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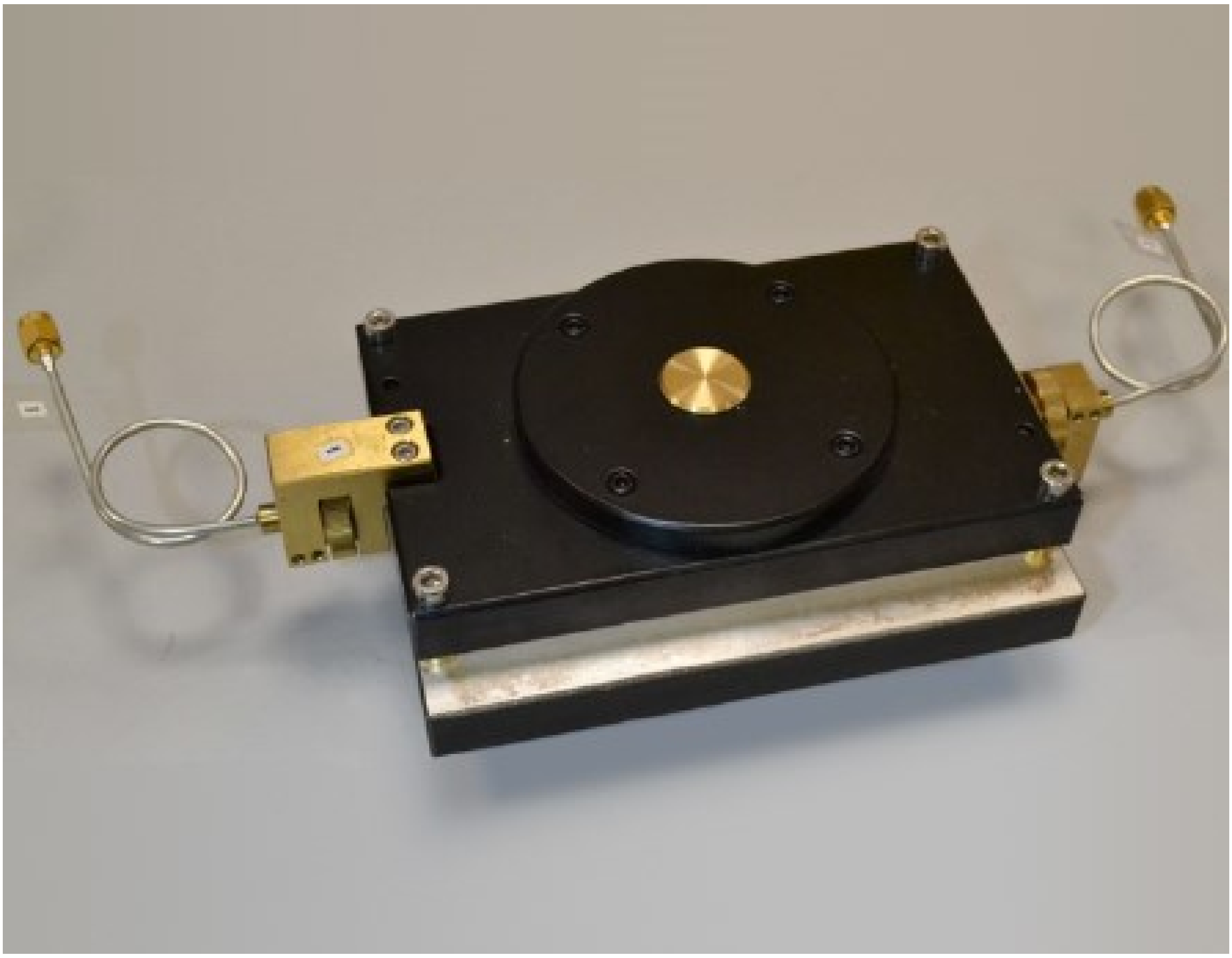
Split-Post Dielectric Resonators for measurement of dielectric permittivity and loss



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NPL has several Split-Post Dielectric Resonators (SPDRs) [1] that can be used to obtain the permittivity and loss angle of low-loss and medium-loss laminar specimens from measurements of Q-factor and resonant frequency [2]. Each SPDR operates at one nominal frequency only (specified frequencies are approximate, and to some extent depend on the specimen). The resolution for loss angle measurement is 50 microradians. The electric field in SPDRs is parallel to the specimen faces (note that this differs from methods based on admittance measurements with parallel-electrode cells [3], for which it is perpendicular). The required specimen dimensions are given in Table 1. Measurements are made at room temperature in accordance with standard BS EN 61189-2-721:2015.

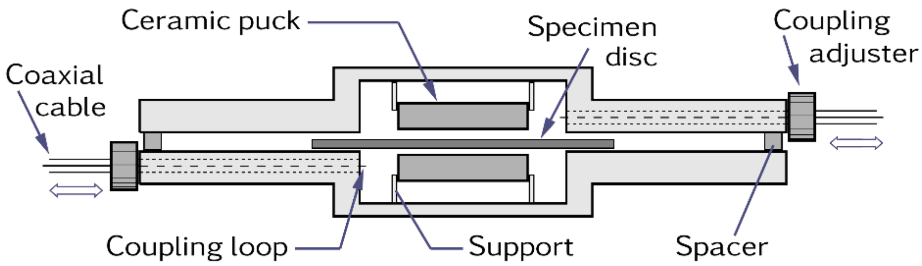

Figure 1: Split-post dielectric resonator (SPDR) for measurement of the permittivity and loss of planar specimens.

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. Larger uncertainties are to be expected for thin specimens as the uncertainty component $\Delta t/t$ (where t is the thickness and Δt represents the variation in thickness caused by surface roughness and any lack parallelism of specimen faces) will be higher for them. For high permittivity materials (permittivity greater than 10), the thickness, t, of the specimen under test should be smaller than the ratio

$$t < \frac{g}{\sqrt{\varepsilon}}$$

where g is the height of the specimen gap in the SPDR and ε is the specimen permittivity, otherwise accurate measurement of the appropriate resonance (i.e. the TE01δ mode) may not be possible because of the appearance of an interfering peak at a nearby frequency. For materials having permittivity just under 10 (such as alumina), it is suggested that the thickness should be smaller than 2/3 g, as otherwise an interfering peak may still cause problems. The SPDR specimen gaps, g, are listed in Table 1. Specimen loss is also a factor in determining the optimum thickness: For medium loss materials (loss angle 10 milliradians or greater) it is recommended that the specimen thickness is reduced, otherwise Q-factors can be rather low which can limit the measurement accuracy. Some example measurements are shown in Table 2.

The shape of specimens (circular, square or rectangular) is unimportant provided that the smallest lateral dimension falls within the specified range. 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.

Thin coatings (e.g. 0.05 mm thickness) on a uniform substrate such as fused silica can be measured provided that an uncoated substrate that is otherwise identical is supplied.

Table 1: Specimen sizes

SPDR Nominal Frequency	Required specimen diameters and maximum thickness
1.8 GHz SPDR	• Diameter in the range 80 – 95 mm • Maximum thickness (*g*) 4.4 mm • See notes 2 & 3 for other methods that can be used with the same specimens.
2.45 GHz SPDR	• Diameter in the range 55 – 100 mm • Maximum thickness (*g*) 3.1 mm • See notes 2, 3 & 4 for other methods that can be used with the same specimens.
4 GHz SPDR	• Diameter in the range 44 – 58 mm • Maximum thickness (*g*) 1.9 mm • See notes 2, 3 & 4 for other methods that can be used with the same specimens.
8.2 GHz SPDR	• Diameter in the range 30 – 65 mm • Maximum thickness (*g*) 0.8 mm • See note 3 for other methods that can be used with the same specimens.
10 GHz SPDR	• Diameter in the range 25 – 78 mm • Maximum thickness (*g*) 1.1 mm • See note 3 for other methods that can be used with the same specimens.
14 GHz SPDR	• Designed for square substrates 10x10x0.5 mm. Larger or thinner substrates can also be accommodated.

Table 2: Example measurements made with the 2.45 GHz SPDR [5]. Uncertainties are shown in brackets. These are based on a standard uncertainty multiplied by a coverage factor *k* = 2 (equivalent to 95% Confidence Level).

Material	Thickness in mm	ε′	δ in μrad
HDPE	2.008 (0.008)	2.36 (0.01)	160 (80)
Fused silica	2.097 (0.004)	3.81 (0.01)	<60 (60)
Macor	2.008 (0.002)	5.72 (0.02)	5270 (90)
Alumina	2.009 (0.004)	9.68 (0.03)	<50 (50)

Notes:

1. 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 then it is related to loss tangent (the ratio of imaginary and real parts of permittivity) by $\delta \approx \tan\delta \times 10^3$ mrad.
2. Specimens may also be suitable for measurement in millimetre-wave open resonators [4] (note that there are special thickness requirements for open resonators). An NPL brochure for this technique is available.
3. Specimens with diameter > 44 mm are generally suitable for measurement with a three-terminal admittance cell [3] at frequencies up to 10 MHz. An NPL brochure for this technique is available.
4. A Hartshorn and Ward 1-70 MHz system [6] can be used to measure rectangular specimens of nominal size 70 x 54 x 2 mm. The thickness can be reduced to 1.9 mm to suit the 4 GHz SPDR.

[1] 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.
[2] A. P. Gregory "Q-factor measurement by using a Vector Network Analyser", *NPL Report MAT 58,* 2021. http://eprintspublications.npl.co.uk/9304/
[3] 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/
[4] R. G. Jones, "Precise dielectric measurements at 35 GHz using an open microwave resonator", *Proc. IEE,* Vol. 123, 1976
[5] https://www.keysight.com/gb/en/product/16451B/dielectric-test-fixture.html
[6] A. P. Gregory, G. J. Hill and M. A. Barnett, "Low loss dielectric measurements in the frequency range 1 to 70 MHz by using a Vector Network Analyser.", *Meas. Sci. Tech.* Vol 32, 85002. http://eprintspublications.npl.co.uk/9220/

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Version 4. April 2022