EE 434
Lecture 11

Basic Semiconductor Processes

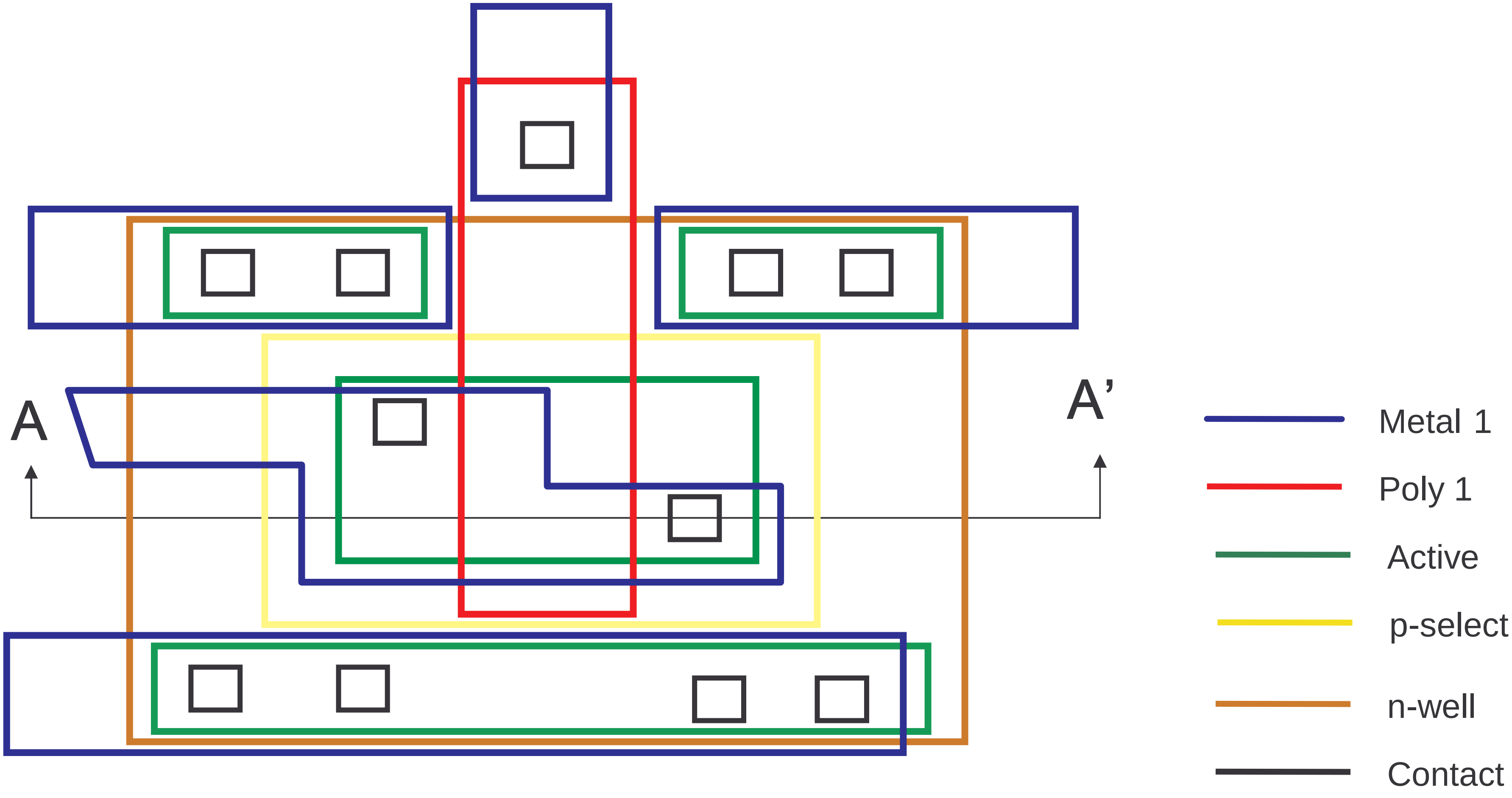
Devices in Semiconductor Processes

Quiz 9

The top view of a device fabricated in a bulk CMOS process is shown in the figure below

a) Identify the device

b) Sketch a cross-section along the AA' section line



And the number is ….

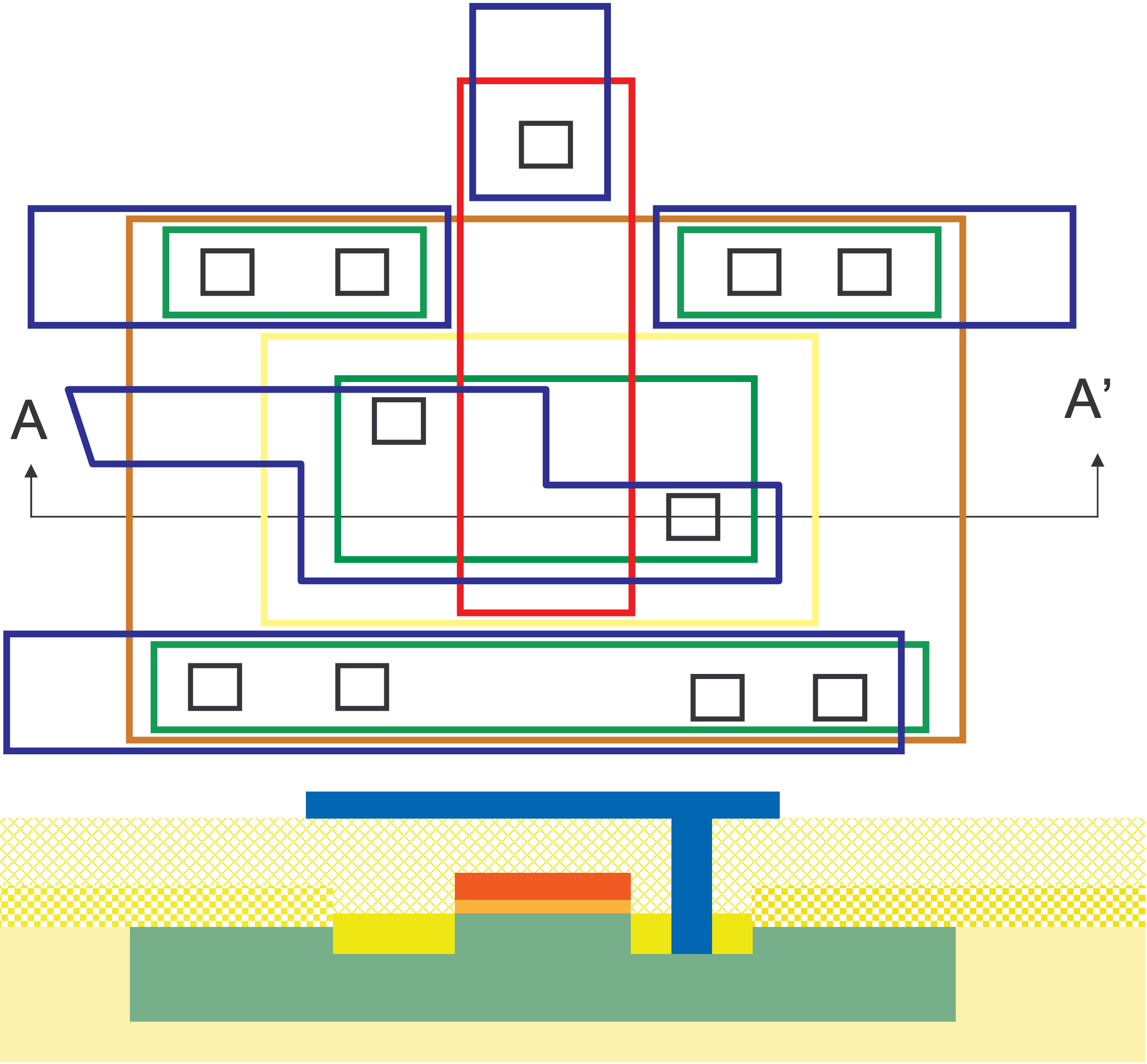
1 8 7 5 3

6 9 4 2

1

Quiz 9 Solution

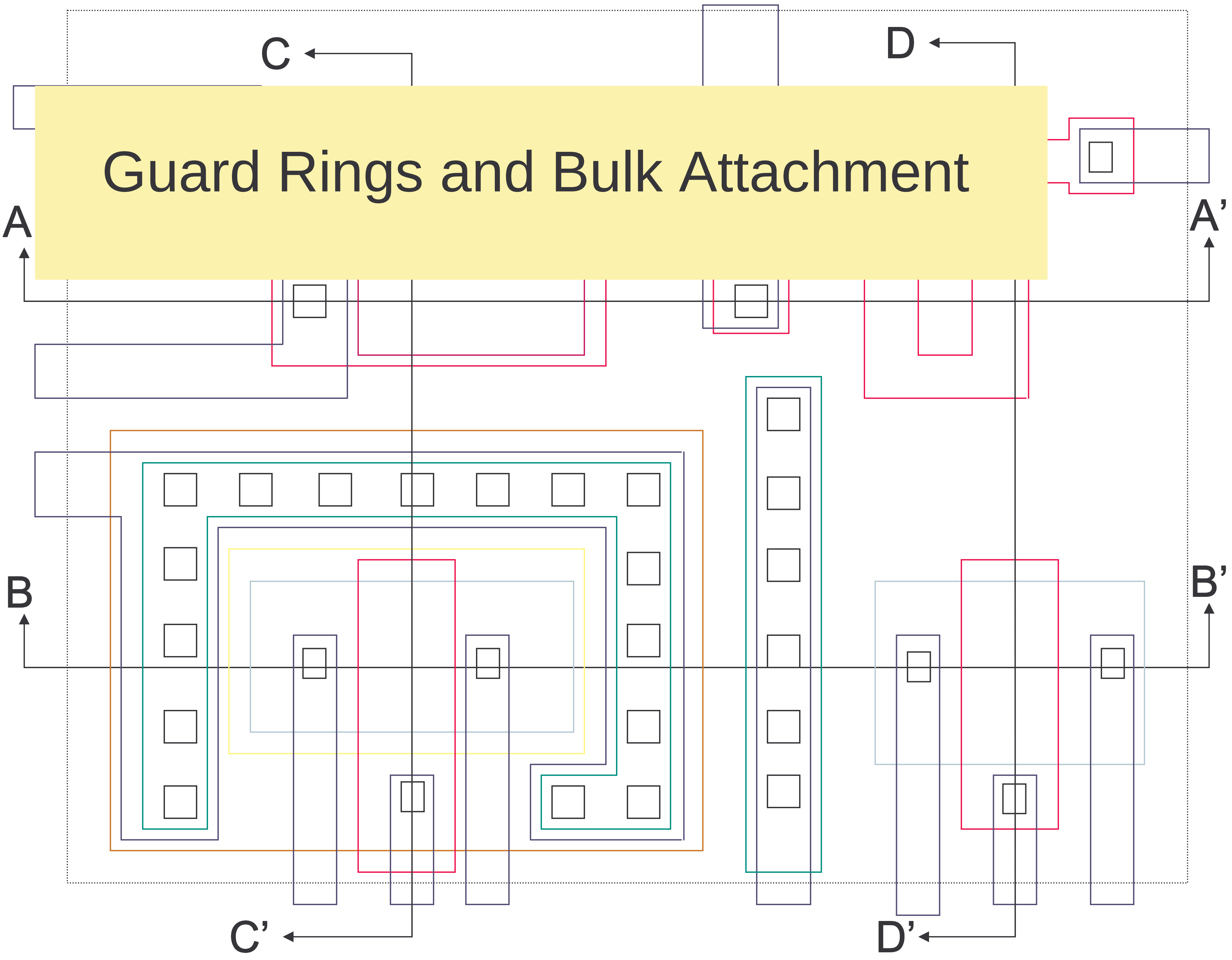
a) p-channel MOS Transistor



Review from Last Time

- Process Flow is a “recipe” for the process
  - Shows what can and can not be made
  - Gives insight into performance capabilities and limitations
- Back-End Processes
  - Die attach options (eutectic, preform,conductive epoxy)
    - Stresses the die
  - Bonding
    - Wire bonding
    - Bump bonding
  - Packaging
    - Many packaging options
    - Package Costs can be large so defective die should be eliminated before packaging

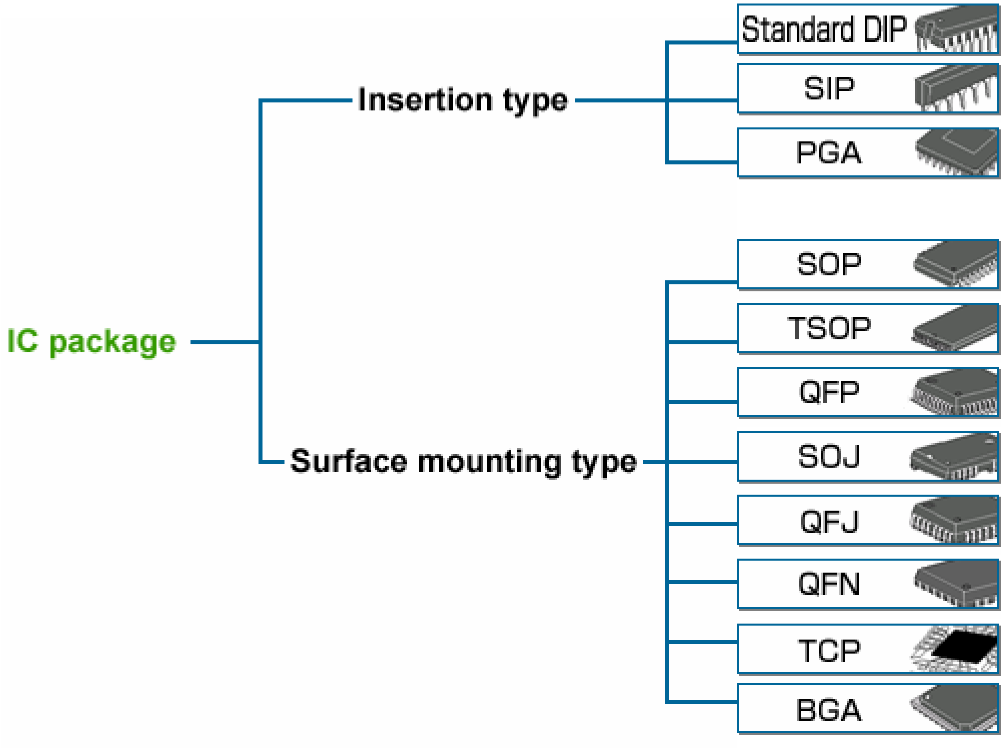
Guard Rings and Bulk Attachment



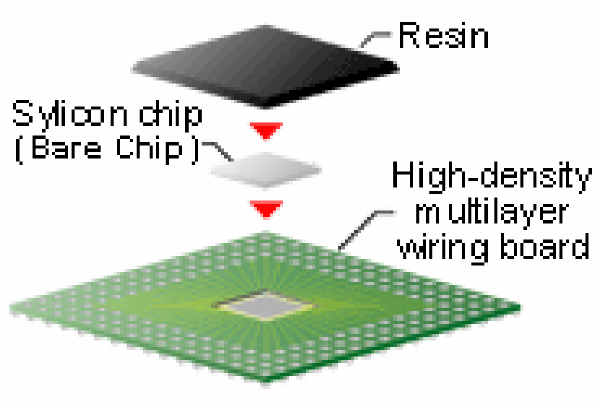
Packaging

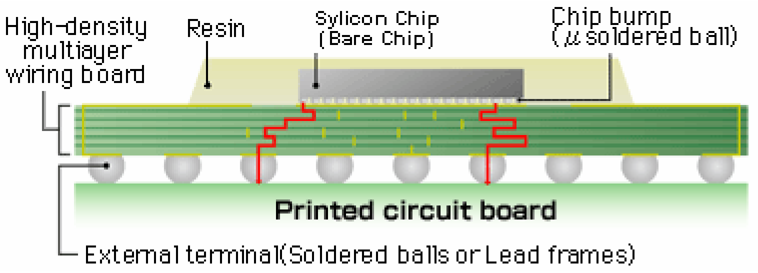
1. Many variants in packages now available
2. Considerable development ongoing on developing packaging technology
3. Cost can vary from few cents to tens of dollars
4. Must minimize product loss after packaged
5. Choice of package for a product is serious business
6. Designer invariably needs to know packaging plans and package models

Packaging


IC package
Insertion type
Standard DIP
SIP
PGA
Surface mounting type
SOP
TSOP
QFP
SOJ
QFJ
QFN
TCP
BGA

Packaging


Resin
Sylicon chip
(Bare Chip)
High-density
multilayer
wiring board


High-density
multilayer
wiring board
Resin
Sylicon Chip
(Bare Chip)
Chip bump
(μ soldered ball)
Printed circuit board
External terminal(Soldered balls or Lead frames)

Basic Semiconductor Processes

MOS (Metal Oxide Semiconductor)

1.	NMOS	n-ch
2.	PMOS	p-ch
3.	CMOS	n-ch & p-ch
–	Basic Device:	MOSFET
–	Niche Device:	MESFET
–	Other Devices:	Diode BJT Resistors Capacitors Schottky Diode

Basic Semiconductor Processes

Bipolar

1. T^{2}L
2. ECL
3. I^{2}L
4. Linear ICs
   - Basic Device: BJT (Bipolar Junction Transistor)
   - Niche Devices: HBJT (Heterojunction Bipolar Transistor)
     HBT
   - Other Devices: Diode
     Resistor
     Capacitor
     Schottky Diode
     JFET (Junction Field Effect Transistor)

Basic Semiconductor Processes

Other Processes

- Thin and Thick Film Processes
  - Basic Device: Resistor
- BiMOS or BiCMOS
  - Combines both MOS & Bipolar Processes
  - Basic Devices: MOSFET & BJT
- SiGe
  - BJT with HBT implementation
- SiGe / MOS
  - Combines HBT & MOSFET technology
- SOI / SOS (Silicon on Insulator / Silicon on Sapphire)
- Twin-Well & Twin Tub CMOS
  - Very similar to basic CMOS but more optimal transistor char.

Summary of Devices by Processes

- Standard CMOS Process
  - MOS Transistors
    - n-channel
    - p-channel
  - Capacitors
  - Resistors
  - Diodes
  - BJT (in some processes)
    - npn
    - pnp
  - JFET (in some processes)
    - n-channel
    - p-channel
- Standard Bipolar Process
  - BJT
    - npn
    - pnp
  - JFET
    - n-channel
    - p-channel
  - Diodes
  - Resistors
  - Capacitors

- Niche Devices
  - Photodetectors (photodiodes, phototransistors, photoresistors)
  - MESFET
  - HBT
  - Schottky Diode (not Shockley)
  - MEM Devices
  - ….

Basic Devices

- Devices in Standard Processes
  - MOS Transistors
    - n-channel
    - p-channel
  - Capacitors
  - Resistors
  - Diodes
  - BJT (in some processes)
    - npn
    - pnp
- Niche Devices
  - Photodetectors
  - MESFET
  - Schottky Diode (not Shockley)
  - MEM Devices
  - ….

Primary Consideration in This Course

Limited Consideration in This Course

Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT

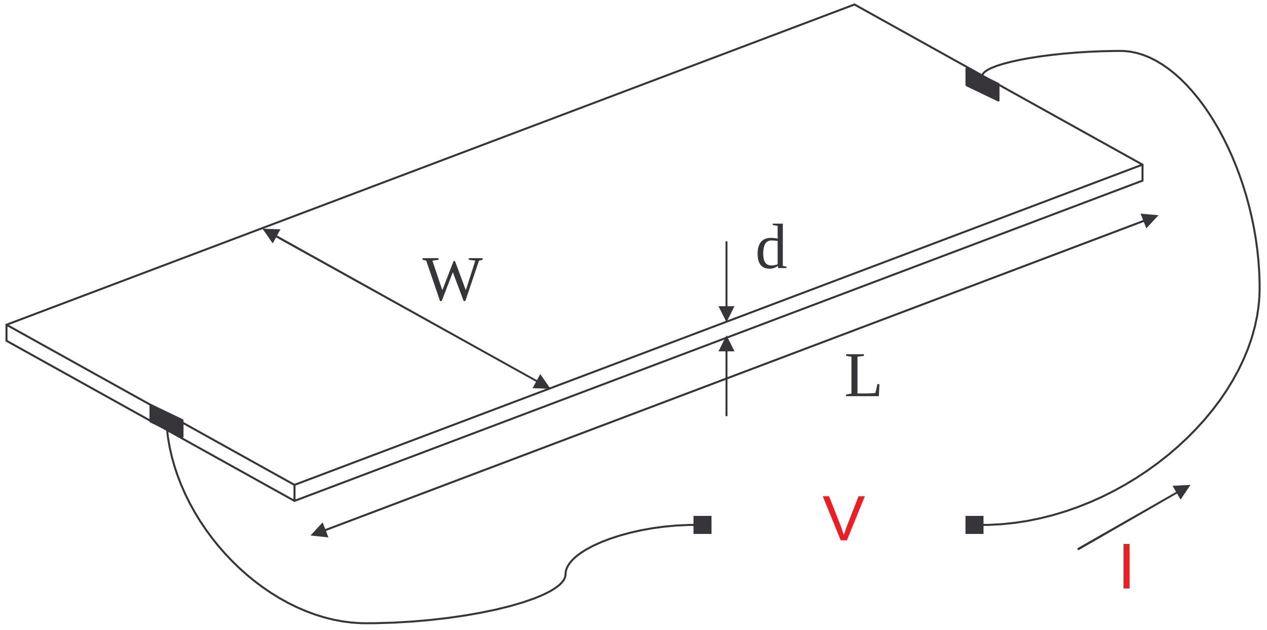
Basic Devices and Device Models

- ➡ Resistor
- Diode
- Capacitor
- MOSFET
- BJT

Resistors

- Generally thin-film devices
- Almost any thin-film layer can be used as a resistor
  - Diffused resistors
  - Poly Resistors
  - Metal Resistors
  - “Thin-film” adders (SiCr or NiCr)
- Subject to process variations, gradient effects and local random variations
- Often temperature and voltage dependent
  - Ambient temperature
  - Local Heating
- Nonlinearities often a cause of distortion when used in circuits
- Trimming possible resistors
  - Laser,links,switches

Resistor Model

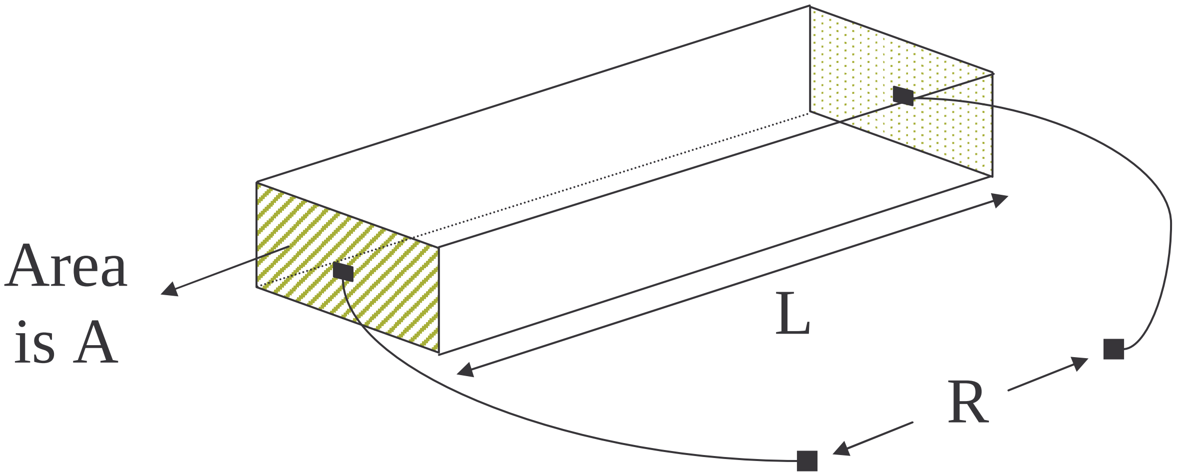


Model:

$$\mathbf{R} = \frac{\mathbf{V}}{\mathbf{I}}$$

Resistivity

- Volumetric measure of conduction capability of a material

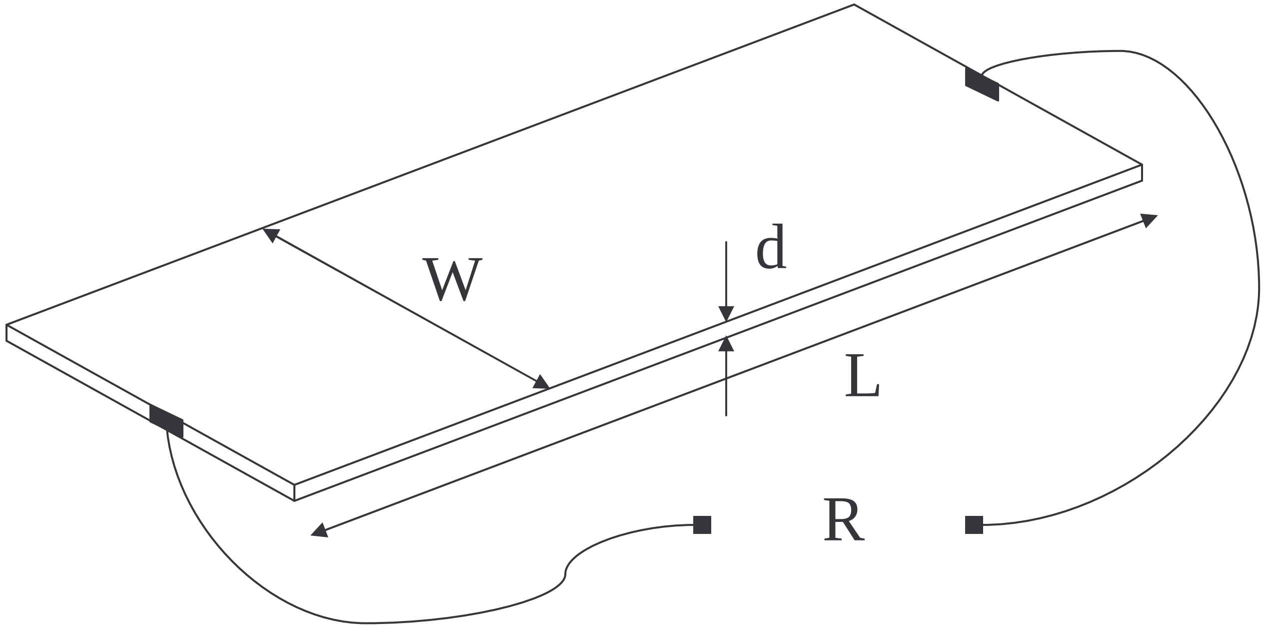


$$\rho = \frac{AR}{L}$$

units : ohm cm

for homogeneous material,
ρ ⊥ A, R, L

Sheet Resistance



$$R_{\square} = \frac{RW}{L}$$ (for d << w, d << L) units : ohms / □

for homogeneous materials, $R_{\square}$ is independent of W, L, R

Relationship between ρ and $R_{\square}$

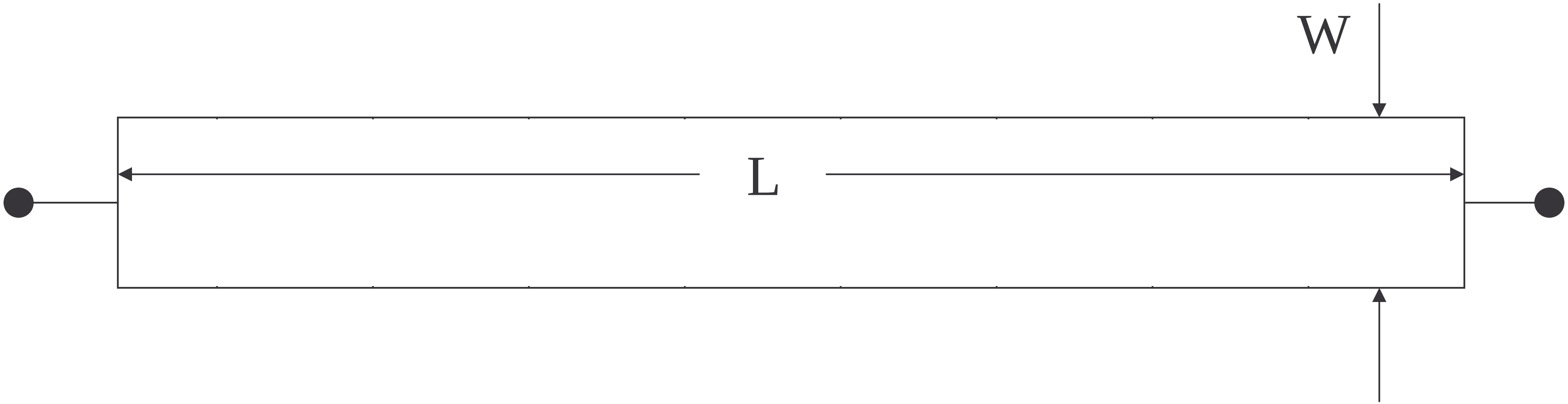
$$\left.\begin{array}{l} R_{\square} = \dfrac{RW}{L} \\[2ex] \rho = \dfrac{AR}{L} \end{array}\right\} \Longrightarrow \begin{array}{l} \rho = \dfrac{A}{W} R_{\square} \\[2ex] A = W \times d \end{array}$$

$$\rho = \frac{A}{W} R_{\square} = \frac{\cancel{W}\, d}{\cancel{W}} R_{\square} = d \times R_{\square}$$

Number of squares, N_S, often used instead of L / W in determining resistance of film resistors

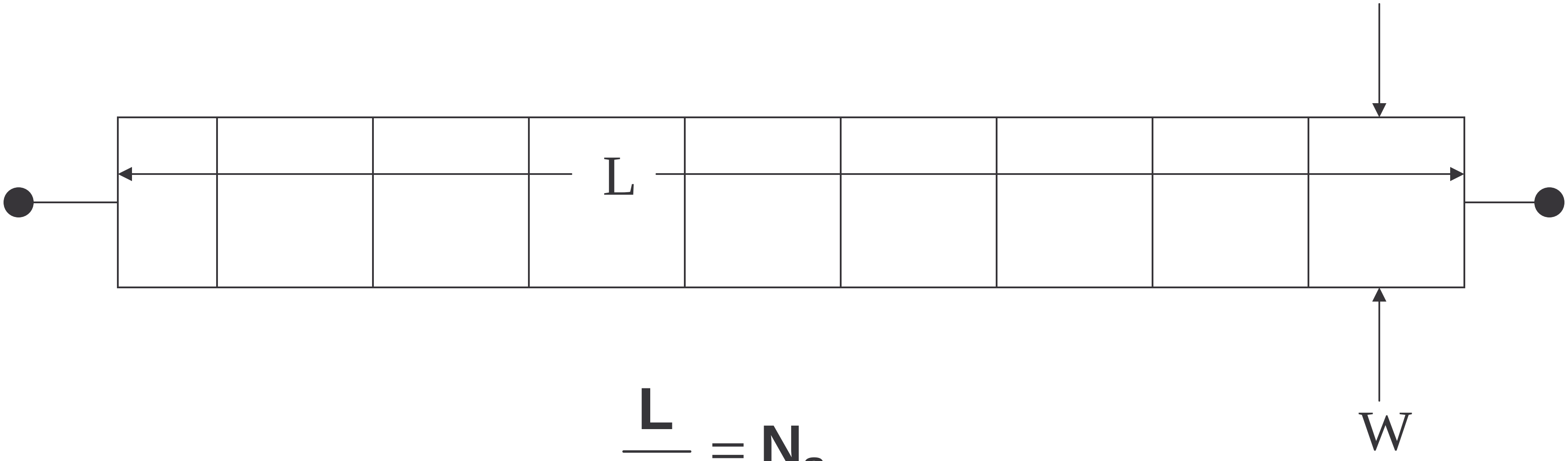
$$R = R_{\square} N_S$$

Example 1



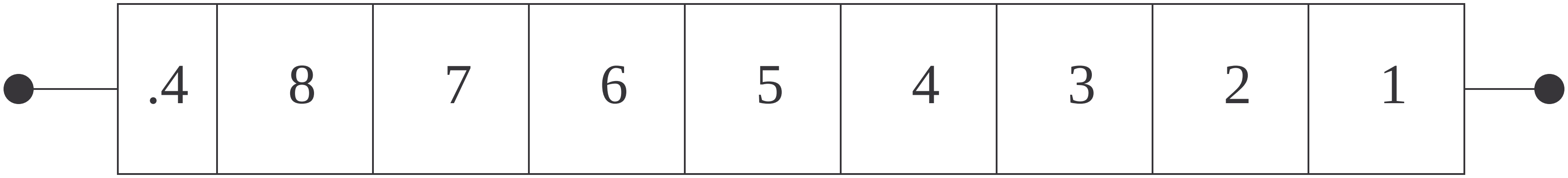
R = ?

Example 1



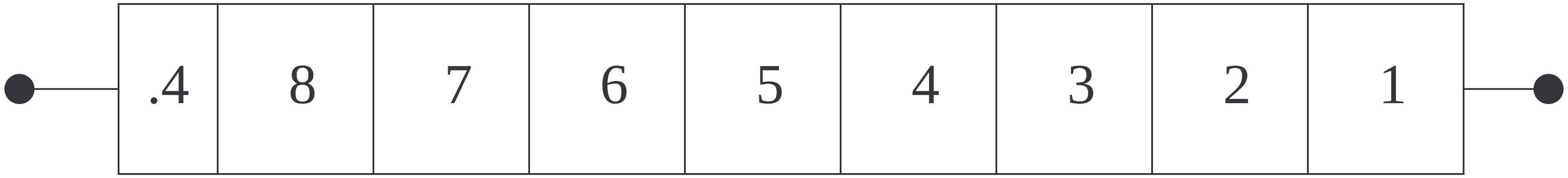
$$\frac{L}{W} = N_S$$

Example 1



R = ?

Example 1

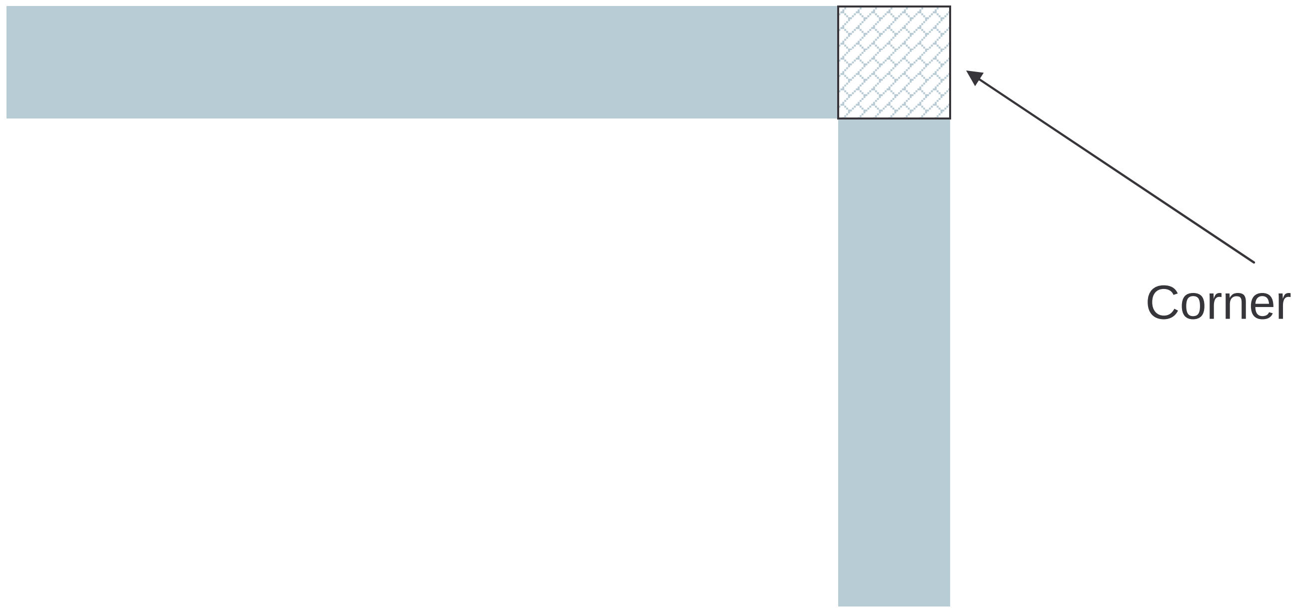


R = ?

N_S=8.4

R = $R_{▯}$ (8.4)

Corners in Film Resistors

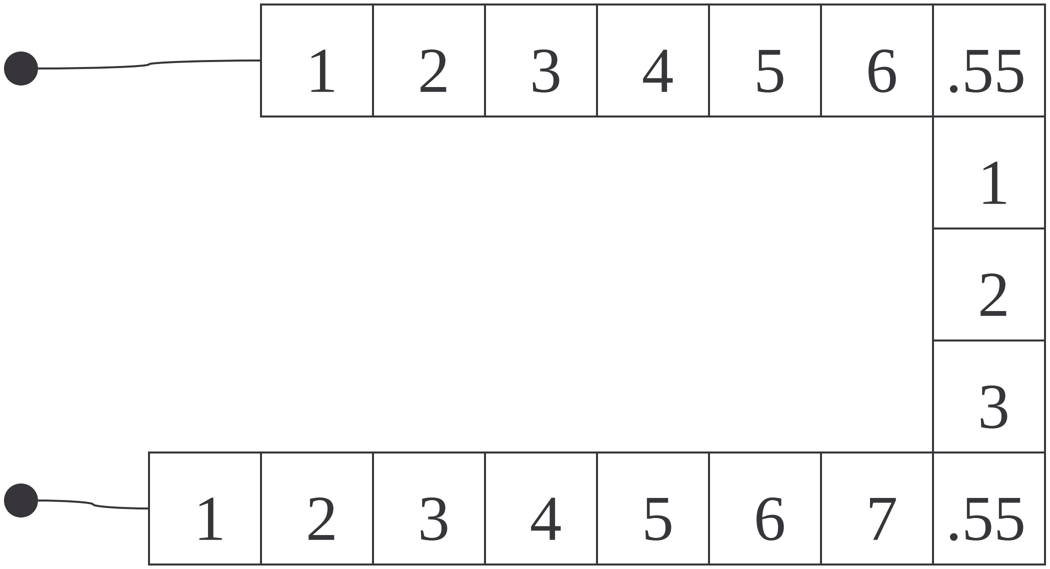


Rule of Thumb: .55 squares for each corner

Example 2

Determine R if $R_{\square} = 100\ \Omega / \square$

Example 2



$N_S = 17.1$

$R = (17.1)\, R_{\square}$

$R = 1710\ \Omega$

Resistivity of Materials used in Semiconductor Processing

- Cu: 1.7*E*-6 Ωcm
- Al: 2.7*E*-4 Ωcm
- Gold: 2.4*E*-6 Ωcm
- Platinum: 3.0*E*-6 Ωcm
- n-Si: .25 to 5 Ωcm
- intrinsic Si: 2.5*E5* Ωcm
- SiO_2: *E*14 Ωcm

Temperature Coefficients

Used for indicating temperature sensitivity of resistors & capacitors

For a resistor:

$$\mathrm{TCR} = \left(\frac{1}{\mathrm{R}}\frac{d\mathrm{R}}{d\mathrm{T}}\right)\Bigg|_{\mathrm{op.\,temp}}^{10^6} \qquad \mathrm{ppm}/{}^\circ\mathrm{C}$$

This diff eqn can easily be solved if TCR is a constant

$$\mathrm{R}(\mathrm{T}_2) = \mathrm{R}(\mathrm{T}_1)\, e^{\frac{\mathrm{T}_2-\mathrm{T}_1}{10^6}\mathrm{TCR}}$$

$$\boxed{\mathrm{R}(\mathrm{T}_2) \approx \mathrm{R}(\mathrm{T}_1)\left[1+(\mathrm{T}_2-\mathrm{T}_1)\frac{\mathrm{TCR}}{10^6}\right]}$$

Identical Expressions for Capacitors

Voltage Coefficients

Used for indicating voltage sensitivity of resistors & capacitors

For a resistor:

$$\mathrm{VCR} = \left(\frac{1}{R}\frac{dR}{dV}\right)\Bigg|_{\text{ref voltage}}^{10^6} \qquad \text{ppm/V}$$

This diff eqn can easily be solved if VCR is a constant

$$R(V_2) = R(V_1)\, e^{\frac{V_2 - V_1}{10^6}\mathrm{VCR}}$$

$$\boxed{R(V_2) \approx R(V_1)\left[1 + (V_2 - V_1)\frac{\mathrm{VCR}}{10^6}\right]}$$

Identical Expressions for Capacitors

Temperature and Voltage Coefficients

- Temperature and voltage coefficients often quite large for diffused resistors
- Temperature and voltage coefficients often quite small for poly and metal resistors