



Ekho

**Realistic and Repeatable
Experimentation for Tiny
Energy-Harvesting Sensors**

Josiah Hester
Timothy Scott
Jacob Sorber

SenSys'14—November 3, 2014

This Talk

1. Testing small devices

2. Energy harvesting difficulties

3. A Tool (Ekho)

RFID-Scale Devices



UMass Moo

RFID-Scale Devices



RFID-Scale Devices



RFID-Scale Devices

As small as possible



- Minimal energy storage (Cap)
- Harvest energy (RF, Solar, Glucose)

UMass Moo

Run when you can

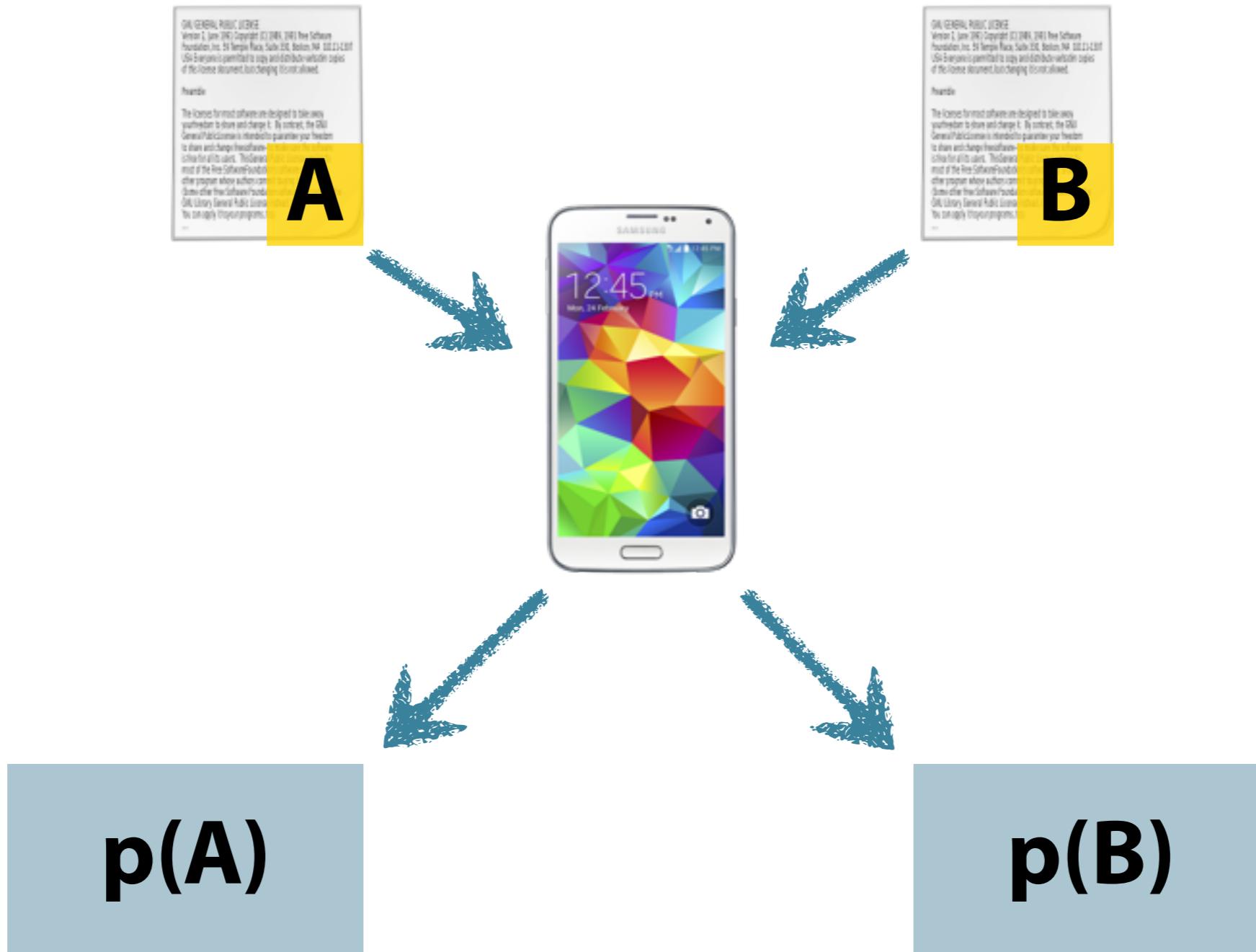
- Frequent failures
- Erratic supply



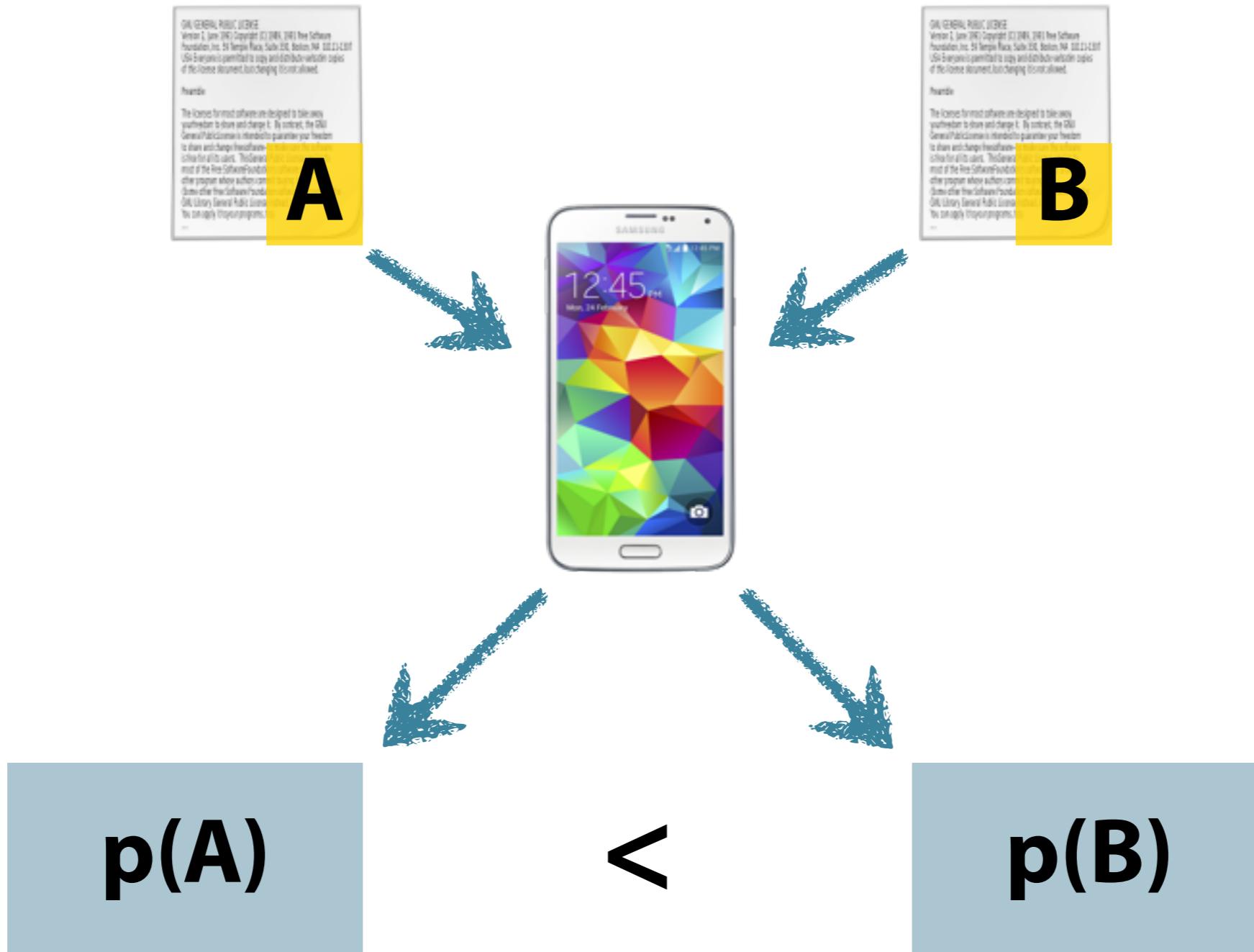
Comparable Outcomes



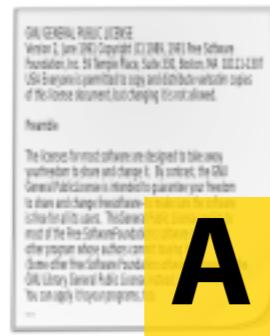
Comparable Outcomes



Comparable Outcomes



Comparable Outcomes



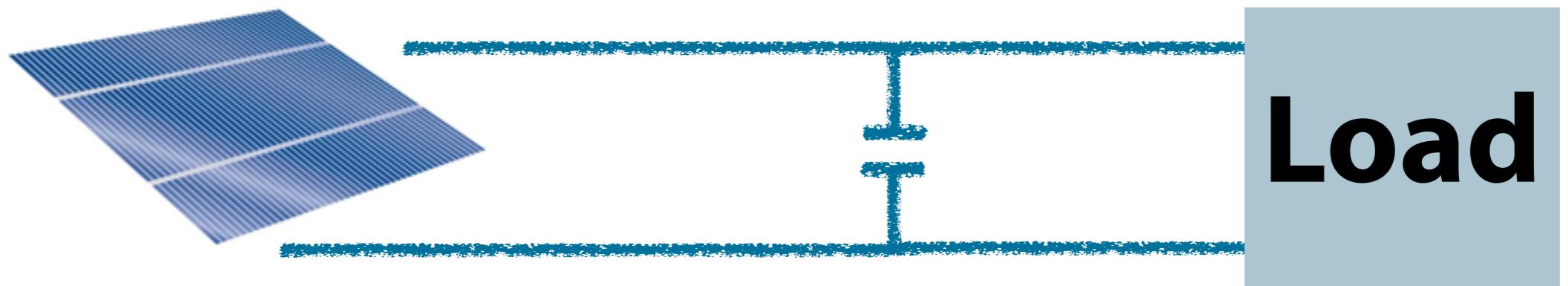
A



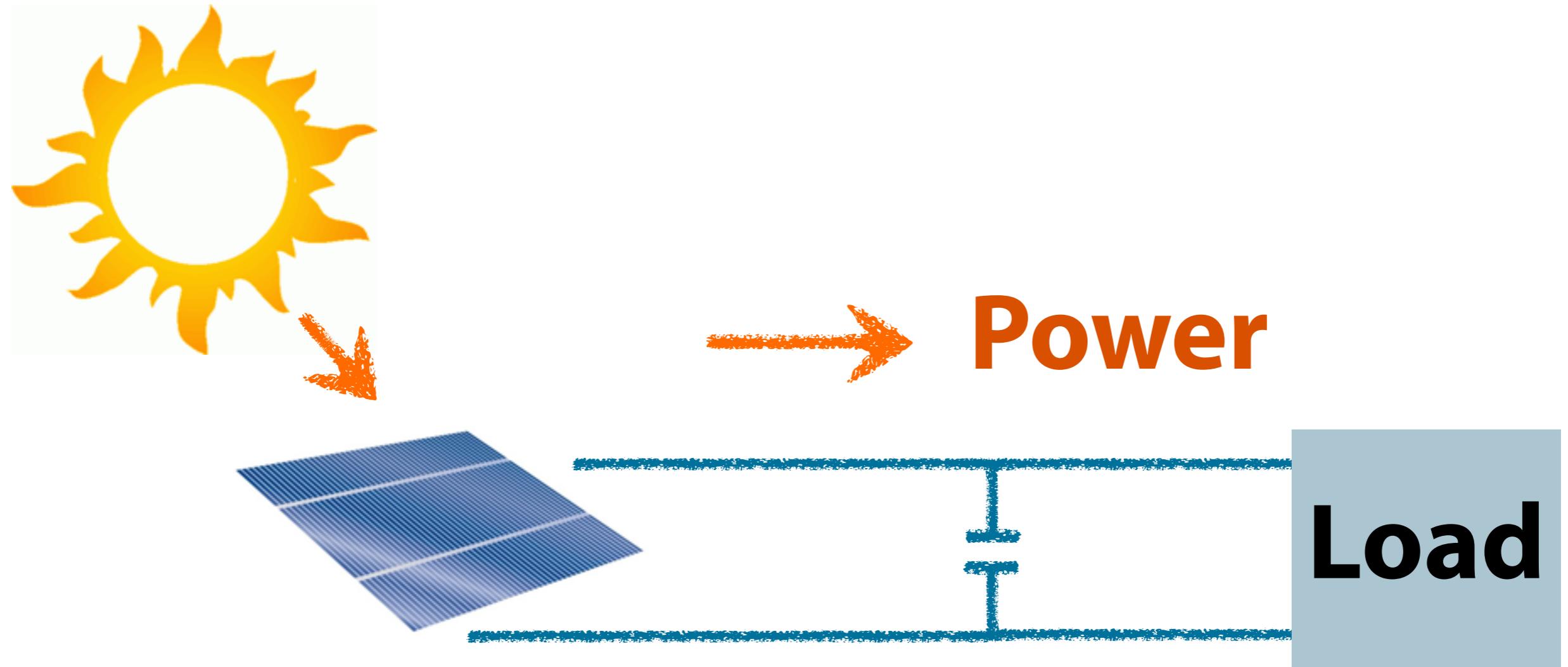
B



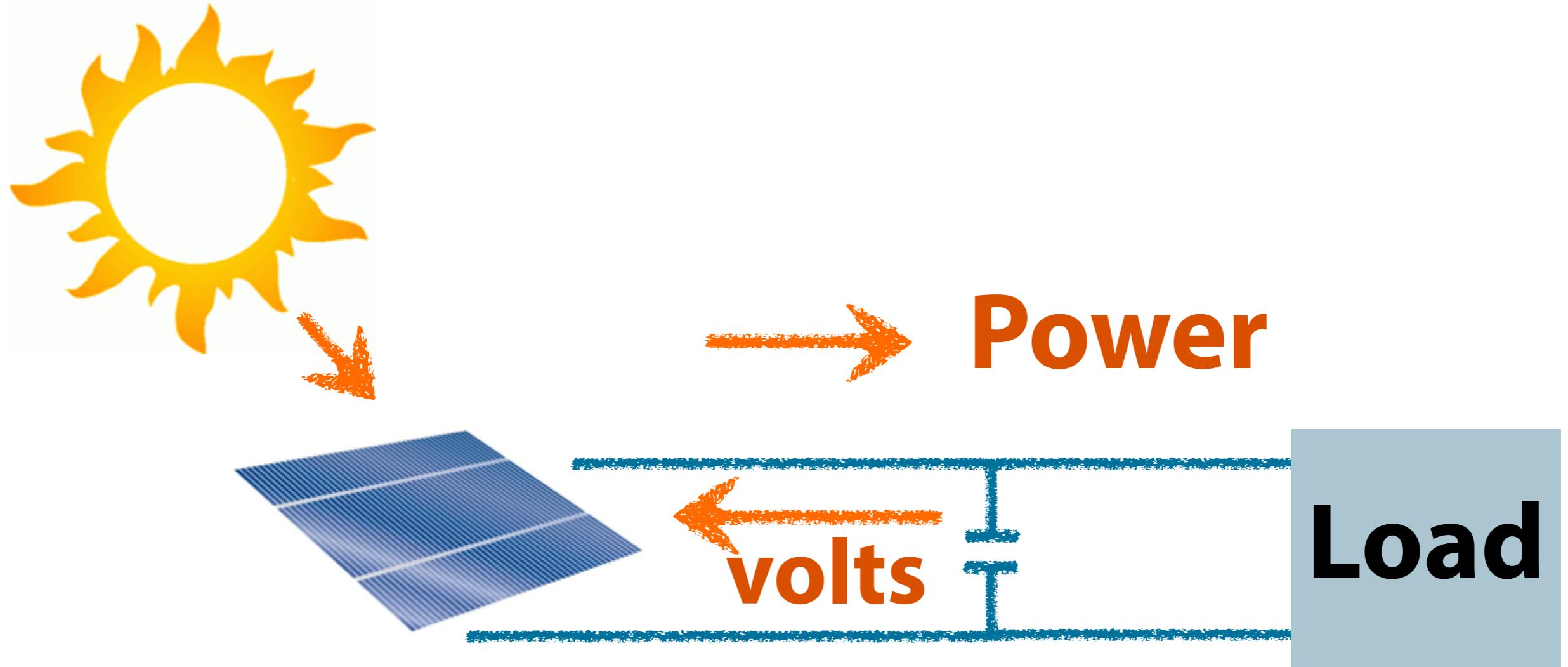
Solar Example



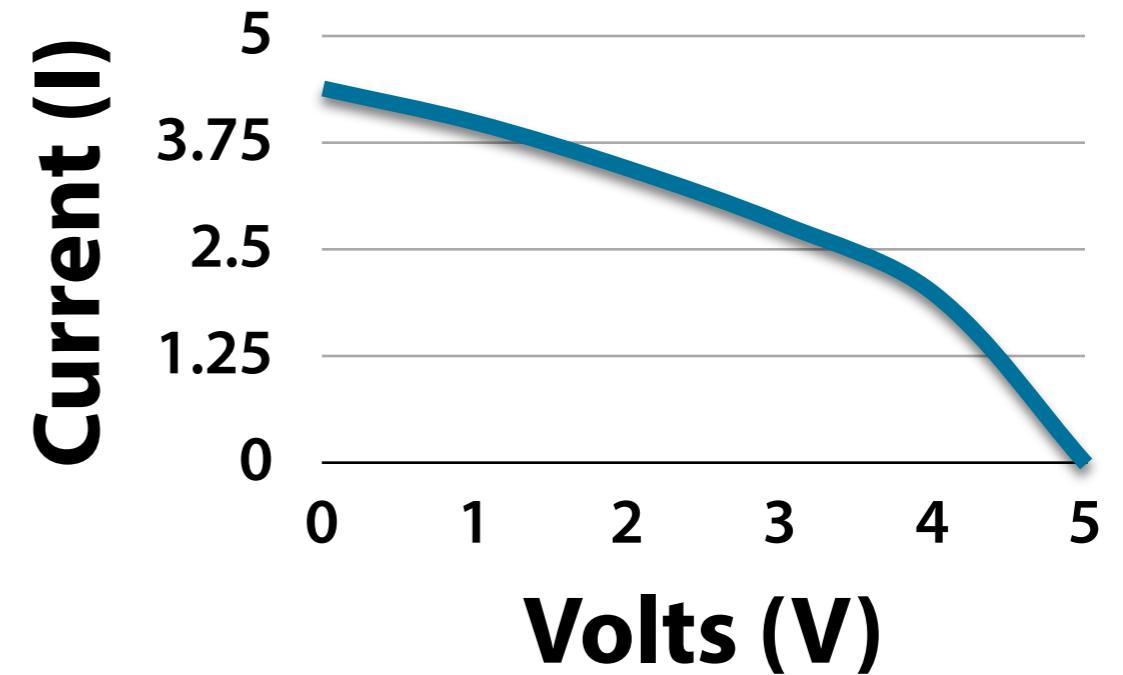
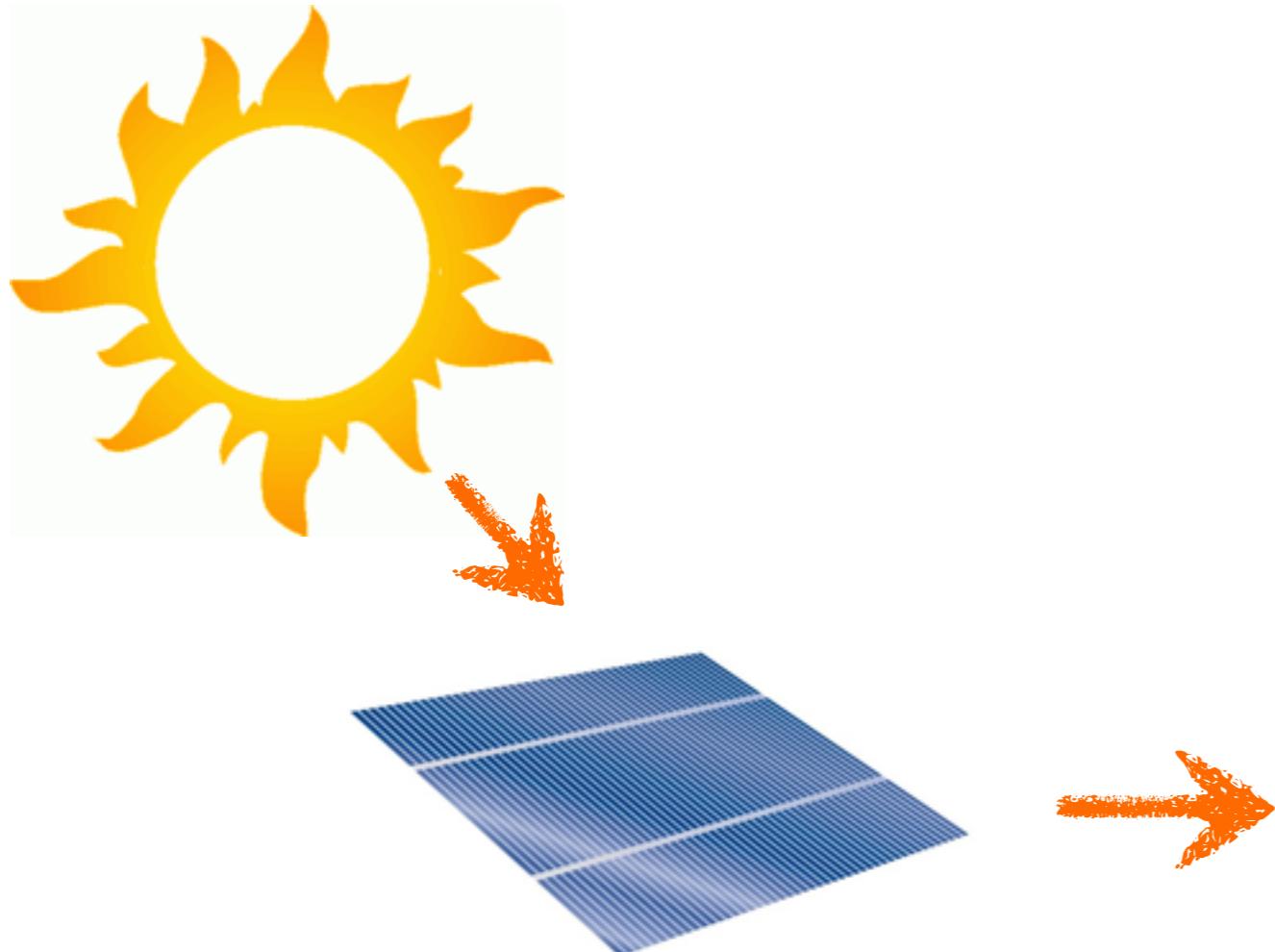
Solar Example



Solar Example

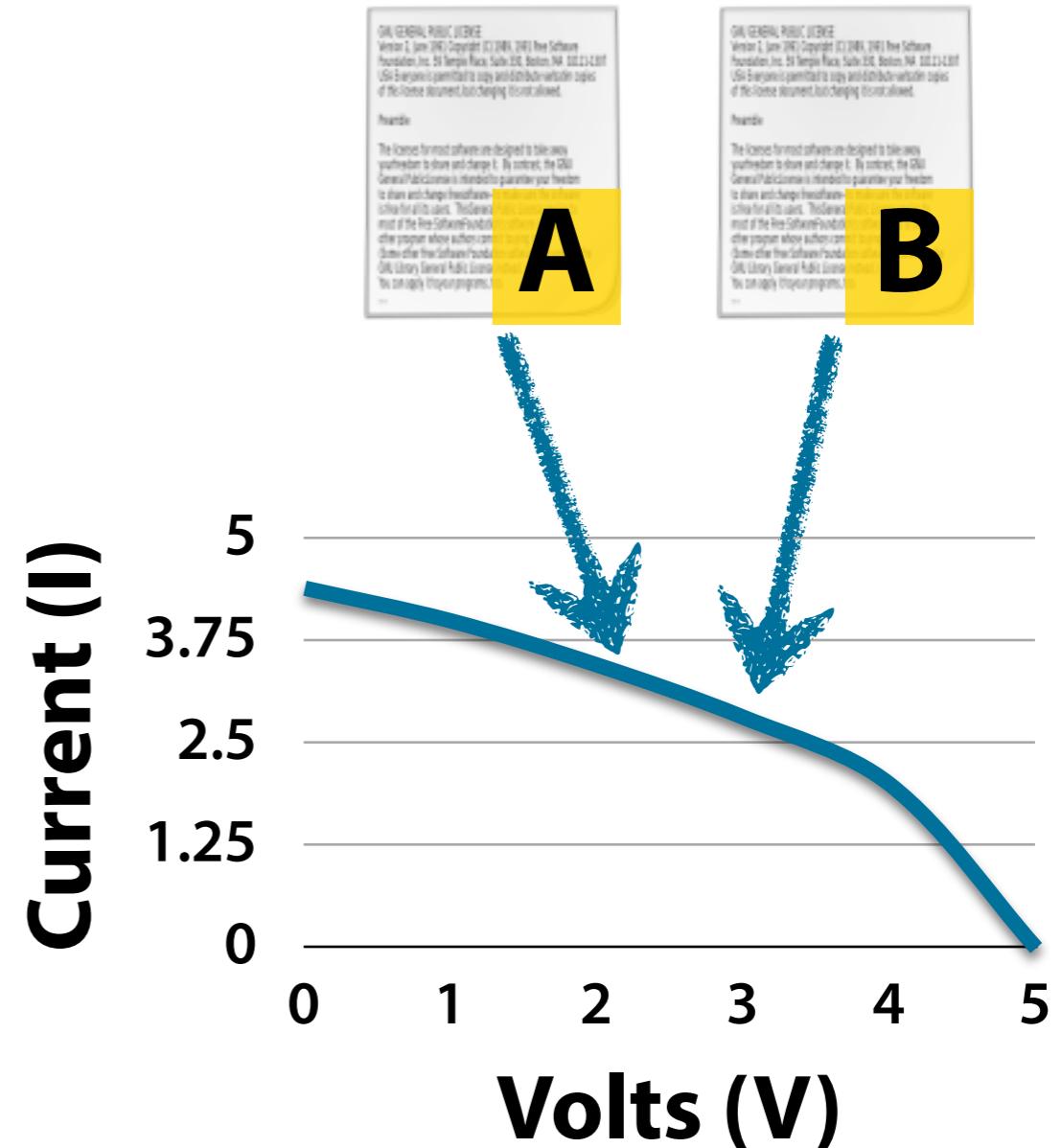
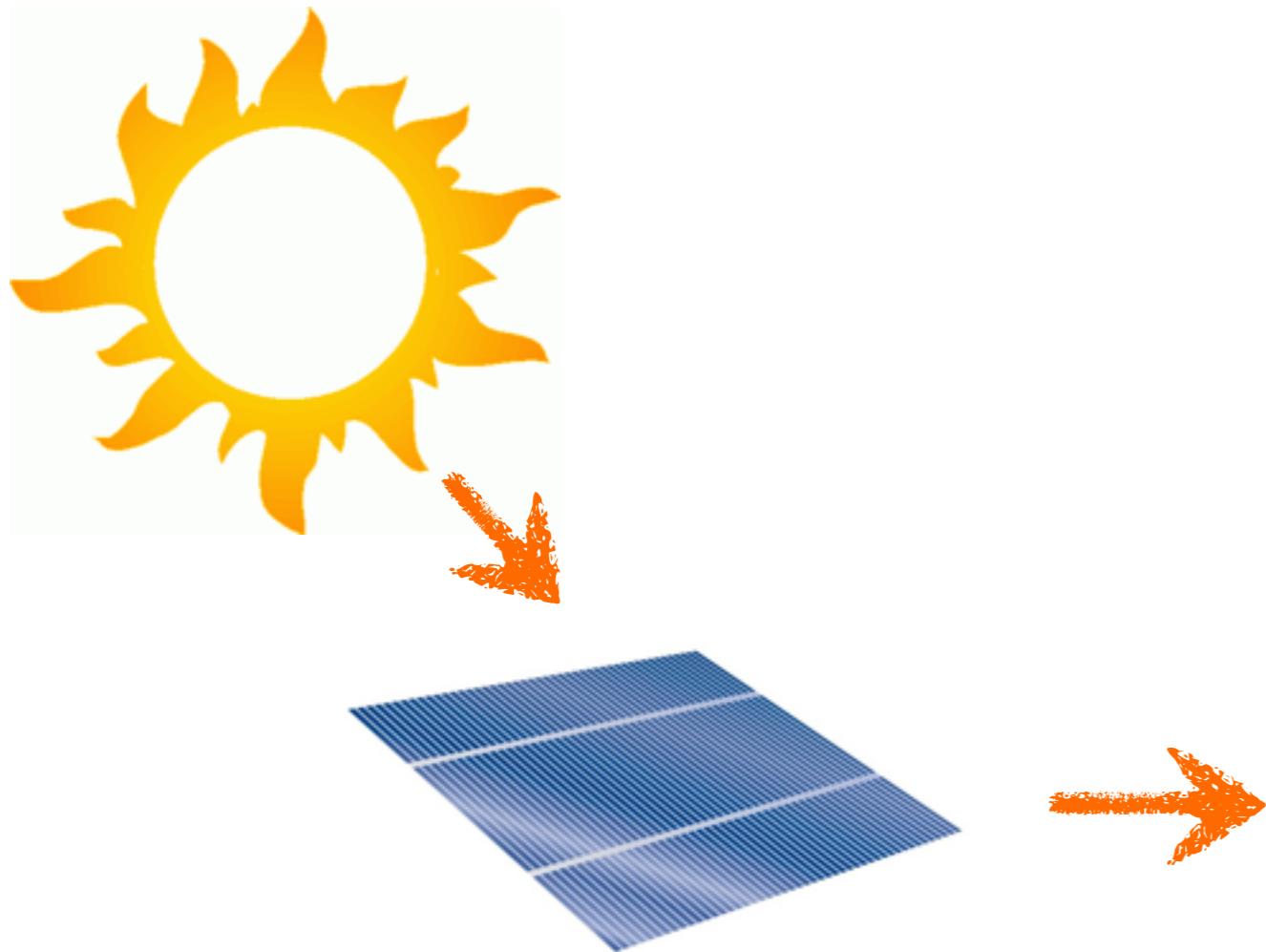


Solar Example

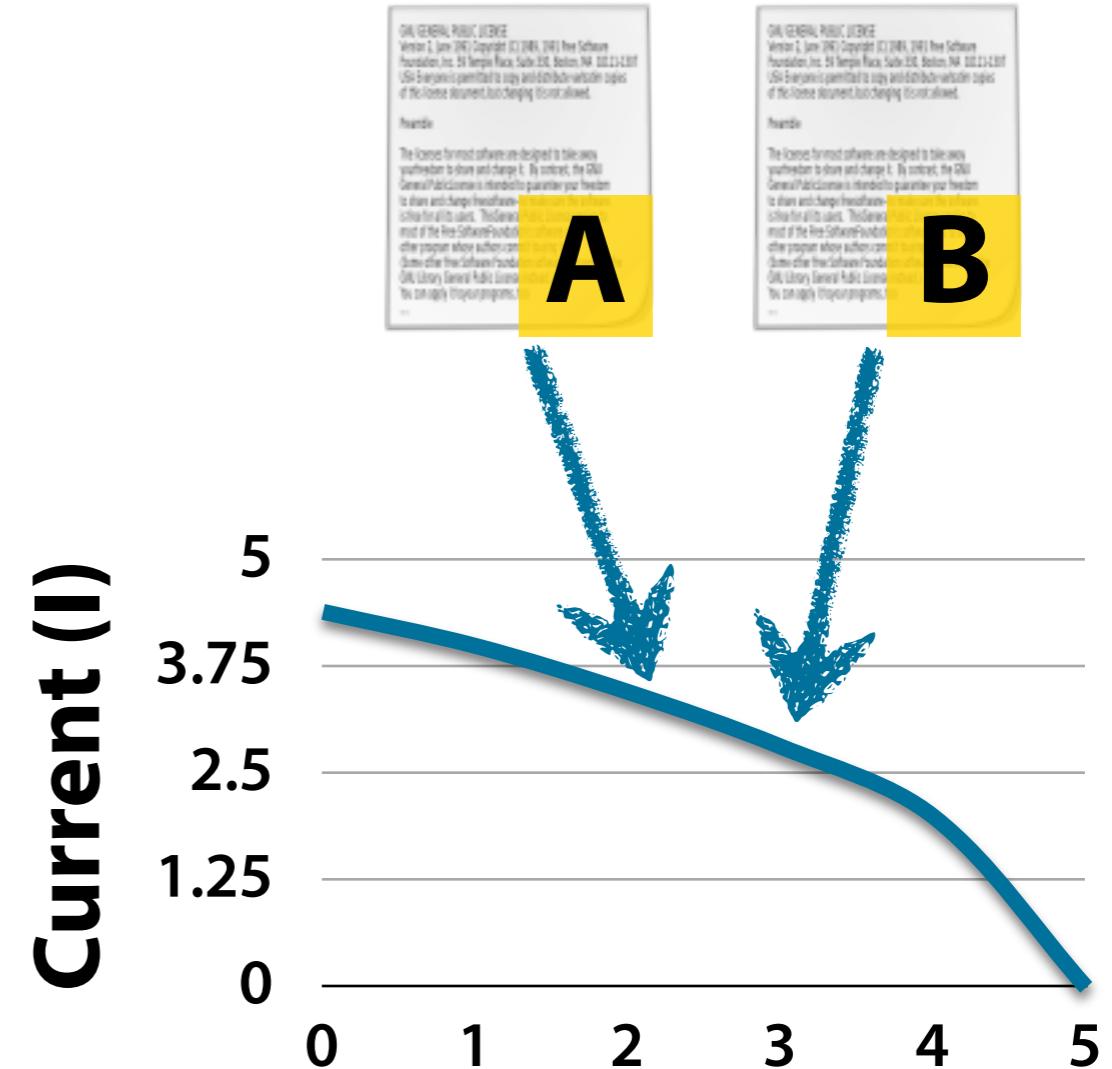
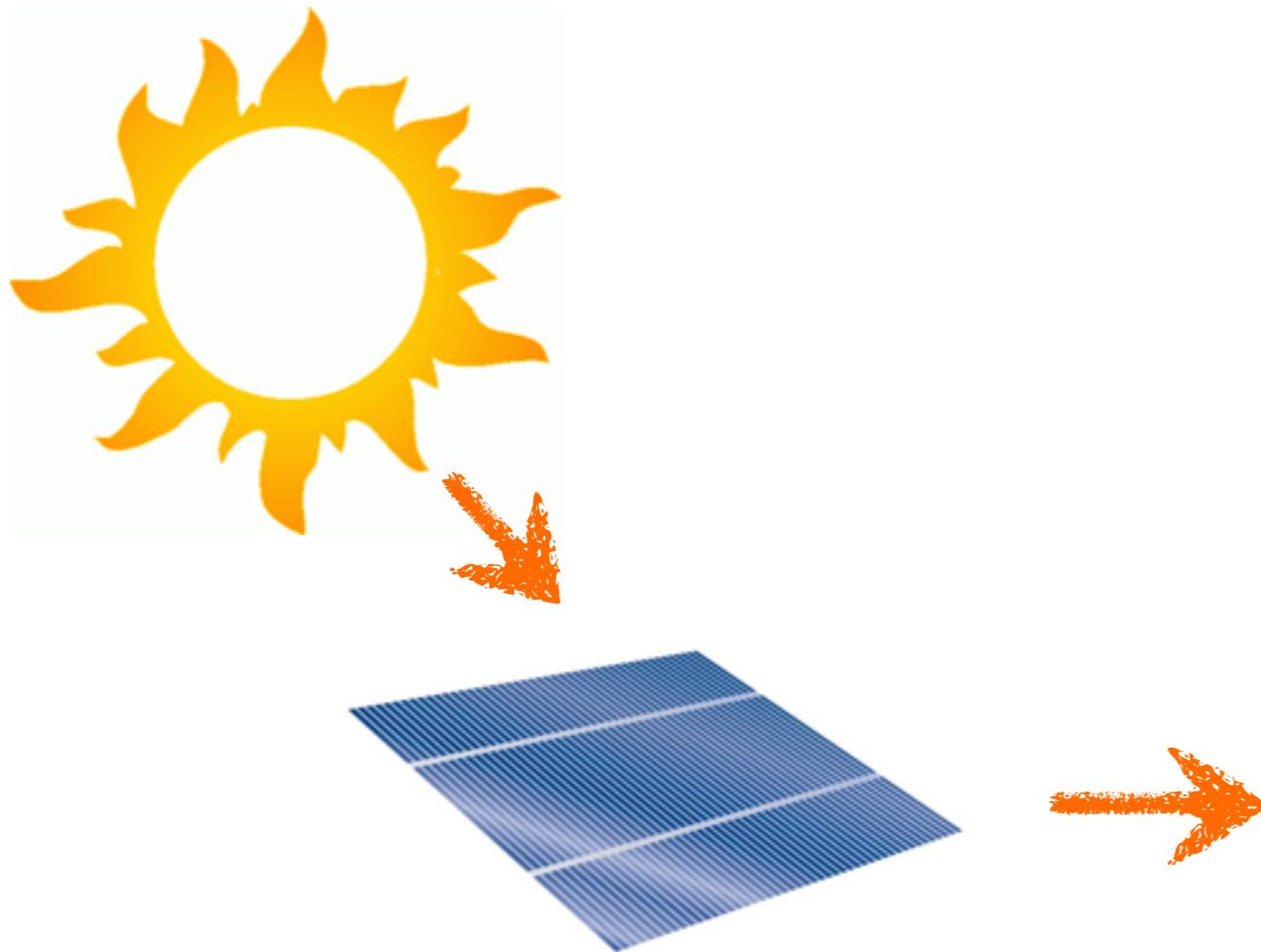


Power, $P=IV$

Predicting Outcomes

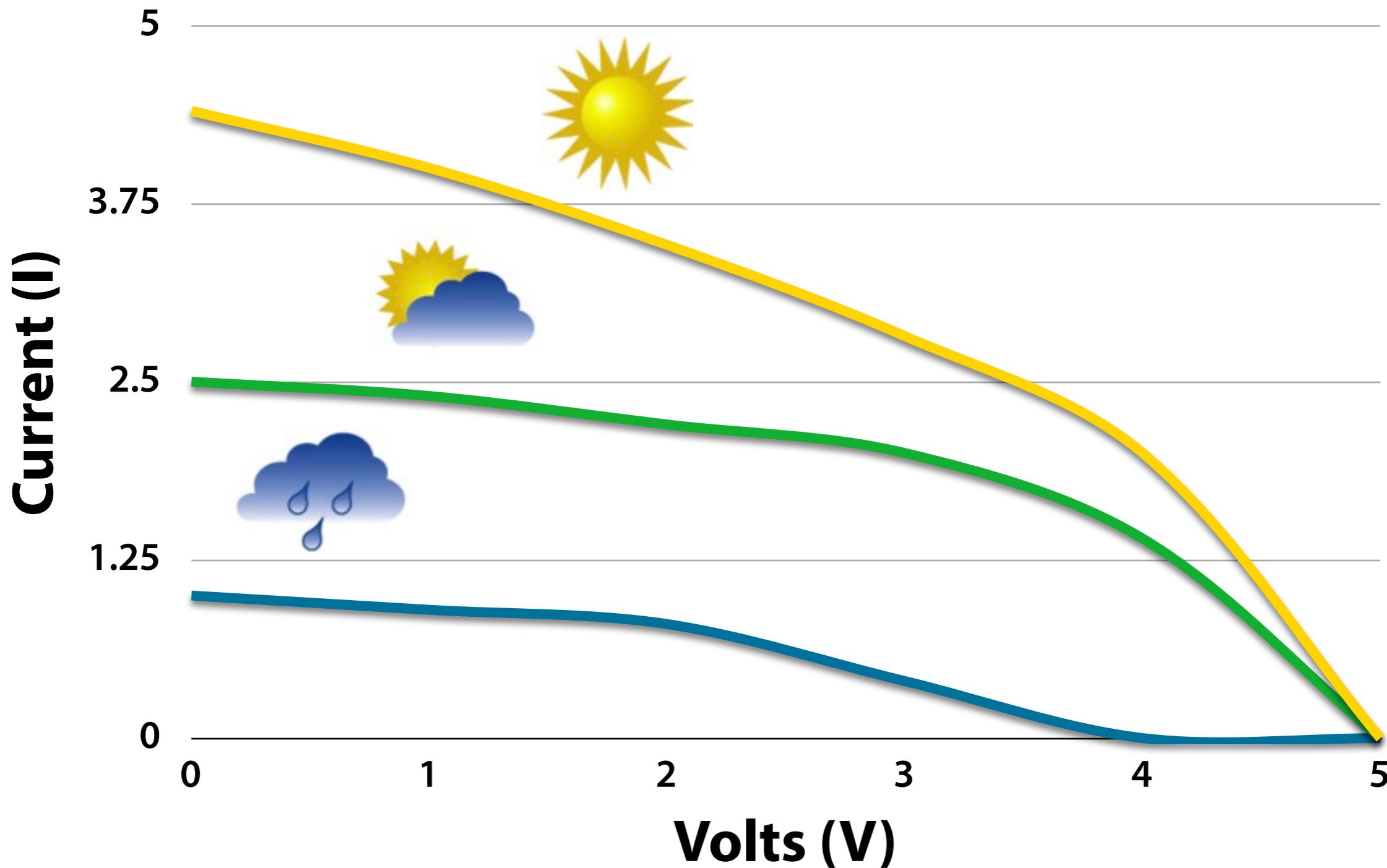


Predicting Outcomes

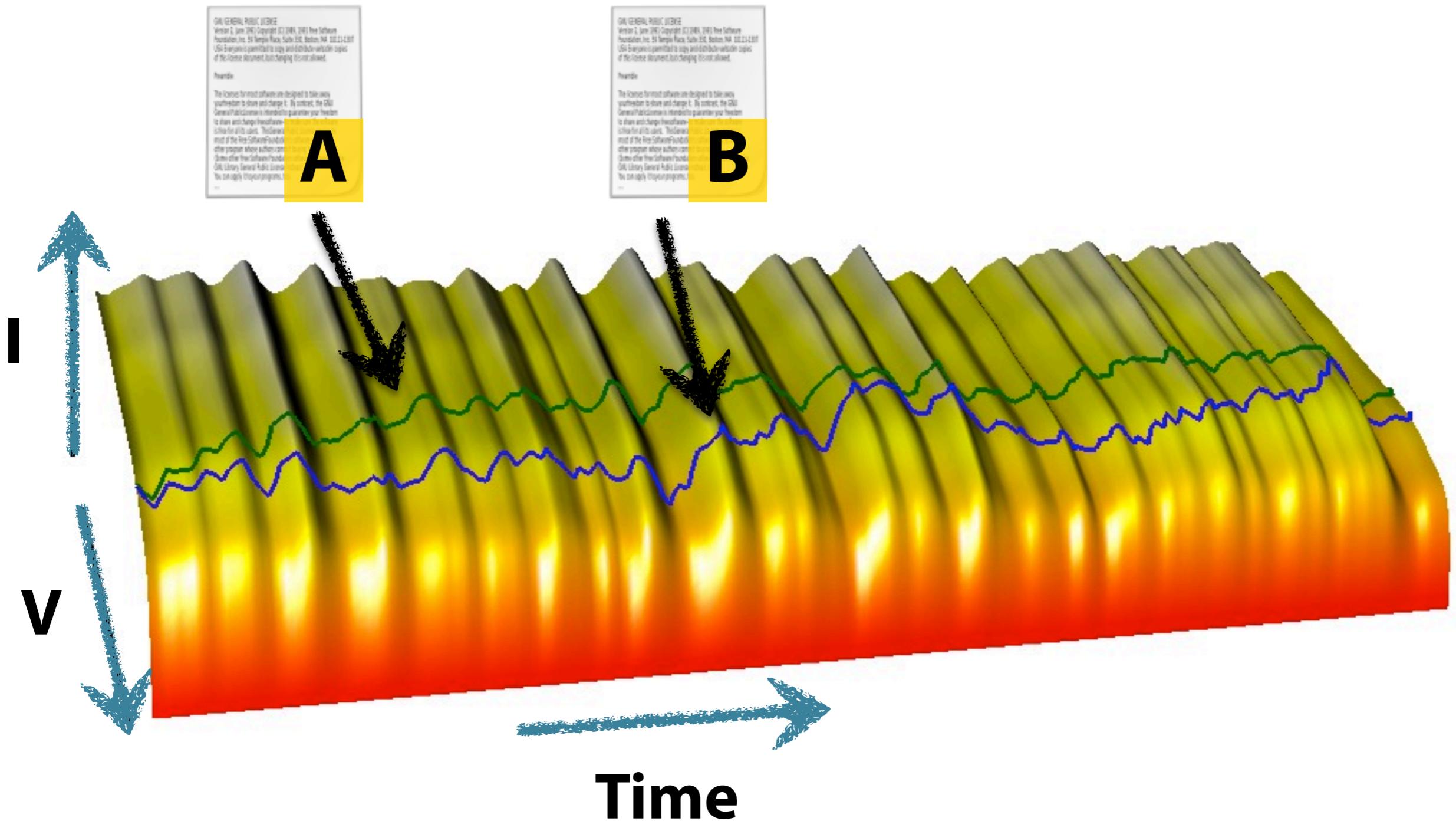


A and B see different power traces.

I-V Curves



An Added Dimension



Ekho

Generality

- Based on I–V Surfaces
- Solar, RF, Kinetic, Thermal

Flexibility

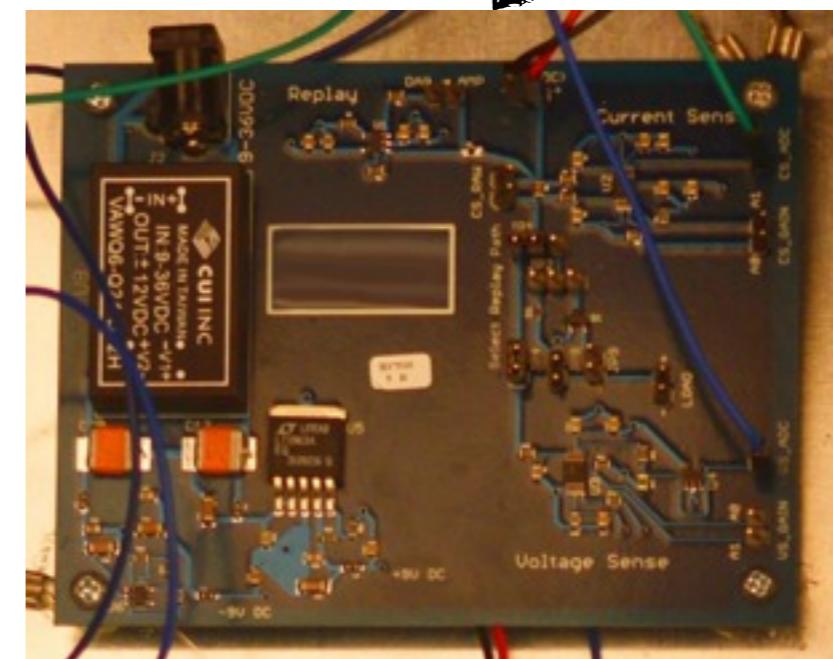
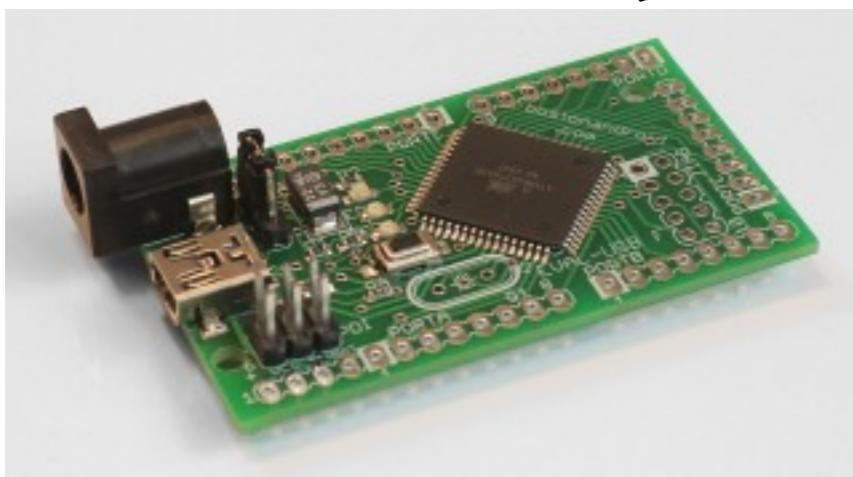
- Replicates energy harvesting in hardware

Ekho

I-V Surface
Manager
(PC)

I-V Curve
Controller

Analog
Front-End



Ekho

Two Modes

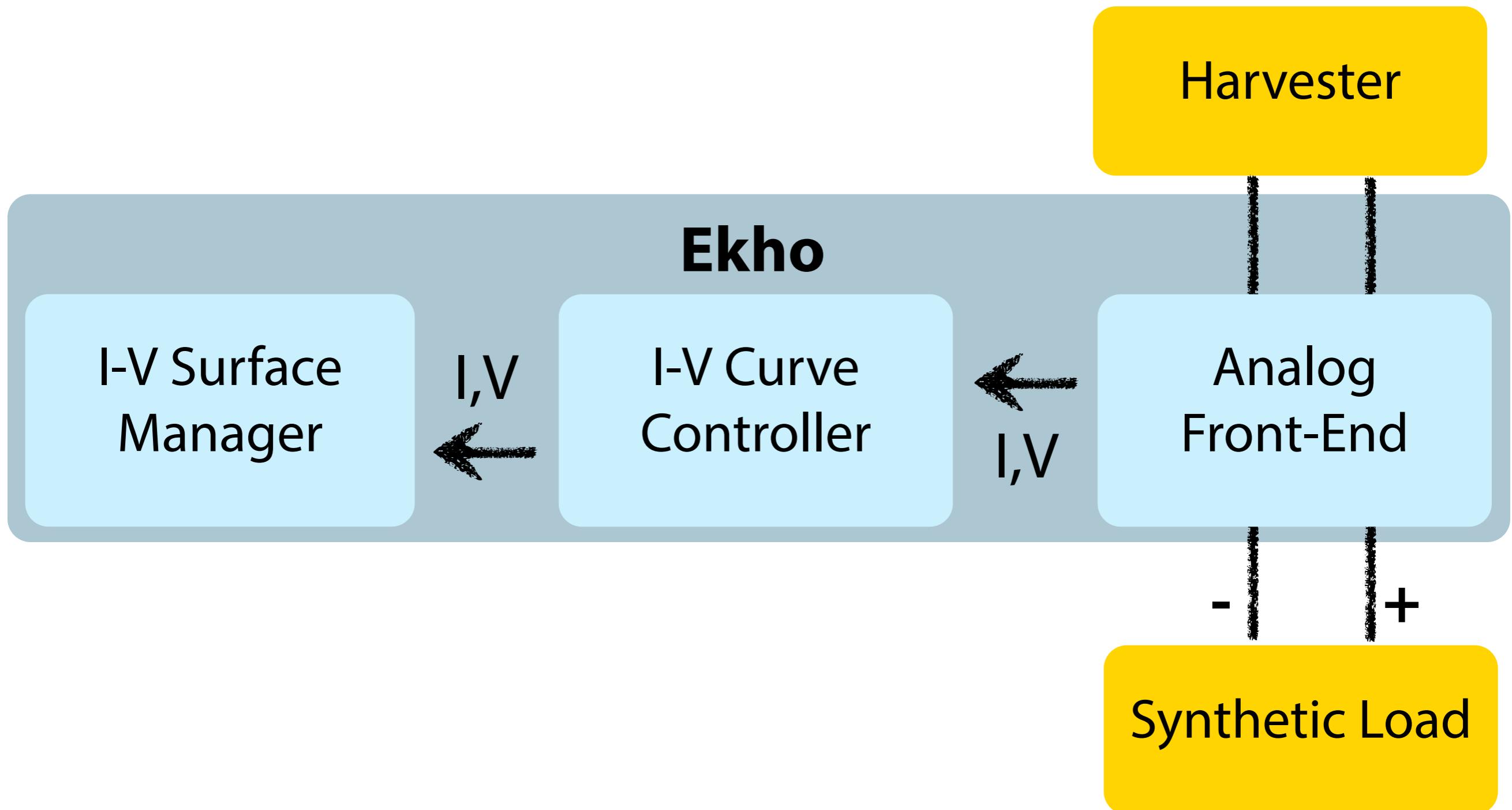
Record

- Estimate an I–V Surface

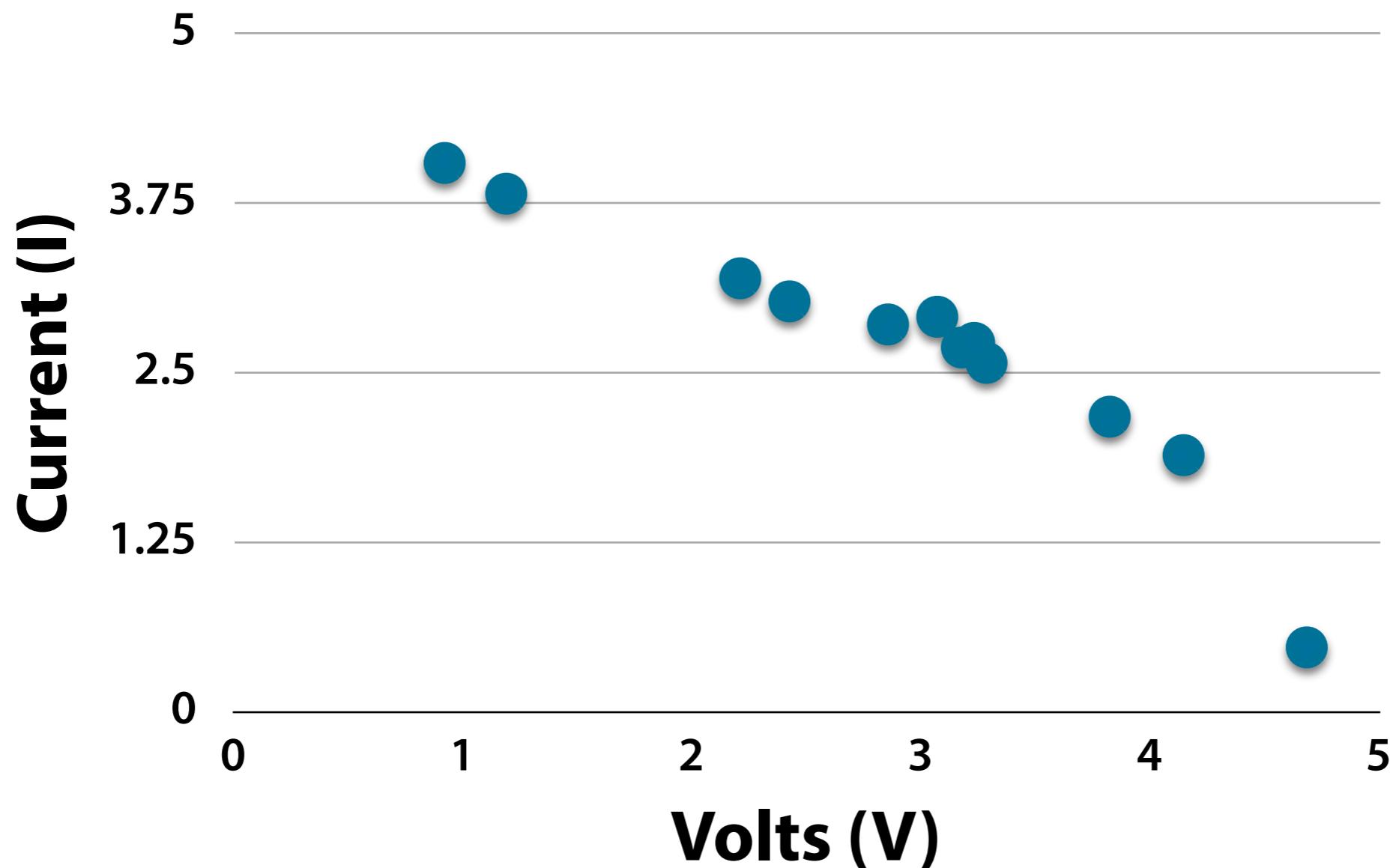
Emulate

- Replay an I–V Surface

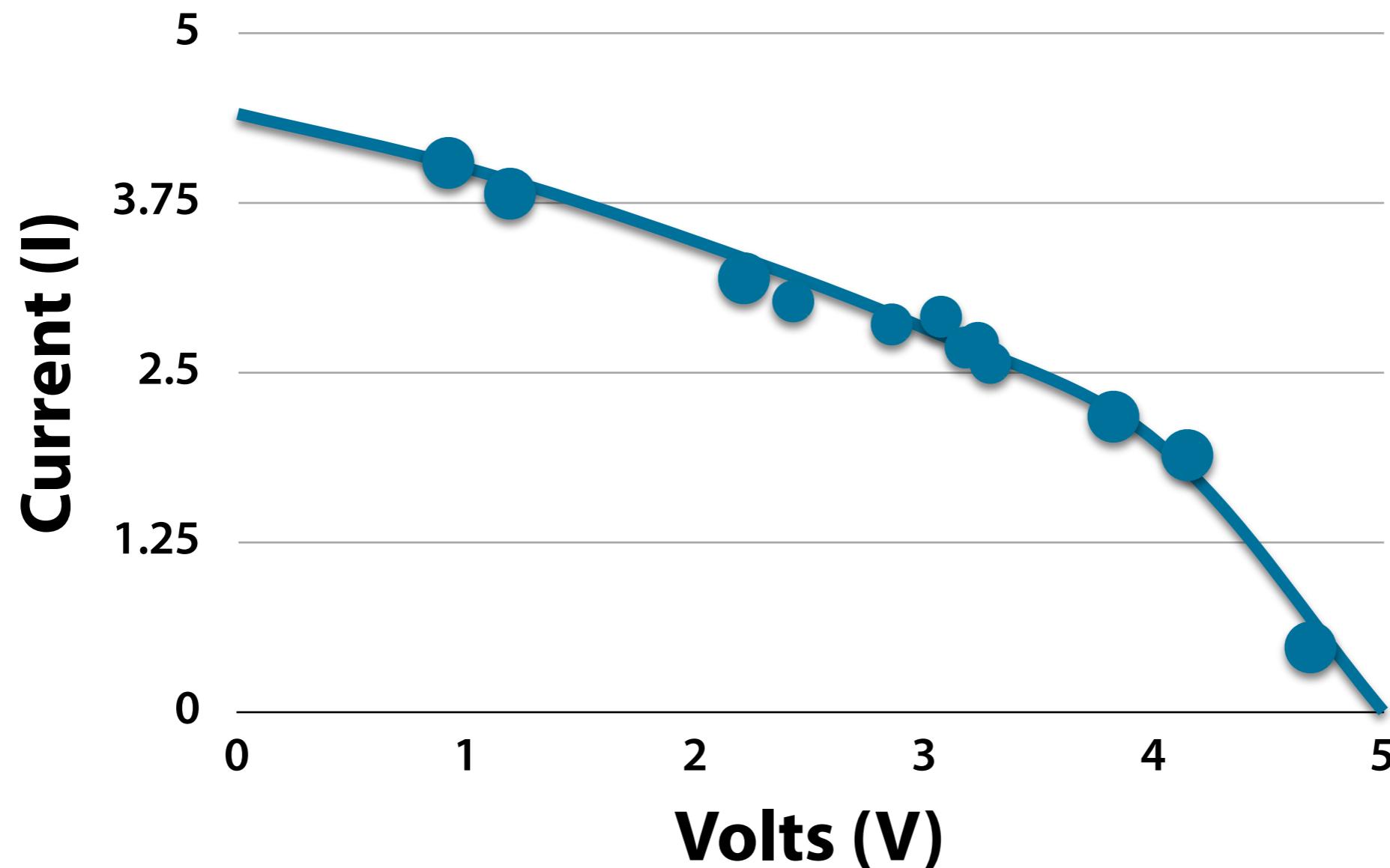
Record



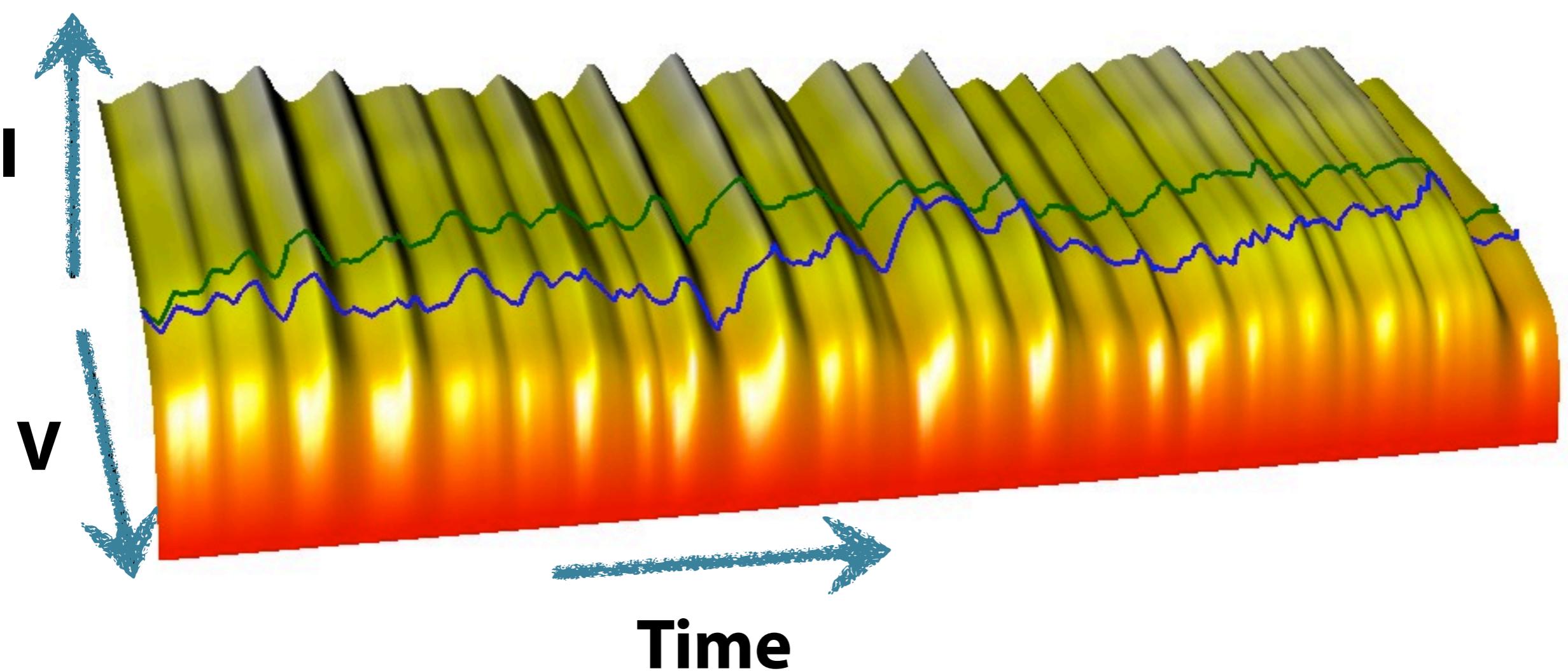
Estimating I-V Curves



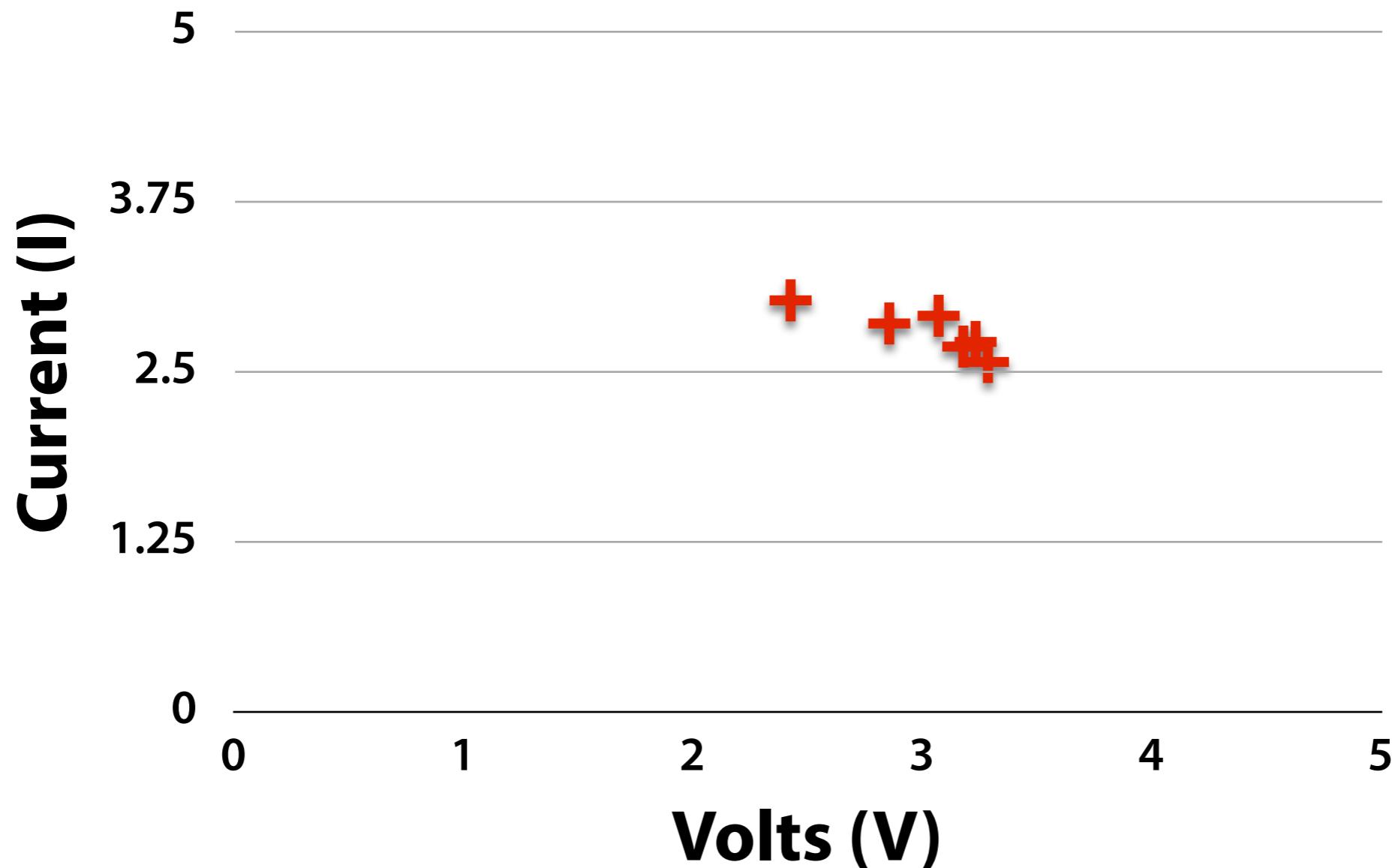
Estimating I-V Curves



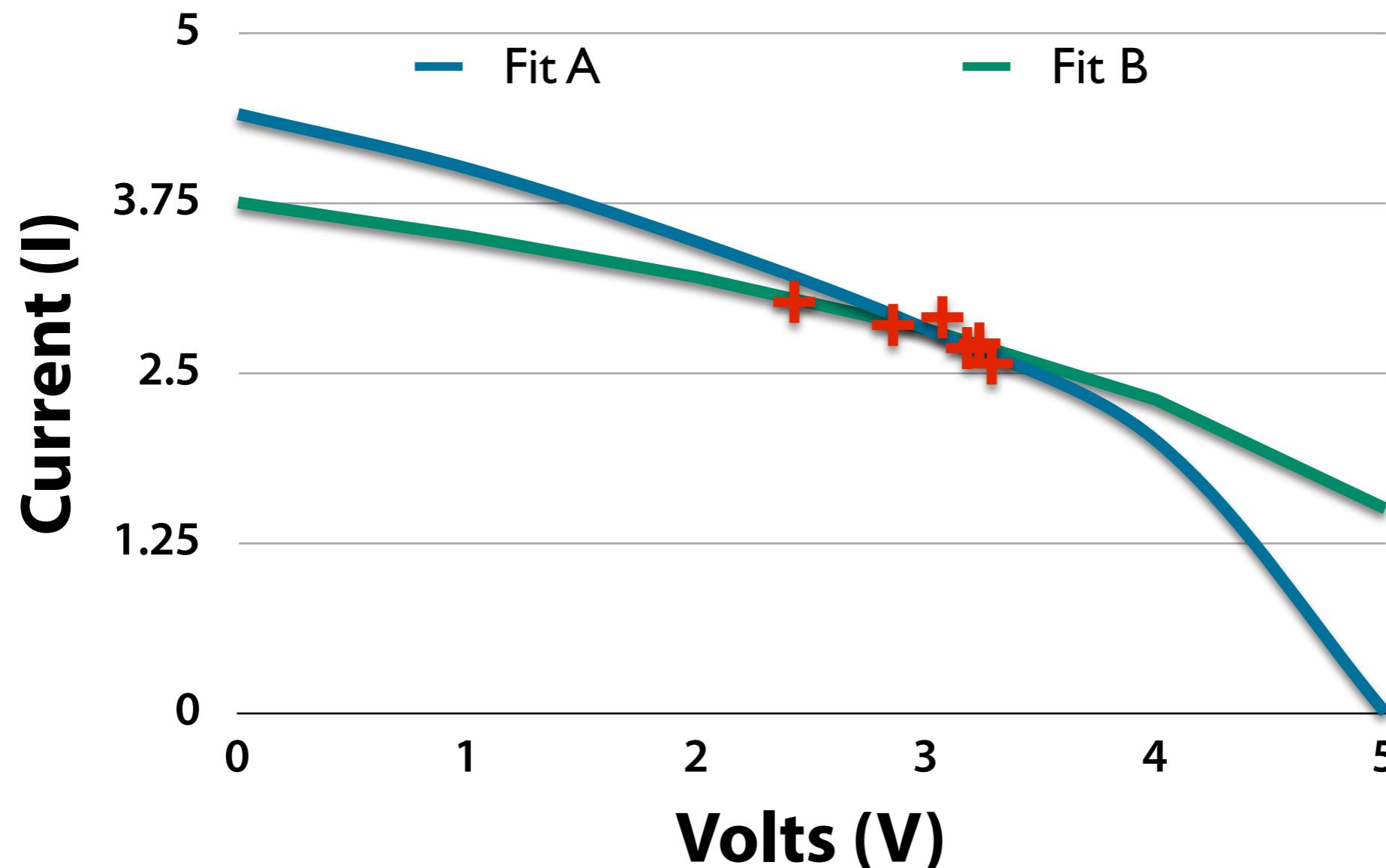
Estimating a Surface



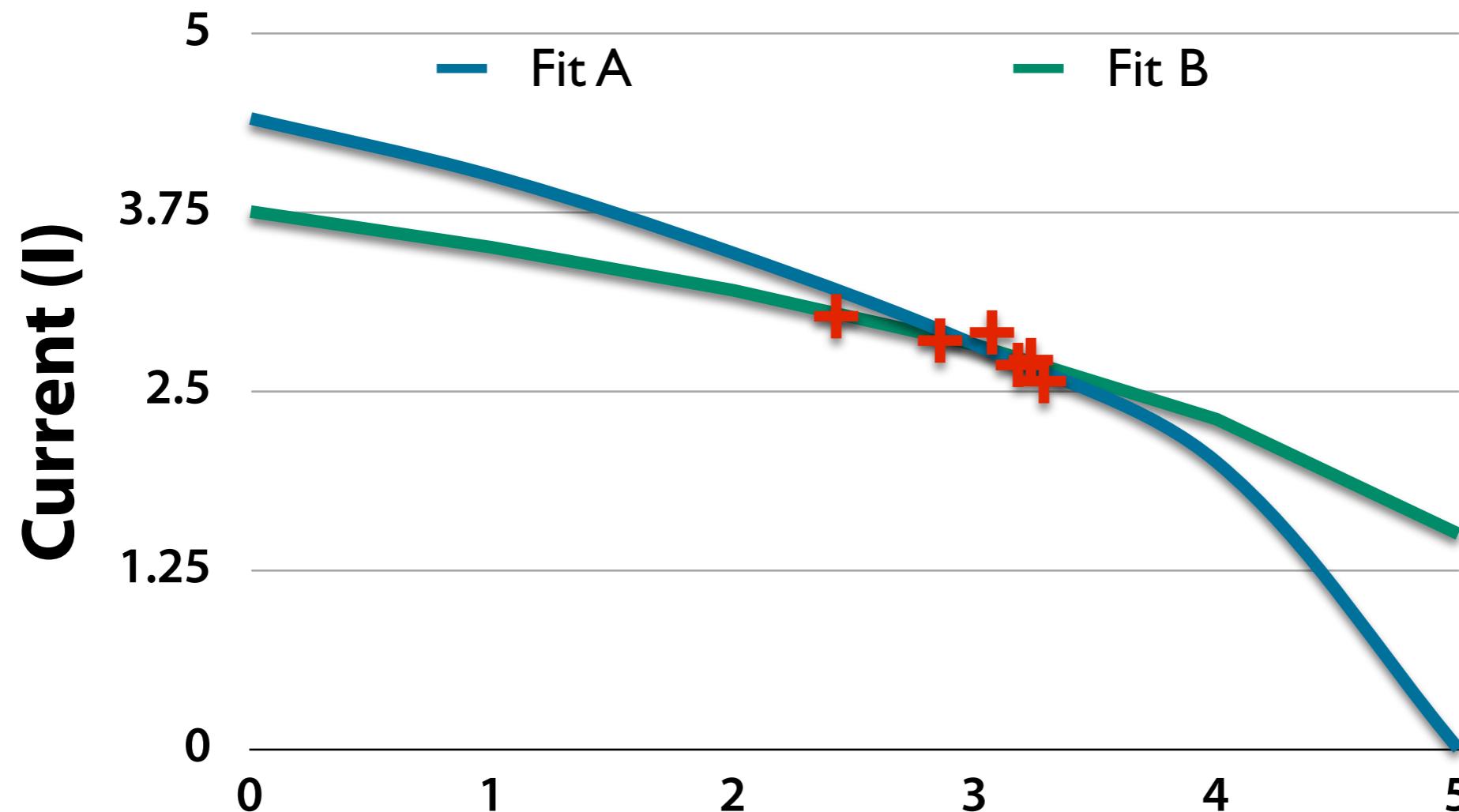
Estimating I-V Curves



Estimating I-V Curves

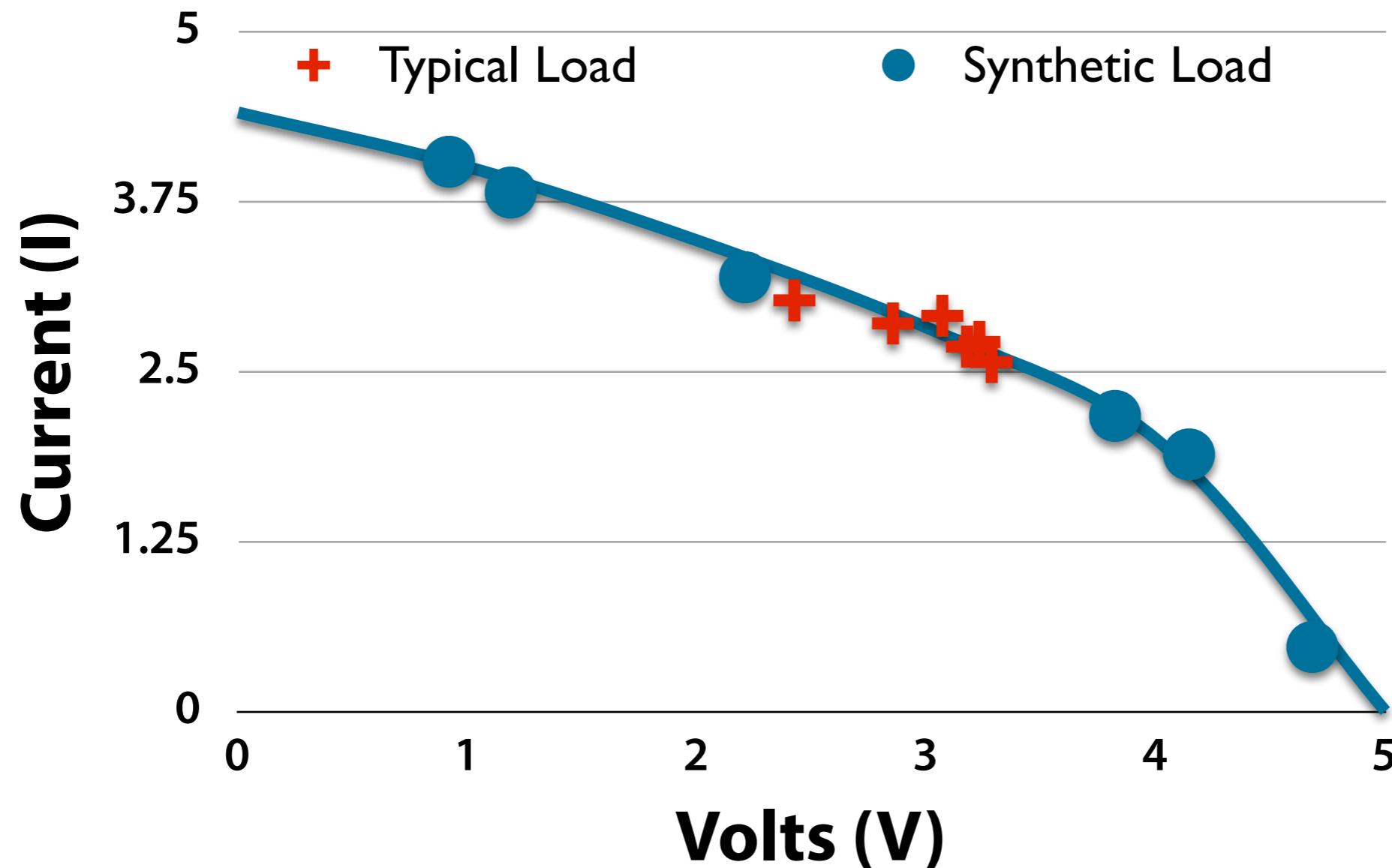


Estimating I-V Curves

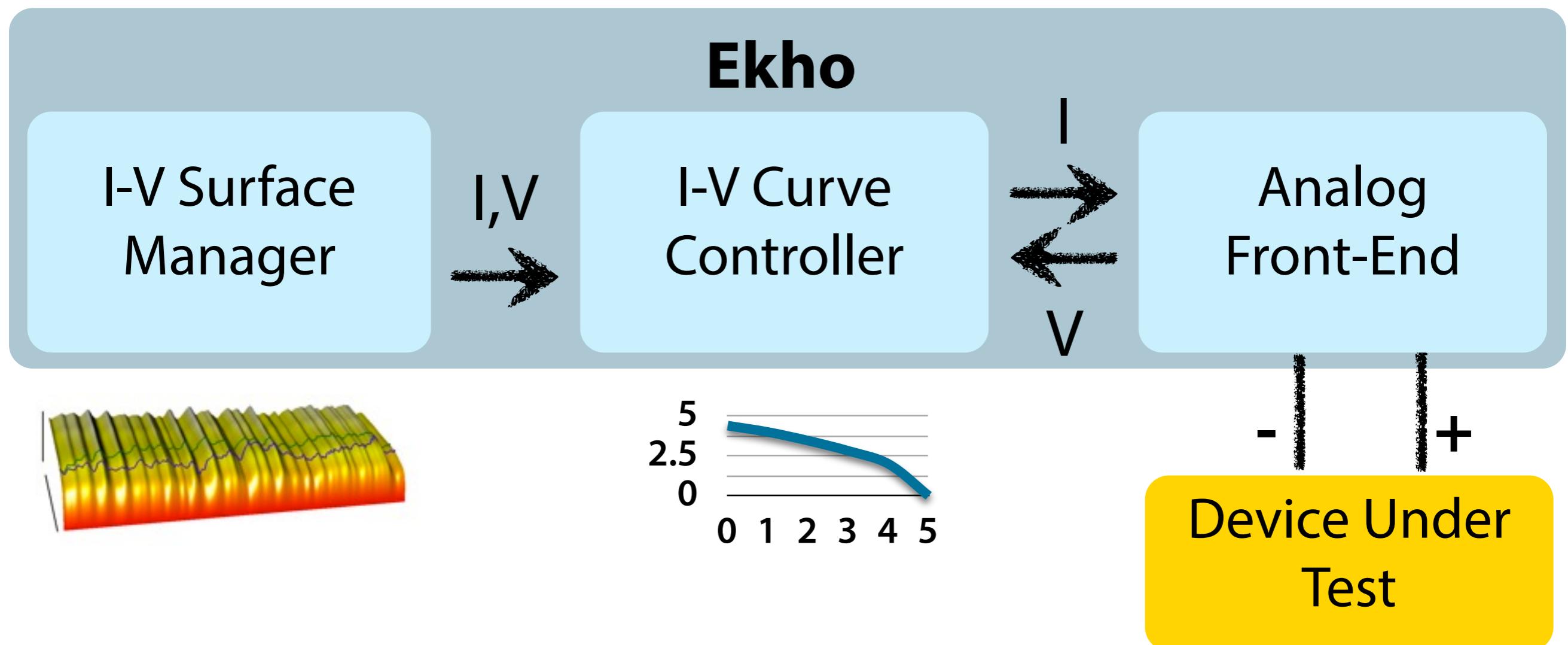


Need a smart load.

Estimating I-V Curves



Replay (emulate)



Emulating an I-V Curve

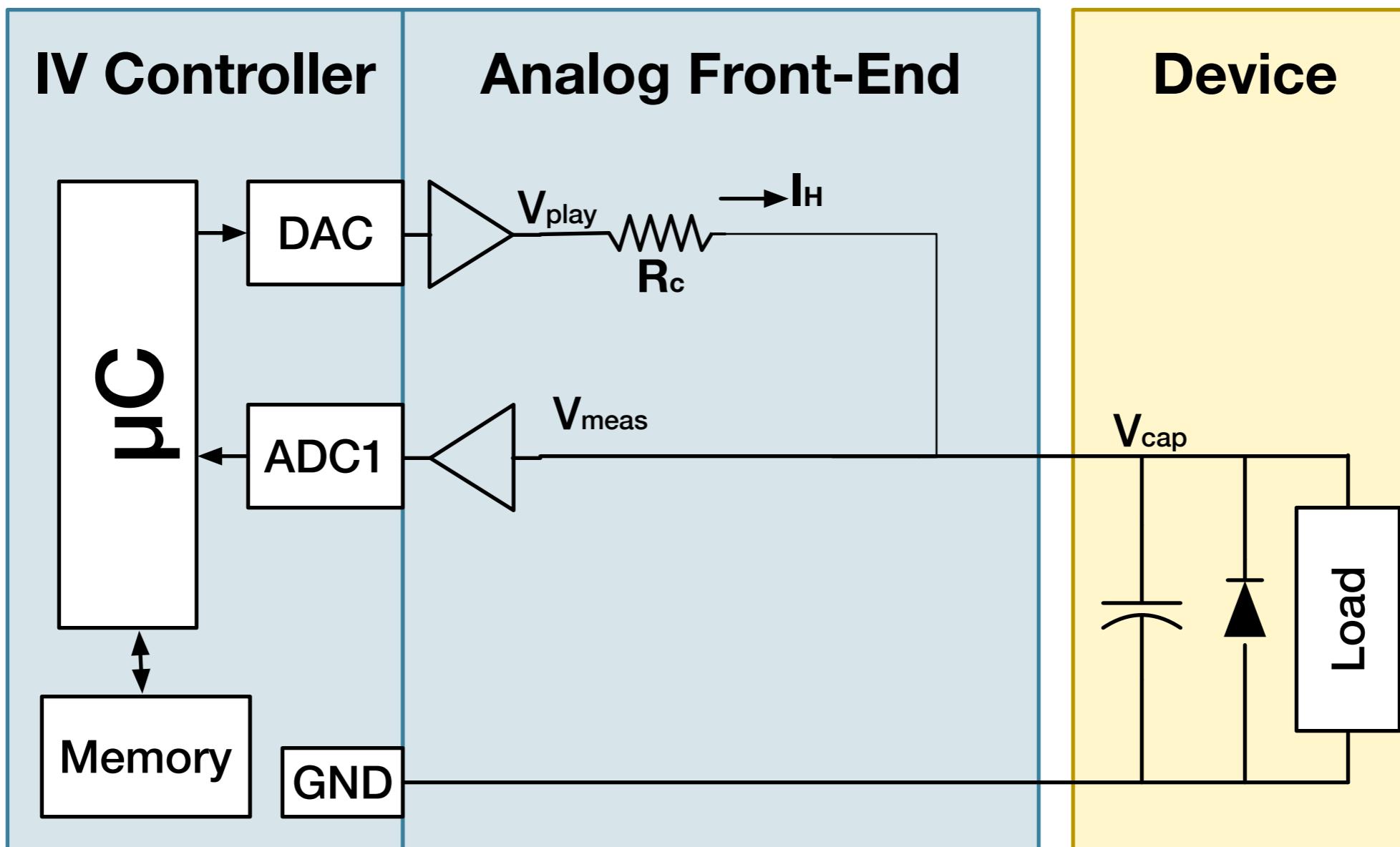
Repeat (quickly and accurately)

{

- Measure capacitor voltage (V)
- Look up current (I) from I-V curve
- Play back appropriate power

}

Controlling Power Output



Implementation

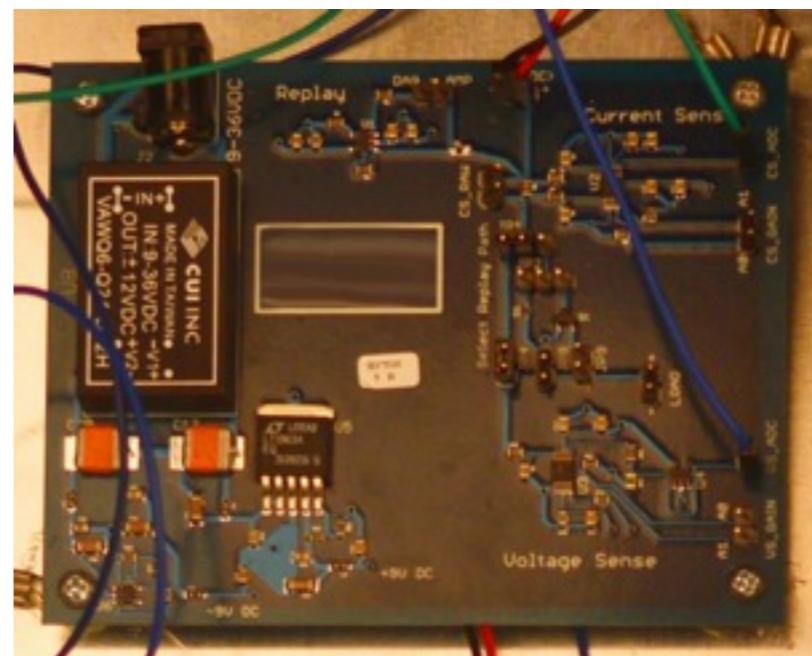
Prototype

- AVR Xmega
- Custom PCB



Coming soon

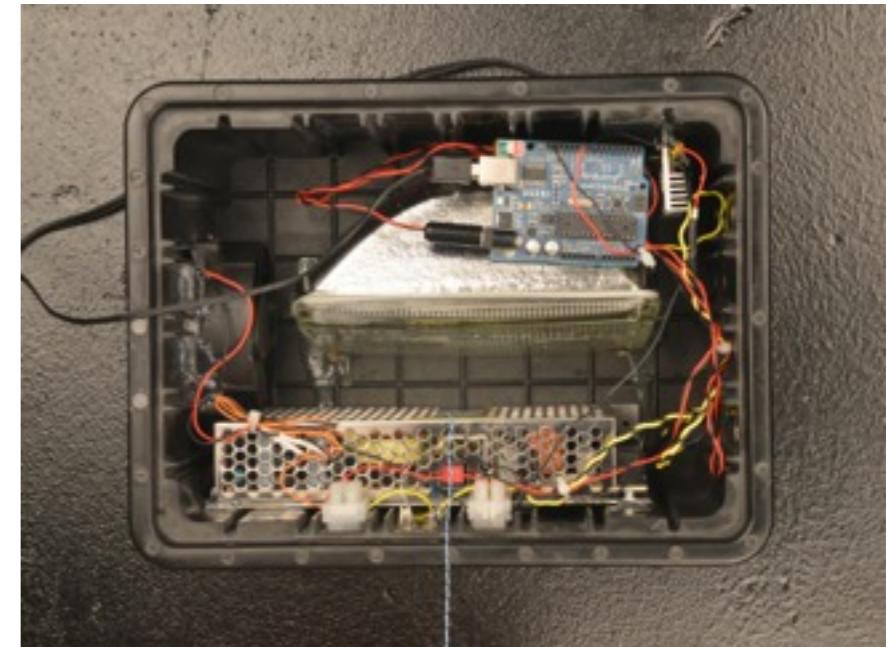
- Wearable Ekho



Energy Environments

Light Box

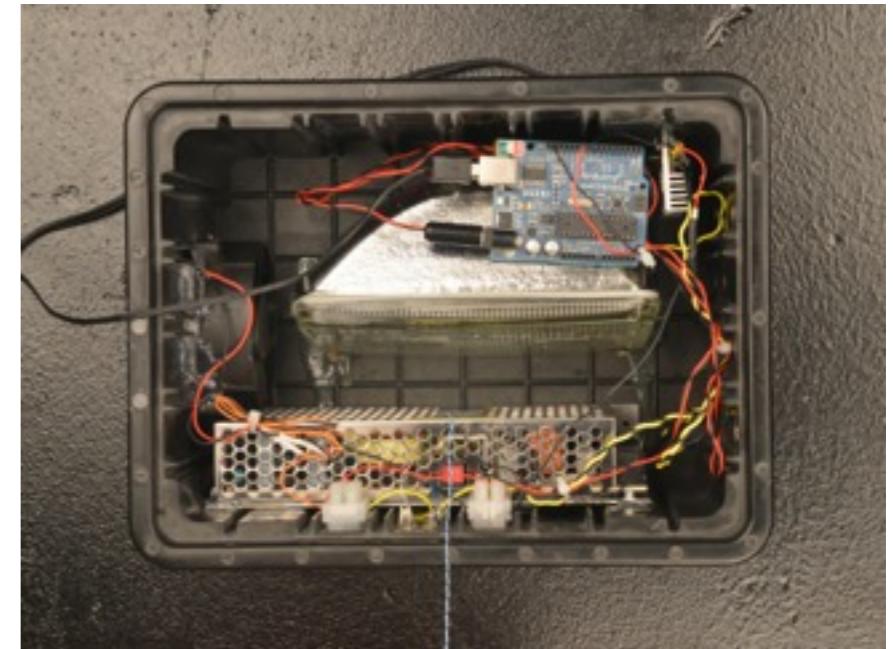
- Headlight
- Solar Panel



Energy Environments

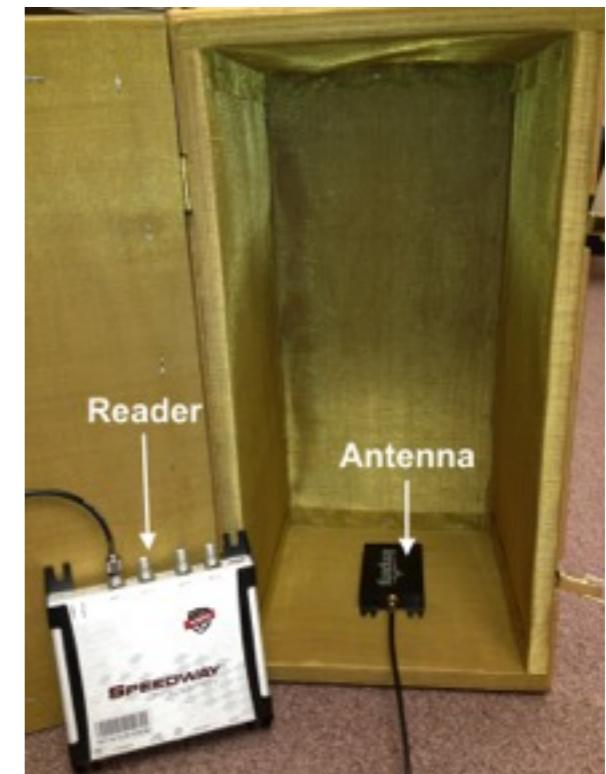
Light Box

- Headlight
- Solar Panel



RF Box

- Faraday Cage
- RFID Reader



Results

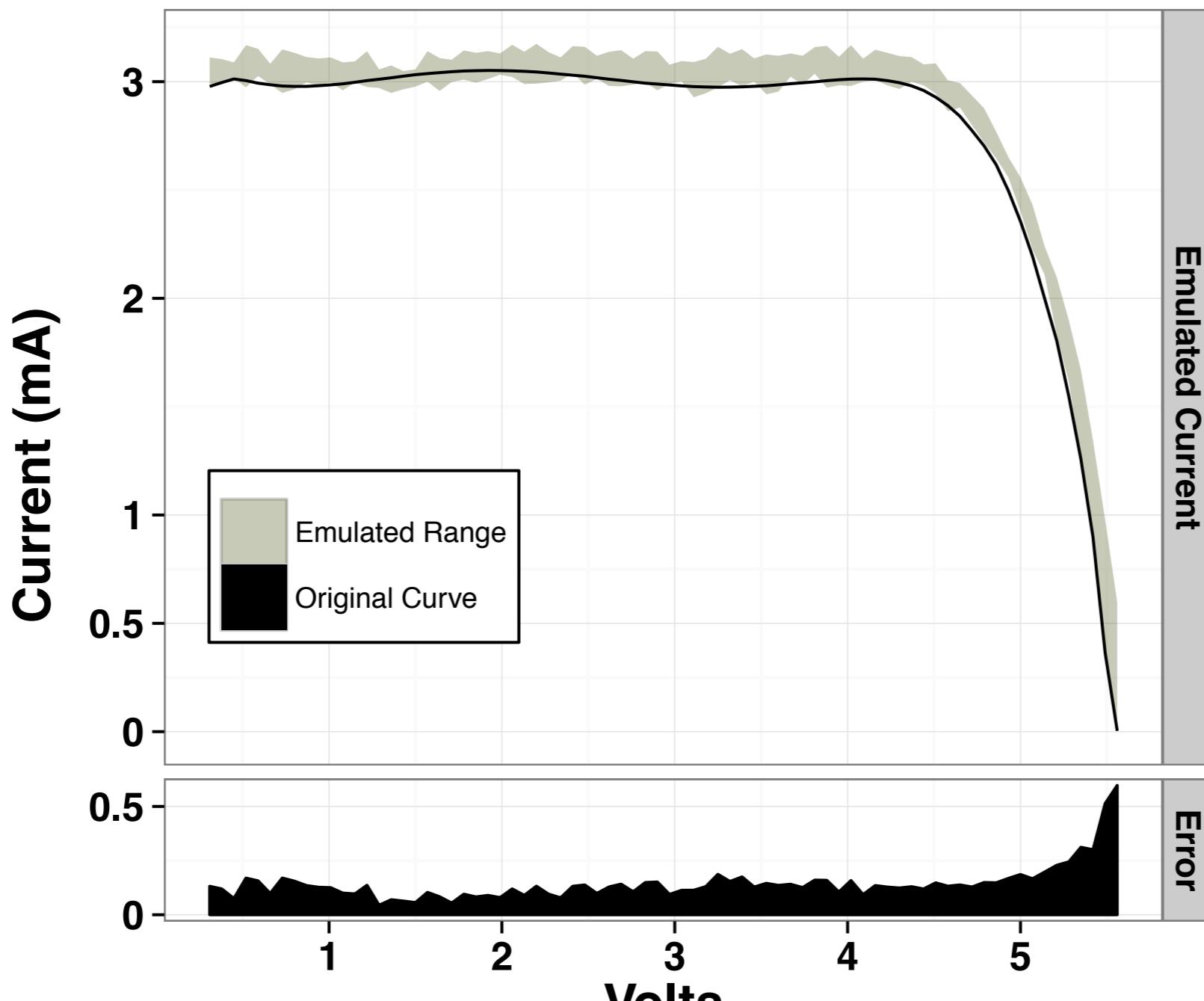
Emulating I-V curves

- Solar accuracy
- Error rates

RFID-Scale Devices

- Accuracy
- Consistency

Results



Solar, within $77.4\mu\text{A}$

RFID-Scale Results

Transmit Power	Harvested Energy	CRC Ekho Mean	CRC RF-Box Mean
+21.25dBm	0.55 mJ	23.6	21.0
+27.75dBm	2.57 mJ	208.7	189.2
+32.50dBm	3.88 mJ	237.3	266.2

Comparable accuracy

RFID-Scale Results

Transmit Power	Harvested Energy	Ekho Error %	RF-Box Error %
+21.25dBm	0.55 mJ	2.3%	39.4%
+27.75dBm	2.57 mJ	0.3%	20.7%
+32.50dBm	3.88 mJ	0.5%	4.7%

Better consistency

Summary

Ekho makes rigorous experimentation
with RFID-scale systems possible.

jhester@clemson.edu

<http://people.cs.clemson.edu/~jsorber/ekho>