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Implementation of Embedded Resistor Trimming for PWB Manufacturing

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Abstract

In the Printed Wiring Board (PWB) industry, the growing demand for a higher number of circuit components to be contained in smaller circuit areas requires that some of the passive components (resistors, capacitors, etc) are now embedded within the board. This allows for tighter component placement with lower via counts and has also increased the reliability of these devices.

For thick film resistors, the resistor paste for embedded resistors is screen-printed on the surface of the PWB laminate (either copper or dielectric) that is patterned according to the circuit design. Current technologies require wet paste that is oven cured after placement. This paste process results in a resistor with a tolerance of 20-50% from the target value. Thin film resistors deposited on the PWB also show variation in their values. Resistor trimming is required to bring this tolerance down to about 1-5% as required by the PWB design. This paper discusses the implementation of passive resistor trimming for large board manufacturing.

Introduction

Resistor trimming of thin film, thick film and chip resistors is a well-established technology. Most of the systems used for this type of trimming accommodate relatively small panel sizes, usually less that 10”x10”. New developments in PWB manufacturing require systems that can handle larger panel sizes and trim physically smaller resistors to tolerances of the order of 1% or better. The continuous demand to decrease the size of individual circuits has led to the development of technology that places discrete components on the internal layers of multilayer PWBs. These embedded components are usually placed on layers close to the core material because this part of the panel shows less distortion during the build-up process. The initial placement of these components takes place in the earlier stages of production of a PWB, at which point the components are on the top surface of the panel. Before the next lamination step, these components can be tested and trimmed. This paper discusses laser trimming of resistors that are to be embedded within a PWB panel.

Embedded Resistor Materials

Two major groups of materials are currently used for embedded resistors in PWBs. The first group comprises thin film resistors made from different metal-based alloys, which are deposited in one form or another on the board surface. The thickness of these resistors is usually less than 1 micron. The thickness of the resistive layer determines the sheet resistance of the material. The thinner the material, the higher will be sheet resistivity for any particular alloy. At present, for most of these thin film resistors the sheet resistivity usually falls within a range of 25 to 250 Ohms/square. Obviously, these thin materials require very careful handling during test, trimming and lamination. Typical materials include Ohmega-Ply® sheets from Ohmega Electronics[1]; Ni/Cr or Ni/Cr/Al/Si alloys from Gould Electronics [2] and Ni-P electroplated material from MacDermid Inc.[3].

In the second group, thick film resistors are formed from carbon or silver-filled epoxy pastes. According to processing instructions for DuPont materials[4], the thick film resistor paste is screen printed onto the copper foil at the proper locations prior to firing in an oven in N_2 atmosphere at 900ºC. After that the pre-printed copper foil is laminated to the dielectric layer of the board and the resistors are exposed through selective etching of the copper.

Somewhat different parameters are required for processing Asahi polymer-based pastes. This company offers several polymer thick film (PTF) paste compositions with sheet resistivity from 15 to 100 kOhm/square, with the printing and curing processes being adjusted for each paste type. The paste is printed at the resistor location directly onto pre-etched copper tracks and the dielectric core and the board are then fired in an oven for a relatively short period of time. The curing temperature varies widely from one material to another, with typical values ranging from 150ºC to 270ºC. As a result, if several paste compositions are used to produce the range of resistor values required for any particular layer, then several cycles of printing and firing are involved in resistor fabrication. During these cycles, one or several pastes will have more than one curing cycle, which makes the issue of predicting of the final values for these resistors quite complex.

Trimming Apparatus

For development of the embedded resistor trimming process, we used an internal PWB trimming system. This system incorporates the field-proven technology of a company based conventional trimming station into a panel handling system capable of processing much larger panels by means of a combination of X-Y table and galvanometer scanning techniques. This system is capable of handling panel sizes of 18"x24" or smaller and includes automatic recognition of fiducial marks on the panels and full alignment to them. Laser trimming is performed with Q-switched Nd:YAG laser operating at 1.064 microns, focused through a telecentric scan lens. The system uses a through-the-lens vision system that allows easy calibration of the scan field as well as X-Y table calibration. Most of the resistors studied were in the range of 30 Ohm to 200 kOhm, which permitted the use of the standard W670 measurement system. This system uses a four wire (full Kelvin) forced voltage current nulling bridge with wire pairs connected at the probe and only one probe in contact with the pad. This technique affords resistor measurement with an accuracy of better than 0.1%.

Trimming of Thin Film Resistors

Ohmega-Ply® thin film resistors are usually uniform in thickness and variations in resistance values are generally attributable to variations in the etching process during resistor exposure. They show a low thermal coefficient of resistance (TCR) and can therefore be trimmed at relatively high speeds. Because of the uniform thickness of the resistor sheet, it is possible to predict the cut length that will be required for any particular target value. A single plunge cut (Figure 1) will typically bring the resistor value to within ± 2% of the target value. An L-cut or double plunge cut is required if the tolerance value is to be better than 1%. No substrate damage or resistor heating was observed during the trimming process for this material.

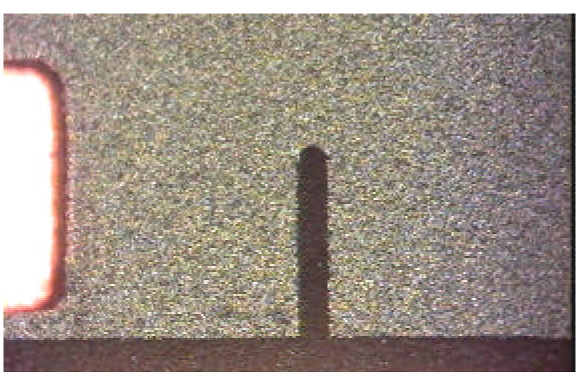

Figure 1 – Single Plunge Cut Laser Trim for Thin Film 50 Ohm Resistor

The low laser power used in processing thin film resistors means that variations in trimming speed do not affect the final value of the trimmed resistor. The width of the trimming cut can be controlled by changing process parameters and can be adjusted depending on the resistor size and other requirements.

A second type of thin film resistor material studied is the Ni-P thin film resistor, which may be deposited directly upon the PWB panel surface using a wet plating process. With this material, changing the power of the trimming laser will create cuts of different width without any degradation or discoloration of the resistor or substrate surfaces (Figure 2). Trimming with an L-cut (Figure 3) or double plunge cut gives a final resistor value within a 1% tolerance of the nominal target value.

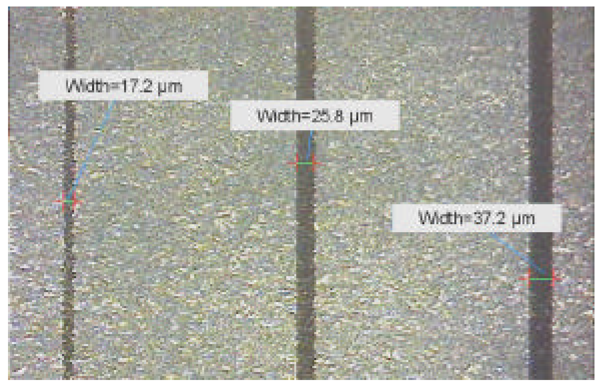

Figure 2 – Trim Cut Widths of 17µm, 26µm and 37µm on a Thin Film Resistor by Varying Laser Power

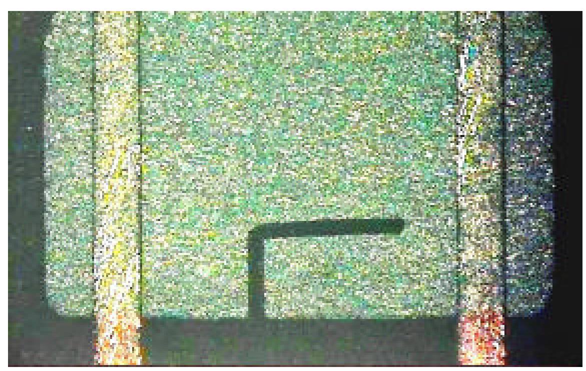

Figure 3 – Thin Film Resistor Laser Trimmed with an L-Cut

For a statistical evaluation of the trimming process, we used a panel with four standard test vehicle boards (MAC-1R) supplied by MacDermid. For the larger resistors sizes (20-55mil squares) we used L-cuts and for the smaller ones (5 and 10 mil squares) we used double plunge cuts. The initial and final distributions of the resistor values before and after trimming are shown in Figure 4 and Figure 5.

The presence of resistors with as-printed values very close to and even above the target value of 50 Ohms results in small tail on the positive side of the final test distribution. This tail is not present for areas on the panel where the printed resistor values are well below the target value.

Analysis of this data shows that the final distribution of the resistor values can depend on a number of factors. Among them are the initial distribution of resistor values, the type of trim cut selected, the trimming speed and the quality of the resistor deposition process.

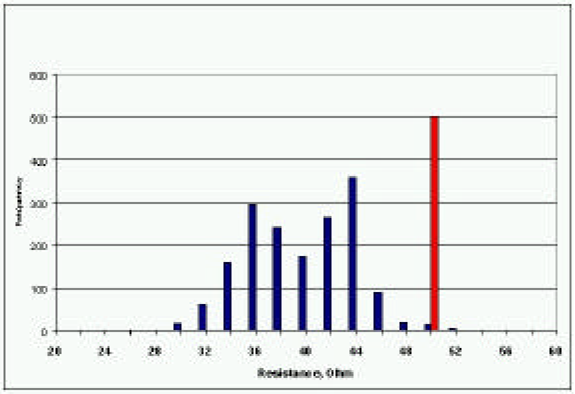

Figure 4 – Pre-Trim (Blue Bars) and Post-Trim (Red Bar) Values for Laser Trimmed Thin Film Resistors - the Target Value is 50 Ohms.

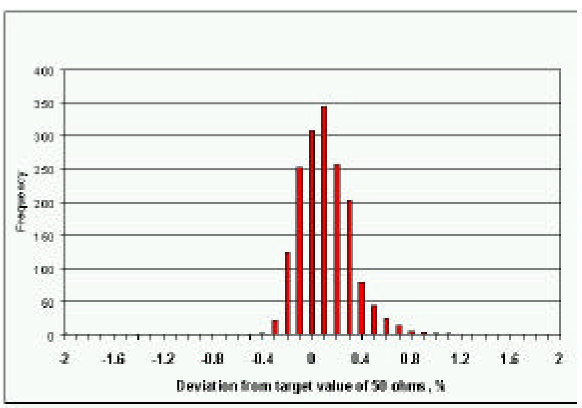

Figure 5 – Expanded View of the Final Distribution of Resistor Values after Trimming

Trimming of Thick Film Resistors

The thick film resistors used in this evaluation were made by screen printing and firing PTF paste. The thickness of these polymer-carbon resistive pastes ranged between 15 - 25 microns. After curing, the resistor profile is not uniform but is thinner at the edges and thicker in the central part of the resistor. The profile is also different for short and long resistors, even when made from paste of the same composition. Obviously, these thickness variations in the resistor paste will present a challenge to selecting laser parameters that will ensure good quality of all trims. Figure 6 and Figure 7 show typical trims in thick film resistors.

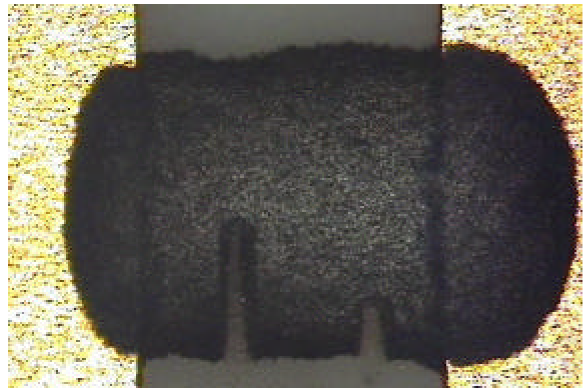

Figure 6 – Thick Film Resistor with Double Plunge Cut

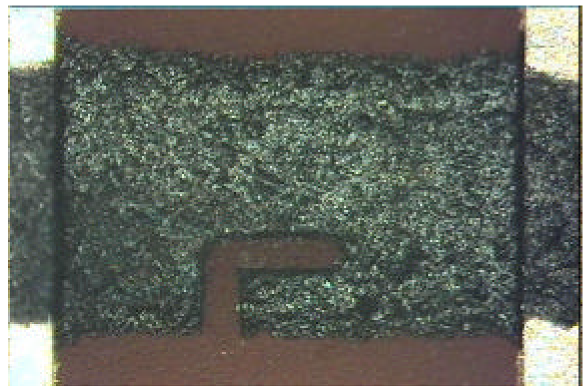

Figure 7 - PTF Resistor Trimmed with L-Cut

The variability of resistor thickness and shape as well as material density variations are clearly visible on these two examples. In general, for these thick film resistors the average laser power required for trimming is several times higher than that needed for thin metal alloy resistors. Despite the higher laser power used, no damage to the resistor material outside the cut or to the dielectric substrate was observed.

For an average sized resistor, the profile between the copper traces with the laser cut is shown in Figure 8.

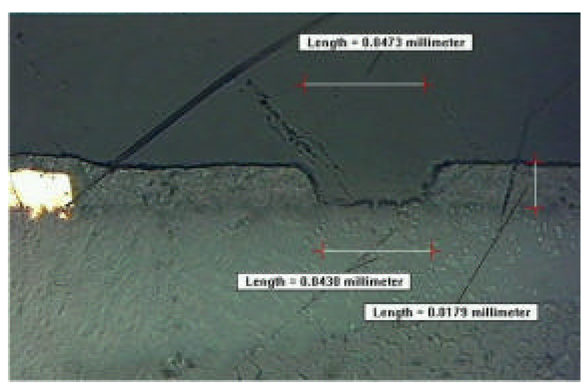

Figure 8 – Cross-Sectional View of the Laser Trim Cut in a PTF Resistor

During their short curing cycle, thick film resistors undergo pressure and temperature-induced shock. This has the potential to cause the build up of stresses in both the resistor material and substrate. It is therefore a concern that the rapid deposition of laser energy during the trimming process can relieve these stresses and cause delamination and/or micro cracking, both of which would lower the reliability of the final device and circuit. We performed SEM analyses of PTF resistors before and after laser trimming and prior to their subsequent lamination. The analysis shows that the micro-crack density is very low in both cases and does not change as a result of trimming. No delamination was observed even at the highest trimming speed. There is no damage to the dielectric substrate as a result of the trimming process, as can be seen from Figure 9.

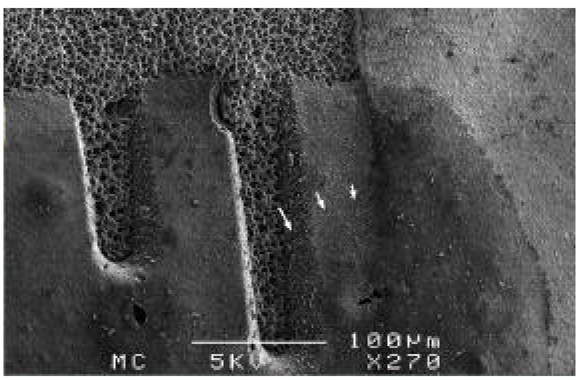

Figure 9 – Scanning Electron Microscope (SEM) Image of Laser-Trimmed PTF Resistor

Trimming these thick film resistors at different speeds demonstrated that different paste compositions show different thermal responses to the laser deposited heat. Pastes with high sheet resistivity (100 kOhm/square and up) proved very sensitive to heat deposition and special care is required to avoid resistor heating during the trimming process. The density variations of high resistivity pastes also poses a problem.

The PTF datasheets for high resistivity pastes show that, due to their lower carbon content, the TCR values for 100-kOhm/square pastes are ±500ppm/ºC, twice the TCR value for 100 Ohm/square paste. This results in increased edge heating effects for the high resistivity materials at faster trimming speeds. This effect may clearly be seen in Figure 10 and Figure 11. They illustrate the distributions of final resistor values for single plunge cut trims, first for low resistivity and then for high resistivity pastes. However, in both cases, the addition of a second plunge cut (or the use of an L-cut) will bring the post-trim final resistor value to within 1% of the target value, with a distribution of values similar to that of Figure 5.

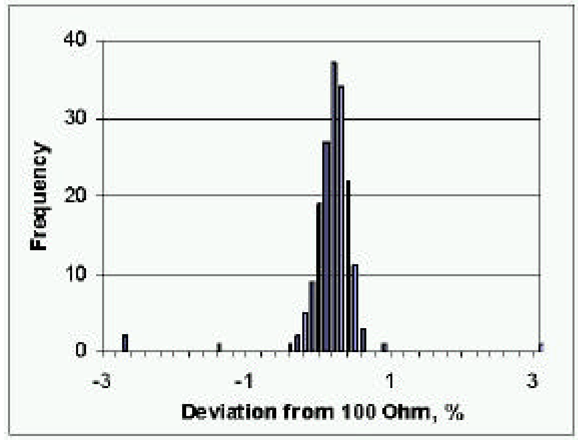

Figure 10 – Trimming Results for Single Plunge Cut on Low Sheet Resistivity Paste

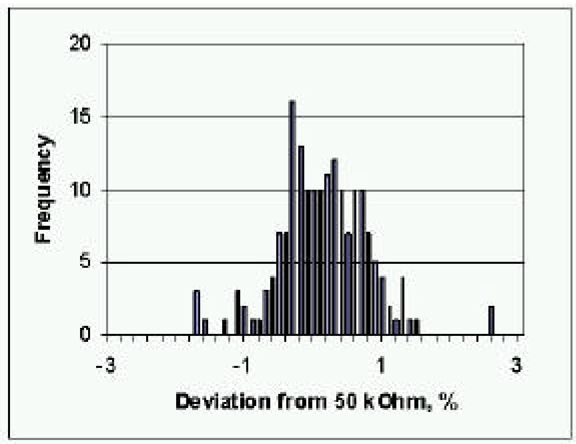

Figure 11 – Final Values Distribution for a Single Plunge Cut on the Paste with High Sheet Resistivity

Discussion

Recent improvements in the screen-printing and curing processes for PTF resistors have resulted in a smaller variation of the "as-printed" resistor values prior to trimming. Locally, within a PWB panel, the spread of resistor values can be as low as 3% from the mean value, which may be acceptable for some applications. However, across the full 18"x24'' panel the spread of the mean value itself results in total variation of more than 5%. The local spread of the resistor values results from variations in resistor shape, local distortions of the substrate dielectric, density variations of the paste, etc. Additional spread in resistor values also comes from the screen-printing process and thermal distortion of the panels during the resistor firing cycle. Screening effects can change the average thickness of the resistors from one side of the panel to the other, which in turn will change the local mean resistor value. The distribution of these mean values varies from one paste to another, as can be seen in Figure 12 and 13, because these pastes are printed with different screen masks and cured in different cycles.

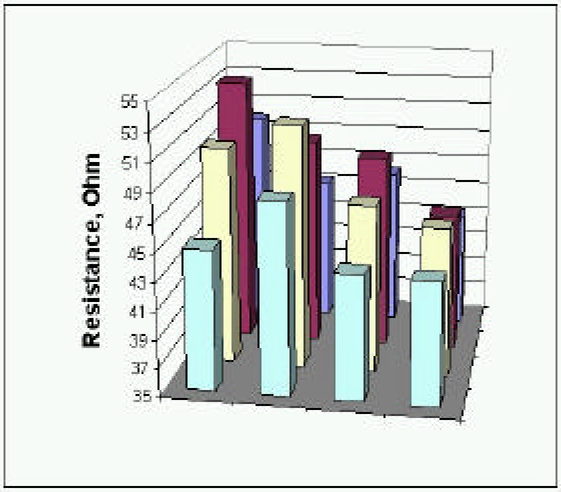

Figure 12 – Distribution of Resistor Means Values Across 18x24" Panel for Resistors of Paste 'A' before Trimming

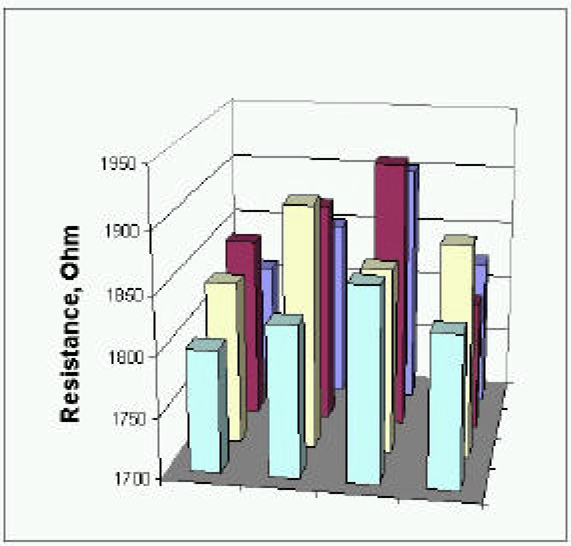

Figure 13 – Distribution of resistor Mean Values Across 18x24" Panel for Resistors of Paste B before Trimming

In order that trimming can be effected, it is necessary that the initial resistor values be designed so that, after the printing and firing process steps, all the resistor values for the entire panel fall below the target value. This will ensure that all resistors can be trimmed to the target value. In a panel meeting this criterion, a typical distribution of untrimmed resistor values with a preferred offset from the post-trim target value is shown in Figure14.

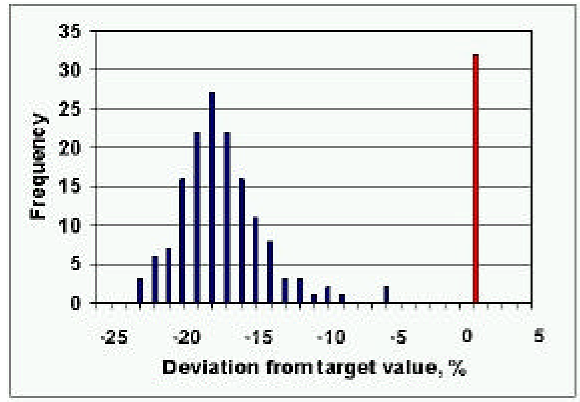

Figure 14 – Distribution of Printed Resistor Values before Trimming (Black) and after Trimming (Red) Relative to the Target Value

The offset between the printed values and the target value is an important parameter, not only from the trimming point of view, but also from the perspective of the power handling performance of the final product. There are optimum trim types and trim lengths that yield precise trimming. However, the final trim configuration must also satisfy the power handling requirements for the resistor. Correct selection of these parameters is required to ensure that, post trimming, the current density in the untrimmed region of the resistor is low enough that it will not result in excessive heating from the current flow required for normal operation. If the offset from the "as-screened" value is too small, some of the resistors will be above the target values, which will decrease the total yield of the process. If the offset is too high, the amount of trimming required increases and the limitation on the current path after trimming becomes more severe. For large offsets (more than 40% from the target value) the resistivity has to be changed substantially which can require long cuts and narrow untrimmed areas, which result in hot spots. The operational reliability of such resistors will decrease. Most of the PTF resistors have non-uniform profiles that change across a large panel. The larger value of the TCR for thick film resistors can also contribute to this problem. Even when trimming conditions that result in accurate resistor values have been established, functional testing is essential to ensure good circuit reliability.

Because several printing and curing cycles are used in the multi-paste process, the final position of the resistor is affected by the print registration accuracy and by distortion of the panel during the preceding curing cycles. The observed positions of the paste do not have a constant offset from the copper traces, but vary across the board. For example, the shrinkage factor of ±20ppm on a 24" panel will result in about 25 microns offset from the expected position. This offset is quite large in comparison with the 300µm width of the resistors and the 100µm wide copper traces. As a result of these distortions, in addition to the initial alignment to the panel fiducial marks, a more localised alignment may well be necessary for precise placement of laser trims. Usually the starting point of the laser trim cut is positioned outside the resistor paste area. This ensures that trimming starts at the edge of the resistor, not inside it, and therefore allows for small variations in the resistor paste position.

Other factors also require that provision be made for localised alignment. Variation in circuit positions due to panel distortion also affects the probing of the resistors. In case of a fixed probe card, the position of each probe is determined by the circuit layout, which is usually taken from a fixed position in the CAD file. The size of the probe tip will typically vary from 25 to 250µm. However, even in the case of the 250-µm probe tip size, the actual contact area is usually less than 50 µm. In the setup of these probes, provision is made for the probe tip to slide a certain distance, usually between 50 and 150 microns, across the pad. This sliding is necessary to ensure a reliable contact between the small area of the probe tip and the pad. Depending on the pad sizes and the panel distortion, the probe tip could slide off the pad or even miss the pad entirely. Pad sizes and probe types must be chosen correctly to allow for panel distortion.

Conclusions

Trimming of embedded resistors on large PWB boards raises a number of specific issues not addressed by the crop of well-established trimmer systems currently available on the market. For thin film resistors, variations in the position and thickness of the resistors come from the deposition or etching process. For thick film resistors formed from different polymer pastes, these variations come from panel distortion and screen-printing errors that are associated with the process. All these problems are more evident for large size panels of 18”x24” than for smaller substrates (mostly ceramic) currently used for trimmed resistors. As a result, several correction techniques have to be used in order to ensure correct trimming of all resistors. Four corner fiducials with known stretch factors can be used for relatively uniform distortions. In other cases, a local alignment technique has to be used, particularly if the resistor and probe pad sizes are smaller than 200 microns. The accuracy of circuit placement is also important for the fixed probe card, which requires sliding action of the probe tip, which can be up to 150 microns.

We have shown that trimming of both thick and thin film embedded resistors can be achieved with better than 1% accuracy and no substrate damage. However, the final spread of resistor values and device performance can be evaluated only after the complete lamination process. Design rules like trim cut placements relative to the copper pads, percentage of area allowed for trimming, trim geometry selection, speed etc. are all very important for further development of trimming techniques appropriate to PWB manufacturing.

Acknowledgement

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References

1. Glen Walther, *Tolerance analysis of Ohmega-Ply resistors in multilayer PWB design*, CircuiTree Magazine, March 2001, p 64.
2. Jiangtao Wang and Sid Clouser, *Thin film embedded resistors*, IPC Printed Circuit EXPO2001. 2001, S08-1-5.
3. Joe D’Ambrisi, Dennis Fritz and Dave Sawoska, *Plated embedded resistors for high-speed circuit applications*, IPC Annual Meeting, October 2001, S02-1-4.
4. William J. Borland and Saul Ferguson, *Embedded passive components*, CircuiTree Magazine, March 2001, p. 94-106.