Design Metrics

DIGITAL GATES
Fundamental Metrics

- Functionality
- Cost
- Reliability, Robustness
- Performance
  » Speed (delay)
  » Power Consumption
  » Energy
Cost of Integrated Circuits

- NRE (Non-recurrent engineering) costs
  - design time and effort, mask generation
  - one-time cost factor
- Recurrent costs
  - silicon processing, packaging, test
  - proportional to volume
  - proportional to chip area

Some Examples (1994)

<table>
<thead>
<tr>
<th>Chip</th>
<th>Metal layers</th>
<th>Metal width</th>
<th>Wafer Cost</th>
<th>Defect/cm²</th>
<th>Area/mm²</th>
<th>Dies/ wafer</th>
<th>Yield %</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>386DX</td>
<td>2</td>
<td>0.90</td>
<td>$900</td>
<td>1.0</td>
<td>43</td>
<td>360</td>
<td>71%</td>
<td>$4</td>
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<tr>
<td>486DX2</td>
<td>3</td>
<td>0.80</td>
<td>$1200</td>
<td>1.0</td>
<td>81</td>
<td>181</td>
<td>54%</td>
<td>$12</td>
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<tr>
<td>PowerPC 601</td>
<td>4</td>
<td>0.80</td>
<td>$1700</td>
<td>1.3</td>
<td>121</td>
<td>115</td>
<td>28%</td>
<td>$53</td>
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<tr>
<td>HP PA 7100</td>
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<td>$1300</td>
<td>1.0</td>
<td>196</td>
<td>66</td>
<td>27%</td>
<td>$73</td>
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<tr>
<td>DEC Alpha</td>
<td>3</td>
<td>0.70</td>
<td>$1500</td>
<td>1.2</td>
<td>234</td>
<td>53</td>
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<td>$149</td>
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<td>SuperSPARC</td>
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<td>0.70</td>
<td>$1700</td>
<td>1.6</td>
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<td>48</td>
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<td>$272</td>
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<tr>
<td>Pentium</td>
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<td>0.80</td>
<td>$1500</td>
<td>1.5</td>
<td>296</td>
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Reliability
Noise in Digital Integrated Circuits

(a) Inductive coupling  (b) Capacitive coupling  (c) Power and ground noise

DC Operation
Voltage Transfer Characteristic
Mapping between analog and digital signals

Definition of Noise Margins
Noise Budget

- Allocates gross noise margin to expected sources of noise
- Sources: supply noise, cross talk, interference, offset
- Differentiate between fixed and proportional noise sources

Impedance - Another Key Reliability Property

- Absolute noise margin values are deceptive
  - a floating node is more easily disturbed than a node driven by a low impedance (in terms of voltage)
- Noise immunity is the more important metric
- Key metrics: Output impedance of the driver and input impedance of the receiver
The Regenerative Property

(a) A chain of inverters.

(b) Regenerative gate

(c) Non-regenerative gate

Fan-in and Fan-out

(a) Fan-out $N$

(b) Fan-in $M$
The Ideal Gate

\[ V_{in} \quad g = -\infty \quad V_{out} \]

\[ R_i = \infty \]
\[ R_o = 0 \]
\[ \text{Fanout} = \infty \]
\[ NM_H = NM_L = V_{DD}/2 \]

VTC of Real Inverter
Delay Definitions

$$V_{in}$$

$$V_{out}$$

$t_{PHL}$

$t_{PLH}$

$V_{in}$

$50\%$

$t_{r}$

$t_{f}$

$50\%$

$10\%$

$90\%$

Ring Oscillator

$T = 2 \times t_p \times N$
Power Dissipation

\[ P_{\text{peak}} = i_{\text{peak}} V_{\text{supply}} = \max(p(t)) \]
\[ P_{\text{av}} = \frac{1}{T} \int_0^T |p(t)| dt = \frac{V_{\text{supply}}}{T} \int_0^T |i_{\text{supply}}(t)| dt \]

**Power-Delay Product**

\[ PDP = t_p \times P_{\text{av}} \]

= Energy dissipated per operation