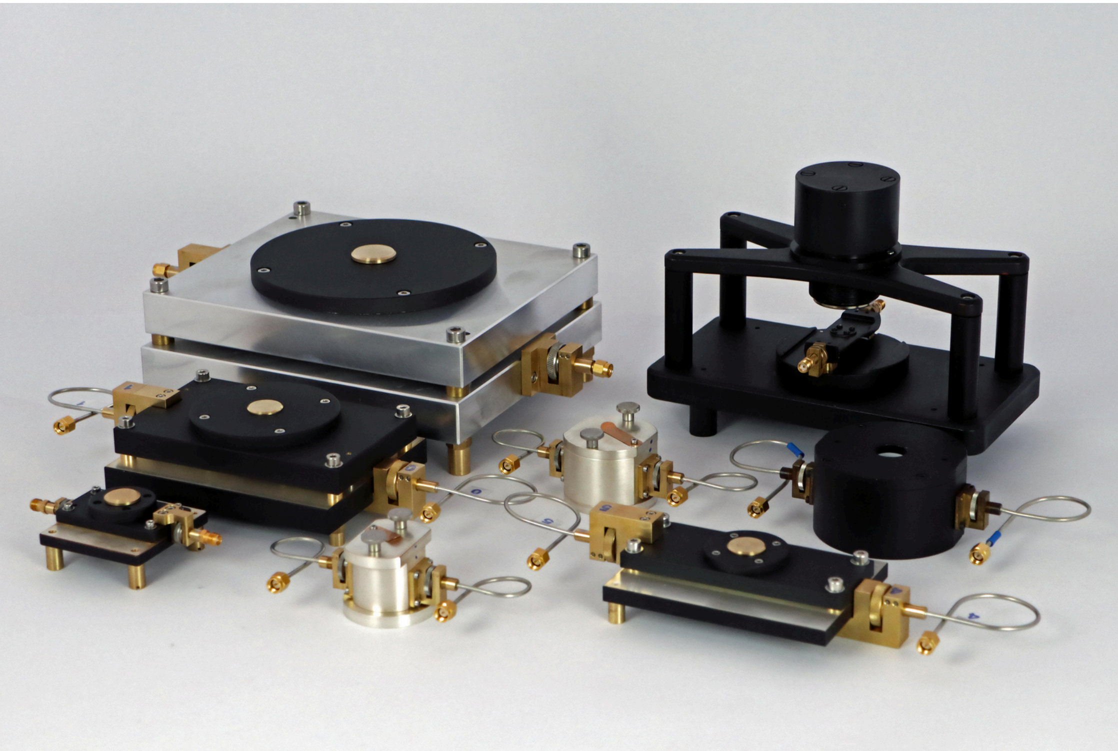
HARDWARE
CATALOG



MICROWAVE MATERIAL TESTING

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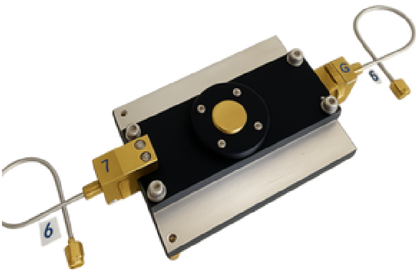
QWED Sp. z o. o.

Table of Contents

Color Legend by materials:

Solid dielectrics	Liquid Dielectrics
Conductors	Semiconductors
Absorbers	Ferromagnetics



Dielectrics

SPDR non-destructively measures in-plane εr and tan δ of flat dielectric sheets.

Polymers

The split-post resonator quantifies εr and tan δ of low-loss polymer laminates and composites.

Ultra-Thin FIlms

Using a film-on-substrate approach, SPDR resolves micrometer-scale coatings by tracking tiny shifts in resonance frequency and Q-factor.

Higly-Resistive Semiconductors

SPDR measures εr and tanδ of high-resistivity Si/SiC; if the loss is mainly conductive, it also yields bulk resistivity (ρ).

Parameters

- Frequency range: **1.1 – 15 GHz***
- Dielectric constant: **Dk = 1 – 100** (achievable accuracy ± 0.15%)
- Loss tangent: **Df > 2 × 10^{-5}** (achievable accuracy ≤ 2%)
- Resistivity: **ρ = 10^{2}– 10^{4} Ω·cm**
- Maximum sample thickness: **0.6 – 6 mm** (depends on frequency)
- Sample diameter: **14 – 120 mm** (depends on frequency)
- Measurement time: **< 30 seconds**
- Temperature: room, **0 – 110 °C**
- Supported standards: **IEC 61189-2-721 (04-2015); IPC-TM-650 2.5.5.15**
- Suitable for low-loss dielectrics, high-resistivity semiconductors & thin films
- Software-controlled measurement

*Each SPDR is manufactured for a single nominal frequency (1.1, 2.45, 5, 10 or 15 GHz).
Other frequencies within 1.1 – 15 GHz are available on request.

Fabry - Perot Open Resonators for Dielectrics

Dielectrics

Non-contact FPOR measurements deliver ε and tanδ of bulk dielectrics.

Polymers

The open resonator quantifies ε and tanδ of low-loss polymer sheets without electrodes.

Ultra-Thin FIlms

FPOR resolves dielectric properties of films just a few μm thick by analysing minute Q-factor shifts,

Higly-Resistive Semiconductors

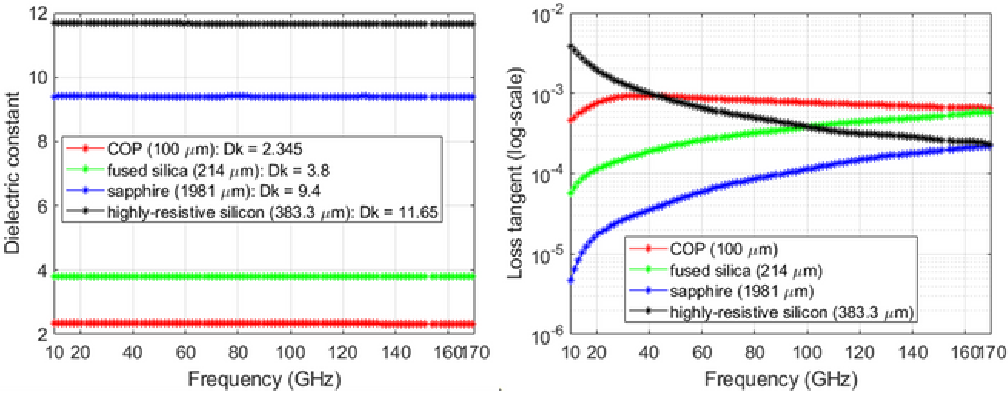
extracts bulk resistivity of semiconductors like Si or SiC.

Parameters

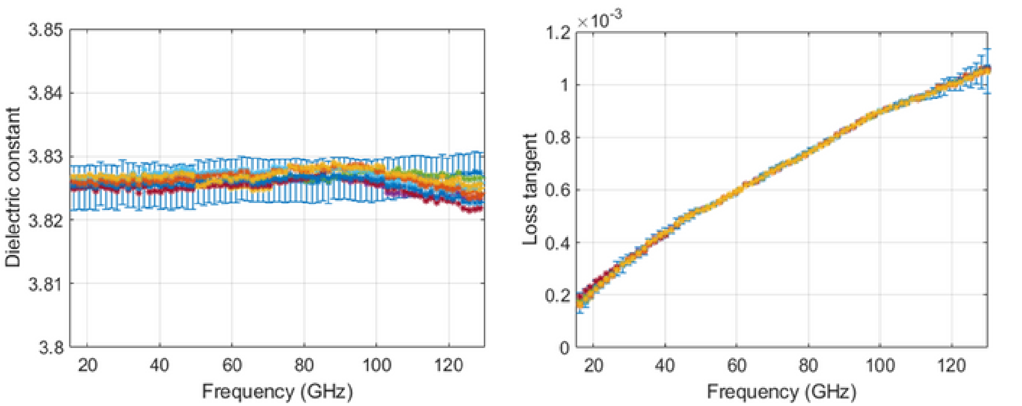
- Frequency range: **10 – 130 GHz***
- Dielectric constant: **Dk = 1 – 15** (achievable accuracy ± 0.25 %)
- Loss tangent: **Df > 5 × 10^{-6}** (achievable accuracy ± 2 %)
- Sample thickness: **1 μm – 3 mm**
- Sample diameter: **50 – 150 mm**
- Measurement time: **> 1 minute**
- Temperature: **room, 0 – 80 °C (on request)**
- In-plane anisotropic materials can be measured
- Fully automated and software-controlled measurement

*Available also in various frequency-range configurations (e.g. 10 – 26.5 GHz, 10 – 43 GHz, 10 – 50 GHz, 10 – 67 GHz, 10 – 110 GHz, etc.)

Measurement Results

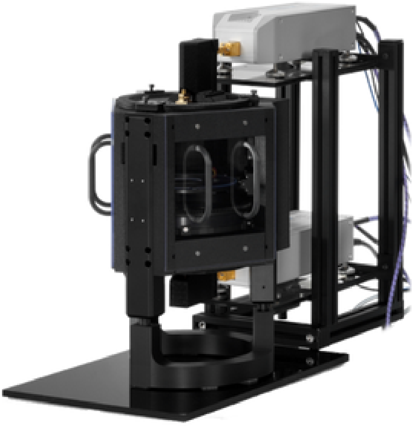


Overview of the FPOR measurement capabilities. Unique possibility of having a single measurement fixture for the whole 10–170 GHz range.



Fused silica wafer (148.15 ± 0.36 μm) measured 10 times, each time removing and inserting the sample again. Dk uncertainty bars arise from thickness uncertainty; Df bars from signal-to-noise ratio. Outstanding Dk repeatability of 0.15 %!

D-Band Fabry-Perot Open Resonator for Dielectrics



Dielectrics

Non-contact FPOR measurements deliver ε and tanδ of bulk dielectrics.

Polymers

The open resonator quantifies ε and tanδ of low-loss polymer sheets without electrodes.

Ultra-Thin FIlms

FPOR resolves dielectric properties of films just a few μm thick by analysing minute Q-factor shifts,

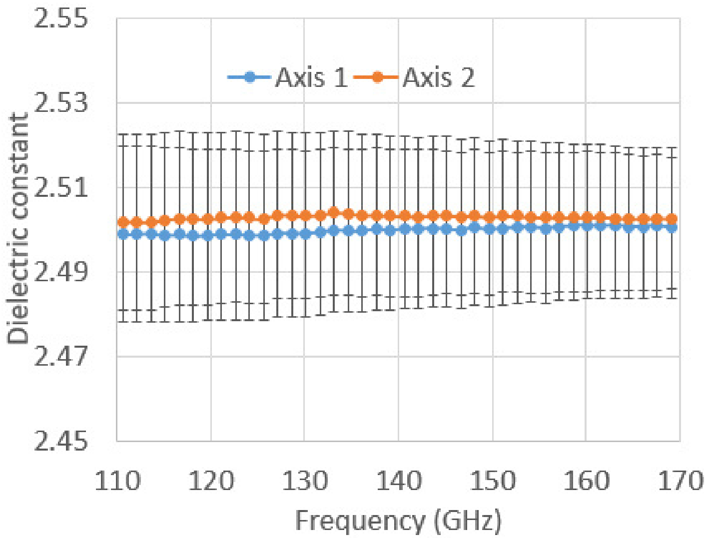
Higly-Resistive Semiconductors

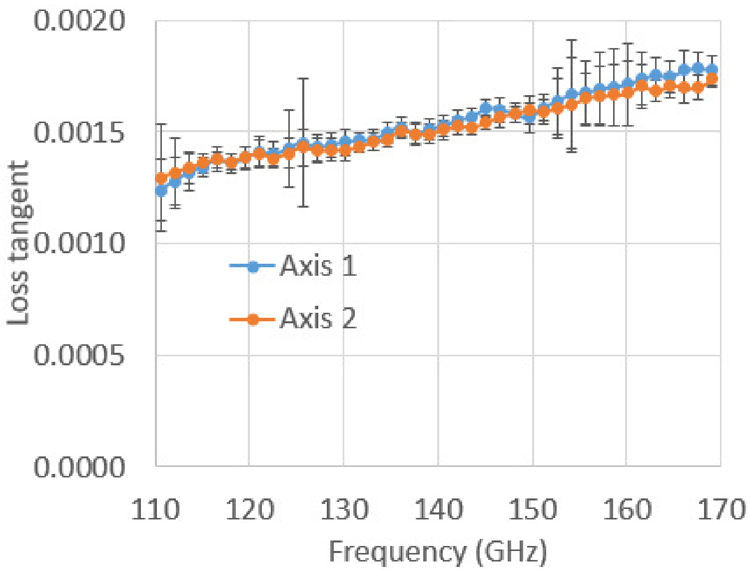
extracts bulk resistivity of semiconductors like Si or SiC.

Parameters

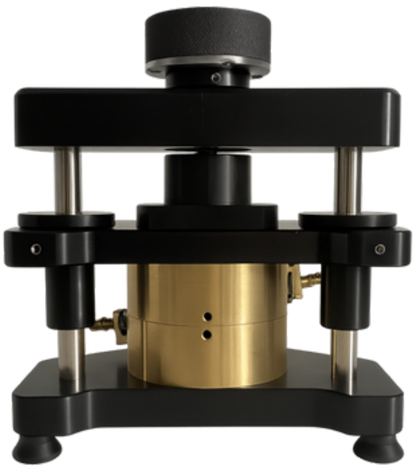
- Frequency range: **110 – 170 GHz**
- Dielectric constant: **Dk = 1 – 15** (achievable accuracy ± 0.5 %)
- Loss tangent: **Df > 5 × 10^{-6}** (achievable accuracy ± 5 %)
- Sample thickness: **1 μm – 3 mm**
- Sample diameter: **> 50 mm**
- Measurement time: **> 3 minutes**
- Temperature: **room**
- In-plane anisotropic materials can be measured
- Fully automated and software-controlled measurement

Measurement Results





Overview of the D-Band FPOR measurement capabilities.



Dielectrics

SPDR non-destructively measures in-plane εr and tan δ of flat dielectric sheets.

Polymers

The split-post resonator quantifies εr and tan δ of low-loss polymer laminates and composites.

Ultra-Thin FIlms

Using a film-on-substrate approach, SPDR resolves micrometer-scale coatings by tracking tiny shifts in resonance frequency and Q-factor.

Higly-Resistive Semiconductors

SPDR measures εr and tanδ of high-resistivity Si/SiC; if the loss is mainly conductive, it also yields bulk resistivity (ρ).

Parameters

- Frequency range: **10 GHz** (higher frequencies coming soon…)
- Dielectric constant: **Dk = 1-15** (achievable accuracy ± 0.2%)
- Loss tangent: **Df > 5 × 10^{-6}** (achievable accuracy ± 2%)
- Sample size: **40 × 40 mm – 100 × 100 mm**
- Sample thickness: **5 µm to 4 mm** (e.g., sapphire)
- Supported standards: **IPC TM-650 2.5.5.13**
- Software-controlled measurement

TE01δ-Mode Dielectric Resonators

Ceramics
Ultra low-loss materials

High dk testing
Microwave resonators. filters. etc.

Cryogenic temperatures
Uniquly accurate measurements at low temperatures

TCK & TCF extraction
Up to 125 °C or higher with custom-designs

Parameters

- Frequency range: **Depends on dielectric constant and dimensions of the sample**
- Dielectric constant: **Dk = 1 – 1000** (achievable accuracy < 0.2%)
- Loss tangent: **Df = 10^{-2}– 10^{-4}** (achievable accuracy < 2%)
- Temperature: **−270 °C – 125 °C** (higher temperature on request)
- Software-controlled measurement

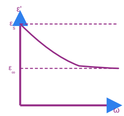
Fabry-Perot Open Resonator for Liquids

Electronic Coolant

highly sensitive measurement of ε_R and tan δ in low-loss fluorinated liquids (e.g., Fluorinert FC-40).

Oil

broadband determination of complex permittivity for vegetable or lubricating oils.



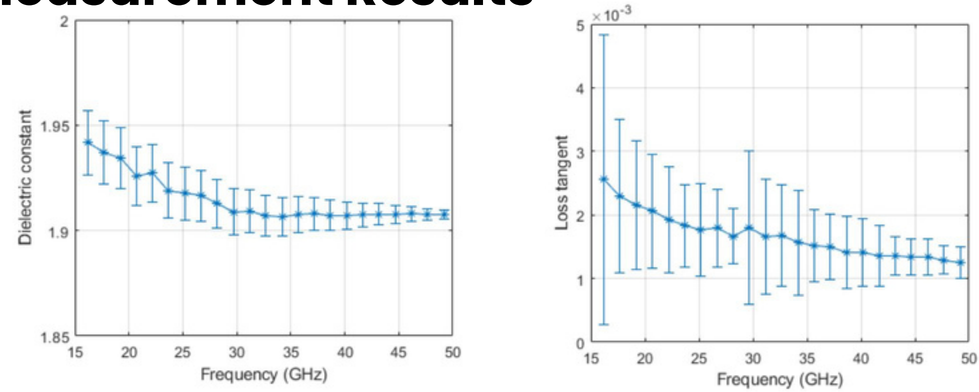
Dispersion

Reveal liquids hidden molecular dynamics by mapping how their dielectric constant and loss tangent change with frequency.

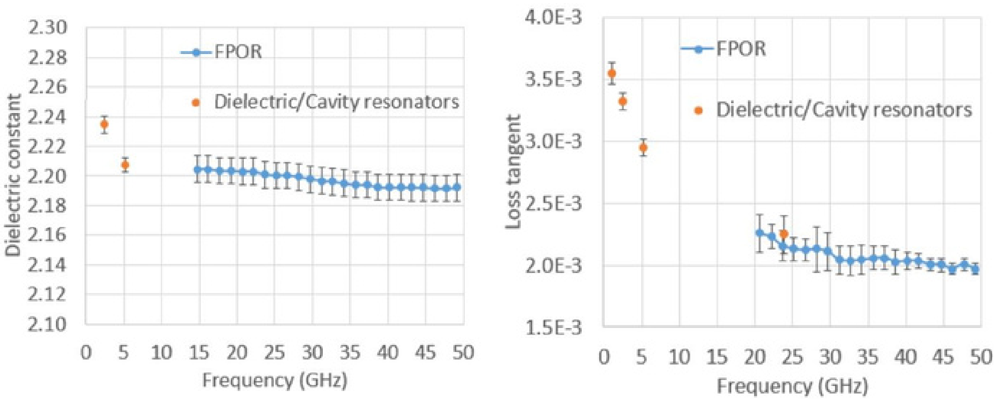
Parameters

- Frequency range: **15 – 67 GHz**
- Dielectric constant: **Dk = 1 – 15** (achievable accuracy < 0.5 %)
- Loss tangent: **Df > 1 × 10^{-4}** (achievable accuracy < 2 %)
- Temperature: **room**
- Required fluid volume: **< 10 mL**
- Fully automated and software-controlled measurement

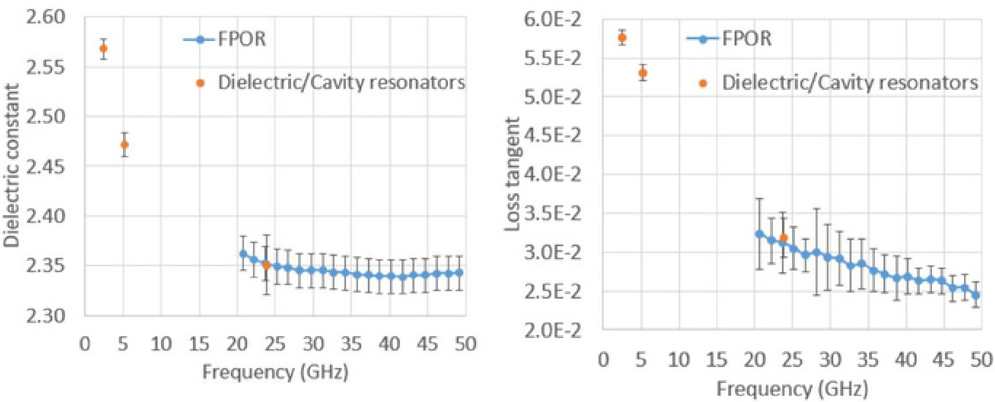
Measurement Results



FPOR for Liquid results for 3M Fluoroinert FC-40.



FPOR for Liquid measurements of engine oil versus dielectric/cavity-resonator



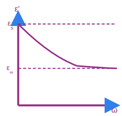
FPOR for Liquid measurements of canola oil versus dielectric/cavity-resonator

Electronic Coolant

highly sensitive measurement of εR and tan δ in low-loss fluorinated liquids (e.g., Fluorinert FC-40).

Oil

broadband determination of complex permittivity for vegetable or lubricating oils.



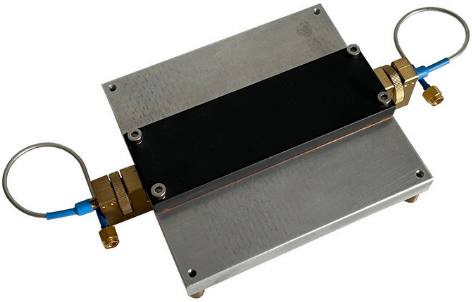
Dispersion

Reveal liquids hidden molecular dynamics by mapping how their dielectric constant and loss tangent change with frequency.

Parameters

- Frequency range: **1 GHz, 2.5 GHz, 5 GHz, 2.5 & 5 GHz, 10 GHz, 24 GHz**
- Dielectric constant: **Dk = 1 – 100** (achievable accuracy < 0.5 %)
- Loss tangent: **Df > 1 × 10^{-4}** (achievable accuracy < 2 %)
- Temperature: **0 - 100 ℃**
- Software-controlled measurement

Single-Post Dielectric Resonator



Conductive Composites

the dielectric properties of composite films just a few micrometers thick

Semiconductors

The SiPDR resonator extracts the bulk resistivity of semiconductor wafers (e.g., SiC) from 10 Ω·cm up to several hundred Ω·cm.

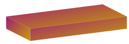
Metamaterials

Contact-less SiPDR measurements deliver dielectric loss data for engineered negative-index metamaterial structures.

Parameters

- Frequency range: **5 GHz** (other bands on request)
- Resistivity (bulk) **$\rho = 10^{-4} – 10^{3}$ Ω·cm** (accuracy ± 2 %)
- Surface resistance (thin films): **$R_s = 10^{-1} – 2 \times 10^{4}$ Ω/sq** (accuracy ± 2 %)
- Sample thickness: **few µm to 1 mm**
- Sample diameter: **30 – 90 mm**
- Measurement time: **≪ 1 minute**
- Temperature: **0 – 110 °C**
- Suitable for lossy thin films, resistive layers & doped semiconductor wafers
- Software-controlled measurement

Fabry-Perot Open Resonator for Conductors



Bulk Metal

rigid sheets or plates of highly-conductive metals (e.g., copper, silver, aluminium).

Conductive Foils

thin, flexible metal foils such as rolled copper; the resonator probes their surface conductivity even at micrometre-level thicknesses.

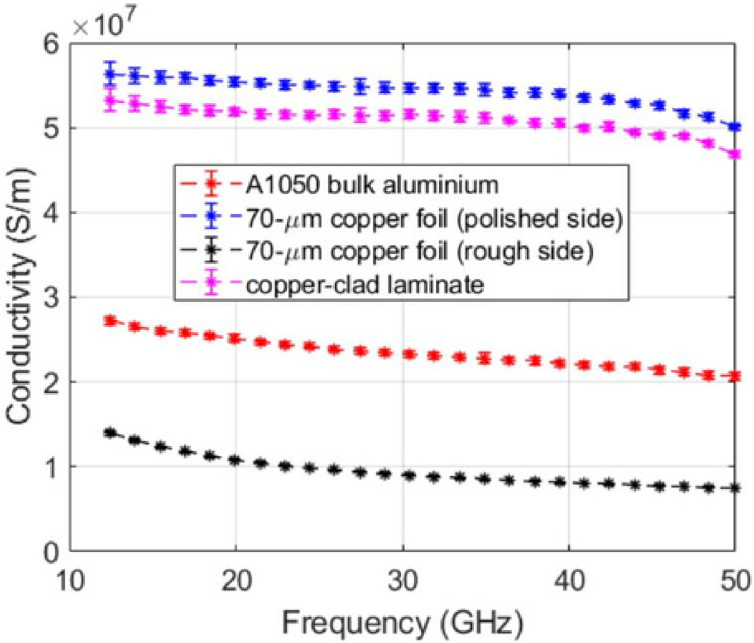
Copper-Clad Laminates

PCB-grade dielectric panels coated with copper; the instrument measures the electrical conductivity of the copper.

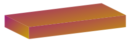
Parameters

- Frequency range: **12 – 50 GHz**
- Conductivity: **$\sigma = 5 \times 10^4 – 6 \times 10^7$ S/m** (achievable accuracy < 5%)
- Sample thickness: **≥ 5 skin depths** (e.g., a few µm for Cu)
- Sample diameter: **150 – 195 mm**
- Measurement time: **a few minutes**
- Fully automated and software-controlled measurement

Fabry-Perot Open Resonator for Conductors



The FPOR for Conductors system measures conductive samples such as bulk aluminium, copper foils with different surface roughness, and copper-clad laminates across the 12 – 50 GHz range.



Bulk Metal

rigid sheets or plates of highly-conductive metals (e.g., copper, silver, aluminium).

Conductive Foils

thin, flexible metal foils such as rolled copper; the resonator probes their surface conductivity even at micrometre-level thicknesses.

Copper-Clad Laminates

PCB-grade dielectric panels coated with copper; the instrument measures the electrical conductivity of the copper.

Parameters

- Frequency range: **14 & 20 GHz or 28 & 44 GHz**
- Conductivity: **$\sigma = 10^5 – 6 \times 10^7$ S/m**
- Sample thickness: **≥ 3 skin depths** (e.g., a few µm for Cu)
- Sample size: **≥25 x 25 mm**
- Software-controlled measurement

MPR Subwavelength cavity for Ferromagnetics

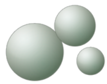
Spheres

The device is equipped is based on a novel electrodynamic model extracting ΔH of the material under test from the frequency and Q-factor of the magnetic-plasmon-resonance (MPR) of the sphere measured for a given vertical position of the magnet knob.

Parameters

- Frequency range: **5 – 9 GHz** (standard; extended 2 – 18 GHz*)
- Usable cavity range: **Up to ~60 GHz****
- Magnetic bias: Hand-held tunable magnet
- Sample diameter: **D < 0.6 mm**
- Linewidth capability (ΔH): **< 0.25 Oe @ 2 GHz**
  < 5 Oe @ 5 GHz
  < 30 Oe @ 18 GHz
- Temperature: **room**
- Software-controlled measurement

* Extended 2 – 18 GHz operation via spacer sleeves and cavity support changes.
** Cavity acts as a mechanical holder up to ~60 GHz; operation beyond 18 GHz requires stronger magnetic bias (e.g., external magnet).



Spheres

The device is equipped is based on a novel electrodynamic model extracting ΔH of the material under test from the frequency and Q-factor of the magnetic-plasmon-resonance (MPR) of the sphere measured for a given vertical position of the magnet knob.

Parameters

- Nominal frequency: **5 GHz** (option: **10 GHz***)
- Magnetic bias: **Hand-held tunable magnet**
- Sample type: **Low-magnetic-loss ferrite spheres**
- Sample diameter: **D < 1.5 mm** (quartz tube holder)
- Temperature: **room**

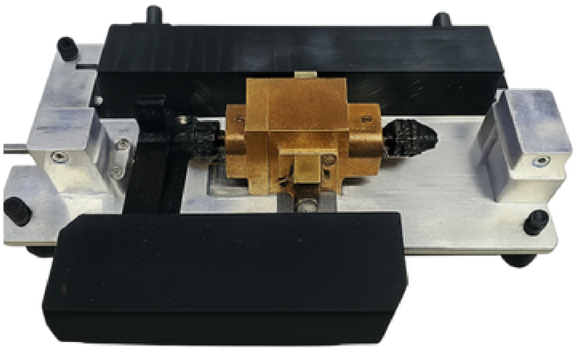
- Measurability examples: **ΔH = 0.2 Oe, D = 0.5 mm, Ms = 1800 Gs**

  ΔH = 3 Oe, D = 1.4 mm, Ms = 1200 Gs

  ΔH = 16 Oe, D = 1.2 mm, Ms = 1700 Gs

  ΔH = 20 Oe, D = 1.0 mm, Ms = 1800 Gs

  (no mode splitting)



Conductive Wires

Fast GHz cavity test for thin wires: clamp once, get conductivity (σ) and effective diameter in seconds.

Parameters

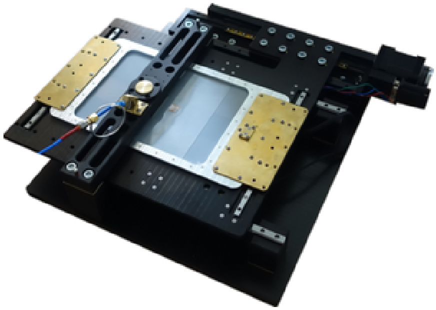
- Frequency range: **from 37 GHz up to 70 GHz**
- Wire parameters: Diameter: **100 – 450 µm**

  Length: > **10 cm**

  Conductivity: **σ > 10 S/m**

  Maximum achievable accuracy: **< 1%**
- Software-controlled measurement

2D Split-Post Dielectric Resonator



Dielectrics

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Polymers

The split-post resonator quantifies εr and tan δ of low-loss polymer laminates and composites.

Ultra-Thin FIlms

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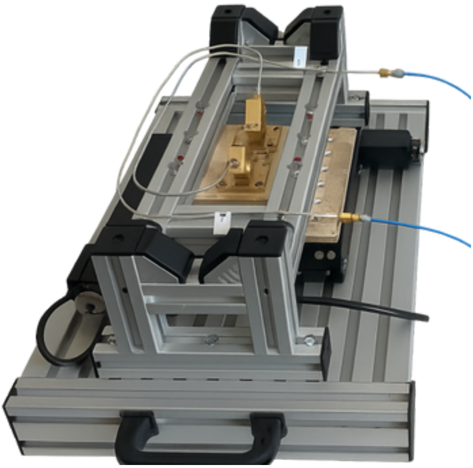
Higly-Resistive Semiconductors

SPDR measures εr and tanδ of high-resistivity Si/SiC; if the loss is mainly conductive, it also yields bulk resistivity (ρ).

Parameters

- Frequency range: **10 GHz**
- Conductivity: **0.1 – 10^{6} 1/(Ω·m)**
- Resistivity (bulk) **ρ = 10^{-4}– 10^{3} Ω·cm**
- Surface resistivity (thin films): **Rs = 10^{-1} – 2 × 10^{4} Ω/sq**
- Sample size: **up to 80 × 120 mm**
- Sample thickness: **few μm up to 1 mm**
- Fully automated, software-controlled measurement



Conductive Composites

the dielectric properties of composite films just a few micrometers thick

Semiconductors

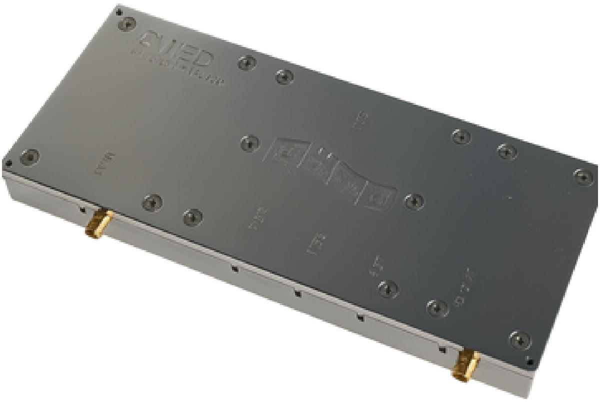
The SiPDR resonator extracts the bulk resistivity of semiconductor wafers (e.g., SiC) from 10^{-4} Ω·cm up to several hundred Ω·cm.

Metamaterials

Contact-less SiPDR measurements deliver dielectric loss data for engineered negative-index metamaterial structures.

Parameters

- Frequency range: **10 GHz**
- Resistivity (bulk) **$\rho = 10^{-4} – 10^{3}$ Ω·cm** (accuracy ± 2 %)
- Surface resistance (thin films): **$R_s = 10^{-1} – 2 \times 10^{4}$ Ω/sq** (accuracy ± 2 %)
- Sample thickness: **few µm to 1 mm**
- Sample diameter: **up to 100 x 100 mm**
- Measurement time: **≪ 1 minute**
- Suitable for lossy thin films, resistive layers & doped semiconductor wafers
- Fully automated, software-controlled measurement



Fast & Easy testing

USB-connected Windows application provides real-time parameter adjustment.

SPDR & SiPDR dedicated

Portable material testing setup.

Alternative to VNA

For materials testing

Parameters

- Interface (data and power): **USB-C** (connect to USB 3.0 port)
- Power consumption: **5 V, 900 mA**
- Accuracy of measurement: **Q: 2% for Q > 1000 F: 2.5 ppm**
- Range of measured Q-factor: **200 ÷ 100 000**
- Frequency range: **8.4 GHz ÷ 10.4 GHz**
- Frequency resolution: **1 kHz**
- Frequency stability: **2.5 ppm**
- Output power: **1 dBm ± 3 dBm**
- Range of input power: **–80 dBm ÷ –30 dBm**

Microwave Frequency Q-Meter

Fast & Easy testing

USB-connected Windows application provides real-time parameter adjustment.

SPDR & SiPDR dedicated

Portable material testing setup.

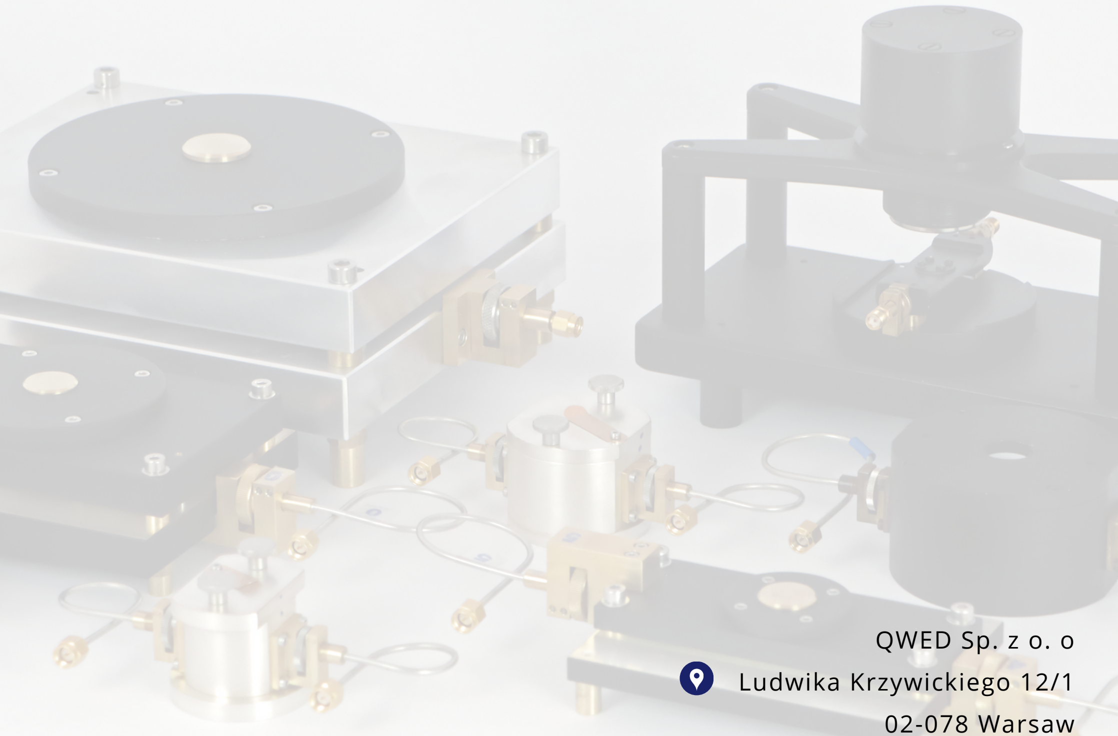
Alternative to VNA

For materials testing

Parameters

• Interface (data and power):	**Mini-USB** (connect to USB port)
• Power consumption:	**5 V, ~400 mA**
• Accuracy of measurement:	**ε: 1% for Q > 1000**
	Δtan δ = ±2·10^{-5} or ±0.03·tan δ
• Range of measured Q-factor:	**200 ÷ 100 000**
• Frequency range:	**Type 1: 4.4 GHz ÷ 5.2 GHz,**
	Type 2: 1.4 GHz ÷ 2.6 GHz,
	Type 3: 0.7 GHz ÷ 1.3 GHz
• Frequency resolution:	**1 kHz**
• Frequency stability:	**2.5 ppm**
• Output power:	**12 dBm ± 3 dBm**
• Range of input power:	**−55 dBm ÷ −5 dBm**
• Measurement time:	**< 10 s**

MICROWAVE MATERIAL TESTING



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