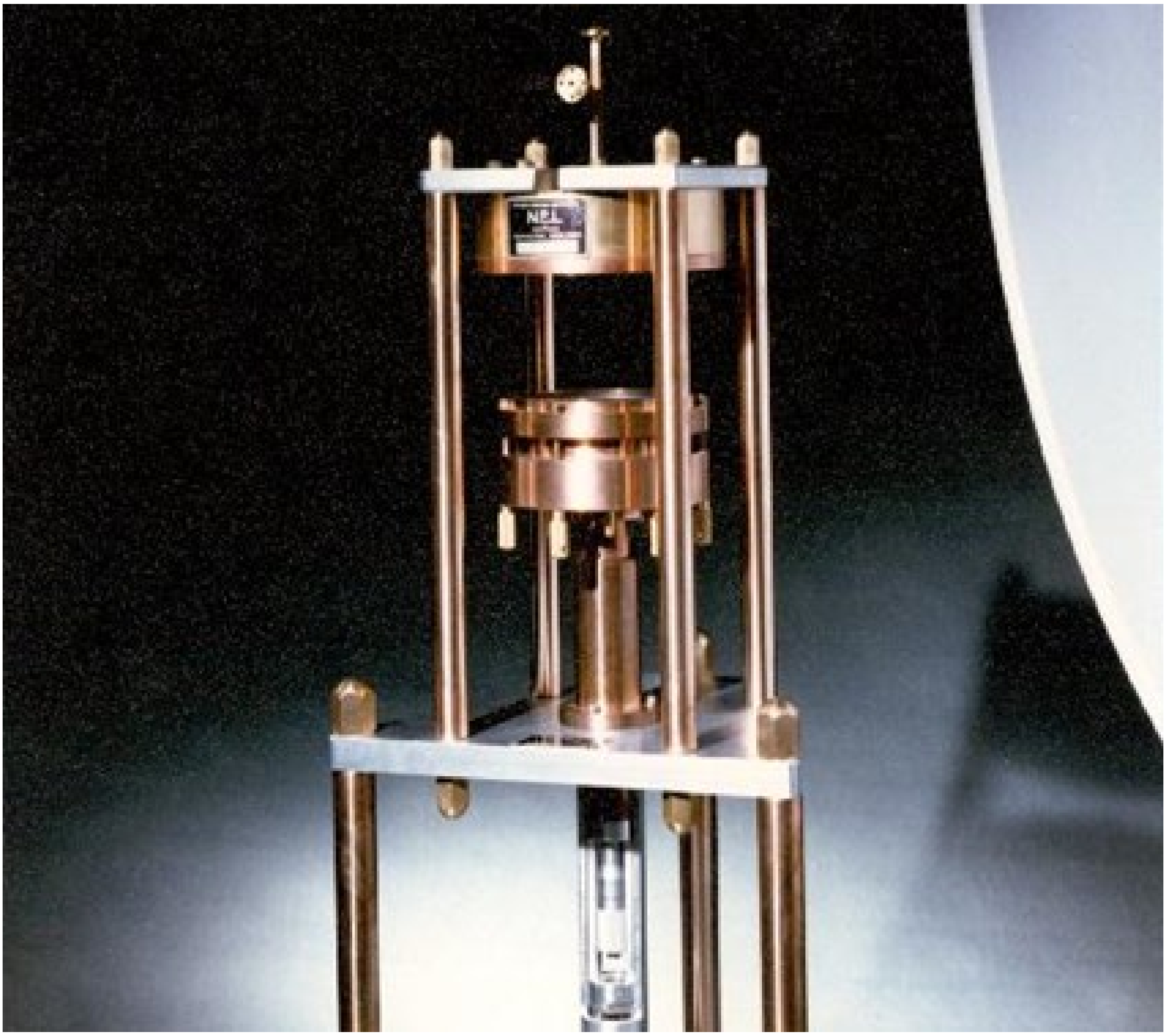
Open Resonators for measurement of dielectric permittivity and loss



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NPL possesses several Open Resonators (ORs)[1,2] for precise determination of permittivity and loss angle at room temperature from measurements of Q-factor and resonant frequency that are made with a Vector Network Analyser. They are used for measurement of low-loss laminar specimens with flat, parallel, faces. Materials with loss angle up to 10 milliradians are measurable in some cases, but in general specimens should have loss angle 3 milliradians or less. Very low loss materials can be measured (loss angle resolution ≲10 microradians).

The ORs are listed in Table 1. Each OR is tuneable over a moderate range of frequencies. If measurements are requested at a particular frequency, the nearest convenient resonant mode would normally be used. Measurements can be undertaken by using variable-length fixed-frequency, or variable-frequency fixed-length methods. Multiple resonances are available, corresponding to different axial modes (the axial mode number is the number of half wavelengths between the two mirrors). Resonances of fundamental-mode Gaussian Beams are used for measurement. For some samples a higher-order-mode resonance can occur at the same frequency as a fundamental mode, which will cause a measurement error. To enable such erroneous measurements to be identified, measurements are typically made with three different axial modes.

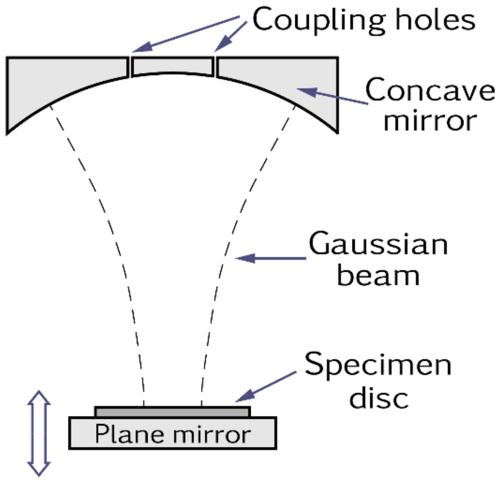

Figure 1 and cover image: Plano-concave open resonator (OR) for measurement of the permittivity and loss of planar specimens. Energy is coupled into and out of the resonator via waveguides that are connected to a Vector Network Analyser.

For best results specimens the specimen thickness should be approximately $n\lambda/2$, (n = 1, 2, 3) where λ is the signal wavelength in the medium of the material. Thicknesses close to $\lambda/4$, $3\lambda/4$ etc. should be avoided. The thickness of specimens is measured at NPL by using a micrometer.

Note that the beam diameter increases as the frequency is reduced. For measurement at the lower ends of the frequency ranges given in Table 1, the minimum diameters specified may be insufficient.

Table 1: Frequency ranges and required specimen diameters for NPL open resonators.

Nominal OR Frequency	Typical frequency coverage and required specimen diameters
10 GHz OR	• Frequency range 8 to 15 GHz • Preferred specimen diameter 120 mm (disc specimens up to 180 mm diameter can be accommodated)
36 GHz OR	• Frequency range 30 to 40 GHz • Minimum diameter 49.6 mm • Preferred specimen diameter 70 mm (disc specimens up to 120 mm diameter can be accommodated)
72 GHz OR	• Frequency range 65 to 80 GHz • Minimum diameter 45 mm • Preferred specimen diameter 70 mm (disc specimens up to 120 mm diameter can be accommodated)
144 GHz OR	• Frequency range 140 to 150 GHz • Minimum diameter 35 mm • Preferred specimen diameter 50 mm (disc specimens up to 120 mm diameter can be accommodated) • Note that at this frequency specimens need to be thin (typically < 1 mm). Thin polymer sheets are prone to warping which will affect measurement accuracy

Specimen sizes are listed as diameters in Table 1, but square specimens can also be measured provided that they are small enough to permit rotation without striking the mirror-supports of the open resonator. The parallelism of the faces of specimens machined on a lathe or by grinding tends to be best for circular specimens.

An initial estimate of the specimen permittivity is required to assist mode identification. If this is not available, a specimen of the material may be needed for measurement in another system, though it may be possible to use the same open resonator specimen for this. A Split-Post Dielectric Resonator measurement is usually the best option for this purpose (see the NPL brochure on this technique for specimen dimensions).

For the OR method the electric field (E-field) is parallel to the specimen faces (note that this differs from methods based on admittance measurements with parallel-electrode cell for which it is perpendicular). The E-field is polarised in a direction parallel to the narrow dimension of the waveguide resonator input/output couplings. Specimens are usually marked at NPL to allow the orientation to be set. Typically, measurements are made in four locations to allow anisotropy to be observed, if present. The four positions are shown in Figure 2.

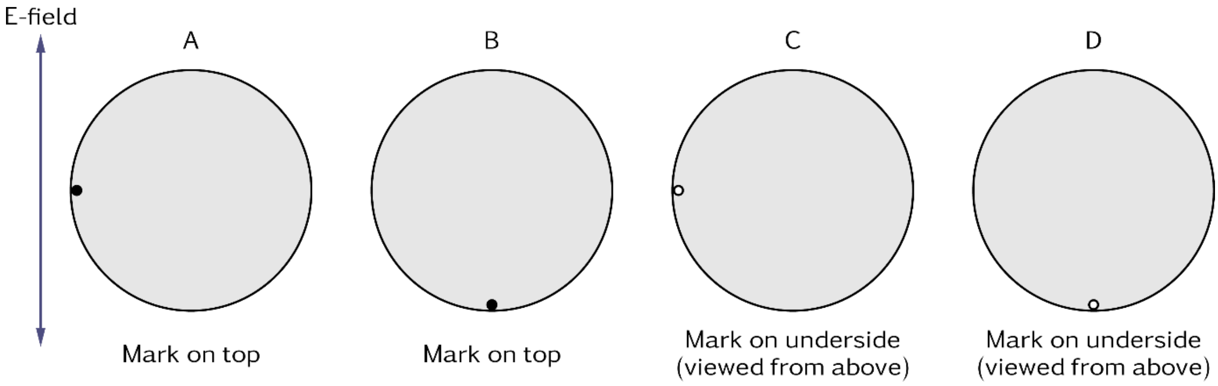

Figure 2: Typical orientations used for measurement

The components of the permittivity and loss angle parallel and perpendicular to the optic axis of suitable specimens of uniaxial single-crystal materials, such as quartz, can be measured.

[1] R. G. Jones, "Precise dielectric measurements at 35 GHz using an open microwave resonator", Proc. IEE, Vol. 123, 1976
[2] 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/
[3] The dielectric loss is reported in terms of the loss angle (δ), which has units of milliradians (mrad) or, for very low-loss materials, microradians (μrad). When δ is low-valued it is related to loss tangent (the ratio of imaginary and real parts of permittivity) by $\delta \approx \tan\delta \times 10^3$ mrad.

For further information please contact Customer Services

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