ECEN3730 Lab 11/12

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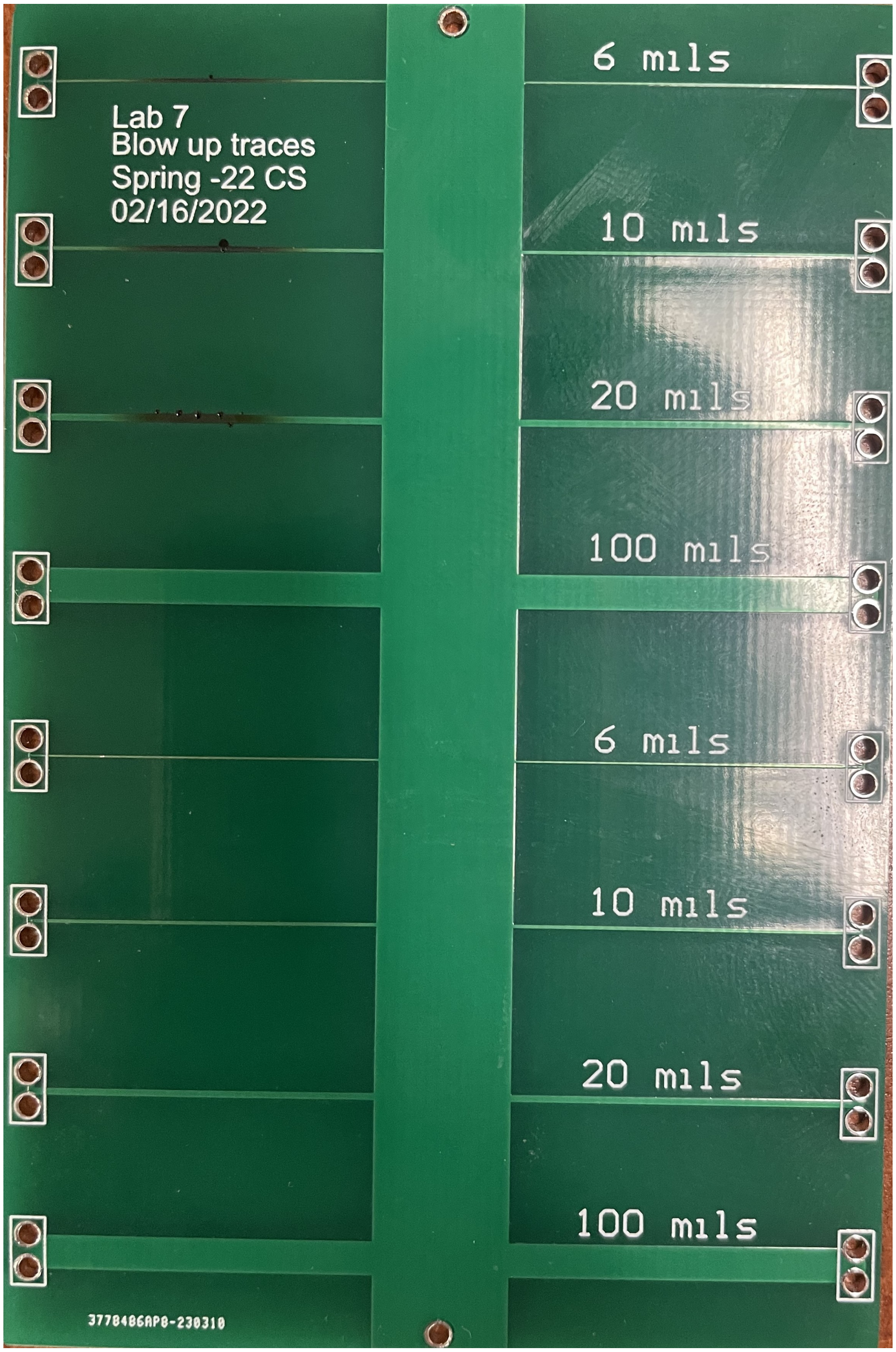

Figure 1: Test Board for Measuring Trace Resistance and Maximum Current

1 Objectives

- Estimate the trace resistance of 1-inch segments of 6 mil, 10 mil, 20 mil, and 100 mil width traces
- Measure the actual resistance of the traces using the 2-wire method with and without the Null function of a DMM and the 4-wire method
- Use Saturn PCB Toolkit to simulate the maximum current through 1-inch segments of 6 mil, 10 mil, 20 mil, and 100 mil width traces
- Measure the actual maximum currents that can be passed through these traces.

2 Trace Resistance

2.1 Estimating Resistance

Estimating the resistance of these traces is as simple as breaking them into squares of 1oz copper such that each square has a resistance of 0.5 mOhms and then counting the number of squares contained in the trace. In this case all traces are 1 inch in length and the number of squares is:

$$n = \frac{L}{W} \tag{1}$$

Where L = Length and W = Width, thus the number of squares for each trace are as follows:

- 6 mil: n $\approx$ 170
- 10 mil: n = 100
- 20 mil: n = 50
- 100 mil: n = 10

This Corresponds to the following resistances:

- 6 mil: R = 85 mOhms
- 10 mil: R = 50 mOhms
- 20 mil: R = 25 mOhms
- 100 mil: R = 5 mOhms

2.2 Two-Wire Measurement

Using the usual method of connecting the two leads of a DMM results in the following trace resistances:

- 6 mil: R = 145 mOhms
- 10 mil: R = 112 mOhms
- 20 mil: R = 90 mOhms
- 100 mil: R = 76 mOhms

However, these values take into account the resistance of the DMM leads which add approximately 76 mOhms making the measurements rather far off of the values estimated in the last section. A diagram of the two-wire setup that displays this issue can be found in Figure 2. Using the Null function of the DMM a more accurate resistance can be determined by offsetting the resistance of the leads:

- 6 mil: R = 67 mOhms
- 10 mil: R = 36 mOhms
- 20 mil: R = 16 mOhms
- 100 mil: R = 1 mOhms

To improve on this further the 4-Wire method can be used:

2.3 Four-Wire Measurement

In the conventional 2-wire method, displayed in Figure 2 current flows through the leads and the voltage is measured and the ends of the leads. The measurement includes the series resistances of the wire leads and the contact resistance of the leads of the device. By using a power supply to send a constant current through the trace and measure the voltage across the test device we can get a more accurate representation of the load resistance. This process is displayed in Figure 3

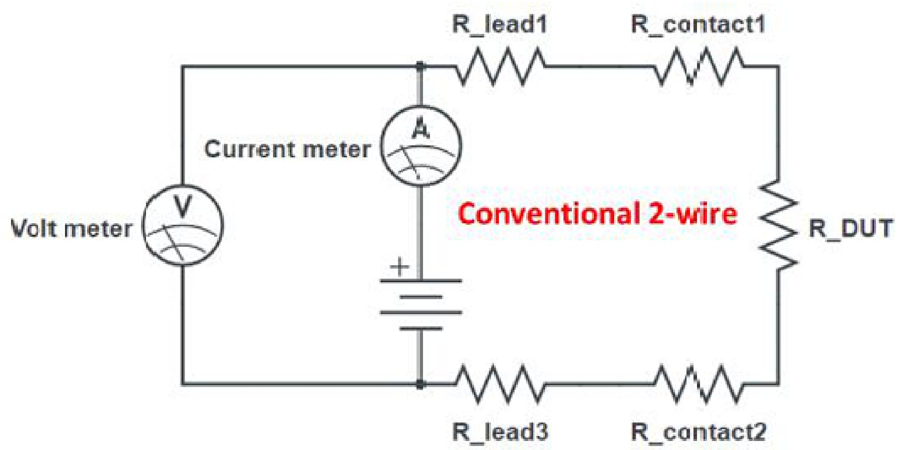

Figure 2: Circuit Diagram of the Two Wire Method to Measure Resistance

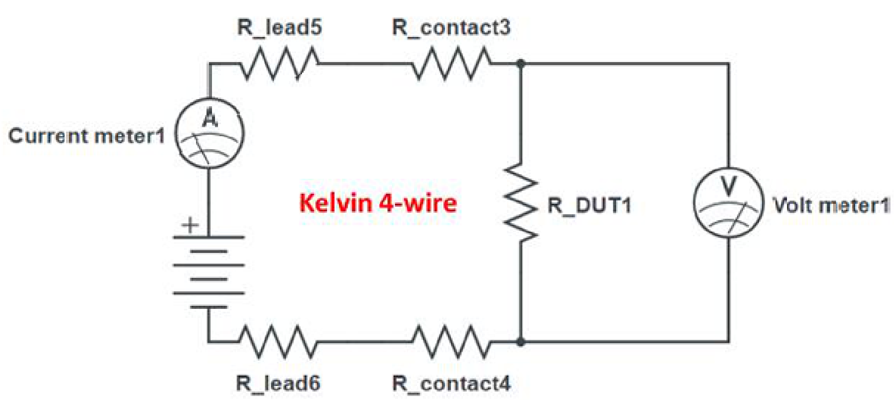

Figure 3: Circuit Diagram of the Four Wire Method to Measure Resistance

Using this method we can use the simple R=$\frac{V}{I}$ relationship. The following voltages were measured with a constant 0.1A source current:

- 6 mil: V = 7.3 mV
- 10 mil: V =4.1 mV
- 20 mil: V = 2 mV
- 100 mil: V = 0.11 mV

This corresponds to the following resistances:

- 6 mil: R = 73 mOhms
- 10 mil: R = 41 mOhms
- 20 mil: R = 20 mOhms
- 100 mil: R = 11 mOhms

These results are much closer to the estimated values.

2.4 Final Results of Resistance Measurements

Line Width	**Estimate**	**2-Wire**	**2-Wire (Null)**	**4-Wire**
6 mil	85 mOhm	210 mOhm	67 mOhm	73 mOhm
10 mil	100 mOhm	180 mOhm	36 mOhm	41 mOhm
20 mil	25 mOhm	160 mOhm	15 mOhm	20 mOhm
100 mil	5 mOhm	140 mOhm	1 mOhm	11 mOhm

3 Determining Maximum Trace Amperage

3.1 Simulation

Before actually passing current through any trace, Saturn PCB Toolkit simulations were made to determine the current required to raise various width traces of 1oz copper 40°C:

- 6 mil: 1.3A
- 10 mil: 1.8A
- 20 mil: 2.9A

3.2 Smoking Traces

Using a power supply in constant current mode, the following currents were passed through 6, 10, and 20 mil wide traces.

- 6 mil: Warm: I = 1.75A, Hot: I = 3.2A, Smoke: I= 4.5A
- 10 mil: Warm: I = 2A, Hot: I = 4.2A, Smoke: I= 6.4A
- 20 mil: Warm: I = 2.4A, Hot: I = 5.8A, Smoke: I= 10.2A

As the point at which the trace is "warm" and when it is "hot" is subjective and no equipment was used to determine what temperature the traces reached at certain currents, it is safe to say that the simulation data was in line with the actual experiment.

4 Conclusion

This experiment successfully estimated and measured the resistance of various copper trace widths using the two and four-wire methods. The 2-wire method, although straightforward, introduced measurement errors due to the resistance of the DMM leads. By using the DMM's 'Null' function, these errors were mitigated, resulting in more accurate resistance readings. However, the 4-wire method provided the most precise measurements compared to the estimated values by eliminating the influence of lead and contact resistances.

Additionally , the Saturn PCB Toolkit simulations of maximum trace amperage aligned well with the experimental results. The traces were subjected to increasing currents until they reached "warm," "hot," and "smoking" states, showing that actual current-carrying capacities exceeded the values simulated, but followed a similar trend. These findings demonstrate the reliability of the simulation and measurement techniques in evaluating PCB trace properties, aiding in future PCB design decisions.

Learning Take-Aways:

- The 4-wire method is more reliable for accurately measuring small resistances, as it eliminates the effects of lead and contact resistance that can skew results in the 2-wire method
- While simulations provide valuable predictions, real-world testing is necessary to confirm those results, especially for determining current-carrying capacity and thermal effects.