UNIVERSITY OF Southampton

Energy-Driven Systems and Compute

Towards Self-powered Embedded Computing Systems

Geoff Merrett
20 October 2020

networking/comms

harvester

power conversion

user

sensors

memory

An *energy harvester* is one part of a *system*

compute

application

user interface(s)

actuators

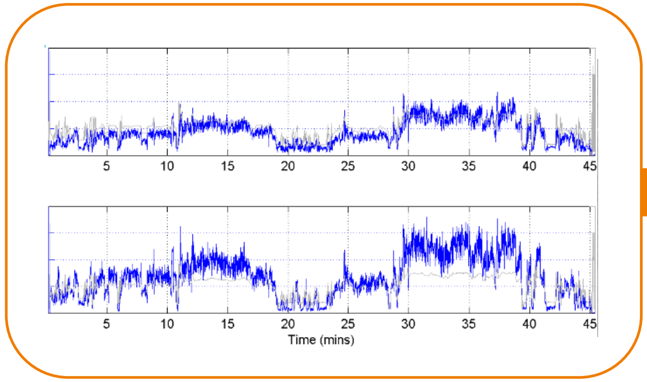
peripherals

energy storage

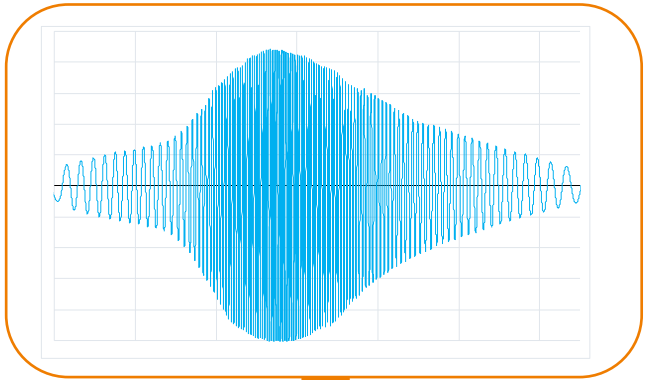
design tools

ENERGY HARVESTING

varies temporally



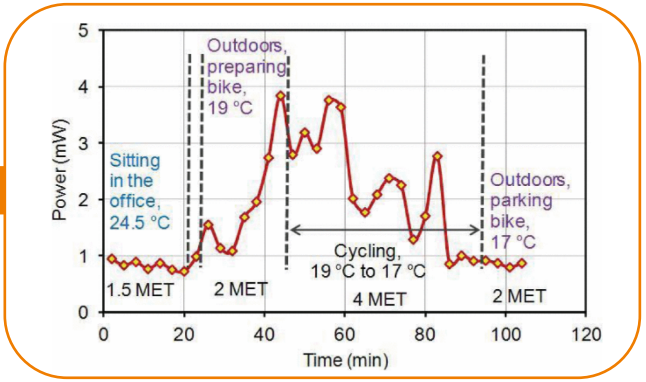
Beeby, S.P. et al. A comparison of power output from linear and non-linear kinetic energy harvesters using real vibration data. Smart Materials and Structures, 22, (7), 075022.



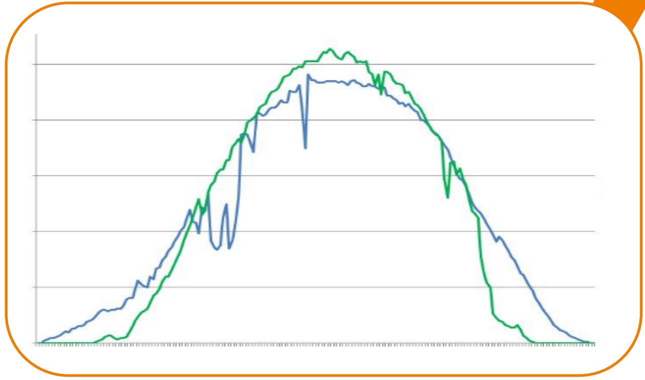
D. Balsamo et al. Hibernus++: a self-calibrating and adaptive system for transiently-powered embedded devices. IEEE TCAD, 1-13.

Power / Energy

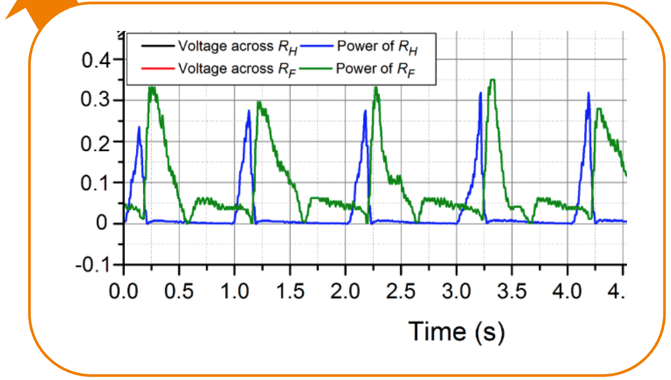
varies spatially



V. Leonov, "Thermoelectric Energy Harvesting of Human Body Heat for Wearable Sensors," IEEE Sensors Journal, vol.13, no.6, pp.2284-91, June13



http://solar.rainham-kent.co.uk

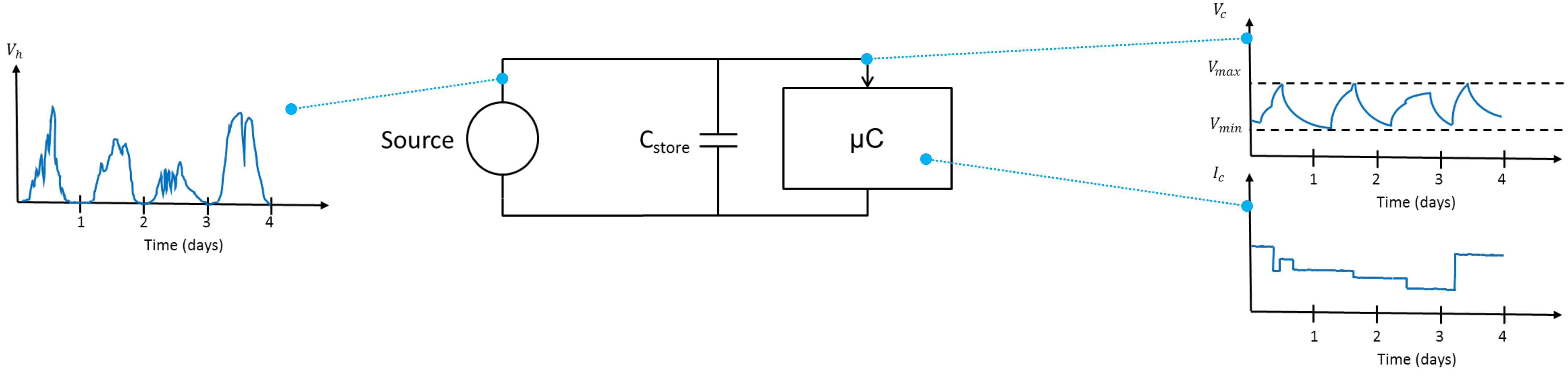


Zhao, J. et al. "A Shoe-Embedded Piezoelectric Energy Harvester for Wearable Sensors," Sensors 2014, 14, 12497-12510.

Highly variable supply + variable consumption!

ENERGY-NEUTRAL COMPUTING

Schematic

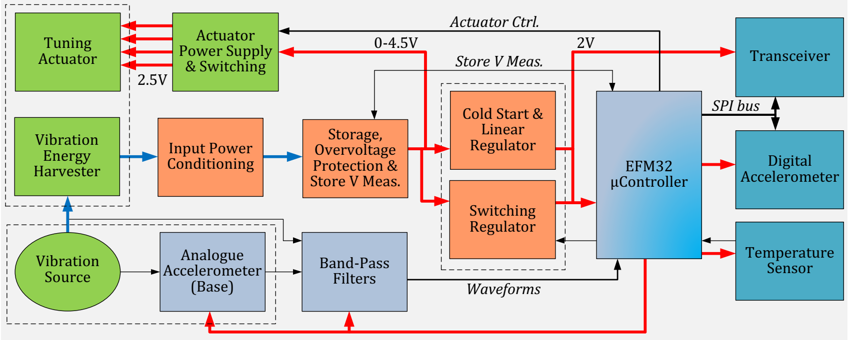


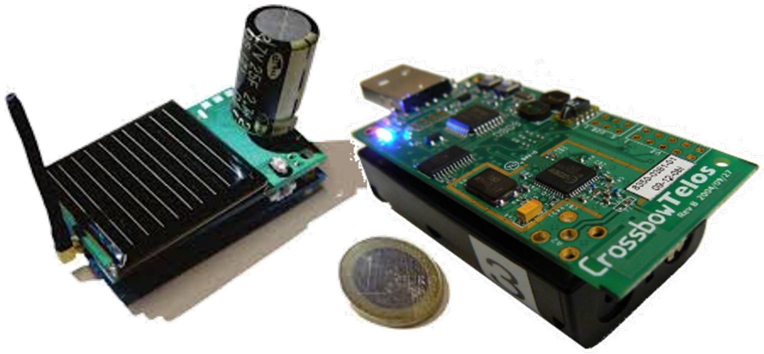
Block Diagram

$$\int_{(n-1)\cdot T}^{n\cdot T} P_h(t)dt = \int_{(n-1)\cdot T}^{n\cdot T} P_c(t)dt$$

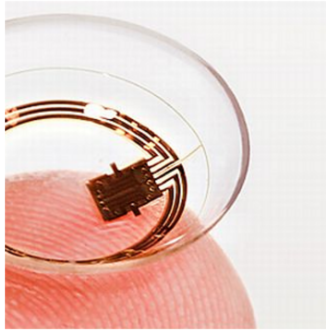
ENERGY-DRIVEN COMPUTING

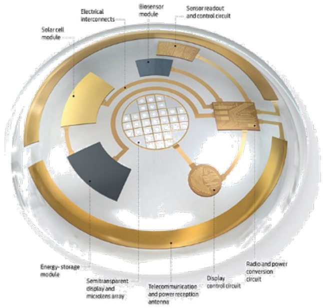
- What's wrong with energy storage and complexity?





- Emerging applications demanding small dimensions, volumes, weight, cost, etc

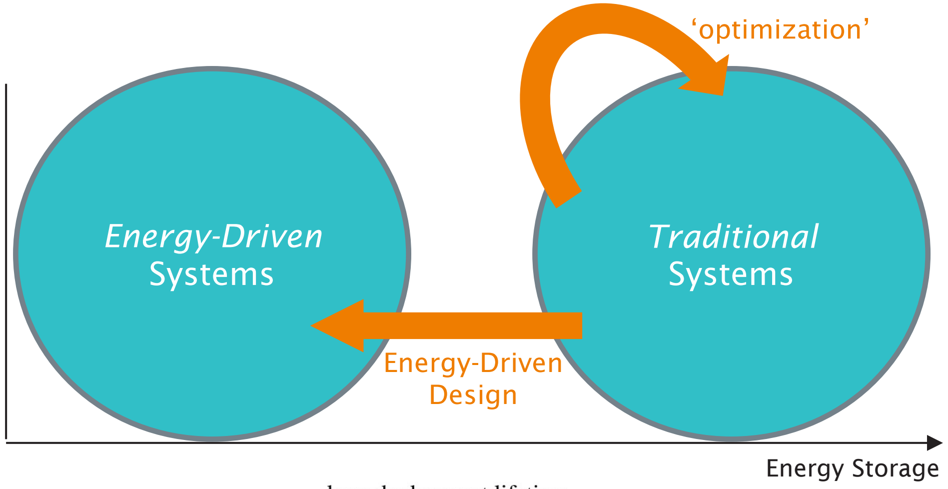


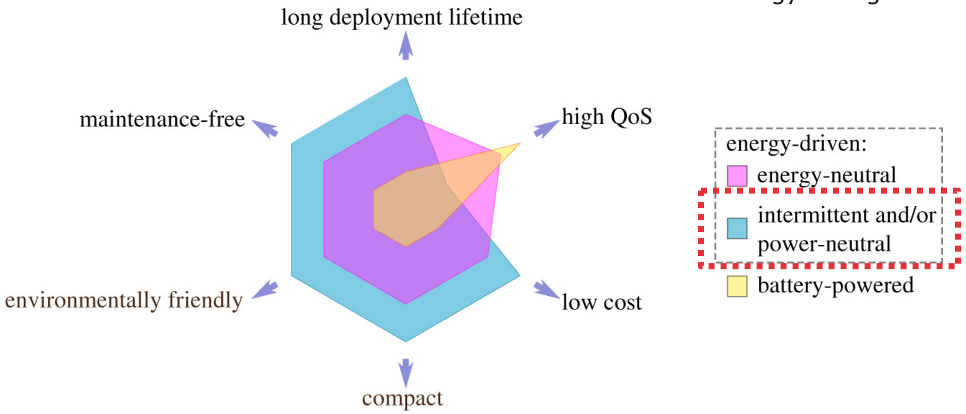


- Properties of energy storage devices (sustainability, maintenance, etc)

ENERGY-DRIVEN COMPUTING

- Rethinking the design of EH systems





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Section

Abstract

1. Introduction

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3. Intermittent computing systems

4. Unsolved challenges in energy-driven computing

5. Discussion

Data accessibility

Competing interests

Funding

Footnotes

Discussion

Energy-driven computing

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Abstract

For decades, the design of untethered devices has been focused on delivering a fixed quality of service with minimum power consumption, to enable battery-powered devices with reasonably long deployment lifetime. However, to realize the promised tens of billions of connected devices in the Internet of Things, computers must operate autonomously and harvest ambient energy to avoid the cost and maintenance requirements imposed by mains- or battery-powered operation. But harvested power typically fluctuates, often unpredictably, and with large temporal and spatial variability. Energy-driven computers are designed to treat energy-availability as a first-class citizen, in order to gracefully adapt to the dynamics of energy harvesting. They may sleep through periods of no energy, endure periods of scarce energy, and capitalize on periods of ample energy. In this paper, we describe the promise and limitations of energy-driven computing, with an

Details | References | Related | Figures

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PDF

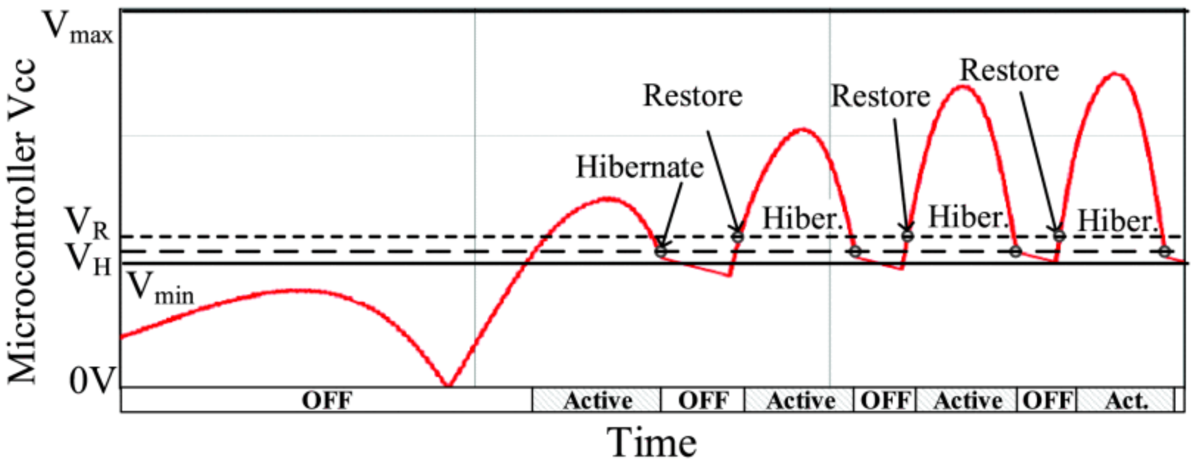
Help

ENERGY-DRIVEN COMPUTING

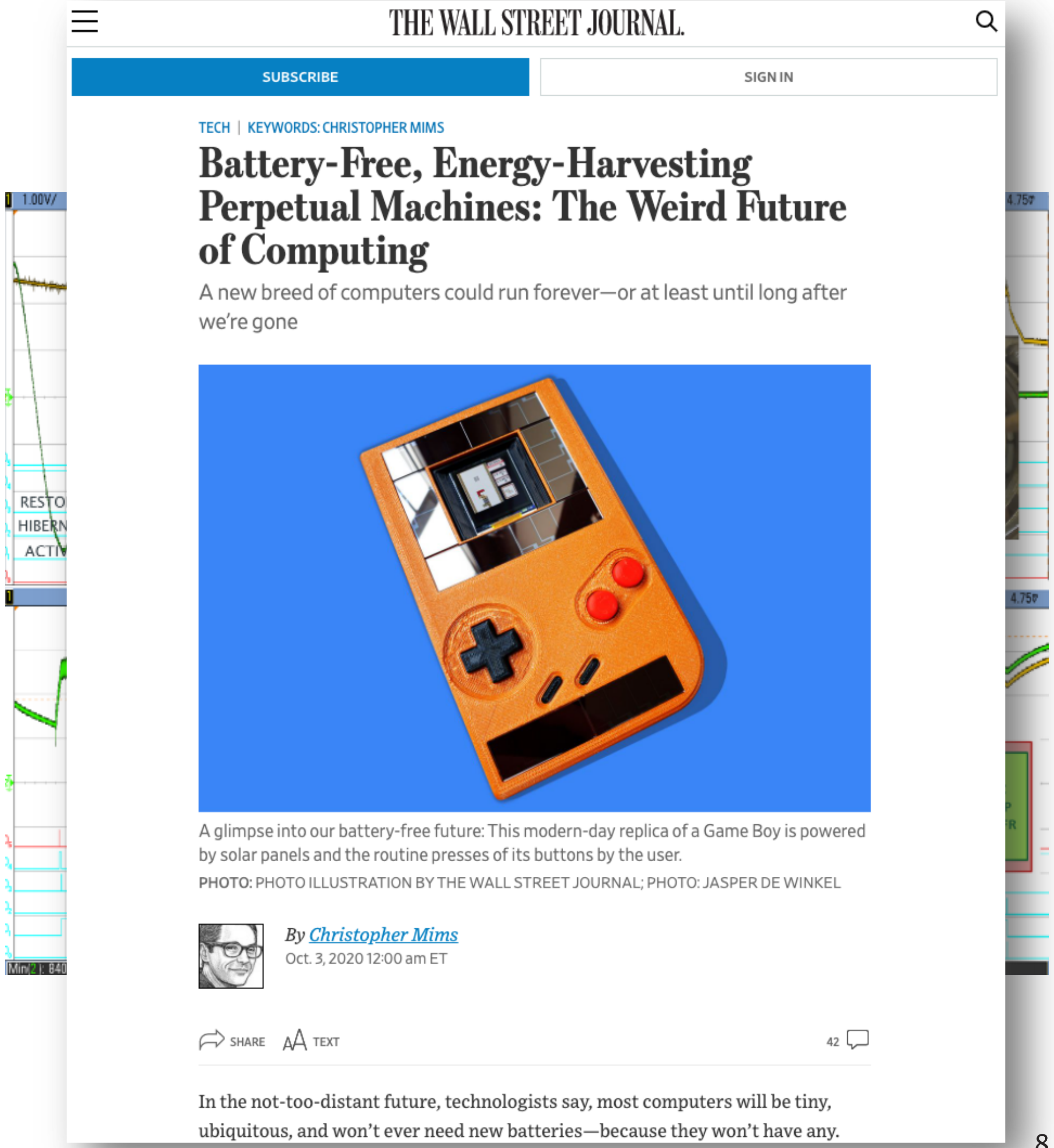
INTERMITTENT COMPUTING

Simplify the system; design for intermittency

Compute across power outages



D. Balsamo, A.S. Weddell, A. Das, A. Rodriguez Arreola, D. Brunelli, B.M. Al-Hashimi, G.V. Merrett, L. Benini, (2016) Hibernus++: a self-calibrating and adaptive system for transiently-powered embedded devices. *IEEE TCAD*, 1-13.



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TECH | KEYWORDS: CHRISTOPHER MIMS

Battery-Free, Energy-Harvesting Perpetual Machines: The Weird Future of Computing

A new breed of computers could run forever—or at least until long after we're gone

A glimpse into our battery-free future: This modern-day replica of a Game Boy is powered by solar panels and the routine presses of its buttons by the user.

PHOTO: PHOTO ILLUSTRATION BY THE WALL STREET JOURNAL; PHOTO: JASPER DE WINKEL

By Christopher Mims

Oct. 3, 2020 12:00 am ET

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In the not-too-distant future, technologists say, most computers will be tiny, ubiquitous, and won't ever need new batteries—because they won't have any.

INTERMITTENT COMPUTING

Compute/Memory

- Self calibration for runtime threshold optimisation (*hibernus*++)
- Adaptive restore based on EH properties (*hibernus*++)
- Efficient state retention (Selective Policies, *ManagedState*)
- Fine-grained power adaption (*PowerNeutrality*)

Peripherals/Sensors/Communication

- Hibernation and restore of external peripheral state (*RESTOP*)
- Support for communication and mesh networking

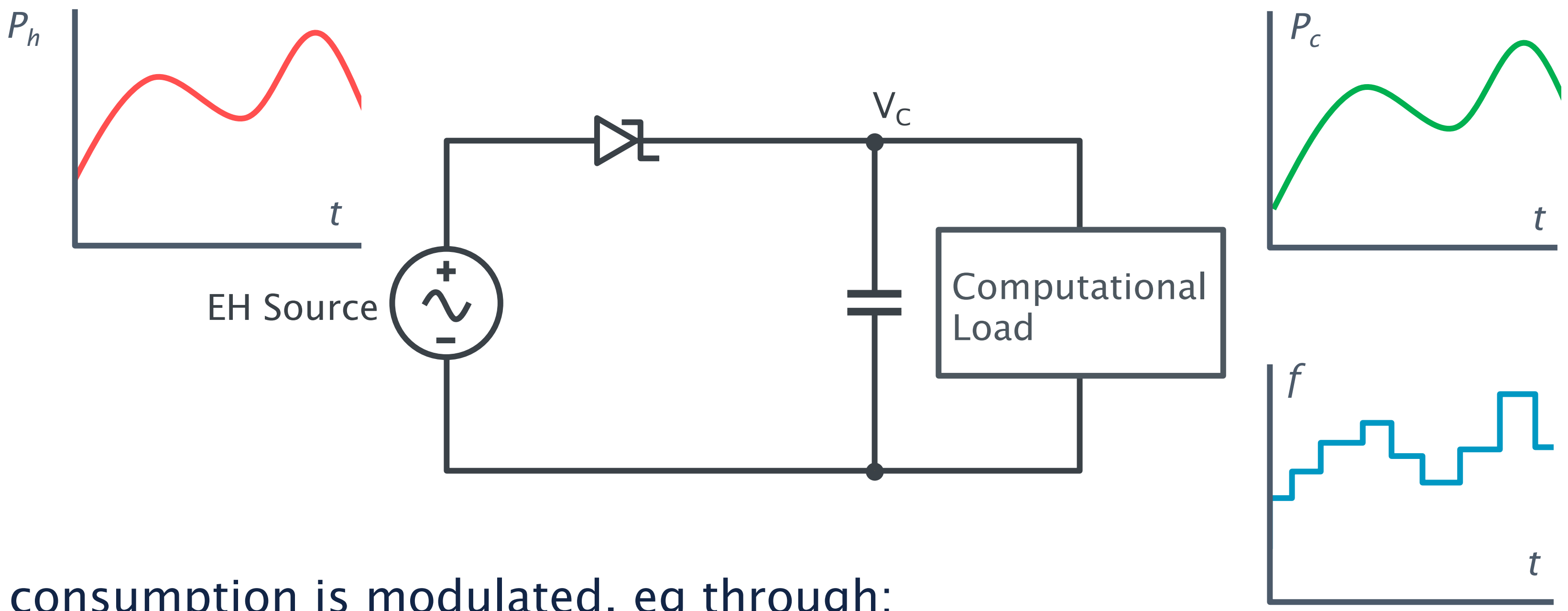
Applications/Users/Interfaces/Design Tools

- Application case studies, e.g. cycle computer, fitness monitor, wall clock, etc
- Design tools, e.g. *ENSPECT*, *FUSED*, Device Sizing, Support for *Arm Mbed*

www.transient.ecs.soton.ac.uk

POWER NEUTRAL COMPUTING

- In Power-Neutral computing, $P_c(t) \cong P_h(t)$
- We can approximate power-neutral behaviour if $V_C(t) \approx k \ , \ \forall t$

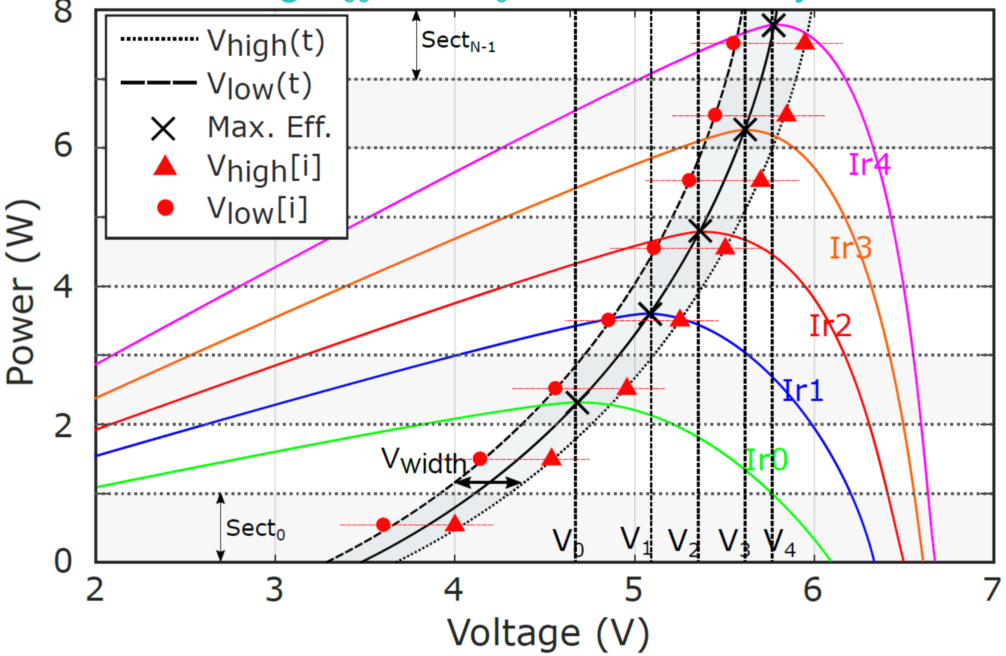


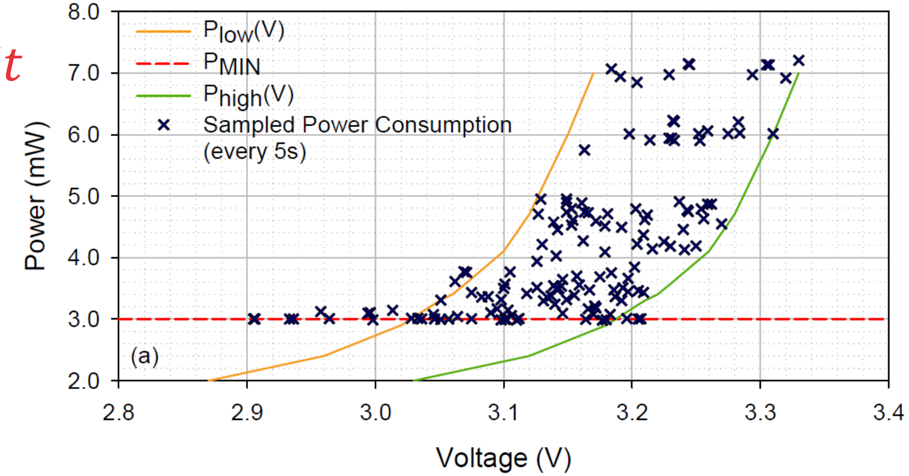
- Power consumption is modulated, eg through:
  - Core frequency and/or voltage
  - Power gating processor elements

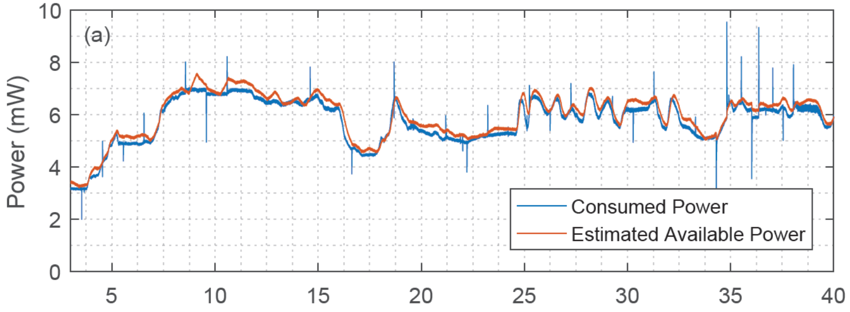
POWER NEUTRAL COMPUTING

- What happens if V_C remains constant ($V_C(t) \approx k\ ,\ \forall t$)?
- MPPT approaches are needed as $V_C(t) \neq V_{H\_MPP}(t)\ ,\ \forall t$
- ‘Software-only’ MPPT modulates *k*: $V_C(t) = V_{H\_MPP}\ (t)$

Estimating V_{cc} and P_c, we can identify MPP





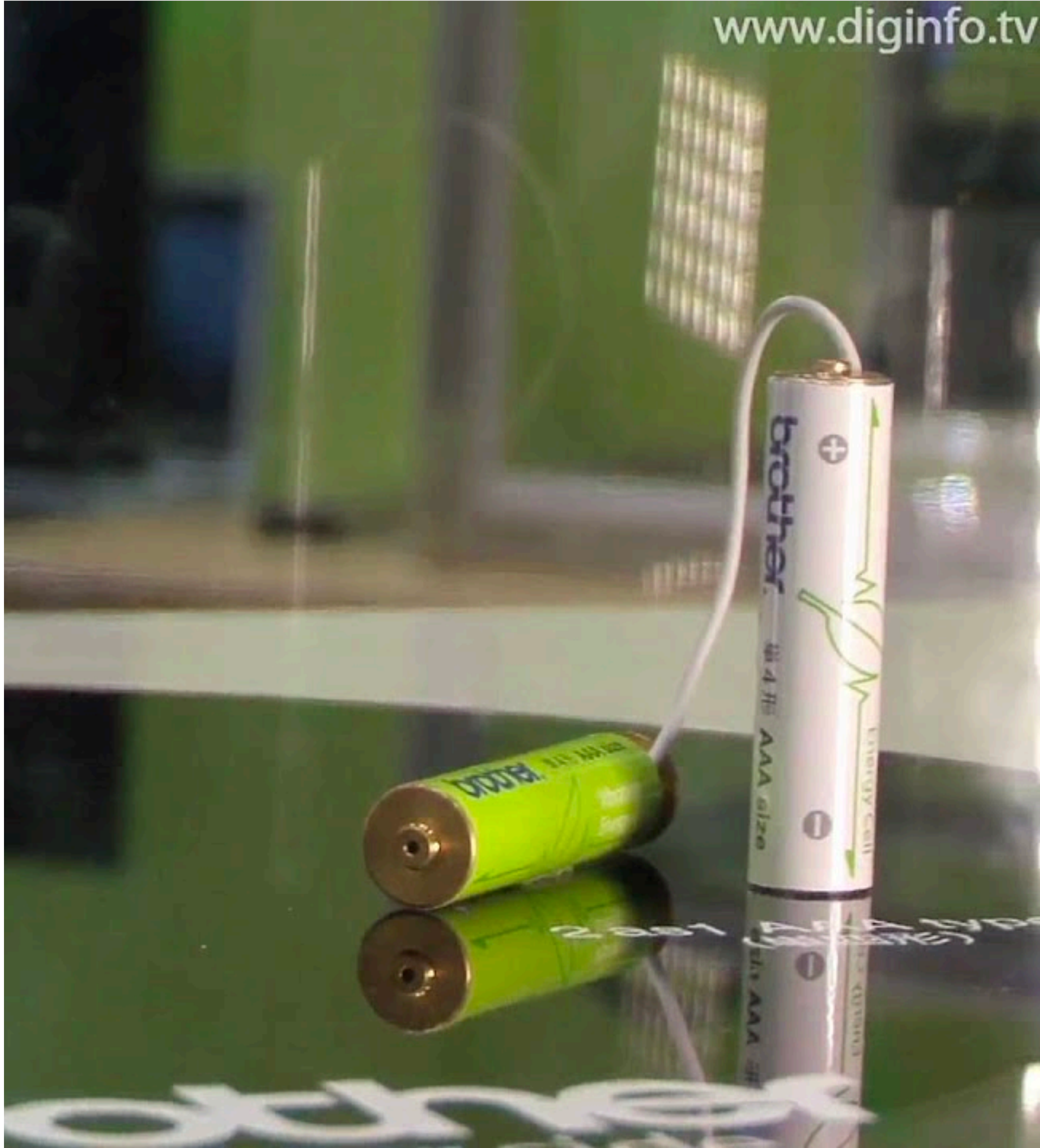


TI MSP430FR MCU

DISCUSSION

- We need to rethink the way that we design self-powered *systems*

- Progress is being made across all aspects of the system, but a wide range of challenges still exist



YOUR QUESTIONS

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