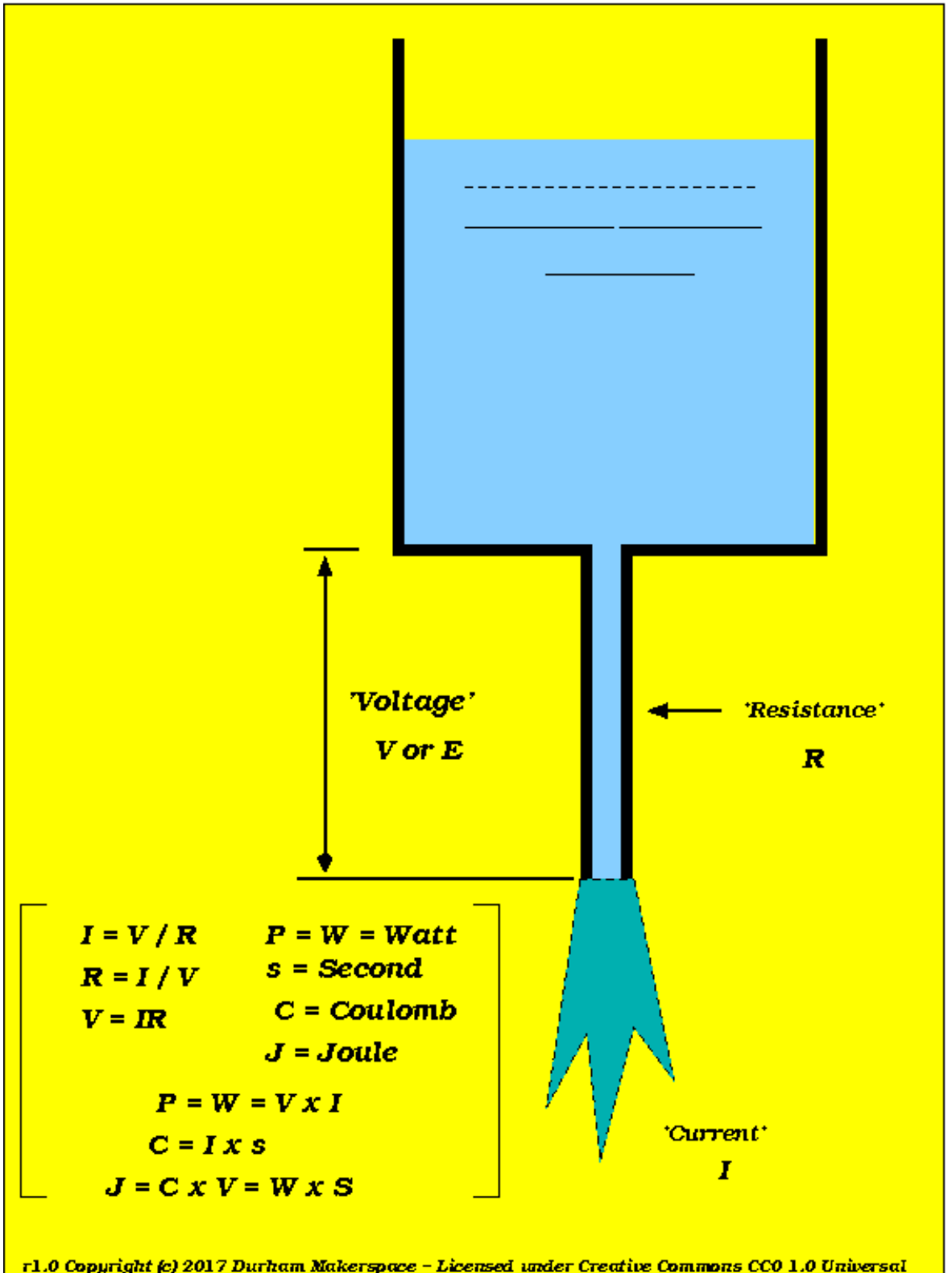
Intro to Transistors

- Orientation and Scope of this session
  - Conventional current flow notations used everywhere
  - Functional, functional, functional
  - References to theory but stressing application
  - A few simple device types and a few use cases
- Starting from Square One: Electricity and Ohm’s Law
  - Water Analogy
  - Resistor combination equations and exercises
- Bipolar transistor operation
  - Hands on Exercises
- N Channel (logic level) Field Effect transistor operation
  - Exercises

Measuring volts easy: amps harder

- We’ll measure voltage in our circuits for three reasons:
  - The digital meter reading voltage usually won’t interfere with the circuit. Measuring current can affect circuit operation due to “burden voltage” (the small, but sometimes significant voltage drop used to measure the current)
  - Have to swap leads with most meters
  - Forgetting to swap back can blow a fuse



Combining Resistors

Rules for combining resistors

Rtotal_in_series = R1 + R2 + R3

In terms of the analogy, 100 feet of pipe offers 100 times the resistance of one foot.

Rtotal_in_parallel = 1 / (1/R1 + 1/R2 + 1/R3)

In terms of the analogy, two pipes of equal bore size offer ½ the resistance of one.

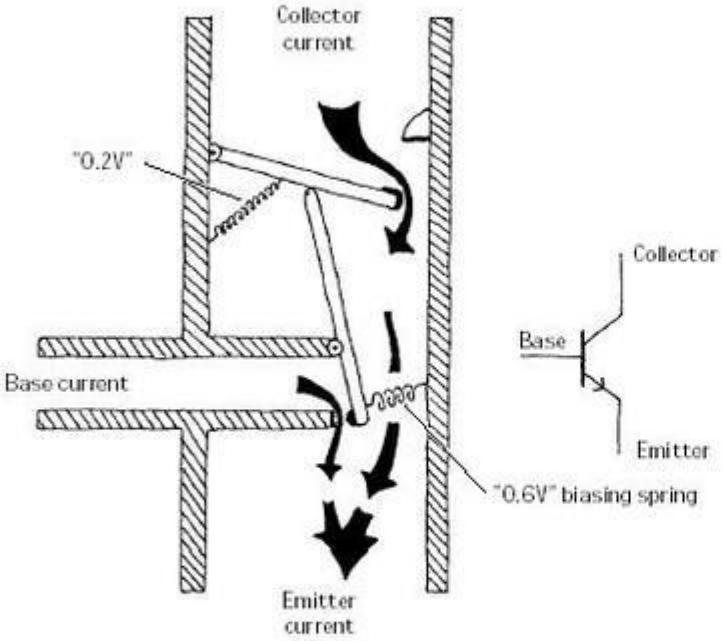
(Complete exercise handout)

Junction Transistors

- Three terminals: Emitter, Base, Collector
- Many sizes and characteristics
- All share this behavior:
  - In normal operation relatively small changes of current flow through the base control larger current flow through the emitter and collector
  - See figure 4.51 on page 436 of Practical Electronics for Inventors, Scherz and Monk, 3rd edition, 2013. (A copy will be passed around at the session)

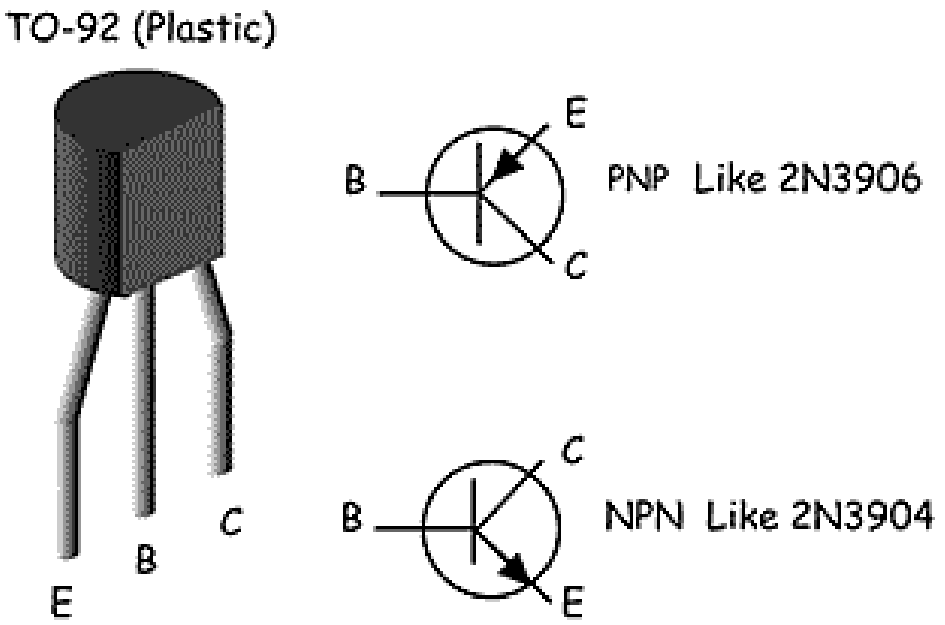
Bipolar Transistor Water Analogy

NPN WATER ANALOGY



The base of the *npn* water transistor represents the smaller tube entering the main device from the left side. The collector is represented by the upper portion of the vertical tube, while the emitter is represented by the lower portion of the vertical tube. When no pressure or current is applied through the "base" tube (analogous to an *npn* transistor's base being open circuited), the lower lever arm remains vertical while the top of this arm holds the upper main door shut. This state is analogous to a real bipolar *npn* transistor off state. In the water analogy, when a small current and pressure are applied to the base tube, the vertical lever is pushed by the entering current and swings counterclockwise. When this lever arm swings, the upper main door is permitted to swing open a certain amount that is dependent on the amount of swing of the lever arm. In this state, water can make its way from the collector tube to the emitter tube, provided there is enough pressure to overcome the force of the spring holding the door shut. This spring force is analogous to the 0.6 V biasing voltage needed to allow current through the collector-emitter channel. Notice that in this analogy, the small base water current combines with the collector current.

Physical vs Schematic

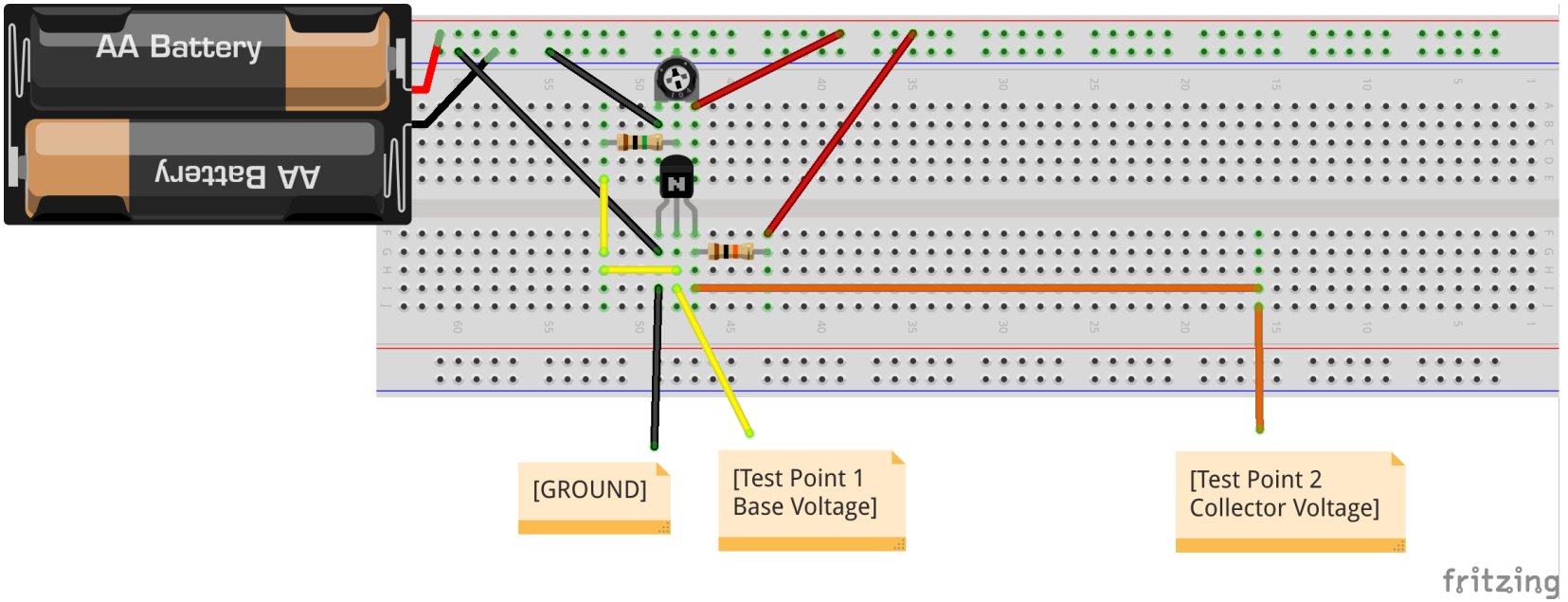


Operation: NPN Details

- (“Simple Common Emitter” simulation with http://everycircuit.com)

Exercise 1: Duplicate the simulation

- Boards set up for first common emitter circuit
- Leave batteries disconnected when changing anything or not exercising circuit
- (Exercise to measure a resistor with the meter)
- (Exercise to measure battery voltage)
- Measure circuit behavior while R1 trim pot (potentiometer – variable resistor) turned between stops.
- Make a table of base and collector voltages

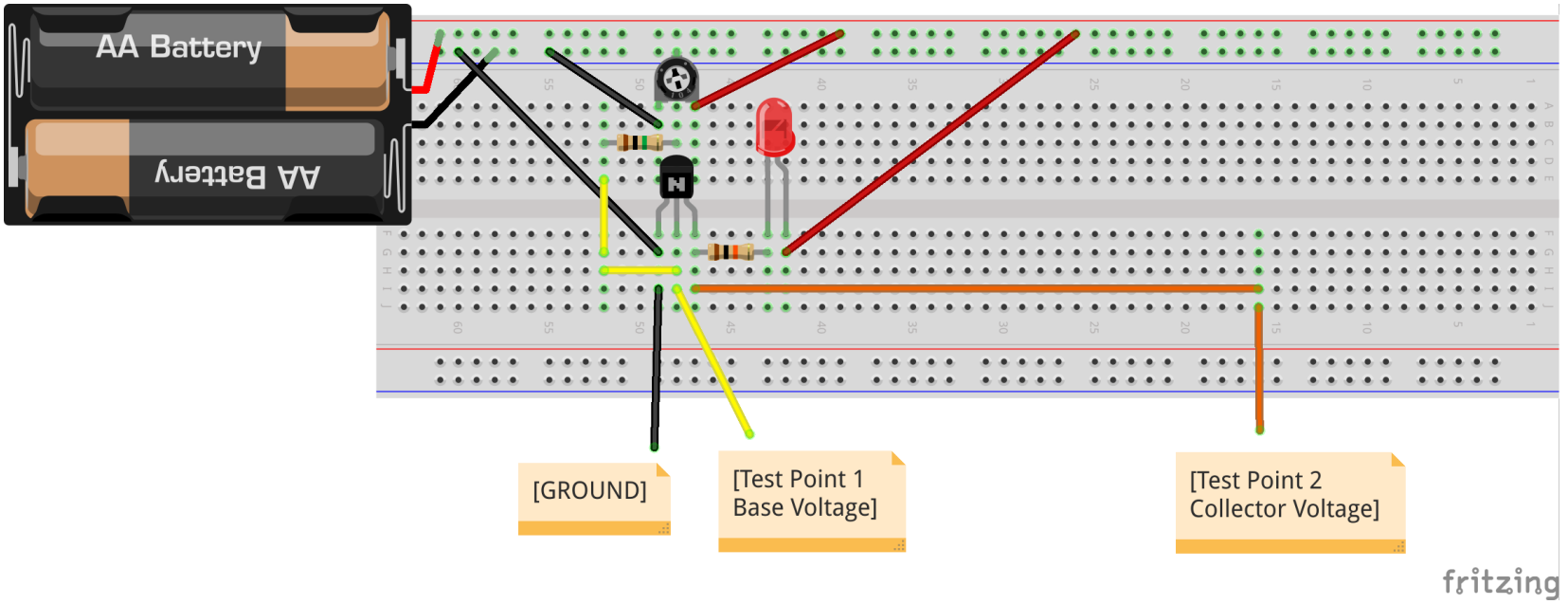

AA Battery
AA Battery
[GROUND]
[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
fritzing

Amps = Volts / Ohms

- Measure voltage from one end to the other of the 10k (10,000 aka “brown black orange”) resistor
- While doing this, adjust the potentiometer
- How does the current through the resistor change?
- Over and over with electronics: having two of the three values for variables of Ohm’s Law reveals the third value.

But it doesn’t DO anything!

- (Getting to Blinky CE simulation 1)
- (Add LED)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[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
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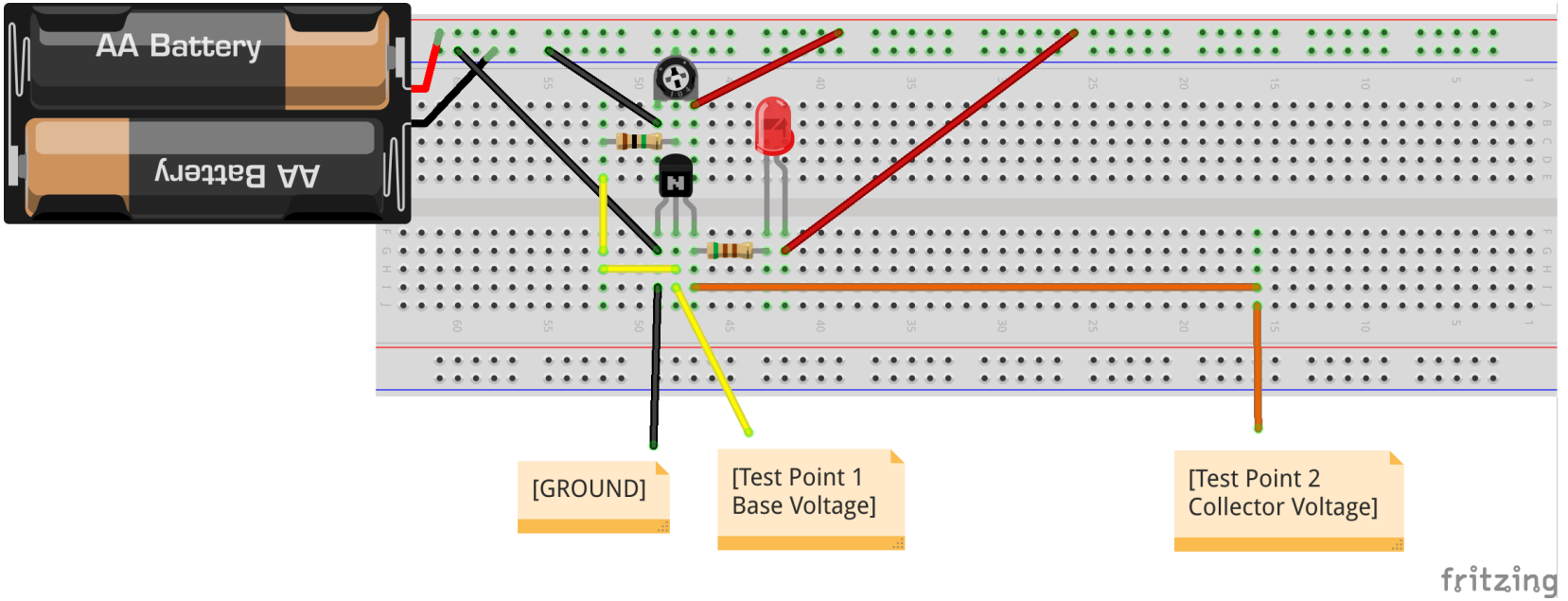
LED not doing anything!

- What could be wrong?
- How much current does the LED require to light? More than 40-odd microamperes!
  - Typical LEDs like this work well with 1-20 milliamperes
- How to get more current?
- Fix the collector resistor
  - LED drops two volts, so resistor drops three (transistor resistance ignored)
  - 5 milliamperes = three volts / 600 ohms (510 close enough)
  - Replace 10k resistor with “green brown brown” 510 ohm resistor


AA Battery
AA Battery
[GROUND]
[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
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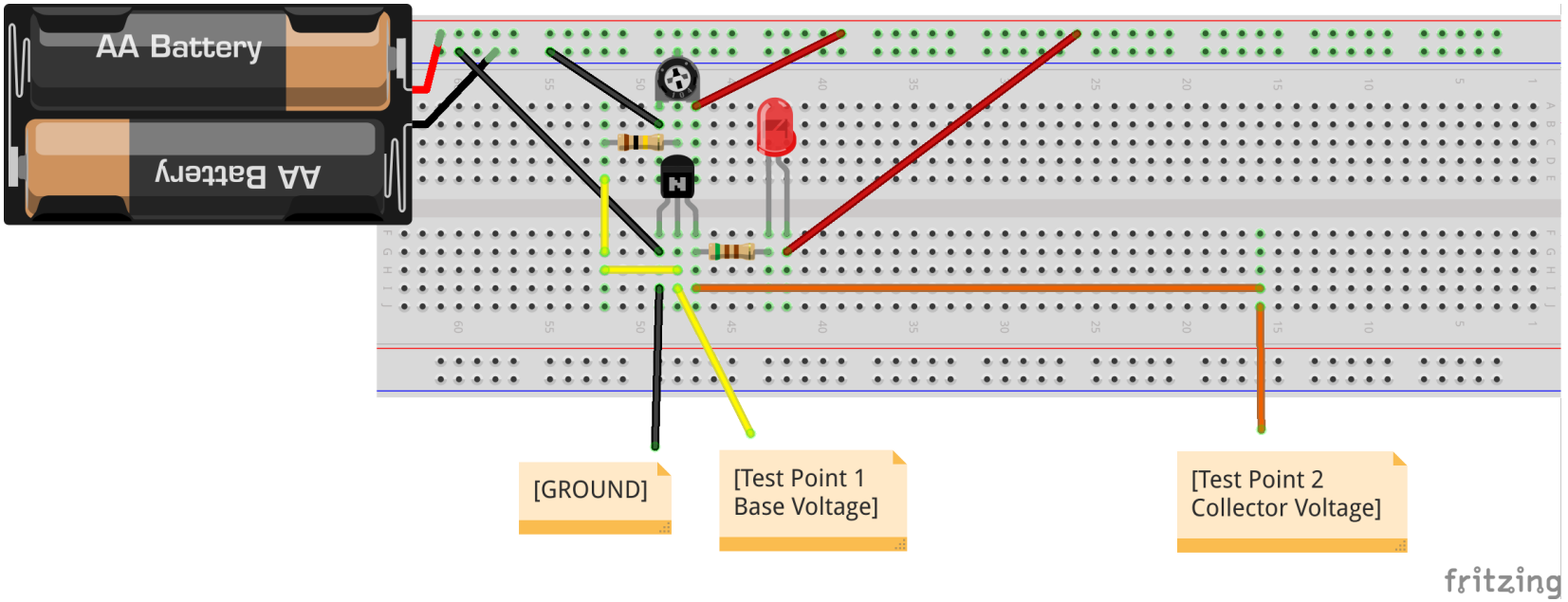
LED Still Not ON???

- What's happening with the LED?
  - Figure out current through LED
- Why isn't there enough current through the LED?
- Transistor gain is 100: To get 5 mA "out", how much current has to go "in" transistor?
- Adjust base resistor
- Readjust trim pot as needed


AA Battery
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[GROUND]
[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
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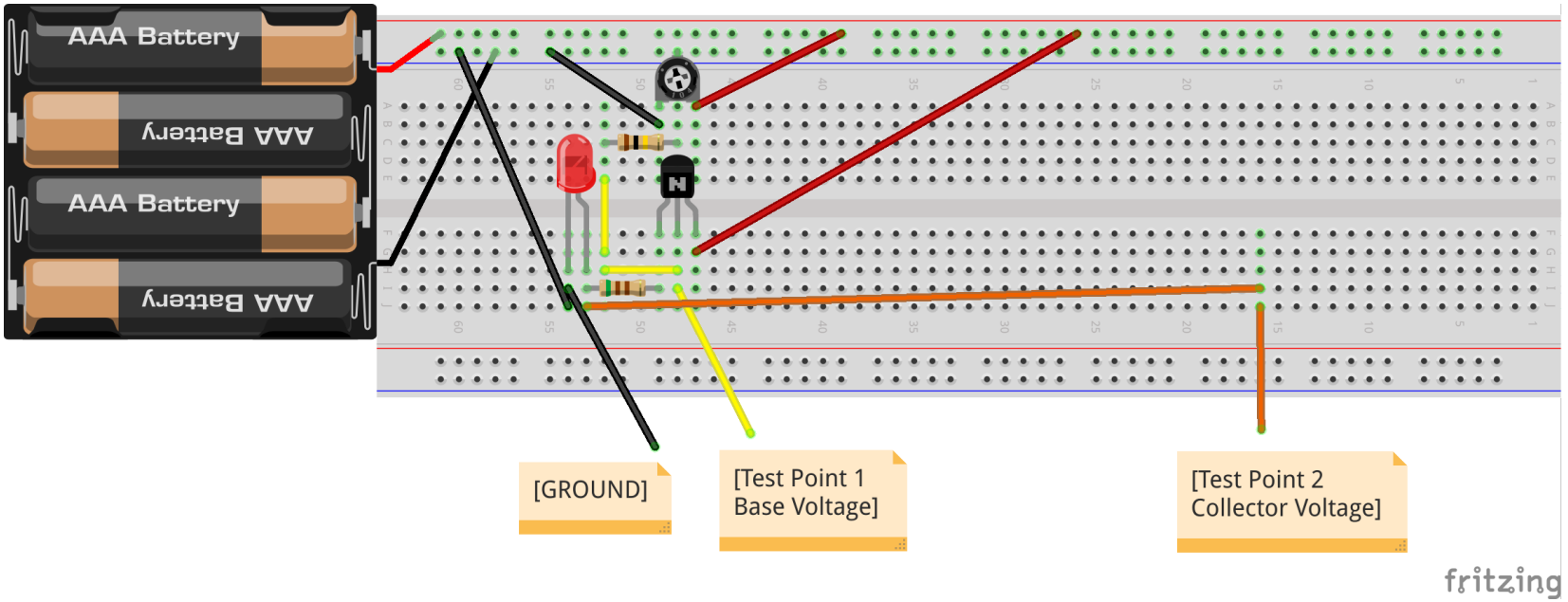
Another amplifier: Common Collector

- Non-inverting
- When switched on, the emitter voltage is just a few tenths (“one diode drop”) lower than the base voltage.
- (Assemble common collector circuit)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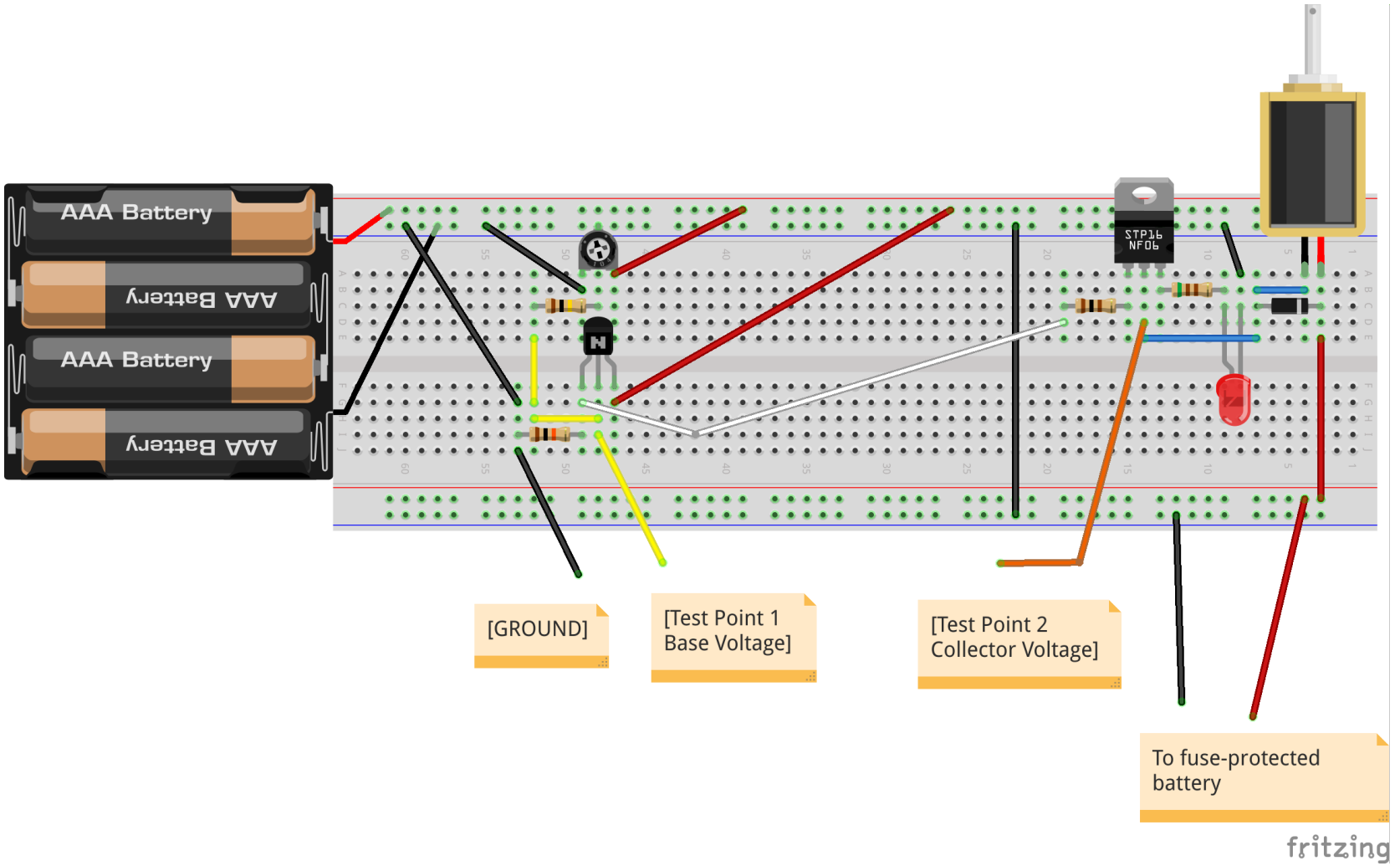
[GROUND]
[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
fritzing

FET Transistor

- Switches current, but switching mechanism basically different
- Rough correspondence of three terminals:
  - Gate similar in function to junction transistor Base
  - Source similar to Emitter (with N-channel and “conventional flow” the current “comes out here”)
  - Drain similar to Collector
- A key point is that the gate part of the transistor is like a capacitor (which we’d have ideally covered, but “next time”). Turning the gate on is effectively charging up a capacitor,but once it’s charged the current needed to keep the transistor on is VERY SMALL
- But this also means the gate can be turned on accidentally with virtually no current

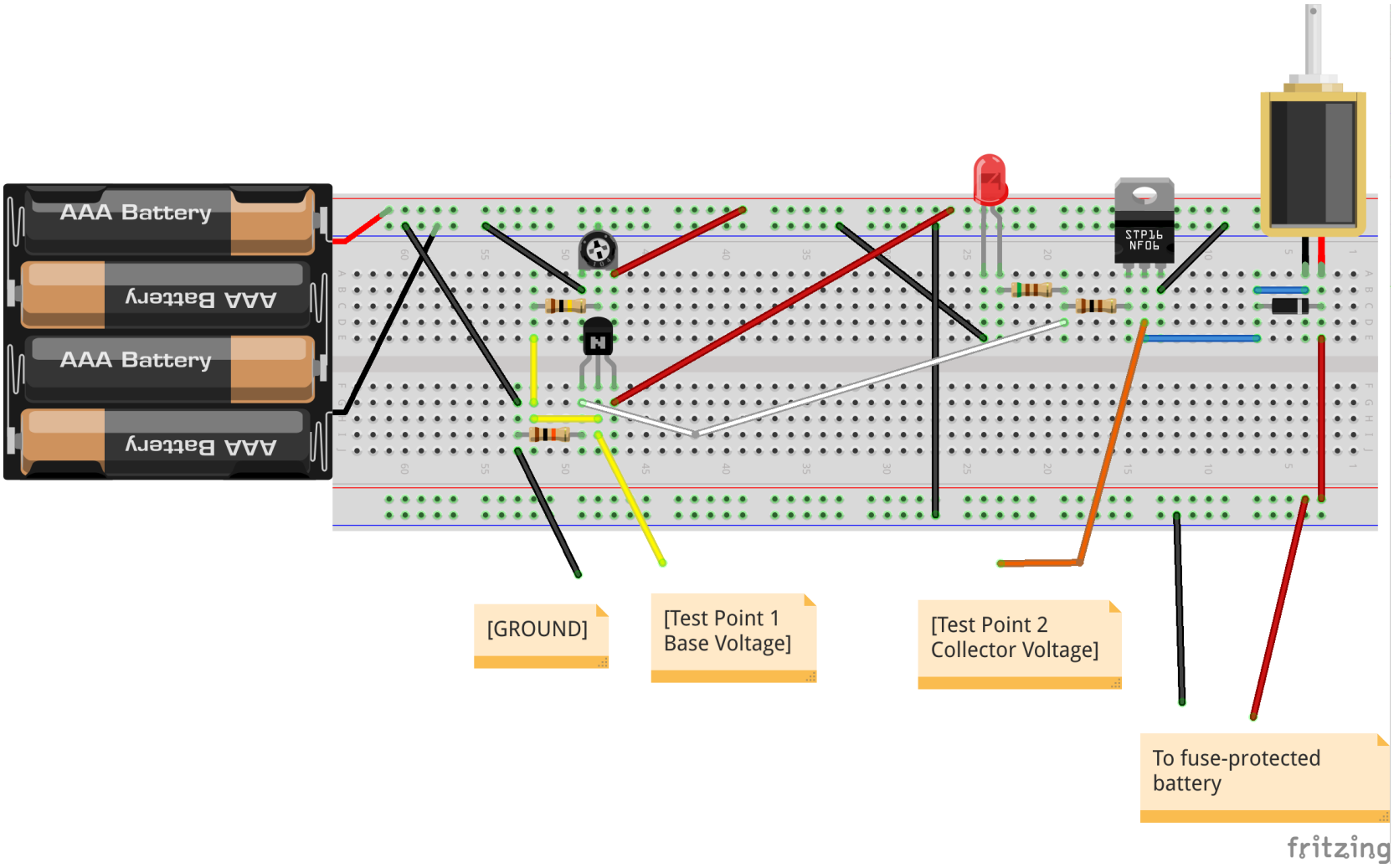
FET Circuit: running a motor

- Add FET, gate resistor, motor, rearrange
- Test to see that the gate is switched above a couple volts
- Double check rectifier diode: this prevents possible ***destruction*** of the FET transistor
- before connecting big battery


AAA Battery
AAA Battery
AAA Battery
AAA Battery
STP16
NF06
[GROUND]
[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
To fuse-protected
battery
fritzing

Motor wimpy or not running?

- Motor needs a lot of current to run
- What’s limiting the current through the motor?
- Fix it


AAA Battery
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[GROUND]
[Test Point 1
Base Voltage]
[Test Point 2
Collector Voltage]
To fuse-protected
battery
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