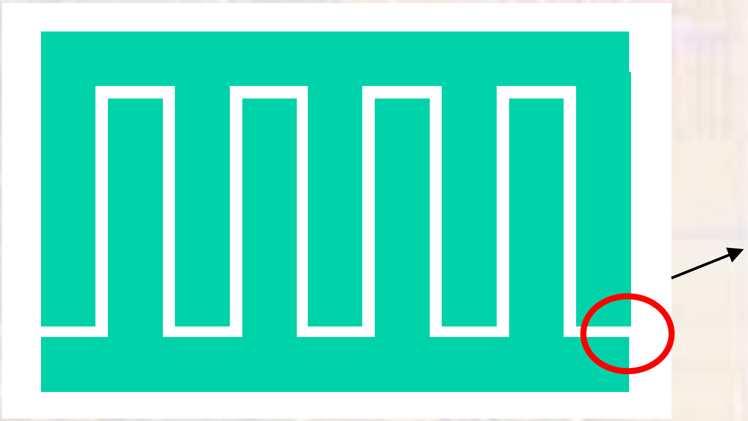
$$C = \frac{\varepsilon_{SiO_2}}{t_{ox}} WL$$

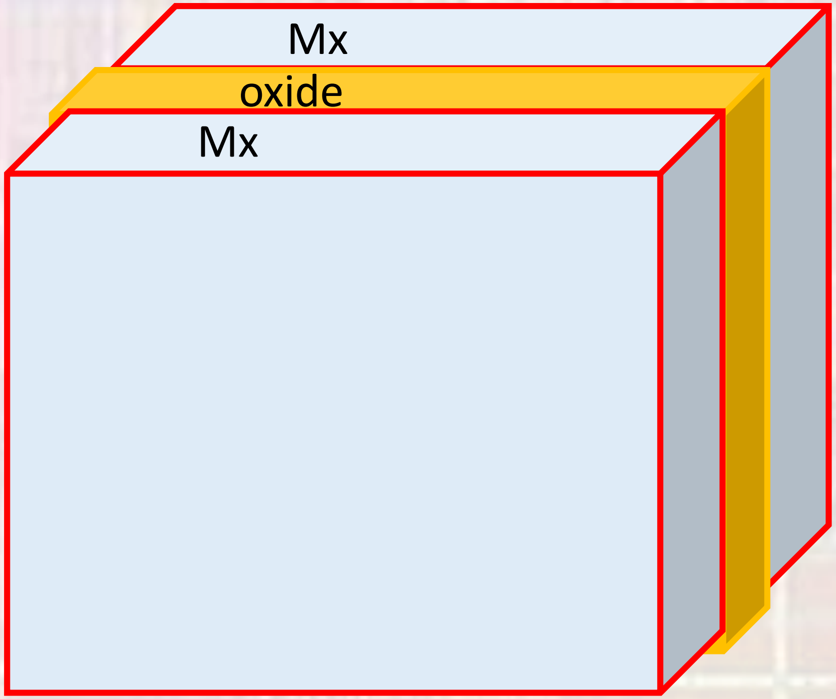


Passive Devices

- Integrated Circuit Capacitors
  - Vertical Capacitor
    - Utilize the oxide between two homogeneous conductors
      - Thick metal layers

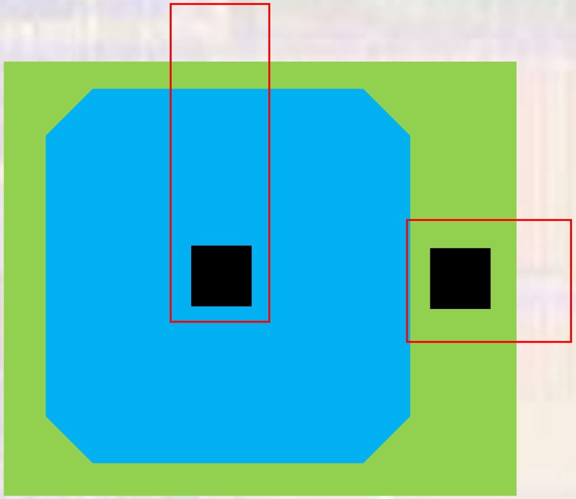
$$C = \frac{\varepsilon_{SiO_2}}{w_{ox}} TL$$

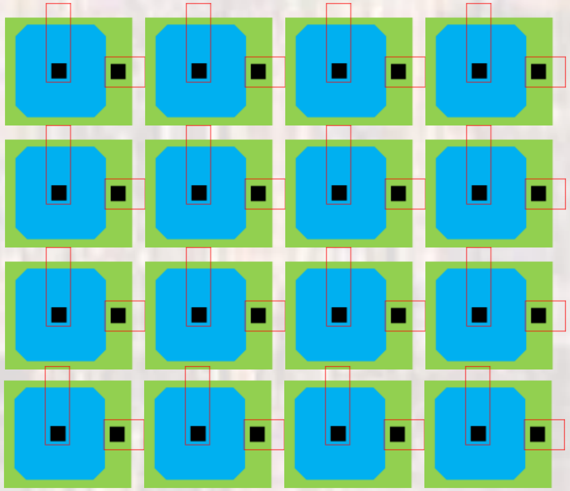




Passive Devices

- Integrated Circuit Capacitors
  - Capacitor matching
    - Use lots of unit cell capacitors





Passive Devices

- Integrated Circuit Capacitors
  - Inductor
    - Spiral of metal
    - Uses mutual inductance of the metal conductor