PHYSICS 108: Electronics Super-Summary

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In these notes, I provide an overview of the parameters we should use for our measurements. As far as the electronics are concerned, there are two key instruments we need to control: the lock-in amplifier (used for voltage readouts, from which we can determine ρ) and the sourcemeter (provides the input current). These two have several nobs we can tune, which is why we should do our best effort to constrain our parameter space appropriately.

1 Sourcemeter

The lock-in parameters are mostly contingent upon the current source. Thus, we take a look at the latter first. The current has two characteristics we will be interested in controlling:

1. the source amplitude
2. the source frequency.

1.1 Source Amplitude

The maximal current we can run in the experiment will be likely determined by heating considerations. Consider an upper bound for the power in the circuit, P_{max}, which is set by the heating rate of the experimental setup. It is straightforward to see that, to stay below threshold under a fixed resistance R, the current must satisfy

$$I < \sqrt{\frac{P_{\text{max}}}{R}}.$$

Recalling that $R = \rho L/A$, we rewrite Eq. 1.1 as

$$I < \sqrt{\frac{AP_{\text{max}}}{\rho L}}. \tag{1}$$

Here, A is the cross-sectional area of the structure we measure (nanowires) and L is the length over with the currect propagates. Based on literature, we estimate that ρ will take values in the order of $\sim 300\mu\Omega{\cdot}\text{cm}$. Similarly, we expect A to in the order of $\pi \cdot 25$ nm^2, and L to be in the order of 2 μm. With these numbers, based on Eq. 1, we obtain the condition

$$I < I_{\max} \sim 0.003 \text{ A}. \tag{2}$$

The above result reduces to 0.0007 A for resistivities in the order of $\sim$ 5 mΩ·cm.

Another relevant consideration to keep in mind is sensitivity. This will set the lower-bound of the currents we should send. As previously mentioned, we expect to measure resistivities in the order of 300 $\mu\Omega$·cm (5 mΩ·cm). As earlier, this means we should expect a resistance of R ~3K (50K) Ω. Our lock-in amplifiers have a maximum sensivity in the order nV's. From the textbook expression $V = IR$, we know that, if we want measurements with variations exceeding the 1 nV threshold, we must require

$$I > I_{\min} = \frac{\Delta V_{\min}}{R}. \tag{3}$$

This fully constraints the operational regime of currents we can work with. In particular, we should make sure to enforce

$$I_{\min} < I < I_{\max} \Rightarrow 3 \times 10^{-13} \ (1 \times 10^{-14}) \text{ A} < I < 0.003 \ (0.0007) \text{ A}. \tag{4}$$

Based on these constraints, we chose $I = 1$ nA.

Note 1. *Because the nanowires are so thin, we are assuming these are the largest contributors to resistance in our system. Thus, we determine all upper and lower bounds based on these –rather than based on the properties of manganin. This is a fairly reasonable assumption. According to Declan's calculations, the total resistance of the wires is of* $\sim 18\ \Omega$.

Note 2. *We have also assumed current does not dissipate over our system. This is fairly reasonable assumption; we are working with electric wires, not fiber optics.*

1.2 Source Frequency

The source frequency might be a bit tricker to determine. Based on conversations with Sandesh, heuristically, we need to stay are around ~100 Hz in order to prevent the undesired effects of parasitic capacitance. Furthermore, to avoid noise from the sockets, we want to avoid frequencies that are integer multiples of 60 Hz. Because of these reasons, conventionally, ω_{source} is chosen to be a prime number. Thus, we set

$$\omega_{\text{src}} = 23 \text{ Hz}. \tag{5}$$

2 Lock-In Amplifier

The lock-in amplifier has three critical nobs. These are:

1. the amplitude of the reference signal
2. the frequency of the reference signal
3. the integration constant
4. the sensitivity.

Note. *We need one lock-in per nanowire sample and additional lock-in for temperature control.*

2.1 Reference Amplitude

Our set-up will consist of the reference amplitude V_{src}, the sample and an additional resistor. Let R_{sample} be the resistance across the sample and R the resistance of the aforementioned resistor. In order to maintain a constant current through the sample, we need R to be significantly greater than R_{sample}. In this case, the current through the entire circuit will approximate to $I \to V_{\text{src}}/R$. Given a target current through the circuit, determined from the heating and sensitivity constraints above, we should enforce $V_{\text{src}} = I_{\text{desired}}R$.

Need to double-check with teaching staff. I was told the external resistor is 100K Ω, but this likely won't be enough to keep the current constant.

2.2 Reference Frequency

To the best of my understanding, we want this frequency to be equal to that of our source signal. This is no problem, for we can control the source frequency experimentally. Thus, the only relevant constraint to be considered here is

$$\omega_{\text{ref}} = \omega_{\text{src}}. \tag{6}$$

For a source frequency of 23 Hz, the period is 0.043 s. This, we set our integration constant to 100 ms (0.1 s).

2.3 The Integration Constant

For reliable readings, we need this constant to be larger than a full oscillation cycle in the lock-in. Thus, we need to enforce

$$\tau_C > 1/\omega_{\text{ref}} = 1/\omega_{\text{src}}. \tag{7}$$

Note that we can't simply make τ_C as large as possible for better accuracy, for doing so would make our measurements exceedingly long. The lock-in provides a limited number of integration constant options. Thus, amongst the ones that satisfy $\tau_C > 1/\omega_{\text{ref}}$, we should pick the smallest. Lastly, when implementing a sweeping routine, we need to make sure that our wait times between each reading allow for enough time for the device to cool down –and for τ_C to pass.

2.4 Sensitivity

This variable is fully determined by $\Delta V_{\rm min}$ –or whatever sensitivity we would like to enforce. For a current of 1 nA and a resistance of $R \sim 3$K (50 K) Ω, we should have

$$V = IR = 10^{-9} \times 50 \cdot 10^3 \approx 50\ \mu\text{V}. \tag{8}$$

For a resistance of 3K Ω, this would become 3 μV. Thus, we set our sensitivity to μV.