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Effect of Pulse Voltage Trimming On Different Characteristics of Polymer thick film Resistors

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Abstract

In this work we study in more details the impact of pulse voltage trimming on different characteristics of thick film resistors based on (PVC-Graphite) resistor compositions. This study focuses on the change of resistivity, thermal coefficient of resistance and current noise. In order to realize a non cut trimming without damage to the resistor surface of thick film resistors for electronic devices, a pulse voltage trimming method (PVTM) has been developed. This trimming method having resistance adjustments are due to pulse peak voltage and the number of pulse group. TCR and current noise of trimmed resistors are considerably improved by this trimming technique in the case of higher resistivity materials and worsen in the case of lower resistivity materials and there is no loss in power handling capacity of trimmed resistors. We propose a description of pulse voltage trimming which can explain the observed changes in characteristics of the samples.

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Key words: polymer thick film resistors, pulse voltagse trimming method (PVTM), resistivity, TCR, Current noise

1. Introduction

In the production of sensitive and reliable up-to-date communication systems stability and precise resistance values widely utilized conventional thick film resistors are of great importance. In general, the susceptibility to high voltage pulses and electrostatic discharges is very important, Constantin J-P et.al (1982), Dziedzic A (2002) and

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Seager CH, et.al (1976) have been investigated for thick film resistors for almost 30 years. Such investigations can be performed with the aid of single rectangular pulses. R.P.Himmel (1971) had been applied high voltage trimming so far to frit glass based thick film resistors and achieved downward trimming in higher resistivity materials and upward trimming in lower resistivity materials. Currently, polymer based pastes are used to fabricate resistors for economical reasons. K.S.R.C.Murthy et.al (1984, 1987) and Y.Srinivasa Rao (2007) have trimmed these polymer resistors by abrasive or laser trimming. The possibility of trimming these resistors by using High Voltage pluses has been investigated in this work. The following section describes the results obtained from these investigations.

2. Pulse Voltage Trimming Method (PVTM):

2.1. Resistor Processing

Polymer paste containing PVC and graphite has been prepared by first dissolving PVC and then blending graphite in to it. The graphite powder (average grain size: 40 to 70 microns) is prepared from a graphite block, supplied by Graphite India Limited, Bangalore, with electrical conductivity of $0.33*10e^5$mho/cm. The PVC powder is supplied by Calico Chemicals Limited, Bangalore and has a density of 1.33 mg/m^3.This paste has been used for printing resistors on PVC substrates with a screen printer. These printed resistors are processed using the usual thick film processing of polymer based films. The heat treatment involves drying at room temperature for 15 minutes, followed by curing at 100^0C for four hours. The thickness of the cured samples is found to be in the range of 40 to 150 microns.

2.2Trimming Procedure

The setup is used for the pulse voltage trimming method for the resistors are very simple as shown in Figure.1. A capacitor is charged to given high voltage (220V to 300 V in our experiment) and then discharged through the resistor to be trimmed. 30 pulses were made for each sample and the evolution of the resistance was monitored. The trimming process involves exposing the entire resistor surface for short periods. It is found that the value of resistance decreases in the case of high resistivity polymer resistors and the value of resistance increases in the case of lower resistivity polymer resistors in each cycle of exposure to pulse voltages.

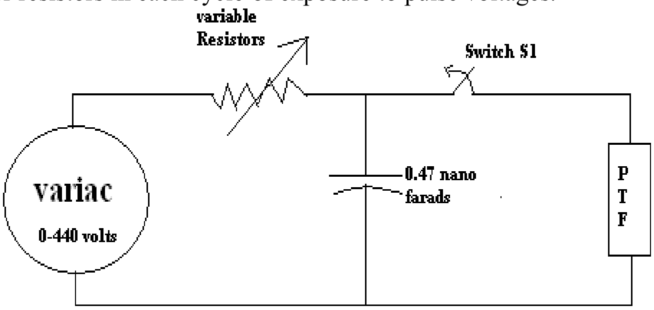
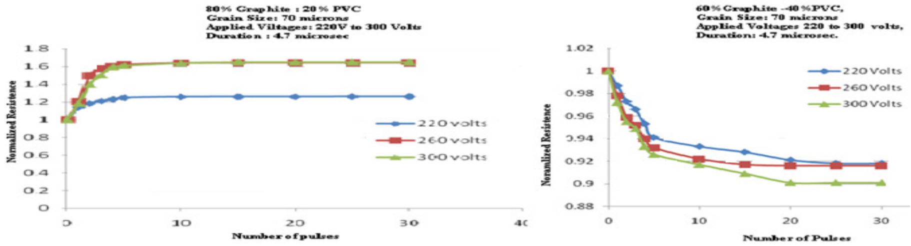


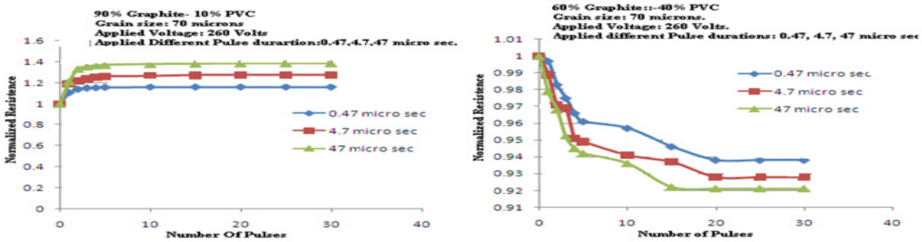
Fig.1. Pulse Voltage test circuit.

It is also found that the value of resistor decreases in the case of high resistivity materials and the value of resistors increases in the case of low resistivity materials with increase in pulse voltage applied, with different pulse amplitudes and with different compositions as shown in Figures.2-3.



(a) (b)

Fig.2. Variation of Normalised Resistance with number of pulses for different pulse voltages. a).Lower resistivities, b) Higher resistivities



(a) (b)

Fig.3. Variation of Normalised Resistance with number of pulses for different pulse Durations. a) Lower Resistivities. b) Higher resistivities

From these Figures, it can be seen that the resistance changes very rapidly in the initial stages and tends to saturate in the later portions of the curves. This behavior is observed in resistors prepared with different compositions. It appears that the factors responsible for the change in resistance are closely connected with the change in temperature.

2.3. Current Noise Index Measurements

The Quan Tech Model 315 Resistor Noise Meter available in LEO’s laboratory of ISRO, Bangalore is used to measure the current noise index of polymer thick film resistors in decibels (dB). The current noise index is defined as the ratio of RMS noise voltage in microvolts to the applied DC voltage in volts, expressed as decibels, when the bandwidth of measurement is 1 KHz and its frequency is geometrically centered at 1 KHz. In the Quan-Tech Noise Meter, the noise index can be measured with these parameters under varied conditions of current. The noise index of each resistor is measured by varying the voltage across the resistors (current through the resistor). The resistors on which measurements are carried out are prepared with 10%, 20%, 30% and 40% of PVC. Typical current noise index measurements are given in Table.1.

Table.1: Typical current noise index measurements with microwave trimming method
Grain Size = 45 Microns
Composition by weight: Graphite: 90% : PVC :10%
Resistor Dimensions: Length: 8mm, Width: 2mm

Percentage change in resistance Due to Microwave Trimming	Current Noise Index (dB)
0	24.8
5	25.2
10	25.3
20	26.6
30	33.7

The current noise index of untrimmed and trimmed resistors is measured using Quan-Tech Noise Meter. These measurements are carried out for various material parameters such as composition, grain size and various pulse parameters such as powers and pulse duration and pulse repetition frequency of microwave radiation. A typical graph is shown in Figure.4

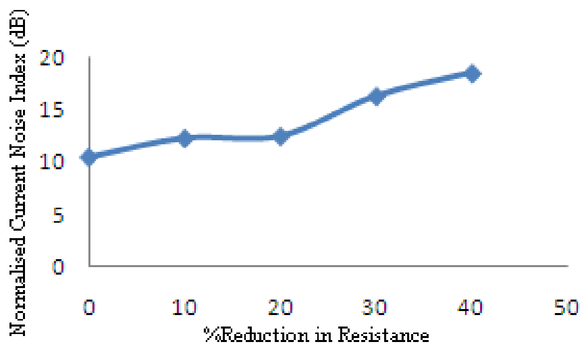


Fig.4. CNI versus percentage reduction in resistance of Polymer Thick Film Resistors (Graphite 60%: PVC 40%).

2.4. TCR Measurements

Temperature coefficient of resistances of polymer thick film resistors are measured as follows. The resistors kept in temperature controlled ovens and the resistances of these resistors are measure by using Fluke Multimeter Model 8842A at room and 50^0C. These measurements are carried out on different PVC-graphite compositions.

Table.2: Variation of TCR with Percentage Change in Resistance of Polymer Thick Film Resistors due to Microwave Trimming.
Grain Size = 45 Microns
Composition by weight: Graphite: 80%: PVC: 20%
Resistor Dimensions: Length: 8mm: Width 4mm

Percentage change in resistance Due to Microwave Trimming	Temperature Coefficient of Resistance ppM/0C (*10e3)
0	31.37
10	22.64
20	20.39
30	15.38

Table.2 gives the temperature coefficient of resistance for untrimmed resistors and 10%, 20%, 30% reduction in resistance of trimmed resistors for graphite (80%:20%) thick film resistors.

3. Electrical Properties of Trimmed Resistors

3.1. Current Noise Index

Current noise index of polymer thick film resistors decreases in case of higher resistivity materials and increases in case of lower resistivity materials with the application of high voltage pulses to them. The decrease or increase in current noise index is found to depend on various material parameters such as composition, grain size and various pulse voltages parameters like different applied voltages, pulse duration and the pulse repetition frequency.

(B) Effect of Material Parameters

The change in current noise index of polymer thick film resistors with the application of high voltage pulses is measured for different compositions of Graphite (60 to 90%) and PVC (10 to 40%). The current noise index versus percentage resistance change due to pulse voltage trimming for resistors with different compositions.

It can be observe that the resistors with higher resistivity are having higher changes in current noise index and also decreased in nature. The changes in current noise index of polymer thick film resistors of different conductor grains (45 to 70 microns) with the application of high voltage pulses are also measured. The resistors prepared with paste containing longer size of conductor grains have higher changes in current noise index with pulse voltage trimming compared to resistors prepared with pastes containing of smaller size of conducting grains.

(C) Effects of Pulse Parameters

The change in normalized current noise index with different pulse amplitudes and different pulse duration has been measured with different number of pulses. The normalized current noise index decreases with an increase in the different pulse amplitudes in the case of higher resistivity materials and the normalized current noise index increases with an increase in different pulse amplitudes in the case of lower resistivity materials, when the pulse amplitudes is greater than the threshold value.

The normalized current noise index decreases with pulse duration with an increase in the voltage of the Pulse amplitude in the case of higher resistivity materials and the normalized current noise index increases with pulse duration with an increase in the voltage of the Pulse amplitude in the case of lower resistivity materials, when the Pulse amplitude is greater than the threshold value.

From all these observations, it may be concluded that the current noise index of polymer thick film resistors decreases in the case of higher resistivity materials and increases in the case of lower resistivity materials with the application of pulse voltage, when the Pulse amplitude is above a certain threshold value. Based on these observations, one may conclude that the changes in current noise index depends on the pulse amplitude, the total duration for which pulse amplitude is applied either through the variation of pulse duration or number of pulses.

3.2. Temperature Coefficient of Resistance

In order to obtain the temperature coefficient of resistance of the samples, the resistance has been measured at two temperatures namely 25^0C and 50^0C and the average temperature coefficient of resistance has been calculated using the formula.

$$TCR = (R_{50} - R_{25}) / (R_{25} * (T_{50}-T_{25})$$

The calculations have been carried out on samples prepared with different compositions of PVC and graphite with a grain size of 45 microns. The range of compositions covered is graphite: 60%: PVC 40% to graphite 90%: PVC 10%. TCR has been measured for both on untrimmed and trimmed resistors with different compositions. The measured temperature coefficient of resistances for different resistors is given in Table.3.

Table.3: TCRs of different compositions of untrimmed and trimmed resistors.

Composition by Weight Graphite: PVC	TCR in PPM/0C (*10e-3) Percentage Reduction in Resistance with Trimming			
	0%	10%	20%	30%
60% : 40%	0.137	0.040	0.040	0.038
70% :30%	0.237	0.123	0.121	0.119
80%: 20%	1.801	2.304	4.523	6.234
90%:10%	3.93	5.013	7.876	10.43

From the Table.3, it may be seems that temperature coefficient of resistance is found to be positive for all polymer thick film resistors before and after pulse voltage trimming when the composition is varied from graphite 60%: PVC 40% to graphite 90%: PVC 10%. It is found that Temperature coefficient of resistance depends on the original composition and as well as the extent of trimming. When the composition is graphite 60%: PVC 40% and graphite 70%: PVC 30%, it is found that the temperature to along with original value.

Pulse voltage trimming closes the open chains around the cavities in the case of higher resistivity materials and breaks the closed chains around the cavities in the case of lower resistivity materials that are present in the polymer thick film resistors, the effective change in resistance has been explained through the change in effective cavity diameter. When the temperature is varied to a higher value, two types of phenomena's seems to be occurring in the material i.e. the insulator (polymer) in the cavity expands and this is equivalent to increase in cavity diameter. From the earlier discussion, increase in cavity diameter increases the resistance. The increase in resistance at higher diameter is more than with the lower diameter. After trimming, since the diameter is small or large, one than that of the resistance without trimming. This is the case, when the percentage of composition is lower (number of chains involved in trimming process is limited). As the percentage of graphite increases and also the diameter of the cavities decreases. This results in decrease in resistance with increase in composition. When temperature is increased the diameter increases and some of the closed chains open. Both these effects result in positive temperature coefficient of resistance. At higher graphite content, even though the change in diameter does not contribute much to the value of temperature coefficient of resistance, the breakage of chains decides the value of temperature coefficient of resistance. However at lower graphite percentages (60 to 70%) the change in diameter as well as the breaking of chains contribute to temperature coefficient of resistance.

3.3. TCR of Trimmed Resistor

The pulse voltage trimming closes some of the open chains around the cavities and also reduces the diameter of the cavity. The effect due to opening of chains with increase in temperature should increase with increase in number of closed chains or increase in trimming. This may be seen to be true from table except for graphite content less than 70% for the first trim of 10%. This can be understood as follows: for the case of lower graphite content the diameter is sufficiently large and it gets reduced by a large amount after trimming. The contribution due to increase in diameter to TCR in the case of untrimmed resistors. Further, this component of TCR seems to be dominant factor compared to increase in TCR due to breakage of conducting chains. Hence after the first trim the TCR decreases. After the 10% trim the situation is similar to the higher graphite case and TCR increase percentage of trimming.

4. Discussion

It is well known that polymer films contains a large number of cavities and start shrinking when the polymer is subjected to a temperature which is above the glass transition temperature. The rates of cavity shrinkages are reported to depend on the viscosity and the surface tension of the polymer film at that temperature. As the cavity size decreases with time, the effective cross-section for the current flow increases and the resistance decreases. This is the basic mechanism when the polymer thick film resistors are exposed to pulse amplitude, which results only downward trimming of polymer thick film resistors which was described by T. Badri Narayana et.al 1992) in their work.

When high voltages are applied to polymer thick film resistors, a different type of conduction mechanism is responsible for downward trimming of polymer thick film resistors. When high voltages are applied, the dielectrophortic forces arises between the two conducting graphite particles due to applied electric field, which is responsible for decrease in resistance of polymer thick film resistors with high voltages which was described by Y.Srinivasa Rao (1997) in their work.

When polymer based thick film resistors are subjected to high voltage pulses, some of the open conducting chains close resulting in decrease in resistance of high resistivity materials and some of the closed conducting chains breaks resulting an increase in resistance of lower resistivity materials. The decrease or increase in resistance of the material is responsible for the decrease or increase in current noise index of polymer thick film resistors. When the percentage of graphite content in PVC- graphite composition decreases, the reduction in resistance of polymer thick film resistors increase with pulse voltage trimming. Similarly the decrease in particle size of graphite results in decrease in resistance change with pulse voltage trimming. When the applied pulse amplitude or pulse duration increases, the decrease or increase in resistance with pulse voltage trimming also increases, which results more decrease or increase in current noise of polymer thick film resistors.

5. Conclusions

A new trimming technology using pulse voltage trimming (PVTM) has been developed for polymer thick film resistors. The following conclusions have been made:

1. This trimming produces structural changes throughout the body of the resistors unlike in other trimming techniques.
2. The effect of pulse voltage trimming on important electrical characteristics of polymer thick film resistors namely current noise and temperature coefficient of resistance has been investigated. It s found that the current noise decrease in the case of high resistivity materials and the current noise increases in the case of lower resistivity materials after trimming and this feature has been attributed to decrease or increase in resistance after trimming. It is also observed that the decrease or increase in current noise with pulse voltage trimming depends on various material parameters like composition, grain size of the graphite and various pulse parameters such as pulse amplitude, pulse duration and pulse repetition frequency.
3. It has been found that temperature coefficient of resistance is positive and decrease in resistors prepared with pastes containing lower graphite contents. This has been attributed to the formation of more conducting chains after trimming. However the resistors prepared with paste containing higher graphite content show an increase in temperature coefficient of resistance after trimming and this perhaps is due to breakage of some of the closed chains with an increase in temperature.

As a result, this trimming method modified the conductive structure and has brought about an increase or decrease in the number of conductive paths in the polymer thick film resistors

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References

A V Prathap Kumar Y. Srinivasa Rao 2009. Conduction Mechanism in 'Polymer Thick Film Resistors" International Journal of Emerging Technologies and Applications in Engineering, Technology and Sciences (IJ-ETA-ETS), vol.2, Issue.2, pp.128-131.

Buechler P R, Encyclopedia of Polymer Science and Technology, vol.13, eds: HF Mark, N.G Gaylord and NM Bikales (Newyork) p.489.

C.A.Harper (ed), 1974. Hand Book on Thick Film Hybrid Microeelctronics, Baltimore, Maryland (Mcgraw-Hill, Newyork) pp.6-42.

Constantin J-P, Moulin M, Ranger J-B. Effect of surge voltages on thin and thick film resistors. In: proc 2nd int microelectronics conf. ISHM-Japan, 1982.p.51-5.

Dziedzic A. "Electrical and structural investigations in reliability characterization of modern passives and passive integrated components". Microelectronics Reliab 2002;42;709-19.

K.S.R.C. Murthy, K. Ram Kumar and M.Satyam,1984. "Electrical properties of PVC- Graphite Thick Films," Journal of Material Science Letters, vol.3, pp.813-816.

K.S.R.C. Murthy and M.Satyam,1987. "Trimming Studies On Polymer Thick Film Resistors," Journal of Material Science, vol.22 pp.1413-1418.

R. P. Himmel.1971." Thick Film Resistor Adjustment by High Voltage Discharges" Proceedings of Electronic Component Conference (ECC), IEEE, pp.504-512.

Shuheinakanura, Atsushi Ito, Hikaru Kato, Sachio Ogasawara and Goro Sawa, 1987. "Temperature Dependence of Electrical Conduction in Carbon – Epoxy Resin Resistor," Journal of Electronics and Communications in Japan, Part 2, vol.70, No.10, pp.103-114.

Seager CH, Pike GE. Electrical field induced change in thick film resistors. In Proc int Microelectronics symp, ISHM- USA, 1976.p. 115-22.

Saitoh Y, Katsuta Y, Suzuki K, Effect of surge voltages on thick film resistors. In: Proc int microelectronics symp, ISHM-USA, 1979.p. 289-94.

T. Badrinarayana, K. Ramkumar and M. Satyam, 1992. "Mechanism for downward Trimming of Polymer resistors," Journal of Physics D : Applied Physics, vol.25,pp.717-721.

Y. SrinivasaRao and M.Satyam, 1997. "The effect of high voltage pulseson PVC-Graphite Thick film resistors", The International journal of Microcircuits and Electronic Packaging, pp.51-56, vol.20, no.1, 5th quarter.
Y. SrinivasaRao and M.Satyam, 2001. "Downward trimming of polymer thick film resistors through high voltage pulse" The International journal of Microcircuits and Electronic Packaging, PP. 338-404, vol. 24, nov,4rth quarter.
Y. SrinivasaRao,2007. "Studies on Electrical Properties of Polymer Thick Film Resistors", Microelectronics International,Vol.24, Issue.1,pp.8-14.
Y. SrinivasaRao,, 2008. "Studies on Temperature Coefficient of Resistance (TCR) of Polymer Thick Film Resistors," Microelectronics International, Vol.25, Issue.3,pp.33-36.