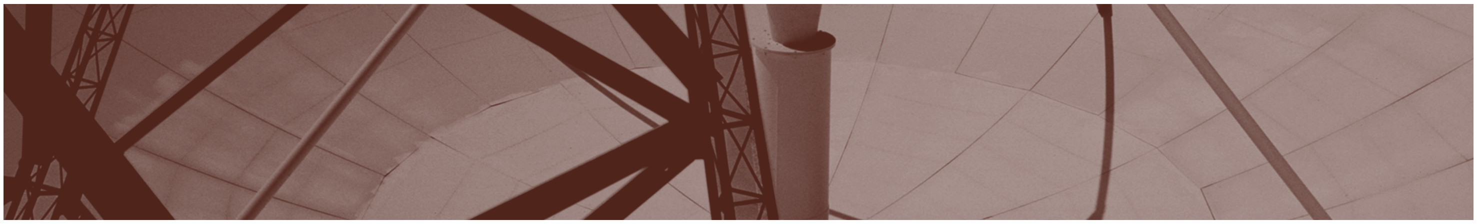


APPENDIX A

Basic Test Methods

Dielectric Constant Measurement

Also known as relative permittivity, K or ε', dielectric constant is tested primarily in one of two ways. For garnet, ferrite, and dielectric materials with dielectric constant values less than ~20, a rectangular waveguide resonant cavity operating in the TE_{10X} mode (where x is odd) at approximately 10 GHz is employed. A dielectric rod sample approximately .050" in diameter is introduced into the center of the cavity perturbing the electromagnetic fields within the cavity. Dielectric constant and loss tangent (1/Q) may then be calculated based on the change in resonant frequency and Q due to the introduction of the sample. This technique is based upon ASTM D-2520, Method B.

For other dielectric materials with higher dielectric constant values, the Courtney "parallel-plate" dielectrometer[1] is employed. With this method, a cylindrical rod resonator sample is placed between two parallel conducting plates. Resonant frequency of the sample in the TE_{011} resonant mode is measured as are the sample dimensions, and from these values dielectric constant is calculated.

Another accurate and reliable method which may be employed for measuring the dielectric constant of thin dielectric substrate specimens is the Resonant Mode Dielectrometer or RMD[2,3]. With this technique, a thin substrate specimen is inserted on the central transverse plane of a cylindrical waveguide RMD cavity. Dielectric constant is calculated based upon the thickness of the sample specimen and its resonant frequency in the H_{011} mode.

Very low frequency (~1 KHz - 1 MHz) capacitance methods may also be used for determination of dielectric constant. Dielectric constant is calculated using very well known relationships among the measured capacitance, area, and thickness of a sample specimen. Care must be exercised to assure complete contact of the conductor to the ceramic surface and to avoid being misled by certain intrinsic low frequency phenomena exhibited by some materials.

Quality Factor (Q) or Loss Tangent Measurement

The quality factor, or Q, is equal to 1/loss tangent. Either method of expression is correct, although quality factor is more commonly associated with microwave circuit design. For the purposes of this catalog, we will refer only to the unloaded quality factor.

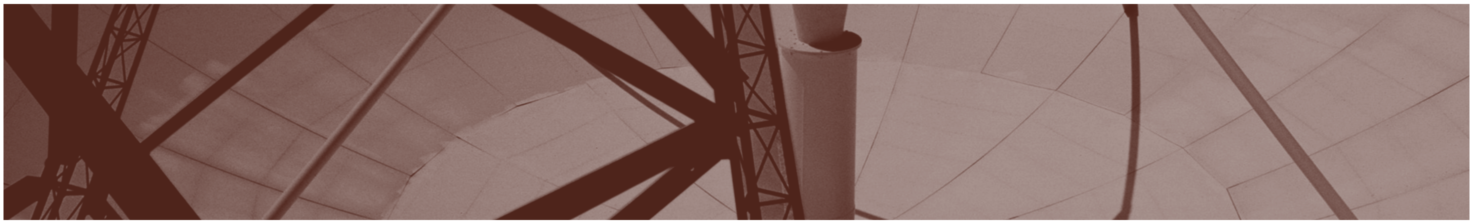
When considering quality factor, one must always bear in mind that from a practical standpoint the measured value of this parameter is highly dependent not only on the intrinsic quality of the ceramic material, but also on the method of measurement, the measurement environment, and the frequency at which the sample is measured. A given material sample may exhibit greatly differing Q values when tested in different test fixtures and environments which may vary in size, shape, conductor quality, coupling, type of sample support, ambient temperature, relative humidity, etc.

Additionally, the intrinsic Q of any given material sample will vary with the frequency of measurement. Often, manufacturers will state that Q vs. frequency is an indirectly proportional linear function such that Q times frequency (often referred to as the $Q*f$ product) is equal to a constant. This concept, however, is overly simplistic and is only suitable for use as a rough first approximation or for use over an extremely narrow range of frequency space. Characterizing Q is further complicated by the difficulty in making electrically identical test fixtures for use at different test frequencies. Therefore, actual measurement of Q, performed under near identical circumstances and at or near the frequency of interest to the end-user is the best way to compare the relative benefits of one material versus another and/or to determine the suitability of a material for a given application.

The method employed for Q measurement of low dielectric constant materials as well as ferrite and garnet materials is discussed above.

Quality factor for higher dielectric constant materials is tested primarily by using a cylindrical resonant cavity made of high conductivity metal with interior dimensions approximately 3-5 times larger than the dimensions of the test sample. The test sample is placed inside the cavity upon a low loss, low dielectric constant support and inductive coupling to the resonator sample is achieved via a coupling loop or bent probe. The S_{21} or transmission characteristics of the $TE_{01\delta}$ resonant mode is measured, and quality factor is calculated using the formula: $Q = (f_0 / \Delta f) / (1-10 ^{(-I.L./20)})$ where f_0 is the resonant frequency, Δf is the -3dB bandwidth, and I.L. is the insertion loss expressed in dB.

Quality factor at very low frequencies (~1KHz -1MHz) may also be measured using various commercially available capacitance or L.C.R. meters and fixtures which give a direct reading of Q. This technique, however, often results in Q data which are extremely inaccurate and potentially misleading unless all variables are properly accounted for, especially for high Q materials. It is best used only for relative comparisons of similar samples.



Temperature Coefficient Of Resonant Frequency (τ_f) Measurement

Temperature coefficient of resonant frequency is measured by using a cylindrical resonant cavity made of high conductivity metal with dimensions approximately 3-5 times larger than the dimensions of the test sample. The test sample is placed inside the cavity on a low loss, low dielectric constant, low thermal expansion support and inductive coupling to the resonator is achieved via a coupling loop or bent probe. The cavity is then placed inside of a temperature chamber and the temperature is cycled over the desired range (usually 25°-60°C). The resonant frequency of the $TE_{01\delta}$ mode is measured at each temperature. Temperature coefficient is calculated as follows and is expressed in parts-per-million-per-degree Celsius (ppm/°C.): $\Delta f_0 / (f_0 \Delta T)$. For more precise applications, polynomials are fitted to the data which can include temperatures below 25°C.

Temperature Coefficient Of Capacitance (τ_c) Measurement

Temperature coefficient of capacitance at ~1KHz - 1MHz is usually measured on samples which have been metallized using a fired-on or electro-deposited high conductivity conductor such as silver or copper. Specially designed and built test fixtures are employed to hold the sample during testing. Capacitance is monitored as the temperature of the samples is cycled and τ_c is calculated as follows and is expressed in parts-per-million-per-degree Celsius (ppm/°C.): $\Delta C_o/(C_o \Delta T)$.

Temperature Coefficient Of Dielectric Constant (τ_k) Measurement

Temperature coefficient of dielectric constant is of primary interest to users of dielectric substrate materials. In most cases, the substrates are tested for temperature coefficient of resonant frequency (τ_f) as if they were a dielectric resonator, and τ_k is calculated using the equation: $\tau_k = -2(\tau_f + \alpha)$, where α is the linear thermal expansion coefficient of the ceramic material.

Ferromagnetic Resonance Line Width (ΔH) Measurement

The sample for this measurement is a polished sphere ~.050" in diameter. The sphere is placed into a TE_{10x} mode waveguide cavity (resonant at ~9.2GHz) which is located between the poles of an electromagnet. A gaussmeter is used to measure the changes in the magnetic field necessary to produce a -3 dB resonance attenuation.

Saturation Magnetization ($4\pi M_s$) Measurement

A sample disk of material is placed between the poles of an electromagnet which is set to produce a field of sufficient strength to completely saturate the sample material. A gaussmeter is used to measure the change in field strength with the sample present as compared to when the sample is not present. The $4\pi M_s$ is calculated based on the change in the field strength reading and the volume of the sample disk.

Hysteresis Loop Characteristics

A toroid sample fitted with a double winding is used as a transformer for measuring the hysteresis loop characteristics B_r (remanent induction), B_m (maximum induction) and H_c (coercive force). The primary winding magnetizes the sample with a low frequency AC signal and the applied H field is proportional to the primary current. The signal, which is then induced in the secondary winding, is proportional to the magnetic flux variation and is integrated to obtain the B_r. The induction value B_m is measured at an applied field of 5 times H_c.

References

1. W.E. Courtney, "Analysis and Evaluation of a Method of Measuring the Complex Permittivity and Permeability of Microwave Insulators", IEEE Transactions on Microwave Theory and Techniques, Volume MTT-18, August 1970.

2. G. Kent, "Nondestructive Permittivity Measurement of Substrates", IEEE Transactions on Instrumentation and Measurement, Volume 45, February 1996, pp 102-106.

3. G. Kent and S.M. Bell, "The Gap Correction for the Resonant-Mode Dielectrometer", IEEE Transactions on Instrumentation and Measurement, Volume 45, February 1996, pp 98-101.