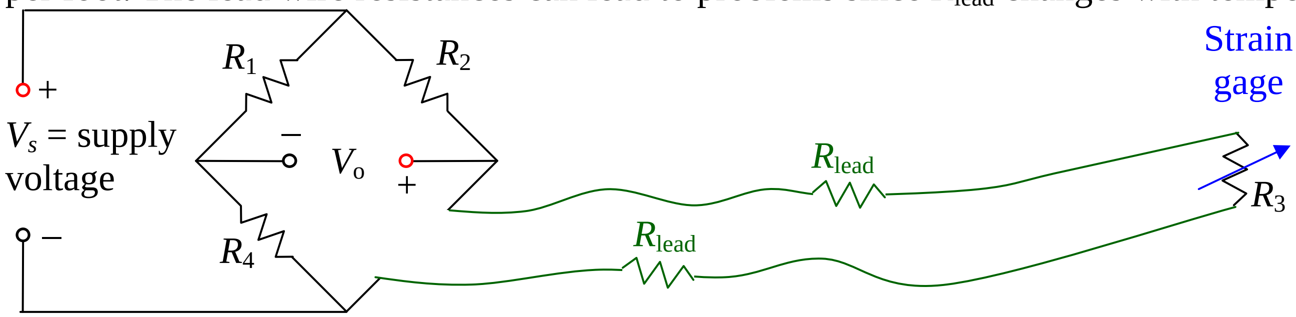
Today, we will:

- Discuss how to compensate for strain gages with long lead wires
- Do a **review** example problem – A/D converters, op-amps, filters, and strain gages

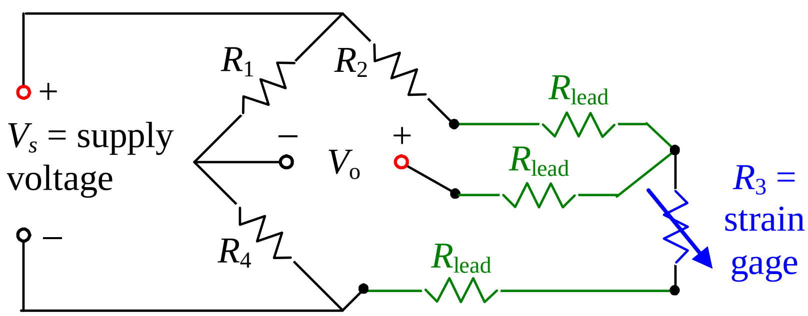
Example: Strain gage with long lead wires – how to compensate

Given: A quarter-bridge strain gage circuit is constructed with 120-Ω resistors and a 120-Ω strain gage as usual. The main problem here is that the experiment is very far away – the lead wires going to the strain gage are 40 ft long, and the lead wires have a resistance of 0.026 Ω per foot. The lead wire resistances can lead to problems since R_{lead} changes with temperature.



To do: Devise a modified circuit that will cancel out the effect of the lead wires.

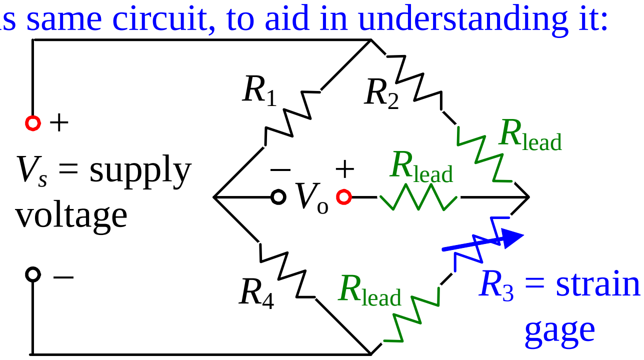
Solution: A clever "trick", using 3 wires connected to the strain gage rather than just 2:



Recall the approximate equation for V_o when all four resistors of the Wheatstone bridge have small changes in resistance:

$$\frac{V_o}{V_s} \approx \frac{R_{2,\text{initial}}R_{3,\text{initial}}}{\left(R_{2,\text{initial}}+R_{3,\text{initial}}\right)^2}\left(\frac{\delta R_1}{R_{1,\text{initial}}}-\frac{\delta R_2}{R_{2,\text{initial}}}+\frac{\delta R_3}{R_{3,\text{initial}}}-\frac{\delta R_4}{R_{4,\text{initial}}}\right)$$

Another way to draw this same circuit, to aid in understanding it:



Example: Strain gages and digital data acquisition [a comprehensive review problem]

Given: A quarter-bridge Wheatstone bridge circuit is used with a strain gage to measure strains up to ±1000 μstrain for a beam vibrating at a maximum frequency of 50 Hz.

- the supply voltage to the Wheatstone bridge is V_s = 5.00 V DC
- all Wheatstone bridge resistors and the strain gage itself are 120 Ω
- the circuit is initially balanced at zero strain
- the strain gage factor for the strain gage is S = 2.04
- there is some unwanted noise in output V_o: f_{noise} = 3600 Hz and amplitude = ±0.50 mV
- the output voltage V_o is sent into a 12-bit A/D converter with a range of ± 5 V
- op-amps, resistors, and capacitors are available in the lab
- all op-amps have a GBP (noninverting) of 1.2 MHz

To do: Design a circuit with the highest possible resolution (i.e., a circuit that utilizes the full range of the A/D converter), and minimizes the noise.

Solution:

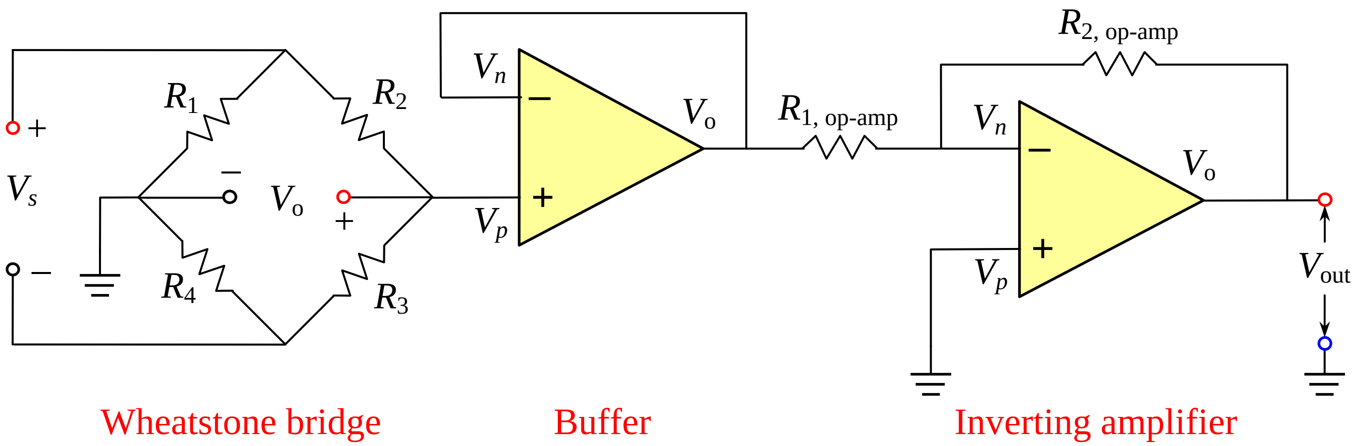
First, we calculate $V_{o,max}$ = max voltage output from the strain gage circuit:

$$V_{o,\,max} = V_s \varepsilon_a \frac{n}{4} S = (5.00\text{ V})(1000 \times 10^{-6})\frac{1}{4}(2.04) = 2.55 \times 10^{-3}\text{ V}$$

Thus, V_o varies between -2.55 mV and +2.55 mV. Now, to utilize the full range of the A/D converter, we need to amplify by a factor of

$$G = \frac{\pm 5.00\text{ V}}{\pm 2.55 \times 10^{-3}\text{ V}} = \pm 1960.78 \text{ [sign depends on type of amplifier]}$$

We suggest this circuit (single stage inverting amplifier) as a starting point:



To achieve the required gain, we would use, say, $\boldsymbol{R_{1,\text{ op-amp}}}$ **= 1 kΩ**, and $\boldsymbol{R_{2,\text{ op-amp}}}$ **= 1.96 MΩ**.

Questions:

1. Why do we ground the Wheatstone bridge at V_0^- instead of at the bottom of the bridge?

2. Why did we put a buffer between the Wheatstone bridge and the amplifier?

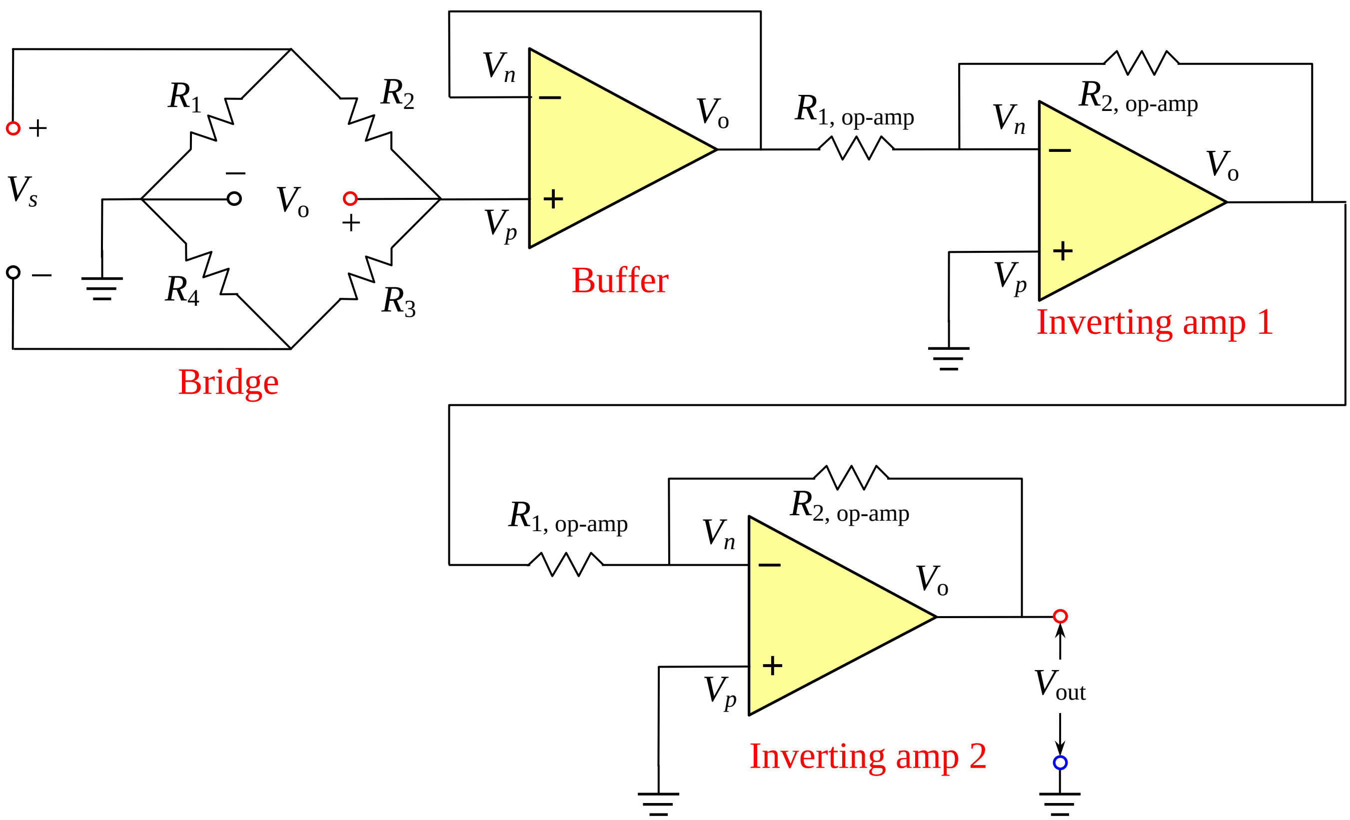
3. Why are we using an *inverting* (rather than a noninverting) amplifier?

4. To get positive V_{out} when the strain is positive, which resistor should be the strain gage?

5. Why is this circuit not so great, and what should we do to improve it?

Answers:

- $R_{1,\text{ op-amp}}$ = 1 kΩ is at the lower recommended limit (not so great input impedance)
- $R_{2,\text{ op-amp}}$ exceeds the recommended 1 MΩ limit (leads to stray capacitance effects)
- G is huge, and can lead to GBP effects as discussed previously
- To improve this circuit, let's instead constructy a ***two-stage amplifier***:



In this case, we can choose better values of the op-amp resistors. Namely, the gain of each amplifier is the square root of the total gain, i.e.,

$$G_{\text{stage}} = -\sqrt{1960.78} = -44.281$$

so we choose, for example, $R_{1,\text{ op-amp}}$ = 10.0 kΩ, and $R_{2,\text{ op-amp}}$ = 442.8 kΩ.

Questions:

1. To get positive V_{out} when the strain is positive, which resistor should be the strain gage?

2. What should we add to get rid of the high frequency (3600 Hz) noise?