New Space ESD-resistant Smart-Antistatic Wires and Cables insulations

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***Abstract*— Space is a harsh environment and especially for polymers materials which can be exposed to ionizing and ultraviolet radiations, atomic oxygen (ATOX), wide temperature cycling and electrostatic discharges (ESD) risks. Axon' with its development and manufacturing solutions in all fields of electrical interconnect, has been exploring and developing various new and innovative products to provide the best performance and optimized mass saving solutions to meet all Space requirements. This paper presents some latest results concerning the development of new materials and antistatic wires and cables solutions with controlled insulation volume resistivities in the range of 10^7 to 10^{15} ohm.cm, in order to prevent surface and internal electrostatic discharge (ESD).**

INTRODUCTION

Wires and Cables ESD Risk in Space

Wires and cables used in Space are susceptible to initiating electrostatic discharges (ESD) under certain conditions. These ESD phenomena are mainly caused by the use of excellent electrical material insulation layers and their ability to store and build-up electrostatic charges due to their intrinsic high resistivity [1].
The incoming charged particles can build-up inside dielectrics up to "break down" threshold levels, leading to electrical arcs discharged into nearby sensitive circuits (Fig 1).

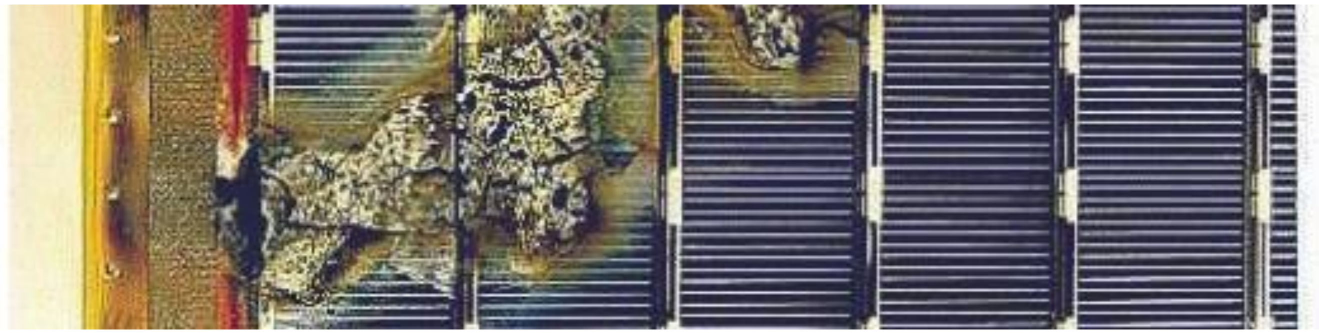


Fig 1. Example of arc damage sustained on a solar array (ESA EURECA)[3]

The approximate regions of concern for charging issues in Space are illustrated in Fig 2. ESD phenomena can lead to catastrophic failures such as occurred on ADEOS-II in 2003 which resulted in the complete loss of the satellite [2].

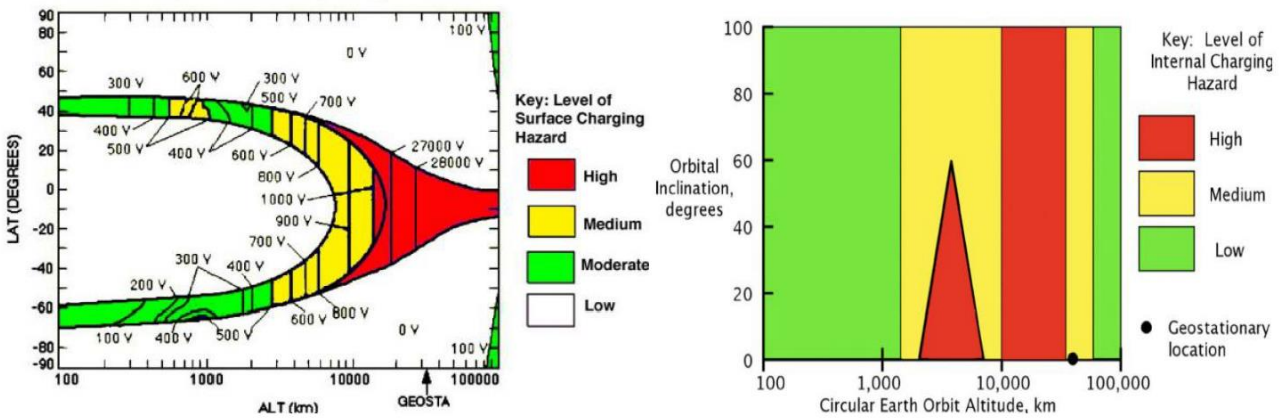


Fig 2. Typical orbits of concerns for surface and internal charging hazards for spacecraft with circular orbits[4]

INNOVATIVE ANTISTATIC WIRES CONCEPT

A standard way to protect electrical harnesses and other ESD sensitive components is to cover them with conductive films, braids or coatings in order to quickly absorb and evacuate most of the incoming charged particles towards the mass of the satellite. The drawback of this solution is the increase in mass, cost and volume, and reduced flexibility of such interconnect system. The thickness of any additional conductive material also needs to be optimized in order to reduce the residual radiation flux low enough to fully prevent any internal ESD (iESD) risk. This conductive surface layer require also a specific grounding, which further increase the mass, cost and complexity of the system.

An innovative approach explored by Axon' to reduce the ESD risk for wires and cables without these drawbacks is to replace all the highly insulating dielectrics with "leaky" materials in order to permit a fast enough evacuation of incoming charged particles to the nearest conductive layer (Fig 3). The main objective of this development, supported by ESA activity ITT AO/1-7877/14/NL/RA, was to explore this concept by formulating, processing and testing new wire and cable insulation materials able to dissipate through the central conductor the electrostatic charges from Space environment.

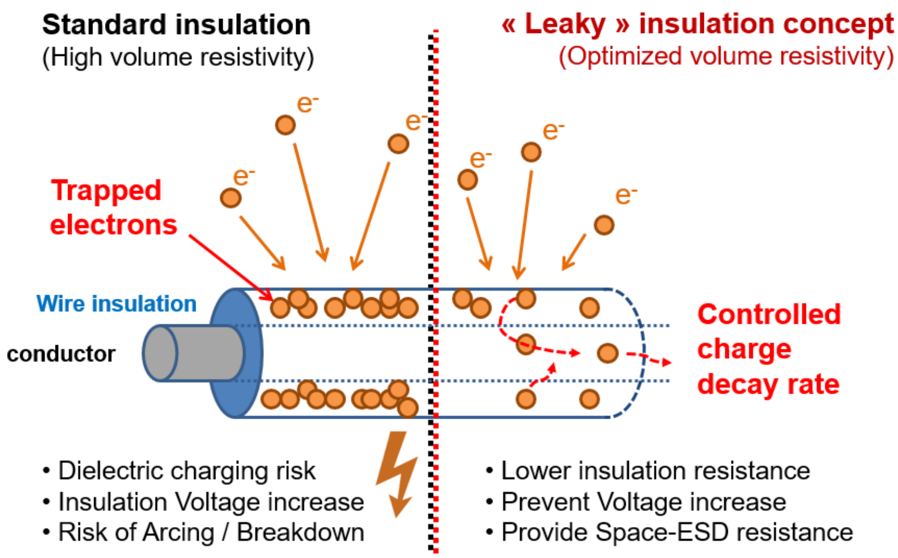


Fig 3. Illustration of the leaky insulation concept explored for the development of new Space ESD resistant wires and cables

The main challenge was to formulate and process new materials with volume resistivities low enough to permit sufficient charge decay speed (to ensure Space-ESD resistance), but at the same time maintaining sufficiently high resistivity values to guarantee the electrical insulation performance of the finished wires (acceptable insulation resistance and dielectric strength).

Bulk Resistivity target for Space ESD-safe insulations

Standard and qualified wire and cables used in Space are built from excellent electrical polymers insulations exhibiting volume resistivities in the range of 10^{16} to 10^{21} ohm.cm. A safe material bulk resistivity value to prevent insulation charge build-up in Space is a function of the worst case radiation scenario considered (current density passing through the insulation), insulation thickness, and the maximum acceptable voltage increase inside the dielectric (dielectric strength).

The ESA Spacecraft charging standard[5] indicates that for dielectric materials laid on top of a more conductive material, the resistivity of the dielectric shall be such that the electric field anywhere within the dielectric does not exceed an E_{MAX} value. This would be fulfilled through the requirement that the resistivity (r) is less or equal to the ratio of E_{MAX} over the current density J (Eq. 1)

$$r \leq \frac{E_{MAX}}{J} \qquad (1)$$

In a similar way, NASA and JAXA Space charging standards guidelines also define some typical worst case scenarios and maximum bulk resistivity values in order to prevent unacceptable charging risk[4-6]. A maximum acceptable volume resistivity value to ensure Space-ESD insulation safety would then be mainly between 10^{11} to 10^{14} ohm.cm based on reviewed references and their associated worst-case charging rate hypotheses.

It should be noted that insulation materials exhibit also different radiation-induced conductivity (RIC) behaviour, which corresponds to an increase in insulation conductivity (decrease of volume resistivity) as a function of the radiation spectra[7, 8]. For materials with high bulk resistivity ($\geq 10^{16}$ ohm.cm) or long polarization decay times, the electrical measurement method used (electrometer at constant voltage, charge storage decay, etc..) has also an important influence on measured resistivities[9, 10].

New Antistatic Wires prototypes results

New modified ETFE-based antistatic formulations and coated AWG24 silver-plated copper wire prototypes have been successfully manufactured and characterized. A summary of achieved volume resistivities range for these new materials and cables prototypes compared to ESA ECSS-E-ST-20-06C and NASA JSC-66552 electrical classification of insulations is presented in Fig 4.

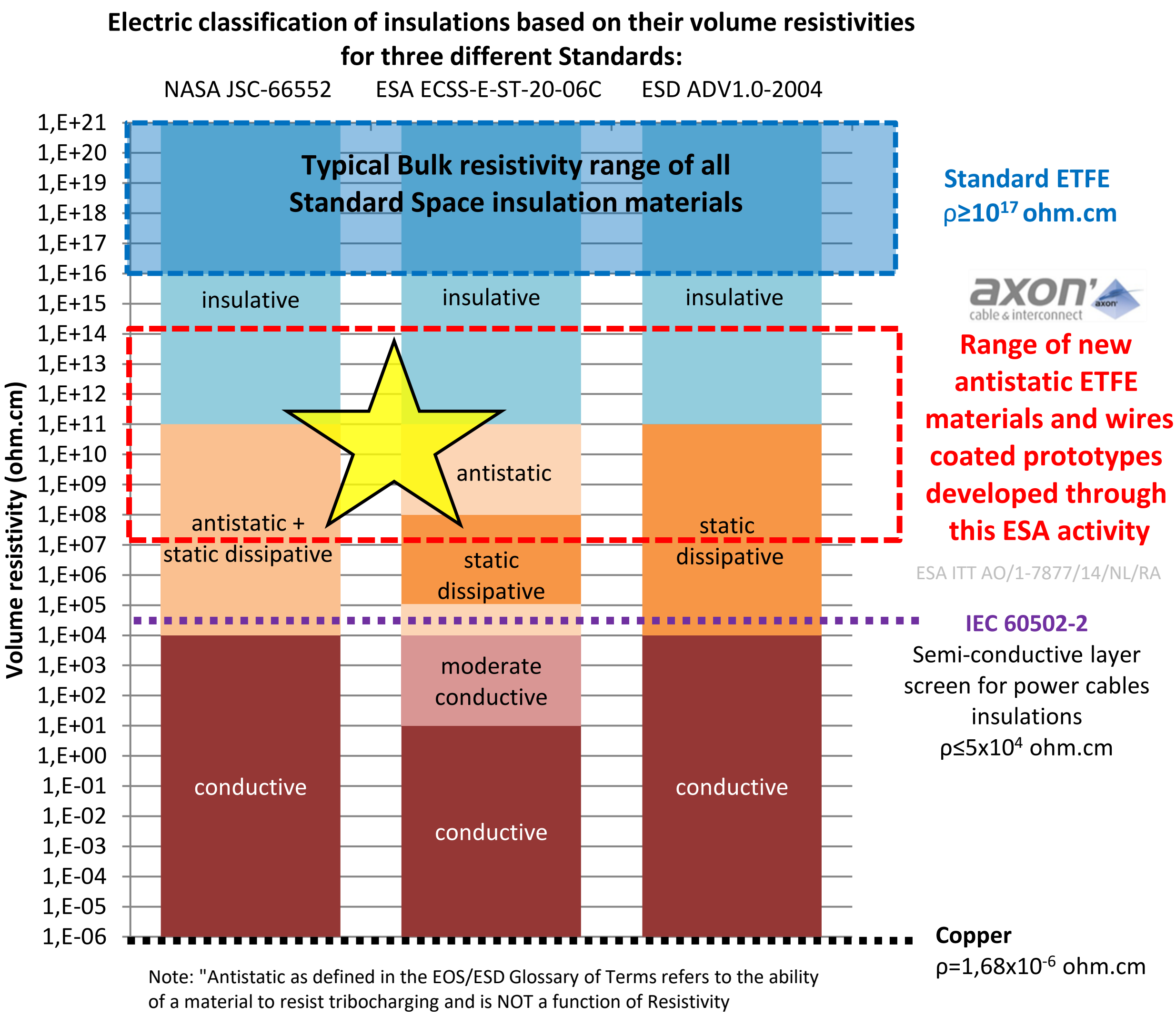


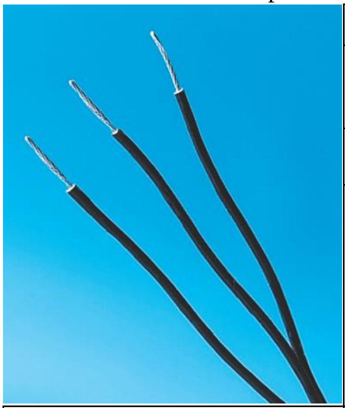
Fig 4. Summary of new modified ETFE-based materials and insulated wires developed through ESA project ITT AO/1-7877/14/NL/RA, as a function of their volume resistivity. Insulation classification ranges based on ESD, ESA and NASA charging standards [5, 11]

The new developed solutions exhibit volume resistivities in the range of $\approx 10^{7}$ to 10^{15} ohm.cm compared to $\geq 10^{17}$ ohm.cm for witness ETFE materials and insulated wires. Measured resistivities vary as function of applied voltage, material formulations, processing methods and parameters used.

Three references of these newly developed antistatic coated wire prototypes have been selected for further electrical, mechanical and thermal characterizations based on ESA ESCC 3901 requirements (generic Space specification for low voltage wires and cables). These include spark test, voltage test, abrasion resistance, cut-through resistance, blocking, shrinkage, cold bend test and thermal accelerated ageing. Complementary tests have also been performed during the development stage, such as tensile properties of the modified insulations, breakdown voltage, dielectric strength and volume resistivity measurements at high and low temperature, and as a function of applied voltage and duration.

The Table 1 presents an extract overview of some test results for one selected antistatic wire prototype intended for low voltage applications (≤100V). It was possible to achieve antistatic coated wires with very thin insulations thickness (≤ 250µm) whilst still maintaining a good balance of electrical and mechanical performance.

Table 1: Evaluation test plan results extract for the Axon W4825M1 antistatic wire prototype

<table>
<tr><td rowspan="6"></td><td colspan="3">Axon' Wire Prototype reference : W4825M1</td></tr>
<tr><td rowspan="2">Wire Conductor</td><td>Type</td><td>SPC AWG 24</td></tr>
<tr><td>Diameter</td><td>Ø 0.64mm</td></tr>
<tr><td>Wire Insulation system</td><td>Insulation material</td><td>Modified Axon Antistatic ETFE</td></tr>
<tr><td rowspan="2">Finished wire</td><td>Diameter Ø (mm)</td><td>≈ 1.10 mm</td></tr>
<tr><td>Linear mass</td><td>≤ 3.40 g/m</td></tr>
<tr><td>Spark test</td><td>ESCC 3901 based</td><td>Max Voltage</td><td>800V - PASS</td></tr>
<tr><td>Voltage test</td><td>ESCC 3901 based</td><td>Max Voltage</td><td>500V - PASS</td></tr>
<tr><td>Abrasion resistance</td><td>ESCC 3901/012</td><td>Minimum 100 cycles</td><td>>2000 cycles</td></tr>
<tr><td>Cut-through resistance</td><td>ESCC 3901/012</td><td>Mini 40 N</td><td>>150 N</td></tr>
<tr><td>Blocking test</td><td>ESCC 3901/012</td><td>200°C - no sticking</td><td>PASS</td></tr>
<tr><td>Shrinkage test</td><td>ESCC 3901/012</td><td>Max 2mm</td><td>< 0.120 mm</td></tr>
<tr><td rowspan="2">Insulation Tensile Properties</td><td rowspan="2">No standard specification or requirements</td><td>Stress at break (MPa)</td><td>>35MPa</td></tr>
<tr><td>Strain at break (%)</td><td>>250%</td></tr>
<tr><td rowspan="5">Insulation bulk resistivity</td><td rowspan="5">Volume resistivity (ohm.cm)
based on ASTM D257
DC voltage
measurement after 60sec</td><td>at 10V</td><td>2.4E+15</td></tr>
<tr><td>at 50V</td><td>1.0E+15</td></tr>
<tr><td>at 100V</td><td>8.3E+14</td></tr>
<tr><td>at 200V</td><td>1.3E+13</td></tr>
<tr><td>at 300V</td><td>1.8E+11</td></tr>
<tr><td rowspan="7">Cold Bend Test
ESCC 3901/012
-80°C
4hours</td><td rowspan="3">Volume resistivity
initial
(ohm.cm)</td><td>at 10V</td><td>5.7E+14</td></tr>
<tr><td>at 50V</td><td>2.0E+13</td></tr>
<tr><td>at 250V</td><td>5.2E+11</td></tr>
<tr><td rowspan="3">Volume resistivity
after Cold bend
(ohm.cm)</td><td>at 10V</td><td>3.0E+13</td></tr>
<tr><td>at 50V</td><td>2.1E+12</td></tr>
<tr><td>at 250V</td><td>1.9E+10</td></tr>
<tr><td>Final Voltage Test</td><td>at 250V</td><td>PASS</td></tr>
<tr><td rowspan="7">Accelerated thermal ageing
ESCC 3901/012
+230°C
120hours</td><td rowspan="3">Volume resistivity
initial
(ohm.cm)</td><td>at 10V</td><td>2.5E+15</td></tr>
<tr><td>at 50V</td><td>1.5E+15</td></tr>
<tr><td>at 250V</td><td>2.4E+12</td></tr>
<tr><td rowspan="3">Volume resistivity
after thermal ageing
(ohm.cm)</td><td>at 10V</td><td>3.1E+12</td></tr>
<tr><td>at 50V</td><td>7.7E+10</td></tr>
<tr><td>at 250V</td><td>1.5E+08</td></tr>
<tr><td>Final Voltage Test</td><td>at 250V</td><td>PASS</td></tr>
</table>

The influence of temperature cycling on the electrical properties of these new materials has also been investigated : it can be seen, for example, that the antistatic material formulation W401B1 with a measured volume resistivity of 10^{10}-10^{11} ohm.cm at 500Vdc remains stable throughout the whole tested temperature range (-60 to +160°C, Fig 5).

Another interesting result is the influence of applied differential voltage on the measured wire insulation resistivity. At low voltage stresses, below a critical level (≈100-250V, the value is function of the antistatic formulation and processing parameters), the coated wire maintain a high electrical resistance with measured volume resistivities in the range of 10^{11} – 10^{15} ohm.cm. The measured resistivity decrease as the applied voltage rises, and enter the "antistatic range" when the differential voltage increases beyond a critical value. At these higher voltage levels, measured resistivities decrease between [10^{7} – 10^{11}] ohm.cm depending on the coated wire reference, the material formulation and the cable manufacturing tooling and processing parameters used. An illustration of this dynamic "smart antistatic" behaviour is presented in Fig 6 for the W4825M1 wire prototype.

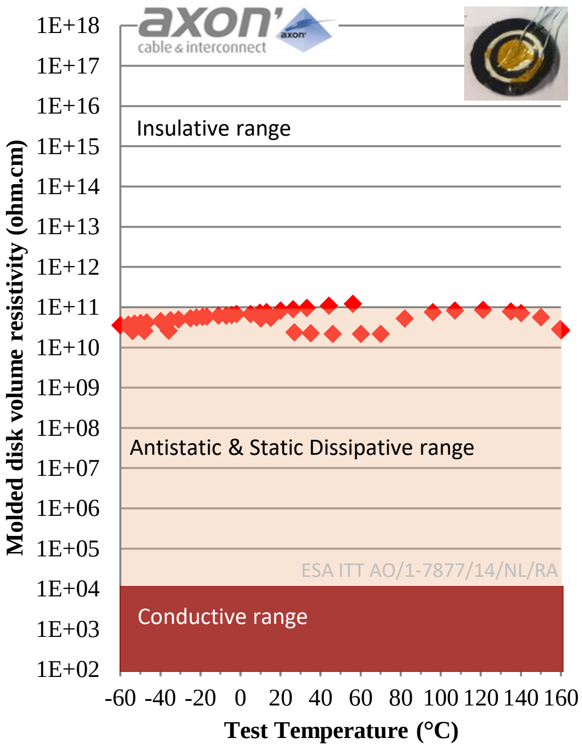


Fig 5. Volume resistivity as function of temperature for an antistatic molded disk specimen W401B1 and measured at 500Vdc. Colored insulation classification range as per ESA and NASA ESD-charging standards [5, 11]

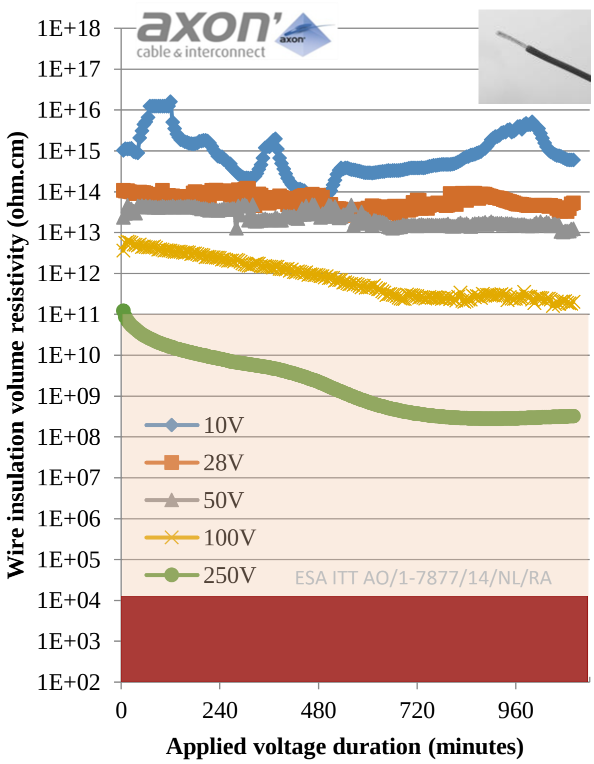


Fig 6. Volume resistivity measurement on the new antistatic modified ETFE wire prototype W4825M1 as function of applied voltage (dc) and testing time duration.

This electrical behaviour could be of special interest for Space applications where bus voltages of many spacecraft power sub-systems are usually in the 28V – 100V range. In such cases, and at operational voltage, these new "smart-antistatic" coated wires would still exhibit good insulating performances, and in case of a voltage anomaly (due to deep dielectric charging for example), the special modified insulation would allow a smooth decay of the charges through the central conductor. This would prevent voltage rising inside the dielectric, and therefore avoid any ESD events such as arcing and subsequent electrical breakdown of the insulation.

CONCLUSION

New Axon' "smart-antistatic" wires prototypes with variable volume resistivities and for different operational voltage applications are now available to the Space community.

Next steps toward a full Space ESCC-type qualification of these new antistatic cables and materials would require the investigation of their RIC parameters and charge decay behaviour when exposed to a GEO-like radiation spectra, in vacuum and thermal cycling between -150 to +150°C. This would help to confirm the effective Space-ESD resistance of this innovative solution, and to optimize if required wires designs and material formulation.

ACKNOWLEDGMENT

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