

Pressure and presence sensors in textile

Eindhoven University of Technology
Industrial Design – Wearable Senses

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Contents

- Theory of resistive pressure sensors
- Making a resistive pressure sensor
- Theory of capacitive touch sensors
- Making a capacitive touch sensor
- Making capacitive touch sensor sensing only one side
- Combining resistive and capacitive touch sensing

Passive electronic components

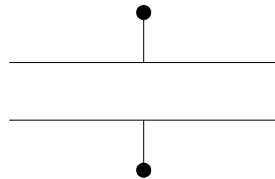
Resistor



Long, narrow path of moderately conductive material

$$V = I \cdot R$$

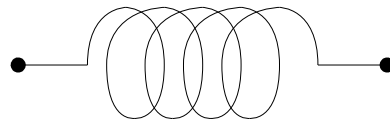
Capacitor



Two parallel plates with insulator in between

$$I(t) = C \cdot \frac{dV(t)}{dt}$$

Inductor

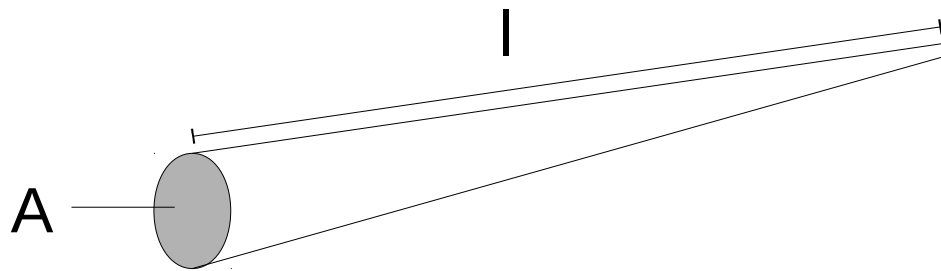


Long wound path of highly conductive material

$$V(t) = L \cdot \frac{dI(t)}{dt}$$

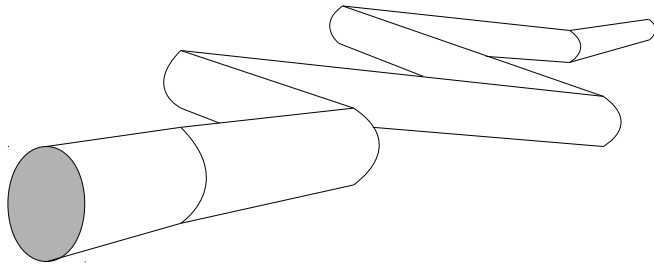
Resistor

- Resistance depends on length and cross-sectional area of wire



$$R = \rho \cdot \frac{l}{A}$$

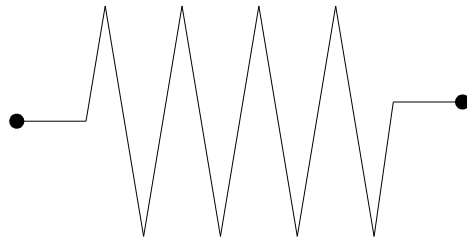
- Fold long wire to create high resistance in small space



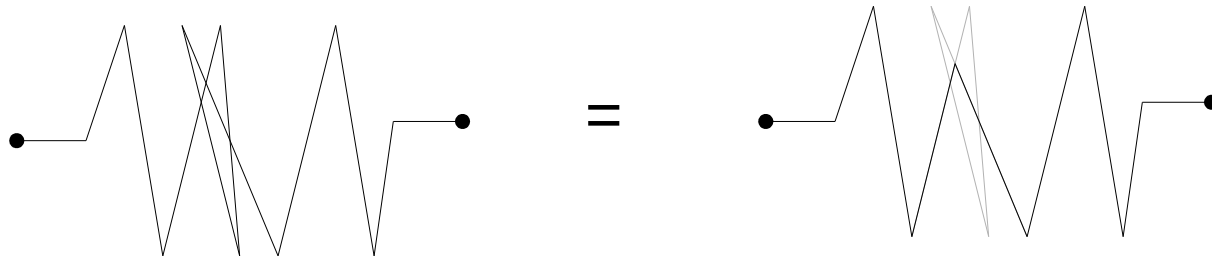
Resistor

- When folding uninsulated wire to make a fixed resistor, take care that the individual segments do not touch or cross.
- If they do touch, the total resistance will be lower, since effective length is smaller.

OK:

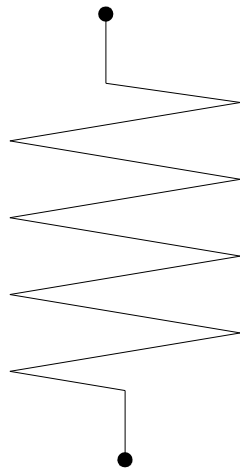


NOT OK:

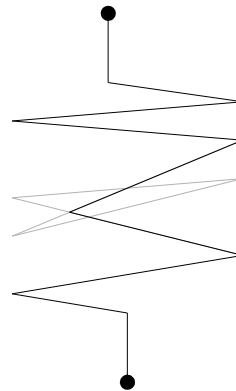


Resistive pressure sensor

Exploits the fact that resistance changes when segments are crossing due to compression



$$R = 40\text{ k}\Omega$$

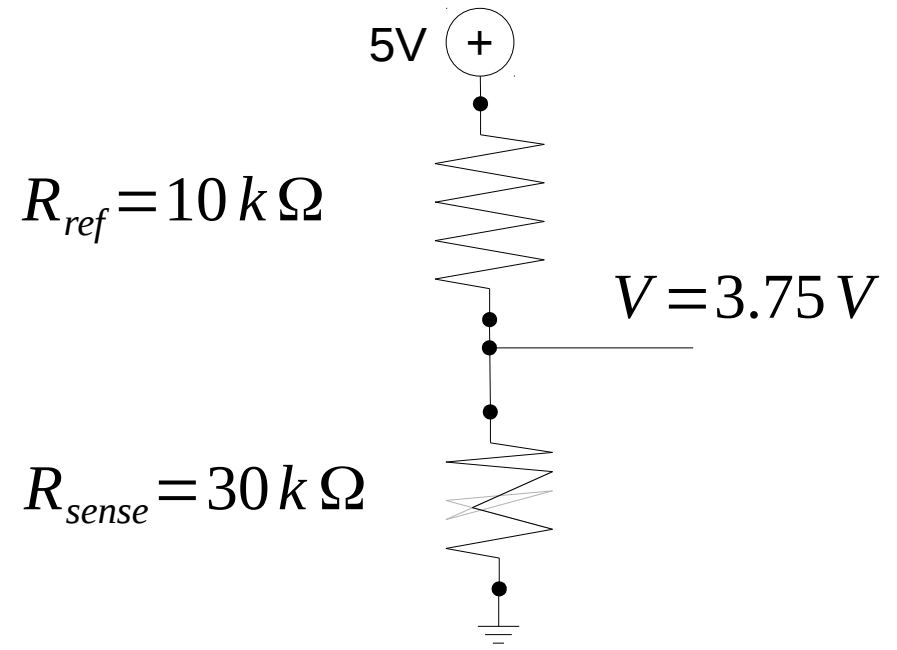
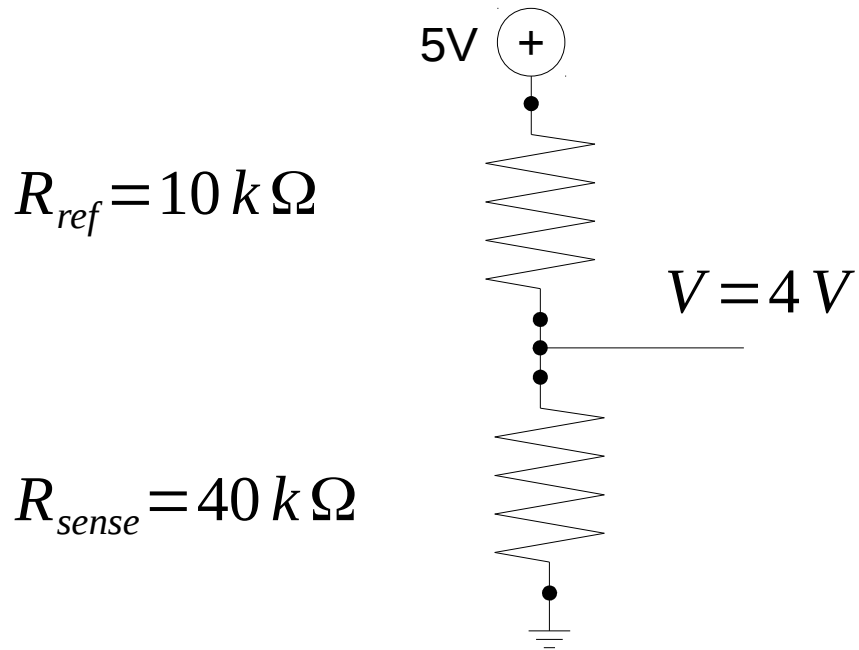


$$R = 30\text{ k}\Omega$$

Pressure sensor circuit

Use fixed resistor as reference

$$V = V_{cc} \cdot \frac{R_{sense}}{R_{ref} + R_{sense}}$$

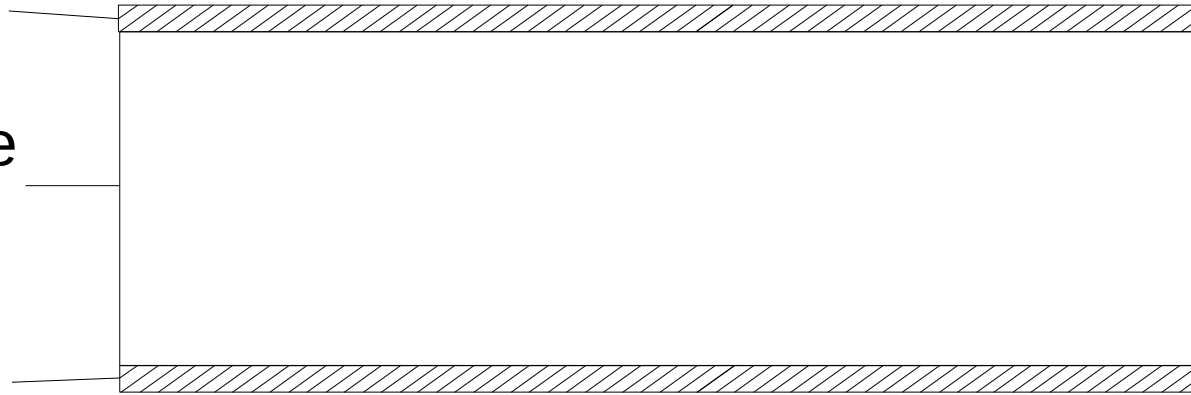


Pressure sensor stackup

Electrode 1

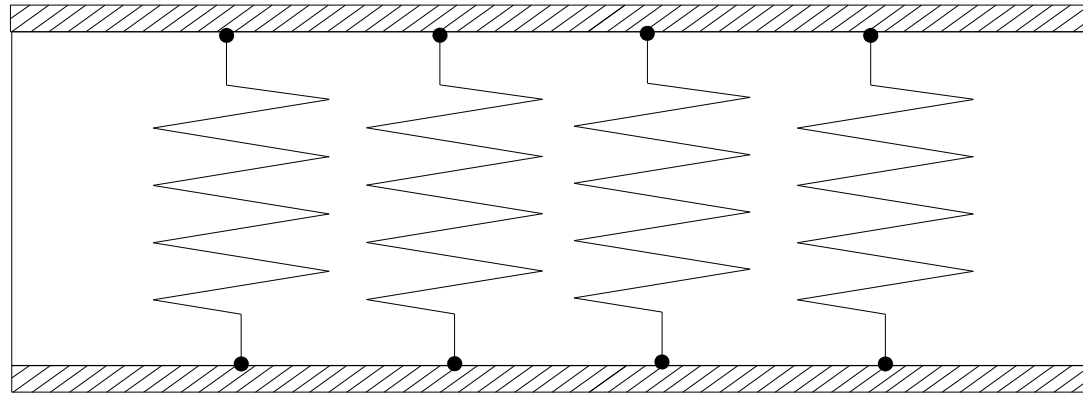
Resistive pressure
sensitive material

Electrode 2

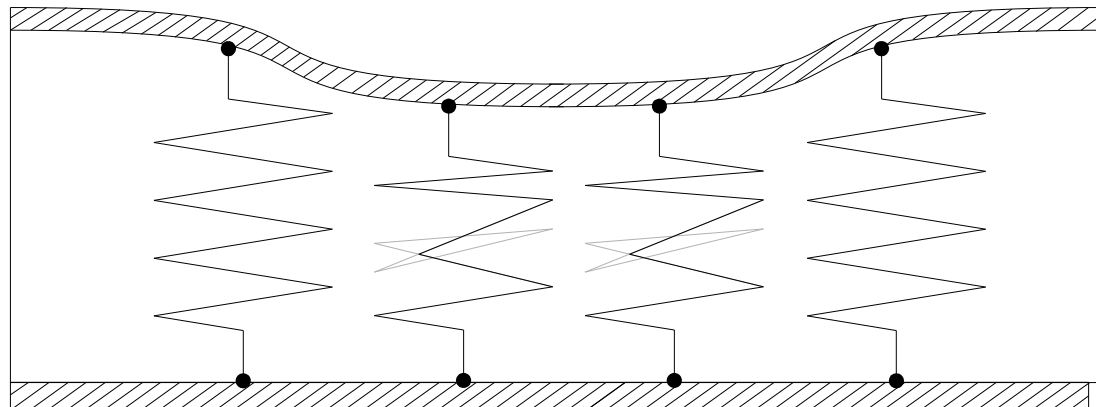


Pressure sensitive material

Unpressed



Pressed

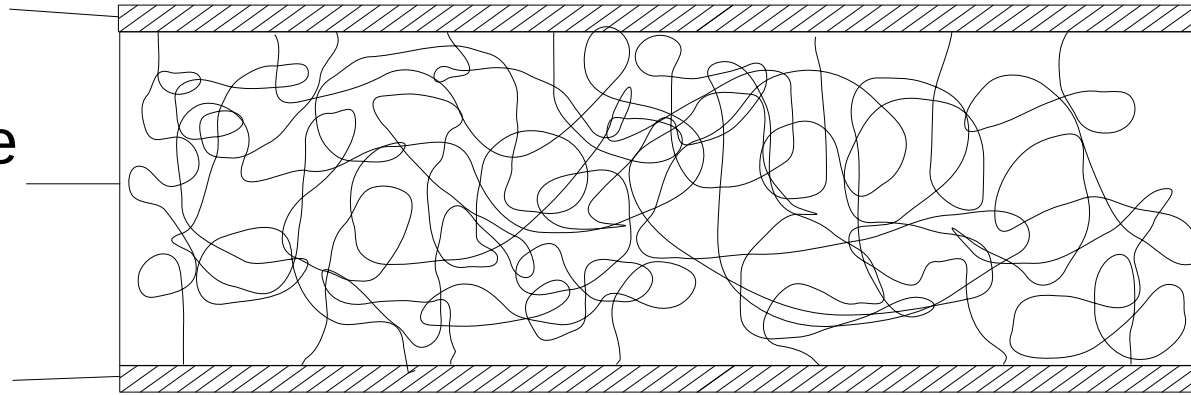


Actual structure

Electrode 1

Resistive pressure
sensitive material

Electrode 2

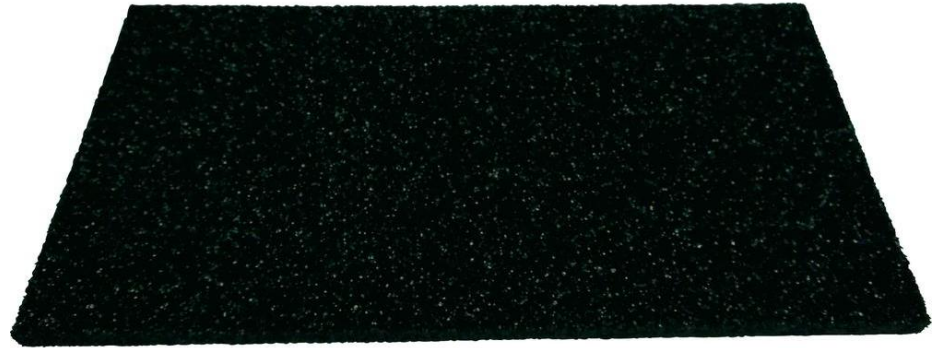


Pressure sensitive material: foam

ESD foam

image: conrad.com

- Low density PU foam
- Impregnated with flexible conductive latex (carbon based)
- Typically about 5 mm thick
- Very compressible



Different types of ESD foam:

- Stiff, not very compressible foam ← DO NOT USE THIS
- High resistivity ← DO NOT USE THIS
- Flexible, medium / low resistivity ← USE THIS

Pressure sensitive material: Velostat

Velostat / Lingstat

image: aura-comms.com

- PE film
- Impregnated with carbon based material
- Typically about 0.2 mm thick
- Slightly compressible



Different types of Velostat:

- High resistivity (50 kOhm/sq – 200 kOhm/sq)
- Medium resistivity (1 kOhm/sq – 50 kOhm/sq)
 - Useful for large pressure sensors
- Low resistivity (< 1 kOhm/sq)
 - Useful for pressure sensors

← DO NOT USE THIS

← USE THIS

← OR USE THIS

Pressure sensitive material

Examples:

- Velostat (plastic sheet)
- Linqstat MVCF series (plastic sheet, large pressure sensors)
- Linqstat XVCF series (plastic sheet, small pressure sensors)
- Eontex Eonyx (fabric)
- Multicomp 1687866 (PU ESD foam)

Shops:

- plugandwear.com (sells Velostat)
- store.arduino.cc (sells Velostat)
- adafruit.com (sells Velostat or Linqstat)
- caplinq.com (sells Linqstat [MVCF](#) and [XVCF](#))
- eeonyx.com (makes Eontex; does not have a store, sells only in large quantities?)
- nl.farnell.com (sells ESD foam)

More info on Eontex:

- <http://www.kobakant.at/DIY/?p=5689>
- <http://www.kobakant.at/DIY/?p=4619>

Conductive textile

Any conductive textile with good conductivity will work.

- Textiles with metal coating or metal woven into is fine
- Textiles with carbon coating or carbon woven into is not preferred (has higher resistivity)
- Textile should not have an insulating coating

Examples:

- Sparkfun [DEV-10056](#) (conductive fabric ripstop)
- Sparkfun [DEV-10055](#) (conductive fabric MedTex180, stretchable in 1 direction)
- Sparkfun [DEV-10070](#) (conductive fabric MedTex130, stretchable in 2 directions)

- PlugAndWear [TAC31608IN1E1000](#) (stainless steel)
- PlugAndWear [PW020](#) (conductive fabric, stretchable in 2 directions)
- PlugAndWear [TPOLALXXLAXX0650](#) (conductive aluminum laminated fabric)

Sensor design

- Electrodes:
 - Size is always a little less than pressure sensitive material (prevents short circuit)
 - Material: conductive fabric or uncoated conductive yarn / wire
 - Conductive fabric based on nylon can easily fray → watch out for short circuits
 - Conductive fabric has lower resistance than yarn / wire
 - Good sensor: $> 40 \text{ k}\Omega$ unpressed, $< 4 \text{ k}\Omega$ pressed
- Pressure sensitive material: resistance can be increased by:
 - Stacking several layers of pressure sensitive material (increases the “length” of the resistor)
 - Decreasing area
 - Using material with lower conductivity
- Pressure sensitive materials usually have a hysteresis
 - Material does not always immediately and completely recover → **sensor still “sees” some pressure after pressure is removed**

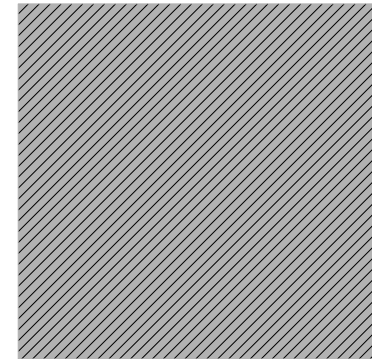
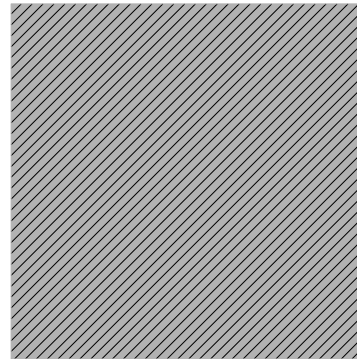
Sensor design: conductive fabric electrodes

Front
electrode

Back
electrode

Prepare electrodes:

Cut out 2 pieces of
conductive fabric



Tip: ripstop fabric easily frays, which can cause short circuits. If you use a sewing machine, this will be taken care of in step 3. If sewing by hand:

- **Laser cutter** (melts the material → no fraying)
- Sew a hem
- Tape edges (when you're lazy)

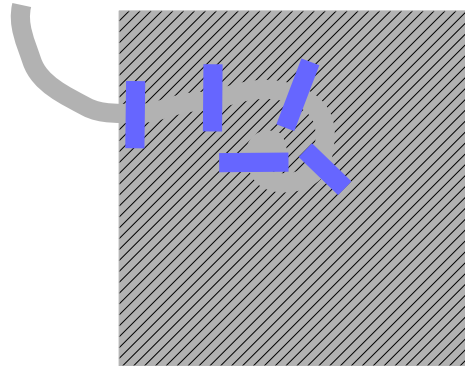
Sensor design: conductive fabric electrodes

Prepare electrodes:

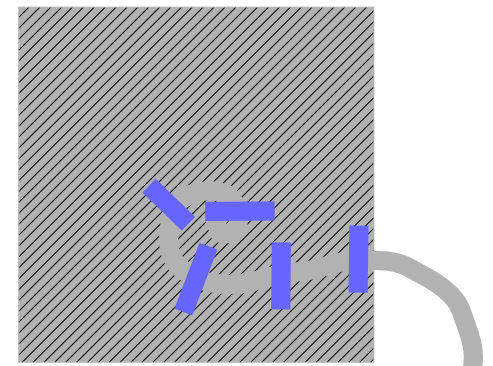
Place uncoated
conductive thread / wire
on electrode and fixate
with stitches

Alternatively: sew thread
directly through electrode

Front
electrode



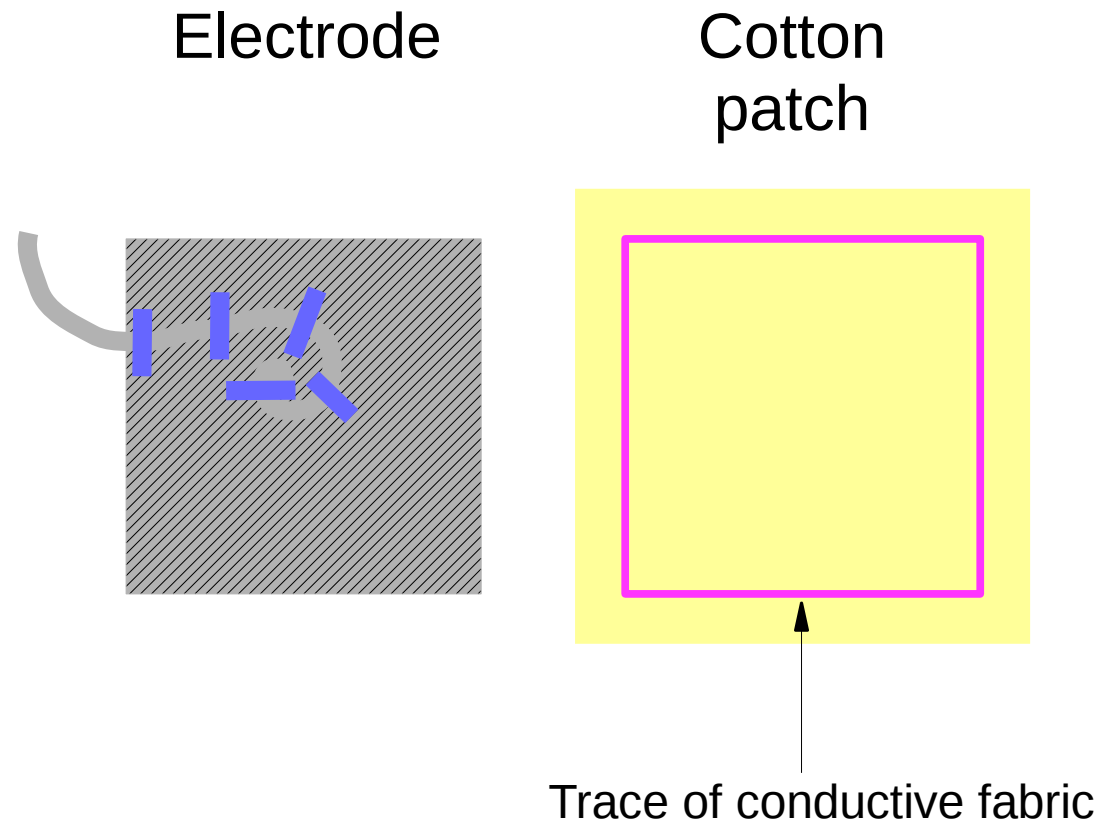
Back
electrode



Sensor design: conductive fabric electrodes

Cut a patch of non-conductive fabric (such as cotton); must be larger than the electrode

Optionally: trace outlines of conductive fabric on cotton patch, such that it is visible on both sides

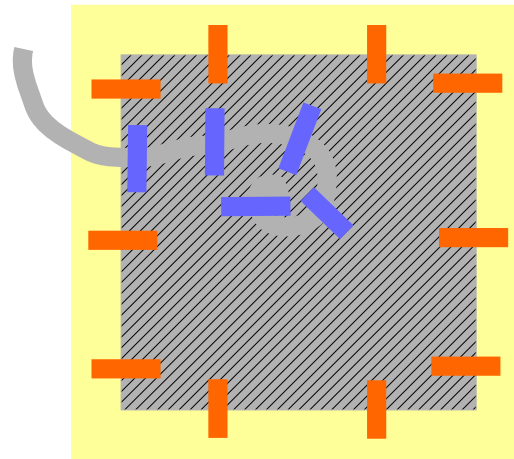


Sensor design: conductive fabric electrodes

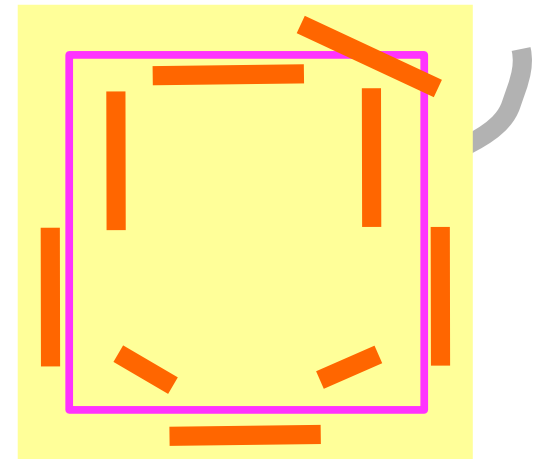
Sew each electrode to its own cotton patch

When using sewing machine: use zigzag to keep in any frays

Front



Back



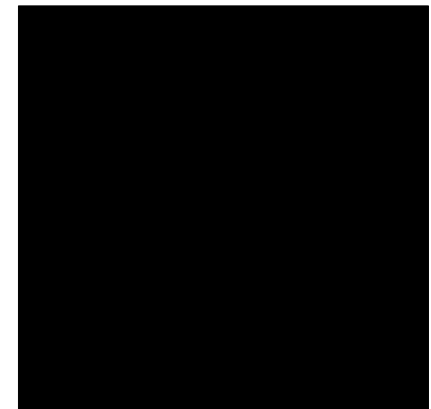
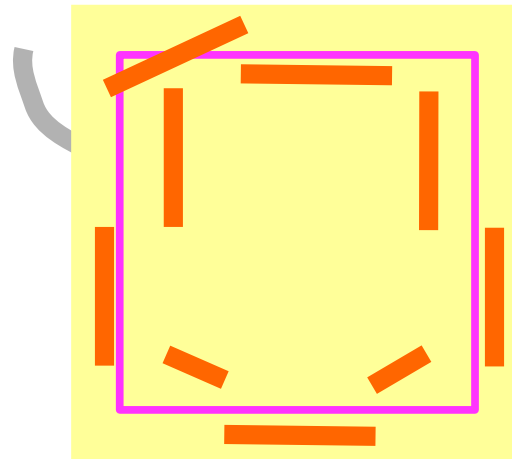
Sensor design: conductive fabric electrodes

Cut out pressure sensitive material

Must be slightly larger than electrode but smaller than cotton patch

Front

Pressure sensitive material

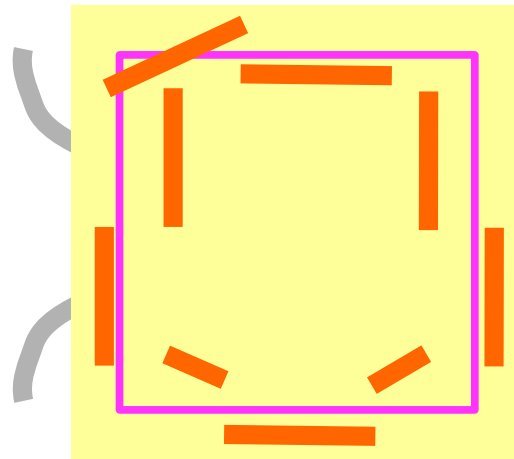


Sensor design: conductive fabric electrodes

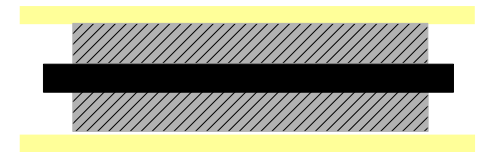
Place pressure sensitive material in between electrodes

Electrodes must face inwards

Front



Side



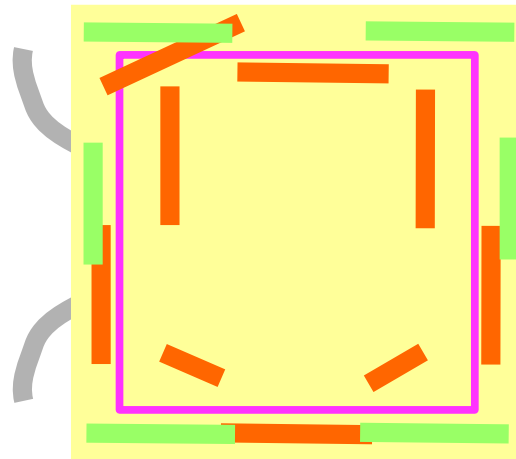
Sensor design: conductive fabric electrodes

Sew sensor together

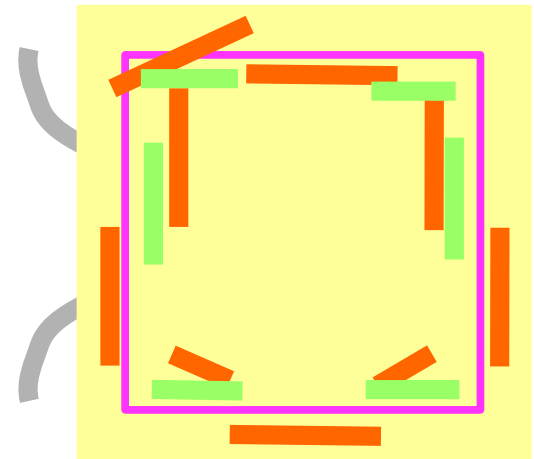
Be careful to not stitch inside the outline, to prevent stitching through conductive fabric and causing short circuit

Do not pull the stitches too tight to prevent too much base pressure

Good



Bad



Sensor design: conductive thread electrodes

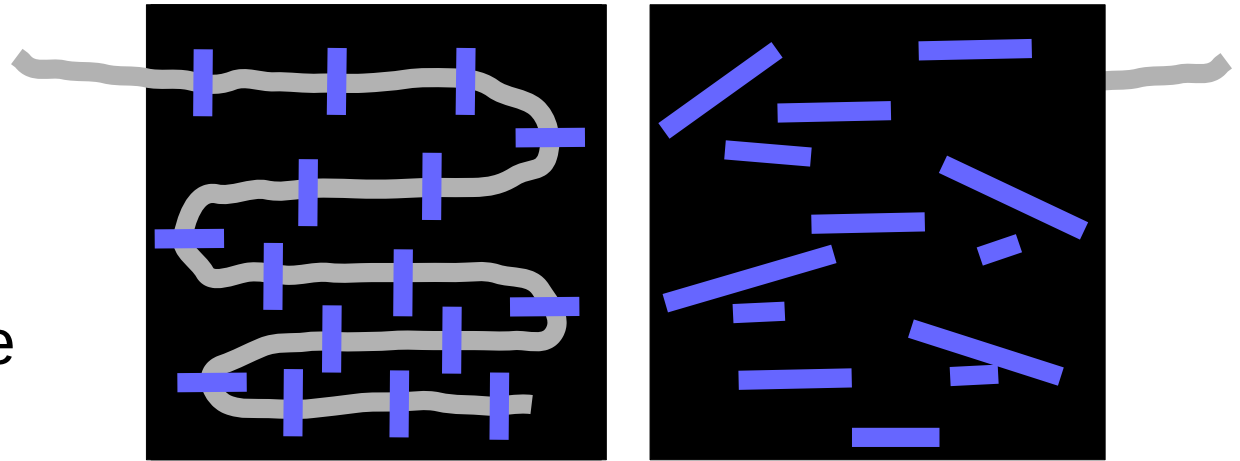
This method is often used in examples on the internet because it is easier. However, connections are often less robust. Not recommended!

First electrode:

Place uncoated conductive thread / wire all over pressure sensitive material and fixate with stitches

Front

Back



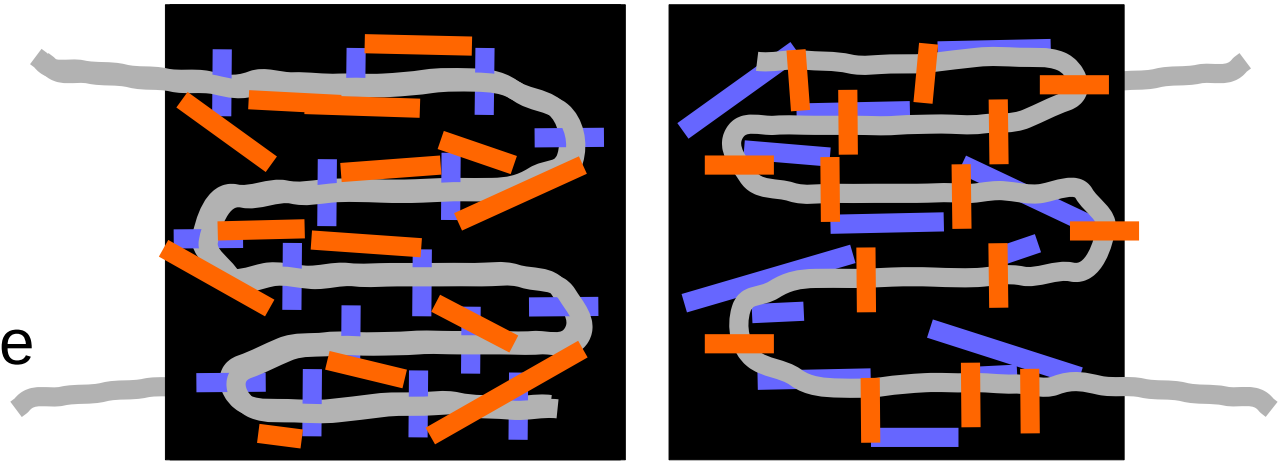
Sensor design: conductive thread electrodes

Front

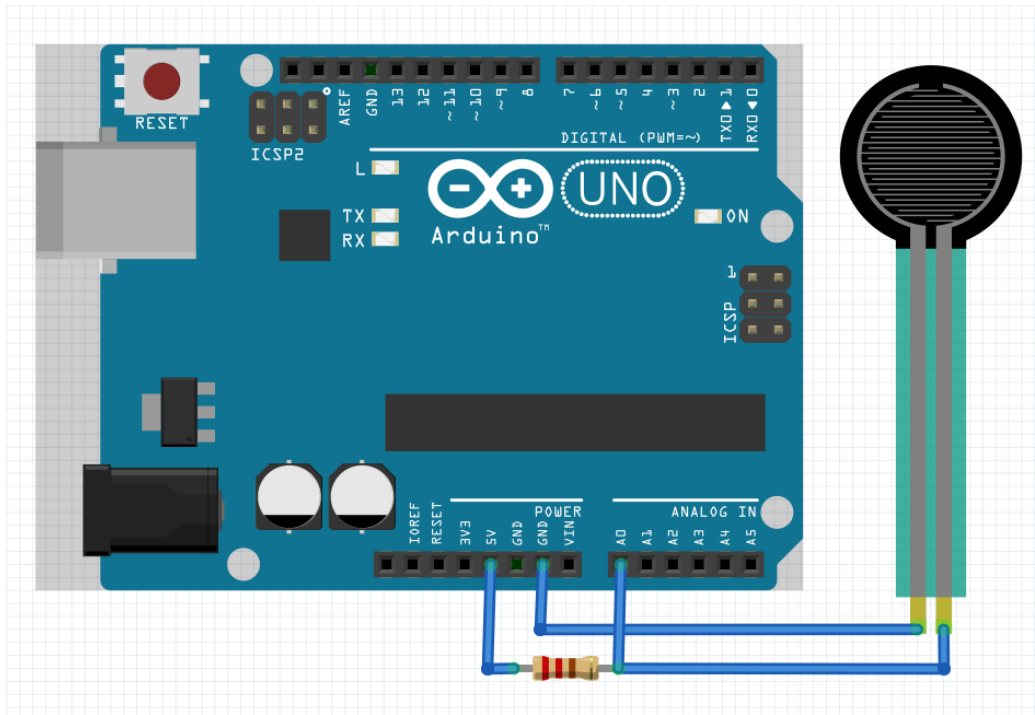
Back

Second electrode:

Place uncoated
conductive thread / wire
all over pressure sensitive
material and fixate with
stitches



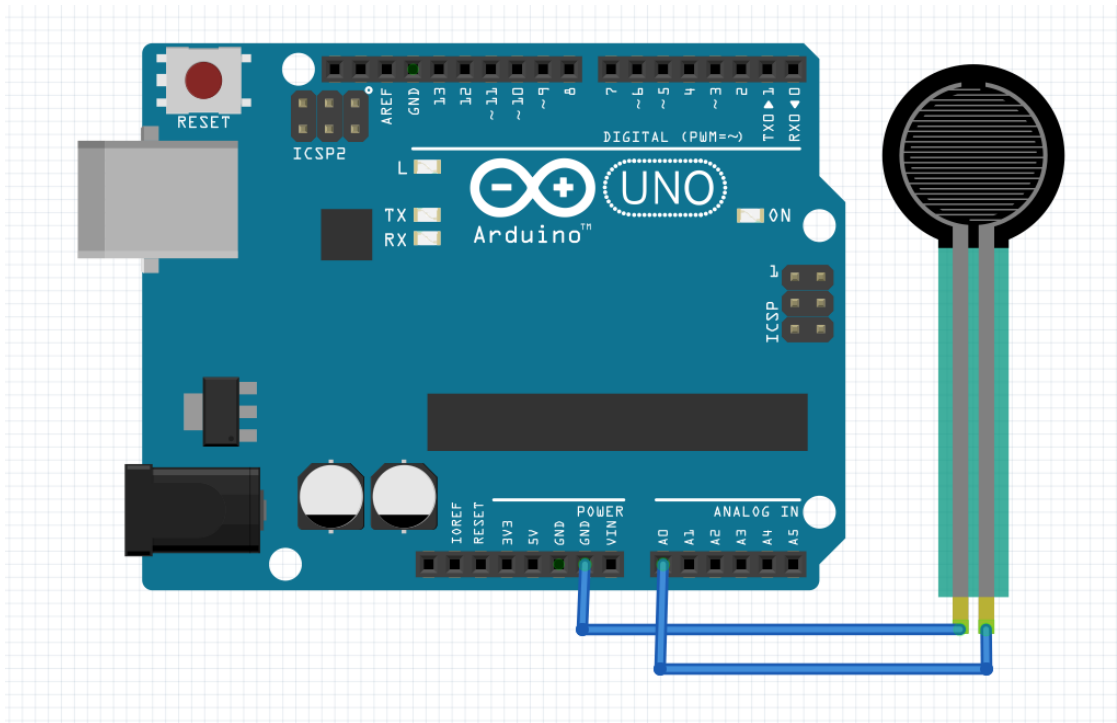
Wiring it all up



```
void setup() {  
    Serial.begin(115200);  
  
}  
  
void loop() {  
    int x;  
  
    x = analogRead(0);  
    Serial.println(x);  
}
```

Simplifying things

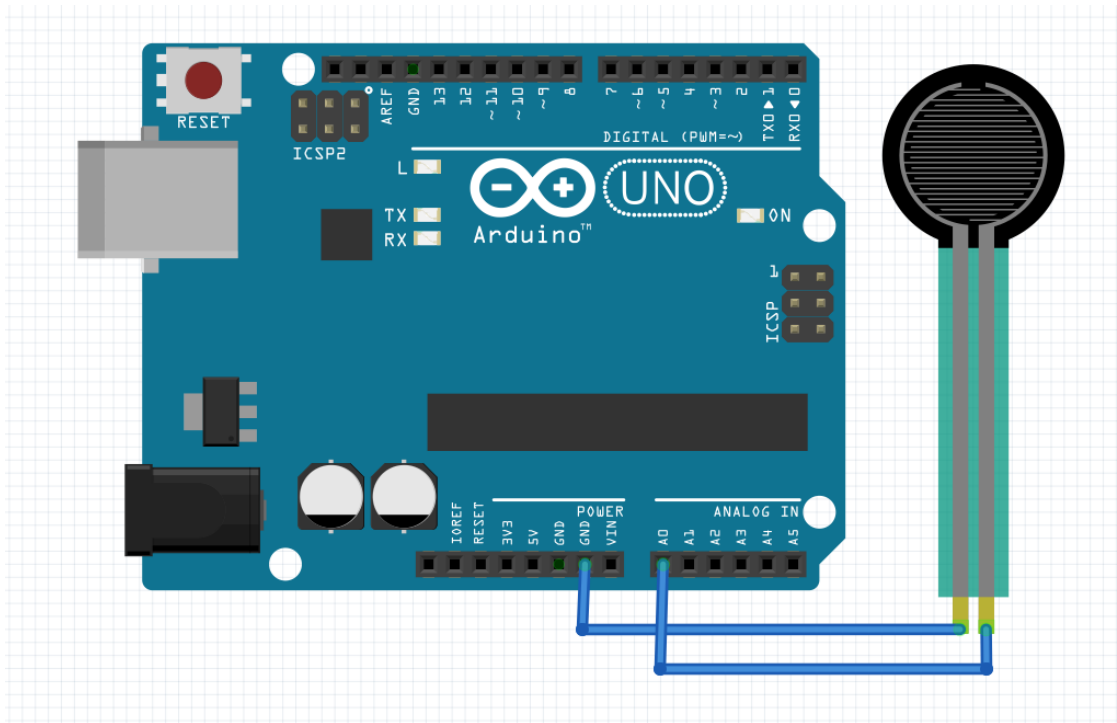
Arduino has internal pull-up resistors on analog input (20 – 50 kOhm)



```
void setup() {  
    Serial.begin(115200);  
  
    pinMode(A0, INPUT);  
    digitalWrite(A0, HIGH);  
  
}  
  
void loop() {  
    int x;  
  
    x = analogRead(0);  
    Serial.println(x);  
}
```

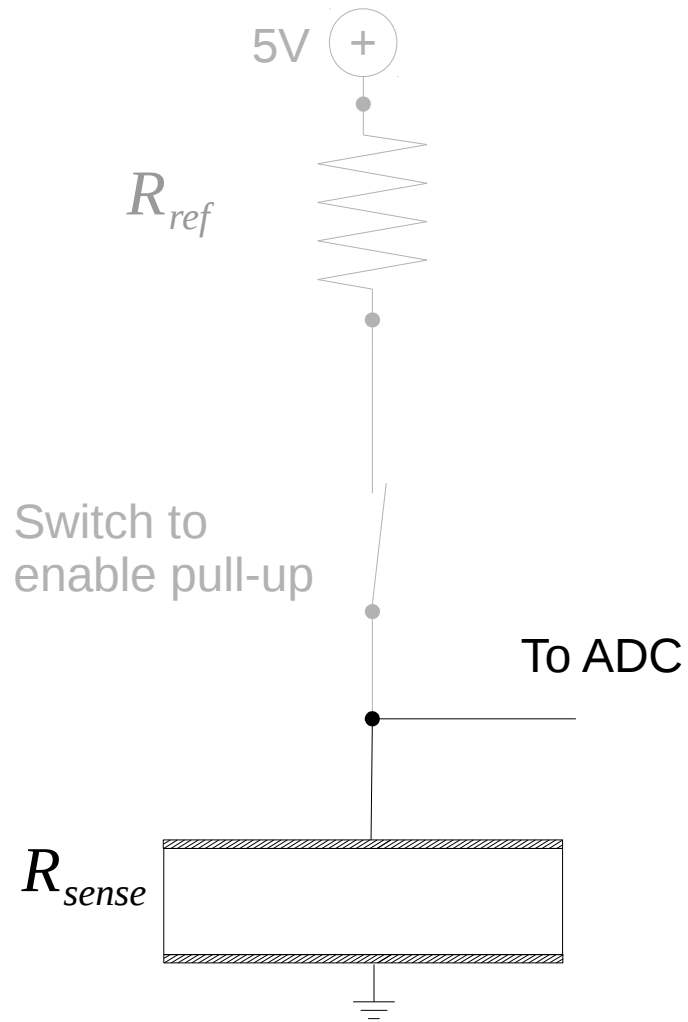
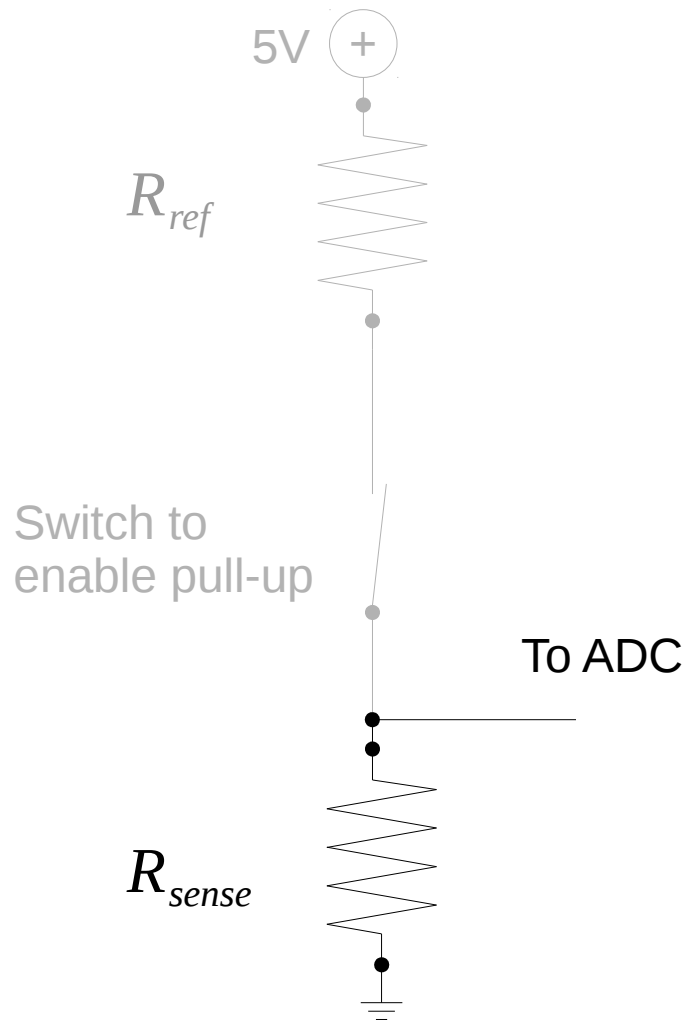
Increasing sensitivity

Use internal 1.1V reference for ADC (instead of 5V) if signal is below 200 when unpressed

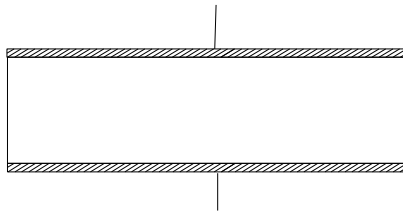


```
void setup() {  
    Serial.begin(115200);  
  
    pinMode(A0, INPUT);  
    digitalWrite(A0, HIGH);  
    analogReference(INTERNAL);  
}  
  
void loop() {  
    int x;  
  
    x = analogRead(0);  
    Serial.println(x);  
}
```

Schematic vs reality



Resistor... or capacitor?



Pressure sensitive material has too low resistance to work as proper insulator.

Instead, both sides of conductive fabric + pressure sensitive material can act as one large (and thick) plate of a capacitor.

Connected to ADC, this can be used as capacitive touch sensor.

Model setup

Charge – voltage relation for capacitors:

$$C = \frac{Q}{V}$$

Relation between plate area, distance and capacitance for parallel plate capacitors:

$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$

For air:

$$\epsilon_0 = 8.854 \text{ pF/m}$$

$$\epsilon_r = 1$$

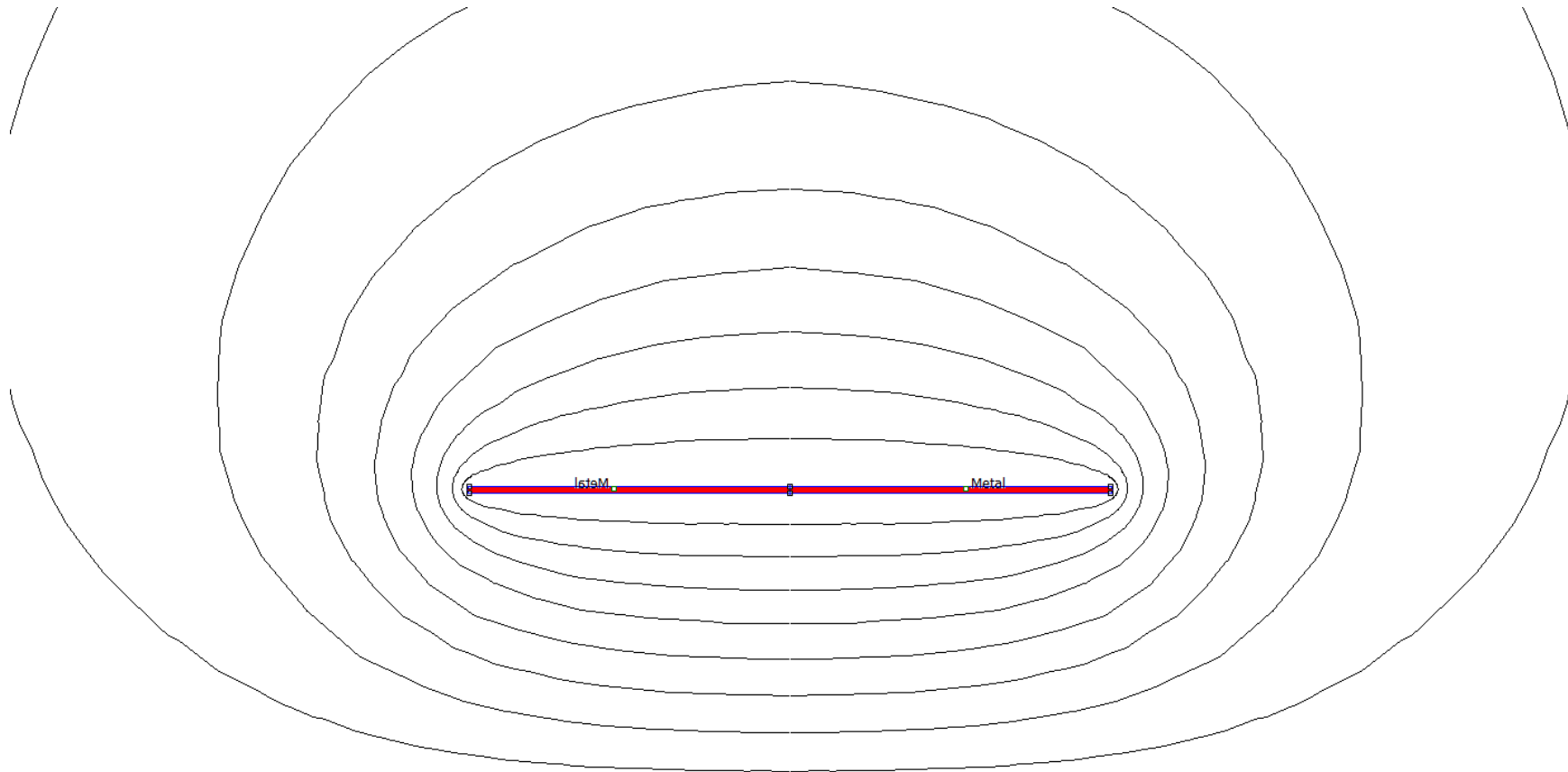
Touch sensor: when loaded with a known charge (Q) the potential (V) is a measure for the capacitance (C) and thus also for the distance (d)



Earth (potential: 0V)



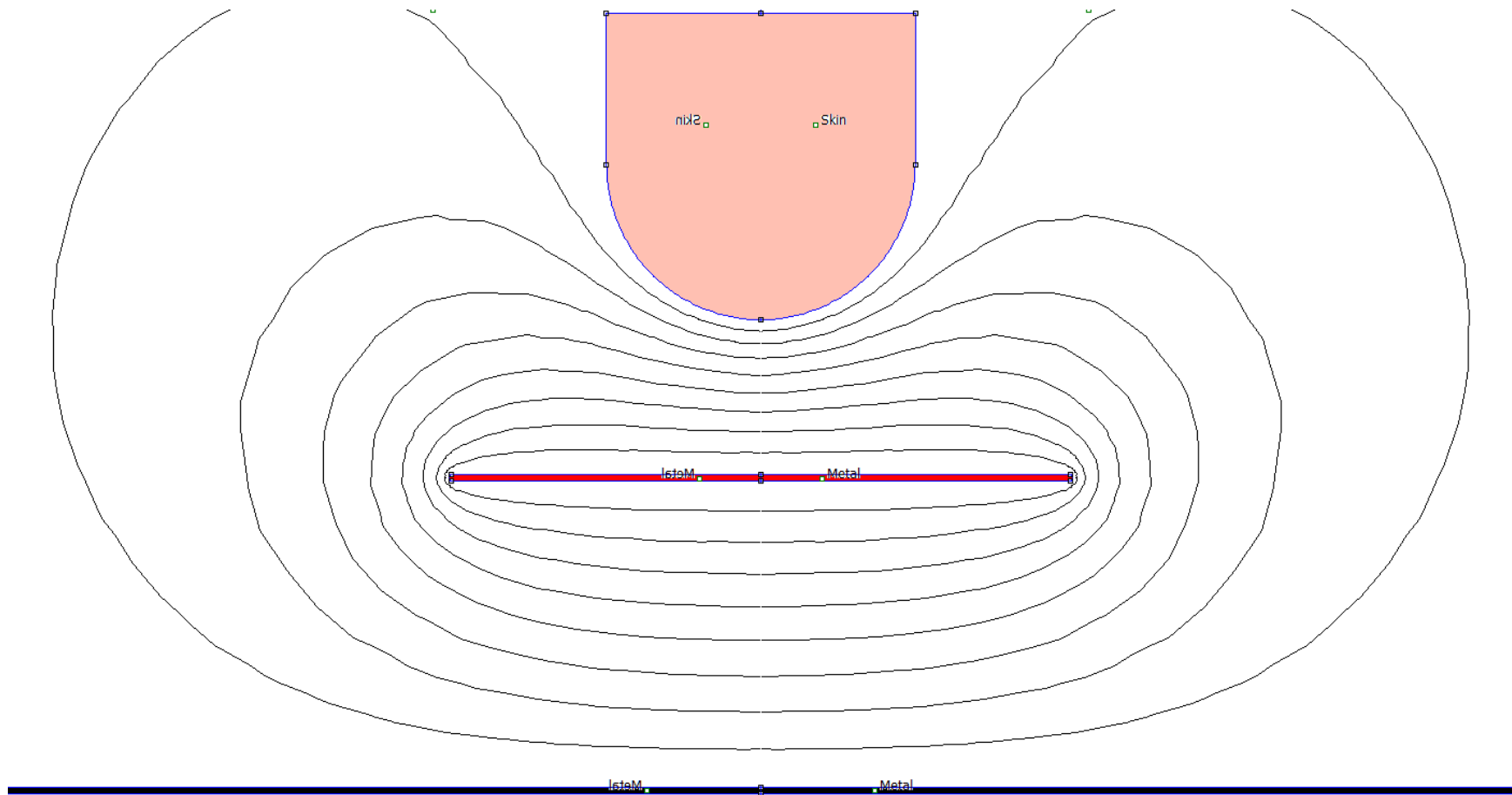
Equipotential lines



1610M

Air

Finger presence



Maximize overlapping area, minimize distance

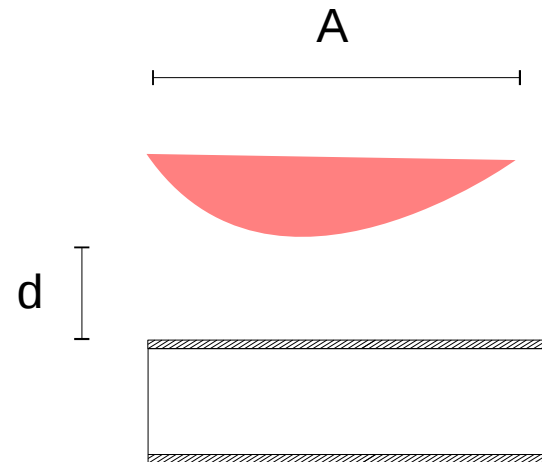
Rule of thumb: area should be about same size and shape of object (hand / finger) you want to detect

Area can be up to 3 x as large / small without much issues though

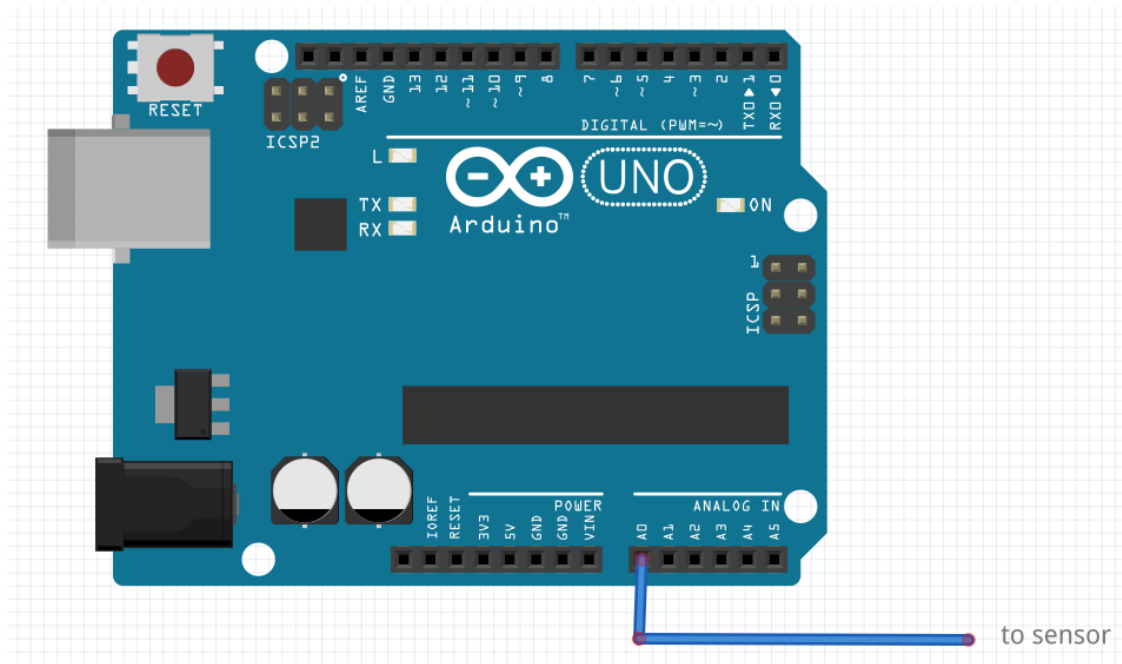
Best to make electrodes from conductive fabric

Electrodes made from conductive thread can be less sensitive / less reliable

$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$

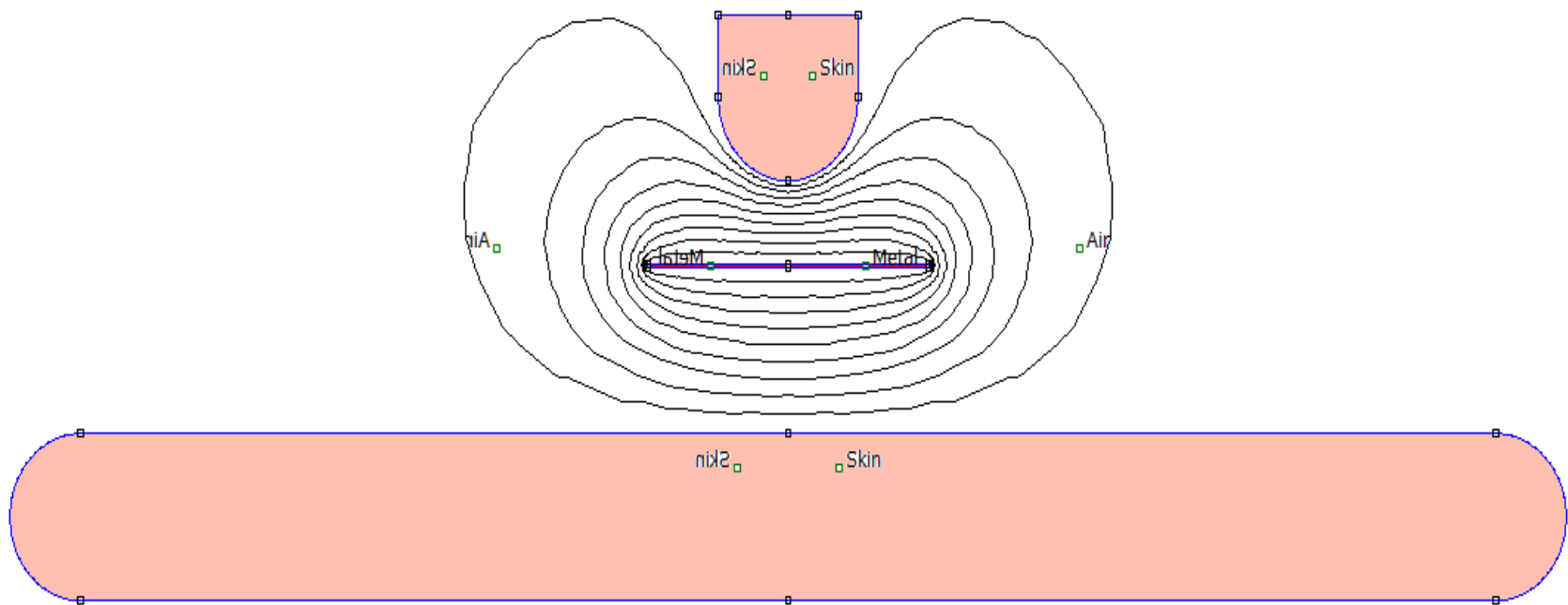


Wiring for capacitive sensor



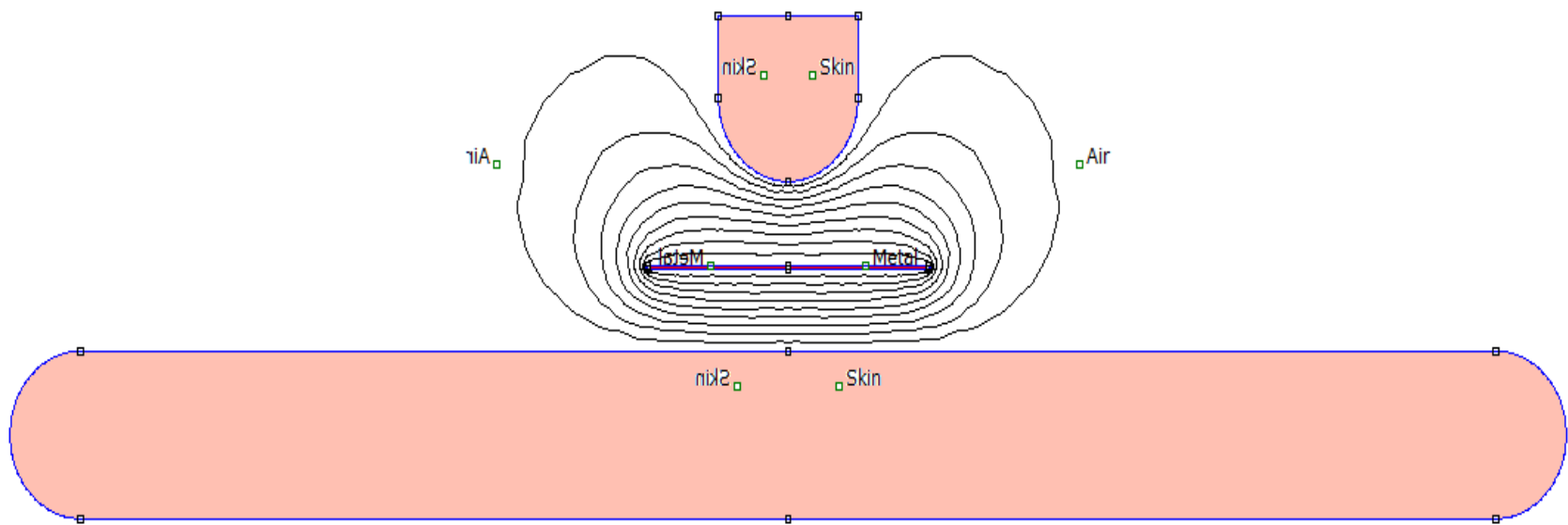
Hardware: just connect conductive plate to analog input on Arduino

Software: out of scope for this workshop, but source code is provided



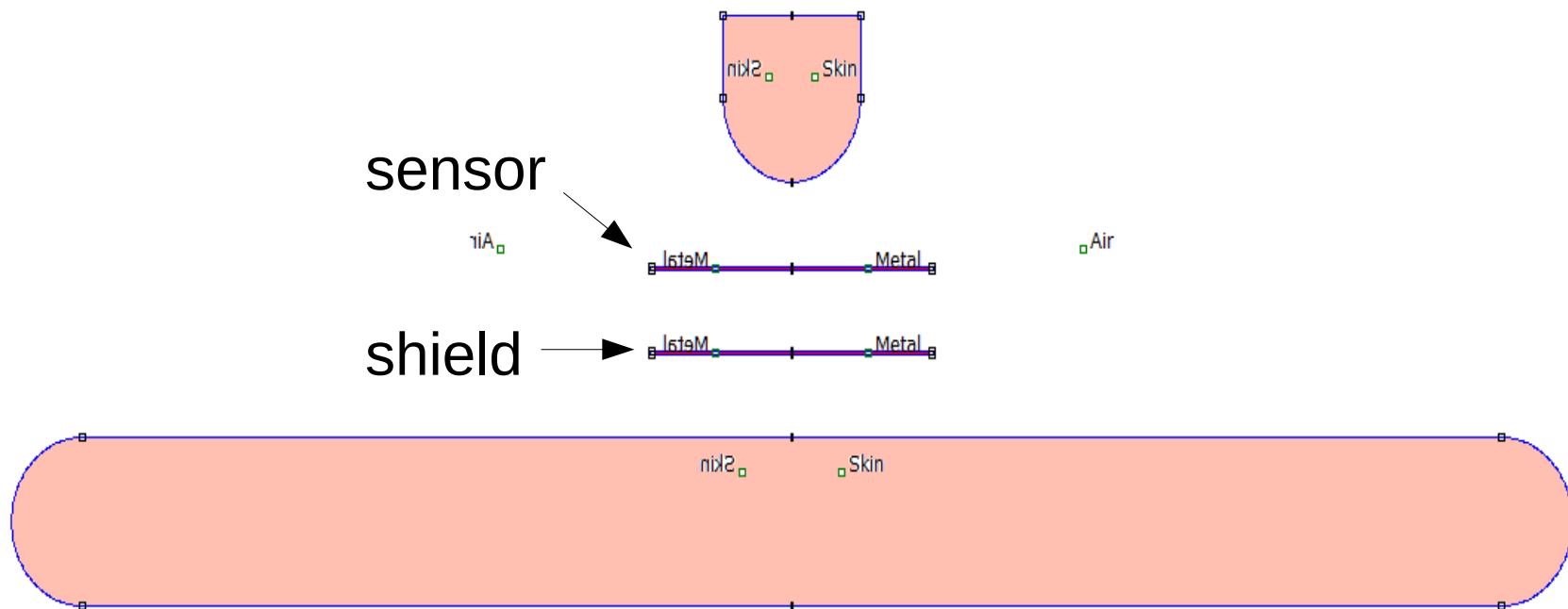
Wearable sensor: unintended touches

If distance between backside of sensor and skin changes, sensor sees unintended touches



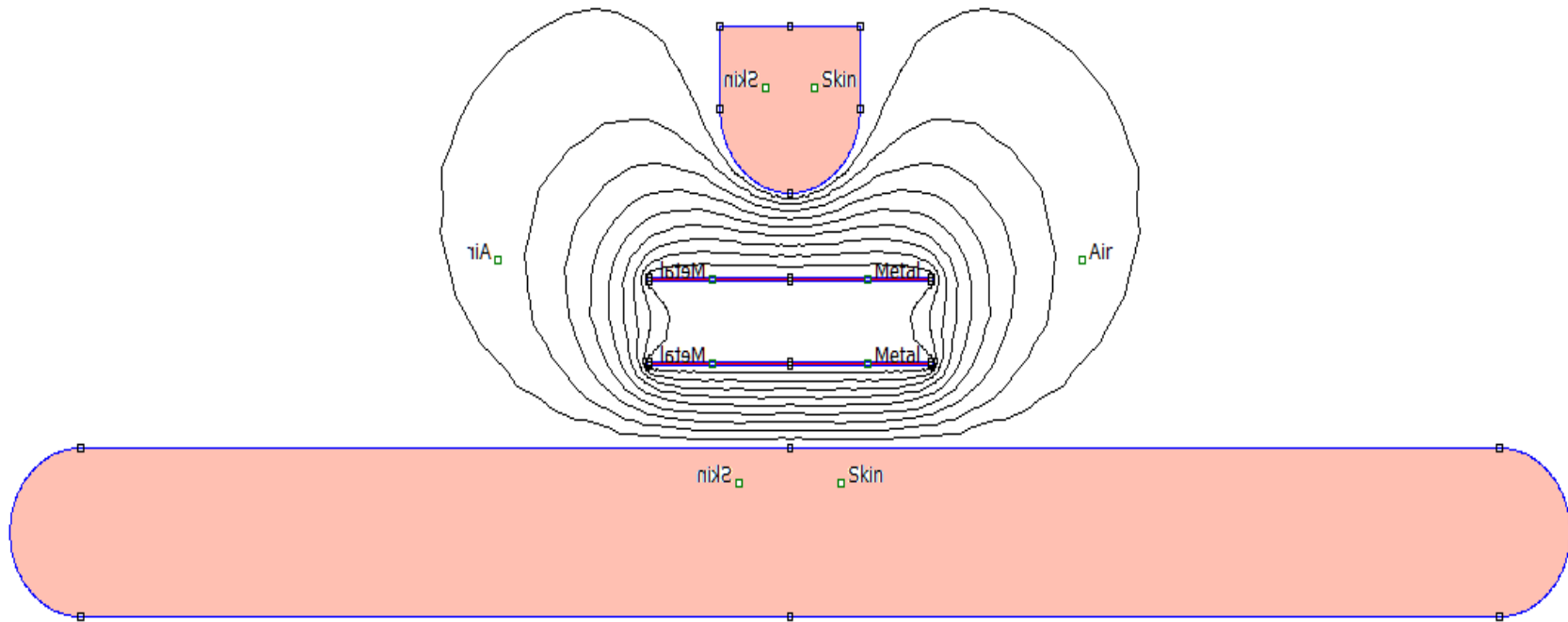
Wearable sensor with shield

- Add another layer of conductive fabric between sensor and skin
- Keep this fabric at same voltage as sensor to act as shield



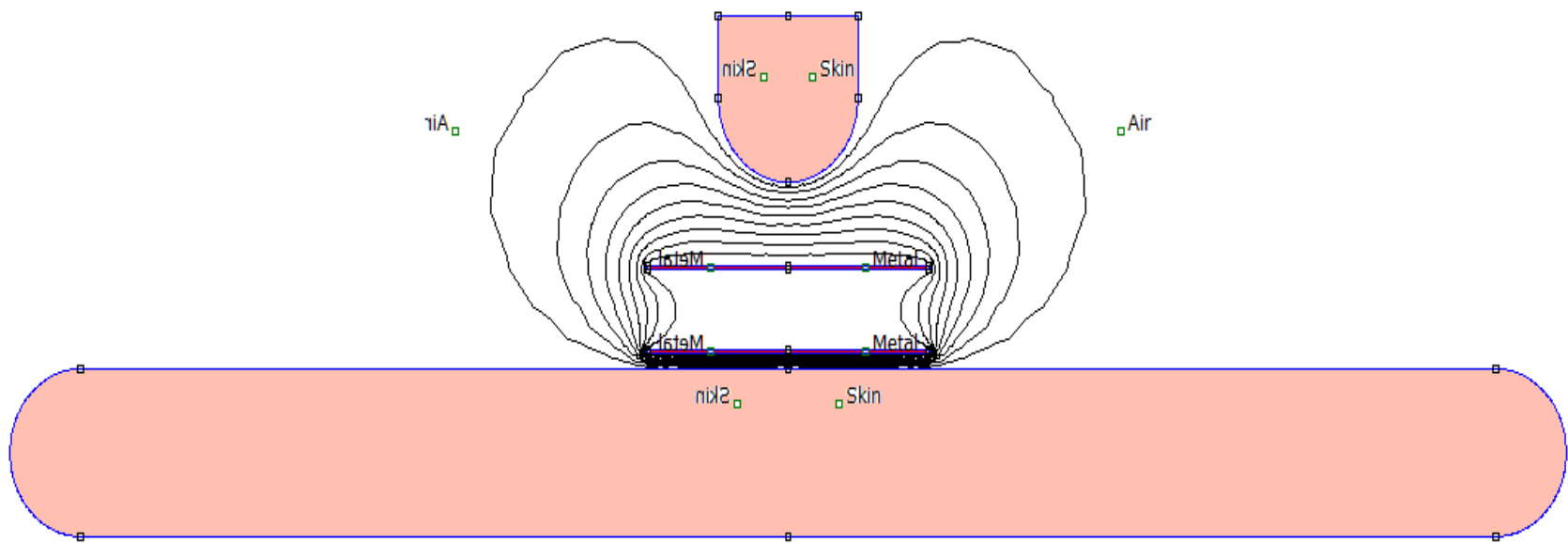
Wearable sensor with shield: no unintended touches

Field lines on back side of sensor do not change → sensor only “looks” in one direction

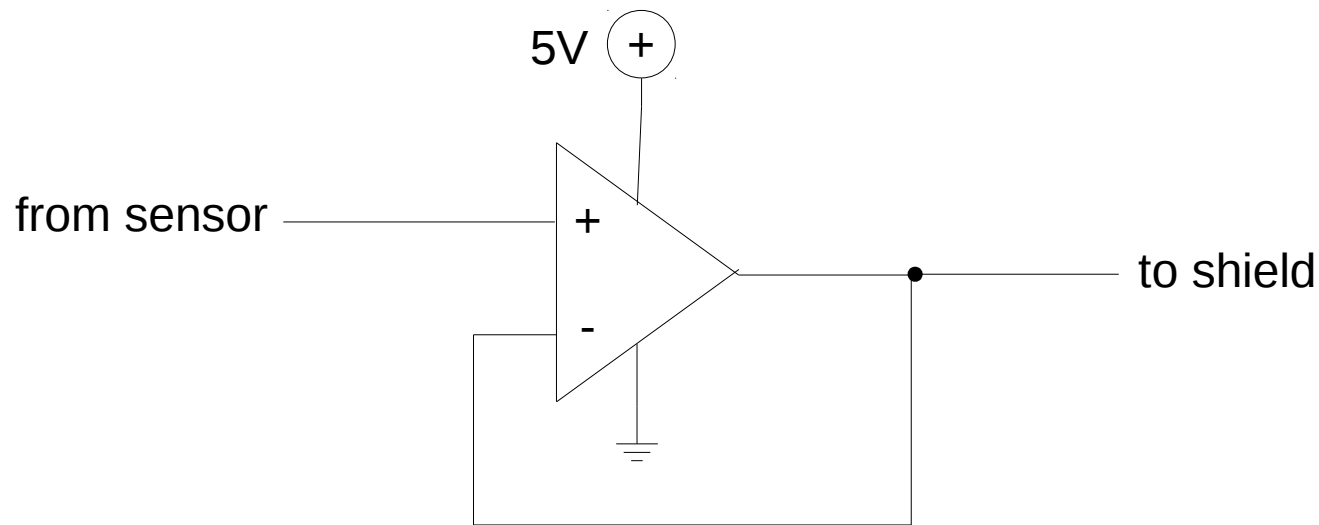


Wearable sensor with shield: no unintended touches

Field lines on backside of shield do change, but field lines on backside of sensor do not → no unintended touches

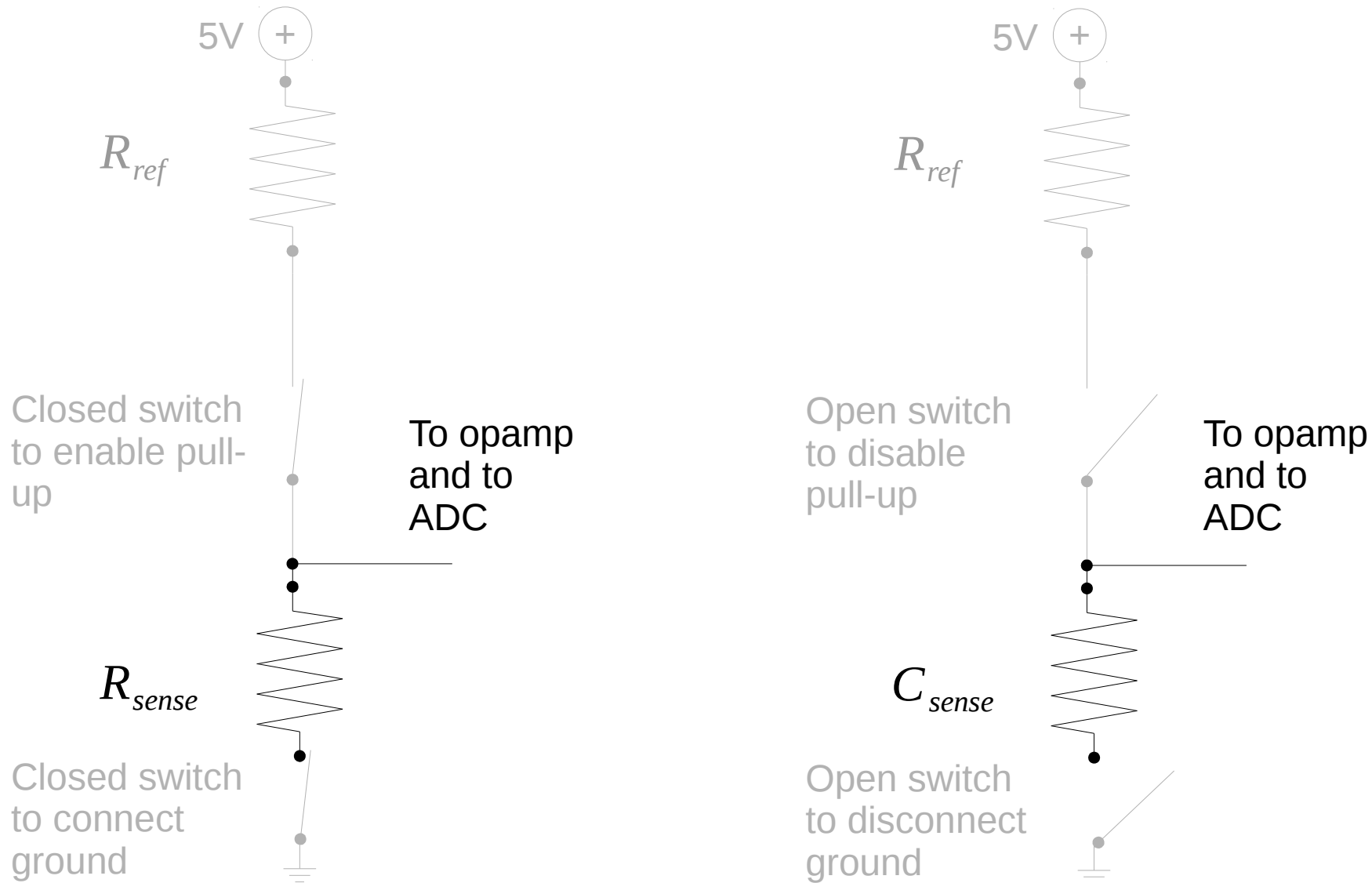


Circuit to keep shield at same voltage as sensor

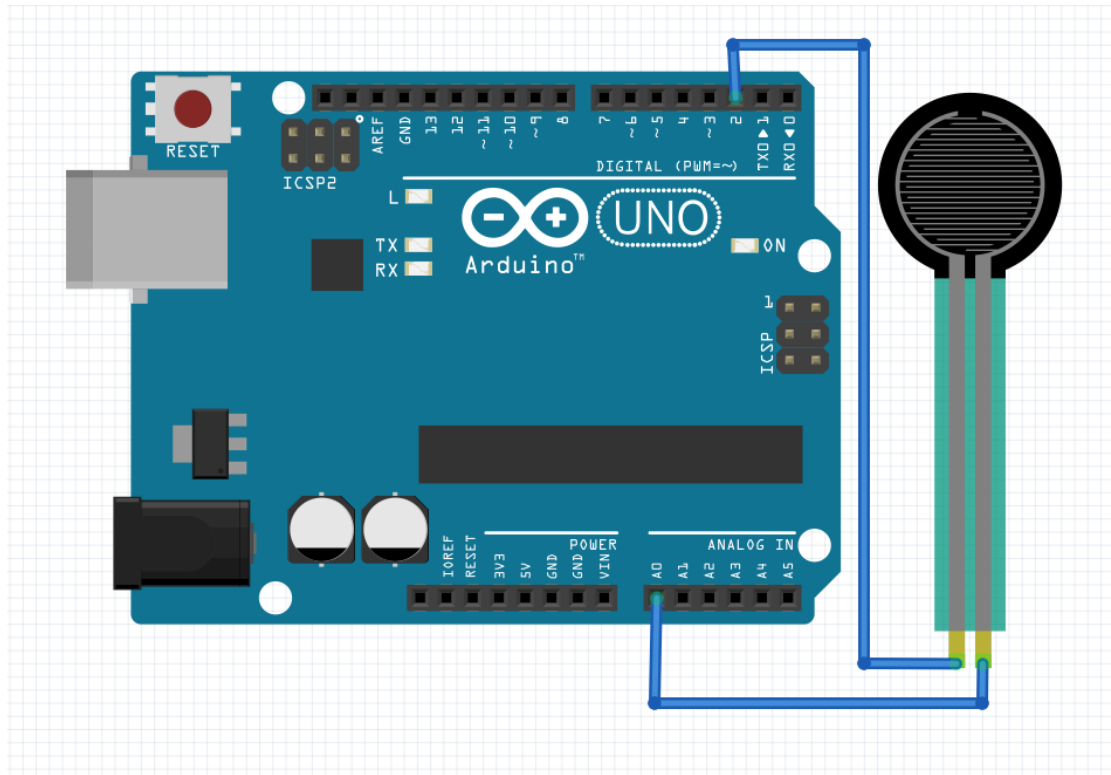


Opamp, for example MCP6242

Combining capacitive and resistive sensing



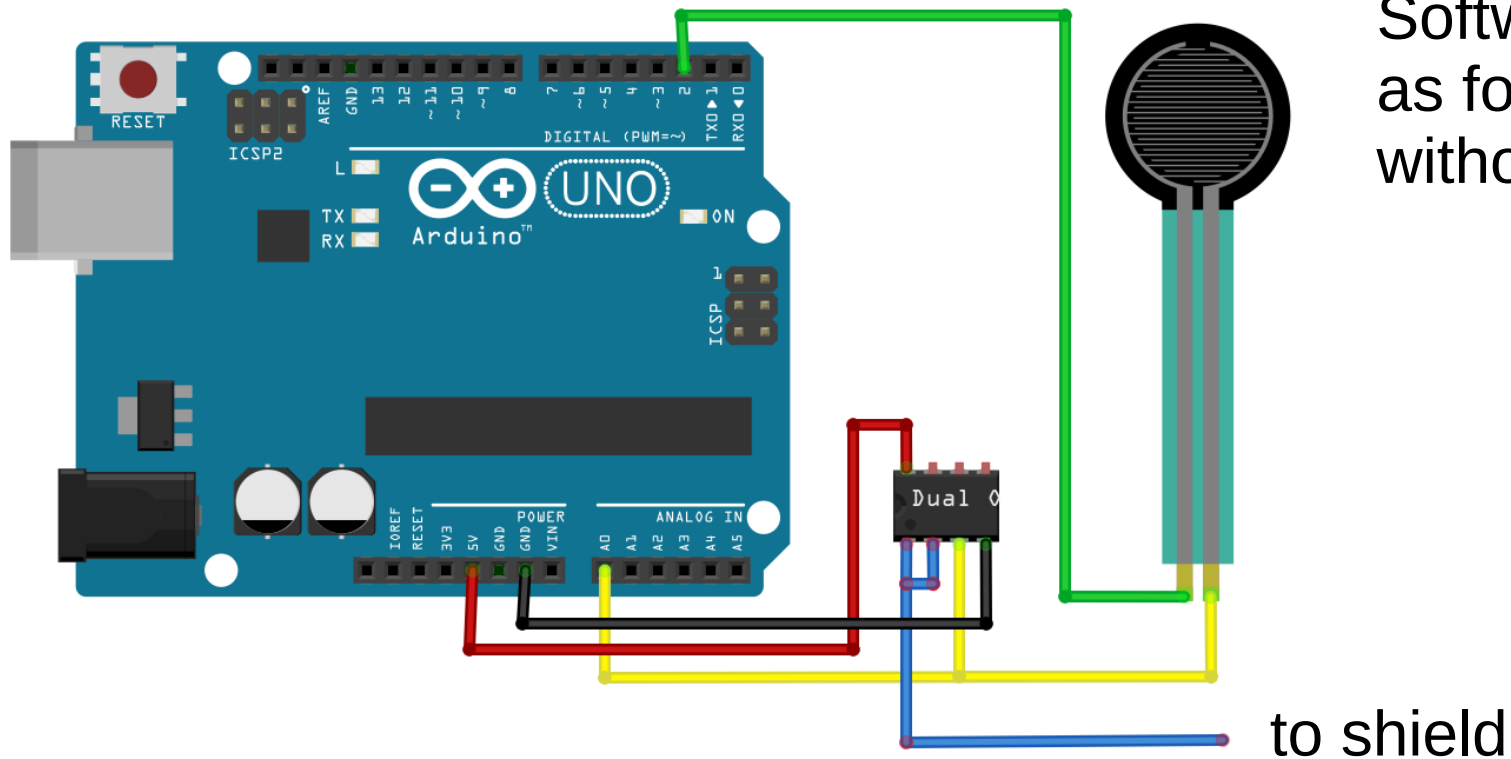
Wiring it all up (without shield)



Software: rapidly switch between capacitive sensing (for distance information) and resistive sensing (for pressure information)

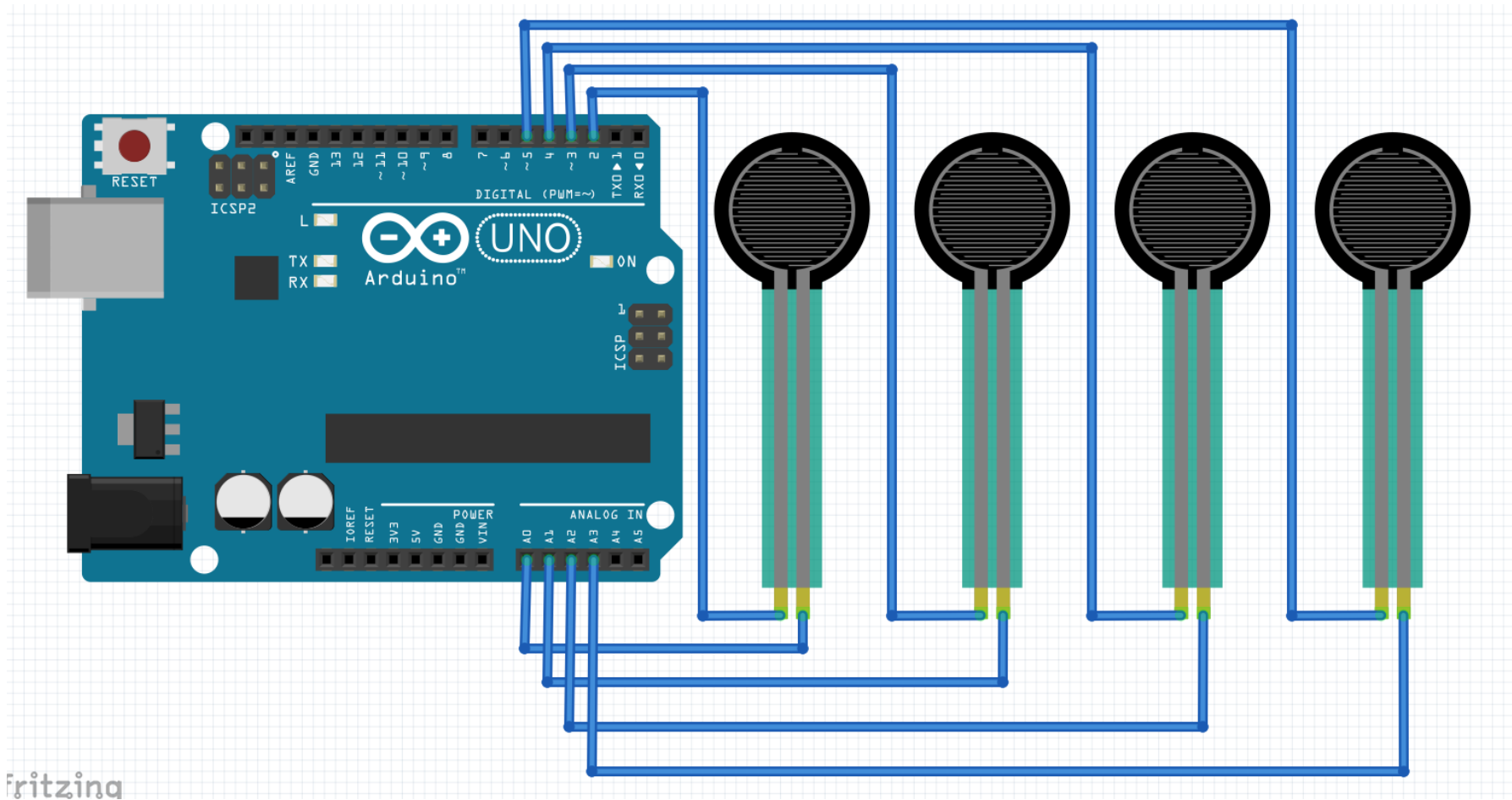
Download: <https://github.com/admarschoonen/resistive-cap-touch>

Wiring it all up (with shield)



Software: same
as for system
without shield

Wiring it all up for 4 sensors (without shield)



Summary

- Resistive sensor: reduce resistance by compressing medium resistive material, reducing path length for electrons
- ESD foam and ESD foil are very suitable
- Influence sensitivity with number of layers and area
- Capacitive sensor: increase capacitance to ground by bringing hand / finger close to sensor, increasing field lines
- Resistive sensor with floating pins is very suitable as capacitive sensor
- Influence sensitivity with area
- Ignore unintended touches from backside by adding a shield
- Capacitive and resistive sensor can be combined in one to measure both distance and pressure