Two-Mode Reentrant RF Resonator for Dielectric Measurements

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The zero-frequency dielectric constant (relative electric permittivity) ϵ of fluids is of interest for fundamental reasons and for modeling intermolecular potentials. The dielectric response of a fluid of conductivity σ can be characterized by ϵ and the time constant $\tau = \epsilon/\sigma$. As long as measurements are carried out at frequencies $\omega/2\pi$ such that $\omega\tau \ll 1$, the fluid's conductivity does not significantly interfere with measurement accuracy. However, for many fluids, this condition cannot be satisfied at audio frequencies. For example, pure water at ambient conditions has the parameters $\epsilon \approx 80$, $\sigma \approx 5 \times 10^{-6}\,\Omega^{-1}\mathrm{m}^{-1}$, and $\tau \approx 0.14$ ms. These values require a measurement frequency well above the kHz range. We plan to obtain the zero-frequency dielectric response through extrapolation of measurements at several frequencies in the MHZ range. We describe a compact rugged resonator suitable for dielectric-constant measurements in fluids at the two frequencies: (220 MHZ)/$\sqrt{\epsilon}$ and (570 MHZ)/$\sqrt{\epsilon}$. The resonator was constructed of two gold-plated stainless steel parts sealed together with a gold O-ring. The resonator could be filled with a pressurized test fluid which contacted only metal parts and glass-insulated feed-throughs. The outside of the resonator was a cylinder of diameter 80 mm and length 140 mm. Inside the resonator, the test fluid filled a volume consisting of two basic units. Each unit consisted of two torroidal sections, one with a relatively large (20 mm) annular gap that behaved as an inductor and a second with a 1 mm annular gap that behaved as a capacitor. A lumped component model of this resonator has two modes. A more detailed model considers each unit to be comprised of two co-axial cylindrical waveguide sections. The detailed model accounts for the finite wavelength of the electromagnetic fields, electrical conductivity in the fluid, electrical conductivity in the resonator's walls, and coupling to external electronics. The pressure and temperature dependencies of the resonator's dimensions were determined by calibration with helium. Measurements of the dielectric constant of argon and other test fluids will be reported.