QWED Sp.z.o.o., Warsaw, Poland

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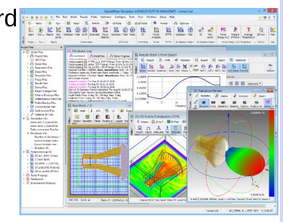
QWED is a Polish SME founded in **1997** by 4 scientists / engineers from the Warsaw University of Technology (WUT), with complementary experiences in microwave technology, mathematical physics, and computational techniques. The primary task of QWED has been to manage the **development and industrial applications of *QuickWave* EM software**, originated by the company co-founders, led by Wojciech Gwarek, IEEE Fellow and Pioneer Awardee for the underlying concepts. *QuickWave* was acclaimed "gem" in IEEE Spectrum Magazine (1998) and awarded with e.g. the **European IT Prize** (1998) and the Prime Minister of Poland Award (1999). In the 2000s QWED estabilished a **branch of microwave hardware** activities based on 4 decades of worldly acknowledged research by Jerzy Krupka, who joined QWED team. QWED manufactures several types of **dielectric resonators for precise measurements** of EM properties of materials in GHz range. A decade average amounts to 100 test fixtures sold per year. Their quality has been recognised by industrial practitioners, leading researchers, and **industrial standard creators** including **Eureka Medaille d'or**. Further technology developments are supported by *QuickWave* modelling and co-funded EU research projects, e.g. MMAMA project.

Business branches & activities

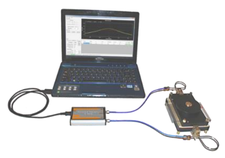
Electromagnetic & Multiphysics modelling & design software, 3D & BOR 2D tools from QuickWave family

Based on 300+ publications by:
Prof. W. Gwarek, IEEE Fellow, DML, Pioneer Award
Dr. M. Celuch, President of QWED



Text-fixtures for precise material measurements

Based on 300+ publications by Prof. J. Krupka, IEEE Fellow



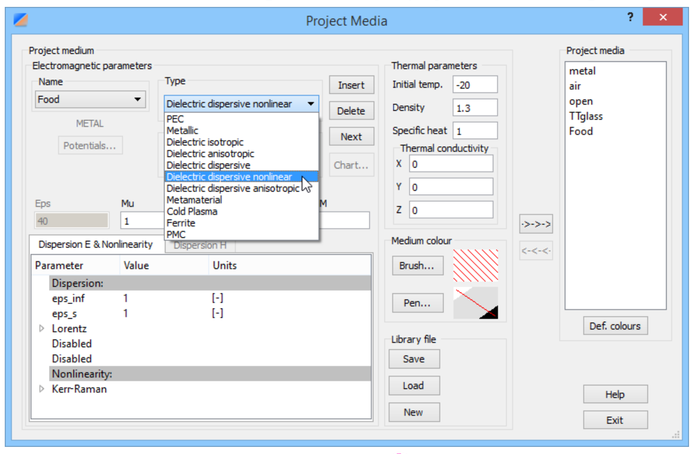
Consultancy & design services based on EM & material characterisation and measurements techniques

team of 10+engineers, 4 PhDs, 2 Profs
key areas: MW power appliances, customised resonators for material measurements, antennas &feeds

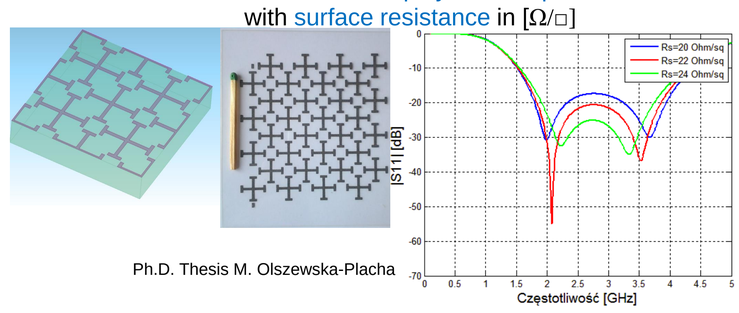
Public co- funded research projects

QuickWave

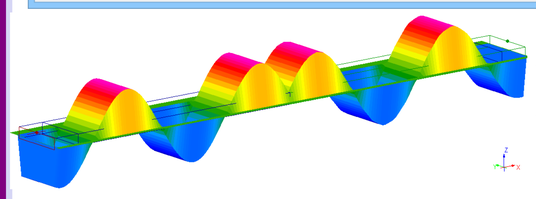
Electromagnetic & Multiphysics modelling software accounting for materials modelling at the continuum level.



Thin sheets of carbon-based polymer composites described with surface resistance in [Ω/□]



Ph.D. Thesis M. Olszewska-Placha

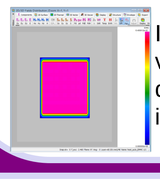


$$\textit{Drude:}\quad \varepsilon_r(\omega) = \varepsilon_\infty + \frac{(2\pi f_p)^2}{(j\omega 2\pi \nu_c - \omega^2)}$$

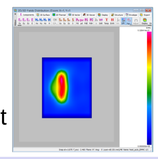
$$\textit{Debye:}\quad \varepsilon_r(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{(1 + j\omega\tau)}$$

$$\textit{Lorentz:}\quad \varepsilon_r(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty (2\pi f_p)^2}{((2\pi f_p)^2 + j\omega 2\pi \nu_c - \omega^2)}$$

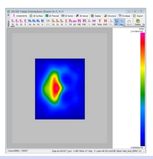
Material parameter dependent on process driving force



Initial loss values distribution in the object

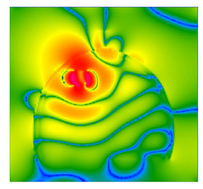


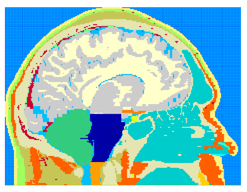
Losses after 30sec of MW heating

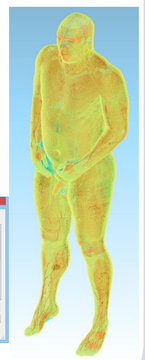


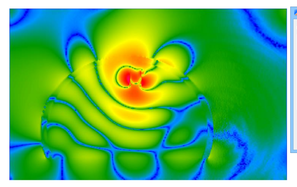
Losses after 90sec of MW heating

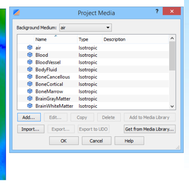
Macroscopic modelling of biological problems





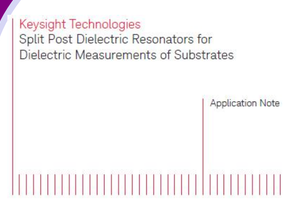






Detection of inhomogeneities, e.g. tumours

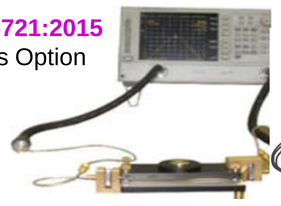
Material measurements



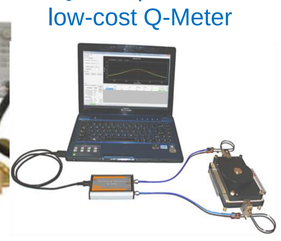
Split-post dielectric resonators for low-loss laminar dielectrics measurements subject of
European Standard IEC 61189-2-721:2015
endorsed by Keysight Technologies Option 003 N1500A

Robust, easy-to-use with:

standard VNA



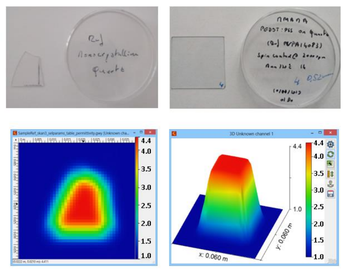
QWED portable low-cost Q-Meter



Recent SPDR-based designs for larger surfaces of:

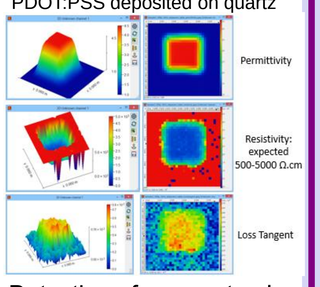
large sheets of glass manual scan @1.9 GHz

semiconductor wafers automatic scan @10 GHz



2D permittivity maps obtained with QWED 10GHz scanner

Semiconductor sample: PDOT:PSS deposited on quartz

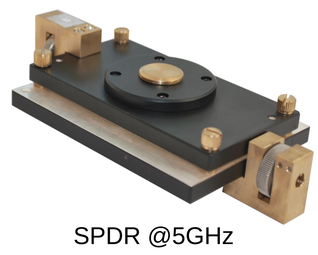


Detection of parameters' inhomogeneities

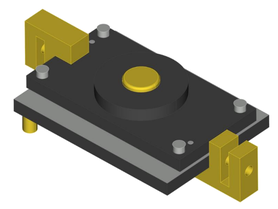
QWED standard SPDRs @ 1.1, 2.45, 5, 10, 15 GHz

Ref.: www.qwed.eu
J. Krupka et al., *J. Eur. Ceramic Soc.*, vol. 21, pp. 2673-2676, 2001.
J. Krupka & J. Mazierska, *IEEE Trans. Instr. Meas*., vol. 56, no. 5,2007.
M. Celuch & al., *IEEE MTT-S IMS*, Boston 2019.
www.mmama.eu recent work under H2020-NMBP-07-2017 grant MMAMA No. 761036

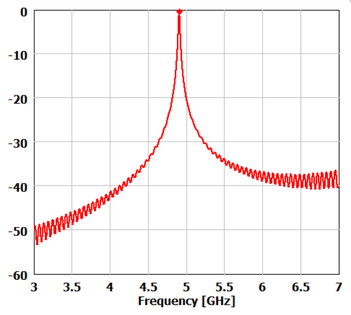
EM Simulations of microwave test-fixtures for material measurements



SPDR @5GHz



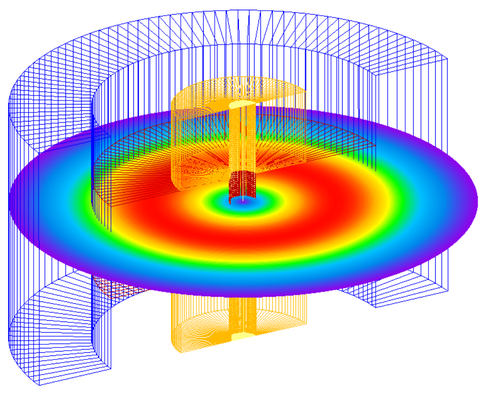
CAD model of SPDR @5GHz



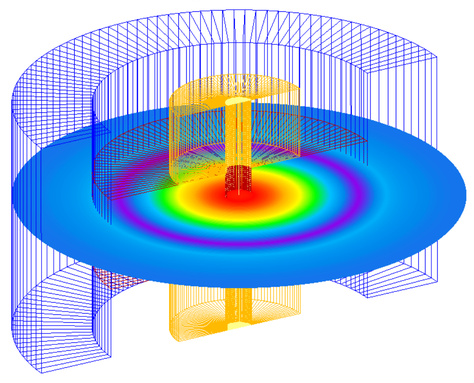
Exemplary |S21| curve for SPDR @5GHz

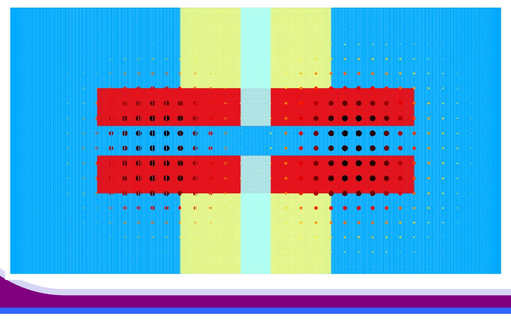
Simulated field distribution in SPDR

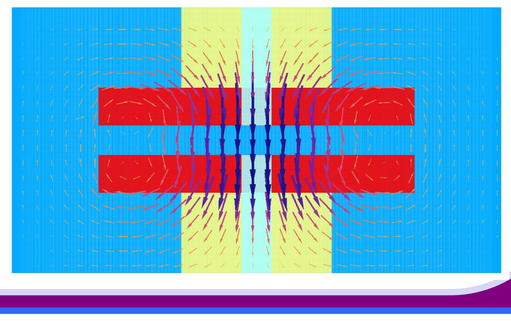
Electric field



Magnetic field

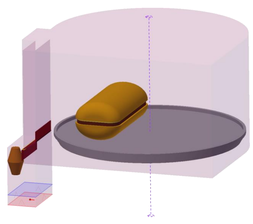






Continuum modelling

- ✓ **Electromagnetic**
- ✓ **Thermal**
- ✓ **Heat Flow**
- ✓ **Fluid Flow**
- ✓ **Parameters dependent on process driving force**
- ✓ **Interfaces to external modules**

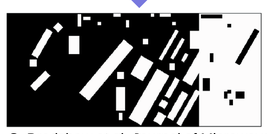


Obtaining equivalent parameters for continuum modelling

Imaging of multi-phase samples

Real scan/picture

Image recognition

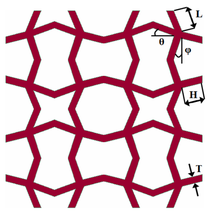


Simulation model

S. Bradshaw et al. Journal of Microwave Power & Electromagnetic Energy, vol.40,no. 4,2007.

Effective equivalent parameters

Artificial structural materials – chiral materials



Effective parameters dependent on building material and chiral geometry

F.Scarpa et al. PSSB, vol.246,no. 9,2009.

Modelling bases for material measurements

EM simulation of SPDR without and with SUT

EM Field differencing

A total of ca. **200 licences** and **1000 test-fixtures for precise material measurements** have been implemented on **6 continents**

Diverse client base, from **radioastronomy laboratories** (e.g. NRAO in US) to world's leading **domestic microwave oven manufacturers**; **microwave imaging** is also supported by *QuickWave*, from biomedical devices to industrial microscopy of materials.

What distinguishes QWED from its larger competitors is openness towards **emerging technologies** and **niche markets**.

QWED seeks collaborations

- to develop **dedicated measurement setups**, for **electric** and **magnetic** properties measurements
- to develop: **new material models** for QuickWave, **new physical solvers, interfaces to other physical processes, promoting modelling & education**

MMAMA

Acknowledgement

Recent QWED works concerning materials modelling has received funding from the European Union Horizon H2020 Programme (H2020-NMBP-07-2017) under grant agreement n°761036.