IMPROVEMENT OF LASER TRIMMED FILM RESISTOR STABILITY BY SELECTION OF OPTIMAL TRIM PATHS

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Abstract. A study comparing post-trim drift performance of laser trimmed film resistors is presented. The influence on resistor stability of type of trim cut, initial trim position, laser adjustment parameters and amount of trim is studied. The study is based on computer simulations. Simple rules of thumb to optimally trim film resistors are derived. With these rules post-trim drift of film resistors can be reduced by as much as a factor four.

I. INTRODUCTION

Laser trimmed film resistors are widely used for the implementation of monolithic and hybrid systems with very high precision requirements [1]-[3]. The accuracy of these systems is ultimately limited by post-trim drift of resistance values due to temperature or aging. The laser trimming process is known to create an unstable region along the edge of the laser cut, called Heat Affected Zone (HAZ) which has different physical characteristics than the rest of the material. This causes trimmed resistors to drift differently from untrimmed resistors. It has also been observed that post-trim drift is strongly dependent on amount of trimming, material, type of trim cut, laser adjustment parameters, etc. In spite of the fact that film resistor laser trimming has been used for more than 25 years, no criterions have been determined to trim optimally film resistors to improve their long term stability.

In this paper, a study comparing post-trim drift performance of rectangular film resistors trimmed with single-plunge and L-cuts is presented. The goal of the study was to determine the influence of following factors on post-trim drift performance: 1) type of trim cut, 2) initial trim position, 3) laser adjustment parameters, and 4) amount of trim. Based on this, simple design guidelines for improved resistor stability were derived. The study was based on computer simulations with the film resistor analysis program FIRE [4], which calculates the field distribution for arbitrarily shaped, arbitrarily trimmed film resistors and determines a figure of merit based on the electrostatic field distribution. This figure of merit, called Heat Affected Zone Sensitivity (SHAZ), is a technology independent measure of post-trim drift performance. It allows a comparison of laser-trimmed film resistors from the point of view of stability. Small values of SHAZ correspond to more stable resistors (with less post-trim drift). For a specific implementation technology, SHAZ allows the calculation of the *actual* time and temperature drift of a laser-trimmed film resistor [4] according to the expression:

$$\frac{\Delta R}{R}\bigg|_{DRIFT} = SHAZ\left(\frac{\Delta R_S^{HAZ}}{R_S^{HAZ}}\bigg|_{DRIFT} - \frac{\Delta R_S}{R_S}\bigg|_{DRIFT}\right) + \frac{\Delta R_S}{R_S}\bigg|_{DRIFT} \qquad (1)$$

where $\frac{\Delta R}{R}\big|_{DRIFT}$ represents the (undesired) post-trim drift of the trimmed value of a laser-trimmed resistor due to drift in the sheet resistances of the HAZ $\frac{\Delta R_S^{HAZ}}{R_S^{HAZ}}\Big|_{DRIFT}$ and of non-heat affected material $\frac{\Delta R_S}{R_S}\Big|_{DRIFT}$. Notice that the first term in (1) is a trim induced change while the second term is (approximately) equal for all resistors on the same die. This common term is unimportant for many practical applications where circuit performance is dependent on resistor ratios.

The comparative study was done using FIRE to simulate *all possible* trim-cuts (single-plunge and L-cuts) on a rectangular film resistor of width W and length L. A single-plunge cut is defined as a cut starting at one edge of the resistor and extending in the vertical direction a distance y into the resistor body (Fig. 1a). An L-cut consists of a vertical cut of length y followed by a horizontal cut of length x (Fig. 1b). In Section II of this paper the algorithm used to scan a resistor with all possible trim-cuts and the factors considered for the comparison are discussed. In Section III, observations obtained from the comparison of simulation data are made. Section IV summarizes simple design guidelines to minimize post-trim drift of laser trimmed film resistors.

II. STRATEGY FOR SCANNING RESISTOR AND INTERPRETATION OF SIMULATION DATA

The strategy to scan a film resistor of length L and width W with all possible trim-cuts is illustrated in Fig. 2. Here xinit defines the initial trim position, s is a trim step (assumed for simplicity to be equal to the width of the laser kerf). The search initiates at the lower left corner (xinit=0). Simulations are performed with trim-cuts moving in the y direction by one step and then changing **x** stepwise from xinit to xmax. Thereafter x is reset to the value xinit, y increased by one step and **x** changed again stepwise from xinit to xmax. This procedure is repeated until y=ymax=W in which case xinit is increased by one step, x reset to xinit, and y reset to 0. The procedure terminates when xinit=xmax=L. This algorithm was implemented on a computer program (SCANRES) which uses a slightly modified version of FIRE as a subroutine. For each possible trim-cut a simulation with FIRE is performed. The large number of simulation data: trim resistance change **ΔR/R** (with respect to the nominal untrimmed resistor value) and SHAZ for each possible trim-cut are then processed with SCANRES to investigate following aspects:

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a) For a given resistance change, **ΔR/R** what is the initial position and type of trim-cut (plunge or L-cut) that leads to the lowest value of SHAZ? To investigate this aspect, the simulation data of all trim cuts leading to a similar trim resistance change **ΔR/R** (within a certain range) were selected to determine the influence of the initial position of the trim-cut and of the type of trim-cut on SHAZ.

b) How do the physical characteristics of the HAZ affect the stability of a laser trimmed resistor? Of special interest is the relative sheet resistance, that is, the relationship between the sheet resistance of the HAZ (R_s^{HAZ}) and that of the untrimmed material (R_s). It is known that due to the intense heat to which it is subjected during trimming, the HAZ acquires very different physical characteristics (significantly lower sheet resistance and TCR). The HAZ drifts more with time and temperature than the rest of the material. This causes laser trimmed film resistors to drift more than untrimmed resistors [6]. The characteristics of the HAZ are strongly dependent on the adjustment parameters of the laser beam: peak power, velocity, etc., and on the material. New film resistor structures have been proposed to alleviate post trim drift problems associated with the HAZ [7], [8]. In order to investigate this aspect each of the simulations described above were performed for several different values of the ratio R_s^{HAZ}/R_s with the purpose of investigating the effect of different adjustment parameters for the laser beam and also of different implementation technologies.

c) How does the value of SHAZ (minimum and maximum) depend on **ΔR/R**? For a given value **ΔR/R**, is there a significant difference between the minimum and maximum value of SHAZ and for which types of trim-cut (single-plunge or L-cut) and initial position are these minimum values obtained?

III. DISCUSSION OF SIMULATION RESULTS

The study lead to following observations:

i) *Influence of the type of trim cut:* Plunge-cuts are characterized by smaller SHAZ values than L-cuts for trim resistance changes of less than approximately 60% and for resistor aspect-ratios L/W from 1 to 4. *For larger trim resistance changes, L-cuts result in lower values of SHAZ than plunge-cuts.* This can be seen in Fig. 3 where a plot of SHAZ vs **ΔR/R** is shown for L-cuts with maximum form factor, (longest possible L-cuts reaching a contact-edge of the resistor) and a plot for plunge-cuts with minimum value of SHAZ. It can be seen that for small values of **ΔR/R** (less than 10%) the value of SHAZ characterizing long L-cuts can be *a factor 4 larger* than that corresponding to a plunge-cut or a short L-cut. Simulations were done assuming a width of the heat affected zone WHAZ = 1 unit, sheet resistances in the heat affected zone $\mathbf{R_s^{HAZ} = 25\ \Omega/\square}$ and in the untrimmed material $\mathbf{R_S = 50\ \Omega/\square}$ and a laser kerf width WK = 5 units. For aspect ratios L/W=2 (L=40 units, W=20 units) the crossing point for the two curves (where curves of plunge and L-cuts have the same **ΔR/R** value) is at **ΔR/R** = 65%. For aspect ratios L/W=2 very similar plots to that of Fig. 3 are obtained, but the crossing points take place at values **ΔR/R** = 58% and 57% respectively. For increasing values of L/W the crossing point decreases only slightly. It can be concluded that the crossing point **ΔR/R** is not very sensitive to the aspect ratio of the resistor, but as it will be shown later it can change significantly with the ratio R_S^{HAZ}/R_S. This ratio was assumed to be 1/2 for the simulations presented and it was based on measurements made on cermet thin film resistors test structures which were developed to characterize the HAZ. Other technologies will be characterized by different values of this ratio. The main implication of the above observations is that by trimming with P-cuts for low **ΔR/R** value and L-cuts for high **ΔR/R** values, the trim resolution (limited by long term stability) of laser-trimmed film resistors can be increased by as much as two bits. Fig. 4 shows plots of SHAZ vs the length of L-cuts for trim cuts with a fixed initial position. Each curve in Fig. 5 corresponds to a different value of **ΔR/R** used as parameter. It can be seen that for low values **ΔR/R** a zero length L-cut (a plunge-cut) has much lower values of SHAZ than a long L-cut for the same resistance change **ΔR/R**. For **ΔR/R** = 50% (close to the crossing point discussed above) the value of SHAZ is approximately the same independent of the length of the cut. The trend of long L-cuts to have lower SHAZ values for high values of resistance change can be seen in the curve for **ΔR/R** = 75%.

ii) *Influence of initial trim position:* The value of SHAZ is always slightly smaller if the trim is performed close to the edges of the resistor, that is, *optimal trimming is obtained by starting the cut close to the edge of the resistor*. Fig. 5 illustrates this with a plot of minimum SHAZ vs xinit (initial position) for several constant values of ΔR/R.

iii) *Influence of sheet resistance of HAZ:* The value of SHAZ for a given resistance change increases significantly as the resistivity of the HAZ decreases. This can be seen in Fig. 6 that shows plots of the minimum SHAZ as a function of **ΔR/R** for several values of R_S^{HAZ}/R_s (sheet resistance of the HAZ relative to that of the non heat affected material). For example, for ΔR/R = 100% SHAZ takes approximate values 0.1, 0.2, and 0.3 for ratios R_S^{HAZ}/R_S = 1.0, 0.5, and 0.25 respectively. This indicates that *the adjustment parameters of the laser beam strongly influence post trim-drift performance* and they constitute one of the most important factors for film resistor stability. Another observation in the same context is that the crossing point of Fig. 3 is also strongly dependent on the relative resistivity of the HAZ. Ratios R_S^{HAZ}/R_S = 1.0, 0.5, 0.25 result in crossing points at values **ΔR/R** = 45%, 65%, and 105% respectively. These observations indicate the need to use materials whose physical characteristics suffer minimum change with the trimming process and also for a given material, the need to adjust laser parameters to minimize changes in the material. In any case, test structures to monitor the ratio R_S^{HAZ}/R_S should be used. Once this value has been determined, simulations similar to the ones described here can be performed to determine the crossing point for a specific implementation technology and laser adjustment parameters.

Another observation from Fig. 6 is that for a fixed value $\boldsymbol{R_S^{HAZ}/R_S}$. The minimum SHAZ increases monotonously with **ΔR/R**. For example, for $\boldsymbol{R_S^{HAZ}/R_S}$ = 0.25, SHAZ takes approximate values 0.17, 0.22 and 0.27 for **ΔR/R** = 40%, 60% and 80% respectively. This indicates the need to use trim algorithms which for improved absolute accuracy require minimum amount of trim whereas for high relative accuracy lead to similar trim changes.

IV. CONCLUSIONS

A comparative study to determine optimal trim paths for rectangular film resistors has been presented. The study lead simple design guidelines to improve resistor stability. These can be summarized in the following rules of thumb: 1) Trim as close as possible to the contact-edge of the resistor, 2) Use plunge-cuts if the required resistance change is less that 60%, and L-cuts otherwise (this is a rough estimate, the actual crossing point has to be determined for each implementation technology), 3) Adjust laser parameters to minimize sheet resistance changes in the Heat Affected Zone, use test structures to monitor sheet resistance in the HAZ, and 4) Trim as little as possible to minimize SHAZ. These rules can help to improve the long term stability of laser trimmed film resistors by as much as two bits.

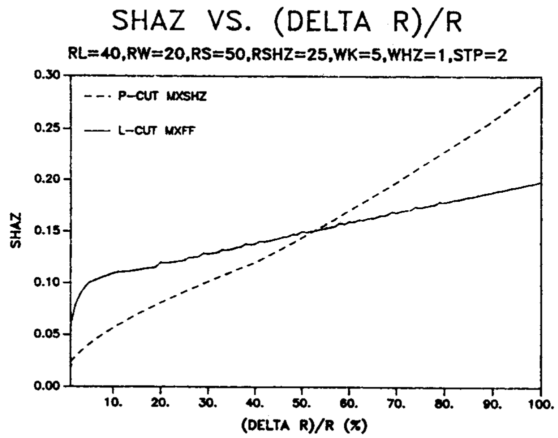

Fig. 3. **Dependence of Heat affected zone sensitivity (SHAZ) with ΔR/R for minimum sensitivity plunge-cut (broken line) and maximum length L-cut (solid line).**

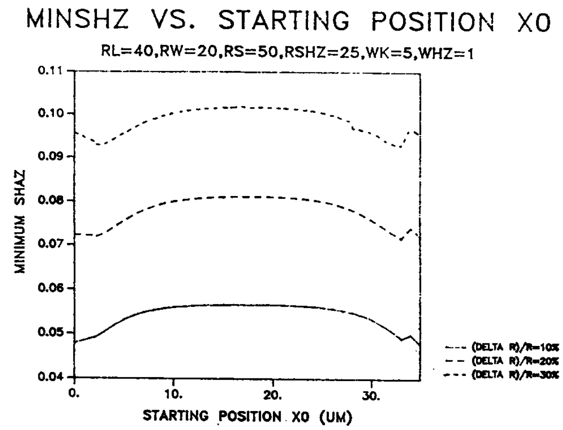

Fig. 5. **Dependence of minimum SHAZ with initial position (xinit). Each curve corresponds to fixed values of resistance change ΔR/R.**

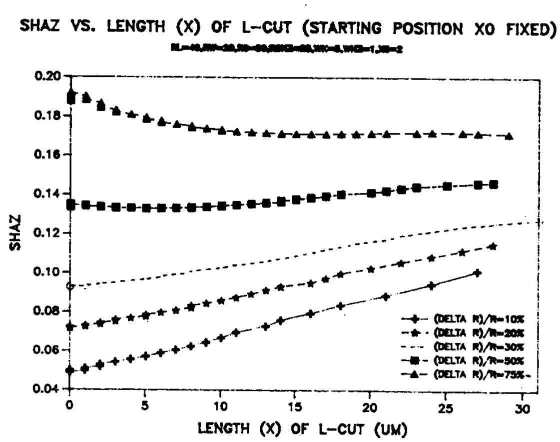

Fig. 4. **Dependence of minimum SHAZ with length of L-cut. Each curve corresponds to a fixed value of resistance change ΔR/R.**

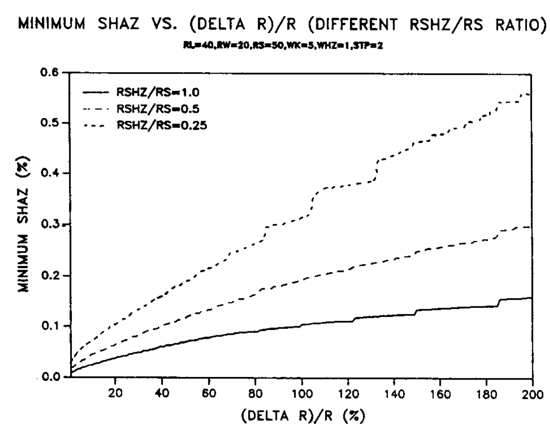

Fig. 6. **Dependence of minimum SHAZ with resistance change ΔR/R and with changes in sheet resistance of the heat affected zone. Each curve corresponds to a fixed value R_S^{HAZ}/R_S.**

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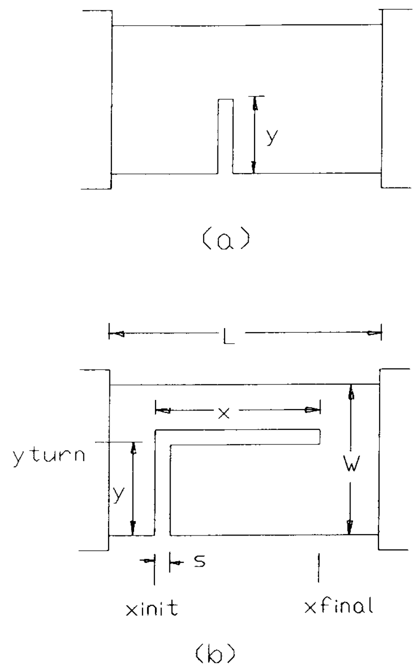

Fig. 1. (a) Plunge-cut of length y, (b) L-cut of height y and length x specified in terms of initial position (xinit), final position (xfinal), turnpoint (yturn) and trim step (s) assumed to be equal to width of trim-cut.

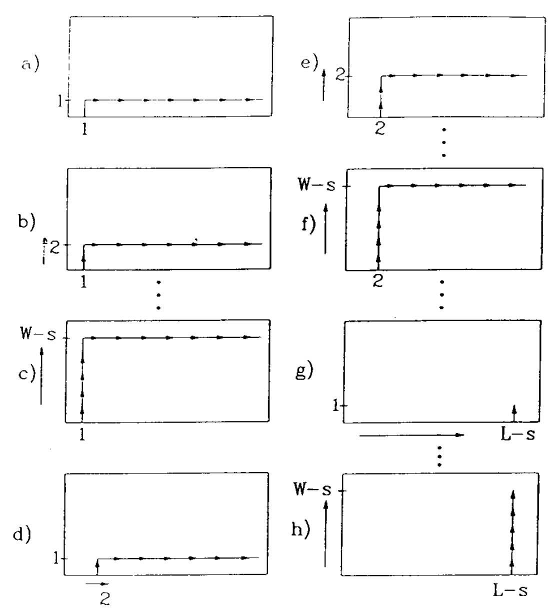

Fig. 2. Illustration of procedure to scan a rectangular film resistor with all possible trim-cuts.