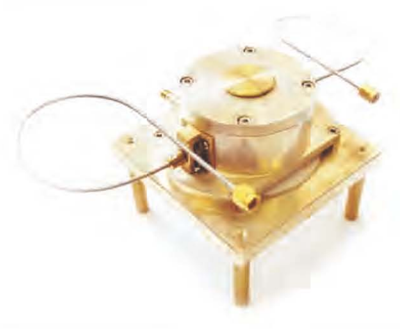
## Table 1. Parameters of Split Post Dielectric Resonators (SPDR)

| | |
|---|---|
| **Application** | SPDRs are intended for the measurements of the complex permittivity of laminar dielectric materials including LTCC substrates, but also thin ferroelectric films deposited on low loss dielectric substrates. Additionally, SPDR's can be used for the measurements of the surface resistance and conductivity of various conducting materials such as commercial resistive layers, thin conductive polymer films or high resistivity semiconductors. Such measurements are only possible for large surface resistance samples with Rs > 5 kΩ/square. |
| **Accuracy of measurements of a sample of thickness *h*** | $\Delta\varepsilon/\varepsilon = \pm\left(0.0015+\Delta h/h\right)$<br>$\Delta\tan\delta = \pm 2\cdot10^{-5}$ or $\pm 0.03\cdot\tan\delta$ whichever is higher |
| **Operational frequency range** | SPDR uses a particular resonant mode. This mode has a particular resonant frequency depending on resonator's dimensions but also, to some extent, on the electrical properties of the measured sample. Thus, each resonator is designed for a particular nominal frequency and the actual measurement is taken at a frequency close to the nominal one. The nominal frequencies of the basic line of SPDRs are: 1.1 GHz, 1.9 GHz, 2.45 GHz, 5 GHz, 10 GHz. Resonators for the other frequencies in the range between 1.1 and 20 GHz can be manufactured upon special request. |
| **Operational temperature range** | -200 $^0$C ÷ 110 $^0$C |
| **Additional equipment needed to perform measurement** | Vector Network Analyser |
| **Measurement procedure** | Resonant frequency and Q – factor of the empty resonator and the resonator with investigated sample are measured. Dedicated software is provided for permittivity and dielectric loss tangent determination.<br>The users who have access to one of the PNA/ENA Series network analysers by Agilent Technologies equipped with 85071E Material Measurement software with Option 300 simply upload the software to the network analyser and obtain the final results directly on its display.<br>The users working with different network analysers need to install the software for dielectric properties calculation on a standard PC computer. |
| **Additional information** | Minimum size of a sample depends on the operating frequency of the resonator. The minimum sizes of samples for the most popular operating frequencies of the resonators are shown in Table 1a. |

## Table 1a. The minimum sizes of sample for operating frequencies

| **Nominal frequency [GHz]** | **Minimum sizes of sample [mm]** | **Maximum thicknesses of sample [mm]** |
|---|---|---|
| 1.1 | 120×120 | 6.0 |
| 1.9 | 70×70 | 4.0 |
| 3.2 | 50×50 | 3.0 |
| 5 ÷ 6 | 30×30 | 2.0 |
| 9 ÷ 10 | 22×22 | 1.0 |
| 13 ÷ 16 | 15×15 | 0.6 |
| 18 ÷ 20 | 10×10 | 0.5 |

# Single Post Dielectric Resonators (SiPDR)



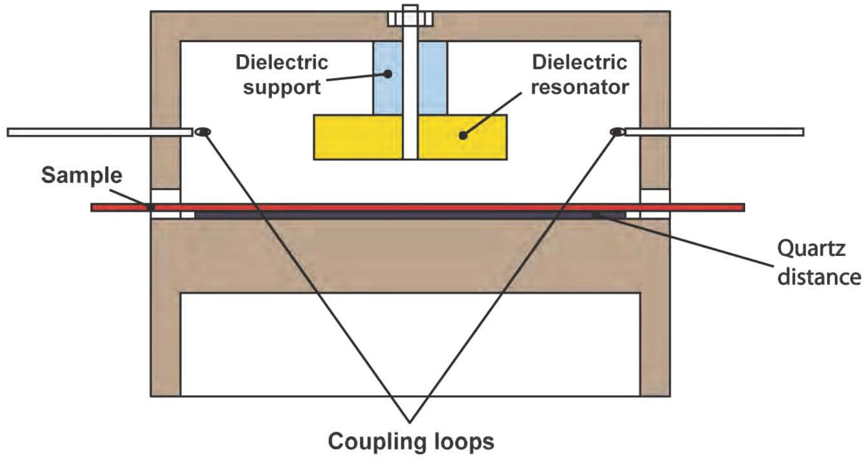


Fig. 2 Cross section of Single Post Dielectric Resonator

## Table 2. Parameters of Single Post Dielectric Resonators (SiPDR)

| | |
|---|---|
| **Application** | SiPDRs are intended for the measurements of the surface impedance of metamaterials and resistive films as well as for the contact-less measurements of the conductivity of semiconductor wafers. Range of thin film materials that can be measured includes resistive layers, thin metal films and conductive polymer films with the surface resistance $R_s < 20$ kΩ/square.<br>For semiconductors wafers the upper limit for resistivity measurements is about 1000 Ωcm. Semiconductors with higher resistivity values can be conveniently measured with split post dielectric resonators.<br>All single post dielectric resonators are custom made. |
| **Accuracy of measurements of a sample of thickness *h*** | The surface resistance is determined with accuracy of about ± 2%. |
| **Operational frequency range** | SiPDRs can be produced at resonant frequencies from 2 GHz to 30 GHz. |
| **Operational temperature range** | -270 $^0$C ÷ 110 $^0$C |
| **Additional equipment needed to perform measurement** | Vector Network Analyser |
| **Measurement procedure** | Resonant frequency and Q – factor of the empty resonator and the resonator with investigated sample are measured. The measured values are saved in a text file in the format specified in the manual of the resonator. Dedicated application (provided together with the resonator) reads the values listed in the file and calculates the surface resistance *R*. |

# TE$_{01\delta}$ Dielectric Resonators

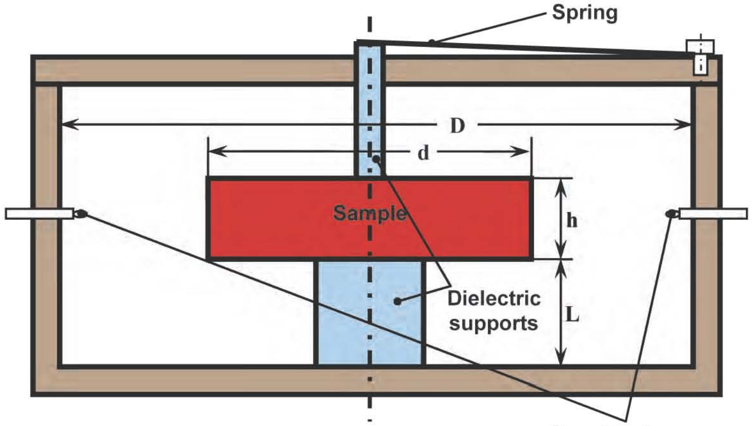
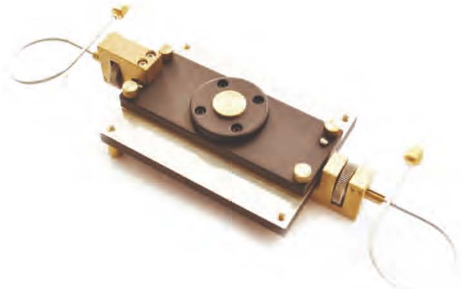
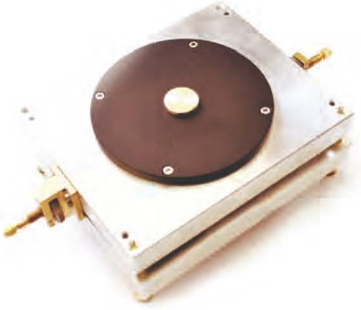
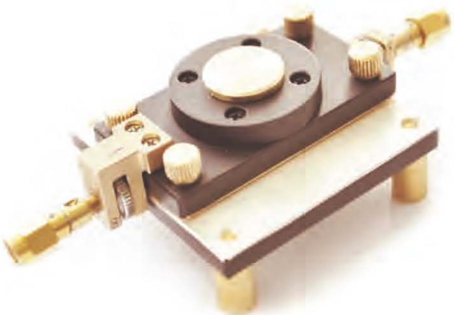


Fig. 3 Cross section of TE$_{01\delta}$ Dielectric Resonator

# Split Post Dielectric Resonators (SPDR)







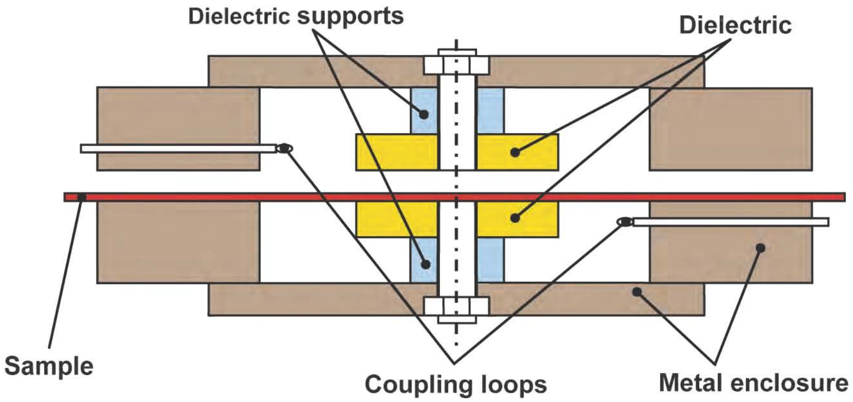


Fig. 1 Cross section of the Split Post Dielectric Resonator (SPDR)

**QWED** manufactures several types of resonators for precise measurements of electromagnetic properties of materials at microwave frequencies, based on years of research led by prof. Jerzy Krupka*. Each resonator is equipped with specialised software for extracting the relevant data from measurements. All resonators manufactured by QWED that are intended for determination of the complex permittivity or other electromagnetic properties of materials require precise measurement of their resonant frequencies and Q – factors. These parameters have to be measured twice, namely in the presence and in the absence of the sample under test. The most accurate apparatus for resonant frequencies and Q – factor measurement at microwave frequencies is automatic network analyser. Once resonant frequencies, Q – factors and dimensions of the sample are measured, appropriate computations have to be performed using dedicated software provided by QWED for a specific resonator.

***Jerzy A. Krupka** is a world recognized expert in electromagnetic property measurements of materials at microwave frequencies. He received the Ph.D. and the D.Sc. in electronic engineering from the Warsaw University of Technology, where he is currently a Professor. Two of his several awards are shown below.

DIPLOMA

BRUSSELS Eureka!

THE BELGIAN AND INTERNATIONAL TRADE FAIR
FOR TECHNOLOGICAL INNOVATION

Jerzy KRUPKA
Politechnika Warszawska - Wydzial Elektroniki i Technik Informacyjnych (Warsaw University of Technology - Faculty of Electronics and Information Technology)

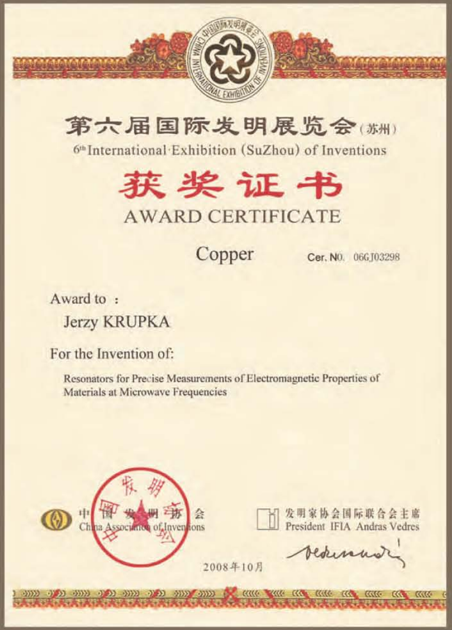
for the innovation

Résonateurs pour des mesures précises des propriétés électromagnétiques de matériaux à bande de fréquence micro-ondes.

**Médaille d'or**

THE PRESIDENT OF THE INTERNATIONAL JURY

THE PRESIDENT



第六届国际发明展览会（苏州）
6th International Exhibition (SuZhou) of Inventions

获奖证书
AWARD CERTIFICATE

Copper

Cer. NO. 06GJ03298

Award to ：
Jerzy KRUPKA

For the Invention of:
Resonators for Precise Measurements of Electromagnetic Properties of Materials at Microwave Frequencies

中 国 发 明 协 会
China Association of Inventions

发明家协会国际联合会主席
President IFIA Andras Vedres

2008年10月

For more information about QWED and prof. Jerzy Krupka refer to
**www.qwed.eu**

## Table 3. Parameters of TE01δ Dielectric Resonators

| | |
|---|---|
| **Application** | TE01δ mode dielectric resonator technique is intended for very precise complex permittivity measurements of bulk low loss disc or cylinder shape dielectric ceramics. Additionally, with this technique the thermal coefficients of permittivity and the dielectric loss tangent can be measured. With this application QWED offers dedicated software for the rigorous computations of the complex permittivity as well as cavities of different size with adjustable coupling mechanisms and low loss dielectric supports.<br>All TE01δ mode dielectric resonator cavities are custom made. |
| **Accuracy of measurements of a sample of diameter *d*** | $\Delta\varepsilon/\varepsilon = T\Delta h/h + (2-T)\Delta d/d$<br>$for \quad 0 < T < 2$<br>$\Delta\tan\delta = \pm 2\cdot 10^{-6}\ or \pm 0.03\cdot\tan\delta$ |
| **Operational frequency range** | Measurement frequency depends on the diameter, height and permittivity of the sample under test, and for typical samples is in the range of 1 ÷ 10 GHz. Measurements at higher frequencies are possible by employing either smaller cavities and samples or higher order quasi $TE_{0mn}$ modes. |
| **Operational temperature range** | -270 $^0$C ÷ 110 $^0$C |
| **Additional equipment needed to perform measurement** | Vector Network Analyser |
| **Sample dimensions** | To obtain the highest precision of the measurements, the size of the sample under test should be in the range of 0.25 ÷ 0.6 of the size of the cavity (for both dimensions: diameter and height). |
| **Measurement procedure** | Sample under test is placed in a metal cavity on a low loss dielectric support. Resonant frequency and Q-factor of the TE01δ are measured. Dedicated software is provided for permittivity and dielectric loss tangent determination. |

## QWED resonators for graphene measurements

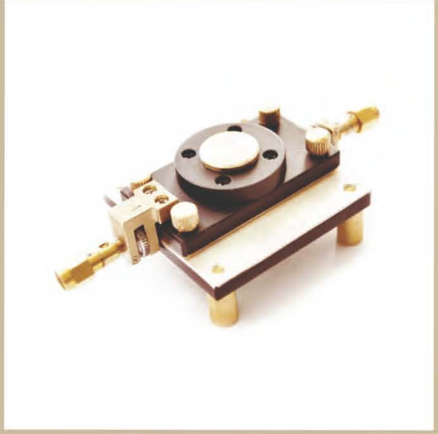
Investigation of graphene properties has been a hot subject in the world's scientific community for the last couple of years. In October 2010, the interest in the subject was additionally fuelled by the Nobel Prize in Physics awarded jointly to Andre Geim and Konstantin Novoselov "for groundbreaking experiments regarding the two-dimensional material graphene".

**QWED is happy to announce that our expert, Prof. Jerzy Krupka, has developed resonators specifically designed for the measurements of electrical properties of graphene deposited on small 10 mm x 10 mm dielectric substrates at microwave frequencies (around 13 GHz). The resonators are now commercially available through QWED.**

**www.qwed.eu**

info@qwed.eu / tel.: +48 22 625 73 19 / fax: +48 22 621 62 99
QWED Sp. z o.o. / ul. Krzywickiego 12 / 02-078 Warsaw / POLAND

# The family of dielectric resonators for precise measurements of electromagnetic properties of materials at microwave frequencies



**www.qwed.eu**