University of Colorado - Boulder

ECEN 5730
Practical PCB Design Manufacture — Fall 2024

Lab 11 and 12 Report - Trace Resistance and Current Limits

Sam Walker

Tim Swettlen

Monday, October 7, 2024

College of Engineering & Applied Science
UNIVERSITY OF COLORADO BOULDER

Introduction

This report documents the results from Lab 11 and 12, where we measured trace resistances and evaluated the maximum safe currents for PCB traces with varying widths. We used both 2-wire and 4-wire measurement methods to assess the accuracy of resistance measurements and to compare the results. Additionally, we pushed the traces to failure using a current-controlled power supply to identify their maximum current capacities.

Measurement Methods: 2-Wire vs. 4-Wire

We employed both 2-wire and 4-wire methods to measure the trace resistances.

- **2-Wire Method:** This method combines both current and voltage measurements through the same leads, adding lead resistance to the final value. For large resistance values, the error introduced by the leads is often negligible, especially if the null method is used to subtract the lead resistance. However, incorrect nulling can lead to large inaccuracies, even producing negative resistance values.

- **4-Wire Method:** This method uses separate pairs of leads for current and voltage, eliminating the lead resistance from the measurement. It is particularly useful for small resistance measurements where lead resistance would otherwise skew the results. The 4-wire method gives the most accurate results in these situations.

Trace Resistance Estimation

To estimate the resistance of the traces, we used a nominal trace resistivity value of 0.5mΩ and held the line distance constant at 1000 mils. The formula used is:

$$R = \frac{\rho \cdot L}{A}$$

Where: - R is the resistance, - ρ is the resistivity (0.5mΩ), - L is the length (1000 mils), - A is the cross-sectional area, depending on the width of the trace.

For example, with a line width of 20 mils, the estimated resistance is calculated as:

$$R = \frac{0.5 \times 1000}{20} = 25\,\text{m}\Omega$$

This estimation was done for all widths, with the results presented below.

Measurements and Results

The table below summarizes the measured resistances for different trace widths using both the 2-wire and 4-wire methods. Additionally, the results using the null function for 2-wire measurements are presented.

Line Width mils	Line Distance mils	Estimate mΩ	2wire mΩ	2wirenull mΩ	4wire mΩ	current mA	voltage mV
6	1000	83.333	170	68	67.652	750	50.739
10	1000	50	140	39	38.045	750	28.534
20	1000	25	121	17	18.272	750	13.704
100	1000	5	106	7	3.877	750	2.908

Figure 1: Measured and Estimated Trace Resistances

The graph below visually compares the resistance values for the different methods.

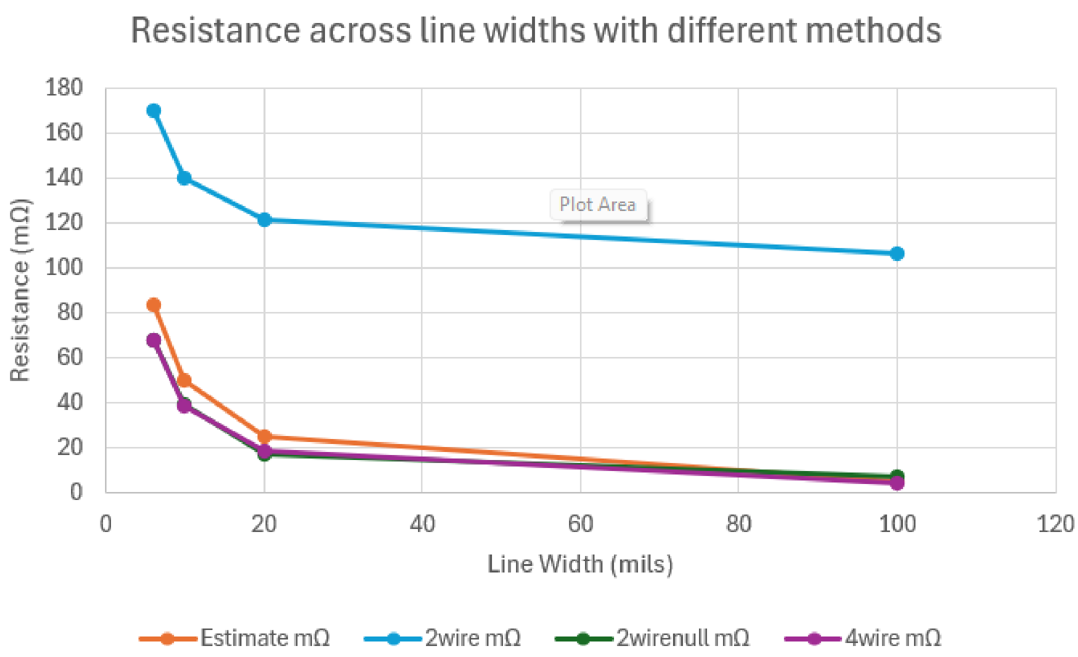

Figure 2: Resistance Comparison Across Methods

As expected, the standard 2-wire method overestimated the resistance by approximately 100mΩ due to the contribution of the leads. The null-corrected 2-wire measurements aligned closely with the 4-wire results, confirming the effectiveness of the nulling process in removing lead resistance.

Maximum Current Through Traces

We also tested the current capacity of the traces by increasing the current through them until failure (smoking or blowing up). The testing setup is shown below, which shows how the different trace widths were connected to measure their resistance and withstand high currents.

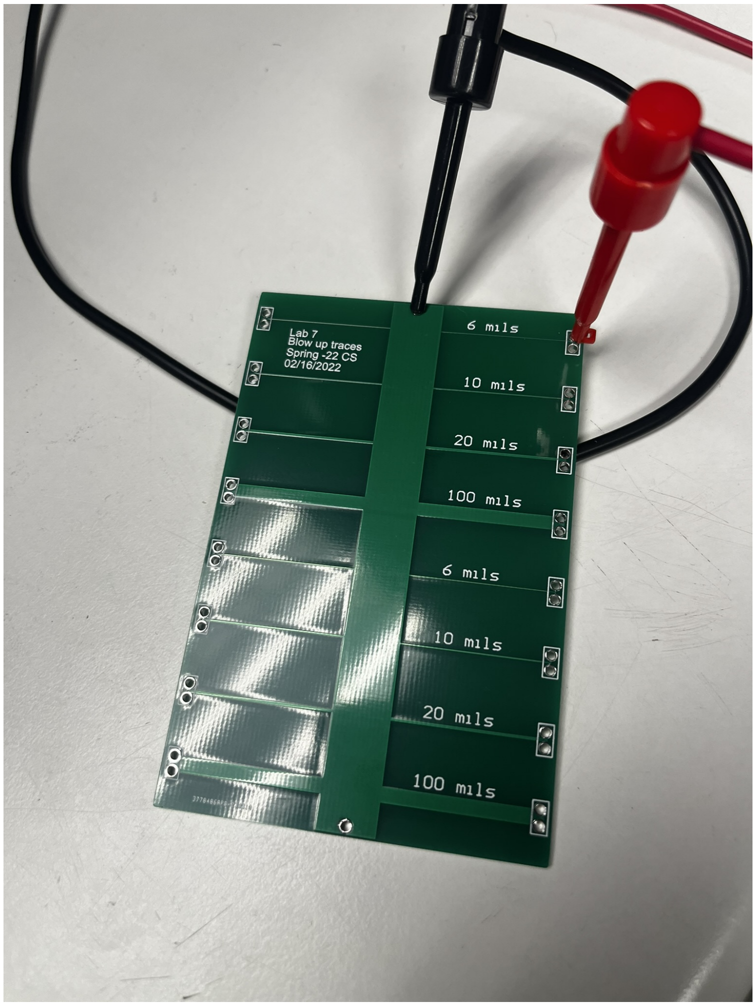

Figure 3: Setup for Measuring Trace Resistance and Testing Currents

The following table shows the results of these tests, including the current estimate, which was estimated using the Saturn PCB estimation tool, the current when the trace became warm, hot, and when it failed.

line width	current estimate A	current when warm A	current when hot A	current when smoking A		voltage rising until smoking starts at 5A
6	1.334	3.1	4.2	5		1.22V
20	2.965	6.5	10	N/A		

Figure 4: Current Limits for Different Trace Widths

Key observations: - The 6 mil trace failed (began smoking) at 5A, with a voltage of 1.22V. As the current remained constant at 5A, the voltage steadily rose from 1V to 1.22V, indicating an increase in resistance as the trace heated up. - The 20 mil trace was tested up to 10A, but the power supply's limitation prevented pushing it beyond this. No failure was observed at this current level.

Why Did Voltage Rise with Constant Current?

The rise in voltage observed in the 6 mil trace is due to the increasing resistance of the trace as it heats up. According to Ohm's Law:

$$V = I \cdot R$$

As the temperature of the trace increases, so does its resistance, which in turn increases the voltage while the current remains constant. The trace eventually failed at 1.22V and 5A.

Safe Current Recommendations

Based on the results of these tests, I recommend the following maximum safe currents for each trace width. These values are roughly 1.5x the estimated safe current, as shown below:

6 mil trace: 2 A

10 mil trace: 3 A

20 mil trace: 4.5 A

100 mil trace: 15 A

These recommendations are based on the tests conducted and reflect a safety margin for typical PCB designs.

Conclusion

In Lab 11 and 12, we measured trace resistances using both the 2-wire and 4-wire methods, confirming that the 4-wire method yields more accurate results, especially for small resistances. The 2-wire method, when paired with nulling, can provide close results but is less reliable for low resistances. We also determined the maximum current limits for different trace widths, demonstrating that traces can handle more current than estimated, but heating effects and increased resistance must be considered. This was evidenced by the voltage rise during the constant current test, which ultimately led to failure of the 6 mil trace. Future designs should take these factors into account when estimating the safe current capacities of PCB traces.