EXPERIMENTAL TEST AND APPLICATION OF 2-D FINITE ELEMENT CALCULATION FOR WHISPERING GALLERY SAPPHIRE RESONATORS*

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Recently, whispering gallery resonators consisting of a sapphire dielectric element in a metallic container have made possible new capabilities for microwave oscillator phase noise and frequency stability. With high azimuthal mode numbers, these resonators isolate radio-frequency energy to the dielectric element and away from the metallic container, thus providing extraordinarily high quality factors (Q's). Design and analysis of such a resonator with a certain frequency and Q requires accurate electromagnetic field calculations to determine (e.g.) conductive losses due to small evanescent fields at the wall of the containing can. The widely disparate field magnitudes pose a challenge for any methodology to resolve the hybrid fields. In particular, a three-dimensional finite element method (FEM) allowing full treatment of sapphire's anisotropic dielectric constant, would require such a large number of elements as to be impractical. Approximate analytical methods are useful for some geometries, but a new approach would be required for every change in geometry. A two-dimensional finite element approach, however, allows easy treatment of any cylindrically symmetric resonator geometry.

Because the dielectric constant for sapphire shows cylindrical symmetry, a two dimensional treatment is allowed for the important case where its crystal c axis is aligned with a physical axis of axisymmetry. While ruling out most anisotropic dielectric configurations, this approach makes possible the first two-dimensional finite element treatment for sapphire "whispering gallery" resonators. For the different modes of a given circularly symmetric geometry the CYRES 2D finite element package under development at the University of Texas at El Paso allows determination of resonant frequencies and visualization of the electromagnetic fields.

A comparison of the predictions of this software with experimental results for a wheel-shaped sapphire resonator gives an error in mode frequency of less than .55%. We also show parts per million agreement with analytical solutions for simple geometries such as an empty coaxial resonator. These results demonstrate the accuracy of the FEM methodology, which may be primarily used for optimization of new resonator designs. The software has proven invaluable for the analysis and identification of modes and mode families for resonators of various geometries. Current design uses include optimum sized dielectric resonators for minimized wall losses, and new resonator geometries for temperature compensated resonators. The operational characteristics of the software and the general methodology for use of the software as a laboratory and design tool are discussed.

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