TECHNICAL INFORMATION

ENERGY AND POWER HANDLING CAPABILITIES OF THIN FILM AND CERAMIC CAPACITORS

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Abstract:

A continual growth of uncertainty and misconception has been prevalent in determining the power and energy capabilities of both ceramic and silicon capacitors. As today's systems are subjected to increasingly more stringent requirements, designers are faced with numerous situations where the components that are used dictate design configurations. This paper addresses the concepts associated with a capacitor's ability to withstand power and energy. Both theoretical and empirical models are developed and used to provide design guidelines.

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I. Energy: The Determining Factor for Transient Waveforms

Dielectric strength is the determining factor for characterizing all energy-related phenomenon. Essentially, the dielectric strength is simply determined by the amount of electric field that is sufficient to initiate breakdown of the dielectric. The process of determining the strength, however, is much more complicated. The strength is a function of homogeneity, geometry, grain size, electrode geometry, and stress mode (AC, DC, non-periodic pulses). Manufacturers generally determine the dielectric strength with DC test conditions and to some extent, this information is very useful and applicable to all scenarios when relating to non-periodic charges and discharges. Ultimately, the energy equations and information should be used for transient analysis whereas the power dissipation equations should be used for continuous waveforms.

Ceramics are very rarely homogeneous and thus discharge failure mechanisms are quite varied and arduous to explain in explicit detail. For instance porosity, a common inhomogeneity, exhibits a mechanism of breakdown that can occur at the pore due to the electric field. The field strength in a pore is greater than the field strength in the surrounding medium, which leads to a lower breakdown voltage. However, defining the exact cause is not obvious and can be explained in numerous manners. At any rate, the inhomogeneities cause a multitude breakdown mechanisms that are not clearly defined. There are, however, ways to determine acceptable reliabilities for transient waveforms with given measurable parameters that are available from the manufacturer.

As we know, the energy that can be stored in a capacitor is given by Equation 1. This is a very useful equation in that the capacitor's transient storage ability can be determined from it under static circumstances. The capacitor can only store a certain amount of energy from an electric field. The energy value is determined by the geometry of the device, the porosity of the materials, etc… All manufacturers list a dielectric breakdown voltage that is tested under DC fields. From this test, capacitor manufacturers determine the voltage rating for each specific part. The actual energy that can be stored by the capacitor is determined by Equation 1 using the manufacturer's voltage rating. This is not to say that the device cannot store more energy, but this is simply a very safe approach to determining a reliable rule of thumb for energy storage. Using the capacitor's energy capabilities, the designer must make sure that the energy that the capacitor is subjected to is less than the energy calculated from Equation 1. The energy in a circuit can be approximated using transient simulators or calculated using Equation 2.

Equation 1: Energy Stored in a Capacitor

$$E = \frac{1}{2} \cdot C \cdot V^2$$

Equation 2: Electrical Energy in a system

$$E = \int_0^t V(t) \cdot i(t)\, dt$$

II. AC Power Dissipation

The most predominant mechanism for breakdown under AC fields is thermal breakdown. If heat is generated in a medium faster than the rate of dissipation, then the resulting rise in temperature leads to loss mechanisms that are detrimental to the device. The medium functionally undergoes a thermal runaway process that ends in breakdown. With AC waveforms, charges occur in the field polarity every half cycle which renders the medium more susceptible to breakdown. The heat dissipation due to continuous AC waveforms is generated from losses due to the real part of the impedance. Therefore, the current handling capability of a device is frequency dependent. The empirical data given in the following passages specifically details the effects of heat transfer in practical capacitor applications.

A. Test Methodology

The circuit chosen for testing the power handling capability provides both theoretical simplicity as well as a practical approach for measurement. The intent was to provide results that could be used in standard applications on generic FR-4 substrates with the recommended layout geometry. Figure 1 shows the actual geometry and layout of both the board and circuit. A parallel tank circuit was selected to simplify the measurement process. Figure 2 is a block diagram of the

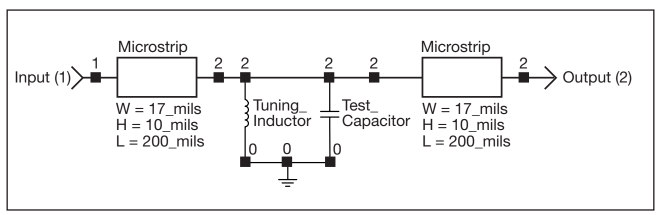

Figure 1: Microstrip Test Circuit

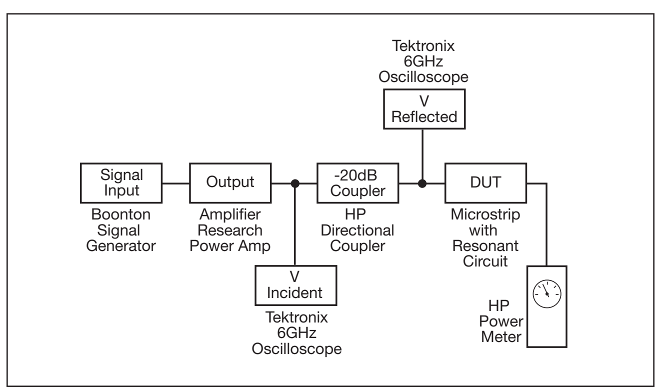

Figure 2: Block Diagram of AC Power Test

actual test setup for determining the heat rise. It can be seen that the power delivered to the load is the incident power minus the reflected power. If the load impedance is equal to the characteristic impedance of the transmission line, the power at the load equals the power incident and is given in Equation 3 when the reflection coefficient is zero. If the generator impedance, however, is not equal to the impedance of the transmission line then a partial standing wave is created which can result in a larger voltage applied to the load. The power delivered to the load is maximum and is equal to the power available from the source when the parallel circuit is resonant or when the VSWR given in Equation 4 is at its lowest. When this occurs, the voltage across the tank circuit is equal to the voltage at the power meter termination. Therefore, the power dissipation and current level can be determined by Equations 5 and 6.

Equation 3: Power delivered to the load

$$P_L = P_{inc} \cdot \left[1 - \left[(|\Gamma_L|)^2 \right] \right]$$

Equation 4: Voltage Standing Wave Ration (VSWR)

$$VSWR = \frac{| V_{max.} |}{| V_{min.} |} = \frac{1 + | \Gamma L |}{1 - | \Gamma L |}$$

Equation 5: Voltage seen by the resonant circuit

$$V_{Line} = \sqrt{50 \cdot P_{meter}} = \frac{1}{2} \cdot \left(\left| \frac{V_{Generator}}{Z_{Generator} + ZConjugate_{Generator}} \right| \right)^2 \cdot ReZ_L$$

Equation 6: Power dissipated by the capacitor

$$P_{Cap} = \left[\frac{(| V_{Line} |)^2}{(| Z_{Cap} |)^2} \cdot ESR = (I_{RMS})^2 \cdot ESR \right]$$

The resonant circuit is comprised of both an inductor coil as well as a capacitor. The technique is quite simple, but arriving at the exact power and current values involves an exacting process that includes both resonant measurements as well as circuit tuning. It has been well documented that the most accurate measurements of both the real and the reactive parts of the impedance of capacitors and inductors are given by measurements performed on a quarter wave resonant tube. Therefore, the Boonton 34A resonant system was used to provide the impedance data up to 7/4 lambda. The resonant circuits were then tuned to the exact Boonton frequency for measurement. Tuning involved adjusting the amount of inductance needed to provide a VSWR less than 1.2 at the desired quarter wave frequency. The VSWR was measured with both a HP8753 network analyzer as well as with two oscilloscopes during measurement as shown in Figure 2. The devices were then subjected to powers at the specified frequencies that generated 10, 20, 30, and 40ºC rises above ambient temperature (24.8ºC). The temperature was measured using a fluoroptic temperature sensor that is unaffected by RF emissions.

B. Results

Once again, the idea behind the given method for testing the power handling capabilities of these capacitors was tailored to practical applications. Multiple heat sinks were not used to provide more favorable data. The ensuing table gives the change in temperature per watt of power dissipated by the device as well as the recommended amount of power necessary for a 20ºC surface temperature rise above the ambient temperature. The change is an average generated from the measured power dissipated versus frequency. The current handling capability can be approximated by obtaining the impedance and ESR values at frequency from the manufacturer and by using Equation 6 to calculate the RMS current.

III. Conclusion

Practical values for determining the amount of energy and power a capacitor can withstand can be obtained with the given information. All circuits and test data were verified with nonlinear (PSPICE) and linear simulation programs (EAGLEWARE). The data given for the continuous power dissipation is subject to change for different board configurations. Power dissipation capabilities are primarily a function of the real loss of the device and the thermal mass. Typical values, however, can be approximated using the method described above. For power calculations, a maximum of 20ºCelsius rise above ambient is recommended for calculating the current. Also, it is recommended that the peak to peak AC voltage is less than 40-70% of the DC rated value and the power dissipation rates are less than those given in the following table unless otherwise notified by the manufacturer.

Capacitor	Thermal Exchange in Degrees Celsius per Watt	Power Rating @ 20°C Rise above an ambient of 25°C
Thin Film Alumina Substrate 1210	59º C/Watt	.34 Watts
Thin Film Alumina Substrate 0805	83.3º C/Watt	.24 Watts
Thin Film Alumina Substrate 0603	106º C/Watt	.186 Watts
Thin Film Alumina Substrate 0402	158º C/Watt	.127 Watts
Procelain 0505	126º C/Watt	.158 Watts
Procelain 1111	67.7º C/Watt	.295 Watts
Ceramic 1210	70.9º C/Watt	.282 Watts
Ceramic 0805	113º C/Watt	.177 Watts
Ceramic 0603	145º C/Watt	.139 Watts
Ceramic 0402	219º C/Watt	.091 Watts

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