Power in Consumer Electronics: The New Model

Wednesday, November 4, 2015

Brian Zahnstecher, Principal

bz@powerrox.com (508) 847-5747

PowerRox™

www.powerrox.com

1125 S Baywood Ave., San Jose, CA 95128

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?

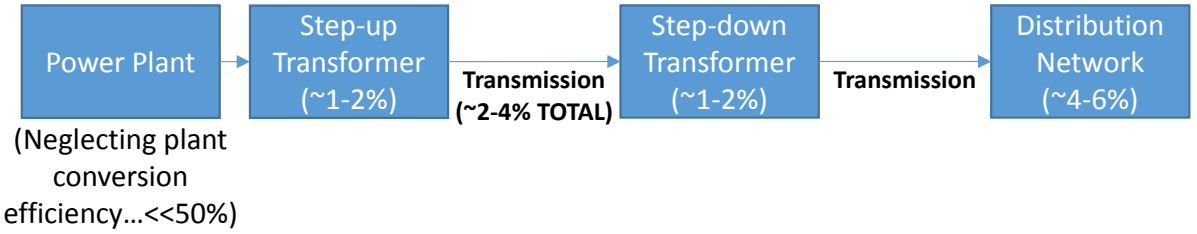
“There is no such thing as waste heat…just underutilized energy recycling opportunities.”

– Brian Zahnstecher

$$ENERGY_{UTILIZATION} = \frac{ENERGY_{IN}}{ENERGY_{OUT}}$$

What does “power efficiency” REALLY mean to you?

What is the true cost of 1W?

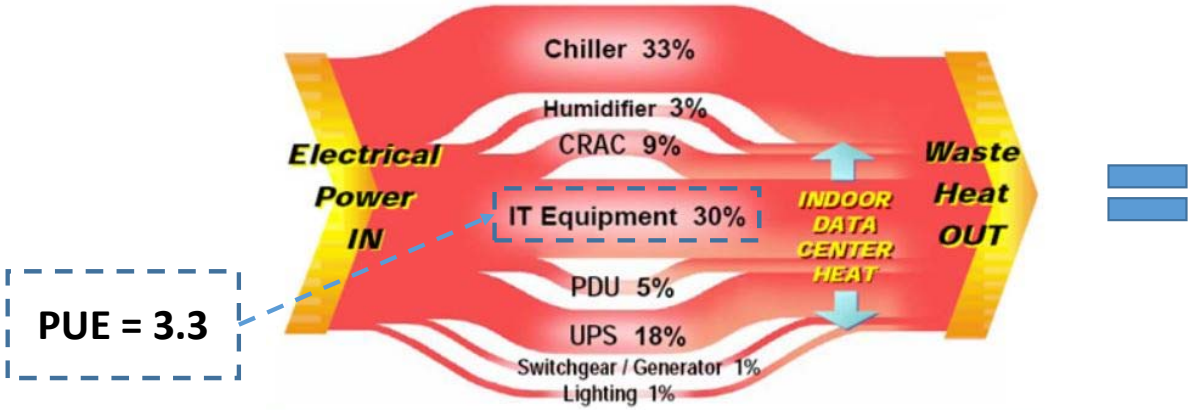


(Neglecting plant conversion efficiency…<<50%)

SOURCE: IEC document “Efficient Electrical Energy Transmission and Distribution” (2007)

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

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



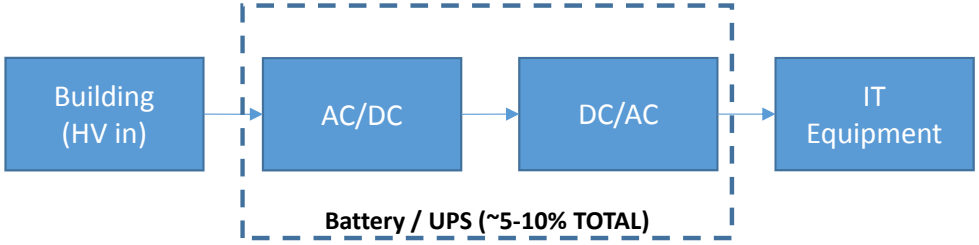
Power flow in a typical data center. Source: APC, Electrical Efficiency Measurement for Data Centers, WP #154

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**

What does “power efficiency” REALLY mean to you?

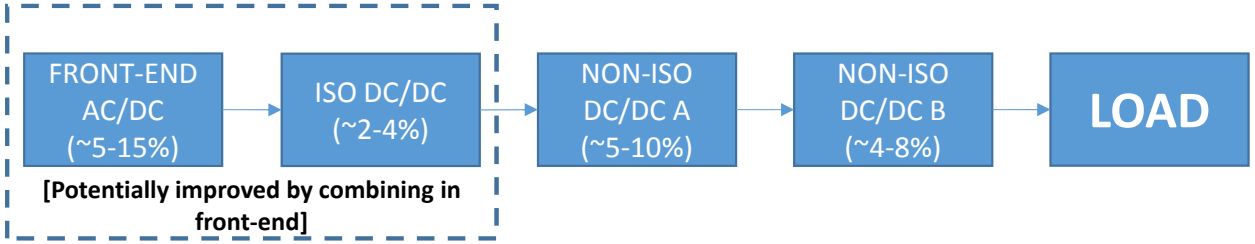
What is the true cost of 1W?



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)

P Rx ™

What does “power efficiency” REALLY mean to you?

What is the true cost of 1W?

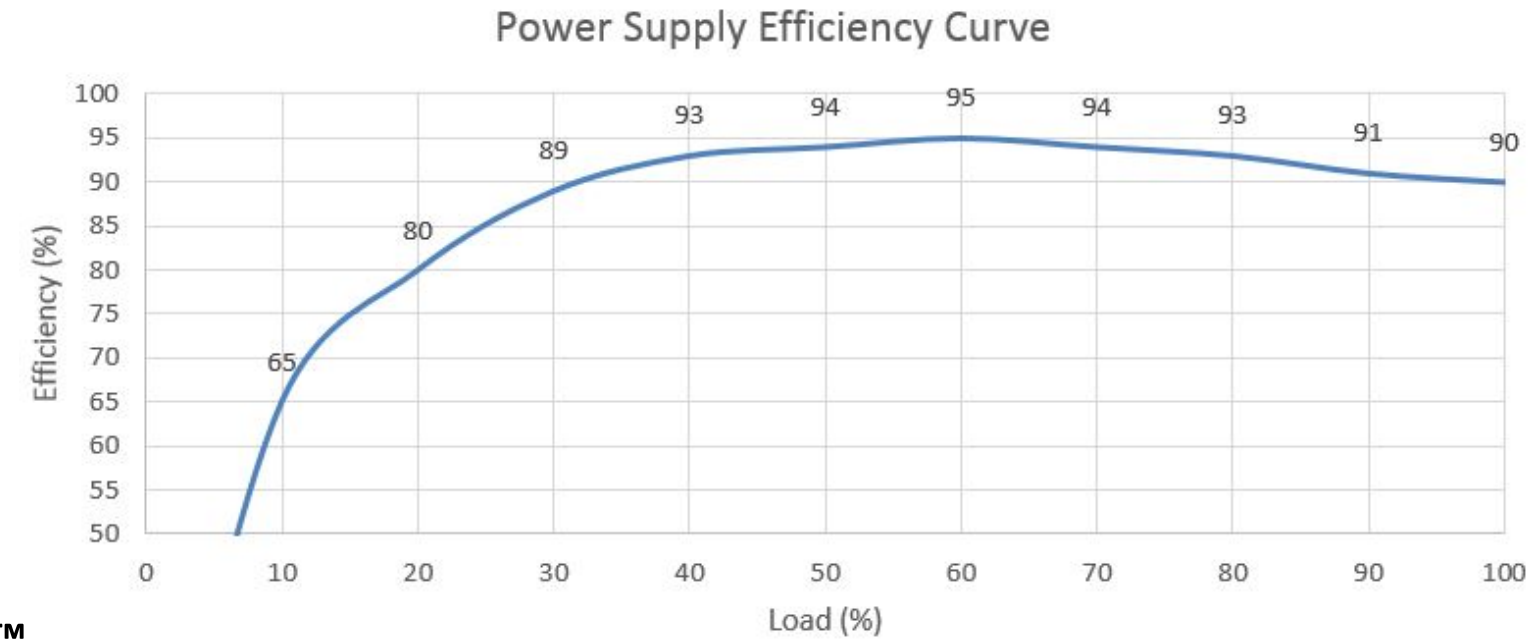
So for each 1W burned at the IT load alone, *1.4-1.9W* need to be generated at the power plant.

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.)

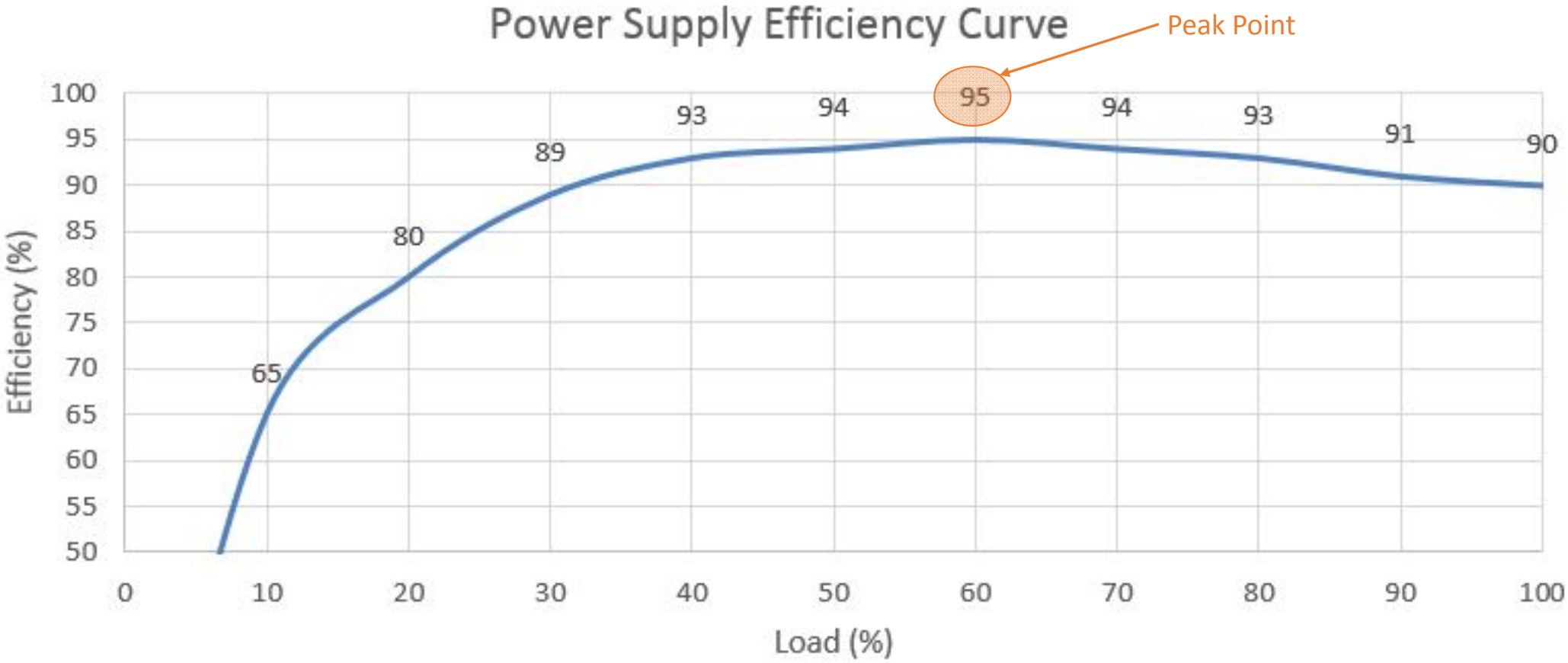
So the true cost of *EACH 1W* of IT load requires *2.5-4.4x* of power generated at the power plant!!!

What does “power efficiency” REALLY mean to you?

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



What does “power efficiency” REALLY mean to you?



What does “power efficiency” REALLY mean to you?

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

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

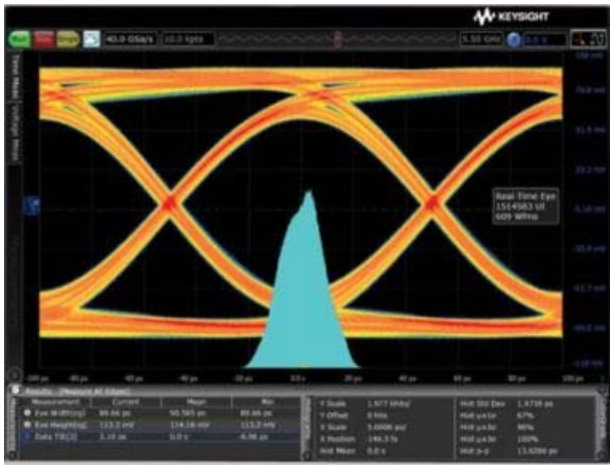
- Even if technically optimized, highly dependent on the user
- Safety is now a function of response time
  - Separate communications protocol
  - Risk increases with power level
- Longer term impacts to health/tissue?
  - Specific Absorption Rate (SAR)
  - "The IEEE and ICNIRP recommend a whole body 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."

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 3.x = 4.5W max [5V] (**2008**)
    - 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 *PLUS* 100W!

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



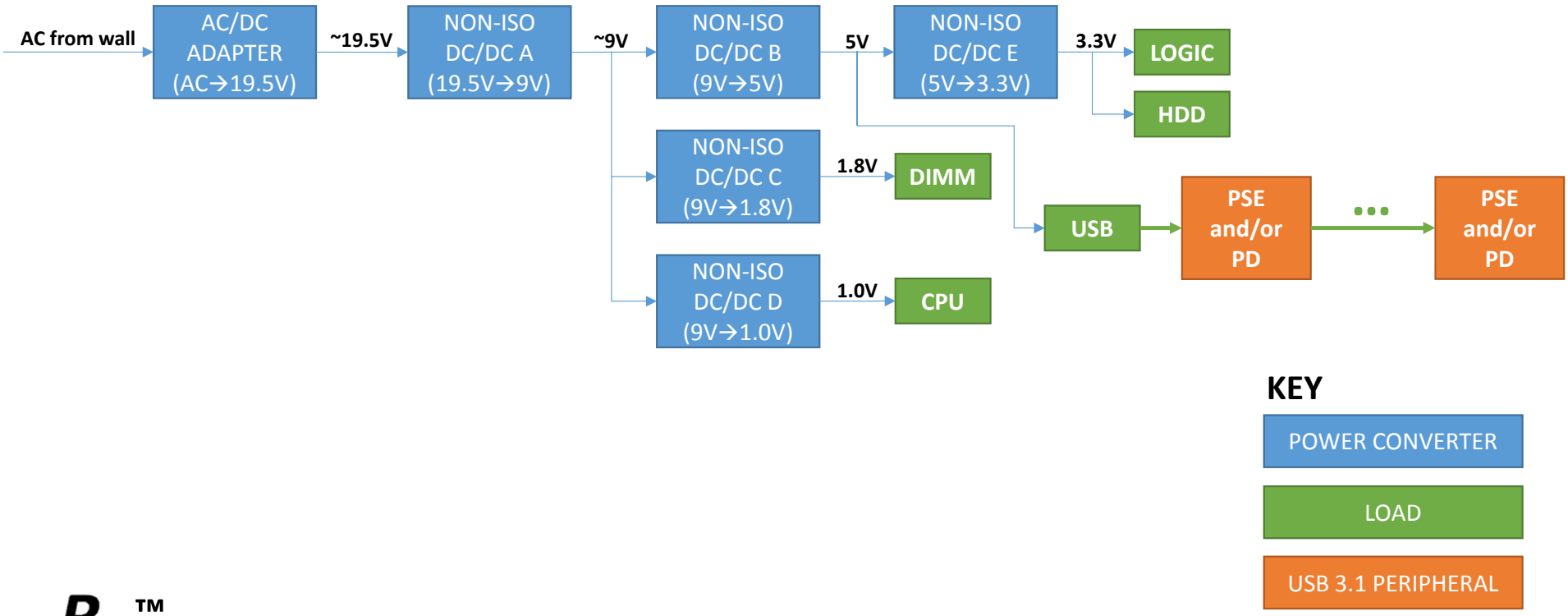
vs.

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??

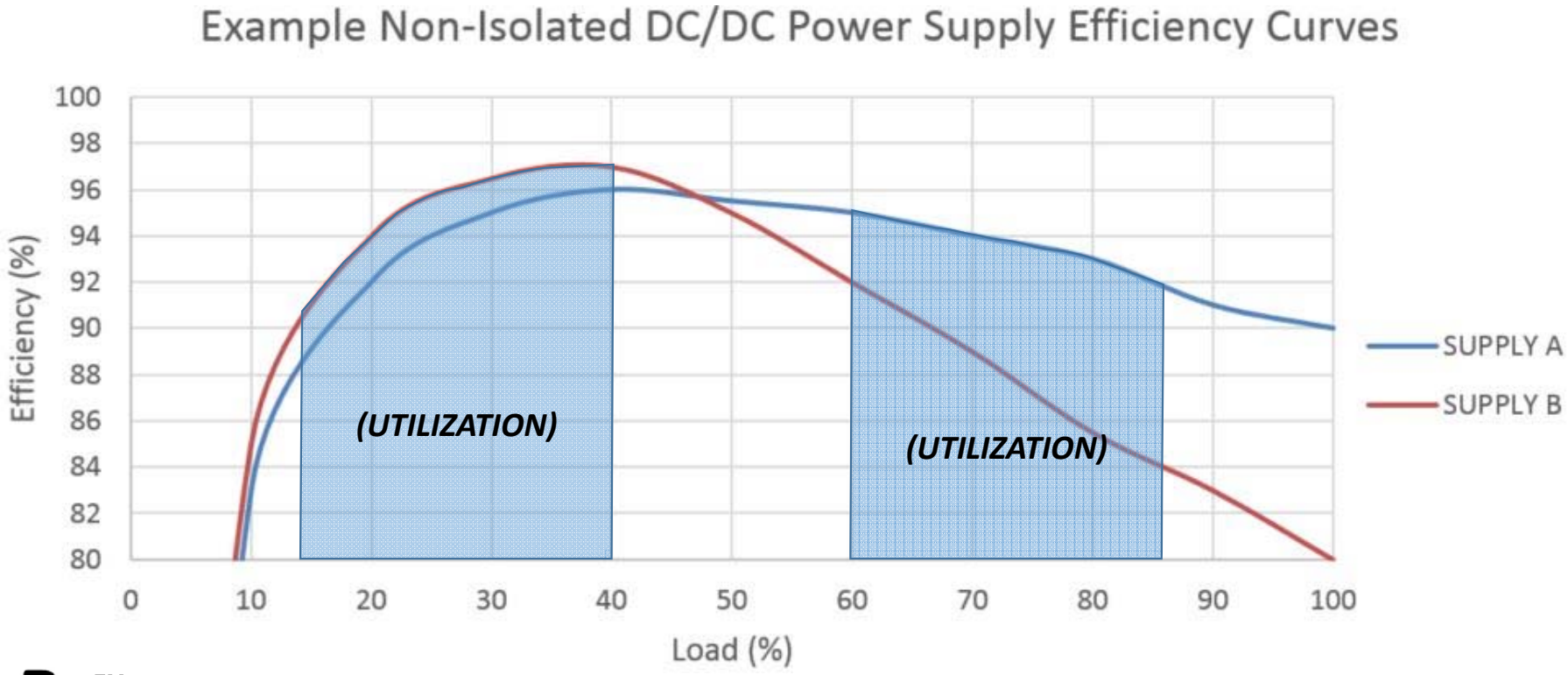
High-speed data *PLUS* 100W!

- 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

- pW → nW → µW → 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? →

$$ENERGY_{UTILIZATION} = \frac{ENERGY_{IN}}{ENERGY_{OUT}}$$

Energy Harvesting

- Component Integration → IoT Enablement

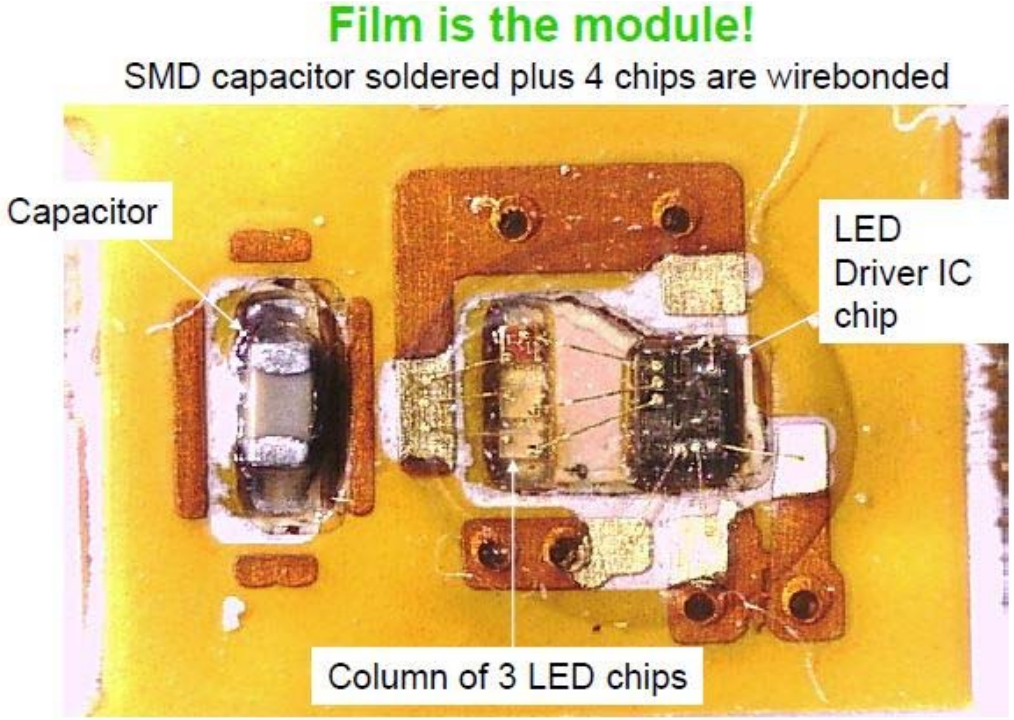
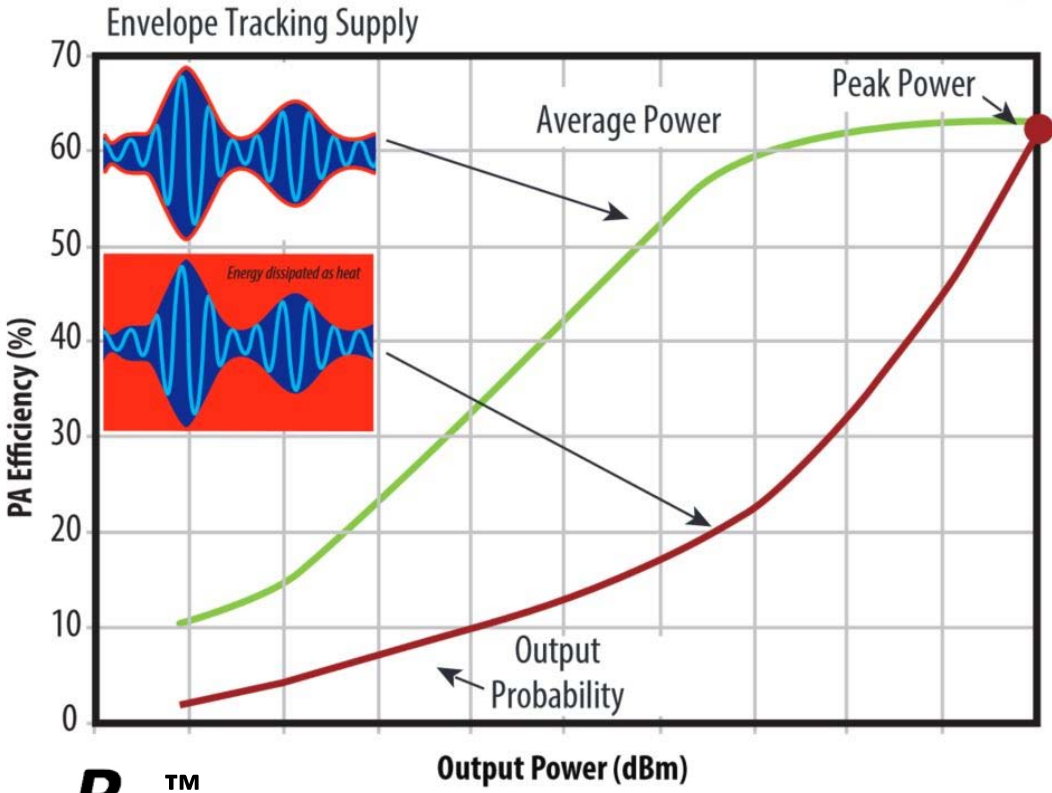


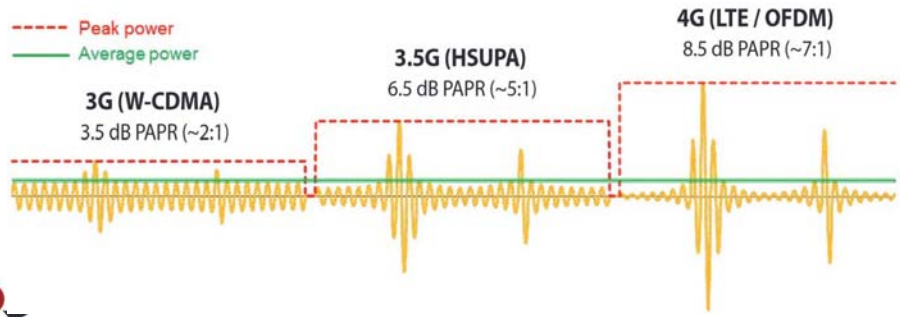
IMAGE CREDIT: Power Gold patented embedding of bare chips into flexible film. www.powergoldconsultant.com

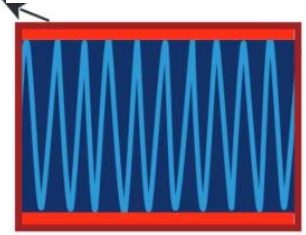
IMAGE CREDIT: Samsung SDI announces Stripe & Band flexible batteries on 10/20/15. http://www.samsungsdi.com/about-sdi/pr-center/sdi-news/view?mode=siteSearch&seqno=1708

Energy Harvesting

- Envelope Tracking



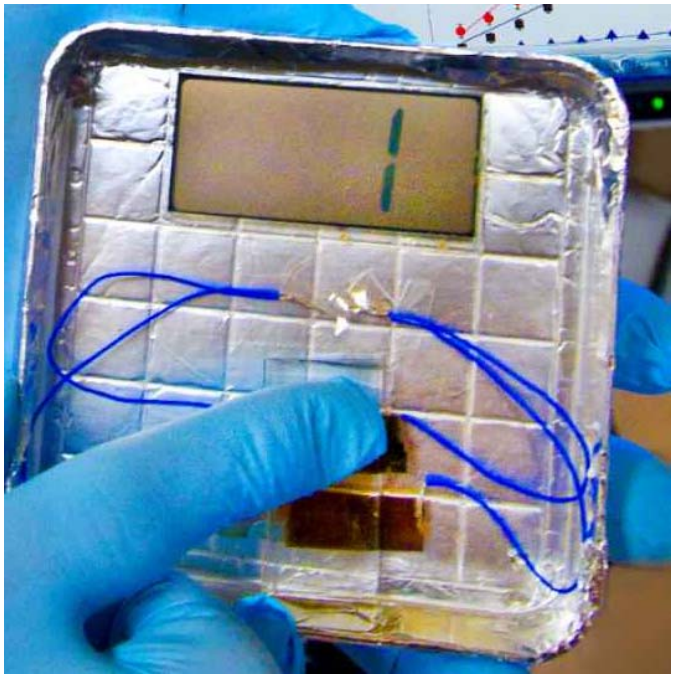




WAVEFORMS TAKEN FROM: EPC AB002. "eGaN FETs for Envelope Tracking Applications." www.epc-co.com

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:

- ***Byung Yang Lee, Jinxing Zhang, Chris Zueger, Woo-Jae Chung, So Young Yoo, Eddie Wang, Joel Meyer, Ramamoorthy Ramesh, Seung-Wuk Lee. Virus-based piezoelectric energy generation. Nature Nanotechnology, 2012; DOI: 10.1038/nnano.2012.69***
- ***Can You Charge Your Phone by Typing? = http://www.wired.com/2011/07/can-you-charge-your-phone-by-typing/***
- ***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.

Test condition		Temp. of CPU	Temp. of Cu plate	Temp. of TEG	Voltage	Current	Impedance matched power
TEG on shunt	Scenario I	77°C	43°C	40°C	87.7mV	14.5mA	0.3 mw
	Scenario II	77°C	43°C	37°C	200.1mV	30.1mA	1.5 mw
TEG on CPU	Scenario III	77°C	59°C	53°C	210.3mV	31.6mA	1.7 mw
	Scenario IV	77°C	59°C	47°C	418.8mv	64.3mA	6.7 mw

Table taken from: Yu Zhou; Paul, S.; Bhunia, S., "Harvesting Wasted Heat in a Microprocessor Using Thermoelectric Generators: Modeling, Analysis and Measurement," in Design, Automation and Test in Europe, 2008. DATE '08 , vol., no., pp.98-103, 10-14 March 2008

REFERENCES:

- ***Benjamin J. Hansen, Ying Liu, Rusen Yang, and Zhong Lin Wang, "Hybrid Nanogenerator for Concurrently Harvesting Biomechanical and Biochemical Energy", ACS Nano, 4 (2010) 3647-3652.***
- ***Will your body be the battery of the future? = http://www.extremetech.com/extreme/135481-will-your-body-be-the-battery-of-the-future***
- **ASHRAE Pocket Guide for Air-Conditioning, Heating, Ventilation, Refrigeration, 8th Ed.**
- **Yu Zhou; Paul, S.; Bhunia, S., "Harvesting Wasted Heat in a Microprocessor Using Thermoelectric Generators: Modeling, Analysis and Measurement," in Design, Automation and Test in Europe, 2008. DATE '08 , vol., no., pp.98-103, 10-14 March 2008**

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

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?

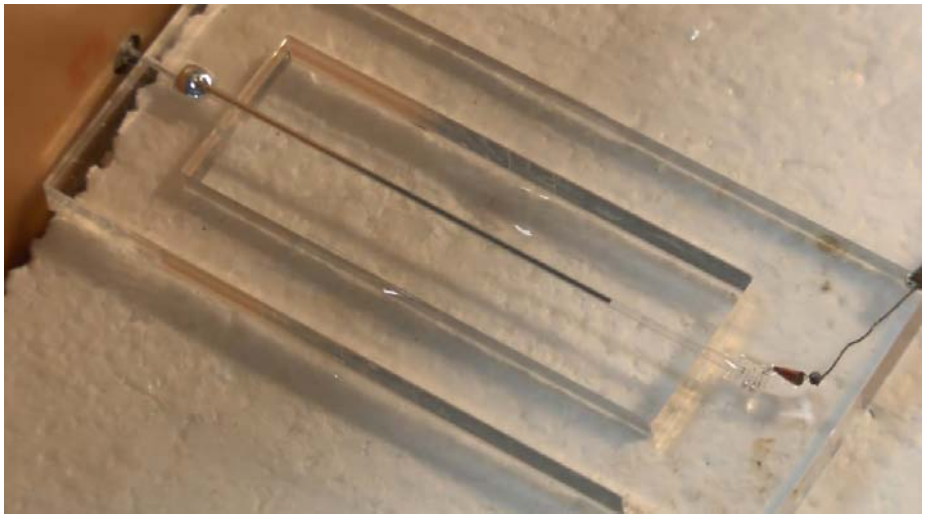


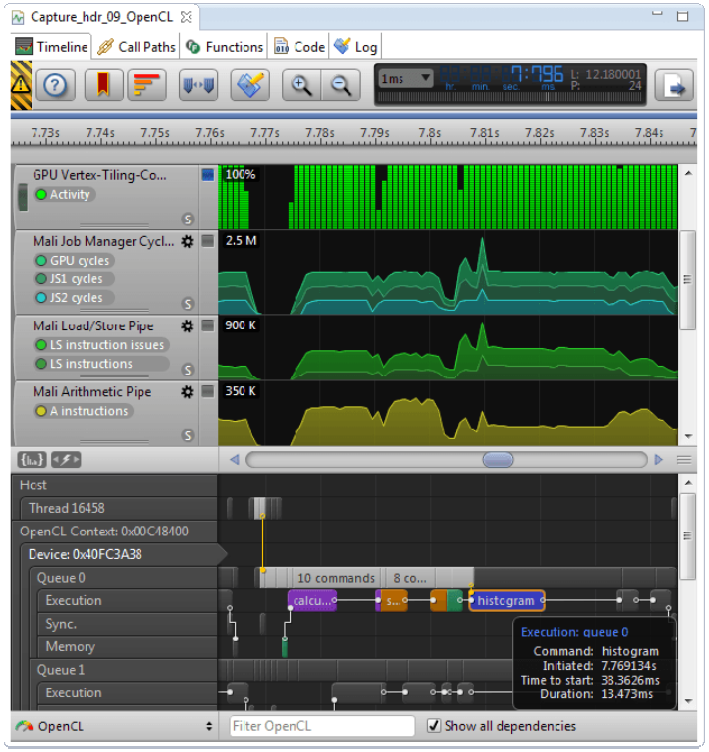
IMAGE CREDIT: David Schneider "Shape-shifting Liquid-Metal Antennas," IEEE Spectrum, Posted 21 Aug 2015. = http://spectrum.ieee.org/video/telecom/wireless/shapeshifting-liquidmetal-antennas

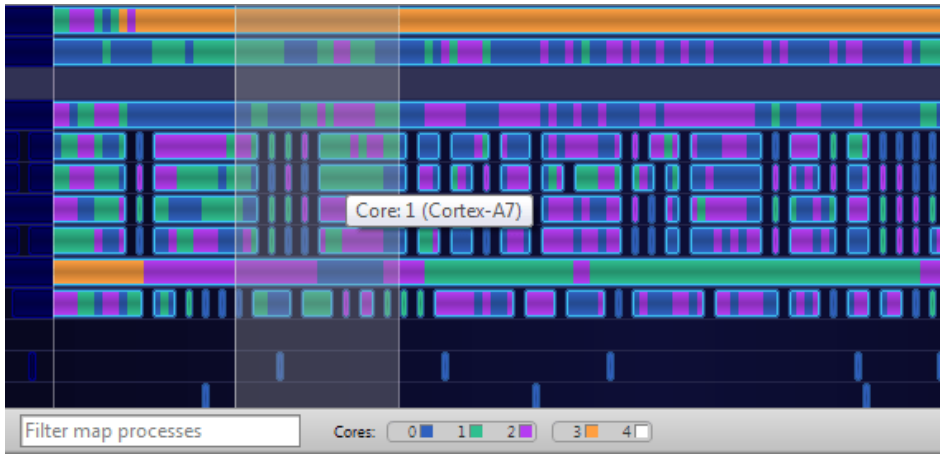
Power-defined Software

- 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





- ***IMAGE CREDIT: ARM Streamline performance analyzer GUI tool.*** http://ds.arm.com/ds-5/optimize/streamline-features/

Power Efficiency & Related Standards

- 80PLUS
  - http://www.plugloadsolutions.com/80PlusPowerSupplies.aspx
  - Test Protocol (Rev 6.7): http://www.plugloadsolutions.com/docs/collatrl/print/Generalized_Internal_Power_Supply_Efficiency_Test_Protocol_R6.7.pdf
- CA Energy Commission (CEC)
  - Desktops/Laptops/Monitors/LEDs/etc.: http://www.energy.ca.gov/appliances/
- IEEE 802.3 PoE standard
  - http://www.ieee802.org/3/
- USB 3.1 / Type-C / Power Delivery
  - http://www.usb.org/developers/docs/
  - Intel Thunderbolt 3: http://www.intel.com/content/www/us/en/io/thunderbolt/thunderbolt-overview-brief.html
- Qi / A4WP & PMA (wireless power)
  - http://www.wirelesspowerconsortium.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
  - http://www.sdisummit.com/

- **Applied Power Electronics Conference (APEC)**
  - *"Power-Defined Software in the Data Center"*
  - March 20-24, 2016, Industry Sessions
  - Long Beach, CA
  - http://www.apec-conf.org/

- **Power Conversion & Intelligent Motion (PCIM)**
  - *"Fundamentals of Power in the Data Center"* **HALF-DAY SEMINAR**
  - May 8, 2016, 2-5:30pm
  - Nuremburg, Germany
  - https://www.mesago.de/en/PCIM/The_conference/Welcome/index.htm

Q&A

Thanks a lot for your time and attention!

Any questions and/or comments?

References

- “Efficient Electrical Energy Transmission and Distribution” IEC (2007)
- “Report to Congress on Server and Data Center Energy Efficiency – Public Law 109-431” U.S. EPA, Energy Star Program (2007)
- PUE = http://www.thegreengrid.org/sitecore/content/Global/Content/white-papers/The-Green-Grid-Data-Center-Power-Efficiency-Metrics-PUE-and-DCiE.aspx
- “Independent Statistics & Analysis” U.S. Energy Information Administration = http://www.eia.gov/electricity/data.cfm
- “How much electricity is lost in transmission and distribution in the United States?” = http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3
- Qi Standard = http://www.wirelesspowerconsortium.com
- A4WP Standard = http://www.rezence.com/
- PMA Standard = http://www.powermatters.org/
- “195 Members Strong; Airfuel™ Alliance Drives Wireless Charging Standards Under One Global Ecosystem,” AirFuel Alliance, Posted 3 Nov 2015 = http://www.airfuel.org/press-release.php
- “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz,” IEEE Std. C95.1-2005.
- “Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (Up to 300 GHz),” ICNIRP Guidelines, International Commission on Non-Ionizing Radiation Protection, Health Physics, 74, no. 4, pp. 494-522, (1998).
- Dr. Morris Kesler, “Highly Resonant Wireless Power Transfer: Safe, Efficient, and over Distance,” WiTricity Corporation, (2013).
- Ascent Solar EnerPlex Surfr phone charging case. http://www.goenerplex.com/products/solar-and-battery-phone-cases/surfr-for-iphone-6-6s
- David Schneider "Shape-shifting Liquid-Metal Antennas," IEEE Spectrum, Posted 21 Aug 2015. = http://spectrum.ieee.org/video/telecom/wireless/shapeshifting-liquidmetal-antennas

References

- Flex Lighting Technology™ Film Electronics, Power Gold LLC, www.powergoldconsultant.com
- “Samsung SDI’s Next-Gen Wearable Battery Unpack…Showing Next-Generation Battery at InterBattery 2015,” Samsung SDI News, Posted 20 Oct 2015 = http://www.samsungsdi.com/about-sdi/pr-center/sdi-news/view?mode=siteSearch&seqno=1708
- EPC AB002 Application Brief. “eGaN FETs for Envelope Tracking Applications.” 2015. www.epc-co.com
- Byung Yang Lee, Jinxing Zhang, Chris Zueger, Woo-Jae Chung, So Young Yoo, Eddie Wang, Joel Meyer, Ramamoorthy Ramesh, Seung-Wuk Lee. Virus-based piezoelectric energy generation. Nature Nanotechnology, 2012; DOI: 10.1038/nnano.2012.69
- Benjamin J. Hansen, Ying Liu, Rusen Yang, and Zhong Lin Wang, "Hybrid Nanogenerator for Concurrently Harvesting Biomechanical and Biochemical Energy", ACS Nano, 4 (2010) 3647-3652.
- Abiral Tamang, Sujoy Kumar Ghosh, Samiran Garain, Md. Mehebub Alam, Jörg Haeberle, Karsten Henkel, Dieter Schmeisser, and Dipankar Mandal. DNA-Assisted BETA-phase Nucleation and Alignment of Molecular Dipoles in PVDF Film: A Realization of Self-Poled Bioinspired Flexible Polymer Nanogenerator for Portable Electronic Devices. ACS Applied Materials & Interfaces 2015 7 (30), 16143-16147. DOI: 10.1021/acsami.5b04161
- Bhaskaran, M., Sriram, S., Ruffell, S. and Mitchell, A. (2011), Nanoscale Characterization of Energy Generation from Piezoelectric Thin Films. Adv. Funct. Mater., 21: 2251–2257. doi: 10.1002/adfm.201002663
- 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
- "Harvesting Vibrational Energy Using Material Work Functions". Scientific Reports 4, Article number: 6799 DOI: 10.1038/srep06799
- Chen Xu, Xudong Wang and Zhong Lin Wang, "Nanowire Structured Hybrid Cell for Concurrently Scavenging Solar and Mechanical Energies", J. Am. Chem. Soc., 131(2009) 5866-5872.
- Benjamin J. Hansen, Ying Liu, Rusen Yang, and Zhong Lin Wang, "Hybrid Nanogenerator for Concurrently Harvesting Biomechanical and Biochemical Energy", ACS Nano, 4 (2010) 3647-3652.
- Aaron Smith, "Americans and text messaging," Pew Research, 19 September 2011

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*
- ASHRAE Pocket Guide for Air-Conditioning, Heating, Ventilation, Refrigeration, 8th Ed.
- Yu Zhou; Paul, S.; Bhunia, S., "Harvesting Wasted Heat in a Microprocessor Using Thermoelectric Generators: Modeling, Analysis and Measurement," in Design, Automation and Test in Europe, 2008. DATE '08 , vol., no., pp.98-103, 10-14 March 2008
- Energy-harvesting rubber sheets could power pacemakers, mobile phones = http://phys.org/news/2010-01-energy-harvesting-rubber-sheets-power-pacemakers.html
- Laptops of the future could be powered by typing, cameras by shooting = http://www.extremetech.com/extreme/88126-laptops-powered-by-typing-piezo
- Mobile devices powered just by tapping your finger = http://www.materialstoday.com/electronic-properties/news/mobile-devices-powered-just-by-tapping-your-finger/
- Piezoelectric Ribbons Printed onto Rubber for Flexible Energy Conversion = http://pubs.acs.org/doi/abs/10.1021/nl903377u
- IMEC reports 40 microwatt from micromachined piezoelectric energy harvester = http://phys.org/news/2007-06-imec-microwatt-micromachined-piezoelectric-energy.html
- Researchers demonstrate new technique for generating electricity = http://phys.org/news/2014-11-technique-electricity.html
- Fraunhofer develops economical process for micro energy harvesting = http://phys.org/news/2014-10-fraunhofer-economical-micro-energy-harvesting.html
- Nanowire Structured Hybrid Cell for Concurrently Scavenging Solar and Mechanical Energies = http://www.nanoscience.gatech.edu/research/index.php
- Hybrid Nanogenerator for Concurrently Harvesting Biomechanical and Biochemical Energy = http://www.nanoscience.gatech.edu/research/index.php
- One Year of Text Messages, Analyzed = http://drafts.jsvine.com/one-year-of-text-messages/
- Can You Charge Your Phone by Typing? = http://www.wired.com/2011/07/can-you-charge-your-phone-by-typing/
- ARM Streamline performance analyzer GUI tool = http://ds.arm.com/ds-5/optimize/streamline-features/