

Electronics for IoT

IoT Application

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Outline

- Up to now:
 - Python
 - Circuits
 - Internet

- Today:
 - IoT Application

What should we build?

- Useful
- Representative
 - Combine key IoT concepts
 - “Model” for other IoT applications
 - The ones you invent
- Our first IoT app
 - Characterize solar cell

IoT App for Solar Cell Characterization

- Measure solar cell power as a function of load resistance
- Collect results
- Graph results and compute maximum power

Step 1: Measure I/V/P

- How can we measure solar cell voltage, current (and power) with the ESP32?
- We need a sensor!

Web Search

INA219 High Side DC Current Sensor Breakout - 26V \pm 3.2A Max ID ...

<https://www.adafruit.com/product/904> ▼
\$9.95

Instead of struggling with two multimeters, you can just use the handy INA219B chip on this breakout to both measure both the high side voltage and DC current draw over I2C with 1% precision. ... Power the sensor itself with 3 to 5VDC and connect the two I2C pins up to your microcontroller.

INA220 26-V, Bi-Directional, Zero-Drift, Low- or High-Side, I2C Out ...

www.ti.com > ... > Current Sense Amplifiers > Current Sense Power / Current Monitors ▼

The INA220 is a current shunt and power monitor with an I²C- or SMBUS-compatible interface. The INA220 monitors both shunt drop and supply voltage. ... The separate shunt input on the INA220 allows it to be used in systems with low-side sensing. The INA220 is available in two grades: A and B.

LTC4151 - High Voltage I2C Current and Voltage Monitor - Linear ...

www.linear.com/product/LTC4151 ▼

Features. Wide Operating Voltage Range: 7V to 80V; 12-Bit Resolution for Both Current and Voltages; I²C Interface; Additional ADC Input Monitors an External Voltage; Continuous Scan and Snapshot Modes; Shutdown Mode (LTC4151) Reduces Quiescent Current to 120 μ A; Split SDA for Opto-Isolation ...

LTC2990 - Quad I2C Voltage, Current and Temperature Monitor ...

www.linear.com/product/LTC2990 ▼

Features. Measures Voltage, Current and Temperature; Measures Two Remote Diode Temperatures; \pm 0.5 $^{\circ}$ C Accuracy, 0.06 $^{\circ}$ C Resolution (Typ); \pm 1 $^{\circ}$ C Internal Temperature Sensor (Typ); 14-Bit ADC Measures Voltage/Current; 3V to 5.5V Supply Operating Voltage; Four Selectable Addresses; Internal 10ppm/ $^{\circ}$ C Voltage ...

SparkFun Current Sensor Breakout - INA169 - SEN-12040 - SparkFun ...

<https://www.sparkfun.com/products/12040> ▼

The INA169 is definitely a cheaper chip, and using a microcontroller's ADC isn't all that bad (you also get to use 1 pin instead of 2). From an Arduino perspective, that's an analogRead() vs. the initialization of the Wire/I2C library. That being said, if there is enough interest for an I2C current sensor, please let us know! It would ...

Power/Current Sensors - Microchip

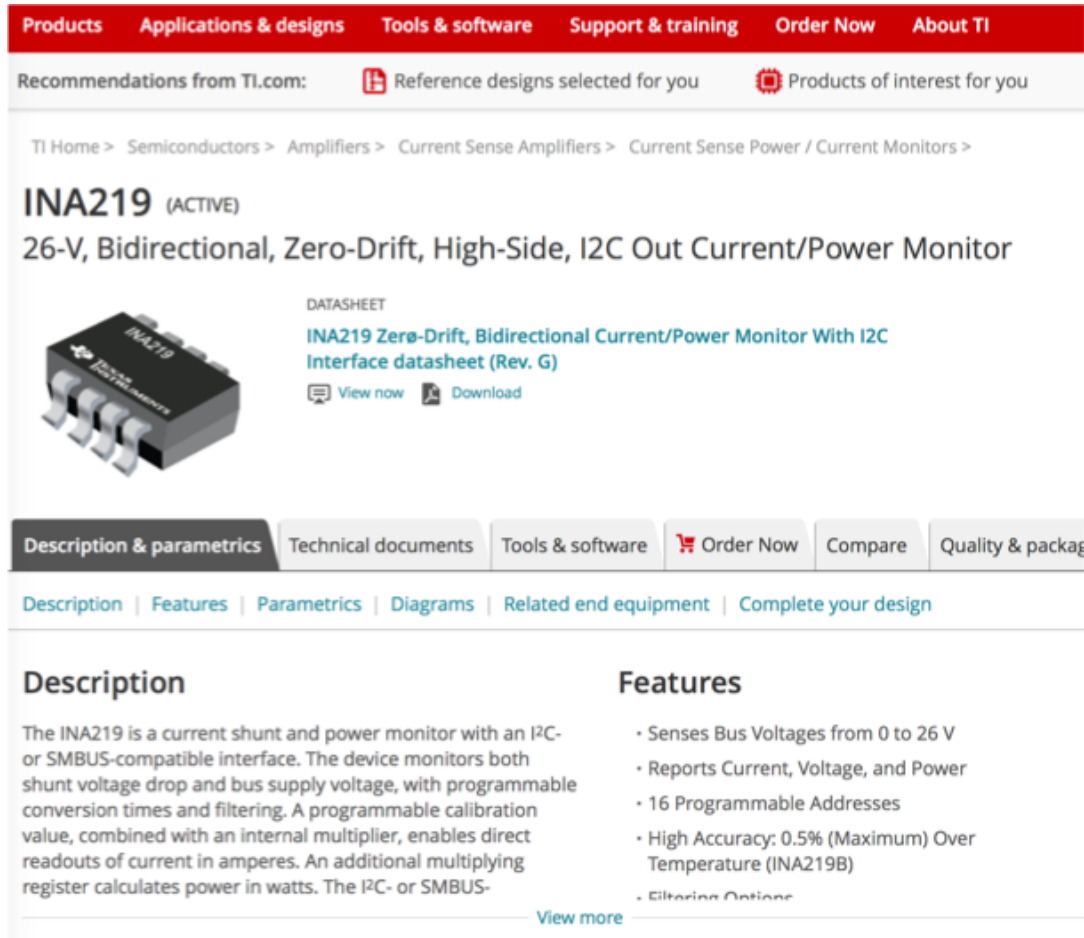
www.microchip.com/powercurrentsensors ▼

EMC1701-1, Samples Available, \$0.76, Current/DC Power Sensor with Temperature Monitoring, 10, 20, 40, 80, \pm 1, 2.5 to 2600, +3 to +24, 1, 0, \pm 0.25 / \pm 1.0, 2, Hardware, SMBus/I2C, yes, 12/QFN.
EMC1701-2, In Production, \$0.65, Current/DC Power Sensor with Temperature Monitoring, 10, 20, 40, 80, \pm 1, 2.5 to 2600, +3 to ...

- Lot's of options
- Any suitable for our needs?
- How are we going to find out

INA 219 Manufacturer Website

- Download datasheet from manufacturer website (TI)



The screenshot shows the TI website page for the INA219. At the top, there is a red navigation bar with links for Products, Applications & designs, Tools & software, Support & training, Order Now, and About TI. Below this is a white bar with recommendations from TI.com, including reference designs and products of interest. The main content area features a breadcrumb trail: TI Home > Semiconductors > Amplifiers > Current Sense Amplifiers > Current Sense Power / Current Monitors >. The product title is **INA219 (ACTIVE)**, followed by the description: **26-V, Bidirectional, Zero-Drift, High-Side, I2C Out Current/Power Monitor**. To the left of the text is an image of the INA219 component. To the right, there is a 'DATASHEET' section with the title **INA219 Zero-Drift, Bidirectional Current/Power Monitor With I2C Interface datasheet (Rev. G)** and two buttons: 'View now' and 'Download'. Below the product information is a horizontal menu with tabs for Description & parametrics, Technical documents, Tools & software, Order Now, Compare, and Quality & package. Underneath this menu is a navigation bar with links for Description, Features, Parametrics, Diagrams, Related end equipment, and Complete your design. The main content area is divided into two columns: 'Description' and 'Features'. The 'Description' column contains text about the device's capabilities, and the 'Features' column lists key specifications. A 'View more' link is located at the bottom of the 'Description' column.

Products Applications & designs Tools & software Support & training Order Now About TI

Recommendations from TI.com: Reference designs selected for you Products of interest for you

TI Home > Semiconductors > Amplifiers > Current Sense Amplifiers > Current Sense Power / Current Monitors >

INA219 (ACTIVE)
26-V, Bidirectional, Zero-Drift, High-Side, I2C Out Current/Power Monitor

DATASHEET
INA219 Zero-Drift, Bidirectional Current/Power Monitor With I2C Interface datasheet (Rev. G)
View now Download

Description & parametrics Technical documents Tools & software Order Now Compare Quality & package

Description | Features | Parametrics | Diagrams | Related end equipment | Complete your design

Description

The INA219 is a current shunt and power monitor with an I²C- or SMBUS-compatible interface. The device monitors both shunt voltage drop and bus supply voltage, with programmable conversion times and filtering. A programmable calibration value, combined with an internal multiplier, enables direct readouts of current in amperes. An additional multiplying register calculates power in watts. The I²C- or SMBUS-

Features

- Senses Bus Voltages from 0 to 26 V
- Reports Current, Voltage, and Power
- 16 Programmable Addresses
- High Accuracy: 0.5% (Maximum) Over Temperature (INA219B)
- Filtering Options

[View more](#)

INA219 Datasheet



INA219

SBOS448G – AUGUST 2008 – REVISED DECEMBER 2015

INA219 Zero-Drift, Bidirectional Current/Power Monitor With I²C Interface

1 Features

- Senses Bus Voltages from 0 to 26 V
- Reports Current, Voltage, and Power
- 16 Programmable Addresses
- High Accuracy: 0.5% (Maximum) Over Temperature (INA219B)
- Filtering Options
- Calibration Registers
- SOT23-8 and SOIC-8 Packages

2 Applications

- Servers
- Telecom Equipment
- Notebook Computers
- Power Management
- Battery Chargers
- Welding Equipment
- Power Supplies
- Test Equipment

3 Description

The INA219 is a current shunt and power monitor with an I²C- or SMBUS-compatible interface. The device monitors both shunt voltage drop and bus supply voltage, with programmable conversion times and filtering. A programmable calibration value, combined with an internal multiplier, enables direct readouts of current in amperes. An additional multiplying register calculates power in watts. The I²C- or SMBUS-compatible interface features 16 programmable addresses.

The INA219 is available in two grades: A and B. The B grade version has higher accuracy and higher precision specifications.

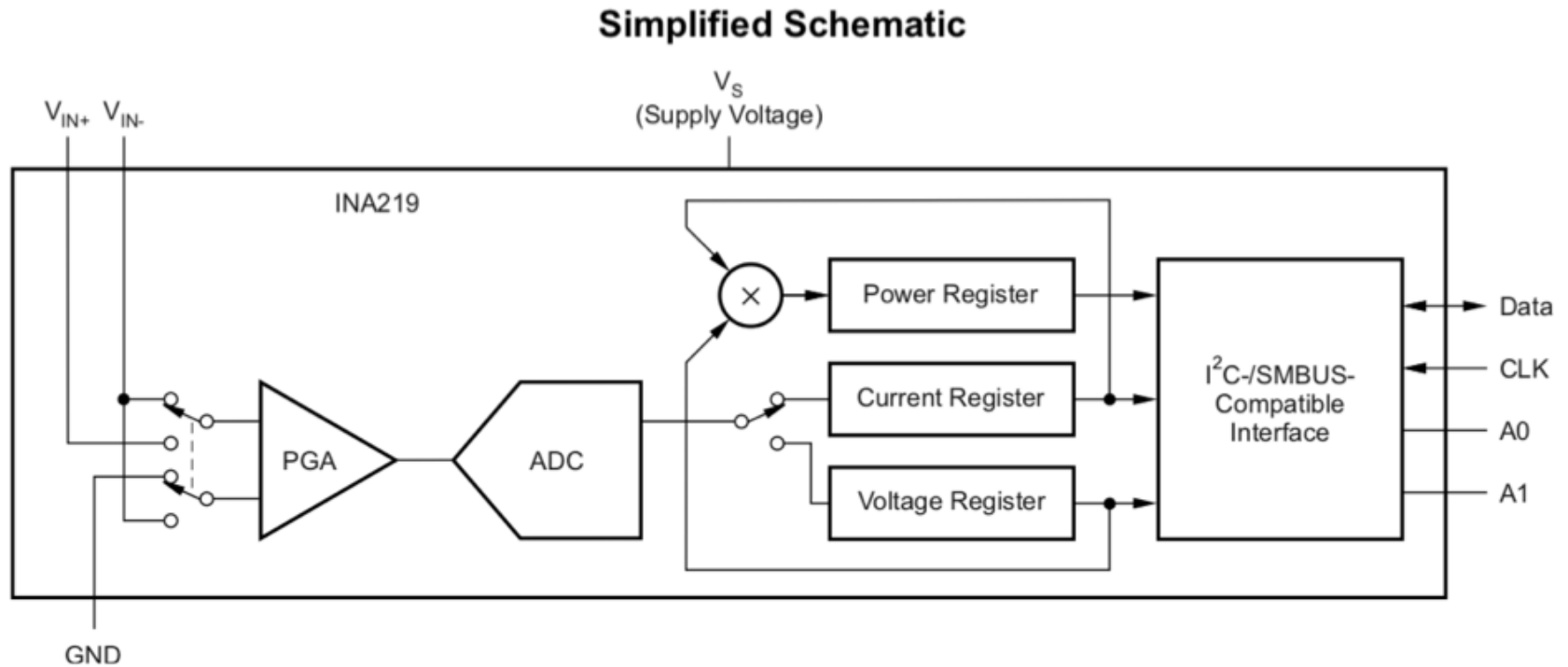
The INA219 senses across shunts on buses that can vary from 0 to 26 V. The device uses a single 3- to 5.5-V supply, drawing a maximum of 1 mA of supply current. The INA219 operates from –40°C to 125°C.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
INA219	SOIC (8)	3.91 mm × 4.90 mm
	SOT-23 (8)	1.63 mm × 2.90 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

INA219 “Simplified Schematic”



INA219 Configured

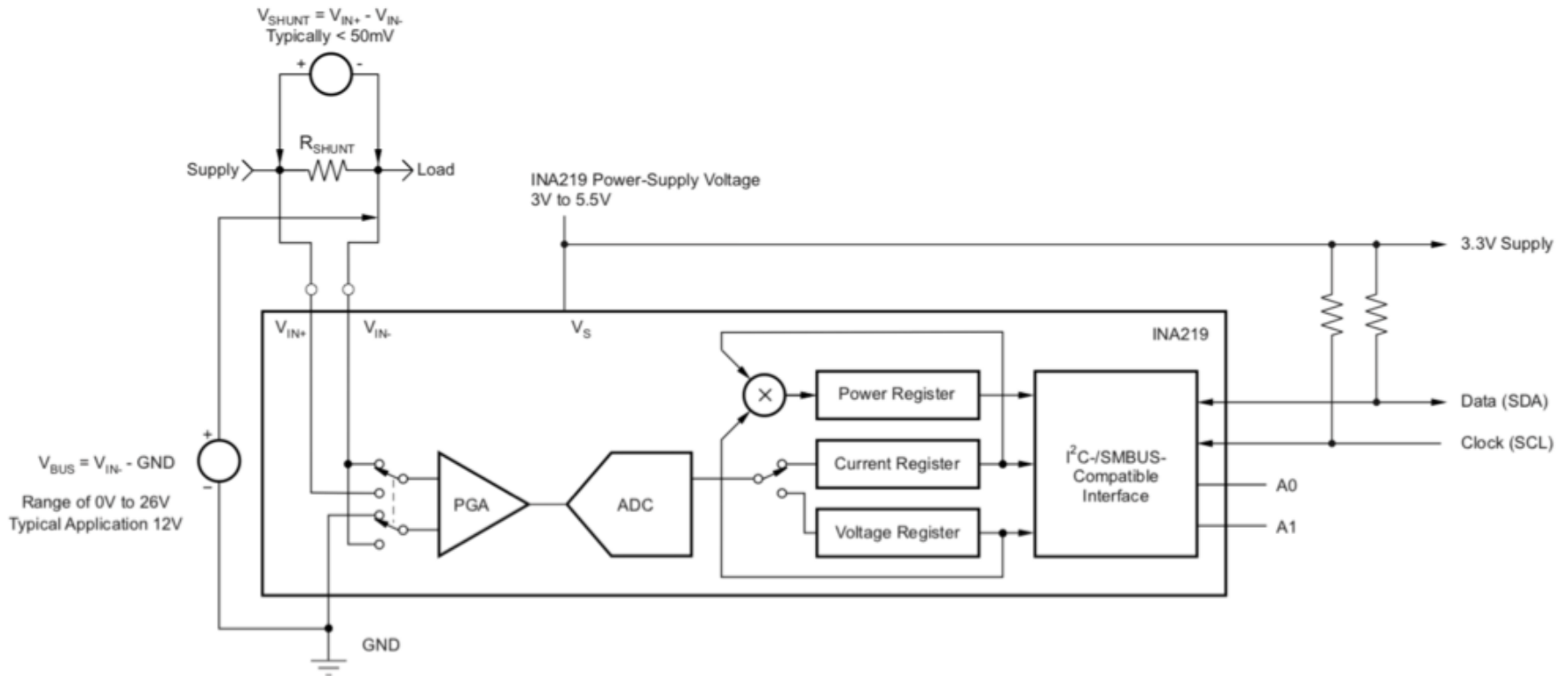


Figure 13. INA219 Configured for Shunt and Bus Voltage Measurement

Let's Redraw this a little ...

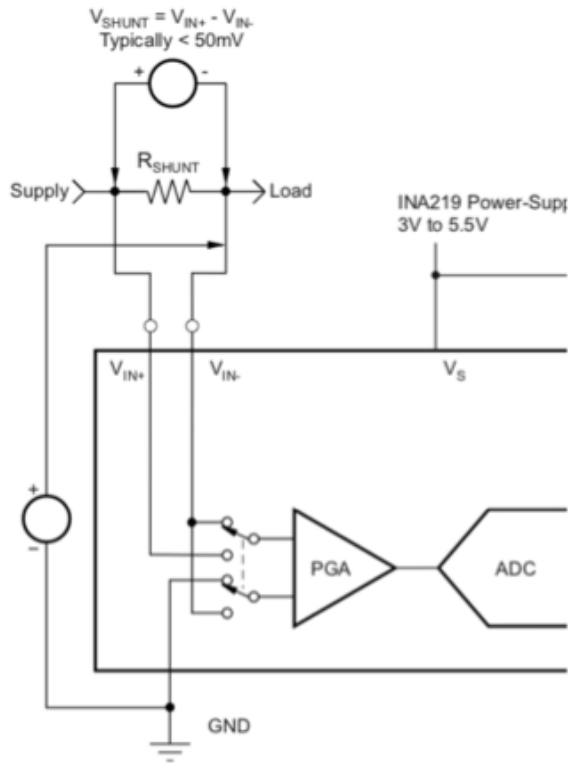
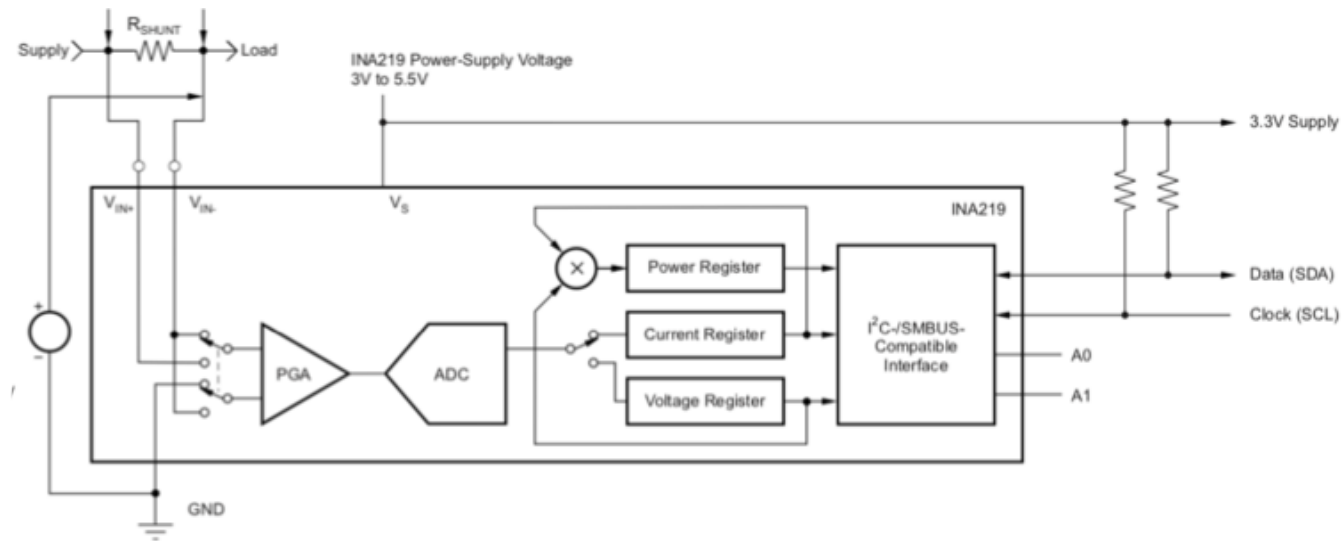


Figure 13. INA219 Configure


Hooking this up to the ESP32



- Just 4 wires:
 - Data (SDA)
 - Clock (SCL)
 - 3.3V supply (Huzzah32 generates this)
 - GND

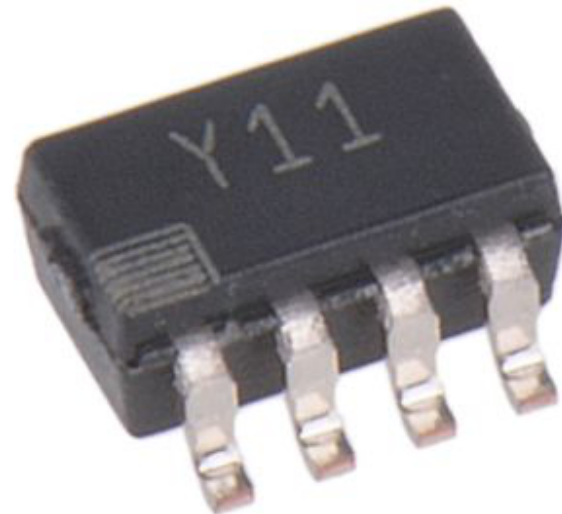
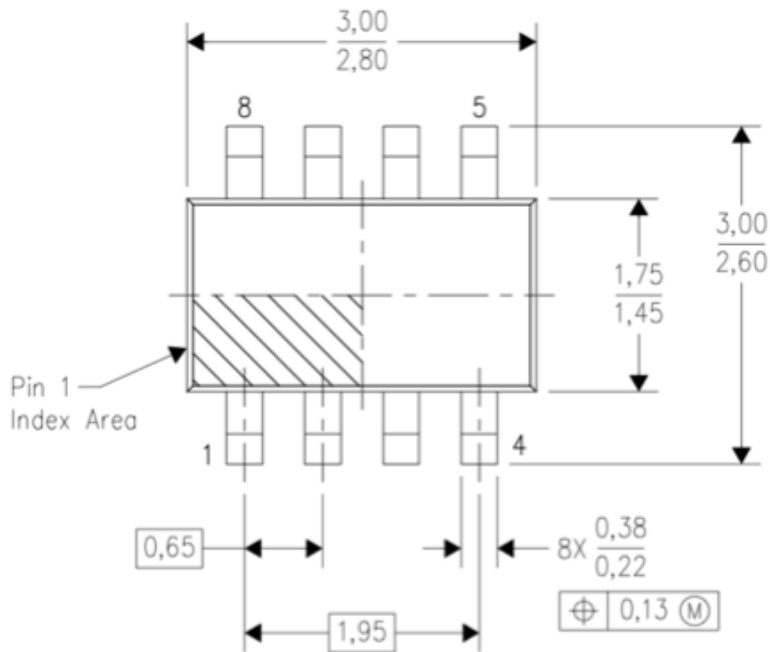
Huzzah32

GPIO	ALT	μ Py		μ Py	ALT	GPIO
	RESET		1			
	3.3V		2			
			3			
	GND		4			
26	DAC2	A0	5	28	VBAT	
25	DAC1	A1	6	27	EN 3.3V	
34	ADC6	A2	7	26	VUSB	
39	ADC3	A3	8	25	A12	LED
36	ADC0	A4	9	24	A11	BOOT
4		A5	10	23	A10	
5	SCK	A16	11	22	A9	ADC5
18	MOSI	A17	12	21	A8	
19	MISO	A18	13	20	A7	ADC4
16		A19	14	19	A6	
17		A20	15	18	A15	SCL
21		A21	16	17	A14	SDA

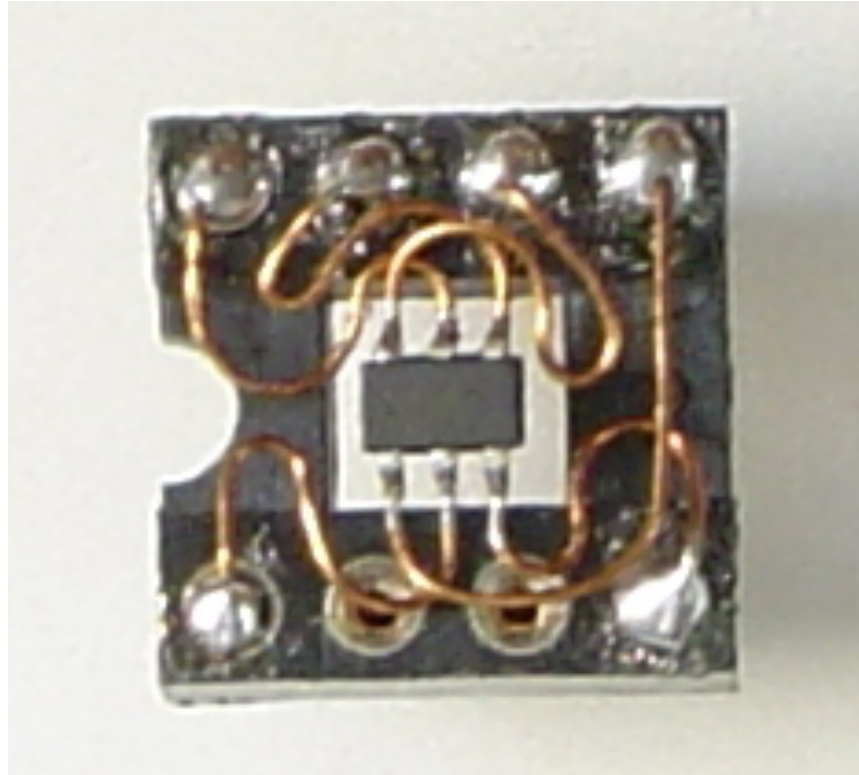


Real INA219

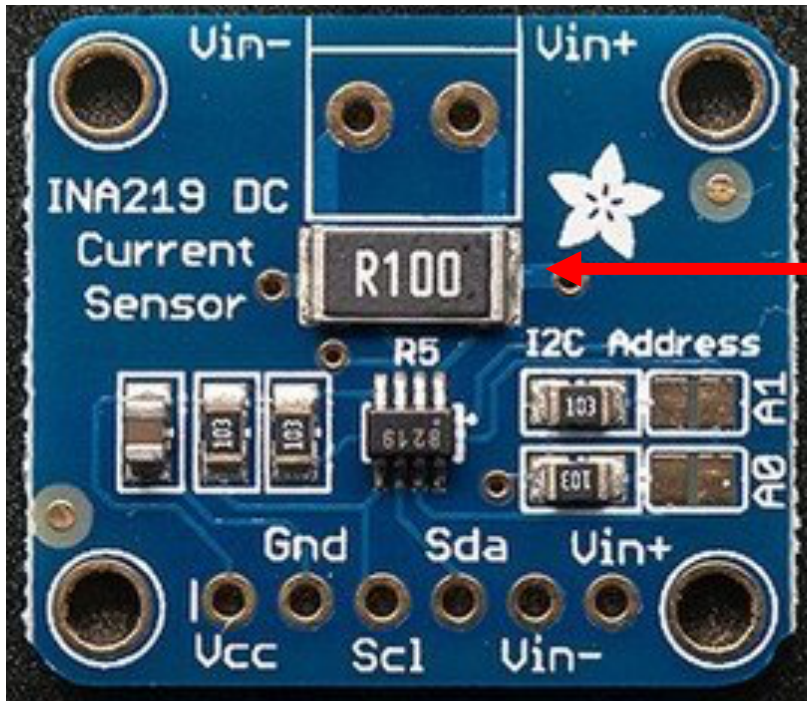
- This thing is tiny
- “big” pepper corn



Hone your soldering skills ...



Or get a breakout board ...



$$R_{SHUNT} = 0.1\Omega$$

- <https://www.adafruit.com/product/904>
- In your “goodies” bag ...

More datasheet ...

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾

		MIN	MAX	UNIT
V_S	Supply voltage		6	V
Analog Inputs IN+, IN-	Differential ($V_{IN+} - V_{IN-}$) ⁽²⁾	-26	26	V
	Common-mode ($V_{IN+} + V_{IN-} / 2$)	-0.3	26	V
SDA		GND - 0.3	6	V
SCL		GND - 0.3	$V_S + 0.3$	V
Input current into any pin			5	mA
Open-drain digital output current			10	mA
Operating temperature		-40	125	°C
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	-65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) V_{IN+} and V_{IN-} may have a differential voltage of -26 to 26 V; however, the voltage at these pins must not exceed the range -0.3 to 26 V.

Electrical Characteristics

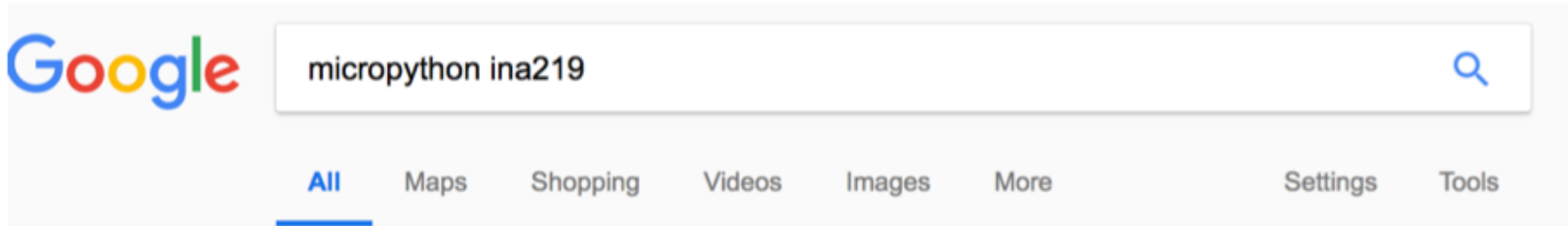
7.5 Electrical Characteristics:

At $T_A = 25^\circ\text{C}$, $V_S = 3.3\text{ V}$, $V_{IN+} = 12\text{ V}$, $V_{SHUNT} = (V_{IN+} - V_{IN-}) = 32\text{ mV}$, $\text{PGA} = /1$, and $\text{BRNG}^{(1)} = 1$, unless otherwise noted.

PARAMETER		TEST CONDITIONS	INA219A			INA219B			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
INPUT									
V_{SHUNT}	Full-scale current sense (input) voltage range	$\text{PGA} = /1$	0		± 40	0		± 40	mV
		$\text{PGA} = /2$	0		± 80	0		± 80	mV
		$\text{PGA} = /4$	0		± 160	0		± 160	mV
		$\text{PGA} = /8$	0		± 320	0		± 320	mV
Bus voltage (input voltage) range ⁽²⁾		$\text{BRNG} = 1$	0		32	0		32	V
		$\text{BRNG} = 0$	0		16	0		16	V
CMRR	Common-mode rejection	$V_{IN+} = 0$ to 26 V	100	120		100	120		dB
V_{OS}	Offset voltage, RTI ⁽³⁾	$\text{PGA} = /1$		± 10	± 100		± 10	$\pm 50^{(4)}$	μV
		$\text{PGA} = /2$		± 20	± 125		± 20	$\pm 75^{(4)}$	μV
		$\text{PGA} = /4$		± 30	± 150		± 30	$\pm 75^{(4)}$	μV
		$\text{PGA} = /8$		± 40	± 200		± 40	$\pm 100^{(4)}$	μV
vs Temperature		$T_A = -25^\circ\text{C}$ to 85°C		0.1		0.1		$\mu\text{V}/^\circ\text{C}$	
PSRR	vs Power Supply	$V_S = 3$ to 5.5 V		10		10		$\mu\text{V}/\text{V}$	
Current sense gain error				± 40		± 40		m%	
vs Temperature		$T_A = -25^\circ\text{C}$ to 85°C		1		1		m%/°C	
IN+ pin input bias current		Active mode		20		20		μA	
IN- pin input bias current V_{IN+} pin input impedance		Active mode		20 320		20 320		$\mu\text{A} \text{k}\Omega$	
IN+ pin input leakage ⁽⁵⁾		Power-down mode		0.1	± 0.5	0.1	± 0.5	μA	
IN- pin input leakage ⁽⁵⁾		Power-down mode		0.1	± 0.5	0.1	± 0.5	μA	
DC ACCURACY									
ADC basic resolution				12		12		bits	
Shunt voltage, 1 LSB step size				10		10		μV	
Bus voltage, 1 LSB step size				4		4		mV	
Current measurement error				$\pm 0.2\%$	$\pm 0.5\%$	$\pm 0.2\%$	$\pm 0.3\%^{(4)}$		
over Temperature		$T_A = -25^\circ\text{C}$ to 85°C			$\pm 1\%$		$\pm 0.5\%^{(4)}$		
Bus voltage measurement error				$\pm 0.2\%$	$\pm 0.5\%$	$\pm 0.2\%$	$\pm 0.5\%$		
over Temperature		$T_A = -25^\circ\text{C}$ to 85°C			$\pm 1\%$		$\pm 1\%$		
Differential nonlinearity				± 0.1		± 0.1		LSB	
ADC TIMING									
ADC conversion time		12 bit		532	586	532	586	μs	
		11 bit		276	304	276	304	μs	
		10 bit		148	163	148	163	μs	
		9 bit		84	93	84	93	μs	
Minimum convert input low time				4		4		μs	

- Needed to write software driver

Someone has already done the work!



About 12,100 results (0.54 seconds)

[MicroPython library for the TI INA219 voltage/current sensor ...](#)

<https://forum.micropython.org> > ... > [Drivers for External Components](#) ▾

May 16, 2017 - https://github.com/chrisb2/pyb_ina219. I have written this library based on one I wrote for the Raspberry Pi. It supports the **INA219** voltage, current and power monitor sensor from Texas Instruments. The intent of the library is to make it easy to use the quite complex functionality of this sensor. Its currently ...

[MicroPython on ESP32 with SPIRAM support - Page 25](#) Jan 10, 2018

[Lolin32 Battery State](#) Aug 14, 2017

[boot.py not executed](#) Aug 2, 2017

[MicroPython driver for TI INA219?](#) Dec 7, 2016

[More results from forum.micropython.org](#)

[GitHub - chrisb2/pyb_ina219: This library for the MicroPython makes it ...](#)

https://github.com/chrisb2/pyb_ina219 ▾

[pyb_ina219](#) - This library for the **MicroPython** makes it easy to leverage the complex functionality of the Texas Instruments **INA219** sensor to measure voltage , current and power.

You've visited this page 4 times. Last visit: 1/12/18

INA219 on Github

chrisb2 / pyb_ina219

Watch 2 Star 3 Fork 1

Code Issues 0 Pull requests 0 Projects 0 Wiki Insights

This library for the MicroPython makes it easy to leverage the complex functionality of the Texas Instruments INA219 sensor to measure voltage, current and power.

micropython ina-219 pyboard esp8266 esp32

30 commits 1 branch 0 releases 1 contributor MIT

Branch: master New pull request Create new file Upload files Find file Clone or download

chrisb2 Fix spelling Latest commit dd5f9eb on Sep 28, 2017

esp32	Fix spelling	4 months ago
esp8266	Add information and frozen byte code to support esp8266	7 months ago
tests	Some working tests	8 months ago
LICENSE.md	fix logging, doc and add license	9 months ago
README.md	Update main README	4 months ago
example.py	Change to use machine.I2C instead of pyb.I2C for better portability a...	9 months ago
ina219.py	Change to use machine.I2C instead of pyb.I2C for better portability a...	9 months ago

INA219 Driver Usage Instructions

Usage

If you want to give it a try then copy [ina219.py](#) onto the flash drive of your pyboard, connect the sensor to the I2C(1) or I2C(2) interfaces on the pyboard, then from a REPL prompt execute:

```
from ina219 import INA219
from machine import I2C

I2C_INTERFACE_NO = 2
SHUNT_OHMS = 0.1

ina = INA219(SHUNT_OHMS, I2C(I2C_INTERFACE_NO))
ina.configure()
print("Bus Voltage: %.3f V" % ina.voltage())
print("Current: %.3f mA" % ina.current())
print("Power: %.3f mW" % ina.power())
```

← Depends on MicroPython port
See next page

https://github.com/chrisb2/pyb_ina219

INA219 Example

```
from ina219 import INA219
from machine import I2C, Pin
from board import SDA, SCL
import time

i2c = I2C(id=0, scl=Pin(SCL), sda=Pin(SDA), freq=100000)

# optional: detect all devices connected to I2C bus
print("scanning I2C bus ...")
print("I2C:", i2c.scan())

# initialize INA219
SHUNT_RESISTOR_OHMS = 0.1
ina = INA219(SHUNT_RESISTOR_OHMS, i2c)
ina.configure()

# read measurements
while True:
    v = ina.voltage()
    i = ina.current()
    p = ina.power()
    print("V = {:.6.2f}, I = {:.6.2f}, P = {:.6.2f}".format(v, i, p))
    time.sleep(0.5)
```

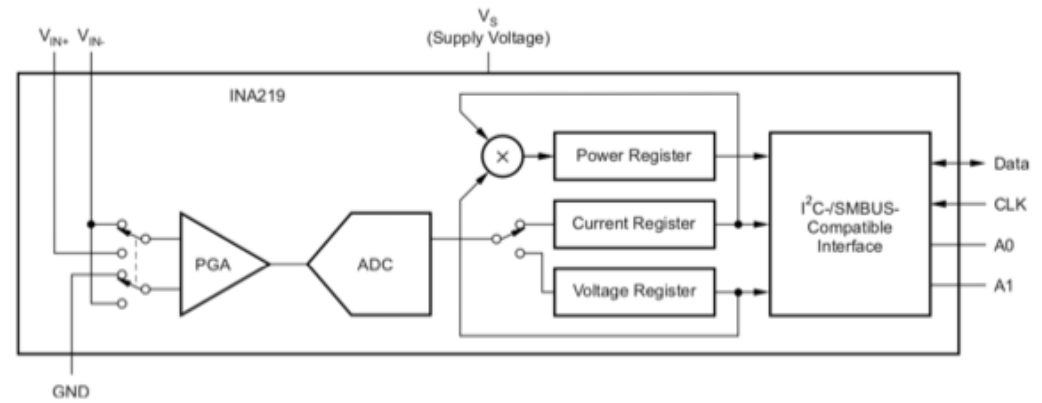
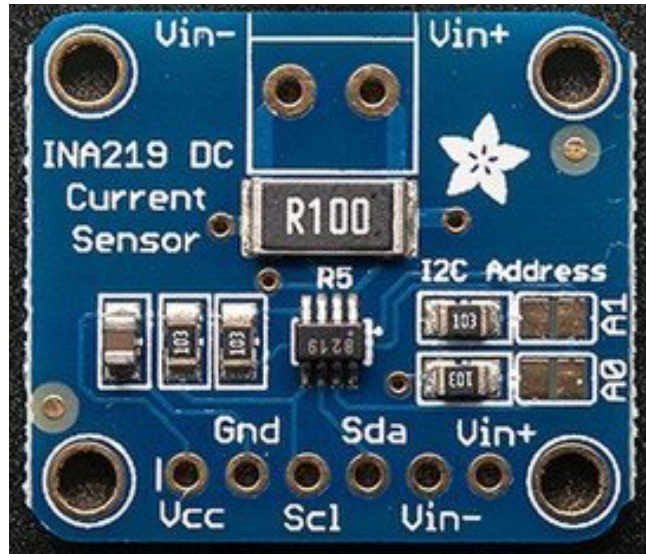
Circuit

- Solar cell characterization
- Components:
 - 1.
 - 2.
 - 3.
 - 4.


Approach

- Symbols
- Circuit diagram
- Optional: wiring diagram

INA219 Symbol



ESP32



GPIO	ALT	μ Py	Pin
RESET			1
3.3V			2
			3
GND			4
26	DAC2	A0	5
25	DAC1	A1	6
34	ADC6	A2	7
39	ADC3	A3	8
36	ADC0	A4	9
4		A5	10
5	SCK	A16	11
18	MOSI	A17	12
19	MISO	A18	13
16		A19	14
17		A20	15
21		A21	16

μ Py	ALT	GPIO	Pin
		VBAT	28
		EN 3.3V	27
		VUSB	26
A12	LED		13
A11	BOOT		12
A10			27
A9	ADC5		33
A8			15
A7	ADC4		32
A6			14
A15	SCL		22
A14	SDA		23

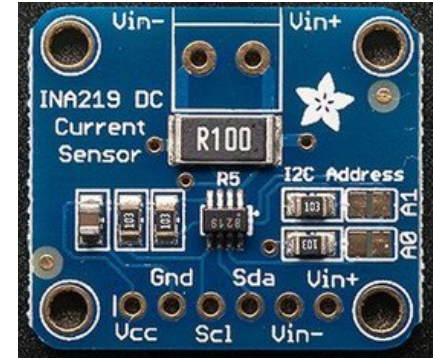
Circuit Diagram

Wiring Diagram

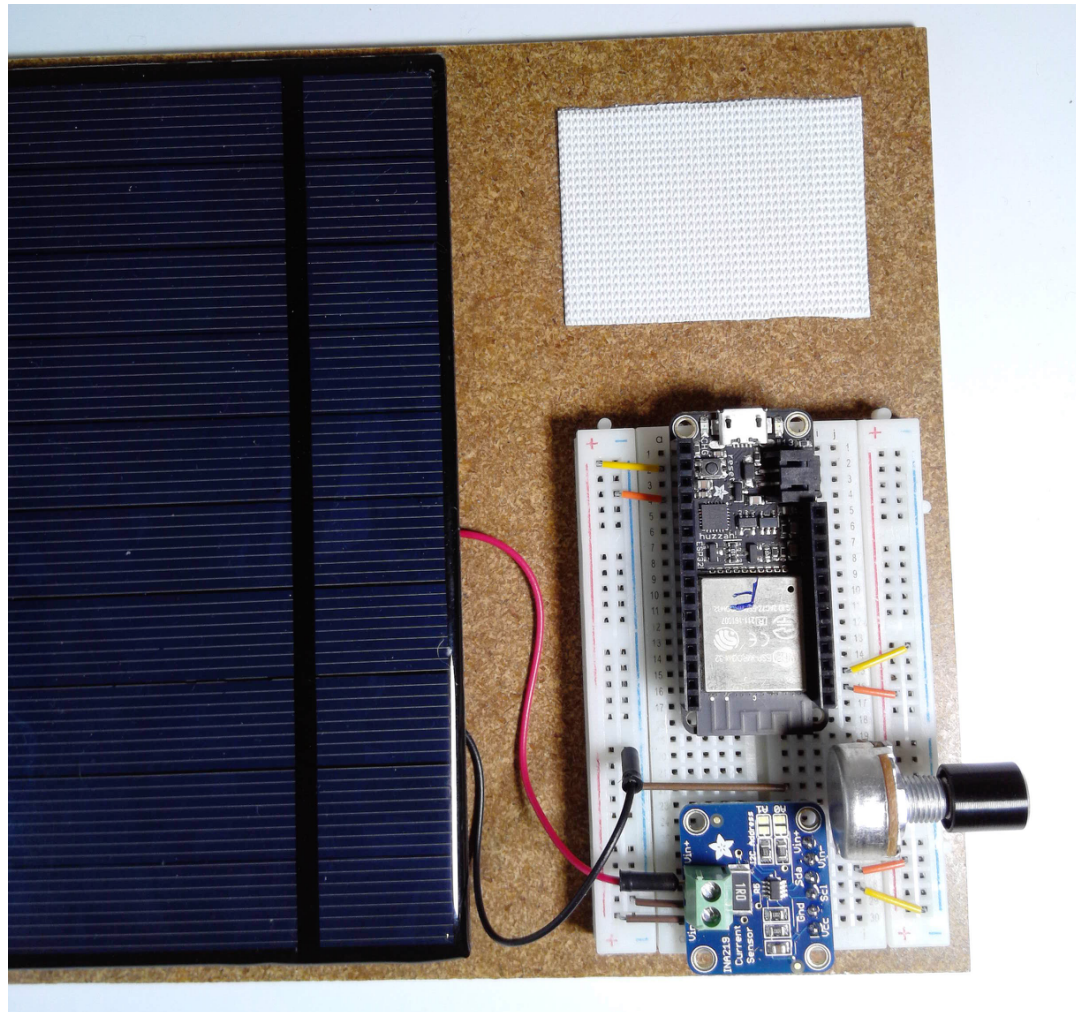
GPIO	ALT	μ Py
RESET		1
3.3V		2
GND		4
26	DAC2	A0
25	DAC1	A1
34	ADC6	A2
39	ADC3	A3
36	ADC0	A4
4		A5
5	SCK	A16
18	MOSI	A17
19	MISO	A18
16		A19
17		A20
21		A21



μ Py	ALT	GPIO
	VBAT	28
	EN 3.3V	27
	VUSB	26
25	A12	LED
24	A11	BOOT
23	A10	
22	A9	ADC5
21	A8	
20	A7	ADC4
19	A6	
18	A15	SCL
17	A14	SDA



Complete Circuit



Testing

V = 5.13V,	I = 1.97mA,	P = 10mW,	R = 2606.30hm
V = 5.16V,	I = 2.10mA,	P = 11mW,	R = 2461.90hm
V = 5.18V,	I = 2.60mA,	P = 13mW,	R = 1989.50hm
V = 5.14V,	I = 3.54mA,	P = 17mW,	R = 1454.50hm
V = 5.11V,	I = 5.16mA,	P = 26mW,	R = 990.10hm
V = 5.12V,	I = 9.43mA,	P = 49mW,	R = 542.80hm
V = 5.13V,	I = 13.40mA,	P = 69mW,	R = 382.70hm
V = 5.13V,	I = 16.16mA,	P = 82mW,	R = 317.50hm
V = 5.08V,	I = 19.63mA,	P = 98mW,	R = 258.70hm
V = 5.05V,	I = 24.76mA,	P = 126mW,	R = 204.00hm
V = 5.07V,	I = 31.23mA,	P = 160mW,	R = 162.20hm
V = 5.04V,	I = 42.50mA,	P = 216mW,	R = 118.60hm
V = 4.38V,	I = 110.48mA,	P = 446mW,	R = 39.60hm
V = 0.16V,	I = 135.02mA,	P = 19mW,	R = 1.20hm
V = 0.23V,	I = 140.01mA,	P = 26mW,	R = 1.60hm
V = 0.13V,	I = 144.61mA,	P = 15mW,	R = 0.90hm
V = 0.12V,	I = 149.01mA,	P = 18mW,	R = 0.80hm

How can we plot the result?

- Connect plotter to ESP32?
 - And run Matlab or Excel?
- Better solution
 - Do the plotting on a computer that's made for this (e.g. laptop)
 - How do we get the data there?

Summary

- IoT Application
 - Circuits
 - Python
 - Internet ...
- Sensors
 - INA219
 - I2C
 - Driver
- Prototyping
 - Wiring
 - Electrical and software testing