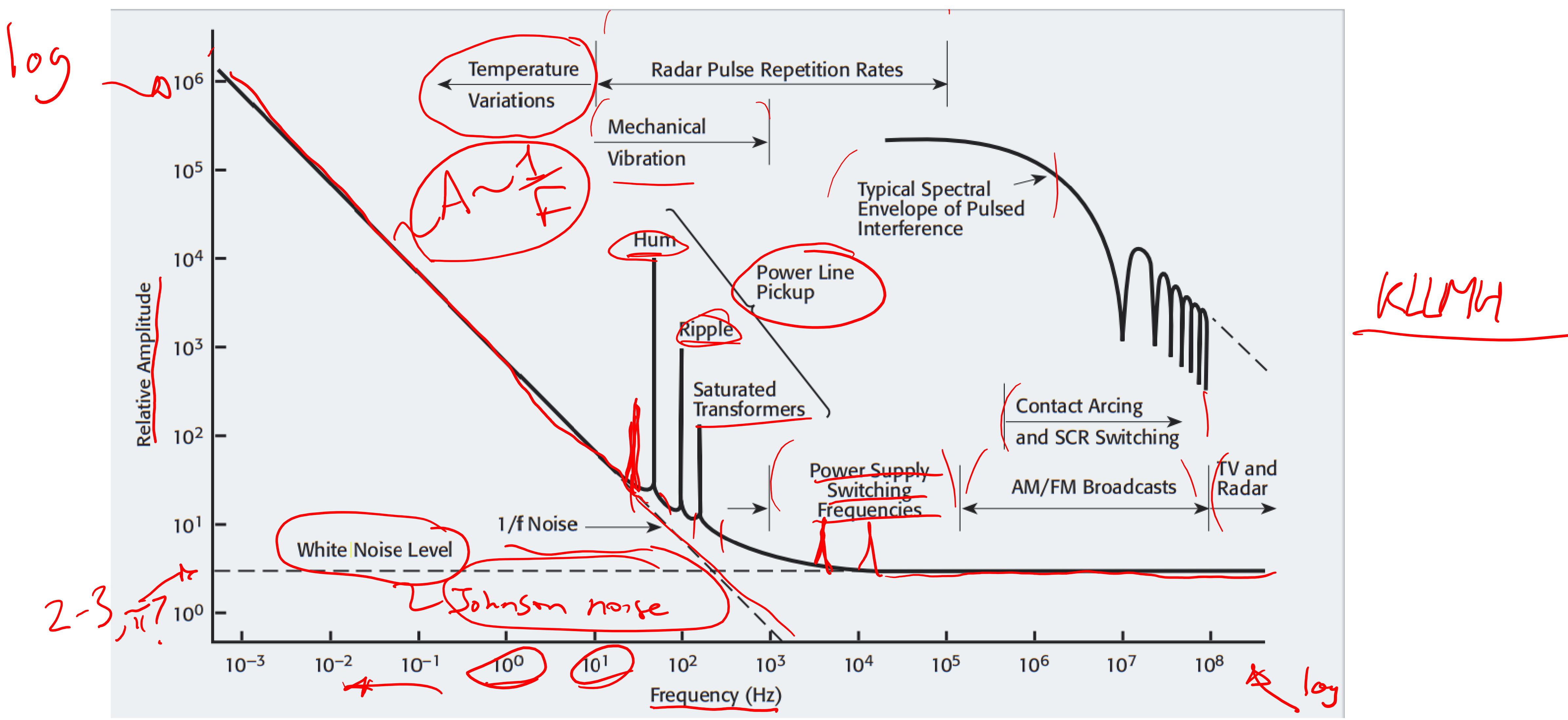
Week 9: Strategies to combat noise sources in electronics measurements

New readings: Troubleshooting low-level measurement problems, Bentham note on lock-in amplification, New instruments can lock out lock-ins (3 pdfs online)

Review reading from last week: Reading: AoE 4.11-4.13, 7.11-7.25. Keithley L.L.M.H. 2.6.5, ch. 3

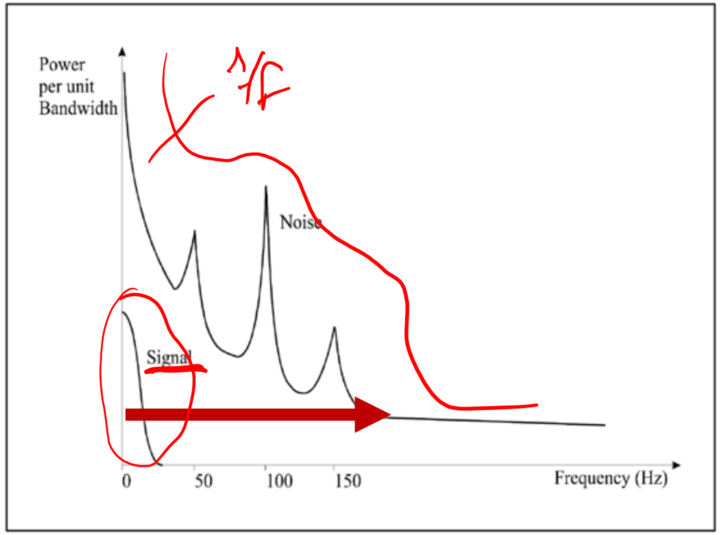
A review of the noise spectrum:

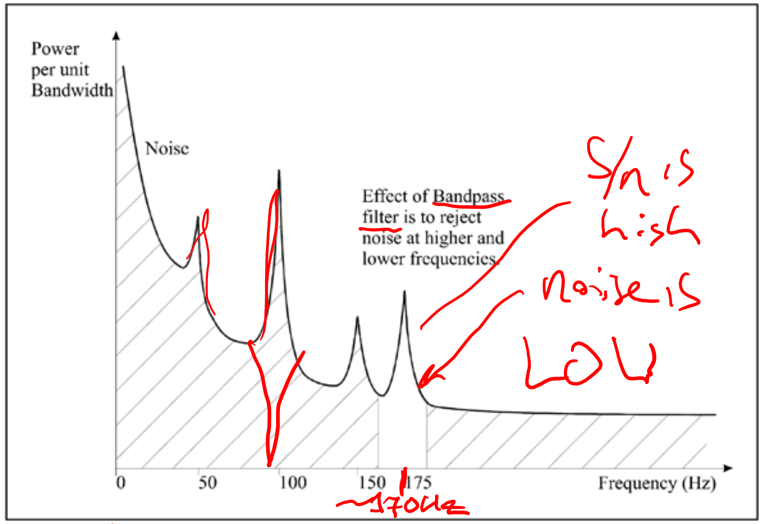


Noise sources for low-V measurements

- **Johnson noise:** when electrons pass through a resistor, they scatter due to thermal energy in the resistor.
- **1/f noise:** This noise is ubiquitous, and is not exclusive to electrical systems
- **Line cycle interference:** The power supply always carries some `line-noise' - this is one component of the RF interference
- **RF / EM interference:** Common sources include power-line pickup, power supply switching, radio broadcasts, Wifi, cellular antennaes…. These show up in the noise spectrum of any measurement in the appropriate frequency range.

Proposed solution: shift measurement in the *frequency domain.* Essentially motivated by R. Dicke's idea of lock-in detection.



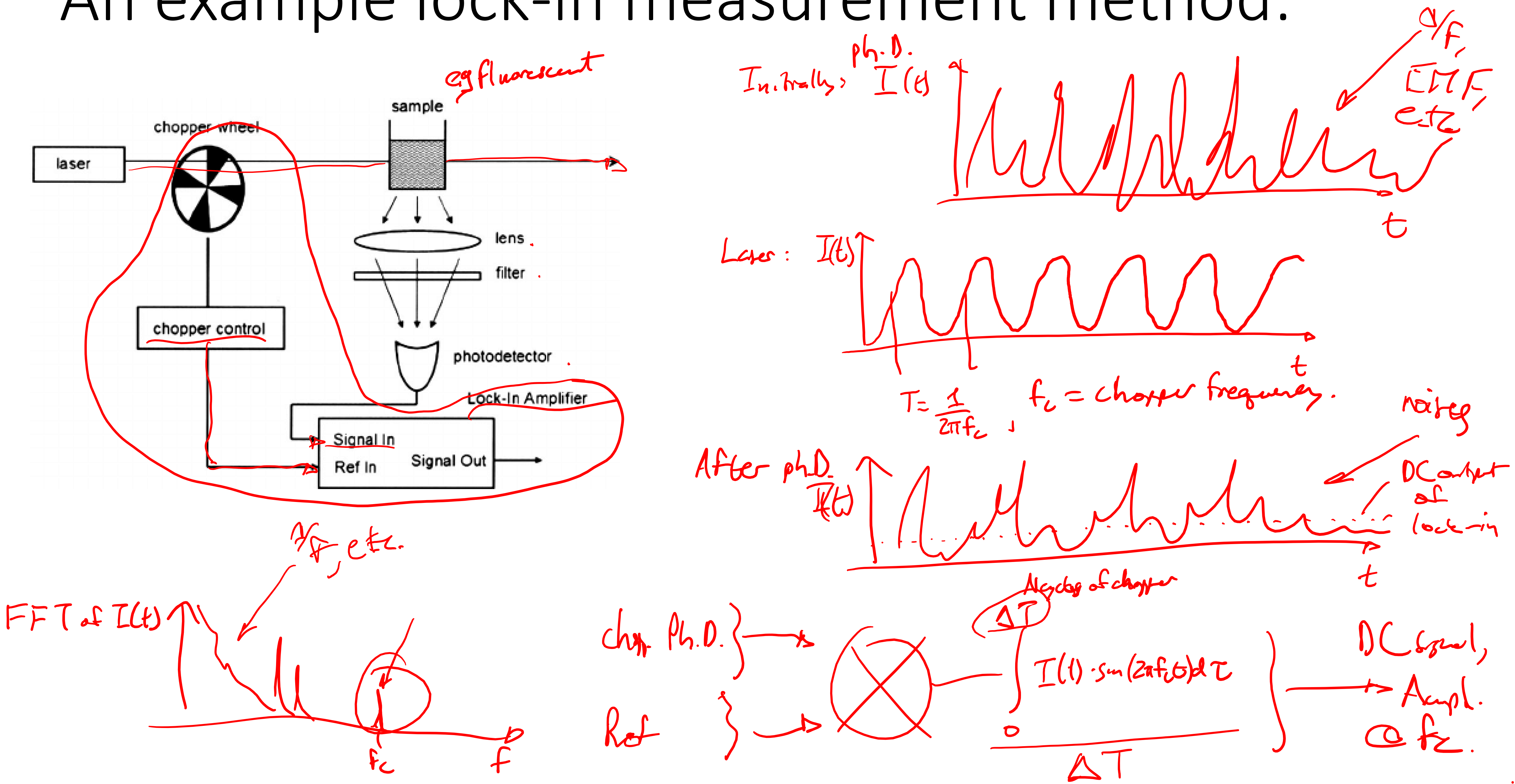


One way to eliminate line noise is with a 50 Hz notch filter. To eliminate line cycle interference, what is recommended in the Keithley manual?

To eliminate RF/EM interference, one can typically enclose the circuit of interest in a metal container. Absorption of radiation is typically accounted for by enclosure manufacturers.

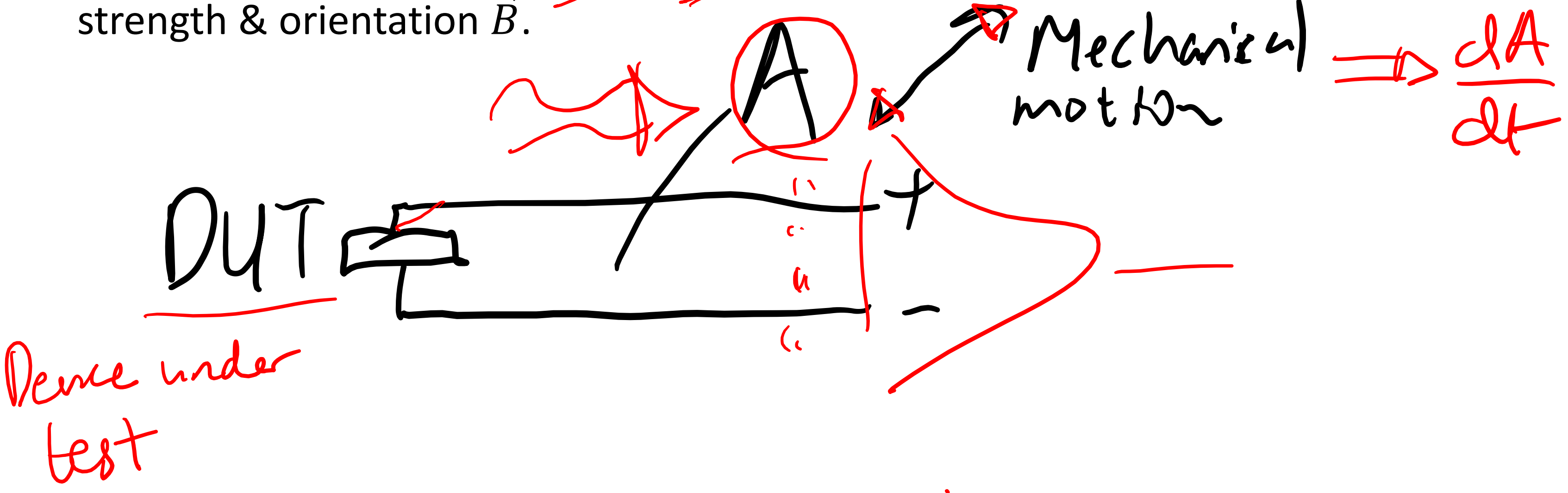
For discussion: why are lock-in amplifiers inadequate for low-resistivity measurements? What are `ideal applications' for lock-in detection?

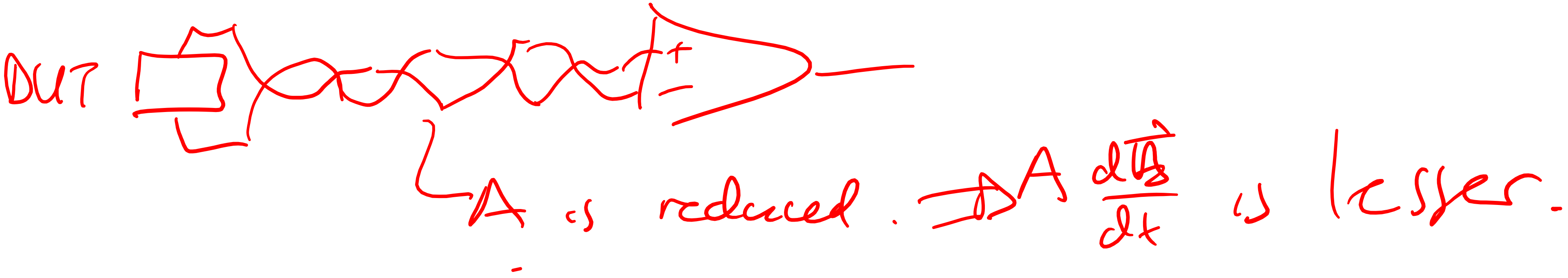
An example lock-in measurement method:



Noise sources for low-V measurements

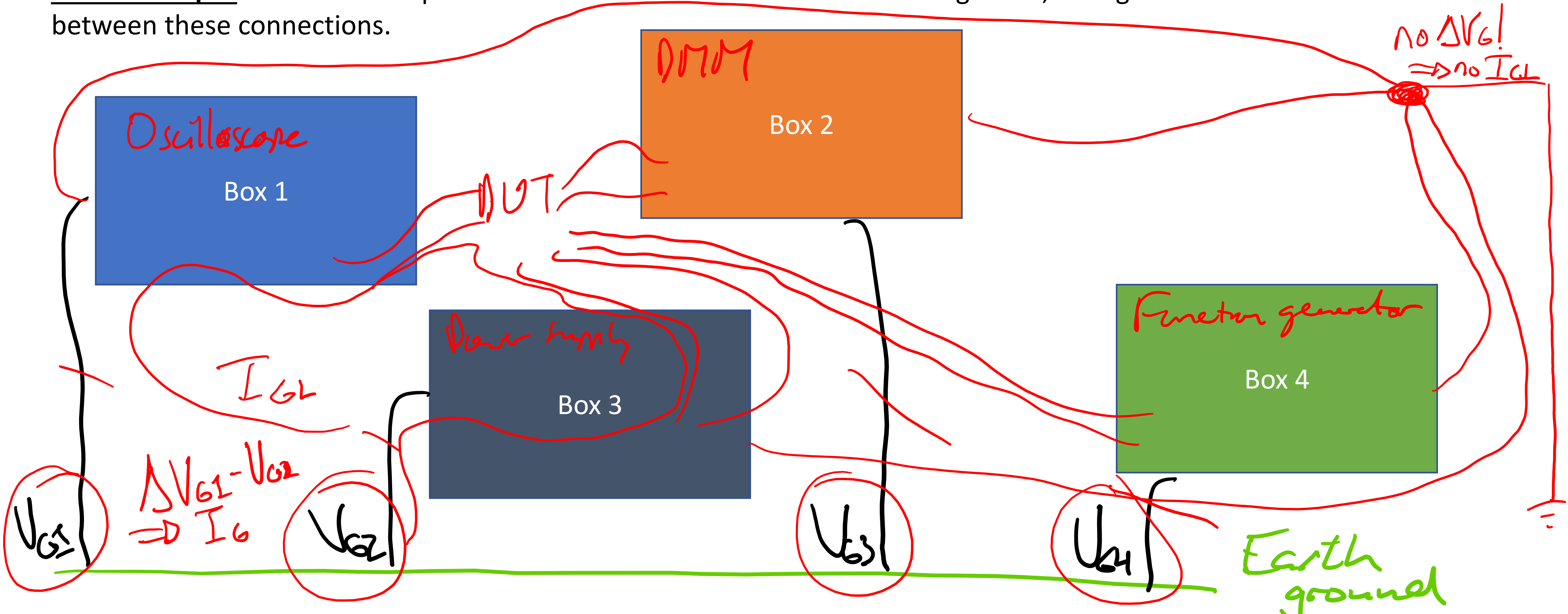
- **Magnetic Fields:** $V_B = \vec{B}\frac{dA}{dt} + A\frac{d\vec{B}}{dt}$ The voltage generated depends on the area of a loop A, and the magnetic field strength & orientation $\vec{B}$.





Noise sources for low-V measurements

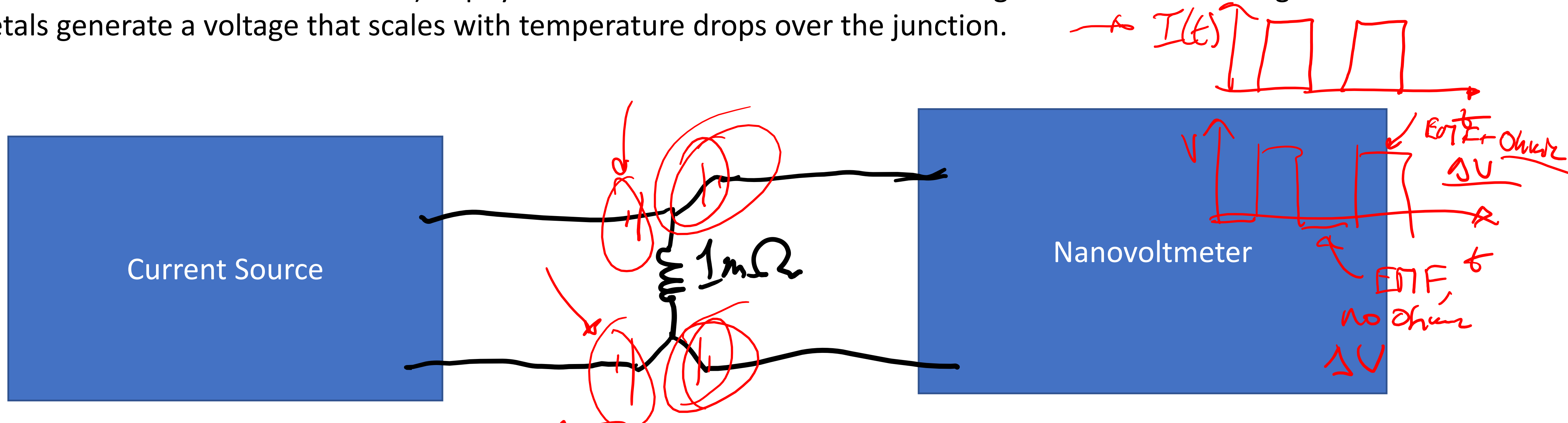
Ground Loops: When two components of a circuit are both connected to a ground, voltage differences can arise between these connections.



*see figs 3-13 a & b in KLLMH for proper grounding of the nanovoltmeter + current source we will use for our measurement

Noise sources for low-V measurements

- **Thermoelectric EMF / Voltages:** These are a common error source in low-V measurements (as occur in junction resistance measurements like ours). A physical effect called the Seeback effect generates these voltages. Dissimilar metals generate a voltage that scales with temperature drops over the junction.



ΔT, difference in metal used @ contact.

→ Delta-mode measurement method:

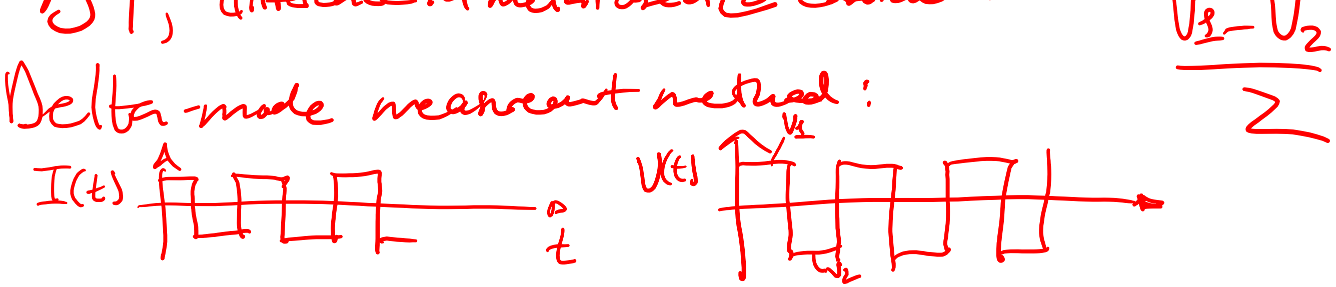


TABLE 3-1: Seebeck Coefficients

Paired Materials*	Seebeck Coefficient, Q_{AB}
Cu - Cu	≤0.2 μV/°C
Cu - Ag	0.3 μV/°C
Cu - Au	0.3 μV/°C
Cu - Pb/Sn	1–3 μV/°C
Cu - Si	400 μV/°C
Cu - Kovar	~40–75 μV/°C
Cu - CuO	~1000 μV/°C

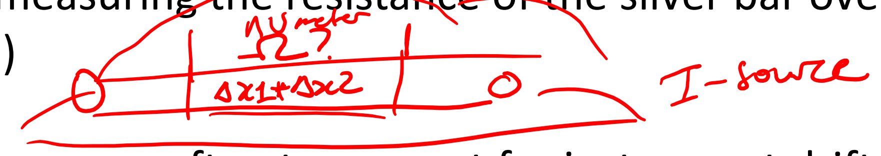
* Ag = silver Au = gold Cu = copper CuO = copper oxide
Pb = lead Si = silicon Sn = tin

Noise sources for low-V measurements

- **<u>Internal offsets:</u>** Here, properly zeroing the instrument is critical. This includes losses due to bulk resistivity of the conductor, for instance, that sit between the test leads and the point where we wish to measure the voltage drop (e.g. the junction)

  - First, allow the instrument to stabilize everything internally. This requires a wait time of 1-2 hours prior to measurement!

  - Second, zero the instrument correctly – accounting for lead resistance drops under applied current for the test. This could be done by measuring the resistance of the silver bar over the equivalent distance for electrode placement. (see sketch)



  - Third, repeat the zero every so often to account for instrument drift.

Exercises

1. Identify a method for eliminating line noise (the 50 or 60 Hz noise from power-supply pickup) that is recommended by Keithley. Can you propose a circuit to carry out this technique? Hint: it might have multiple components, such as an integrator and a zero-crossing detector. (no-LTSpice model – sketch).
2. Explain in detail why the lock-in technique will not work as well as the delta measurement method for our measurement. This should be included in your report in the methods section. 3rd reading today.
3. Conceive a way to implement either the delta mode measurement or the offset compensation method for your current source.
4. Using simulated thermoelectric potentials, verify that with the current source implemented you've implemented can be used to recover a 1 mOhm resistance via Ohm's law. (in presence of TE potentials)
5. Determine a means of introducing line noise into your LTSpice model. Can you also include white noise in the line noise to make it more realistic? Post your LTSpice models for the line noise on Piazza.
   separate from existing LTSpice models

Bonus: can you design a lock-in or phase-sensitive detection scheme for your load cell? There is a design proposed on the Analog website that could prove useful: https://www.analog.com/en/analog-dialogue/articles/transducer-sensor-excitation-and-measurement-techniques.html. This part is not available in LTSpice; perhaps you can find a zero-drift alternative, which implements a chopper-stabilization method similar to phase-sensitive detection?

9 a.m. on Zoom!