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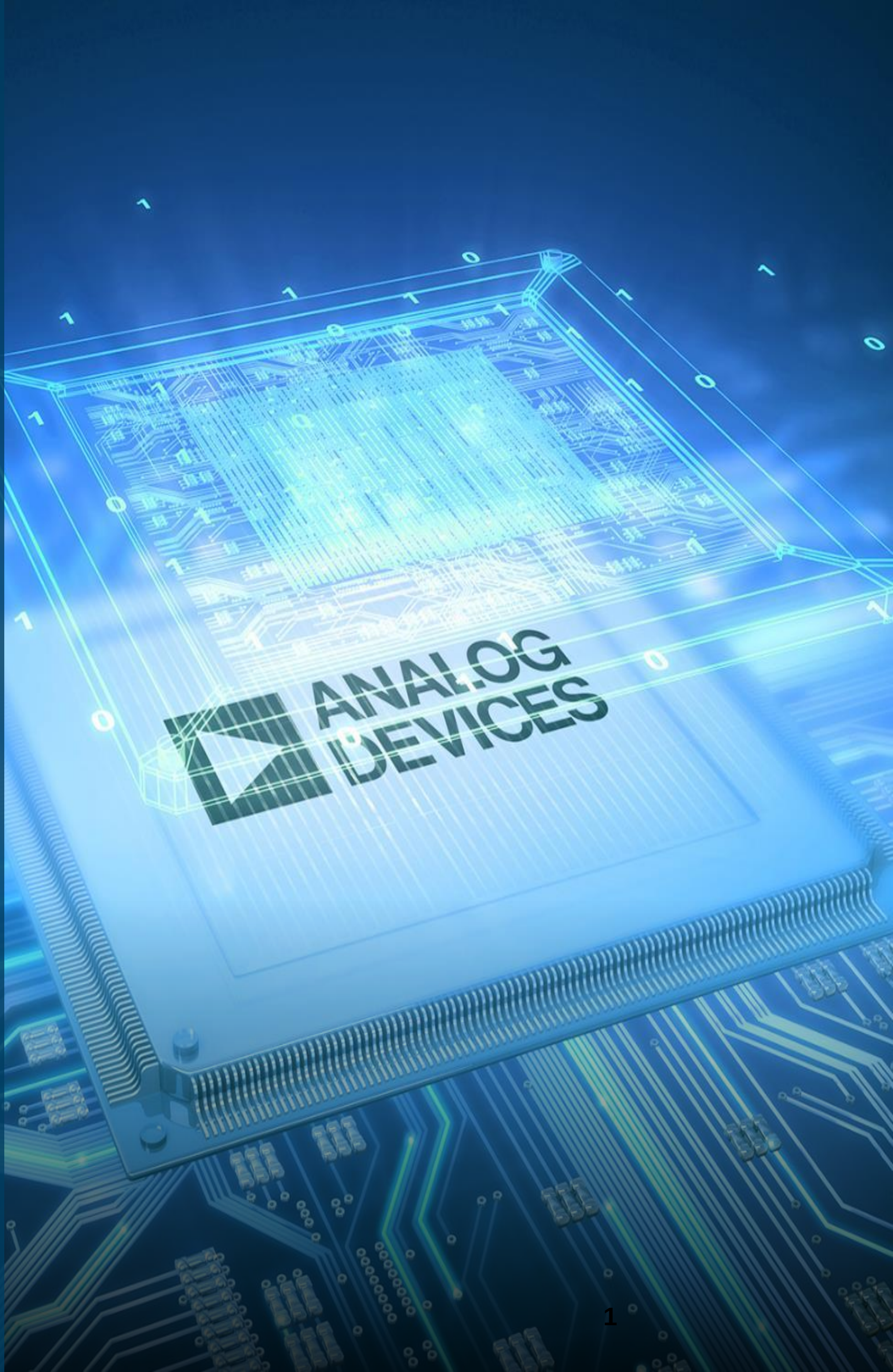
Measurement of the Photoelectric Effect with the ADA4530-1 Electrometer Op Amp

SCOTT HUNT

SYSTEM APPLICATIONS ENGINEER

LAB & FIELD SCIENTIFIC INSTRUMENTS

ANALOG DEVICES, INC.



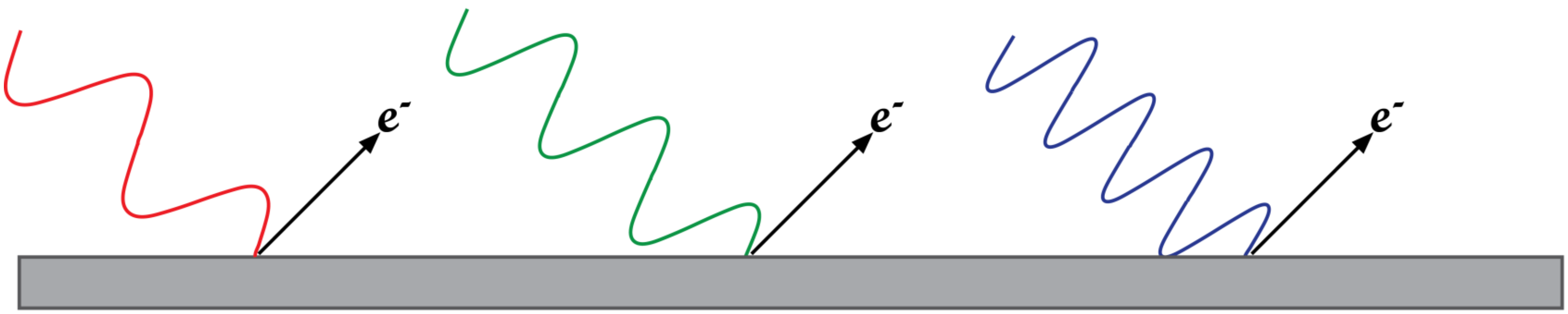
Outline

- **Introduction**
  - Background on the Photoelectric Effect
- **ADA4530-1 Overview**
  - Performance (vs competition)
  - Applications and what you can do with it
- **How to make a very low-leakage measurement**
  - Layout, guarding, shielding, components, board materials
  - Techniques used in the Picoammeter System Board
- **The Photoelectric Effect demo as a case example**
  - Explanation, Pictures, Results, and Conclusions

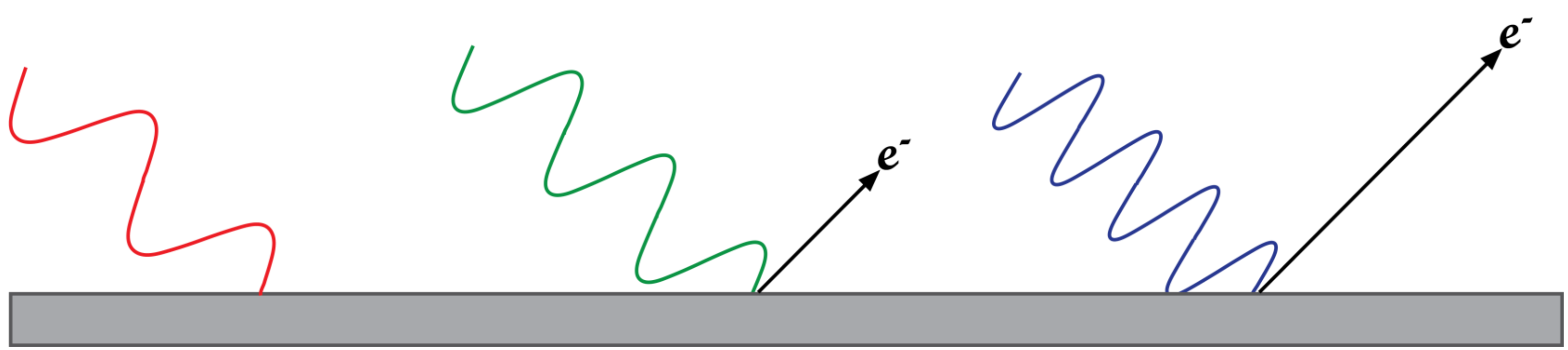
The Mystery of the Photoelectric Effect

- Discovered by Heinrich Hertz (1887)
- Characterized by Philipp Lenard and later, Robert Millikan

EXPECTED RESULTS

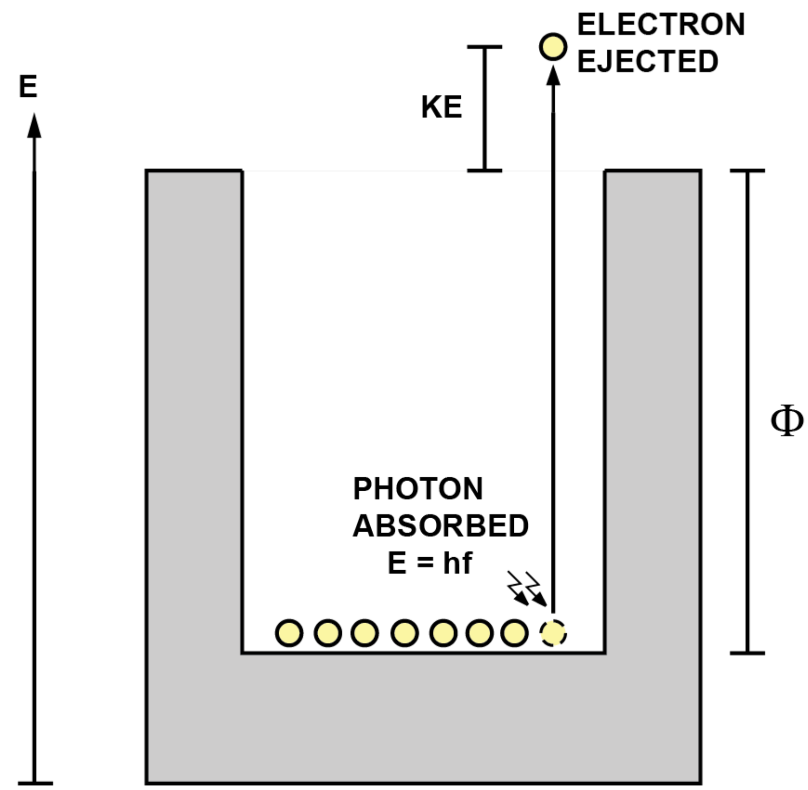


ACTUAL RESULTS



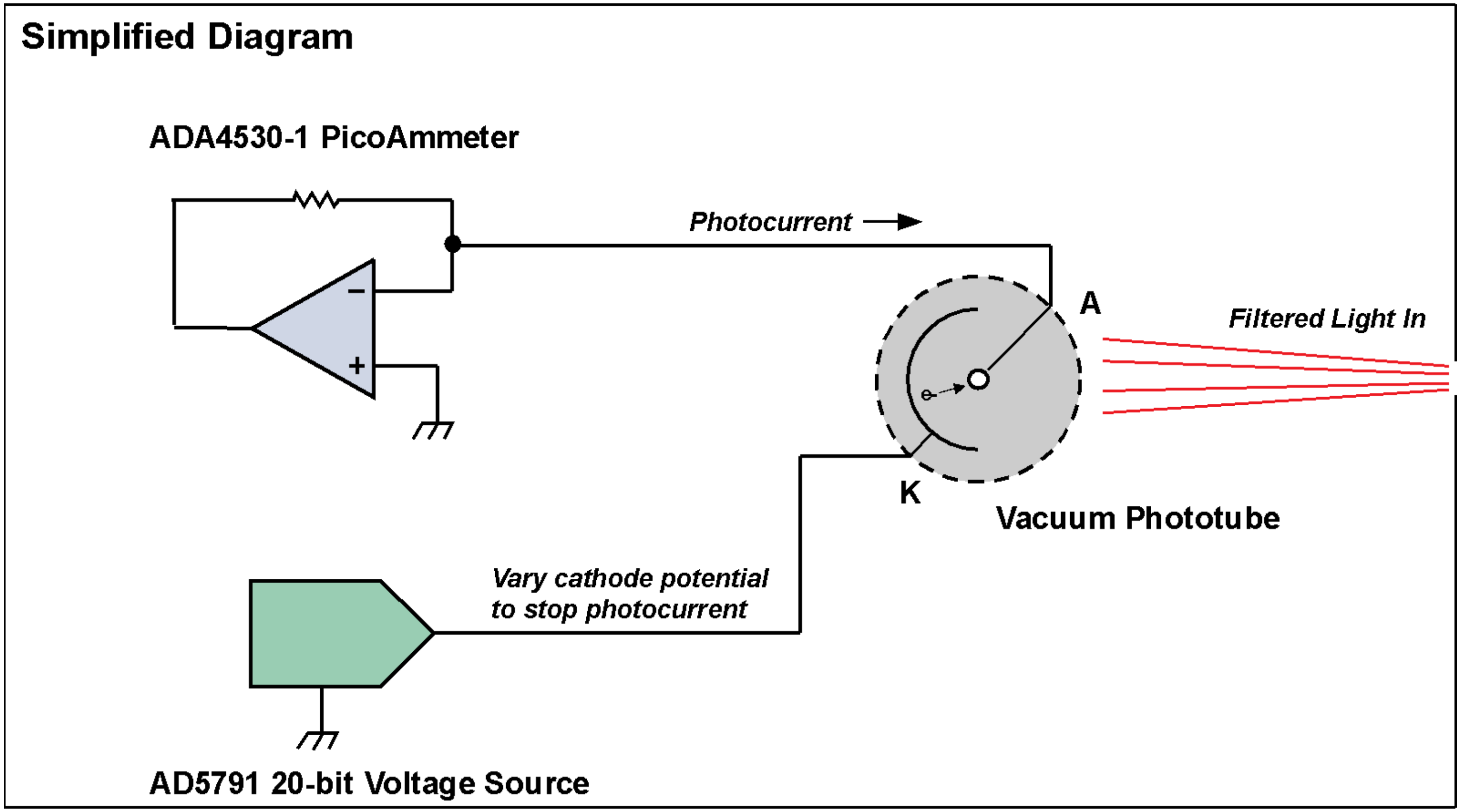
Albert Einstein: Light energy is quantized (photons)

- Photon energy is proportional to frequency (E = hf), so when a photon strikes an electron, the electron is ejected with a specific kinetic energy
- $KE = hf - \Phi$
- We can measure kinetic energy (KE) by applying a reverse electric field
  (the stopping potential)
  - $KE = e*V_o$
- This was cited as the reason Einstein won the 1921 Nobel Prize
- Millikan won the 1923 Nobel Prize for the photoelectric effect and the oil drop experiment



THE WORK FUNCTION ILLUSTRATED AS AN ENERGY WELL

Reproducing Lenard's and Millikan's Observations



- Use a vacuum tube with an anode and a cathode
- Measure the photocurrent
- Apply a voltage opposing the electron flow to measure KE

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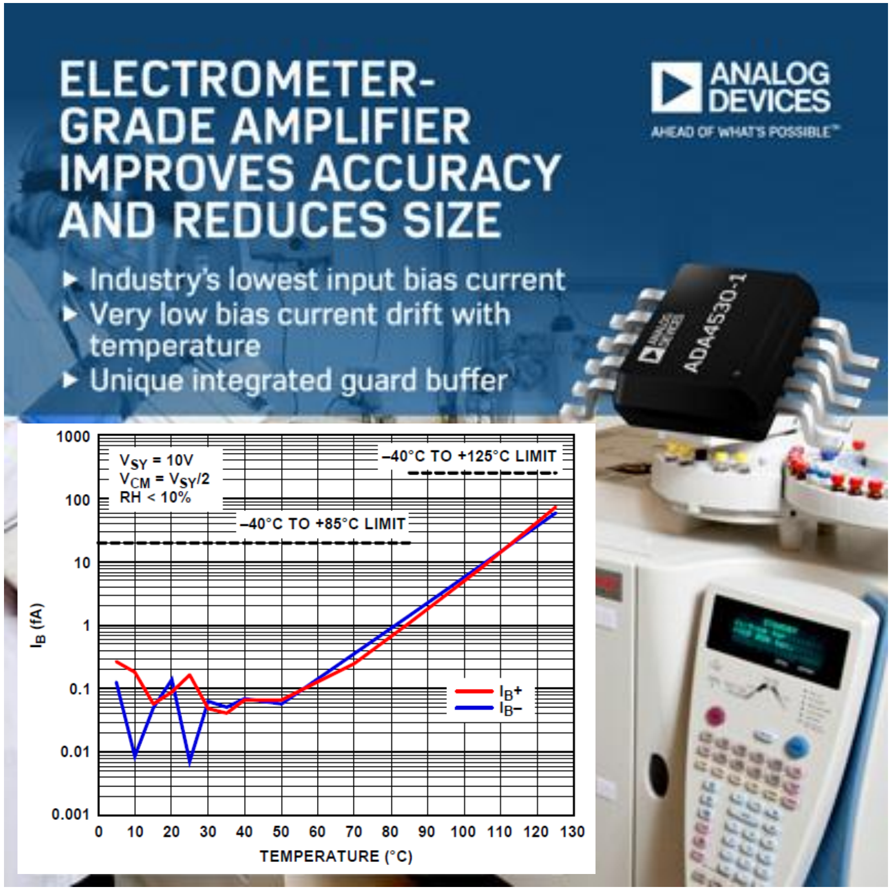
ADA4530-1 Overview

WHAT IS SPECIAL ABOUT IT AND WHAT CAN IT DO?

ADA4530: Not your typical amplifier!

Key Benefits

- ▶ Ultra Low Input Bias Current Electrometer Amplifier
- ▶ New level of sensitivity!
  - 20fA max IB at 25C
  - 250fA max IB at 125C
  - 0.1fA typ IB at 25C **624 electrons / sec !**
- ▶ Easy to use
  - Integrated guard buffer
  - Surface mount package
  - Pin out optimized for input pin isolation from power supplies



ADA4530 achieves 45x lower input bias current than the leading competitor part

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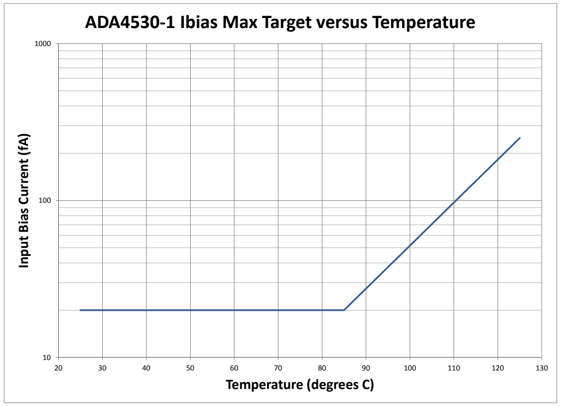
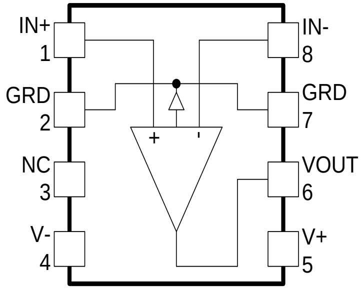
ADA4530: Electrometer Op Amp
Ultra Low Bias Current Op Amp with Guard Ring Driver

Key Features

- Ultra low bias current
  - 20 fA @ room max (Production Tested)
  - 20 fA @ 85°C max
  - 250 fA @ 125°C max (Production Tested)
- Integrated Guard Buffer
- Wide supply voltage:
  ±2.5 to ±8V or 5 to 16V



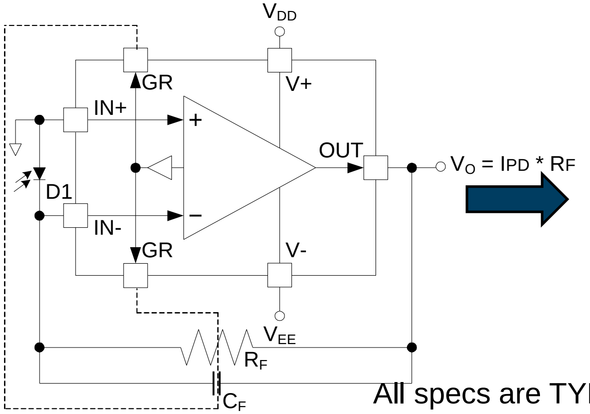


Functional Block Diagram
And Pin Out

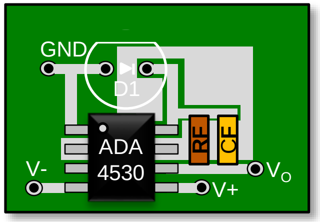
Applications

- Laboratory and Analytical Instrumentation: Spectrophotometers, Chromatographs, Mass Spectrometers, Potentiostatic and Amperostatic Coulometry
- Instrumentation: Picoammeters, Coulombmeters
- Transimpedance Amplifier for Photodiodes, Ion Chambers, and Working Electrode measurements
- High Impedance Buffering for Chemical Sensors and Capacitive Sensors

Photodiode TIA Application



Conceptual PCB Layout



All specs are TYP unless otherwise stated

I_{BIAS}	$V_{OS\ max}$	$T_CV_{OS\ max}$	I Noise	V Noise	I_{SY} Max	Bandwidth	Op. Voltage	Temp
20 fA max	50 µV	0.5 µV/°C	0.01 pA/√Hz	16 nV/√Hz	1.3 mA	2 MHz	4.5 V – 16 V ±2.75 to ±8V	-40°C – 125°C

Single ***Released***

- ***Package: SOIC-8; 1k OEM $11.40***

Electrometer Applications

As detection limit gets lower and lower, there is a higher need for a precise electrometer that does not introduce error

- Chemical Analyzers
- Chromatography
  - Gas
  - Liquid
- Spectroscopy
  - UV/VIS
  - Near IR
  - Fluorescence
- Mass Spectrometer
- Particle Analysis
- NDIR Gas Detection
- Colorimetry
- Water Quality/Testing
- Flame Detection

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Low-Leakage Design

A FEW TIPS AND CONSIDERATIONS

(MAKE SURE TO CATCH GUSTAVO CASTRO'S TALK TOMORROW @12:30 FOR MUCH MORE!)

Guidelines on PCB layout, board and solder paste material

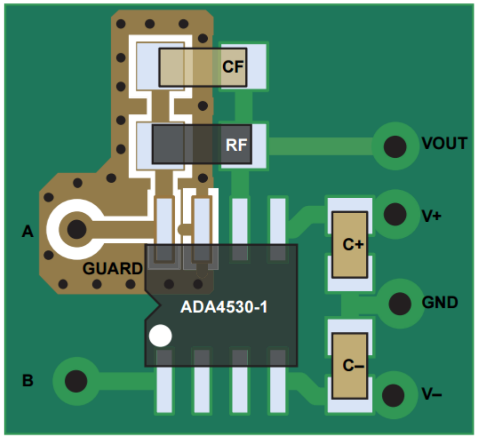


Figure 122. TIA Circuit Layout

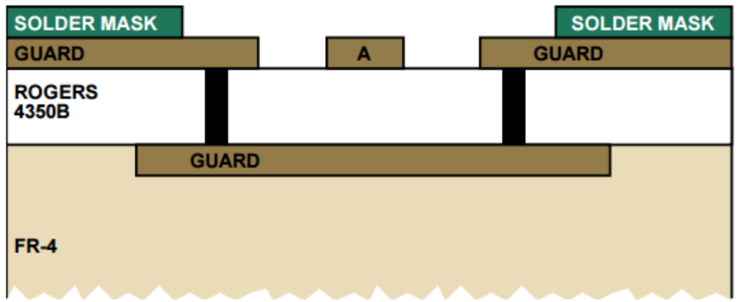


Figure 123. Layout Cross Section with Guard Plane

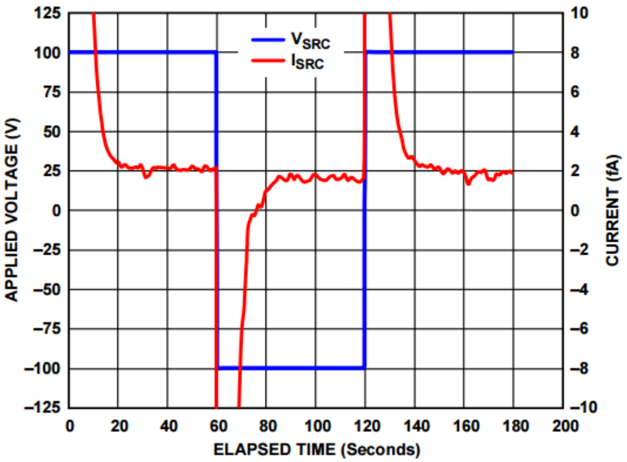


Figure 111. Rogers 4350B Dielectric Relaxation Performance

Table 7. Recommended Cleaning Procedures for Different Solder Paste Material

Solder Paste Type	Solder Paste Part Number	Recommended Cleaning Procedure[1]
RMA	AIM RMA258-15R	15 min clean time in an ultrasonic cleaner with fresh IPA, followed by 1.5 hours of bake time at 125°C
Water Soluble	SAC305 Shenmao	1.5 hours clean time in an ultrasonic cleaner with fresh IPA, followed by 1.5 hours of bake time at 125°C
No Clean	SAC 305 AMTECH LF4300	3 hours clean time in an ultrasonic cleaner with fresh IPA, followed by 3 hours of bake time at 125°C

LTD and Effects of Humidity

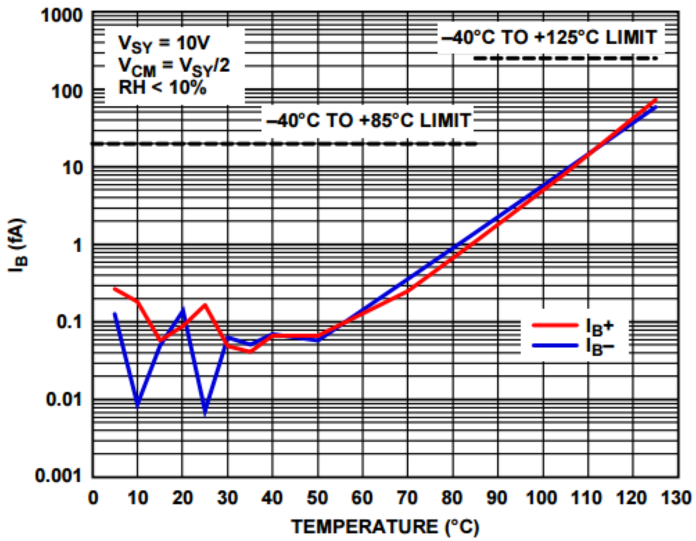


Figure 2. Input Bias Current (I_B) vs. Temperature, V_{SY} = 10 V

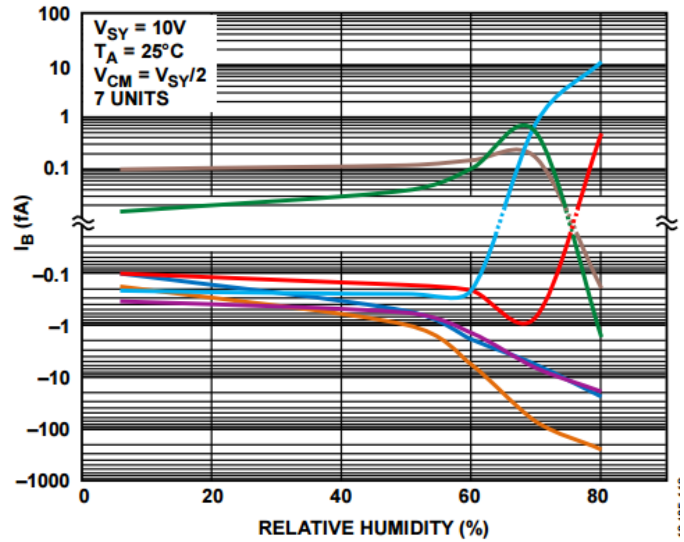


Figure 112. Effective Input Bias Current vs. Relative Humidity

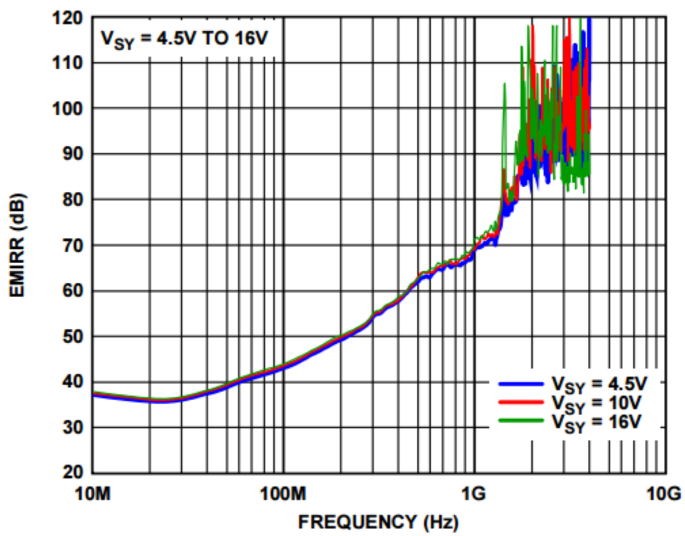


Figure 104. EMIRR vs. Frequency

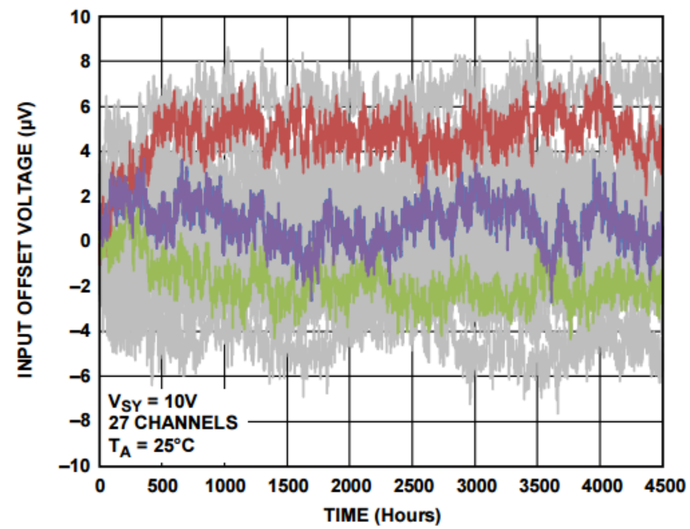
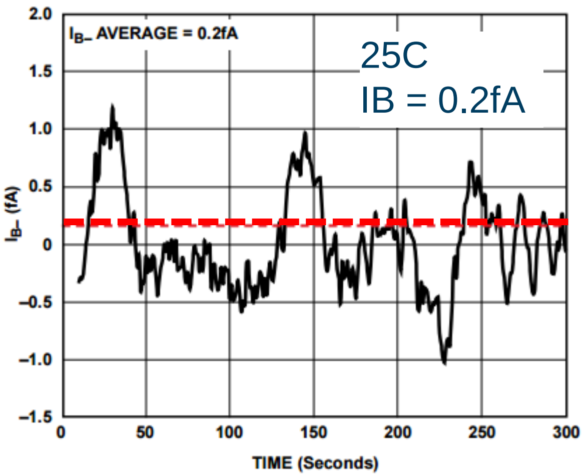
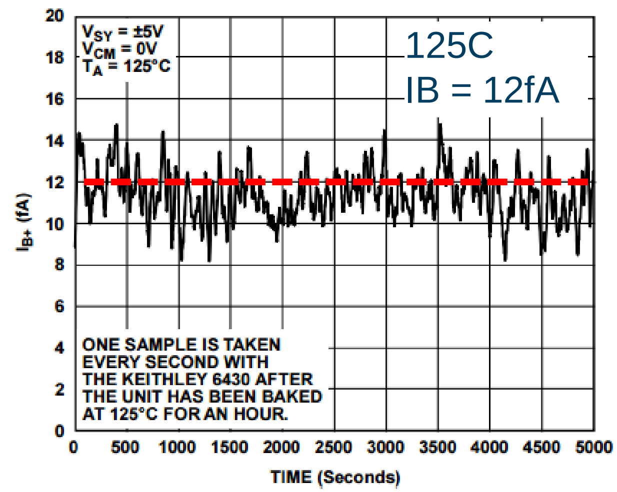


Figure 19. V_{OS} Long-Term Drift

Performance evaluation board

- ✓ Allows customers to evaluate performance of the ADA4530
- ✓ Shows guidelines for layout, shielding, guarding
- ✓ Cleaned and tested for 1 fA sensitivity





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App Note, User Guide, Evaluation Board

ANALOG DEVICES

AN-1373
APPLICATION NOTE

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106, U.S.A. • Tel: 781.329.4700 • Fax: 781.461.3113 • www.analog.com

ADA4530-1 Femtoampere Level Input Bias Current Measurement

INTRODUCTION

The ADA4530-1 is a single, electrometer grade operational amplifier with a femtoampere (10^{-15}) level input bias current (I_B) and an ultralow offset voltage. Its ultralow input bias currents are production tested at 25°C and 125°C to ensure that the device meets its performance goals in a system application. Figure 1 and Figure 2 show the outstanding input bias current performance of the device over temperature and input common-mode voltage.

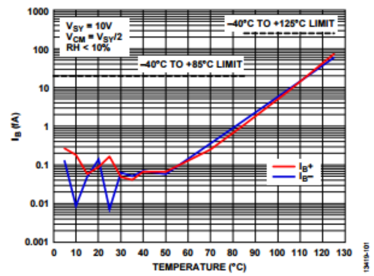

Figure 1. Input Bias Current (I_B) vs. Temperature

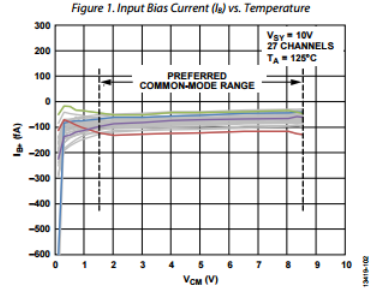

Figure 2. Noninverting Input Bias Current (I_{B+}) vs. Common-Mode Voltage (V_{CM})

The ADA4530-1 operates over the −40°C to +125°C industrial temperature range and is available in an 8-lead SOIC package. It is well suited for applications that require very low input bias current and low offset voltage, such as preamplifier for a wide variety of current output transducers (photodiodes, photomultiplier tubes), spectrometry, chromatography, and high impedance buffering for chemical sensors.

The ADA4530-1 has a unique pinout. The input and supply pins are placed on opposite sides of the package to prevent leakage. For ease of user design, the ADA4530-1 features an integrated guard buffer. The guard buffer drives the guard ring surrounding the input pins, thus minimizing both input pin leakage in a printed circuit board (PCB) design and board component count. The guard buffer output pins are also strategically placed next to the input pins to enable easy routing of the guard ring. For more information on guarding and physical implementation of guarding techniques, refer to the ADA4530-1 data sheet.

Low input bias current amplifiers are also typically available in T0-99 packages. These packages allow users to air wire the high impedance input pins or to use Teflon® insulator standoffs to prevent leakage current. These techniques increase manufacturing costs and are incompatible with modern automated PCB assembly processes. The surface-mounted, plastic package provided by the ADA4530-1 bypasses this legacy assembly approach and is reliable in a modern surface-mount manufacturing environment.

This application note highlights several different methods for measuring the ADA4530-1 femtoampere level input bias current feature in the SOIC package using the ADA4530-1R-EBZ-TIA or the ADA4530-1R-EBZ-BUF evaluation board.

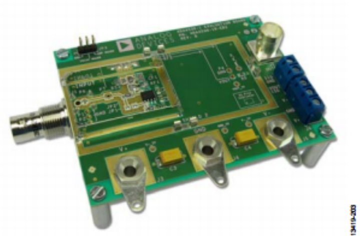

Figure 3. Photograph of the ADA4530-1R-EBZ-TIA

Figure 3 shows a photograph of the ADA4530-1R-EBZ-TIA. Note that hereafter, ADA4530-1R-EBZ refers to both the ADA4530-1R-EBZ-TIA and the ADA4530-1R-EBZ-BUF.

For full details on the ADA4530-1, see the ADA4530-1 data sheet. The ADA4530-1R-EBZ user guide (UG-865) should also be consulted in conjunction with this application note.

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ADA4530-1R-EBZ User Guide
UG-865

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Evaluation Board for the ADA4530-1 8-Lead SOIC Package

FEATURES

Footprint for ADA4530-1 8-lead SOIC package
Footprints for passive components
Available in buffer or transimpedance configuration
Easy modifications to other standard configurations
Guard ring to minimize leakage current
Assembled with metal shields
Enables quick prototyping
Easy connection to test equipment

GENERAL DESCRIPTION

The ADA4530-1R-EBZ is an evaluation board for the ADA4530-1 offered in an 8-lead SOIC package. The ADA4530-1R-EBZ is a 4-layer printed circuit board (PCB) designed to minimize leakage currents with its guard ring features for femtoampere input bias current (I_B) measurement.

The ADA4530-1R-EBZ is available in two default configurations: buffer (ADA4530-1R-EBZ-BUF) and transimpedance (ADA4530-1R-EBZ-TIA). Both boards are populated with the necessary passive components, banana jacks/terminal blocks for supply voltages, BNC/terminal blocks for the output voltage, multiple test pins, and metal shields. All components are placed on the primary side with the exception of the triaxial (triax)/ coaxial (coax) input connector (J1) and SHIELD3.

The ADA4530-1R-EBZ also has unpopulated resistor and capacitor pads that allows quick prototyping with different configurations, such as noninverting gain and inverting gain.

Specifications for the ADA4530-1 are provided in the ADA4530-1 data sheet available from Analog Devices, Inc. The ADA4530-1 data sheet and the AN-1373 Application Note should be consulted in conjunction with this user guide when using the evaluation board.

Figure 1 shows the top view of the evaluation board, and Figure 2 shows the bottom view. For more views of the evaluation board images, see the ADA4530-1R-EBZ Evaluation Board Photographs section.

EVALUATION BOARD PHOTOGRAPHS

Figure 1. ADA4530-1R-EBZ Top View

Figure 2. ADA4530-1R-EBZ Bottom View

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The Photoelectric Effect Demo

AS A LOW-LEAKAGE MEASUREMENT CASE-STUDY

Why does this require electrometer-grade performance?

- ADA4530-1 has less than 0.1fA typical bias current at 25°C

- 0.1fA = 10^{-16} Coulombs/sec
  - $10^{-16}/q$ = 624 electrons per second

- To measure the stopping potential, we are trying to see the point where Zero electrons are reaching the anode

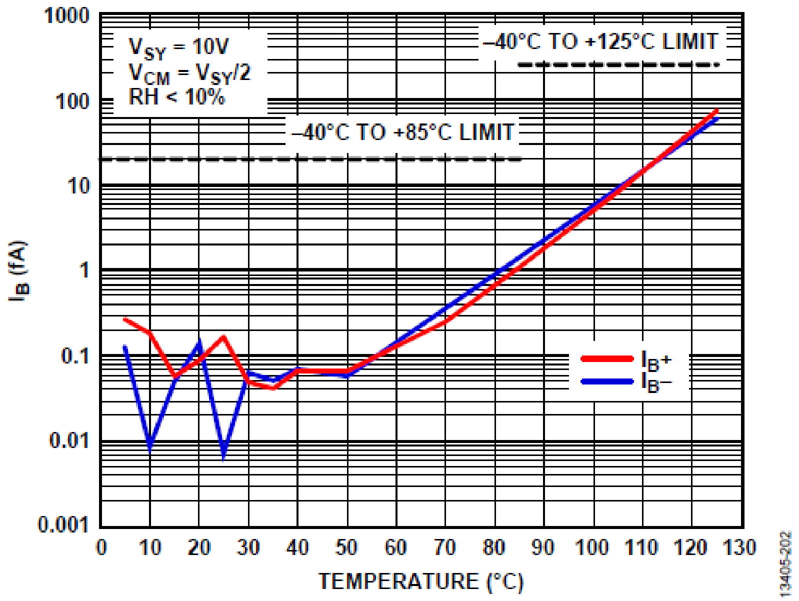
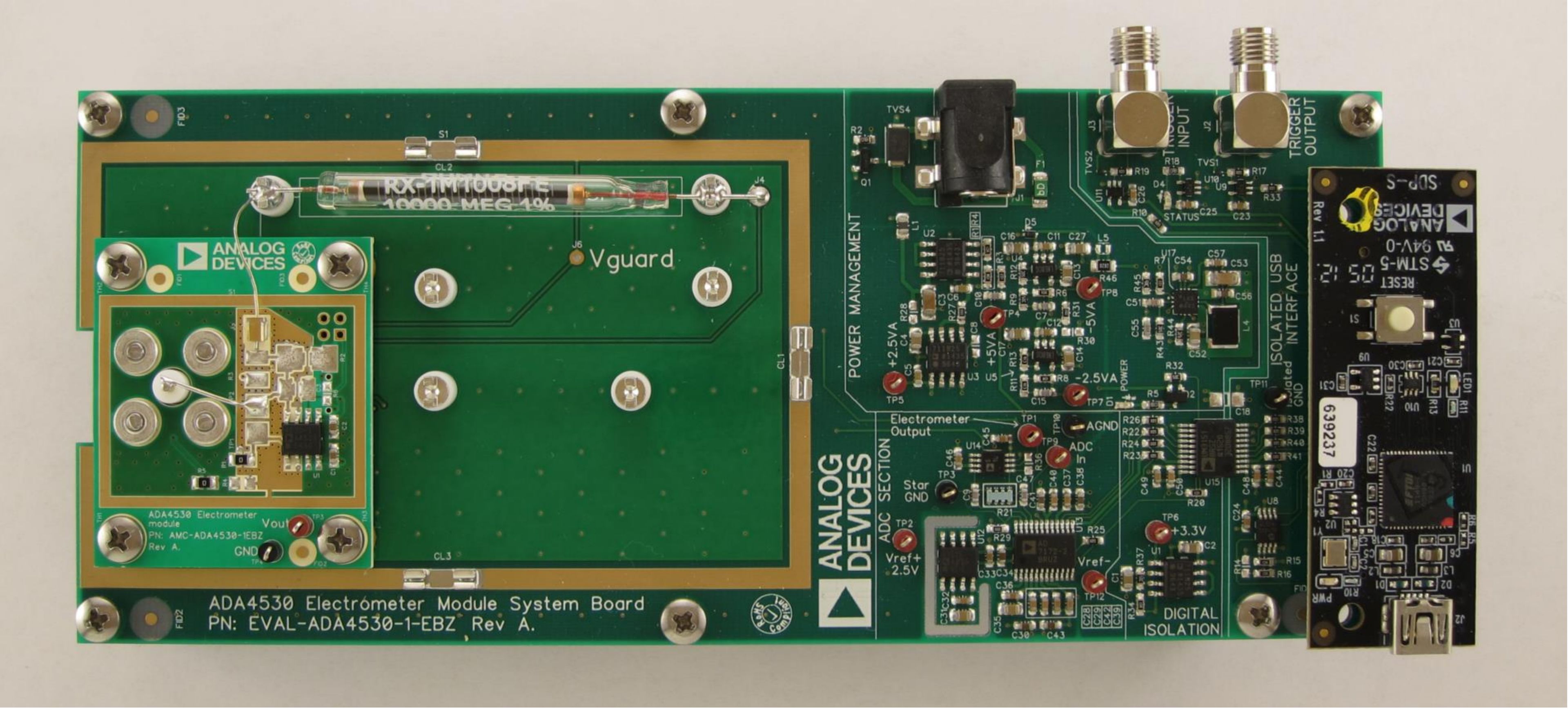


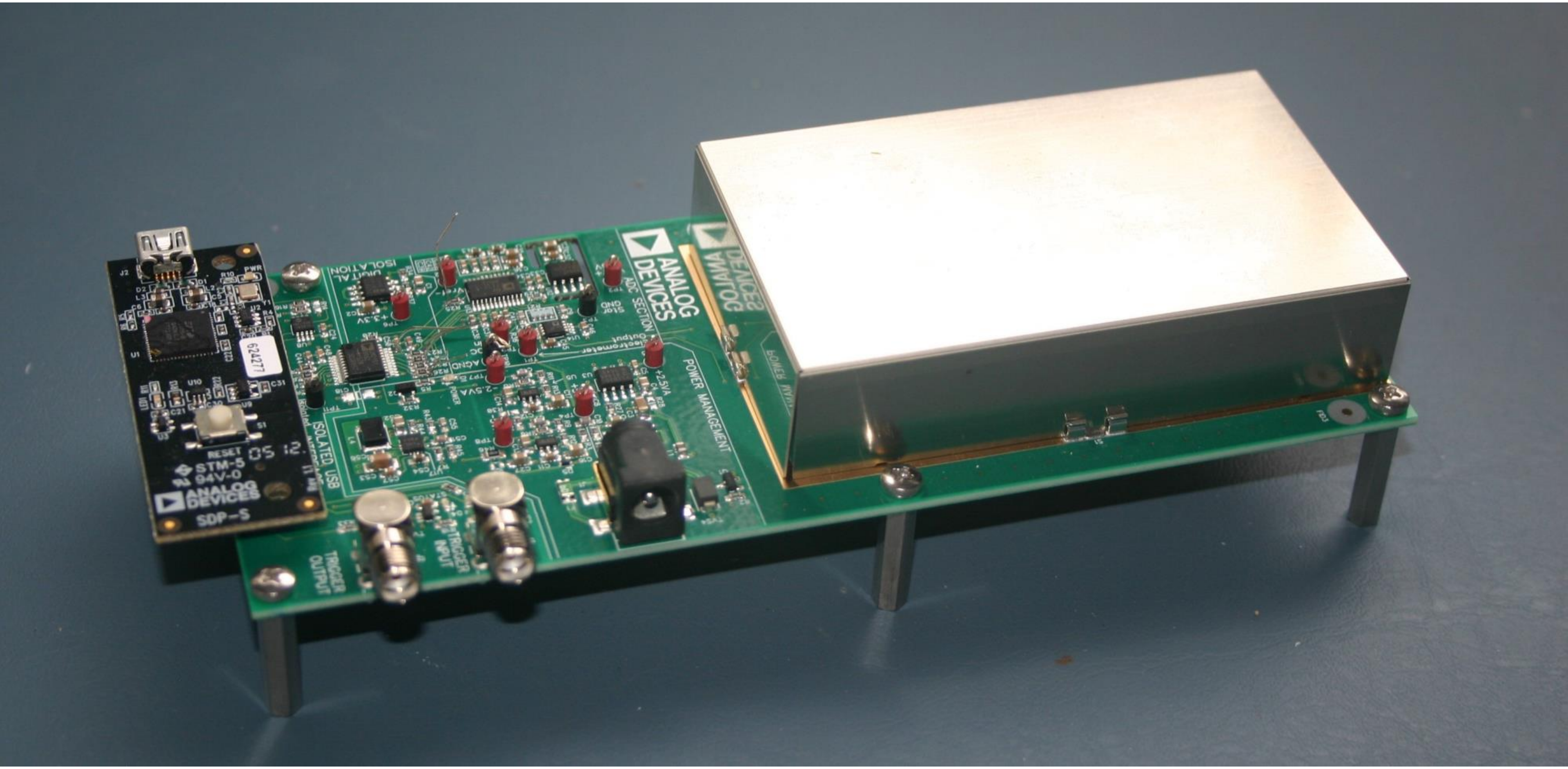
Figure 2. Input Bias Current (I_B) vs. Temperature, V_{SY} = 10 V

The ADA4530-1 Picoammeter System Module



Learn about this board in more detail in Gustavo Castro’s talk here at 12:30 tomorrow!

The ADA4530-1 Picoammeter System Module



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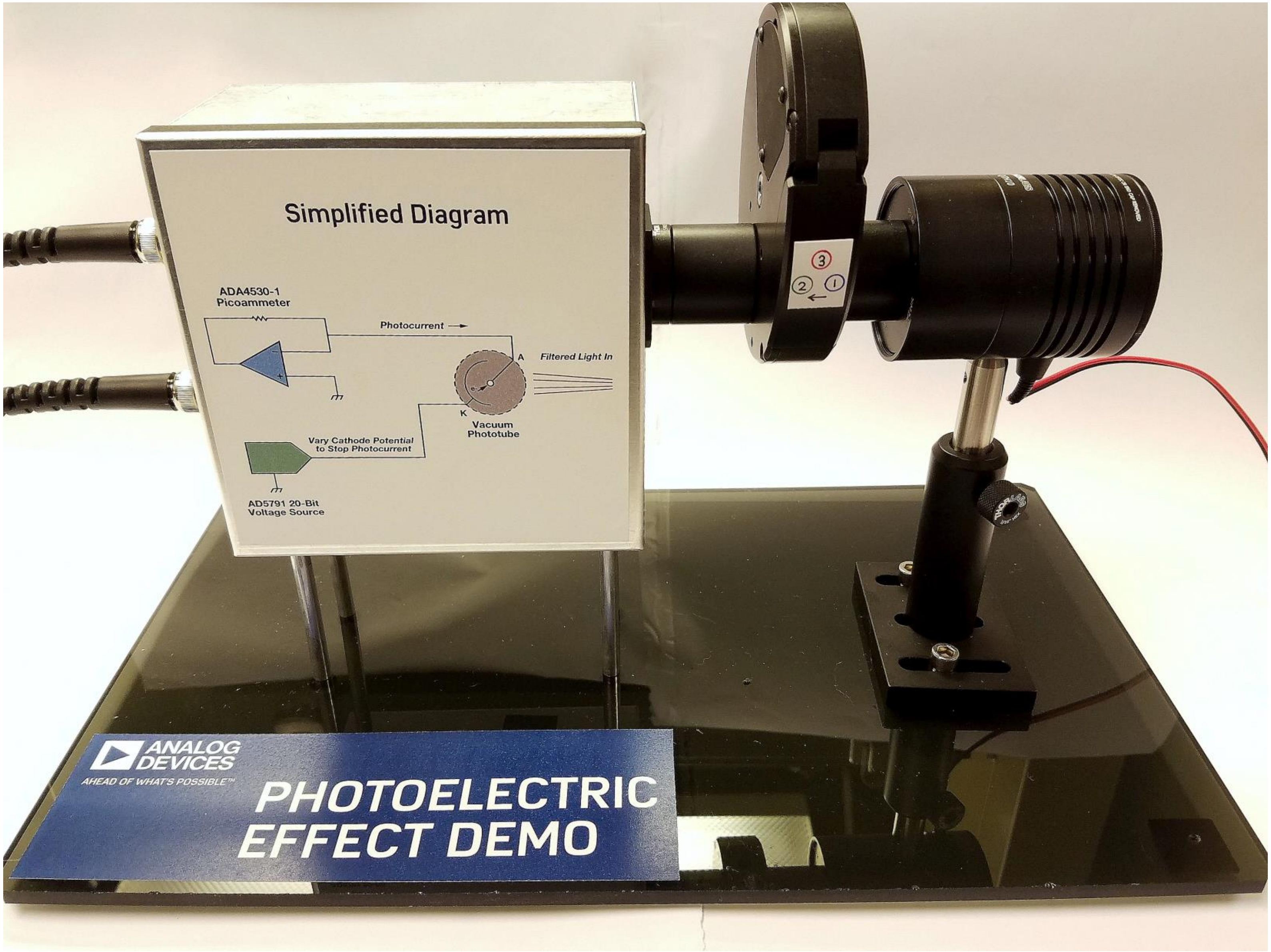
Final Setup


Simplified Diagram
ADA4530-1
Picoammeter
Photocurrent
Filtered Light In
A
K
Vacuum
Phototube
Vary Cathode Potential
to Stop Photocurrent
AD5791 20-Bit
Voltage Source
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EFFECT DEMO

Sensors Expo

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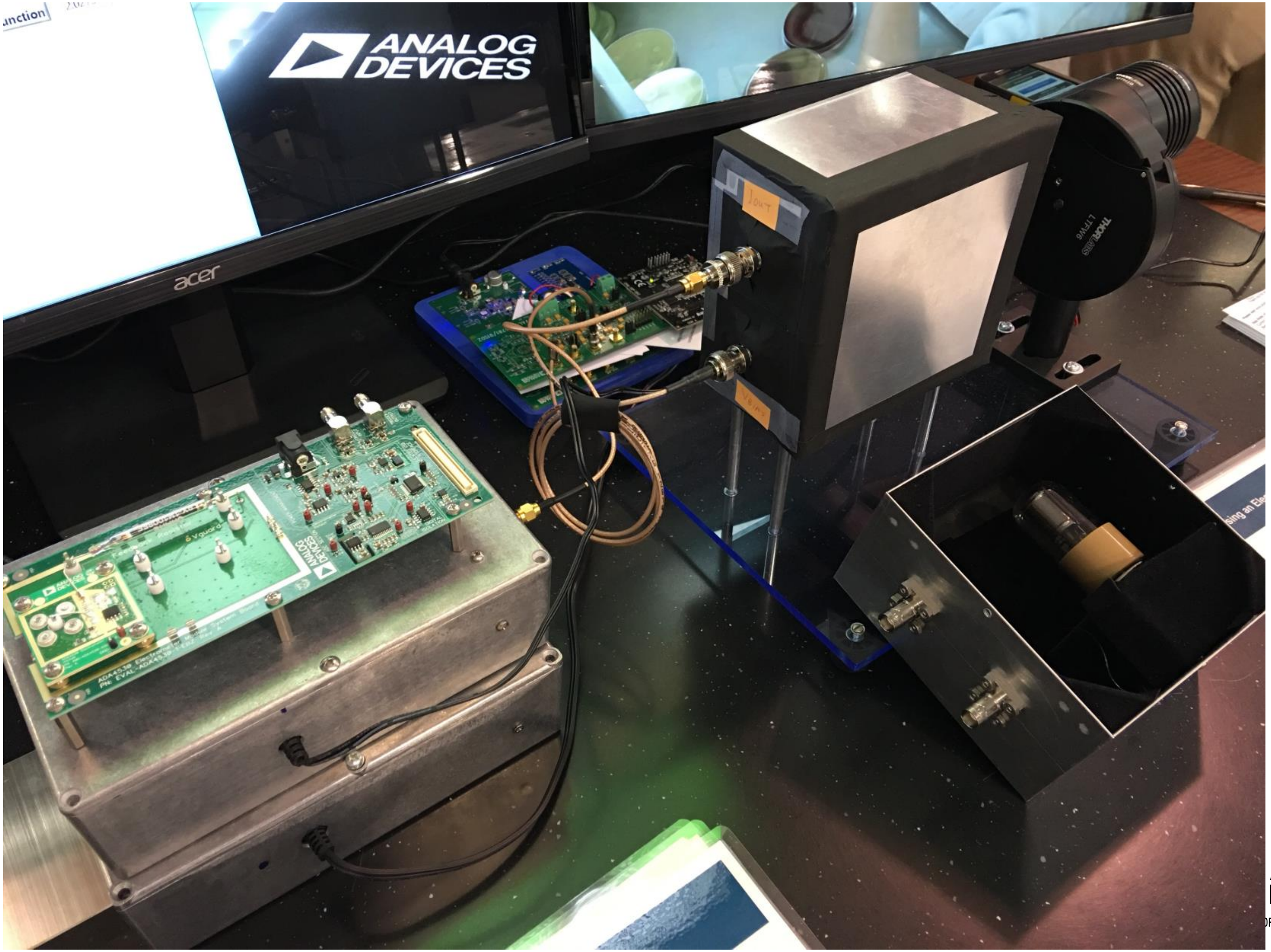

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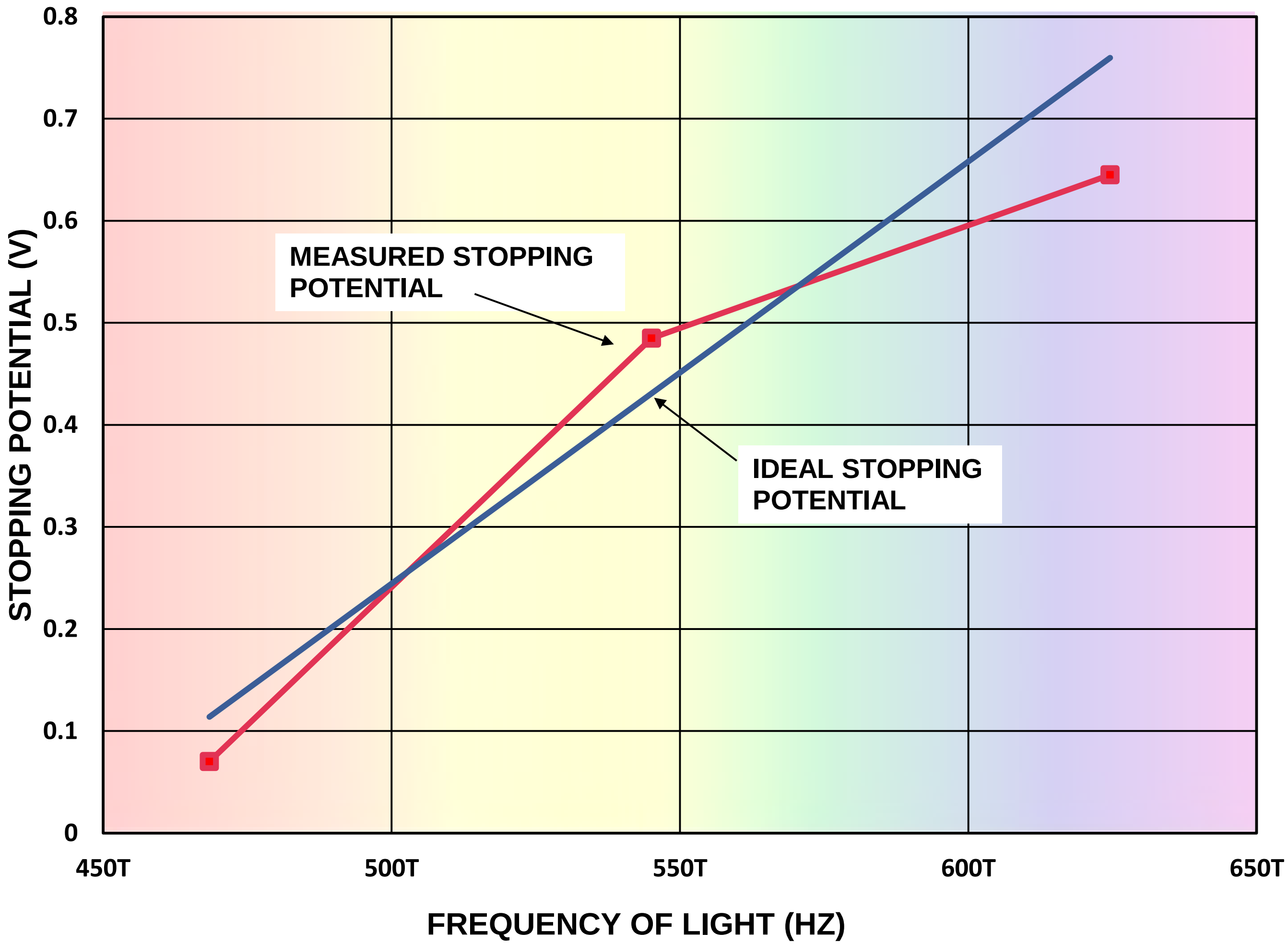
Measurement Results



- The stopping potential varies with light frequency as expected
- The slope is within 11% of Planck's constant
  - The optical setup needs to be adjusted to improve this further

Conclusions

- The Photoelectric Effect has been measured using the ADA4530-1 and the AD5791
  - The stopping potential has been shown to be higher for higher frequency light

- Low-current measurement techniques and applications have been discussed

- Further improvements to the demo could be made
  - Finer line width light source such as a mercury lamp
  - Work Function varies based on brightness, better linearity could be obtained by adding a light sensor and controlling the light intensity to be equal for each color

Thank you!