MEASUREMENTS OF COAXIAL DIELECTRIC SAMPLES EMPLOYING BOTH TRANSMISSION/REFLECTION AND RESONANT TECHNIQUES TO ENHANCE AIR-GAP CORRECTIONS+

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Abstract – **High-permittivity dielectric samples have been measured employing a transmission/reflection method in 7 mm coaxial transmission lines with an air- gap correction implemented that is based on a single-frequency measurement of these specimens using a $TE_{01\delta}$ mode dielectric resonator technique. This allows an improvement of systematic uncertainties for high-permittivity materials.**

1. Introduction

The coaxial-line transmission/reflection method is commonly used for measuring the complex permittivity of dielectrics over a broad frequency band [1-3]. A typical measurement setup for this technique is shown in Fig.1a. One of the major sources of measurement error in this method are small air gaps between the sample and the coaxial line [3,4]. The air-gap capacitance is a nonlinear function of the specimen's complex permittivity, and the uncertainties substantially increase with the real part of permittivity. The presence of small air gaps have traditionally limited the use of transmission-line methods to relative permittivities of less than 10. The systematic effects of the air gap can be reduced by measuring the space between the sample and the holder and then using the commonly accepted algorithm[4]. However, precise measurements of the gap between the inner conductor of coaxial line and the sample are extremely difficult. It is possible to estimate an air gap by the measurement of the real part of the permittivity of the specimen at one frequency using an accurate $TE_{01\delta}$ mode dielectric resonator measurement system as depicited in Fig.(1b) [5].

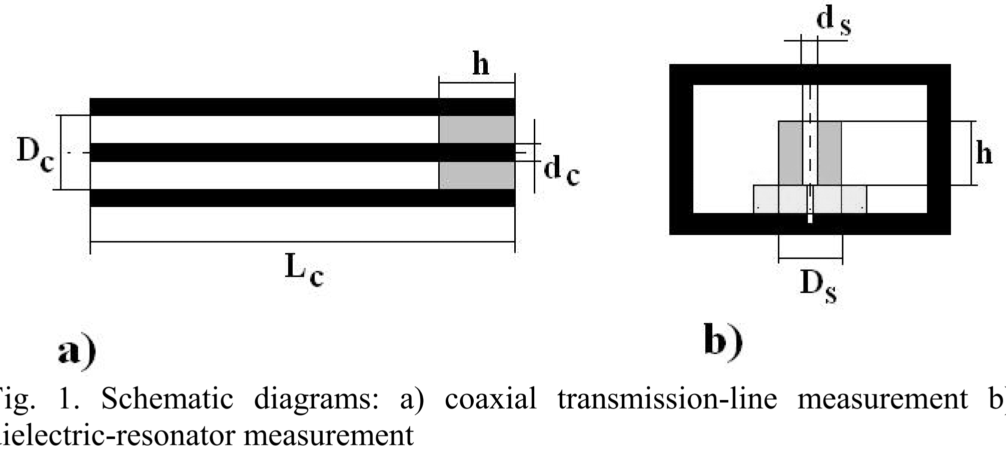

Fig. 1. Schematic diagrams: a) coaxial transmission-line measurement b) $TE_{01\delta}$ mode dielectric-resonator measurement

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The samples measured in the dielectric resonator had precisely-machined holes in the center for later fitting in the coaxial line. The presence of the center holes are accounted for in the dielectric-resonator measurement. Once the permittivity is measured at this frequency in the resonator, its value can be used to determine the effective coaxial sample inner radius and then this radius can be used to calculate the air gap for broad-frequency transmission-line measurements. This combines the strengths of the two methods. The resonant method is limited to a single frequency, whereas the coaxial line is limited by the air gap error [3,4]. Other methods have been used in the past to mitigate air gaps such as the use of conducting pastes or larger diameter coaxial lines [6].

2. Results of experiments

The same samples were measured employing a $TE_{01\delta}$ mode dielectric-resonator technique. Results of the measurements of the permittivity and dielectric loss tangent of three samples having different permitivities are shown in Table I. The same samples were measured employing a coaxial-line transmission/reflection method and the permittivity was evaluated with and without an air-gap correction. In the air-gap correction only the internal diameters d_s of the samples have been varied to fit the real permittivity values measured by the $TE_{01\delta}$ mode dielectric resonator technique. Results of the experiments are shown in Figs. 2 to 4. Note that in Fig. 2, whereas the random uncertainties with and without the air correction are similar, the systematic corrections are significant. In Table I, Type A relative expanded uncertainities for ε'_r in the dielectric resonator are U=0.005, and for the absolute expanded uncertainty for $\tan\delta$ are U=0.0005. In Figs. 2 to 4 relative uncertainities for ε'_r in the coaxial line are 5 %.

Table I. $TE_{01\delta}$ mode dielectric-resonator measurements of coaxial samples.

Material	f(GHz)	Q	Ds	ds	h	ε_r	$\tan\delta$
Alumina	11.409	15500	6.980	3.075	11.84	10.01	5.8×10^{-5}
D50	6.887	3540	6.985	3.070	2.992	48.96	2.8×10^{-4}
BST	2.479	310	6.991	3.058	7.622	263.3	3.2×10^{-3}

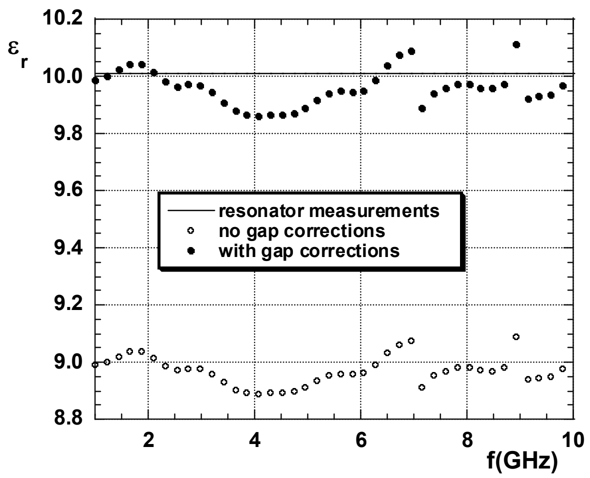

Fig.2. The real part of the permittivity for an alumina sample versus frequency, measured with and without an air-gap correction[4] in a 7 mm coaxial line.

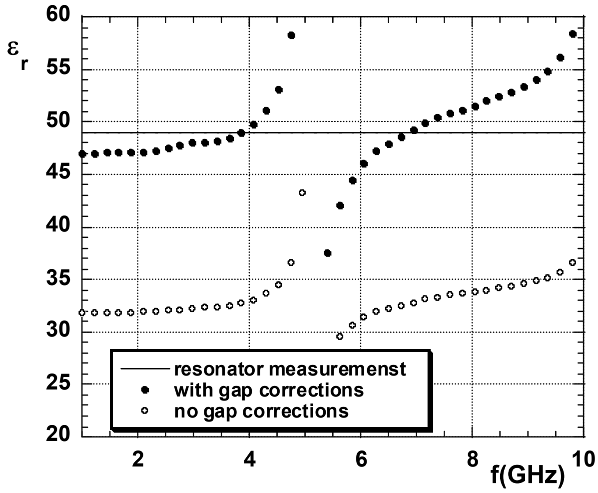

Fig.3. The real part of the permittivity line of a ceramic sample (D50) versus frequency measured with and without an air-gap correction in a 7 mm coaxial.

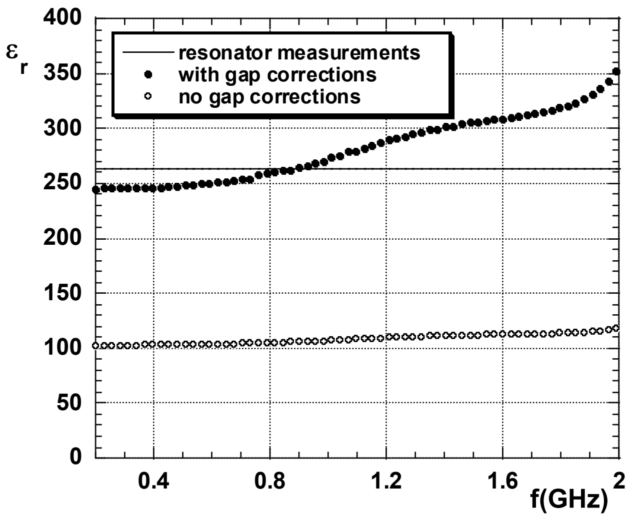

Fig.4. The real part of the permittivity of barium-strontium-titanate (BST) versus frequency measured with and without an air-gap correction in a 7 mm coaxial line.

Table II. The measurements of the effective gap used in the permittivity evaluation in Figs.2 to 4. The air line had an outer diameter the coaxial line b=7.0026 mm and air line length L_a=100 mm. Dc and ds refer to diameters of the inner and outer conductors of the sample

Material	dc (mm)	ds (mm)	(ds-dc)/2 (mm)
Alumina	**3.0436**	**3.075**	**0.0157**
D50	**3.0436**	**3.070**	**0.0132**
BST	**3.0436**	**3.058**	**0.0072**

For BST, the coaxial line measurement had a higher-mode resonance at 2.4 GHz, so we used the resonator measurement of permittivity at 2.4 GHz in the correction at 2 GHz. The D50 material had been used in a previous round robin[7]. The results of measurements in this paper are much closer than what was achieved by air-gap corrections in that intercomparison.

3. Conclusions

We have determined that for the real part of the complex permittivity a substantial improvement can be obtained over the commonly used air-gap correction methods in coaxial air line measurements by use of tandem coaxial line-resonator techniques to correct for the systematic air-gap error. Since the permittivity used from the resonant measurement has well-documented uncertainties[5], the resulting air-gap correction uncertainties in the transmission line measurements can be accurately determined.

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