

Embedded Instruments

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Outline

- Introduction
- Two instruments
 - mini-FDPM Breast Cancer Detector
 - Battery Emulator
- Research Directions

Introduction

- Scientific Instruments
 - Network analyzer, spectrum analyzer, signal analyzer, data acquisition module...
- For scientific / medical research
 - Measurement (ADC, motion/light...)
 - Control & actuation
 - Signal processing and conditioning

Issues with Instruments

- Generality
 - Good for rapid prototyping by scientists
 - Expensive, bulky, high power
- Not tracking C&C technology curve
 - mostly still GPIB
 - not using latest communication technology



Embedded Scientific Instruments

- Optimization through specialization
 - Eliminate 99% of unused functions
- Exploit commodity technology
 - Processors, NIC, storage devices
 - Communication components (analog)
- Design Space Exploration

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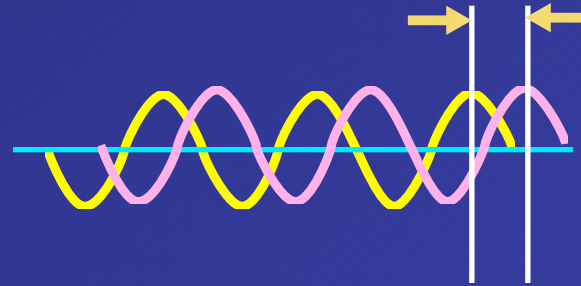
Instrument #1: mini-FDPM

- Breast Cancer Detector
 - Shine laser light into patient's tissue
 - Extract information from reflection

Cancer? Healthy?



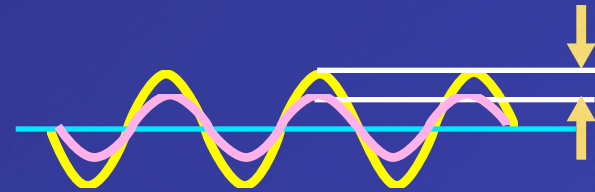
Detection



- Phase shift
 - Photons slow down while in tissue
- Amplitude drop
 - Scattering and absorption of photons
- Analysis
 - Tumors will respond differently from healthy tissues

Detection

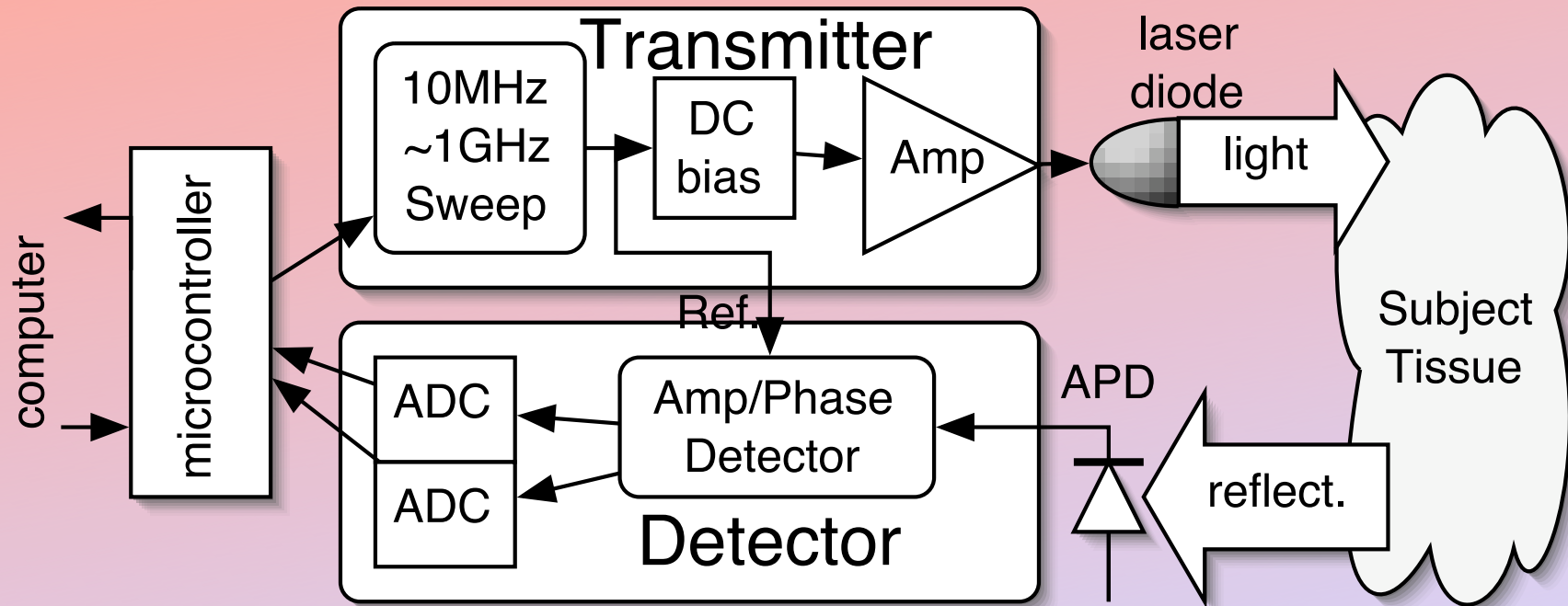
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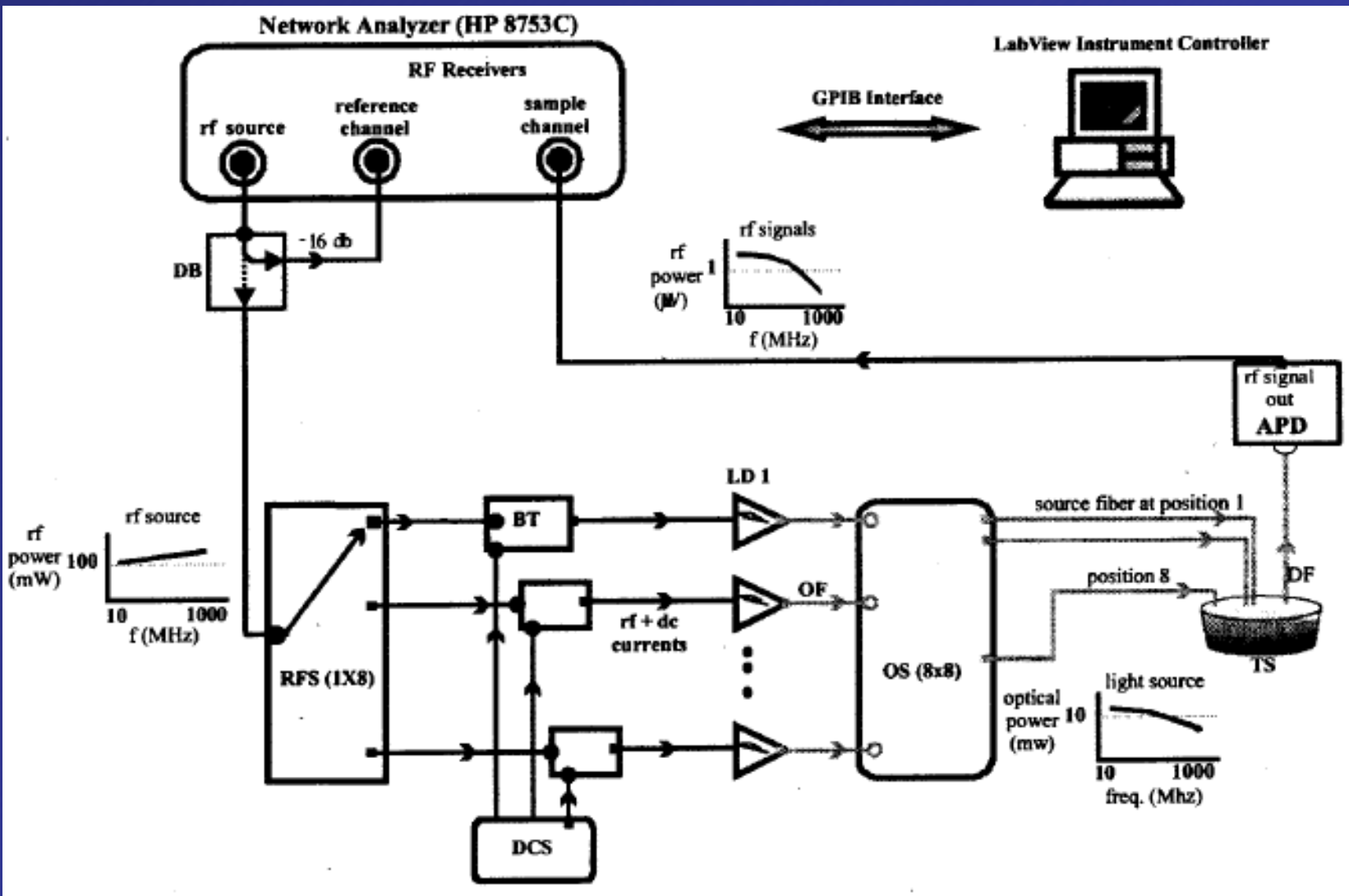
Broadband Approach

- Sweep frequency from 10MHz to 1GHz
 - 2.5MHz frequency steps
 - Amplitude modulation of light waves
- Determine a “signature” of tissue content
- Advantages
 - noninvasive, reliable, fast

Block Diagram



First Prototype



First Prototype

- Network analyzer
 - Signal generation
 - Data acquisition; measure phase/amplitude
 - Postprocessing on PC
 - Send data over GPIB to workstation
 - curve-fit in MatLab
 - Currently in use

Evaluation

- Thumbs up:
 - Movable on a cart, Programmable, reconfigurable
 - By scientists rather than engineers
- Thumbs down:
 - Expensive (\$150,000)
 - Bulky, high power

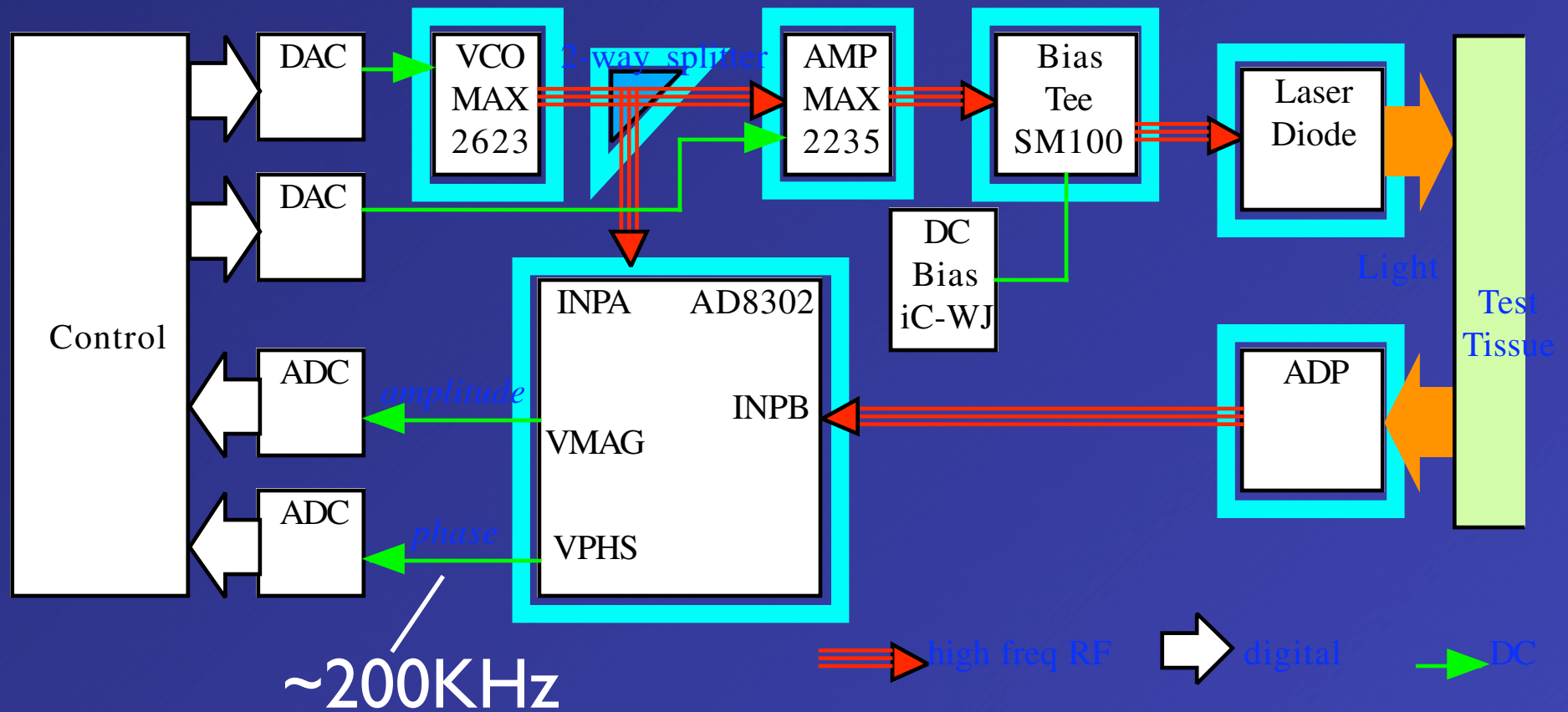
How to improve it?

- Specialization
 - Remove unnecessary generality
- Use commodity components
 - digital: CPU, microcontroller
 - analog: communication circuits
- Explore digital/analog trade-offs

2nd version: use C&C

- Frequency sweeping
 - VCO: voltage-controlled oscillators
e.g., Maxim 2623
- Amplitude and phase detection
 - previously, need separate circuits
 - now, single IC (e.g., AD8302)
- Amplifiers, splitters, mixers, ...

Second Attempt: C&C



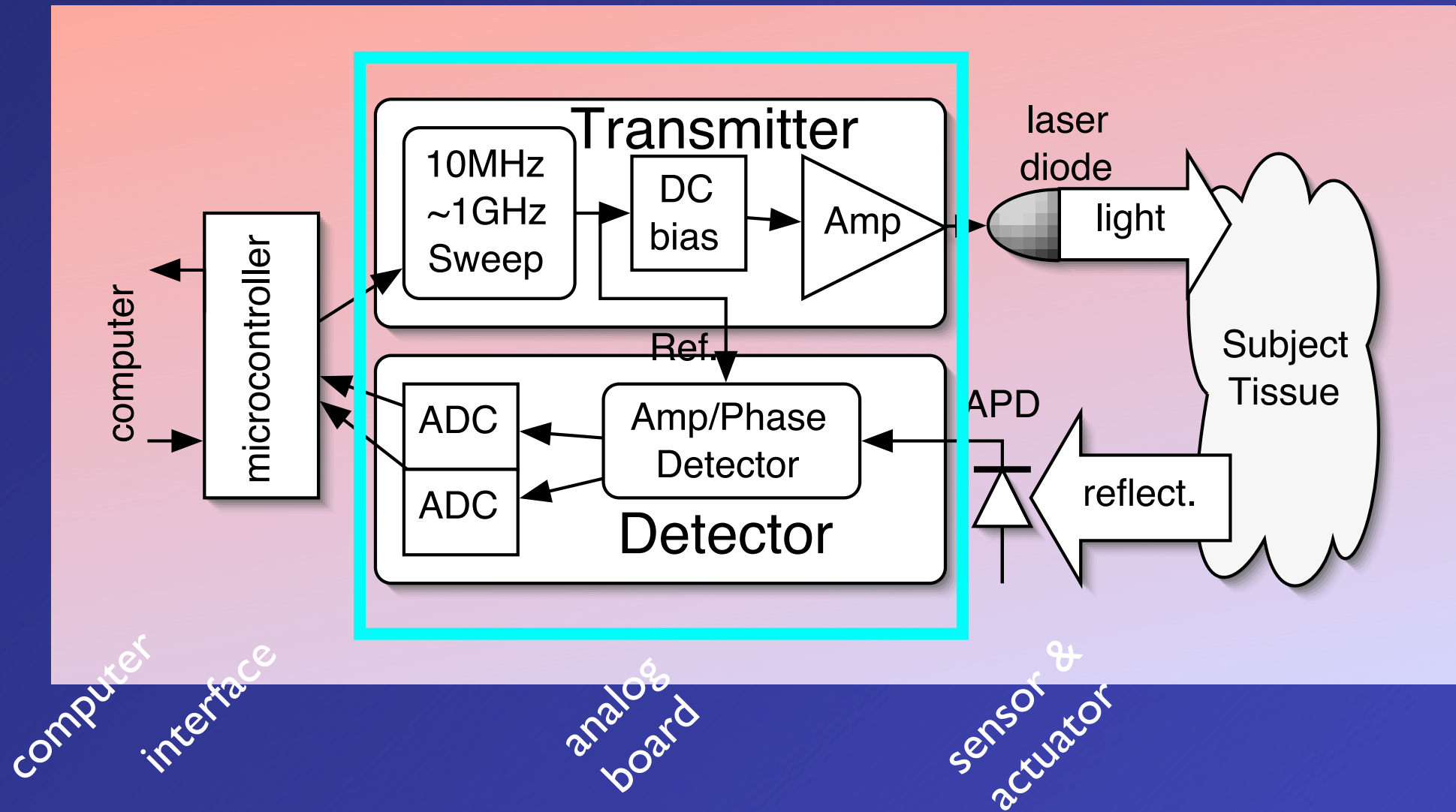
Evaluation of 1st C&C version

- Cheaper & Smaller
 - \leq \$50 of parts
- Data acquisition front-end only
 - not including laser diode & photo diode
 - not including postprocessing
- Problems
 - phase noise, linearity

Design space exploration

- Functional partitioning
 - On-board vs. off-board curve fitting
 - Digital vs. analog processing
- Digital co-design
 - Communication vs. storage
 - Hardware vs. software
 - ASIP, network processors, FPGA...

Functional partitioning



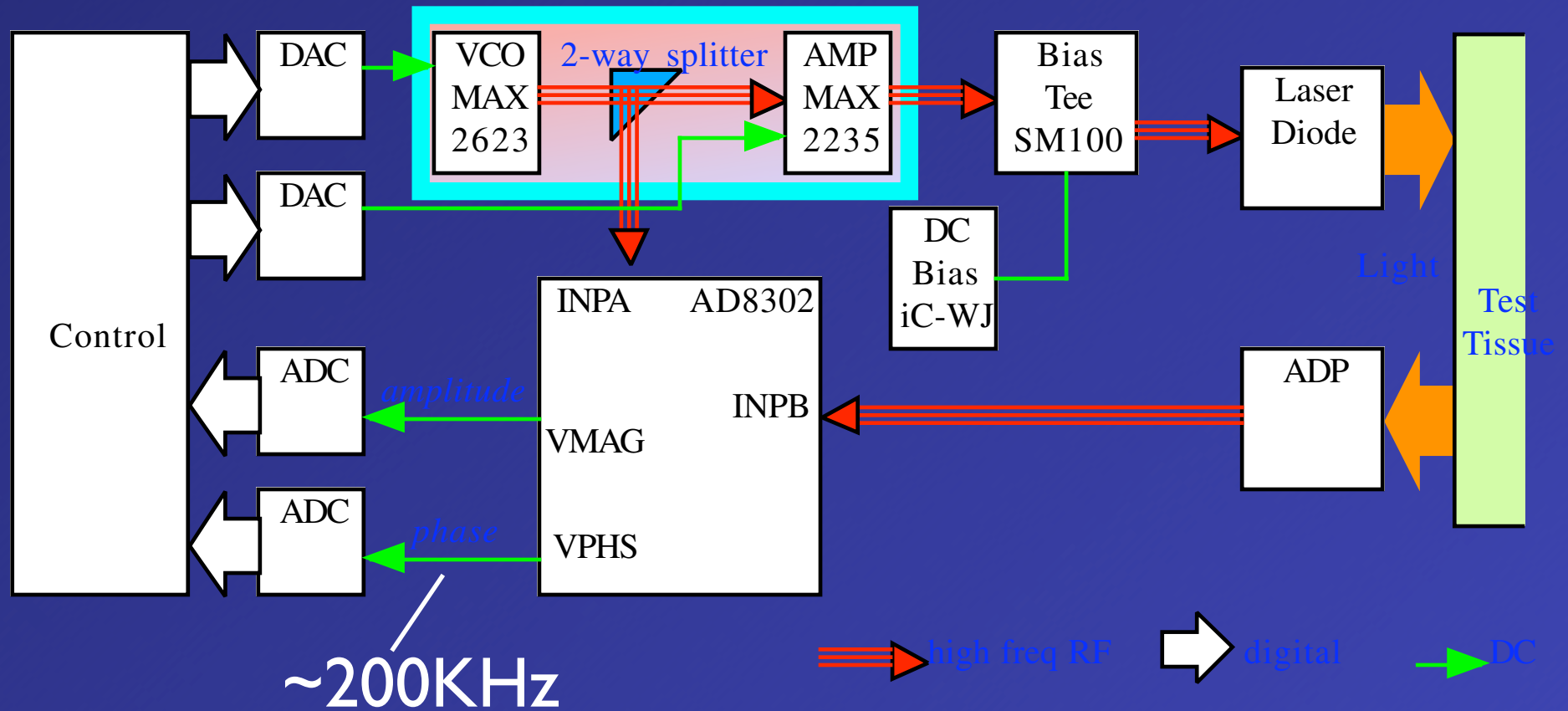
Issues Encountered

- Phase noise with VCO
 - Max 2326 designed for narrow band
 - optimized for 900MHz, w/ ± 50 MHz noise!
- Linearity of Amplifier
 - Narrow band amp (Max 2235)
 - Drop off sharply outside 850-950MHz
 - Broadband amps are expensive ($\geq \$150$)

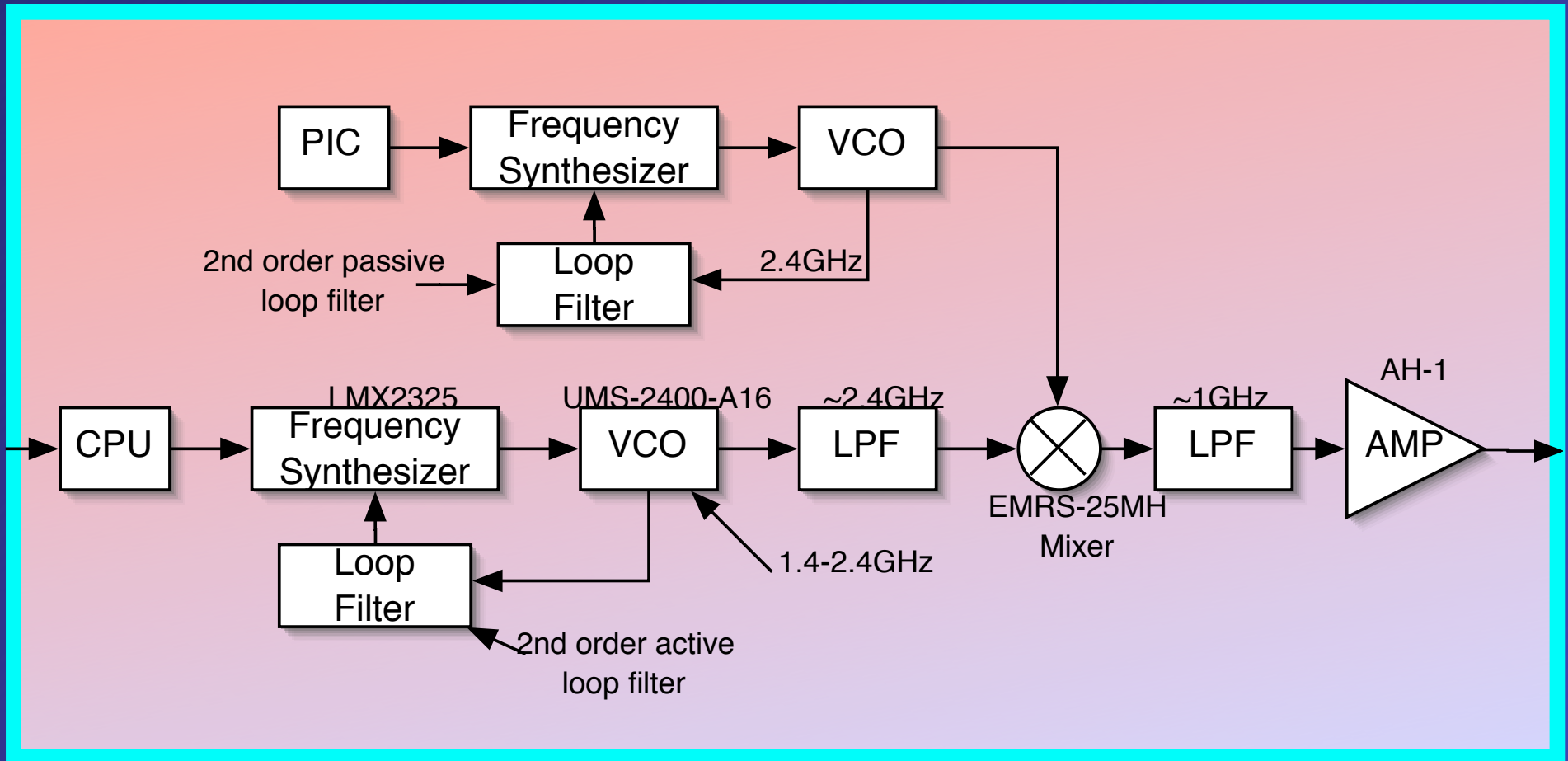
2nd Attempt

- Oscillator circuitry
 - fixed freq Local oscillator w/ TCXO
 - 2nd Oscillator to vary freq
 - Down-mix for low phase noise
- Broadband amplifier

Old Block Diagram



New Block Diagram (Freq. synthesizer)



Research Directions

- Broadband active sensor
 - Emits a signal modulated over broadband
 - Measures reflection
- High-speed Sensors
 - (with Professor Stuart Kleinfelder)
- Broadband Circuits & Physical Design
 - (with Professor Payam Heydari)

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Battery Emulator

- Power supply that behaves like a battery
 - Voltage drops as it discharges
 - Eventually dies
- How it works
 - Power circuit: senses I , controls V
 - Software: real-time battery simulation

Why battery emulator

- Experiments on power-aware designs
 - Scheduling, mode selection, schedule selection, DVS, ...
 - Want to maximize battery life
- Approaches
 - Use real batteries
 - Run battery simulation

Problems w/ using real batteries

- Environmental friendliness
 - Non-rechargeables: dispose of after use
- Reproducibility
 - Memory effect, aging effect, ...
- Slow
 - 13-14 hours to drain a small battery on a really low power device (ltsy)

Battery simulators

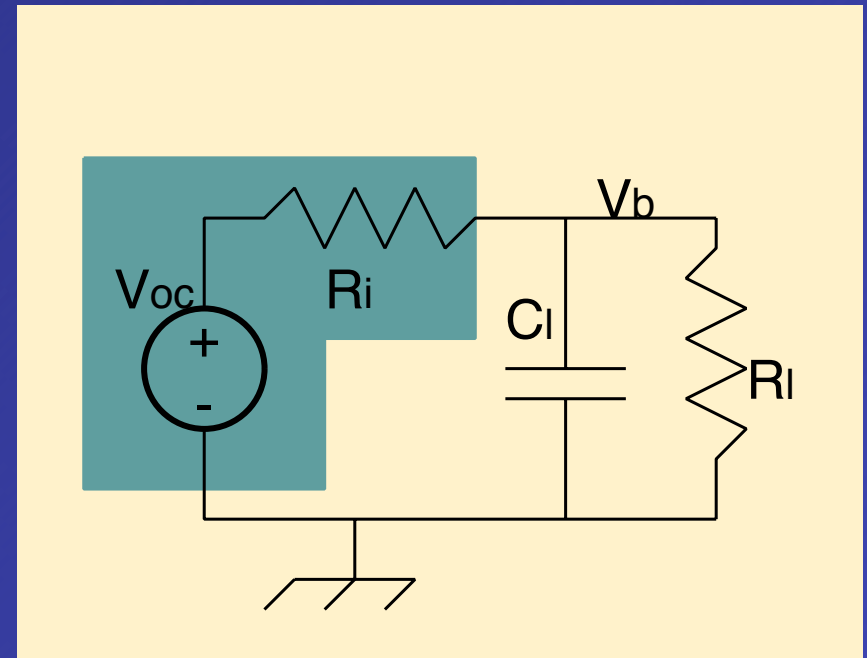
- Electro-chemical models
 - Dualfoil (Newman, UC Berkeley)
 - Detailed, solving differential eqn in Fortran
- Circuit models (SPICE)
- Discrete time VHDL model
- Stochastic model

Problems w/ using battery simulators

- Accuracy vs. speed trade-offs
 - Dualfoil: accurate but slow
 - VHDL: fast but high error
- Still need system model in software
 - Simulate the system to get power load
 - Impractical to model at RTL for off-the-shelf systems (not chips)

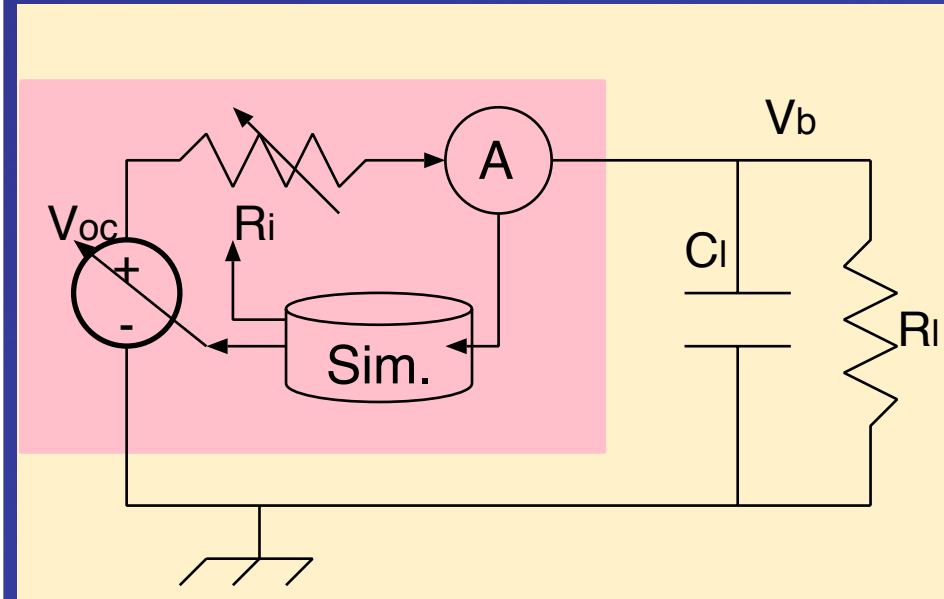
Battery Circuit Model

V_{oc}	open-circuit volt.
R_i	internal resistance
V_b	actual batt. volt.
C_l	load capacitance
R_l	load resistance
I	current



Battery Emulator Circuit

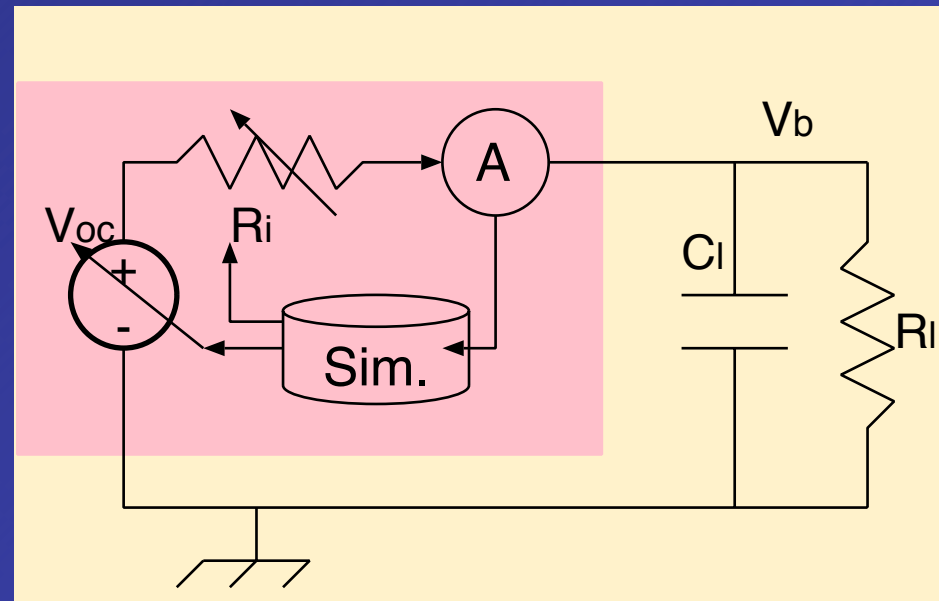
V_{oc}	open-circuit volt.
R_i	internal resistance
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I	current



$$V_b = V_{oc} - I * R_i$$

Battery Emulator Problem Statement

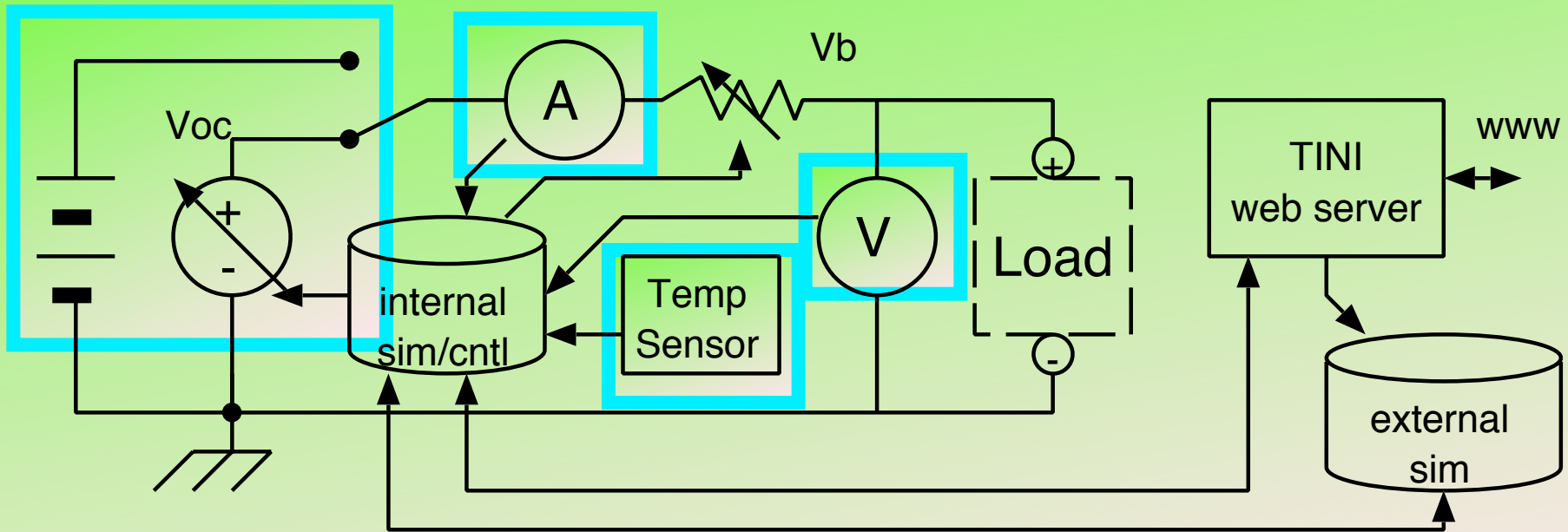
- Measure current (I)
- Run Simulator
- Set voltage (V_{oc}) and resistance (R_i)
- Repeat



Battery Emulation: Timing

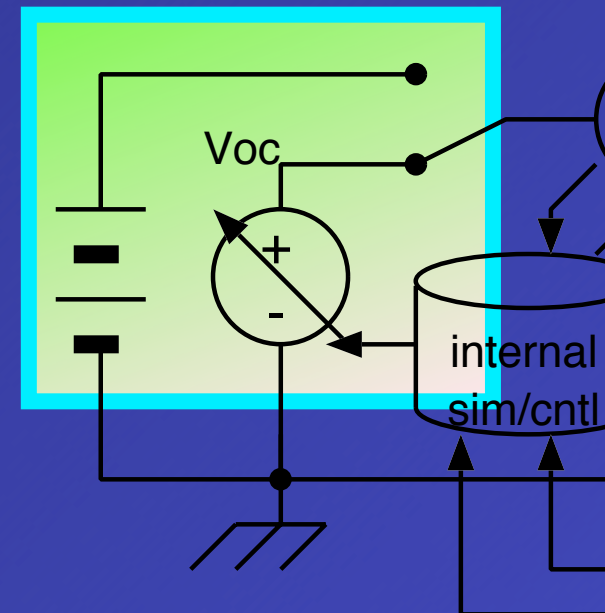
- Sampling period
 - time between successive current samples
 - frequency of Voc updates
- Latency
 - should mimic real battery's response time
 - simulator must run faster than latency

Emulator Design



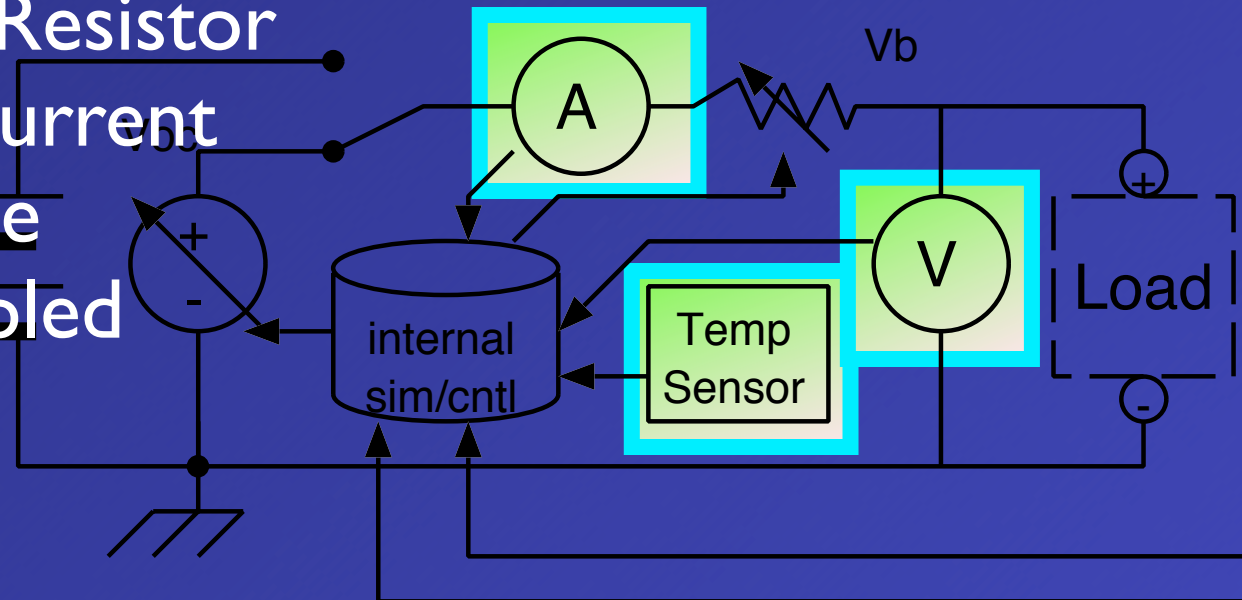
2 supply power sources

- Actual battery
 - for data acquisition/training
- Voltage regulator
 - Controlled by an ADC
 - 1-4.5V, 800mW max



Sensor circuits

- Sensors
 - Current, temperature, voltage
- Everything is sampled by 10-bit ADC
- 35mOhm Resistor converts current into voltage to be sampled



Internal simulator

- Table-driven: 2-D table
 - Voltage[ChargeState][Current]
 - Update ChargeState over time
- Advantages: Simple, quick
- Disadvantages: Does not model
 - Rate capacitive, Rate recovery effects
 - Aging effects

External simulator

- Many available
 - Experiment with dualfoil
- Advantages: accurate
 - Models rate capacitive/rate recovery
- Disadvantages:
 - Does not model Aging effects
 - Possibly slow

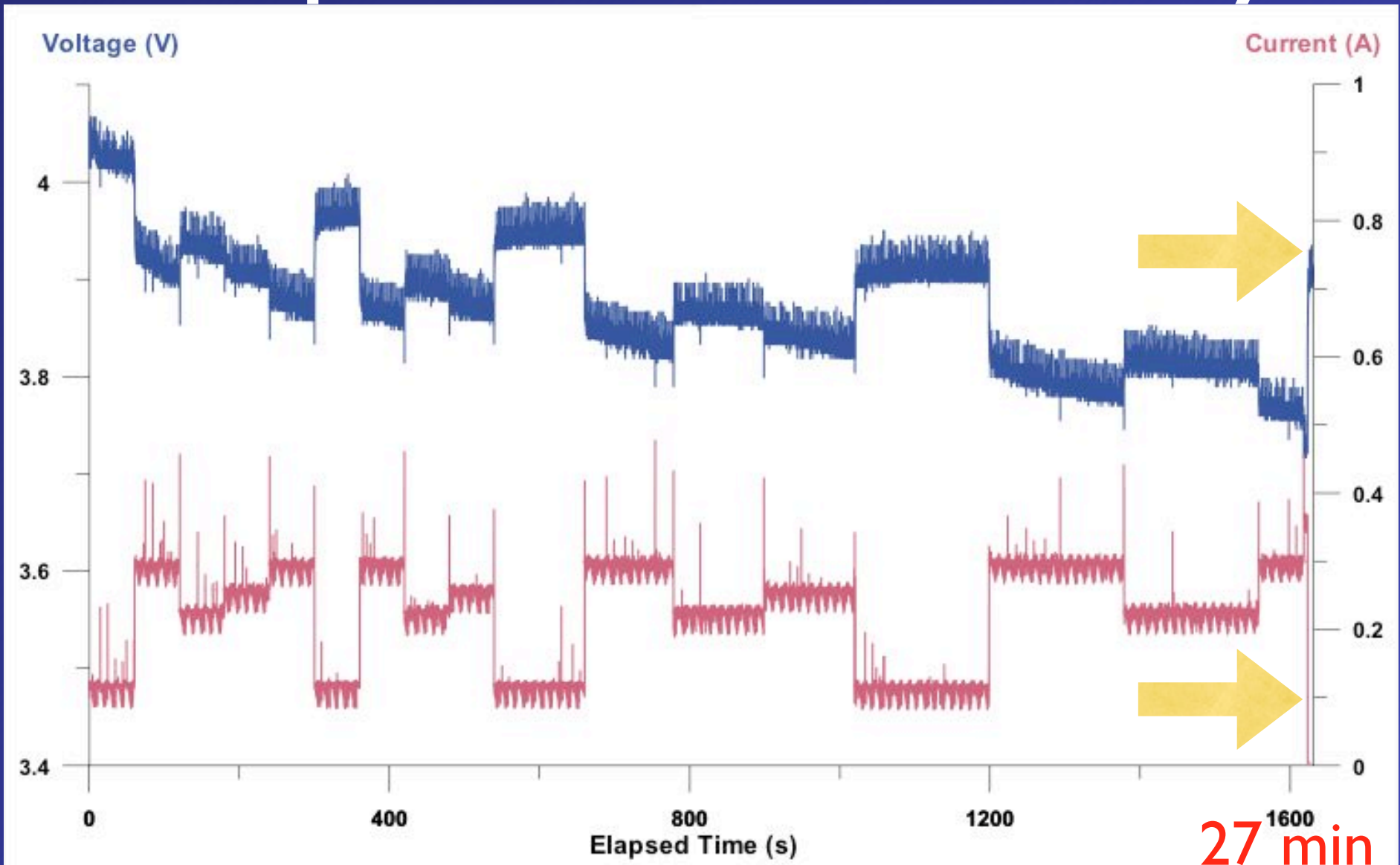
How slow is the external simulator?

- Platform
 - Experiment with dualfoil
 - running on 2GHz Xeon processor
- Timing:
 - 31-91ms of real time to simulate 20ms of battery time
 - Not quite real time, but within 2-4x.

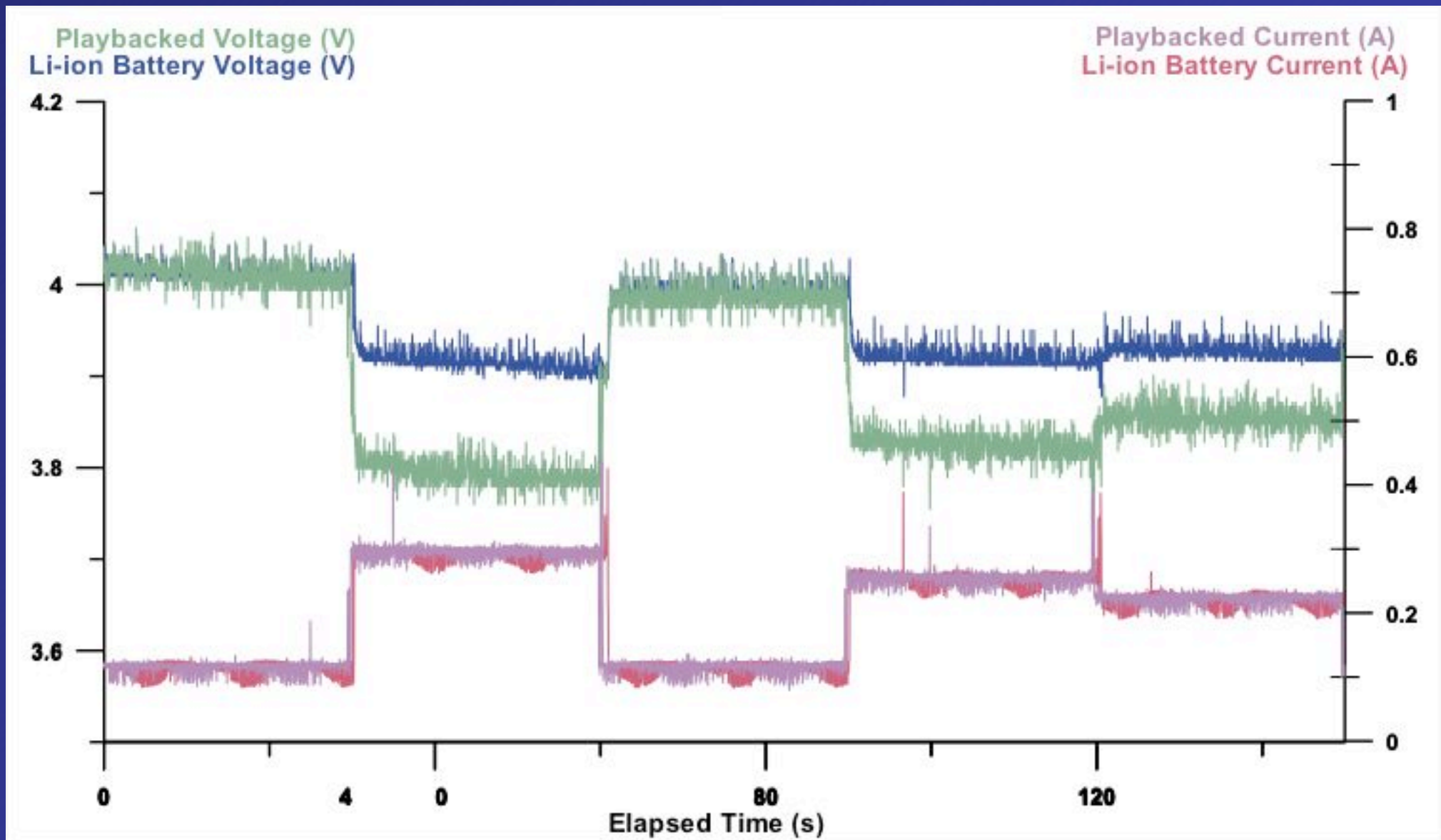
Experiments

- Platforms
 - Palm IIIe, Compaq iPaq, Casiopeia
- Questions:
 - current/voltage profile
 - verify internal resistance
 - battery response time

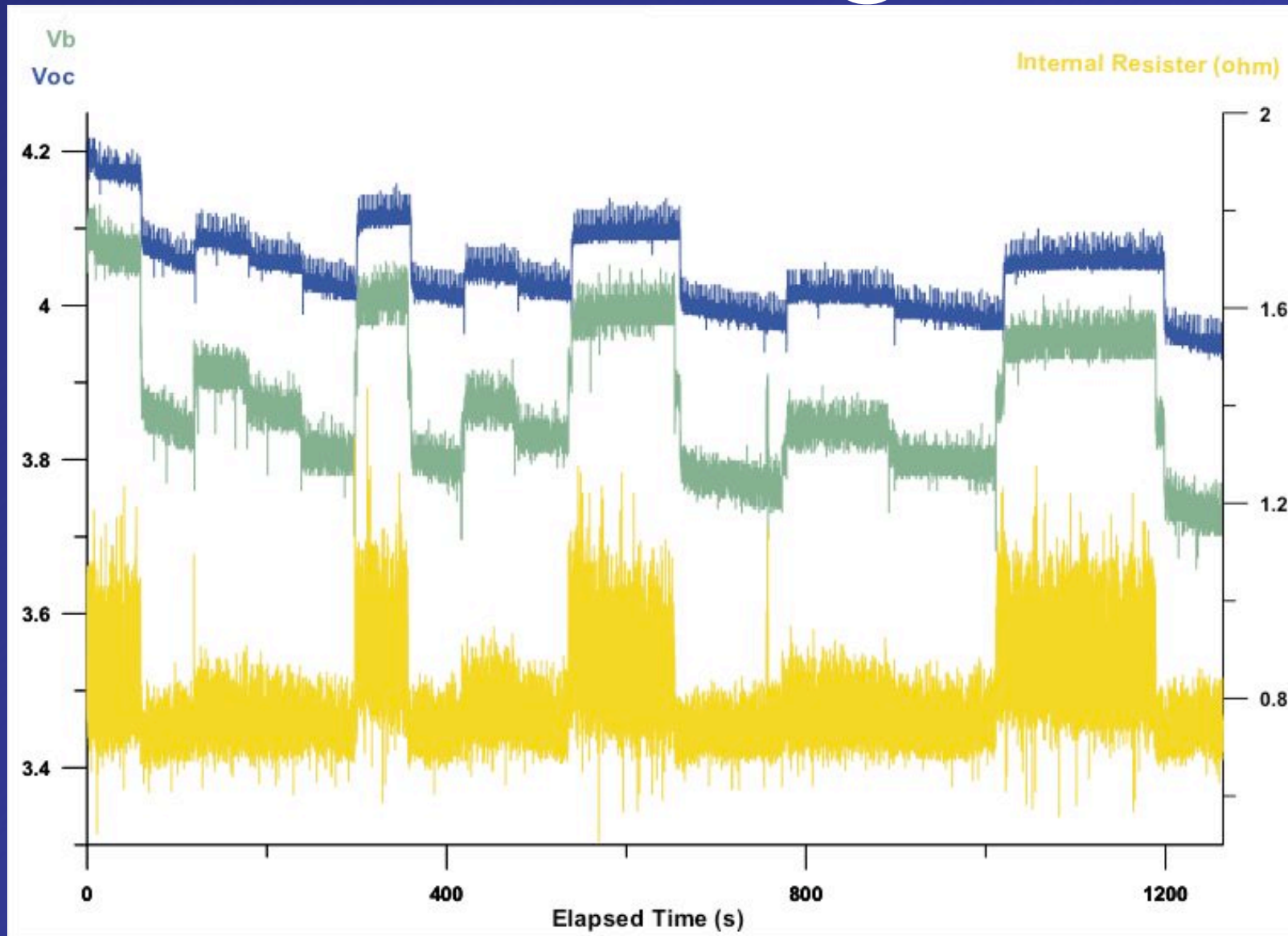
iPaq w/ built-in battery



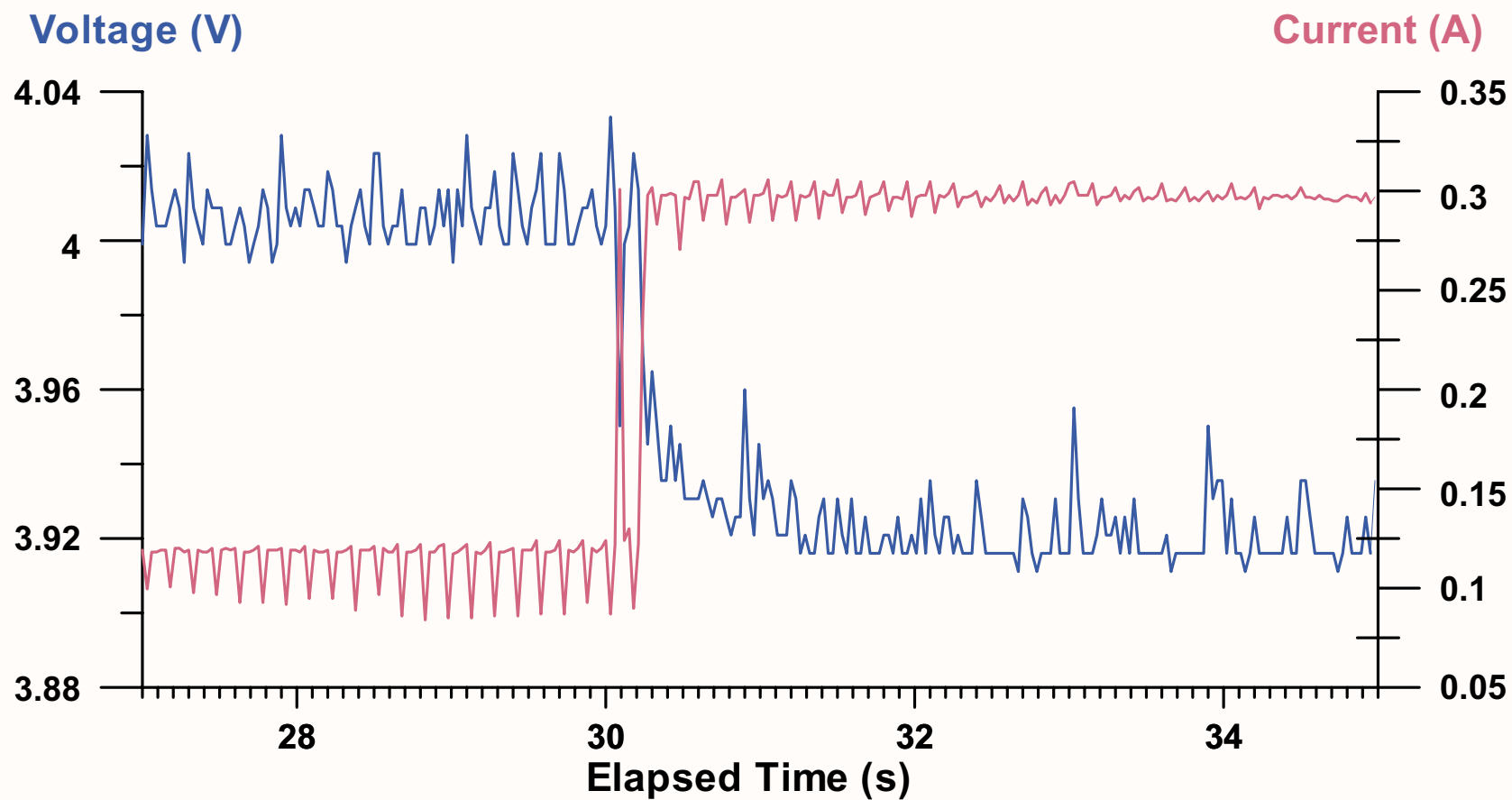
Measured vs. Playback



Ri of linear regulator



Battery response time



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Research Directions

- FDPM: Miniaturization
 - Sensor-on-a-Chip
- Battery emulator
 - HW: recharge circuitry
 - SW: high performance
 - Battery model: fast, efficient

Acknowledgments

- mini-FDPM
 - George Niemela, Keun-sik No, Ilya Katsnelson
- Battery emulator
 - Chulsung Park, Jae Park, Kien Pham
- Beckman Laser Institute
 - Bruce Tromberg, Albert Cerussi