# Pressure and presence sensors in textile

Eindhoven University of Technology
Industrial Design – Wearable Senses

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2016-02-18

# 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

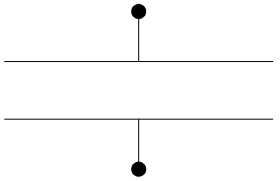
# Passive electronic components

Resistor

Long, narrow path of moderately conductive material

$$V = I \cdot R$$

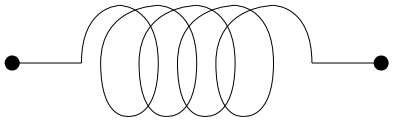
Capacitor



Two parallel plates with insulator in between

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

Inductor

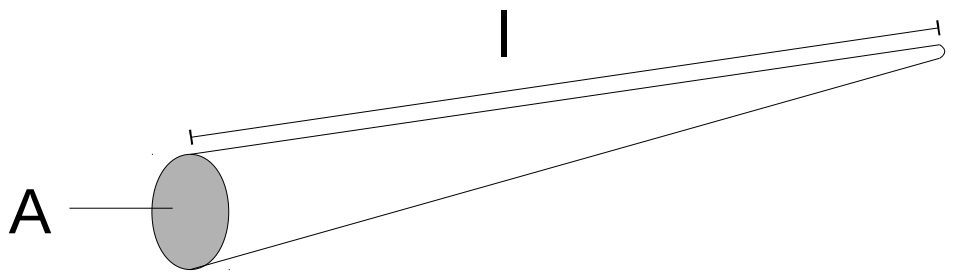


Long wound path of highly conductive material

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

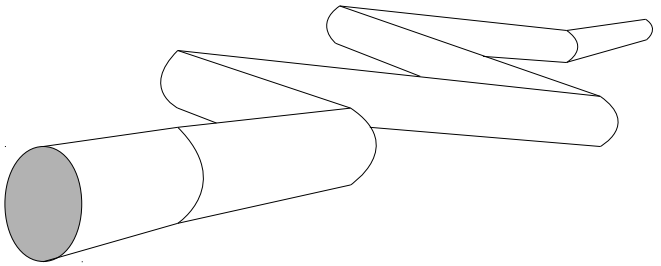
# Resistor

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




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

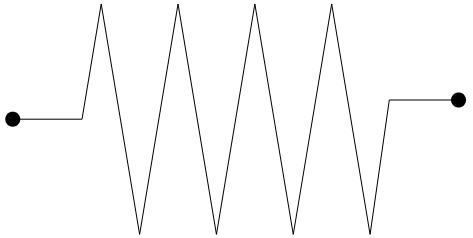
- Fold long wire to create high resistance in small space



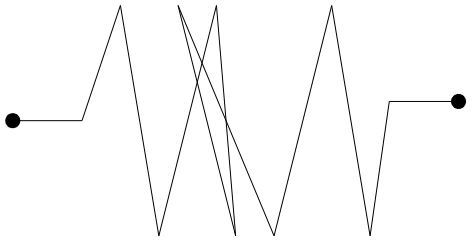
# Resistor

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

OK:



NOT OK:



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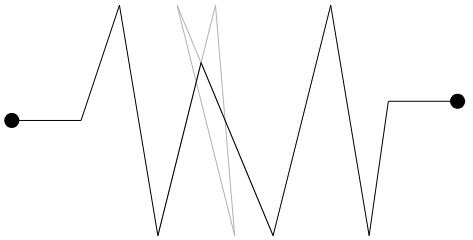
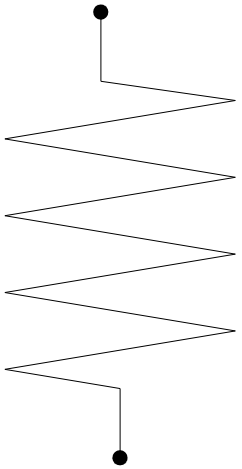
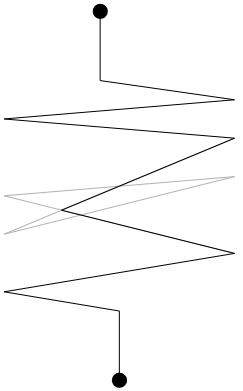


# Resistive pressure sensor

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



$R = 40\,k\,\Omega$



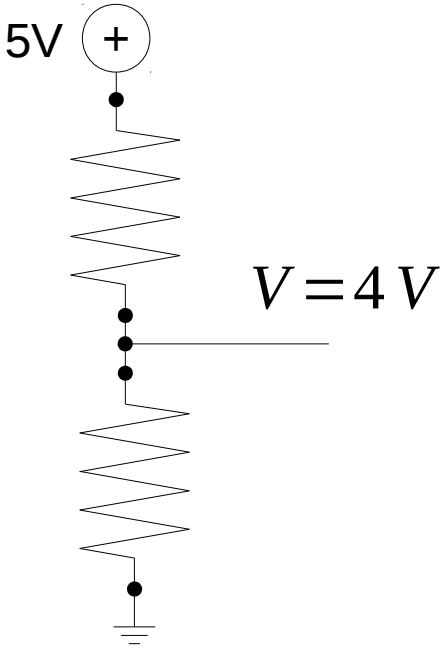
$R = 30\,k\,\Omega$

# Pressure sensor circuit

Use fixed resistor as reference $V = V_{cc} \cdot \frac{R_{sense}}{R_{ref} + R_{sense}}$

$R_{ref} = 10\,k\Omega$

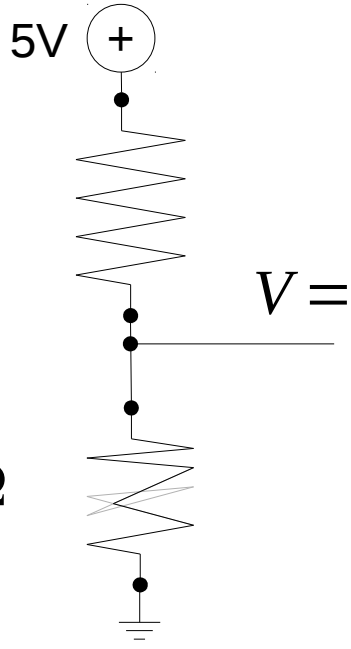
$R_{sense} = 40\,k\Omega$




$V = 4\,V$

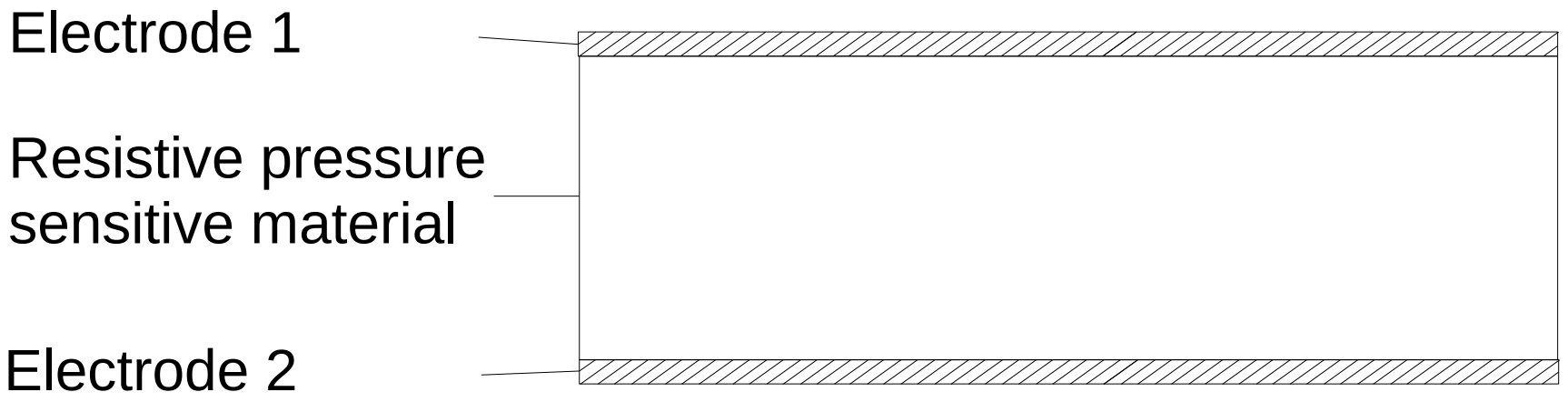
$R_{ref} = 10\,k\Omega$

$R_{sense} = 30\,k\Omega$



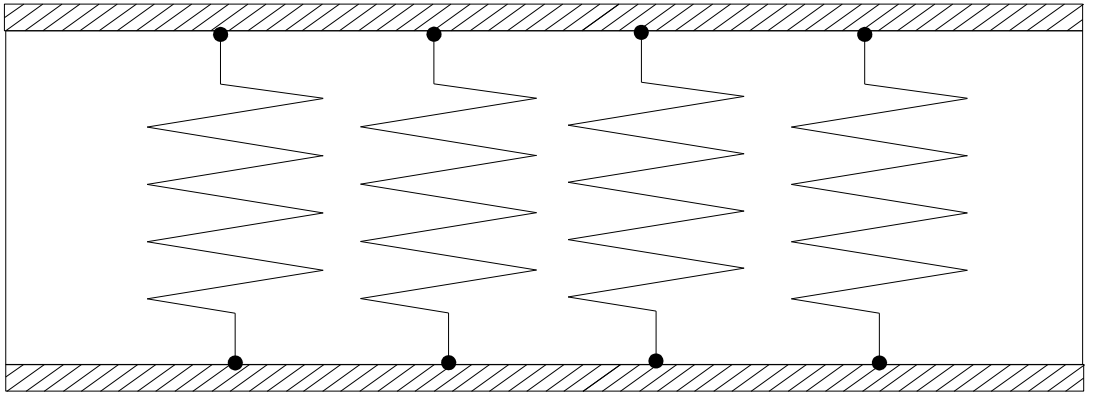

$V = 3.75\,V$

# Pressure sensor stackup

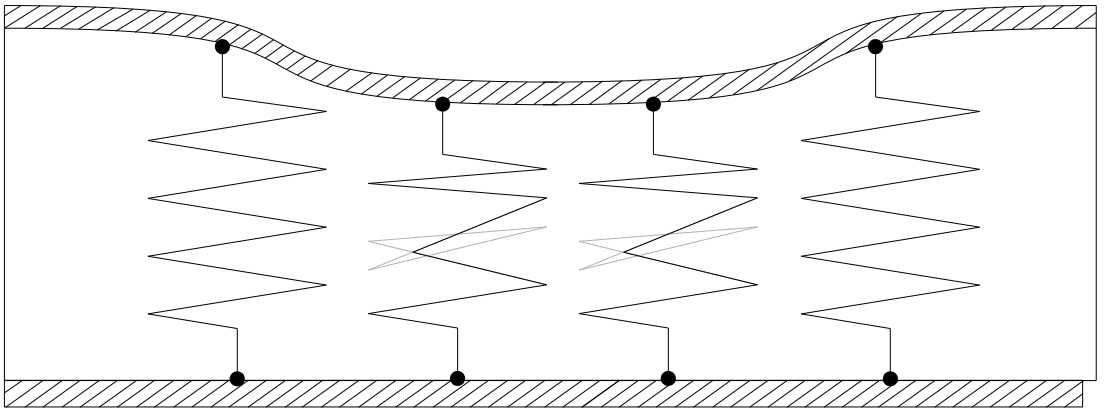


# Pressure sensitive material

Unpressed



Pressed

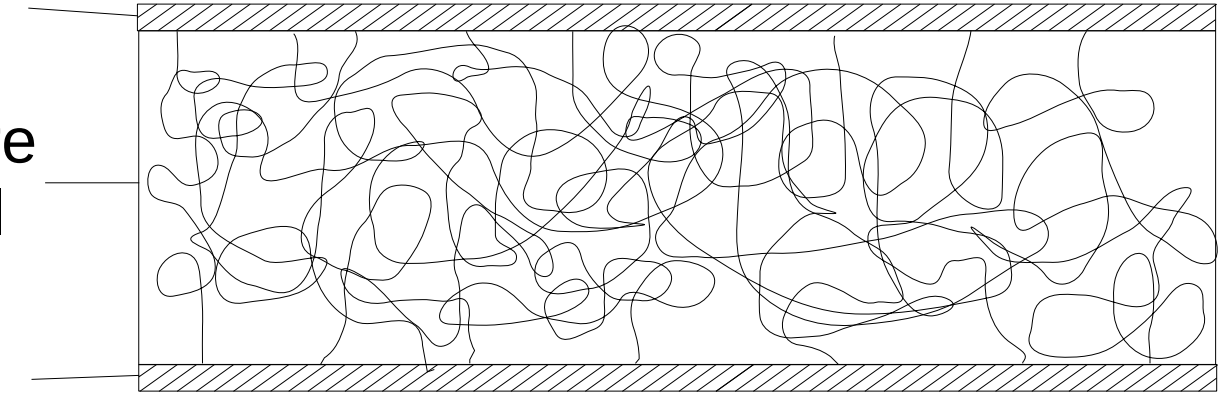


# Actual structure

Electrode 1

Resistive pressure sensitive material

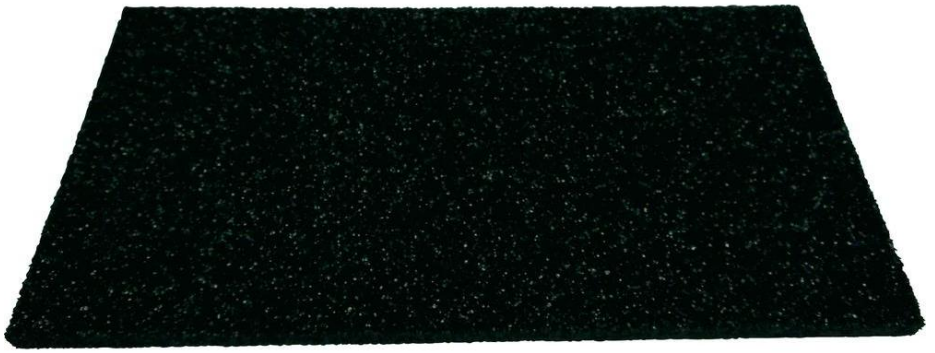
Electrode 2



# 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 / Linqstat

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) ← DO NOT USE THIS
- Medium resistivity (1 kOhm/sq – 50 kOhm/sq) ← USE THIS
  - Useful for large pressure sensors
- Low resistivity ( < 1 kOhm/sq) ← OR USE THIS
  - Useful for pressure sensors

# 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, strechable in 1 direction)
- Sparkfun DEV-10070 (conductive fabric MedTex130, strechable in 2 directions)

- PlugAndWear TAC31608IN1E1000 (stainless steel)
- PlugAndWear PW020 (conductive fabric, strechable 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 kOhm unpressed, < 4 kOhm 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**

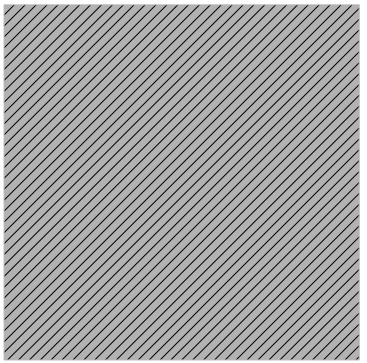
# Sensor design: conductive fabric electrodes

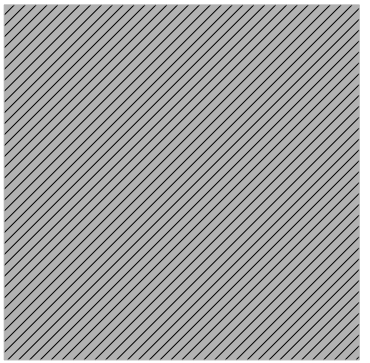
Front electrode

Back electrode

Prepare electrodes:

Cut out 2 pieces of conductive fabric





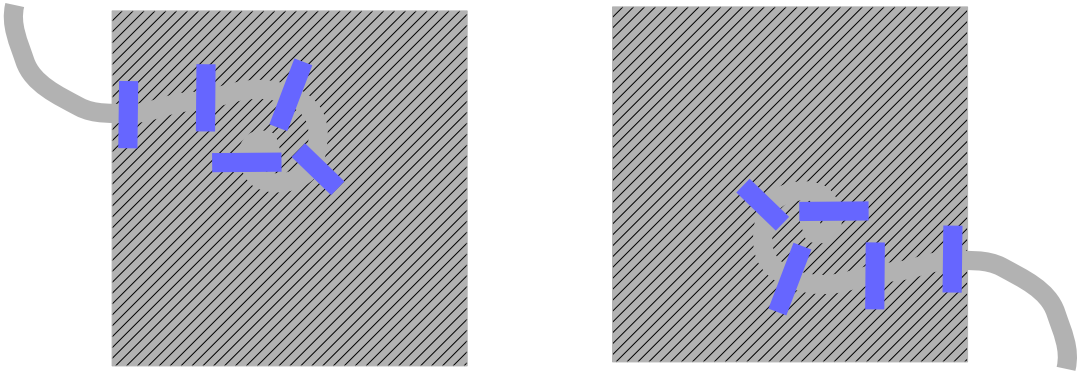
Tip: ripstop fabric easily frays, which can cause short circuits. If you use a sewing machine, this will be taken care of in step 3. If sewing by hand:

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

# Sensor design: conductive fabric electrodes

Front electrode

Back electrode



Prepare electrodes:

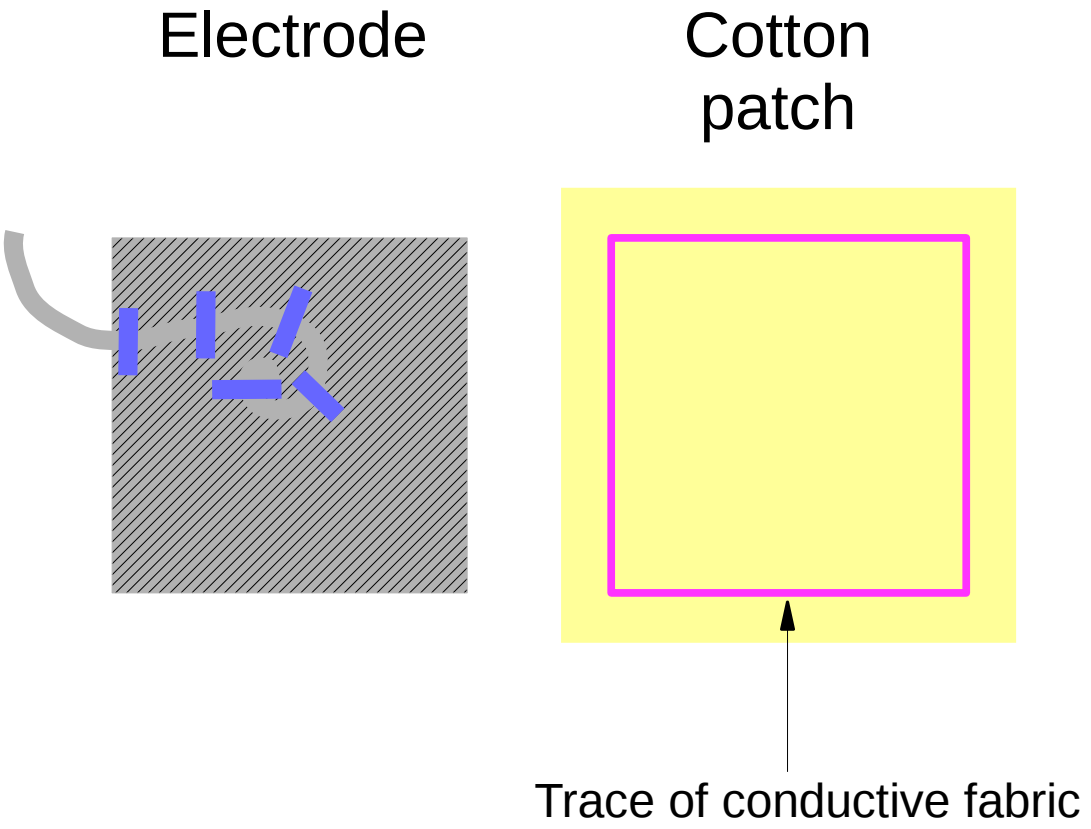
Place uncoated conductive thread / wire on electrode and fixate with stitches

Alternatively: sew thread directly through 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



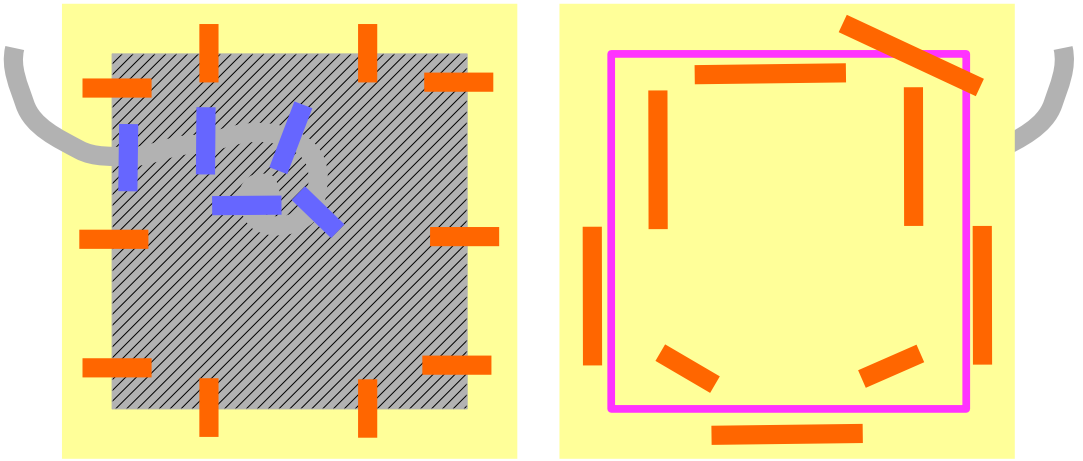
# Sensor design: conductive fabric electrodes

Front

Back

Sew each electrode to its own cotton patch

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



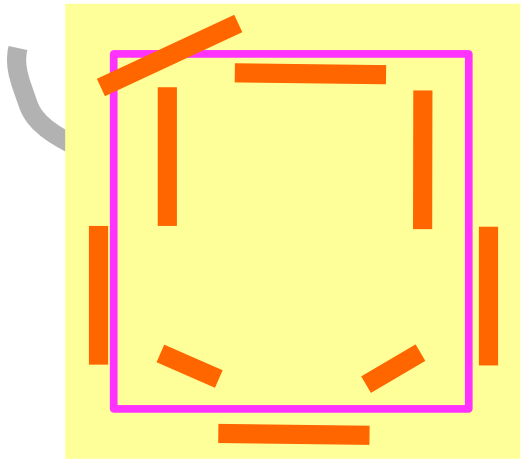
# Sensor design: conductive fabric electrodes

Front

Pressure sensitive material

Cut out pressure sensitive material

Must be slightly larger than electrode but smaller than cotton patch



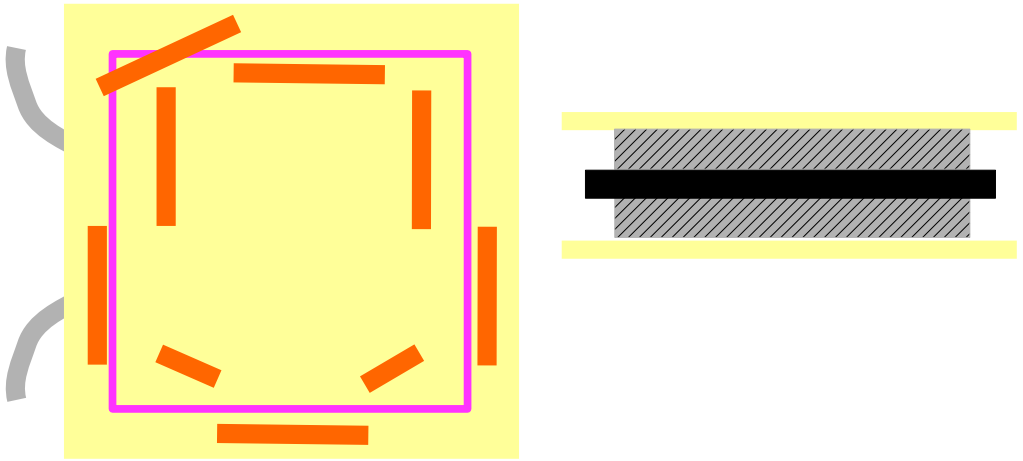
# Sensor design: conductive fabric electrodes

Front

Side

Place pressure sensitive material in between electrodes

Electrodes must face inwards



# Sensor design: conductive fabric electrodes

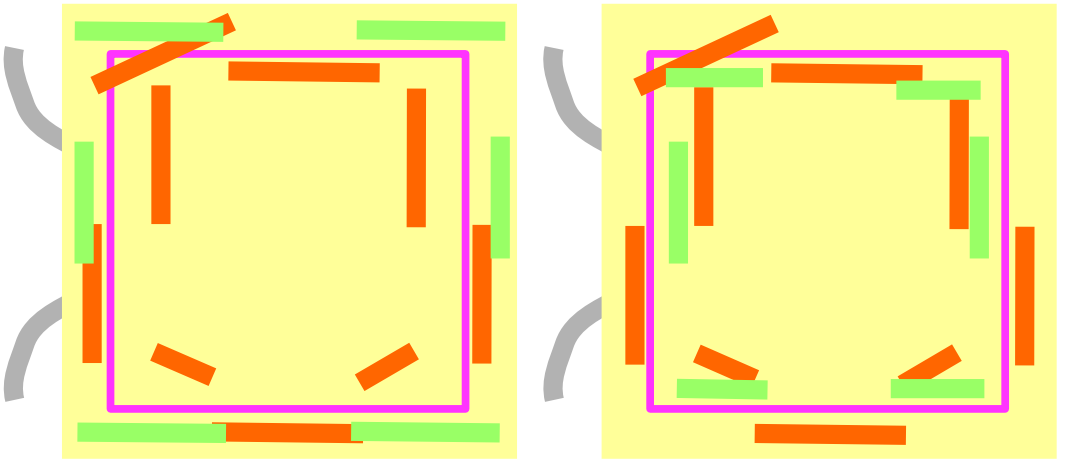
Sew sensor together

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 must base pressure

Good

Bad



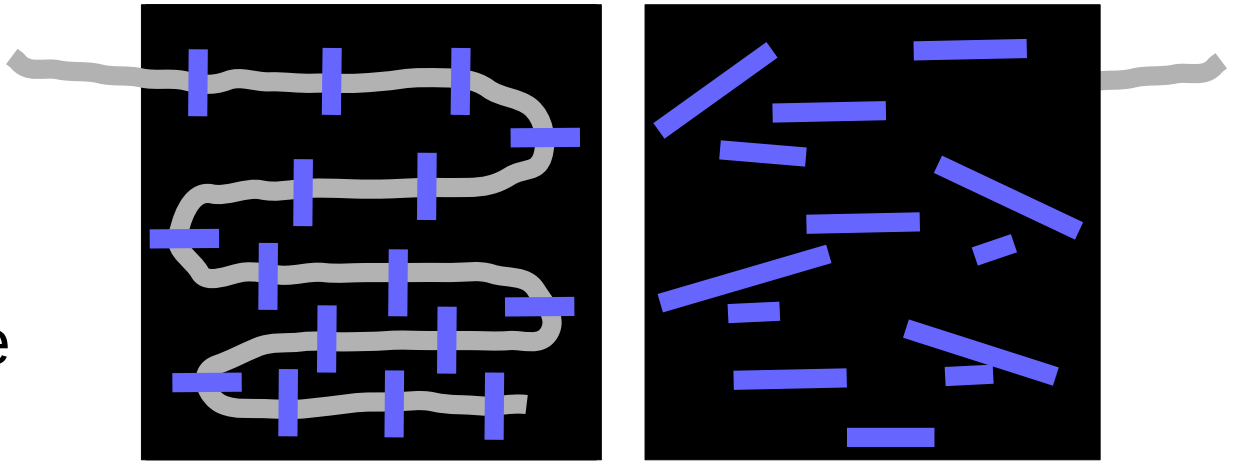
# Sensor design: conductive thread electrodes

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

Front Back

First electrode:

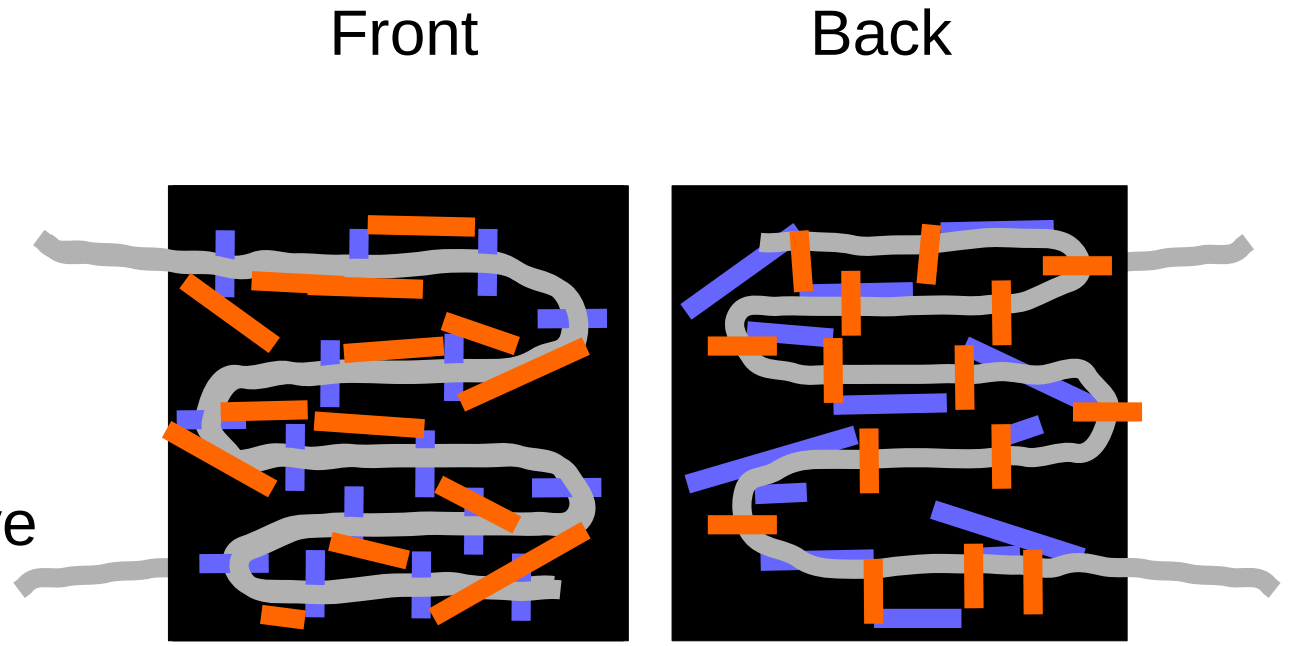
Place uncoated conductive thread / wire all over pressure sensitive material and fixate with stitches



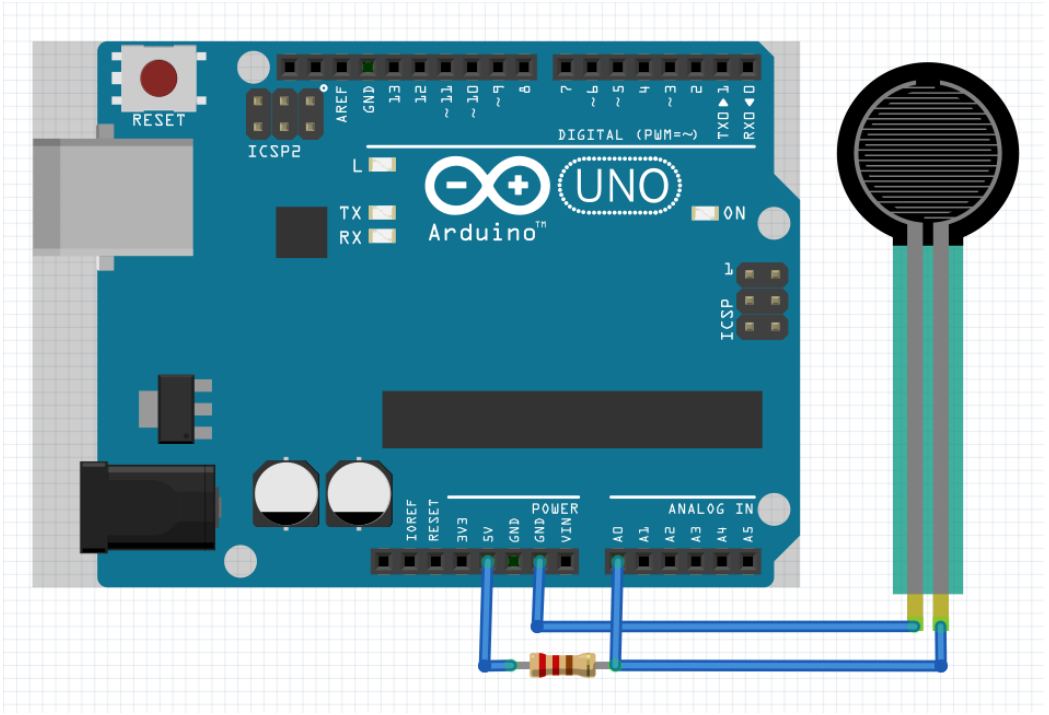
# Sensor design: conductive thread electrodes

Second electrode:

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



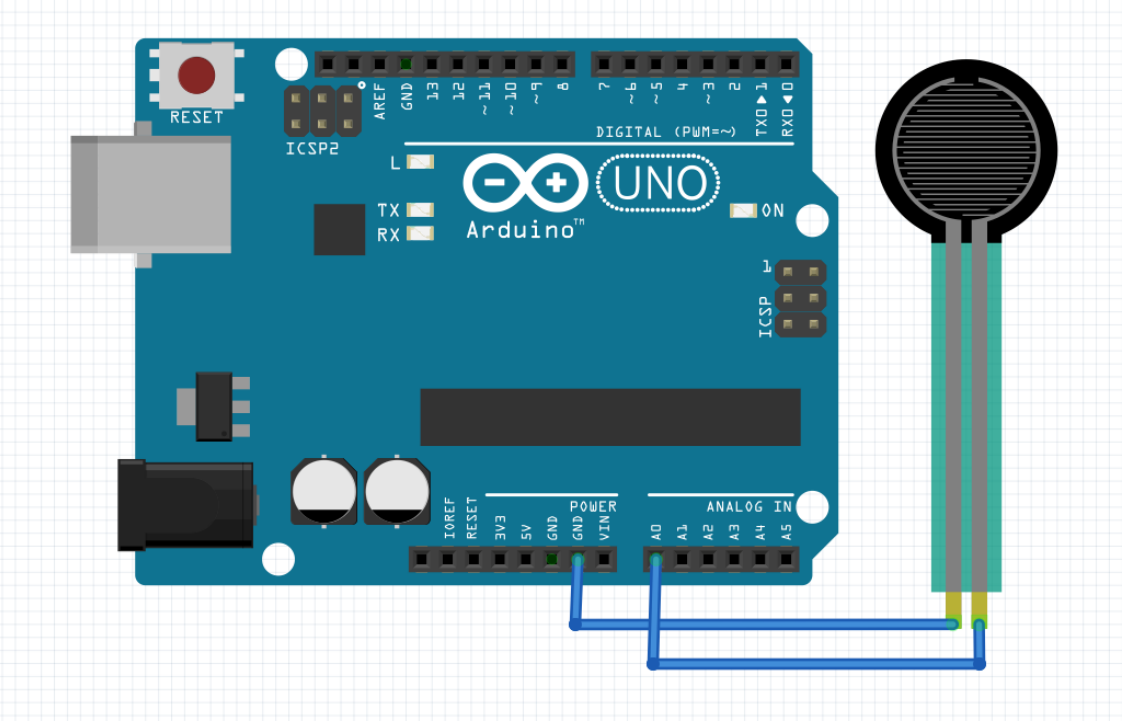
# Wiring it all up




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




}

void loop() {
    int x;

    x = analogRead(0);
    Serial.println(x);
}
```

# Simplifying things

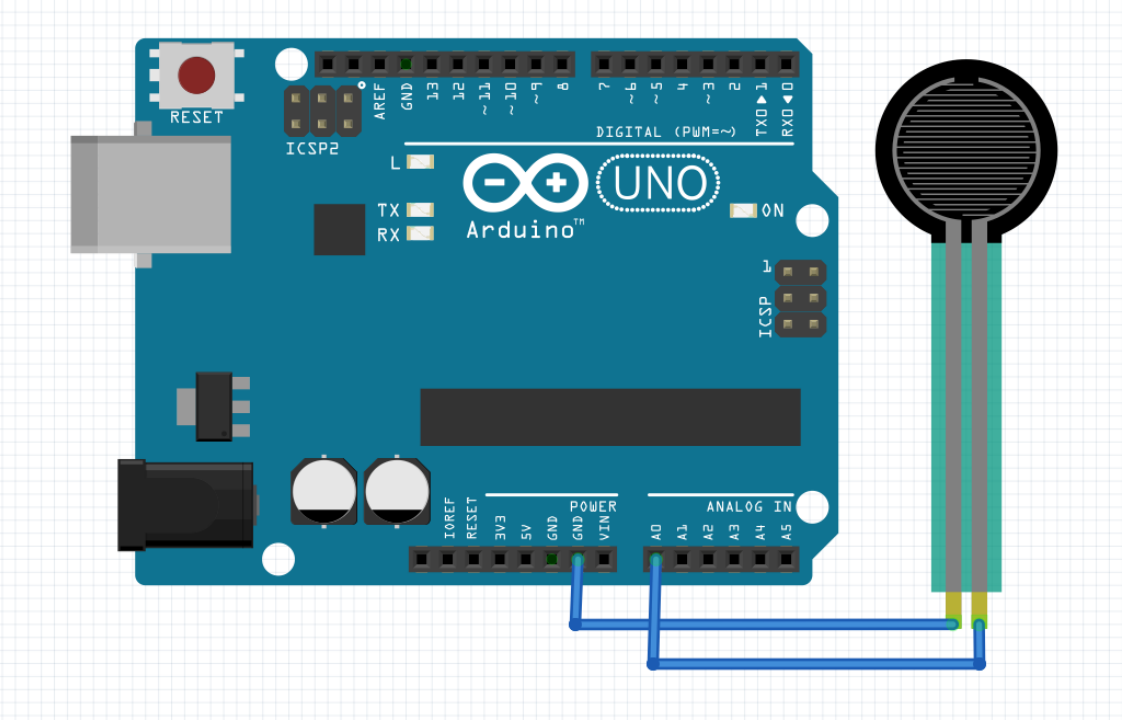
Arduino has internal pull-up resistors on analog input (20 – 50 kOhm)




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

    pinMode(A0, INPUT);
    digitalWrite(A0, HIGH);

}

void loop() {
    int x;

    x = analogRead(0);
    Serial.println(x);
}
```

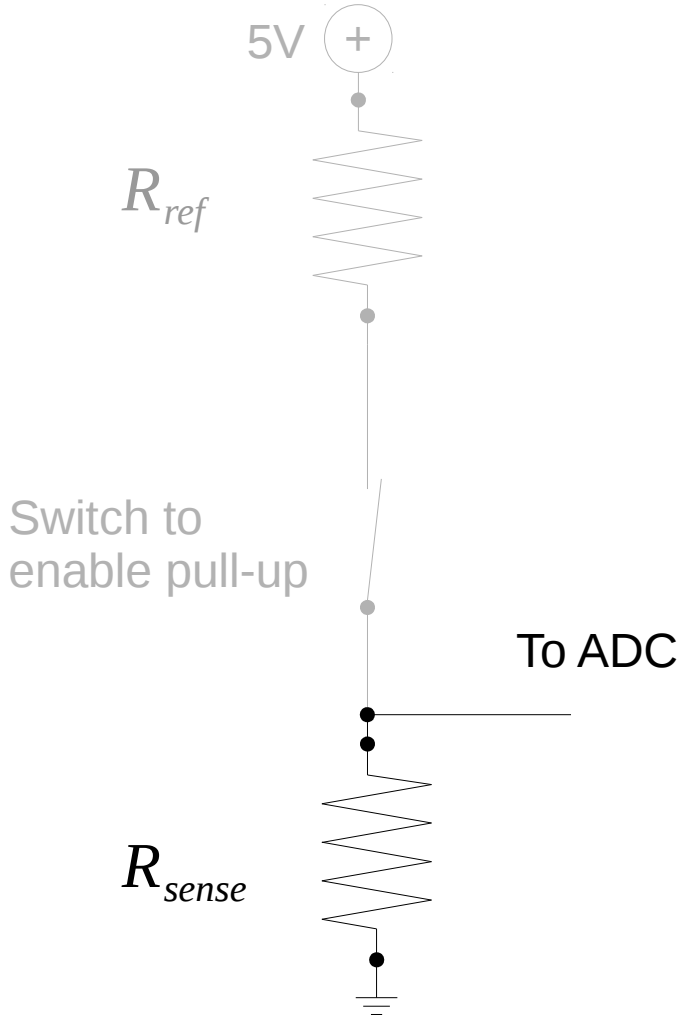
# Increasing sensitivity

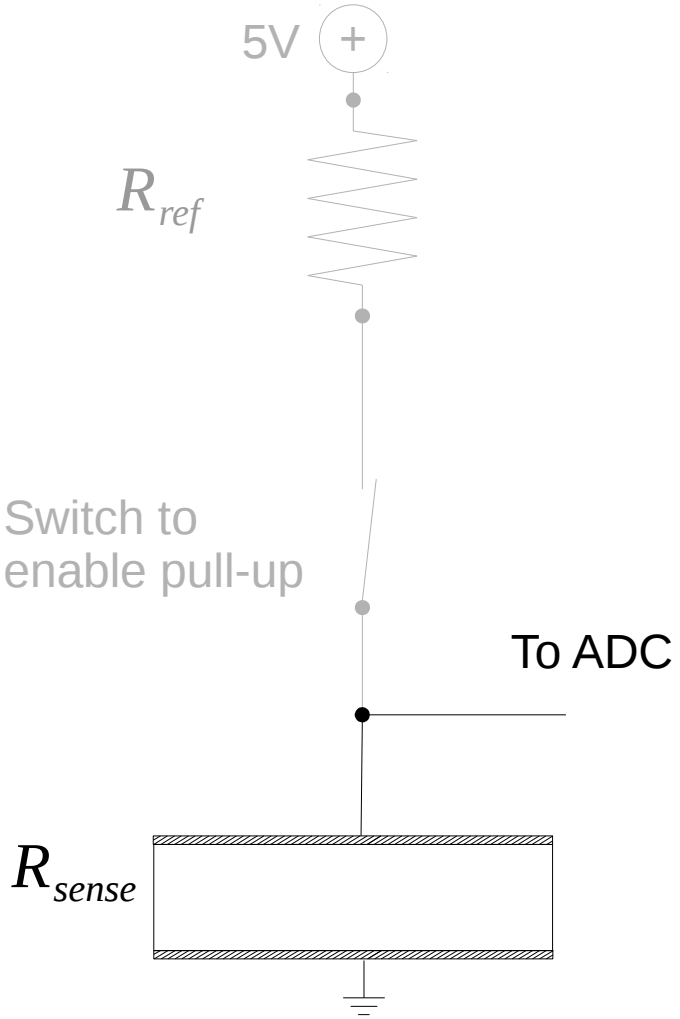
Use internal 1.1V reference for ADC (instead of 5V) if signal is below 200 when unpressed



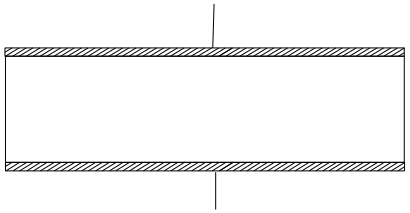

```
void setup() {
    Serial.begin(115200);

    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:

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

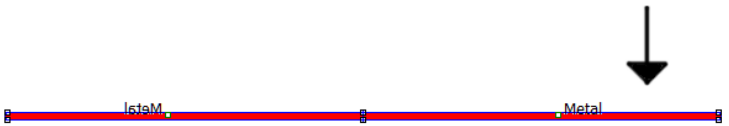
Relation between plate area, distance and capacitance for parallel plate capacitors:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

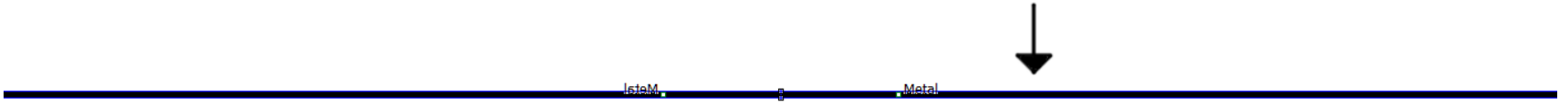
For air:

$$\varepsilon_0 = 8.854\ pF/m$$
$$\varepsilon_r = 1$$

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)



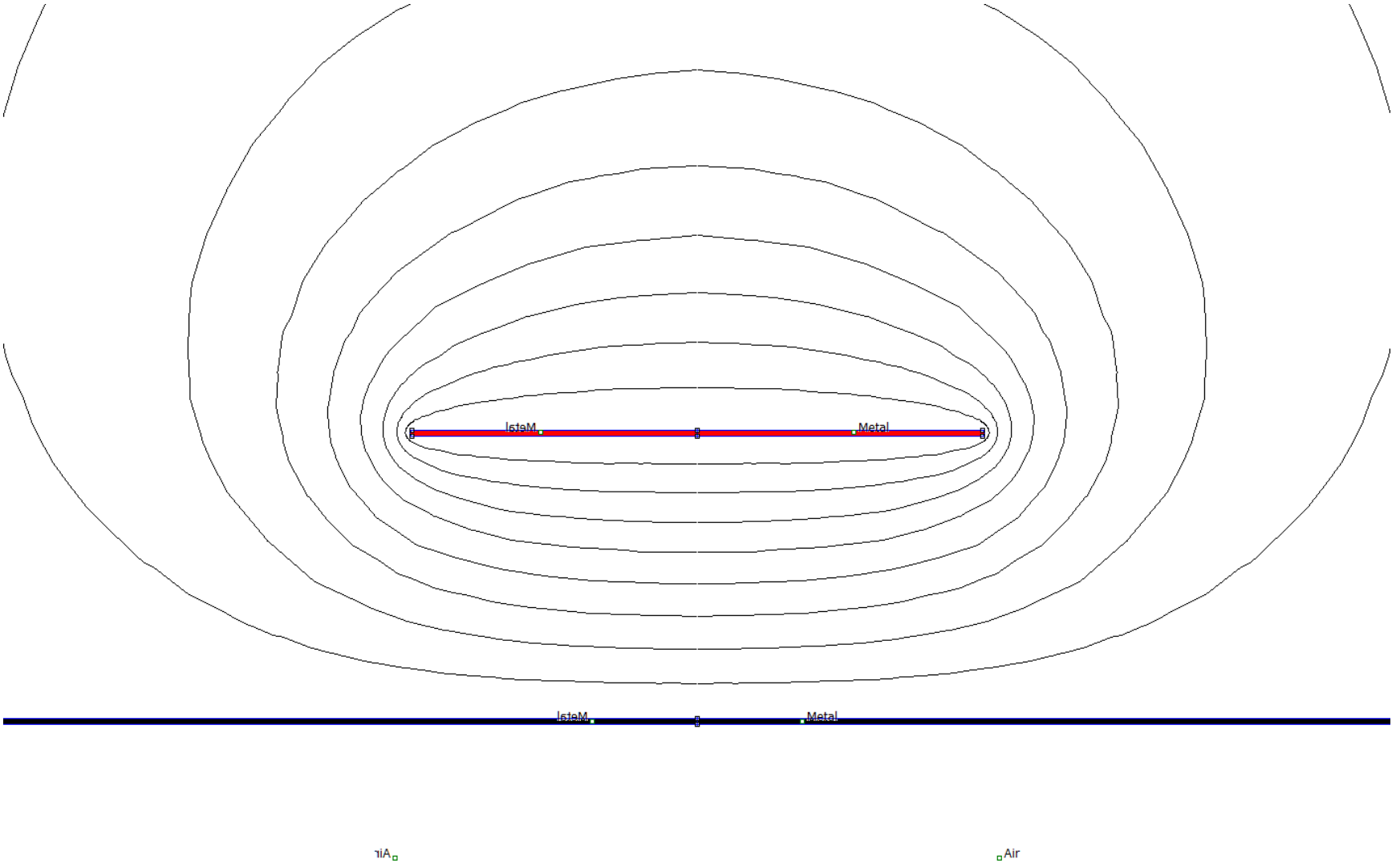

Earth (potential: 0V)



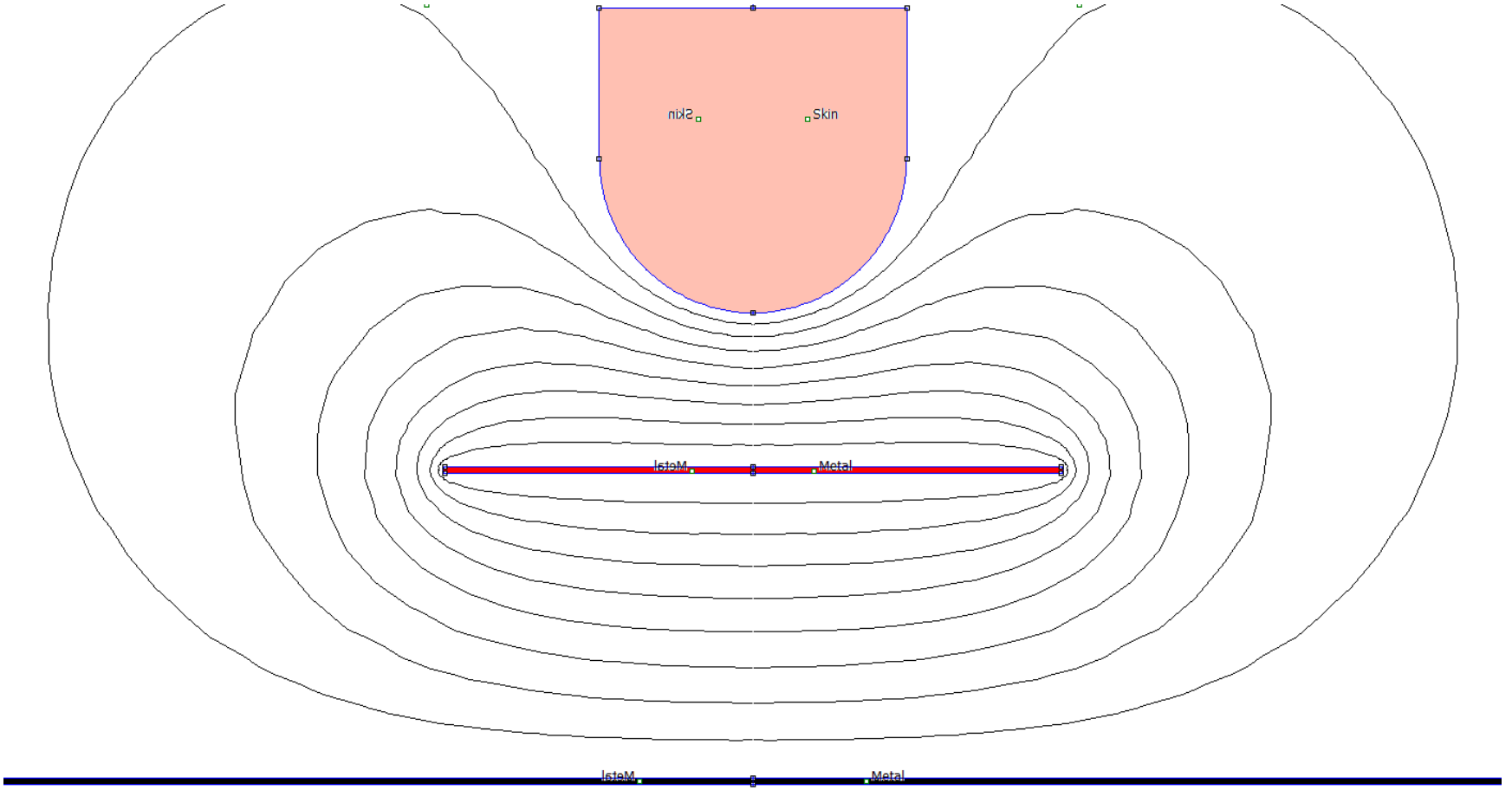

Air

Air

# Equipotential lines



# Finger presence

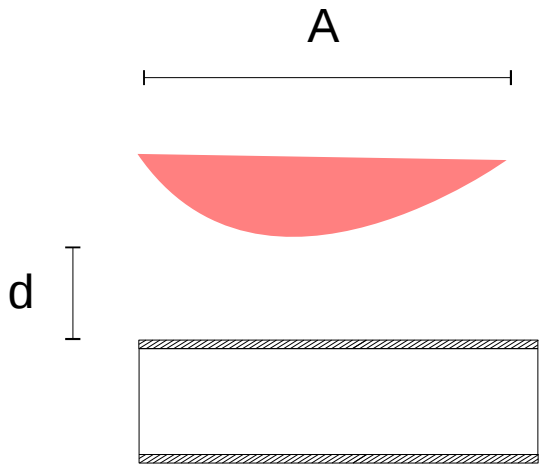


# Maximize overlapping area, minimize distance

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

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

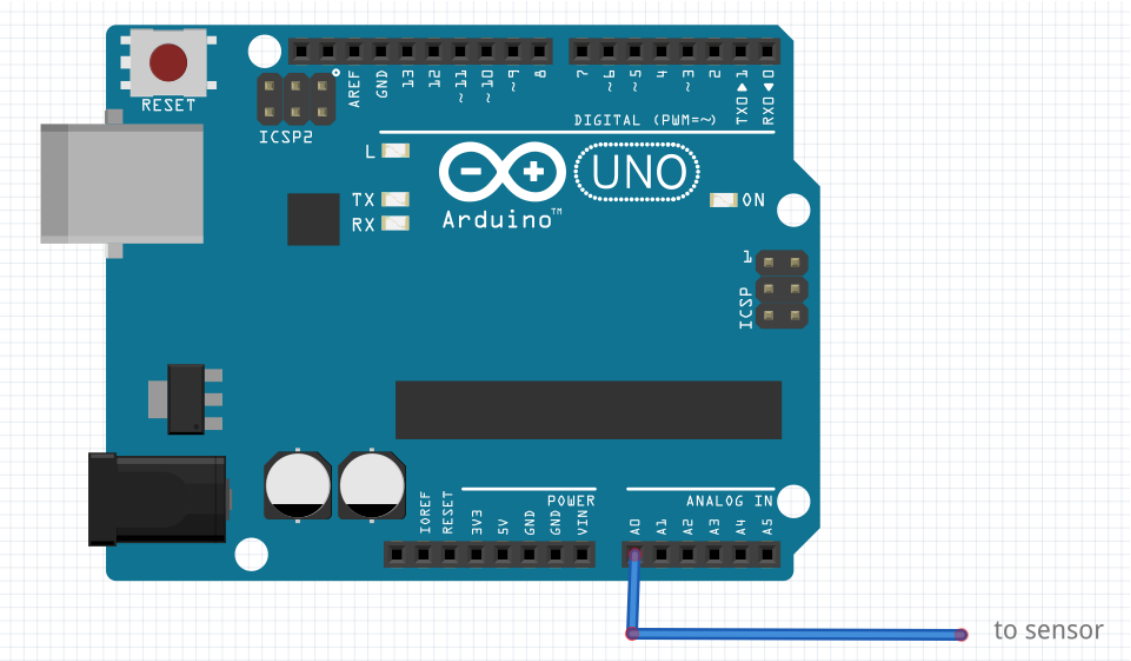
Area can be up to 3 x as large / small without much issues though




Best to make electrodes from conductive fabric

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

# Wiring for capacitive sensor

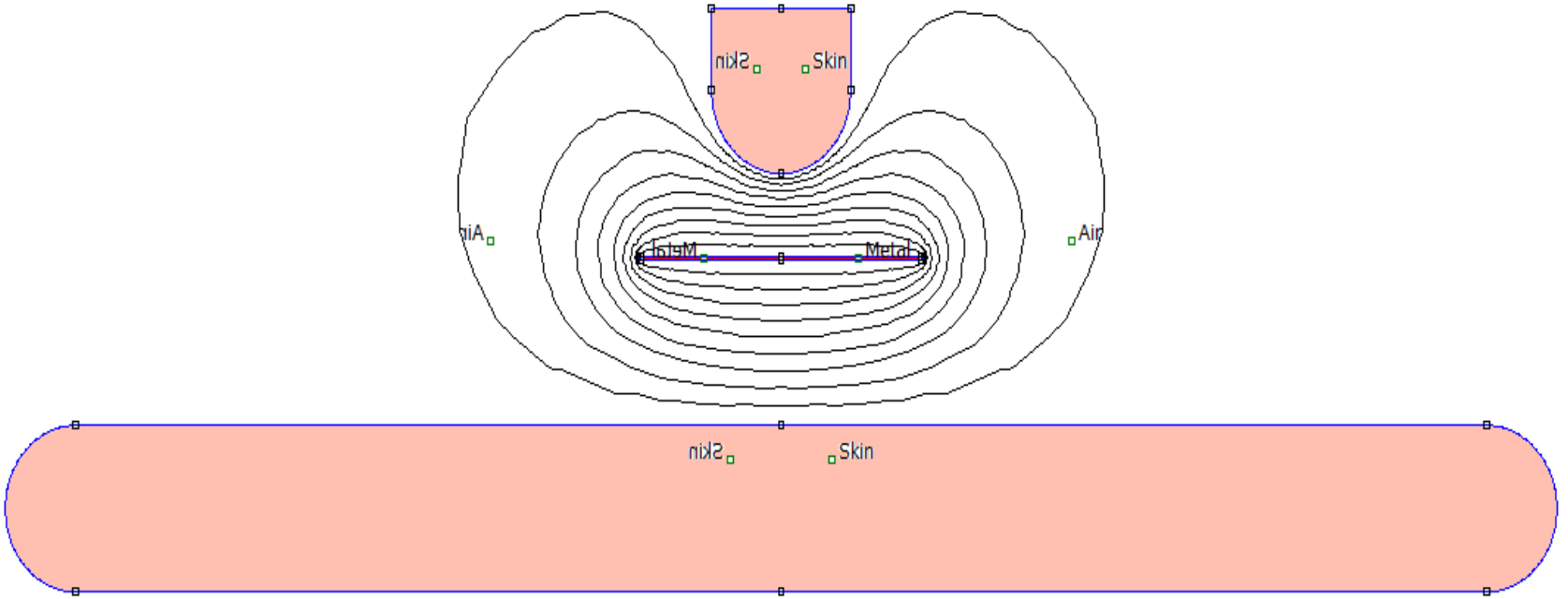



Hardware: just connect conductive plate to analog input on Arduino

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

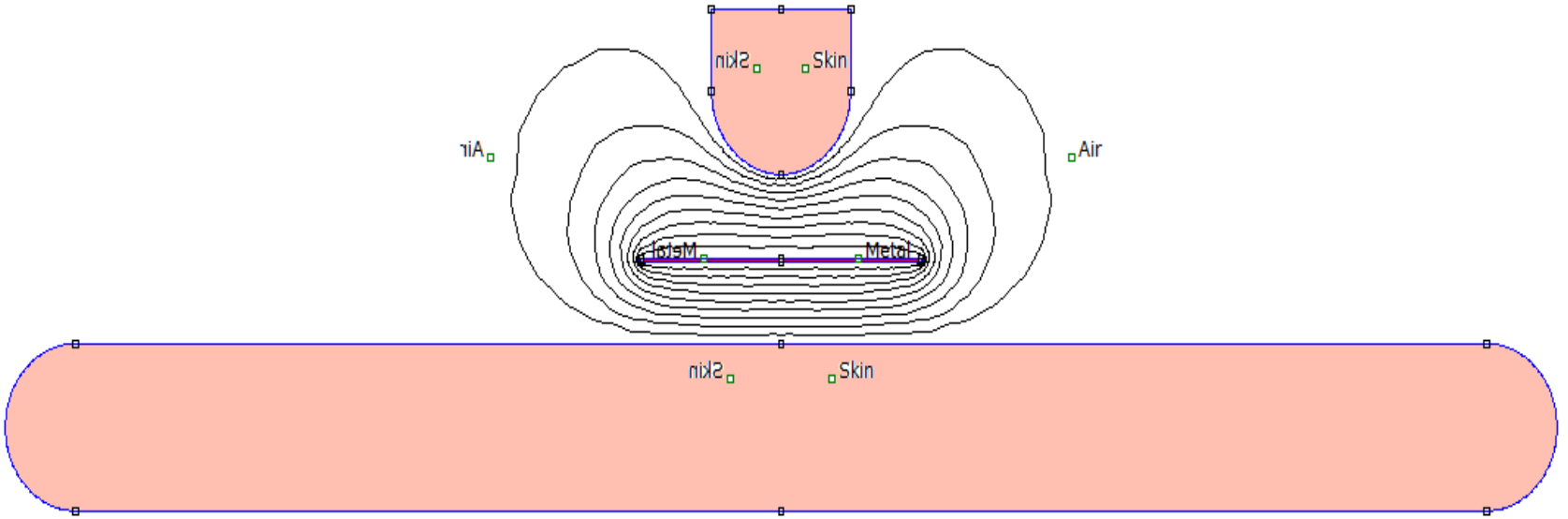
# Wearable sensor: unintended touches

Field lines are on both sides of sensor



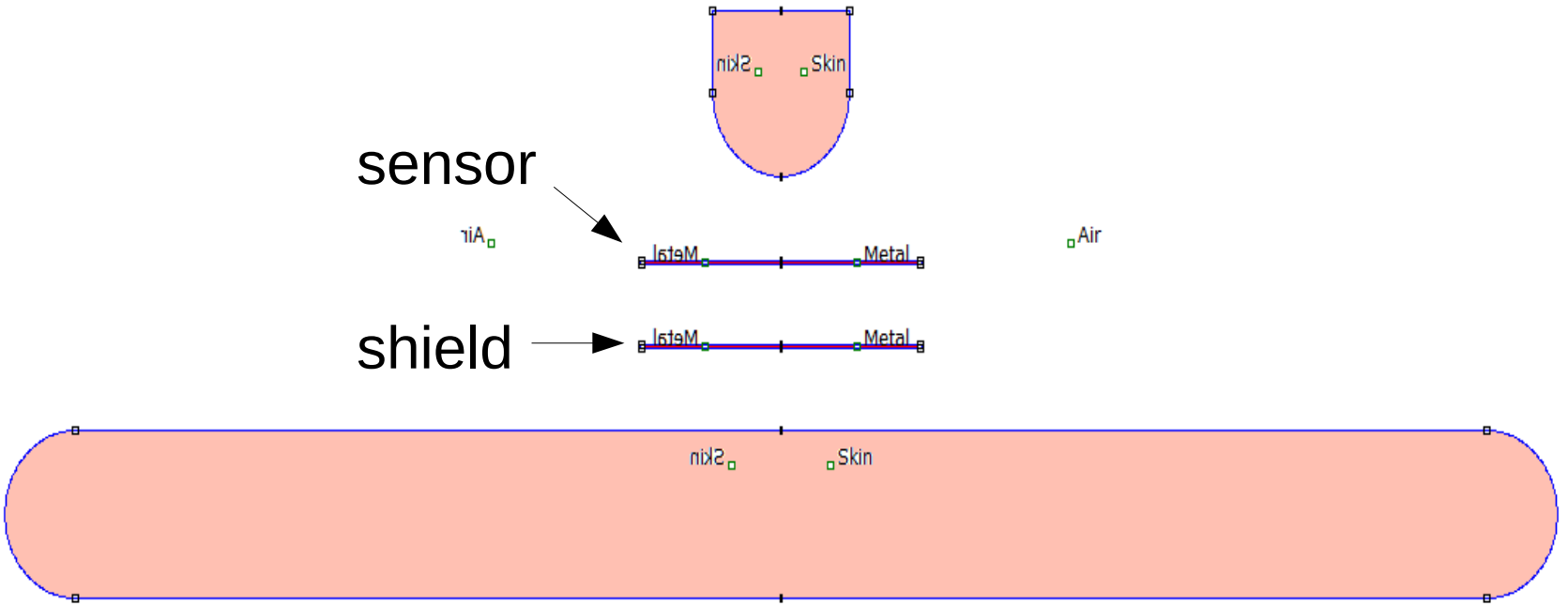
# Wearable sensor: unintended touches

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



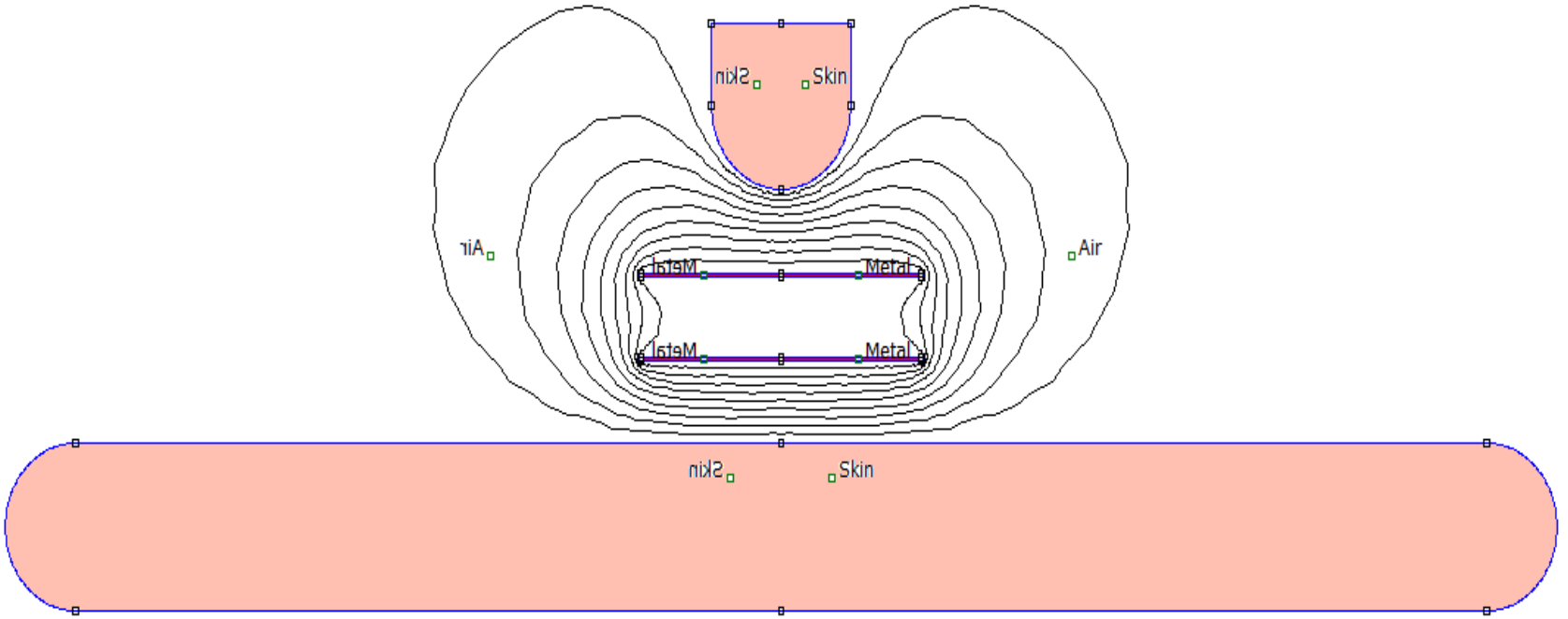
# Wearable sensor with shield

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



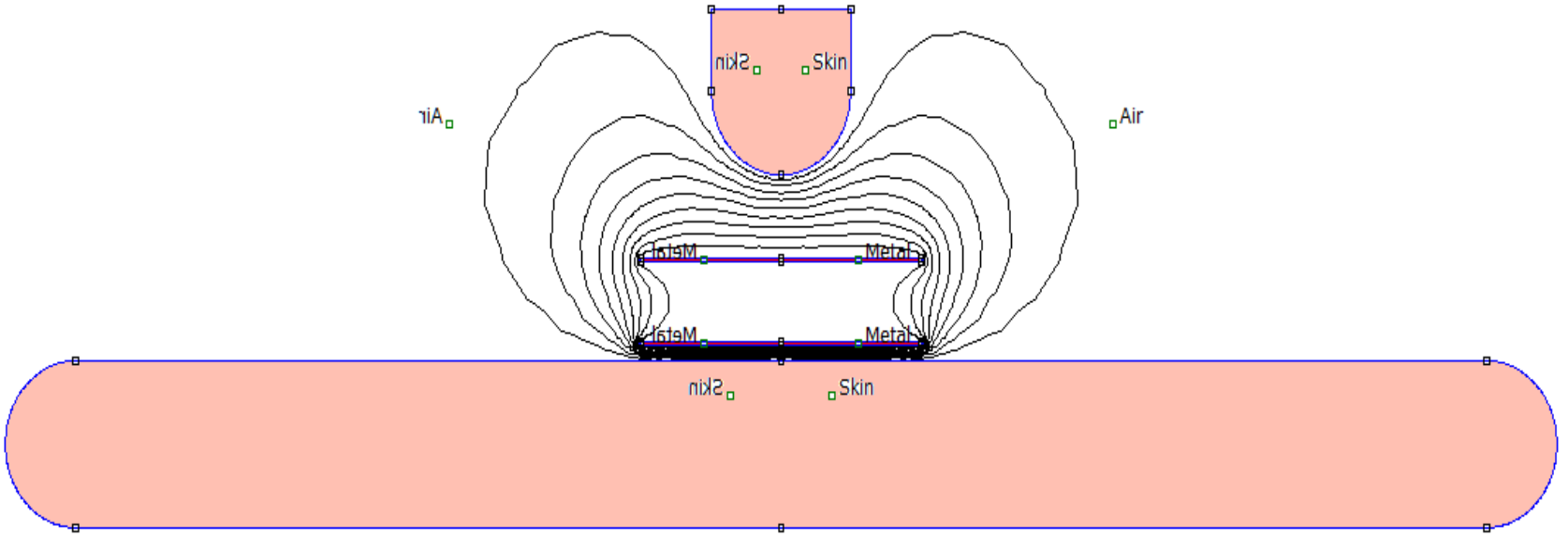
# Wearable sensor with shield: no unintended touches

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

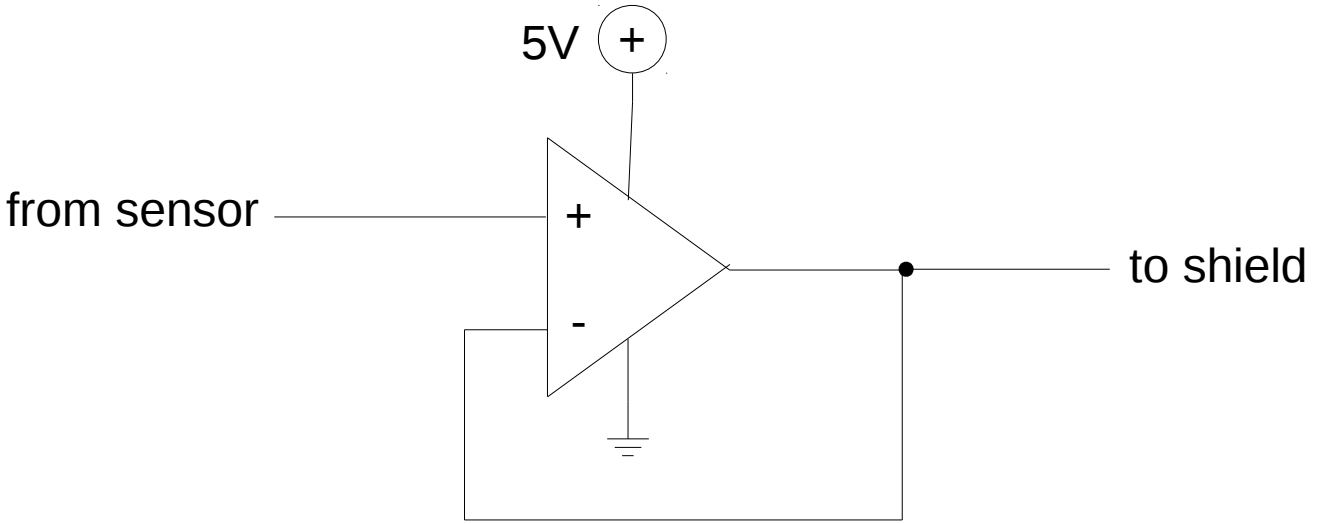


# Wearable sensor with shield: no unintended touches

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

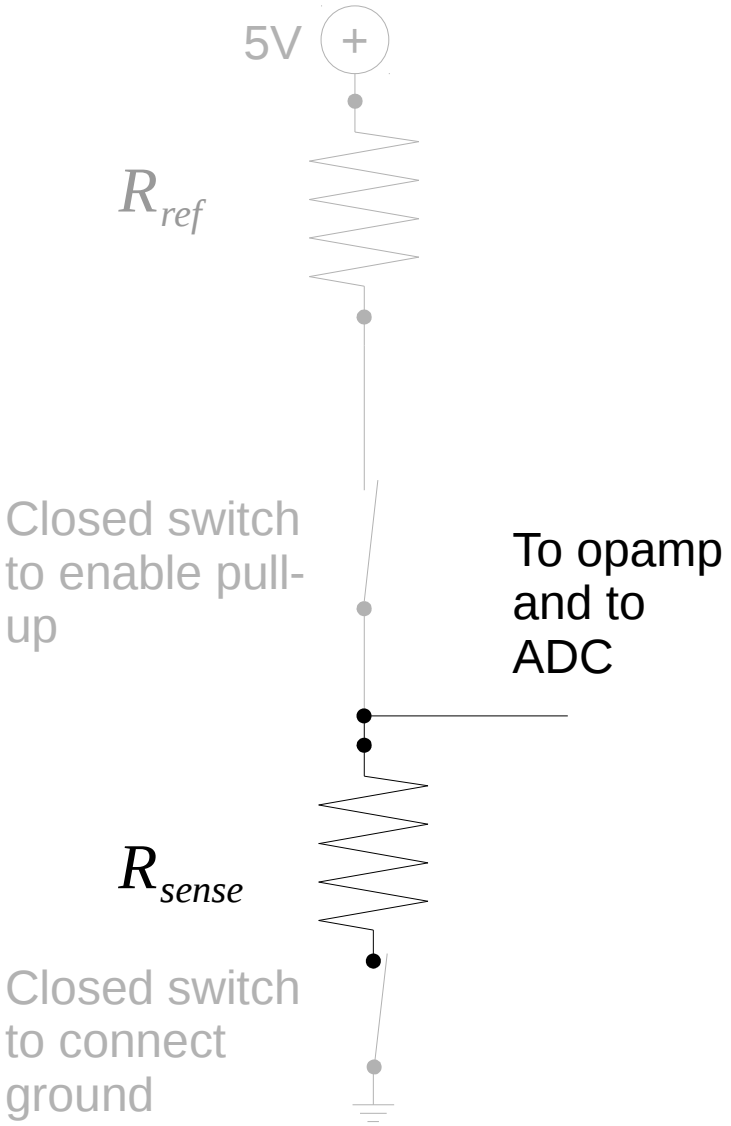


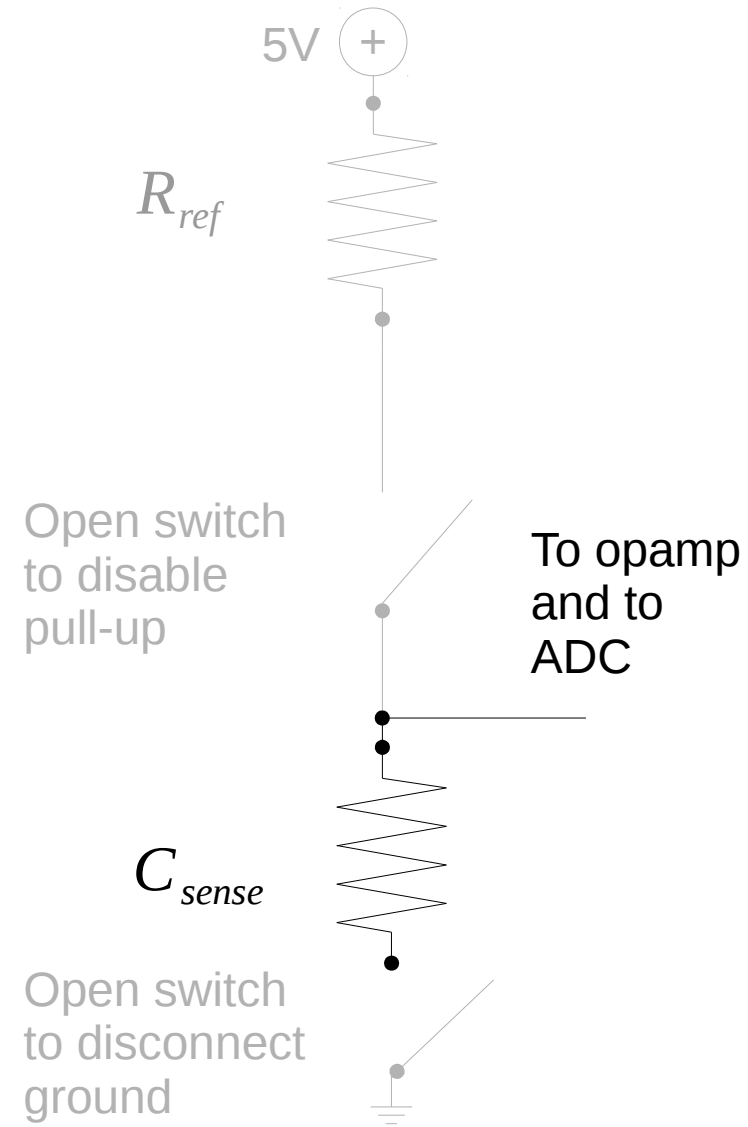
# Circuit to keep shield at same voltage as sensor



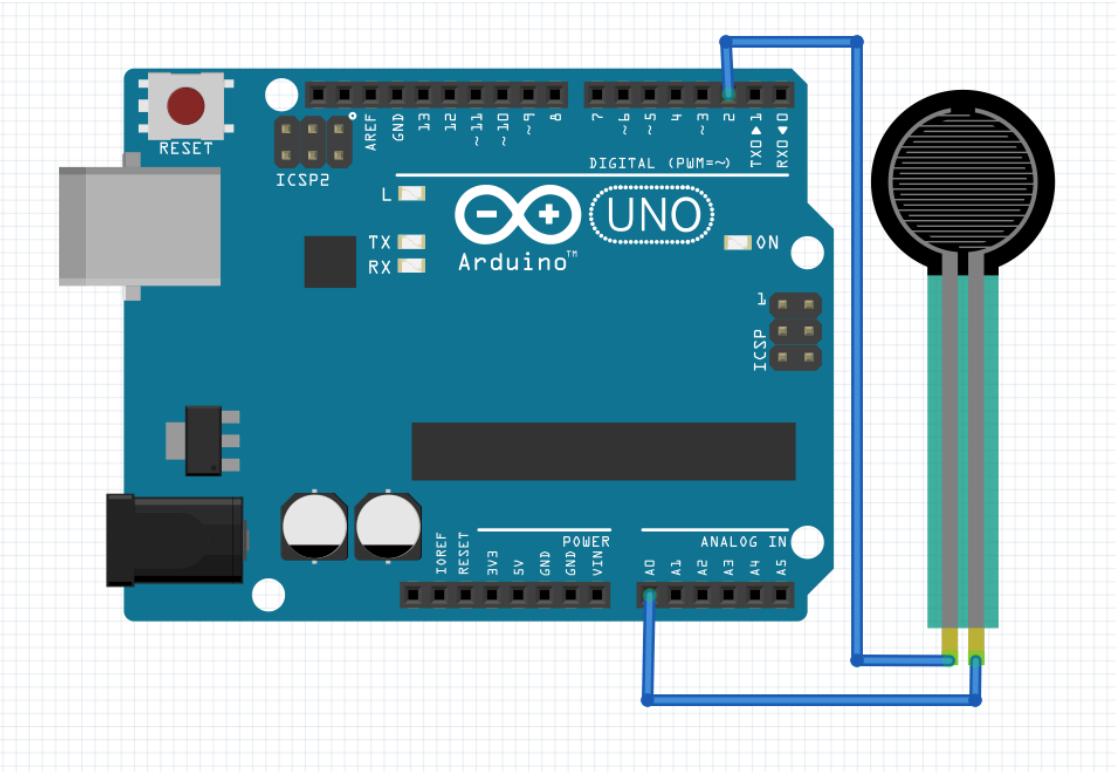

Opamp, for example MCP6242

# Combining capacitive and resistive sensing



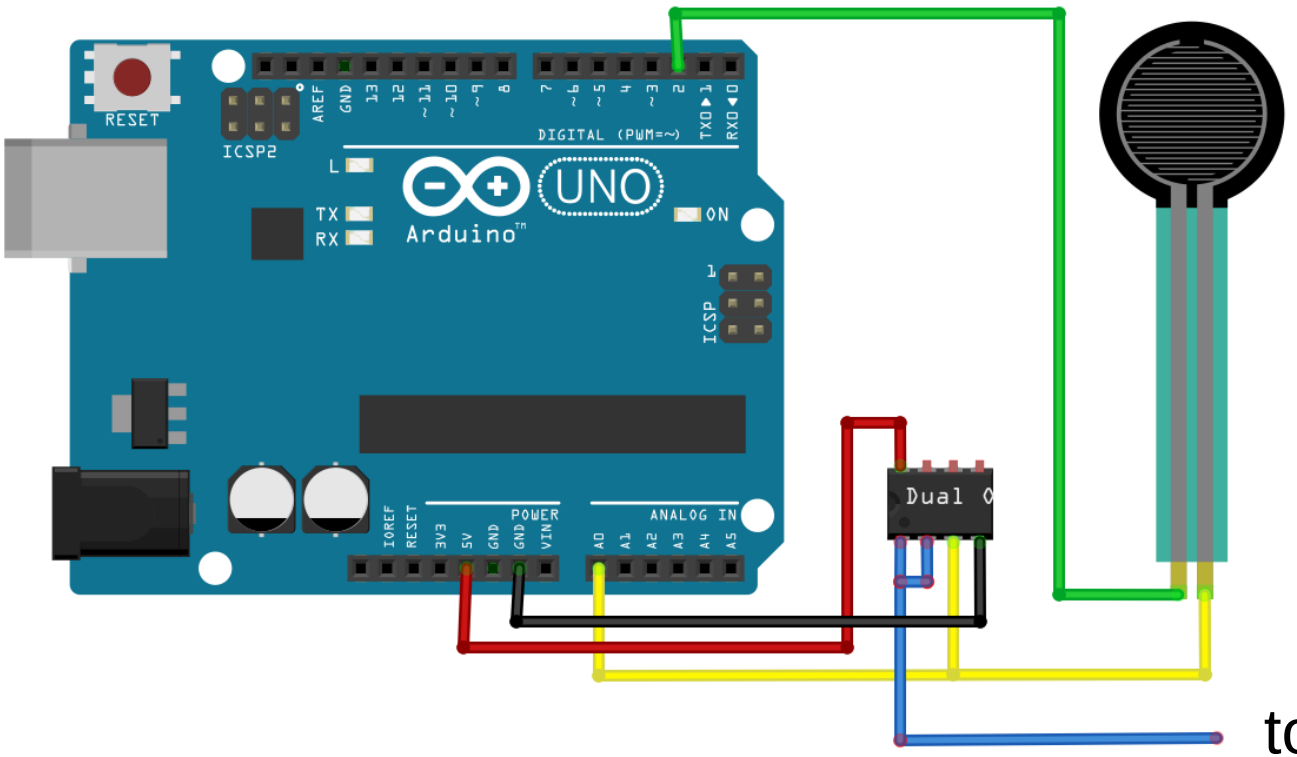
# Wiring it all up (without shield)




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)

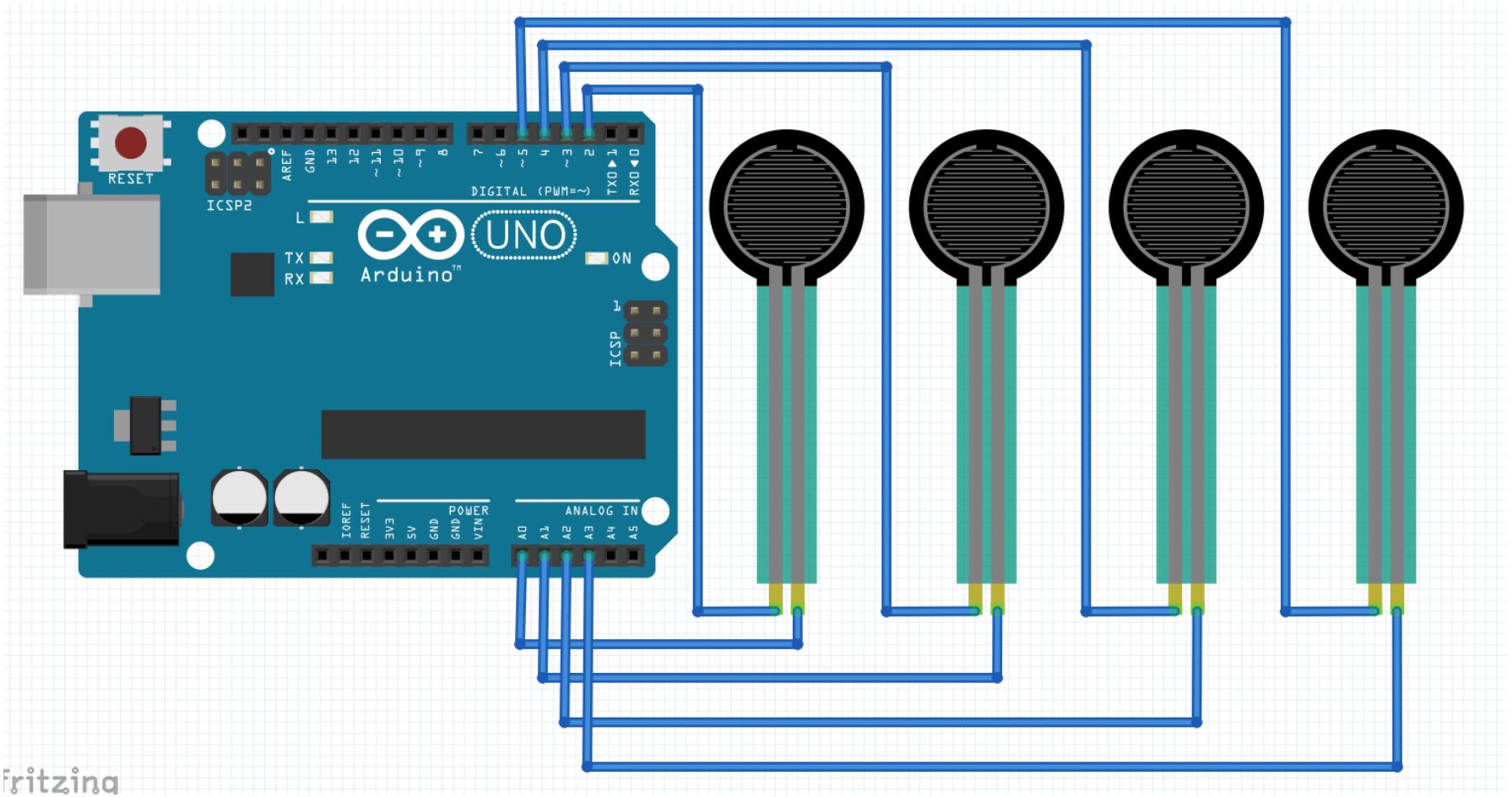



Software: same as for system without shield

to shield

Note: wires to / from capacitive sensor (green and yellow) are sensitive to skin presence as well →keep wires as short as possible and twist shield wire (blue) around green and yellow wires to reduce this effect. If possible, use coax cable where you can use mantle of cable as wire to 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