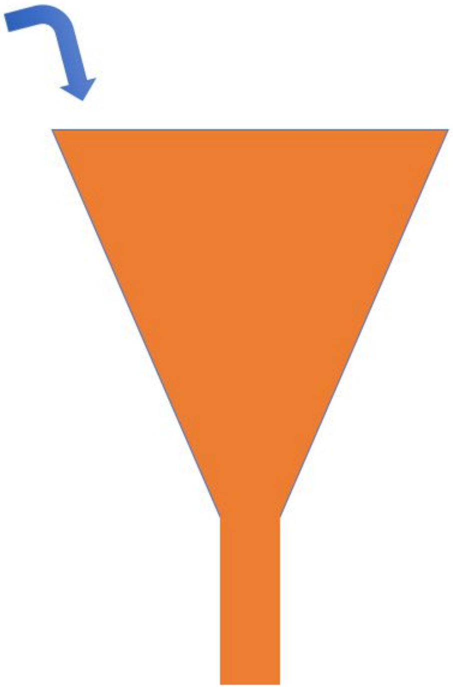
Electronics

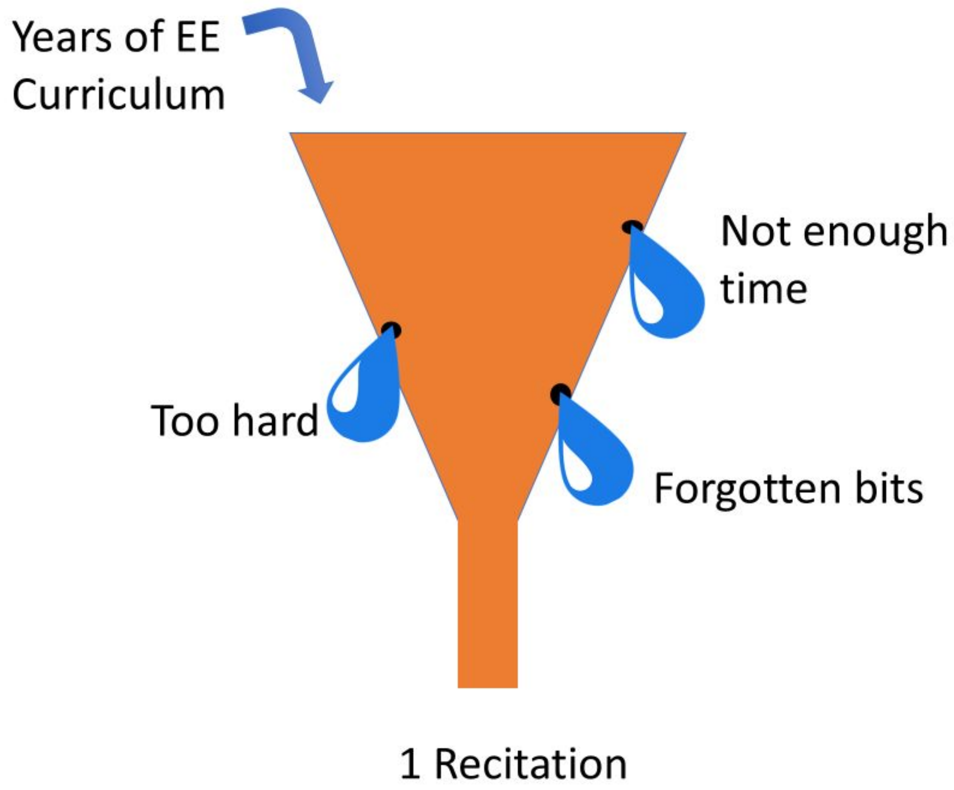
Today’s goals

Years of EE Curriculum



Hopefully useful nuggets for your projects/life

Reality


Years of EE
Curriculum
Not enough
time
Too hard
Forgotten bits
1 Recitation

The next few weeks have a simple task!

1. Learn (or recall) basic electrical engineering
2. Use it to design a custom circuit board in a new software program (EDA)
3. Mill/lase it and solder on all the parts properly
4. Program your board to do something

But where do we start?

- Theory?
- Practice?
- Components?
- Ideal models?
- Hardware or software?
- Can we even separate them?

In the spirit of this course let’s try looking at this through a lens that I’m going to dub “everything everywhere all at once.” We’ll focus on hardware and dip into theory as the components require it.

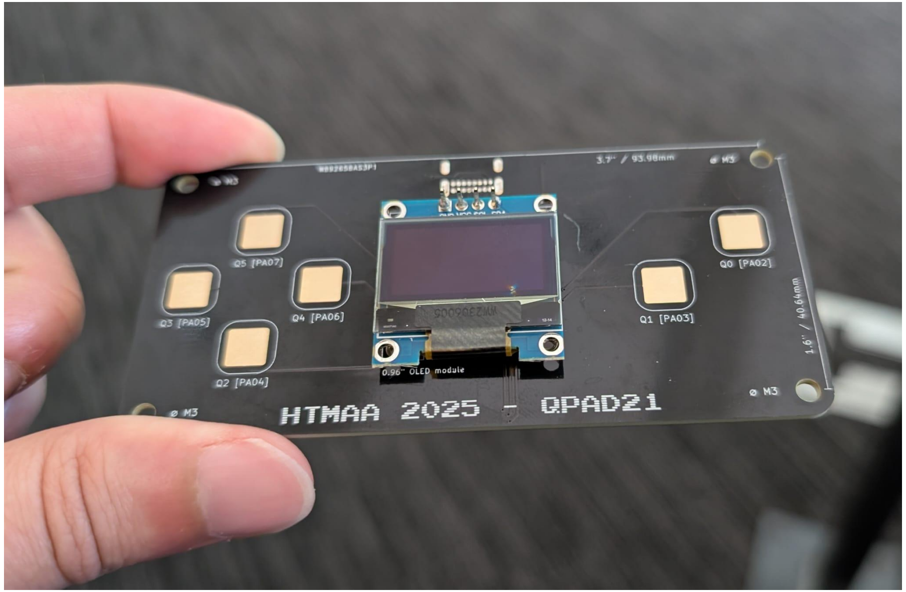
“the limits of my language mean the limits of my world” - Ludwig Wittgenstein

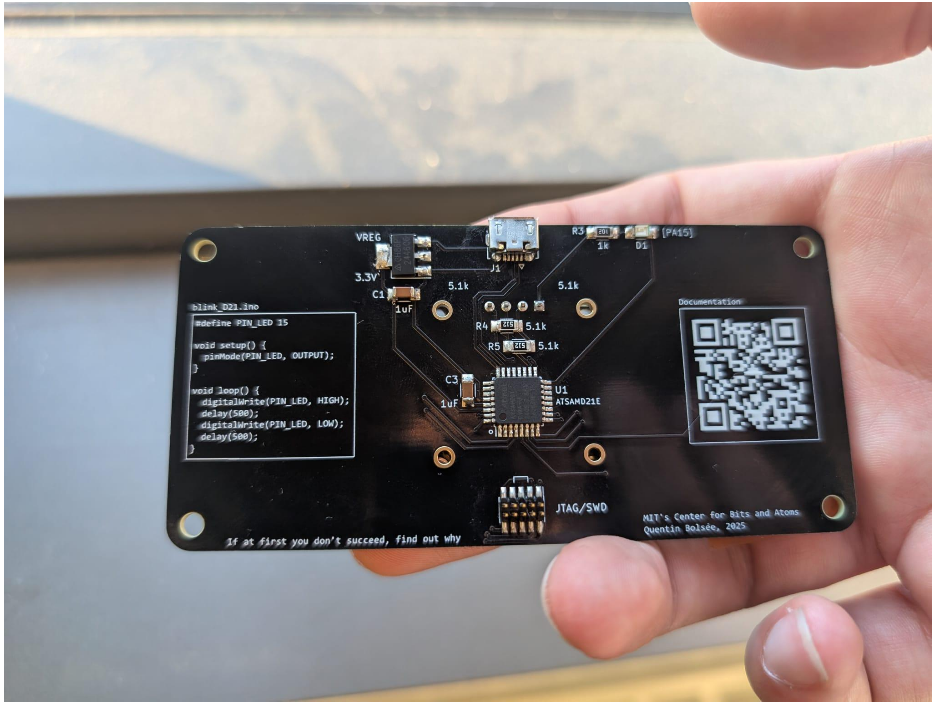
Parallels amongst other fields

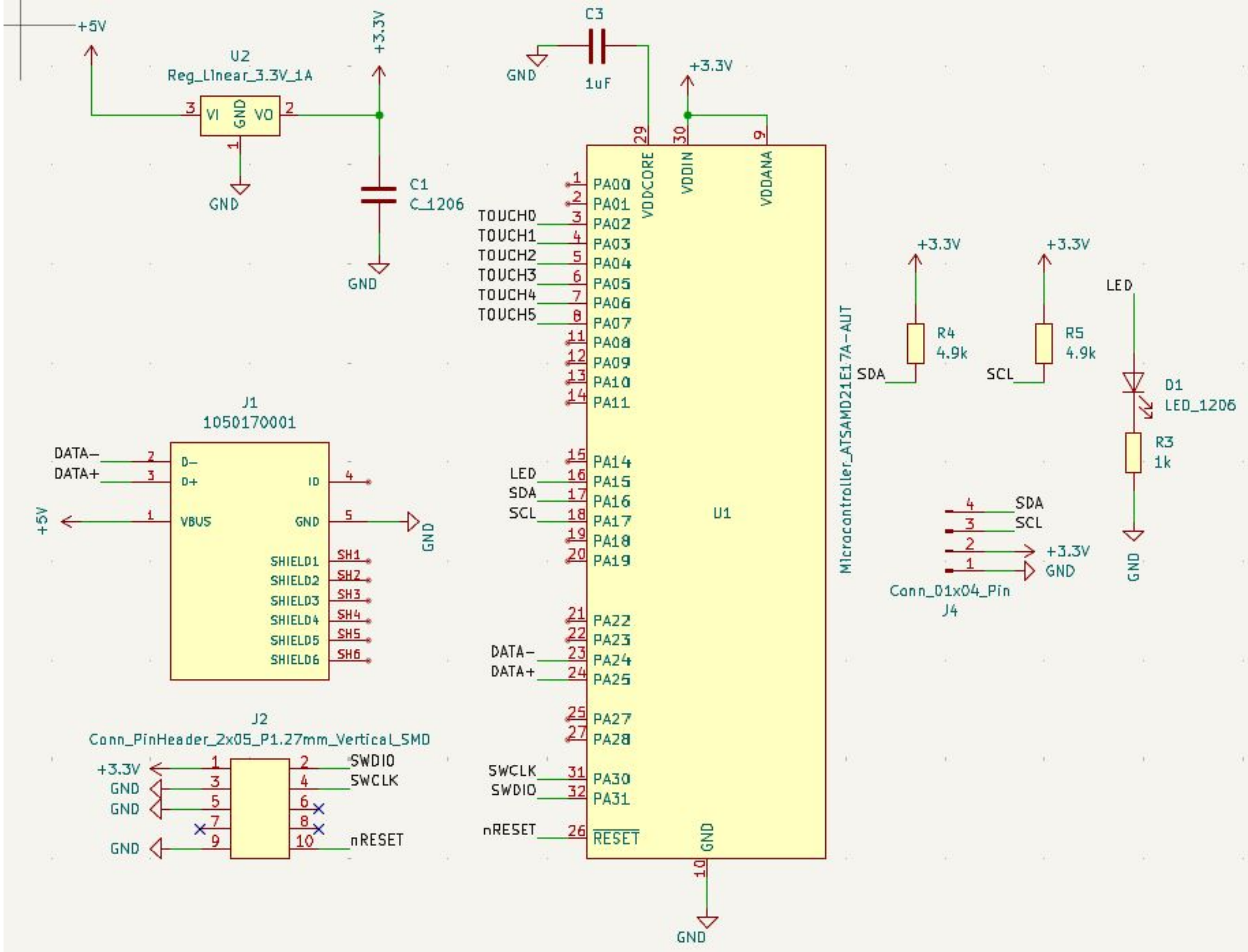
Mech formula	Concept		Elec formula
F=MA	Force	Voltage	V=IR
Keq=K1+K2	Springs in parallel	Caps in parallel	Ceq=C1+C2
$\frac{1}{Keq} = \frac{1}{K1} + \frac{1}{K2}$	Springs in Series	Caps in Series	$\frac{1}{Ceq} = \frac{1}{C1} + \frac{1}{C2}$
$\boldsymbol{E = \frac{1}{2}MV^2}$	Kinetic energy	Energy in a cap	$\boldsymbol{E = \frac{1}{2}CV^2}$
$\sum F = 0$	Sum of the forces	Sum of voltage drops	$\sum Vd = 0$
Static friction			Diodes?

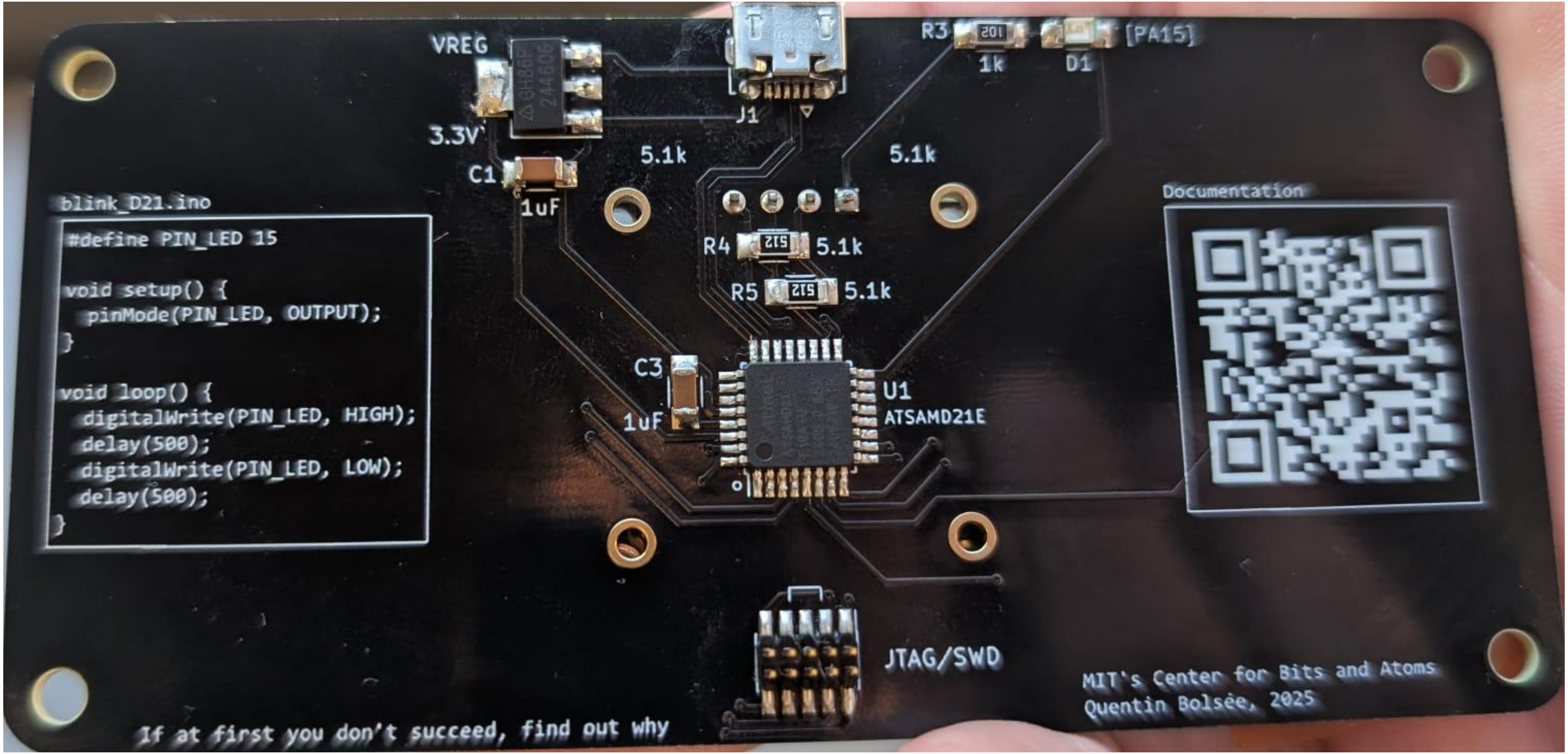
Mechanics=Fluids=Thermo=Electronics
Different constants similar formulas

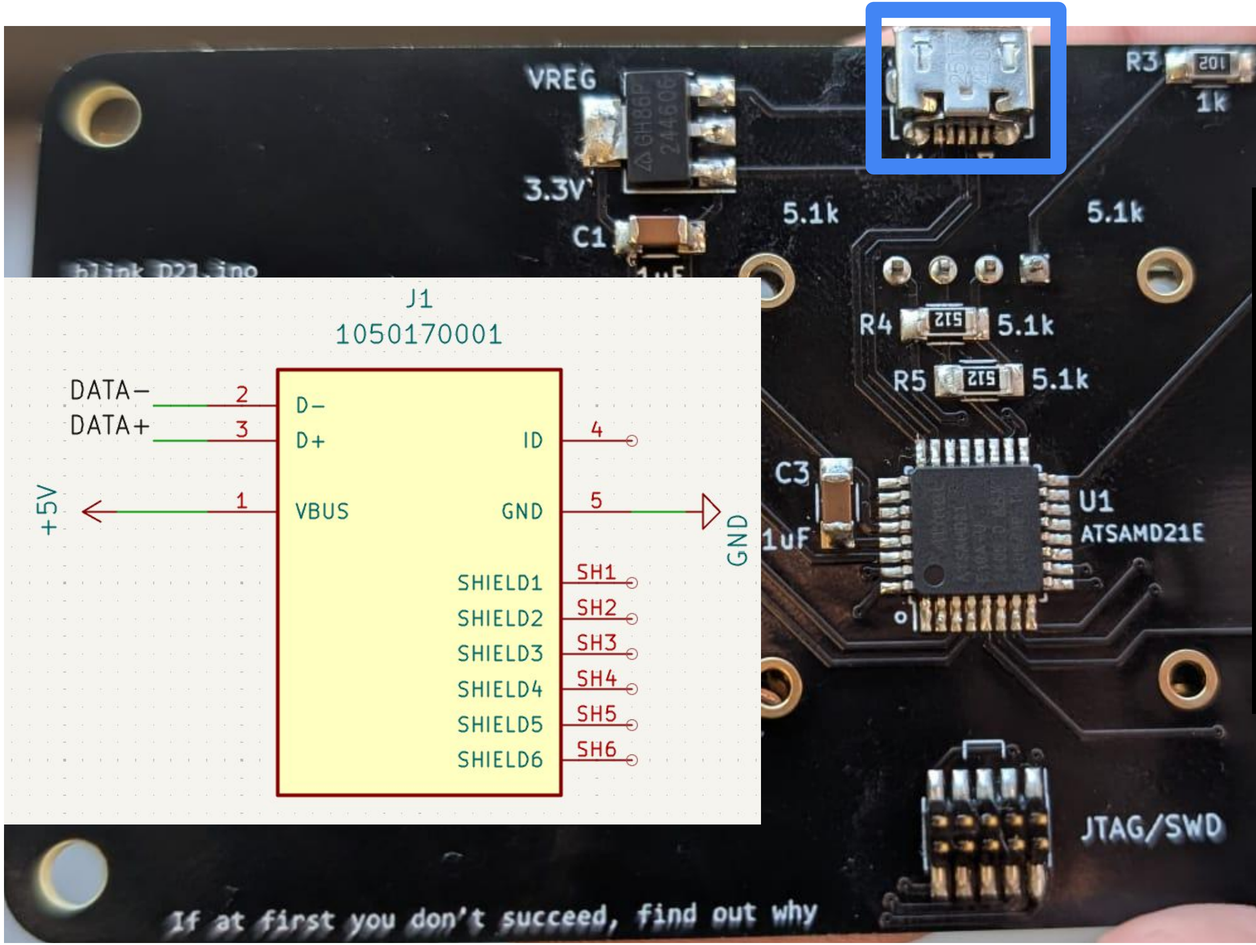
What you’re making this week






+5V
U2
Reg_Linear_3.3V_1A
VI
GND
VO
+3.3V
C1
C_1206
GND
C3
1uF
VDDCORE
VDDIN
VDDANA
TOUCH0
TOUCH1
TOUCH2
TOUCH3
TOUCH4
TOUCH5
PA00
PA01
PA02
PA03
PA04
PA05
PA06
PA07
PA08
PA09
PA10
PA11
PA14
PA15
PA16
PA17
PA18
PA19
PA22
PA23
PA24
PA25
PA27
PA28
PA30
PA31
RESET
U1
Microcontroller_ATSAMD21E17A-AUT
LED
SDA
SCL
DATA−
DATA+
SWCLK
SWDIO
nRESET
J1
1050170001
D−
D+
ID
VBUS
SHIELD1
SHIELD2
SHIELD3
SHIELD4
SHIELD5
SHIELD6
SH1
SH2
SH3
SH4
SH5
SH6
J2
Conn_PinHeader_2x05_P1.27mm_Vertical_SMD
R4
4.9k
R5
4.9k
D1
LED_1206
R3
1k
Conn_01x04_Pin
J4

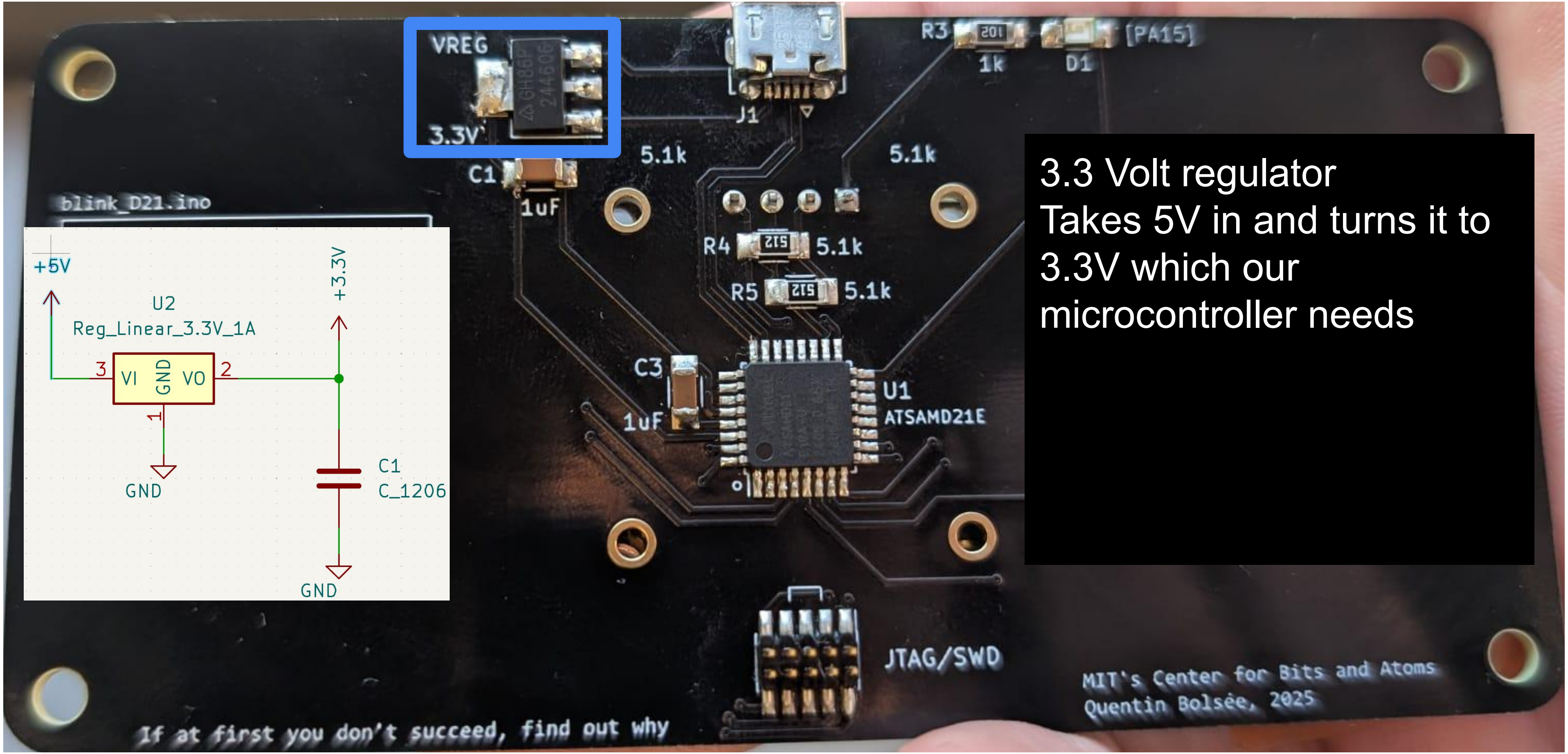

VREG
3.3V
J1
R3
1k
D1
[PA15]
C1
1uF
5.1k
5.1k
R4
5.1k
R5
5.1k
C3
1uF
U1
ATSAMD21E
blink_D21.ino
#define PIN_LED 15
void setup() {
pinMode(PIN_LED, OUTPUT);
}
void loop() {
digitalWrite(PIN_LED, HIGH);
delay(500);
digitalWrite(PIN_LED, LOW);
delay(500);
}
Documentation
JTAG/SWD
MIT's Center for Bits and Atoms
Quentin Bolsée, 2025
If at first you don't succeed, find out why



Micro USB connector

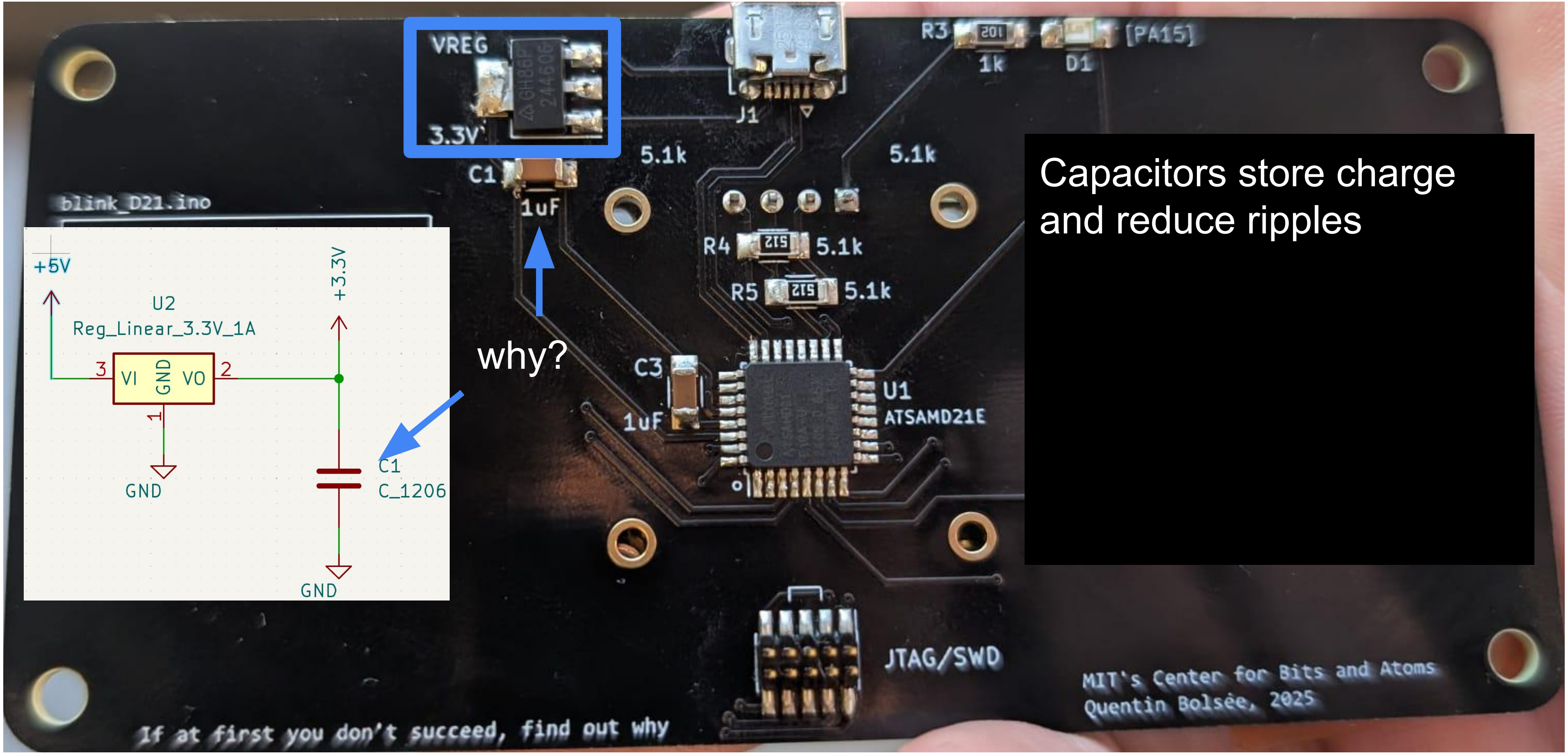
Provides 5V and ground connections

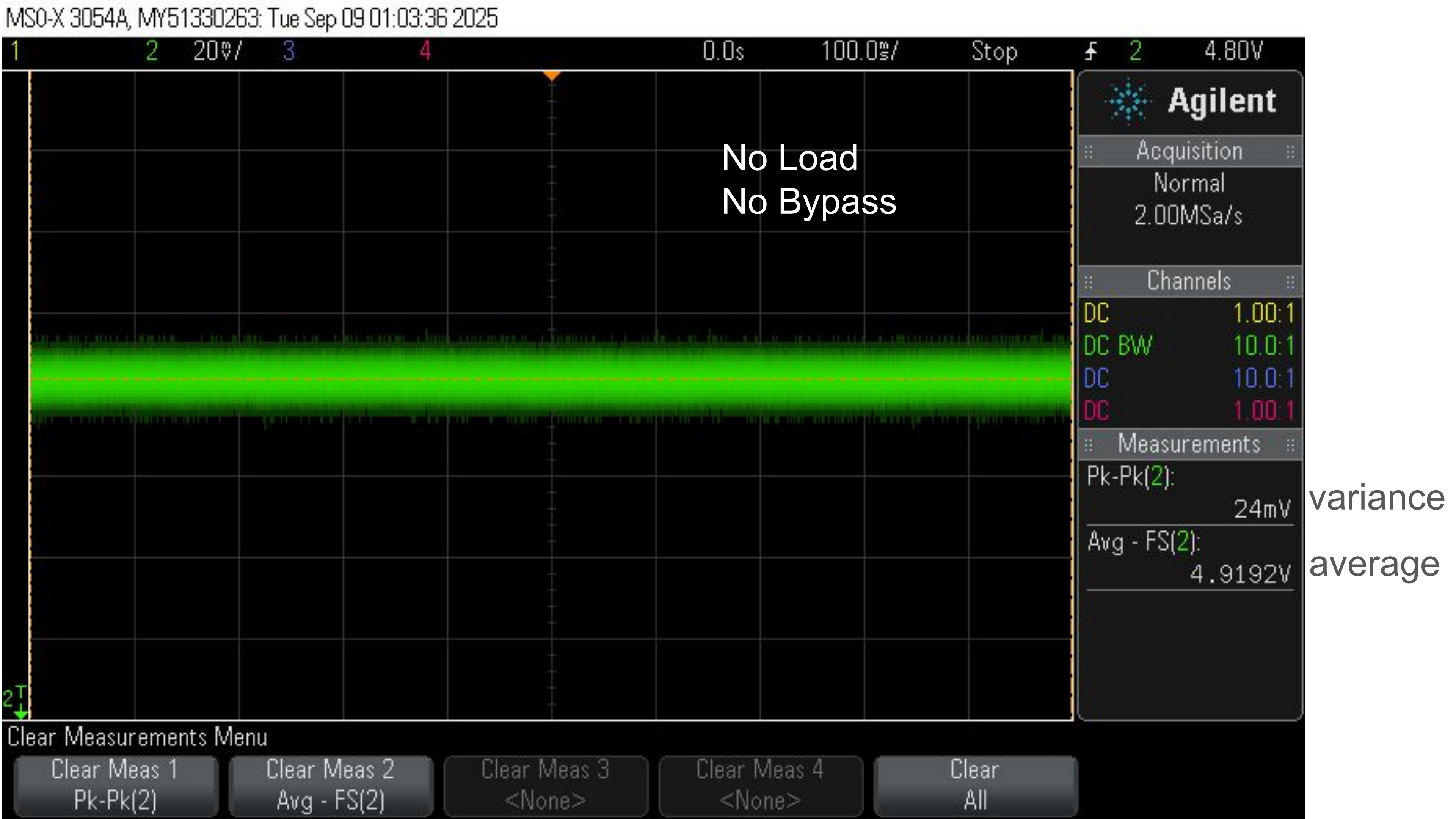
Data transfer for programming and debugging

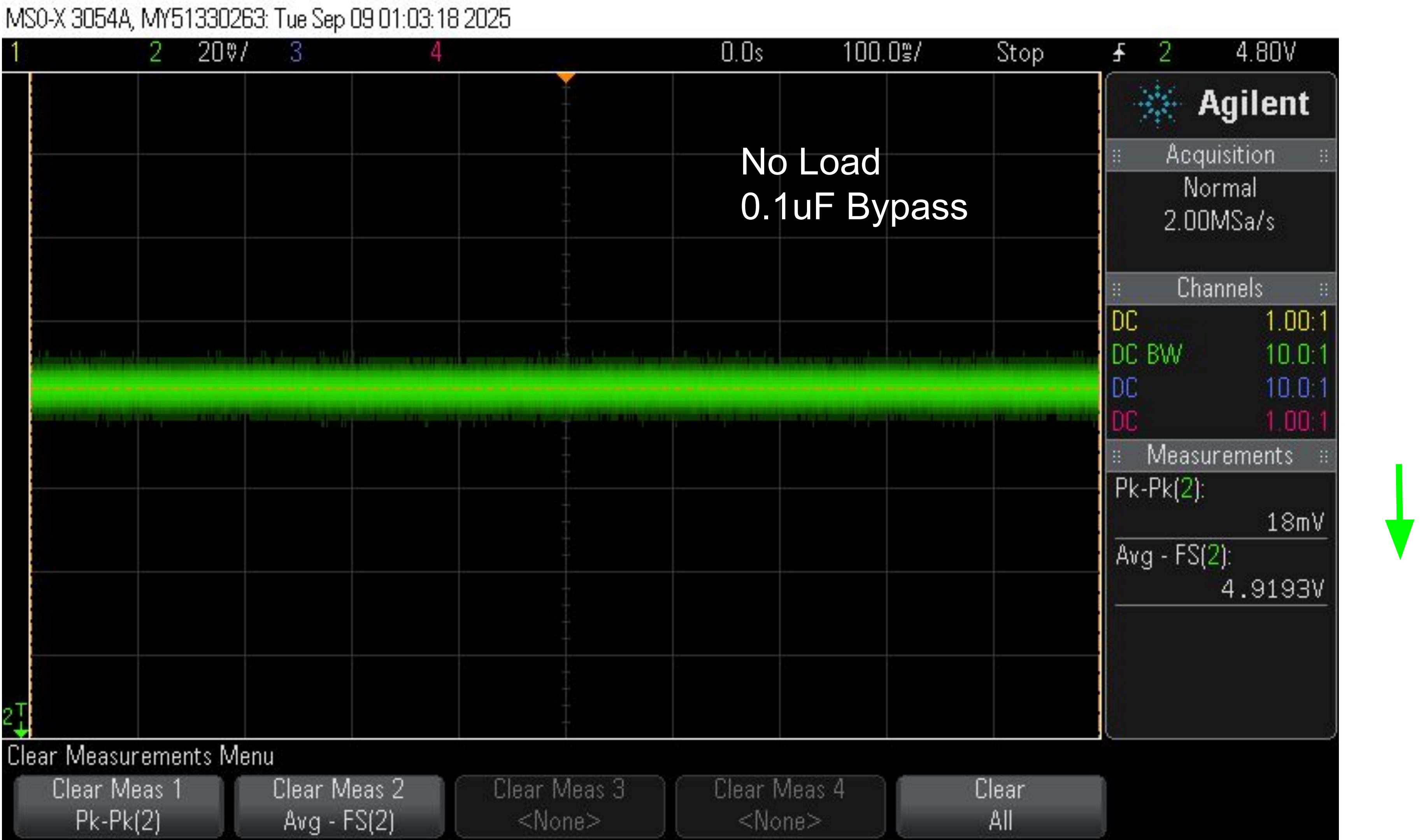


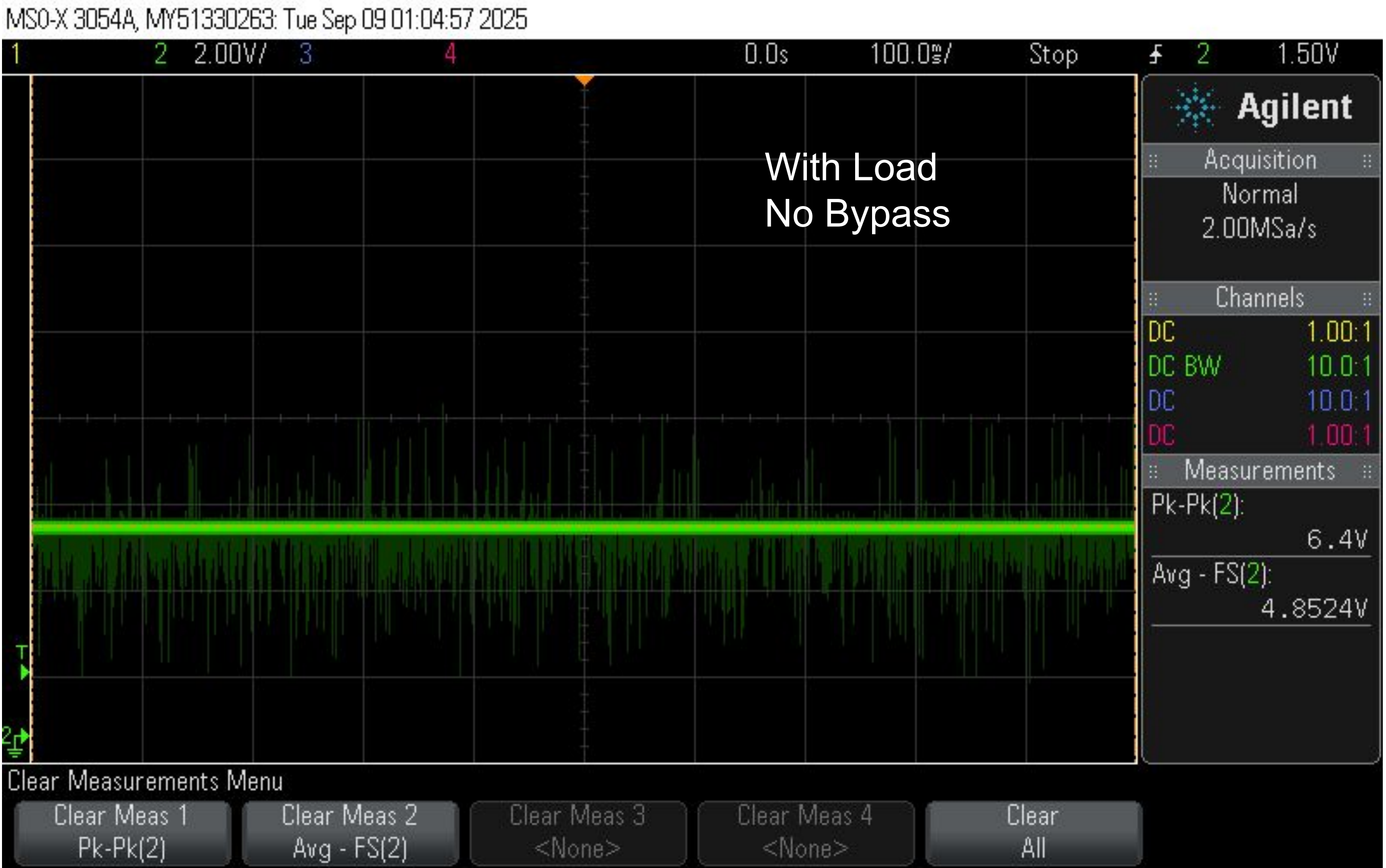
3.3 Volt regulator
Takes 5V in and turns it to 3.3V which our microcontroller needs

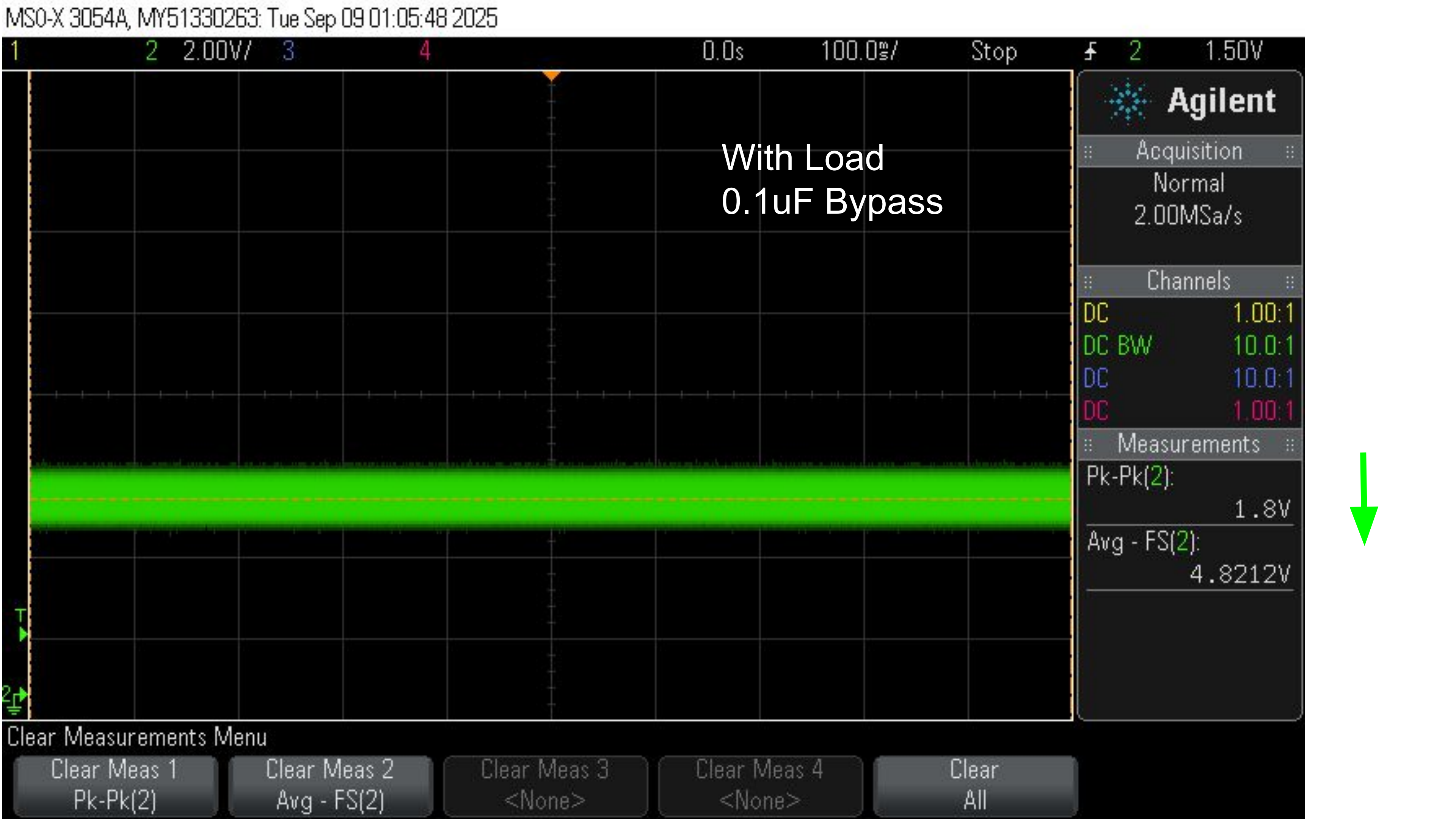
Capacitors store charge and reduce ripples

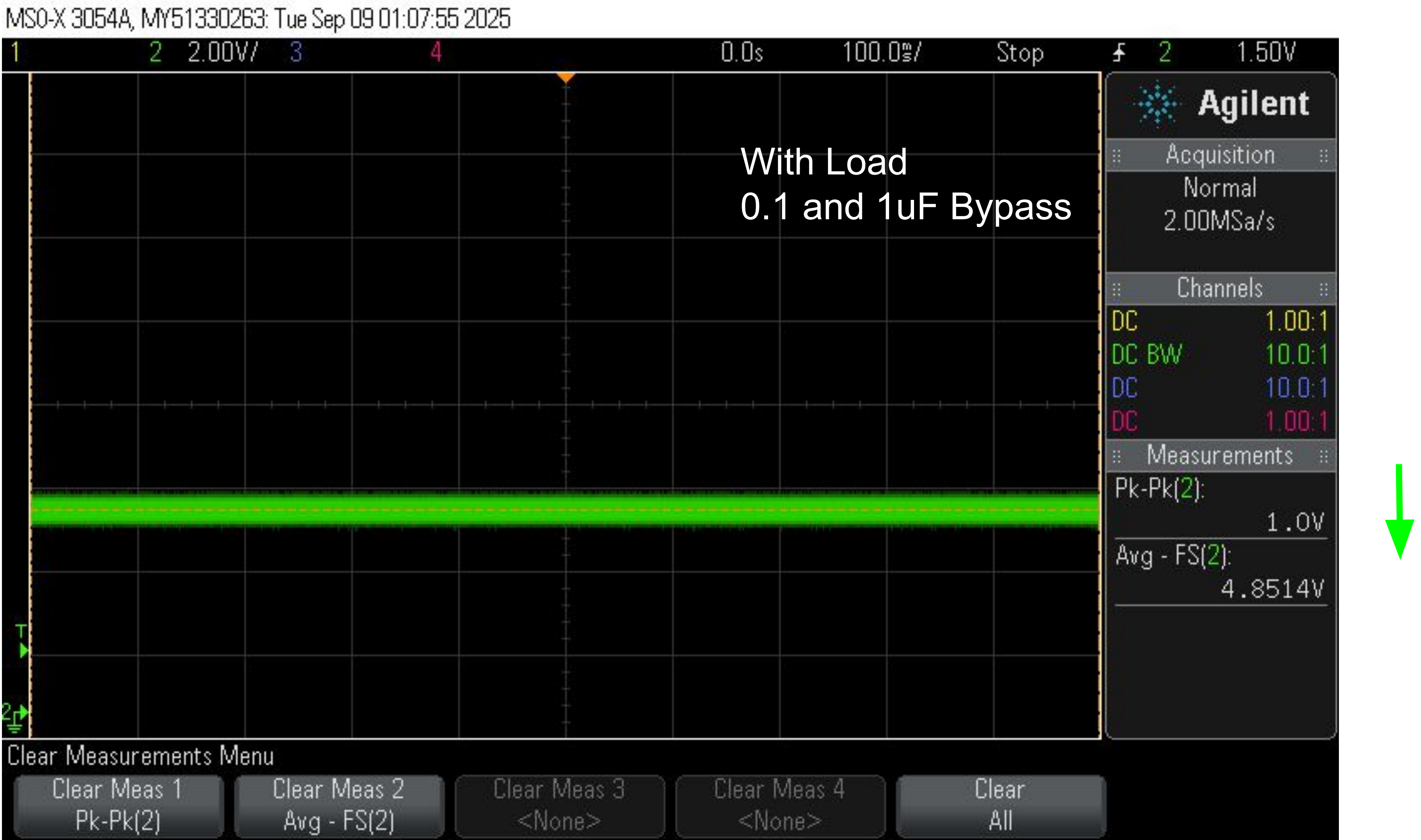


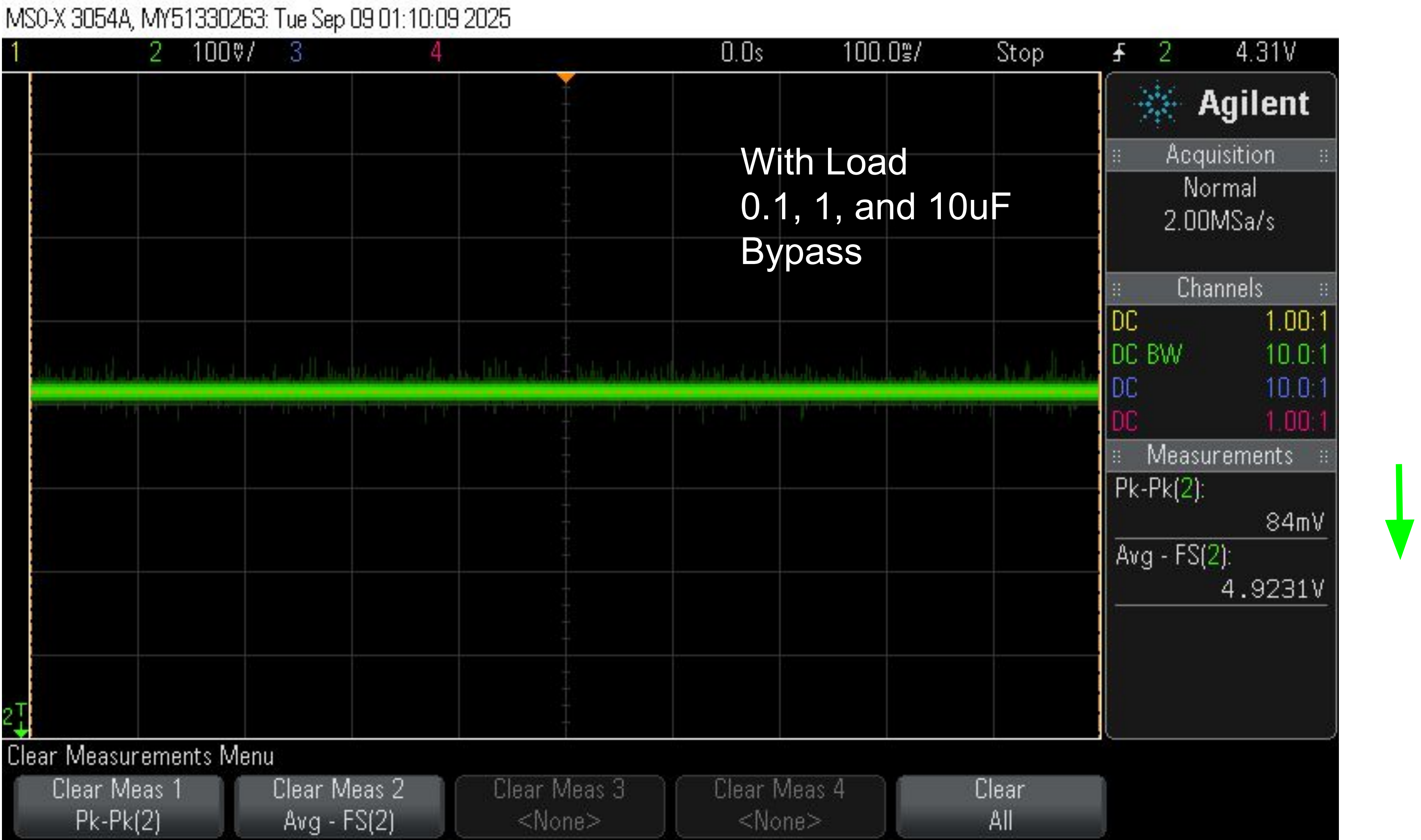

MSO-X 3054A, MY51330263: Tue Sep 09 01:03:36 2025
1
2 20mV/
3
4
0.0s
100.0us/
Stop
2 4.80V
No Load
No Bypass
Agilent
Acquisition
Normal
2.00MSa/s
Channels
DC 1.00:1
DC BW 10.0:1
DC 10.0:1
DC 1.00:1
Measurements
Pk-Pk(2):
24mV
Avg - FS(2):
4.9192V
variance
average
Clear Measurements Menu
Clear Meas 1
Pk-Pk(2)
Clear Meas 2
Avg - FS(2)
Clear Meas 3
<None>
Clear Meas 4
<None>
Clear
All

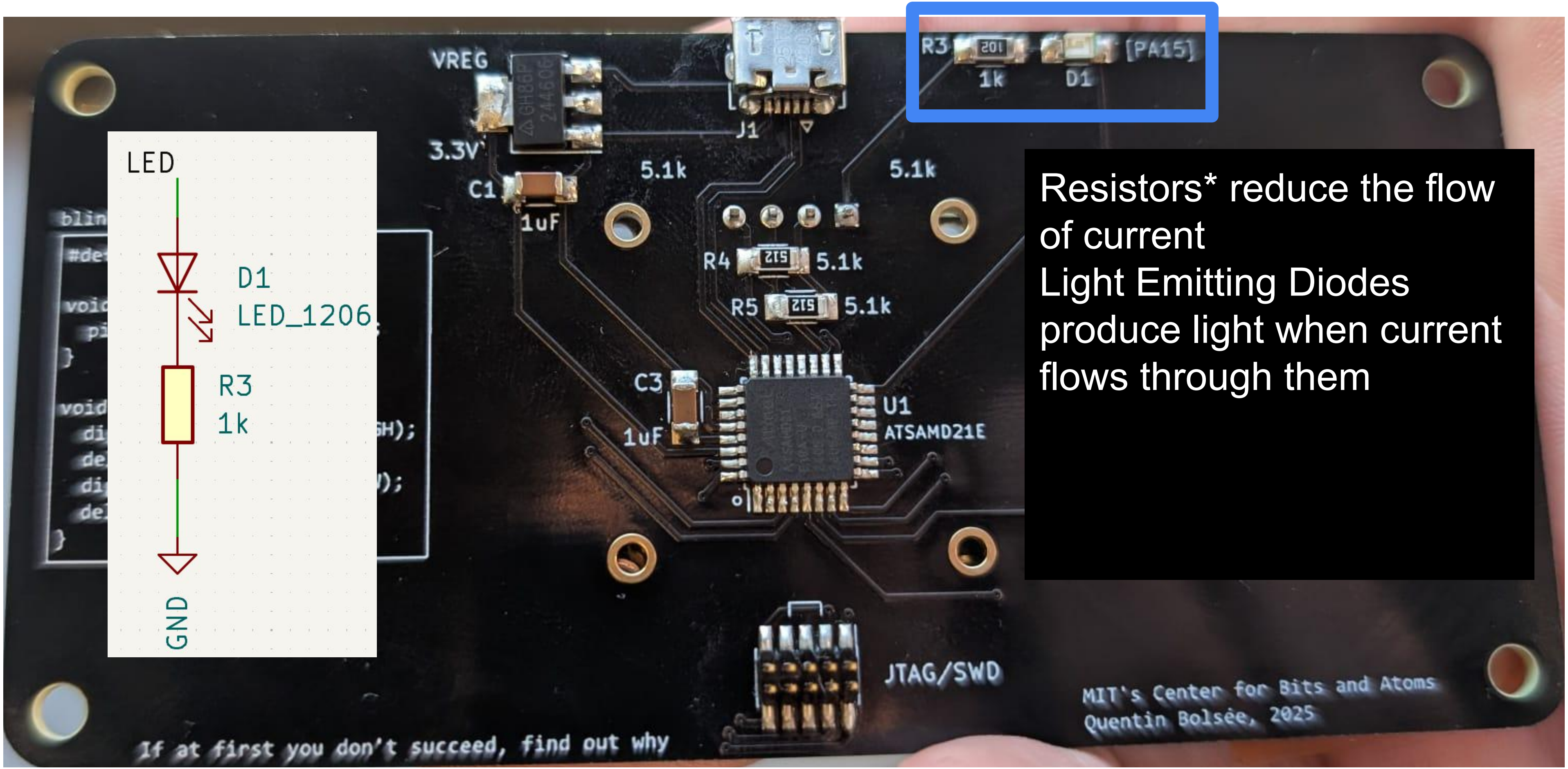

MSO-X 3054A, MY51330263: Tue Sep 09 01:03:18 2025
1
2 20mV/
3
4
0.0s
100.0µs/
Stop
2 4.80V
No Load
0.1uF Bypass
Agilent
Acquisition
Normal
2.00MSa/s
Channels
DC 1.00:1
DC BW 10.0:1
DC 10.0:1
DC 1.00:1
Measurements
Pk-Pk(2):
18mV
Avg - FS(2):
4.9193V
Clear Measurements Menu
Clear Meas 1
Pk-Pk(2)
Clear Meas 2
Avg - FS(2)
Clear Meas 3
<None>
Clear Meas 4
<None>
Clear
All


MSO-X 3054A, MY51330263: Tue Sep 09 01:04:57 2025
1
2 2.00V/
3
4
0.0s
100.0µs/
Stop
2 1.50V
With Load
No Bypass
Agilent
Acquisition
Normal
2.00MSa/s
Channels
DC 1.00:1
DC BW 10.0:1
DC 10.0:1
DC 1.00:1
Measurements
Pk-Pk(2):
6.4V
Avg - FS(2):
4.8524V
Clear Measurements Menu
Clear Meas 1
Pk-Pk(2)
Clear Meas 2
Avg - FS(2)
Clear Meas 3
<None>
Clear Meas 4
<None>
Clear
All


MSO-X 3054A, MY51330263: Tue Sep 09 01:05:48 2025
1
2 2.00V/
3
4
0.0s
100.0ms/
Stop
2 1.50V
Agilent
Acquisition
Normal
2.00MSa/s
Channels
DC 1.00:1
DC BW 10.0:1
DC 10.0:1
DC 1.00:1
Measurements
Pk-Pk(2):
1.8V
Avg - FS(2):
4.8212V
With Load
0.1uF Bypass
Clear Measurements Menu
Clear Meas 1
Pk-Pk(2)
Clear Meas 2
Avg - FS(2)
Clear Meas 3
<None>
Clear Meas 4
<None>
Clear
All

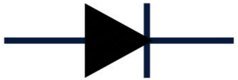

MSO-X 3054A, MY51330263: Tue Sep 09 01:07:55 2025
1
2 2.00V/
3
4
0.0s
100.0us/
Stop
2 1.50V
With Load
0.1 and 1uF Bypass
Agilent
Acquisition
Normal
2.00MSa/s
Channels
DC 1.00:1
DC BW 10.0:1
DC 10.0:1
DC 1.00:1
Measurements
Pk-Pk(2):
1.0V
Avg - FS(2):
4.8514V
Clear Measurements Menu
Clear Meas 1
Pk-Pk(2)
Clear Meas 2
Avg - FS(2)
Clear Meas 3
<None>
Clear Meas 4
<None>
Clear
All

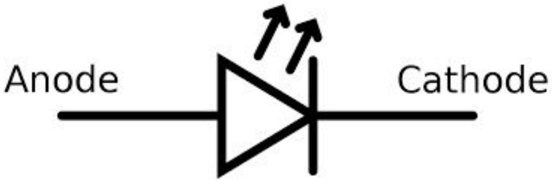

MSO-X 3054A, MY51330263: Tue Sep 09 01:10:09 2025
1
2 100mV/
3
4
0.0s
100.0µs/
Stop
2 4.31V
Agilent
Acquisition
Normal
2.00MSa/s
Channels
DC 1.00:1
DC BW 10.0:1
DC 10.0:1
DC 1.00:1
Measurements
Pk-Pk(2):
84mV
Avg - FS(2):
4.9231V
With Load
0.1, 1, and 10uF
Bypass
Clear Measurements Menu
Clear Meas 1
Pk-Pk(2)
Clear Meas 2
Avg - FS(2)
Clear Meas 3
<None>
Clear Meas 4
<None>
Clear
All



Resistors* reduce the flow of current
Light Emitting Diodes produce light when current flows through them

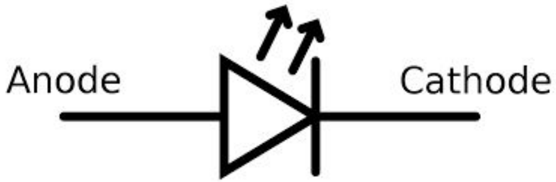
Diodes:

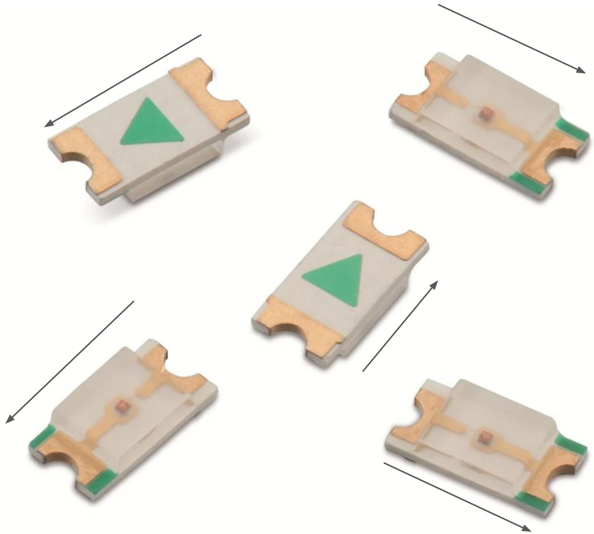




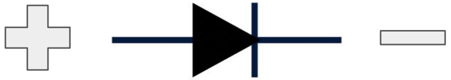
Diodes:

Light emitting diode (LED)





Diodes:



Current flows in one direction only*

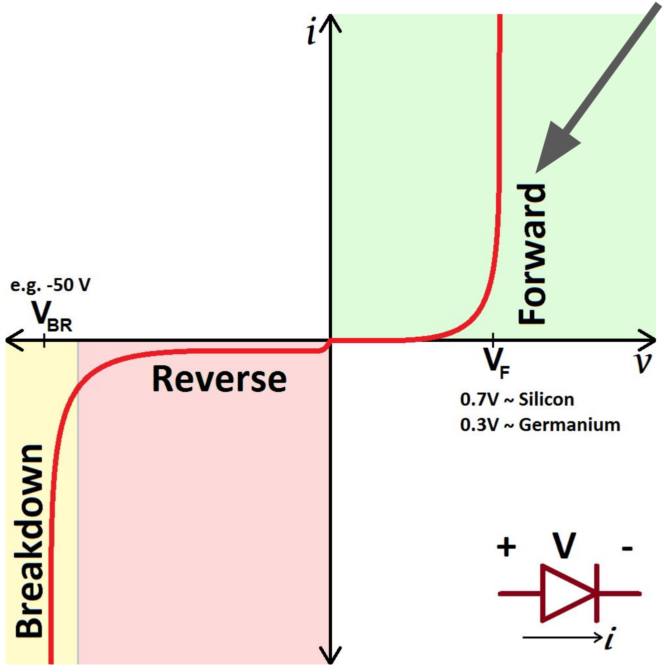
Require a resistor to limit the current

No current - nothing happens

A little current - nice happy lights

Lots of current - fire, burnt parts, sadness

Very sensitive here



Img: https://cdn.sparkfun.com/assets/4/4/a/5/b/5175b518ce395f2d49000000.png

Current won't flow* until voltage exceeds the forward voltage drop (Vfd) of the LED
Knowing max current of the LED lets us set an appropriate current limiting resistor

0.025A=(3.3-2)V/R
R=1.3/0.025=52 Ohms

I=(3.3-Vfd)/R

ELECTRO-OPTICAL CHARACTERISTIC TA=25℃

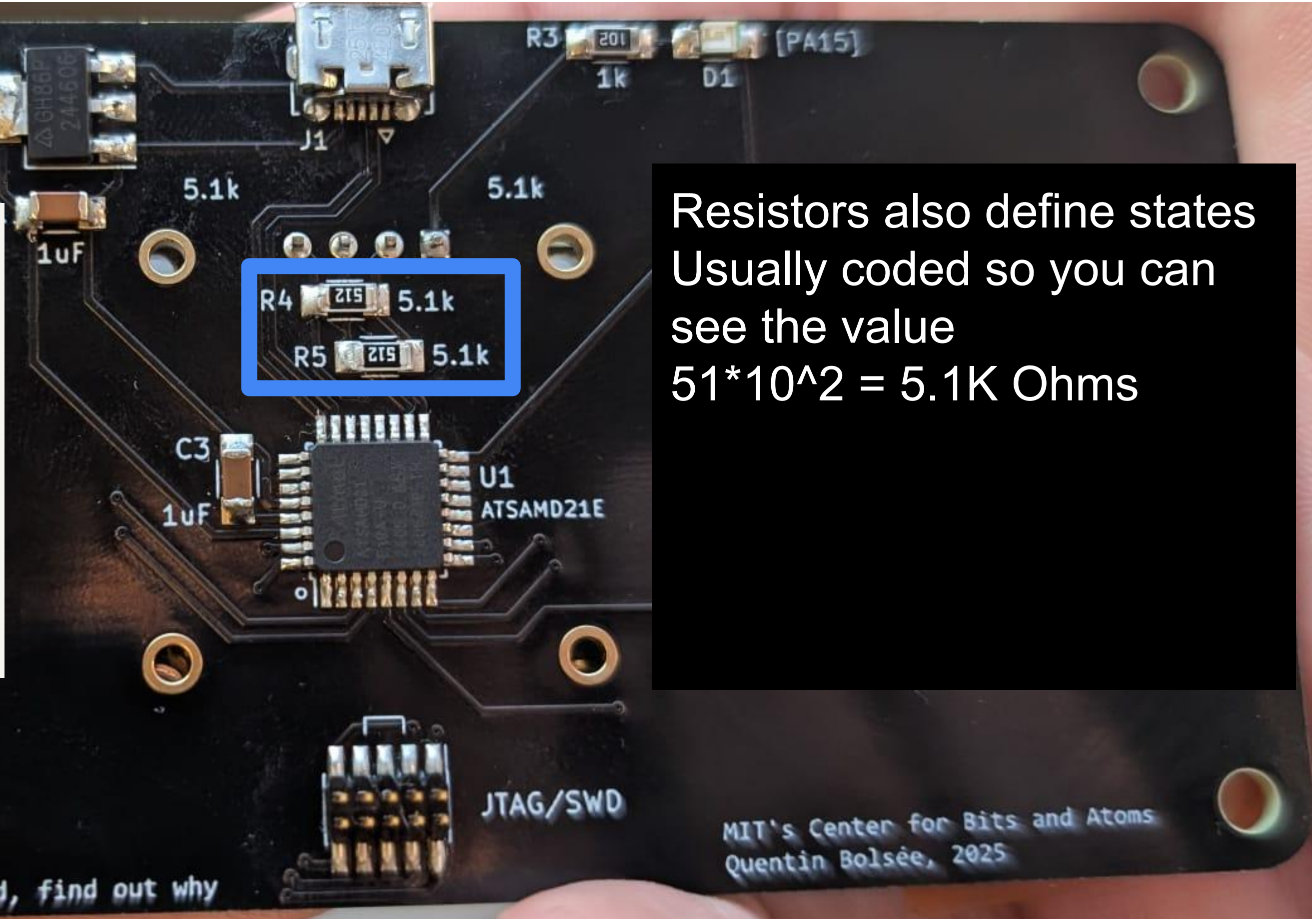
PARAMETER	MIN	TYP	MAX	UNITS	TEST COND
PEAK WAVELENGTH	-	632	-	nm	If=20mA
FORWARD VOLTAGE	-	2.0	2.4	Vf	If=20mA
REVERSE CURRENT	-	-	10	uA	VR=5V
LUMINOUS INTENSITY	-	38	-	mcd	If=20mA
VIEWING ANGLE	-	130	-	2x theta1/2	-
EMITTED COLOR	RED				
EPOXY LENS FINISH	WATER CLEAR				

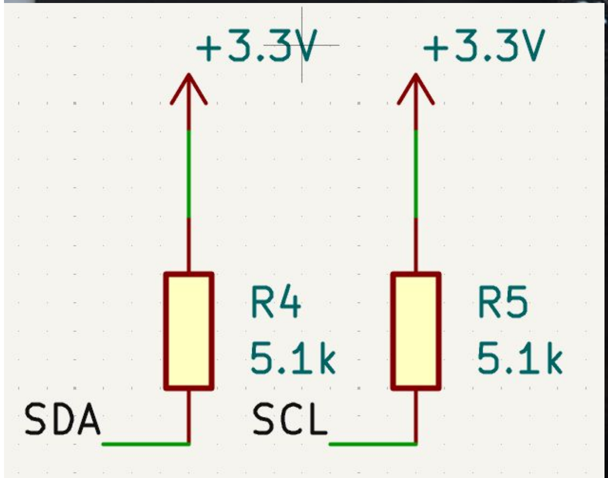
ABSOLUTE MAXIMUM RATINGS TA=25℃

PARAMETER	MAX	UNITS
PEAK FORWARD CURRENT*	60	mA
FORWARD CURRENT	25	mA
REVERSE VOLTAGE	5	V
POWER DISSIPATION	60	mW
STORAGE TEMPERATURE	-40 TO +90	℃
OPERATING TEMPERATURE	-40 TO +85	℃

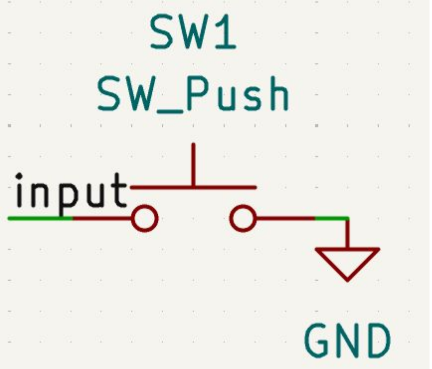
* 1/10 DUTY CYCLE 0.1ms PULSE.

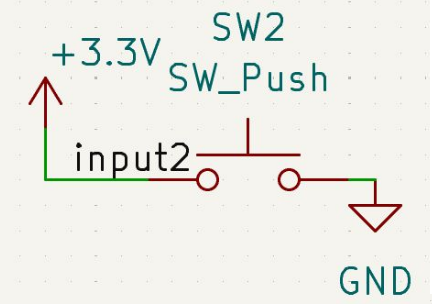
Resistors also define states
Usually coded so you can see the value
$51 * 10^2 = 5.1K$ Ohms

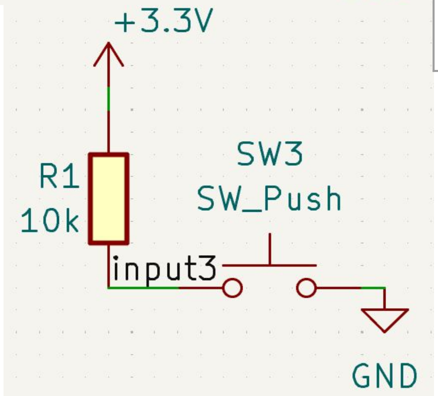




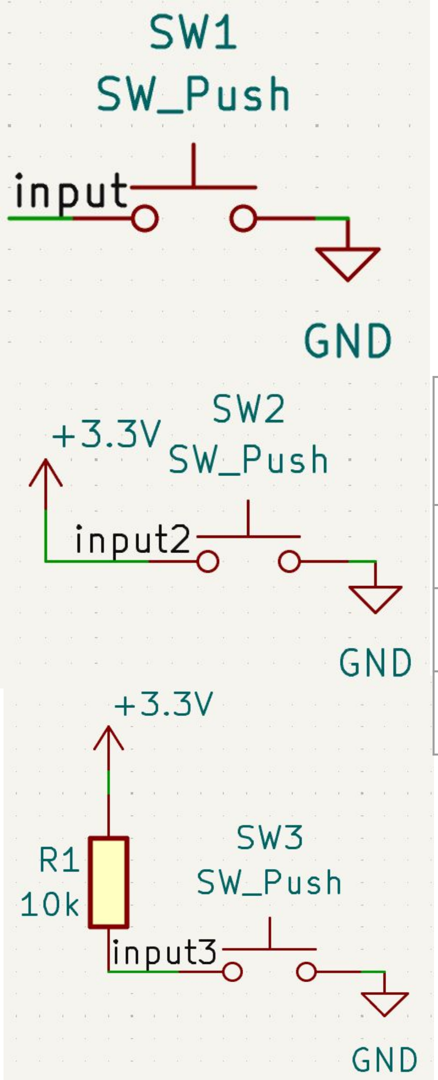
What is the voltage of a wire that is just hanging out in space?



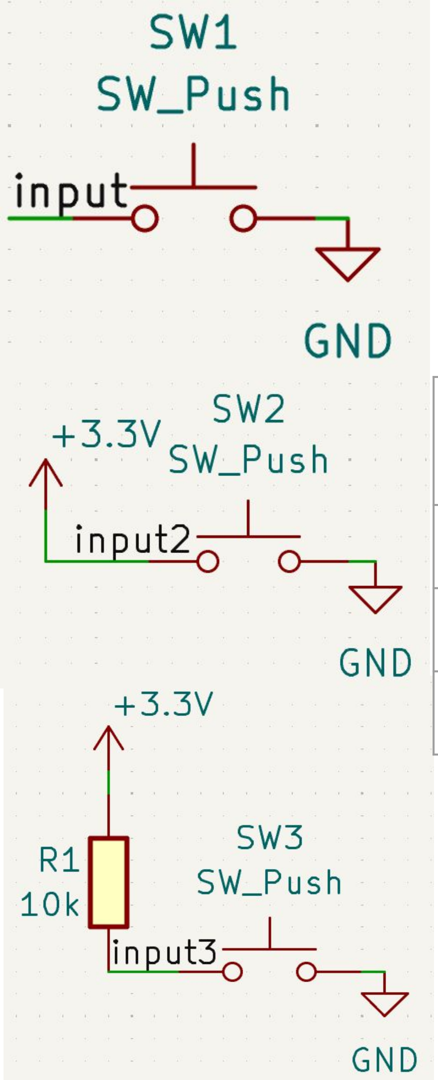




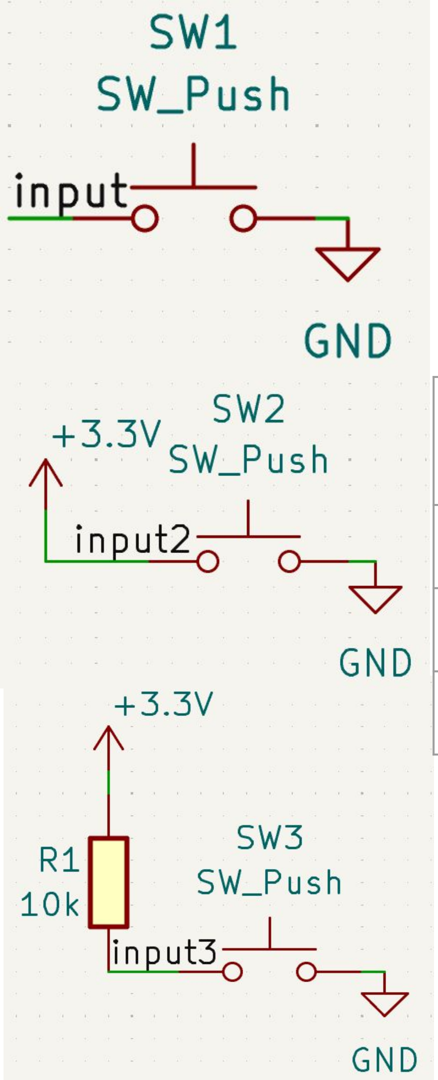
Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1		
SW2		
SW3		



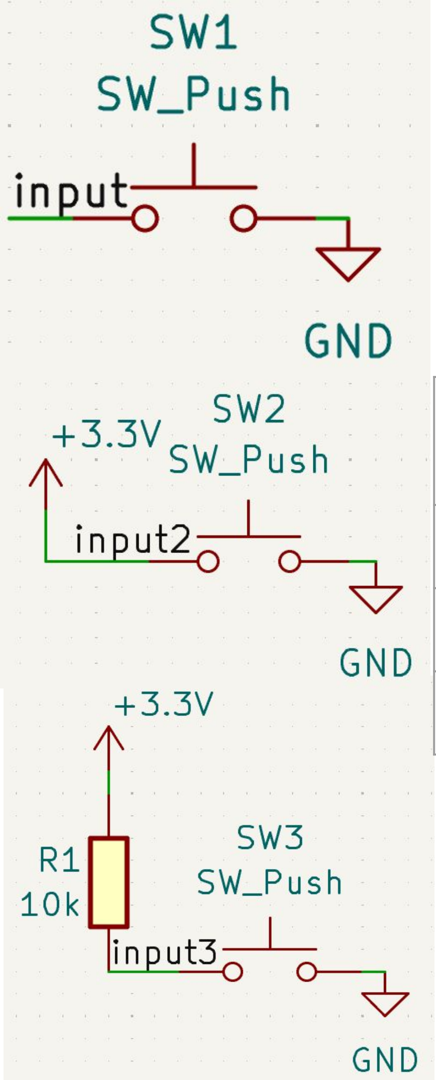
Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1	???	
SW2		
SW3		



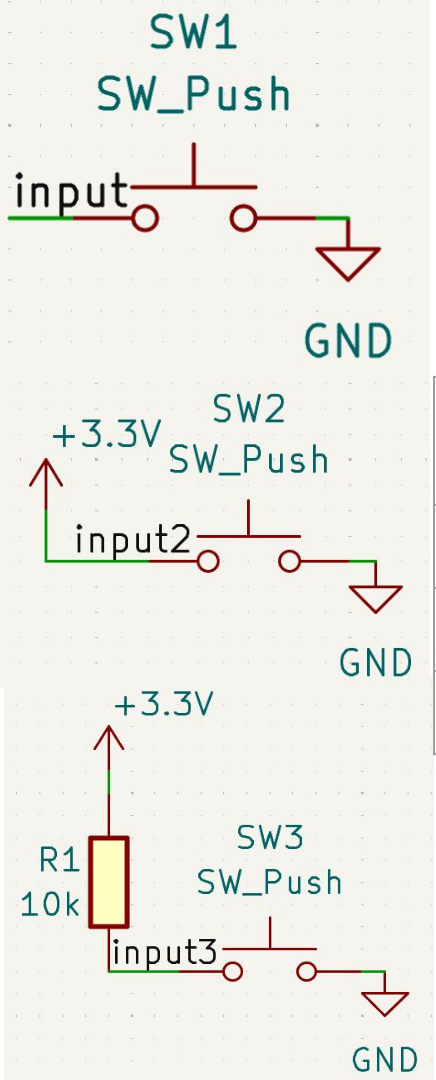
Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1	???	Gnd (0 Volts)
SW2		
SW3		



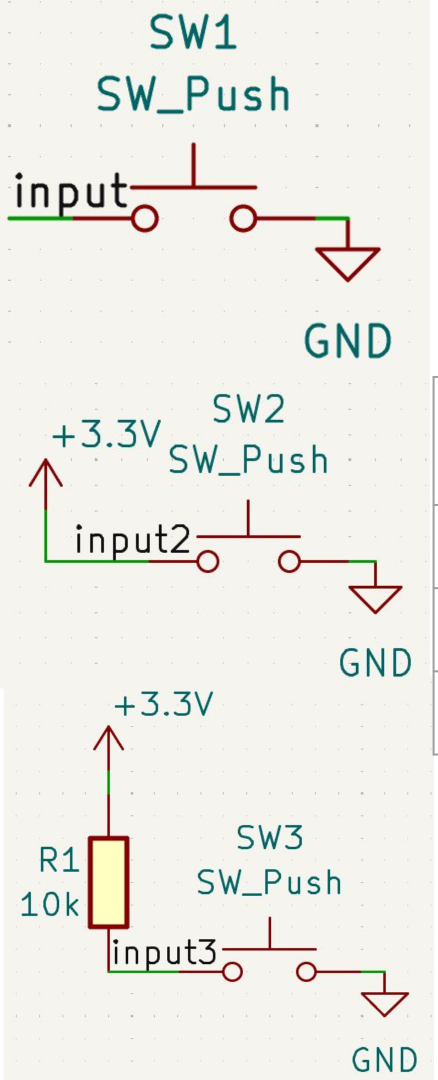
Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1	???	Gnd (0 Volts)
SW2	3.3V	
SW3		



Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1	???	Gnd (0 Volts)
SW2	3.3V	3.3/Gnd/ 🔥
SW3		



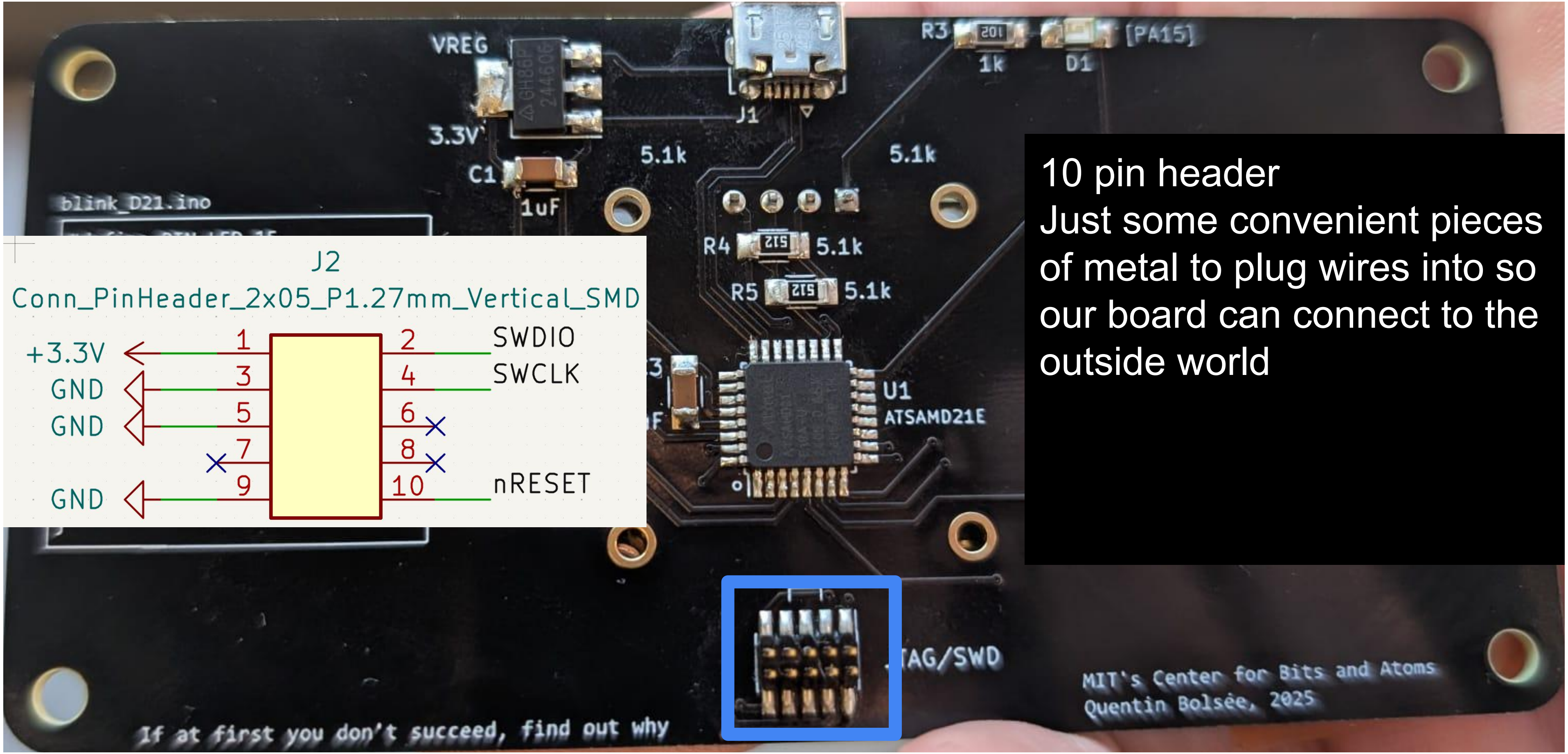
Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1	???	Gnd (0 Volts)
SW2	3.3V	3.3/Gnd/
SW3	3.3V	

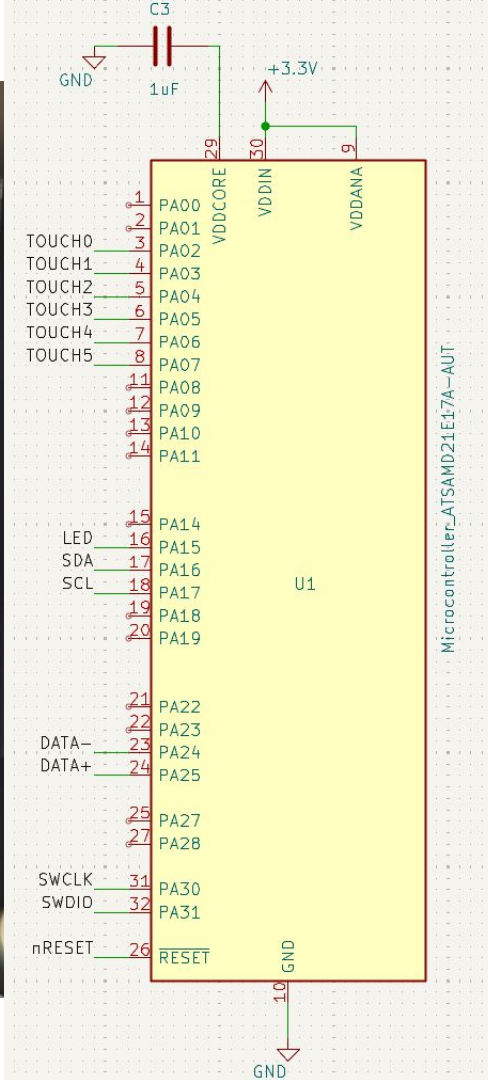


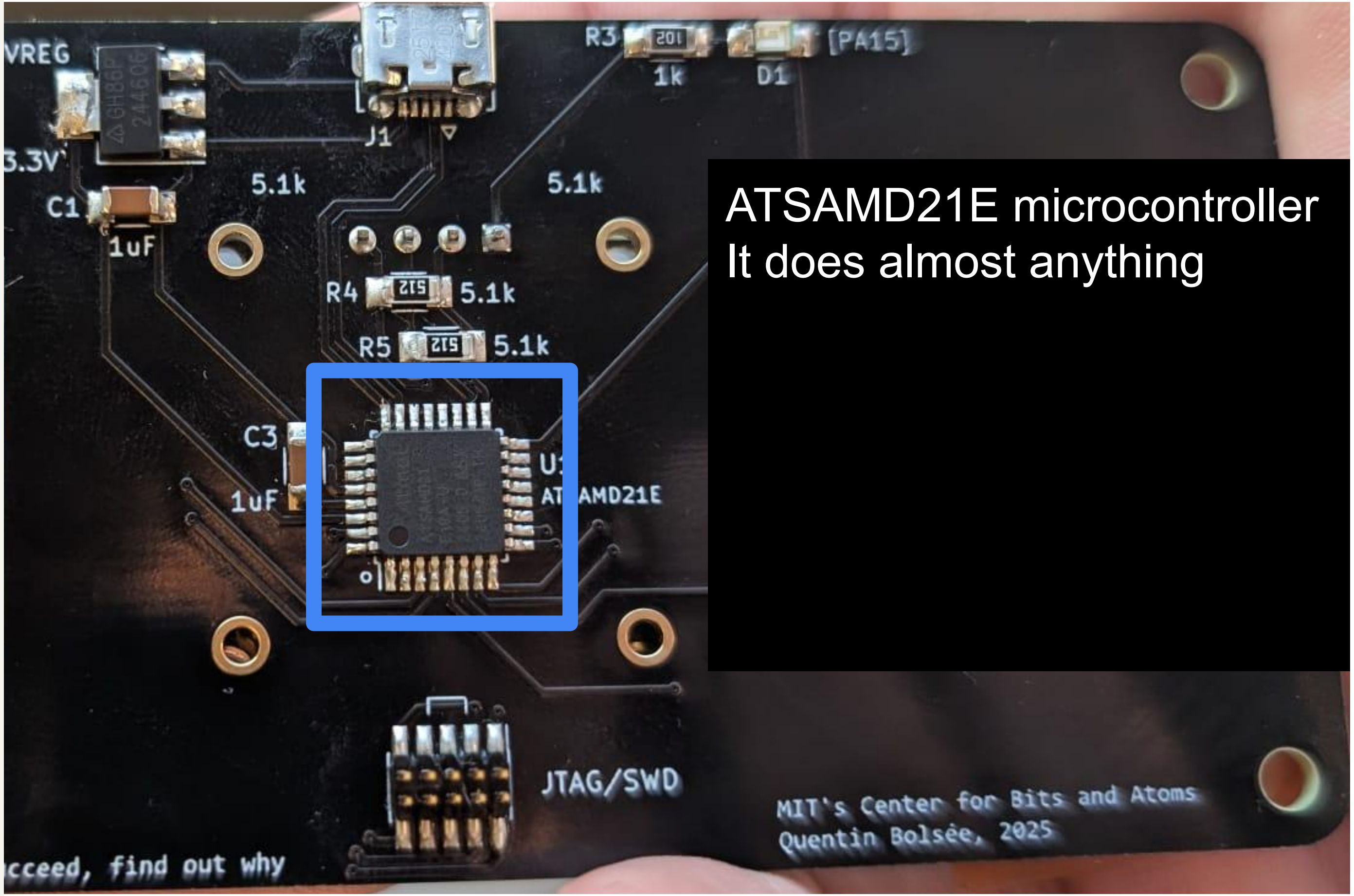
Scenario	Voltage at input when not pushed	Voltage at input when pushed
SW1	???	Gnd (0 Volts)
SW2	3.3V	3.3/Gnd/ 🔥
SW3	3.3V	Gnd (0 Volts)

With a power dissipation of only 1mW

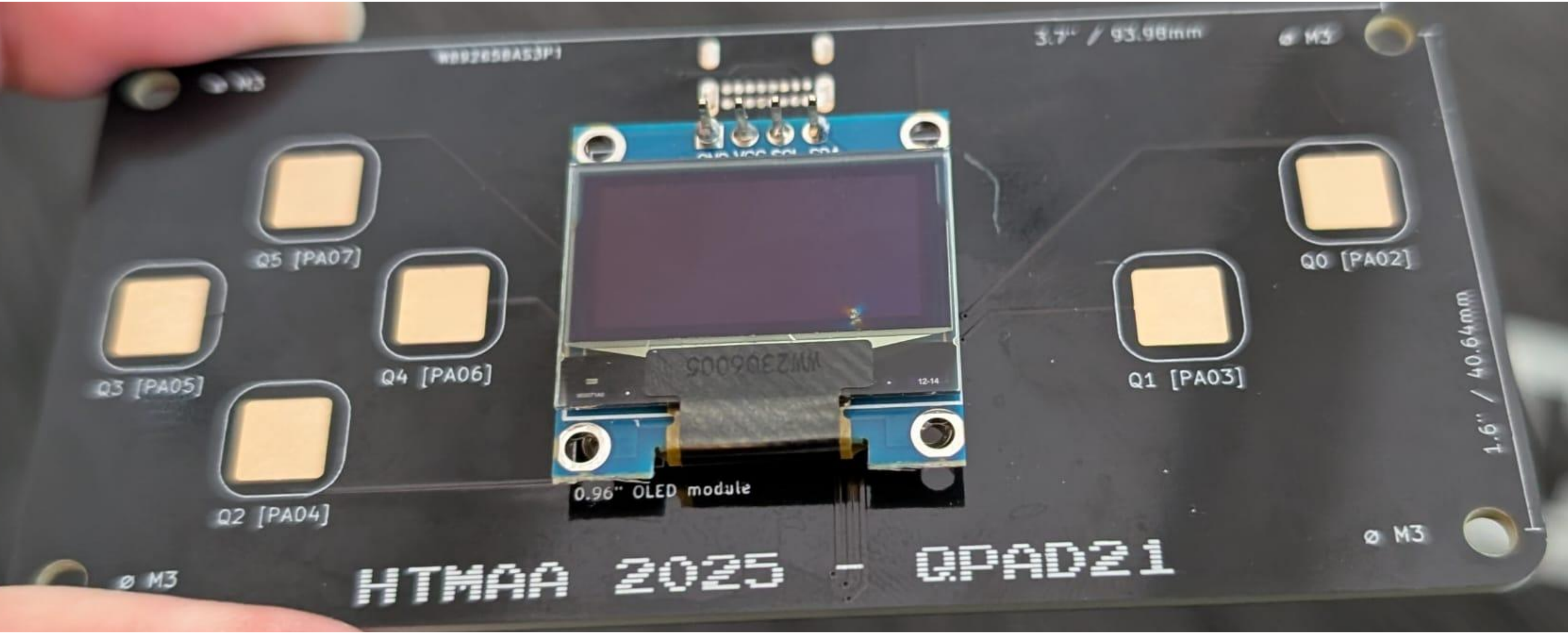
10 pin header
Just some convenient pieces of metal to plug wires into so our board can connect to the outside world

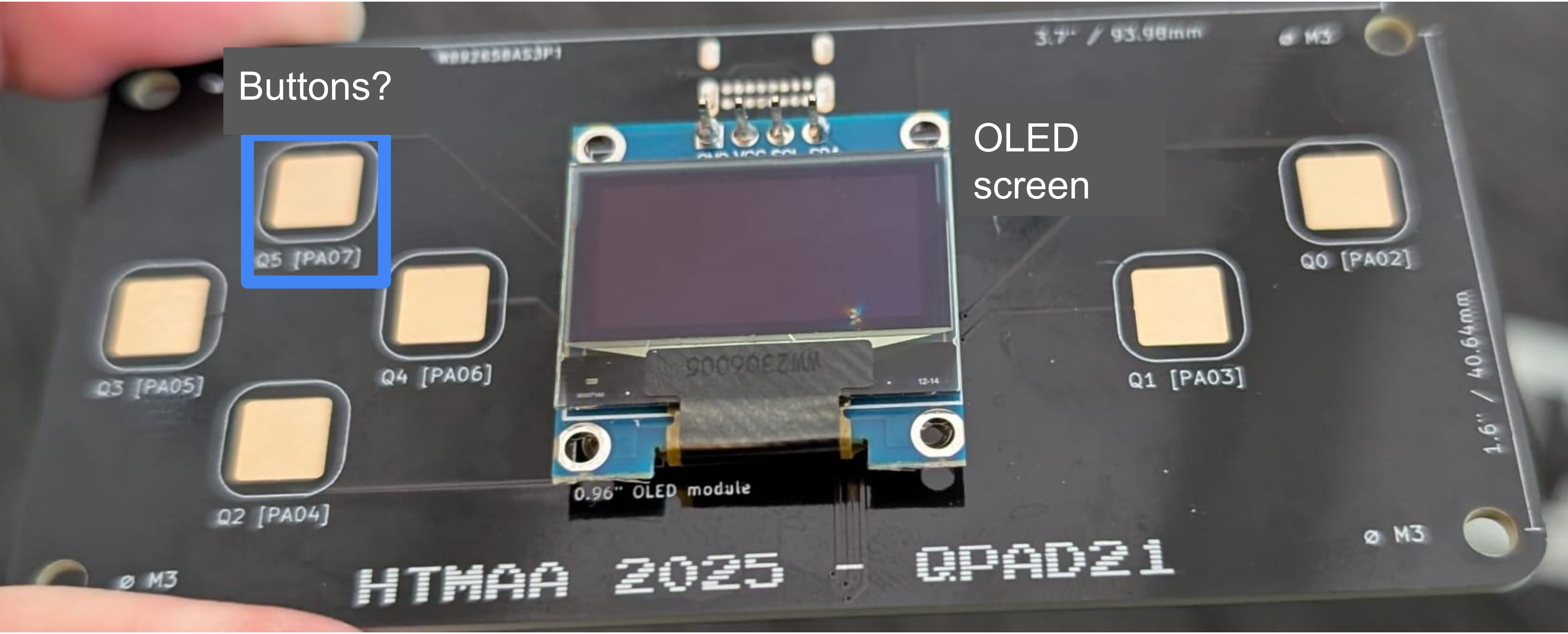






ATSAMD21E microcontroller
It does almost anything

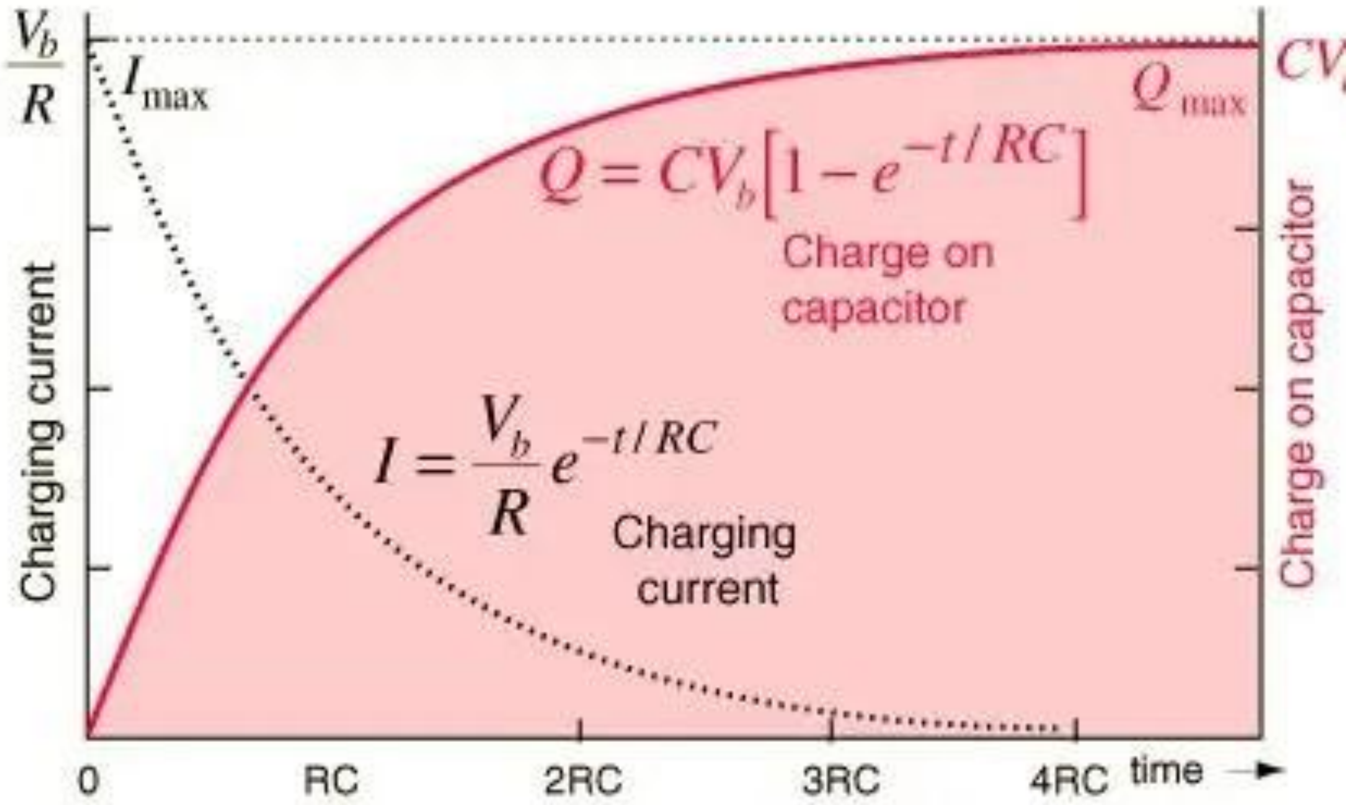

3.7" / 93.98mm
ø M3
ø M3
Q5 [PA07]
Q0 [PA02]
Q3 [PA05]
Q4 [PA06]
Q1 [PA03]
Q2 [PA04]
0.96" OLED module
1.6" / 40.64mm
ø M3
ø M3
HTMAA 2025 - QPAD21


Buttons?
OLED
screen
3.7" / 93.98mm
⌀ M3
Q5 [PA07]
Q4 [PA06]
Q3 [PA05]
Q2 [PA04]
Q0 [PA02]
Q1 [PA03]
0.96" OLED module
1.6" / 40.64mm
⌀ M3
⌀ M3
HTMAA 2025 - QPAD21

How is that a button?

Capacitive sensing/step response is a bit of magic that can be employed in many different scenarios

Either measure rise time
Or wait a fixed time and measure voltage

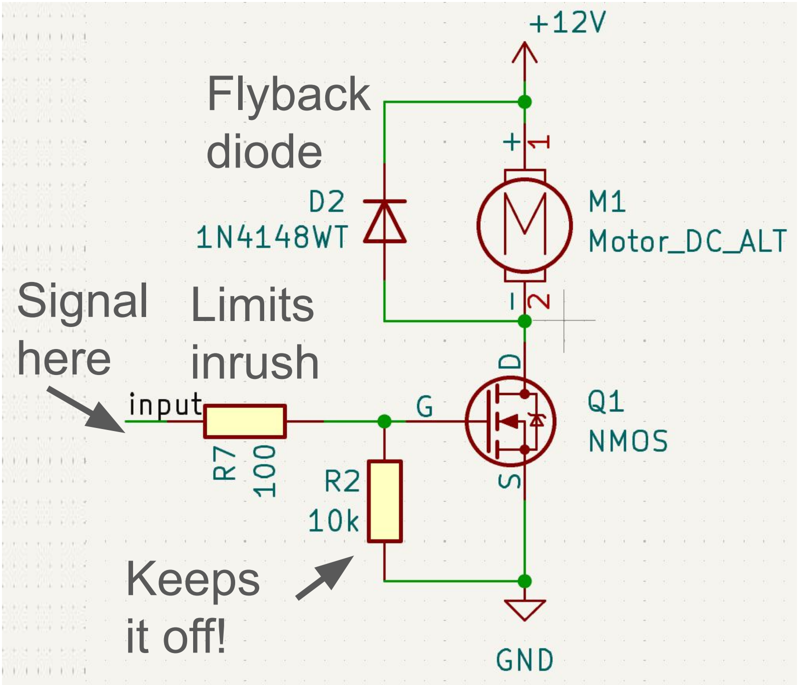


More components not used in this design

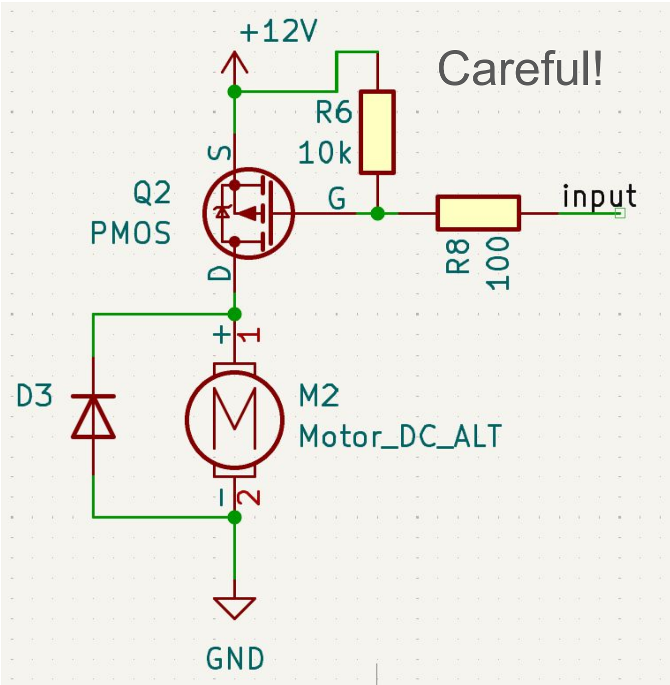
- Mosfets
  - Control large power devices with small power signals
  - Incredibly useful
- Inductors
- Opamps
  - Do math on signals
  - Multiplication, division, integration, addition, subtraction, etc
- Relays

Mosfets

- Come in 2 flavors, N and P channel
  - N channel conduct current when the Gate is high and go below the load
  - P channel conducts current when the Gate is low and go above the load (less useful)
- Allow microcontrollers to enable/disable very large loads - normally can only handle ~20mA ie 1 or 2 bright LEDs per pin.
- Remember to include the pull-up/down resistor, current limiting resistor, and maybe a flyback diode!

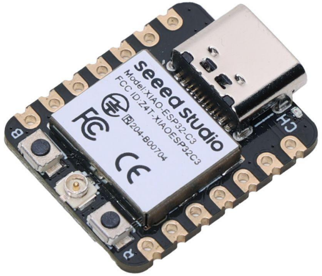


pull-up/down resistors keep the device off at rest.
Input resistors reduce inrush current.
Voltage spikes arise from inductive loads
V=L*dI/dT

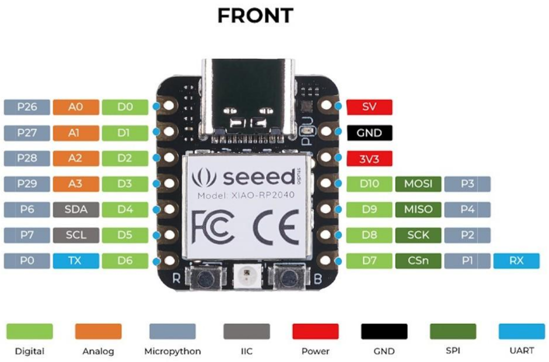


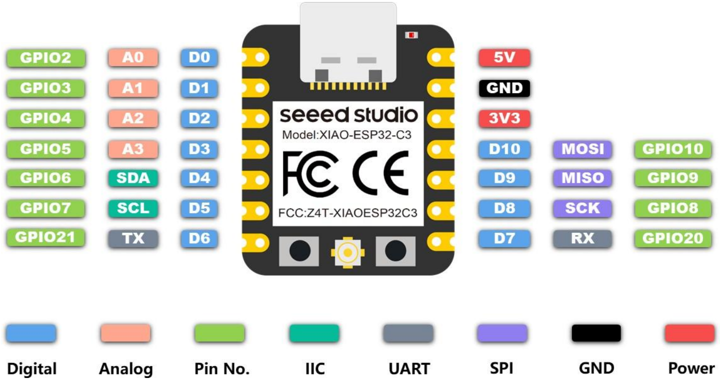
Seeed XIAO ("小”： means ”small”)

RP2040

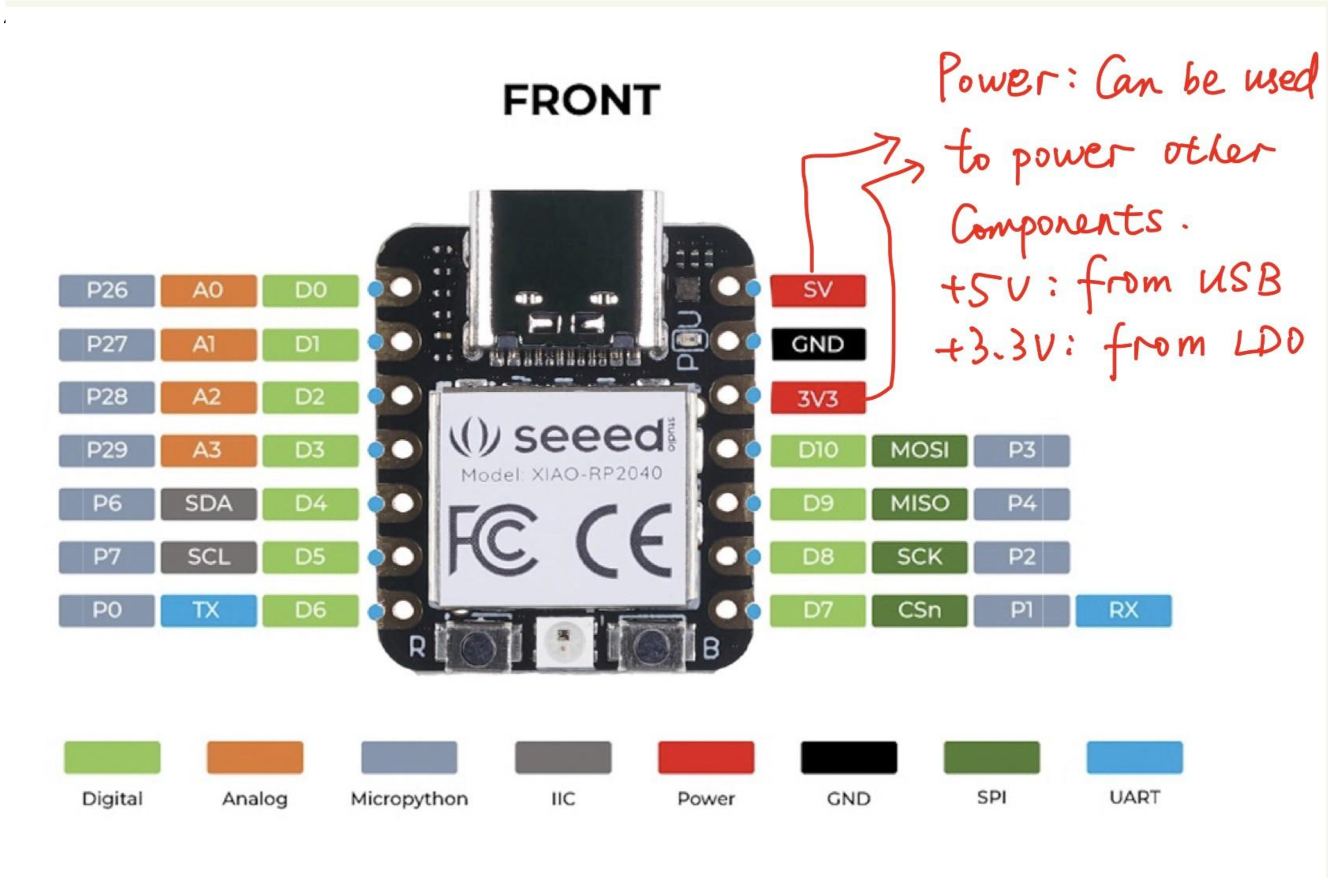


ESP32C3





Seeed XIAO ("小”: means ”small”



Simulation in Wokwi vs Falstad

Wokwi

Pros

- Easy
- Intuitive
- Pretty
- Large libraries
- Has Wifi implemented*

Cons

- No notion of voltage, current, power, etc. can lead to blown components
- Bigger/private projects want the paid tier

Falstad

Pros

- Actually powerful
- Graphs of voltage current power etc

Cons

- Has that opensource look (like my slides)
- Less widely used
- No Wifi

Digital Simulation in Wokwi/Falstad

Link1
Link2
Link3