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 ±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 120µA; 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; ±0.5°C Accuracy, 0.06°C Resolution (Typ); ±1°C Internal Temperature **Sensor** (Typ); 14-Bit ADC Measures Voltage/**Current**; 3V to 5.5V Supply Operating Voltage; Four Selectable Addresses; Internal 10ppm/°C Voltage ...

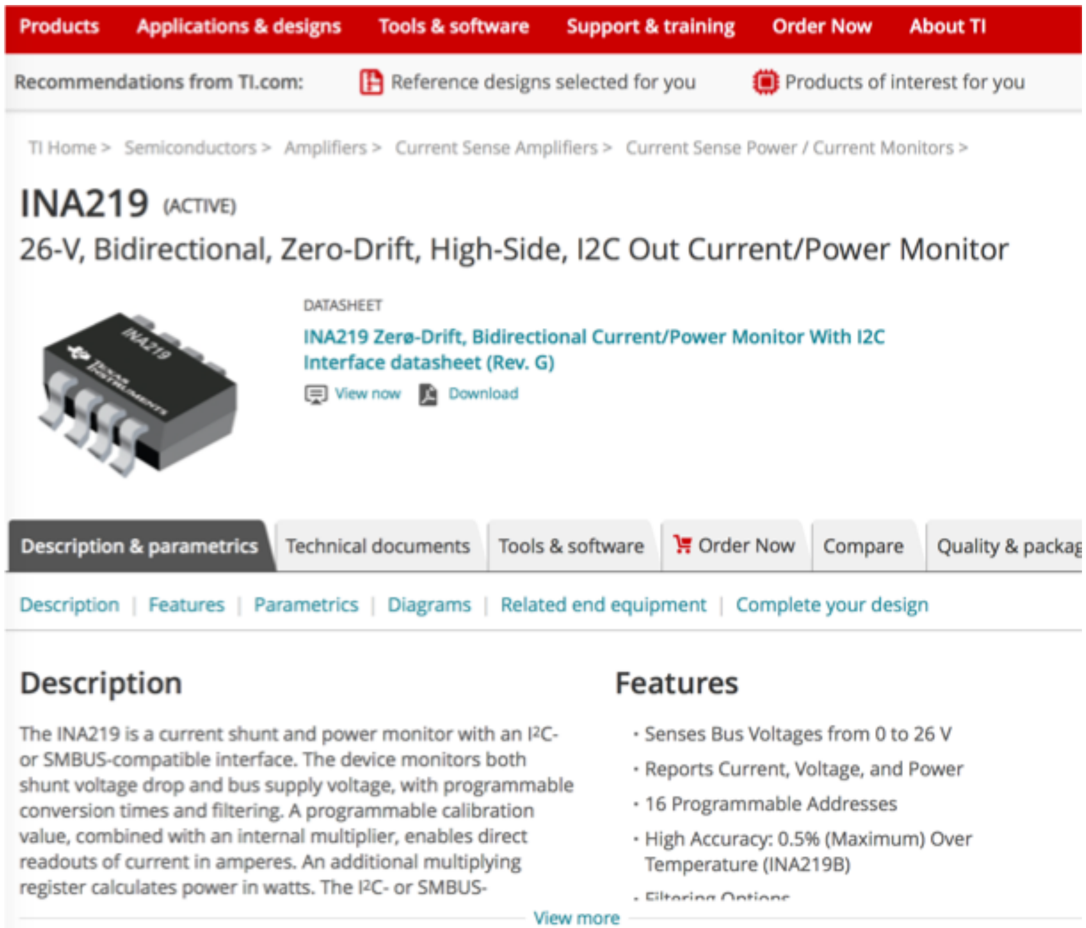
SparkFun Current Sensor Breakout - INA169 - SEN-12040 - SparkFun ...
https://www.sparkfun.com/products/12040
The INA169 is definitely a cheaper chip, and using a microcontroller's ADC isn't all that bad (you also get to use 1 pin instead of 2). From an Arduino perspective, that's an analogRead() vs. 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, ±1, 2.5 to 2600, +3 to +24, 1, 0, ±0.25 / ± 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, ±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)



INA219 Datasheet

TEXAS INSTRUMENTS

INA219

SBOS448G – AUGUST 2008 – REVISED DECEMBER 2015

INA219 Zerø-Drift, Bidirectional Current/Power Monitor With I^2C 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 I^2C- 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 I^2C- 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.

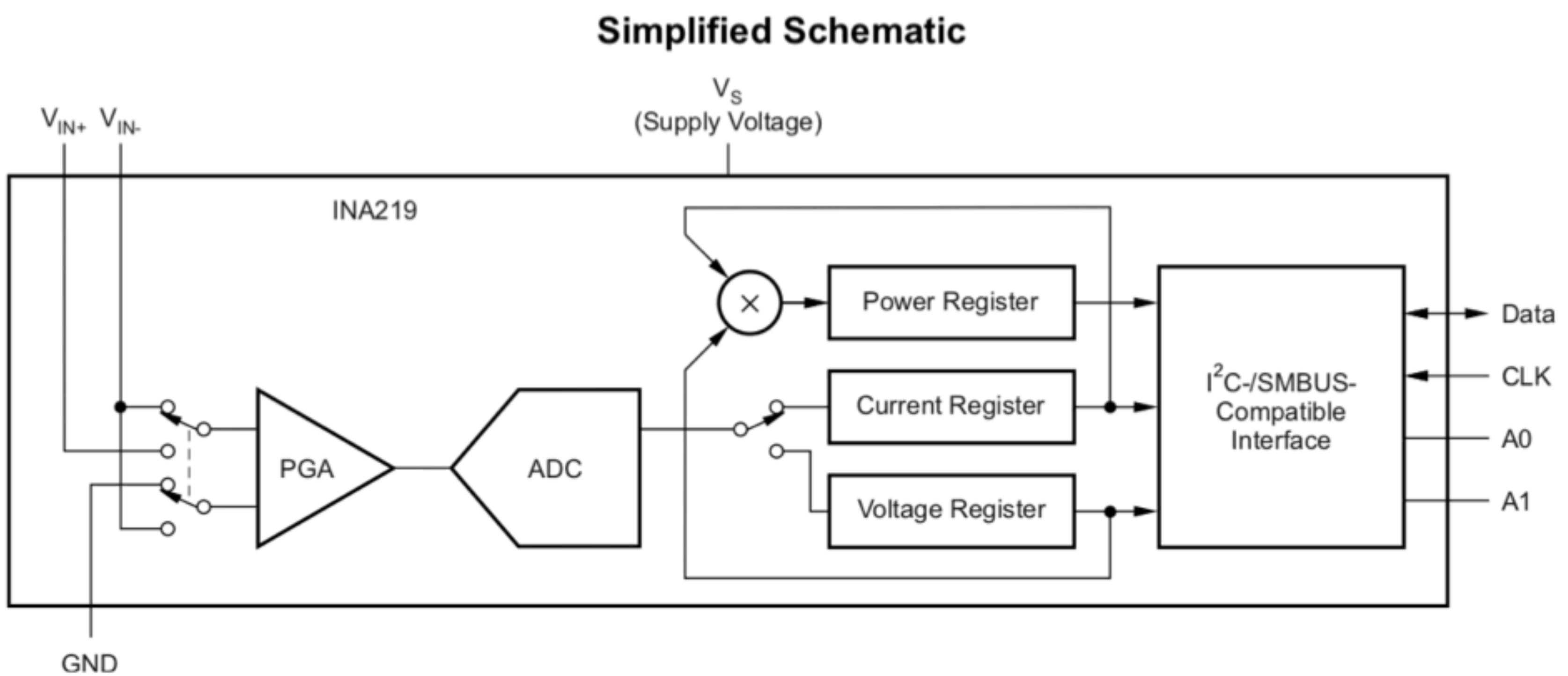
The INA219 senses across shunts on buses that can vary from 0 to 26 V. The device uses a single 3- to 5.5-V supply, drawing a maximum of 1 mA of supply current. The INA219 operates from –40°C to 125°C.

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

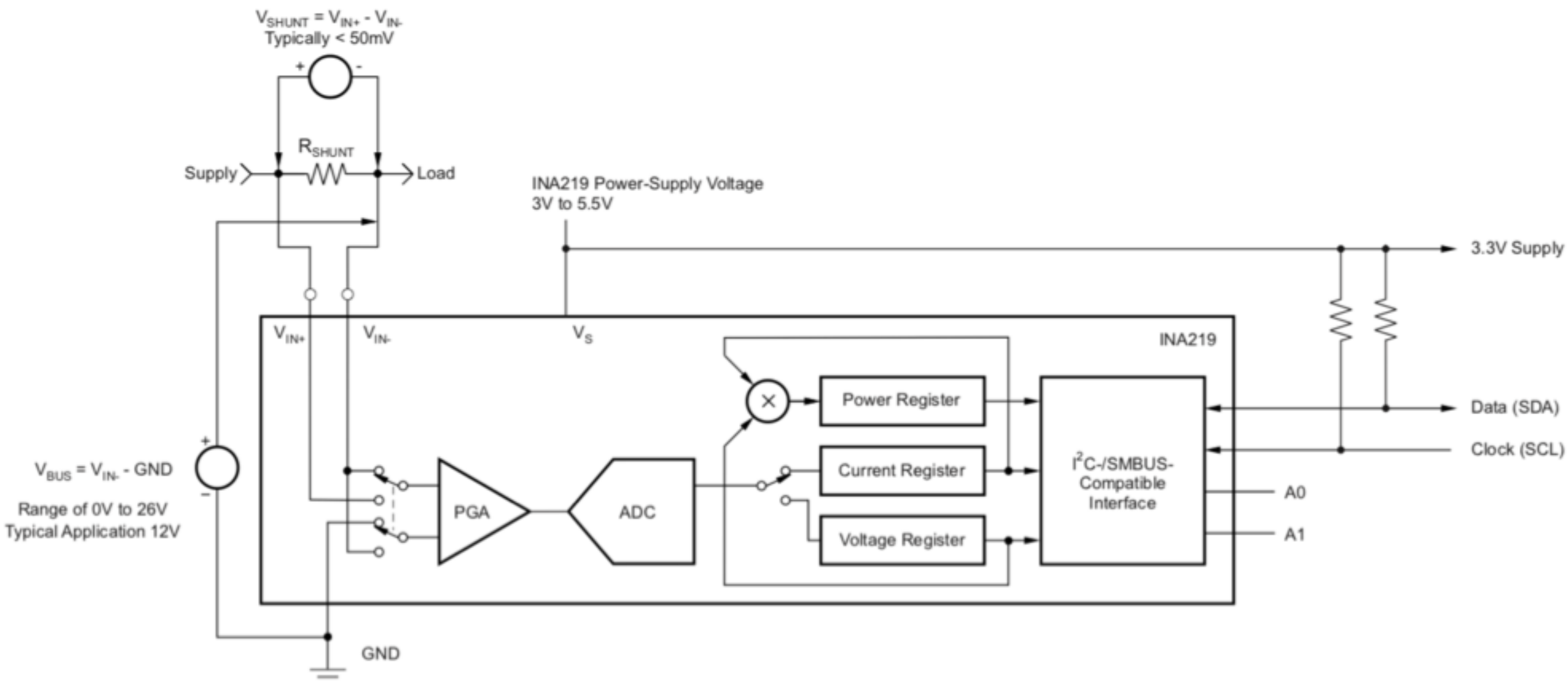


Figure 13. INA219 Configured for Shunt and Bus Voltage Measurement

Let's Redraw this a little …

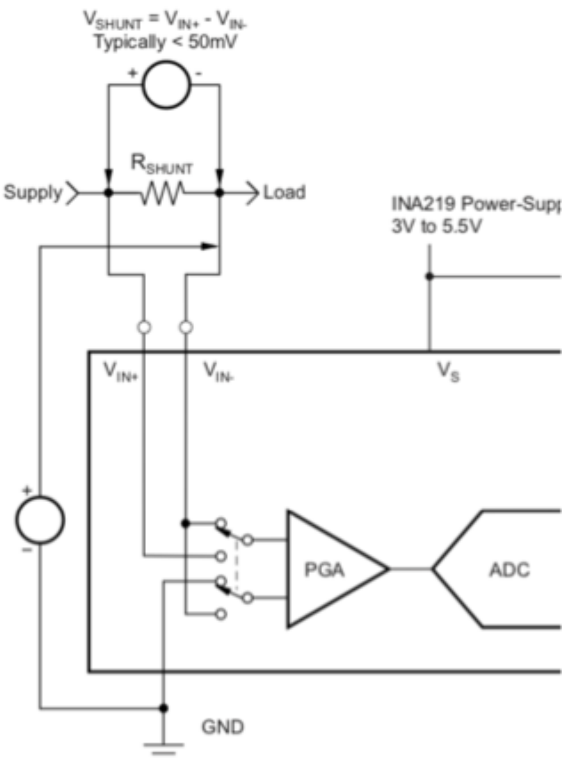
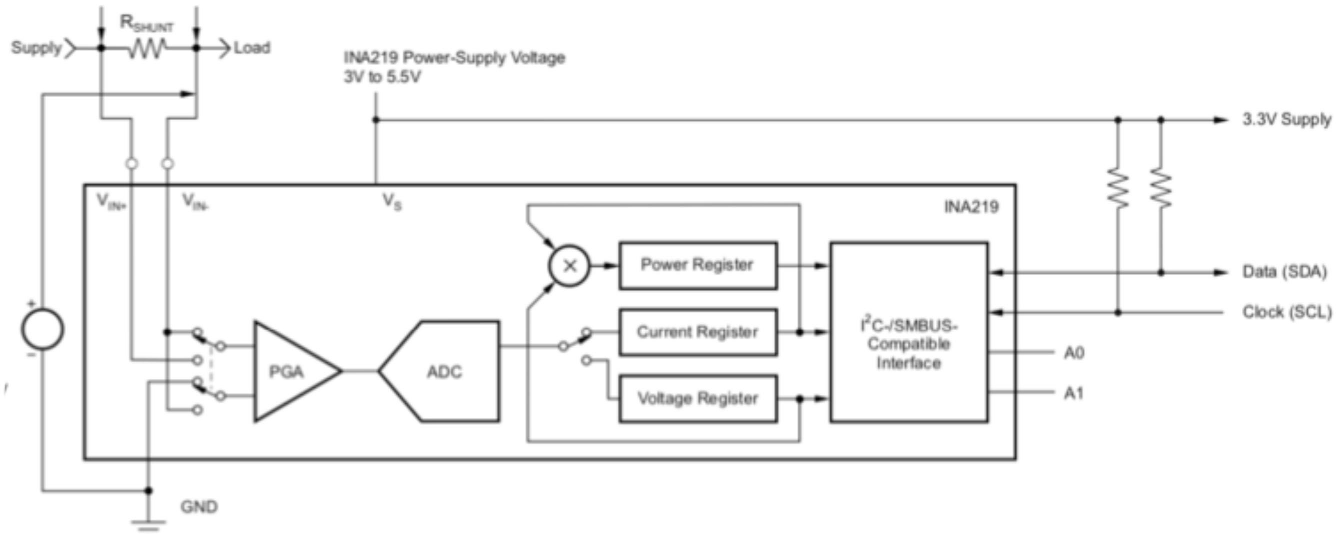


Figure 13. INA219 Configure

Hooking this up to the ESP32



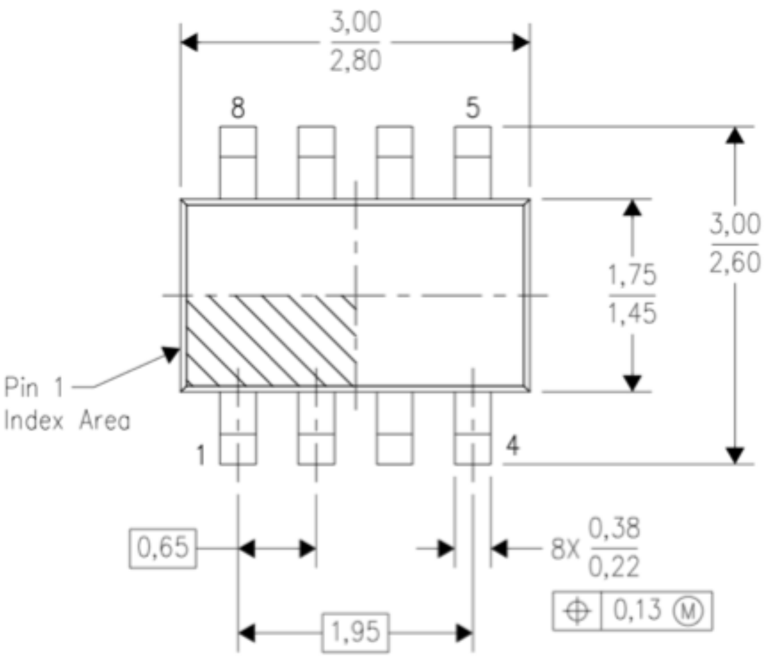
- Just 4 wires:
  - Data (SDA)
  - Clock (SCL)
  - 3.3V supply (Huzzah32 generates this)
  - GND

Huzzah32

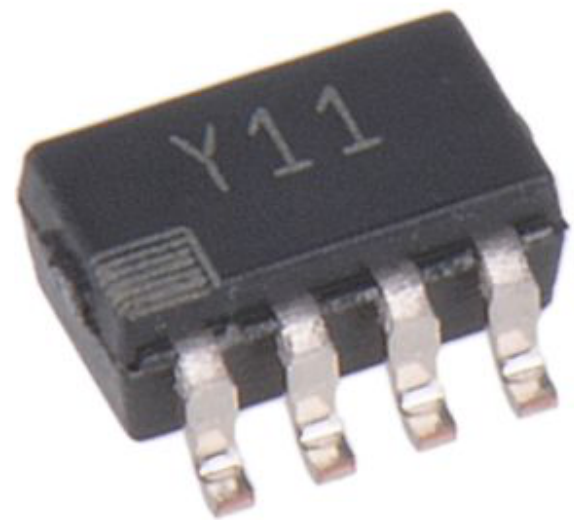
GPIO	ALT	µPy	
	RESET		1
	3.3V		2
			3
	GND		4
26	DAC2	A0	5
25	DAC1	A1	6
34	ADC6	A2	7
39	ADC3	A3	8
36	ADC0	A4	9
4		A5	10
5	SCK	A16	11
18	MOSI	A17	12
19	MISO	A18	13
16		A19	14
17		A20	15
21		A21	16

	µPy	ALT	GPIO
28		VBAT	
27		EN 3.3V	
26		VUSB	
25	A12	LED	13
24	A11	BOOT	12
23	A10		27
22	A9	ADC5	33
21	A8		15
20	A7	ADC4	32
19	A6		14
18	A15	SCL	22
17	A14	SDA	23

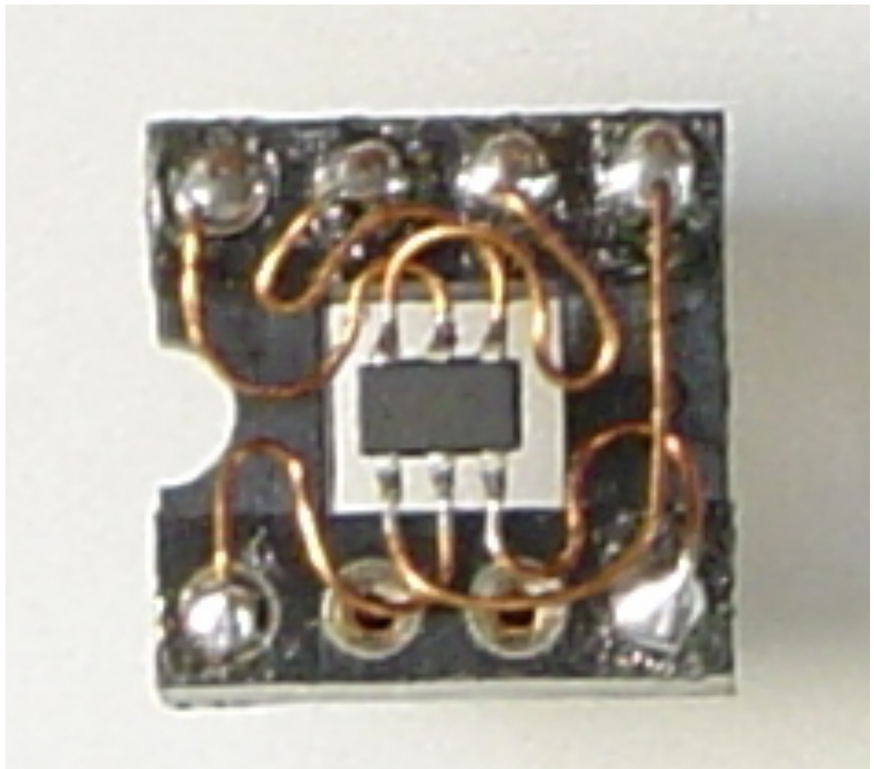
Real INA219



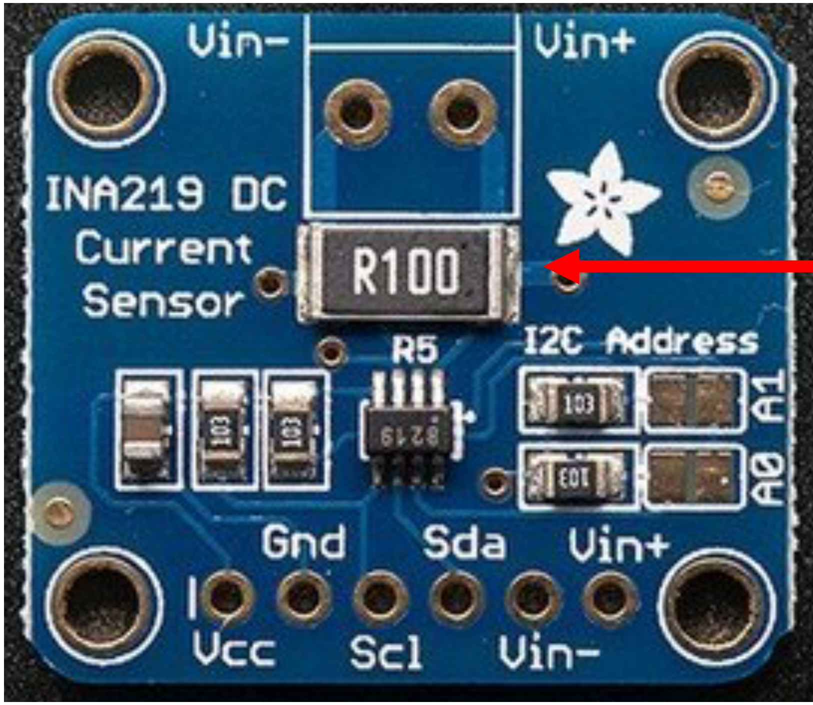
- This thing is tiny
- “big” pepper corn



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°C, V_S = 3.3 V, V_{IN+} = 12V, V_{SHUNT} = (V_{IN+} – V_{IN-}) = 32 mV, PGA = /1, and 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	PGA = /1	0		±40	0		±40	mV
		PGA = /2	0		±80	0		±80	mV
		PGA = /4	0		±160	0		±160	mV
		PGA = /8	0		±320	0		±320	mV
	Bus voltage (input voltage) range[2]	BRNG = 1	0		32	0		32	V
		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]	PGA = /1		±10	±100		±10	±50[4]	μV
		PGA = /2		±20	±125		±20	±75[4]	μV
		PGA = /4		±30	±150		±30	±75[4]	μV
		PGA = /8		±40	±200		±40	±100[4]	μV
	vs Temperature	T_A = –25°C to 85°C		0.1			0.1		μV/°C
PSRR	vs Power Supply	V_S = 3 to 5.5 V		10			10		μV/V
	Current sense gain error			±40			±40		m%
	vs Temperature	T_A = –25°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		μA || kΩ
	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			±0.2%	±0.5%		±0.2%	±0.3%[4]	
	over Temperature	T_A = –25°C to 85°C			±1%			±0.5%[4]	
	Bus voltage measurement error			±0.2%	±0.5%		±0.2%	±0.5%	
	over Temperature	T_A = –25°C to 85°C			±1%			±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!

Google

micropython ina219

All Maps Shopping Videos Images More Settings Tools

About 12,100 results (0.54 seconds)

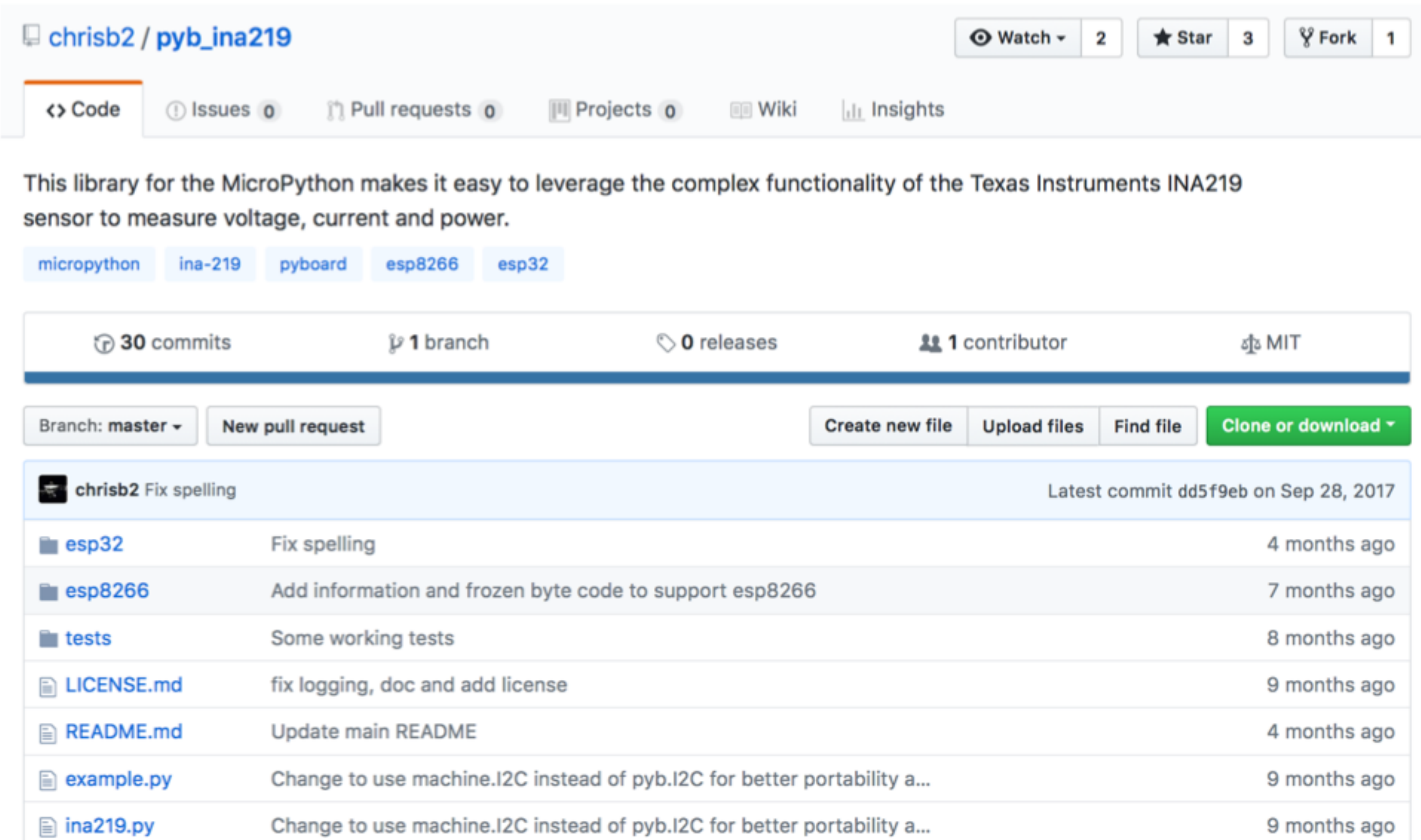
Micropython library for the TI INA219 voltage/current sensor ...
https://forum.micropython.org › ... › Drivers for External Components
May 16, 2017 - https://github.com/chrisb2/pyb_ina219. I have written this library based on one I wrote for the Raspberry Pi. It supports the **INA219** voltage, current 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



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)
```

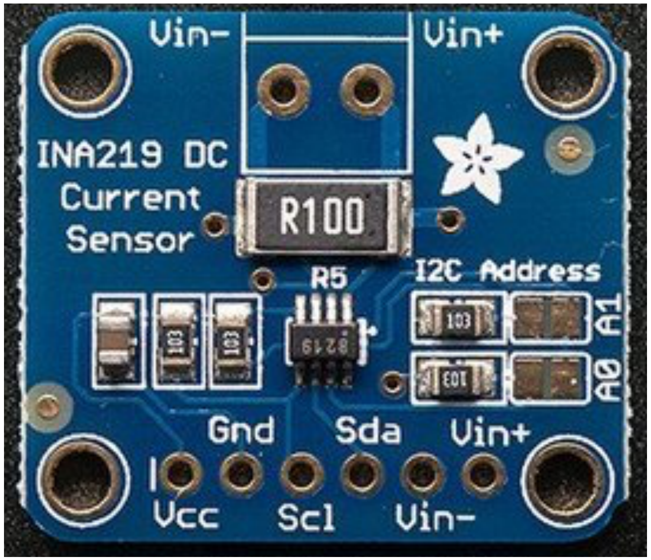
Circuit

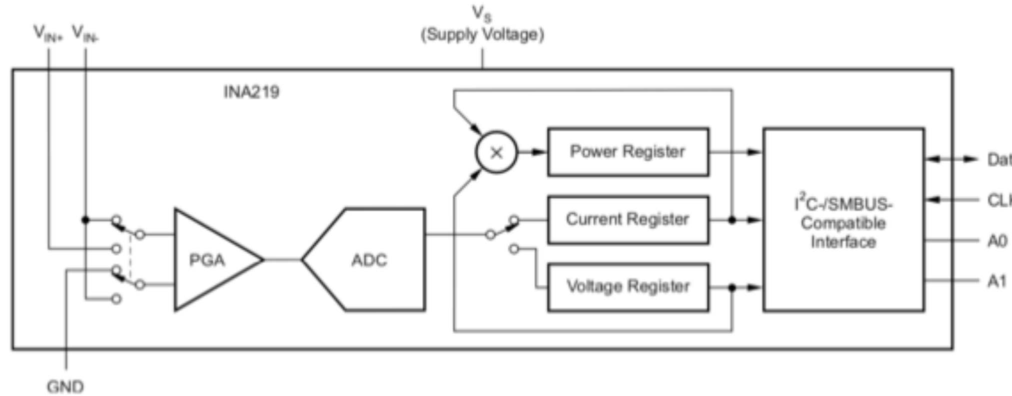
- Solar cell characterization
- Components:
  1.
  2.
  3.
  4.

Approach

- Symbols
- Circuit diagram
- Optional: wiring diagram

INA219 Symbol





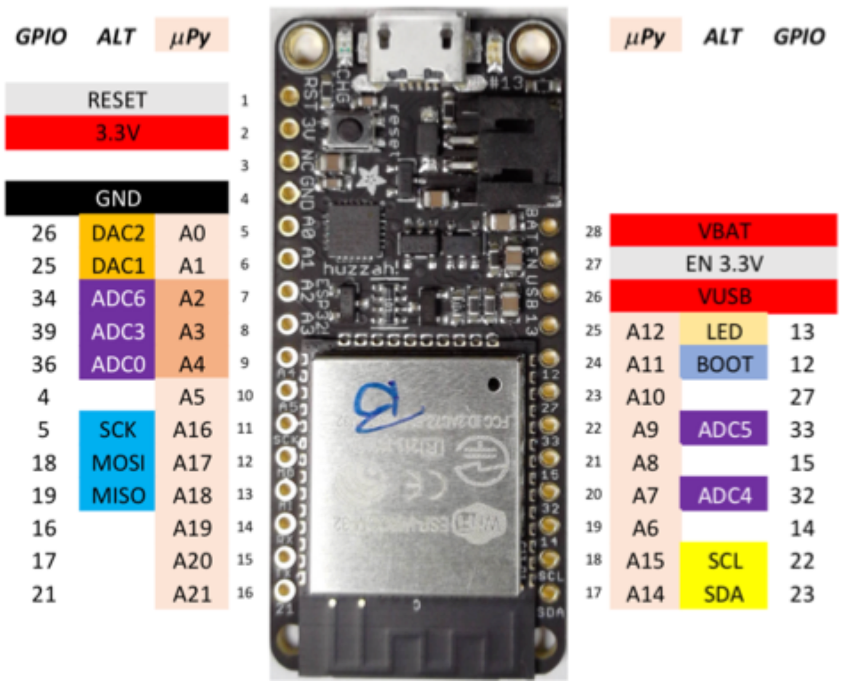
ESP32

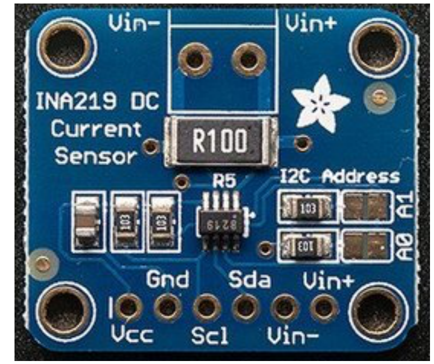
GPIO	ALT	μPy	
RESET			1
3.3V			2
			3
GND			4
26	DAC2	A0	5
25	DAC1	A1	6
34	ADC6	A2	7
39	ADC3	A3	8
36	ADC0	A4	9
4		A5	10
5	SCK	A16	11
18	MOSI	A17	12
19	MISO	A18	13
16		A19	14
17		A20	15
21		A21	16

	μPy	ALT	GPIO
28	VBAT		
27	EN 3.3V		
26	VUSB		
25	A12	LED	13
24	A11	BOOT	12
23	A10		27
22	A9	ADC5	33
21	A8		15
20	A7	ADC4	32
19	A6		14
18	A15	SCL	22
17	A14	SDA	23

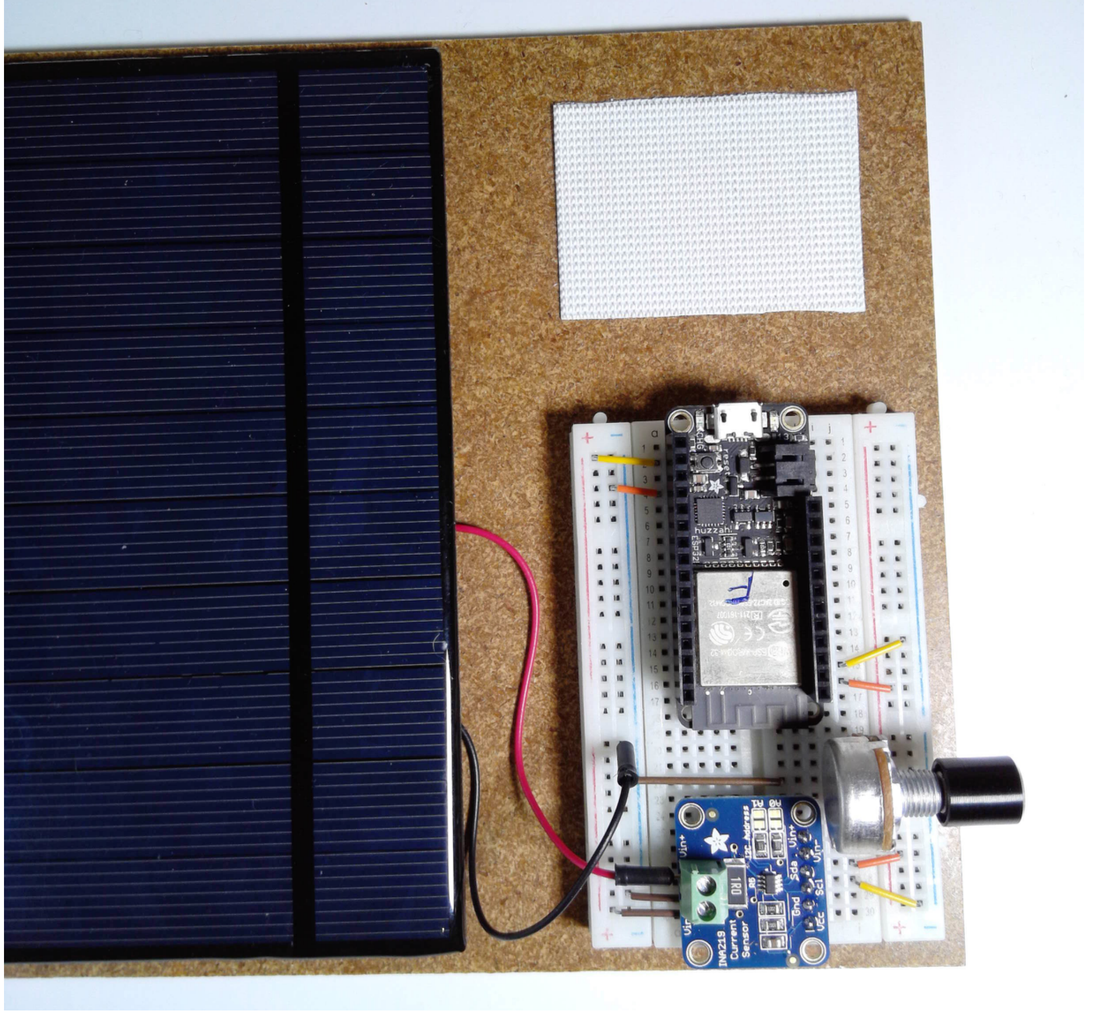
Circuit Diagram

Wiring Diagram





Complete Circuit



Testing

```
V =  5.13V, I =   1.97mA, P =   10mW, R = 2606.3Ohm
V =  5.16V, I =   2.10mA, P =   11mW, R = 2461.9Ohm
V =  5.18V, I =   2.60mA, P =   13mW, R = 1989.5Ohm
V =  5.14V, I =   3.54mA, P =   17mW, R = 1454.5Ohm
V =  5.11V, I =   5.16mA, P =   26mW, R =  990.1Ohm
V =  5.12V, I =   9.43mA, P =   49mW, R =  542.8Ohm
V =  5.13V, I =  13.40mA, P =   69mW, R =  382.7Ohm
V =  5.13V, I =  16.16mA, P =   82mW, R =  317.5Ohm
V =  5.08V, I =  19.63mA, P =   98mW, R =  258.7Ohm
V =  5.05V, I =  24.76mA, P =  126mW, R =  204.0Ohm
V =  5.07V, I =  31.23mA, P =  160mW, R =  162.2Ohm
V =  5.04V, I =  42.50mA, P =  216mW, R =  118.6Ohm
V =  4.38V, I = 110.48mA, P =  446mW, R =   39.6Ohm
V =  0.16V, I = 135.02mA, P =   19mW, R =    1.2Ohm
V =  0.23V, I = 140.01mA, P =   26mW, R =    1.6Ohm
V =  0.13V, I = 144.61mA, P =   15mW, R =    0.9Ohm
V =  0.12V, I = 149.01mA, P =   18mW, R =    0.8Ohm
```

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