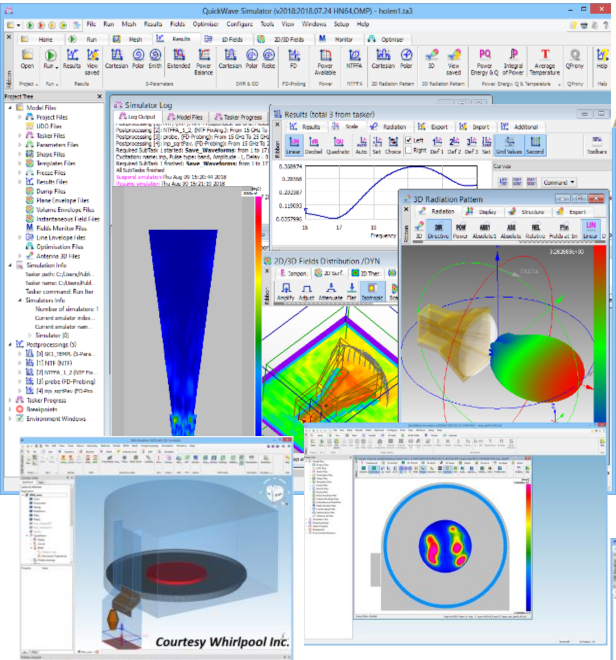
Computer modelling – a virtual laboratory for emerging technologies

M. Olszewska-Placha, M. Celuch, QWED Sp. z o.o.

Polish high-tech SME - 24 years on the world's market

Business branches and competences



Electromagnetic and Multiphysics simulation & design software QuickWave

based on 300+ publications by the founders

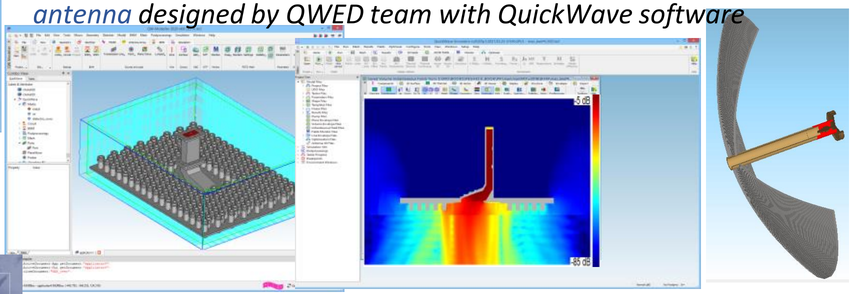
THE EUROPEAN INFORMATION TECHNOLOGY PRIZE Winner

Consultancy & design services based on EM expertise & tools

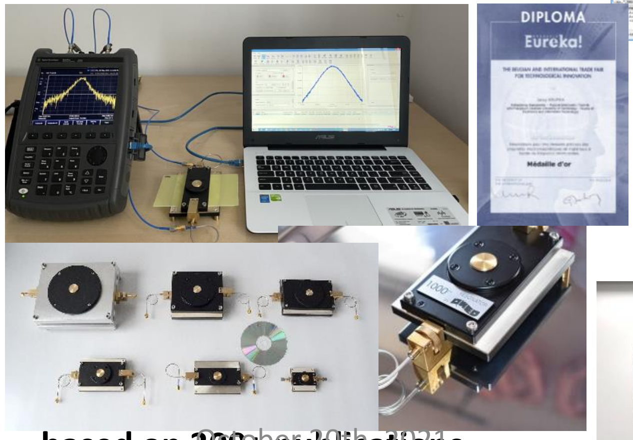
team of 10+engineers, 4 PhDs, 2 Profs

key areas: *MW power appliances, customised resonators, antennas &feeds*

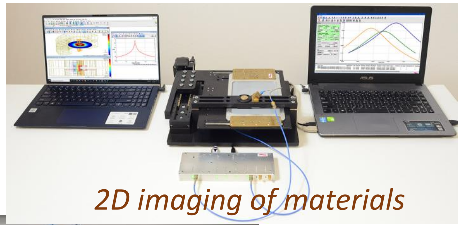
Microwave applicator for bituminous surfaces and dual-reflector antenna designed by QWED team with QuickWave software



Test-fixtures for precise material measurements



based on 300+ publications by prof.J.Krupka, IEEE Fellow

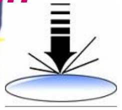


2D imaging of materials

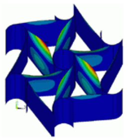
Characterisation of battery materials

Millimetre-wave characterisation of materials for 5G

R&D projects



FP6 SOCOT – development and validation of an optimal methodology for overlay control in semiconductor industry, for the 32 nm technology node and beyond.



FP6 CHISMACOMB – development, modelling, and applications of chiral materials → EM validation of mixing rules

Eureka E! 2602 MICRODEFROST MODEL – innovative software-based product development tool for simulating and optimising heating and defrosting processes in microwave ovens

SYNTHETIC ENVIRONMENT RESEARCH PROGRAM HIRF

FP7 HIRF SE (High Intensity Radiated Field Synthetic Environment) - numerical modelling framework for aeronautic industry

Eureka FOODWASTE – developing new microwave treatment system for high water content waste

ERA-NET MNT NACOPAN – applications and modelling of nano-conductive polymer composites

PBS Program Badań Stosowanych

NGAM2 – designing an industrial device for thermal bonding of bituminous surfaces with the aid of microwave heating

MMAMA

MMAMA (Microwave Microscopy for Advanced and Efficient Materials Analysis and Production) – accelerating the development of high efficiency solar cells through application and enhancement of material measurement techniques

Nano Bat

NanoBat - developing a novel nanotechnology toolbox for quality testing of Li-ion and beyond Lithium batteries with the potential to redefine battery production in Europe and worldwide.

ULTCC6G_EPac - developing a novel functional materials and their processing techniques feasible for 5G and beyond.

What is a simulation/modelling?

- Modelling is mimicking a real phenomena with another one that is easier for us to understand and that we are able to describe with a known processes
- The aim is to predict the course of the phenomena with reference to changing parameters
- Choose parameters' values allowing for achieving the desired behaviour
- Hoping for real-life object to behave the exact way the simulation model is

What is a computer simulation?

- Describing a real-life phenomena with numbers/bits, which are a subject to digital processing

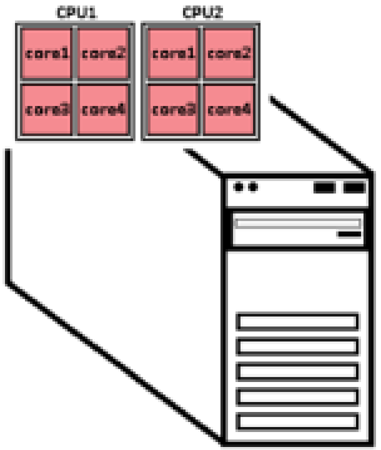
- Modelling algorithms are the digital twins of real-life objects and phenomena

- Implementation on a computer platforms serves as virtual laboratory

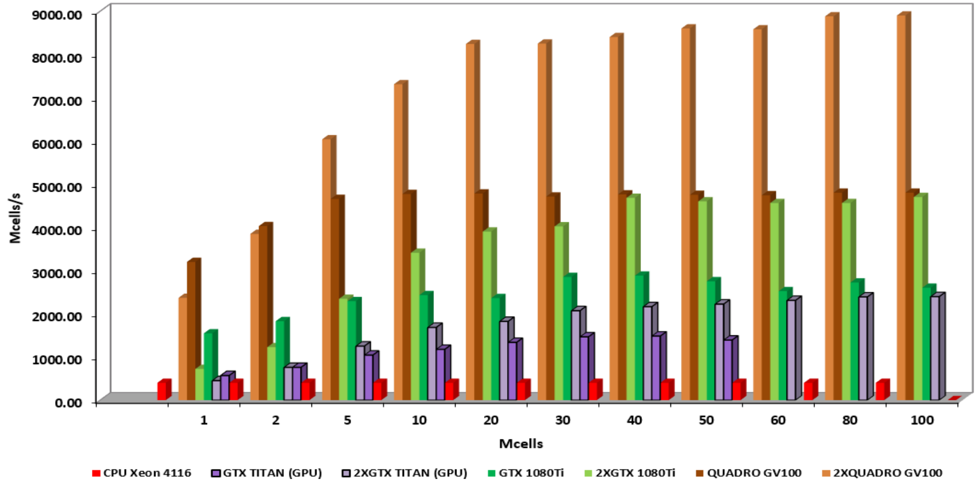
- Assures effective development of new technologies

Computer simulations in science and technology

- Science and technology aim at using physics-based modelling
- Development of physics-based modelling is owed to:
  - *mathematic tools for modelling of physical phenomena (e.g. academic research resulted in enormous progress in solving Maxwell equations using numerical methods in the 80s/90s),*
  - *continuous progress in information and computer technology*



- 80s/90s rapid development of physics-based simulation tools
- Firstly, much scepticism among scientists and engineers
- At present, it is hard to imagine the world without physics-based modelling, both at academia and in industry



GPU speed ups compared to Open MP technology – for EM simulation

Computer simulations – why do we use them?

- ✓ To understand physics
- ✓ To design a device with desired performance
- ✓ To get insight in what is going on in our system
- ✓ To increase effectiveness and decrease costs of technological process
- ✓ To stimulate progress in science and technology thanks to “inexpensive” verification of new solutions

Do we actually need computer simulation for new technologies development?

Electromagnetic and thermodynamic simulations with QuickWave software

Where to use EM & thermodynamic simulations?

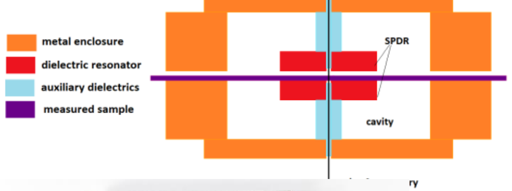
- Antenna design
  - Space
  - Automotive
  - Telecommunication (internet, SATCOM, 5G, etc.)
- Biomedicine
- Microwave heating applications
  - Domestic microwave ovens
  - Industrial microwave power systems
- Design of test-fixtures for material measurements
  - Organic semiconductors (e.g. photovoltaic panels)
  - Battery materials
  - Graphene-based composites
- Radioelectronics (e.g. absorbers, filters, polarisers, etc.)

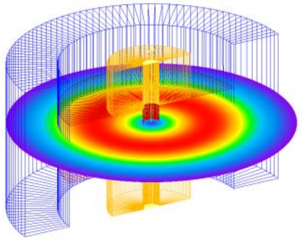
Measurement devices for material characterisation

Electromagnetic characterisation of materials with QWED test-fixtures:

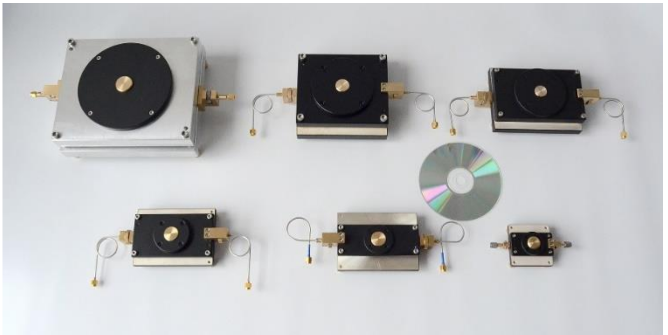
- Complex permittivity (relative permittivity and loss tangent)
- Resistivity
- Surface resistance

Family of QWED's SPDR resonators

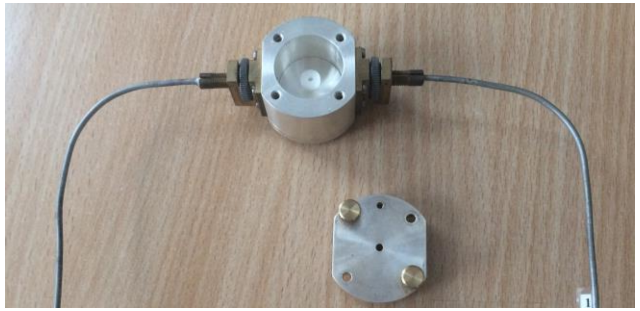


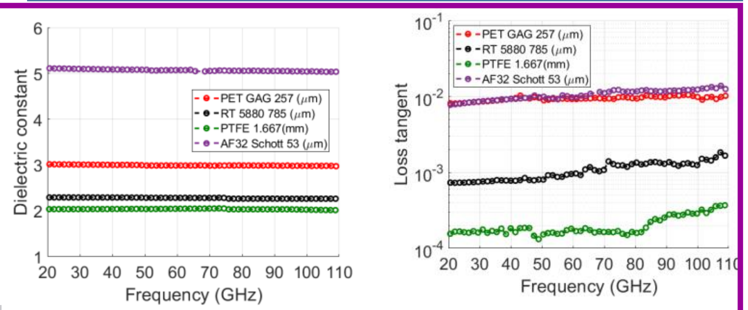


QWED's FPOR resonator for µWave& mmWave ranges



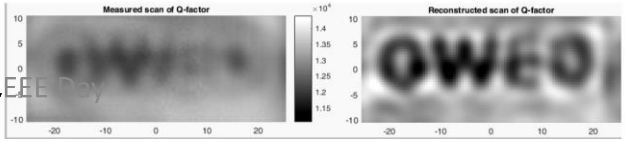
QWED's TE01delta cavity for ultra low-loss materials





Used within international iNEMI project for 5G materials characterisation

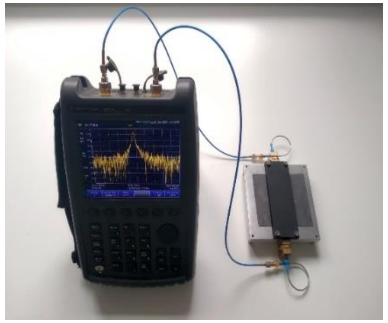
2D surface map of measured Q-factor of „QWED" pattern made of organic semiconductor deposited on quartz



**courtesy MateriaNova, Belgium*

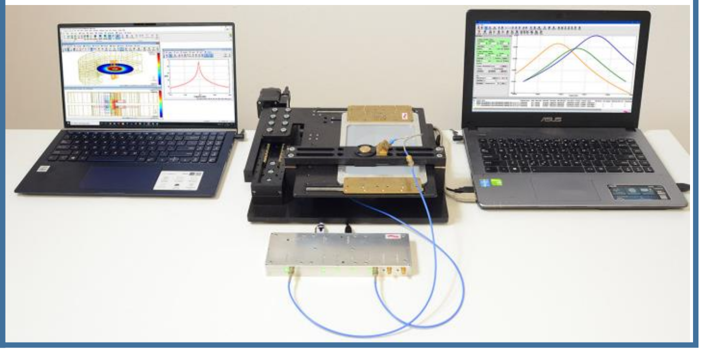
Characterisation of graphene anodes for batteries

SiPDR device



2D imaging of conductive material

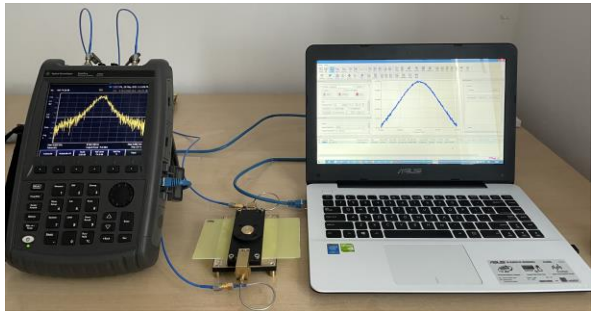
10GHz SPDR scanner - 2D imaging of dielectric and high-resistivity materials



Measurement devices for material characterisation

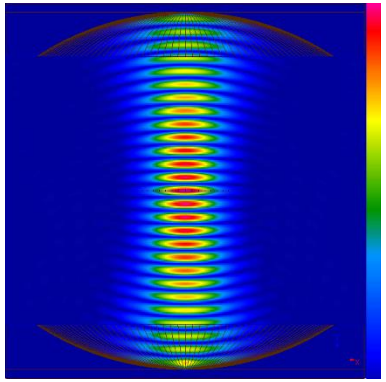
QWED's test-fixtures for material measurements are widely used for materials quality control and characterisation in a variety of science and industrial domains:

- electronics (e.g. printed electronics, semiconductor materials and structures, etc.),
- radioelectronics (e.g. antennas, filters, diplexers, etc.),
- space technology,
- automotive technology (e.g. car elements covering radar antennas)
- energy saving technology (e.g. elements of photovoltaics systems, battery cells),
- biology,
- biomedicine,
- chemistry, etc.

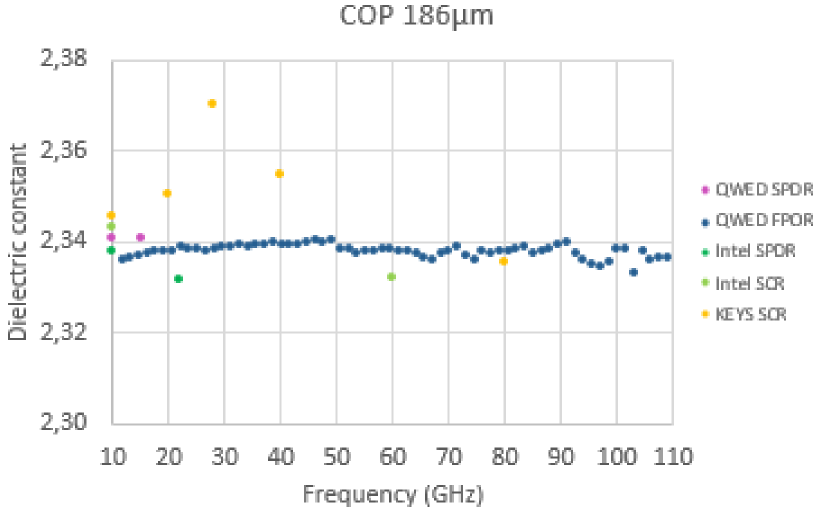


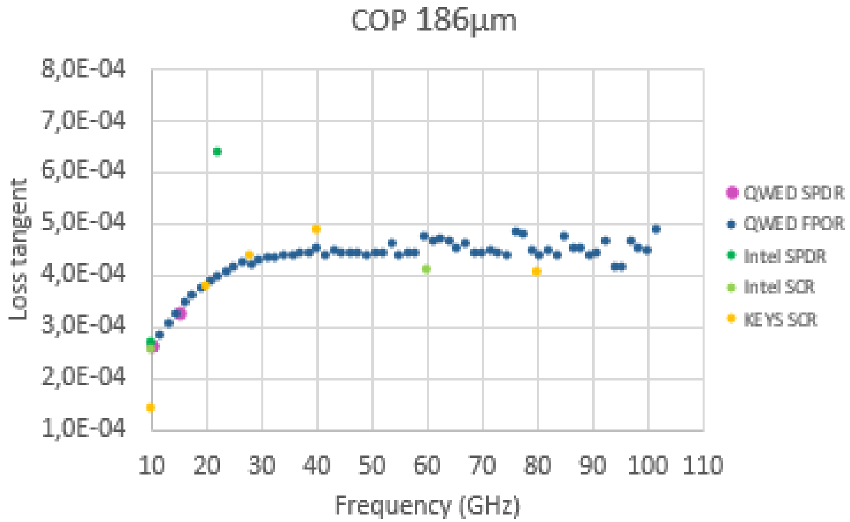
Used within international iNEMI project for 5G materials characterisation

*Gaussian **TEM00q** modes*



Electric field distribution - simulation model in QuickWave software



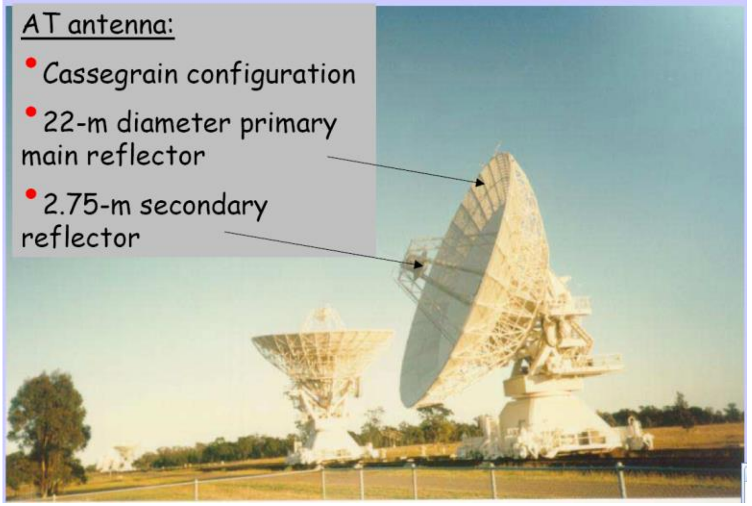


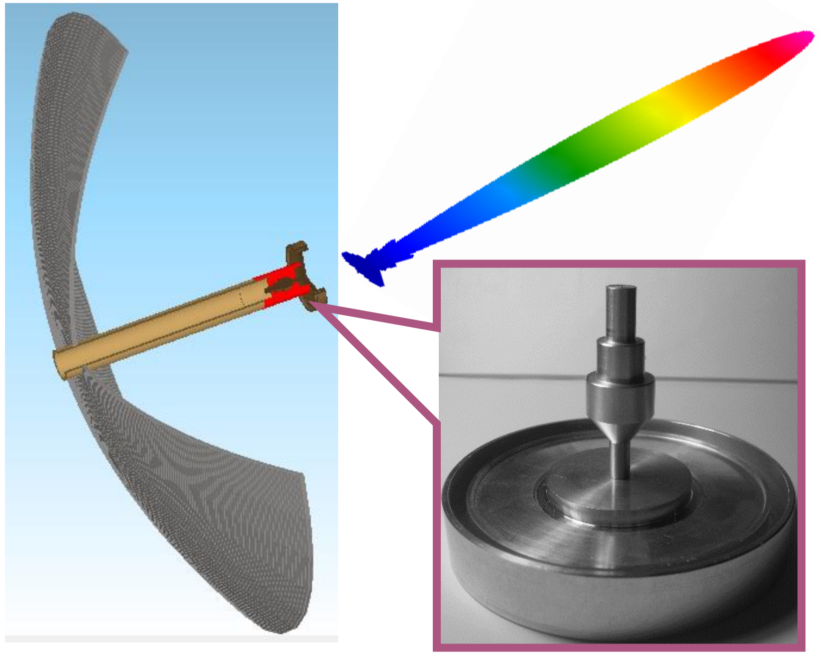
"Benchmarking of GHz resonator techniques for the characterisation of 5G / mmWave materials" – *accepted for EuMW 2022 (QWED, Intel Corp. US, Keysight Tech. US, IRE PW, iNEMI)*

Antenna & feed systems design – for space industry application

Large dual reflector antennas: *Cassegrain, Gregorian, etc.*

QuickWave-3D:
world's recognised 3D EM simulation tool

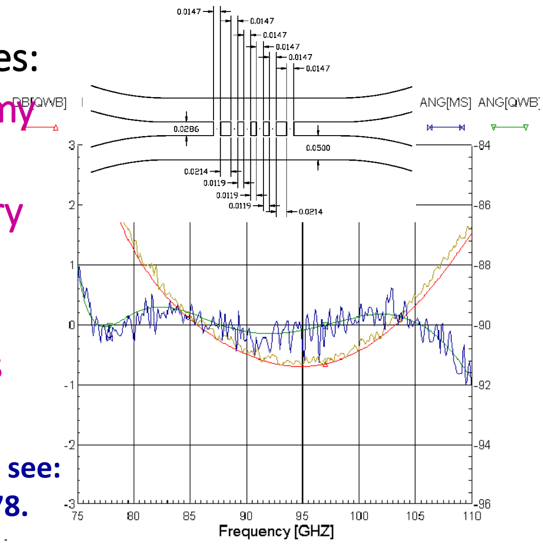


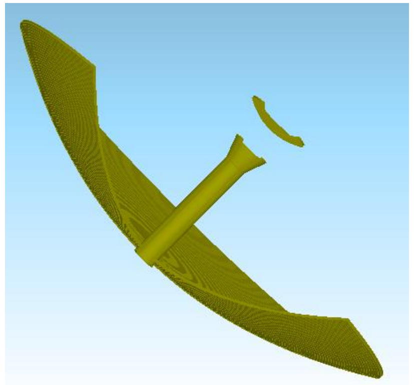


Antenna feed systems designed by NRAO

Space research:
NASA related laboratories:
National Radio Astronomy Observatory (VA US),
Jet Propulsion Laboratory (CA US)
Universities:
CALTECH (US), Chalmers (S), etc.

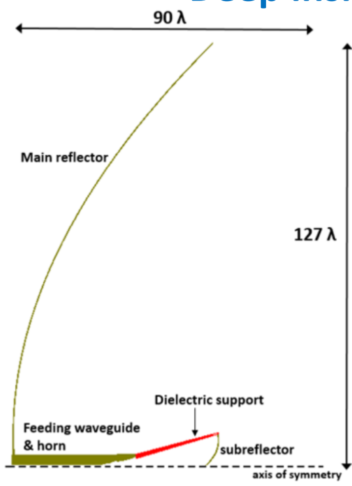
QuickWave 3D results at NRAO, see:
ALMA Memos 381, 343, 325, 278.



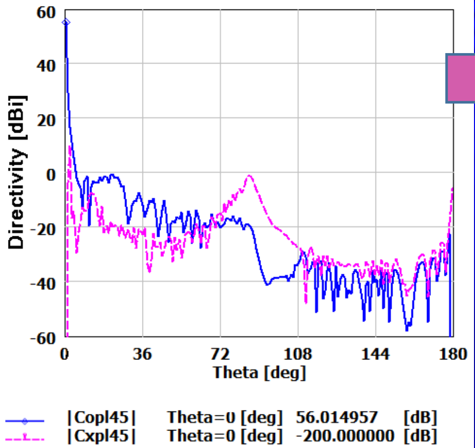


9m – diameter main reflector
Time to solution: **8 min**
Radiation pattern **@24 freq.**,
Δθ=1deg : **5 s**

Deep insight into device performance

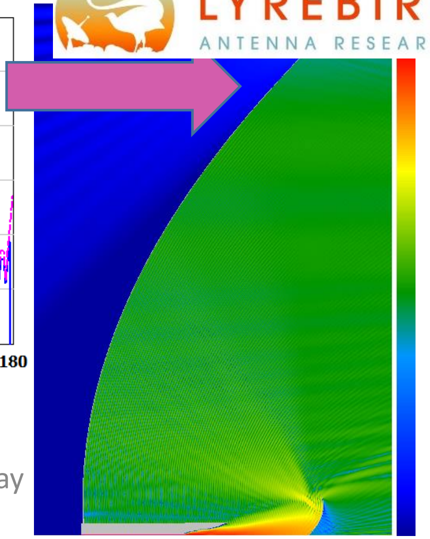


Dual -reflector antenna



Insight into EM near-field

LYREBIRD
ANTENNA RESEARCH



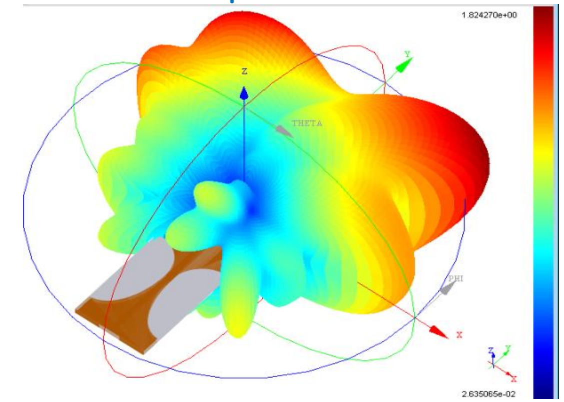
BOR FDTD

Unique, ultra-fast vector 2D Bessel & FDTD hybrid solver for design & analysis of devices with axial symmetry

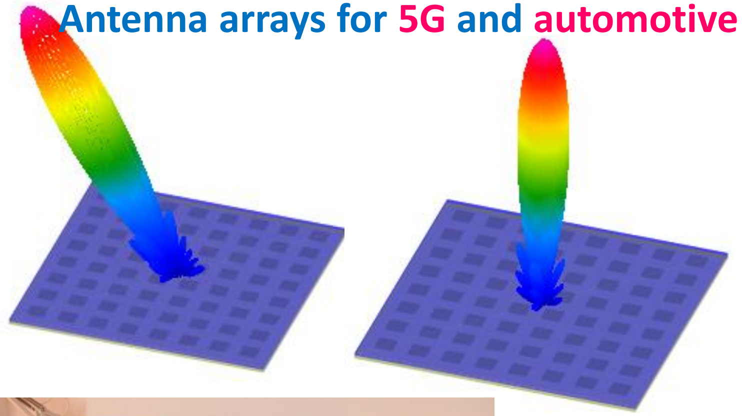
Scenarios modelled full-wave:
2500 λ on popular PC
5000 λ on top-shelf PC

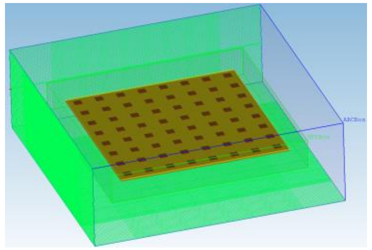
Antenna & feed systems design – for various application

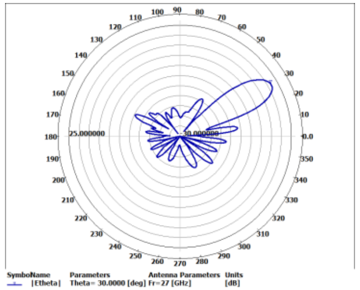
Balanced antipodal Vivaldi antenna & 3D radiation pattern at 10 GHz.



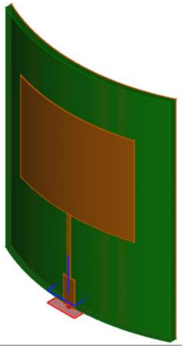
Antenna arrays for 5G and automotive radar application

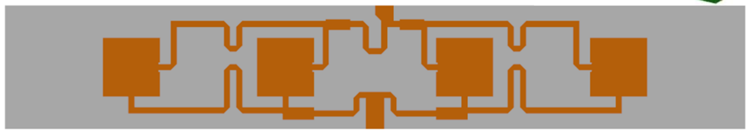


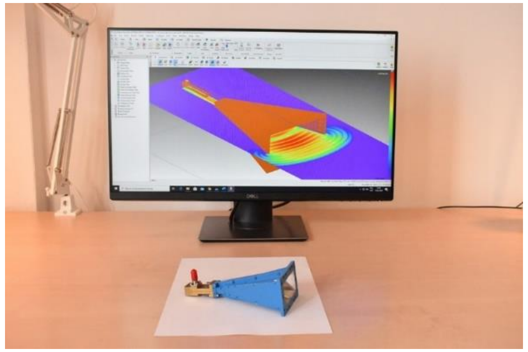




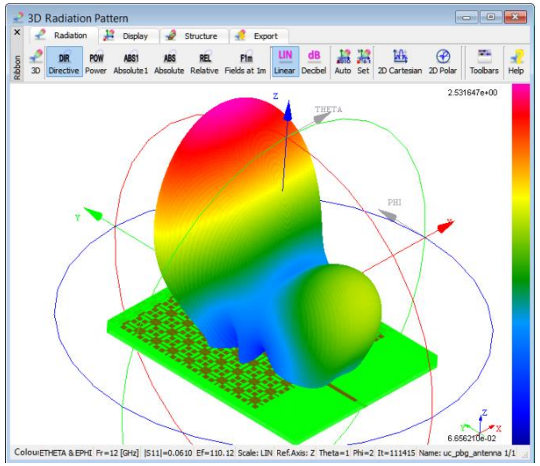
Planar antennas for smart bio-sensors





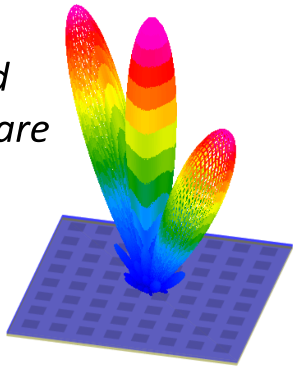


Horn antenna designed with QuickWave software

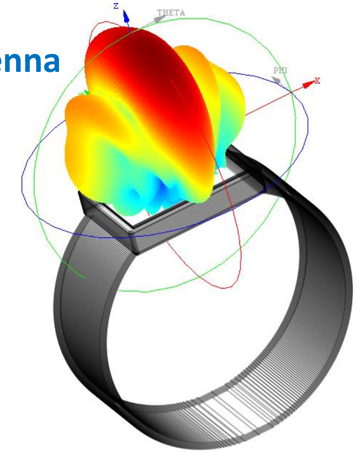


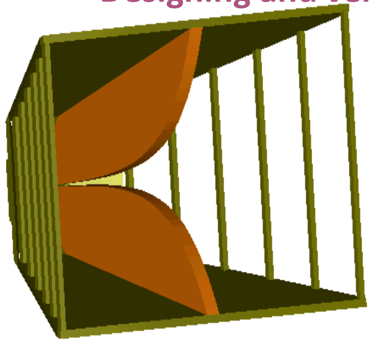
Aperture-coupled patch antenna on uniplanar photonic bandgap substrate & its radiation pattern at 12 GHz.

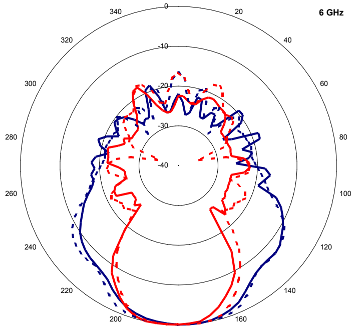
Designing and verifying tracking capabilities



Smartwatch with embedded patch antenna

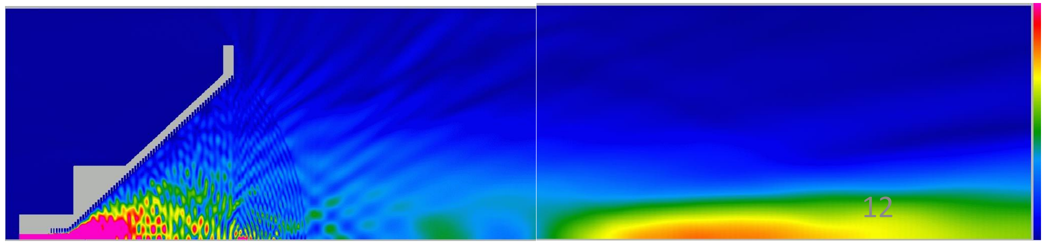




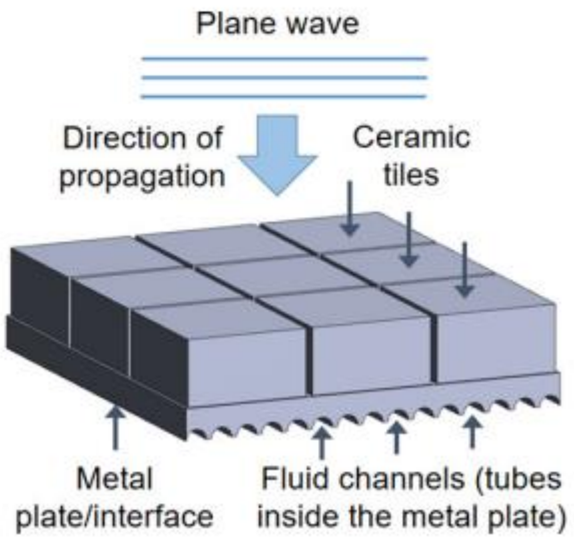


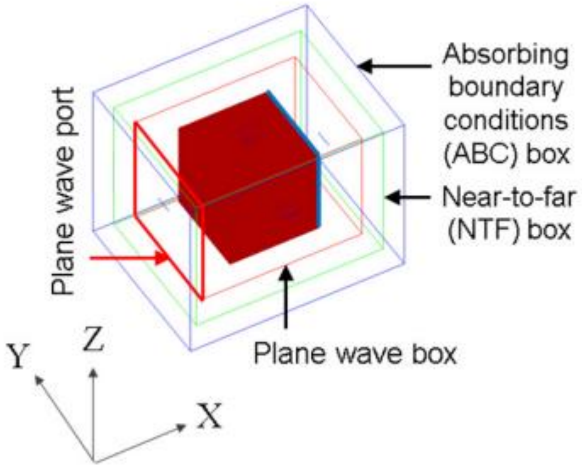
Pyramidal horn antenna for military surveillance measured (courtesy prof.B.Stec) & simulated patterns

Corrugated horn antenna for material measurements



Wireless energy transfer – millimetre wave heat exchanger



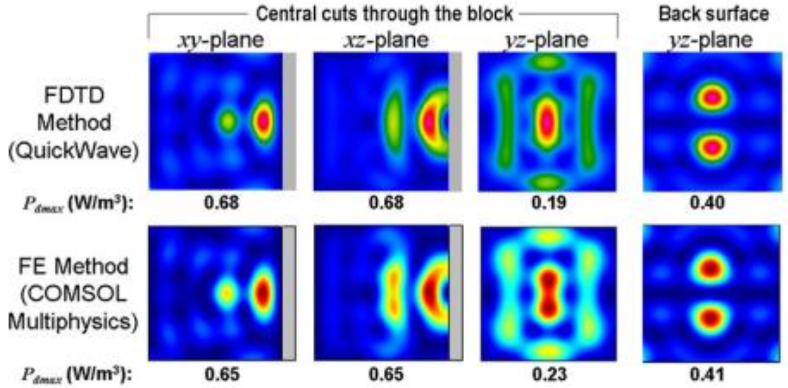


EM energy

Heat dissipation

Fluid flow

Mechanical work



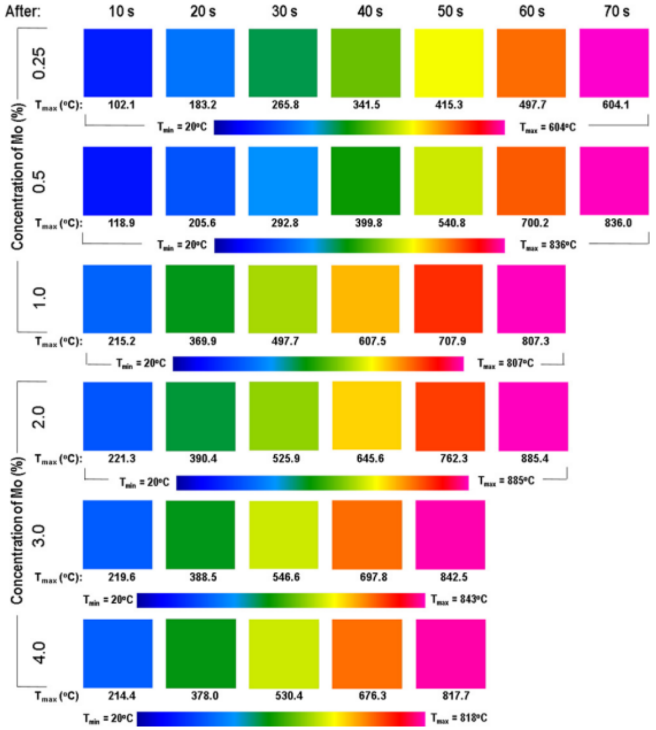


Figure 8. Temperature distributions on the back surface (YZ-plane) of the AlN:Mo block with Mo = 0.25%, 0.5%, 1.0%, 2.0%, 3.0% and 4.0% and along with maximum values of temperature (T_{max}) in each pattern. Patterns are normalized to the minimum temperature of the process (20°C); heating time steps are 5 (Mo = 0.25% and 0.5%), 2.5 (Mo = 1.0% and 2.0%), and 2.0 s (Mo = 3.0% and 4.0%); P_{din} = 1.0 W/mm^2; t = 10 mm

Electromagnetic-thermal model of a millimeter-wave heat exchanger based on an AlN:Mo susceptor, P. Kumi et al. COMPEL 2019 (Worcester Polytechnic Institute, Air Force Research Lab., US Naval Research Lab)

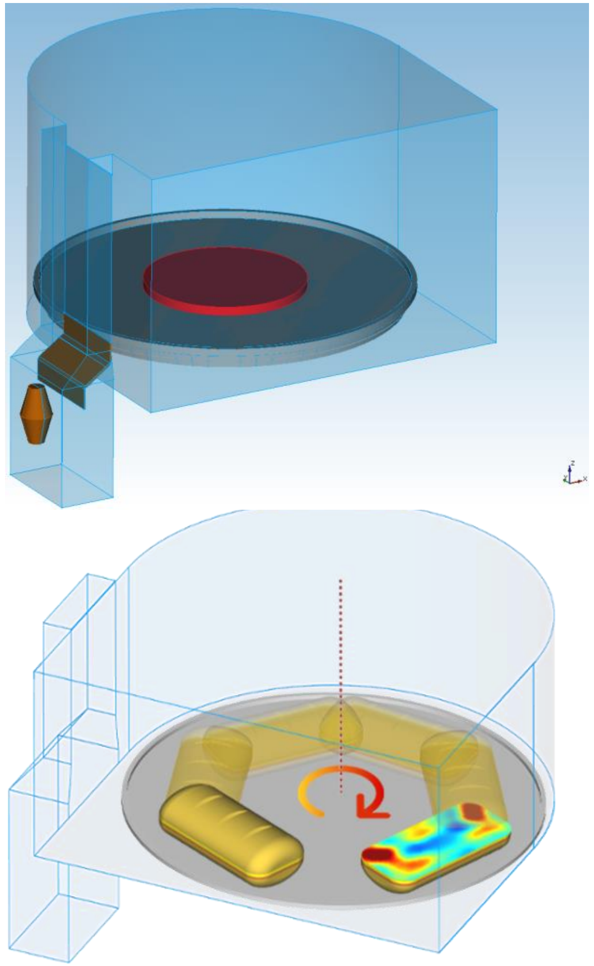
Microwave power applications – domestic microwave oven

Domestic microwave oven - a billion dollar business

Coupled electromagnetic – thermodynamic simulations used for the purpose of designing and improving performance of household devices:

- ➢ Popcorn popping
  - ⟶ microwave susceptors
- ➢ Crispy skin
  - ⟶ specially designed crispy plates
- ➢ Packaging design
  - ⟶ containers for intelligent food heating
- ➢ Preparing nutritious and healthy food
  - ⟶ smart devices
- ➢ etc.

Whirlpool Max oven**



Modelling of MW heating effects in domestic oven

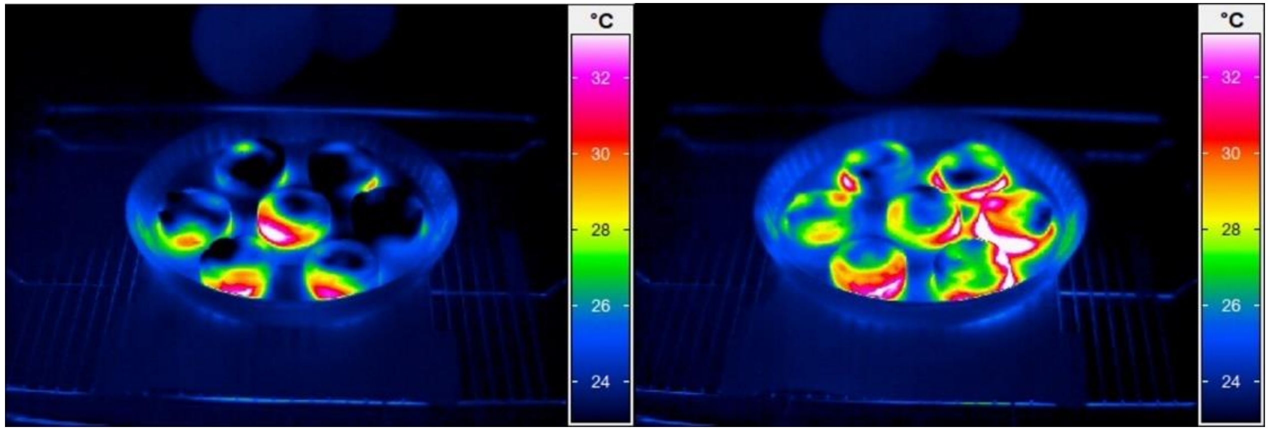
- ✓ Delivering microwave power
- ✓ heat transfer
- ✓ load dynamics (Load rotation during heating)
- ✓ temperature dependence of material parameters
- ✓ etc.

** Considered by M.Celuch, P.Kopyt & M. Olszewska-Placha in eds. M. Lorence, P. S. Pesheck, U. Erle, *Development of packaging and products for use in microwave ovens*, 2nd Ed. by Elsevier.

Microwave power applications – domestic microwave oven: exam

Solid-state sources new technology for microwave power application

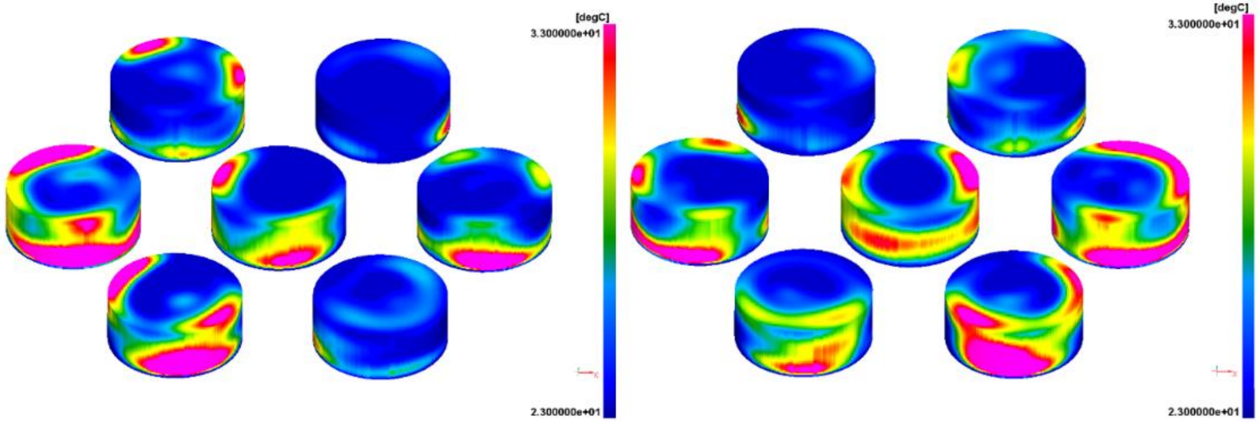
Temperature distribution (infrared camera - phase shift between the two presented cases differs by 110 degrees.
Photos courtesy of BSH HAUSGERATE GMBH, Traunreut, Germany.



Industrial experiment

- ✓ dual-aperture microwave oven prototype
- ✓ fed with two computer-controlled solid-state sources (feedback information about the reflection coefficient), by QWED
- ✓ sources set to operate at 2.45 GHz and 155 W output power
- ✓ oven loaded with mashed potato cookies
- ✓ heating time: 60 s
- ✓ temperature distribution measured with the use of infrared camera

3D display of temperature distribution (QuickWave 3D coupled EM-thermal analysis) - phase shift between presented scenarios differs by 110 degrees

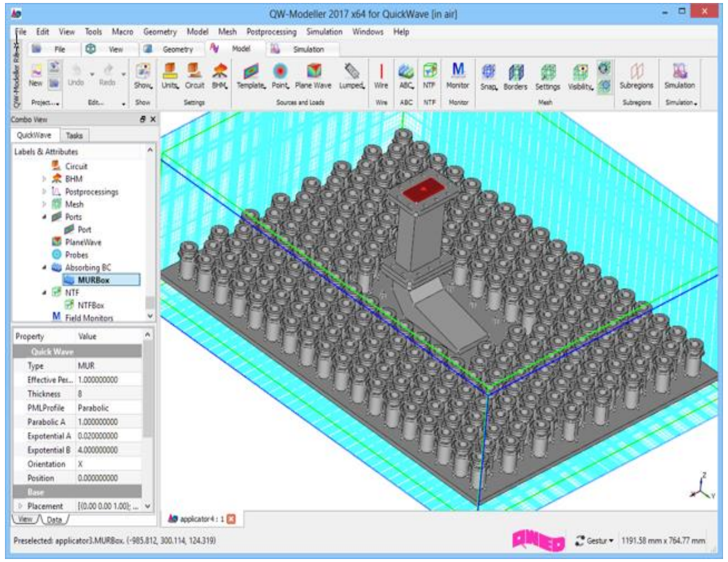


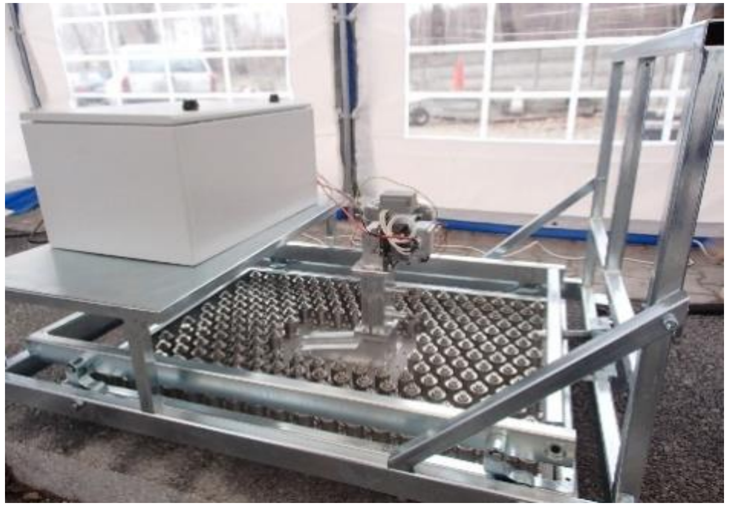
*Celuch, M., Gwarek, W., Olszewska-Placha, M. **Ch.20** in: *Development of packaging and products for use in microwave ovens*, Elsevier, 2020, 531-555.

High microwave power applications – industrial systems

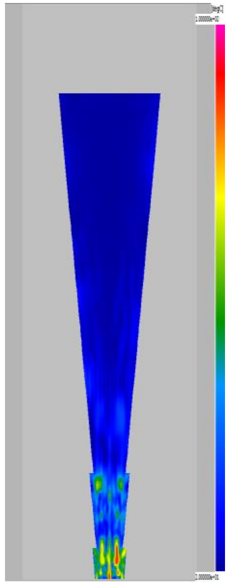
Microwave power systems for:

- **Food industry**
  - **Heating**
  - **Drying**
  - **Lyophilisation**
  - **Sterilisation**
  - **etc.**
- **Waste treatment**
- **Wood treatment**
- **Chemistry systems**
- **etc.**



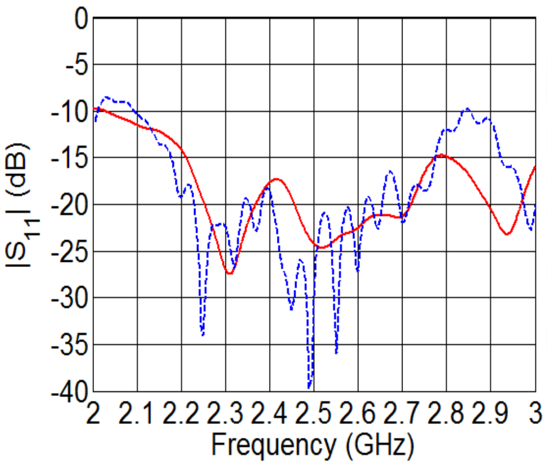


Free-fall waste processing systems on ships (Eureka FOODWASTE)

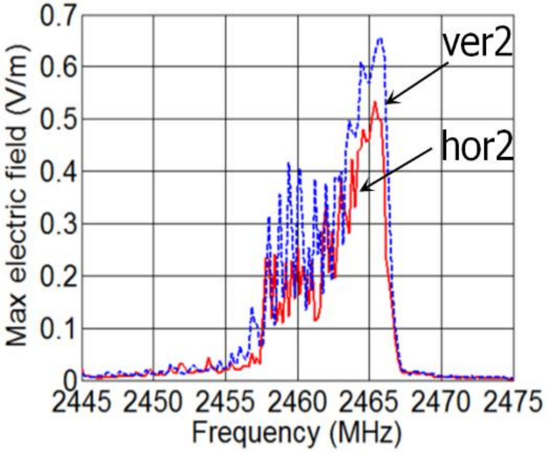


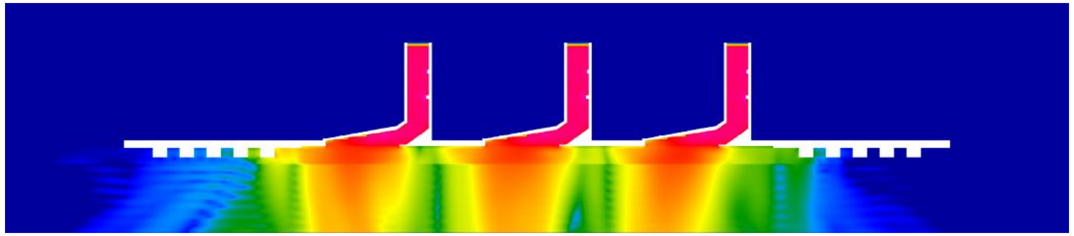
High power applicator for MW treatment of bituminous surfaces (road repair, NGAM project)

Simulation and measurement results



Undesired EM radiation below EU exposure limits





System of three MW power applicators with feeding system and leakage preventing chokes: designed, manufactured, tested

B.Salski et al., *IEEE MTT Trans.*, vol.65, Sep.2017.

High microwave power applications – industrial systems

Foods **2021**, 10, 311.
https://doi.org/10.3390/foods10020311

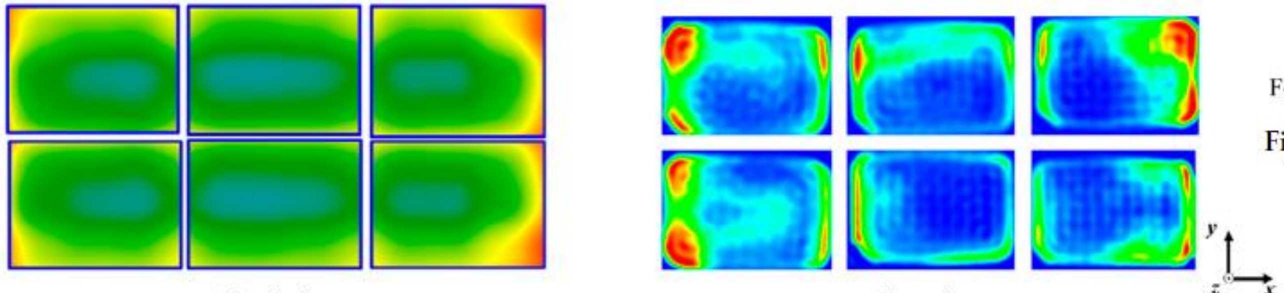
foods

MDPI

Article

Effect of Electric Field Distribution on the Heating Uniformity of a Model Ready-to-Eat Meal in Microwave-Assisted Thermal Sterilization Using the FDTD Method

Yoon-Ki Hong [1,*], Roger Stanley [2], Juming Tang [1], Lan Bui [3] and Amir Ghandi [3]



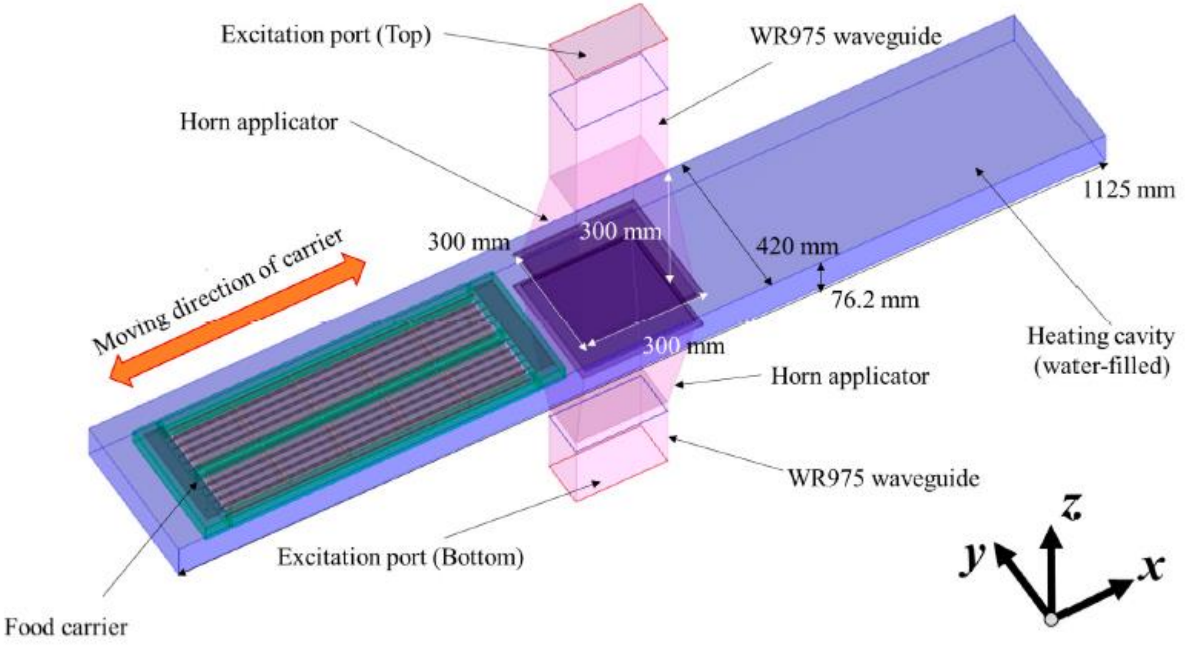
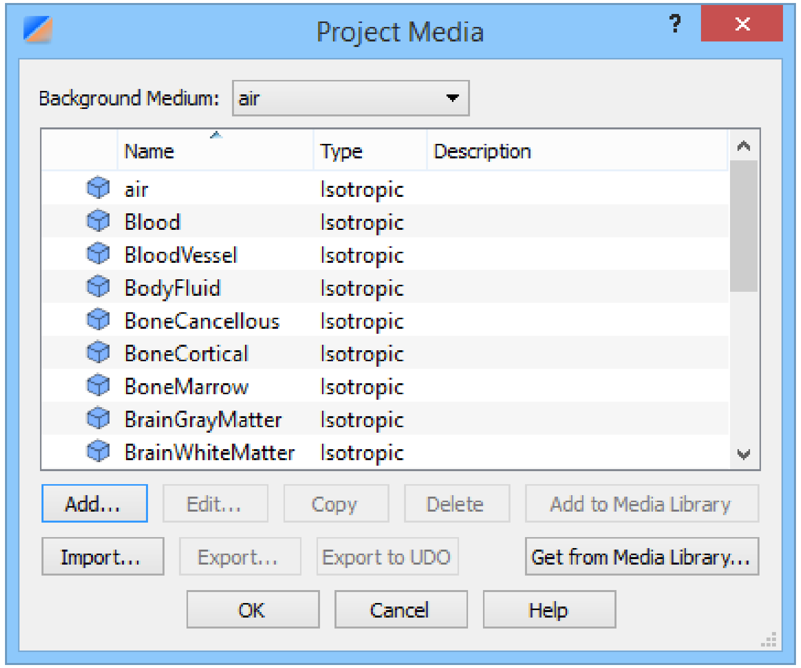


Figure 1. 3D geometry of the MATS system with food transportation carrier in Quickwave software.

MATS is an advanced thermal processing method applied to produce pre-packaged, shelf-stable food products.
Washington State University has been QuickWave user for many years.

Electromagnetic simulations in biomedical applications

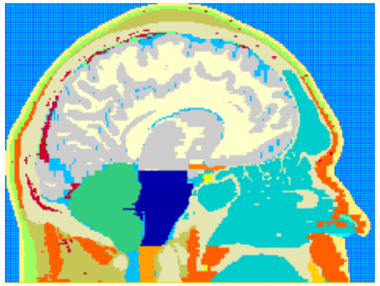
Macroscopic modelling of biological problems



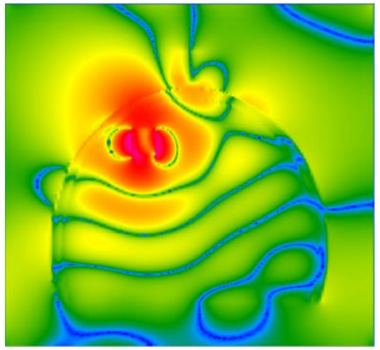
AustinMan model* converted to **QuickWave EM** software for Mälardalen University, Sweden

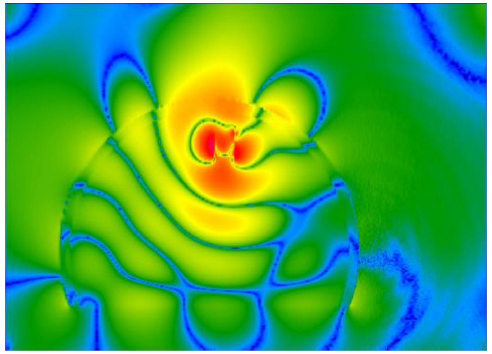
* https://sites.utexas.edu/austinmanaustinwomanmodels/

EM fields based medical systems



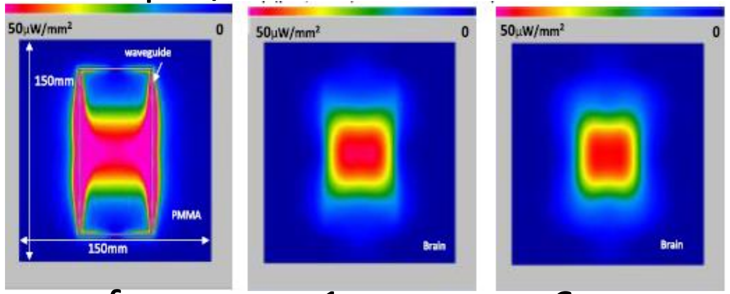
- ✓ **Tumours & haemorrhages detection**
- ✓ **Optimisation of multiantenna tomographic systems**





5G interactions with human tissues

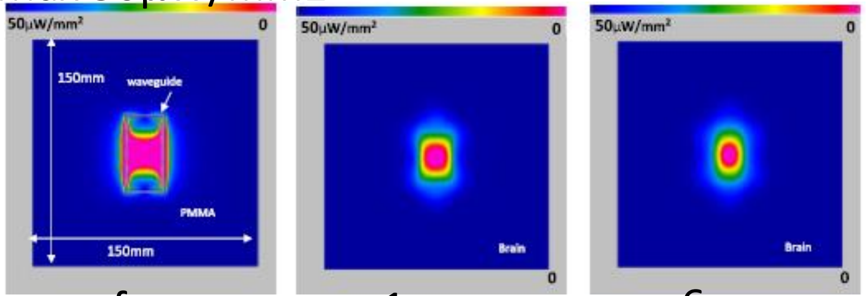
Max 50µW/mm2



surface 1mm 6mm

1.9 GHz

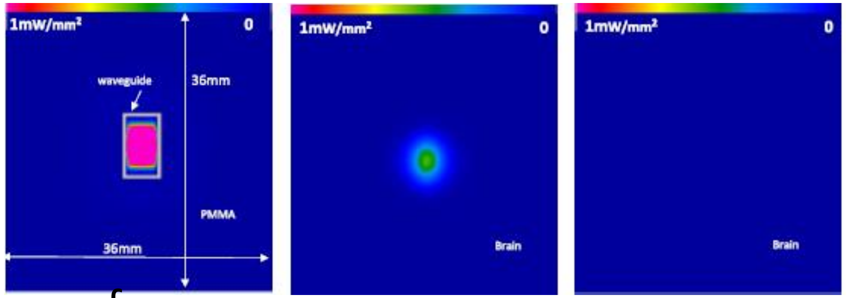
Max 50µW/mm2



surface 1mm 6mm

4 GHz

Max 1mW/mm2



surface 1mm 6mm

39 GHz

D. Gultekin, P. Siegel, „Absorption of 5G Radiation in Brain Tissue as a Function of Frequency, Power and Time", IEEE Access, vol. 8, June 2020.

Conclusions

- Physics-based computer simulations are widely used in science and technology
- Multiphysics modelling, involving electromagnetic & thermodynamic simulations, is crucial for continuous and efficient progress in emerging technologies development
  - ➢ Providing an insight in device performance
  - ➢ Decreasing the need of prototyping intermediate solutions