**INTERCONNECT**

**RESISTANCE**

\[ R = \frac{P \cdot l}{t \cdot w} \]

WHERE

- \( P \) is resistivity in \( \text{m} \cdot \Omega \cdot \text{cm} \)

COPPER \( P = 1.7 \ \mu \Omega \cdot \text{cm} \)

GOLD \( P = 2.2 \)

ALUMINUM \( P = 2.8 \)

TUNGSTEN \( P = 5.3 \)

**DEFINE**

\[ R_0 = \frac{P}{t} \quad \text{units} \ \Omega \]

**IF**

\[ R_0 = 10 \ \Omega \]

**THEN** \( R = 30 \ \Omega \)
### SHEET RESISTANCES

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistance Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion (Unsilicided)</td>
<td>50 - 200 Ω</td>
</tr>
<tr>
<td>Polysilicon (Unsilicided)</td>
<td>50 - 400 Ω</td>
</tr>
<tr>
<td>Diffusion (Silicided)</td>
<td>3 - 10 Ω</td>
</tr>
<tr>
<td>Polysilicon (Silicided)</td>
<td>3 - 10 Ω</td>
</tr>
<tr>
<td>Metal 1</td>
<td>0.08 Ω</td>
</tr>
<tr>
<td>Metal 2</td>
<td>0.05 Ω</td>
</tr>
<tr>
<td>Metal 6</td>
<td>0.02 Ω</td>
</tr>
</tbody>
</table>

### CAPACITANCE

#### Classical Parallel Plate (Ignores Fringing Effect)

\[
C = \varepsilon_0 \varepsilon_l \frac{w l}{h}
\]

\[
\varepsilon_0 = 3.9 \varepsilon_l
\]

For SiO₂, \( \varepsilon_l = 10\varepsilon_0 \)

\[
\varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m}
\]

\[
\varepsilon_l = 8.854 \times 10^{-3} \text{ F/mm}
\]

\[
\frac{1}{C} = \frac{h}{w l}
\]

Good for large \( w + l \) compared to \( h \)

\( \text{i.e., } h \ll w + h \ll l \)
INCLUDING FRINGING EFFECT

\[ C = E_0 x l \left[ \frac{w}{h} + 0.77 + 1.06 \left( \frac{w}{h} \right)^{0.25} + 1.06 \left( \frac{t}{h} \right)^{0.5} \right] \]

ACCURATE WITHIN 6°70° FOR

\[ \frac{w}{h} > 0.3 \quad \text{and} \quad \frac{t}{h} < 10 \]

(EMPIRICALLY FOUND)
**EXAMPLE**

**METAL 1**

\[ w = 250 \text{ mm} \quad t = 480 \text{ mm} \]

\[ h = 800 \text{ mm} \]

\[ C = E_0 \times \left[ 0.3125 + 0.77 + 0.7925 + 0.8211 \right] \]

\[ = E_0 \times \left[ 0.3125 + 2.384 \right] \]

\[ = 0.094 \text{ F/F/mm} \]

*Fringe is \( 8 \times \) that of parallel plate cap*
EXAMPLE METAL 6

\[ w = 860 \text{ mm} \quad t = 1720 \text{ mm} \]

\[ h = 9380 \text{ mm} \]

\[ w = 860 \text{ mm} \quad t = 1720 \text{ mm} \]

Here \( \frac{w}{h} \leq 0.3 \)

So perhaps 20\% ACCURATE

\[ C_{m6} = E_{0x} \left[ 0.092 + 0.77 + 0.5833 + 0.4539 \right] \]

\[ = E_{0x} \left[ 0.092 + 1.81 \right] \]

\[ = 0.066 \text{ fF/mm} \] CAPACITANCE PER UNIT LENGTH

FRINCE IS 20\% THAT OF PARALLEL PLATE CAP
WIRE IS DISTRIBUTED RC

\[ R = \frac{M}{I_C} \]

Given \( R_W \) and \( C_W \)

\[ [\Omega/\text{mm}] \quad [\text{F/\text{mm}}] \]

\[ R = R_W L \quad C = C_W L \]

WHERE \( L \) IS WIRE LENGTH

BREAK INTO \( n \) SEGMENTS

\[ \frac{R_{1/n}}{I_{C_{1/n}}} \quad \frac{R_{1/n}}{I_{C_{1/n}}} \quad \frac{R_{1/n}}{I_{C_{1/n}}} \]

FOR LARGE \( n \)
Elmore's Delay

\[ \tau = \frac{C}{N} \left( \frac{R}{N} \right) + \frac{C}{N} \left( \frac{2R}{N} \right) + \frac{C}{N} \left( \frac{3R}{N} \right) + \cdots + \frac{C}{N} \left( \frac{nR}{N} \right) \]

\[ = \left( CR \right) \left( \frac{1}{N^2} \right) \left( 1 + 2 + 3 + \cdots + N \right) \]

\[ = CR \frac{N(N+1)}{2N^2} = CR \frac{N+1}{2N} \]

As \( N \to \infty \)

\[ \tau = \frac{CR}{2} \]

\[ \tau = \frac{(Rw) (Cw l^2)}{2} = \frac{(Rw Cw l^2)}{2} \]

So \( \tau \) increases as square of \( l \)
For small \( N \), use \( \frac{R}{N} \) model.

\[ \frac{R}{N} \quad \Leftrightarrow \quad \frac{R}{N} \]

Can often use only 3 lumped segments to simulate an RC.

Example: Consider 5mm long wire.

320 mm wide where \( R_0 = 0.05 \Omega \)

\( + \) \( C_w = 0.2 \text{ fF/mm, construct} \)

3 segment \( \frac{R}{N} \) model for wire.

\[ R = R_0 \left( \frac{L}{W} \right) = (0.05) \left( \frac{5000}{0.32} \right) = 781 \Omega \]

\[ C = C_w L = (0.2) (5000) = 1000 \text{ fF} \]

\[ \begin{array}{c}
\frac{260}{167+} \quad \frac{260}{333+} \quad \frac{260}{333+} \quad \frac{260}{167+}
\end{array} \]
Compare Earmore delay of 3 segments to $\frac{RC}{2}$.

\[ t_1 = \frac{RC}{2} = \frac{(781)(1000)}{2} = 390 \text{ ps} \]

\[ t_2 = (333)(260) + (333)(520) + (162)(781) = 390 \text{ ps} \]
CROSS TALK

DELAY

\[ A \rightarrow \begin{array}{c}
C_{AB} \\
C_A
\end{array} \rightarrow B \rightarrow Q = CV \]

\[ \begin{array}{c}
C_B \\
\end{array} \]

CONSIDER "A" SWITCHING

1) IF "B" HEED CONSTANT

LOAD ON "A" IS \( C_A + C_{AB} \)

\( \Delta Q_{AB} = V_{DB} \)

2) IF "B" SWITCHES SAME DIRECTION AS "A" THEN \( \Delta V_{AB} = 0 \) SO \( \Delta Q_{AB} = 0 \)

LOAD ON "A" IS \( C_A \)
3) If "B" switches opposite direction of "A" then \( \Delta V_{AB} = 2V_{DD} \) and \( \Delta \alpha_{AB} = 2V_{DD} \alpha_{AB} \)

So load on "A" is \( \alpha_{CA} + 2\alpha_{AB} \)

**Example** \( \alpha_{CA} = \alpha_{AB} = 100 \ \text{ff} \)

Shortest delay

\( C_L = \alpha_{CA} = 100 \ \text{ff} \)

Longest delay

\( C_L = \alpha_{CA} + 2\alpha_{AB} = 300 \ \text{ff} \)

3:1 ratio of slowest to fastest.