THE ART AND SCIENCE OF PCB DESIGN

# lecture 5 - DEBUGGING!

**Electrons, often** don't like doing what they're told. **Now we want to** *use our advanced electrical engineering knowledge* **to figure out how** and why they may be unhappy!



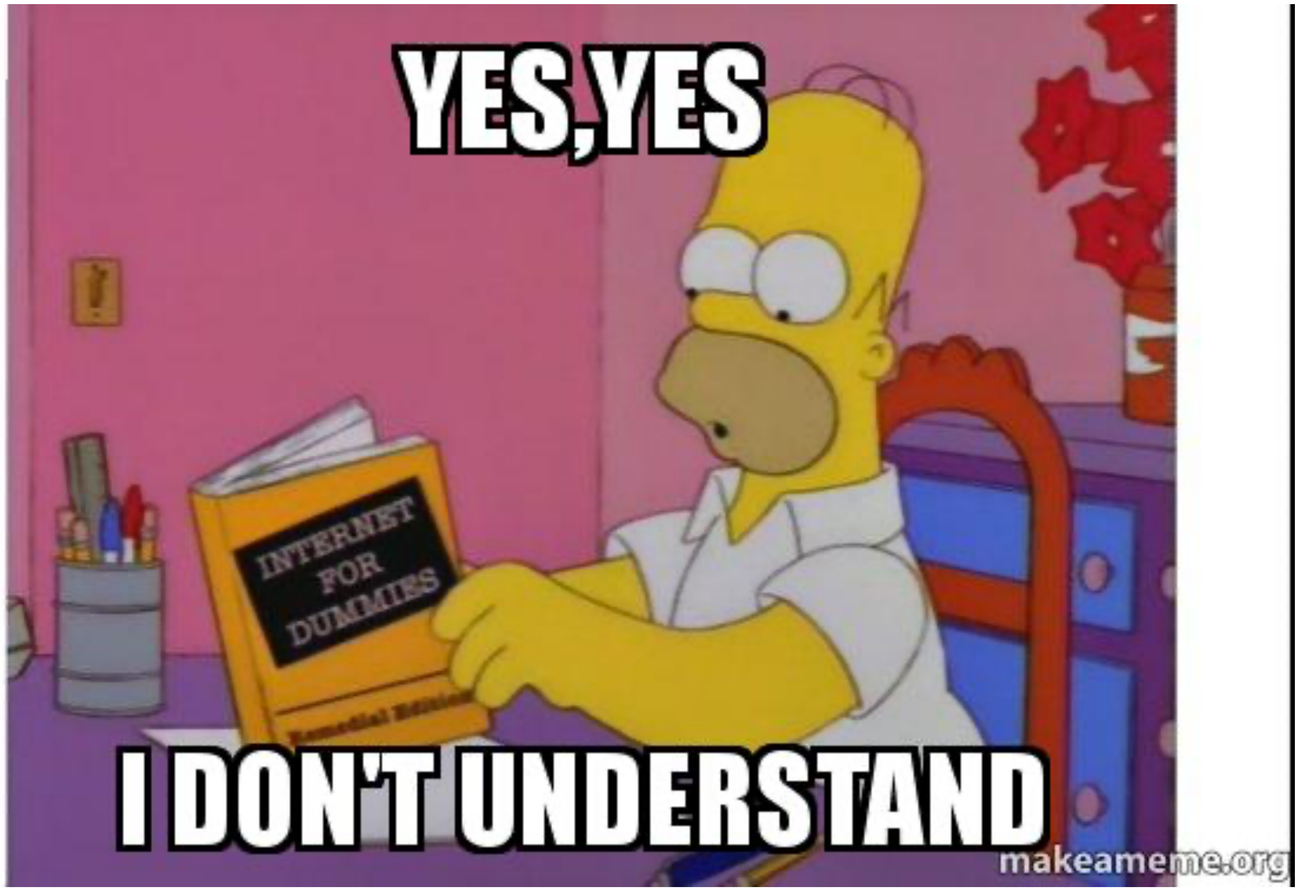
@ MIT

# 1) subject evals!
# 2) DR Signups!

# Interrogating your Circuit

# <!— w/ Agent Rick Dicker ofc —>

# STEP 1 — let’s understand the system



# What does a BMS Do?

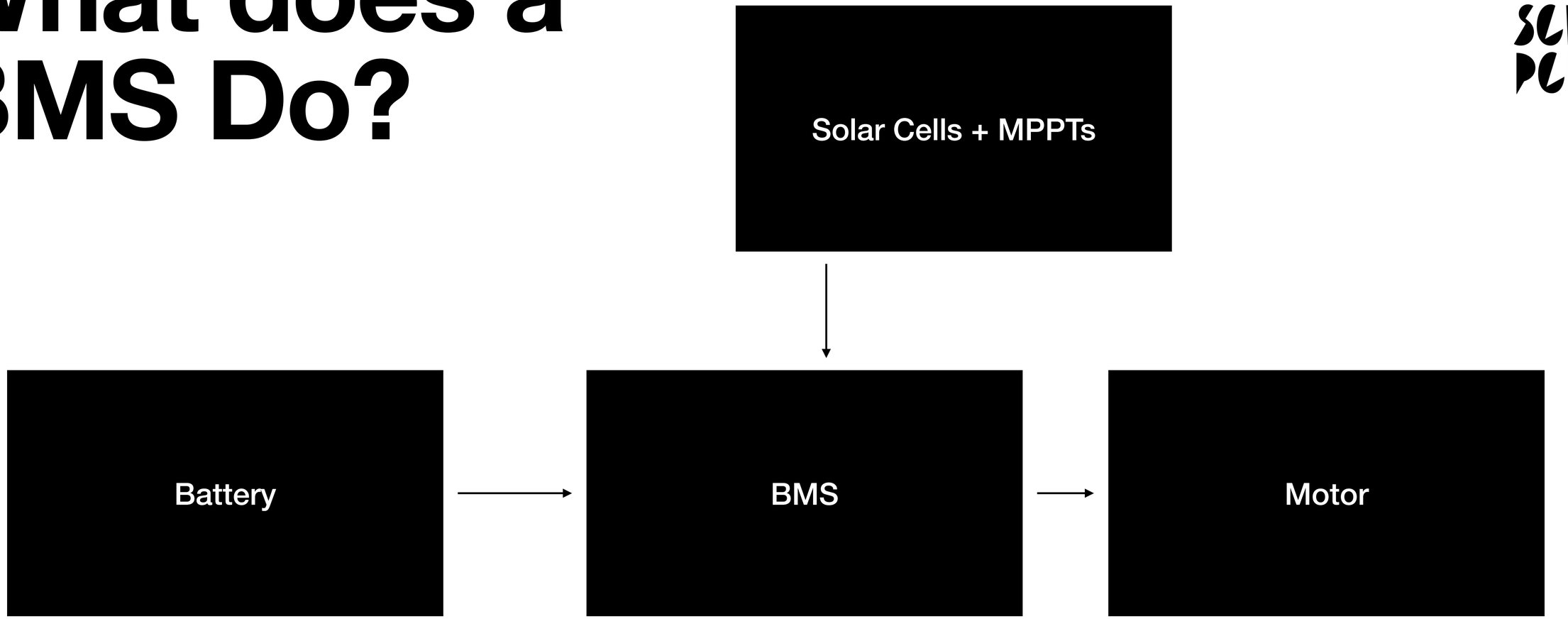
THE ART AND SCIENCE of PCB DESIGN

# What does a BMS Do?

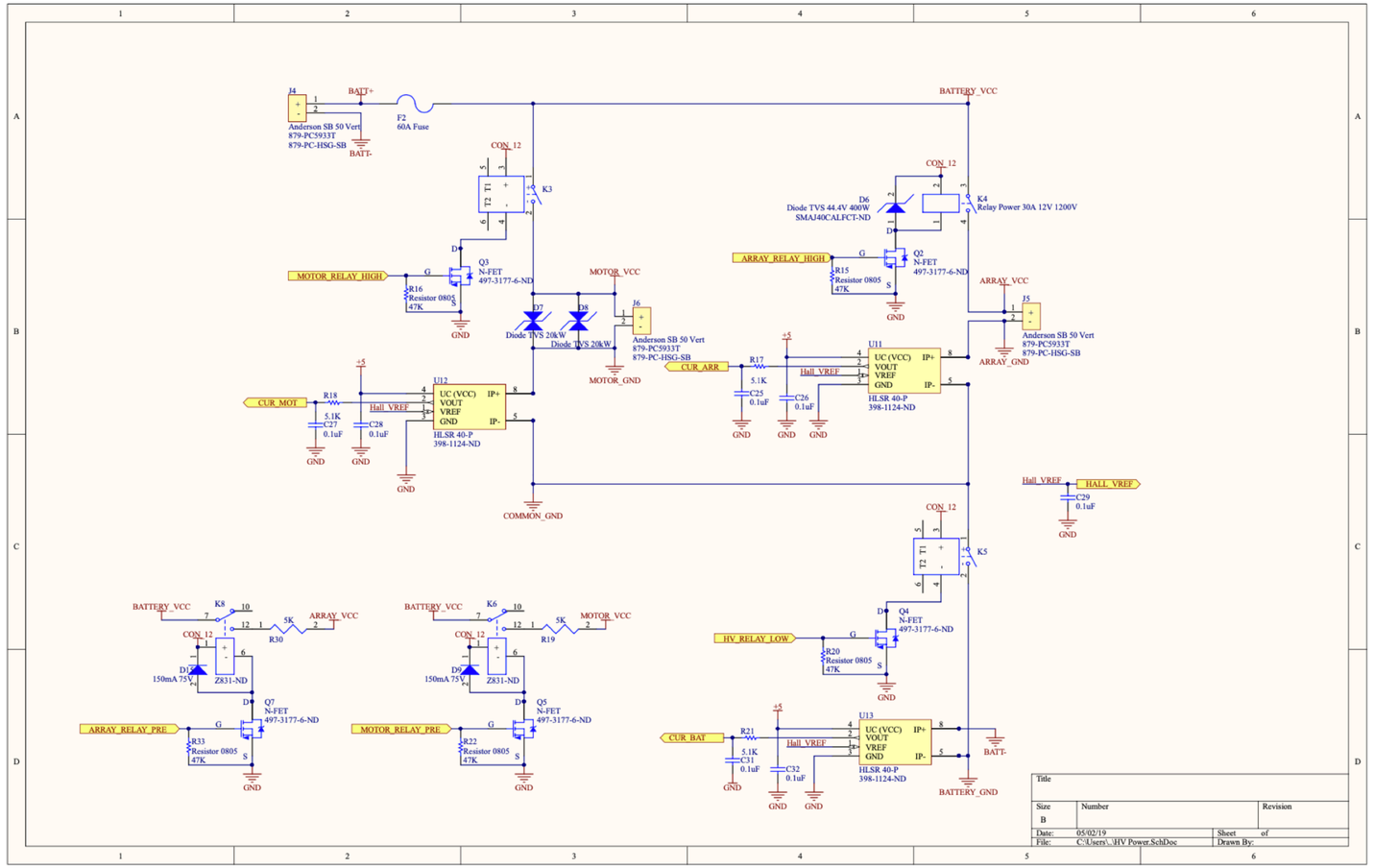
THE ART AND SCIENCE OF PCB DESIGN

**E1 - E-Stop**
**E2 - Under-voltage Lockout**
**E3 - Overvoltage Lockout**
**E4 - Overcurrent Lockout**
**E5 - Overtemperature Protection**
**E6 - Communications Error**

# What does a BMS Do?



# What does a BMS Do?



# STEP 2— identify the problem

# Ok so what if I told you…

# Ok so what if I told you…

THE ART AND SCIENCE OF PCB DESIGN

## 1) I plugged in the battery to the car…

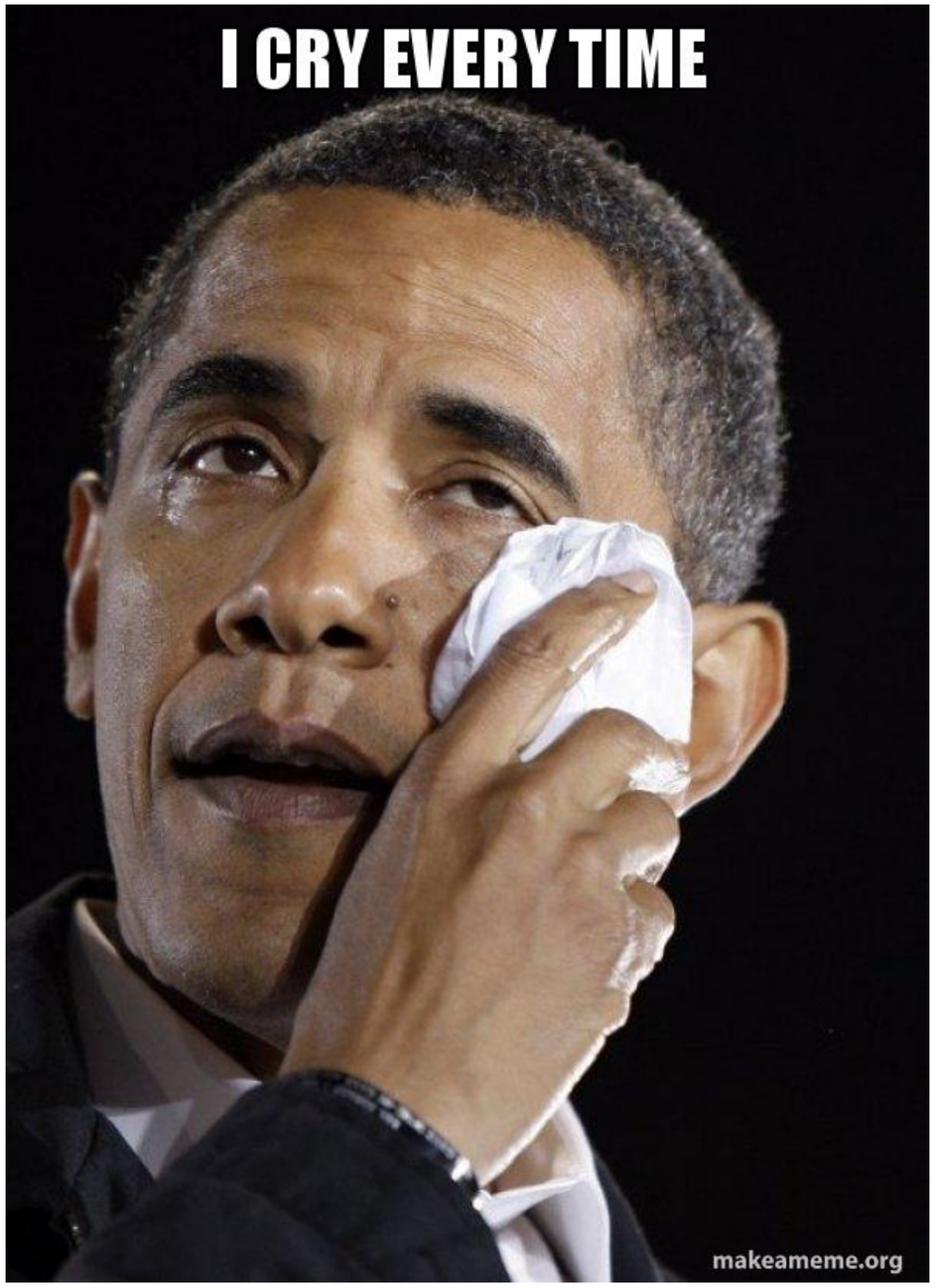
# Ok so what if I told you…

1) I plugged in the battery to the car…
2) I turned on the car…

# Ok so what if I told you…

1) I plugged in the battery to the car…
2) I turned on the car…
3) I IMMEDIATELY got an E4 error

# WHAT DO I DOOOOOOO??????????


I CRY EVERY TIME
makeameme.org

# Ok let's do some debugging on the board pull up the schematic from here —> https://pcb.mit.edu/lectures/lab_02/headboard.pdf

Step 1 —> unplug the array + motor + plug them in one at a time

Step 1 —> unplug the array + motor + plug them in one at a time

Just motor, no E4?

Something going on w/ the Array, MPPTs, or array power circuit

Just Array, no E4?

Something going on w/ the Motor controller, or motor power circuit

THE ART AND SCIENCE OF PCB DESIGN

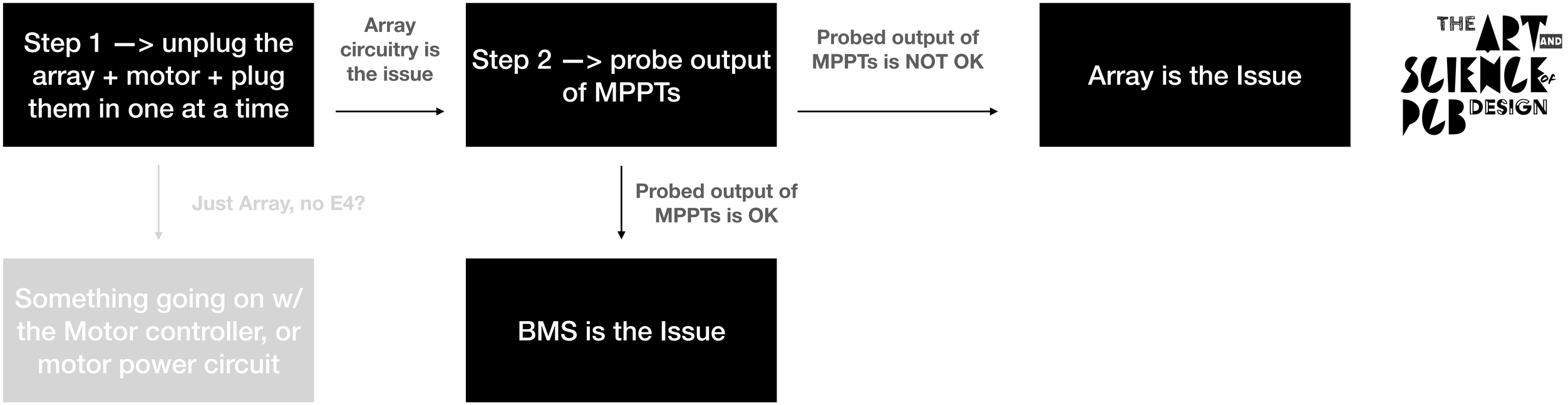
Step 1 —> unplug the array + motor + plug them in one at a time

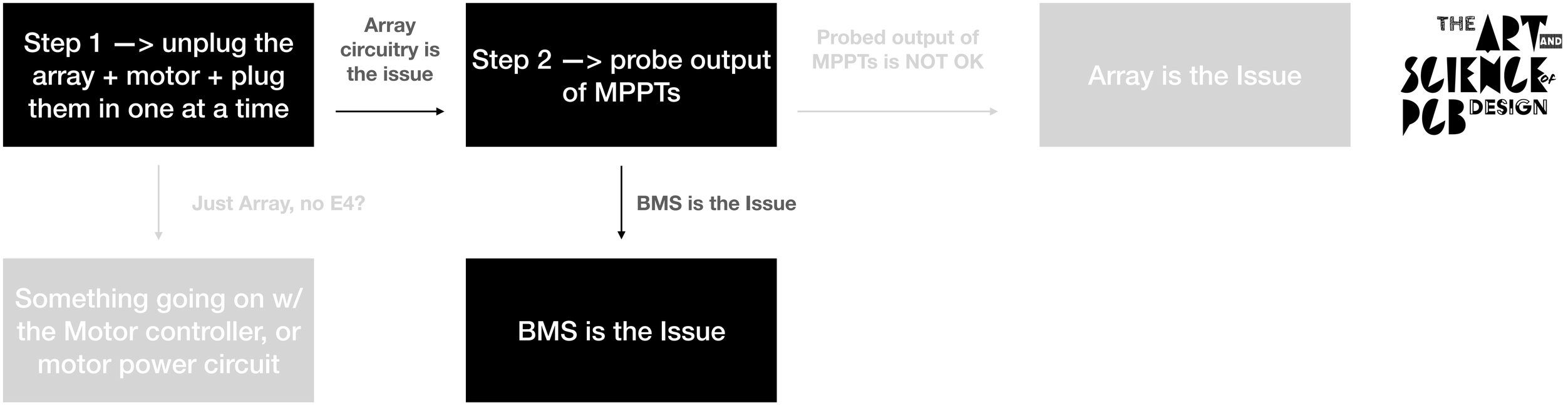
Just motor, no E4? → Something going on w/ the Array, MPPTs, or array power circuit

Just Array, no E4? → Something going on w/ the Motor controller, or motor power circuit

THE ART AND SCIENCE OF PCB DESIGN

**We get E4 when the array is plugged in if the motor is ON, or they the array is ON, but not if they're both OFF!**


Step 1 —> unplug the array + motor + plug them in one at a time
Array circuitry is the issue
Step 2 —> probe output of MPPTs
Probed output of MPPTs is NOT OK
Array is the Issue
Just Array, no E4?
Probed output of MPPTs is OK
Something going on w/ the Motor controller, or motor power circuit
BMS is the Issue


Step 1 —> unplug the array + motor + plug them in one at a time
Array circuitry is the issue
Step 2 —> probe output of MPPTs
Probed output of MPPTs is NOT OK
Array is the Issue
Just Array, no E4?
BMS is the Issue
Something going on w/ the Motor controller, or motor power circuit
BMS is the Issue

Step 1 —> unplug the array + motor + plug them in one at a time

Array circuitry is the issue

Step 2 —> probe output of MPPTs

Probed output of MPPTs is NOT OK

Array is the Issue

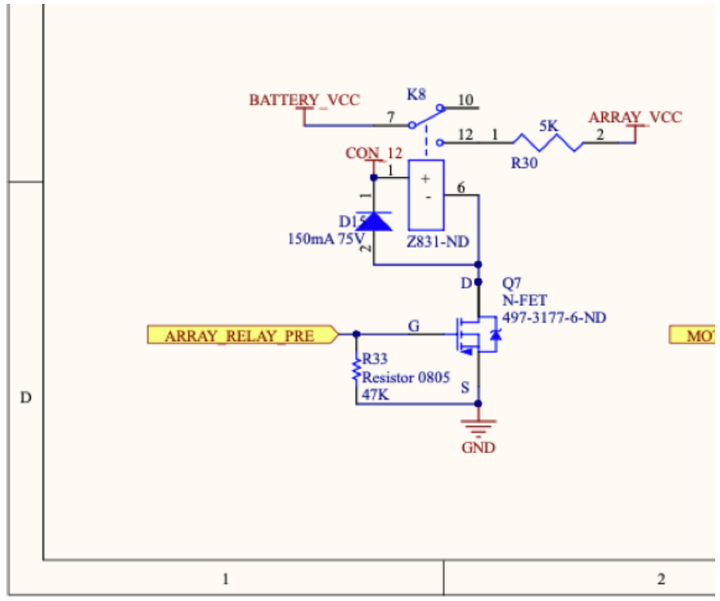
THE ART AND SCIENCE of PCB DESIGN

Just Array, no E4?

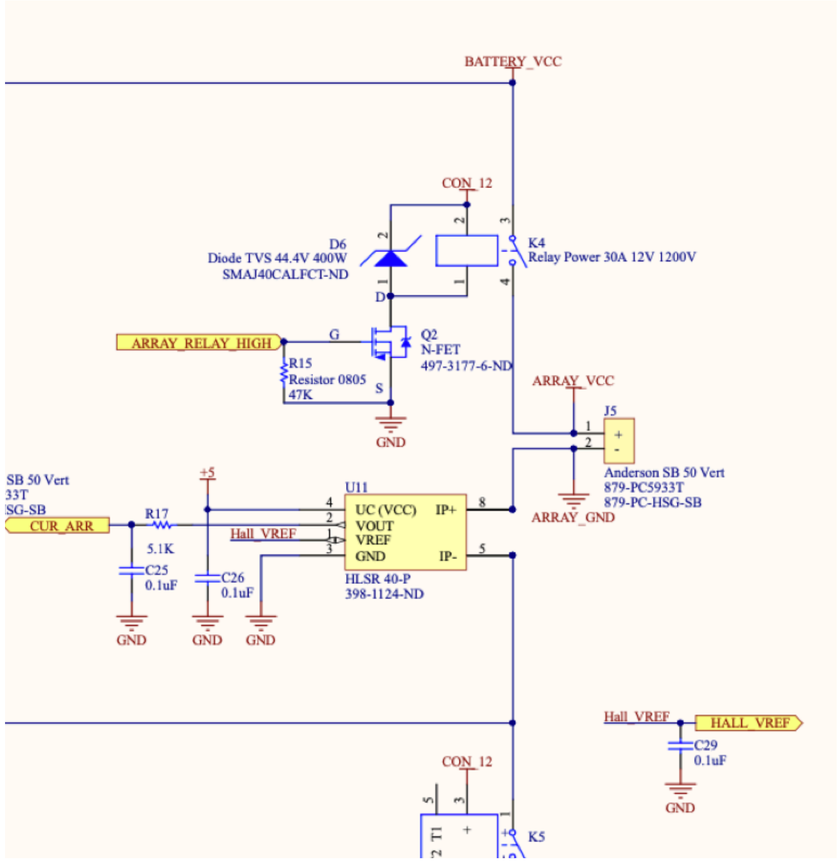
Something going on w/ the Motor controller, or motor power circuit

BMS is the Issue

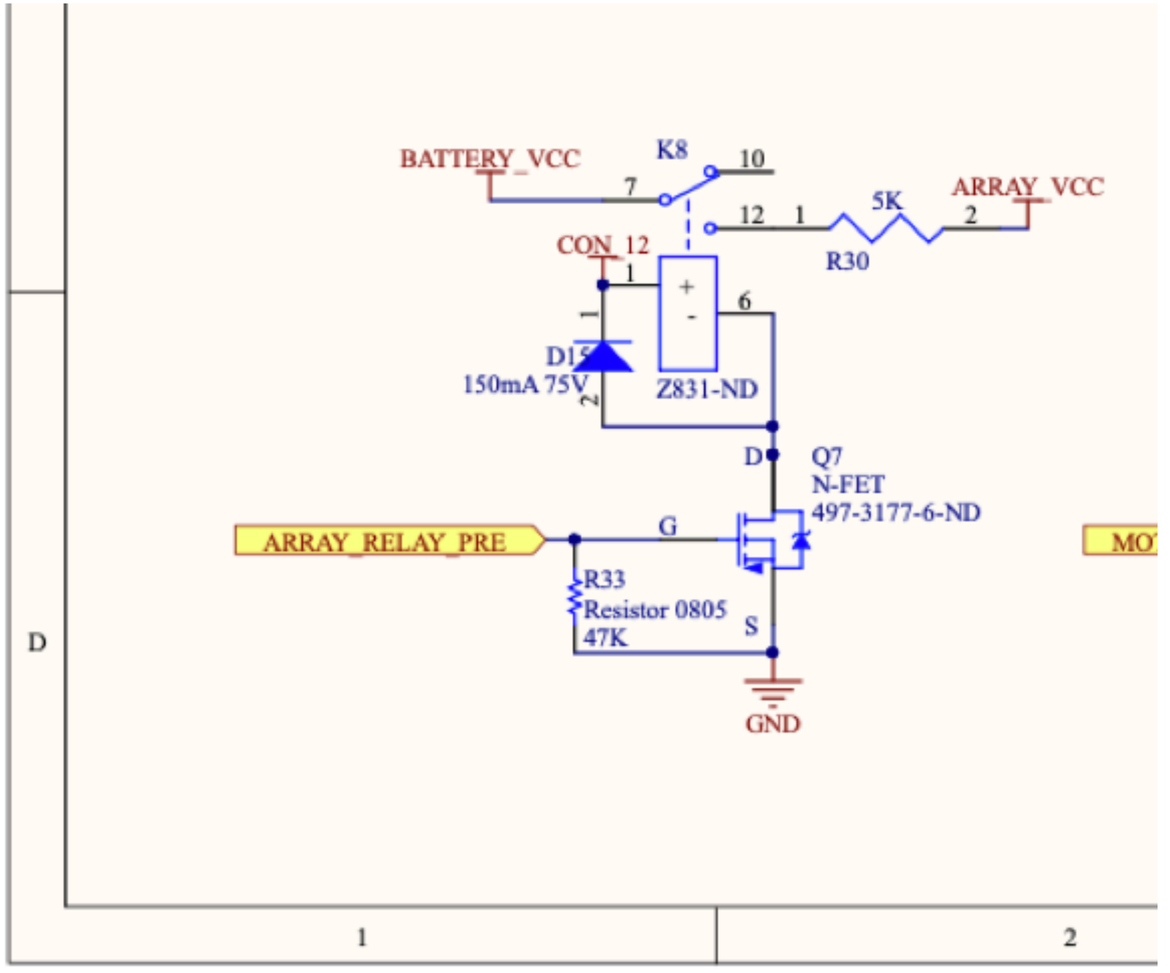
BMS is the Issue

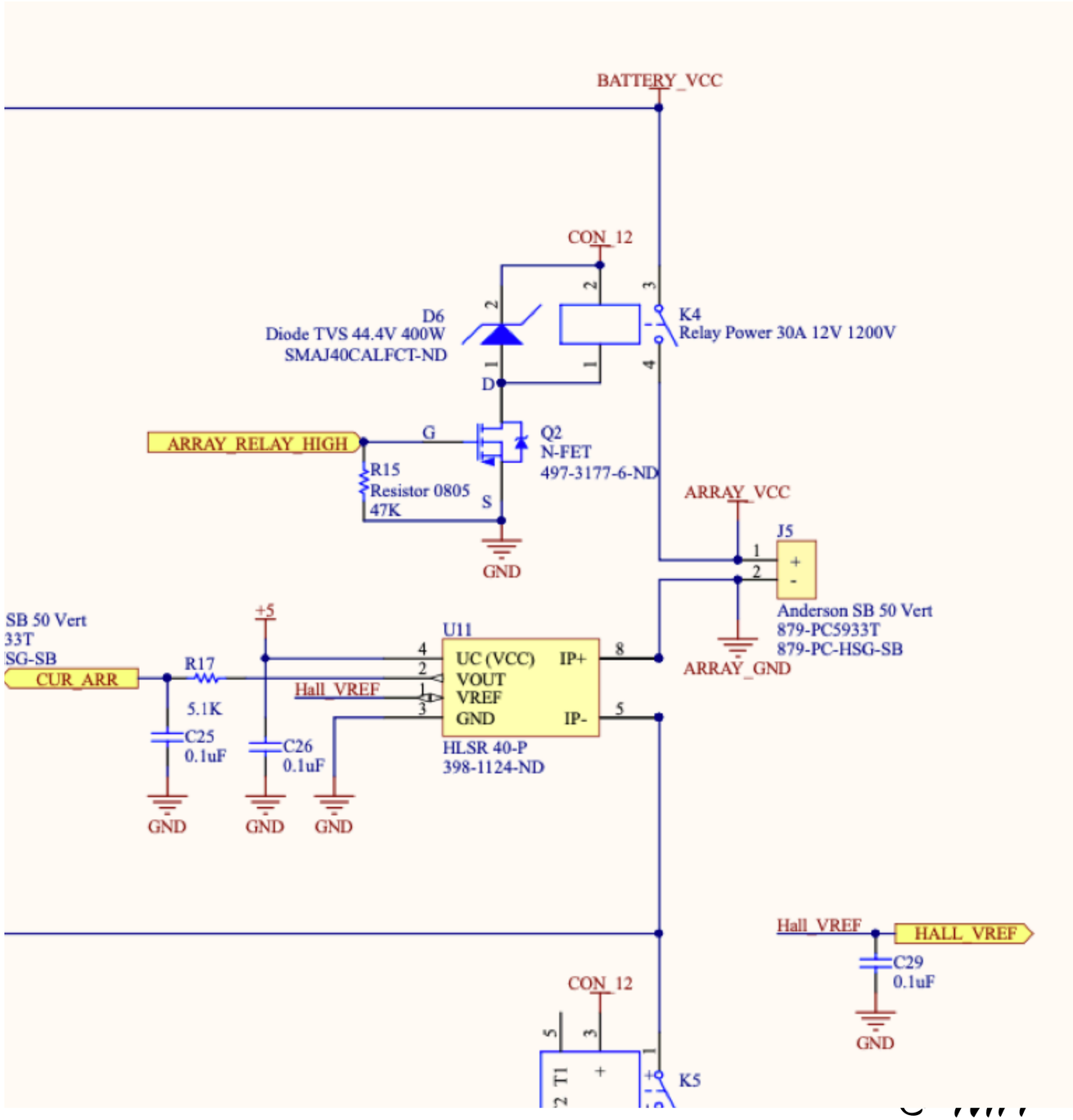



Look @ the Schematic!

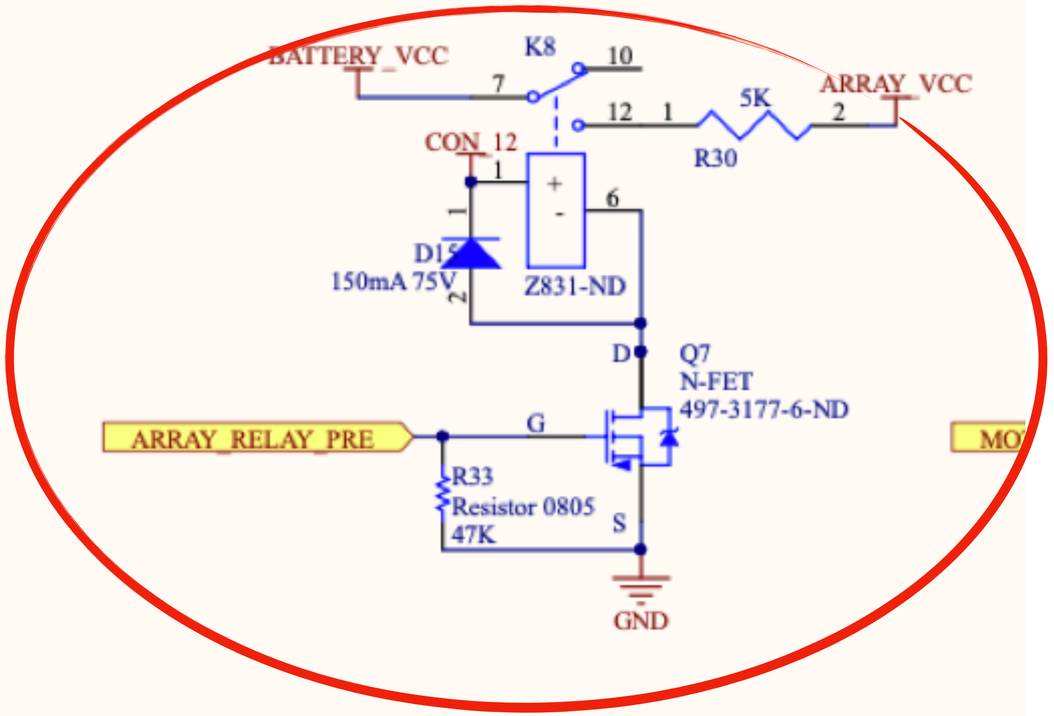


## Ok so let's think...

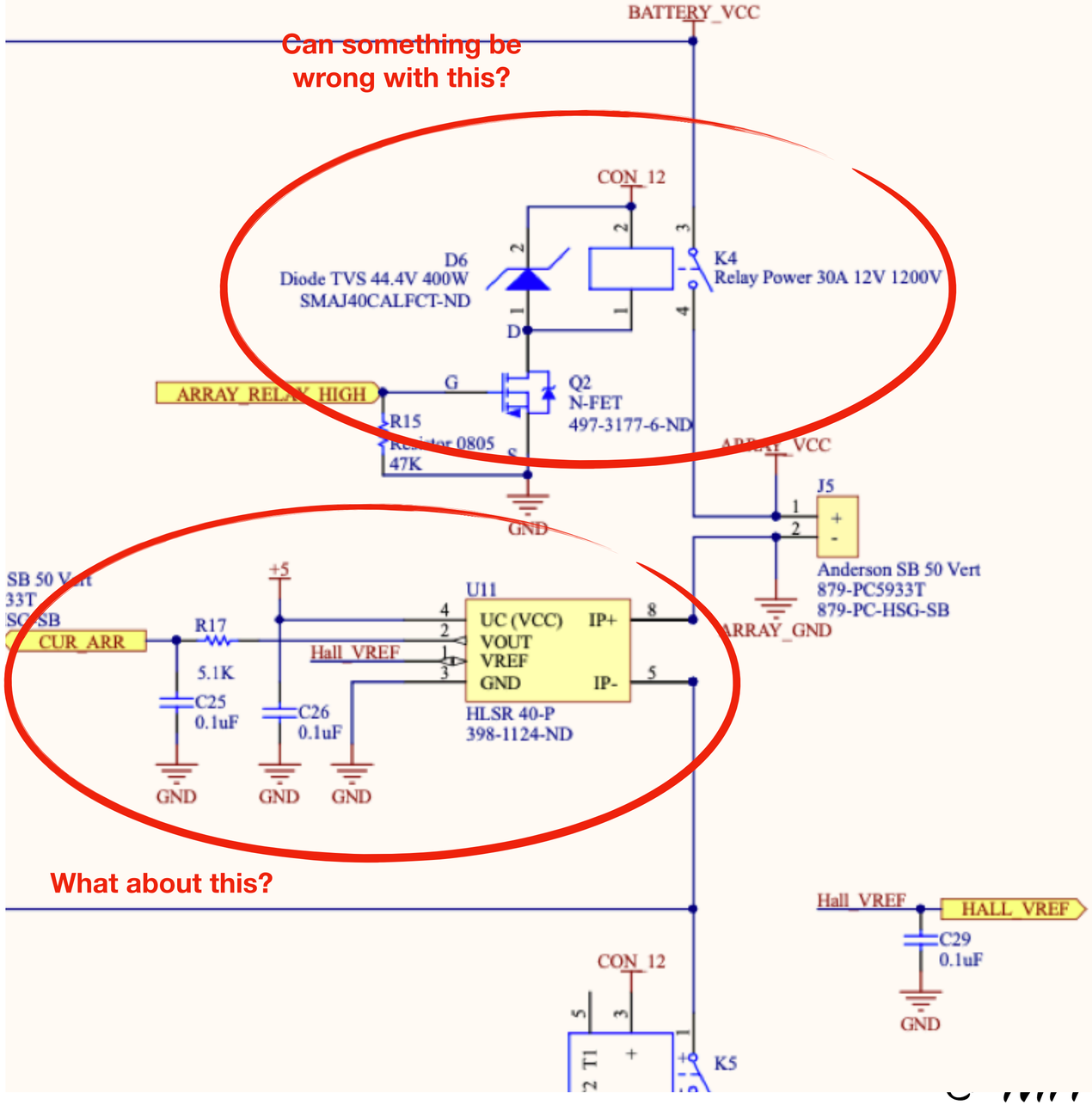


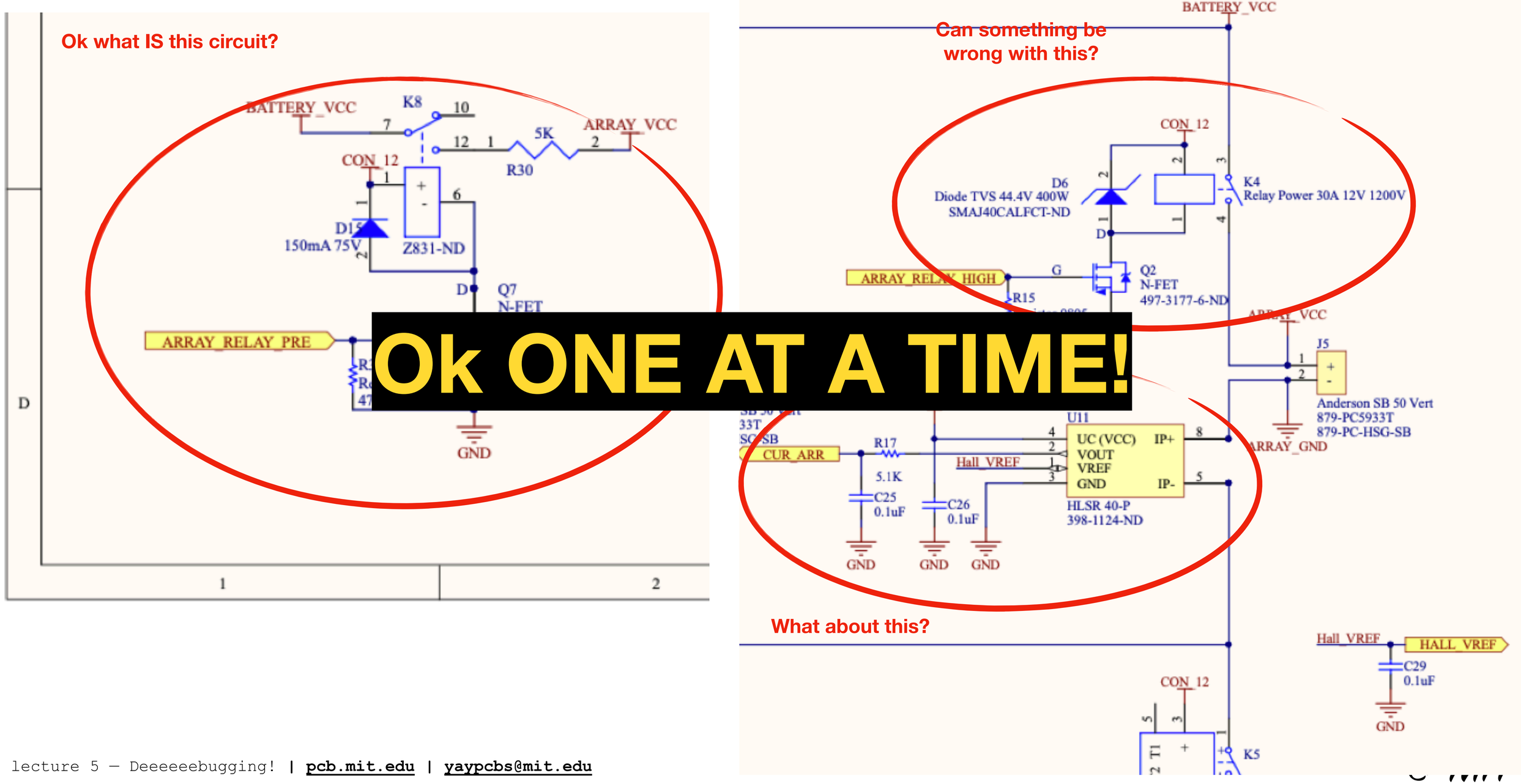



Ok what IS this circuit?



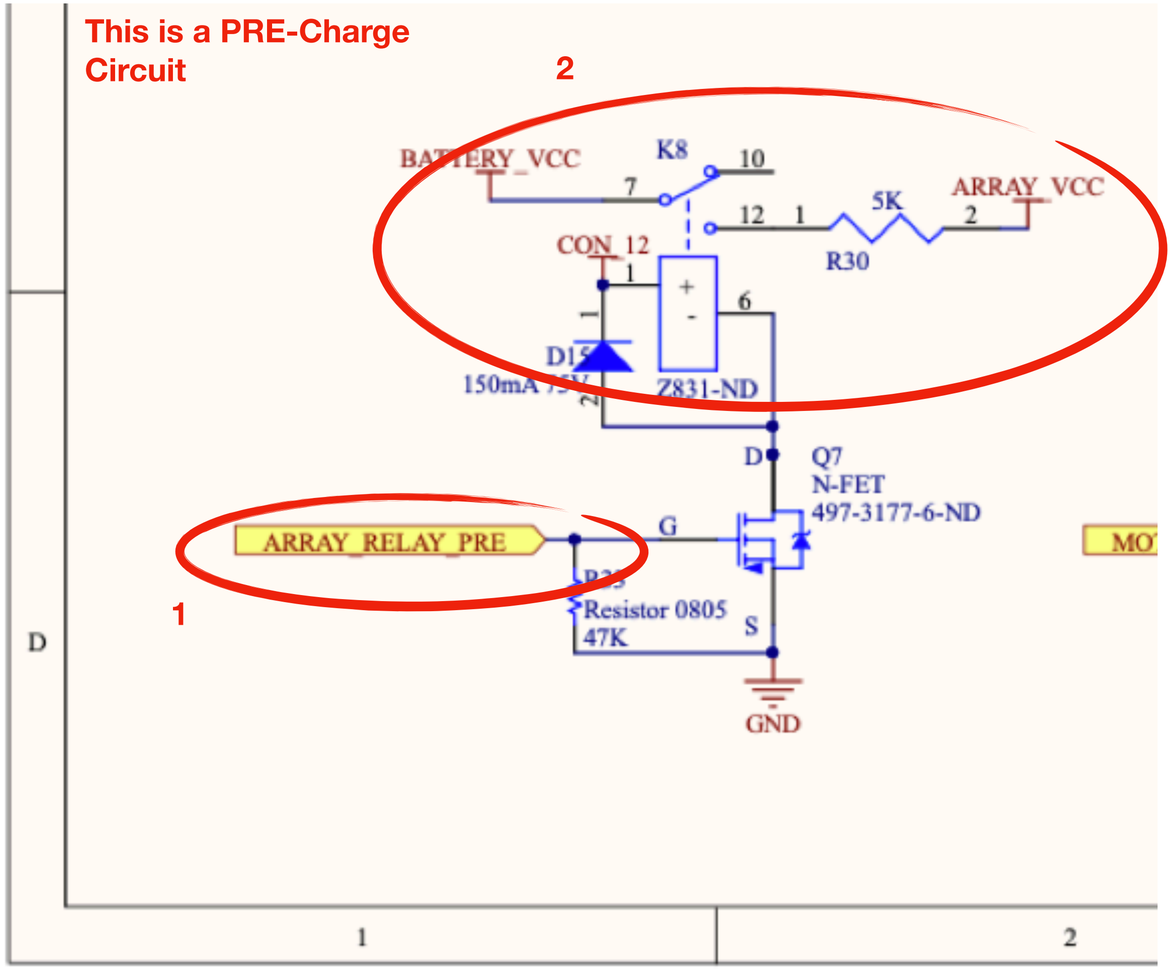

Can something be wrong with this?




Ok what IS this circuit?
BATTERY_VCC
K8
10
7
12
1
5K
R30
ARRAY_VCC
2
CON_12
1
6
D15
150mA 75V
Z831-ND
D
Q7
N-FET
ARRAY_RELAY_PRE
GND
Ok ONE AT A TIME!
Can something be wrong with this?
BATTERY_VCC
CON_12
D6
Diode TVS 44.4V 400W
SMAJ40CALFCT-ND
K4
Relay Power 30A 12V 1200V
D
G
Q2
N-FET
497-3177-6-ND
ARRAY_RELAY_HIGH
R15
J5
Anderson SB 50 Vert
879-PC5933T
879-PC-HSG-SB
ARRAY_GND
U11
UC (VCC)
VOUT
VREF
GND
IP+
IP-
HLSR 40-P
398-1124-ND
CUR_ARR
R17
5.1K
Hall_VREF
C25
0.1uF
C26
0.1uF
GND
What about this?
CON_12
K5
Hall_VREF
HALL_VREF
C29
0.1uF
GND

# Let’s talk about how each of these three circuits work in detail.

- What’s pre-charge?
- What’s a relay?
- What’s a contractor?
- How does a current sensor work?




# If pre-charge doesn't work, that can cause large start-up currents.

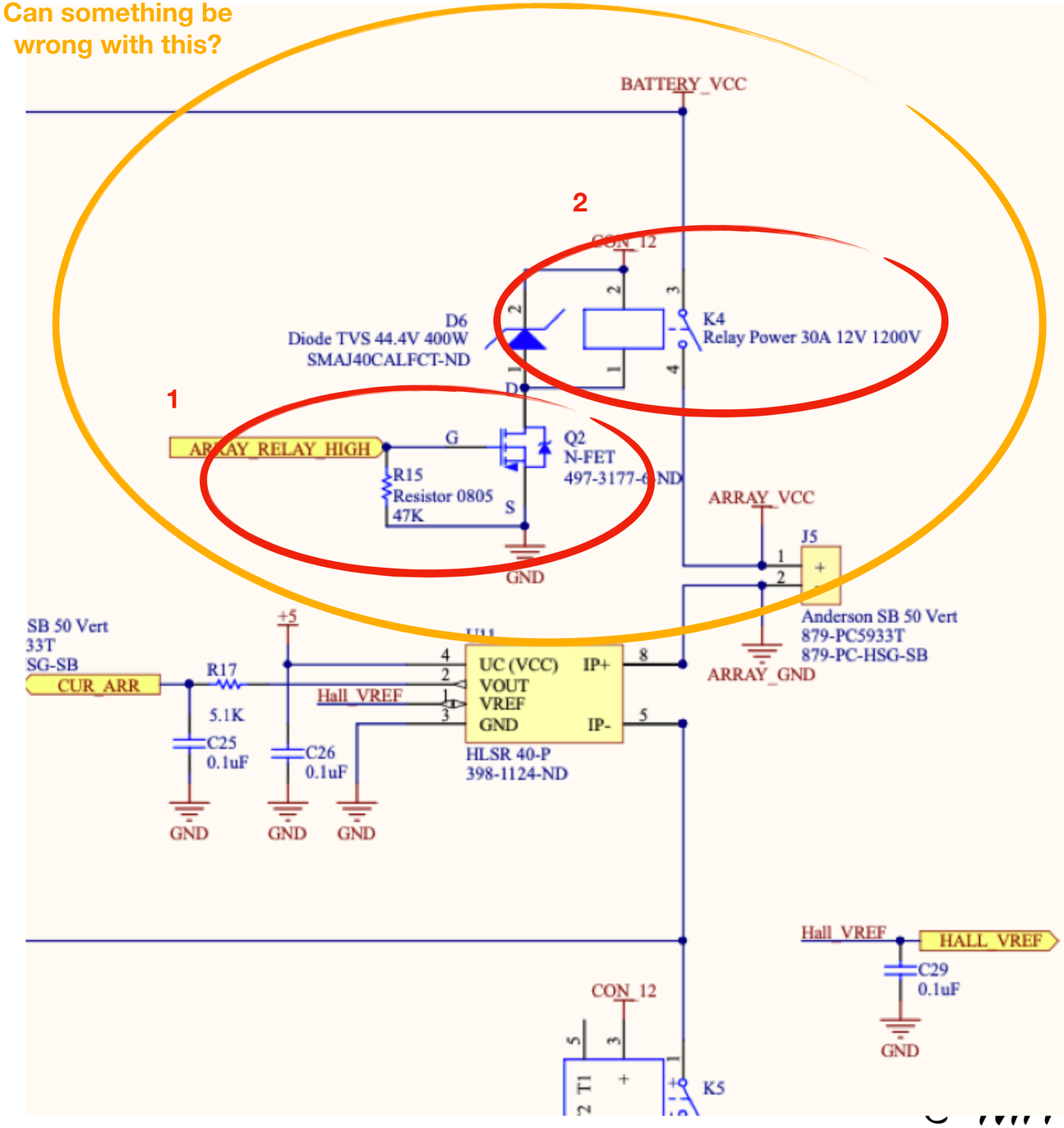
1 —> pre-charge isn't getting a signal from the microcontroller or the pre-charge TIME is too short

2 —> pre-charge IS getting a signal but for some reason isn't turning on… or isn't pre-charging the circuit

# This is the contractor, if it failed in the ON position we could be reading high startup currents since the system would be bypassing the pre-charge circuit!

1 —> something is WRONG with the signal going into the contractor, it's always on or turning on too soon?

2 —> something is wrong with the contractor itself, either it failed open or something else is weird



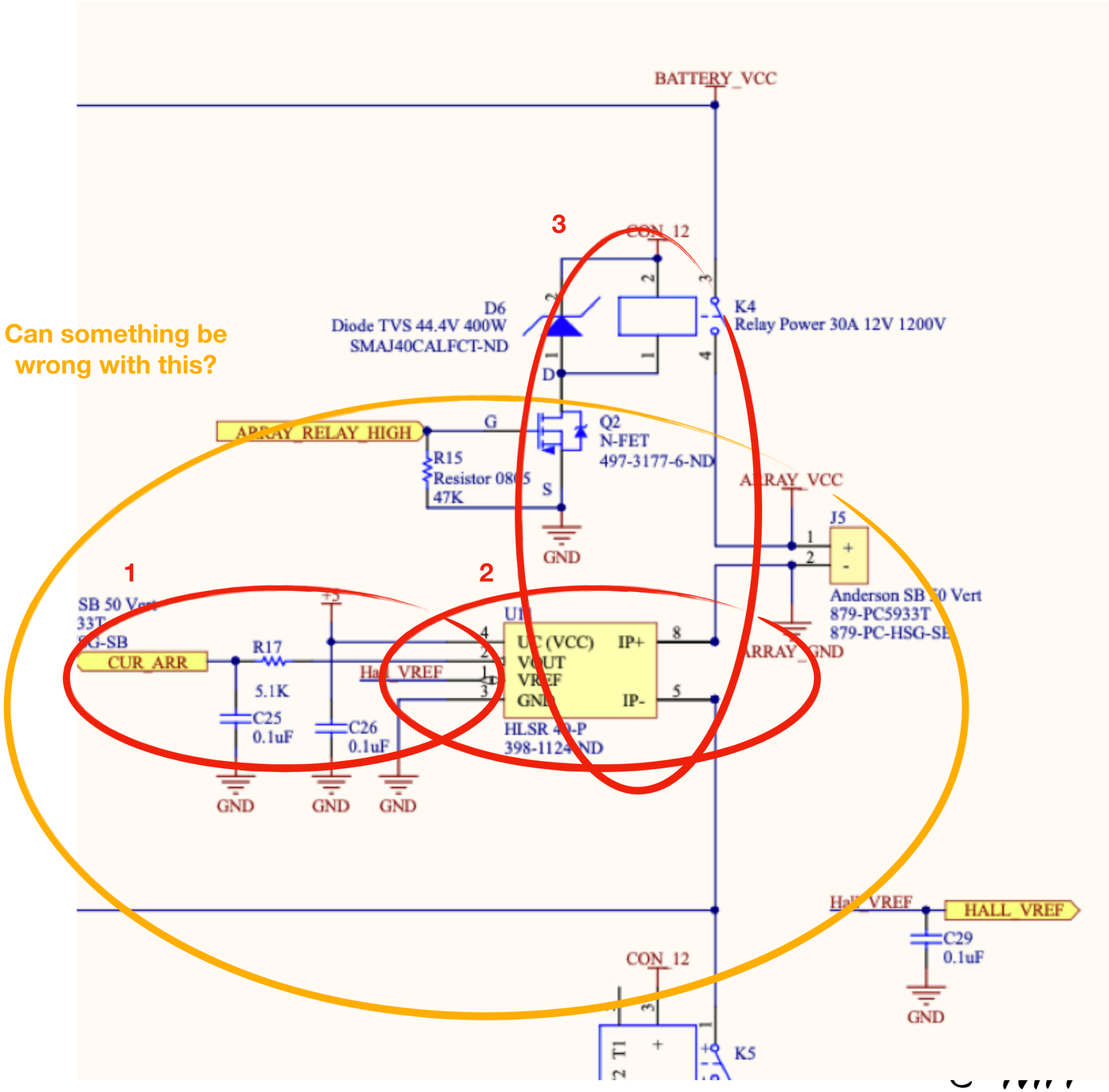
# This is the Current sensor, it's suspicious because that's where we get the current readings from.

Can something be wrong with this?

1 —> all the signals are correct but for some reason it's being READ incorrectly or being disrupted by the time it gets to the MC

2 —> something is wrong with the CURRENT sensor, it's blown or faulty or something

3 —> there's interference with the contractor and the current sensor when the contractor turns on because contractors produce a magnetic field

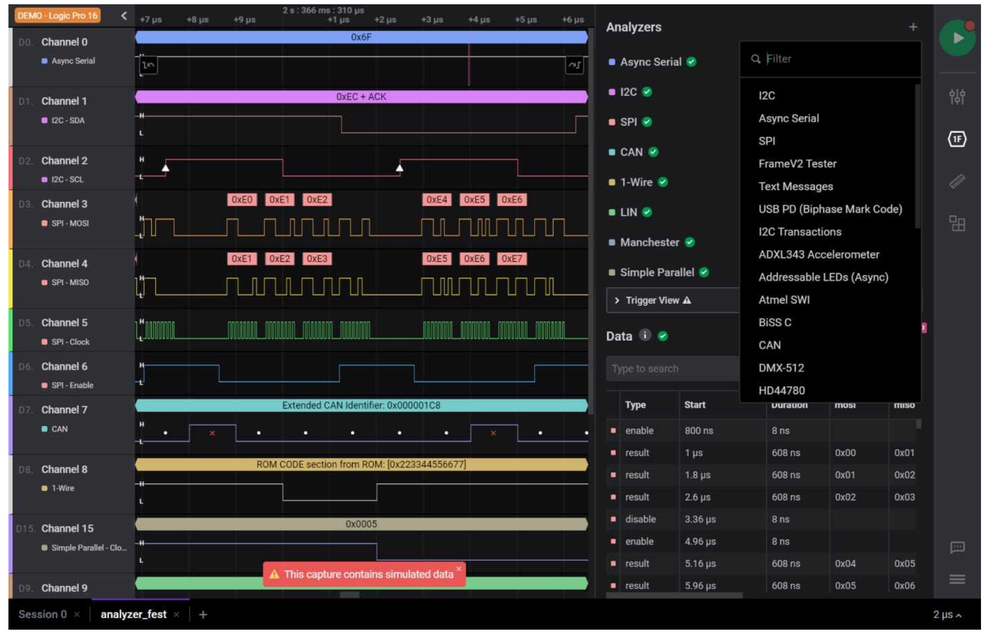


# Ok what are we MOST SUSpicious of?

# Ok what are we MOST SUSpicious of?

## (Or what's the easiest thing to check?)

# Scope —> analog
# Logic Analyzer —> digital
# + communications



THE ART AND SCIENCE OF PCB DESIGN @ MIT

# Your turn, what would you probe?

# You tell me, I'll give you info, and let's see if we can solve the problem.

**In summary…**

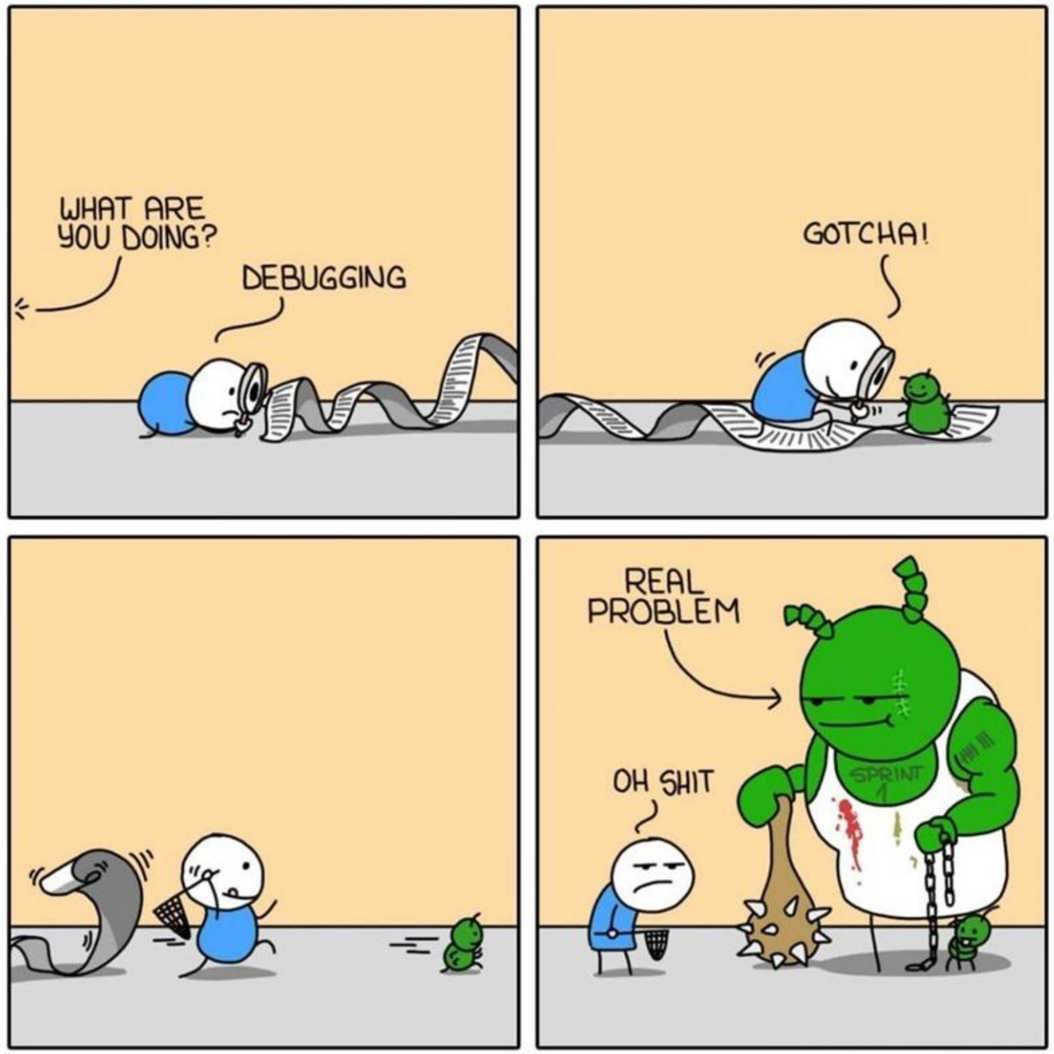
**The pre-charge relay blew which caused high inrush current. So no pre-charge, so overcurrent error.**

**The high inrush current welded the contacts of the contractor together. So the problem persisted when the motor was turned on, because the array was ALWAYS on!**

THE ART AND SCIENCE OF PCB DESIGN

# TIPs for deBUGging

## (Especially during initial bring-up)






@ MIT

# ‘Bring-up’ is the stage where we slowly + methodically put together + test electrical hardware.

THE ART AND SCIENCE of PCB DESIGN

# ‘Bring-up’ is the stage where we slowly + methodically put together + test electrical hardware.

THE ART AND SCIENCE of PCB DESIGN

## 1 - don’t assume things are connected (continuity check everything)

# ‘Bring-up’ is the stage where we slowly + methodically put together + test electrical hardware.

THE ART AND SCIENCE of PCB DESIGN

## 1 - don’t assume things are connected (continuity check everything)
## 2 - don’t assume things that worked “yesterday” work “today”

# ‘Bring-up’ is the stage where we slowly + methodically put together + test electrical hardware.

1 - don’t assume things are connected (continuity check everything)
2 - don’t assume things that worked “yesterday” work “today.”
3 - always double check everything is powered, check your voltages, check your signals - sanity check the easy things to get them out of the way so you can find the hard things

# ‘Bring-up’ is the stage where we slowly + methodically put together + test electrical hardware.

1 - don’t assume things are connected (continuity check everything)
2 - don’t assume things that worked “yesterday” work “today.”
3 - always double check everything is powered, check your voltages, check your signals - sanity check the easy things to get them out of the way so you can find the hard things
4- USE YOUR EXPERIENCE, ONCE A PROBLEM, ALWAYS A PROBLEM!!!!

THE ART AND SCIENCE OF PCB DESIGN

**Be. Safe. Be Slow. Be Careful.**

**Don’t voltage test a battery on current mode using a multimeter.**

**This has been empirically tested.**

**By me.**

THE ART AND SCIENCE OF PCB DESIGN

# GET HELP!

miters.mit.edu

pcb.mit.edu

Your friends!!! Lab staff!! Ppl you know!

Learn from those around you <3

# Final tips.

**Debugging requires PATIENCE + PRACTICE, there's NO SHORTCUT, even if it can be very frustrating**

**Think of it this way, every time you debug something, it's an opportunity to LEARN SOMETHING NEW**

**And learning, is a truly beautiful thing <3**