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Pipelining

How would you pipeline?
The path is halved. What would be the issue?
We need to delay wa. What else?
Data Hazard

REGFILE (async read)

Data hazard when wa_p == ra1 or wa_p == ra2.
Data Hazard: Stalling

Stall using CE. MUX to disable next write.
Data Hazard: Forwarding

Forward wd to rd's in parallel with write-back.

REGFILE (async read)
Power

- Dynamic power
  - Switching power
  - Short-circuit power
- Static power
  - Leakage power = Leakage current * Vdd
Discharging Capacitor

Energy dissipated:

\[ \int I V \, dt = \int \frac{dQ}{dt} V \, dt = \int C \frac{dV}{dt} V \, dt = \int CV \, dV = \frac{1}{2} CV_{dd}^2 \]
Charging Capacitor

Energy provided from source:

$$\int IV_{dd} dt = V_{dd} \int \frac{dQ}{dt} dt = V_{dd} \int dQ = CV_{dd}^2$$

One half is charged to capacitor; the other half is dissipated.
Switching Power

If the output flips every cycle, \[ \frac{1}{2} CV_{dd}^2 f \]

If the output flips with the probability \( \alpha \) for each cycle, \[ \frac{1}{2} \alpha CV_{dd}^2 f \]
Tricky Example

Why is this tricky?
Tricky Example

How much energy dissipated?
- when 0 -> (Vdd - Vth)
- when Vdd -> Vth
Tricky Example

Energy provided from source:
\[ \int IV_{dd} dt = V_{dd} \int \frac{dQ}{dt} dt = V_{dd} \int dQ = CV_{dd}(V_{dd} - V_{th}) \]

Energy charged in capacitor:
\[ \frac{1}{2} C(V_{dd} - V_{th})^2 \]

Energy dissipated:
\[ CV_{dd}(V_{dd} - V_{th}) - \frac{1}{2} C(V_{dd} - V_{th})^2 = \frac{1}{2} CV_{dd}^2 - \frac{1}{2} CV_{th}^2 \]
Tricky Example

Energy originally in capacitor:
\[ \frac{1}{2}CV_{dd}^2 \]

Energy remaining in capacitor:
\[ \frac{1}{2}CV_{th}^2 \]

Energy dissipated:
\[ \frac{1}{2}CV_{dd}^2 - \frac{1}{2}CV_{th}^2 \]
Short-Circuit Current

Measure here for $A = 0 \rightarrow 1$