New Trim Configurations for Laser Trimmed Thick-Film Resistors – Experimental Verification

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Abstract

Laser trimming is the most effective and popular trimming method of thick-film and LTCC resistors at present. It is also still a subject of continuing theoretical and experimental analysis and optimization. Very recently a new approach to this process was suggested. It consists in replacing two-contact bar resistors by three-contact distributed structures trimmed by narrow cuts just around additional contact of different shape [1,2]. This paper presents experimental verification of such an approach. The relative trim characteristic and sensitivity are analyzed as a function of additional contact shape and cut length. Next long-term stability, pulse durability and low frequency noise are compared for two- and three-contact resistors *versus* trim pathway length. These investigations are completed by simulation of electrical potential distribution in two- and three-contact resistors with various length of trimming kerf.

Key words

thick-film, resistor, laser trimming, long-term stability, pulse durability, low frequency noise.

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1. Introduction

Screen-printed and fired thick-film and LTCC resistors typically have ±20% tolerance (sometimes even up to ±30%). Therefore they have to be trimmed. Two methods are widely used today – air abrasive and laser trimming and since approximately ten years an intensive search has been made to develop a third method of trimming by using high energy electrical pulses fed into resistors [3,4]. Prior to the widespread acceptance and use of laser trimming air abrasive trimming was the standard process. However this method has some disadvantages, for example it opens up the natural protective glaze of the resistor, causing degradation of long-term stability and low frequency noise. As was shown in [5] some resistor systems trimmed by series of voltage pulses have worse stability and larger current noise index after long-term thermal ageing. This is why laser trimming is the most effective and popular trimming method for thick-film and LTCC resistors at this very moment.

Because of this laser trimming is still a subject of permanent theoretical and experimental analysis and optimization. For example, the Boundary Element Method is used to simulate laser correction process, this means to calculate the relative trim characteristic (describing how resistance is changed in relation to the untrimmed one) *versus* trim pathway length and its first derivative, i.e. the relative trim sensitivity [6,7].

In general long-term thermal stability of untrimmed and laser trimmed thick-film resistors is very similar [5,8]. However there are some proposals, which additionally eliminate resistance drift by minimizing long-term annealing effects appearing in the heat-affected zone adjacent to the cut. One solution of this problem is to trim by link cutting in the case when trimmed resistors are connected in square or hexagonal grid [9]. The second one is based on cutting such a Swiss Cheese structure in typical bar resistor that trimming forces current crowding only in non-heat-affected regions [10].

Very recently a new resistor configuration was proposed for laser trimming – two-contact resistors were replaced by three-contact distributed structures trimmed by narrow cuts just around additional contacts of different shapes [1,2]. This paper presents experimental verification of the above idea. The resistance of test resistors is analyzed *versus* shape of additional contact and cut length. Next long-term stability, pulse durability and low frequency noise are compared for two- and three-contact resistors with various length of trimming kerf.

2. Test Sample Fabrication and Laser Trimming

All electrical and stability measurements were performed using thick-film resistors with 2×1, 2×2, 3×1.5 and 3×3 mm^2 planar dimensions made of DP 2021 (100 Ω/sq.) or DP 2041 (10 kΩ/sq.) inks, screen-printed through 325 mesh stainless steel screen on alumina substrates with prefired PdAg-based terminations. A portion of the resistors had a third contact, electrically isolated, shaped as a rectangle or semicircle.

Sheet resistance and its distribution is given in Table 1. As one should expect the presence of third contact diminishes the resistance between the other contacts by about 15-25%. But the level of changes is dependent also on kind of used resistive ink – somewhat larger changes are visible in the case of 100 Ω/sq. paste. The resistance distribution is similar in two and three-contact structures and varies between 5 and 10%.

Table I
Sheet resistance and its distribution (in kOhm) for untrimmed test resistors

Resistor dimensions	DP 2021		
	2-contact structure	with rectangle additional contact	with semicircle additional contact
3×3 mm^2	0.135±0.010	0.107±0.012	0.112±0.011
2×2 mm^2	0.125±0.009	0.097±0.006	0.097±0.007
3×1.5 mm^2	0.274±0.011	0.212±0.014	0.217±0.014
2×1 mm^2	0.246±0.012	0.173±0.013	0.190±0.011
Resistor dimensions	DP 2041		
	2-contact structure	with rectangle additional contact	with semicircle additional contact
3×3 mm^2	11.91±0.87	10.37±0.86	10.87±0.78
2×2 mm^2	12.05±0.53	10.27±0.53	10.40±0.47
3×1.5 mm^2	23.38±1.23	19.89±1.30	20.34±1.24
2×1 mm^2	22.60±0.85	18.60±1.03	19.39±1.07

The Aurel NAVS-30 laser trimming and cutting system, working in the mode of stabilized current of arc lamp (I = 15 A), Q-switch rate f = 200 Hz and speed of laser beam v = 1 mm/s, was used for resistor trimming. The resistors were cut just around the additional contact with a clearance of 0.2 mm from its edge. The shape and length of such cuts for three-contact structures with semicircular and rectangular contacts are shown in Fig. 1. Two-contact resistors, served as reference point, were trimmed in the same manner as those with rectangular third contact.

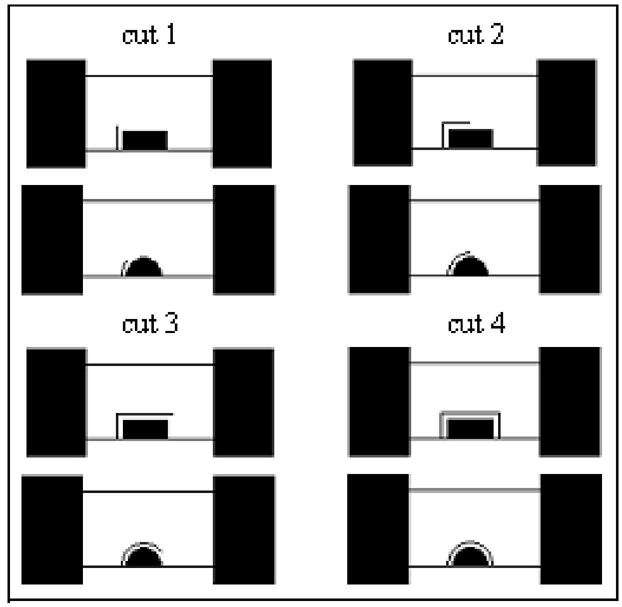

Fig. 1. Illustration of laser cut length used in three-contact resistors with rectangular and semicircular additional contact

The increase of resistance for DP 2021 resistors *versus* cut number (length) is shown in Fig. 2, 3 and 4. It is interesting to note, that three-contact distributed structures exhibit much larger resistance increase in comparison with two-contact ones for similar length of laser kerf. Relative trim sensitivity for bar resistors and three-contact structures with rectangular additional contact is the strongest for cut length between cut 0 and 1. The same parameter for structures with and semicircular additional contact exhibit maximum between cut 1 and 2.

3. Electrical and Stability Measurements - Results and Discussion

Most often post-trim stability is characterized by resistance drift. Herewith we compared long-term thermal stability of resistors aged at 200°C for 500 h. The relative resistance changes are shown in Fig. 5, 6 and 7. In general the small

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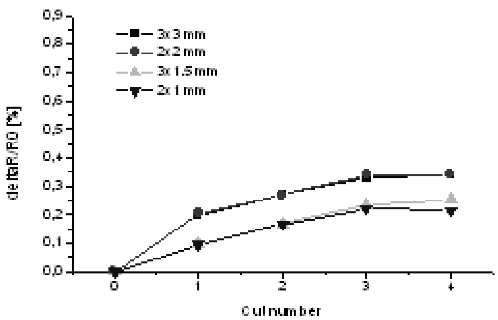

Fig. 2. Changes of resistance versus cut-length for DP 2021 resistors (100 ohm/sq.) - two-contact resistor

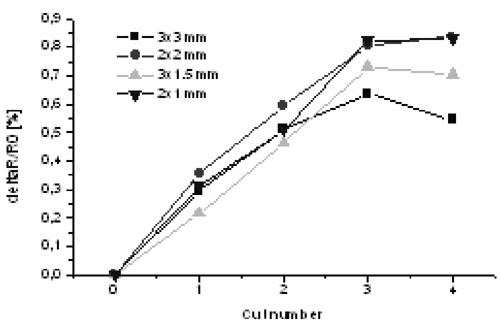

Fig. 3. Changes of resistance versus cut-length for DP 2021 resistors (100 ohm/sq.) - three-contact resistor with rectangle additional contact

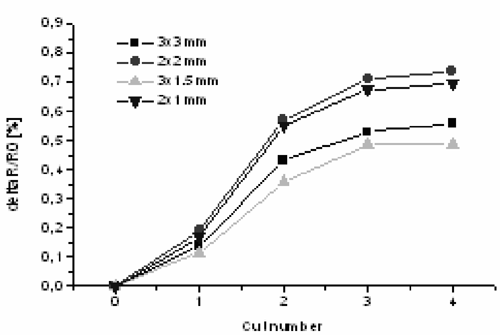

Fig. 4. Changes of resistance versus cut-length for DP 2021 resistors (100 ohm/sq.) - three-contact resistor with semicircular additional contact

resistance increase (not larger than 0.5%) is noted for DP 2021 resistors independent of resistor configuration, shape of additional contact and cut length. Pulse durability is very promising and efficient characterization method for thick-film and LTCC resistors. During the measurements the 0.05 and 5 ms rectangular voltage pulses with 2 seconds off time between pulses were applied to the untrimmed and laser trimmed two- or three-contact resistors. It was assumed, that the pulse voltage can be called critical for particular pulse duration if after the series of 2 identical rectangular pulses the resistance of exposed components was changed by ±10% or they were destroyed completely.

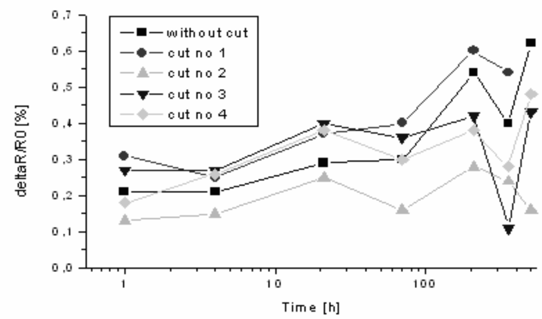

Fig. 5. Long-term stability of DP 2021 2×1 mm^2 thick-film resistors versus cut length (ageing temperature 200^{o}C) - two-contact resistor

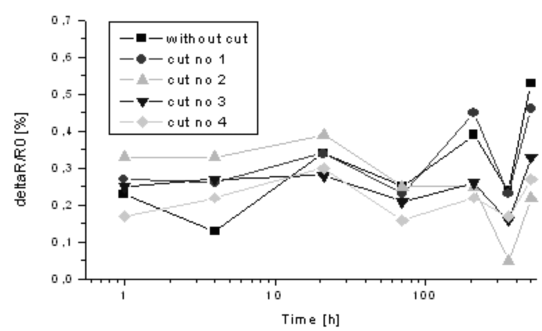

Fig. 6. Long-term stability of DP 2021 2×1 mm^2 thick-film resistors versus cut length (ageing temperature 200^{o}C) - three-contact resistor with rectangle additional contact

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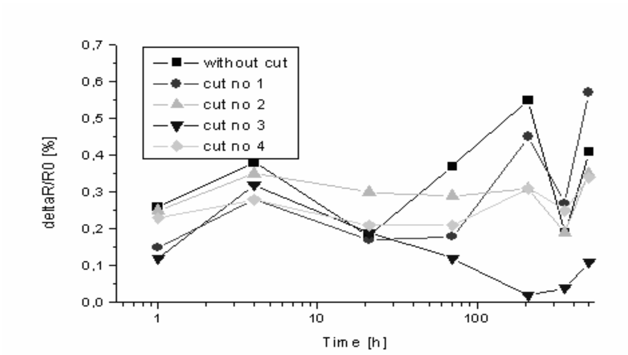

Fig. 7. Long-term stability of DP 2021 2×1 mm^2 thick-film resistors versus cut length (ageing temperature 200°C) - three-contact resistor with semicircular additional contact

Values of critical voltage and their relation with resistor configuration, shape of additional contact, length of trimming kerf and pulse duration are shown in Fig. 8, 9 and 10. Untrimmed two-contact resistors need larger voltages than three-contact ones to be destroyed. The resistors after cut no 1 are much less durable to voltage pulses than untrimmed ones – probably after this cut there are some microcracks perpendicular to the kerf in the area of primary current flow. Next cuts improve pulse durability in comparison with cut no 1. In the case when the end of cut is outside the primary current flow the increase of trim path affects critical voltage rather insignificantly. The rounded corners present in three-contact resistors with semicircular additional contact eliminate voltage and heat stresses. Therefore these resistors with long cut length (cuts 3 and 4) have the same pulse durability as untrimmed ones.

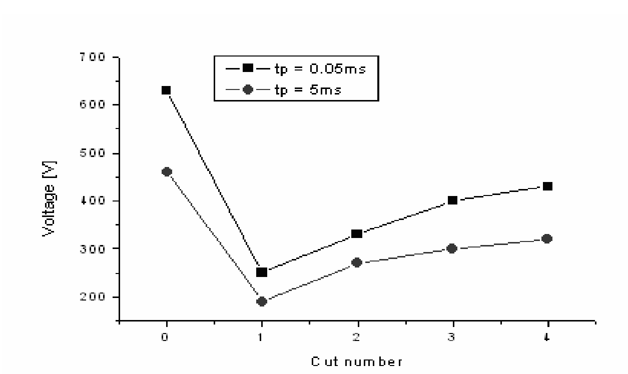

Fig. 8. Pulse durability of DP 2021 3×3 mm^2 resistors versus cut length (pulse duration: 50 µs or 5 ms) - two contact resistor

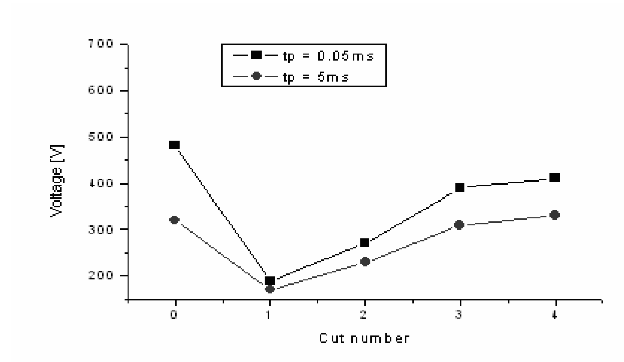

Fig. 9. Pulse durability of DP 2021 3×3 mm^2 resistors versus cut length (pulse duration: 50 µs or 5 ms) three-contact resistor with rectangle additional contact

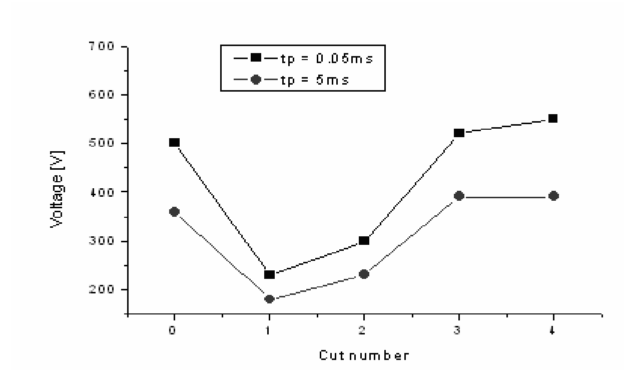

Fig. 10. Pulse durability of DP 2021 3×3 mm^2 resistors versus cut length (pulse duration: 50 µs or 5 ms) three-contact resistor with semicircular additional contact

The low frequency noise is used time to time as a diagnostic tool of thick-film resistors. In this paper we analyze power spectral density of two- and three-contact resistive structures. Noise measurements were carried out by a standard DC technique. The sample of resistance R was biased through the ballast wire wound resistor R_B from a DC source. The noise signal was AC-coupled to the low-noise preamplifier. Then it was sent to the digital oscilloscope in which the power spectral density was calculated over the frequency range 5-1000 Hz. The relative power spectral density was calculated over the frequency range 5-1000 Hz. The relative power spectral densities of "excess" low frequency noise are shown in Figs. 11 and 12.

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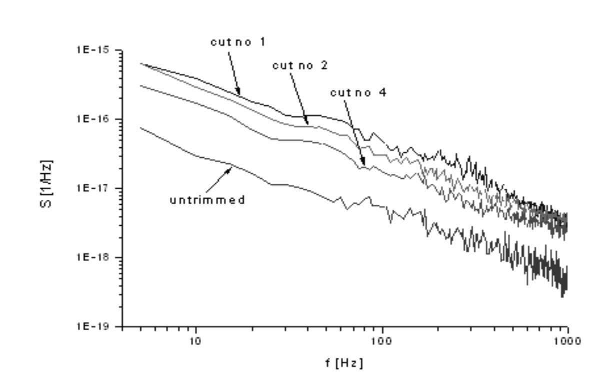

Fig. 11. Power spectral density of “excess" low - frequency noise for untrimmed and laser trimmed two-terminal 2×1 mm^2 DP 2041 resistors

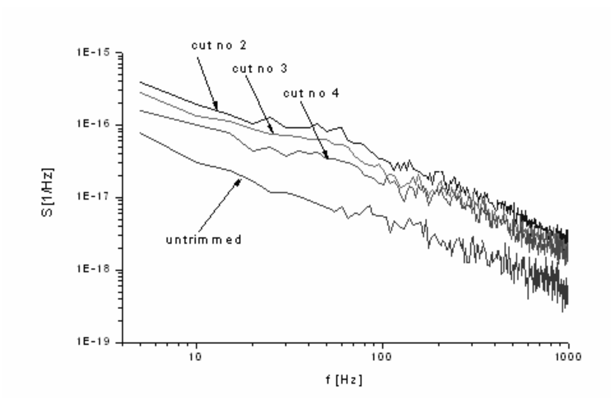

Fig. 12. Power spectral density of “excess” low frequency noise for untrimmed and laser trimmed three-terminal with rectangle additional contact (down) 2×1 mm^2 DP 2041 resistors

It is clear that the noise spectra have 1/*f* shape both for untrimmed and laser trimmed resistors. The untrimmed structures have noticeably lower noise level than trimmed ones. The largest noise level corresponds to cut 1, which can be treated as single cut perpendicular to the resistor length. This cut results in terminating the kerf in the area of high current density. The microcracks, propagating from the end of this cut, interfere directly with current flow through the remaining portion of resistor width. Further increase of cut length leads to decrease of noise level. The noise level of two- and three-contact structures is very similar.

The laser kerf disturbs simple electrical potential and current density distribution in comparison with situation characteristic for simple bar resistor. Therefore the distributions of both these quantities were performed for two- and three-contact structures using ANSYS software. Resistors with various configuration and shape of additional contact and cut length are shown in Fig. 13. The simulation was made for potential of left contact equal to 0 V and 1 V for right contact.

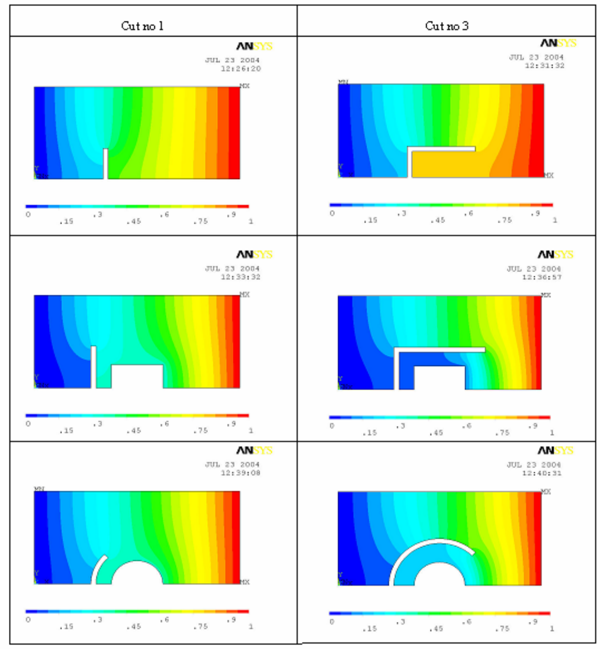

Fig. 13. Simulation of voltage distribution in 2×1 mm^2 thick-film resistors as a function of number and shape of additional contact and cut length

However it appeared that in steady state conditions the distribution of electric potential and current density inside the resistive film did not affect temperature distribution onto the surface of 5×5×0.25 mm^2 alumina chip with variously trimmed 2×1 mm^2 two- or three-contact resistors. The maximum temperature on the black-painted surface was about 113^{o}C for 0.3 W supply power and 169^{o}C for 0.5 W supply power (measurement performed with the aid of thermographic system).

4. CONCLUSIONS

Very recently new configurations were proposed for laser trimmed thick-film resistors. Two-contact resistors were replaced by three-contact distributed structures trimmed by narrow cuts just around additional contacts of different shapes. In this paper we presented experimental verification of the above idea. The resistance of test resistors was analyzed *versus* shape of additional contact and cut length. Next long-term stability, pulse durability and low frequency noise were compared for two- and three-contact resistors with various length of trimming kerf. During these investigations the following was found:

- Three-contact resistors exhibit larger range of

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resistance increase than two-contact ones for the same length of trim cut.
- The shape of additional contact affects the maximum of relative trim sensitivity function *versus* trim pathway length.
- Long-term thermal stability of tested resistors does not depend on resistor configuration, shape of additional contact and cut length.
- Trimmed resistors have larger noise level and worse pulse durability independently on resistor configuration.
- Cut 1, which can be treated as typical single P-cut, causes the strongest deterioration of noise level and pulse voltage durability.
- The three-contact structure with semicircular additional contact seems to be the most appropriate for proper pulse durability, even when long trimming kerf is necessary.

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ADDITIONAL JOURNAL INFORMATION

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