CIRCUIT DESIGNER'S NOTEBOOK

Understanding Insulation Resistance

Insulation Resistance (IR) is a measure of the insulating property of dielectric materials and is typically expressed in meg-ohms. The insulation resistance includes both volume and surface resistance and can be expressed as the parallel combination of the two.

Insulation Resistance = $R_V \times R_S / (R_V + R_S)$

Volume resistivity: R_V (ohms cm) also called bulk resistance represents the resistance per unit volume associated with a dielectric material.

Surface resistance: R_S (ohms/sq.) also called sheet resistance represents resistance per unit area and accounts for the leakage path on the outside surfaces of the capacitor. This is a material property; however, surface contamination and porosity also influence this parameter.

IR Measurements:

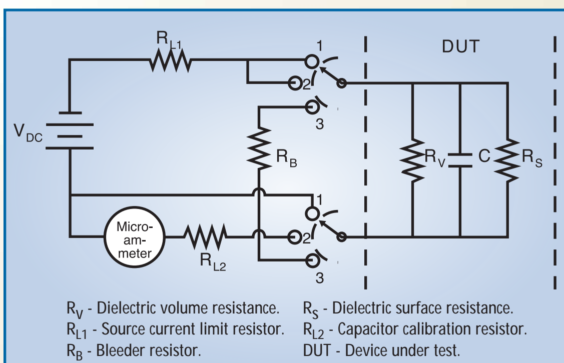
An IR meter is set up to measure insulation resistance by applying a voltage, typically equal to the capacitor's rated working voltage (WVDC), for about one minute. After the capacitor has been charged, the leakage current is then measured. The IR value is determined by taking the ratio of the applied dc voltage across the capacitor and the resultant leakage current after the initial charging period. This value is expressed as leakage or *insulation resistance*. A typical IR for an ATC porcelain chip capacitor is in the order of 10^{12} ohms at 25°C.

The figure represents a simplified circuit of an IR meter with a capacitor IR model depicted between the dotted lines. R_{L1} is placed in series with the dc source in order to limit the charging current to 50ma. In addition R_{L1} will limit the current in instances where the IR is very low or the test sample is shorted. R_{L2} is placed in series with the microammeter in order to calibrate the leakage current into the appropriate insulation resistance value. The bleeder resistor (R_B) is placed across the capacitor in order to discharge the test sample after the measurement has been performed.

Factors Affecting IR:

Dielectric material properties and processing play a major role in determining the IR characteristics of ceramic chip capacitors. Specific formulations as well as ceramic firing profiles are major factors that determine the insulation resistance. Microstructural defects such as voids, cracks, delaminations, and foreign materials are also associated with variations of insulation resistance. These defects are undesirable and require tight control of manufacturing processes to prevent their occurrence.

Insulation resistance is primarily influenced by ionic imbalances in the ceramic crystal structure creating charge carriers that become mobile in the presence of an electric field.



Schematic of IR meter with capacitor IR Model.

Increased numbers of mobile charge carriers result in leakage current paths that degrade the IR. Charge carrier mobility also increases with temperature, hence leading to lower insulation resistance at elevated temperatures. At 125°C the IR will degrade approximately one order of magnitude. Capacitors from various manufacturing lots are frequently tested at the highest rated operating temperature to make it easier to uncover defects in the dielectric. Other factors that effect IR are listed below.

Additives: Chemical additives used in the dielectric formulation may exhibit a valence that will influence the IR of the dielectric. Care in selecting chemical additives such as various oxides must be exercised in order to optimize the IR.

Particle Size & Grain Boundaries: Small ceramic particle sizes will provide a fine grain structure in the ceramic. This is desirable because small grain sizes yield the greatest number of grain boundaries and will therefore act as a barrier to leakage current, thereby enhancing the IR.

Binder Systems: Used in the preparation of ceramic slurry and electrode paste and subsequently removed. This is accomplished during a slow heating cycle in which organic compounds are decomposed and eliminated. If the binders are not properly removed they may leave traces of carbon and other impurities in the ceramic. These residual elements, reacting with the dielectric during sintering, may alter the distribution of mobile charge carriers and create conductive paths, thereby degrading the insulation resistance.

Impurities: Care must be taken throughout the manufacturing process to avoid process contamination. This condition can degrade the dielectric's IR property and therefore must be tightly controlled.

Surface Contamination: Solder flux, moisture, salts and any number of environmental contaminants can easily degrade the capacitor's insulation resistance. Care must be taken to clean the surface free of foreign materials.

Density/Porosity: Ceramic dielectrics must be manufactured as close to the theoretical density of the dielectric material as possible to minimize pores in the ceramic. Large pores in the ceramic microstructure can absorb environmental contaminants as well as moisture leading to degraded IR. This effect is most evident under high operating humidity and can be temporarily reversed by heating the capacitor, thereby baking out the moisture.

Application Considerations:

- Low IR can alter the bias condition of an FET amplifier by offering additional shunt resistance in the bias network.
- Capacitors used in dc blocking and coupling applications need to exhibit high IR to prevent dc leakage current from flowing.
- Filter and matching applications require high IR so that the overall circuit Q remains unaffected.
- The capacitors low frequency dissipation factor (DF) can be affected by low IR. This will make IR appear as a significant part of the dielectric loss, thereby degrading the DF. This degradation occurs because IR appears as a shunt resistance in parallel with the capacitor.
- Low IR in a high power bypass application may result in excessive heat dissipation and degraded circuit performance.
- Overall circuit performance and reliability may be affected over time by voltage stresses and elevated operating temperatures if the IR is initially degraded.

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