High Mega-ohm Resistor Performance for low Voltage Applications

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Resistors are common devices required for today's electronics. It is so prevalent in design, we often tend to think they do not require close attention to their inherent properties. While many applications can be designed using performance assumptions gained from years and years of experience, this is not the case for all resistors, all of the time.

When using very high value resistors, there are a number of common resistor behaviors that may not apply, or in some case are backwards of traditional thinking. One such counter-intuitive relationship is Voltage Coefficient of Resistance (VCR). VCR is the relationship between the voltage seen by the resistive element and the corresponding resistance measured by a given device. One of the most important parameters of precise high-ohmic resistors is the VCR. The goal of resistor manufacturers is to try to create a resistor device that has consistent stated value of resistance, but does not have varying resistance values across broad voltage ranges.

The Voltage Coefficient is the change in resistance with applied voltage over a specific voltage range. We measure the stability of the resistor with respect to changes in voltage. A resistor with a VCR of 100 ppm/V will change 0.1% over a 10 Volt change and 1% over a 100 Volt change.

The rate of change in resistance value per 1 volt in the prescribed voltage range is expressed by the following formula:

VCR (ppm/V) = (Ro -R)/Ro X 1/(Vo -V) X 10e6 R: Measured resistance (Ω) at base voltage
Ro: Measured resistance (Ω) at upper voltage
V: Base voltage
Vo: Upper voltage

For an example of a 50 ohm resistor at 100ppm/V, a 10 volt range contributes a total of .1% to the ohmic value tolerance, or .005 ohms and 1 % over a 100 V change. Where tolerances of thick film resistors are common at 1% and 5%, this represents an extremely low stack-up to the uncertainty of the resistor's value due to voltage change. This relationship is not negligible when it comes to high ohmic value, precise components. A similar component to the above example at 1 Giga-ohm may have a VCR of 10,000 ppm/V. While this seems quite high, one must remember that this equals about 10% of value over a 10 volt range or 100 Mega-ohms for a 1 Giga-ohm product.

A designer may require a 500 Mohm resistor in a design, but assumes 500 Mohms of resistance across all working voltages for the design, not just one. In the case of a various voltage input application, the compensation of the resulting signal would not be the theoretical value, but may reflect the theoretical value plus the modification of whatever effect the voltage had on the resistor.

Part of the reason the TCR value is high for ohmic values above 500 Mohm has to do with the fact we are observing the change as a relationship to rote resistance value where that value is now several order of magnitude higher than "typical" resistor values. A second reason has to do with the extremely low resulting current that is produced as a result of modifying a signal at such a voltage. The voltage is impeded in the thick film material such that conductive phases at a microscopic level may not even be in direct contact with one another in order to allow for current to flow. This produces a very high resistance, but also sets up a more volatile mechanical environment where small changes in current may dramatically affect the effective current path and resulting resistance of the resistor. In other words, the resistor is so good at "resisting", it becomes difficult to hold this attribute when the voltage is low and varying. This also means that VCR performance is not linear across all voltages as it would be assumed in the lower standard resistance value ranges.

In reality, the Voltage Coefficient will vary for every resistance value for a given resistor model. This is why one should be careful with data sheets that specifiy a single voltage coefficient. Unless this specification states that it is the worst case Voltage Coefficient for a given model, it is usualy the best voltage coefficient for the model. The difference between 1V and 5V may be a higher

VCR than the difference between 5 and 9V even though the change in voltage is the same. This is particularly important when designers are using high ohmic value parts as offsets in designs and want the resulting current to be proportional to voltage over low common voltage ranges like 1-5V. A high value resistor analyzed for VCR at very high voltage will not carry that VCR performance down to 1V.

To demonstrate this, a study was conducted to evaluate low voltage performance of resistors. IMS RCX series 0603 resistors were compared against equivalent competitor resistors. The competitor advertises 5000ppm/V VCR for tested value. IMS resistors do not have an advertised VCR, but are estimated at 5000-7000ppm at 5V. Ten - 100 Gohm random components from each manufacturer were selected and analyzed. **Table 1** contains the resulting measured data.

Table 1 – Measured Ohmic Value and resulting VCR of RCX and Competitor equivalent 0603 size, 100Gohm 20% tol.

IMS	Value @5V		VCR 1-5V	VCR 5-10	VCR 1-10
Avg	1.09E+11	Avg	-5688	-10507	-8506
Max Abs	1.17E+11	Min Abs	-2315	-3774	-3145
Min Abs	9.98E+10	Max Abs	-11161	-16000	-11530
StdDev	6.00E+09	StdDev	2678	3841	2845
Competitor					
Avg	9.26E+10	Avg	-7391	-11904	-10109
Max Abs	9.65E+10	Min Abs	-2307	-2543	-2927
Min Abs	8.75E+10	Max Abs	-16630	-25273	-17551
StdDev	3.43E+09	StdDev	4645	6286	4614

The measured results from parts of both manufacturers were outside a 5000ppm/V VCR max estimate. What is most noteworthy is the fact that there was a significant difference in VCR calculated depending on both the magnitude and the range of the test voltages.

IMS RCX series resistors were measured closer to the "par" value of 100 Giga-ohm, they had lower average VCR's across the 10 piece study and much less std. deviation of values when it came to consistency of the VCR's across the sample lot.

High-ohmic resistors are playing a very important role in modern designs especialy those used in devices for meters and measurements products. High resistance chips are typically used in high impedance instruments, test equipment circuits, temperature measurement circuits and other high impedance amplifier circuits. Since high ohmic values are used for specialty applications, it is important to consider these factors of actual performance when evaluating the stated specifications of products. IMS testing facilities are second to none with advanced facilities in world-leading metrology and engineered laboratory spaces that are specially designed to remove effects of electro-magnetic pollution, triboelectric interference and RF contaminating noise when measuring the extremely low currents required to evaluate high ohmic value products, especially at very low voltages.

When selecting components for high resistance applications, it is more important than ever before to select a proven component as well as a manufacturer with experience in measuring and handling these devices in order to achieve the best results in applications.