Power consumption analysis

- Almost all power consumption comes from switching behavior.
- Static power dissipation comes from leakage currents.
- Surprising result: power consumption is independent of the sizes of the pullups and pulldowns.

Power consumption circuit

- Input is square wave.

Power consumption

- A single cycle requires one charge and one discharge of capacitor: \( E = C_L(V_{DD} - V_{SS})^2 \).
- Clock frequency \( f = 1/t \).
- Energy \( E = C_L(V_{DD} - V_{SS})^2 \).
- Power = \( E \times f = f \times C_L(V_{DD} - V_{SS})^2 \).

Observations on power consumption

- Resistance of pullup/pulldown drops out of energy calculation.
- Power consumption depends on operating frequency.
  - Slower-running circuits use less power (but not less energy to perform the same computation).
Speed-power product

- Also known as power-delay product.
- Helps measure quality of a logic family.
- For static CMOS:
  - \( SP = \frac{P}{f} = CV^2 \).
- Static CMOS speed-power product is independent of operating frequency.
  - Voltage scaling depends on this fact.

Parasitics and performance

- \( a \): Capacitance on power supply is not bad, can be good in absence of inductance. Resistance slows down static gates, may cause pseudo-nMOS circuits to fail.

- \( b \): Increasing capacitance/resistance reduces input slope.
- \( c \): Similar to parasitics at \( b \), but resistance near source is more damaging, since it must charge more capacitance.
Driving large loads

- Sometimes, large loads must be driven:
  - off-chip;
  - long wires on-chip.
- Sizing up the driver transistors only pushes back the problem—driver now presents larger capacitance to earlier stage.

Cascaded driver circuit

Optimal sizing

- Use a chain of inverters, each stage has transistors a larger than previous stage.
- Minimize total delay through driver chain:
  - \( t_{\text{tot}} = n(C_{\text{big}}/C_p)^{1/n} t_{\text{min}} \).
- Optimal number of stages:
  - \( n_{\text{opt}} = \ln(C_{\text{big}}/C_p) \).
- Driver sizes are exponentially tapered with size ratio \( \alpha \).