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# Effects of varying laser trimming geometries on thin film resistors



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| Journal: | *Circuit World* |
| Manuscript ID | CW-11-2016-0058 |
| Manuscript Type: | Research Paper |
| Keywords: | Laser trimming process, optimization, thin film resistor |
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# Effects of varying laser trimming geometries on thin film resistors

**Abstract**
**Purpose -** This paper studies the effects of varying laser trim patterns on several performance parameters of thin film resistors such as the temperature coefficient of resistance (TCR) and target resistance value.

**Design/methodology/approach -** The benefits and limitations of basic trim patterns are taken into consideration and the plunge cut, double plunge cut and the curved L-cut were selected to be modelled and tested experimentally. A computer simulation of the laser trim patterns has been developed for the modelling process of the resistors. The influence of the trim length and resistor dimensions on the TCR performance and resistance value of the resistors is investigated.

**Findings -** It is found that variation in trim length, within the range of 5 to 15 mm, can give significant increases in the TCR of the thin films. Thus, for the plunge TCR cut can reach up to 11.51 ppm/$^{o}$C, for the double plunge cut up to 14.34 ppm/$^{o}$C and for the curved L-cut up to 5.11 ppm/$^{o}$C.

**Originality/value –** Research on the effects of various laser trimming geometries on the TCR and target resistance accuracy is limited, especially for patterns such as the curved L-cut, which is investigated in this paper.

**Keywords** Laser trimming process, optimization, thin film resistor.

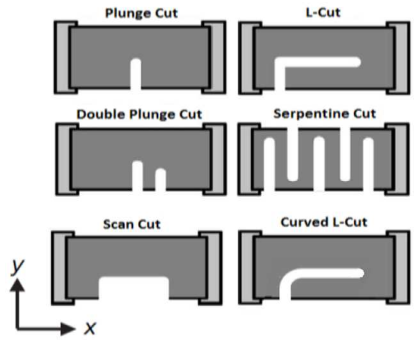
**Paper type** Research Paper

## 1. Introduction

Nowadays, there is a high demand for cost-effective electronic devices with tolerances better than ±10% (Elshabini-Riad & Bhutta, 1993). Thin film resistors with such accuracy and low resistivity are required especially in portable devices in order to reduce energy consumption (Fjeldsted & Gottfried, 2004; Nowak *et al.*, 2009). Laser trimming is the most popular trimming method for the manufacture of thin and thick film resistors (Deluca, 2002; Meier, 2006). In general, resistors are fabricated to lower resistance values than needed and then the target value is increased by trimming away sections of the material.

There is a variety of different trim patterns, as presented in Figure 1, that are commonly used in the manufacture of thin film resistors such as the plunge cut, L-cut, double plunge cut, serpentine cut and scan cut. The plunge cut is simple and economical and it consists of a single kerf orthogonal to the current flow but its tolerance accuracy is limited. The L-cut consists of a cut perpendicular to the current flow in the resistor which quickly increases the resistance close to the target value and then the direction of the trim changes to parallel to the current flow in order to fine trim to the desired value (Albin & Swerson, 1971). It is commonly used due to its stability and tolerance accuracy (Deluca, 2002; Birkett & Penlington, 2013).

**Figure 1** Basic resistor trimming patterns (Sandborn & Sandborn, 2008).




As for the double plunge cut, an additional plunge is added to the side of the first plunge cut. This method allows even tighter resistance tolerances to be achieved due to the fact that the kerf is cut in an area of low current density but it is more expensive because of the additional trimming time needed (Deluca, 2002). The scan cut is mostly used in high frequency applications but it is very time consuming and thus not cost-effective for general use (Birkett & Penlington, 2013). Another trimming pattern is the serpentine cut that consists of multiple cuts in areas of high current density in order to give large increases in resistance value and improvements in tolerance accuracy but it appears to have stability issues (Deluca, 2002; Birkett & Penlington, 2013). However, the performance of these patterns can be optimized in order to achieve resistance tolerances of ±1% and better stability. Thus, further study of specialized cuts like the curved L-cut is needed.

Previous studies on modelling of trimmed resistors include numerical trim simulations using computer aided design, finite difference method and boundary element method in order to design and predict trimmed resistors (Papp, 1993; Schimmanz & Jacobsen, 2001; Wronski *et al.*, 2005).

In this paper, a simulation model is described and is verified experimentally by trimming resistive paper. The model can make comparisons between the selected trim patterns investigating the effect of the trim length, resistor dimensions and TCR.

## 2. Resistor Trim Modelling

### 2.1 Simulation of resistor trimming

For the modelling procedure, a numerical simulation is proposed in which different trim patterns can be modelled and analyzed. The resistance value $R$ is given by:

$$R = \frac{\rho L}{A} = \frac{\rho L}{TW} = \frac{\rho}{T}\left(\frac{L}{W}\right) = R_{\square}\left(\frac{L}{W}\right) \quad (1)$$

Where; $\rho$ is the bulk resistivity, $A$ is the cross-sectional area of the resistor, $R_{\square}$ is the sheet resistance, and $L$, $W$ and $T$ are the length, width and thickness of the resistor respectively (Sandborn & Sandborn, 2006; 2008).

For the plunge cut, see Figure 2, the formulations are given by equations 2 and 3 (Sandborn & Sandborn, 2006).

$$R = R_1 + R_2 + R_3 \quad (2)$$

$$R = r\sum_{i=1}^{n}\left[\frac{\frac{x_1}{n}}{W-\left(\frac{D}{n}\right)\left(\frac{2i-1}{2}\right)}\right] + r\left(\frac{x_2}{W-D}\right) + r\sum_{i=1}^{m}\left[\frac{\frac{x_3}{m}}{W-\left(\frac{D}{m}\right)\left(\frac{2i-1}{2}\right)}\right] \quad (3)$$

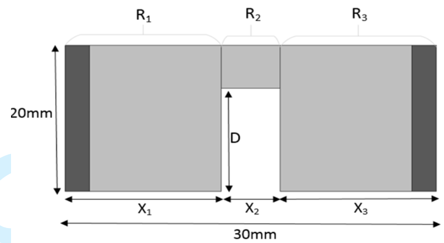
Where; $n$ and $m$ are the number of rectangles on either side of the trim and $r$ is a specified value which depends on the normalized resistance value (Shier, 1988; Schimmanz & Jacobsen, 2001).

The TCR is determined as follows:

$$TCR = \frac{R_{T2}-R_{T1}}{R_{T1}(T2-T1)} \times 10^{-6} \quad (4)$$

Where; $R_{T1}$ is the resistance value at room temperature, $T_1$, and $R_{T2}$ is the resistance value at operating temperature, $T_2$ (Ramirez-Angulo *et al.*, 1987; 1988).

**Figure 2** Model for the plunge cut (Sandborn & Sandborn, 2006).




Moreover, the change of the resistance value due to the effect of the TCR is given by:

$$R_{delta} = R_{nominal} \times T_{delta} \times TCR \quad (5)$$

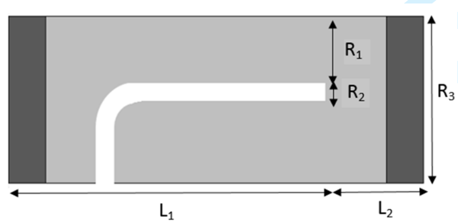
Where $R_{nominal}$ is the initial resistance value, $T_{delta}$ is the increase or decrease of the temperature and $TCR$ is the temperature coefficient of resistance. A similar approach to the one above for the plunge cut was followed for the double plunge cut in order to calculate the resistance and TCR (Barlage, 1973; Shier, 1988).

As for the L-cut, it is shown in Figure 3 that the total resistance is the parallel-series combination of $R_1$, $R_2$ and $R_3$ and the following equation was used:

$$R = \frac{R_1 \times R_2}{R_1 + R_2} + R_3 \quad (6)$$

Where; $R_1$ and $R_2$ are two resistors in parallel and $R_3$ is in series with the parallel combination of $R_1$ and $R_2$ and is the area that is not affected by the laser trimming (Bulger, 1975; Schimmanz & Jacobsen, 2001).

**Figure 3** Model for the curved L-cut.




### 2.2 Experimental analysis

The experimental procedure concerns tests with the use of resistive paper (PASCO Scientific PK-9025) with resistivity of approximately 5000 Ω/▫. The resistance value of the paper was found to vary slightly from sheet to sheet and normalization of the measurements was needed.

To normalize the various sheets, 10 initial measurements from each sheet were taken before trimming and then the measurements were averaged.

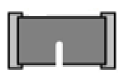
For a constant ratio ($\frac{L}{W}$), resistors of varying sizes can have similar resistance characteristics. Thus, the desired shape of the resistive paper is a rectangle with dimensions 30mm x 20mm. These dimensions were chosen for the experiments in order to depict the change in temperature effectively.

Then, five samples of each of the selected trim patterns were created using an Epilog Laser Mini Model 8000. Carbon ink contacts were added to the two ends of the resistor and spring loaded clips were then connected to measure the resistance value at room temperature. It was found that with the addition of the carbon contacts the measurement error could be significantly reduced. The temperature change was also measured each time with the use of a thermal camera (Model: FLIR B620) with a potential of 10V applied across the resistor element. Thus, the TCR could be determined from the resistance measurements at different temperatures.

## 3. Results and discussion

The room temperature for the modelling and experiments was 23°C. The width of the trim of the samples was 3mm for the plunge and double plunge cut and 5mm for the curved L-cut. Some indicative experimental results for the TCR of different samples with various trim lengths are shown in Table 1.

**Table 1** Experimental results for Temperature and TCR.

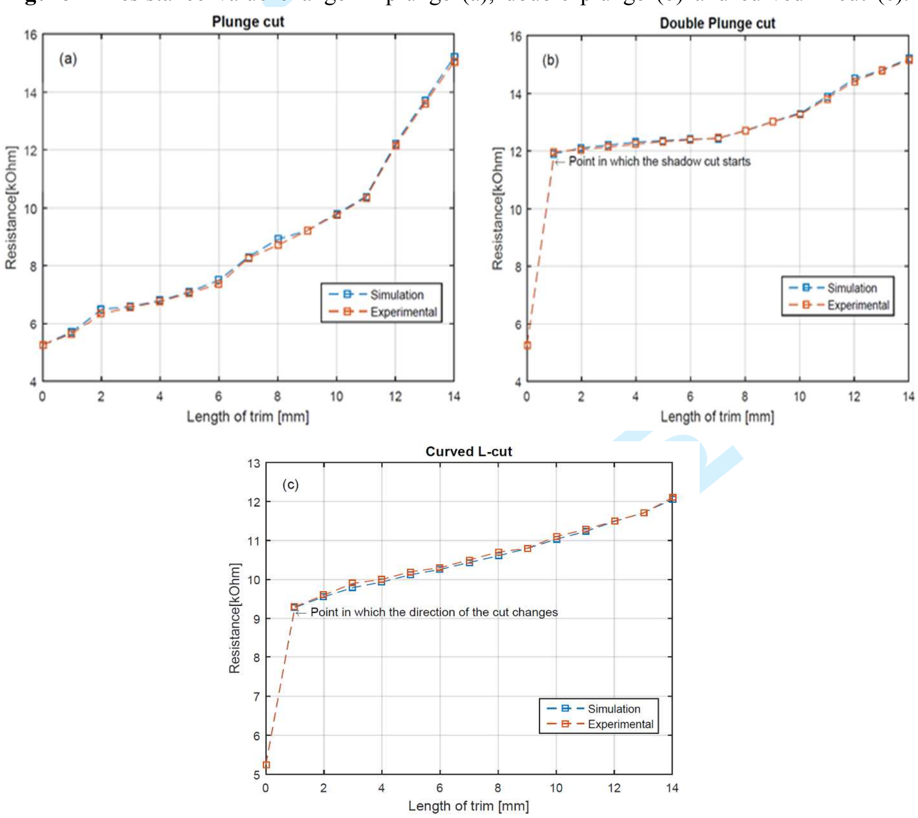
| Type of cut | | Trim length (mm) | Temperature (°C) | TCR (ppm/°C) |
|---|---|---|---|---|
|  | Plunge cut | 5 | 30 | 2.6 |
| | | 10 | 33.8 | 10.81 |
| | | 15 | 34.5 | 11.51 |
|  | Double Plunge cut | 5 | 24.3 | 12.14 |
| | | 10 | | |
| | | 5 | 26.3 | 12.74 |
| | | 15 | | |
| | | 10 | 27 | 14.34 |
| | | 15 | | |
|  | Curved L-cut | 3 | 25.7 | 4.10 |
| | | 5 | 27.5 | 4.91 |
| | | 10 | 28.1 | 5.11 |

It is worth commenting that the resistor with the plunge cut has a significant rise in temperature when voltage is applied to it. Thus, for the trim length of 5mm the temperature reaches up to 30°C while for the trim length of 10mm and 15mm, the values of temperature are 33.8°C and 34.5°C respectively. It is clearly shown that the increase in temperature is more significant when the length of the cut is larger. For the double plunge cut, the temperature for trim length of 5/10mm is 24.3°C. For the cuts of 5/15mm as well as 10/15mm, the values of temperature are 26.3 °C and 27 °C respectively. As for the curved L-cut, the temperature is 25.7°C, 27.5°C and 28.1°C for trim lengths of 3mm, 5mm and 10mm, respectively.

The value of the TCR was calculated based on the values of the temperature. It is also shown that the TCR varies in relation to the trim geometry and length. For the plunge cut, the TCR can reach 11.51 ppm/°C and 14.34 ppm/°C for the double plunge cut and it can be related to the flow of the current. The current flow lines are constant in untrimmed resistors and the trimming of the resistor to different geometries can cause a disturbance of the flow of the current (Licari & Enlow, 1998). The plunge cut is supposed to cause a larger disturbance in the current flow lines but also in the case of the double plunge, the flow of the current is also disturbed given the fact that this trimming pattern consists of two plunge cuts. As for the curved L-cut, the value of TCR is lower in comparison with the plunge and double plunge cut, with values of 5.11 ppm/°C. The flow of the current for the curved L-cut is expected to be smooth because the cut does not consist of any sharp edges which could cause large disturbances in the current flow lines such as in the other two types of cuts. However, according to the results, it is worth noting that the double plunge and the curved L-cut seem to have an advantage in this area in relation to the plunge cut.

The change in the resistance value for the trim length with range of 0-14mm from simulations in comparison with the experiments for the plunge cut, double plunge and the curved L-cut are shown in Figure 4.

**Figure 4** Resistance value change in plunge (a), double plunge (b) and curved L-cut (c).



It is shown that the results from the simulations are close to those obtained from the experiments for all three patterns. The normalized resistance value before trimming is 5.25 kΩ for all the samples and the highest resistance value for trim length of 14mm is around 15kΩ for plunge and double plunge cut and around 12kΩ for the curved L-cut.

The progression that the resistance makes as the trim length is increased is clearly depicted in the plots. It is worth commenting that the resistance value in the plunge cut increases faster and less trimming time is needed to perform this cut than the other two patterns. Furthermore, for the double plunge cut, it is shown that the resistance value increases fast for the first plunge and then for the second cut (shadow) the increase is slower. This cut seems to be a good option but the additional trimming time needed, increases the production costs.

As for the curved L-cut, the resistors were trimmed so that the trim changed direction after 10mm. In the plot, the change of direction of the cut is shown when the slope of the line changes. The highest trimmed value for this pattern was 12.2 kΩ for a trim length of 14mm. It is worth noting that once again the resistance value increases fast until the point in which the cut changes direction after 10mm. As a result, this type of cut can be considered to be the most accurate pattern in comparison with the other ones.

**4. Conclusion**

This paper describes the development of a numerical model for laser trim patterns which is also verified experimentally. The importance of appropriate laser trim pattern design and the effect of trim length and TCR of the thin film resistor material was demonstrated.

It is found that variation in resistor dimensions, trim length and type of cut play an important role in the fabrication of thin film resistors due to their affect on the final resistance value.

In addition to this, significant increases in the TCR were shown especially for the plunge and double plunge cut. Trimming patterns affect the resistance value, as the plunge cut shows a rate of resistance increase in relation to the double plunge cut. Thus, both trim patterns can produce a high target resistance fast. As for the curved L-cut, it is shown to have different characteristics as far as the rate of increase in the resistance value is concerned which is slower than the other patterns. This is an effect of the removal of sharp turns in the geometry of the cut. Thus, it can be thought as a potential method to control the rate of change of resistance leading to more accurate results.



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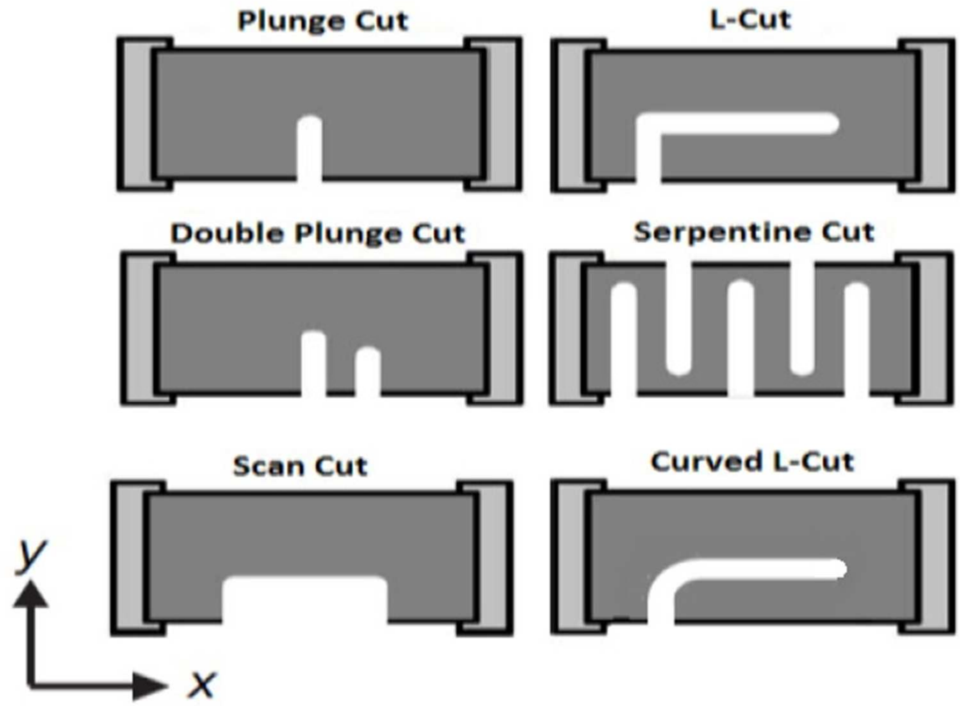
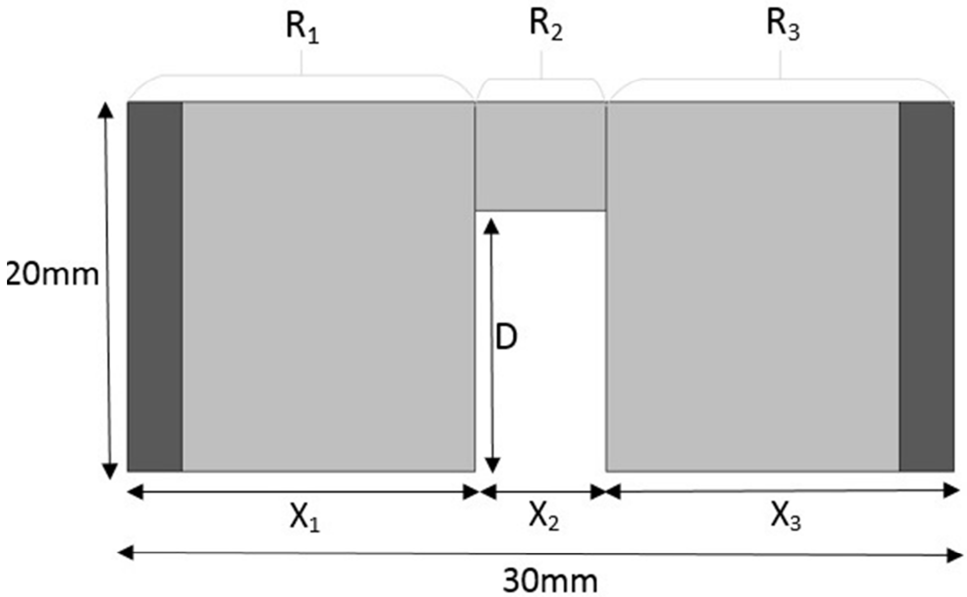



166x119mm (96 x 96 DPI)

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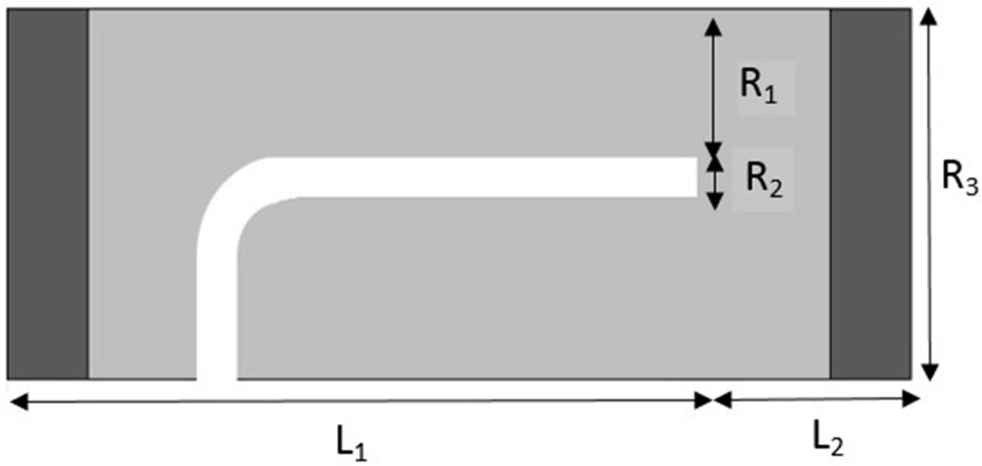


146x71mm (96 x 96 DPI)

| Type of cut | | Trim length (mm) | Temperature (°C) | TCR (ppm/°C) |
|---|---|---|---|---|
|  | Plunge cut | 5 | 30 | 2.6 |
| | | 10 | 33.8 | 10.81 |
| | | 15 | 34.5 | 11.51 |
|  | Double Plunge cut | 5 | 24.3 | 12.14 |
| | | 10 | | |
| | | 5 | 26.3 | 12.74 |
| | | 15 | | |
| | | 10 | 27 | 14.34 |
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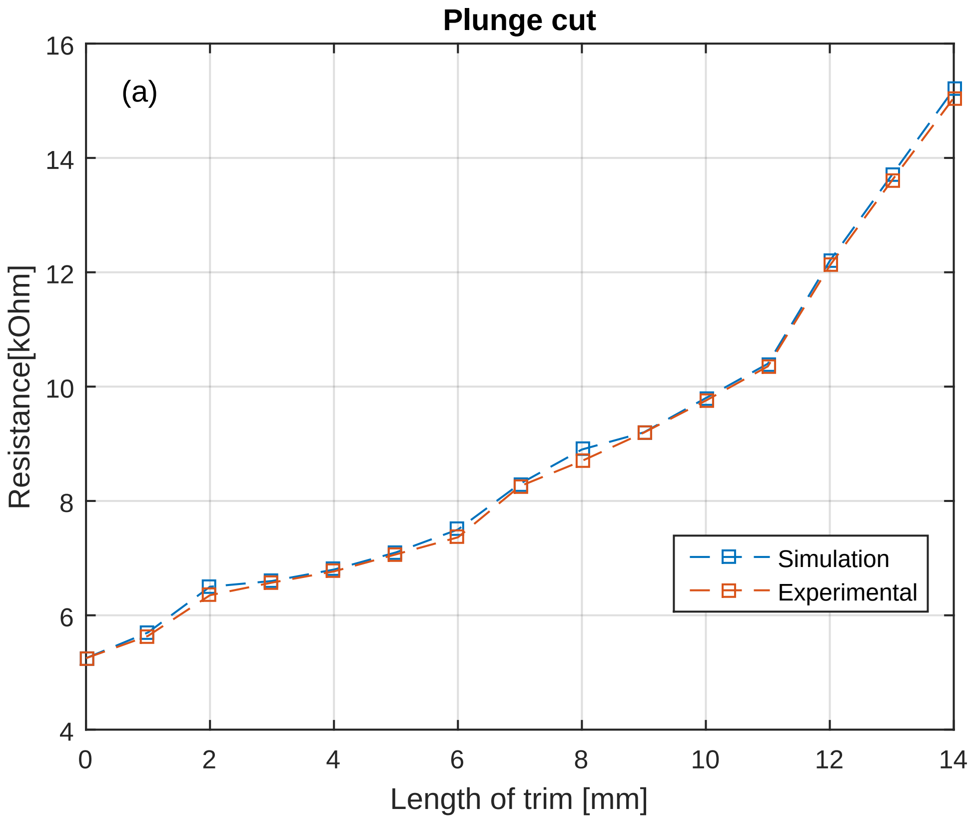
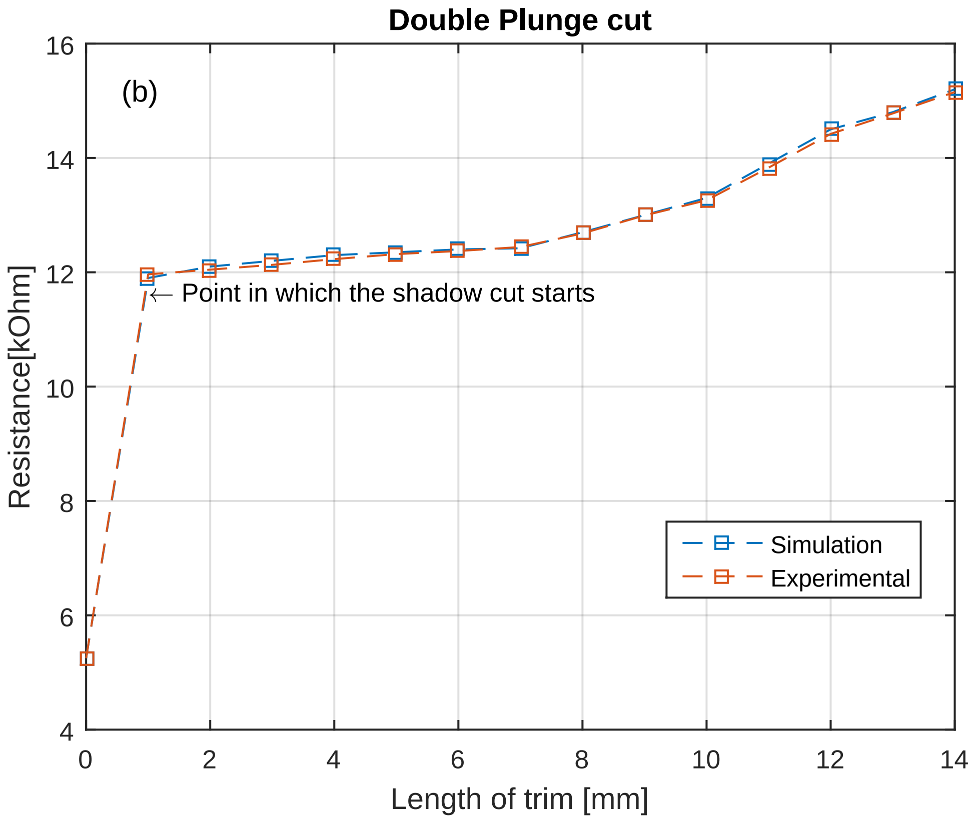
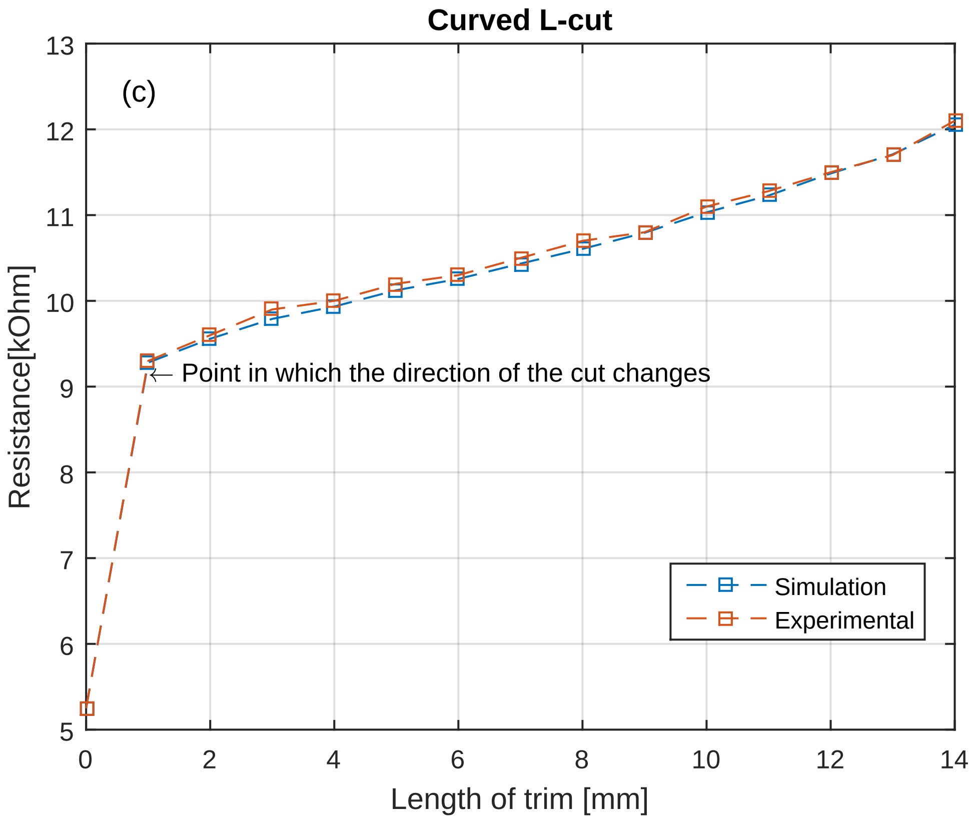

Plunge cut
(a)
Resistance[kOhm]
Length of trim [mm]
Simulation
Experimental
16
14
12
10
8
6
4
0
2
4
6
8
10
12
14


Double Plunge cut
(b)
← Point in which the shadow cut starts
Resistance[kOhm]
Length of trim [mm]
Simulation
Experimental
16
14
12
10
8
6
4
0
2
4
6
8
10
12
14


Curved L-cut
(c)
Point in which the direction of the cut changes
Simulation
Experimental
Resistance[kOhm]
Length of trim [mm]
0
2
4
6
8
10
12
14
5
6
7
8
9
10
11
12
13