Reliability of Electronics in Harsh Environments: Preventing Electrical Leakage and Corrosion Caused By Sub-micron Pollutant Particles

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In many parts of the world, soft coal is the primary energy source. Combustion of soft coal produces sulfur dioxide, which oxidizes in the atmosphere to form sulfuric acid and other oxidized sulfur-containing molecules. When electronic equipment and devices are contaminated with particles derived from these gases, subsequent exposure to atmospheric moisture can cause failure due to electrical leakage and arcing in the presence of electric fields.

The most important components of the environment with respect to degradation of electronic devices are particles and water vapor. Most of the mass of particulate matter in the atmosphere exhibits a bimodal distribution. Particles 2.5 - 15 µm are largely derived from natural materials and are usually called coarse particles, while particles 0.1 - 2.5 µm, usually called fine particles, are largely derived from anthropogenic sources. The combined mass of fine and coarse particles. defined here as total suspended particulate (TSP), is typically 30-40 $\mu g/m^3$ outdoors and 5 $\mu g/m^3$ indoors for telecommunications equipment rooms in the U.S.. Typical sulfate levels are 4-6 $\mu g/m^3$ outdoors and 0.6-0.8 $\mu g/m^3$ indoors. For the new work reported here for locations in eastern and southeastern Asia, TSP levels in excess of 200 $\mu g/m^3$ have frequently been measured outdoors, especially in eastern Asia. The sulfate portion of this mass is often >15 $\mu g/m^3$. Indoor TSP concentrations are frequently in excess of 30 $\mu g/m^3$.

Coarse particles form predominantly by abrasion processes, e.g., construction activity or the action of wind on soils. The main source of fine particles in populated areas is fossil fuel combustion, though volcanic and geological activity can also contribute. Due to their different origin, coarse particles tend to have a lower fraction of water-soluble ionic components (5 - 20%) than fine particles (25 - 50%) , excluding H^+, OH^-, and $CO_3^=$. With any particle, the higher the fraction of water-soluble ions, the higher is the corrosivity. As a result, fine particles are more corrosive than coarse particles. Key to the corrosive behavior of fine particles is their critical relative humidity (CRH). CRHs at 24^o C of some of the major ionic compounds found in fine particles in most urban environments are: NH_4HSO_4, 40%; NH_4NO_3, 65%; NaCl, 75%; $(NH_4)_2SO_4$, 81%. The electrolyte films that form on surfaces contaminated with fine particles when they absorb moisture are corrosive to many metals and can lead to electrolytic corrosion or leakage currents when an electric field exists between conductors.

In the U. S., indoor concentrations of fine particles in buildings with central air handling systems can range from 20 - 50% of the outdoor concentrations, depending on: (1) the efficiency of air filtration systems, including both building systems and equipment filters; (2) the rate at which outdoor air is brought into the building; and (3) indoor sources, e.g., smoking or human activity. Concentrations within homes, sheds, and utility huts can range from 20 to 75% of the outdoor concentration due to: (1) the penetrability of particles through air-leakage pathways or open doors or windows; (2) the absence of efficient particle air filtration; and (3) indoor sources like those mentioned above, as well as aerosols derived from liquid processes. In eastern Asia, cooling of electronic equipment rooms is typically accomplished with internal air conditioners using re-circulated water as the cooling medium. In this case the relationship between indoor and outdoor concentrations depends predominantly on the rate of leakage of outside air into and out of the equipment room. Our measurements show indoor/outdoor ratios of particles > 0.5 µm diameter ranging from 0.05 to over 0.6. At the low end, the hazard of hygroscopic dust to equipment is comparable to that typical of the U.S. At the high end, conditions are an order of magnitude harsher.

On circuit boards, the absorption of moisture by deposited particles or other ionic contaminants may result in the formation of an electrolyte around electrical leads. Bridging of leads can result in leakage currents. The current may lead to soft errors or "cross talk." If the electrolyte extends over a defect in the covercoat and the defect sits above a conductor operating at a different voltage from that on the lead, arcing can occur between the lead and the conductor. Typically, the leakage current increases approximately exponentially with RH. Covercoats can be effective in preventing hazardous leakage currents. However, device leads and electrical contacts are not usually covered by covercoats. The maintenance of the RH in electronic equipment locations below 55% minimizes the risk of hazardous leakage currents. The electrical leakage of dust from the more polluted environments of the world tends to be significantly higher at a given RH than dust from the U.S. In addition to electrical leakage and arcing, dust and other ionic contaminants can lead to direct corrosion of metal conductors and ultimately to open circuits. A water-soluble corrosion product may also migrate to the negative conductor, where it can be reduced to form a metallic deposit that grows toward the positive conductor, eventually forming a short circuit. In some situations, an arc may occur. Severe arcing can pyrolyze circuit boards to form conductive carbon bridges. In the absence of appropriate limitation of current, a fire could result. Again, the combination of contamination, moisture, and bias are required. To minimize leakage currents and corrosion in field operations, it is essential that: (1) design rules and specifications with respect to bond pad and line spacings are strictly followed; and (3) the environment is maintained within design specifications. In eastern Asia, minimizing infiltration of outside air reduces the hazard of hygroscopic dust to performance, and minimizes operational costs of equipment rooms.