Power in Consumer Electronics: The New Model
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Intro

• Food for thought

• How are new standards/products changing the entire power ecosystem?

• Wireless Power
  • Awesome!!!
  • ....or terrible?!? 😞

• What is the impact at the device level? At the global level??

• Yesterday, today, and tomorrow
Overview

• Why EVERYONE is a Power Engineer (whether you realize it or not)!
• What does “power efficiency” REALLY mean to you?
• Wireless Power
• High-speed data PLUS 100W!
• Where is the low-hanging fruit in efficiency optimization?
• Energy Harvesting
• Power-defined Software
• Power Efficiency & Related Standards
• Summary/ Conclusions
• Q&A
Why *EVERYONE* is a Power Engineer (whether you realize it or not)!

- Electrical (EE, Signal Integrity, Analog/Power Engineer)
- Software/Firmware (...more on this later)
- Mechanical/Thermal
- Program Manager
- Test/Qualification
- Manufacturing
- Commodity Manager
- Marketing
- Sales
What does “power efficiency” REALLY mean to you?

“There is no such thing as waste heat...just underutilized energy recycling opportunities.”

– Brian Zahnstecher

\[ \text{ENERGY}_{\text{UTILIZATION}} = \frac{\text{ENERGY}_{\text{IN}}}{\text{ENERGY}_{\text{OUT}}} \]
What does “power efficiency” REALLY mean to you?

What is the true cost of 1W?

**Power Plant**

- Step-up Transformer (~1-2%)
- Transmission (~2-4% TOTAL)
- Step-down Transformer (~1-2%)
- Transmission
- Distribution Network (~4-6%)

= You have lost ~8-15% of your power just getting from the power plant to your door.

**EFFICIENCY FOR THIS STAGE = ~92% (BEST-CASE)**

**PUE = 3.3**

Best to worst PUE is ~1.1-3.3. This translates to a typical IT usage of ~50%* and ranges from 30-90%.

*2012 Uptime Institute Industry Survey

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What does “power efficiency” REALLY mean to you?

What is the true cost of 1W?

You have lost ~5-10% of your power just getting from the door to your system.

EFFICIENCY FOR THIS STAGE = ~95% (BEST-CASE)

SERVER EXAMPLE (AC Input)

You have lost ~15-32% of your power getting from the system input to the load.

EFFICIENCY FOR THIS STAGE = ~85% (BEST-CASE)

FROM POWER PLANT TO LOAD = 0.92 x 0.95 x 0.85 = ~74% (BEST-CASE)

FYI = ~53% (WORST-CASE)

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What does “power efficiency” REALLY mean to you?

What is the true cost of 1W?

So for each 1W burned at the IT load alone, 1.4-1.9W need to be generated at the power plant.

When you do the rest of the calculations for typical data to account for the infrastructure, there is an additional cost of 1.1-2.5W. (In general, infrastructure equipment efficiency will be worse than IT equipment.)

So the true cost of EACH 1W of IT load requires 2.5-4.4x of power generated at the power plant!!!
What does “power efficiency” REALLY mean to you?

- Efficiency curves vs. power bills
  - i.e. – Marketing vs. Reality
  - CAPEX vs. OPEX

![Power Supply Efficiency Curve](image-url)
What does “power efficiency” REALLY mean to you?

Power Supply Efficiency Curve

Efficiency (%) vs Load (%)

Peak Point

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- Do more with same watts or do same with less watts?

- Early engagement with team stakeholders is key

- What is the most efficient system?
Wireless Power

• Standards established, but can use improvement
  • A4WP / PMA: Loosely coupled resonance, up to 50W, up to 5cm, multiple receivers
  • Qi: Inductive charging, up to 1kW, up to 4cm

• Even if technically optimized, highly dependent on the user

• Safety is now a function of response time
  • Separate communications protocol
  • Risk increases with power level

• Longer term impacts to health/tissue?
  • Specific Absorption Rate (SAR)
  • “The IEEE and ICNIRP recommend a whole body average SAR limit of 0.4 W/kg, for workers in controlled environments (also called occupational exposure), and a SAR limit of 0.08 W/kg for the general public.”

Late-breaking update as of 11/3/15: A4WP / PMA merger has now rebranded and launched as the AirFuel™ Alliance (http://www.airfuel.org/)
High-speed data *PLUS* 100W!

- Combining power with high-speed data is not a new concept

  - Universal Serial Bus (USB)
    - Swappable, multiple Power Sourcing Equipment (PSE) & Powered Device (PD) solutions
    - USB 1.x & 2.0 = 2.5W max [5V] (2000)
    - USB Battery Charging (BC) 1.0 = 7.5W max [5V] (2007)
    - USB Type-C v1.0 = 15W max [5V] (2014)
    - USB Power Delivery (PD) 2 v1.0 = 100W max [5/12/20V] (2014)

  - Power over Ethernet (PoE)
    - Cisco pre-PoE = 7W (Cisco, 2000)
    - PoE = 15.4W (IEEE 802.3af, 2003)
    - Cisco PoE+ = 30W (Cisco, 2007)
    - PoE+ = 25.5W (IEEE 802.3at, 2009)
    - Cisco UPoE (non-IEEE) = 60W (Cisco, 2011)
    - PoE++ = 100W? (IEEE 802.3bt, 2017)
High-speed data \textit{PLUS} 100W!

- Signal Integrity (SI) vs. Power Integrity (PI) concerns

\textbf{vs.}
High-speed data PLUS 100W!

• Signal Integrity (SI) vs. Power Integrity (PI) concerns

• Design Implications
  • Overprovisioning
  • Complicated dynamic power allocation
  • Ditch the “wall wort”

• Side Thoughts / Roadmap Enablers
  • Pushing the switching frequency to shrink the adapter (i.e. – Zolt, FINsix, etc.)
  • Integrated power (i.e. – granular power, Power System on Chip (Power SoC))
  • Wide bandgap (WBG) components
  • Point-to-point networks??

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High-speed data *PLUS* 100W!

- How can a “typical” device use this extra power?
  - Laptop Basic Example
Where is the low-hanging fruit in efficiency optimization?

- What is the optimal efficiency curve?
Where is the low-hanging fruit in efficiency optimization?

• What is the optimal efficiency curve?

• Think of utilization, not efficiency.

• Power Simulations

• Inform the uninformed...educate the user.
Energy Harvesting

- $\text{pW} \rightarrow \text{nW} \rightarrow \text{µW} \rightarrow \text{mW}$

- ICs in standby can run on nW & µW

- Harvest from multiple sources with multiple methods

- Combine with improved utilization and intelligent power management to multiply the value of each µW

- Now we are approaching mW!

Remember this? $\text{ENERGY}_{\text{UTILIZATION}} = \frac{\text{ENERGY}_{\text{IN}}}{\text{ENERGY}_{\text{OUT}}}$
Energy Harvesting

- Component Integration → IoT Enablement

*Film is the module!*

SMD capacitor soldered plus 4 chips are wirebonded

IMAGE CREDIT: Power Gold patented embedding of bare chips into flexible film. www.powergoldconsultant.com


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Energy Harvesting

- Envelope Tracking

Energy Harvesting

- Mechanical / Kinetic (Piezoelectric)

Upon doing some minor research:
- Best I found was ~2.4nW/tap
- A person sent 1,514 text messages with an average of 69 characters/message
- WIRED article calculates 4.5mJ/tap
  - An iPhone4 battery has a capacity of 18.9kJ (or 5.25Wh)
  - So 4.2 million taps is a lot, but it is a step in the right direction!

REFERENCES:
- One Year of Text Messages, Analyzed = http://drafts.jsvine.com/one-year-of-text-messages/
Energy Harvesting

• Mechanical / Kinetic (Piezoelectric)

IMAGE CREDIT: http://i01.i.aliimg.com/wsphoto/v0/490395881/5267-NEW-3-LED-lights-font-b-Dynamo-b-font-Hand-Pressing-Flash-Light-1135.jpg
Energy Harvesting

• Thermal

- That 18.9kJ iPhone4 battery is merely ~4.5kcal
- The ASHRAE pocket guide gives the approximate electrical power a person generates while seated as 110 watts/hr, and during heavy work it is 550 watts/hr.
- Anyone remember the movie “The Matrix”?

Table III. Measurement results of energy recycled and the temperature of the CPU and TEG.

<table>
<thead>
<tr>
<th>Test condition</th>
<th>Temp. of CPU</th>
<th>Temp. of Cu plate</th>
<th>Temp. of TEG</th>
<th>Voltage</th>
<th>Current</th>
<th>Impedance matched power</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEG on shunt</td>
<td>Scenario I</td>
<td>77°C</td>
<td>43°C</td>
<td>40°C</td>
<td>87.7mV</td>
<td>14.5mA</td>
</tr>
<tr>
<td></td>
<td>Scenario II</td>
<td>77°C</td>
<td>43°C</td>
<td>37°C</td>
<td>200.1mV</td>
<td>30.1mA</td>
</tr>
<tr>
<td>TEG on CPU</td>
<td>Scenario III</td>
<td>77°C</td>
<td>59°C</td>
<td>53°C</td>
<td>210.3mV</td>
<td>31.6mA</td>
</tr>
<tr>
<td></td>
<td>Scenario IV</td>
<td>77°C</td>
<td>59°C</td>
<td>47°C</td>
<td>418.8mV</td>
<td>64.3mA</td>
</tr>
</tbody>
</table>


REFERENCES:
- Will your body be the battery of the future? = http://www.extremetech.com/extreme/135481-will-your-body-be-the-battery-of-the-future

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Energy Harvesting

- Solar (Photovoltaic)

IMAGE CREDIT: Ascent Solar EnerPlex Surfr phone charging case. 
http://www.goenerplex.com/products/solar-and-battery-phone-cases/surfr-for-iphone-6-6s

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Energy Harvesting

- RF Near-field
  - Wireless Power Transfer (already discussed)

- RF Far-field
  - Lots of energy flying through the air at all kinds of frequencies
  - Fancy antennas
  - Negative impact?

Power-defined Software

• Power Management
  • Power Capping
  • Power Shedding
  • Power Sharing/Allocation
  • Multi-phase Power

• Power Supplies are SW/FW-driven
  • Most contain MULTIPLE microcontrollers
  • Digital control can range from a wrapper (i.e. – telemetry) to fully digital control
Power-defined Software

- EXTREME Code Power Characterization
  - Brings a new meaning to coding efficiency
  - Requires extremely careful instrumentation, but doable

Power Efficiency & Related Standards

• 80PLUS
  • Test Protocol (Rev 6.7):

• CA Energy Commission (CEC)
  • Desktops/Laptops/Monitors/LEDs/etc.: [http://www.energy.ca.gov/appliances/](http://www.energy.ca.gov/appliances/)

• IEEE 802.3 PoE standard
  • [http://www.ieee802.org/3/](http://www.ieee802.org/3/)

• USB 3.1 / Type-C / Power Delivery
  • [http://www.usb.org/developers/docs/](http://www.usb.org/developers/docs/)

• Qi / A4WP & PMA (wireless power)
  • [http://www.wirelesspowerconsortium.com/](http://www.wirelesspowerconsortium.com/)
  • [http://a4wppmamerge.com/](http://a4wppmamerge.com/)
Summary / Conclusions

• There is no such thing as waste heat...everything is an energy source.
• Think about optimizing utilization, not purely efficiency. Use it or lose it!
• Power-efficient designs are the responsibility of ALL stakeholders.
• The power landscape is changing, especially for consumer. Wireless power, energy harvesting, & IoT apps major drivers.
• SW plays an ever-growing role on power design, management, and utilization...let us not forget that.
Shameless Plugs

- **Software-Defined Infrastructure (SDI) Summit**
  - “Software IS Power Engineering”
  - December 3, 2015, 2-3:15pm
  - Santa Clara, CA

- **Applied Power Electronics Conference (APEC)**
  - “Power-Defined Software in the Data Center”
  - March 20-24, 2016, Industry Sessions
  - Long Beach, CA

- **Power Conversion & Intelligent Motion (PCIM)**
  - “Fundamentals of Power in the Data Center” **HALF-DAY SEMINAR**
  - May 8, 2016, 2-5:30pm
  - Nuremburg, Germany

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Q&A

Thanks a lot for your time and attention!

Any questions and/or comments?

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- Yi Qi, Noah T. Jafferis, Kenneth Lyons, Jr., Christine M. Lee, Habib Ahmad, and Michael C. McAlpine. Nano Letters 2010 10 (2), 524-528. DOI: 10.1021/nl903377u
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- Piezoelectric Ribbons Printed onto Rubber for Flexible Energy Conversion = http://pubs.acs.org/doi/abs/10.1021/nl903377u
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