Measurement of dielectric permittivity and loss of solids and liquids in the range 1 kHz to 10 MHz by using admittance cells

www.npl.co.uk

NPL uses a modified Hewlett-Packard /Keysight 16451B admittance cell to obtain the permittivity and loss angle of laminar specimens at room temperature. An LCR meter (HP4284A or HP4285A) is used for measuring capacitance and dielectric loss. Measurements are made by the Lynch method described in standard BS 7663. This is a single-frequency substitution technique (measurements at more than one frequency can be requested). Measurements can be made in the range 1 kHz to 10 MHz. The admittance cell is of the three-terminal type, which reduces the effect of fringing fields. A three-terminal cell for measuring the permittivity of liquids at 1 MHz is also available.

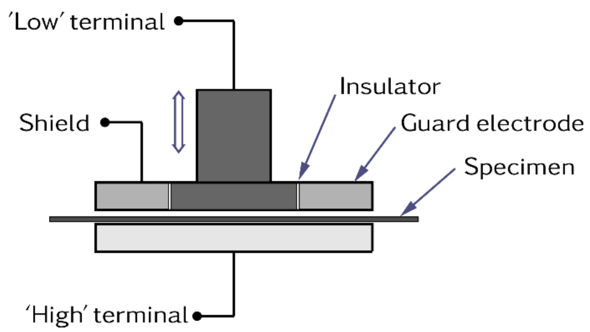

Figure 1: Three-terminal admittance cells for measurement of permittivity and loss. Left: schematic of the cell used to measure laminar solid specimens [2]. The 'low' terminal is 38 mm diameter. Right: NPL liquid cell.

Laminar solid specimens

Measurements of permittivity and loss are made by the Lynch air-substitution method [1]. A modified Hewlett-Packard /Keysight admittance cell (model 16451B [2]) is connected to an LCR meter via a four-terminal-pair (four coaxial cables) to reduce the effects of stray capacitance and inductance. Uncertainties are smallest for permittivity values less than 4, which is ideal for measuring polymers. Materials that have permittivity up to 10 can be measured with increased uncertainty. The resolution of loss angle measurements is typically 100 µrad (see Note 1). Some example measurements are shown in Table 1.

Specimens must be machined flat, ideally with a variation in thickness of less than 0.01 mm. Specimens much thinner than the maximum specified thickness are generally measurable but larger uncertainties are to be expected for thin specimens as the uncertainty component $\Delta t / t$ will be higher (t is the thickness and Δt represents the variation in thickness caused by surface roughness and any lack parallelism of specimen faces). It is recommended that the thickness is in the range 0.7 to 3 mm (where possible 2 to 3 mm is suggested).

The shape of specimens (circular, square or rectangular) is unimportant provided that the smallest lateral dimension exceeds 44 mm. The parallelism of the faces of specimens machined on a lathe or by grinding tends to be better for circular specimens than for square or rectangular specimens. Specimens can be machined at NPL.

Table 1: Example measurements on solid specimens from reference [3]. Uncertainties are shown in brackets. These are based on a standard uncertainty multiplied by a coverage factor k = 2 (equivalent to 95% Confidence Level). The measurement frequency was 6 MHz.

Material	Thickness in mm	ε´	δ in µrad
HDPE	2.008 (0.008)	2.36 (0.02)	100 (65)
Fused silica	2.097 (0.004)	3.83 (0.03)	<60 (60)
Macor	2.008 (0.002)	5.82 (0.05)	2630 (110)
Alumina	2.009 (0.004)	9.7 (0.2)	<100 (100)

Liquids

The permittivity and loss of insulating liquids such as oils can be measured in a three-terminal liquid cell (Figure 1, right). This is normally used at 1 MHz.

Notes:

1. The dielectric loss is normally reported in terms of the loss angle (δ), which has units of milliradians (mrad) or microradians (µrad). When δ is low-valued then it is related to loss tangent (the ratio of imaginary and real parts of permittivity) by $\delta \approx \tan\delta \times 10^6$ µrad.
2. The Lynch method is described in standard BS 7663 (1993). The Lynch method is not described precisely by the ASTM D150 standard, but NPL measurements meet its general requirements.
3. Traceability can be offered for the real part of permittivity. Formal traceability cannot be offered for measurements of dielectric loss. The consistency of measurements compared to other techniques has been demonstrated [3].
4. Laminar specimens may also be suitable for measurement in millimetre-wave open resonators [4] and split-post dielectric resonators [5] (note that there are special thickness requirements for open resonators). NPL brochures for these systems are available.
5. The resolution of measurement of loss is approximately 100 µrad. If better resolution is required, measurements by using a Hartshorn and Ward 1–70 MHz system [3] can be undertaken. This technique can resolve loss angles smaller than 10 µrad. It requires rectangular specimens with dimensions 70 x 54 x 2 mm.

[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. http://eprintspublications.npl.co.uk/2905/
[2] https://www.keysight.com/gb/en/product/16451B/dielectric-test-fixture.html
[3] 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. http://eprintspublications.npl.co.uk/9220/
[4] R. G. Jones, "Precise dielectric measurements at 35 GHz using an open microwave resonator", *Proc. IEE,* Vol. 123, 1976
[5] J. Krupka, A. P. Gregory, O. C. Rochard, R. N. Clarke, B. Riddle and J. Baker-Jarvis, "Uncertainty of complex permittivity measurements by split-post dielectric resonator technique", *J. of the European Ceramic Soc.,* Vol 21., 2001.

For further information please contact Customer Services

email: **measurement_services@npl.co.uk**

call: **+44 20 8943 7070**

contact form: **www.npl.co.uk/products-services/products-services-contact-form**

National Physical Laboratory
Hampton Road
Teddington
Middlesex
United Kingdom
TW11 0LW

Switchboard: **+44 20 8977 3222**

Website: **www.npl.co.uk**

Version 2. February 2022