DC volume resistivity, through-flange resistance, and shielding effectiveness of nickel-graphite filled elastomer gaskets

Under installed gasket conditions, several factors contribute to measured values.

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Conductive elastomers for EMI shielding were first introduced in the early 1960s. Silver particles were the original conductive fillers. Since then, conductive elastomers with other types of electrically conductive fillers have been developed. These were created to meet evolving customer needs for EMI shielding, environmental sealing, and other application specific requirements.

New forms of conductive elastomer EMI gaskets continue to evolve, fueled by the growing use of shielding gaskets in commercial electronics, especially cellular telephones and computers. Because these consumer electronic products have short product lifetimes and rapid price erosion, cost has become a critical EMI gasket design parameter.

THE EMERGENCE OF NICKEL-PLATED GRAPHITE FILLERS

Replacing or reducing fillers that use silver, a precious metal, achieved some EMI gasket cost reductions. With this change came the introduction of nickel-plated graphite, also called nickel-graphite, which is now widely used as an EMI gasket filler.

No lower cost filler other than nickel-graphite provides the high levels of EMI shielding effectiveness needed to address increases in equipment operating frequencies and correspondingly more stringent EMI regulations. The pure silver-filled materials originally used as fillers are still produced, but their high cost limits their use to extremely sensitive applications, in which only the most conductive materials will suffice.

Silver-plated copper, silver-plated aluminum, and silver-plated glass spheres, together with nickel-plated graphite, now account for about 90% of all conductive elastomer fillers used in EMI shielding gaskets. In fact, these are the fillers of choice for most high performance EMI shielding applications. Other filler systems such as silver-plated nickel or pure nickel are less widely specified. Low cost carbon-loaded elastomer gaskets are used mainly for electrostatic discharge (ESD) protection and for low level shielding applications.

STRONG CORROSION RESISTANCE FROM NICKEL-GRAPHITE

Besides their economy, nickel-plated graphite filled elastomers provide superior galvanic corrosion resistance. This design advantage has been demonstrated by salt spray environmental exposure testing of aluminum flanges with nickel-graphite filled elastomer EMI gaskets. Table 1 shows the results of one such salt spray test.

RESISTANCE AND RESISTIVITY OF CONDUCTIVE FILLERS

When evaluating conductive elastomer EMI

Test Description	6061 T6 Al MIL-C-5541 Class III
Nickel-graphite filled conductive elastomer FIP gasket 1.0 mm Bead with Aluminum Coupons	
Results	Median Wt. Loss: 2.0 mgs

Table 1. Salt fog exposure results of an aluminum coupon tested with a form-in-place (FIP), nickel-graphite filled silicone elastomer. After 168 hours, minimal change is observed in the surface finish, and minimal weight loss (corrosion) of the aluminum disk is found. The black coloration is residual gasket material.

Electrical Resistivities of Selected Metals	Micro-Ohm-cm
Silver (Ag)	1.6
Copper (Cu)	1.7
Aluminum (Al)	2.7
Nickel (Ni)	7.0
Graphite (C)	762

Table 2. A comparison of the inherent resistivities of materials commonly used as conductive elastomer gasket fillers.

gaskets, it is important to know the difference between *resistance* and *resistivity*. When a voltage is applied to a circuit of conductive material, the current flow through that material is restricted to moving from one point to another. This restriction can be measured and is called resistance. The higher the resistance, the more difficult it is for current to flow.

Materials regarded as good electrical conductors, such as silver (Ag) and copper (Cu), have relatively low resistance when measured using a DC ohmmeter. However, their overall resistance is a function of the material as well as other physical parameters, including the dimensions of the conducting path and the amount of material used. Resistance, therefore, is a property of a particular part of the specified dimensions of a certain material.

In contrast, resistivity is an inherent property and a material constant, *i.e.*, the resistance of one cubic centimeter of a material. Copper has a very low resistivity. A short length of copper wire shows relatively low resistance when measured; but if one measures a 1000-meter length of the same copper wire, the resistance will increase dramatically. The resistivity of the copper, however, remains the same.

Resistance and resistivity are directly analogous to density and weight. The weight (and the resistance) of a wire or other conductor depends on the specific part. The density (and resistivity) of copper is a constant material property. Table 2 shows the resistivities of some common filler metals.

DETERMINING VOLUME RESISTIVITY

The resistivity of EMI gaskets is measured as volume resistivity (not surface resistivity). The "standard" surface probe test method for measuring the volume resistivity of conductive elastomer gaskets is documented in the U.S. military specification MIL-DTL-83528B. This procedure was originally derived from ASTM D991.

At the time MIL-DTL-83528B (initially designated MIL-G-83528) was developed, the use of conductive elastomer EMI gaskets in commercial shielding applications was minimal. Thus, the surface probe method currently used to measure volume resistivity began within a military procurement standard. Many EMI gasket manufacturers have incorporated this method into their internal standards for testing conductive elastomers.

The MIL-DTL-83528B method requires a 200- to 240-gram volume resistivity pressure probe. The device consists of two parallel, one-inch (2.54 cm) wide, flat (versus pointed tip) silver-plated brass electrodes, separated by one inch (2.54 cm) of Delrin (acetal) insulator. The electrodes are connected to a DC ohmmeter sensitive to 10 milliohms.

The probe is placed on a molded sheet of conductive elastomer so that the entire width of the material is in contact with the electrodes. The weight of the electrodes is uniformly distributed on the material. This measurement procedure provides the volume resistivity as follows:

$$\text{Volume Resistivity (ohm-cm)} = \text{R (ohms) x A (cm}^2\text{)/L}$$

In the above equation, R is the resistance measured in ohms, A is the cross-sectional area of the material, and L is the distance between the two electrodes, one inch or 2.54 cm.

The measured volume resistivity will not vary with different thicknesses of material. When the material sample is a relatively small, dispensed bead of conductive elastomer, the probe must be placed on the bead with moderate pressure.

VOLUME RESISTIVITY IN FORM-IN-PLACE (FIP) EMI GASKETS

As apparent from the values shown in Table 2, the volume resistivity of FIP gaskets containing nickel-plated graphite (Ni/C) fillers is 10 to 25 times higher than gaskets made with silver-plated copper (Ag/Cu) fillers. Conductive elastomer

FIP EMI gaskets contain a homogenous distribution of filler particles. The filler-loading level is critical to establishing the volume resistivity of the material. Filler amounts must be precisely determined and controlled. Filler loading also affects other material properties such as specific gravity and hardness that are used to verify material performance.

In the case of FIP gaskets with nickel-plated graphite fillers, measurements show DC volume resistivities on the order of 0.02 ohm-cm. For silver-plated copper-filled materials, the volume resistivities are typically 0.001 ohm-cm. Given this comparison, one might expect lower shielding performance from nickel-plated graphite materials and thus avoid using them in high performance shielding applications in favor of silver-plated, copper-filled gaskets. However, this assumption is erroneous.

Dispensed conductive elastomer FIP gasketing must be applied so that the desired shielding is obtained when the enclosure is closed. To ensure adequate shielding, sufficient force must be applied to the material to optimize the conductivity of the closed flange. The metal or metallized plastic enclosure is the actual shield, but the gasketing in the flange must also be conductive enough to provide the required shielding levels. It must also be installed properly. In actual use conditions, nickel-graphite filled elastomers provide very good, *i.e.*, low, through-flange DC resistance values that are comparable to those of silver-plated copper-filled elastomers.

Under installed gasket conditions, several factors contribute to measured resistance values. Besides gasket resistance, one factor is the contact resistance at the gasket/flange interface. The relatively smaller size of nickel-plated graphite particles, along with their slightly irregular shape, hardness, and coarse finish, provides excellent gasket-to-flange coupling and low interstitial (contact) resistance (Figure 1).

DETERMINING THROUGH-FLANGE RESISTANCE

If one considers the total flange resistance as R_T, the gasket resistance as R_G, and the two (combined) gasket-to-flange interstitial (contact) resistances as R_I, then the through-flange resistance of a gasketed joint can be expressed as:

$$R_T = R_I + R_G + R_I$$

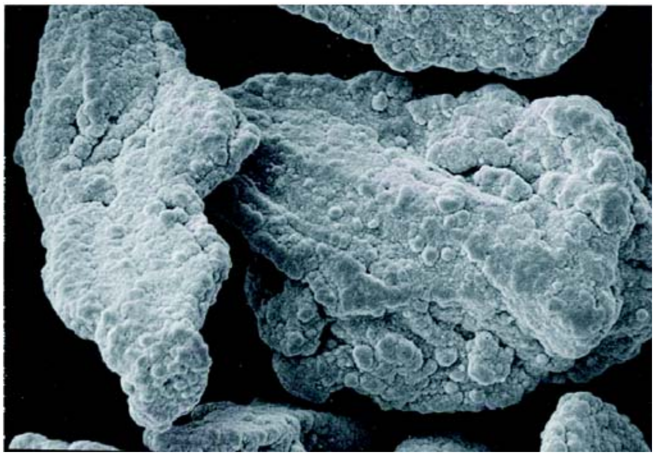

Figure 1. Microscopic photo of nickel-plated graphite particles used as conductive elastomer fillers (1500X magnification).

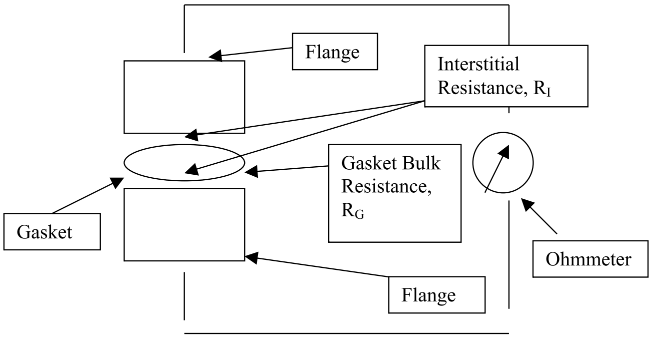

Figure 2. An EMI gasket compressed inside a flange with highlights on the different resistance areas.

The resistance of a silver-plated copper-filled elastomer gasket is lower than that of a nickel-plated graphite filled gasket.

$$R_{G\ (Ag/Cu)} << R_{G\ (Ni/C)}$$

If the through-flange resistance (R_T) is similar when either a nickel-plated graphite or a silver-plated copper-filled elastomer gasket is used, the interstitial (R_I) resistance must account for the difference. Thus, in this example the interstitial resistance for nickel graphite elastomers is much lower than for silver-plated copper elastomers.

$$\text{If } R_{T\ (Ni/C)} \sim R_{T\ (Ag/Cu)}$$

then

$$R_{I\ (Ni/C)} << R_{I\ (Ag/Cu)}$$

In 1993, prior to the widespread acceptance of nickel-plated graphite fillers, one gasket manufacturer's scientists found a correlation among volume resistivity, through-resistance, and shielding effectiveness for conductive gaskets. These scientists fabricated hollow circular, 0.25-inch OD (outside diameter) and 0.125-inch ID (inside diameter) gaskets using different conductive elastomer materials. Volume resistivity, through-resistance, and shielding effectiveness were measured for each gasket sample.

As seen in Table 3, the shielding performance is quite good for materials with volume resistivities from 0.0019 to 0.16 ohm-cm, and with corresponding through flange resistance from 0.005 to 0.075 ohms. Even the carbon-filled material showing 2 ohms DC through-resistance provided acceptable shielding for many applications.

Note that the shielding effectiveness values shown are heavily dependent on the standardized test methodology used. In this case it was measured using the gasket manufacturer's test procedure. This test involves the use of an EMI shielded room with a two-foot by two-foot open aperture on one wall. This opening comes with a metal coverplate, under which a

Gasket Filler/Binder	Volume Resistivity (Ohm-cm)	Through Resistance (Ohms)	Avg. Shielding Effectiveness 0.2 – 10 GHz (dB)
Ag/Cu silicone	0.0019	0.005	102
Ag/Al fluorosilicone	0.0031	0.005	102
Ag silicone	0.0050	0.007	101
Ag/Al fluorosilicone	0.0062	0.01	103
Ag/Al silicone	0.0067	0.01	104
Ag/Glass silicone	0.0069	0.01	103
Carbon silicone	5.0	2.0	60
Carbon silicone	22.4	34.0	38
Note: Accuracy of shielding effectiveness data is ± 4 dB			

Table 3. A comparison of resistivity, resistance, and shielding effectiveness among conductive elastomers with different fillers.

peripheral EMI gasket is mounted. The test procedure consists of establishing the radiated signal strength through the open aperture (reference level), and then measuring the reduced signal strength after the gasketed coverplate is installed over the aperture. The difference in signal strength is the shielding effectiveness in decibels. While this test methodology is widely used in industry, true shielding performance is always a measurement taken in the actual application.

More recent tests compared nickel-plated graphite filled silicone form-in-place material to silver-plated copper and silver-plated aluminum-filled silicone FIP material. These tests were performed in a similar fashion to those described above, and the results, shown in Table 4, were similar.

These gaskets were also retested after 1000 hours exposure to 85°C (results not shown.) There was little or no difference in DC through-resistance or shielding effectiveness in any of these materials.

RELATING VOLUME RESISTIVITY TO SHIELDING EFFECTIVENESS

The above data raise an important question: why doesn't volume resistivity, or at the very least through-flange resistance, predict shielding effectiveness? The answer is that there is another aspect of EMI shielding to be considered. Shielding is achieved by a combination of the reflection and absorption of unwanted electromagnetic energy. Returning (reflecting) radiation back from a surface provides some shielding—the primary shielding method for metal surfaces. The other method for EMI shielding is absorption. As the name implies, during absorption the actual amount of electromagnetic radiation is reduced. Some of the radiation is absorbed by the gasket and is converted from electromagnetic wave energy to resistive heat loss.

All EMI gaskets provide both shielding mechanisms. However, one class of shielding materials, *i.e.*, microwave absorbers, contains fillers that are especially effective at absorbing electromagnetic energy. Graphite is a microwave absorbing filler. Thus, nickel-plated graphite fillers in EMI gaskets can function both as microwave absorbers and as conductors. These gaskets thereby provide much higher levels of shielding than would be expected from through-flange resistance values.

Gasket Filler/Binder	Volume Resistivity (Ohm-cm)	Through Flange Resistance (Ohms)	Avg. Shielding Effectiveness 0.2 – 10 GHz (dB)
Ni/C silicone	0.1	0.038	70
Ag/Cu silicone	0.001	0.003	70
Ag/Al silicone	0.002	0.009	70

Table 4. Resistivity, resistance, and shielding effectiveness testing on nickel-plated graphite filled elastomer gaskets and alternative commercial-grade materials.

SUMMARY

The above data show that DC resistance is not always an accurate predictor of shielding effectiveness. Among fillers that function similarly (Ag, Ag/Cu), the DC resistance will correlate to shielding effectiveness. However, given the inherently different properties of Ag and Ni, DC resistance does not accurately predict relative shielding effectiveness of gaskets using these fillers.

When high shielding effectiveness is required, there is a strong role for nickel-plated graphite fillers in conductive elastomer EMI gasketing applications. Despite the relatively high DC volume resistivity of nickel-plated graphite filled elastomers, the actual *in situ* through-resistance and resultant shielding effectiveness allow these materials to be extremely effective EMI shielding solutions.

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