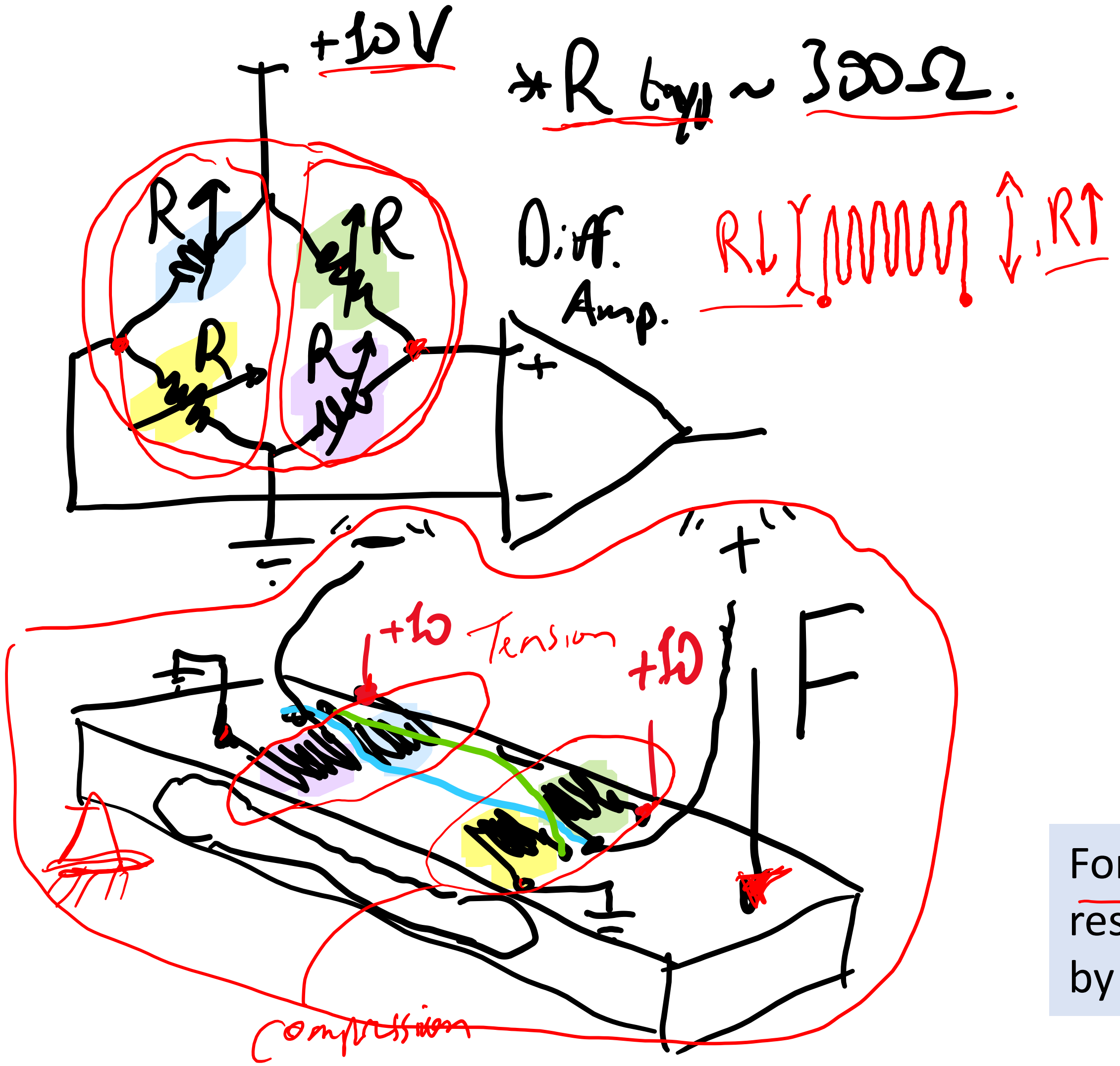
Instrumentation amplifiers, load-cell amplification, a review of the experiment, current measurement and some current sources

Week 7: AoE 7.09-7.12; 15.03

Keithley low-level measurements handbook

An introduction by way of example: a strain gauge circuit in the Wheatstone-bridge configuration:



Upon application of force, F, the strain gauges respond by changing their resistance. Under *compression,* the resistance *decreases;* under *tension,* the resistance *increases.*

Thus we can quickly see that the differential voltage will systematically change in response to applied force, as the v-dividers formed by the strain gauges in each side of the load cell will change their primary voltage values in a levered-fashion.

Nevertheless, the mean value sits around **5 V!**

− There is intrinsically a high common-mode voltage.

For discussion on Piazza: why would one wish to ensure that the resistors in each leg see the same amount of current, as is achieved by this bridge configuration?

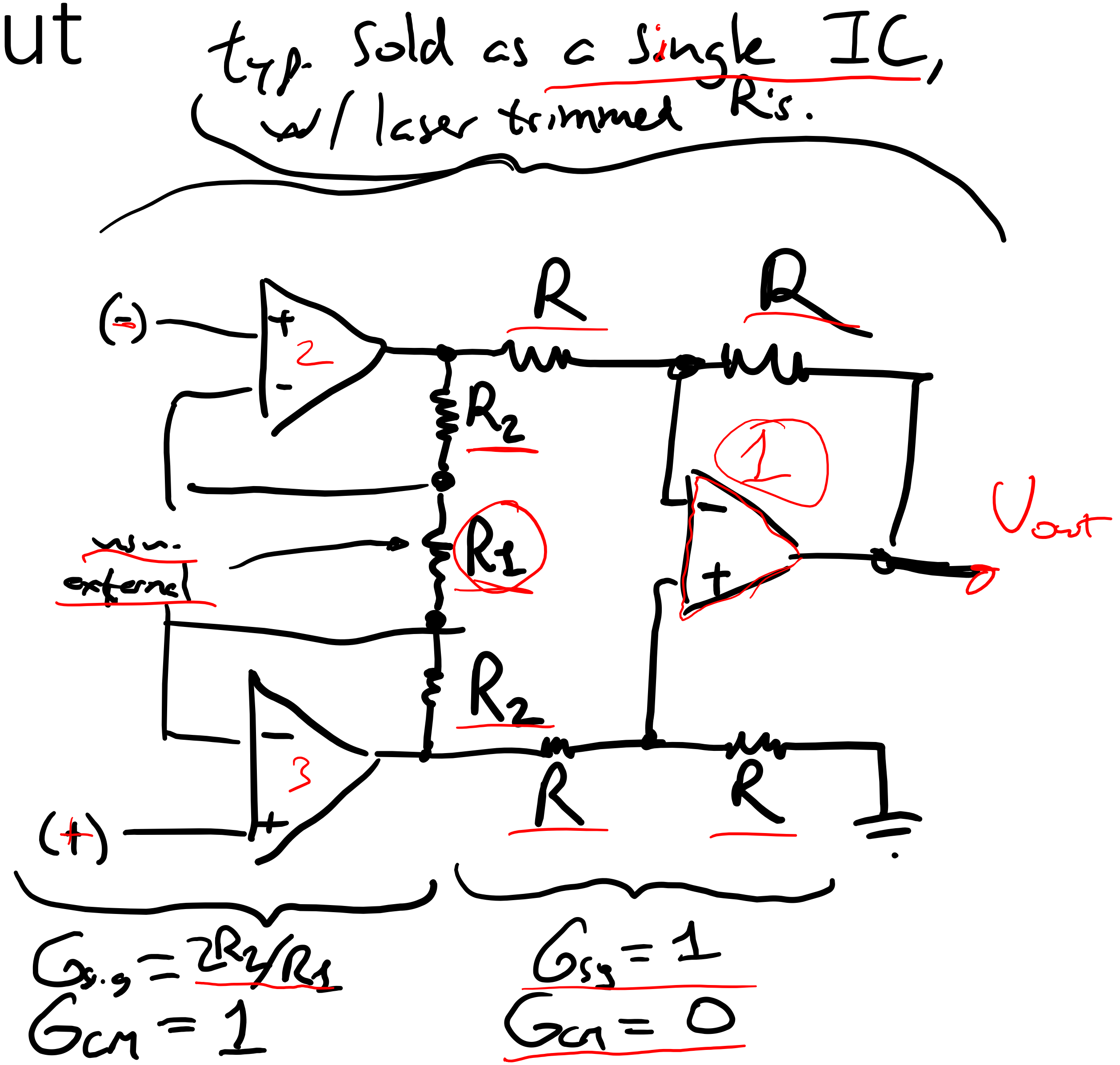
Often we are tasked with the measurement of a transducer's output

The main challenge addressed by instrumentation amplifiers is *high rejection of common-mode voltage (CMRR)*

The high CMRR is necessary because often transducers (such as load cells) have high common-mode signals (of order several V), while the signal of interest is a differential signal in the mV-scale.

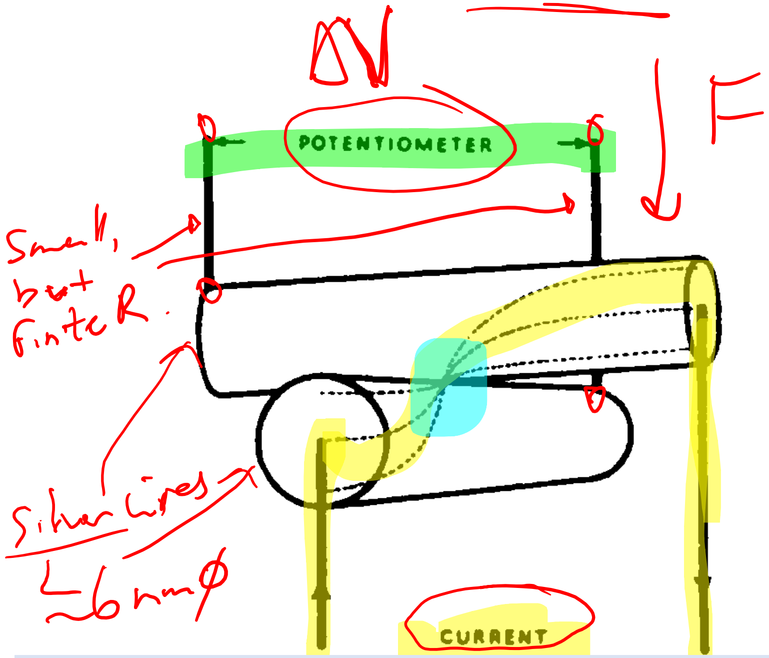
If we want a 0.1% accuracy of a mV signal, say, then we must reject 5 V-common-mode down to the microvolt level (!) this corresponds to a rejection of over a million times the common-mode!

How can we achieve this?



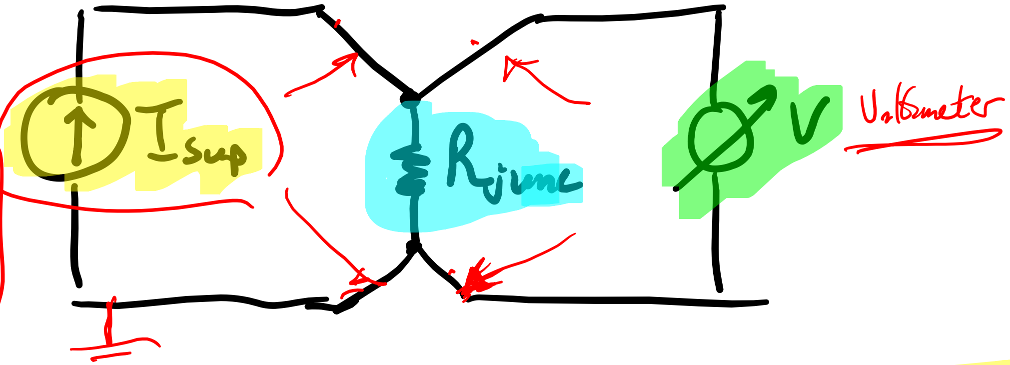
The instr. amp will measure the load-cell signal. What else do we need for the Tabor exp?

Let's look at the schematic:



A very basic schematic:

From Ohm's law: $\boxed{V = I_{sup} R_{junc}}$



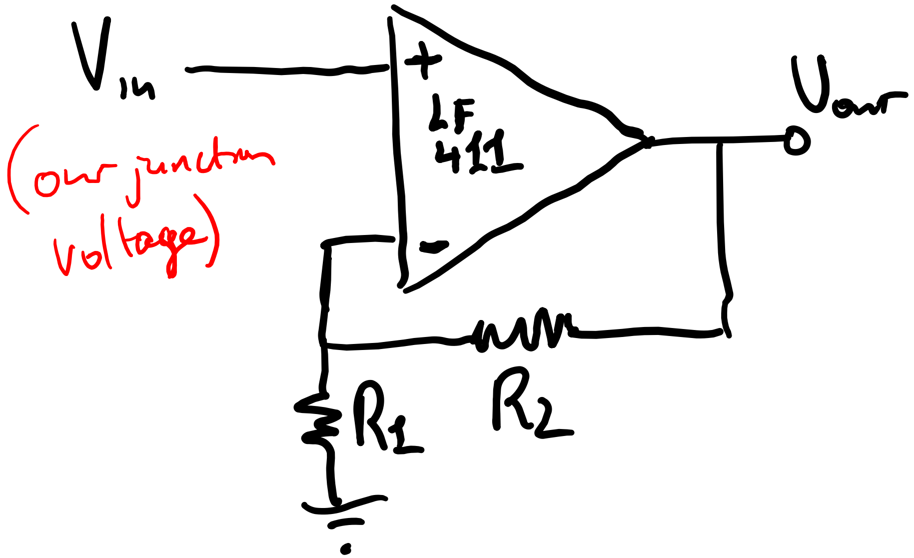
So we need: * a precision current source

* a precise Voltmeter

For discussion on Piazza:

1. What are typical values of R_{junc} for silver wires 6 mm in diameter at a contact force of up to 0.3 kg? (see Tabor paper for guidelines)
2. Given the values of R_{junc} what are the challenges in this measurement? (see Keithley low-level measurements handbook)

We've already seen a precision voltage amplifier:



This circuit is a non-inverting amplifier.

$$\boxed{G = 1 + \frac{R_2}{R_1}}$$

$$\frac{OLG}{10}$$

According to Ohm's law, the voltage range we'll be required to accurately measure depends strongly on the current source magnitude, in addition to the junction resistance.

In the exercises, you're asked to determine what voltage gain you'll be required to achieve in order to obtain a $\boxed{0.1V}$ ~~1V?~~ signal using a current of no more than 10 mA.

← Isupply   Rjunc is estimated from Tabor paper / W2 contact

A smorgasboard of current sources:

Using BJTs

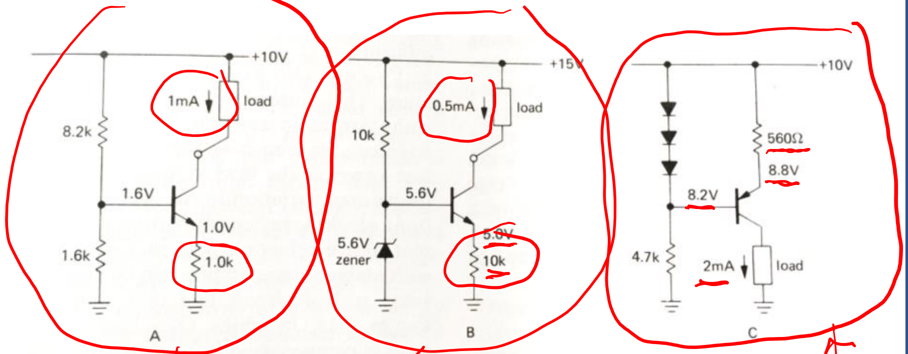
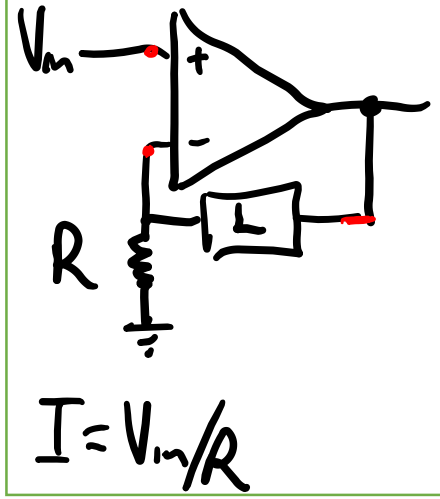
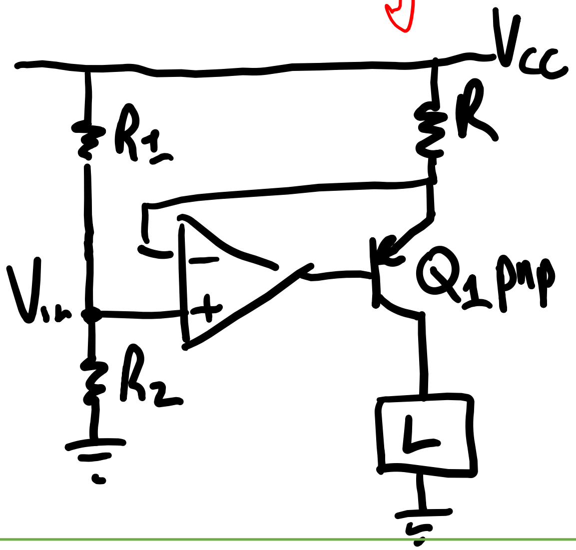
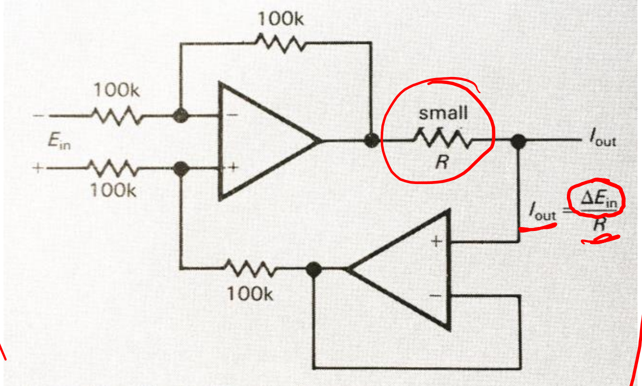


Figure 2.22. Transistor–current–source circuits, illustrating three methods of base biasing; *npn* transistors *sink* current, whereas *pnp* transistors *source* current. The circuit in C illustrates a load returned to ground.

Using op-amps:







L. precision bipolarity current source

Using precision voltage refs:

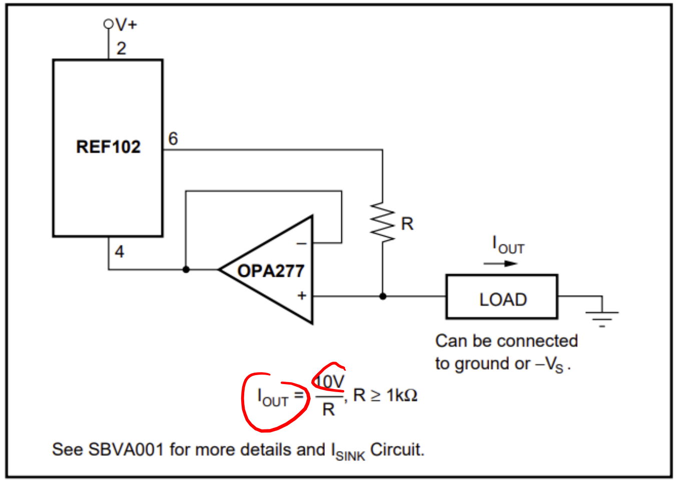


FIGURE 10. Positive Precision Current Source.

There are many other current sources described in the REF102 datasheet (available on the wiki)

Exercises for this week:

1. Devise an experiment using LTSpice that demonstrates the enhanced performance of the instrumentation amp (LT1167) compared with the standard op-amp (AD711) for a differential signal at high common-mode voltage, with comparable gain. For a guide, consider the standard output levels of a strain-gauge signal driven with 10V supply, varying up to 20 mV at full scale.

2. Using the points for discussion on the instruments required to perform the Tabor measurement, in particular the challenges mentioned in the Keithley low-level measurement handbook, develop a schematic that includes the non-trivial elements of the measurement – e.g. thermoelectric effect, etc. Implement these circuit elements in LTSpice.

3. What are the strategies advocated by the Keithley handbook for making low-R measurements? Will these require any special circuitry to achieve? If so, what performance will you require for your current source?

4. On the basis of the requirements identified in exercise 3, design and test a current source that can complete your measurement, that will drive the current to ground through the load, capable of sourcing up to 10 mA. Using a resistive load, measure the voltage drop over the junction when the current passes through it.

Tomorrow: a special Zoom session to discuss class logistics see in light of Covid. → at end of class tomorrow: 11:30a.m. - Bazza [illegible].