EE 434
Lecture 13

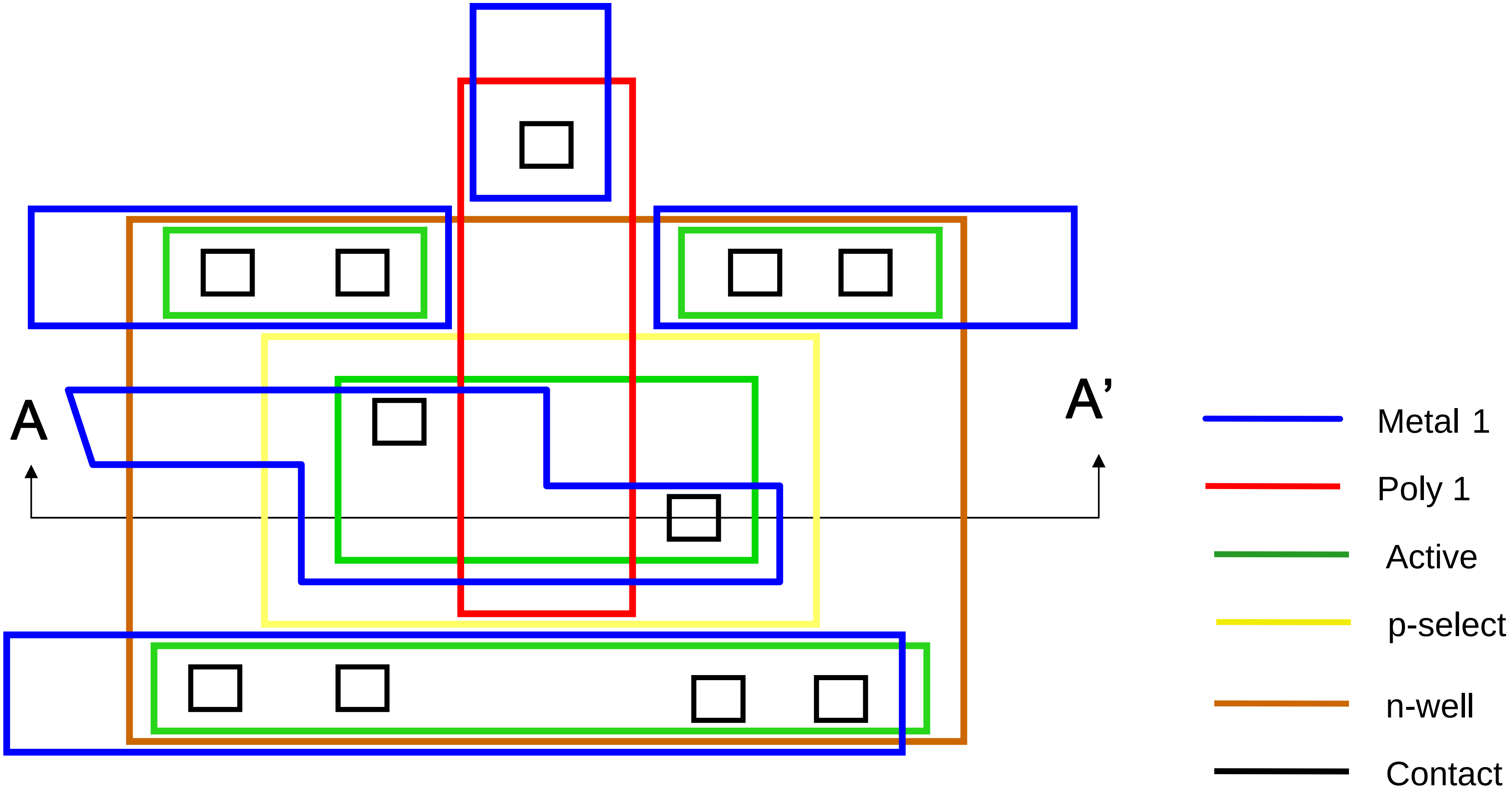
Basic Semiconductor Processes
Devices in Semiconductor Processes

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 ….

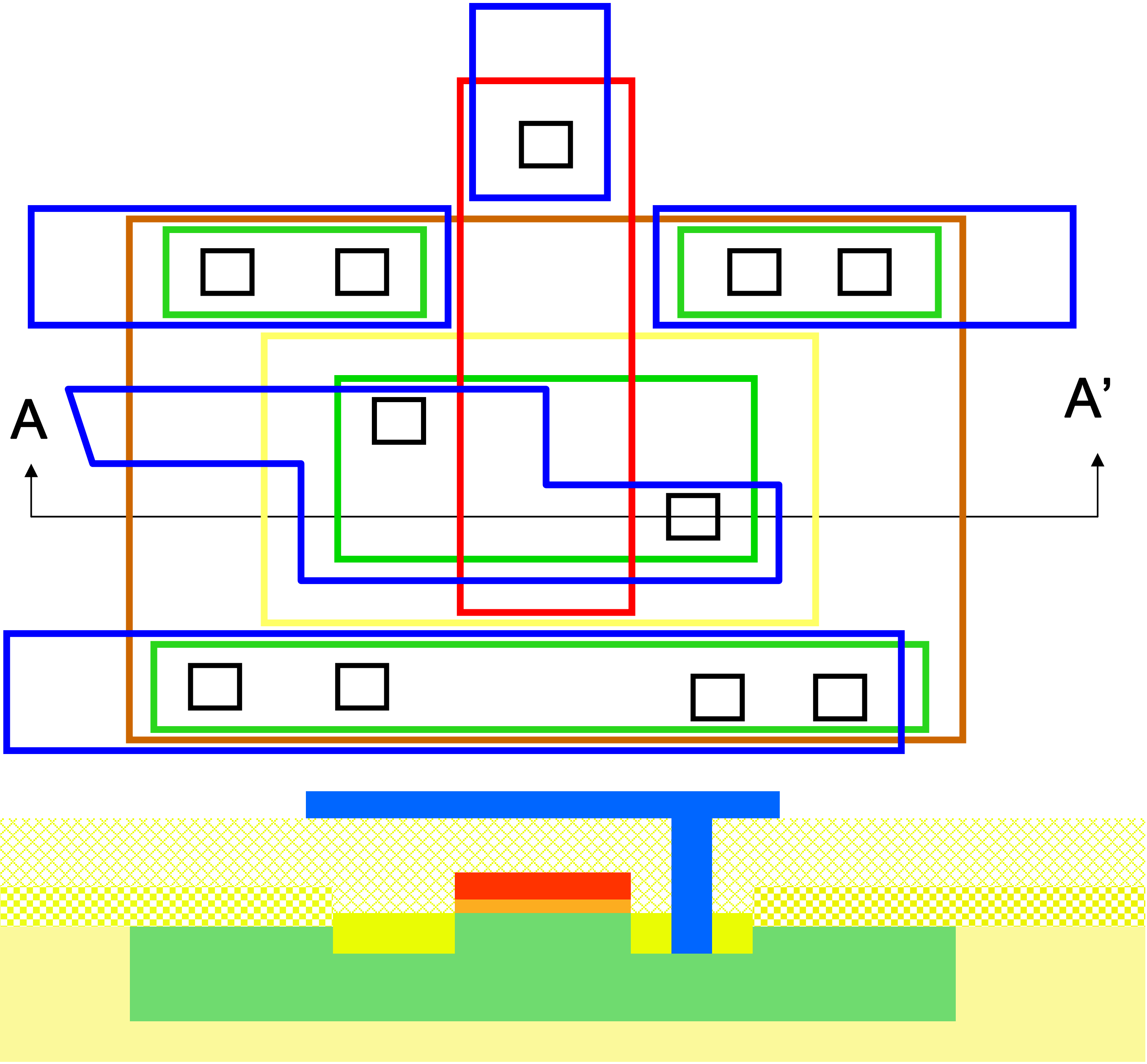
1 8 7 5 3

6 9 4 2

1

Quiz 9 Solution

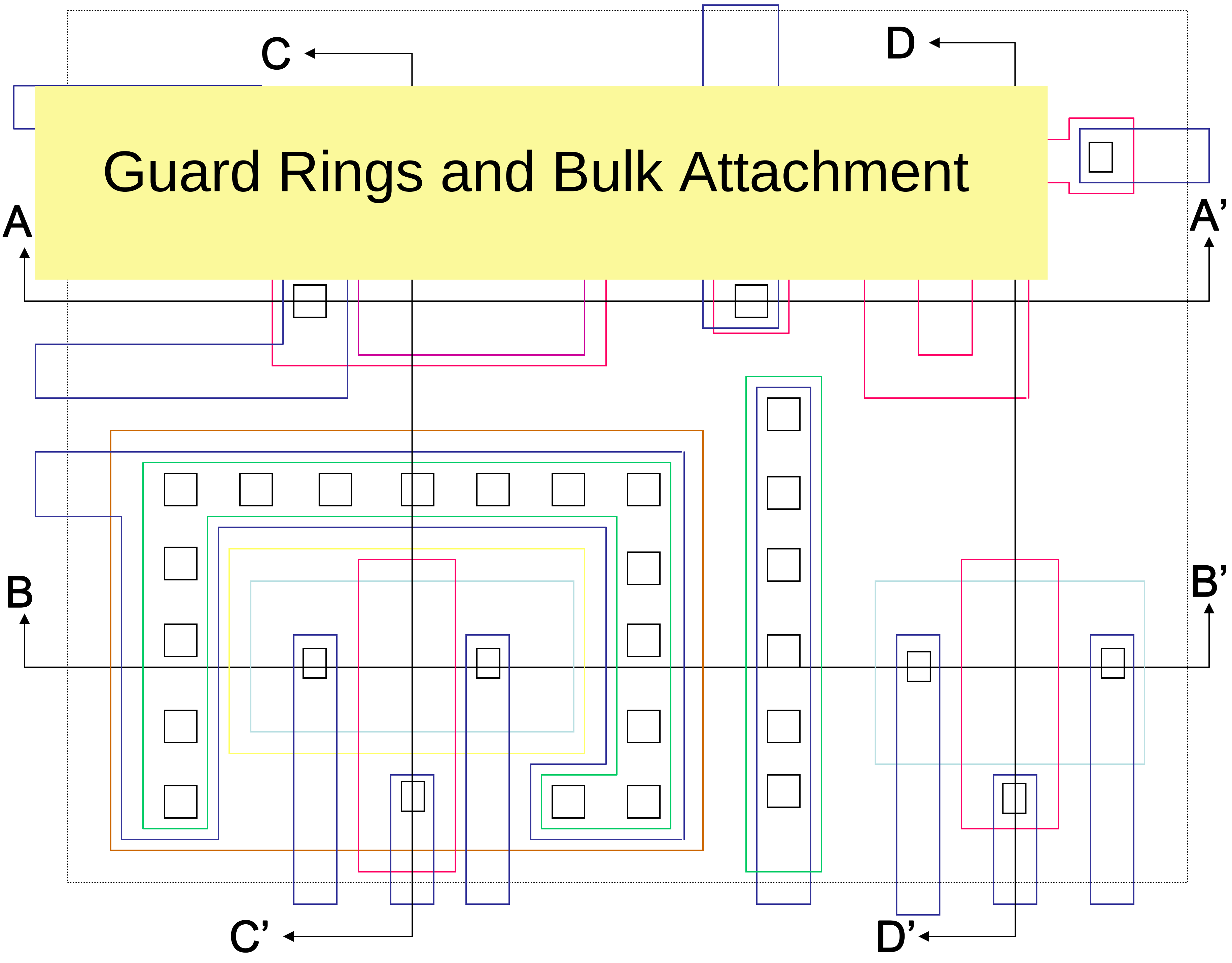
a) p-channel MOS Transistor



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
  - Designer has control only of top view
  - Some masks may be automatically generated
  - Geometric Description File (GDF) contains all information about a layout and serves as interface with foundry

Guard Rings and Bulk Attachment



Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT

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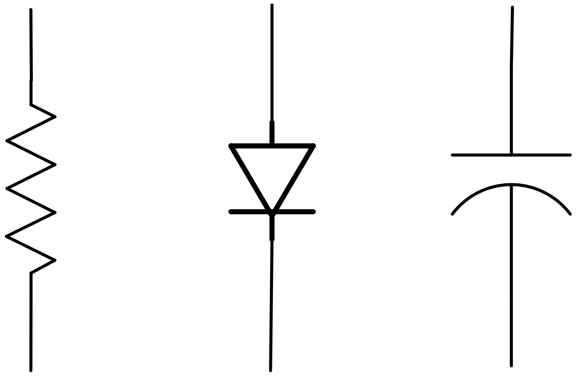
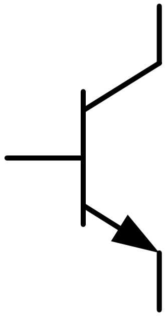
Device Modeling

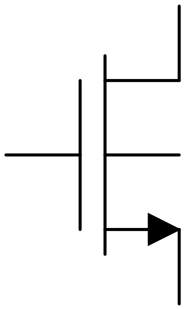
Goal: Obtain a mathematical relationship between the port variables of a device.



2-terminal device



3-terminal device

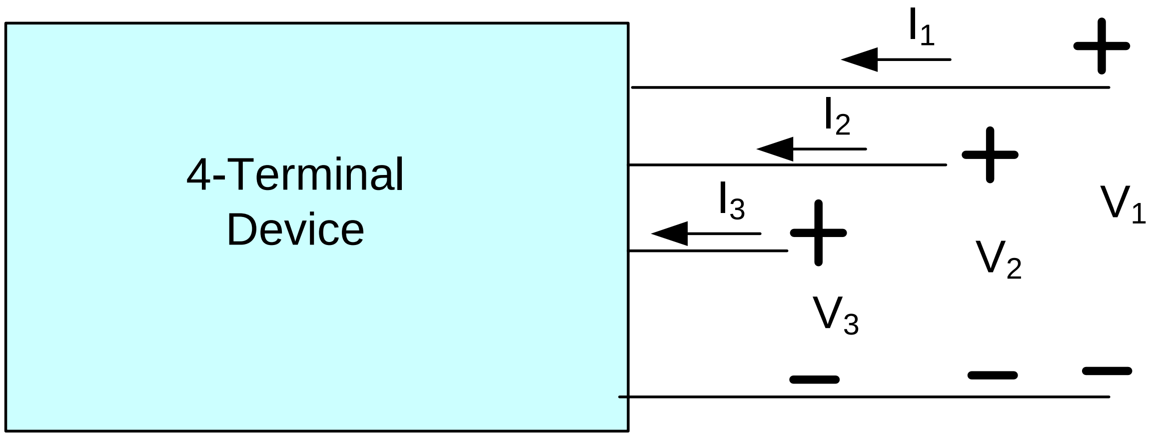


4-terminal device

Device Modeling

Goal: Obtain a mathematical relationship between the port variables of a device.

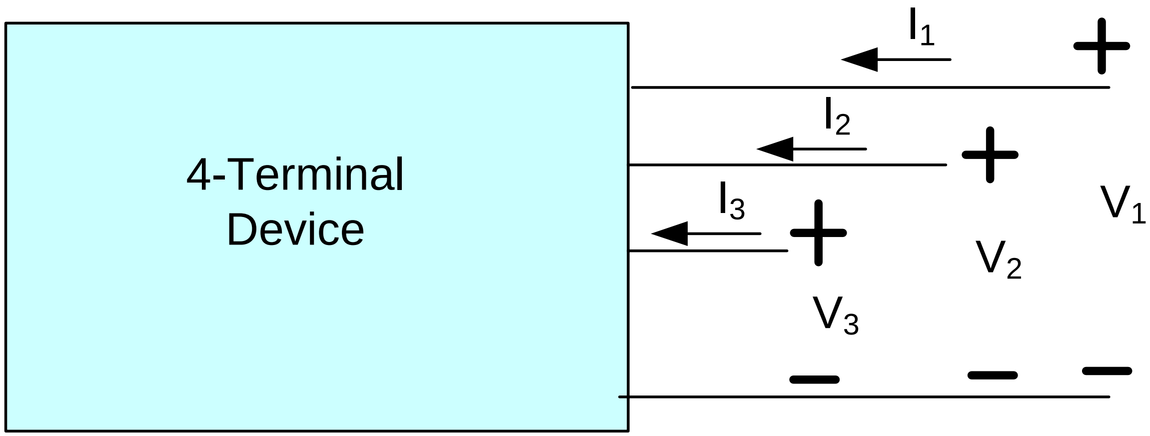
Without loss of generality, one terminal can be selected as a reference
(this can be done in one of 4 ways!)



Thus modeling problem is that of determining mathematical relationship
Between the six variables I_1, I_2, I_3, V_1, V_2, and V_3

Device Modeling

Goal: Obtain a mathematical relationship between the port variables of a device.



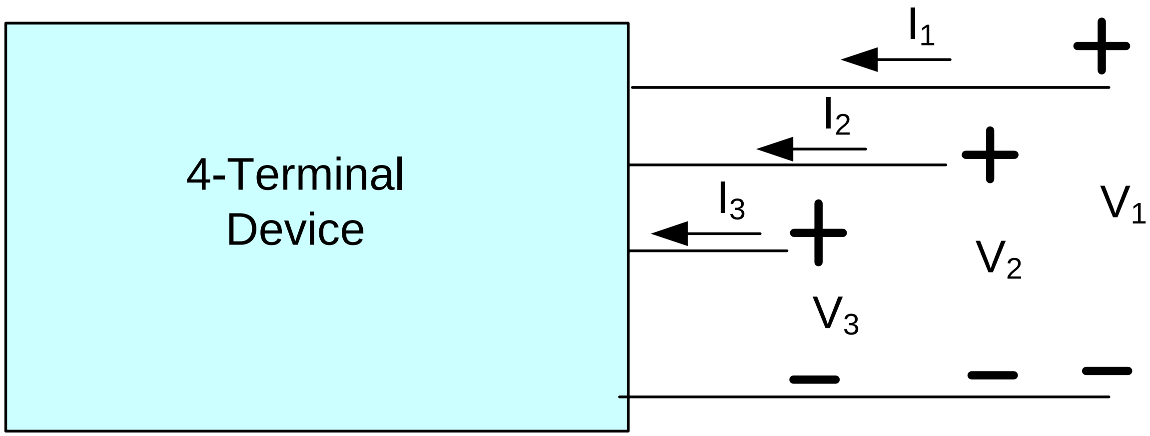
Any 3 of the 6 variables $\{I_1, I_2, I_3, V_1, V_2, V_3\}$ can be selected as independent variables and the remaining 3 variables can be selected as dependent variables

There are $\binom{6}{3} = \frac{6!}{3!3!} = 20$ ways this can be done

Thus there are 4x20=80 different mathematical representations of a 4-terminal device and all predict identical performance !

Device Modeling

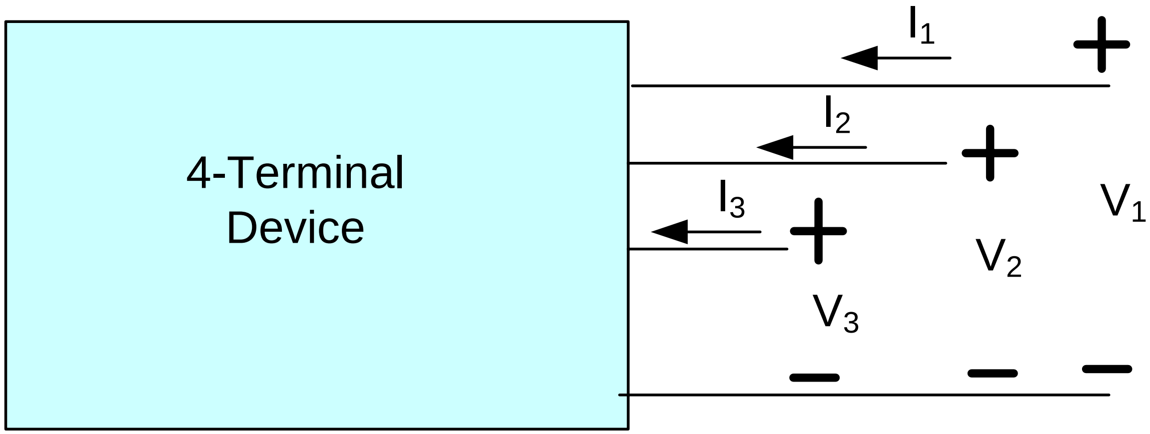
Goal: Obtain a mathematical relationship between the port variables of a device.



By convention, will pick $\{V_1, V_2, V_3\}$ as the independent variables and $\{I_1, I_2, I_3\}$ as the dependent variables

Device Modeling

Goal: Obtain a mathematical relationship between the port variables of a device.

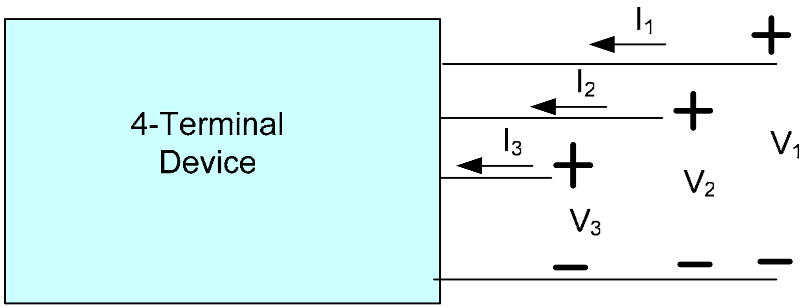


Modeling Goal: Obtain f_1, f_2, and f_3 that sufficiently accurately characterize the device

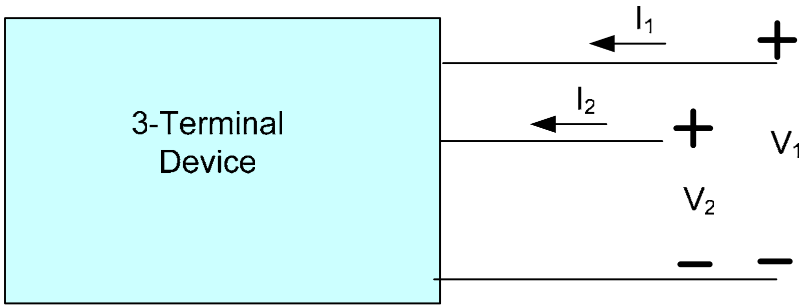
$$\left.\begin{array}{l} \mathbf{I_1 = f_1(V_1, V_2, V_3)} \\ \mathbf{I_1 = f_1(V_1, V_2, V_3)} \\ \mathbf{I_1 = f_1(V_1, V_2, V_3)} \end{array}\right\}$$

Device Modeling

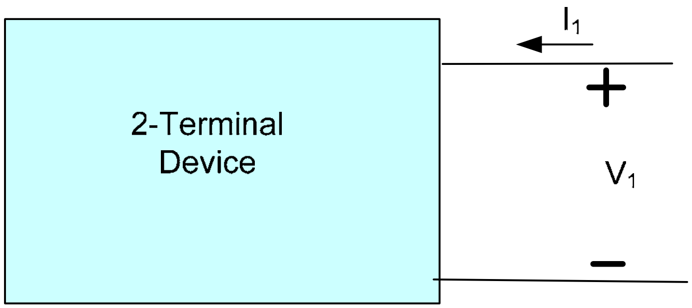
Goal: Obtain a mathematical relationship between the port variables of a device.



$$\left.\begin{aligned} I_1 &= f_1(V_1, V_2, V_3) \\ I_2 &= f_2(V_1, V_2, V_3) \\ I_3 &= f_3(V_1, V_2, V_3) \end{aligned}\right\}$$



$$\left.\begin{aligned} I_1 &= f_1(V_1, V_2) \\ I_2 &= f_2(V_1, V_2) \end{aligned}\right\}$$

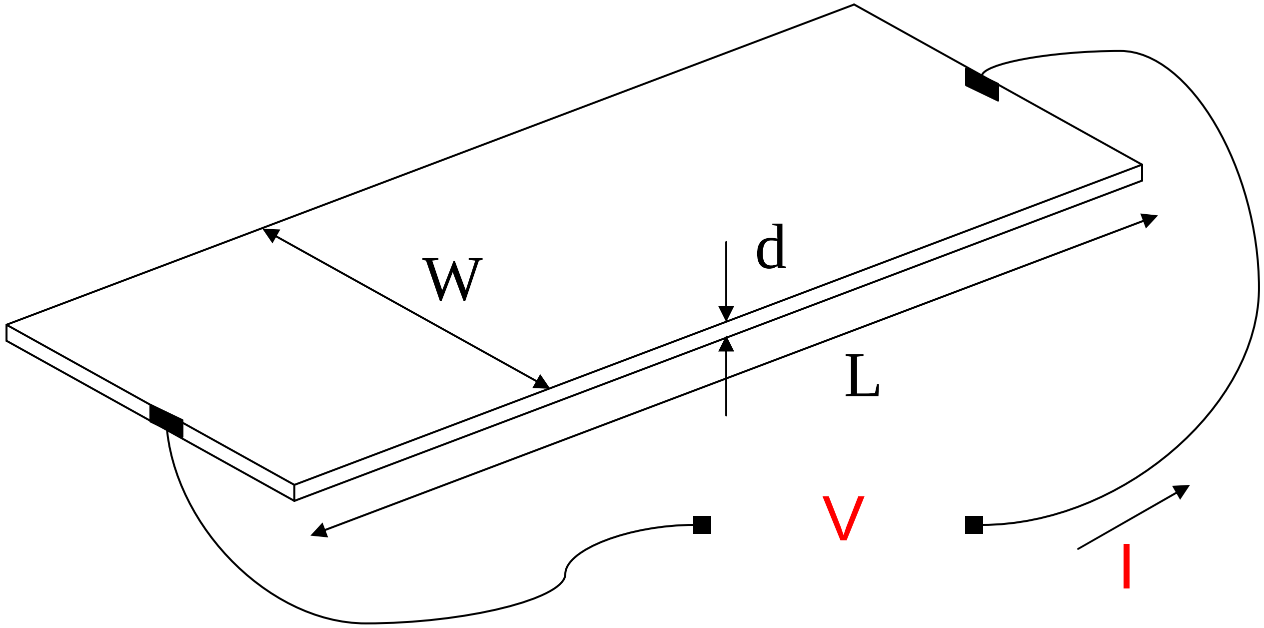


$$\left. I_1 = f_1(V_1) \right\}$$

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

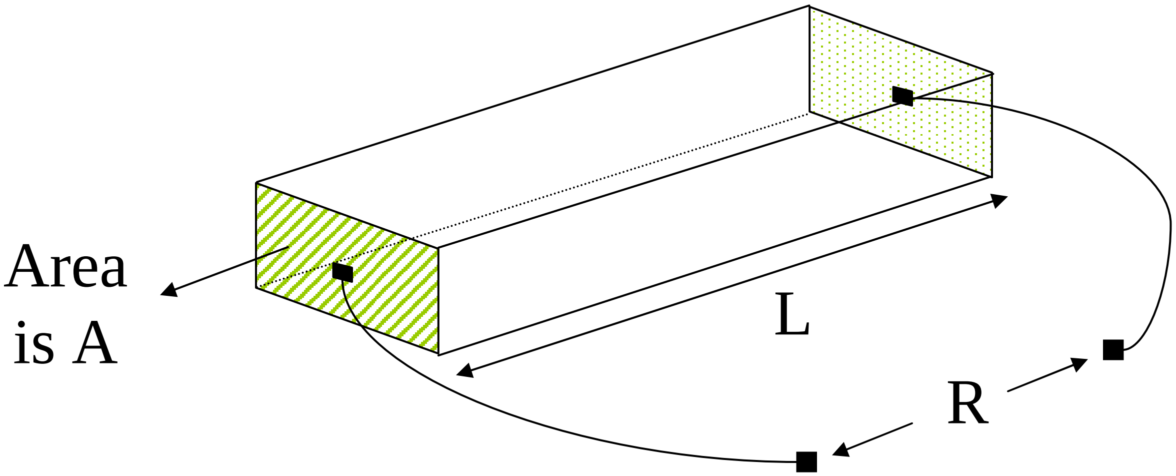


Model:

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

Resistivity

- Volumetric measure of conduction capability of a material

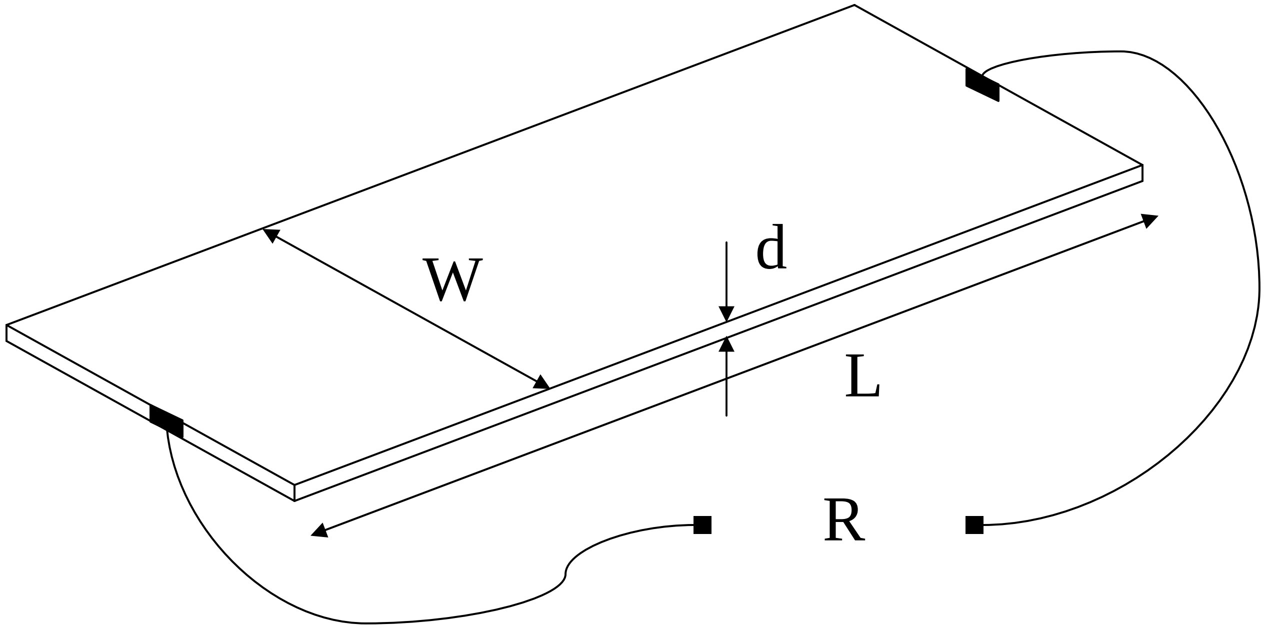


$$\rho = \frac{AR}{L}$$

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   is independent of W, L, R

Relationship between ρ and R

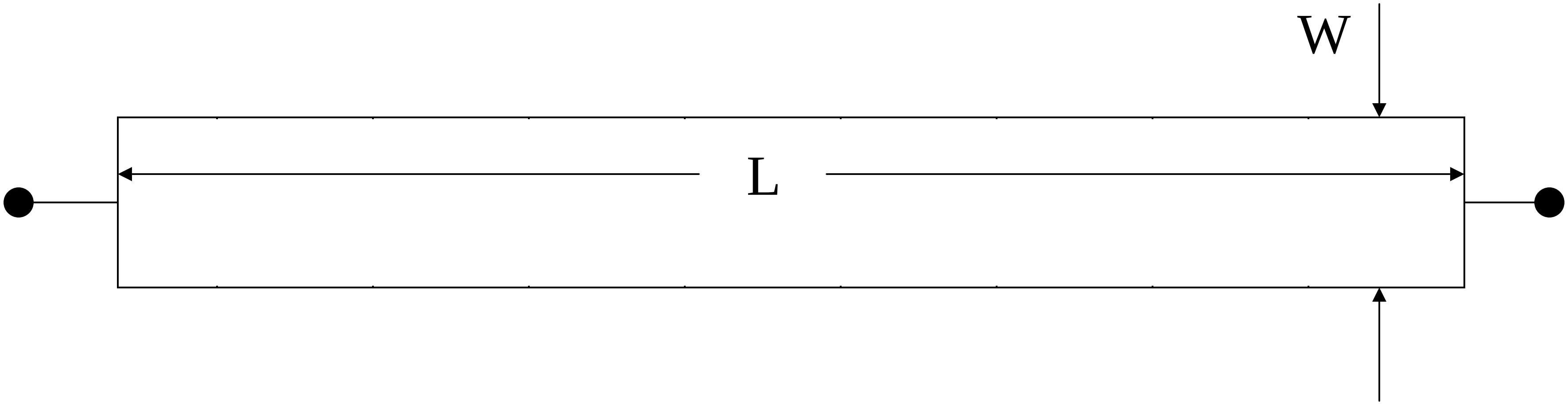
$$\left.\begin{aligned} R_\square &= \frac{RW}{L} \\[2em] \rho &= \frac{AR}{L} \end{aligned}\right\} \Longrightarrow \begin{aligned} \rho &= \frac{A}{W} R_\square \\ A &= W \times d \end{aligned}$$

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

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

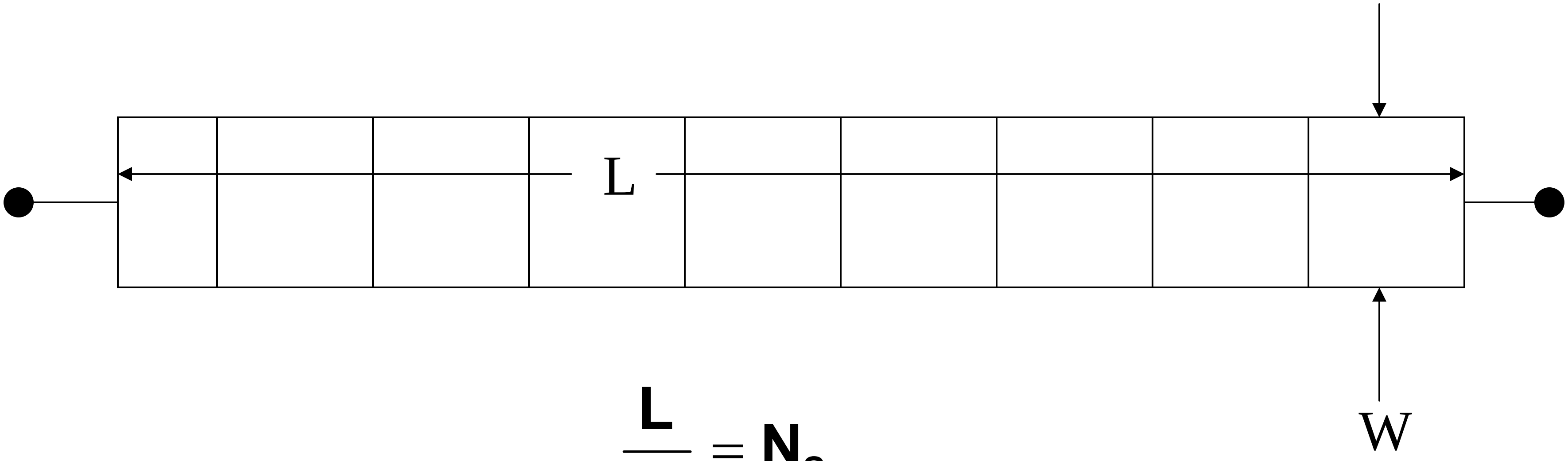
$$R = R_\square N_S$$

Example 1



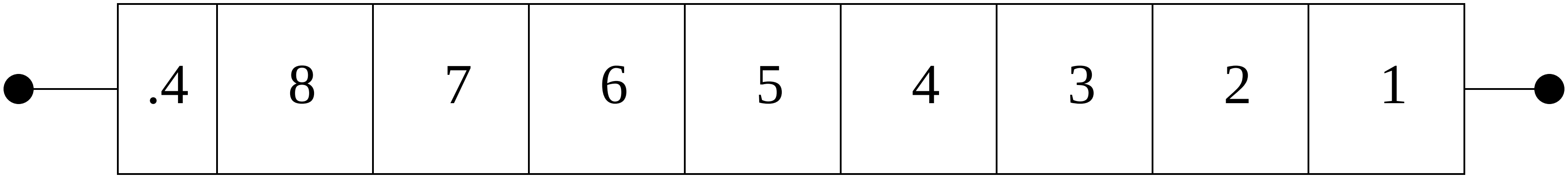
R = ?

Example 1



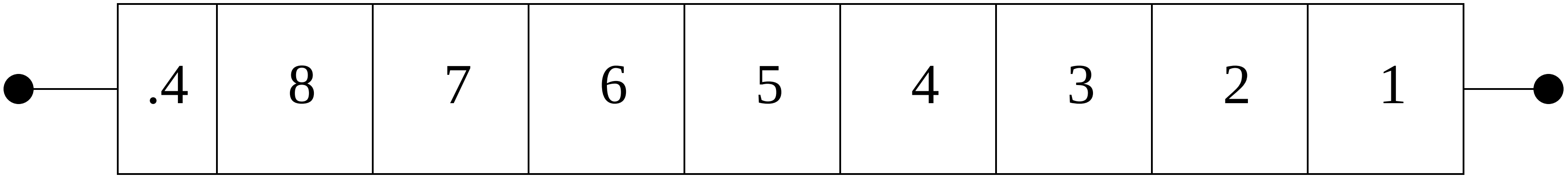
$$\frac{L}{W} = N_S$$

Example 1



R = ?

Example 1

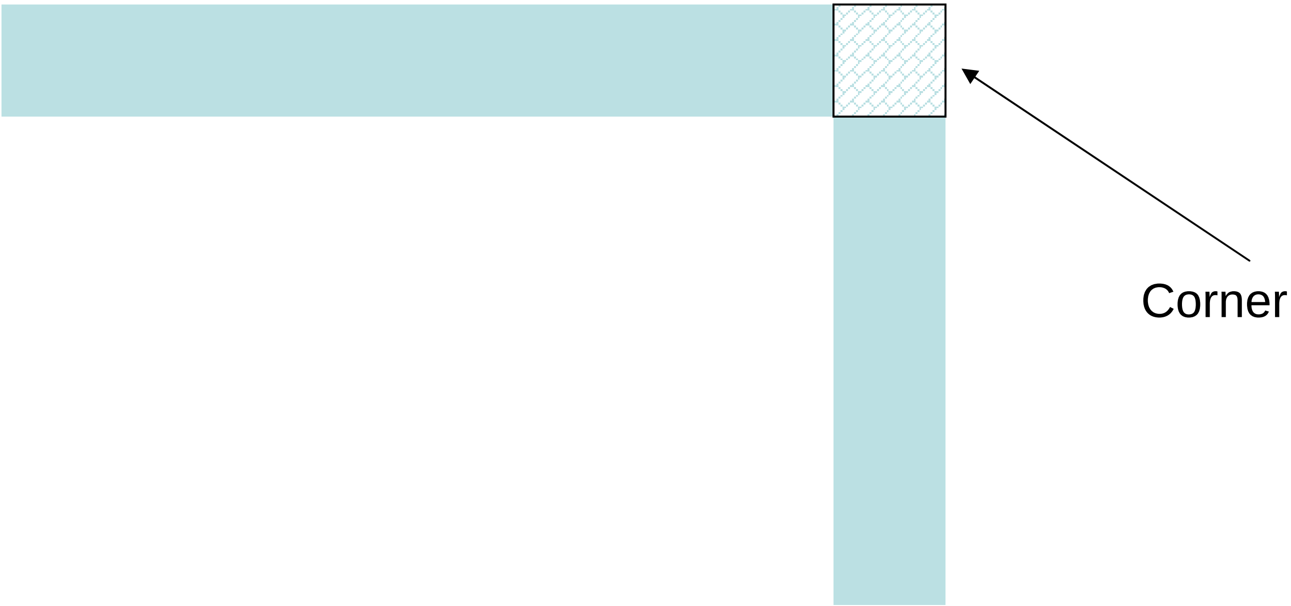


$R = ?$

$N_S = 8.4$

$\mathbf{R = R_{\square}\ (8.4)}$

Corners in Film Resistors

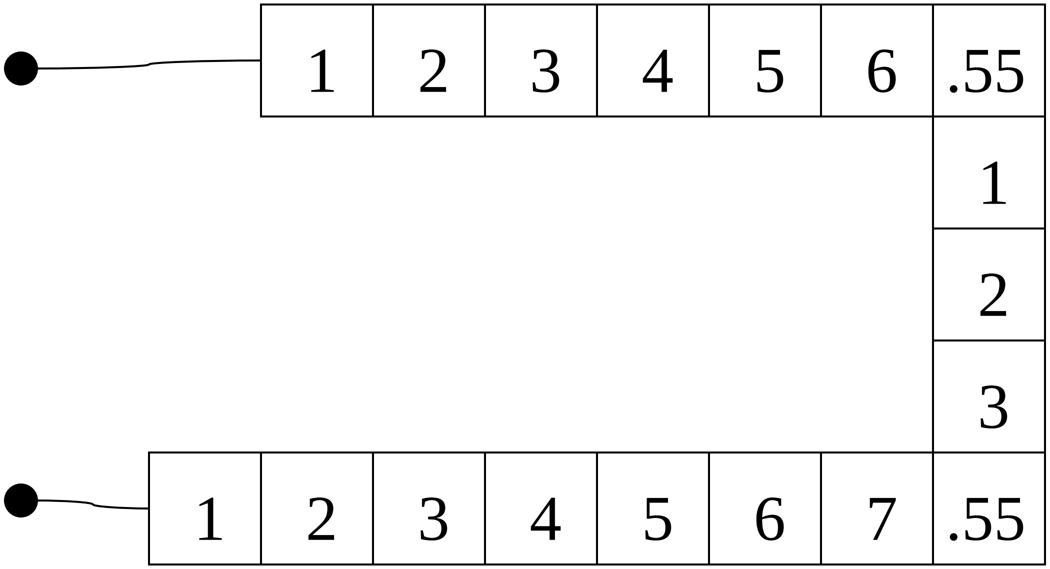


Rule of Thumb: .55 squares for each corner

Example 2

Determine R if R = 100 Ω /

Example 2



N_S=17.1

R = (17.1) R

R = 1710 Ω

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:

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

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:

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

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

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

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

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

End of Lecture 13