NOVEL HIGH-VOLTAGE RANGE RESISTORS FOR AC-DC THERMAL CONVERTERS

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Abstract – This paper discusses the factors contributing to the ac-dc differences of high-voltage thermal converters. A novel resistor designed to minimize these contributions is described and measurements illustrating its performance are summarized.

I. Introduction

The development of a new generation of thermal transfer standards based on thin-film technology and structures similar to micro-electro-mechanical systems has been undertaken(1). The performance of the new thin-film, multijunction thermal converters (MJTCs) is close to that of existing national standards. Thermal transfer standards rated above a few tens of volts, high-voltage thermal converters (HVTCs), consist of a thermoelement (TE) in series with a multiplying resistor and are limited by the characteristics of multiplying range resistors. In general, the contribution of the resistor dominates the overall ac-dc difference of the HVTC(2). The ac-dc difference of the HVTC may vary as a function of warm-up time, applied frequency, applied voltage, temperature, and possibly age. Voltage coefficients between 500 V and 1000 V can be several hundred microvolts per volt (μV/V) or more for some worst-case resistors. A recent international intercomparison of HVTCs at high voltage and high frequency reported differences among the participating laboratories of as much as 122 μV/V in ac-dc difference at 1000 V and 50 kHz(3). The resistors described in this paper were designed and constructed in new ways to minimize the

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effects of capacitance and temperature in order to reduce both the ac-dc difference and voltage coefficients of the HVTC.

II. Construction of Conventional HVTCs

The range resistors for HVTCs are normally mounted in grounded enclosures, often cylindrical, to provide good electrical definition, shielding from external signals, and a safety ground. In general, for HVTCs constructed without any internal compensating shields, the ac-dc difference contribution from the transmission line effect, δ_T, can be expressed as[3]:

$$\delta_T \approx \frac{\omega^2}{6}\left[\frac{R_r^2 C_r^2}{30} - L_r C_r - L_{TE} C_{TE} - 2 L_{TE} C_r\right] \tag{1}$$

where ω is the angular frequency of the applied ac voltage, L_r, C_r, and R_r are the distributed inductance, distributed capacitance to the grounded enclosure, and resistance of the multiplying range resistors, and L_{TE} and C_{TE} are similar parameters for the TE. Normally, the leading term will dominate this expression. If lower-order small quantities are neglected, then

$$\delta_T \approx \frac{\left(\omega R_r C_r\right)^2}{180} \tag{2}$$

Equation (2) indicates that ac current is bypassed through the distributed capacitance from the resistor to the grounded enclosure, so less ac current flows through the thermoelement producing a positive ac-dc difference. The ac-dc differences calculated using this relationship are in general agreement with experimental results for such simple structures containing no internal shields. The calculated results indicate that contributions such as transmission line effect in the input connectors, current standing-wave in the TE, skin effect in the cylinder and skin effect in the magnetic leads of the TE may be significant for lower voltage ranges. These effects can generally be neglected, however, compared to the contribution to ac-dc difference given by equation (2) for the larger volt-hertz products of HVTCs. The distributed capacitance between the unshielded range resistor and the outer grounded enclosure, which permits ac current to bypass the TE to ground, is therefore a main source of error. In general, the distributed capacitances between all current carrying parts of the structure inside the external cylinder contain dielectric materials. The dielectric loss of the substrate for the resistors, if it is ceramic, may be very small and stable; however, the dielectric loss of any protective coating or insulating material may be much larger and may be temperature dependent, and therefore voltage dependent, and may change with age. To improve frequency flatness and reduce voltage level dependence, conventional HVTC range resistor modules are commonly made with a driven internal shield structure that reduces the ac-dc differences at frequencies above 20 kHz.

III. Improved HVTC Range Resistors

We describe new HVTC range resistors containing a novel internal shield structure. Due to the particular geometry of the new internal shield elements and to the specific location of the resistor body inside the shield, the new shield structure essentially eliminates the effect on the transfer function of stray capacitance from the main resistor body to the external grounded shield. This construction eliminates the need for shunting a capacitive divider across the resistor and is the subject of a pending patent application[4]. A schematic diagram for the new resistor modules is shown in Figure 1. Modules with R_1 resistance values ranging from 200 kΩ to 500 kΩ have been built. A small circuit is connected in shunt with the thermal converter heater to provide fine trim on the frequency flatness.

The mechanical design consists of an outer perforated cylindrical body 10.5 cm long by 6.4 cm in diameter fitted with type GR-874 input and output connectors along with a 5 V dc power jack for the miniature internal cooling fan. An internal rectangular shield structure housing the main range resistor is supported inside the outer, safety ground cylinder by concentric butyl rubber rings. A photograph of the module is shown in Figure 2 and an exploded view is given in Figure 3.

V. Performance of New Range Resistors

The frequency response of the new range resistors has been trimmed to reduce the ac-dc differences at 50 kHz and 100 kHz, and the ac-dc differences has been measured against NIST working standards. The preliminary results are shown in Figure 4. The data show frequency flatness comparable to other well-made HVTC range resistors with a voltage coefficient between 500 V and 1 kV of less than 30 μV/V[5].

VI. Summary

We report the construction and availability of new high-voltage range resistors for thermal voltage converters based on novel shielding and frequency compensation. The new resistance modules have high resistance values making them suitable for small current applications such as new thin-film MJTCs and digital voltmeter circuits, yet the new compensation gives small voltage level dependence and good frequency flatness. The use of resistor elements with low temperature coefficients of resistance and an internal cooling fan gives quick warm-up and low thermal drift.

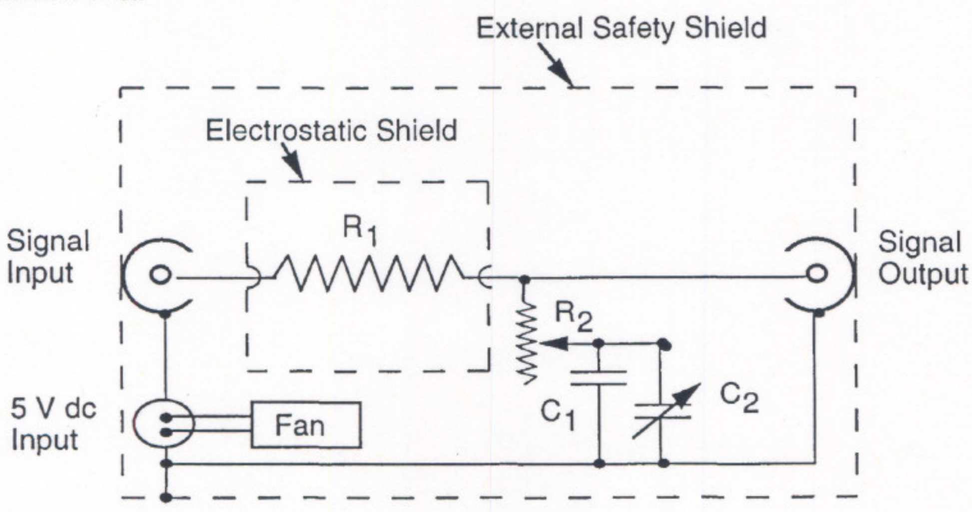

Figure 1. Schematic of the new resistor module.

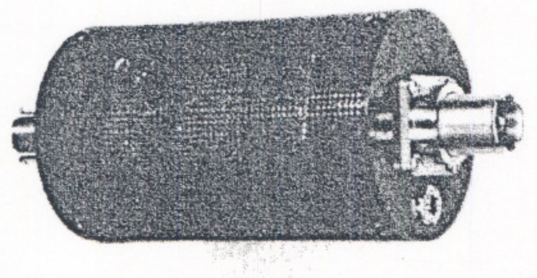

Figure 2. Exterior view of 1000 V range resistor.

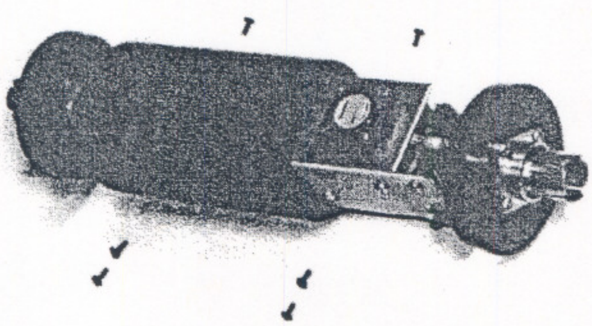

Figure 3. View of 1000 V range resistor showing internal structure.

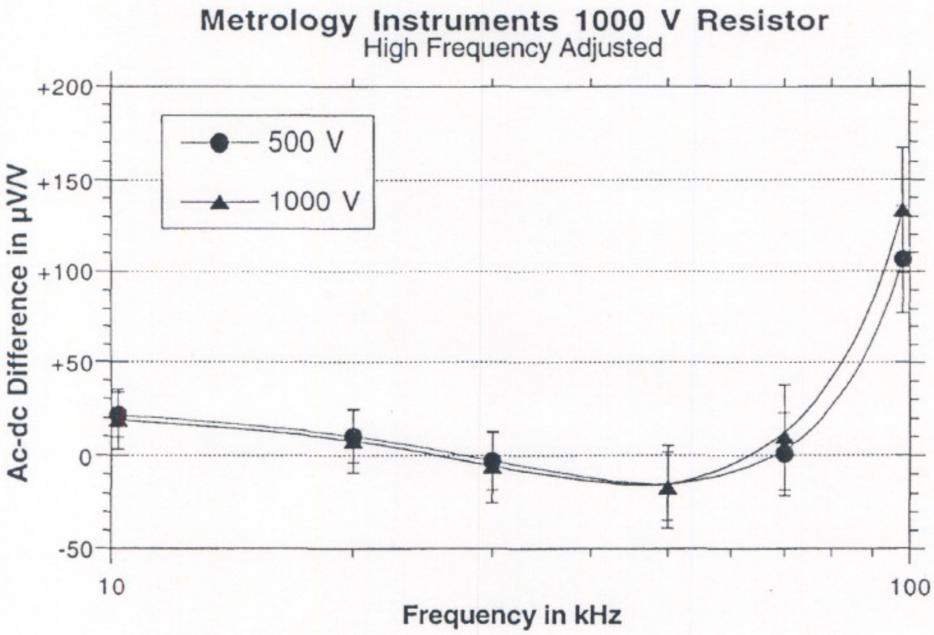

Figure 4. Preliminary results for a 1000-V resistor measured against NIST working standards. The frequency response of the resistor has been adjusted. The uncertainties are the normal NIST expanded uncertainties for the measurements.

References

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