# Elevated Temperature Impact on Performance of LTCC Dielectrics

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## Abstract

An adoption of higher frequency telecommunication protocols, a growing need to incorporate control and monitoring systems next to heat generating units, plus a high demand for power electronics set new requirements for the temperature ranges at which electronic components need to operate. The majority of current materials for the electronic components was designed for a “traditional” temperature range, from -55°C to +125°C, whereas the new applications require electronics to operate reliably up to 350°C and higher. In the past, the need for specific design rules related to elevated temperatures for microelectronic applications were limited mostly to applications like aerospace and oil exploration. The total number of components needed for those applications was relatively low, which enabled engineers to individually design each component using a trial and error approach. Such an approach is costly and time consuming, but the risk of failure of the entire unit in those unique applications warranted additional design costs. Nowadays, with limited time-to-market and a growing pressure to minimize manufacturing costs, a proper selection of the appropriate materials become even more important.

Low Temperature Co-fired Ceramic (LTCC) modules are multi-layer ceramic substrates, which are co-fired with low resistance metal conductors, such as Au, Ag or Cu, at low firing temperatures, less than 1000°C. LTCC materials are often referred to as "Glass Ceramics", because their main composition consists primarily of glass and metal oxide filler(s). LTCC materials are used for an integration of various electronic components to a single module or package. Signal propagation and electrical resistivity of the LTCC material are two of the most important aspects for the electronic packaging. The signal propagation delay, $t_d$, is a direct function of the relative permittivity of the ceramic, which surrounds the conductor lines, and can be expressed as

$$t_d \sim l\sqrt{\varepsilon_r}/c$$

where $l$ is the line length, $\varepsilon_r$ is the relative permittivity of the substrate and $c$ is the speed of light. Thus LTCC materials with low relative permittivity are required to increase the speed of the signal. The electrical resistivity of the LTCC material governs not only frequency at which the package can reliably operate via the value of the dielectric loss, but also the package density via the size of the separation gap between the adjacent conductor lines. As the operating temperature elevates, the conductivity losses occurring in the glassy phase of the glass-ceramic LTCC material may not only significantly increase dielectric losses of the LTCC packages, but also contribute to the increase of relative permittivity of the ceramic, suppressing the signal propagation. Understanding the temperature impact on the electrical and physical properties of the LTCC materials is a good way to understand when the current design rules need to be questioned for higher temperature applications.

The goal of this paper is to evaluate how commercially available LTCC ceramic dielectric materials behave at elevated temperatures to gage their applicability for the high temperature application. The properties of two popular LTCC ceramic systems having different microstructure forming mechanisms, Ferro A6M-E and Ferro L8, were measured in the temperature range from room temperature up to 450°C. One dielectric (A6M-E) consists of a crystallizing glass while the other (L8) consists of a ceramic-filled glass composite. The two materials exhibited considerably different relative permittivity, dielectric losses, and insulation resistance dependence on the operating temperature suggesting different temperature applicability range for each of the dielectric.