Energy Monitoring Frameworks & Energy Harvesting in Sensor Networks

Presenting: Giannis Kazdaridis

Network Implementation Testbed Laboratory

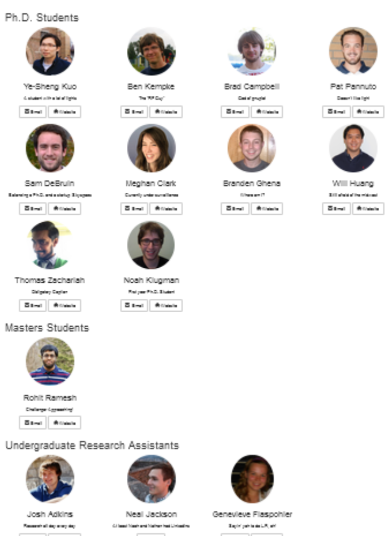
Date: 28/01/2015

CERTH

UNIVERSITY OF THESSALY

Prof. Prabal Dutta

Prabal Dutta

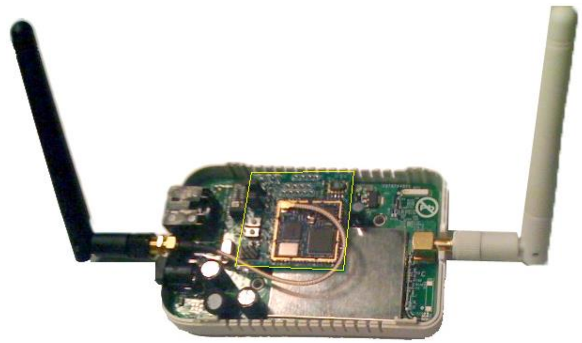


PhD & Ms students

- ✓ He earned a Ph.D. in Computer Science from the University of California, Berkeley (2009).
- ✓ Assistant Professor at the University of Michigan.
- ✓ Coordinator of the Embedded Systems Research Lab at the University of Michigan.
- ✓ He researches the circuits, systems, sensor networks, computing, and communications.
- ✓ Has won several design awards (ISLPED'10, ISLPED'08, PC Week's Comdex Best of Show).
- ✓ Has been commercialized by Aginova, Arch Rock (now Cisco), Crossbow (now Memsic), Moteiv (now Sentilla), Moteware, Sonnonet, and Vectare.

Prabal Dutta's Developments

Epic mote



Gateway node

Low-power SDR Platform

AC Energy Monitoring

CC2538 mote

Energy Harvesting (Solar)

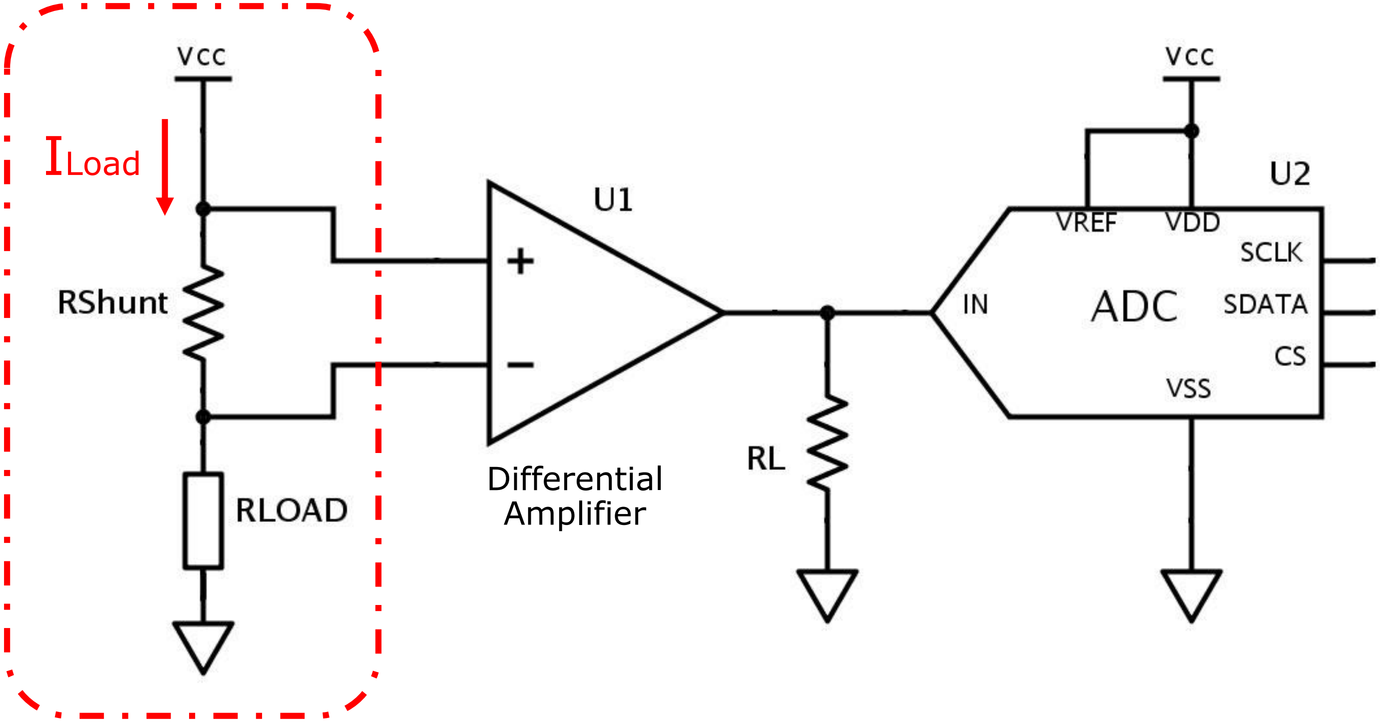
Presentation Outline

- ✓ Section 1: Energy Monitoring Frameworks
  - ✓ Basic principles in Energy Monitoring based on Current Shunt Monitors.
  - ✓ Micro Power Meter for Energy Monitoring of Wireless Sensor Networks at Scale.
  - ✓ Improvements in NITOS ACM.
- ✓ Section 2: Energy Harvesting in Sensor Networks
  - ✓ Basic Energy-Harvesting Thermoelectric Sensing for Unobtrusive Water and Appliance Metering.

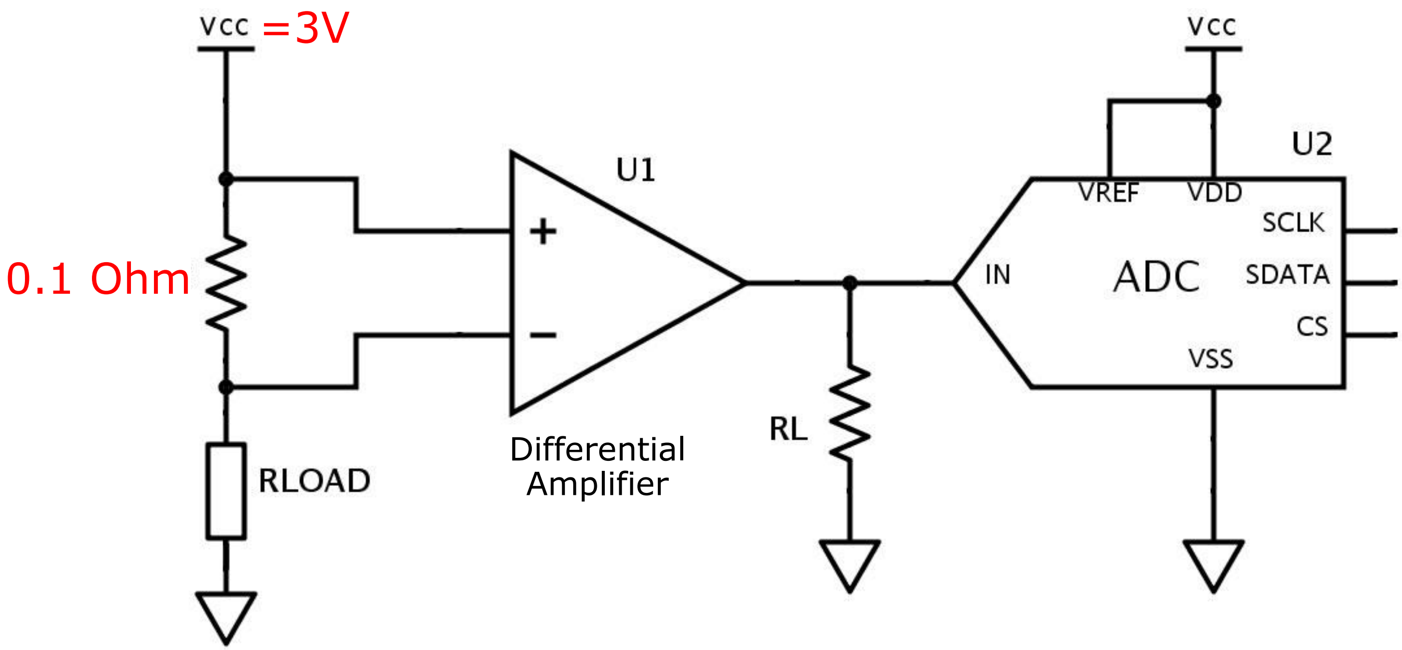
Motivation

- ✓ Unprecedented penetration of mobile devices in everyday life.
- ✓ It is vital to minimize the power consumption of mobile devices in order to extend battery's duration.
- ✓ Inability of existing models to accurately estimate energy consumption even in non-composite scenarios.
- ✓ Researchers need accurate tools/methods to evaluate the power consumption profile of their devices, algorithms and protocols.

Basic Principles in Energy Monitoring

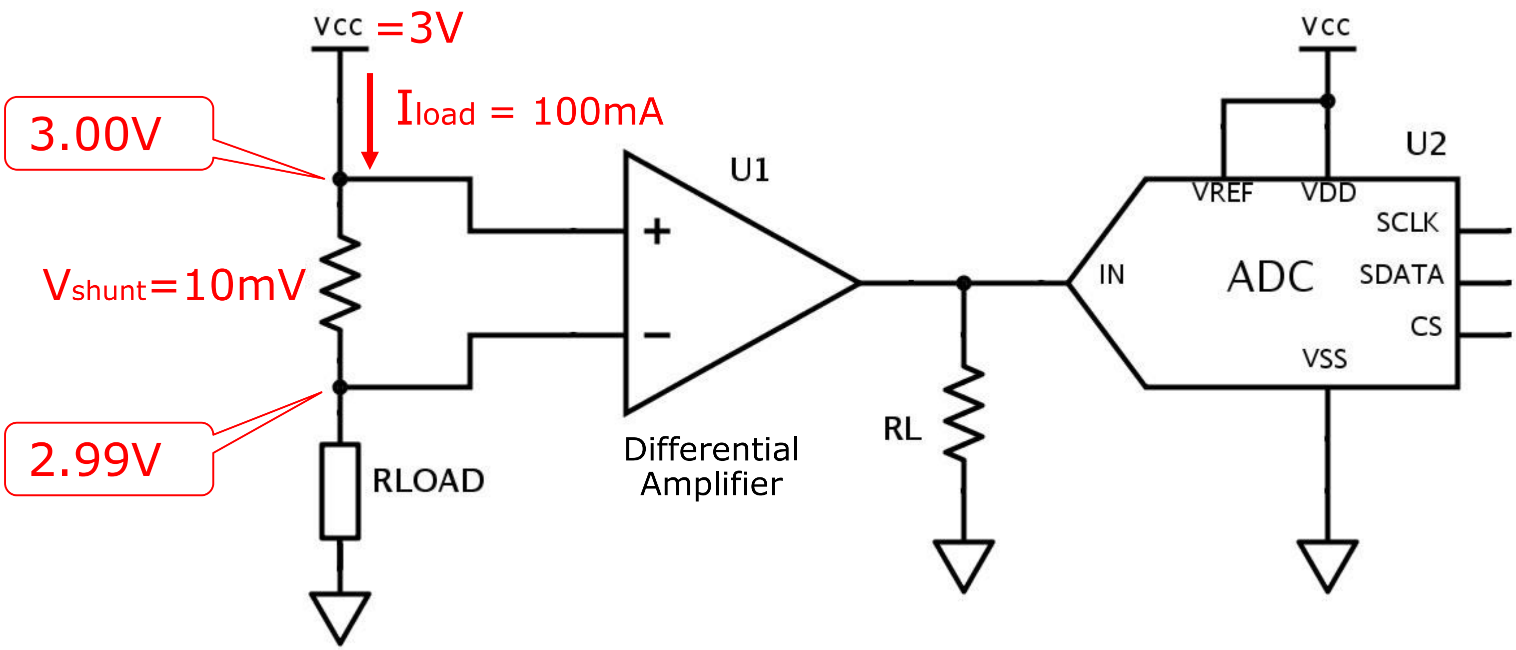


Basic Principles in Energy Monitoring

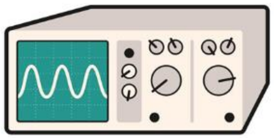


Basic Principles in Energy Monitoring

- ✓ Considering that the instantaneous power consumption of RLOAD is 100mA the voltage drop on the Shunt Resistor will be 10mV.

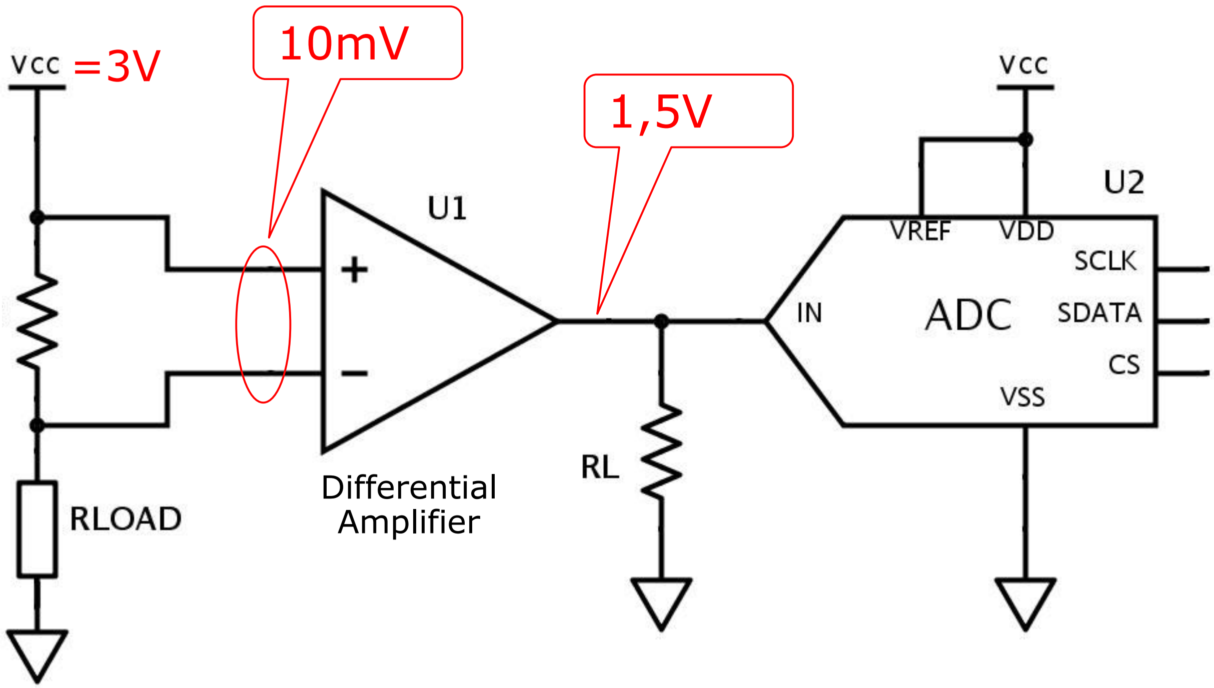


- ✓ We need a fast sampling device to continuously monitor and record the voltage on the shunt resistor.



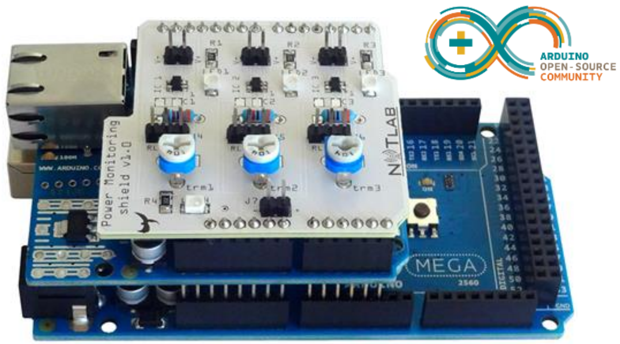
Basic Principles in Energy Monitoring

- ✓ Considering a Differential Amplifier configured to provide a gain of 150.

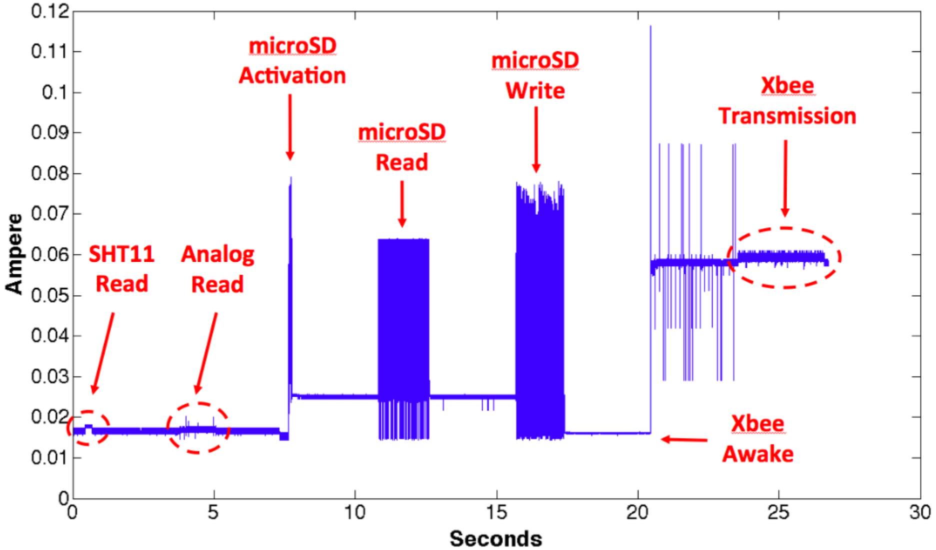


NITOS EMF

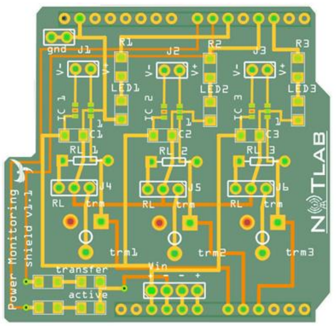
- ✓ We have already implemented an Energy Monitoring Framework based on the aforementioned principles.



NITOS Energy Monitoring Device



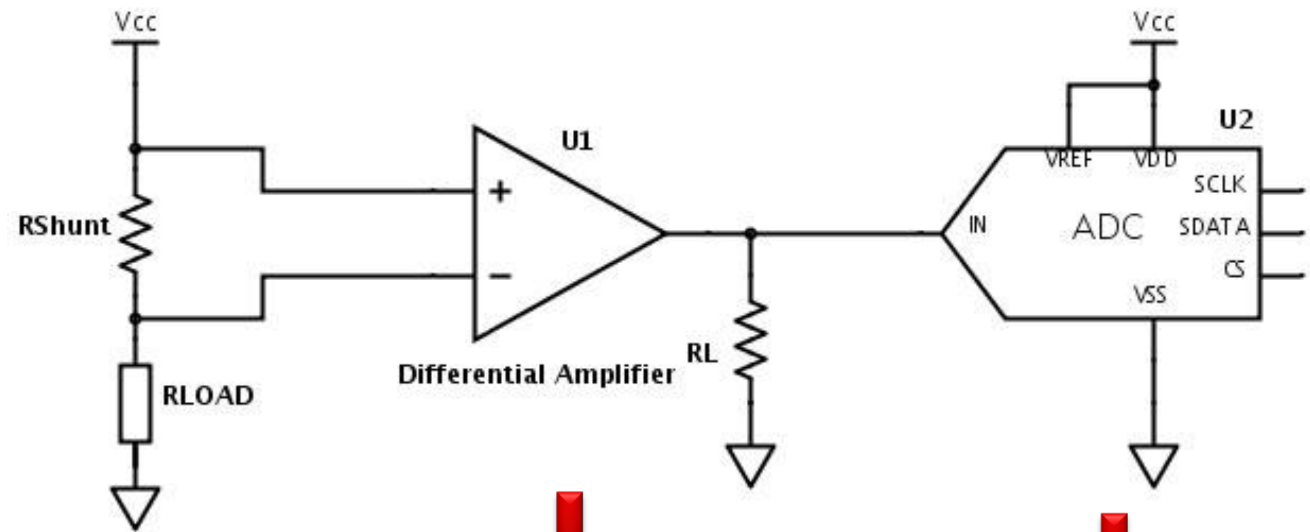
Power Consumption of Bicycle’s Sensing Device

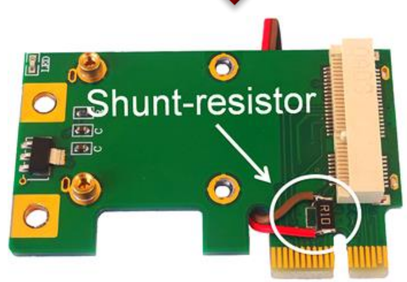


Designed PCB

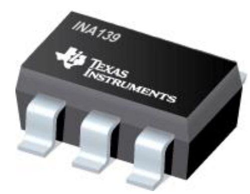
- ✓ Published in WinTech 2013
- ✓ Authors: S. Keranidis, G. Kazdaridis, V. Passas, T. Korakis, I. Koutsopoulos and L. Tassiulas

NITOS EMF

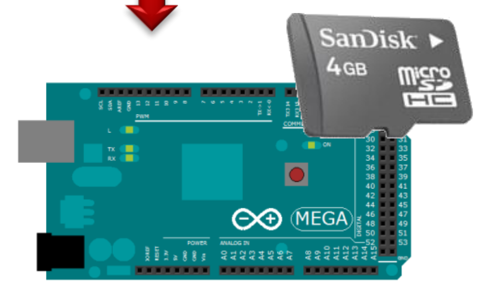




Wireless Interface Adapter



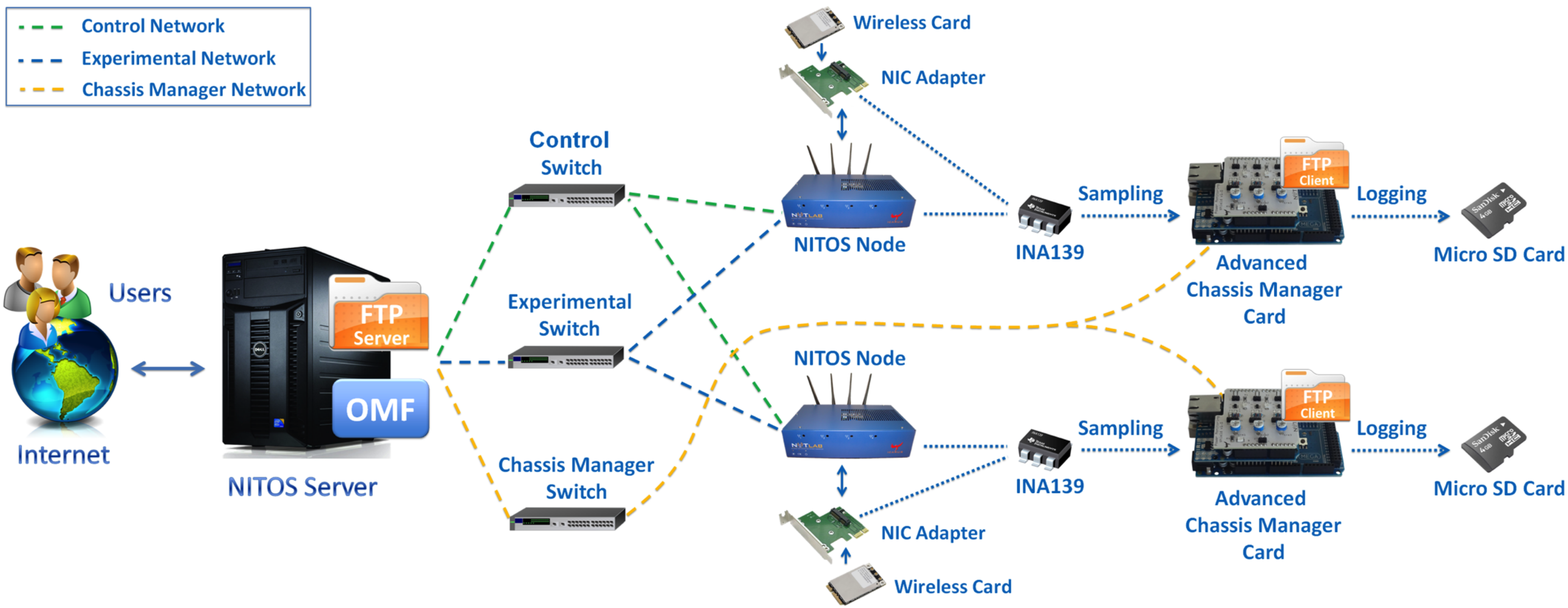
INA139
(Differential
Amplifier)



Arduino Board
(embedded ADC)

NITOS EMF Architecture

Integration with NITOS Testbed architecture



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Dutta’s Power Meter

Title:

Micro Power Meter for Energy Monitoring of Wireless Sensor Networks at Scale

Authors:

Xiaofan Jiang, Prabal Dutta, David Culler, and Ion Stoica

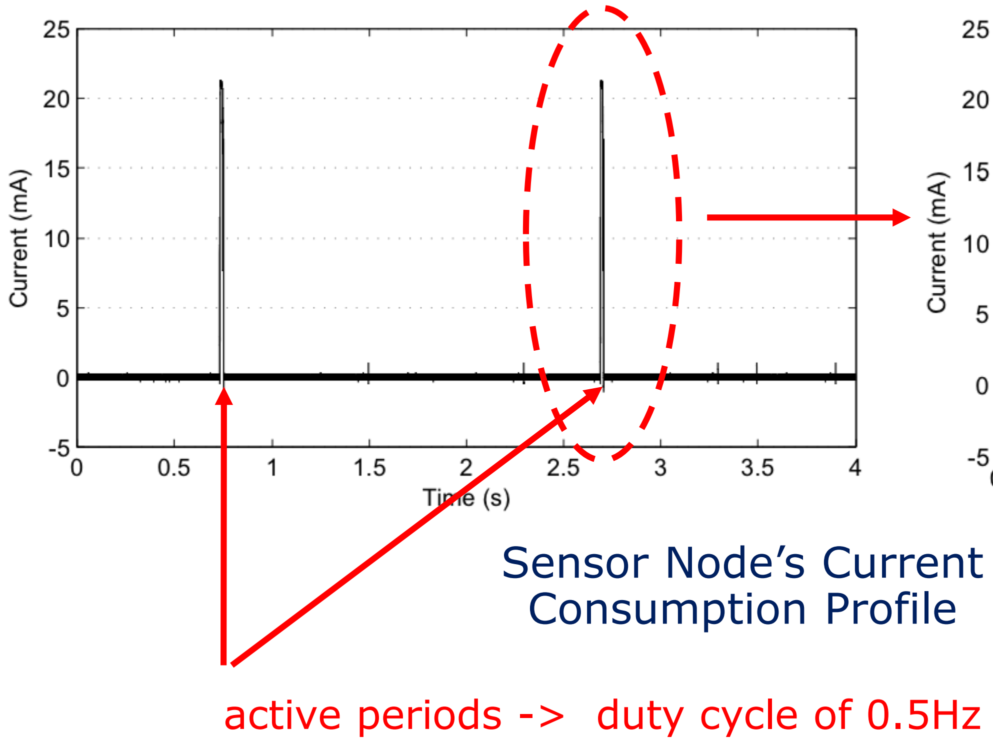
Dept. of Computer Science, University of California, Berkeley

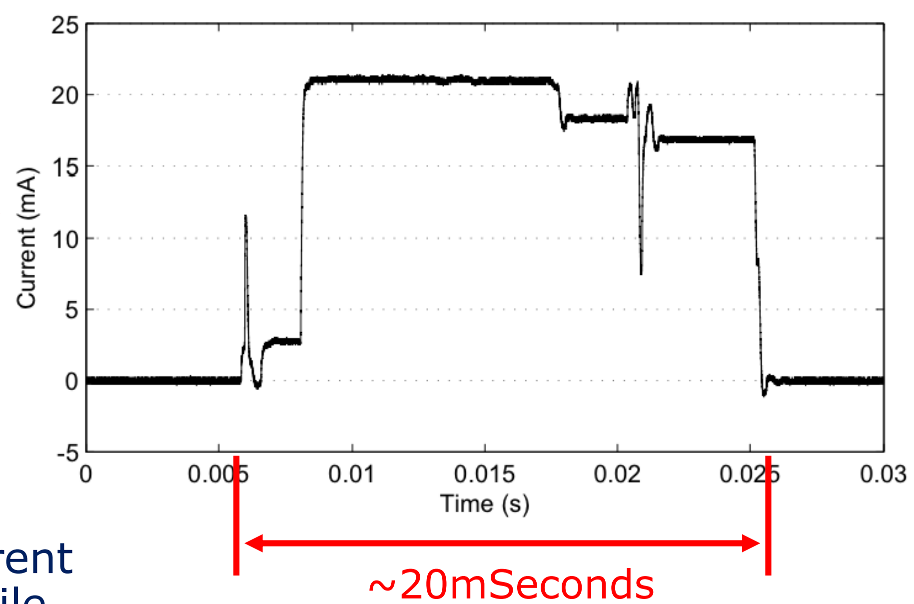
Conference:

Information Processing in Sensor Networks (IPSN) 2007

Typical nodal current profile

- ✓ Typical sensor node activity is characterized by long periods of low-current (sleep mode) that is intercepted by short periods of high-current (active mode).



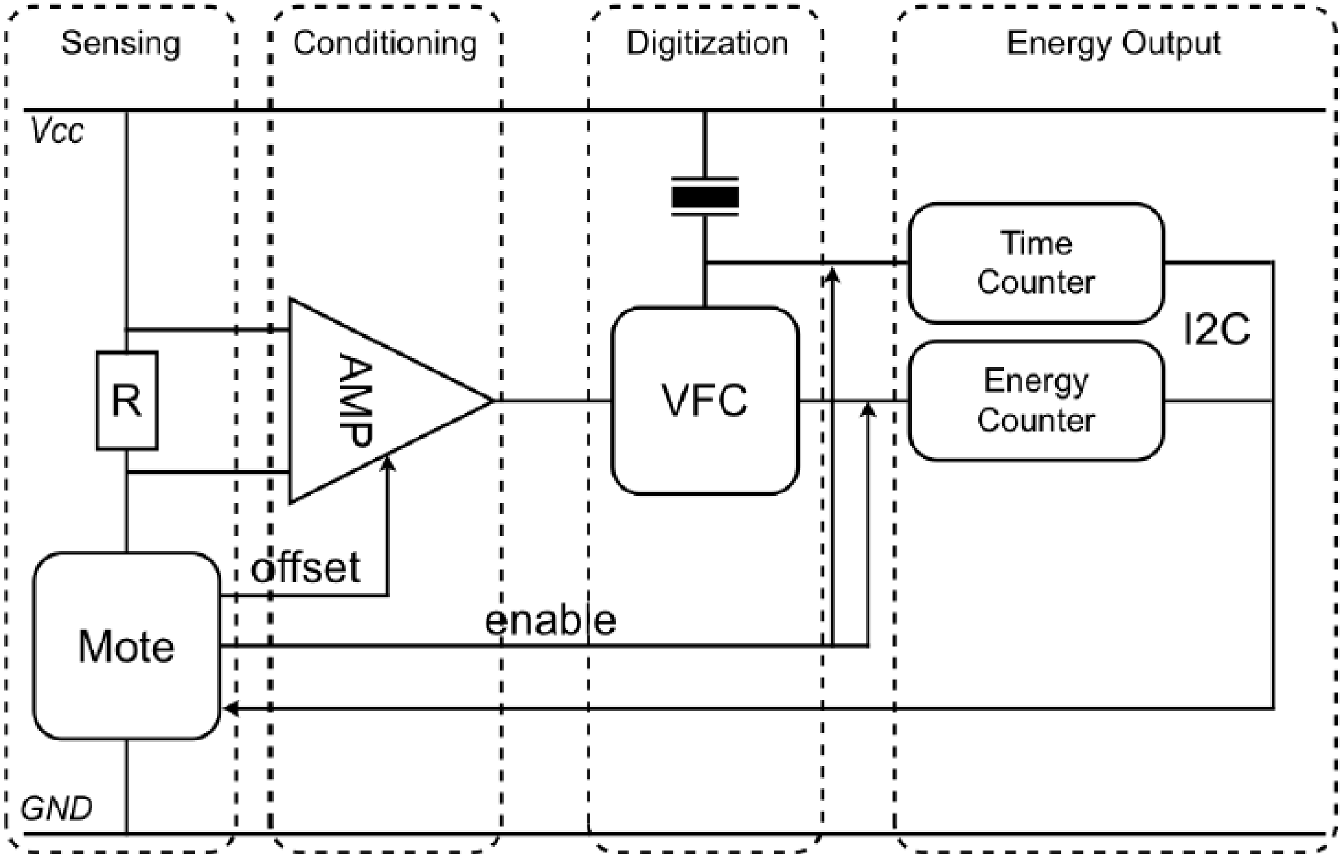


Sensor Node's Current Consumption Profile

Requirements

- Dynamic Range:
  - Since the current draw in **active** mode is up to **40mA**
  - And in **sleep** mode is **2uA**
  - A dynamic range of **10.000:1** is required.
- Sampling Rate:
  - Intuitively, we can see that to capture most of the energy content in the 20ms active cycle we need a frequency of 10kHz. (once every 0.1ms)
  - To capture the entire Power Spectral Density (PSD) we need 20kHz of sampling frequency, since there is placed a Low-Pass Filter (LPF) with cutoff frequency of 20kHz.
- Minimal perturbation to the device under test:
  - Device should not affect the measured device. (separate power source)
- Ease of Integration

Architecture



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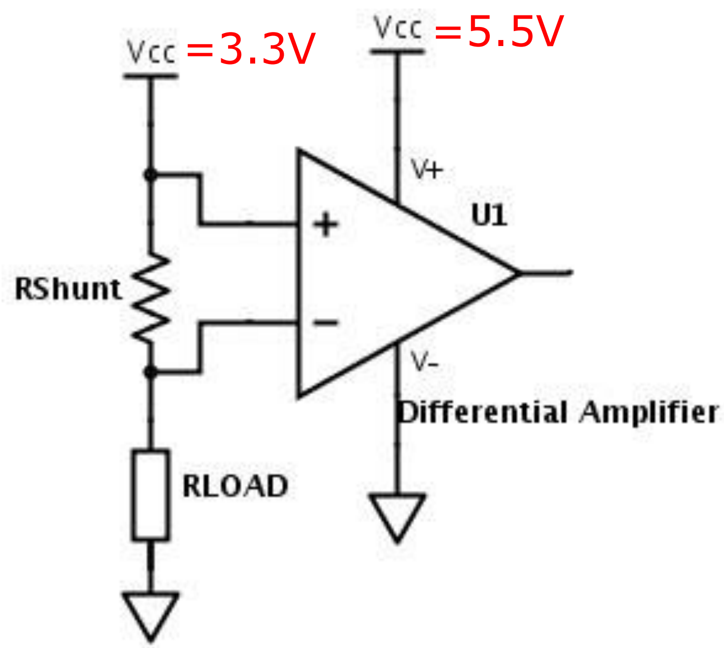
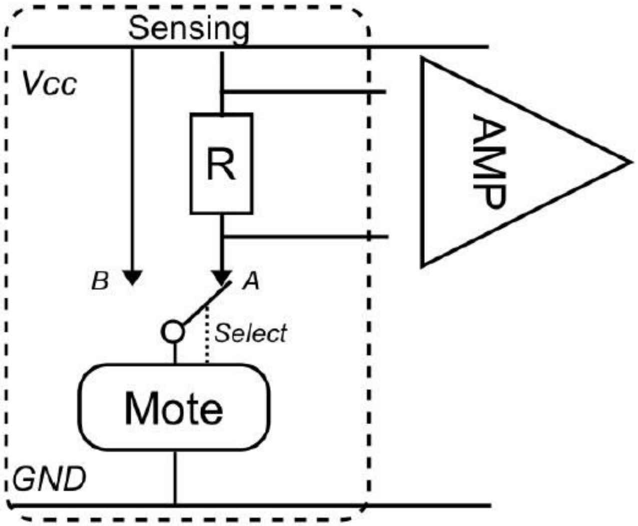
Differential Amplifier

- ✓ Need for second voltage supply to power the amplifier, higher than the voltage of the input signal.



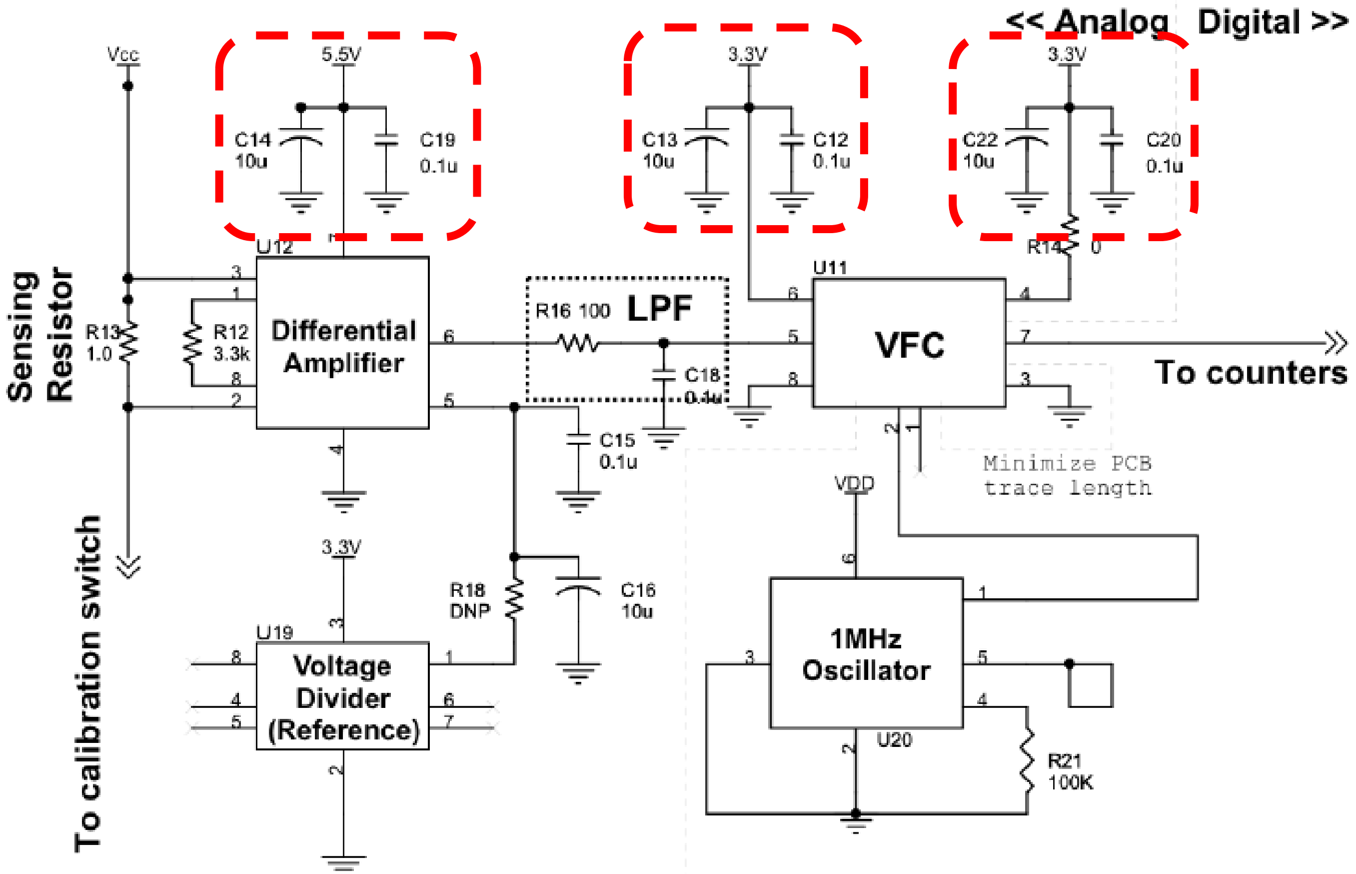
Differential Amplifier – Output Offset

- Differential amplifiers consists of pairs of **CMOS gates** which sizing are usually **not perfectly matched**.
- As a result, there will be **non-zero output** even when the input is zero, called **offset**.
- Authors subtract offset recorded in the output when input was set to zero.



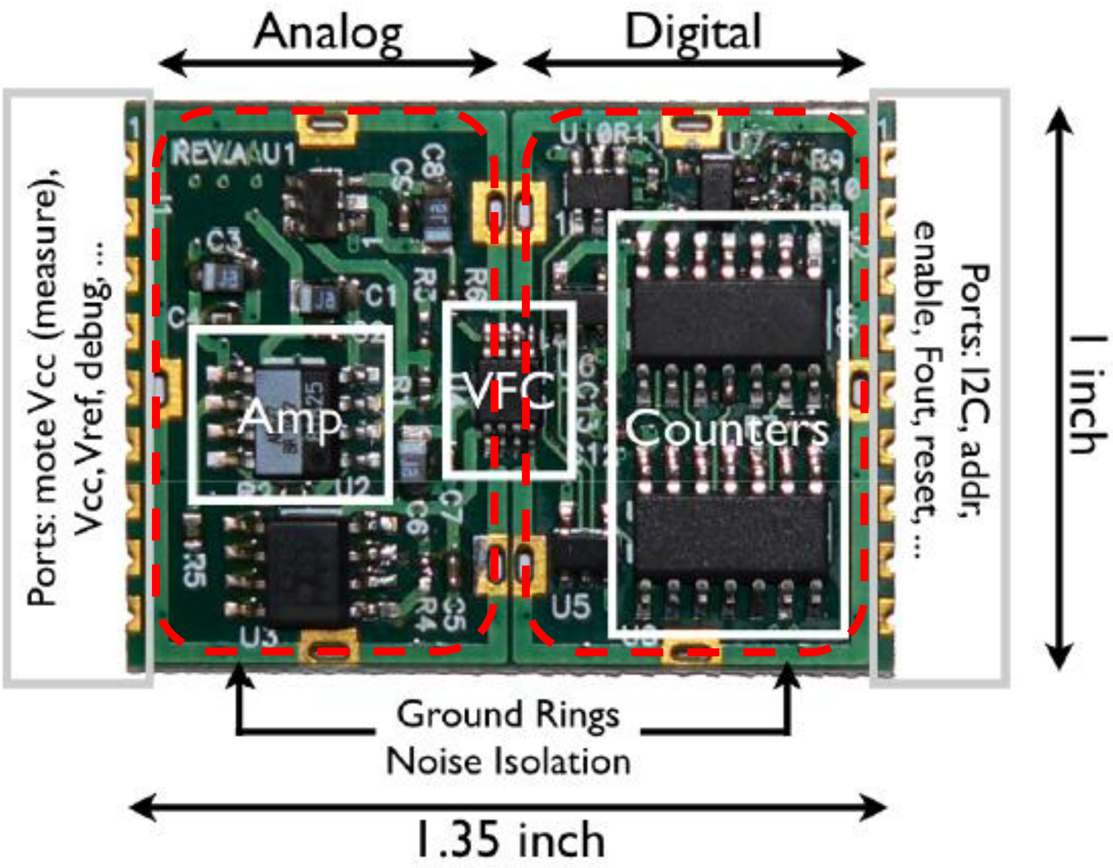
Effect of Noise

- To **reduce noise**, several filters have been placed around the chip power supply lines.



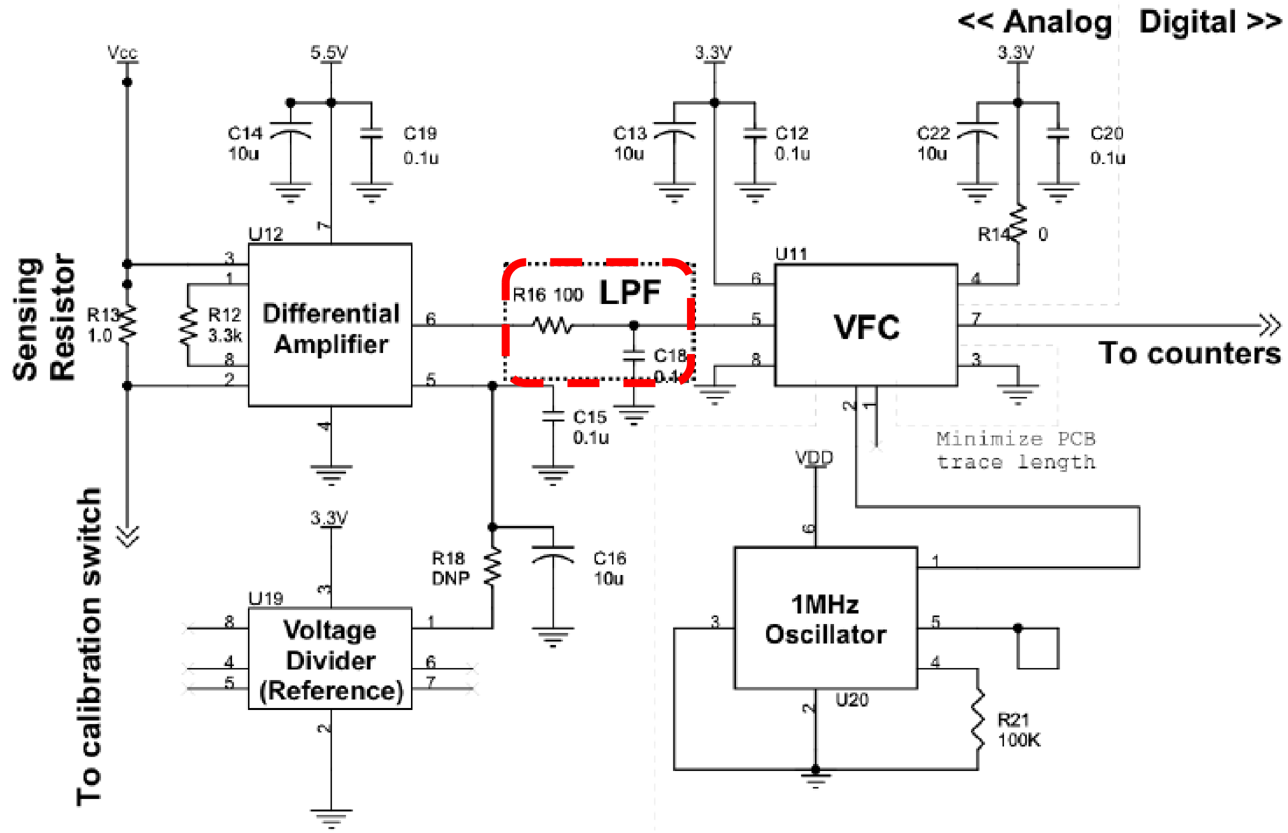
Effect of Noise

- ✓ Also **slotted ground guard rings** placed **around** the analog and digital circuits, in a way to separate them.



Low pass Filtering

- ✓ To **avoid false readings due to high frequency components** in the signal a Low-pass filter is placed between the amplifier and the VFC with a cutoff frequency of 20kHz.



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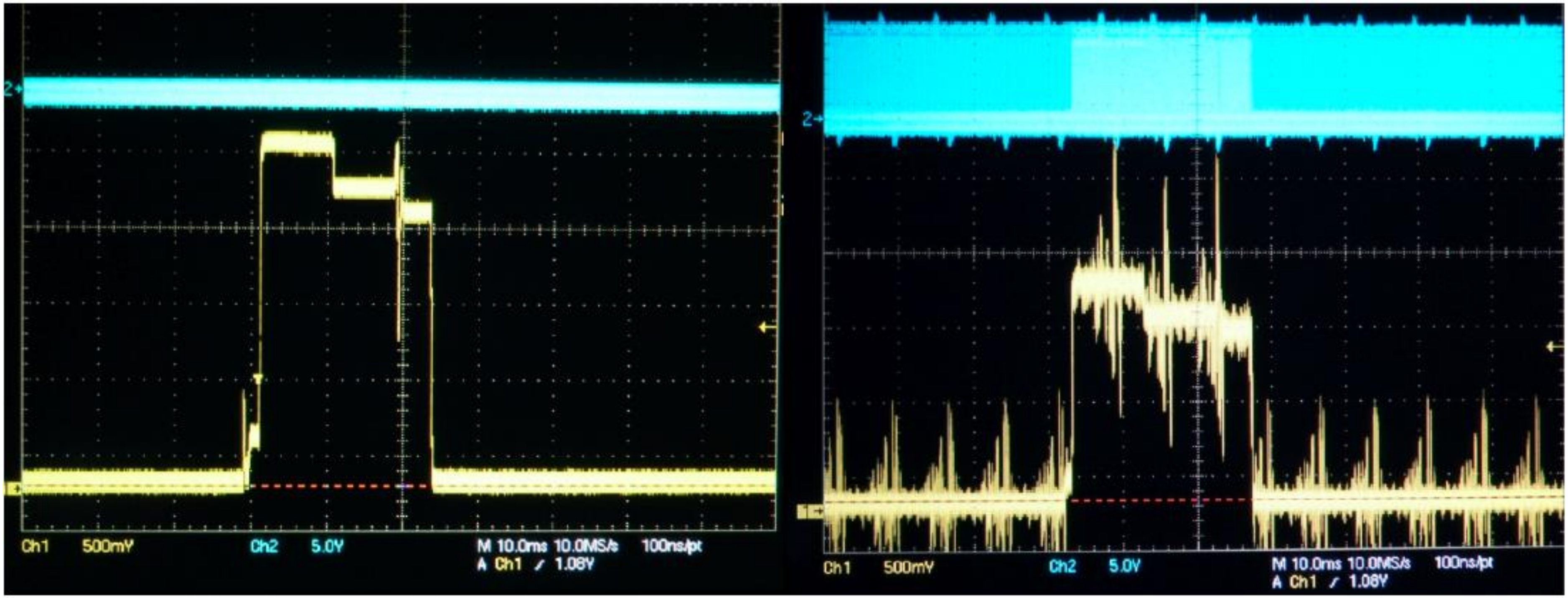
NITLAB NETWORK IMPLEMENTATION TESTBED LABORATORY

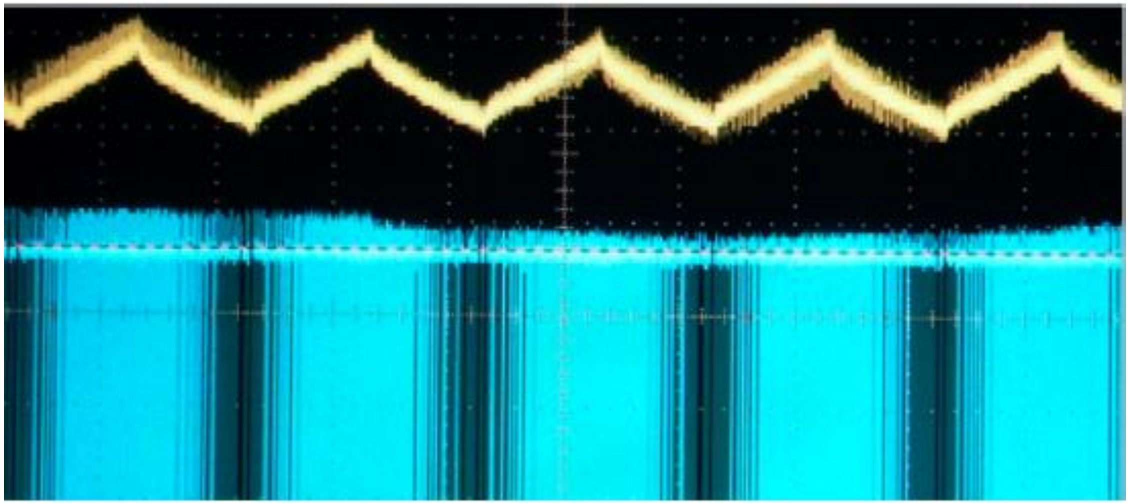
Low pass Filtering

✓ Elimination of noise introduced by the oscillator.

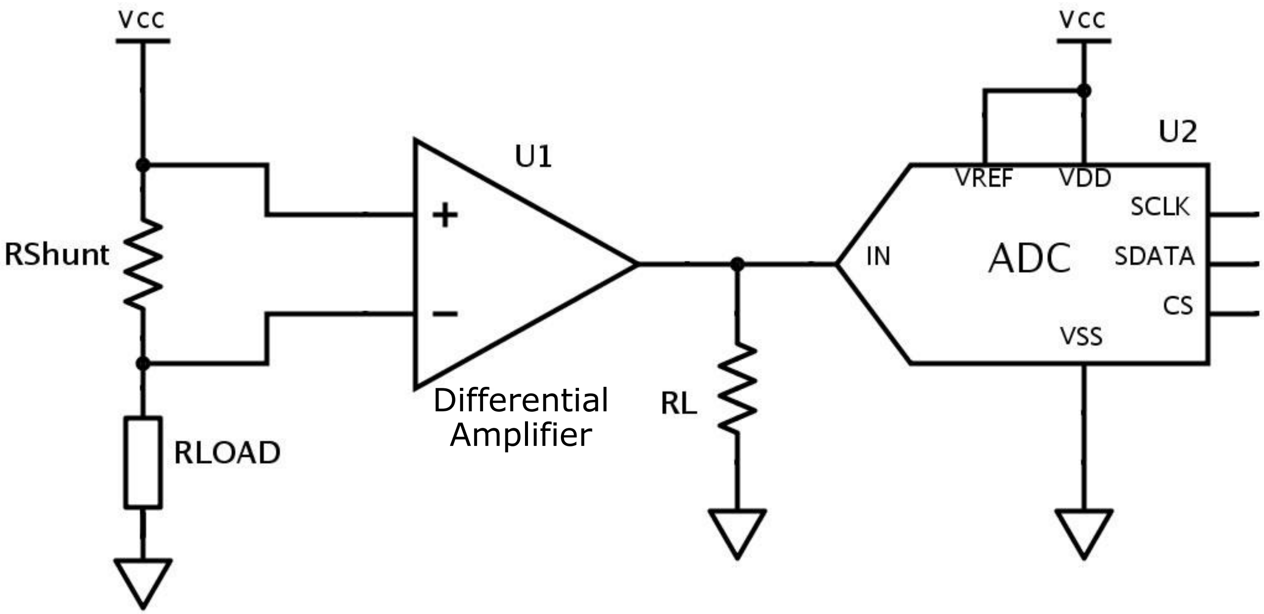


Voltage to Frequency Converter

- ✓ Instead of Digitizing the signal with the aid of an ADC authors used a Voltage to Frequency Converter (VFC).
- ✓ VFC is a low-cost device that outputs a simple digital pulse that represents the input voltage signal.



Improvements in NITOS ACM



- ✓ Calibrate Dif. Amplifier
- ✓ Bias the Dif. Amplifier
- ✓ Insert LPF
- ✓ Insert ground guard rings
- ✓ Place Noise Filters

- ✓ Seek for Differential Amplifiers with improved characteristics.
- ✓ Seek for external ADCs.
- ✓ Place buffer between Dif. Amplifier and ADC unit.

Differential Amplifier – Current Monitor

Current Shunt Monitors											
	Accuracy	Output	Power Supply	Input Offset	Gain	CMRR (dB)	package	Iq	Bandwidth	V Sense	Price
INA139	0.50%	Current	2.7-40V	1mV	1-100	120	sot-23	0.125	440kHz	??	1.86e
INA139QPW		Current	2.7-40V	1mV	1-100	120	tssop-8	0.125	440kHz	10-150mV	1.99e
INA210	1.00%	Voltage	2.7-26V	35uV		105dB			14kHz		
INA213				100uV		100			80kHz		
INA216		Voltage		100uV		90	too small		20kHz		
INA219		I2C		50uV		120		44			
INA223									25kHz		
INA226		I2C				140					3.5e
INA282	0.20%	Voltage	-14 to 80V	70uV		120		0.9	10kHz		2.72e
AD8210											
AD8217	0.10%	Buffered	4.5 to 80V	250uV		90	msop-8		500kHz		2.49e
AD8219	0.10%	Buffered	4.5 to 80V	200uV		94	msop-8		500kHz		2.40e
AD8418	0.20%	Buffered	-2 to 70V	250uV		90	msop-8		-		2.24e
LT6100	0.50%	Buffered	2.7-36V	300uV		120	msop		150kHz		2 pounds
LTC6800				100uV		116					

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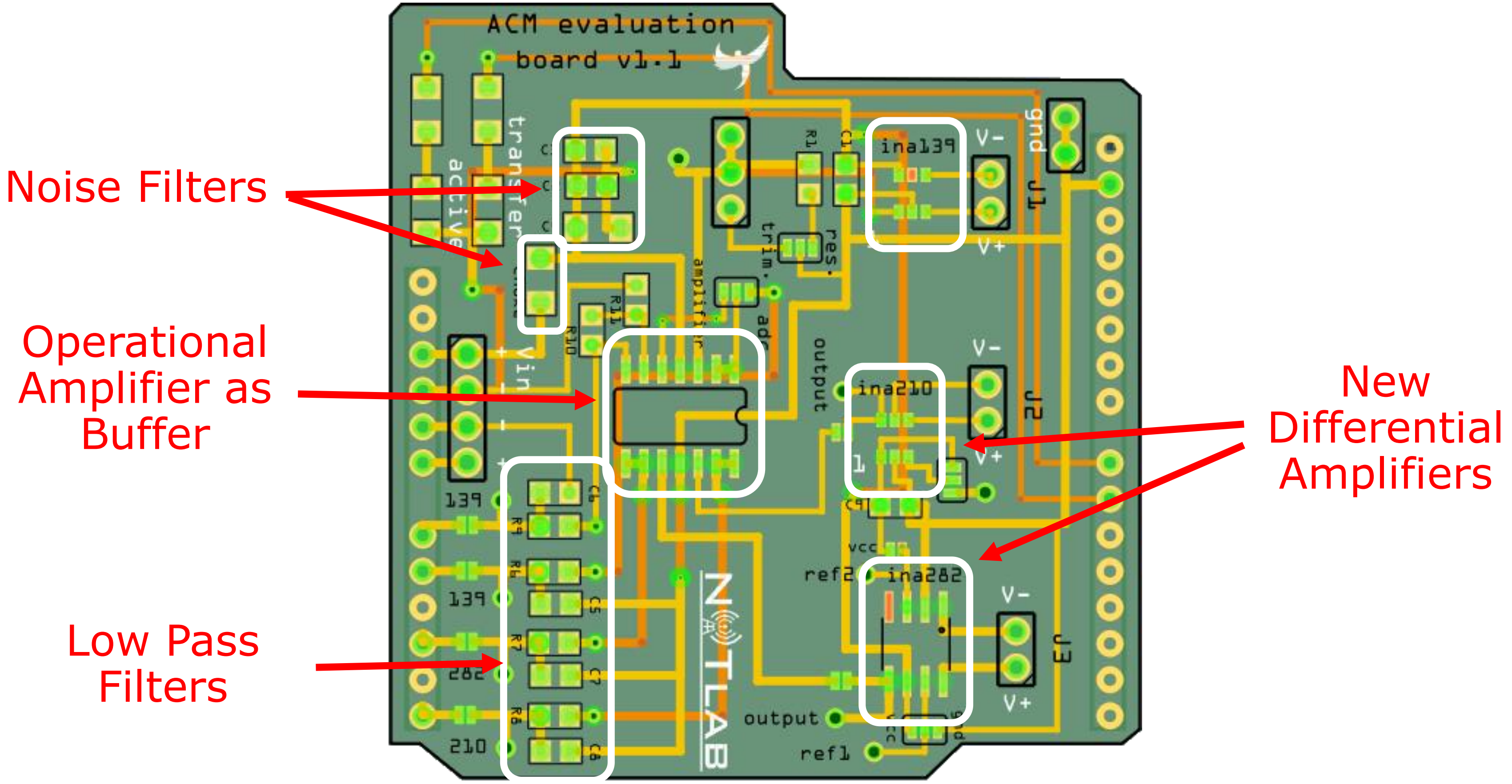
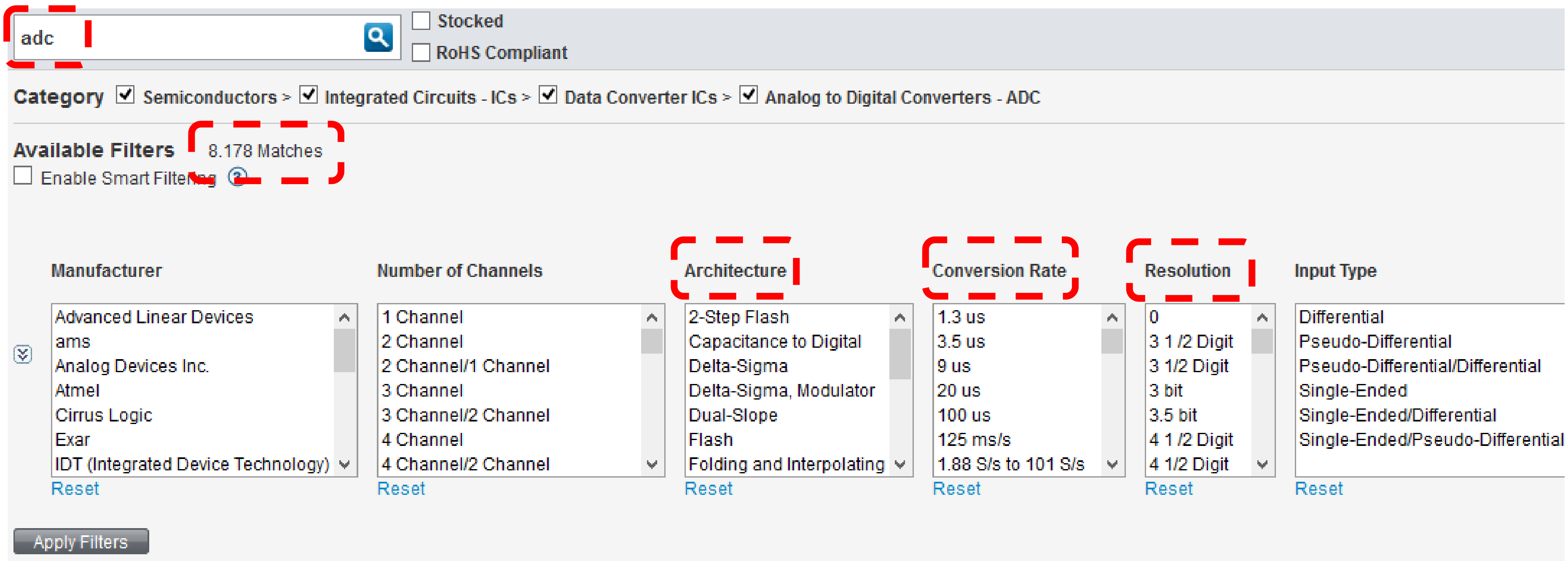
Differential Amplifiers Evaluation Board



New Designed PCB

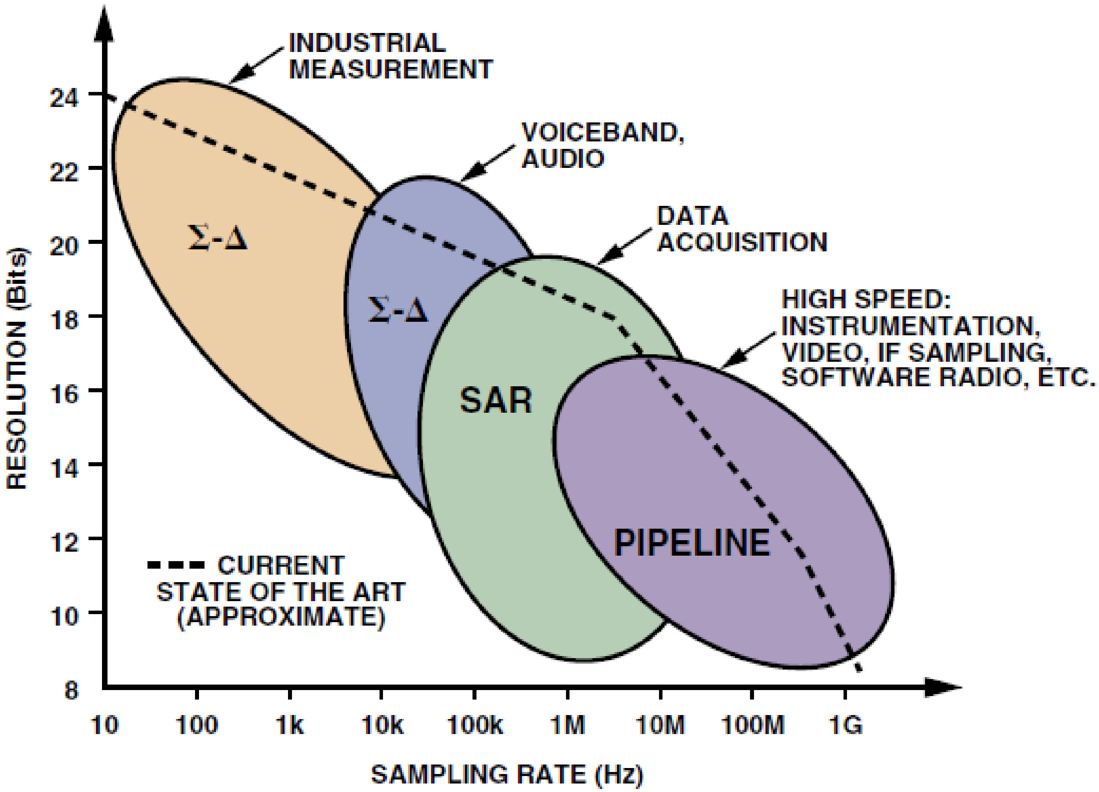
ADC Selection

- ✓ There is a huge variety of ADC ICs in the market.



- ✓ Several parameters are critical for the selection:
  - ✓ Architecture
  - ✓ Sampling Rate
  - ✓ Resolution
  - ✓ SNR

ADC Architectures - Solutions

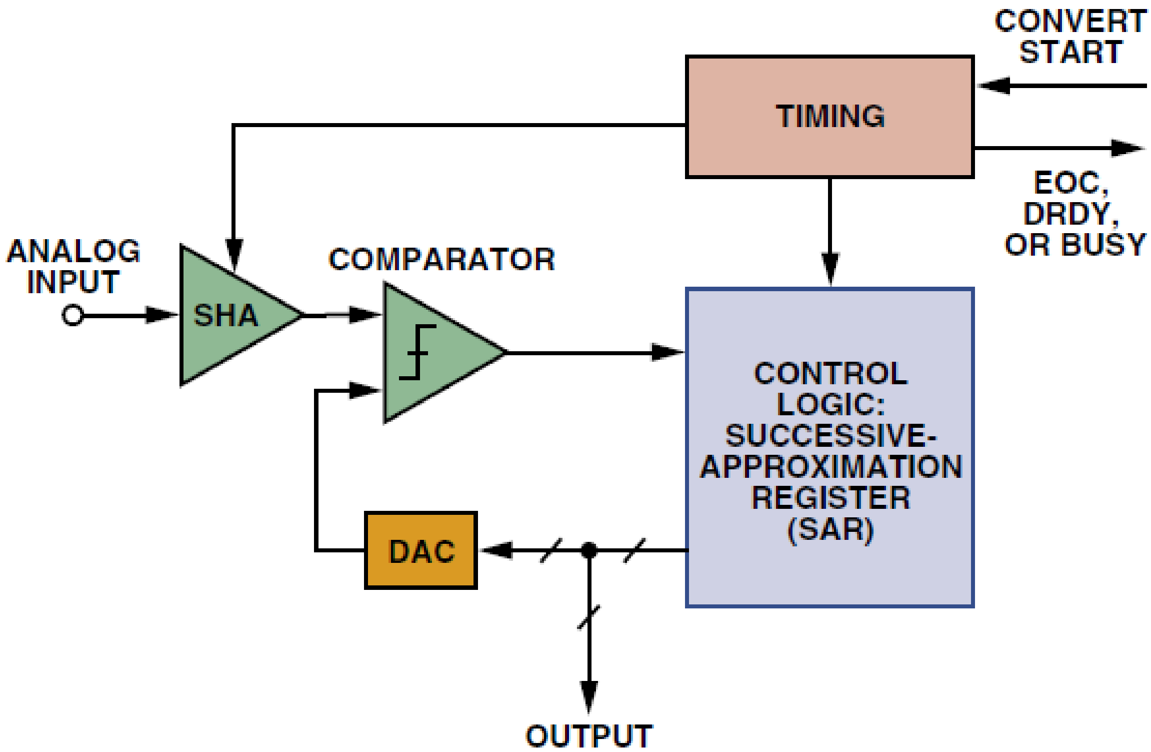


ADC architectures, applications, resolution, and sampling rates

ADC Ics:

- LTC2145:
  - Linear Technology
  - Pipeline, 125Msps, 14-bit
  - SNR: 73.1dB
  - 59 dollars
- ADS8330:
  - Texas Instruments
  - SAR, 1Msps, 16bit
  - SNR: 92dB
  - 16.39 euros
- AD7689:
  - AnalogDevices
  - SAR, 250ksps, 16bit
  - SNR: 93.5dB
  - 10.73 euros

SAR ADC Architecture



Basic successive-approximation (SAR) ADC

Dutta's Energy Harvesting Mote

Title:

Energy-Harvesting Thermoelectric Sensing for Unobtrusive Water and Appliance Metering

Authors:

Bradford Campbell, Branden Ghena, and Prabal Dutta

Electrical Engineering and Computer Science Department
University of Michigan

Conference:

Energy Neutral Sensing Systems (ENSSys) 2014
Workshop of ACM Sensys

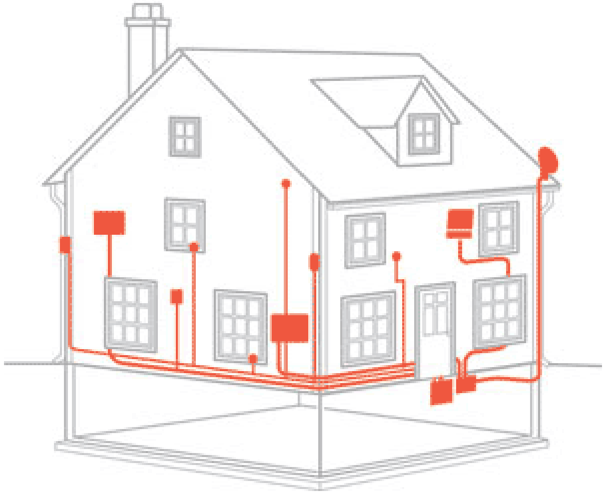
Motivation

- ✓ Energy metering in homes and buildings towards understanding the usage pattern can provide useful results and recommendations to building's users.

- ✓ An essential obstacle is the **inability to replace** sensor nodes **batteries** when already deployed in a building.

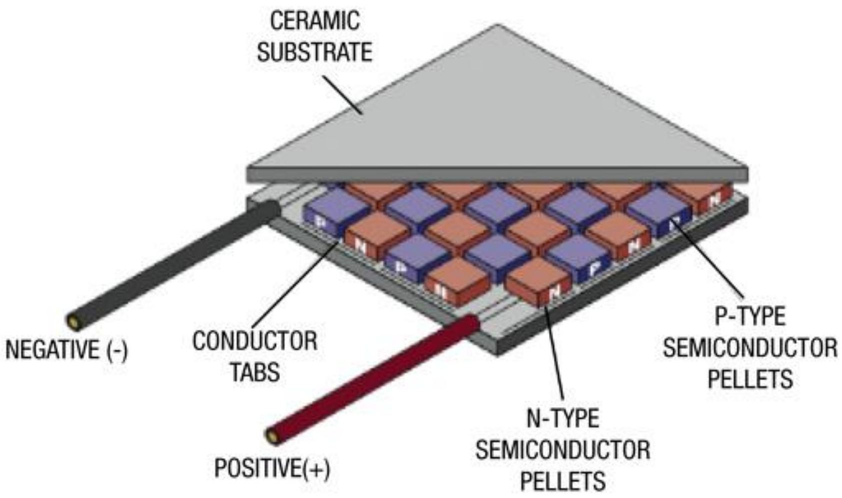
- ✓ Energy harvesting is a promising technique to generate power.

- ✓ One potential source of energy is the temperature difference.



Thermoelectric Generator

- ✓ The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa.
- ✓ A thermoelectric device creates voltage when there is a different temperature on each side.
- ✓ Conversely, when a voltage is applied to it, it creates a temperature difference.



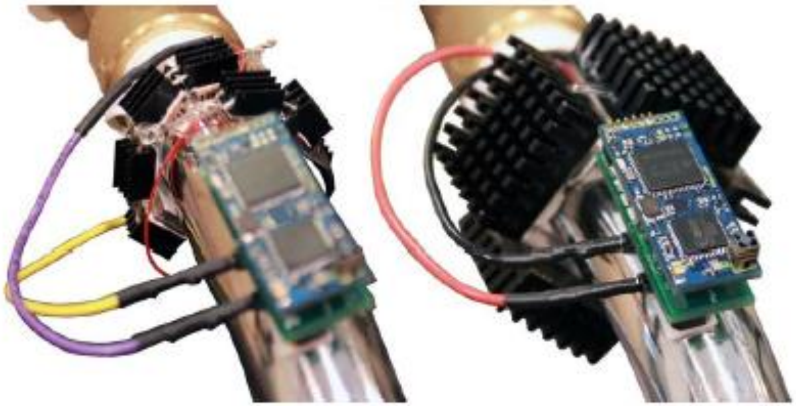
Thermoelectric Generator (TEG)

Idea

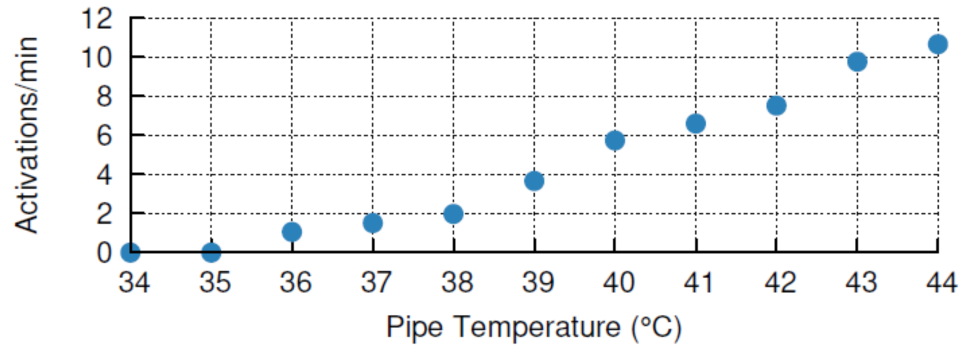
- Use of a **thermoelectric generator** (TEG) to harvest the temperature differential between **hot water** flowing in a **pipe** and the ambient air.
- The rate of harvesting is **proportional to the temperature differential** and, by extension, the temperature of the water in the pipe.
- The goal is to detect **water events** and the rate at which energy-harvesting power supply is able to harvest.

- To achieve this, a **bank of capacitors** is used to store power.
- Once sufficient energy has been accumulated, the power supply activates the node which immediately transmits a packet.
- Node's MCU maintains a counter (even when off) which illustrates the number of activations.

Developed Device



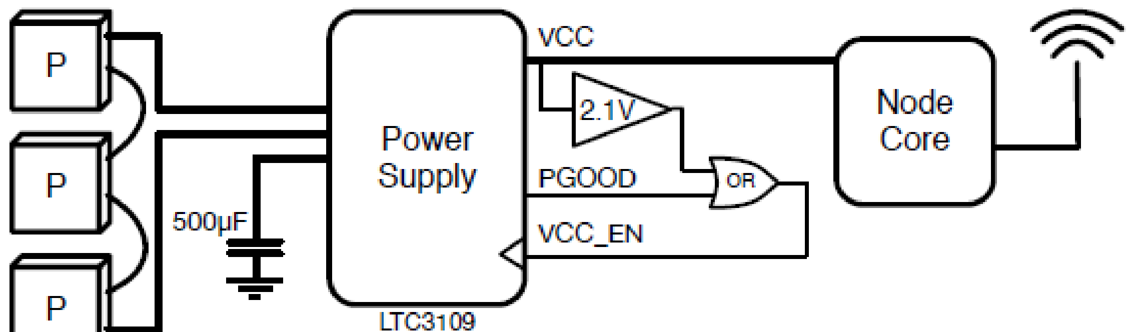
Developed Devices attached to Water Pipes



Activation Rate

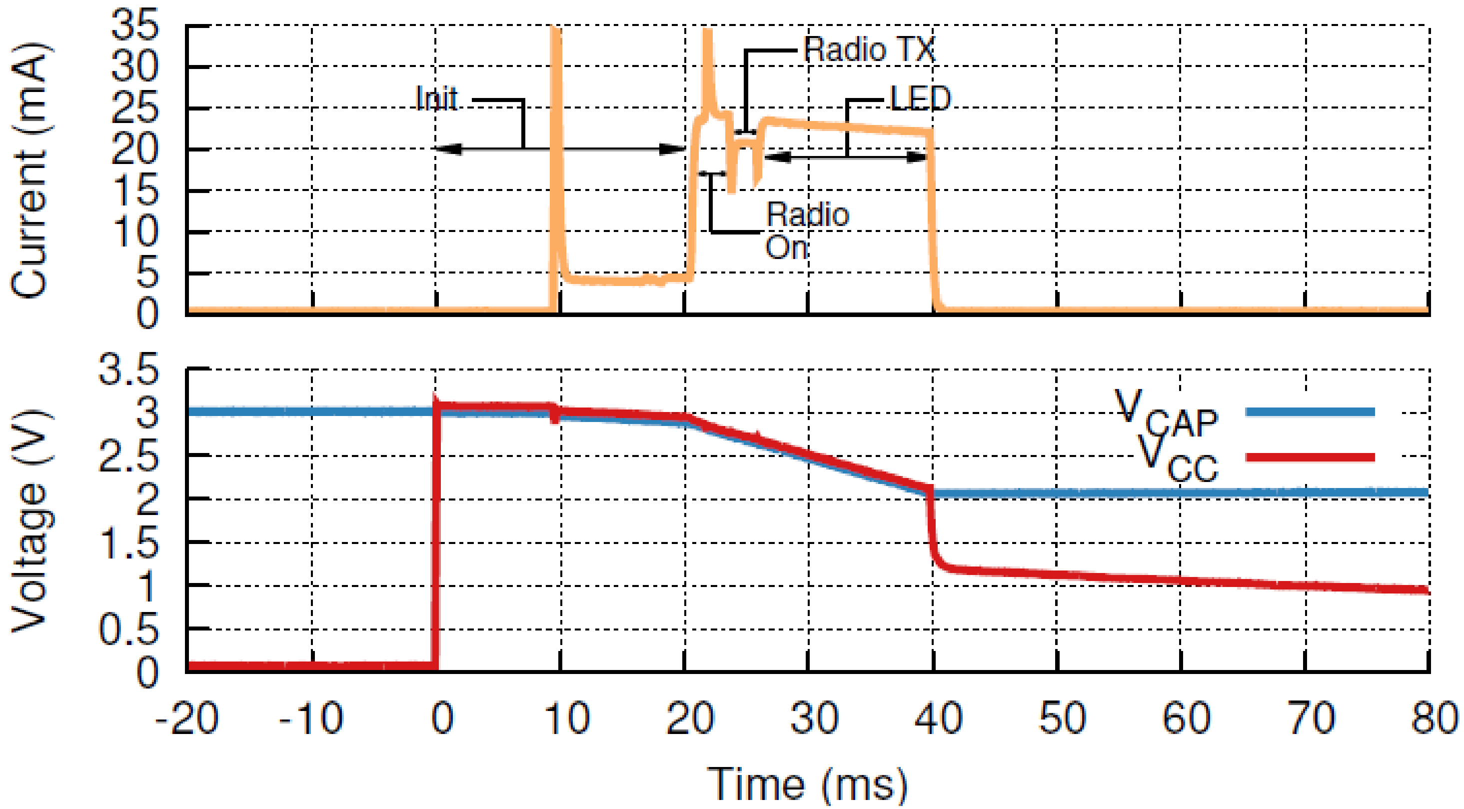
LTC3109

- ✓ Low-voltage requirement (30mV)
- ✓ Auto-polarity feature
- ✓ Attached to a 500uF bank of capacitors
- ✓ Outputs 3.3V



Developed Devices Architecture

Developed Device



Sensor's Current & Vcapacitor and Vcc draw

Thank You!

Network Implementation Testbed Laboratory

Date: 28/01/2015