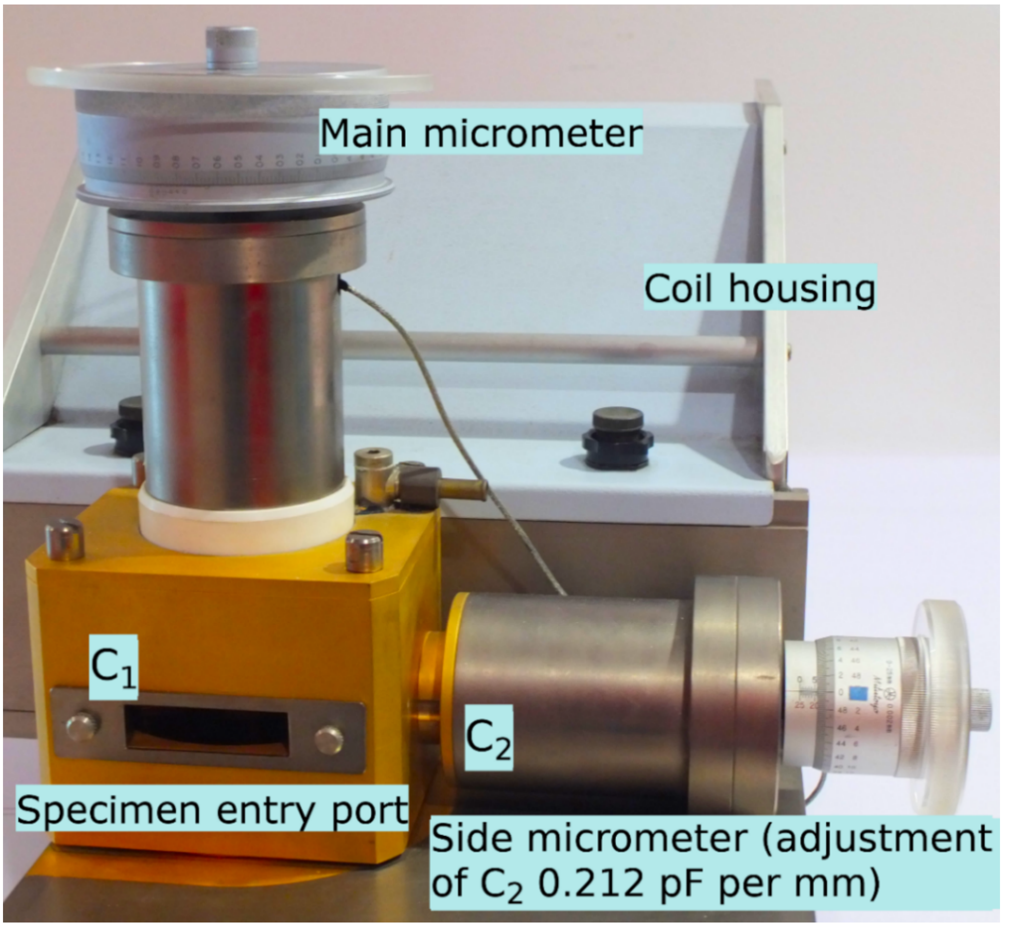
Measurement of the permittivity and loss of low-loss sheet materials by resonance at MHz frequencies



NPL possesses a set of resonant systems for measuring the loss angle (or loss tangent) of low loss sheet materials in the `crossover' VHF and UHF regions. Loss angles smaller than 10 microradians‡ can be resolved. The measured data can be useful for characterising the performance of alumina RF windows used in high-power applications, and for measuring the loss of polymers used in electronic circuits and cables.

Hartshorn and Ward method

The Hartshorn and Ward method [1] uses a resonant circuit consisting of an inductance coil and a parallel-plate-electrode capacitor that accommodates specimens to be measured (see Figure 1). The method was developed at NPL in the 1930s. We possess a Hartshorn and Ward system manufactured by ERA Technology in the 1980s that has been enhanced to work with a Vector Network Analyser [2]. It enables the loss of ideal specimens of insulating materials that have very low loss (loss angle < 10 microradians‡) to be resolved. In reference [2], measurements by this and other techniques are compared.

The system available at NPL is suitable for measuring rectangular specimens (70 x 54 mm) that have permittivity < 10. The thickness of specimens should be approximately 1.5 mm, 2 mm, 2.5 mm or 3 mm. The surfaces of specimens should be flat and parallel. If required, laminar specimens can be machined by the NPL workshop (note: Material Safety Data must be provided).

Tweezers are used for inserting and removing specimens via a rectangular aperture (see cover picture). The permittivity and loss angle are determined by an air-substitution (Lynch) method from measurements of Q-factor and resonant frequency [3]. The technique requires measurements at resonance on the specimen and the empty cell at the same frequency, so frequency-dependent conductor loss has no overall effect (tuning is enabled by a micrometer adjustment). A set of interchangeable inductance coils allows resonant frequencies in the range 0.5 MHz and 70 MHz to be selected (the exact frequency depends on the material thickness and permittivity). Corrections for the effects of fringing capacitance have been developed at NPL to improve measurement accuracy [2, 4].

‡This is equivalent to loss tangent < 0.00001.

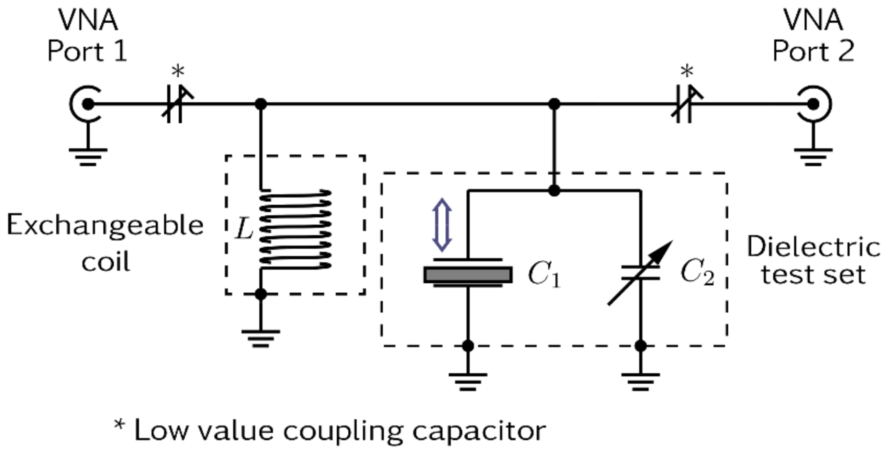


Figure 1 and cover image: Hartshorn and Ward apparatus for measuring permittivity and loss angle by RF resonance.

Reentrant cavities (also known as Parry cavities and as hybrid cavities)

Two reentrant cavities [5] that operate at UHF frequencies (nominally 300 MHz and 600 MHz) are available at NPL for measuring the loss angle of low loss materials (Figure 2). The permittivity and loss angle are determined by an air-substitution (Lynch) method from measurements of Q-factor and resonant frequency [3]. The technique requires measurements on specimens and the empty cavity at the same frequency (tuning is enabled by a micrometer adjustment), so frequency-dependent conductor loss has no overall effect. The exact measurement frequency depends on the material thickness and permittivity. The reentrant-cavity technique used currently does not fully account for fringing-capacitance effects. Therefore, small systematic measurement errors can occur (particularly for the real part of permittivity), and uncertainties can be under-estimated. These cavities are not normally used for measuring the real part of permittivity because more accurate measurements can be obtained at a higher frequency by using Split-Post

Dielectric Resonators [1, 6] (note: the real part of the permittivity of low-loss materials varies negligibly in the relevant frequency range [1]).

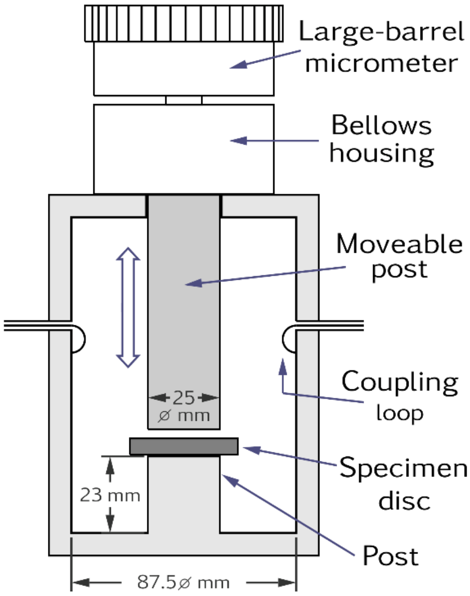


Figure 2: NPL 300 MHz reentrant cavity. The 600 MHz cavity is similar in design, but smaller.

Disc-shaped and rectangular specimens with thickness between 0.5 mm and 4 mm are suitable for measurement in the reentrant cavities. Other dimensions are shown in Table 1. Rectangular specimens machined for NPL's Hartshorn and Ward system can be measured in the 300 MHz cavity.

Table 1: Specimen dimensions for NPL reentrant cavities.

Cavity	Minimum diameter*	Maximum diameter*
300 MHz	30 mm	54 mm
600 MHz	28 mm	34 mm

* Length of shortest side for rectangular specimens.

Example measurements

Table 2: Measurements on spectrosil fused silica. Thickness 2.097 (0.004) mm.

Measurement frequency	System	ε'	δ (μrad)
1 MHz	Hartshorn and Ward (data from reference [2])	3.81 (0.02)	< 2 (2)
6 MHz		3.81 (0.02)	< 2 (2)
32 MHz		3.81 (0.02)	< 2 (2)
77 MHz		3.81 (0.02)	< 6 (6)
315 MHz	Reentrant cavity	3.9 (0.1)	< 5 (5)

Table 3: Measurements on high-purity alumina. Thickness 2.009 (0.004) mm.

Measurement frequency	System	ε'	δ (μrad)
1 MHz	Hartshorn and Ward (data from reference [2])	9.6 (0.2)	17 (3)
6 MHz		9.5 (0.2)	14 (2)
27 MHz		9.6 (0.2)	15 (3)
64 MHz		9.6 (0.2)	13 (7)
240 MHz	Reentrant cavity	9.7 (0.3)	11 (6)

In Tables 2 and 3, uncertainties (in brackets) are shown for a coverage factor of $k = 2$, which is equivalent to a Confidence Level of approximately 95%.

NPL reports and papers

[1] R. N. Clarke (Ed.) "Guide to the characterisation of dielectric materials at RF and microwave Frequencies", The Institute of Measurement, Control, and The National Physical Laboratory, London, 2003. https://eprintspublications.npl.co.uk/2905/

[2] A. P. Gregory, G. J. Hill and M. A. Barnett, "Low loss dielectric measurements in the frequency range 1 to 70MHz by using a Vector Network Analyser", Meas. Sci. Tech. Vol 32, 85002. https://eprintspublications.npl.co.uk/9220/

[3] A. P. Gregory "Q-factor measurement by using a Vector Network Analyser", NPL Report MAT 58, 2021. https://eprintspublications.npl.co.uk/9304/

[4] A. P. Gregory, T. E. Hodgetts, R. N. Clarke and G. J. Hill "Calculations of fringing capacitance for cylindrical electrodes", NPL Report TQE 28, 2023. https://doi.org/10.47120/npl.TQE28

[5] B. Givot, J. Krupka, K. Lees, R. Clarke and G. Hill, "Accurate Measurements of Permittivity and Dielectric Loss Tangent of Low Loss Dielectrics at Frequency Range 100 MHz - 20 GHz", MIKON 2006. https://doi.org/10.1109/MIKON.2006.4345157

[6] NPL Brochure "Split-Post Dielectric Resonators for measurement of dielectric permittivity and loss". https://www.npl.co.uk/products-services/electromagnetic-materials/measurements

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