

## BROADBAND COMPLEX PERMITTIVITY MEASUREMENTS OF LIQUIDS

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In this paper we report on broadband complex permittivity measurements of various liquids using a shielded open-circuited sample fixture. We discuss the various metrological aspects of this method, including the calibration of the fixture and the full-mode model used to determine the complex permittivity of a liquid from measurements of the shielded open-circuited fixture's reflection coefficient.

The need for accurate, broadband dielectric measurements of liquids is important for applications in the biotechnology, petroleum, chemical, and food industries. The dielectric properties of many liquids can vary dramatically as a function of frequency and temperature, making accurate measurements difficult. Traditional resonator methods offer the highest accuracy, but only at single frequencies, while transmission-line techniques offer broad frequency coverage, often at the expense of measurement accuracy.

The shielded open-circuited method can be used for broadband dielectric measurements while maintaining a high level of accuracy. Other advantages of this technique include the ability to perform rapid measurements, simplicity of fixture design, and ease of inserting and removing liquid from the fixture. However, the difficulties of this method, which we address in this paper, include a complex model for determining the permittivity of the liquid from measurements of the fixture's reflection coefficient and the difficulty of fixture calibration.

We developed a full-mode model for the shielded open-circuited fixture that includes not only the fundamental TEM mode, but also the evanescent  $TM_{0n}$  modes that are excited at the boundaries of impedance mismatches within the shielded open-circuited fixture. The inclusion of the higher-order evanescent modes is an improvement over previous models that include only the fundamental TEM mode, and we present permittivity results comparing the full-mode model with previous models.

Calibration of the shielded open-circuited fixture is complicated by the fact that the calibration is performed at a reference plane that is separated from the liquid by a polymer bead. We examined two possible calibration methods. The first method requires a calibration at the connector of the shielded open-circuited holder and then performs a reference-plane rotation through the polymer bead. The second method eliminates the need to rotate the calibration reference plane through the polymer bead by taking a ratio of reflection coefficient measurements at the connector of the fixture.

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