Facts at a Glance

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How Smaller Form Factors Exacerbate ESD Risks and How Foil Resistors Can Help

Understanding the Risks of ESD

For most of us, electrostatic discharge (ESD) and static electricity are little more than the shocks received when touching a metal doorknob after walking along a carpeted floor, or when opening a car door. The level of the voltage produced depends on a number of factors, such as the affinity of the two bodies and the air humidity. Even so, these "harmless" shocks can reach values over 25,000 V.

ESD can be defined as a rapid transfer of charge between bodies at different electrical potentials – either by direct contact, arcing, or induction – in an attempt to become electrically neutral. The human threshold for feeling an ESD is only around 3000 V, so any discharge that can be felt is above this voltage level. Because the duration of this high voltage spike is less than a microsecond long, the net energy is small compared to the size of the human body over which it is spread. From the human body's point of view, ESD does no harm. But when the discharge is across a small electronic device, the relative energy density is so great that many components can be damaged by ESD at levels as low as 3000 V or even 500 V.

ESD damage can occur at any stage of the component's life, from manufacturing to service. For many years it was thought that semiconductor components such as diodes and transistors were particularly susceptible to ESD, but now we know that passive components such as resistors can sometimes be more sensitive to ESD than active components. Unless specific precautions are taken, then, a wide range of electronic components can be damaged by ESD. The most common cause of ESD damage is direct transfer of an electric charge from either a human body or a charged material to an ESD-sensitive (ESDS) device.

Resistors and ESD

In resistors, ESD sensitivity is a function of size, value, physical construction and thickness of the resistive layer. The smaller the resistor, the less space there is to spread the energy caused by an ESD pulse. When this energy is concentrated in a small area of a resistor's active element, and in particular where there is a high current density or hot spots, it causes the element to heat up, which can lead to irreversible damage. With the growing trend of miniaturization, electronic devices, including resistors, are becoming smaller and smaller, causing them to be more prone to ESD damage. Resistance changes due to ESD damage, like load-induced changes, are permanent and can be either positive or negative depending upon the resistor's design and technology.

Three Categories of ESD Damage

Parametric Failure
Parametric failure occurs when the ESD event alters one or more device parameters (resistance in the case of resistors), causing it to shift from its required tolerance. This failure does not directly pertain to functionality; thus a parametric failure may be present while the device is still functional. For example, if a 10 kΩ resistor with a 1 % tolerance undergoes an ESD event that changes its resistance to 11 kΩ (a 10 % deviation), the device would still be able to function as a resistor. But now its parameters have been altered, and it is no longer suitable for its original function. The consequences of such changes may not be immediately apparent but rather may manifest themselves only during circuit temperature excursions, thermal shocks, load life, or any other parametric-shifting influence that would normally be accommodated through error-envelope planning for net accumulated shift limitations.

Catastrophic Damage
Catastrophic damage has occurred when the ESD event causes the device to immediately stop functioning. This may occur after one or a number of ESD events with diverse causes, such as human body discharge or the mere presence of an electrostatic field.

Latent Damage
Latent damage has occurred when the ESD event causes moderate damage to the device, which is not noticeable, as the device appears to be functioning correctly. However, the load life of the device has been dramatically reduced, and further degradation caused by operating stresses may cause the device to fail during service. Latent damage is the source for greatest concern, since it is very difficult to detect by re-measurement or by visual inspection, since damage may have occurred under the external coating.

Resistor Technologies and ESD Sensitivity

Different resistor technologies exhibit various levels of sensitivity to ESD damage. Damage to an ESDS device depends on the device's ability to dissipate energy and withstand the energy of the voltage levels involved, and in resistors is generally exhibited by a change in the electrical resistance of the device. This is especially crucial in resistors requiring high precision and reliability.

The three most common resistor technologies are thin film, thick film, and Bulk Metal® Foil. Each has specific characteristics related to ESD sensitivity.

Thin film resistors are composed of a metal layer that is only a few hundred angstroms thick. This severely limits the device's capability to withstand the energy that is passed through it during an electrostatic discharge, causing it to be very sensitive to ESD damage. As a result, thin film resistors are sensitive to energy and can experience value changes of up to 5 % before the ESD causes the film to rupture or to melt.

Thick film resistors are comprised of a random dispersion of conducting metal particles within a non-conducting particulate medium, usually ceramic; hence they are also known as "cermet" resistors. Current through the resistor follows along the random contacts formed among the metal particles. Power surges cause breakdowns in some of the inter-particulate isolation, thereby reducing resistance by establishing new additional current paths. Thus, ESD surges almost always cause a reduction in resistance. This fact is so well established that thick film manufacturers use controlled power surges to tune the resistors to the required resistance and tolerance, which typically ranges from 5% to 20%. The susceptibility to change does not stop at manufacture and the resistor is subject to similar changes every time the resistor experiences an ESD event. ESD-induced changes while in service can cause resistance changes up to 50%, which is easily sufficient to cause a malfunction.

Bulk Metal® Foil resistors have a number of characteristics that make them superior to both thin and thick film when it comes to withstanding ESD. Bulk Metal® Foil resistors are comprised of a single layer of special metal alloy rolled into a foil and mounted on a high thermal conductivity ceramic substrate with maximum foil-ceramic interface contact for maximum conduction of heat. As a foil, the molecular structure of the resistance element is the same as the base alloy and therefore has the same metallurgical stability and the same ability to withstand power surges and long-term drift. The foil is typically 100 times thicker than thin film, and therefore the heat capacity of the resistive foil layer is much higher compared to the thin film layer.

Testing Resistors for ESD Sensitivity

Manufacturers test for ESD sensitivity (ESDS) per customer request, but usually do not publish ESDS specifications in their data sheets. However, the ESD of precision chip resistors depends on the following:

- Resistive material
- Production technology (thick film, thin film, or foil)
- Chip size
- Ohmic value
- Resistive layer's thickness
- Resistor's construction
- Design of the resistive pattern

In testing the influence of above factors, the results depend also on the test method used.

Table 1 shows typical specifications for two main technologies used in production of high precision surface mounted chip resistors: Bulk Metal® Foil and thin film.

TABLE 1 - ELECTRICAL SPECIFICATIONS OF FOIL AND THIN FILM CHIPS

PRODUCT TECHNOLOGY	BEST TCR, MIL. RANGE	RANGE OF OHMIC VALUES, ALL CHIP SIZES
Bulk Metal Foil	0.2 ppm/°C	5 Ω to 150 kΩ
Thin Film	10 ppm/°C	30 Ω to 3 MΩ

Bulk Metal® Foil chips are produced by cementing a special nickel-chromium alloy foil, rolled to a thickness between 2 and 10 microns, to a ceramic substrate. Thin film chip production involves deposition (by evaporation, sputtering or similar methods) on a ceramic substrate of a film, mainly nickel-chromium or Tantalum Nitride. A typical thickness of the thin film layer is about 1/100 of the Bulk Metal® Foil.

Table 2 represents chips which are made in standardized sizes, in rectangular shapes. In the middle of the rectangle is a pattern formed in the resistive layer of foil or thin film, connected on two sides to two termination pads.

TABLE 2 - CHIP RESISTOR STYLES, ASSIGNED ESD TEST VOLTAGE AND ENERGY DENSITY

STYLE		RESISTIVE LAYER'S DIMENSIONS (1) (mm)	LAYER'S AREA (mm^2)	ESD TEST VOLTAGE (2) (V)	ESD ENERGY (E mJ)	ENERGY DENSITY (E mJ/mm^2)
METRIC	INCHES					
RR1005M	RR0402	0.5 x 0.5	0.25	500	0.019	0.076
RR1608M	RR0603	1 x 0.8	0.8	1000	0.075	0.094
RR2012M	RR0805	1.4 x 1.2	1.7	1500	0.169	0.100
RR3216M	RR1206	2 x 1.6	3.2	2000	0.300	0.094
RR5025M	RR2010	4 x 2.5	10	3000	0.675	0.068

Notes

(1) Approximate dimensions of the part of chip's surface occupied by the pattern, in mm

(2) Per draft International Standard prEN140401-801:200X

Tables 3, 4, and 5 show the results of ESD tests on thin film, thick film, and foil resistor chips – number of units, out of a group of 20, which showed a shift within a given percentage range. The superiority of Bulk Metal® Foil precision resistors over thin film, when subjected to ESD, is attributed mainly to their greater thickness (foil is typically 100 times thicker than thin film), and therefore the heat capacity of the resistive foil layer is much higher compared to the thin film layer. Thin film is created through particle deposition processes (evaporation or sputtering), while foil is a bulk alloy with a crystalline structure created through hot and cold rolling of the melt. Tests show that Bulk Metal® Foil chip resistors can withstand ESD events above 25 000 V, while thin film chip resistors have been seen to undergo catastrophic failures at electric potentials as low as 3000 V and parametric failures at even lower voltages. If the application is likely to confront the resistor with ESD pulses of significant magnitude, the best resistor choice is Bulk Metal® Foil.

TABLE 3 - 2 kV ESD DISCHARGE - COMPARISON OF DEVIATIONS, FOIL VS. THIN FILM							
TYPE AND VALUE	> 0.5 %	0.2 % to 0.5 %	0.1 % to 0.2 %	0.05 % to 0.1 %	0.02 % to 0.05 %	0.01 % to 0.02 %	< 0.01 %
Foil, 30 Ω	0	0	0	0	1	6	13
TF1, 30 Ω	12	8	0	0	0	0	0
TF2. 30 Ω	0	1	1	2	8	4	4
Foil, 1000 Ω	0	0	0	0	0	0	20
TF1, 1000 Ω	20	0	0	0	0	0	0
TF2, 1000 Ω	20	0	0	0	0	0	0

TABLE 4 - 3 kV ESD DISCHARGE - COMPARISON OF DEVIATIONS, FOIL VS. THIN FILM							
TYPE AND VALUE	> 0.5 %	0.2 % to 0.5 %	0.1 % to 0.2 %	0.05 % to 0.1 %	0.02 % to 0.05 %	0.01 % to 0.02 %	< 0.01 %
Foil, 30 Ω	0	0	0	0	1	8	11
TF2. 30 Ω	4	10	3	2	1	0	0
Foil, 1000 Ω	0	0	0	0	0	0	20

TABLE 5 - 24 kV ESD DISCHARGE - FOIL CHIPS ONLY							
TYPE AND VALUE	> 0.5 %	0.2 % to 0.5 %	0.1 % to 0.2 %	0.05 % to 0.1 %	0.02 % to 0.05 %	0.01 % to 0.02 %	< 0.01 %
Foil, 30 Ω	0	0	1	1	14	3	1
Foil, 1000 Ω	0	0	0	0	0	0	20

Conclusions:

- When it comes to withstanding ESD, foil resistors have a clear advantage over thin film chips.
- Foil chips can handle an order of magnitude more ESD energy than thin film chips without experiencing a change in their resistance.
- The standard for ESD protection in chip resistors ranges from 1 kV to 3 kV, but Bulk Metal® Foil resistors can handle ESD pulses > 24 kV with no significant shift in resistance (measured shifts were less than 0.1 % for a 30-Ω resistor and less than 0.01 % for a 1000-Ω resistor)
- Thin film chips from different sources and with different values show non-uniform behavior with respect to ESD. This may be due to a pattern design that was not optimized for ESD, or a non-uniform film deposition process, or a substrate material that was not of the best quality.

APPENDIX

Standards for ESD Testing Of Chip Resistors

- The international standard IEC 61340-3-1 describes the testing of electronic components for ESD compatibility by using the Human Body Model (HBM).
- A test simulator generates an adjustable voltage ESD pulse by discharging a 150 pF capacitor to the device under test (DUT) with a discharge resistor of 330 Ω connected in series.

- The ESD exponential waveform which was calibrated with a discharge resistance of 330 + 2 Ω will have a time constant which is twice as long when the DUT is a resistor of 332 Ω and much longer with a high Ohmic value DUT. Test voltages are listed in table 2. The limit of allowed change of resistance is set for all chip stability levels at 0.5 % + 0.05 Ω.

RC time constant = (330 + 2) x 150 x 10-12 Ω x (s/Ω) = 49.8 x ns (compared to 150 ns, per ANSI standard).

Energy of ESD Absorbed By a Resistor Chip

- The ESD is simulated by charging a capacitor of C = 150 pF to a specified voltage V.
- The stored energy E = 0.5 CV2 is discharged into two resistors connected in series: discharge resistor RDIS of 330 Ω representing the resistance of a human body and RDUT - of the DUT, in our case the tested chip. As a result, the following voltage VDUT and energy EDUT are applied to the chip:
    - VDUT = V x RDUT /(330 + RDUT)
    - EDUT = E x RDUT /(330 + RDUT)

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