Is Power Consumption Important?

“The internet and wireless services are getting married”, Simon Segars

Motivation

Why should a digital designer care about power consumption?

• **Portable devices:**
  - handhelds, laptops, phones, MP3 players, cameras, … all need to run for extended periods on small batteries without recharging
  - Devices that need regular recharging or large heavy batteries will lose out to those that don’t.

• **Power consumption important even in “tethered” devices.**
  - System cost tracks power consumption:
    • power supplies, distribution, heat removal
    • power conservation, environmental concerns
  - *In a span of 10 years we have gone from designing without concern for power consumption to (in many cases) designing with power consumption as the primary design constraint!*

Outline

• Motivation for design constraints of power consumption
• Power metrics
• Power consumption analysis in CMOS
• How can a logic designer control power?
Battery Technology

- Battery technology has moved very slowly
  - Moore's law does not seem to apply
- Li-Ion and NiMh still the dominate technologies
- Batteries still contribute significant to the weight of mobile devices

Nokia 61xx - 33%
Handspring PDA - 10%
Toshiba Portege 3110 laptop - 20%

Basics

- Power supply provides energy for charging and discharging wires and transistor gates. The energy supplied is stored and dissipated as heat.

\[ P = \frac{dw}{dt} \]

Power: Rate of work being done w.r.t time.
Rate of energy being used.

Units: \( P = \frac{E}{\Delta t} \)
Watts = Joules/seconds

- If a differential amount of charge \( dq \) is given a differential increase in energy \( dw \), the potential of the charge is increased by: \( V = \frac{dw}{dq} \)

- By definition of current: \( I = \frac{dq}{dt} \)

\[ \frac{dw}{dt} = \frac{dW}{dq} \times \frac{dq}{dt} = \frac{P}{V \times I} \]

A very practical formulation!

\[ W = \int P dt \] total energy

If we would like to know total energy

Basics

- Warning! In everyday language, the term “power” is used incorrectly in place of “energy.”
- Power is not energy.
- Power is not something you can run out of.
- Power can not be lost or used up.
- It is not a thing, it is merely a rate.
- It can not be put into a battery any more than velocity can be put in the gas tank of a car.

Metrics

- One popular metric for microprocessors is: MIPS/watt
  - MIPS, millions of instructions per second.
    - Typical modern value?
    - Watt, standard unit of power consumption.
    - Typical value for modern processor?
  - MIPS/watt is reflective of the tradeoff between performance and power. Increasing performance requires increasing power.
  - Problem with “MIPS/watt”
    - MIPS/watt values are typically not independent of MIPS
      - techniques exist to achieve very high MIPS/watt values, but at very low absolute MIPS (used in watches)
    - Metric only relevant for comparing processors with a similar performance.
  - One solution, MIPS²/watt. Puts more weight on performance.
**Metrics**

- How does MIPS/watt relate to energy?
- Average power consumption = energy / time
  
  \[ \text{MIPS/watt} = \frac{\text{instructions/sec}}{\text{joules/sec}} = \text{instructions/joule} \]
  
  - therefore an equivalent metric (reciprocal) is energy per operation (E/op)
  
- E/op is more general - applies to more that processors
  
  - also, usually more relevant, as batteries life is limited by total energy draw.
  
  - This metric gives us a measure to use to compare two alternative implementations of a particular function.

**Power in CMOS**

**Switching Energy:**

Energy used to switch a node

Calculate energy dissipated in pullup:

\[
E_{sw} = \int_0^t P(t)dt = \int_0^t (V_{dd} - v) \cdot i(t) dt = \int_0^t (V_{dd} - v) \cdot c \left( \frac{dv}{dt} \right) dt = \frac{cV_{dd}}{2} \int_0^t dv = cV_{dd}^2 - \frac{1}{2} cV_{dd}^2 = \frac{1}{2} cV_{dd}^2
\]

Energy supplied

Energy stored

Energy dissipated

An equal amount of energy is dissipated on pulldown.

**Switching Power**

- Gate power consumption:
  
  Assume a gate output is switching its output at a rate of:

  \[
  P_{avg} = \frac{E}{\Delta t} = \text{switching rate} \cdot E_{sw}
  \]

  Therefore:

  \[
  P_{avg} = \alpha \cdot f \cdot \frac{1}{2} c V_{dd}^2
  \]

- Chip/circuit power consumption:

  \[
  P_{avg} = n \cdot \alpha \cdot f \cdot \frac{1}{2} c_{avg} V_{dd}^2
  \]

  number of nodes (or gates)

**Other Sources of Energy Consumption**

- “Short Circuit” Current: 10-20% of total chip power

- Junction Diode Leakage: ~1mWatt/chip

- Device Ids Leakage: ~3pWatts/transistor

- Low voltage processes much worse.
Controlling Energy Consumption

What control do you have as a designer?
- Largest contributing component to CMOS power consumption is switching power:

\[ P_{\text{avg}} = n \cdot \alpha_{\text{avg}} \cdot f \cdot 1/2 \cdot c_{\text{avg}} \cdot V_{dd}^2 \]

- Factors influencing power consumption:
  - \( n \): total number of nodes in circuit
  - \( \alpha \): activity factor (probability of each node switching)
  - \( f \): clock frequency (does this effect energy consumption?)
  - \( V_{dd} \): power supply voltage

- What control do you have over each factor?
- How does each effect the total Energy?

In EECS150 design projects, we will not optimize for power consumption.

Power / Cost / Performance

- In lecture 23 we discussed using parallelism to trade cost for performance. As we trade cost for performance what happens to energy?

- The lowest energy consumer is the solution that minimizes cost without time multiplexing operations.