

Noninvasive Power Metering for Mobile and Embedded Systems

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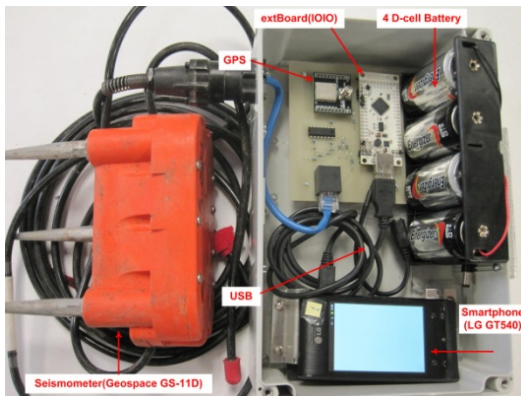
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Mobile & Embedded Systems

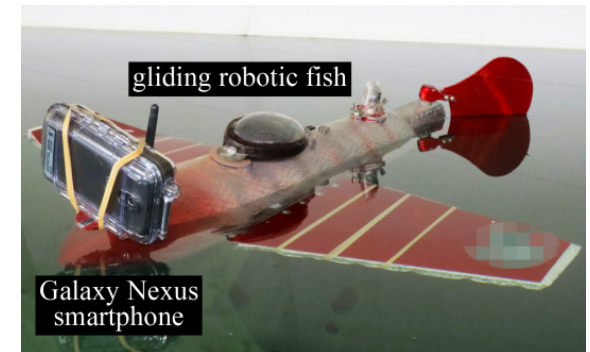
- Smartphones, tablets, wearables...
- Embedded sensor systems
 - Motes, Gumstix, etc.
- Smartphone-based embedded systems



Smartphone-based seismic sensor



Tungurahua deployment, 7/2012



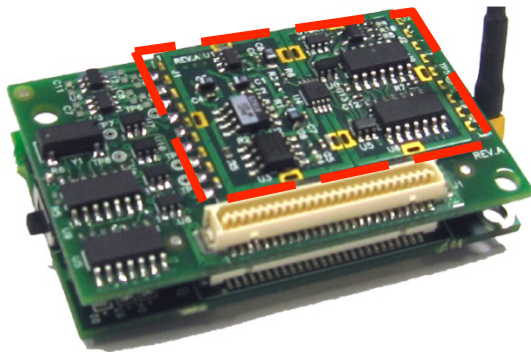
Smartphone-based robotic sensor for aquatic monitoring

Motivation for Power Metering

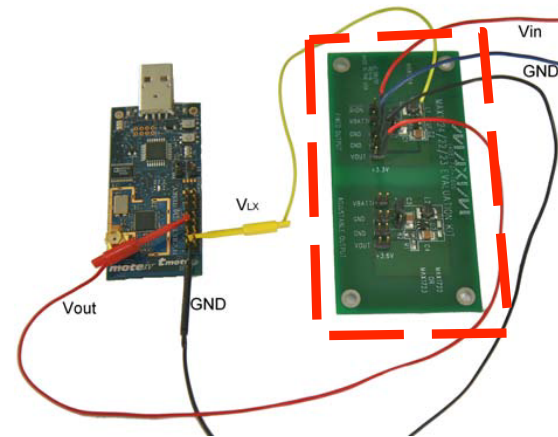
- **In-Situ power meters**
 - Measure power consumption in real-time
- **Evaluate claims of existing power saving solutions**
- **Provide hosts feedback for runtime adaptation**
- **Challenges for mobile & embedded systems**
 - Diverse and compact form factors
 - 1uA-100mA dynamic range, high resolution, KHz high sampling rate

State of the Art

- **SPOT[IPSN'07], iCount[IPSN'08]**
- **Low sampling rate/resolution**
 - Cannot capture sleep power consumption or power transients



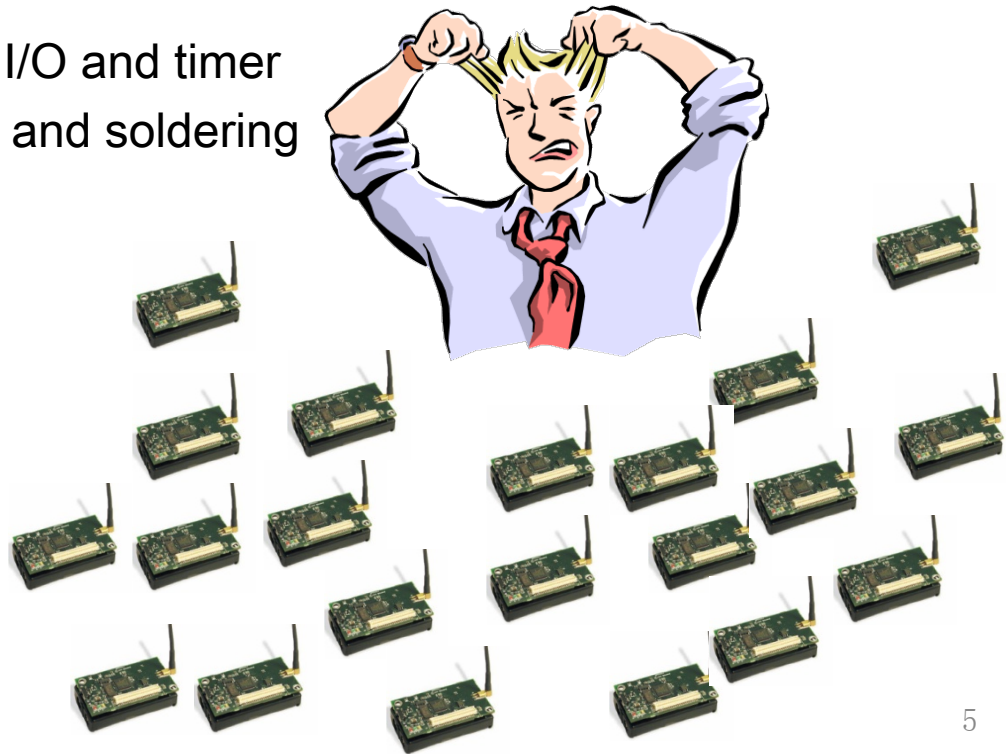
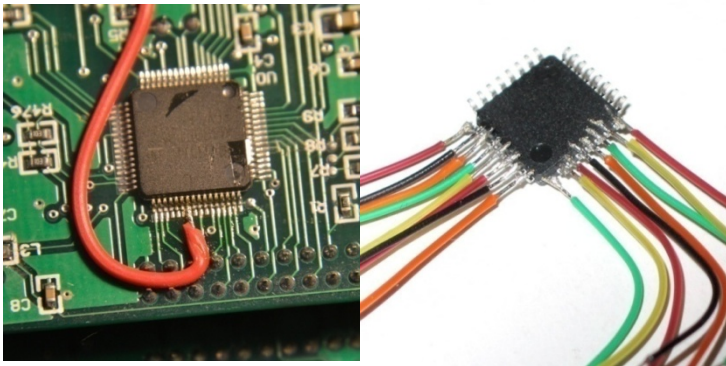
SPOT mounts on MicaZ



iCount with Telos

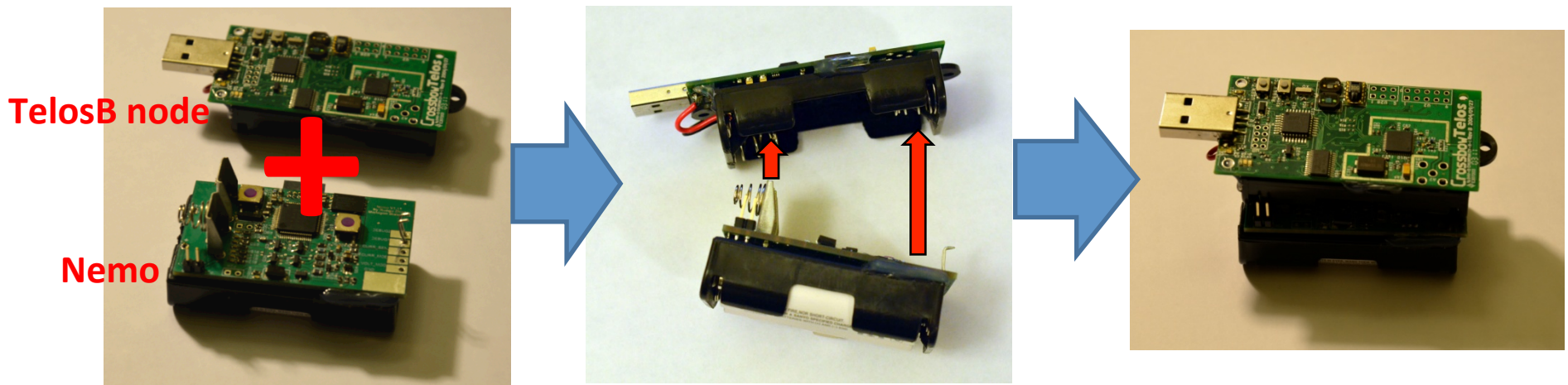
State of the Art

- **SPOT[IPSN'07], iCount[IPSN'08]**
- **Low sampling rate/resolution**
 - Cannot capture sleep power consumption or power transients
- **Invasive to host node**
 - Require host CPU, RAM , I/O and timer
 - Installation requires wiring and soldering



A High-Fidelity Noninvasive Power Meter

- Retrofit after-market platforms w/ power metering
- Noninvasive to host node
 - Standalone meter, plug & play, work with virtually any platform
- High measurement fidelity
 - 10^5 (1uA-100mA) dynamic range, >5 KHz sampling rate, <1uA resolution

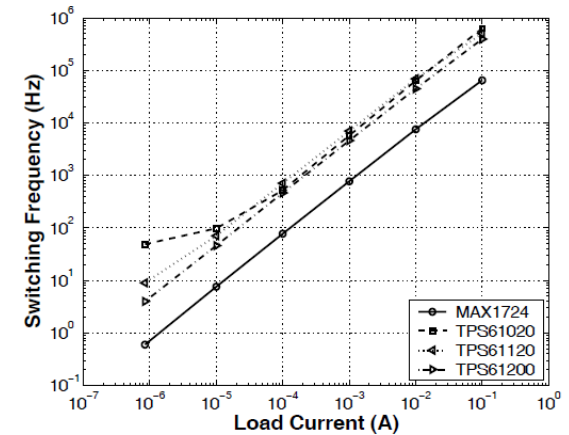


A High-Fidelity Noninvasive Power Meter

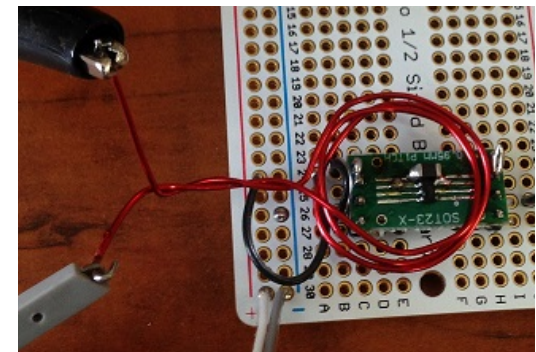
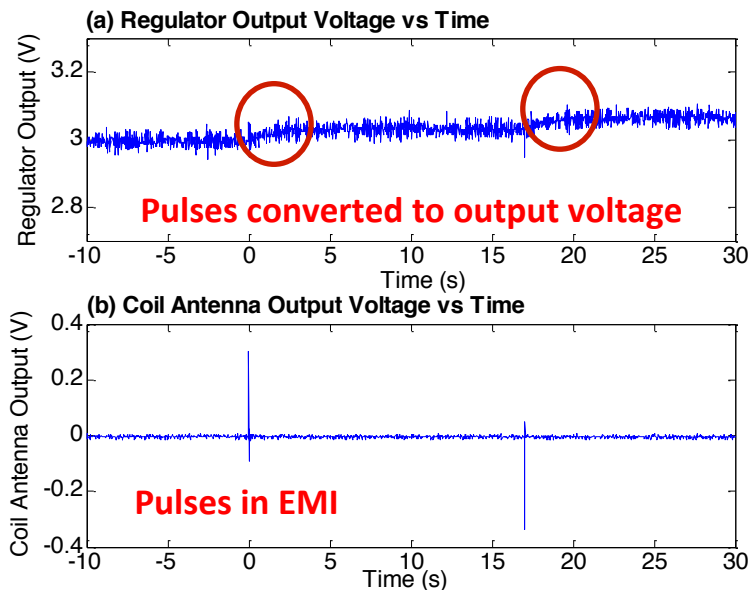
- **Retrofit after-market platforms w/ power metering**
- **Noninvasive to host node**
 - Standalone meter, plug & play, work with virtually any platform
- **High measurement fidelity**
 - 10^5 (1 μ A-100mA) dynamic range, >5 KHz sampling rate, <1 μ A resolution
- **Real-time communication with host**
 - Enable real-time monitoring and energy-aware runtime adaptation
 - **Modulate supply voltage of host to transmit measurements**
 - **Host decodes by sampling supply voltage**
 - Most built-in ADCs can be programmed to measure supply voltage

Contactless Power Meter for Mobiles

- **Smartphone's built-in power metering**
 - A few smartphones have hardware power meters
 - Low sampling rate (A few Hz), large errors (mA)
- **Infer device power consumption from EMI**
 - Linear relationship b/w pulse frequency and pwr
- **Measured EMI vs power**
 - Max1724 regulator; loop antenna to pick up EMI
 - Pulses in EMI is correlated /w output power

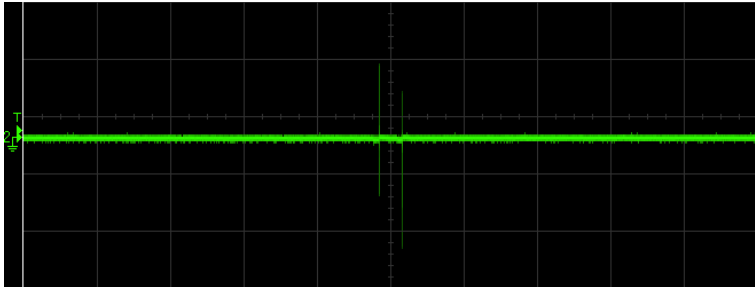


Current Load vs Switching Frequency
iCount [IPSN'08]



Max1724 regulator and loop antenna

EMI vs Current

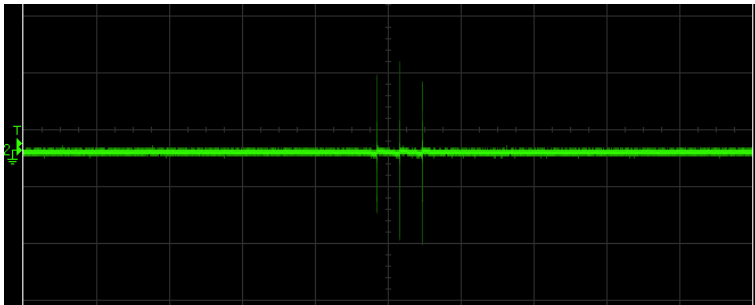


Switching Freq.

Current

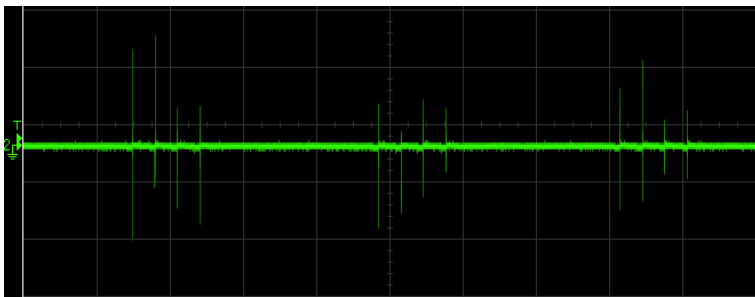
10Hz

0.05mA



990Hz

1mA



31KHz

30mA

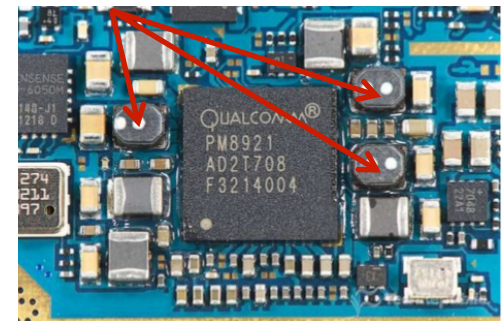
Conclusion

- **In-Situ power metering for mobile & embedded systems**
 - System debugging and runtime feedback
 - Challenging due to compact factors, wide dynamic range, etc.
- **New noninvasive power meter design**
 - Utilize voltage/current modulation for host-meter communication
 - Utilize EMI for contactless power measurement

Switching Regulator

- **Adopted in nearly all modern battery powered devices**
 - Small and energy-efficient
 - Generate stable voltages from battery
- **Operation Principle (PFM regulators)**
 - Generate pulses from input voltage
 - Each pulse contains a fixed amount of energy
 - Inductors convert pulses to a stable output voltage

Inductors



Power management circuit on smartphone motherboard

- **Pulses create EMI**
 - Radiate via inductors
 - EMI contains the pulses signals

