The Birnie Group solar class and website were created with much-appreciated support from the NSF CRCD Program under grants 0203504 and 0509886. Continuing Support from the McLaren Endowment is also greatly appreciated!

Introduction Class: History with Solar Car Racing and Student Solar Design Projects

Slides on these *other topics* might also be of interest (most collected during teaching years 2004 and 2005):

http://www.rci.rutgers.edu/~dbirnie/solarclass/BandGapandDopingLecture.pdf	Band Gap Engineering of Semiconductor Properties
http://www.rci.rutgers.edu/~dbirnie/solarclass/MultijunctionLecture.pdf	Multi-Junction Solar Device Design
http://www.rci.rutgers.edu/~dbirnie/solarclass/MBEgrowth.pdf	Molecular Beam Epitaxy
http://www.rci.rutgers.edu/~dbirnie/solarclass/amorphousSi.pdf	Amorphous Silicon Solar Cells
http://www.rci.rutgers.edu/~dbirnie/solarclass/TransparentConductors.pdf	Transparent Conductors for Solar
http://www.rci.rutgers.edu/~dbirnie/solarclass/ARCoatings.pdf	Anti-Reflection Coatings for Solar
http://www.rci.rutgers.edu/~dbirnie/solarclass/OrganicPV.pdf	Organic PV
http://www.rci.rutgers.edu/~dbirnie/solarclass/DSSC.pdf	Dye Sensitized Solar Cells
http://www.rci.rutgers.edu/~dbirnie/solarclass/MotorPrimerGaTech.pdf	Working with Simple DC Motors for Student Solar Projects
http://www.rci.rutgers.edu/~dbirnie/solarclass/2005ProjectResultsindex.htm	Examples of Previous Years' Student Solar Projects

Note: in some cases it may be possible to design custom courses that expand on the above materials (send me email!)

Journal Publications of Some Recent Research: (best viewed through department home index: http://mse.rutgers.edu/dunbar_p_birnie_iii)

Other Birnie Group Research:

Sol-Gel Coating Quality and Defects Analysis (mostly Spin Coating):	http://www.coatings.rutgers.edu
Solar Research at Rutgers: Broader Overview	http://www.solar.rutgers.edu
Solar and Electric Vehicles System Projects (early stage emphasis)	http://www.rave.rutgers.edu

RUTGERS UNIVERSITY

Professor Dunbar P. Birnie, III (dunbar.birnie@rutgers.edu)
Department of Materials Science and Engineering
http://mse.rutgers.edu/faculty/dunbar_p_birnie

Solar Cell Design and Processing

Fall 2004

Dunbar P. Birnie, III

http://www.rci.rutgers.edu/~dbirnie/solarclass

Outline

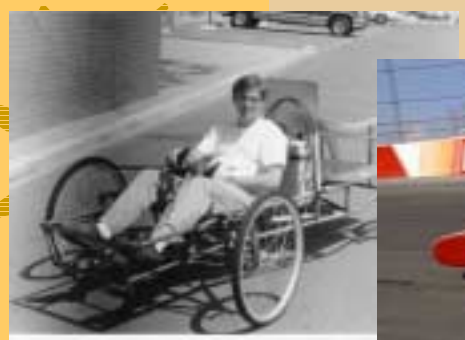
- Introduction
- Class Content Outline
- Design of Solar Collector – Subject to Specific Materials Limitations
- Design of Electrical Load – Subject to Current-Voltage Response of Solar Cell
- Communication of Design

My Background

- New to Rutgers – Came from Arizona
- Experience in Sol-Gel Coatings for Many Applications
- BS Thesis: Using Photovoltaic Effect to Split Water – and Characterize the Semiconductor Properties
- Faculty Advisor to the Arizona Solar Racing Team for 6 Years
- Coming to Rutgers with Intention of Building an Interdisciplinary Solar Engineering Program

Solarcar History at UA

1997 1998 1999 2000 2001 2002 2003



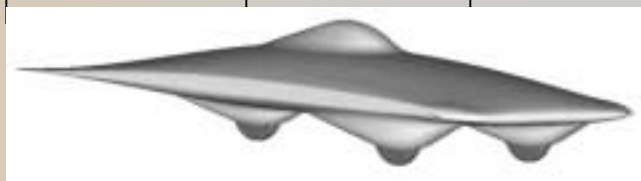
The Mule



Daedalus

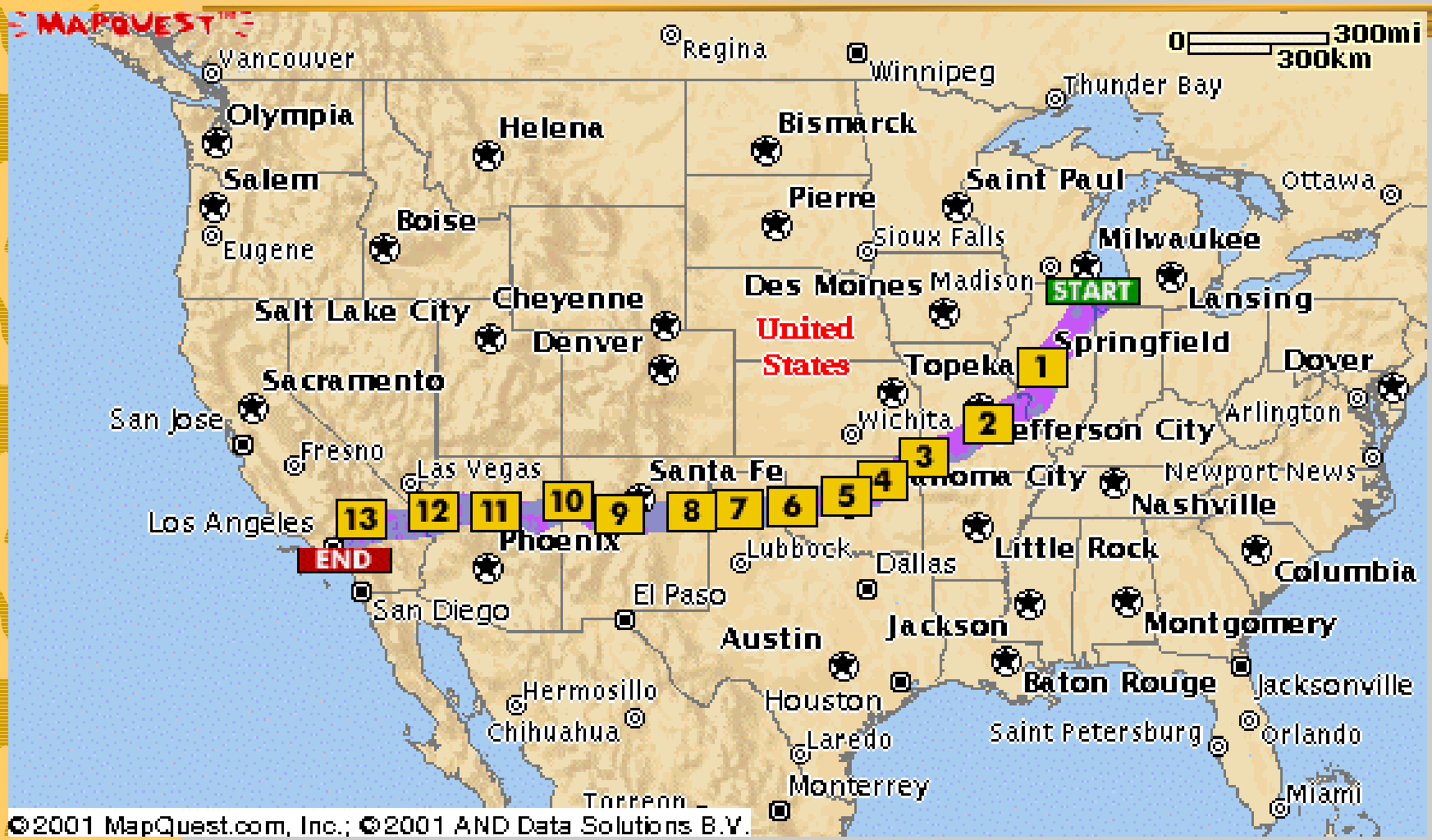


Monsoon

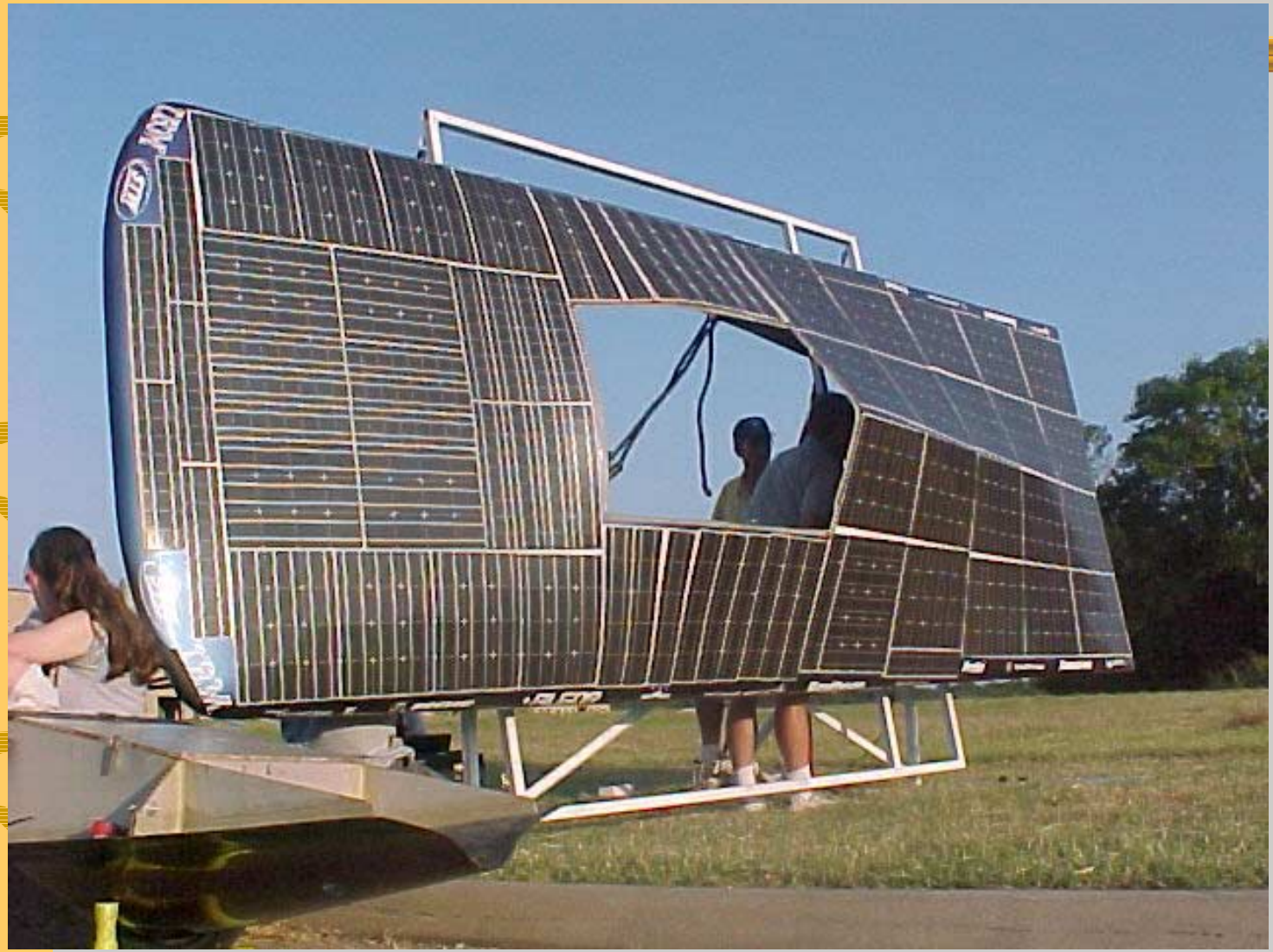


Turbulence

Race Route


MAPQUEST
0
300mi
300km
Regina
Winnipeg
Thunder Bay
Vancouver
Olympia
Helena
Bismarck
Salem
Pierre
Saint Paul
Ottawa
Boise
Eugene
Sioux Falls
Milwaukee
Des Moines
Madison
START
Lansing
Salt Lake City
Cheyenne
United States
Springfield
Denver
Topeka
Dover
Sacramento
1
San Jose
Wichita
2
Arlington
Fresno
3
Las Vegas
Santa Fe
4
Newport News
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10
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8
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Nashville
Los Angeles
Phoenix
Lubbock
Dallas
Little Rock
Columbia
END
San Diego
El Paso
Jackson
Montgomery
Austin
Baton Rouge
Jacksonville
Hermosillo
Houston
Chihuahua
Saint Petersburg
Orlando
Laredo
Monterrey
Miami
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Near Tulsa



Class Content

- Basic Semiconductor Physics – Electronic Structure – Capture of Light – Motion of electrons and holes – Generation of Voltage – “Doping” with Impurities
- Processing Steps for Constructing Solar Cells – Design Choices for Optimizing Output
- Hands-On Project with Solar Cells – Power Output Optimization

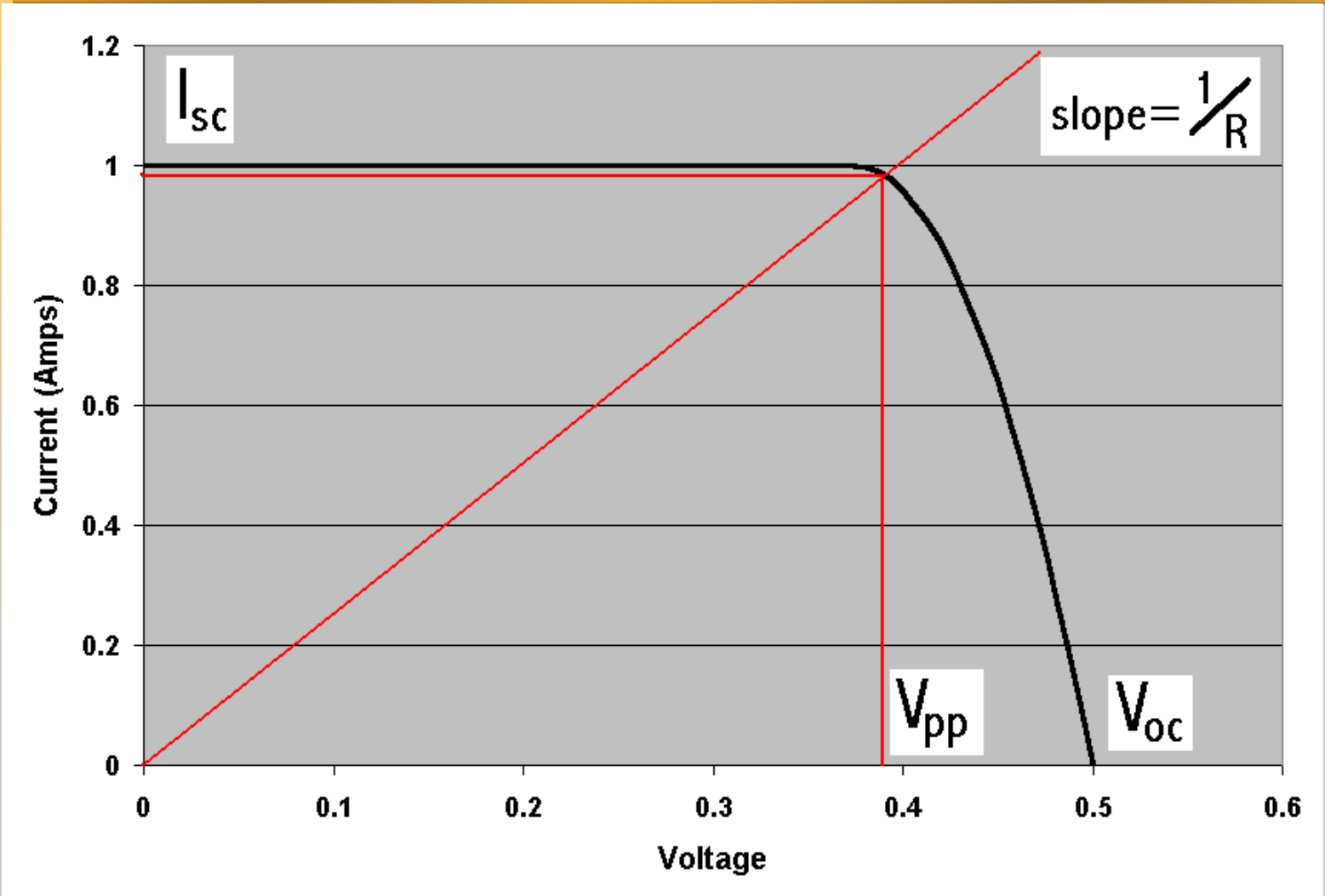
Class Design Project

- Design of Solar Collector – Subject to Specific Materials Limitations
- Design of Electrical Load – Subject to Current-Voltage Response of Solar Cell
- Communication of Design

Photovoltaic Cell Background

- Current-Voltage Trade-Off
- Higher Current at Lower Voltage
- Higher Voltage, but Lower Current
- Peak Power → Somewhere In-Between
- Depends on Exact Shape of IV Response
- Ideal Load Resistance Depends on IV

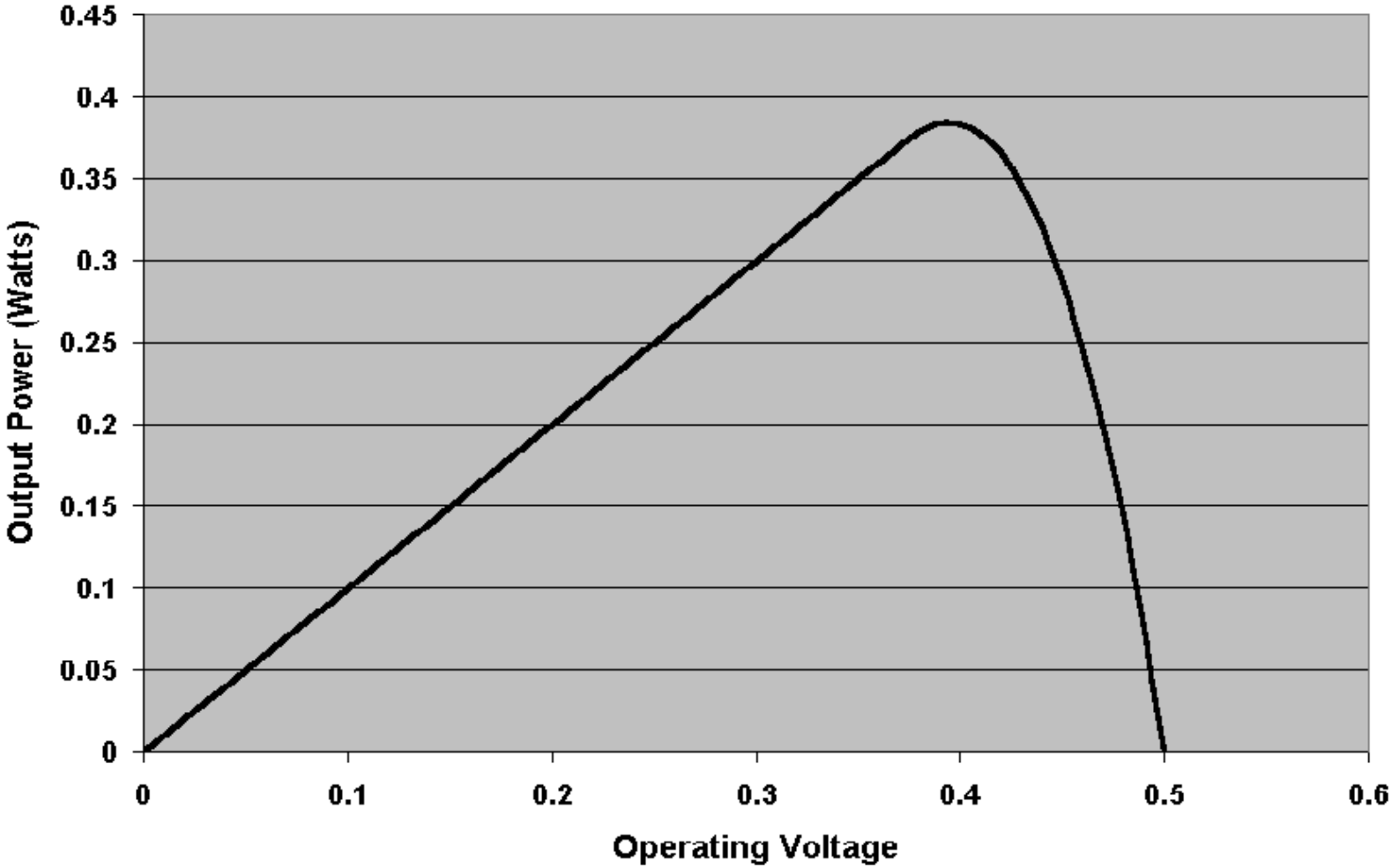
Schematic Current-Voltage Response



*Power = Current * Voltage*

- I-V Response Dictates Power Collection
- Higher Current at Lower Voltage
- Higher Voltage, but Lower Current
- **Either Extreme Degrades Power**
- Power Drops Off Rapidly on Both Sides
- Depends Strongly on Details of Real IV Response

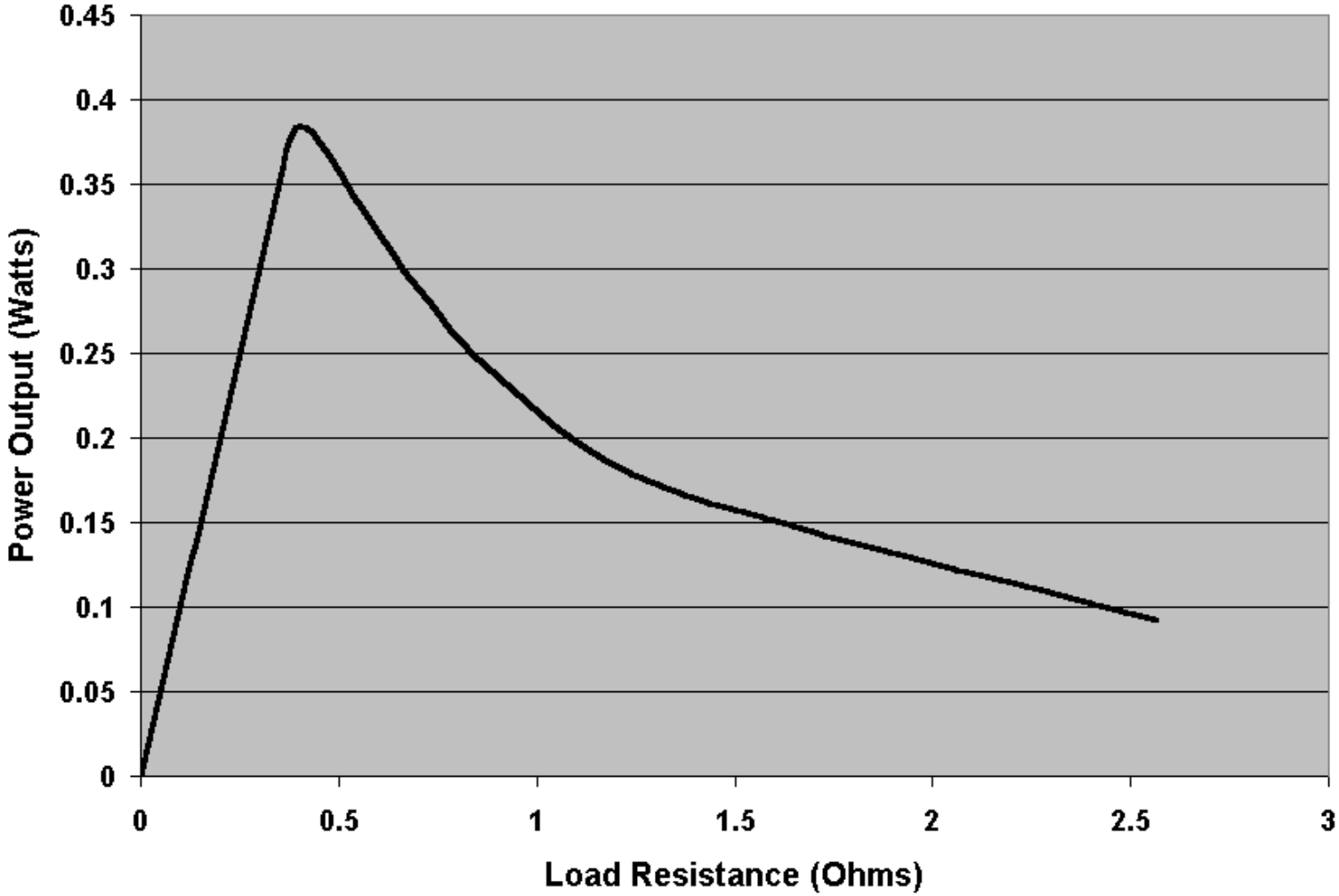
Schematic Power-Voltage Response



Resistance = Voltage/Current

- I-V Balance Results from Selecting a Different Resistance
- Higher Resistance Reduces Current
- Lower Resistance Reduces Voltage
- Want to Select Resistance to Optimize Power Collected
- Target the "**Peak Power Point**" on IV Curve

Power-Resistance Trade-Off



IV Implications with Reflectors

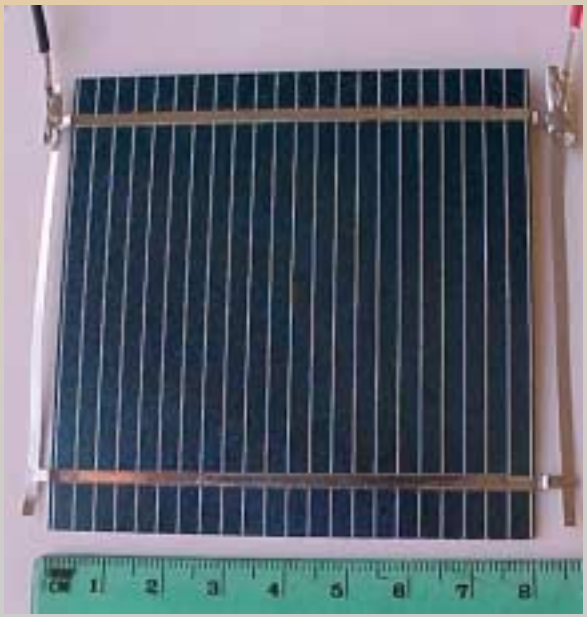
- Addition of a Reflector/Concentrator will Boost the Amount of Light Collected
- Current Values will be Larger
- Thermal Load will be Larger (Since Most of Absorbed Light is Converted to Heat Instead of Electricity).
- Heating will Lower the Voltages Slightly

IV Implications with Reflectors

- Higher Current and Lower Voltage
- Net Effect is that Peak Power Point Shifts to **Lower Resistance Values**
- Note: IV Response for Bare Cell is NOT Useful for Optimizing (Cell + Reflector) Systems → Mainly Because of Much Higher Current that is Produced

Project Implementation

- Cell Area = 8 cm x 8 cm
- V_{oc} = around 0.56 Volts
- I_{sc} = around 1 Amp – full sun, at noon



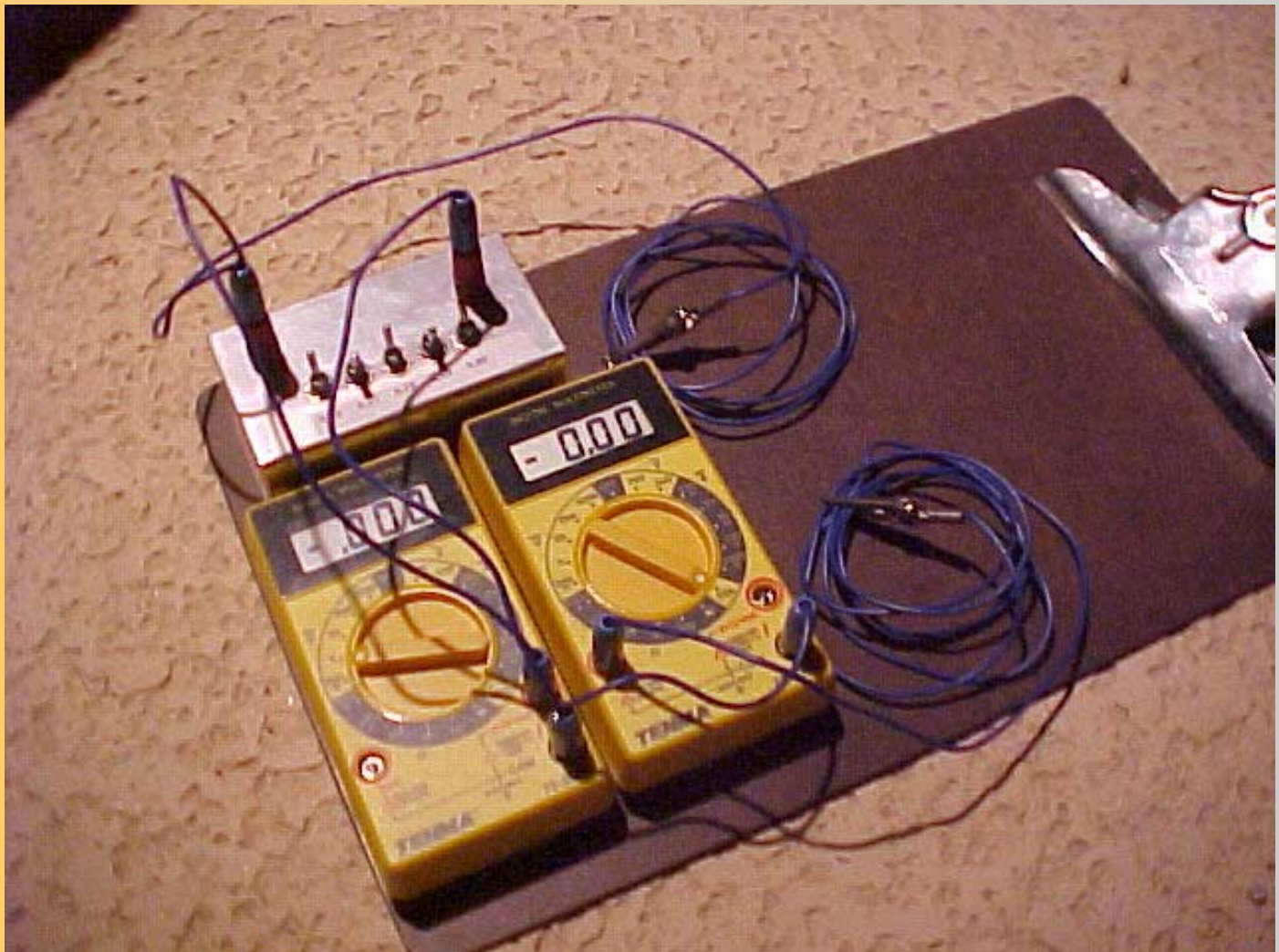
Specific Deliverables Assigned

- Concentrator Construction
- I-V Plot Measurement for Cell
- Preferred Resistance Value Selected
- Nominal Power Output Predicted
- Limits Placed on Reflector Materials
- Limits Placed on “Active” Cooling

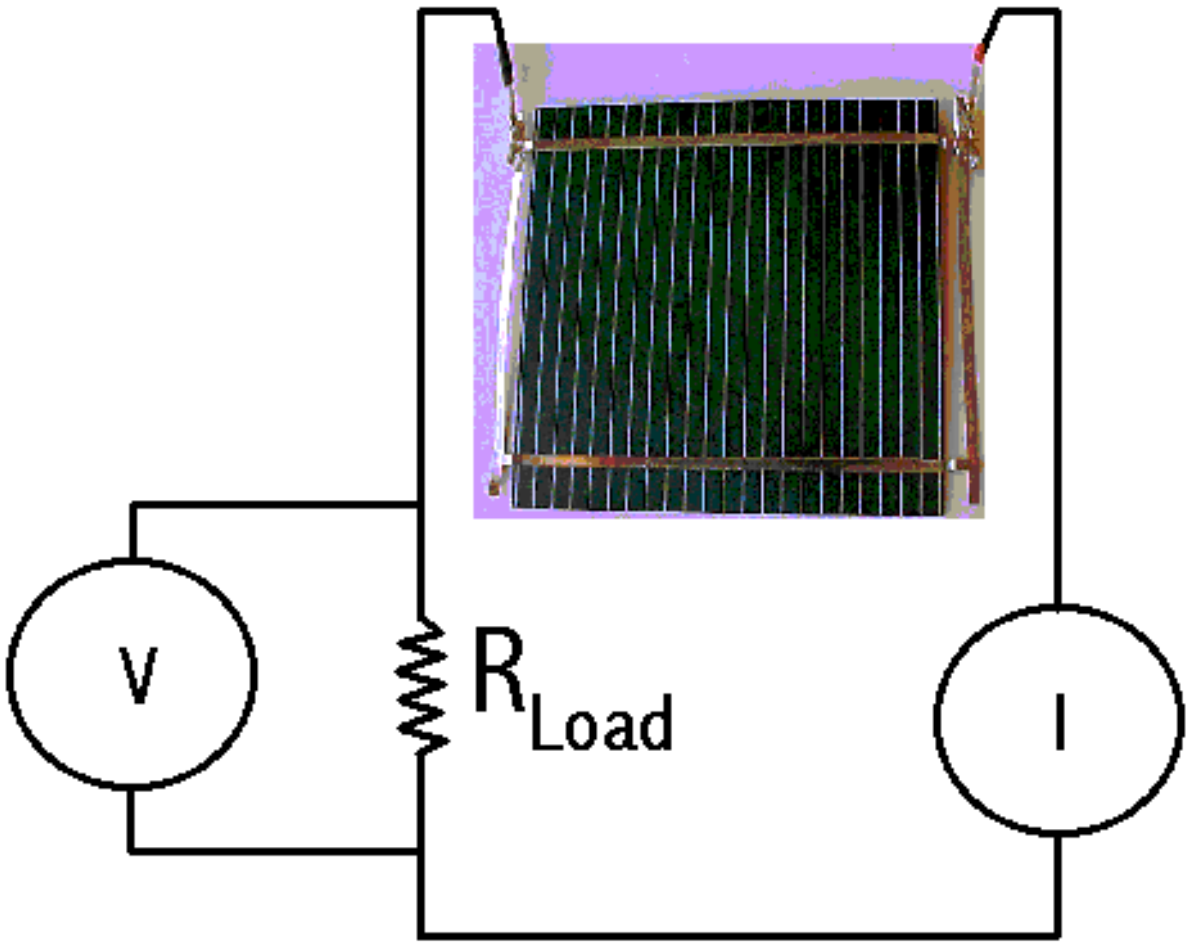
Testing Equipment Design

- Important: Must be Easy to Trace I-V Curve
- Select R Values and Measure I and V
- Need Two Meters (one for I and one for V)
- Need Easy Adjustment of Resistance

Test Equipment Design



Schematic of Test Circuit



Meter Adjustments

This Meter Measures the Voltage (DC 2Volts Max)



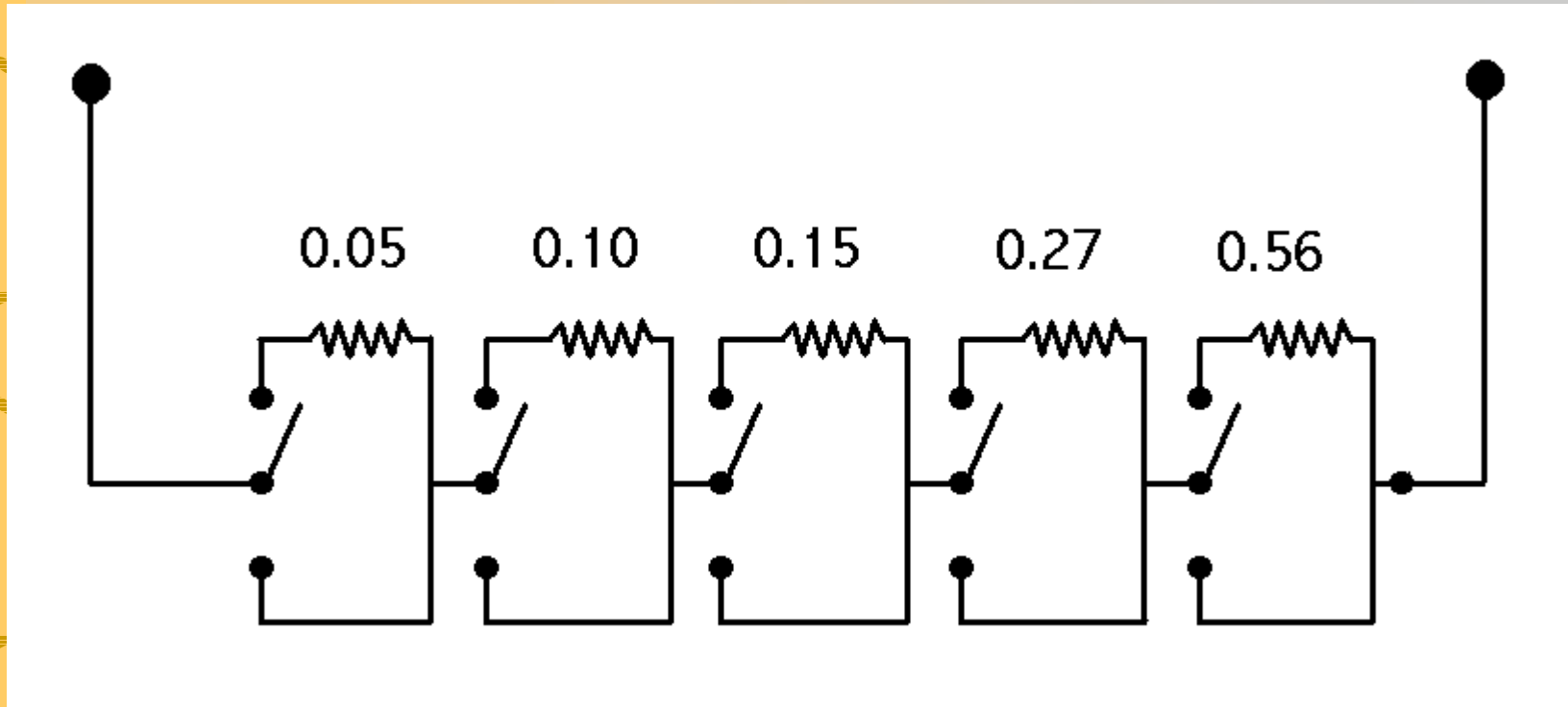
This Meter Measures the Current (DC 20 Amps Max)



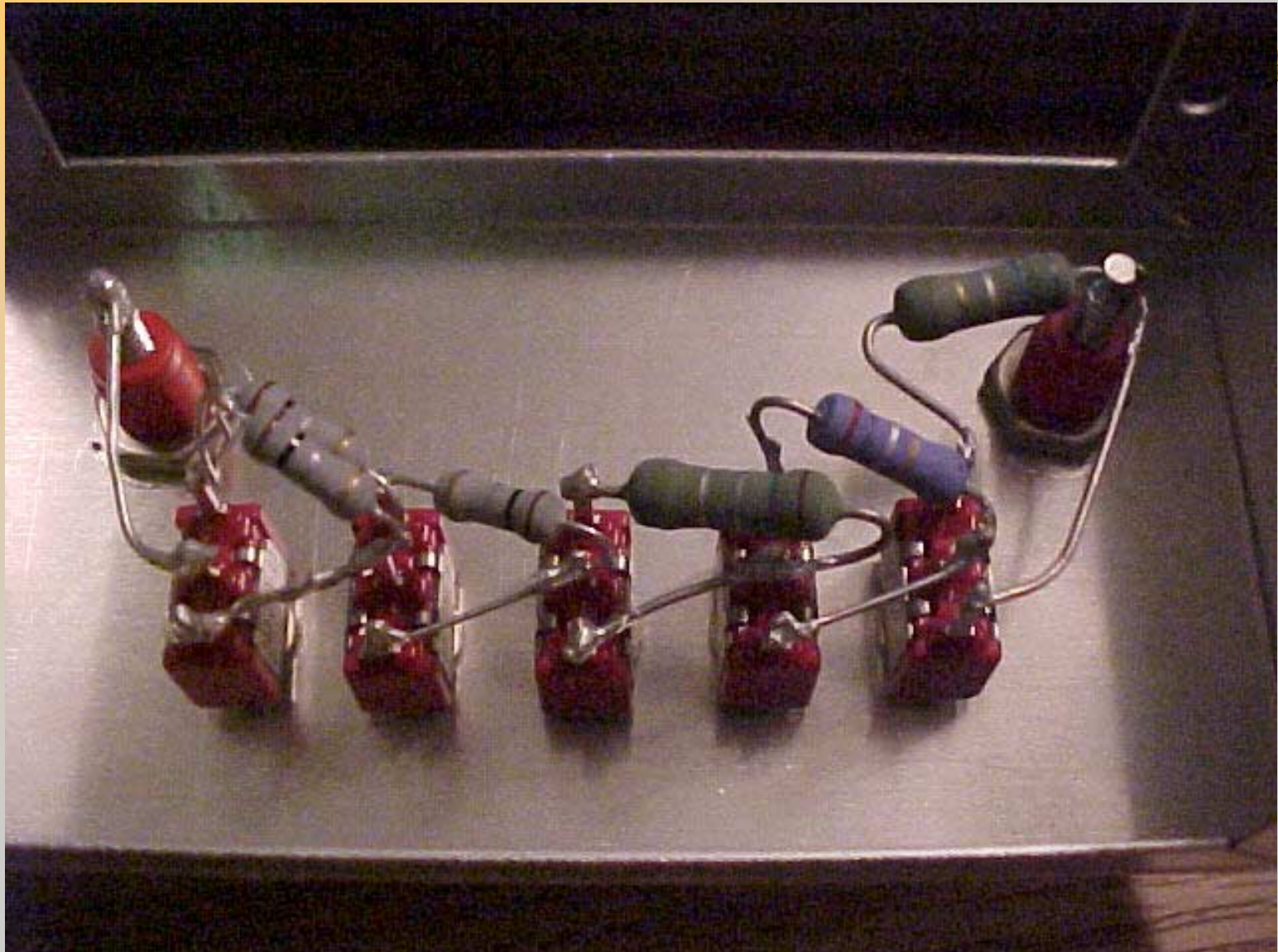
Testing Equipment Design

- Easy Selection of Resistance Value
  - Toggle Switches Chosen
- Fine Resolution of Resistance Value
  - Sub-Ohm Resistance Values
  - Set Up as $R_2=R_1/2$ etc
  - Down to 0.05 Ohms
  - Toggle Resistances are **Additive** (in Series)

Schematic of Custom Load R



SwitchBox Innards



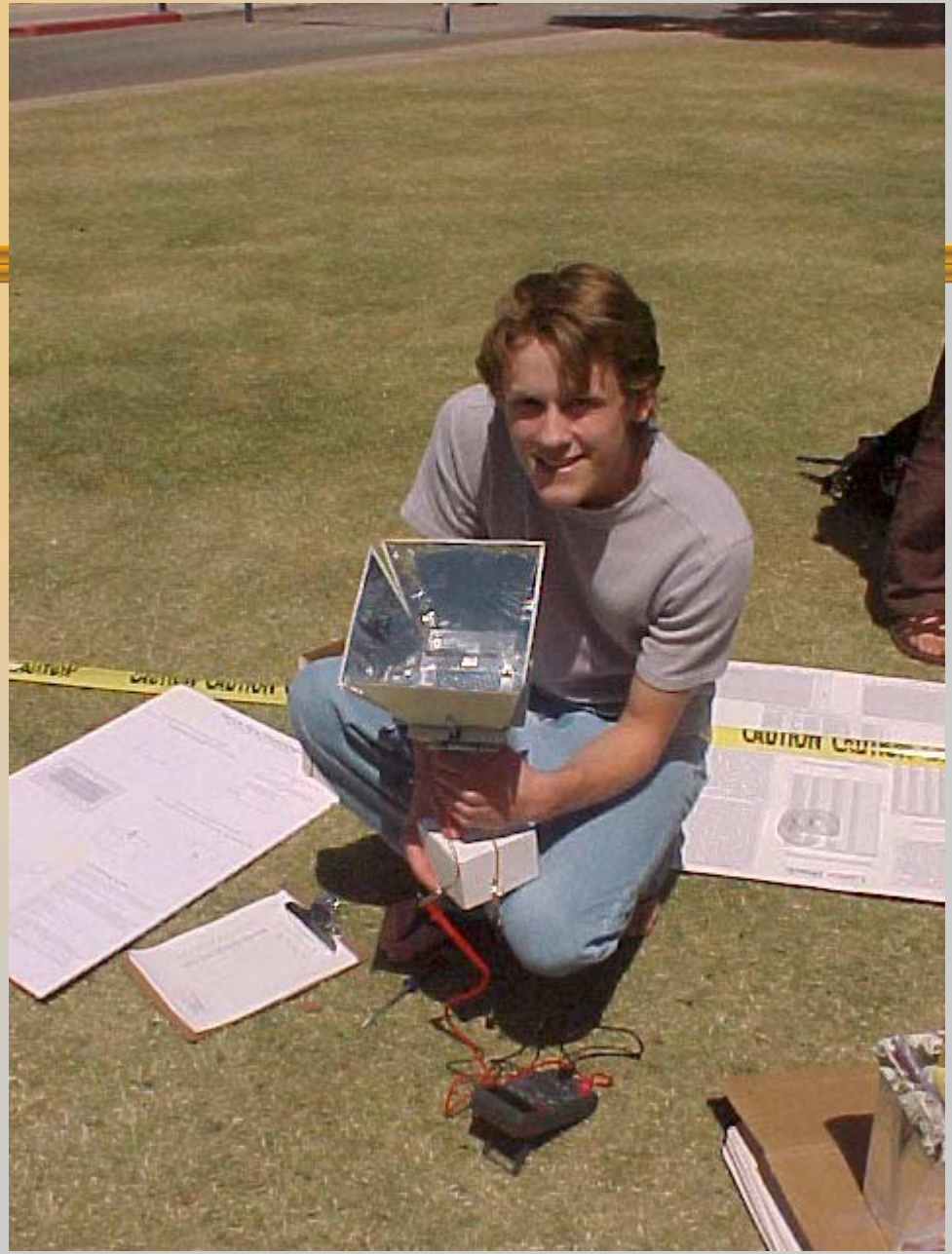
Switching R Value: 0.37 Ohms



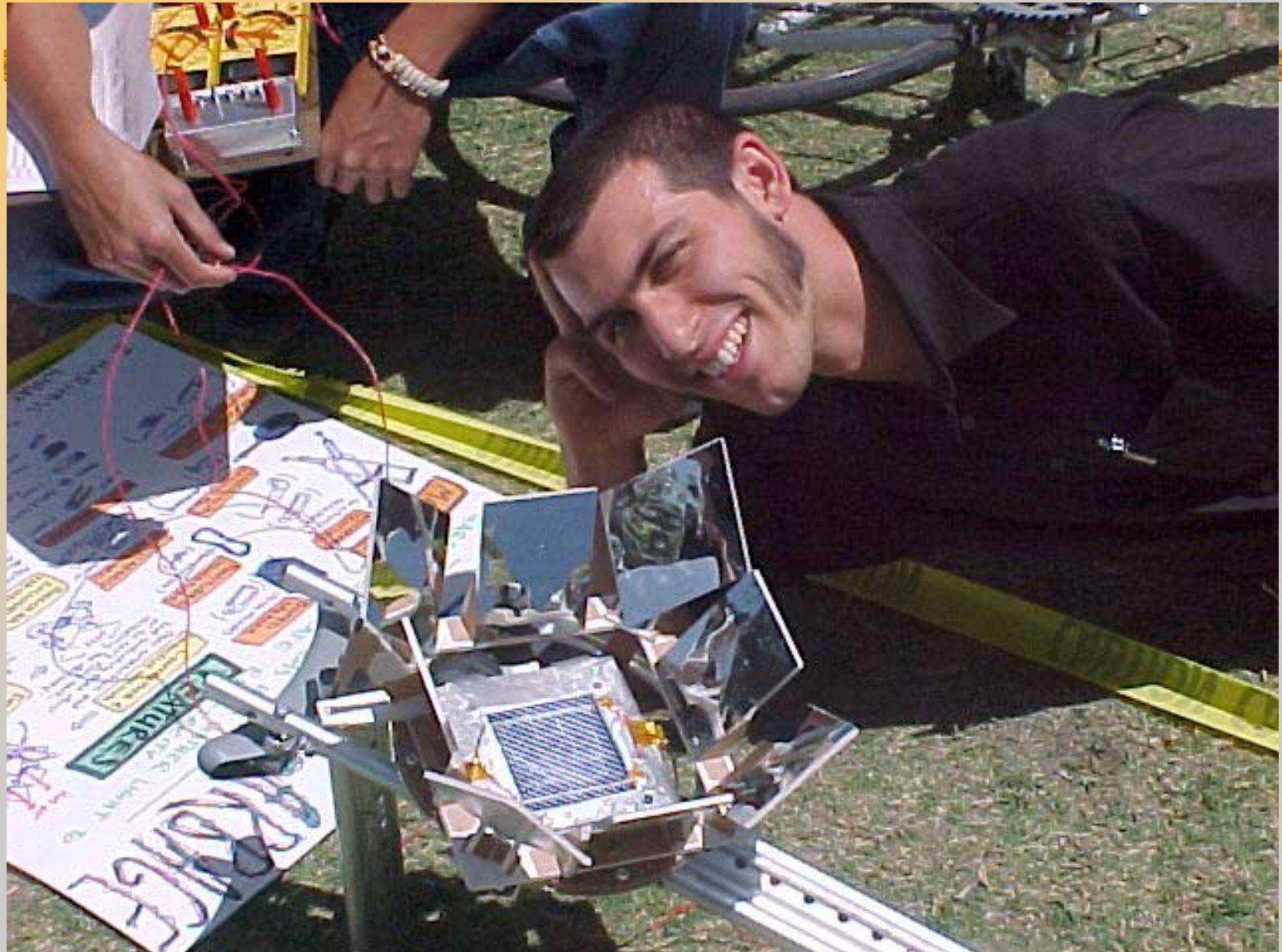
Example Collector: Diagonals



Example Collector: Square Cone



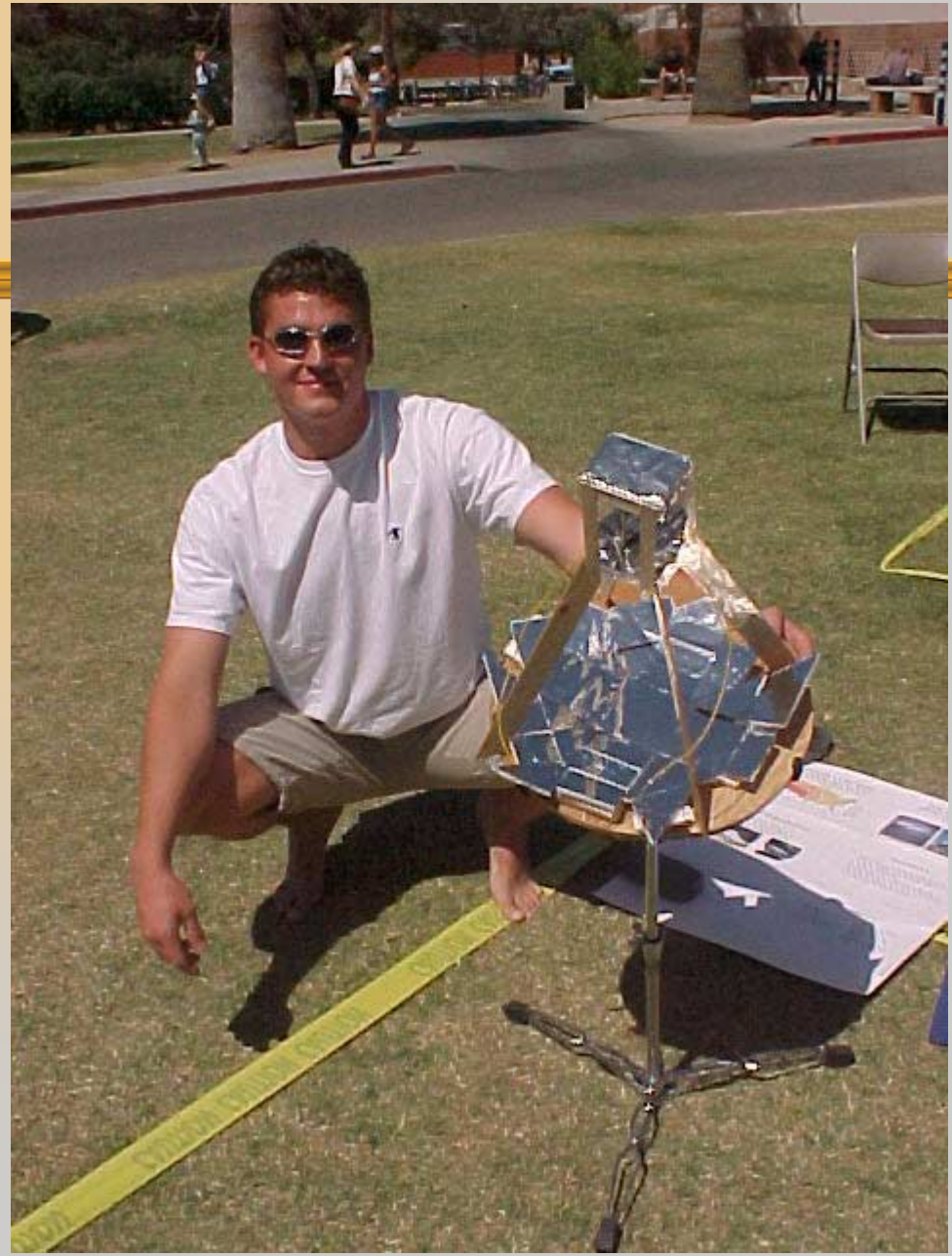
Example Collector: Heat Sink



Example Collector: Mirror Ring



Example Collector: Inverted Design



Example Collector: Specific Angles and Tripod



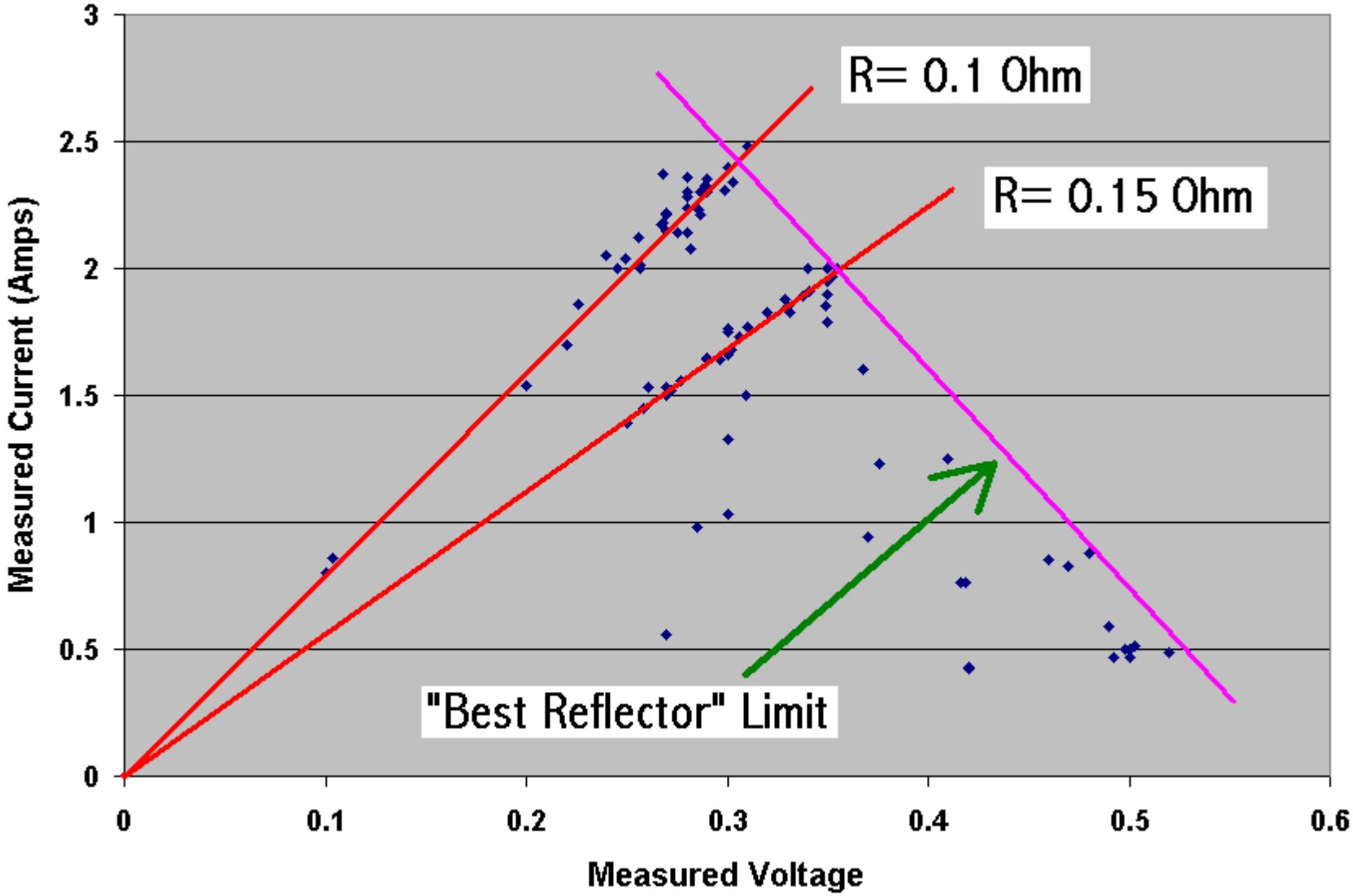
Example Collector: Double Reflections (and Heat Sink too!)



Power Data From Competition

- Current and Voltage Logged
- Power Measured Three Times
- Best Measurement Used for Scoring
- Could Use three R values of Choice
- Three Equipment Sets Standardized this way too.

Analysis of Power Generated



Effect of Heat Sink Use

- Average Power without Heat Sink:

  0.47 Watts Total

- Average Power with Heat Sink:

  0.62 Watts Total

- Net Improvement with Heat Sink:

  32% Better!!

Student Assessment of Project

- Test Equipment Worked Well
- Better Physical Protection of Cells Required – Very Fragile
- Provide Standardized Heat Sinks
- Want a Cooler Full of Refreshments!

Other Things

- Possible Guest Lectures from Industry and Faculty in Different Departments (Any Suggestions??).
- Graduate Students Give Special Topic Presentations.
- I do In-Class Activities to Emphasize Technical Points.

Conclusion

- Next Week Schedule:
  - Monday is a Holiday
  - Thursday I'm on Travel
- Any Questions???

- Have a Good Labor Day Weekend!!!