

New Materials and Method for Laser Trimmable NTC Thermistors

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Abstract

Standard thick film NTC thermistors provide a number of advantages over discrete thermistors, including low physical profile, ease of integration, and economy. However, they are inferior with respect to temperature sensitivity, particularly at low ohmic values, and it is not practical to obtain tight resistance distribution by laser trimming. This paper introduces a new series of thick film pastes, which are capable of producing NTC effects when they are printed and fired between two parallel plates, the same way that thick film capacitors are fabricated. Built in this manner, the new materials provide Beta coefficients that are 40% to 300% higher than those of standard thick film thermistors with comparable resistance value. It is in particular much easier to produce low ohm thermistors with high Beta in small areas, a feature that is very useful in building temperature compensated microwave attenuators. It is also much easier to incrementally laser trim these thermistors by cutting a portion of the termination.

Key Words: Thermistor, Microwave, Attenuator, NTC, Beta, TCR, Planar, Stacked

Introduction

Thick film NTC thermistors are used in a variety of temperature sensing and compensation applications, e.g. in microwave attenuators. Attenuators are used in applications that require signal level control. Level control can be accomplished by either reflecting a portion of the input signal back to its source or by absorbing some of the signal in the attenuator itself. The mismatch, which results from using a reflective attenuator, can create problems for other devices in the system, such as nonsymmetrical two-port amplifiers. It is for this reason that absorptive attenuators are more

popular, particularly in microwave applications. The important parameters of an absorptive attenuator are: attenuation as a function of frequency; return loss; and stability over time and temperature.

It is known that variations in temperature can affect various component parts of a microwave system, causing differences in signal strengths at different temperatures. In many cases, it is impossible or impractical to remove the temperature variations in some Radio Frequency (RF) components. For example, the gain of many RF amplifiers is temperature dependent. In order to build a system with constant gain, a

temperature-dependent attenuator is placed in series with the amplifier. The attenuator is designed such that a temperature change which causes the gain of the amplifier to increase, will simultaneously cause the attenuation of the attenuator to increase such that the overall gain of the amplifier-attenuator system remains relatively constant.

EMC Technology has patented technology to construct attenuators that exhibit this temperature compensating behavior utilizing positive temperature coefficient thermistor (PTC) materials in conjunction with negative temperature coefficient thermistor (NTC) materials. High shifting thick film NTC thermistor materials have existed for a long time, but the high resistance of such materials made them impractical to use for high frequency attenuators because the overall part size (less than 125 mils square) restricted the size aspect of the thermistor that could be screen printed. With a novel technique for constructing the thermistors and newly developed materials introduced in this paper, attenuators can be fabricated that will increase the amount of change over temperature and still maintain excellent electrical properties at higher frequencies.

Standard thick film thermistors are usually printed much the same way as thick film resistors, i.e., a *planar* configuration with the resistor or thermistor bridging the gap between two printed termination pads. The authors have devised a novel *stacked* approach to NTC thermistor fabrication, involving the bridging of the gap between two parallel plates with the thermistor, the same way that thick film capacitors are constructed¹. Further, one or both plates may be made of a series of finely spaced lines connected at one end, similar to a hair comb, rather than solid pads (see schematics and pictures). This allows *incremental* trimming of the thermistor by severing predetermined numbers of lines using a laser, once the as-fired resistance is measured. The incremental trimming concept can also be applied to standard planar thermistors. However, it further reduces the range on the low resistivity end, since a portion of the termination would be taken up by

spaces which do not contribute to electrical conduction.

The new approach to NTC thermistor fabrication requires completely new materials, as the average electrical path through the thermistor is reduced, from mils in the planar configurations, to microns in the stacked configuration. A range of thermistor and electrode metallization compositions are introduced by KOARTAN. The new system allows the fabrication of stacked thermistors with at least 40% higher Beta constant than their planar counterparts of the same resistance. The improvement is much more pronounced at lower resistance ranges, which are of particular interest in the microwave application discussed.

Experimental

Since in the stacked configuration electrical conduction is in the Z direction, the concept of sheet resistivity no longer applies. It would be useful if the thermistor formula^{2,3} would be expanded to take into account thermistor thickness and termination or electrode area, as well. The area effect is fairly straight forward to take into account; data on this aspect will be shown in this paper. But determining the thickness effect was not within the scope of the current work, since it is not linear and it may itself depend on material aspects of the thermistor. In this work all major characterizations were performed on 0.040" x 0.040" pads, with similar construction as shown in schematic figure 1, with an average fired thickness of 40 microns. Laser trimming was also performed in a construction similar to that of schematic figure 2.

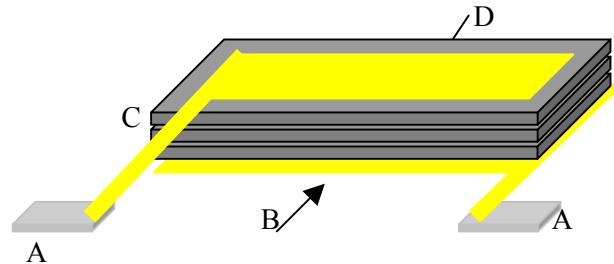


Fig. 1 Stacked Thermistor Schematic

In figure 1 the order of printing and firing was from "A" to "D". The solder pads "A" were constructed with KOARTAN 4496 gold. The electrodes "B" and "D" were fabricated with KOARTAN thin print gold 4550. This material produces highly dense, micron-thick film⁴. Because of its high fired film density, it must be printed on top of the solder or bond pad; otherwise, it would result in blistering of the pad. Three layers of the thermistor "C" were sequentially printed and fired.

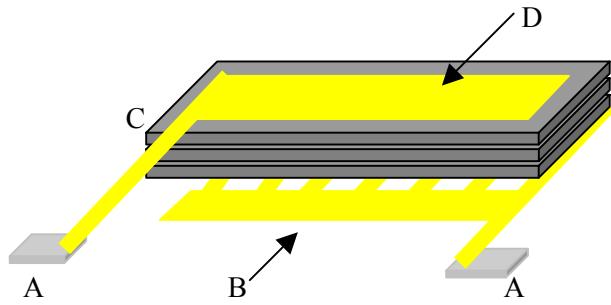


Fig. 2 Stacked Thermistor with Line Electrode

Standard NTC pastes, such as KOARTAN 7321 series, are available in resistivity ranges of $100 \Omega/\square$ to $100 K\Omega/\square$. Lower resistivity is of course desirable, as explained above. But reducing the resistivity below $100 \Omega/\square$ would rapidly reduce Beta, making it ineffective. There is no technical obstacle to extending the high end into $M\Omega/\square$ or even $G\Omega/\square$ range. But there are no known applications for such high resistivity values. By contrast, the newly developed KOARTAN 7380 series pastes can readily be extended on both sides, if desired. Table 1 depicts the nominal data for most commonly sought end members of the system.

Table 1
7380 Series Electrical Characteristics

	7381	7382	7383	7384	7385
R Ohms	10	100	1 K	10 K	100 K
TCR $+25$ to $+125^\circ\text{C}$	-7000	-8750	-9200	-9550	-9775
Beta $+25$ to $+125^\circ\text{C}$	-1600	-2500	-3000	-3750	-4500

It is worth noting once more that the above data was obtained on $0.040'' \times 0.040''$ pads with 40 microns of NTC fired thickness. If the 7381 is printed on planar $0.040'' \times 0.040''$ pads, the resistance is expected to be in the range of 10^{12} - 10^{16} ohms.

Results and Discussion

As indicated, the basic measurement unit for the 7380 series thermistors is the resistance of a $0.040'' \times 0.040''$ pad at 40 microns fired thickness. From the parallel resistor formula, one would expect the resistance for different size pads, at the same thickness, to be inversely proportional to the pad area, i.e., doubling the area to cut the resistance in half. This is in fact the case. Figures 3 and 4 show the resistance of 7381 and 7384 on various size pads.

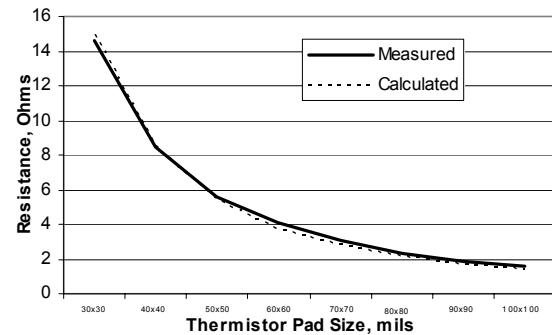


Fig. 3 Resistance vs. Pad Size, 7381

All the pads used to generate the data for figures 3 and 4 were on the same pattern and printed at the same time. The thicknesses were not precisely 40 microns, but were assumed to be the same for the closely-spaced pads. The figures show the measured data in bold, accompanied by those which were calculated by assuming parallel resistive paths. The same type of data was also generated for 7382, 7383, and 7385. These curves also showed similarly close correlation between the measured and the calculated data.

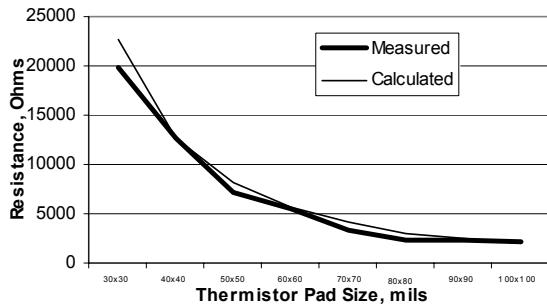


Fig. 4 Resistance vs. Pad Size, 7384

The effect of thickness was not systematically determined in this work. But at 40 microns thickness it clearly does not follow the series resistor formula, i.e., doubling the thickness increases the resistance far greater than twofold. As a rule of thumb, for every one percent thickness deviation from the nominal, three percent change in resistance should be expected. The ratio further increases as thickness deviation from the nominal increases.

Laser Trim Trials

From the discussion above one may conclude that each line in figure 2 would behave like a discrete thermistor, and that the total circuit resistance would be that of the individual units in parallel. To test this, a new pattern including one mil and two mil lines was devised. Figure 5 shows close ups of parts of thermistors built using this pattern.

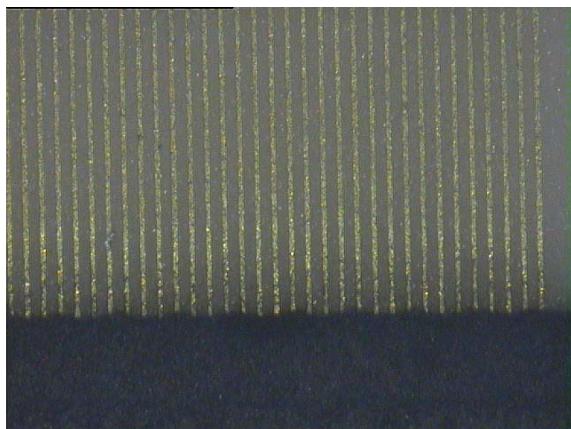


Fig. 5a Close up of 1 mil line bottom electrode

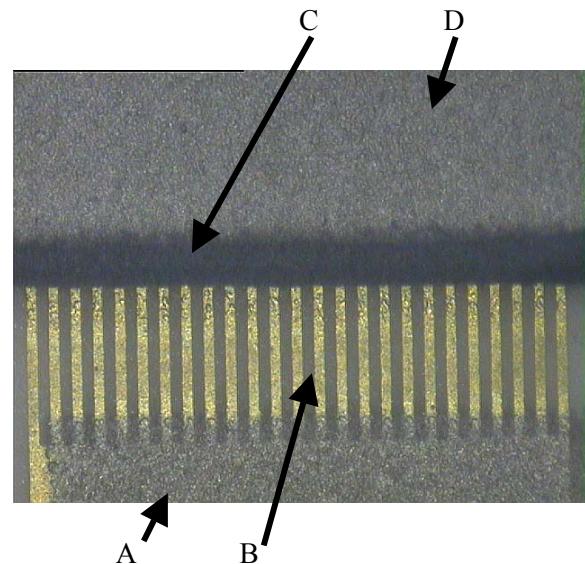


Fig. 5b Thermistor with 2-mil lines

The 7381 was printed on the new pattern. In both cases the resistance was measured. Then the lines were cut, one at a time, and the resistance was measured again. Figure 6 shows the resistance measurements after each step. It is seen that the results are indeed those which are expected from the parallel resistor formula. This can readily be discerned from the plot by

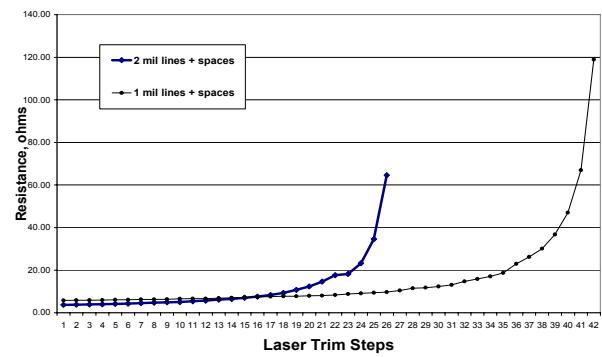


Fig. 6 Laser Trimming Results of 7381

looking at the resistance of the last remaining line. Comparing to when there were two lines, it is seen that the resistance was about half as much; when there were three lines left, the resistance was about one third, and so on.

Figure 6 clearly indicates that the more lines there are, the more accurate the trim. It also

indicates that about 25 lines are sufficient for fairly accurate trimming. In this case, one should aim for a total resistance of about 16/25 of the desired resistance. For example, if 10 ohm is desired, then one should aim for 6.4 ohms. If the actual as-fired total resistance comes out as low as 3.2 ohms, then about 16 lines must be cut. If the actual resistance comes out to 9.2 ohms, then only two lines need to be cut. The trimmed accuracy is better if the actual as-fired resistance is a little higher than the target. But it, of course, must not exceed the desired resistance.

It is possible to passively trim these thermistors by cutting away a predetermined portion of the top electrode. But for small thermistors this may not be as reliable as the method described above, since the laser heat may further change the resistance or cause shorting.

Termination Effects and Stability

When ordinary resistors and thermistors are printed in the planar configuration on various types of metallization, elements from the termination diffuse into the resistor. The diffusion area typically extends several mils into the resistor and can dramatically alter the properties in that narrow band. In case of the 7380 series, the entire bulk of the thermistor is a diffusion area, since the thickness is only about one and a half mils. As a result, the thermistor fired film characteristics are greatly dependent on the termination composition. The series is calibrated on a low-frit thin-print gold conductor. Fairly similar results are obtained with most ordinary wire bondable gold pastes as the termination. High silver content pastes are not compatible with these thermistors, since silver diffusion can readily lead to shorting. Palladium-silver pastes with a Ag:Pd ratio of 6:1 or lower do not exhibit the shorting problem, but most commercial palladium-silver pastes contain large amounts of binder frit which diffuse into the thermistor, increasing its resistance and decreasing its Beta.

The 7380 series thermistors have considerably less porosity than their planar counterparts. Encapsulation with a low temperature glaze or polymer encapsulant is, nevertheless, recommended. The data in figure 7 was obtained by placing unglazed parts in a CO₂-cooled chamber, Delta Design model 2300. The parts were connected to a multimeter via long wires and alligator clips. They were measured at 25°C, removed, glazed, and measured again.

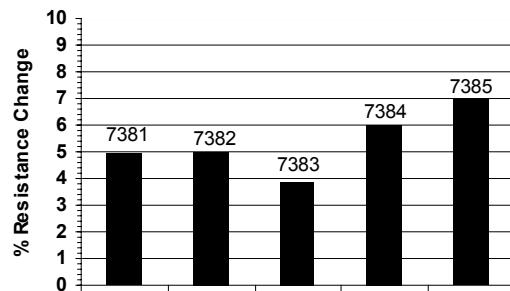


Fig. 7 Percent resistance change due to glazing

A similar procedure was used to determine any shift due to high temperature storage. Two inch long tinned copper wires were soldered to as-fired thermistors. Insulated wires were then soldered to the ends of the tinned wires and placed in the chamber for 25°C measurements. The insulated wires were then removed and the coupons along with the tinned wires were subjected to 100 hours of storage at 125°C. The insulated wires were reattached and the measurements at 25°C were repeated.

Due to excellent temperature sensitivity of the 7380 series thermistors, a set of 7321 planar thermistors were also tested alongside, as a benchmark. These thermistors had previously shown an average drift of about 0.5% after 48 hours at 150°C. The results are shown in figures 8 and 9.

The results for the 7231 series, although a bit higher than expected, particularly at the low end, are nevertheless in fairly good agreement with previous experience. The results for the 7380 series indicate a much more stable system. In fact the real shift in this series may be very close to zero. The observed shifts may be entirely due

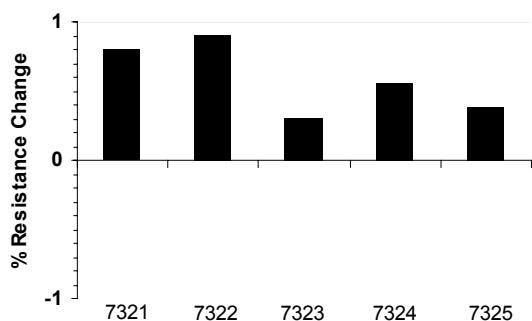


Fig. 8 Resistance drifts of 7321 series thermistors

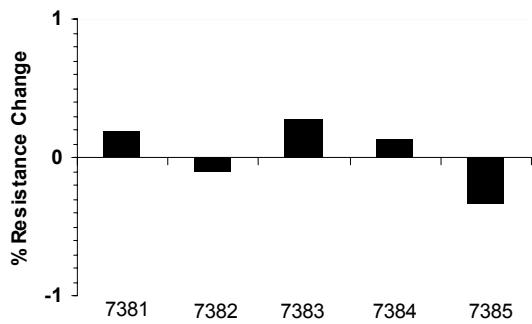


Fig. 9 Resistance drift of 7380 series thermistors

to measurement error. The gas-cooled chamber is not capable of controlling the temperature at 25°C better than $\pm 0.05^\circ\text{C}$. For such highly temperature sensitive thermistors, the error in resistance measurement due to temperature fluctuation within this range is greater than the shifts shown in figure 9. It should also be considered that, in spite of a wide resistivity range, the compositions of the 7380 series members are actually quite close. No physical or chemical attribute could be found to explain why some members would shift positive and some negative, further indication that the shifts in figure 9 may in the most part be due measurement error.

Conclusions

A novel method for constructing thick film NTC thermistors and a new series of blendable pastes were introduced. These innovations allow the

fabrication of highly sensitive units, especially at low ohmic values, which are particularly useful in such applications as temperature-compensating microwave attenuators. High sensitivity at very low resistance values also leads to this system's ability to be effectively laser trimmed for better accuracy and tight resistance distribution.

References

1. Nabatian, David J., "New Dielectrics for Single Layer Capacitors", IMC Proceedings, Kobe, Japan, PP. 262-266, (1986).
2. Nabatian, David J., "A Study of Factors Affecting Characteristics of NTC Thermistors", Proceedings of 35th International Symposium on Microelectronics, IMAPS 2002, Denver, Colorado, PP. 433-436, (2002).
3. Sachse, Herbert B., Semiconducting Temperature Sensors and Their Applications, John Wiley & Sons, Inc., New York, 1975.
4. D. J. Nabatian, et.al., "A Study of Microwave Behavior of a Thin-Print Gold Ink", Proceedings of 35th International Symposium on Microelectronics, IMAPS 2002, Denver, Colorado, PP. 875-879, (2002).