Operating Range of Variable Resistors Extended Into Low Microamp Range With Advance in Cermet Thick Film Technology

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ABSTRACT

Today's evolving trend toward high speed low current circuitry requires a new generation of high performance variable resistors, featuring an operating range that extends beyond present applications into the low microamp range.

The primary limiting factor of the variable resistors presently available for operation in the low microamp range is output instability as a result of changes in contact resistance. These changes result from non-conductive films and dielectrics forming over time between the resistor element and the wiper contact.

An advancement in cermet technology greatly reduces the effects of contact resistance. The newly developed Palirium system improves output stability by creating a precious metal-to-metal contact point between the resistor's element and its wiper, or moving contact.

PURPOSE

Developments in integrated circuit technology that allow operation at higher input impedance and lower source voltages have pushed the demands on trimming potentiometers to their performance limits. The principal limitation is the ability of potentiometers to operate reliably in a rheostat mode with ultra low wiper currents. In particular, the performance criteria that are most affected by low current levels are the output stabilities.

It will be the purpose of this paper to discuss a new development in cermet variable resistor technology that extends the performance operating range of these devices into the microamp range common in today's evolving high speed low current circuitry. This technology development significantly improves variable resistor element output stability by reducing contact resistance.

INTRODUCTION

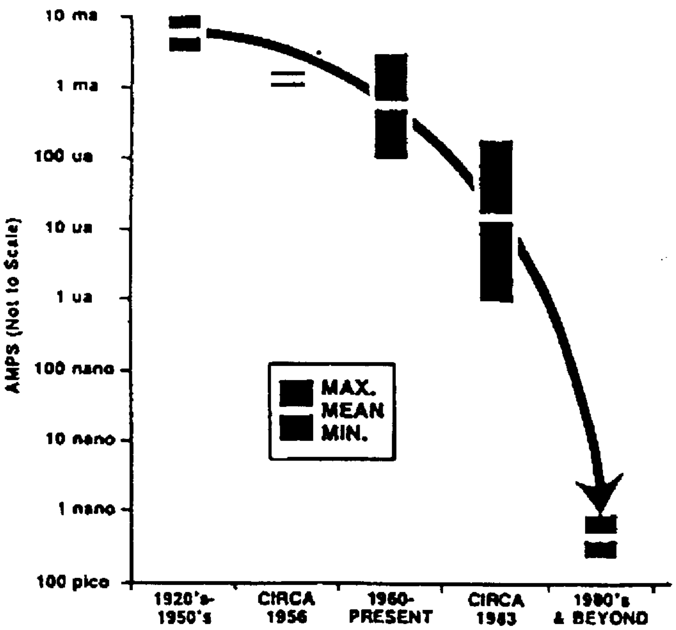
Change is the characteristic of the electronics industry that has remained constant throughout the decades. It's an old, but accurate cliché that portrays the dynamics of the high-tech electronics business. The continuous demands for end-equipment improvements are driven by desire for faster, more powerful, more cost-effective, more functional products. These same developments have led us to the need for a significant improvement in cermet variable resistor technology.

Table 1 briefly outlines the technology improvements or advancements that have taken place from the introduction of the vacuum tube to the emerging IC technology of today. You can see that the pace has quickened since the early 1980's.

Table 1

Electronics Evolution

(Low Current, High Impedances)



TECHNOLOGY	HISTORY	POWER SUPPLY VOLTAGES	INPUT IMPEDANCES (Ω)	TYPICAL WIPER CURRENTS
Vacuum Tubes	1920s—1950s	120—450	1 Meg Ω	5—10ma
Germanium Transistors	Circa 1956	18—30	10—20K Ω	1—2ma
Silicon Transistors	1960 to Present	6—18	100K Ω	100ua—5ma
MOS, P-MOS, C-MOS, J-FET	1983	3—12	2 Meg Ω Up to 1K Meg	1ua—500ua
GaAs, Bi-Polar	In Develop-ment	1.5—3	20 Meg Ω** Over 1K Meg Ω	Low Nano Amps

The production of devices that operate with high input impedance and low source voltage has resulted in trimmer wiper currents in the mid to low microamp range. With current levels this low, any change in wiper movement or the integrity of the wiper contact to the resistance element (contact resistance) could cause a significant change in the output of the potentiometer (setting stability) and, consequently the output of the functional circuit with which it is associated.

These changes in stability can result from either environmental, primarily thermal, or mechanical shifts. The environmentally induced instabilities are more complex and are affected by the selection of the element materials and the performance levels desired.

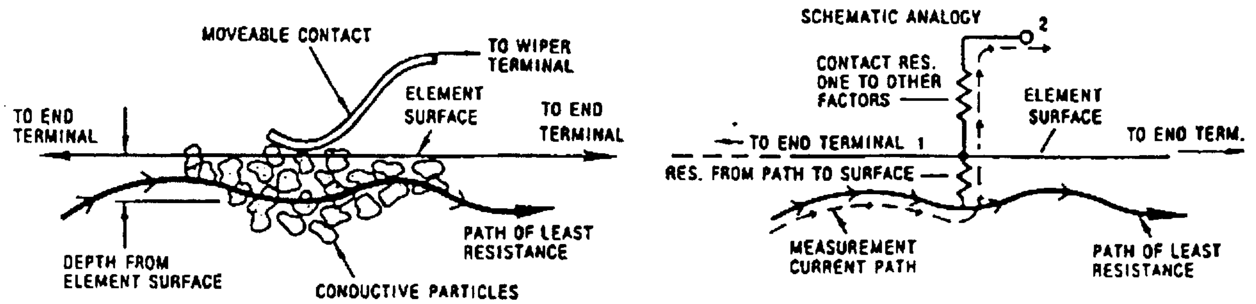
The most significant factor affecting setting stability from an environmental standpoint is contact resistance. The various aspects of contact resistance include the resistance that is built up between the wiper contact and the resistance element as a result of the formation of nonconductive films and dielectrics that form over time at this junction are shown in figure 1.

The formation of these films is accelerated with the presence of heat and moisture. The heat can be from internal or external sources. The moisture can be induced from external sources due to poor seals or can be captured in the devices during manufacture. In a static wiper position , the contact resistance can cause significant changes in the output of the circuit beyond its desired levels.

We can see in figure 2 that contact resistance is also a function of the current passing through the

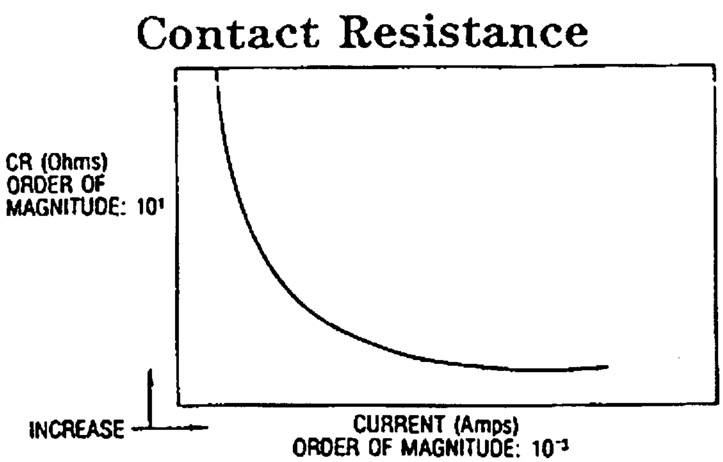
Fig. 1.

Contact Resistance



junction. In a dynamic mode, the contact resistance can cause output noise, but is less critical because the wiper motion tends to burnish or clean the wiper to element interface. This burnishing action will allow the user to eventually set the trimmer to a desired position. It is this contact resistance characteristic with which we are most concerned in the advancement or cermet technology.

Fig. 2.



In the industry today, there are several resistance element materials that are being used in trimming potentiometers. Each has its advantages and its limitations. A comparison of the performance characteristics is needed in order to select the device that will best suit the needs of the circuit function we are attempting to perform. The element styles we are referring to are: cermet (by far the most popular), wirewound, and bulk metal.

Cermet

Cermet is a thick film process incorporating resistive inks whose composition varies according to the desired results. The inks are generally composed of finely powdered inorganic metals or metal oxides (silver, palladium, platinum, rhodium, ruthenium or gold) mixed with a powdered glass frit and suspended in an organic (resin) vehicle. This ink is deposited onto a ceramic substrate using silk screening techniques and then fired in a kiln at between 800(C and 1200(C.

Wirewound

In wirewound elements, small diameter resistance wires are wrapped around a coated copper mandrel and then formed into various shapes (straight, round or helical) to form the desired potentiometer product. The coating on the mandrel insulates the functional element from the mandrel.

A varnish material on the wrapped wires helps to keep them separated during manufacture of the potentiometer. The resistance wire is most commonly an alloy of nickel-chromium but could be either copper-nickel or gold-platinum. Other alloys are also employed but are less common.

Bulk Metal

A substrate is laminated with a foil layer of, typically, nickel-chromium resistance material in bulk metal elements. This layer is then precision etched in a geometric pattern to increase the effective length of the element, if needed, to raise the total resistance of the element to the desired value.

Table 2.

Variable Resistor Technology Comparison

ELEMENT TECHNOLOGY	MATERIAL & PROCESS	RESISTANCE RANGE	CONTACT RESISTANCE	RESOLUTION
CERMET	•Thick Film •Inorganic Metal Oxides •Fired at High Temp	Excellent	Good	Excellent, Smooth
WIREWOUND	•Ni-Chrome Alloys •Wrapped on Insulated Mandrel •Formed into Straight or Curved Elements	Fair	Very Good	Good, Stepped
BULK METAL	•Ni-Chrome Alloys •Plated Substrate •Etched Patterns	Poor	Excellent	Good, Stepped

ELEMENT TECHNOLOGY	TEMPCO	POWER HANDLING	PACKAGE OPTIONS	TECHNOLOGY FIT
CERMET	Good	Good	Excellent	Trade-Offs
WIREWOUND	Very Good	Very Good	Fair	Trade-Offs
BULK METAL	Very Good	Good	Poor	Trade-Offs

Table 2 shows a comparison of some of the more important performance characteristics associated with trimming potentiometers in today's applications. Additional details are included here:

Cermet

Since cermet elements are screened onto the substrate, there is essentially an infinite output resolution. They have a very wide total resistance range and good temperature coefficient of resistance performance.

Wirewound

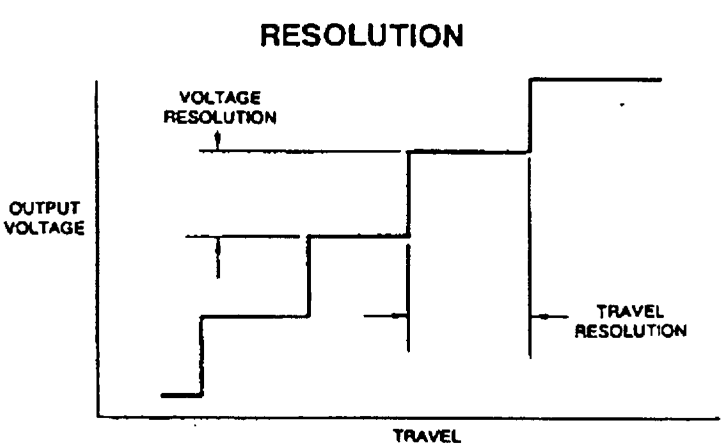
Wirewound elements have stepped outputs due to the resolution characteristics of the windings of resistance wire around a mandrel. They have excellent temperature coefficient of resistance performance but have a rather limited total resistance range.

Bulk Metal

There is also a stepped output (for TR values 200 ohms and above) in bulk metal elements due to the serpentine appearance of the resistance element resulting from the photoetching of the material. They have excellent temperature coefficient of resistance performance but a limited total resistance range.

Note that the resolution function (figure 3) can limit the overall performance settings of a circuit due to the lack of intermediate settings that are not possible to achieve. This characteristic should be given serious consideration when designing any new circuit.

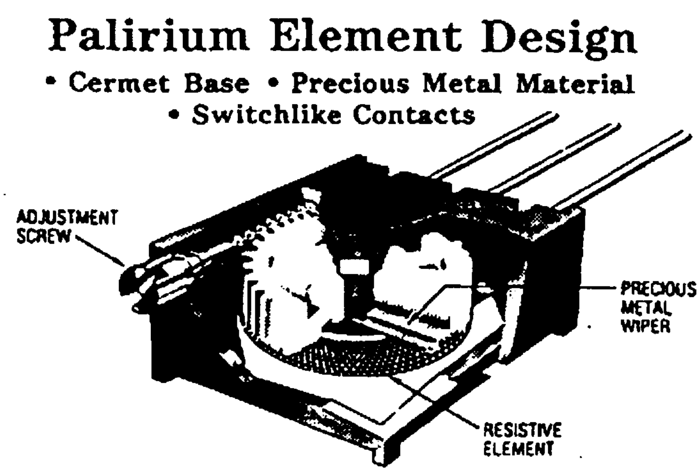
Fig. 3.



In order to address the issues that arise with current trimming potentiometer technology and those generated by the emerging needs of the IC industry, a totally new approach for cermet technology had to be developed. This patented proprietary cermet process (Palirium) was developed to maintain very low contact resistance , a wide total resistance range and stable output settings over time and temperature (specifically in low current rheostat mode applications).

The use of gold and other precious metals to reduce contact resistance in low power switches and connectors is well known. Now this same solution can be extended to variable resistors using the Palirium element. Precious metal multi-fingered wipers contact the cermet element through islands of highly conductive precious metal material. The islands are applied in a regular pattern (Fig.) and fused to the basic cermet element at high temperature.

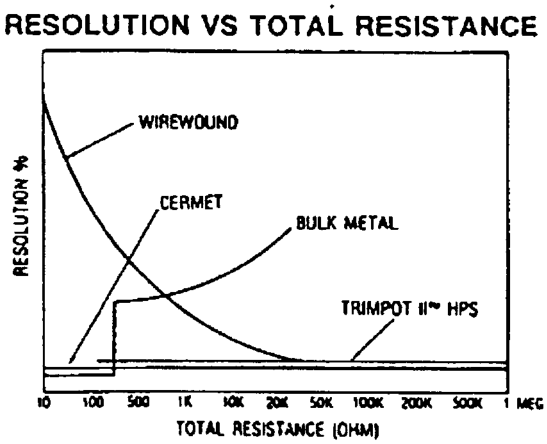
Fig. 4.



These conductive metal-to-metal contacts offer the best insurance against the buildup of surface films (sulfides, oxides, chlorides, etc.) that are the main contributors to contact resistance instabilities. The deposition of conductive islands onto the cermet surface does impact the resolution, slightly, the resolution performance of a pure cermet element.

However, when compared to wirewound and bulk metal elements as seen in Fig. 5, the resolution performance of the new technology is not appreciably different than that of standard cermet. Additionally, by using multiple fingers on the wiper, the contact resistance characteristic becomes reduced by the parallel resistance effects of the multiple points of contact as well as the inherently low characteristic resistance of the precious metal materials.

Fig. 5.

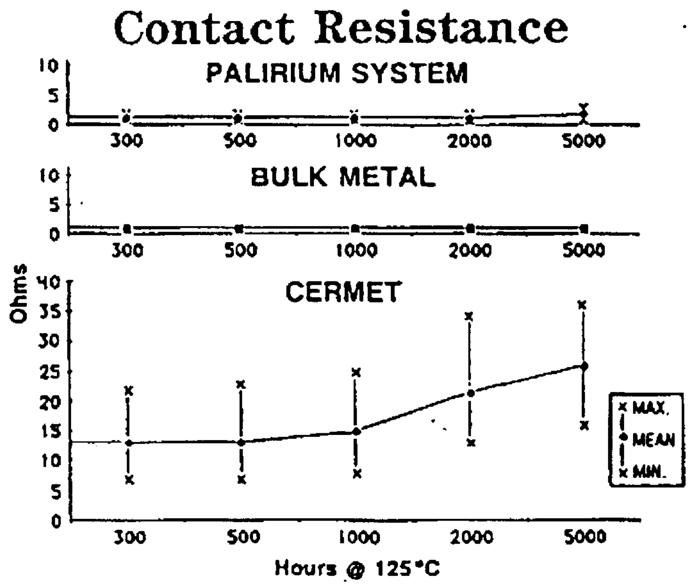


TEST RESULTS

Since the materials used to produce both the wirewound and bulk metal elements are very similar in their characteristics we are only going to show the comparative test results of standard cermet materials and bulk metal elements to those of the new Palirium system. The testing for all devices was carried out on nominal 2k ohm elements, because 2k ohm is a popular resistance value within the range of each of the element types.

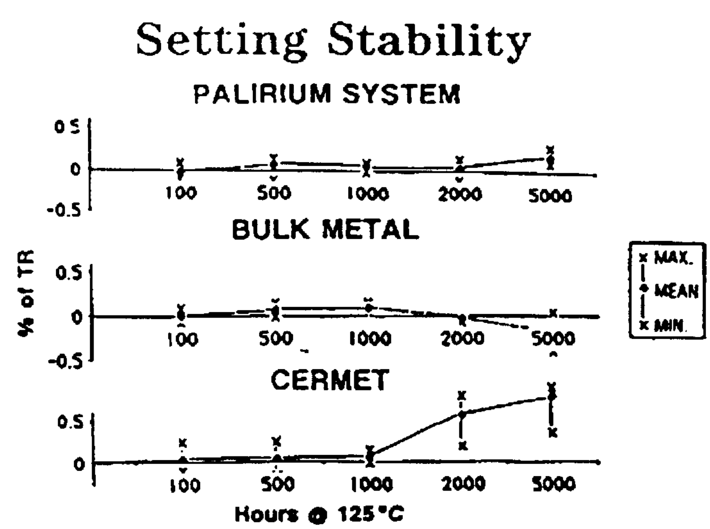
We tested the contact resistance at 125(C for 5,000 hours (Figure 6). The units were tested with the wipers set at approximately 50 percent output and measured the contact resistance between the wiper and the element using a maximum test current of 10ua. The results of this test are displayed in Figure 6. These tests were to establish a starting point from which to compare these two element types.

Fig. 6.



Of prime importance to the user is the performance effects over the long run. In Figure 7, we are comparing the exposure to elevated temperature (+125(C), resistance shift through the wiper, including contact resistance shift (all measurements through the wiper are taken with 10ua current). In this test we are using standard cermet, bulk metal and Palirium. For ease of comparison, in all cases the same relative scale was used for the parameter being evaluated.

Fig 7.



A further note regarding the test data: we displayed the average values of each parameter as well as the range of values for each. In every case you will notice the performance of the new Palirium system is at least comparable to that of bulk metal. Additionally, the resolution on the new Palirium element will remain constant as a percent of total resistance through the high end of 1Megohm> Bulk metal resolution becomes courser at higher resistances and seldom exceed 10k ohms or 20k ohms.

Many of the applications that are expected to make use of these devices manufactured with Palirium elements include feedback loops and gain functions on operational amplifiers. These include both rheostat and voltage divider modes of operation where high stability is of prime concern to the designer and user. They will be especially useful in applications where very high input impedances and low currents are required due to low power consumption of IC packages.

With the trend in the electronics industry to improve performance, lower power consumption, operate at high input impedances and lower source voltage, the pressure is on the manufacturers of trimming potentiometers to keep abreast of the needs of their customers.

The need for long-term stability in many new applications that are emerging as a result of improved IC technology has driven the performance levels of potentiometeric devices to new limits.

The Palirium system effectively responds to the needs of the industry by offering an alternative approach to solving the problems of contact resistance and long term setting stability.

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