NEW MICROWAVE APPLICATIONS FOR THICK FILM THERMISTORS

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Abstract

New microwave applications for temperature sensitive thick film materials are described. The first is a power sensing termination, which is based on a linear Negative Temperature Coefficient (NTC) thick film thermistor. This is used in combination with a linear Positive Temperature Coefficient (PTC) material to convert RF power to DC voltage. It can be used with a coupler to monitor power and compensate for temperature variations. This is most useful in telecommunications and other applications where power monitoring and control is critical. The passive device described here is linear and represents an inexpensive replacement for currently used active devices, which are non-linear and can cause signal distortion. It reports true RMS power where some active devices are frequency selective. Its simplicity also results in better reliability. The device can also be used to detect power leakage through an isolator. Processing and properties of the screen-printed, specially formulated linear PTC and NTC thermistor materials will be presented.

The second application involves the use of thick film thermistor materials to fabricate a temperature compensating attenuator. This is another passive replacement for more complex active devices that compensate for amplitude variation with temperature. In this design, highly non-linear NTC materials are combined with PTC materials in "T" and "Π" configurations to maintain signal level at constant impedance in microwave circuits. Device needs and how they may be met with hybrid thick film materials and processing are discussed

Introduction:

As the microwave business grows, the demand for better reliability and lower cost components increases. Consumer applications such as cell phones, pagers, PCS and WLAN require simple, reliable, inexpensive components. This can be accomplished to a great extent by replacing complex active circuits with passive devices made with the use of thick and thin film technologies. This paper describes two applications of thick film thermistors in devices that can be used up to 20 GHz. This is possible due to the development of new thick film thermistor materials (1) that have higher TCRs, improved printability and a linear resistance/temperature curve capability(2). Passive circuits can also be designed using chip components with higher TCRs, but the range of resistance values necessary requires a large, costly inventory be maintained. Blendability and geometric flexibility make thick film manufacturing more desirable.

Device design along with the materials and processing used to achieve the required properties are described in this paper.

Materials:

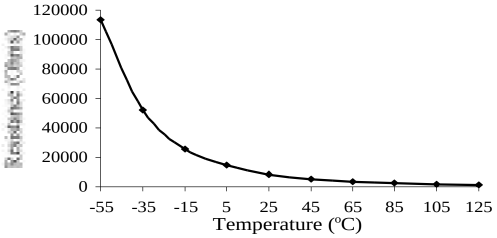
The properties of the Negative Temperature Coefficient (NTC) thick film pastes developed for these applications are shown in Table 1. NTC pastes are based on semiconductor materials that have a strong non-linear variation of resistivity with

Table 1
Summary of NTC (2100 Series) Compositions

Designation	Nominal Resistivity* (ohms/sq.)	Range** (ohms)	Cold TCR (ppm/°C)	Hot TCR (ppm/°C)	Beta (-55 to 125) K
D-NTC-2131	30	3 to 300	- 3,000	-3,000	300
D-NTC-2112	100	10 to 1,000	-10,000	-5,000	850
D-NTC-2113	1K	100 to 10K	-100,000	-7,500	1,700
D-NTC-2114	10K	1K to 100K	-160,000	-8,300	2,125
D-NTC-2115	100K	10K TO 1M	-300,000	-8,750	2,500
D-NTC-2116	1M	100K to 10M	-550,000	-9,200	3,100

*Measured on 0.040 x 0.040 resistors at 25°C and 22.5u dried film
** Resistive element geometry ranging from 1/10 to 10 squares

temperature (Figure 1). The 30 Ω/☐ paste in this series is unique in that it has a constant TCR over the temperature range of interest.



NTC Resistance -vs- Temperature
Figure 1

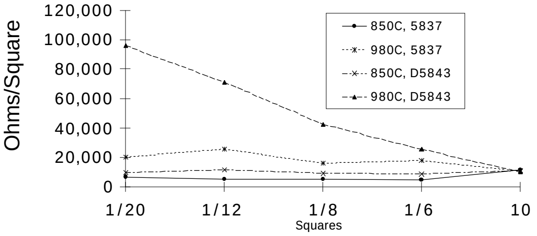
Since the temperature variation is non-linear for the rest of the series, the TCR defined from 25°C to the reference temperature (e.g. –55°C) is not characteristic of the slope variation at any other point on the curve. These materials are typically characterized by the value

$$ß = (T_1T_0/\Delta T) \text{ x } \ln(R_{T1}/ R_{T0}). \qquad [3]$$

which is a material characteristic that is constant over a wide range of temperatures and is used as a design parameter for chip thermistors. The values for ß for the thick film pastes are given in Table 1.

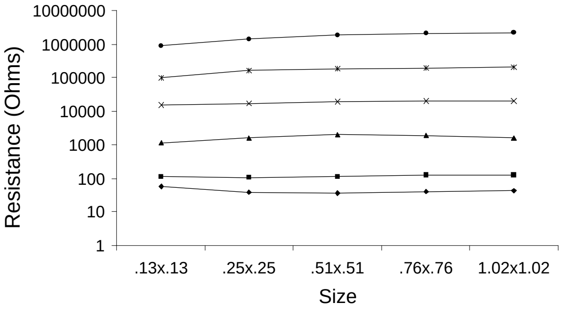
Blendability is critical to the usefulness of thick film materials. The entire NTC series from 30 Ω/☐ to 1 MegΩ/☐ is blendable and intermediate values are predictable on a log R vs. concentration curve.

Geometric flexibility is also critical to these applications. Conductor interaction with resistors printed as fractional squares down to 1/20 is minimal and resistors as small as 1/100 square are being used in this application with predictable results. The choice of conductor and peak firing temperature is important since interaction with metallizations can cause variation of resistance with resistor length. Figure 2 shows that 850°C fire with either of the two conductors shown yields excellent results. At 980 °C, Pt/Au D5843 is significantly more interactive than Pt/Au 5837. Microwave applications require the use of small components. Higher frequencies require smaller geometries. Figures 3 and 4

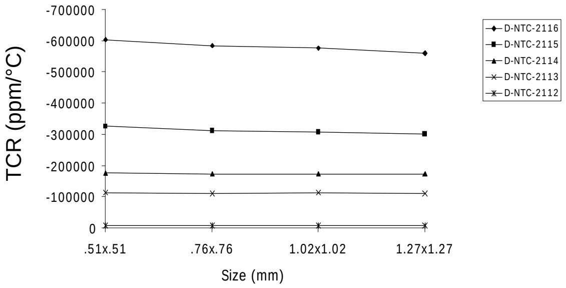


NTC Conductor Selection
Figure 2

show resistance and TCR as a function of resistor size. Both of these parameters are invariant as component size decreases.

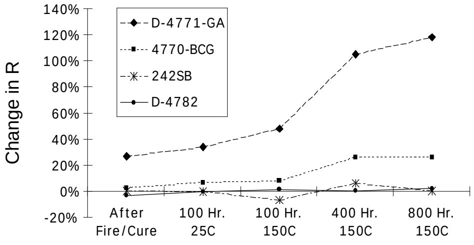


Resistance Vs Size
Figure 3



TCR Vs. Size
Figure 4

Stability of NTC pastes is always a concern. The high temperature materials used in the development of the NTC series are difficult to sinter at normal thick film processing temperatures (850°C) and therefore require an overcoat to insure stability. D-4782 and 242SB provide excellent results under ambient and accelerated aging conditions. D-4782 was developed to provide maximum stability for and minimum interaction with the NTC composition. Figure 5 shows these two along with two less effective overcoats.



Ageing with Overcoats
Figure 5

Characterizing parameters for the Positive Temperature Coefficient (PTC) pastes developed are shown in Table 2. The low resistivity compositions PTC-2650 and PTC-2611 have very high TCRs and excellent stability at ambient and elevated temperatures. It is therefore not necessary to encapsulate or stabilize these resistors. They show excellent linearity and no hysteresis is observable. The higher values of resistance (100 Ω/☐->10,000 Ω/☐) are provided by the D-PTC-6200 and D-PTC-2600A series of pastes. These are all blendable so that a continuous range of resistances is obtainable. Resistance vs. temperature is also linear over the entire range of resistivities. All the compositions are laser trimmable and stability is not affected by this procedure. These compositions are also compatible with Pd/Ag (ESL 9635A) metallizations.

Processing:

The processing conditions required for these thermistor materials are the same as those used for conventional thick film materials. Standard 850°C firing profiles are used on films printed to dried print thickness of 22.5µ. Pt/Au (ESL 5837). metallizations were used in the evaluation of the thermistor compositions. Subsequent testing showed Ag/Pd (ESL 9635A) gave comparable results. Due to the very sensitive nature of these compositions, all resistance measurements up to 1000 Ω were done using four wire Kelvin probes. For higher resistance values, standard two wire measurements were made.

Table 2

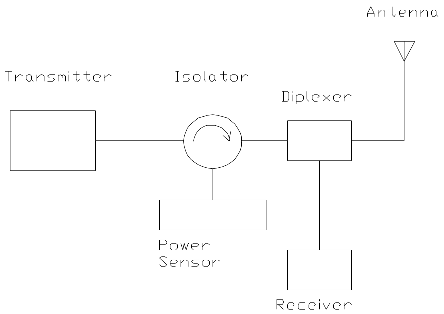
Summary of PTC Compositions

Designation	Resistivity (Ω)	Cold TCR (PPM/°C)	Hot TCR (PPM/°C)
PTC-2650	5	4,300	4,100
PTC 2611	10	4,000	3,700
D-PTC-6212	100	2,900	2,650
D-PTC-6232	300	2,750	2,450
D-PTC-2613A	1K	2,400	2,400
D-PTC-2614A	10K	2,200	2,200

Applications:

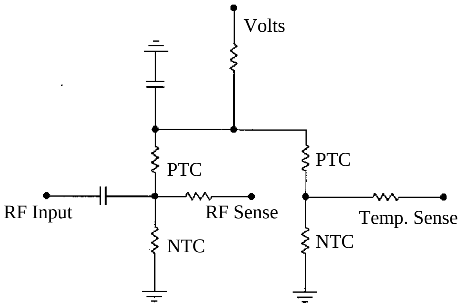
Power Sensing Termination:

In many microwave circuits, power control is required to insure proper functionality of a complex device. It is therefore necessary to sense the power level at several places in the circuit and feedback the information required to control the power level. Directional couplers are used for this purpose. A signal is induced in the coupler, which is proportional to the signal in the circuit. The power level at the termination port of the coupler can then be measured without disrupting the signal in the circuit. A power sensing termination is used to accomplish this. Popular power detection methods include Shottky diodes, tunnel diodes, and bridge circuits. These are expensive, complex devices. Replacement with passive thick film devices would be desirable. Another common device used in microwave applications is an Isolator. This device may be used to separate outgoing and incoming signals. In this application it is important to measure the degree of isolation with a power sensor (Figure 6)



Power Sensor in an Isolator Application

Figure 6

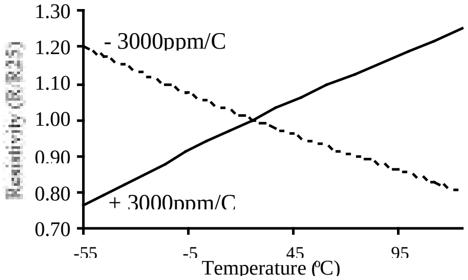


Power SensingTermination Schematic

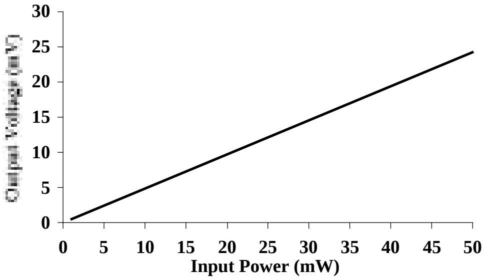
Figure 7

PATENT PENDING

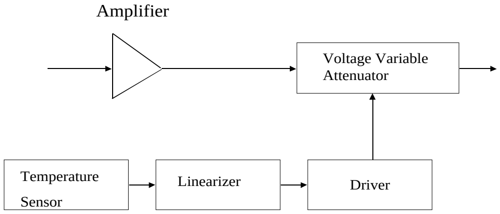
The ability to use a thick film passive device in this application improves reliability and cost effectiveness. The design schematic of the power sensing termination is illustrated in Figure 7. Temperature compensation for this device is provided through the use of linear NTC and PTC thick film materials of which the temperature vs. resistance curve is given in Figure 8. The Smartload® is frequency independent and has a voltage standing wave ratio (VSWR) of less than 1.25:1 up to 6 GHz. The device features a linear relationship between input power and output voltage as shown in Figure 9.



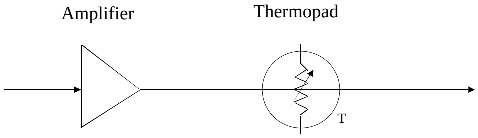
Resistance -Vs- Temperature
Figure 8



Power Sensing Termination (Smartload)
Figure 9



External Amplifier Temperature Compensation
Figure 10



Amplifier Compensation using Thermopad^{â}
Figure 11

<u>Temperature Variable Attenuator:</u>

Temperature Variable Attenuators (TVAs) are used in applications that require signal level control (4). These include GaAs FET and Si Bipolar amplifiers, transmission lines, mixers, voltage controlled oscillators and other signal processing components. Reflective attenuation accomplishes this goal, but often causes problems for other devices in the system. Attenuation can also be accomplished by absorption. This eliminates the problems caused by reflective attenuators and is generally preferred. A schematic of a typical amplifier temperature compensation circuit is shown in Figure 10. A single passive device (Figure 11) which provides temperature compensated attenuation can replace the multiple components used. The TVA is an absorptive temperature - compensating element, which provides power dissipation that varies at a controlled rate with change in temperature while maintaining an impedance (5) that is substantially constant. The range of compensation is determined by the temperature coefficient of the thermistors used in the circuit. The new compositions developed provide improved compensation over a wide range of temperatures while the insensitivity to print geometry contributes to the enhanced high frequency performance up to 20 GHz.

Improved signal attenuation capability was achieved using thick film materials described earlier. Figure 12 shows the improvement in attenuation compensation of a 1 dB device. Most of the improvement comes at low temperatures due to the higher TCRs of the new pastes.

Figure 13 shows VSWR for a 10 dB device using the new thermistor materials. The improved performance results from the use of smaller geometries (0.1” x 0.1” vs.

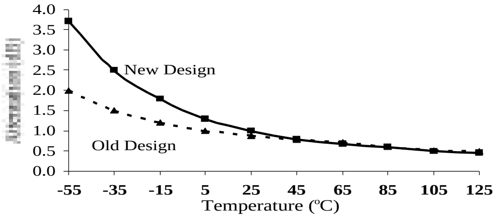


Figure 12
Attenuation -vs- Temperature

0.122” x 0.145” overall size) in the 10 dB layout which is made possible because of the higher TCRs of the new materials. The attenuation performance shown in Figure 14 is modest for the old design up to 6 GHz, however it degrades quickly due to reflections (VSWR) as shown in Figure 13. The overall performance improvement is quite good extending the frequency range of the new design up to 20 GHz (Figure 14)

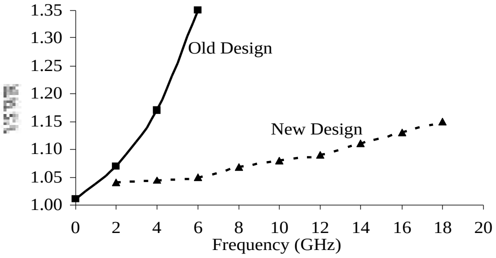


Figure 13
Thermopad® Frequency Response

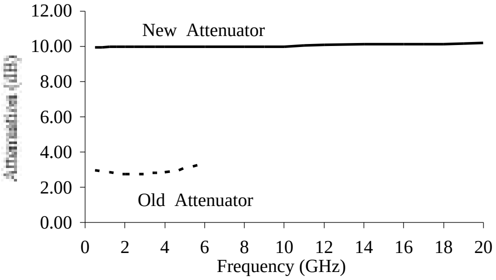


Figure 14:
Thermopad® Frequency Response

Summary and Conclusions:

A temperature compensated power sensing termination was developed by combining NTC and PTC thick film thermistor materials having linear resistance vs. temperature characteristics. Resulting devices exhibited frequency independent behavior and a VSWR of less than 1.25:1 up to 6 GHz. It provides true RMS power detection with linear output characteristics.

Temperature compensated temperature variable attenuators were designed with improved performance using these new materials. Attenuation compensation increased from 0.007 to 0.009 dB/dB/°C and frequency range coverage increased from 6 to 20 GHz.

Thick film thermistors designed for use in high frequency applications were developed. Negative Temperature Coefficient (NTC) compositions covering the resistivity range from 30 Ω/☐ to 1 MegΩ/☐ were formulated. ß values up to 3100 and HTCRs as high as –9200 ppm/°C were achieved. The PTC materials had TCRs from 2200 ppm/°C to about 4000 ppm/°C with a resistivity range coverage of 5 Ω/☐ to 10,000 Ω/☐. The thermistor devices, compatible conductors and protective overglazes were produced using standard thick film processing methods and equipment.

References:

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