Lecture 15

ESP32 and Arduino

Agenda

01. ESP32 Overview
02. Arduino Software
03. PicoKit ESP32 Hardware Caveats
04. Level Shifting 3.3V using MOSFETS

01

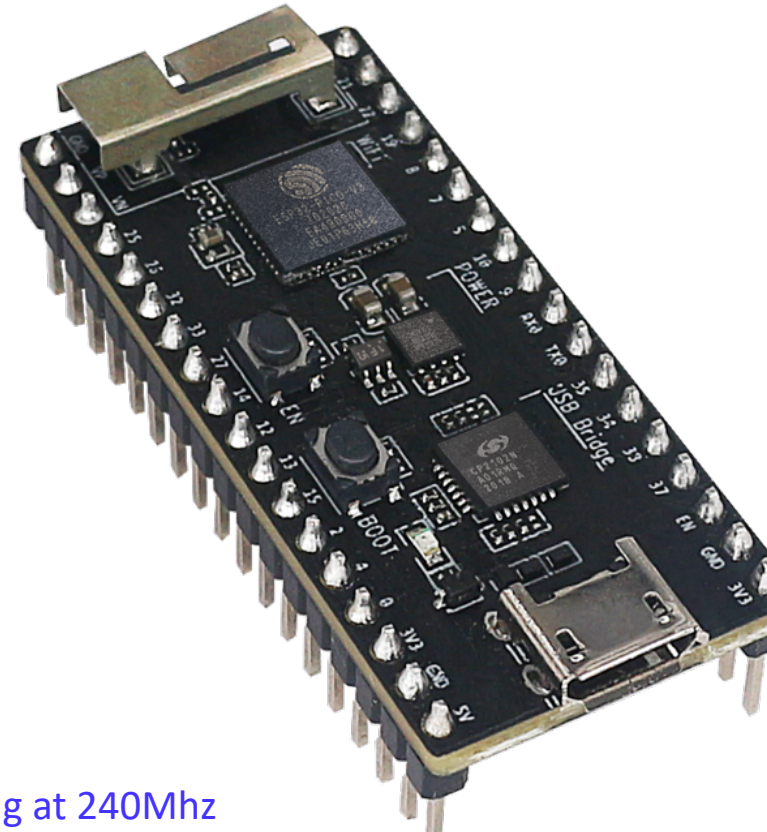
ESP32 Overview

Typical important functions on a microcontroller

- Computation (integer, FPU, single core, dual core)
- Memory (flash, RAM, EEPROM)
- Inputs (digital, analog)
- Outputs (digital, analog)
- Timers (input capture, output compare, PWM)
- Analog to Digital Converter (higher resolution, faster is better)
- Communication (USB, UART, SPI, I2C, wireless)

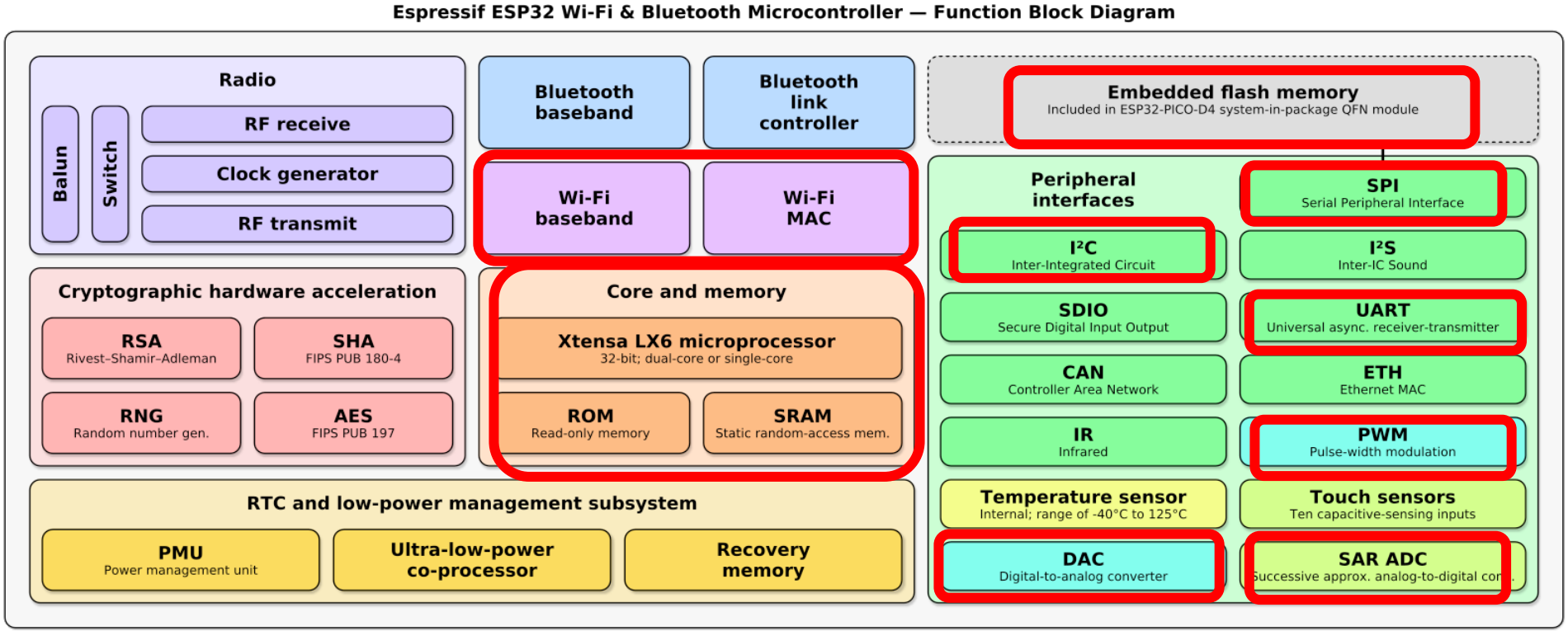
ESP32

- ESP32 *Wifi* Module plus Bluetooth
  - ~50 foot range
- Operating voltage = 3.3V
- USB interface
- 520 KiB SRAM, 4MB of flash memory
- 160 MHz clock speed (dual core)
- Floating point coprocessor

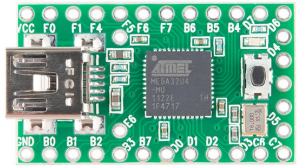


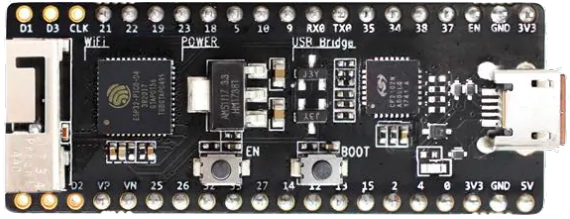
On ESP32 S2 no Bluetooth, no FPU, single core running at 240Mhz

ESP32 Block Diagram



ATmega 32U4 VS ESP32

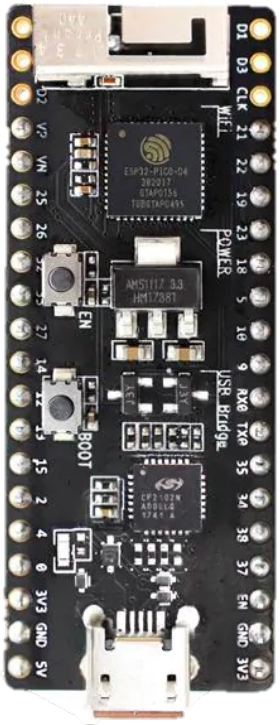




	ATMEGA 32U4	ESP32	ESP32 Difference
Processor Speed	16MHz, 8bit RISC	160Mhz, 32bit RISC	~20x faster comp
Memory	32k Flash; 2.5K RAM	4M Flash; 512K RAM	>100x's more
GP Input/Output	21 @ 5V	17 to 32 @ 3.3V	Similar
IO Current	20 mA (40 mA max)	10mA (20-40mA max)	Uncertain
ADC	12 channels 10-bit	16 channels 12-bit	33% More hi-res
Communication	SPI/UART/I2C	SPI/I2S/UART/I2C/BT/...	Much more
cost	$20	$10	half the price

ESP32 Board Variants

~$10
No controllable LED

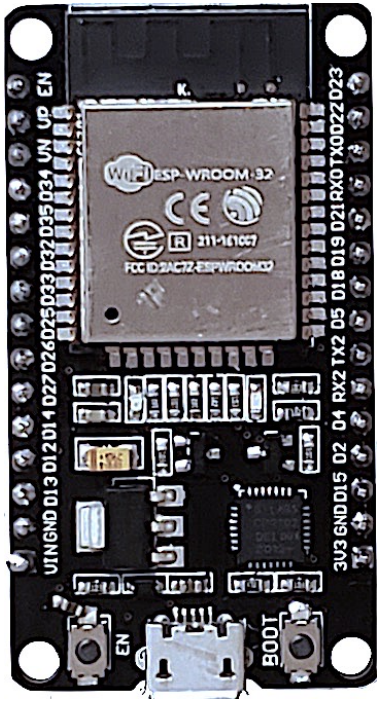


PicoKit

~$10
Pin labels underneath

HiLetGo
NodeMCU

Cheapest, @ ~$7
Too wide for protoboard
(only one side exposes pins)



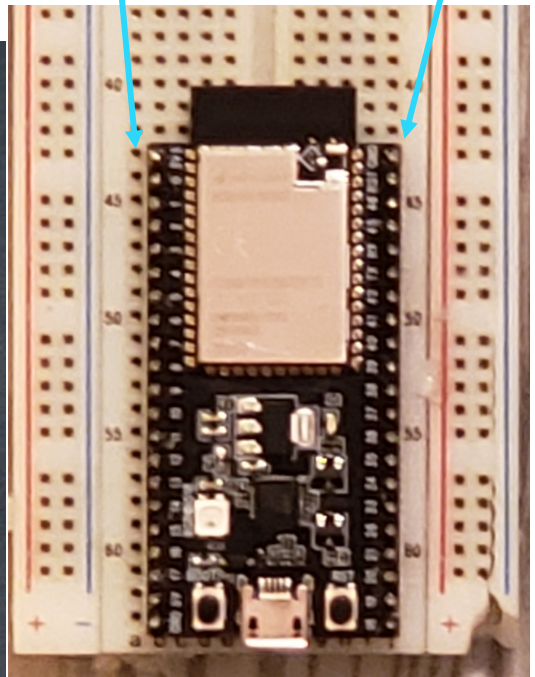
Dorhea
NodeMCU

Newer, better board $8
single core, no FPU, no BT

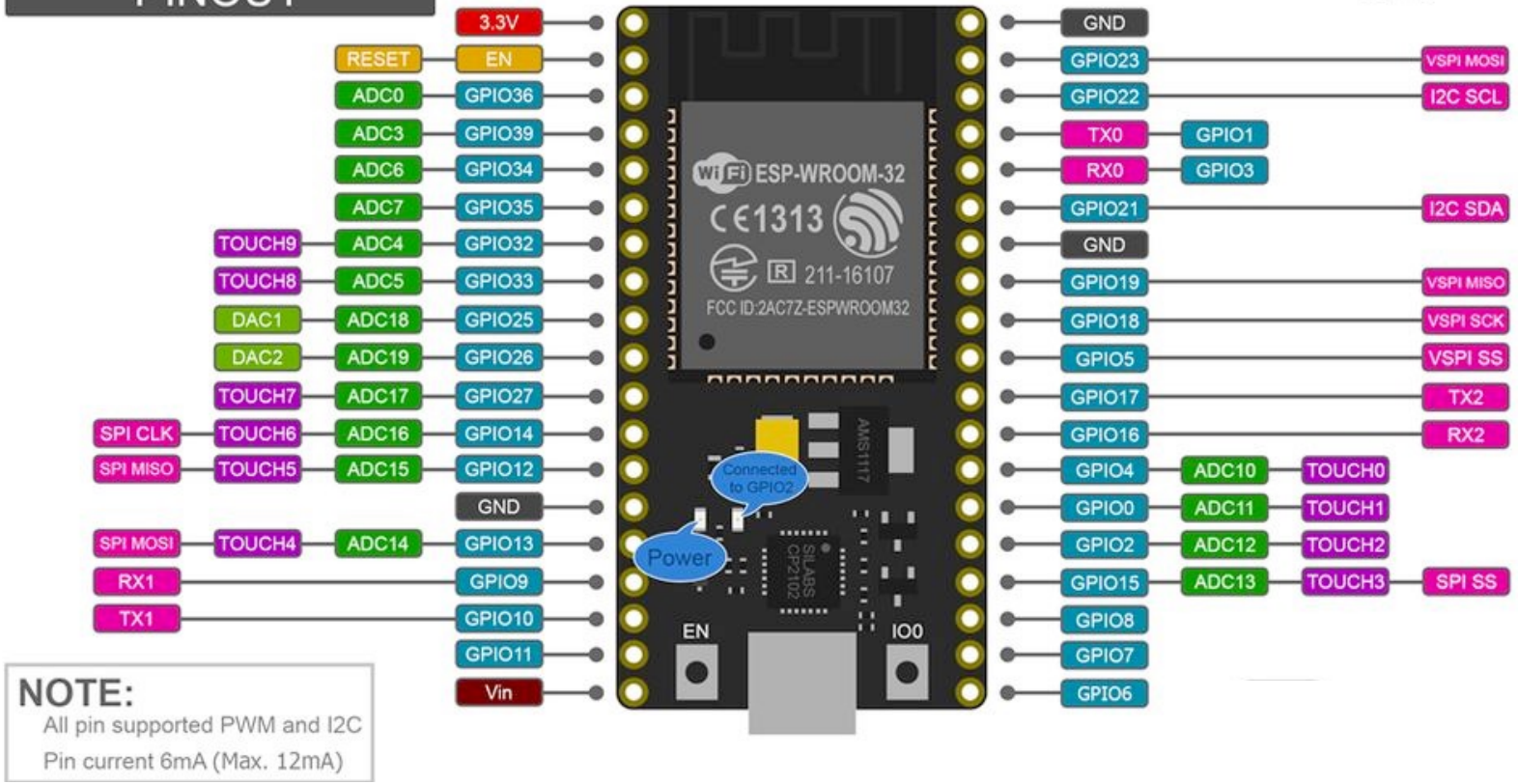
ESP32 S2
Saola 1R

ESP32 Board Problems

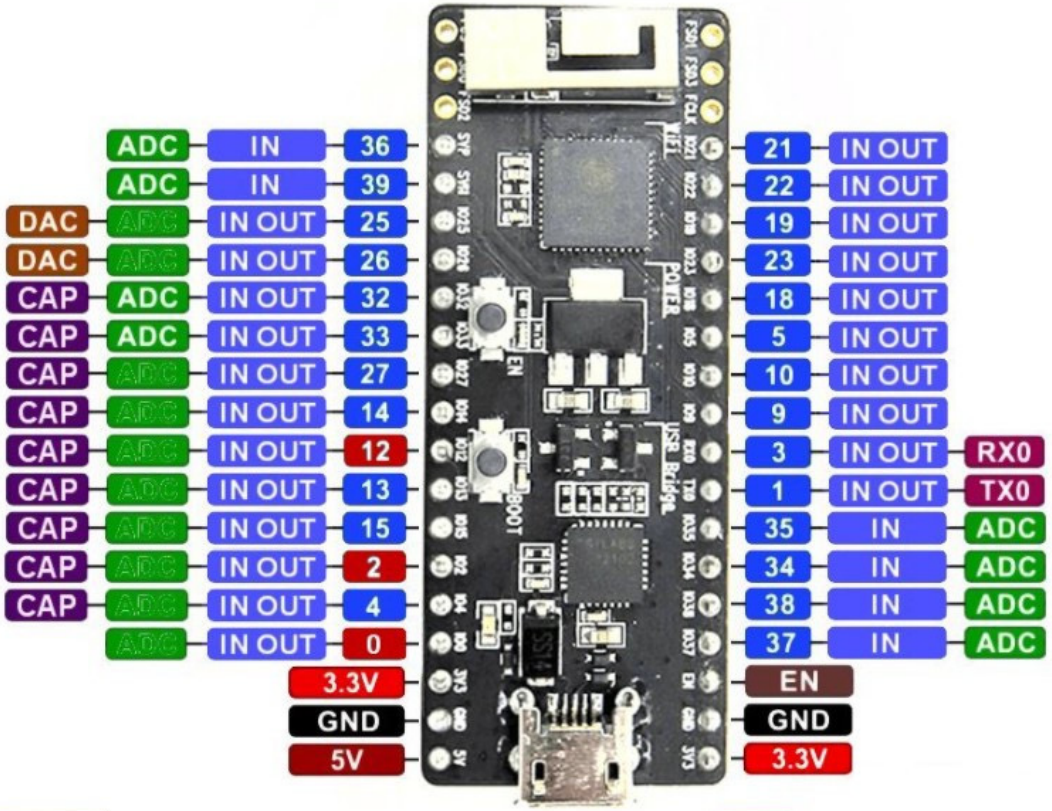
- HiLetGo Board labeling
- Boards too wide.



GPIO = General Purpose Input/Output
GND = ground or negative power line
VIN = positive power (5V typically)



Pico-kit v4
ESP32 Pinout



IN = Inputs only, and no pullups

IN OUT = DigIn / Counter / Period / Encoder
DigOut / Pwm / Servo

ADC = Adc when WiFi is not active

RX0 TX0 = Used by serial debugger

0 = Pin "0" must be high at startup and low while programming

2 = Pin "2" must be low while programming

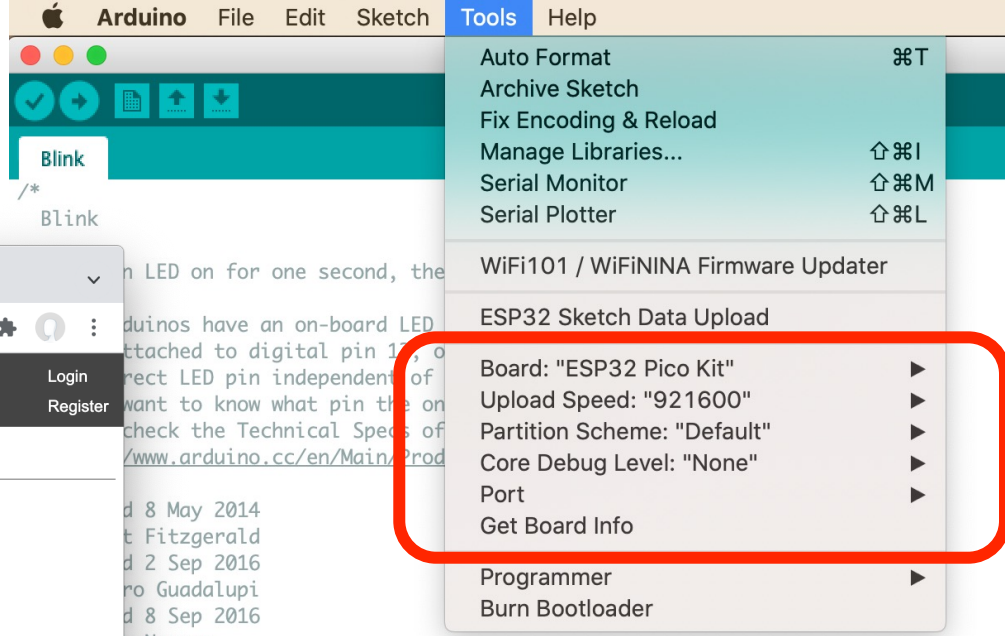
12 = Pin "12" must be low at startup and while programming

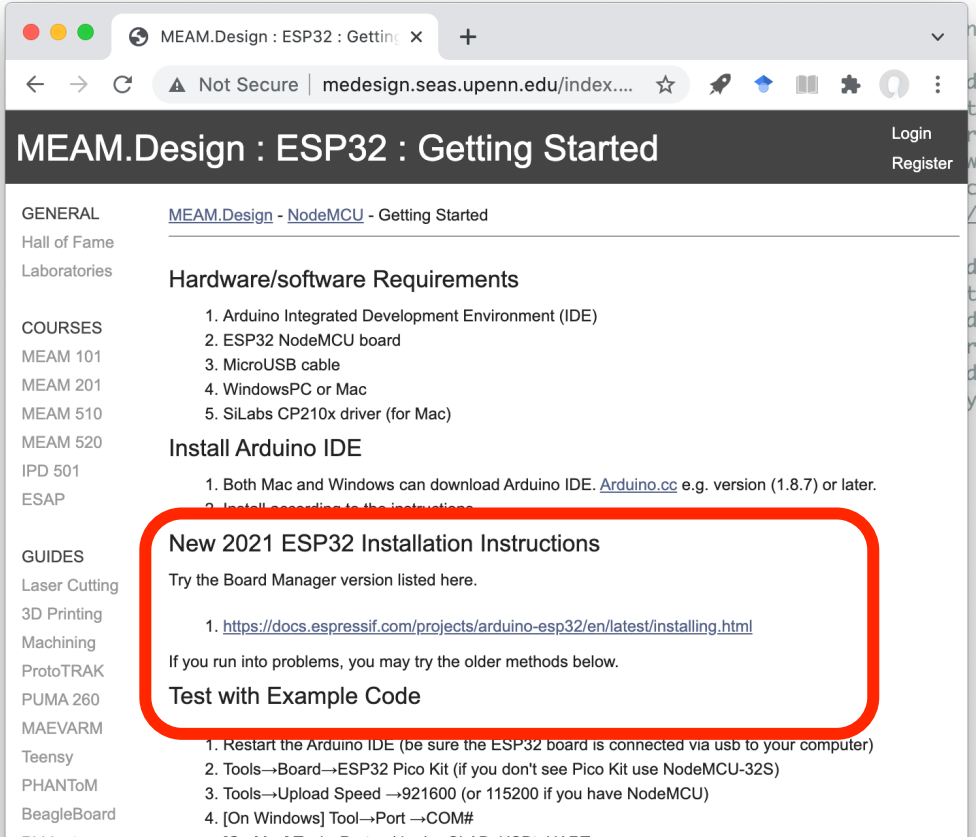
https://meanderingpi.com/connection-details/

02

Software - Arduino

Arduino Set-up





http://medesign.seas.upenn.edu/index.php/Guides/ESP32-gettingstarted

Arduino Code Breakdown

Every Arduino "Sketch" (essentially c++ program):

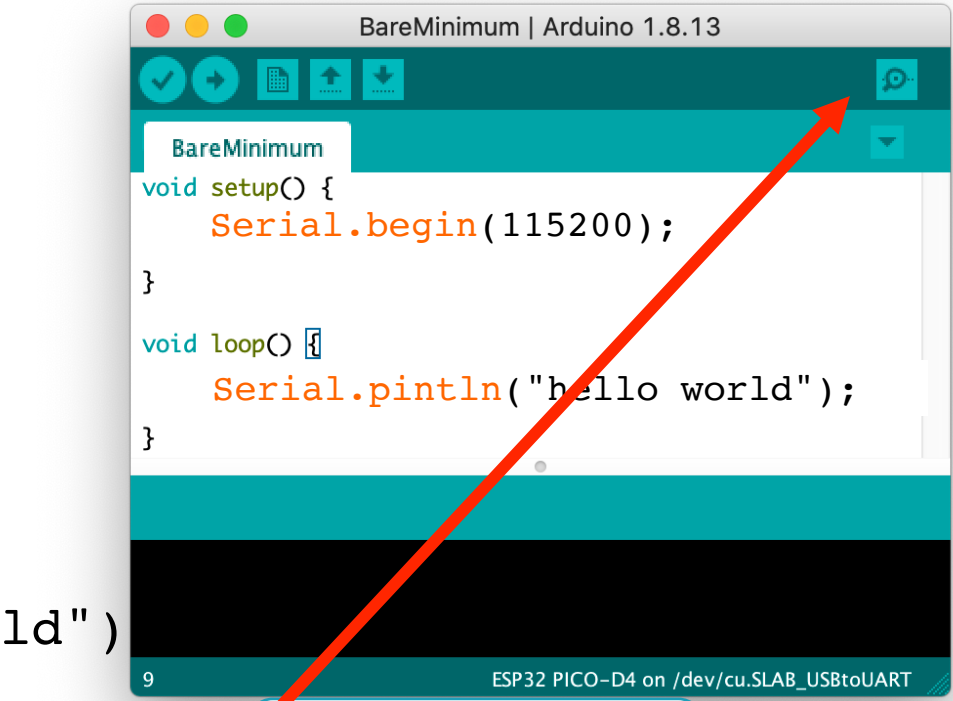
`setup()` runs once [first]

`loop()` repeats over and over.

```
void setup() {
    // put your setup code here, to run once:
    // These are comments "//"
}

void loop() {
    // put your main code here, to run repeatedly:
}
```

"Hello World" in Arduino

1. Open:
<Files-> Examples -> 01.Basic -> BareMinimum>
2. Add the lines:
`Serial.begin(115200);`
in `setup()` section.
`Serial.println("hello world")`
in `loop()` section.
3. Click (✓) <Verify> to compile
4. Click (➔) <Upload> to Flash code to Arduino.
5. Click (magnifying glass) <serial monitor> (upper rt corner)



Restoring OscilloSorta to ESP32

- Same steps except find:
  - Oscillosorta folder in canvas -> files -> resources
- Copy whole folder (all files inside) to your Arduino directory
- Double click *OscilloSorta1_3.ino*
- Arduino requires .ino file to be inside a folder of the same name
- Click (➔) <Upload> to Flash code to Arduino.

Q1. In public chat: list 5 functions we use with Teensy pins

Command Summary

Teensy	ESP32 Arduino
set/clear (DDRx, pin#)	• pinMode(pin#, INPUT/OUTPUT)
set/clear (PORTx, pin#)	• digitalWrite(pin#, HIGH/LOW)
bit_is_clear/set(PINx,pin#)	• digitalRead(pin#)
ADC routines…	• analogRead(pin#)
Timer routines…	• ~~analogWrite(pin#, value/255)~~ Not on ESP32
	• ledc routines… (will cover later)
	• dacWrite(pin#)
m_usb_init()	• Serial.begin(baudrate)
m_usb_tx_string(X)	• Serial.println("text")
_delay_ms()	• delay(ms)

Arduino Blink Sketch (like Lab 1)

LED_BUILTIN doesn't exist on pico

```
void setup() {
  pinMode(LED_BUILTIN, OUTPUT); // Initialize the LED_BUILTIN pin as an output
}


// the loop function runs over and over again forever
void loop() {
  digitalWrite(LED_BUILTIN, LOW);   // Turn the LED on
  delay(1000);                      // Wait for a second
  digitalWrite(LED_BUILTIN, HIGH);  // Turn the LED off
  delay(2000);                      // Wait for two secs
}
```

Functions: in Blink

`pinMode(pin,OUTPUT);`

- Tells the micro that `pin` is an output pin (sets data direction register).
- Modes can be INPUT, OUTPUT, INPUT_PULLUP, INPUT_PULLDOWN

Available on ESP32, not most other MCUs

`digitalWrite(pin,HIGH);`

- Sets the state of digital pin # `pin` to HIGH (3.3V), LOW=0V,
- `pin` is the GPIO number, can be 0, 1, 2… 39 for ESP32
- Similar to `set(PORT,PIN);` and `clear(PORT,PIN);`

`delay(1000);`

- Delays further execution of code for 1000 milliseconds. (Busy waits)

Digital Input/Output States

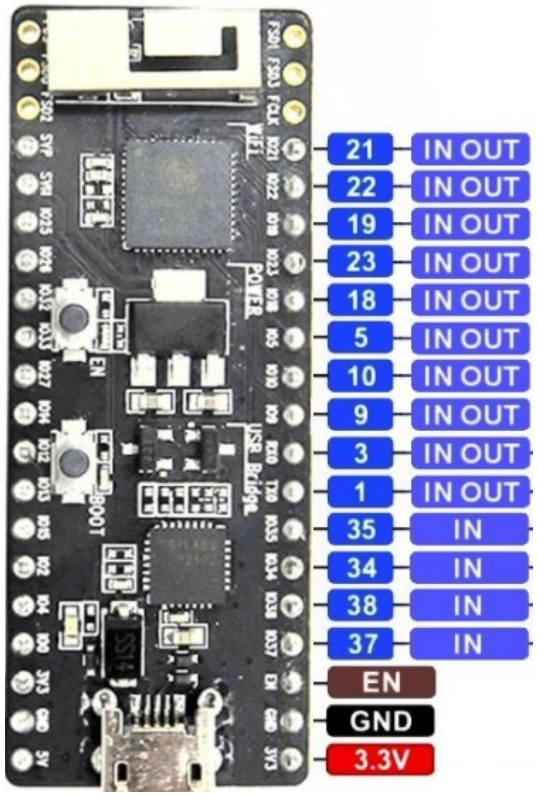
Three possible internal states:

1. HIGH
2. LOW
3. Tri-state (high-impedance)

ESP32 only

PINMODE	Internal	External	Result
OUTPUT	High	High	High
OUTPUT	High	Low	Contention
OUTPUT	High	Float	High
OUTPUT	Low	High	Contention
OUTPUT	Low	Low	Low
OUTPUT	Low	Float	Low
INPUT	Float	High	High
INPUT	Float	Low	Low
INPUT	Float	Float	unknown
INPUT_PULLUP	Float	High	High
INPUT_PULLUP	Float	Low	Low
INPUT_PULLUP	Float	Float	High
INPUT_PULLDOWN	Float	High	High
INPUT_PULLDOWN	Float	Low	Low
INPUT_PULLDOWN	Float	Float	Low

How do we know what to call a pin?



In Arduino/hardware/espressif/esp32/variants/pico32/ pins_arduino.h

```
#ifndef Pins_Arduino_h
#define Pins_Arduino_h

#include <stdint.h>

#define EXTERNAL_NUM_INTERRUPTS 16
#define NUM_DIGITAL_PINS        40
#define NUM_ANALOG_INPUTS       16

#define analogInputToDigitalPin(p)  (((p)<20)?(esp32_adc2
#define digitalPinToInterrupt(p)    (((p)<40)?(p):-1)
#define digitalPinHasPWM(p)         (p < 34)

static const uint8_t TX = 1;
static const uint8_t RX = 3;

static const uint8_t SDA = 21;
static const uint8_t SCL = 22;
```

Other Functions

`digitalRead(pin);`

- Returns the state of digital pin # `pin` as HIGH or LOW,
- `pin` can be 0, 1, 2 ... 39

`delayMicroseconds(x);`

- Delays further execution of code for `x` microseconds.

`Serial.begin(115200);`

- Needed for serial comms.
- 115200 is the baudrate. 9600 is another standard rate.

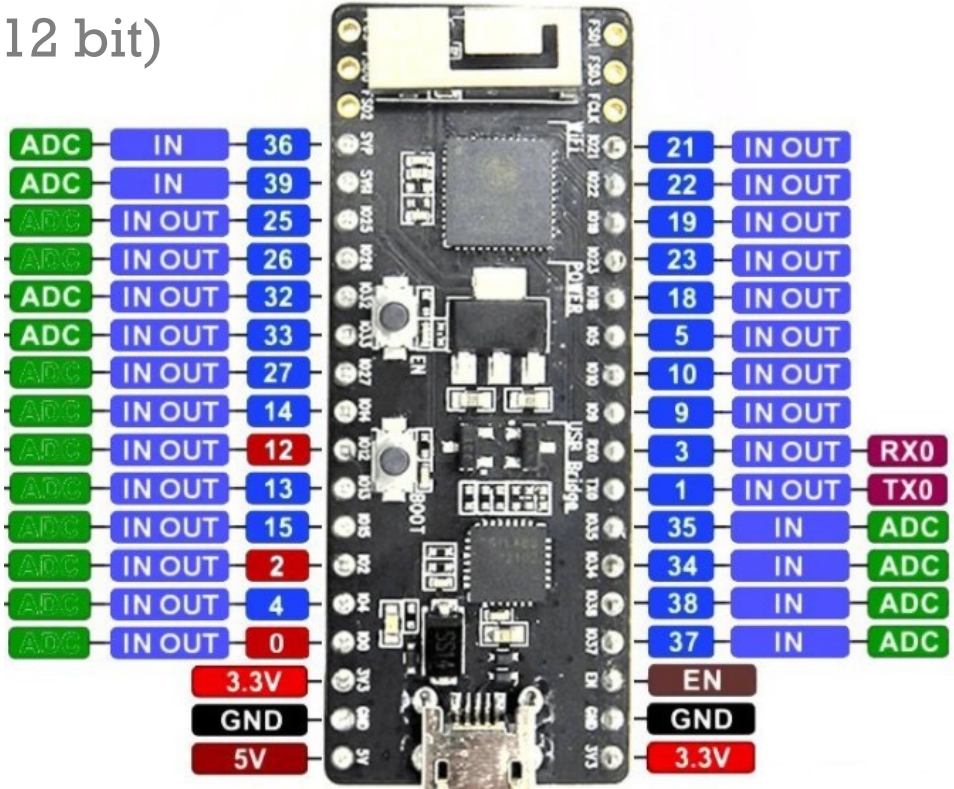
`Serial.println(x);` `Serial.print("string");`

- `println()` with carriage return, `print()` without carriage return.

analogRead(pin)

- Reads the ESP32 ADC (one of 16 channels) associated with pin.
- Returns an integer from 0 – 4095 (12 bit)

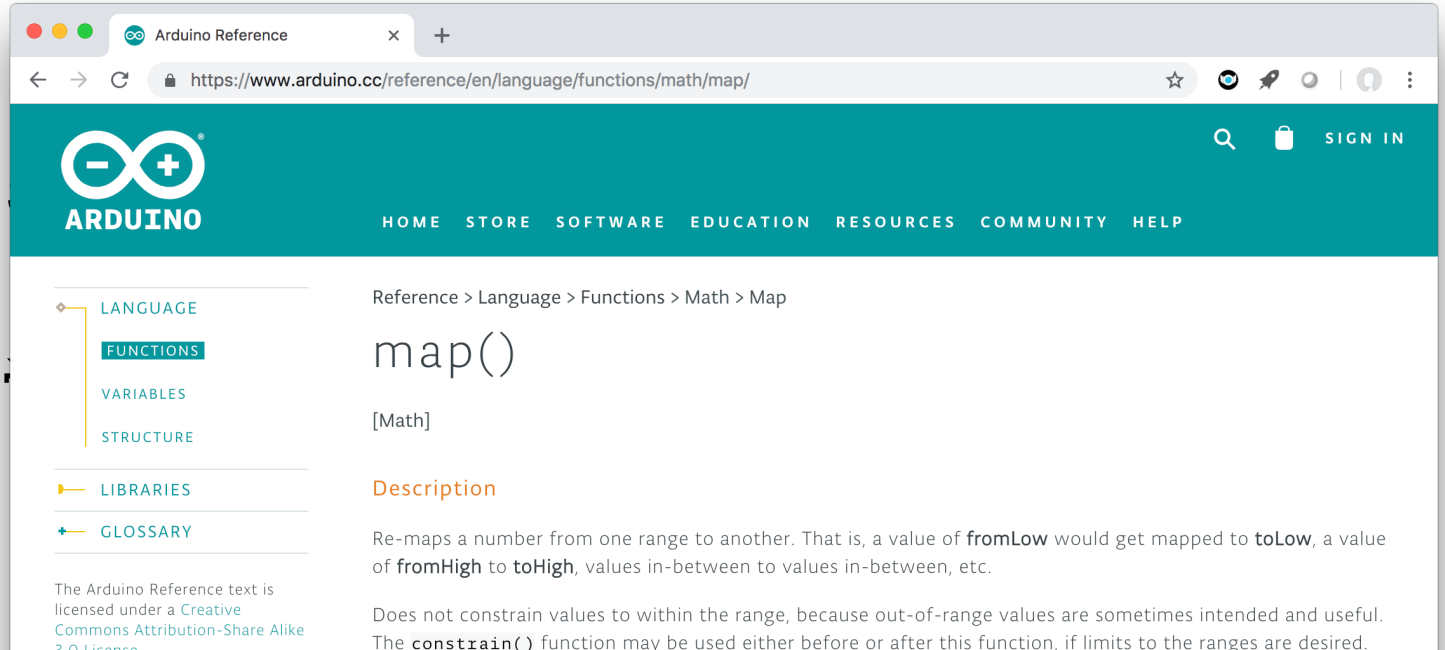
```
void setup() {
  Serial.begin(115200);
}

void loop() {
  Serial.println(analogRead(A0));
  delay(200);
}
```



analogRead(), map(value,inL,inH,outL,outH)

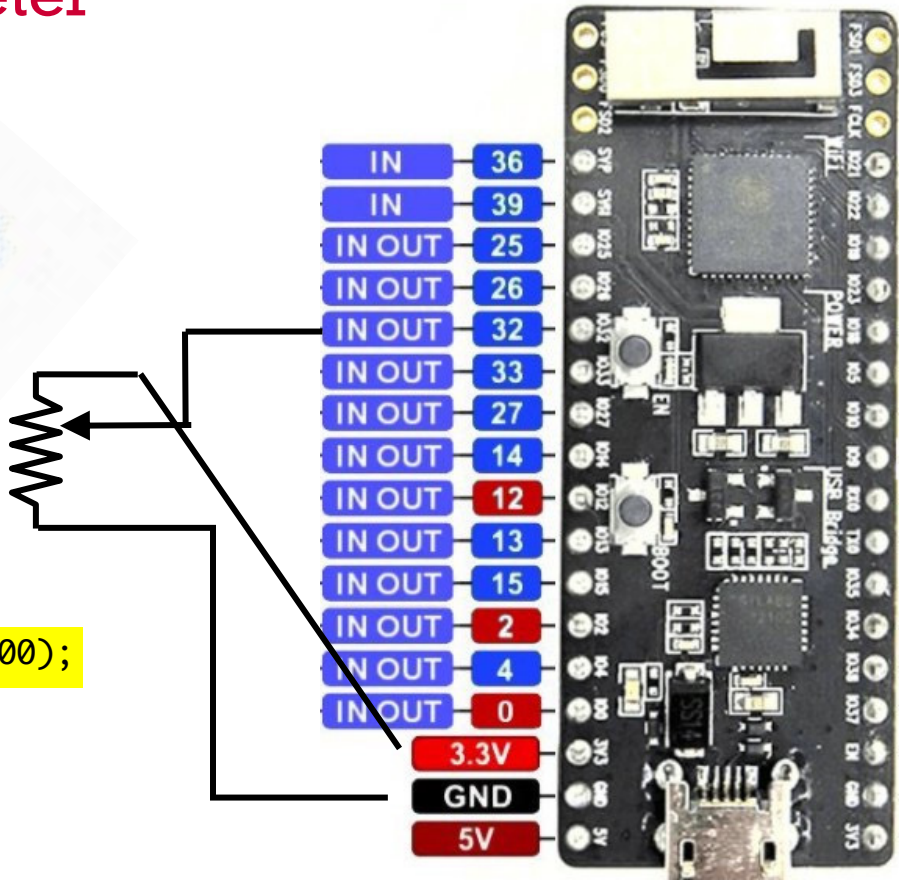
- Can use arduino `map()` to convert linear units. E.g. from ADC counts (0-4095) to millivolts (0-3300).

https://www.arduino.cc/reference/en/language/functions/math/map/



Example reading a potentiometer

```
#define ANALOG_PIN A4 //pin 32
void setup() {
  Serial.begin(115200);
}

void loop() {
    int mv;
    mv = map(analogRead(ANALOG_PIN),0,4095,0,3300);
    Serial.println (mv);
       // prints 0-4095 <-> 0 – 3300mV
    delay(500);
}
```



Q2 Circle what we would change to make the code read ADC channel A4 and print value in Volts (not mv)

```
long map(long x, long in_min, long in_max, long out_min, long out_max)
{
  return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}
```

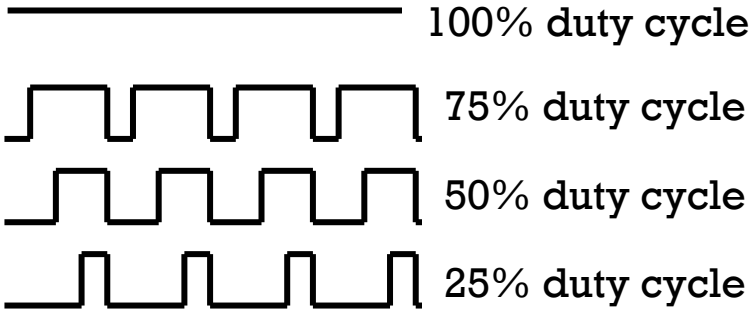
```
void setup() {
  Serial.begin(115200);
}
void loop() {
    int mv;
    mv = map(analogRead(A4),0,4095,0,3300); // map 0-4095 <-> 0 – 3300mV
    Serial.println (mv);
    delay(500);
}
```

Q3 What would we write in this line to print Volts?

`analogWrite()` (actually pseudo "analog")

- In Arduino analogWrite is Actually a modulated wave whose pulse width varies to set the effective voltage (PWM).

```
analogWrite(PIN1, 255);
analogWrite(PIN1, 192);
analogWrite(PIN1, 128);
analogWrite(PIN1, 64);
```



- A real analog write would use a digital to analog converter. It would output smooth voltage, not a modulated wave form.

- NOTE: This Arduino library function `analogWrite` is not yet available for ESP32!

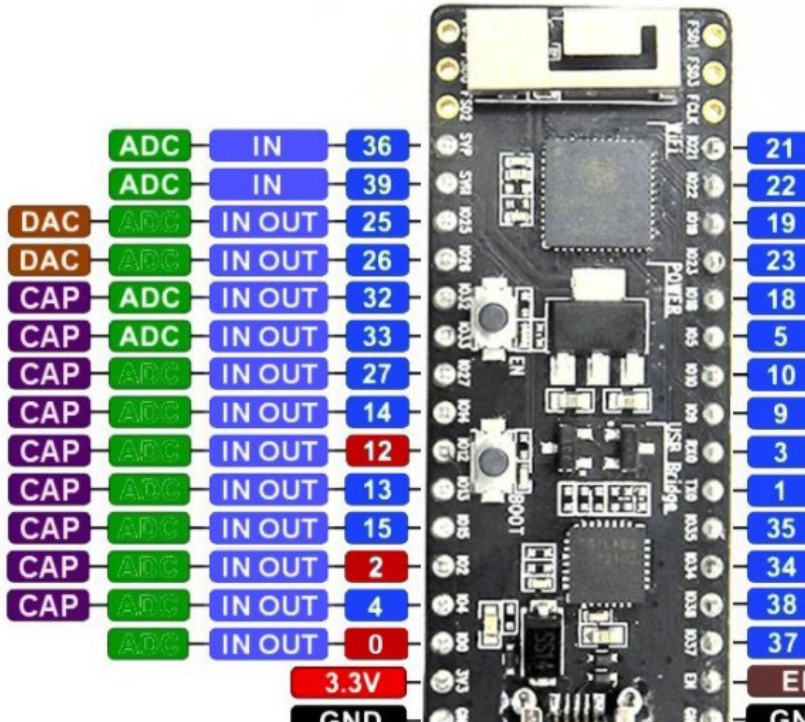
dacWrite() (a real "analog" Write)

- **ESP32 has two Digital to Analog converters (GPIO 25 or 26)**

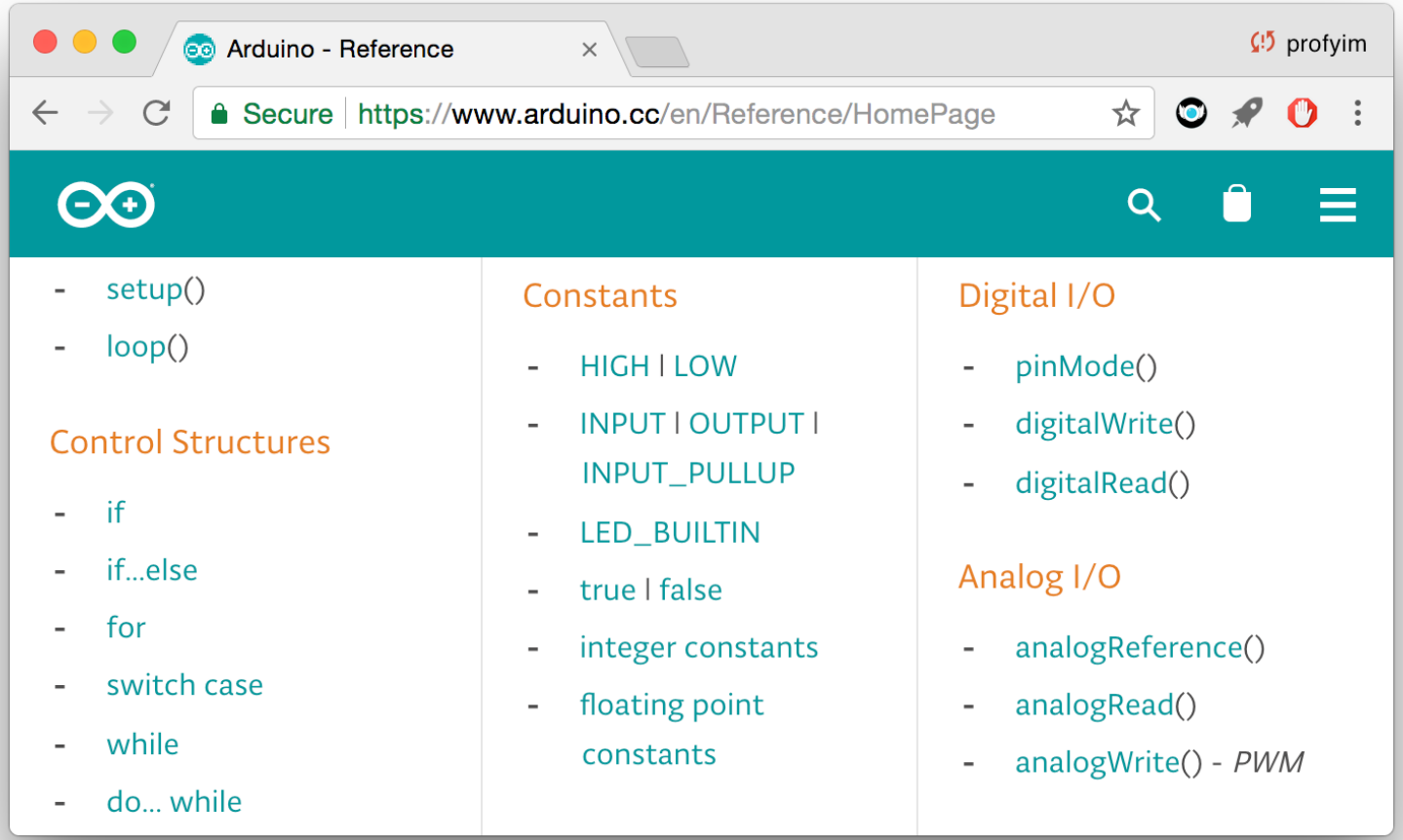
```
dacWrite(GPIOpin#, [0:255]); // 0 = 0V, 255=3.3V
```

```
void setup() {
  Serial.begin (115200);
}

void loop() {
   int i;
   for( i=0;i<256;i++)) {
      dacWrite(25,i);
      Serial.println(i);
      delay(100);
   }
}
```

Ex: this one



References online (www.arduino.cc)



Many resources

http://medesign.seas.upenn.edu/index.php/Guides/ESP32-pins
http://www.esp32.com/

Arduino File Edit Sketch Tools Help

New ⌘N
Open... ⌘O
Open Recent ▶
Sketchbook ▶
Examples ▶
Close ⌘W
Save ⌘S
Save As... ⇧⌘S
Page Setup ⇧⌘P
Print ⌘P

Built-in Examples
01.Basics ▶
02.Digital ▶
03.Analog ▶
04.Communication ▶
05.Control ▶
06.Sensors ▶
07.Display ▶
08.Strings ▶
09.USB
10.StarterKit_BasicKit
11.ArduinoISP

Examples for any board
Adafruit Circuit Playgrou
Bridge
Ethernet
Firmata
LiquidCrystal
SD
Stepper
Temboo
RETIRED

Examples for NodeMCU
ArduinoOTA
BluetoothSerial
DNSServer
EEPROM
ESP32
ESP32 BLE Arduino
ESPmDNS

Blink | A

Blink

```
/*
  Blink

  Turns an LED on for one second,

  Most Arduinos have an on-board
  it is attached to digital pin 1
  the correct LED pin independent
  If you want to know what pin th
  model, check the Technical Spec
  https://www.arduino.cc/en/Main/

  modified 8 May 2014
  by Scott Fitzgerald
  modified 2 Sep 2016
  by Arturo Guadalupi
  modified 8 Sep 2016
  by Colby Newman
```

MEAM.Design : ESP32 : Board

Not Secure | medesign.seas.upenn.edu/index.php/Guides/ESP32-pins

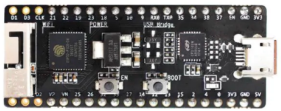
COURSES
MEAM 101
MEAM 201
MEAM 510
MEAM 520
IPD 501
ESAP

GUIDES
Laser Cutting
3D Printing
Machining
ProtoTRAK
PUMA 260
MAEVARM
Teensy
PHANToM
BeagleBoard
Phidget

ESP32 Pico Kit

Top Side Pins of Pico Kit

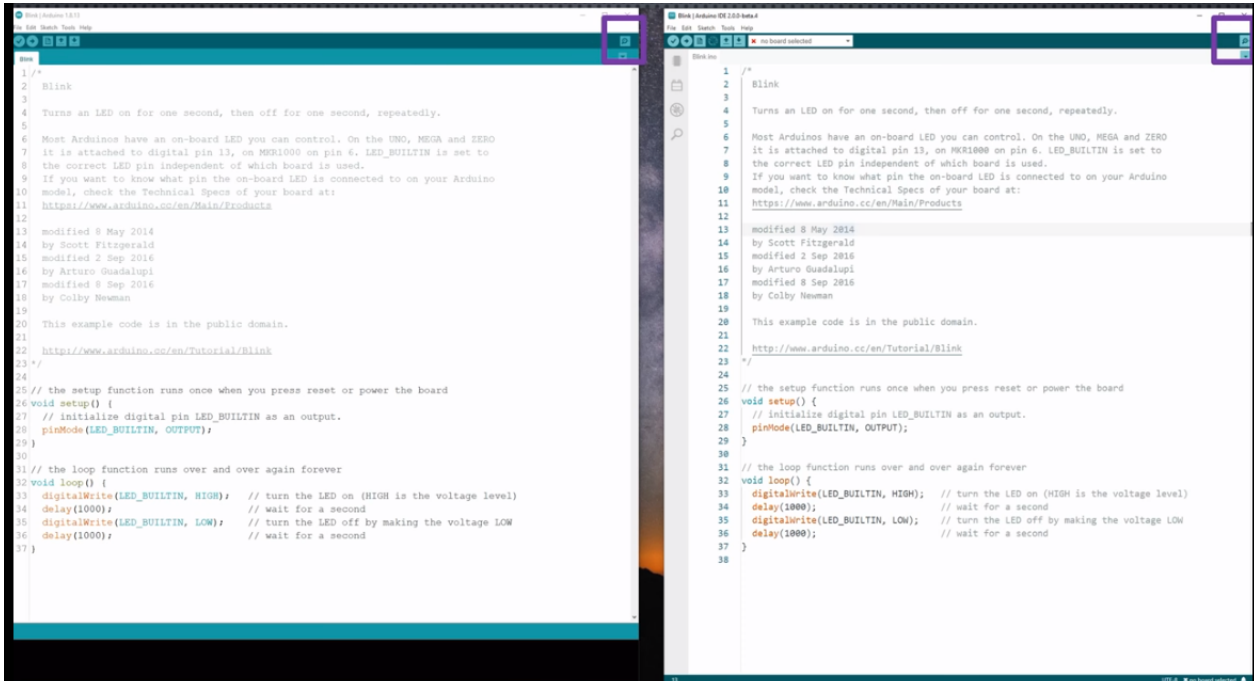
D1	Internal Flash, Don't use
D3	Internal Flash, Don't use
CLK	Internal Flash, Don't use
21 / VSPI HD	
22 / VSPI WP	
19 / VSPI Q	
23 / VSPI D	
18 / VSPI CLK	
5 / VSPI CS0	Boot strap pin, must be high on boot
10 / TXD1	
9 / RXD1	
RX0 / GPIO3	used for USB Serial.



Arduino 2.0 Beta

https://www.arduino.cc/en/Tutorial/getting-started-with-ide-v2/ide-v2-downloading-and-installing

- Very similar
- Adds Code completion
- Adds debugging, but not ready.
- Better board support
- No ESP32 support
- Not likely to be ready before end of semester.



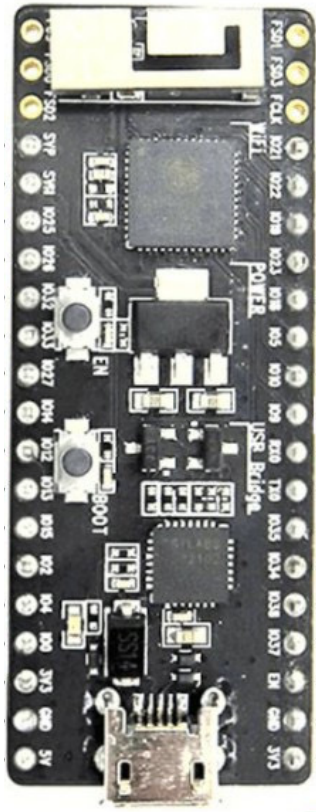
Andreas Spiess
https://www.youtube.com/watch?v=nlI_5vxm3bk

03

ESP32 PicoKit Hardware Caveats

General Purpose Input/Output (GPIO)

- 29 pins labeled as GPIO (only 20 are safe to use, see next slides for explanation)
- 14 GPIO pins can be input or output
- All use 3.3V
  - HIGH = 3.3V
  - LOW = 0V
- Internal pullup or pulldown
- RED LED turns on if powered.



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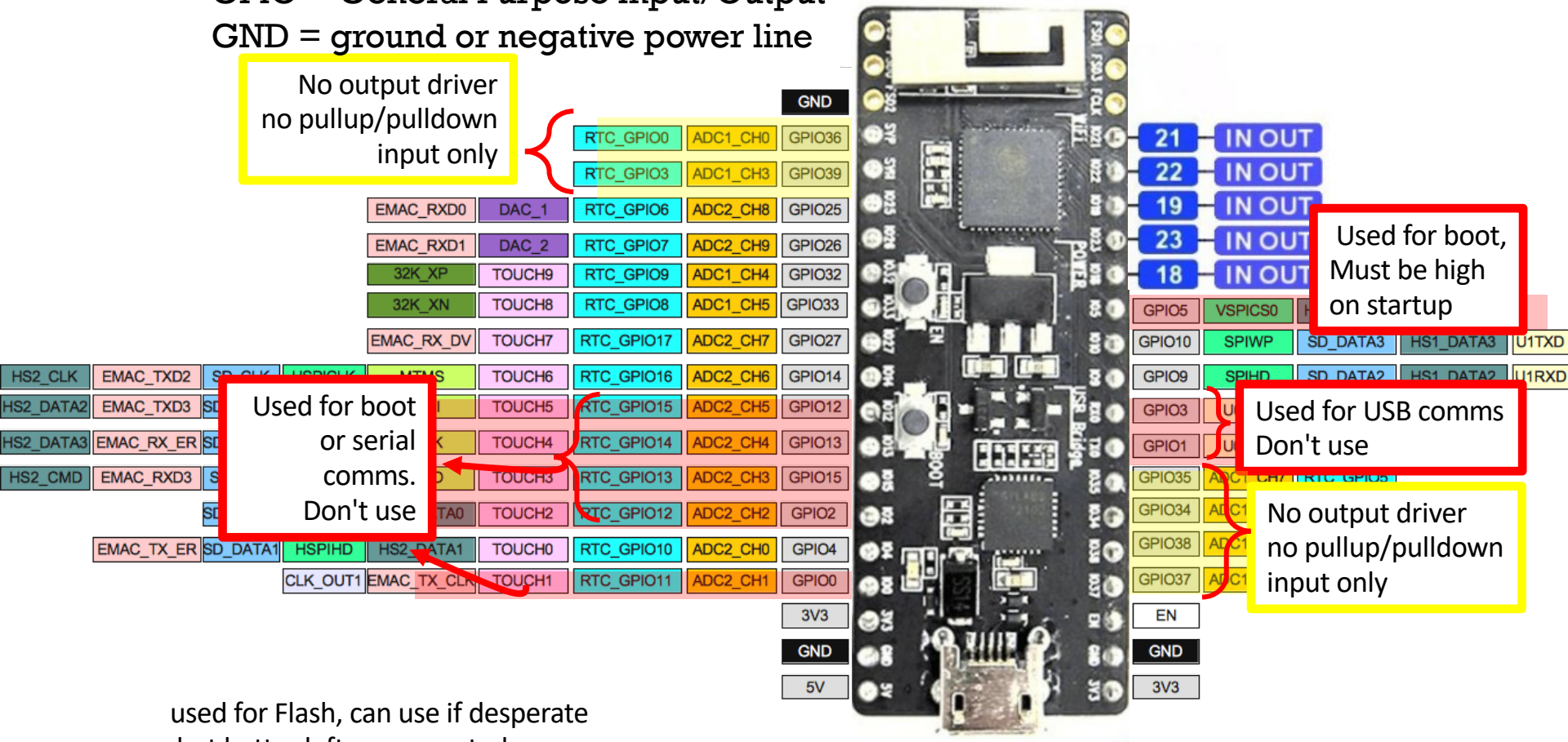
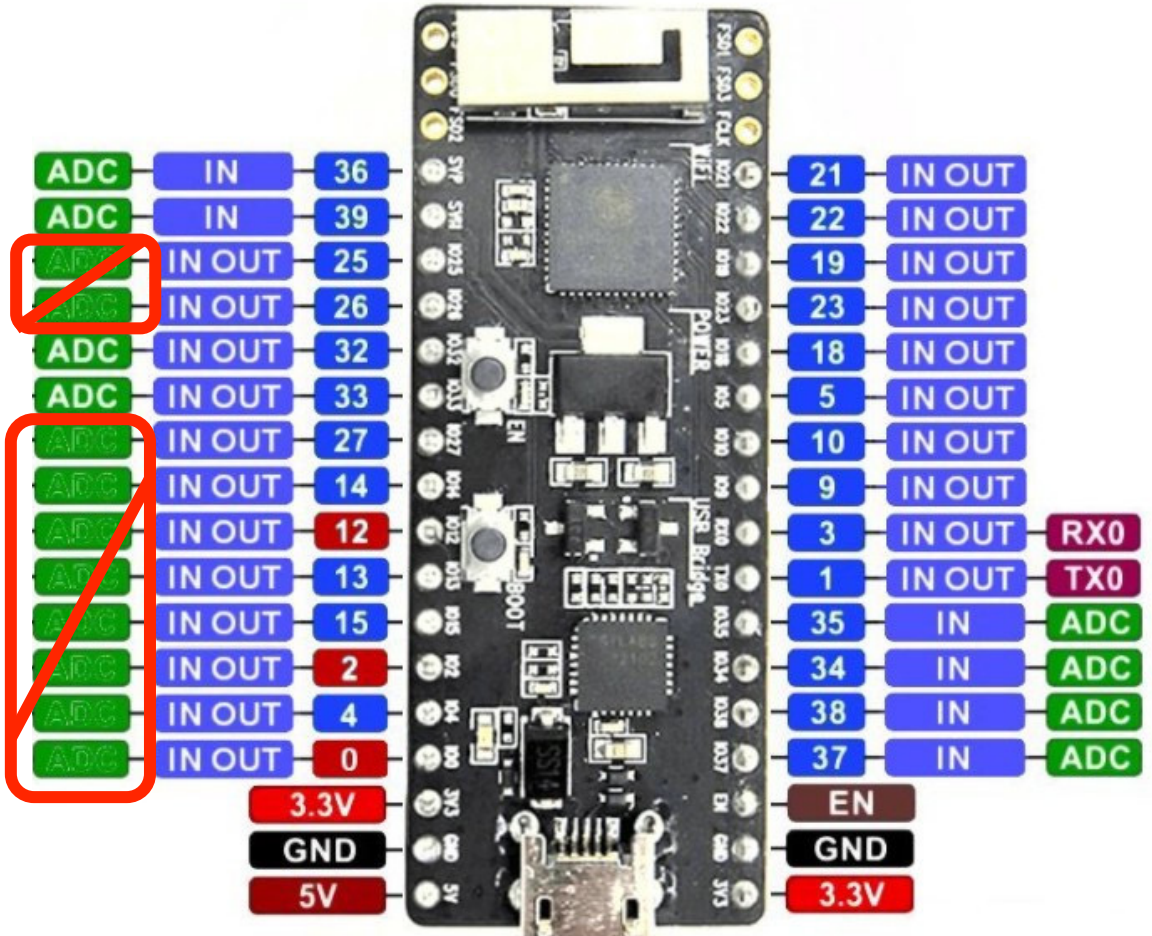
GND = ground or negative power line



More ESP Issues – WiFi conflicts with some ADC

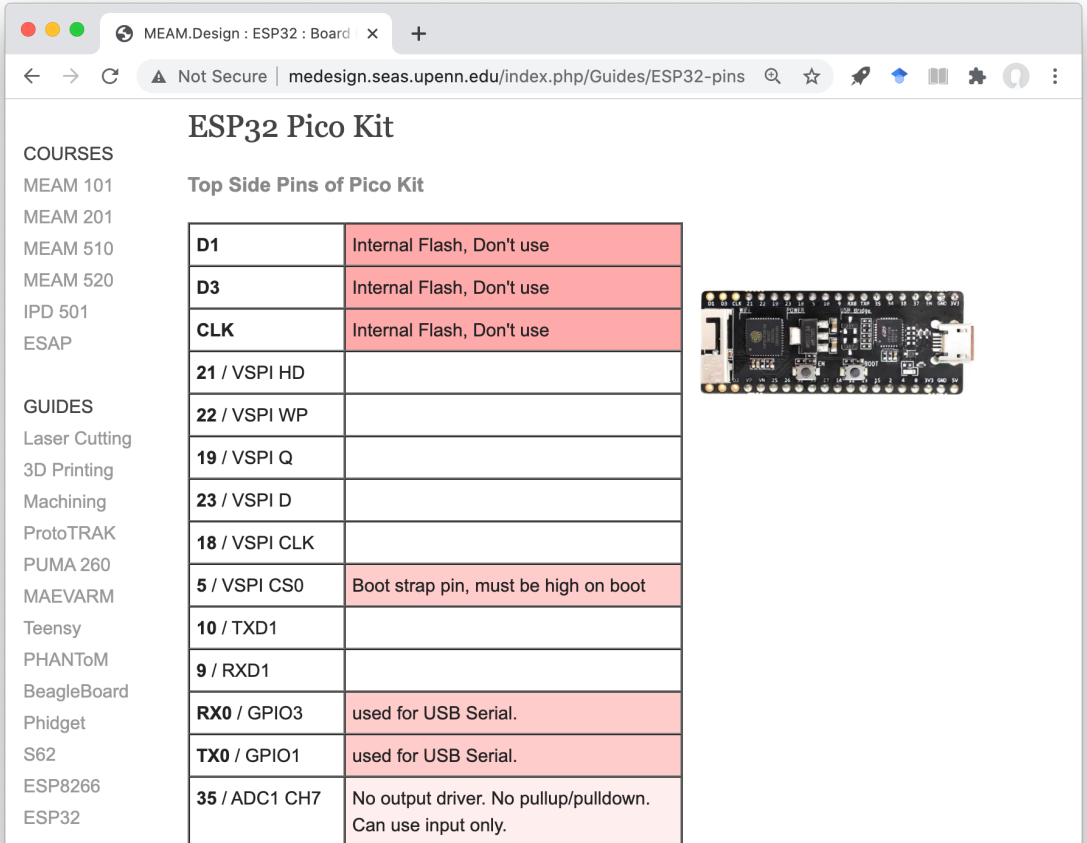
- On PicoKit 18 ADC pins are available.
- 10 of them (ADC#>9) do not work when WiFi is on.



Refer to medesign website for summary of caveats

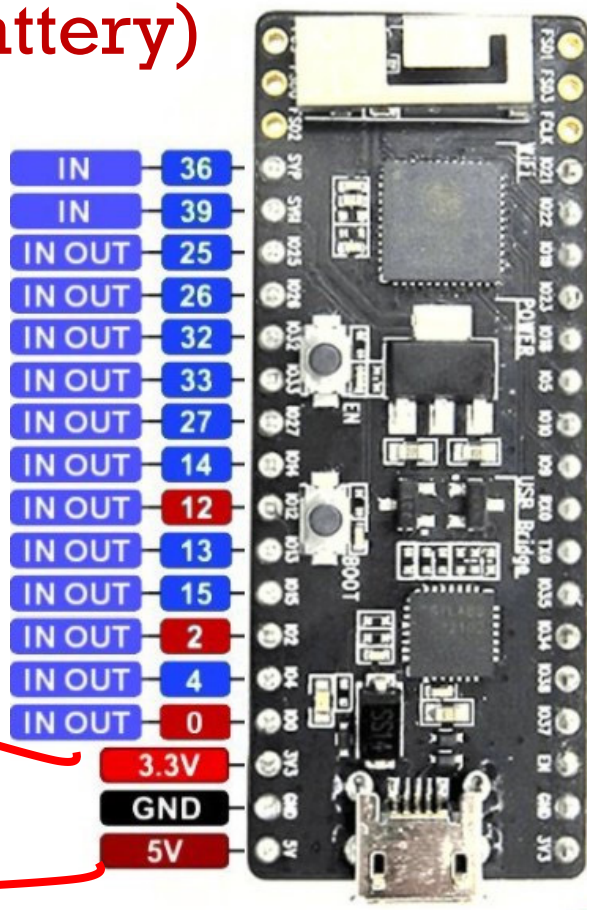
http://medesign.seas.upenn.edu/index.php/Guides/ESP32-pins

- Don't use the pins that are highlighted in red



PicoKit w/external power (e.g. battery)

- The PicoKit has a protection diode for your USB. So you can connect up to 12V on the Vin pin
  - even while USB is plugged in!
- Their design of the protection diode and voltage regulator is not great, so it causes problems we'll talk about later...

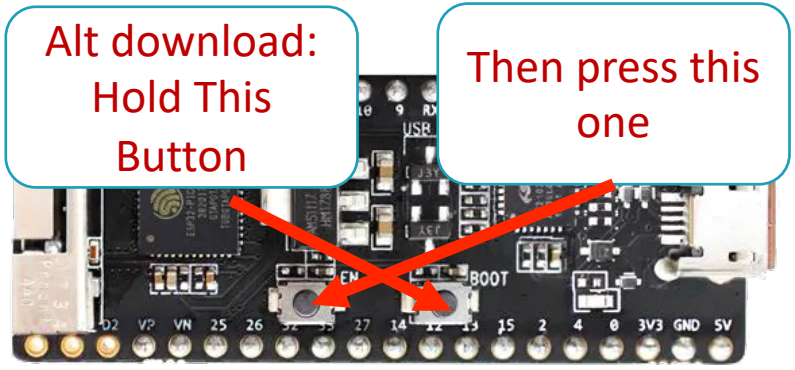


Both 3.3V source if USB powered or supply external 3.3V power

Both 5V source if USB or supply external power up to 12V

ESP32 Issues

- If ESP32 mysteriously stop loading.
  - It is likely dead. We suspect that it is Electrostatic Static Discharge (ESD).
  - **Solution: Be sure to ground yourself always before touching ESP32 including hitting the download button.**
- NodeMCU and PicoKit may not work with all USB cables. The power design is not great.
  - **Use supplied USB cable. Later use external power.**



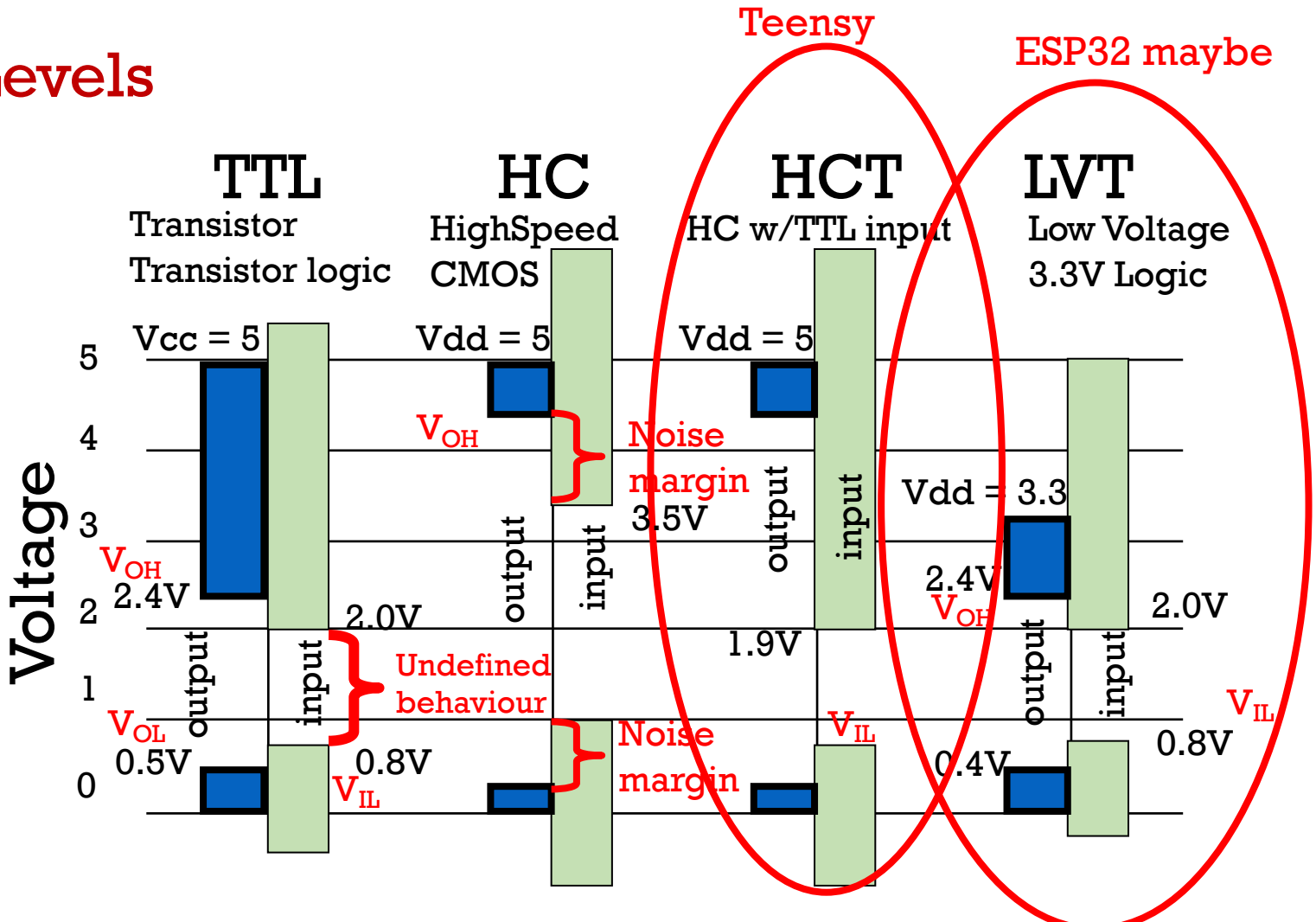
04

Level Shifters 3.3 <-> 5V

Logic Levels

Valid Output Levels

Valid Recognized Input Levels



Level shifting 3.3V to 5V with pullups

- For many devices we need 5V logic (TTL or HC)
  - 3.3V output should work on TTL and HCT
  - 3.3V not guaranteed for HC
- In setup()

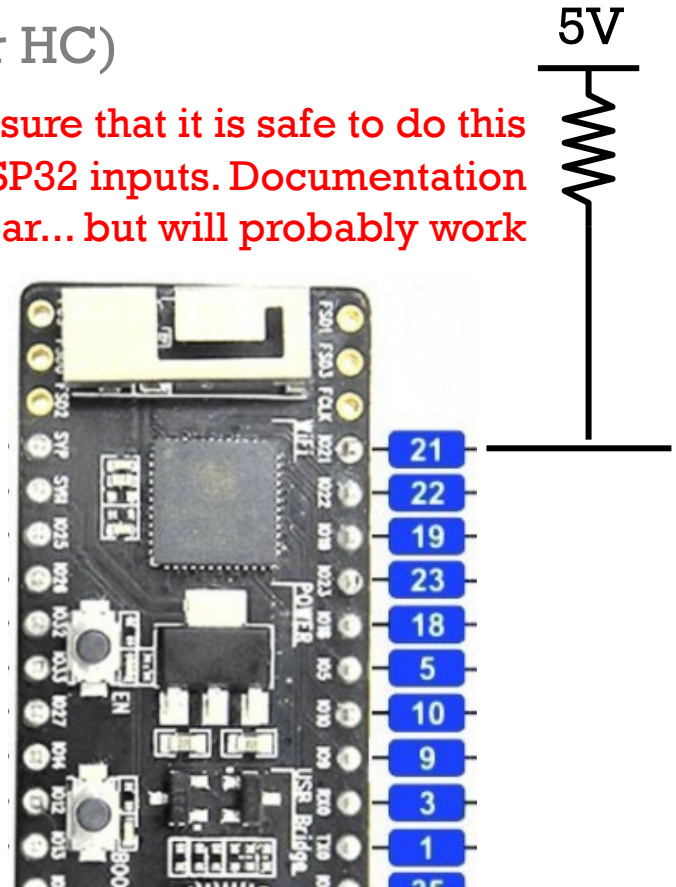
```
pinMode(21,INPUT);
digitalWrite(21,LOW);
```

- Don't use `digitalWrite`.
  - Instead use pullup:
  - For high values we use:

```
pinMode(21,INPUT);
```

  - For low values we use:

```
pinMode(21,OUTPUT);
```

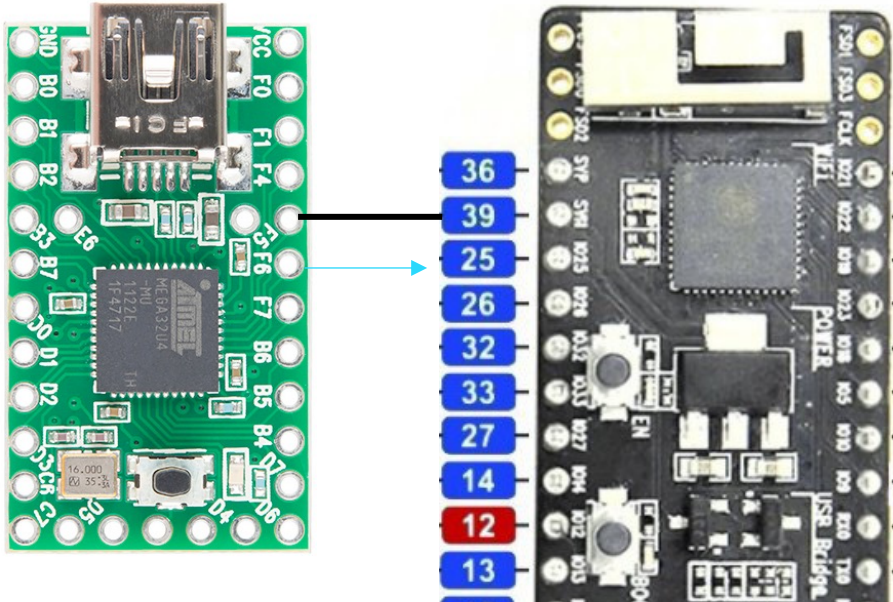


Level shifting 5V output to 3.3V input

- Is ESP32 5V safe or 5V tolerant?
- The ESP32 documentation is not clear.. One spec says 3.9V max
- One Espressif engineer:

For "slow" 5V signals, it should be possible (though hacky) to use a single high value series resistor (1K or, ideally, more) to limit the current into the I/O pin's input protection circuitry, preventing it from damage. This is probably OK for a quick hack, but I would not recommend it for production hardware design or something where you need maximum reliability over the long term.

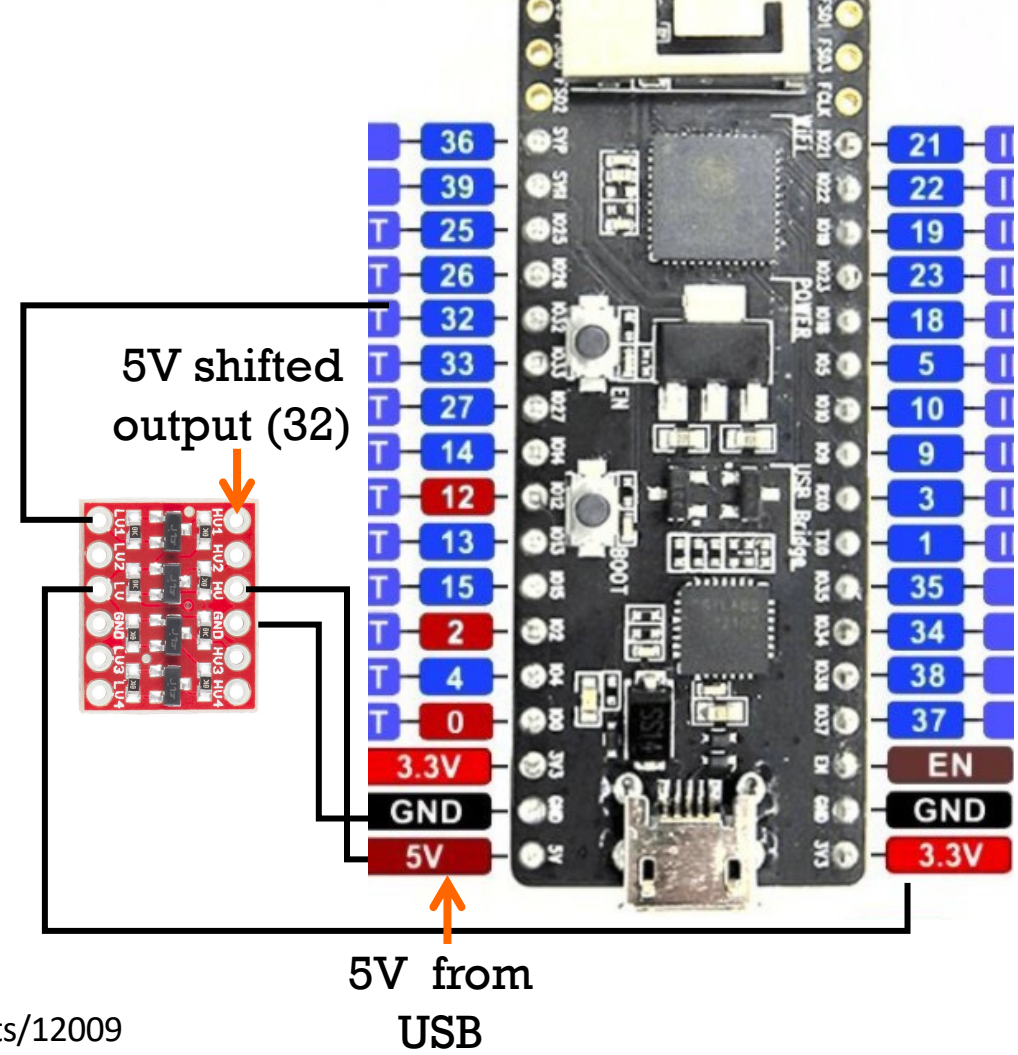
In those cases, level shifting is the best approach.



https://esp32.com/viewtopic.php?t=877

Better Level Shifting

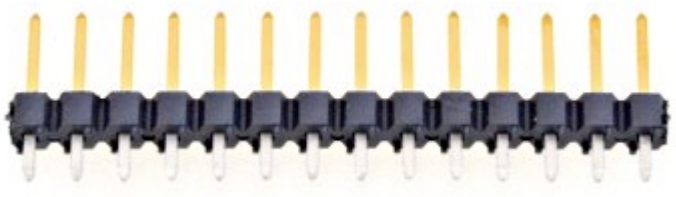
- Can use a level shifter and 5V from USB (Vin) as our 5V source.
- If Pin 32 is 3.3V, the output pf level shifter is 5V. Otherwise both are gnd.
- Four channel level shifter from sparkfun
  - Can shift 4 pins input or output

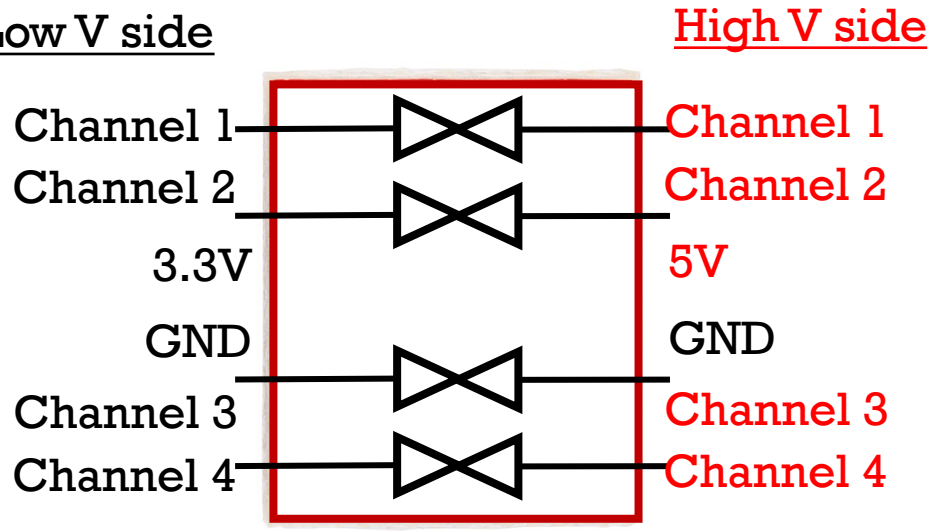


https://www.sparkfun.com/products/12009

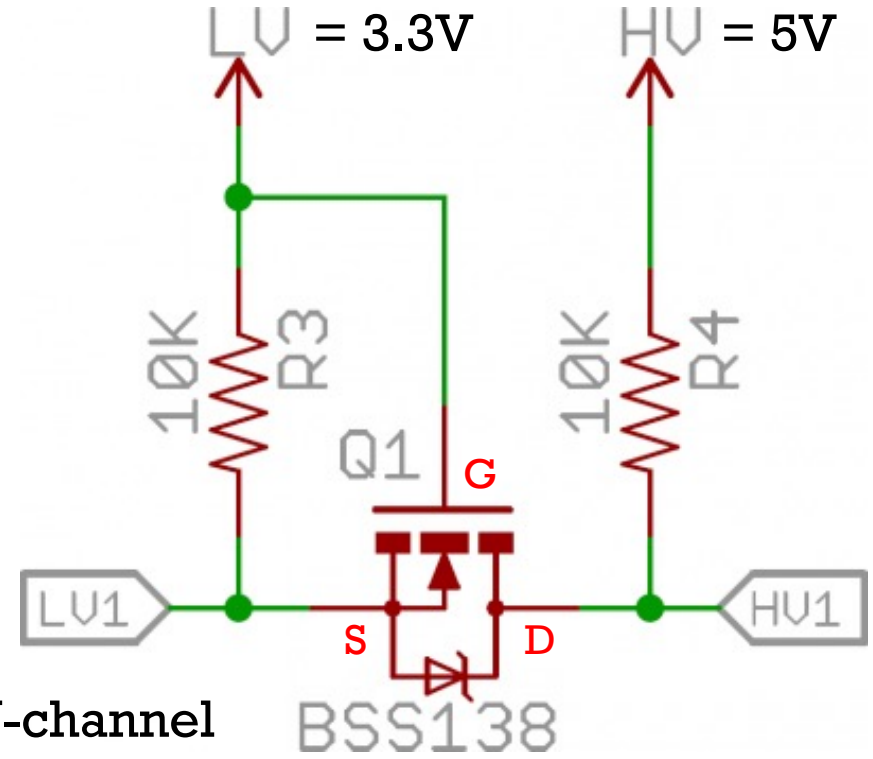
Soldering level shifter (BOB 12009)

- Logic levels on one side are translated to corresponding logic levels on opposite side.
- Also provides a level of safety between devices.
- You will need to solder headers in first like with teensy
- Solder in breadboard.





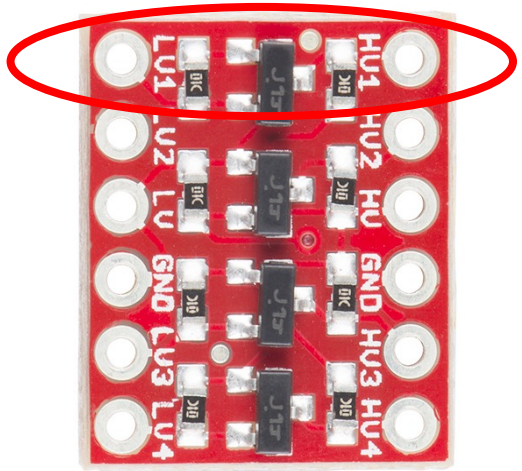
Level Shifter



N-channel MOSFET

$V_{GS(Threshold)} = 1.5V$

- N-channel MOSFET
  - Becomes a low value resistor between S and D when $V_G > V_S$ by ~2.5V
  - Otherwise very high resistance between S and D
  - G-S and G-D are not connected (infinite resistance)



Level Shifter

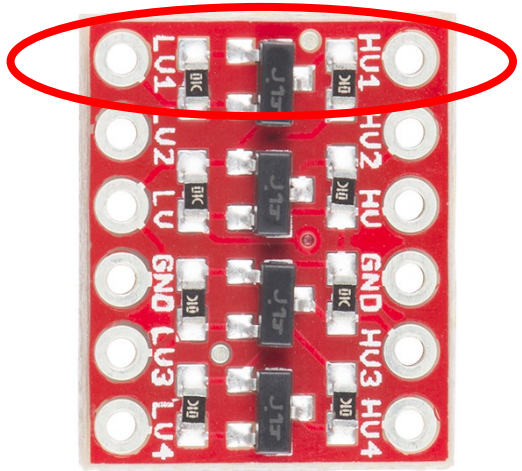
Four cases:

- LV1 is output HIGH driving HV1
- LV1 is output LOW driving HV1
- HV1 is output HIGH driving LV1
- HV1 is output LOW driving LV1

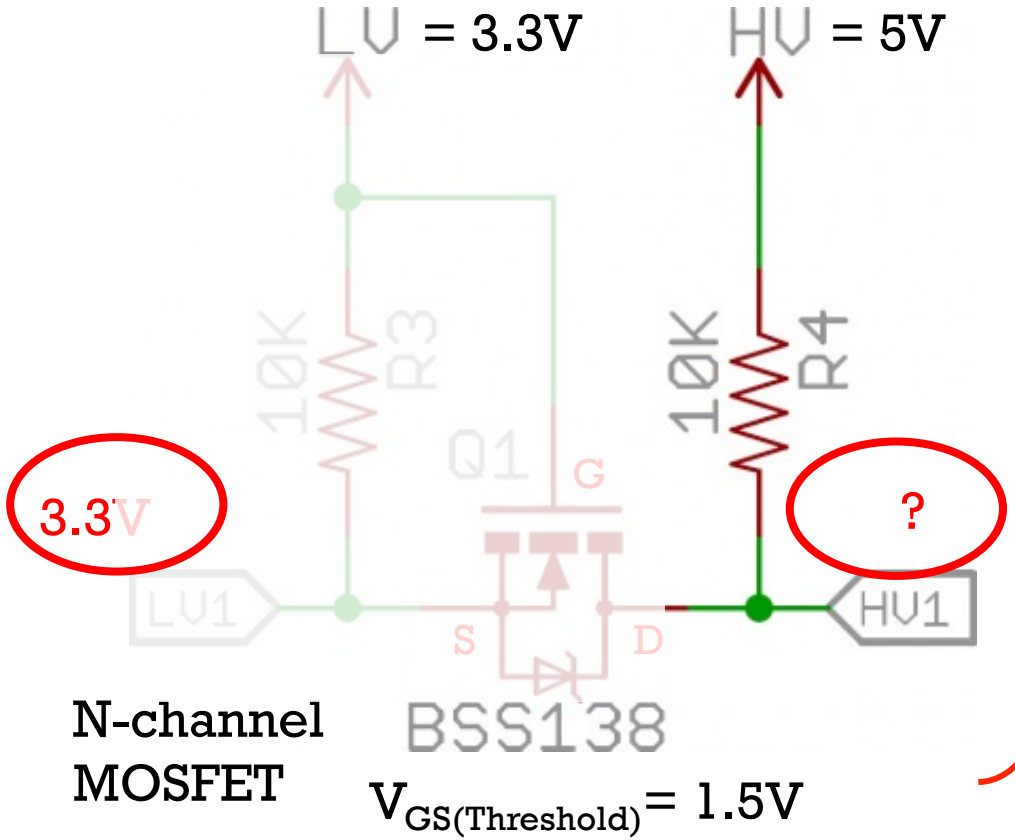
N-channel MOSFET

$V_{GS(Threshold)} = 1.5V$

- N-channel MOSFET
  - Becomes a low value resistor between S and D when $V_G > V_S$ by ~2.5V
  - Otherwise very high resistance between S and D
  - G-S and G-D are not connected (infinite resistance)



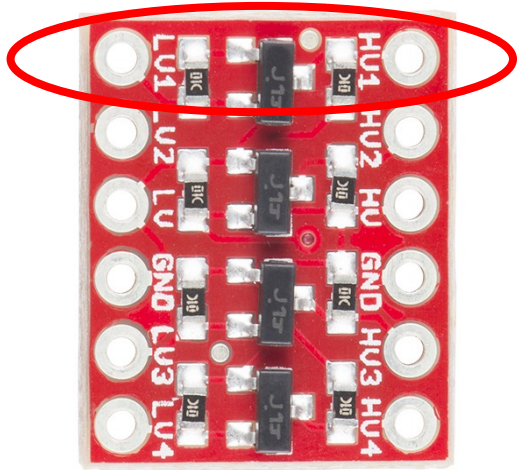
Q4: Level Shifter



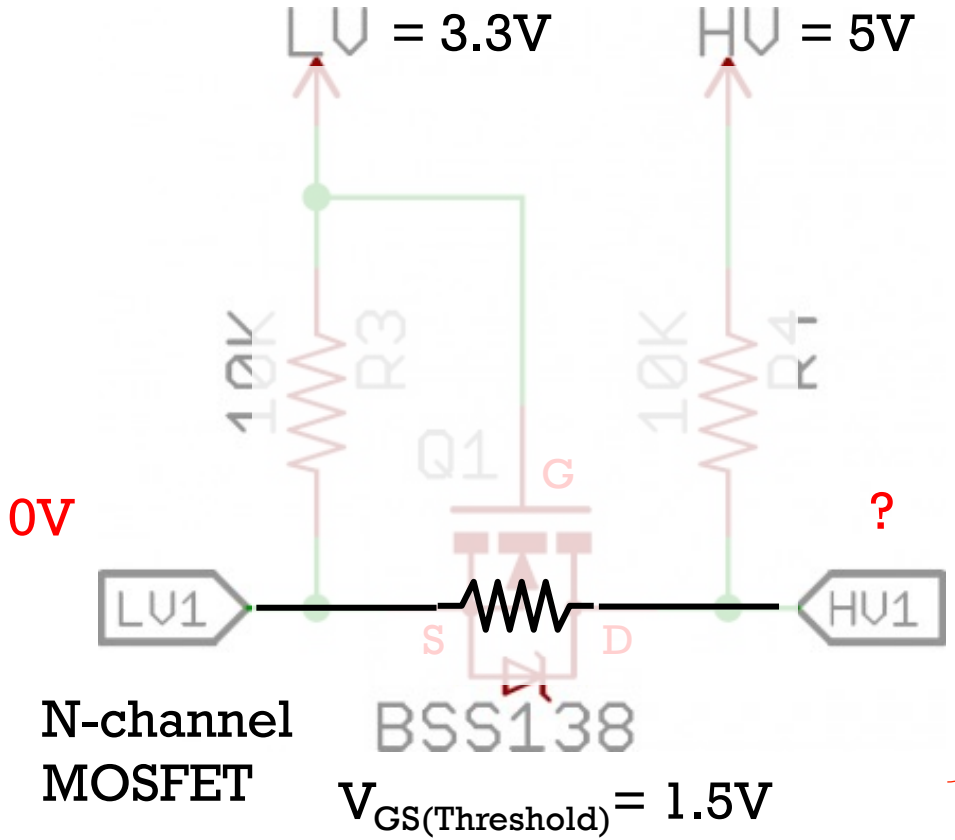
N-channel MOSFET

$V_{GS(Threshold)} = 1.5V$

- With 3.3V at LV1, what voltage is at HV1 and what is the max current supplied to HV1 to maintain proper logic levels?



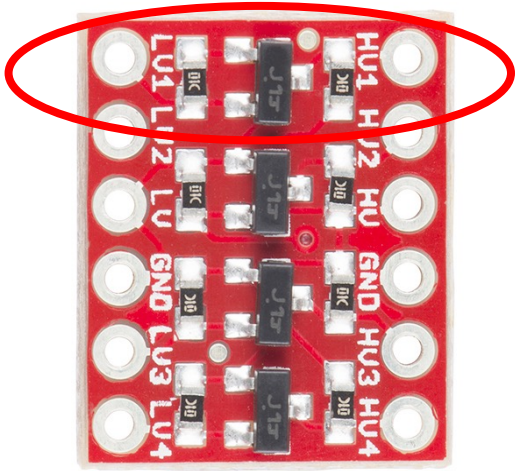
Q5: Level Shifter



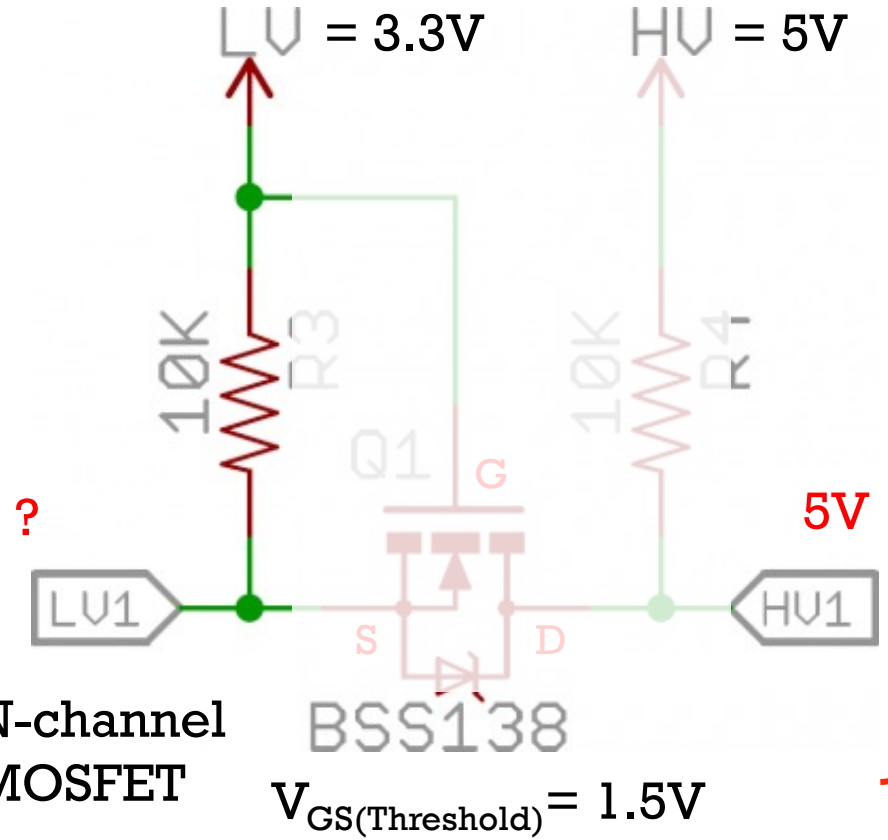
N-channel MOSFET

$V_{GS(Threshold)} = 1.5V$

- With 0V at LV1, what voltage is at HV1 and what is the max current supplied to HV1 to maintain proper logic levels?



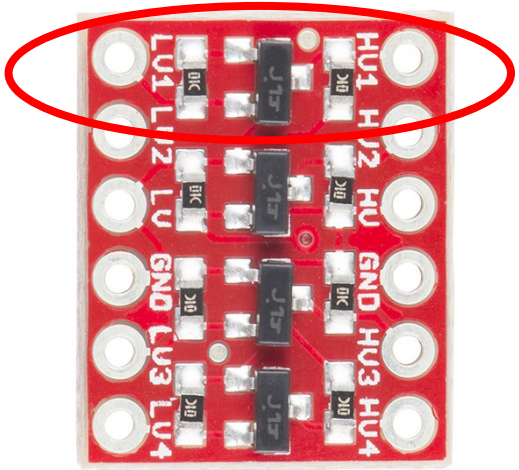
Q6: Level Shifter



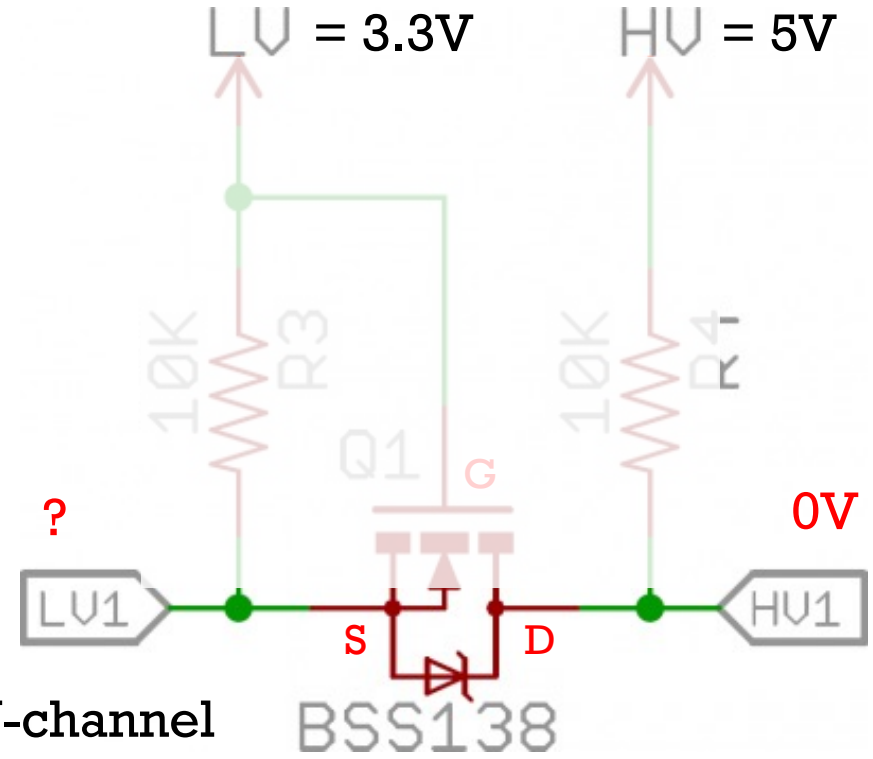
N-channel MOSFET

$V_{GS(Threshold)} = 1.5V$

- With 5V at HV1, what voltage is at LV1 and what is the max current supplied to LV1 to maintain proper logic levels?



Q7: Level Shifter



N-channel MOSFET

$V_{GS(Threshold)} = 1.5V$

- With 0V at HV1, what voltage is at LV1 and what is the max current supplied to LV1 to maintain proper logic levels?

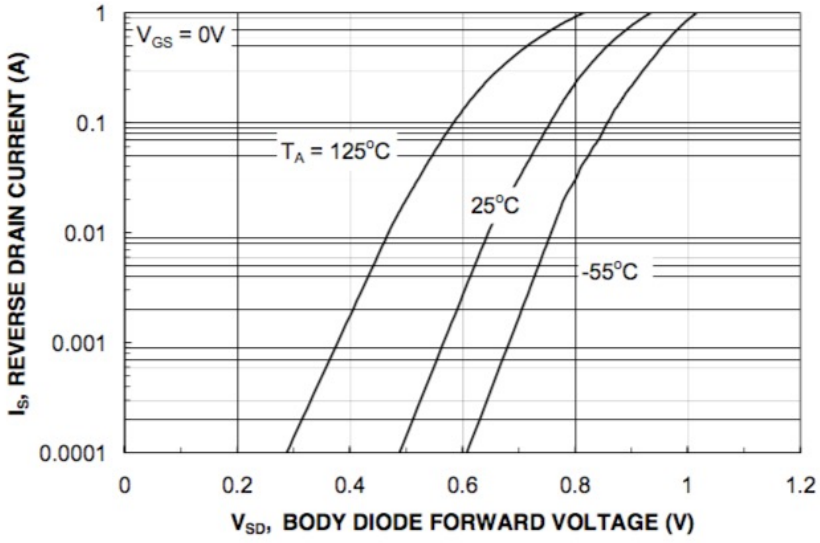


Figure 6. Body Diode Forward Voltage Variation with Source Current and Temperature.

The Good

1. WiFi on a chip - easy to setup a webpage
2. Full TCP/IP stack firmware w/RTOS
3. Very cheap ($3 for module, $10 for board)
4. Arduino SDK
5. DIY community is eating it up.
6. ~1M available program space
7. Enough I/O to do many things
   A. 18 ADC
   B. 2 SPI
   C. 2 UART
   D. I2S, I2C
   E. ~17 useful GPIO

The Bad

1. WiFi to internet is complicated.
2. Arduino SDK only partially implemented
   A. No servo library
   B. TCP is slow and timing is inconsistent
   C. WiFi Latency ~130ms per packet
   D. UDP is reasonably fast though ~500 packets /sec.
3. Timing not guaranteed (in arduino, PWM can be glitchy)
4. Downloading is much slower than Teensy
5. Power circuit design is borderline bad
6. QA for hiletgo is bad - ~2% failure out of box

The Ugly

1. 3.3V interface (ports not quite 5V safe?)
   A. Use 5V level shifters from sparkfun (elegant design)
2. Documentation is horrendous (getting better)
3. RTOS and dual core adds complexity
4. Many ports are multi-use in default conditions (e.g. GPIO used for startup)
5. Standard ADC accuracy is not great.
6. Randomly gets hot and dies… ESD?

Summary

- ESP32 is much more powerful than teensy.
- ESP32 uses 3.3V logic
- ESP32 documentation is nonstandard and difficult to parse.
- When developing with ESP32 be careful of ESD!
- We will use Arduino SDK.