DEMOCRITUS UNIVERSITY OF THRACE | DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

Space & Telecommunications Sector

Microwaves Laboratory

# Modular FR3 RF Front-End Testbed for Early 6G Validation and Technology Integration

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## Outline

- Europe's FEM Vision
  - Vision
  - Scope
- Microwaves Lab
  - Democritus University of Thrace
  - Department of Electrical and Computer Engineering
  - MWLab
- Proposal

## Europe's FEM Vision for 6G FR3

| **Strategic Objective:** | **Why FR3 Matters** | **Key Technological Challenges:** | **European Strategic Priorities:** | **Realistic Near-Term Focus Current SNS/Chips JU actions target:** |
|---|---|---|---|---|
| **Develop a European sovereign Front-End Module (FEM) ecosystem for 6G FR3 (7–15 GHz),**<br><br>**enabling:**<br>• high-capacity wireless infrastructure,<br>• scalable massive MIMO,<br>• Integrated Sensing and Communications (ISAC),<br>• future AI-native radio systems. | **FR3 combines:**<br>• higher capacity than FR1 (<6 GHz),<br>• better coverage and energy efficiency than FR2/mmWave,<br>• suitability for:<br>  ○ cellular evolution,<br>  ○ Fixed Wireless Access (FWA),<br>  ○ sensing and radar integration.<br>**FR3 is considered a key global 6G deployment layer.** | • 20–30× higher processing complexity vs current FR1 systems<br>• Integration of hundreds of TRx chains and potentially >1000 antenna elements<br>• Heterogeneous integration of:<br>  ○ CMOS / FD-SOI,<br>  ○ GaN,<br>  ○ SiGe,<br>  ○ RF SOI,<br>within advanced System-in-Package (SiP) architectures<br>• Thermal management and packaging constraints<br>• Energy-efficient beamforming and mixed-signal integration | • Strengthen European telecom and semiconductor sovereignty<br>• Develop European know-how in RF System-in-Package integration<br>• Align SNS and Chips Joint Undertaking roadmaps<br>• Prepare transfer toward pilot lines:<br>  ○ APECS,<br>  ○ FAMES,<br>  ○ WBG<br>• Enable downstream industrialization of 6G FEM technologies | • subsystem-level innovation,<br>• architecture validation,<br>• RF and mixed-signal demonstrators,<br>• TRL4/TRL5 integration platforms,<br>• controlled laboratory validation.<br><br>The goal is to:<br><br>**de-risk technologies and architectures before large-scale industrial deployment.** |

## Scope

| | 5G | 6G | | | Technology challenges |
|---|---|---|---|---|---|
| Spectrum | 3.5 GHz | 6- 8 GHz | 10-15 GHz | | New frequency components |
| Antenna | 128-192AE | 768AE | 1536AE | | |
| TRXs | 32-64TRX | 128TRX | 256TRX | 8x | Converters, TRX, PA, filtering, etc |
| Bandwidth | 100 MHz | 200 MHz | 400 MHz | 4x | 32x |
| MIMO | 16 layers | 24 layers | 64 layers | 4x | Receiver and beamforming processing |
| Cell peak | 6 Gbps | 18 Gbps | 100 Gbps | 20x | |

32x more RF processing capability required
20x capacity with more complex processing

**The SNS activity is expected to cover:**

- **FEM detailed design for FR3 Operations (7-15 GHz), (200 MHz channels), fulfill ITU 2030. The design includes FEMs for beamforming and support of ICAS;**
- **In-lab testing and validation under controlled (e.g. cabled) conditions.**
- **Address two designs (e.g. CMOS and FDSOI based, with e.g. GaN for the PA/LNA part).**
- **massive MIMO antenna array systems (AAS) in a compact form factor. Up to 1000 antenna elements can be integrated in the same size as the current 3.5 GHz massive MIMO AAS used in current 5G networks.**
  - ⇨ **reuse of existing 5G cell sites for 6G FR3 deployments.**
- **Two highly use cases that dimension the FEM radio design - SBFD/ISAC and HBF/TDD.**
- **The chipset building blocks will have to cover a plethora of functions, such as baseband and data conversion (including RF DAC and RF ADC for the lower part of FR3), beam forming ICs, analog front-end ICs (Mixers/PA/LNA/TRX-Switch), etc.**
- **Depending on the antenna fan-out and needed output power level, a combination of CMOS technology (e.g., 22FDX) and GaN/Si is envisaged.**
- **Limited budget (12M€) => small but strategic fabrication activity may be envisaged to make it possible to validate sub-systems and the initial integration/packaging approach.**



**Democritus University of Thrace (DUTH**) is a highly prominent, fully self-administered Greek state university. It ranks as the 4th largest university in Greece and serves as the primary regional educational hub for northeastern Greece. Founded in 1973, it is named after the **ancient philosopher Democritus**, who pioneered the atomic theory.

**The "Polycentric" Multi-Campus Setup**

DUTH is famous for being Greece's first "polycentric" university. Instead of one central campus, its facilities are scattered across seven different cities in the Eastern Macedonia and Thrace region.

- **Xanthi:** Home to the **Engineering School.**
- Komotini: The administrative seat and home to law, physical education, humanities, and economic sciences.
- Alexandroupoli: Focused heavily on health sciences, featuring a massive University General Hospital.
- Orestiada & Didymoteicho: Agricultural sciences and localized departments.
- Kavala & Drama: Recently integrated campuses expanding the university's technical and administrative reach.

**Statistics**

- **Student Population:** Roughly 30,000 total students (spanning undergraduate, postgraduate, and PhD tracks).
- **Academic Scope:** Comprises 10 distinct schools and 28 or 30 specialized departments.
- **Staff:** Supported by over 600–700 teaching and research faculty members.


The **Department of Electrical and Computer Engineering (DECE)** at Democritus University of Thrace is a premier, highly rigorous engineering department. It is located on the **Kimmeria Campus in Xanthi**, functioning as a cornerstone of DUTH's Faculty of Engineering.
Founded in 1975, the department awards a 5-year engineering degree recognized as a continuous **Integrated Master's (300 ECTS)**.

**Academic Structure & Specializations**

The first 5 semesters cover common core courses in mathematics, physics, and basic engineering principles. From the 6th semester onward, students split into one of three major specializations:

- **Electrical Energy**: Focuses on power systems, renewable energy, smart grids, and electrical machines.
- **Electronics and Information Technology Systems**: Focuses on computer architecture, software engineering, digital systems, and VLSI design.
- **Telecommunications and Space Science**: Covers signal processing, network architecture, antennas, and satellite communications.

The 10th semester is entirely dedicated to writing and defending a mandatory Diploma Dissertation.

**Research Sectors & Labs**

Academic and experimental work is divided into five distinct sectors:

1. Electronics and Information Technology Systems
2. Power Systems
3. Telecommunications and Space Science
4. Software and Application Development
5. Physics and Applied Mathematics

- Electrical Circuits, Signal and Image Processing Laboratory
- Electronics Laboratory
- Integrated Circuits Laboratory
- Automatic Control Systems and Robotics Laboratory
- Micro & Nano Technology Laboratory
- Laboratory of Computer Architecture & High Performance Systems
- Mechatronics & Systems Automation Laboratory
- Energy Economy Laboratory
- Electrical Machines Laboratory
- Nuclear Technology Laboratory
- Electric Power Systems Laboratory
- Electromagnetic Theory Laboratory
- Microwaves Laboratory
- Telecommunication Systems Laboratory
- Internetworked Systems Laboratory
- Physics Laboratory

**Relevant Facilities and Expertise**

**AI & Robotics**

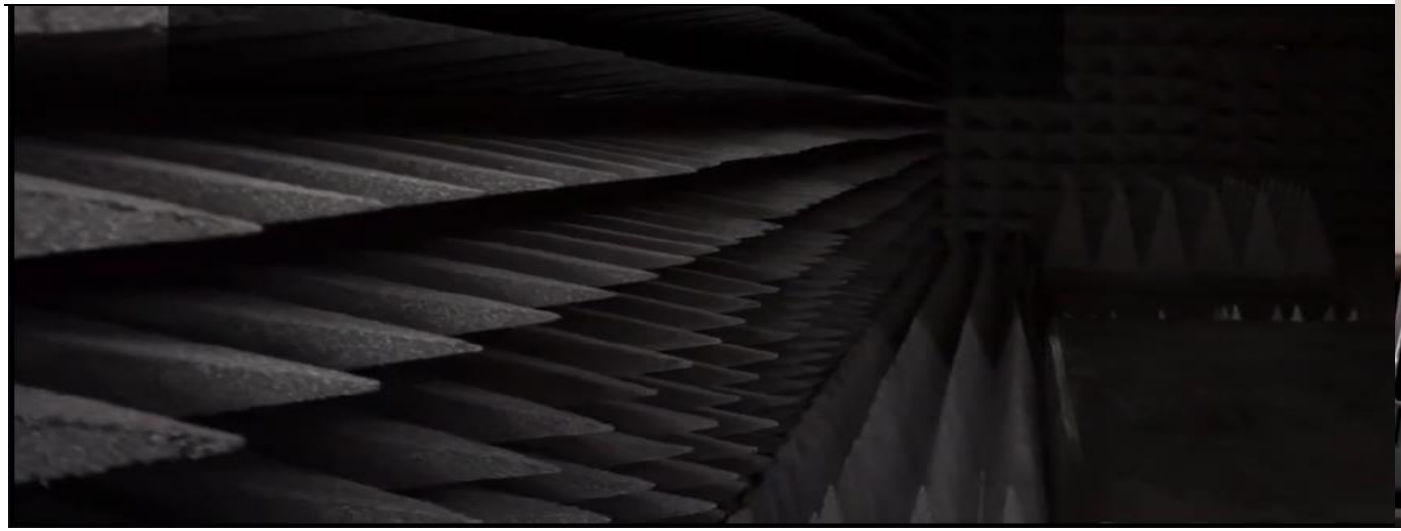
- **AI-assisted optimization**
- **Signal processing**
- **Intelligent control systems**
- **Machine Vision**

**Clean Room**

- **Prototype fabrication support**
- **Sensor and microelectronics experimentation**

**VLSI**

- **IC and mixed-signal design**
- **FPGA and hardware prototyping**


**Microwaves Laboratory**
**Lab Subject**

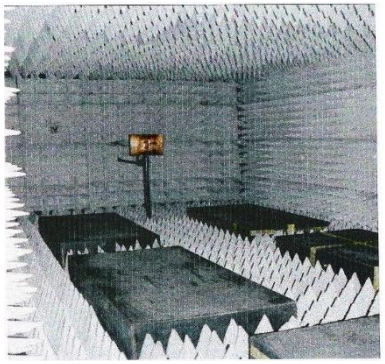
Microwave Theory. Waveguides. Antennas. Microwave applications. Elements of Electronic Optics and their applications. (ID 219, ΠΔ 671, 8-10-1975)

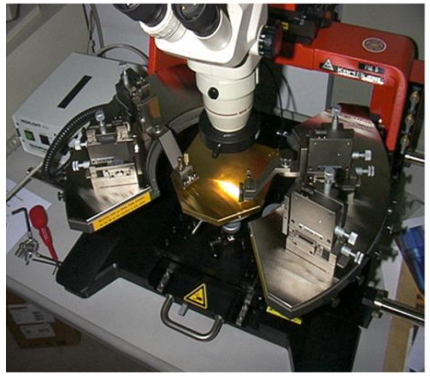
**Lab Administration**

**Director:** G. Kyriakou, Professor
Building B, Office 2.04, tel. +30 25140 79592
**Members:**
G. Kyriakou, Professor
T. Kaifas, Professor

**Contact Details**
**Address:** Democritus University of Thrace, Department of Electrical and Computer Engineering, Panepistimioupoli of Kimmeria, Building B, Microwaves Laboratory, 67100, Xanthi, Greece
**Tel.:** +30 25410 79503
Secretariat: Building B, 2nd floor, Office 2.02

## Facilities and Measurement Equipment

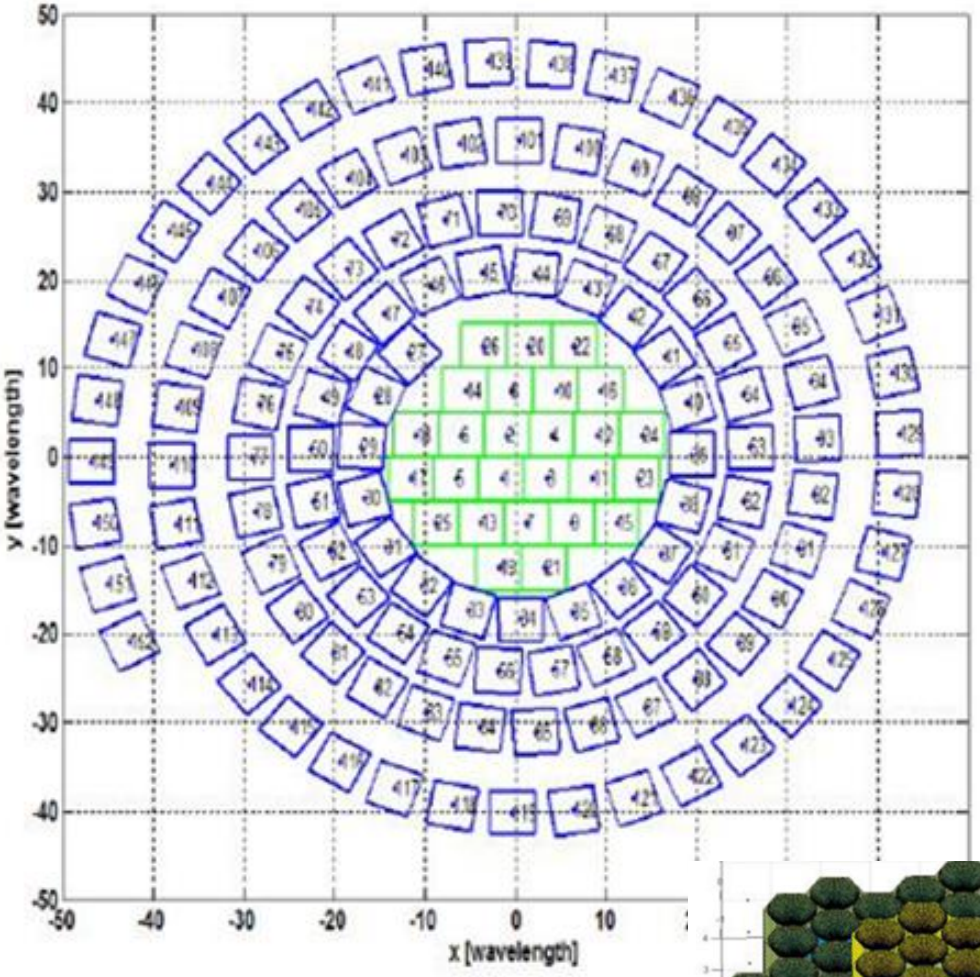


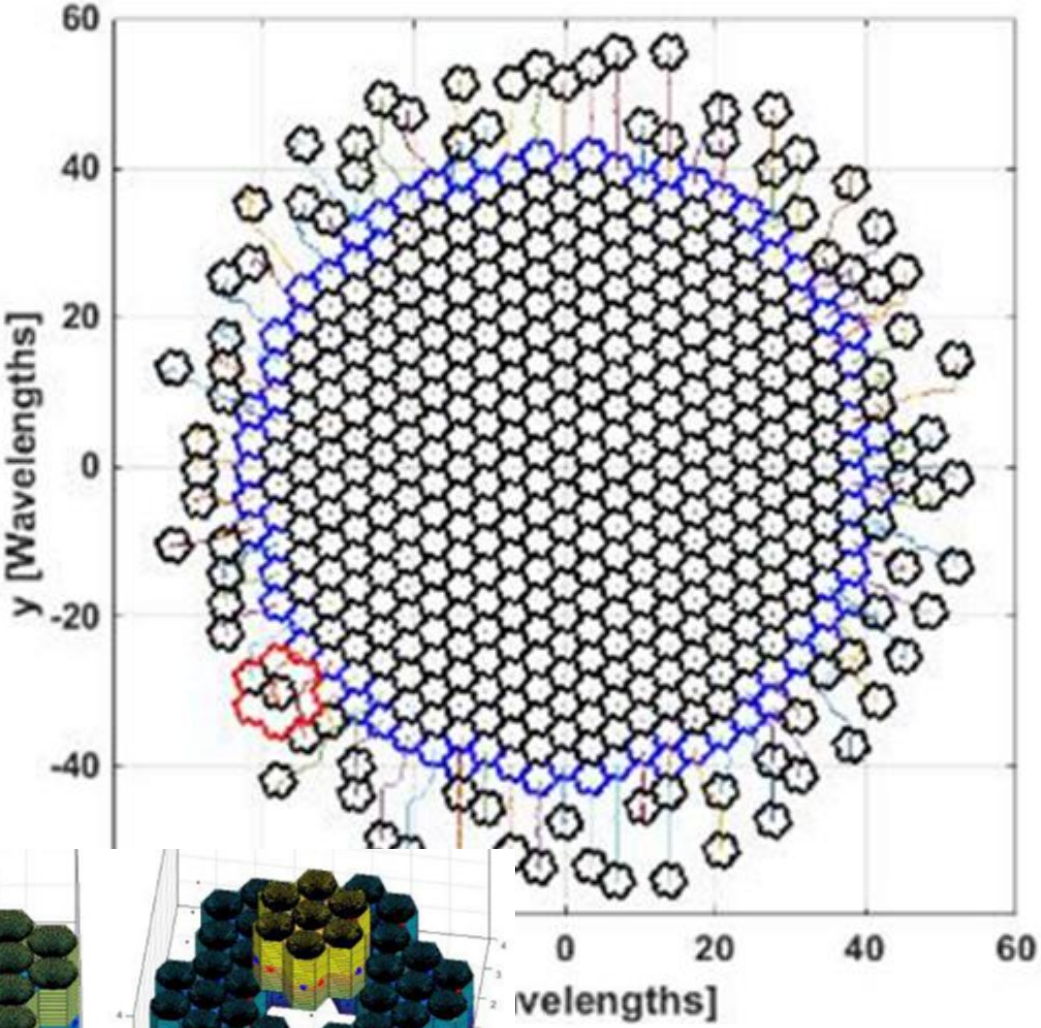




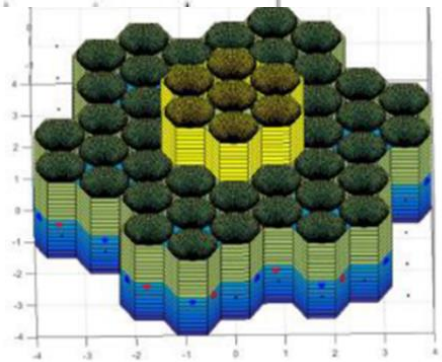
**Microwaves Lab FR3 Focus**

# Antennas



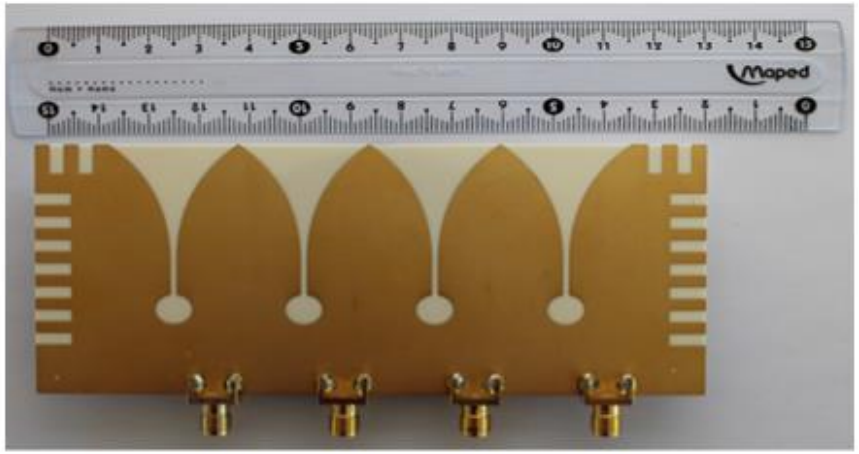



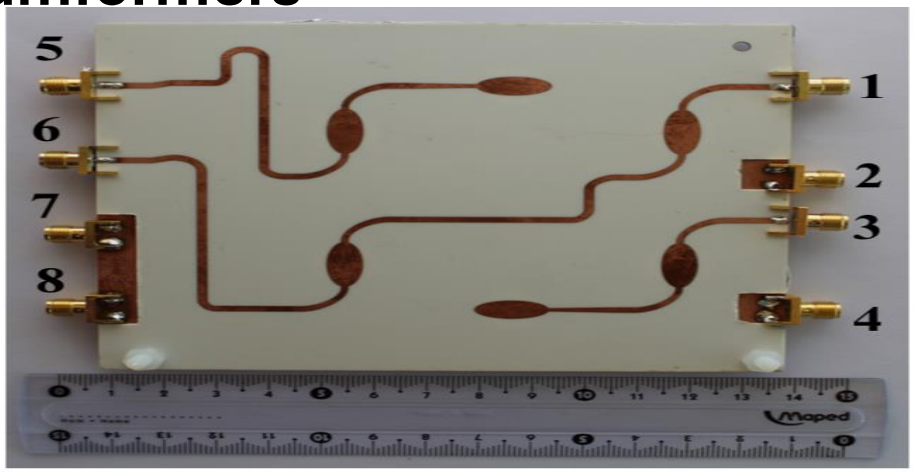


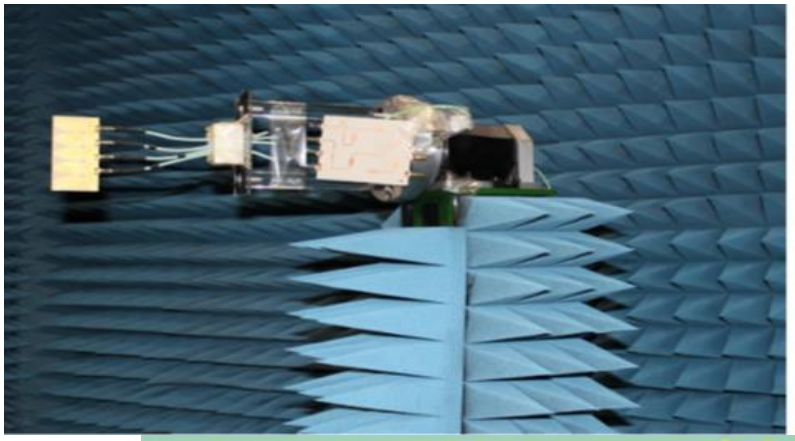


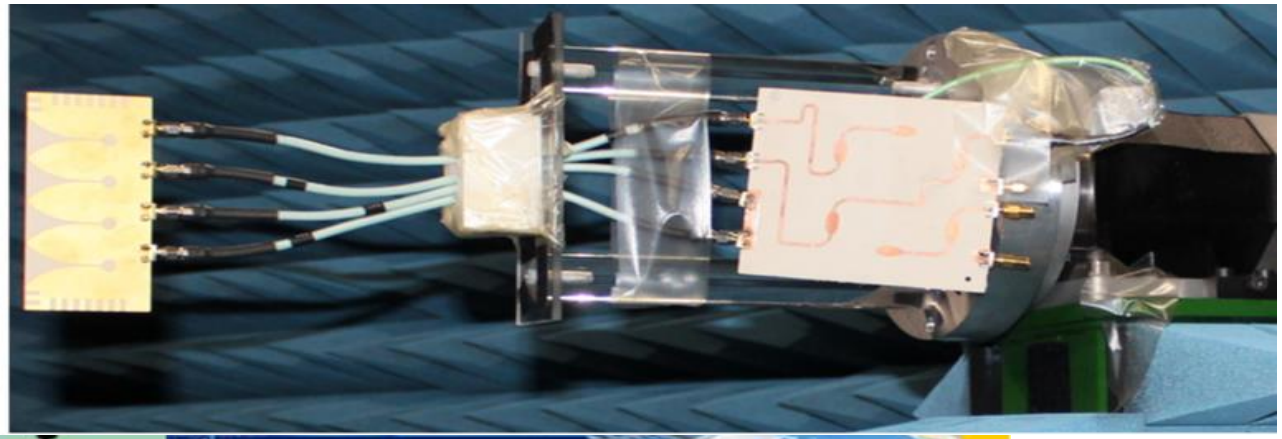


# Antennas + Beamformers



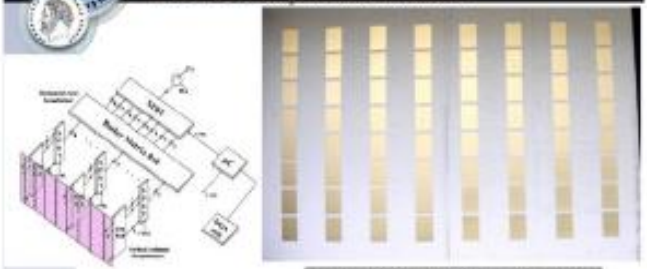





# Beamformers

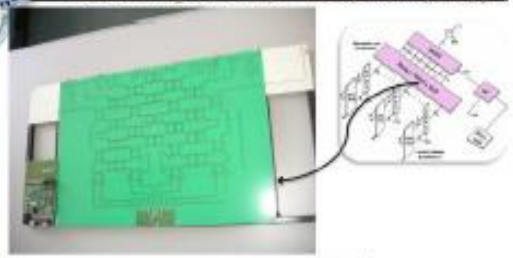
## Σύστημα Μεταγωγής Δέσμης Επίπεδη Συστοιχία



Κατασκευασμένη Επίπεδη Συστοιχία 64 στοιχείων

**Δραστηριότητα:** Σχεδιασμός - Κατασκευή - Μέτρηση γραμμικής στοιχειοκεραίας
**Παραδοτέο:** Συστοιχία 8 στοιχείων.

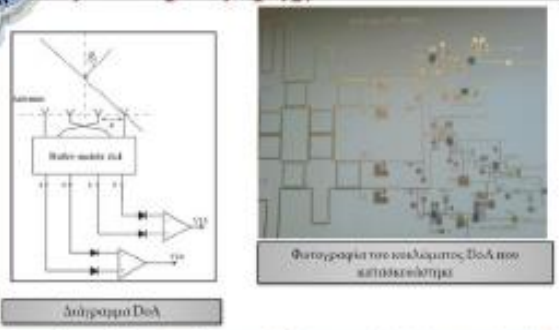
## Σύστημα Μεταγωγής Δέσμης Οριζόντιος Πίνακας Butler-Διακόπτες (SP8T) - Μικροελεγκτής



Οριζόντιος πίνακας Butler 8 εισόδων – 8 εξόδων και κατασκευάστηκε μαζί με τους δρομολογητικούς διαύλους και τον μικροελεγκτή

**Δραστηριότητα:** Σχεδιασμός – Κατασκευή - Μέτρηση μονάδας μεταγωγής δέσμης
**Παραδοτέο:** Μονάδα μεταγωγής 8 δεσμών.

## DoA (Μονάδα μέτρησης γωνίας άφιξης)

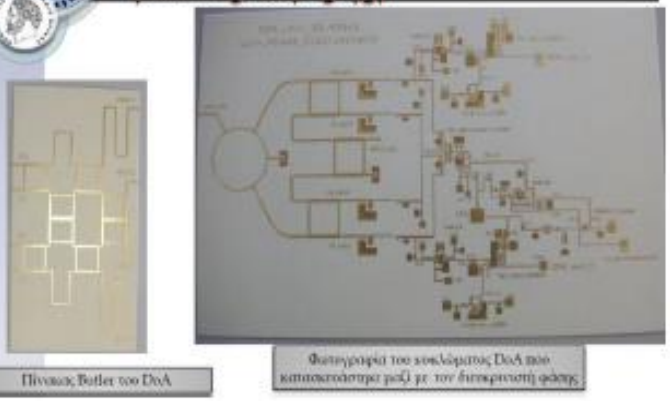


Διάγραμμα DoA

Φωτογραφία του κυκλώματος DoA που κατασκευάστηκε

**Δραστηριότητα:** Σχεδιασμός – Κατασκευή -Μέτρηση μονάδας μέτρησης γωνίας άφιξη
**Παραδοτέο:** Μονάδα μέτρησης της γωνίας άφιξης (DOA).

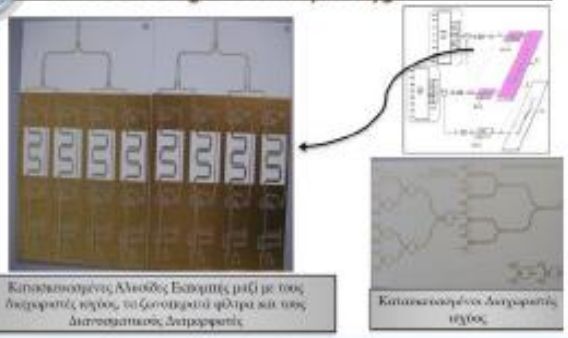
## DoA (Μονάδα μέτρησης γωνίας άφιξης)



Πίνακας Butler του DoA

Φωτογραφία του κυκλώματος DoA που κατασκευάστηκε μαζί με τον διπερικτυπή φάσης

## Προσαρμόσιμο Σύστημα Αλυσίδες Εκπομπής

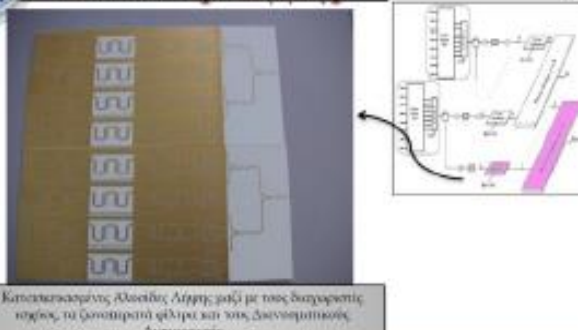


Κατασκευασμένες Αλυσίδες Εκπομπής μαζί με τους διαχωριστές ισχύος, τα ζωνοπερατά φίλτρα και τους Διανυσματικούς Διαμορφωτές

Κατασκευασμένοι Διαμορφωτές ισχύος

**Δραστηριότητα:** Σχεδιασμός – Κατασκευή - Μέτρηση προσαρμόσιμης μονάδας εκπομπής
**Παραδοτέο:** Προσαρμόσιμη μονάδας εκπομπής 8 καναλιών

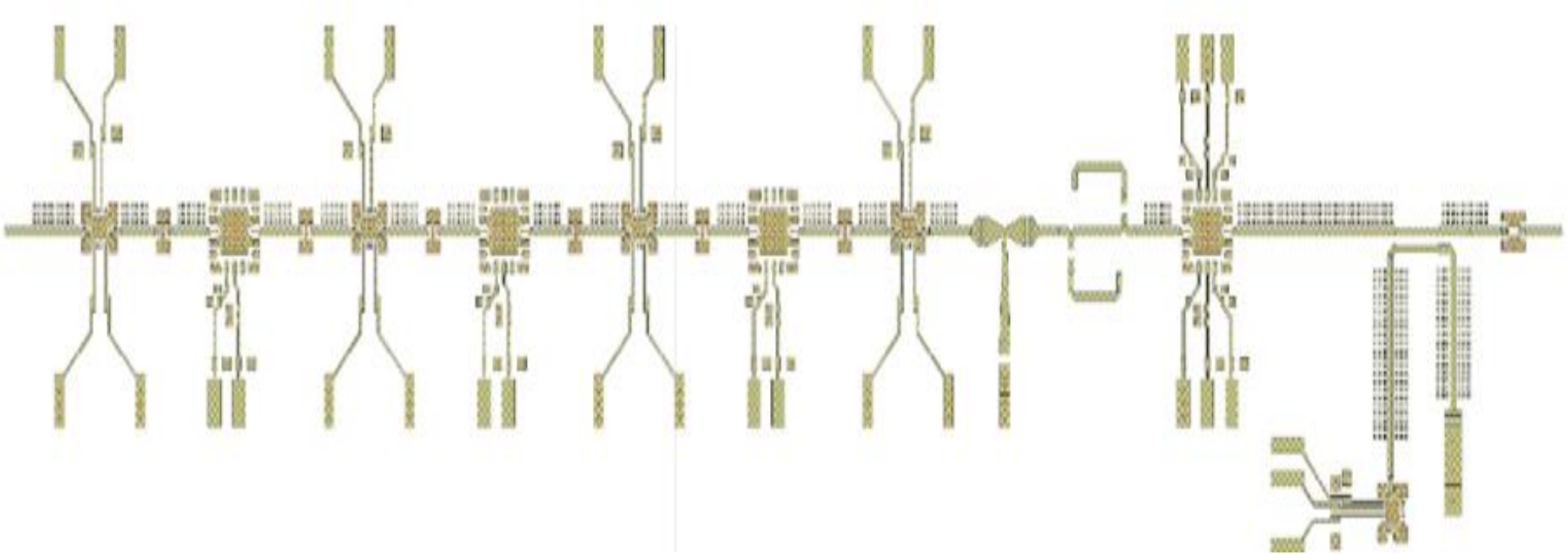
## Προσαρμόσιμο Σύστημα Αλυσίδες Λήψης



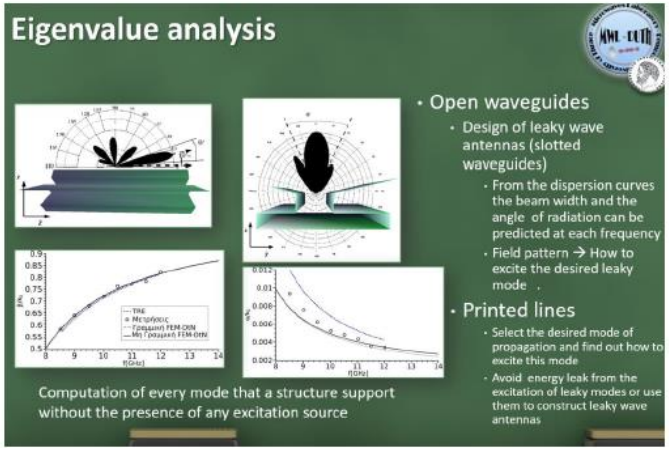
Κατασκευασμένες Αλυσίδες Λήψης μαζί με τους διαχωριστές ισχύος, τα ζωνοπερατά φίλτρα και τους Διανυσματικούς Διαμορφωτές

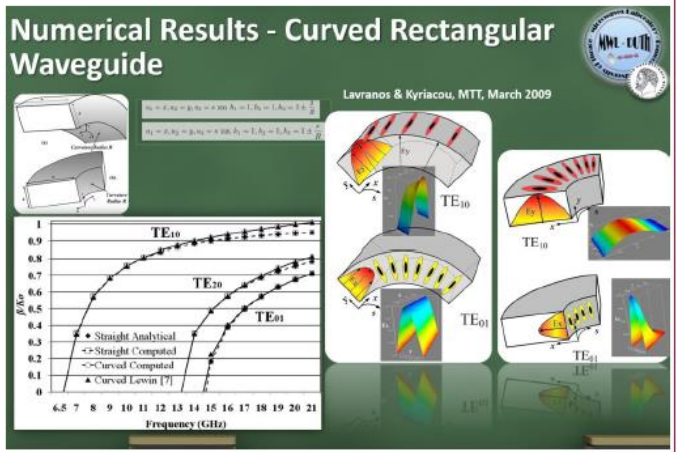
**Δραστηριότητα:** Σχεδιασμός – Κατασκευή - Μέτρηση προσαρμόσιμης μονάδας λήψης
**Παραδοτέο:** Προσαρμόσιμη μονάδας λήψης 8 καναλιών

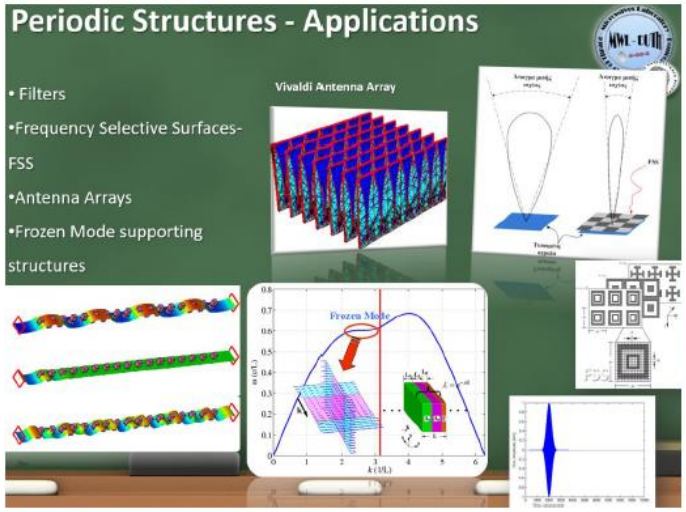
# Power Amplifier

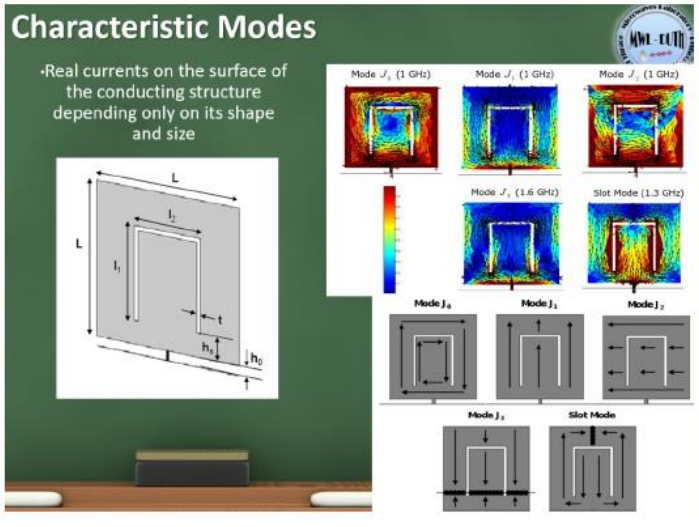


**Studies**


Eigenvalue analysis
• Open waveguides
• Design of leaky wave antennas (slotted waveguides)
• From the dispersion curves the beam width and the angle of radiation can be predicted at each frequency
• Field pattern → How to excite the desired leaky mode .
• Printed lines
• Select the desired mode of propagation and find out how to excite this mode
• Avoid energy leak from the excitation of leaky modes or use them to construct leaky wave antennas
Computation of every mode that a structure support without the presence of any excitation source


Numerical Results - Curved Rectangular Waveguide
Lavranos & Kyriacou, MTT, March 2009
TE10
TE20
TE01
Straight Analytical
Straight Computed
Curved Computed
Curved Lewin [7]
Frequency (GHz)


Periodic Structures - Applications
• Filters
•Frequency Selective Surfaces- FSS
•Antenna Arrays
•Frozen Mode supporting structures
Vivaldi Antenna Array
Frozen Mode


Characteristic Modes
•Real currents on the surface of the conducting structure depending only on its shape and size
Slot Mode (1.3 GHz)
Slot Mode


2026 CALL FOR PROPOSALS
on Front End Module
€14M EU FUNDING TO SECURE EUROPE'S 6G FUTURE


6GSNS
Call 2026 on Front End Module
INFO DAY & BROKERAGE EVENT

DEMOCRITUS UNIVERSITY OF THRACE | DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

# **Proposal:** Modular FR3 RF Front-End Testbed

## Project Vision

Development of a modular and scalable FR3 RF Front-End experimental platform supporting:

- Early validation of FR3 RF technologies
- Beamforming subsystem experimentation
- Antenna/RF co-integration studies
- Wideband mixed-signal experimentation
- Controlled TRL4/TRL5 demonstrations

## Technology Stack

| Function | Candidate Technology |
|---|---|
| RF MMICs | GaN-on-SiC / RF SOI |
| Beamformer ICs | RF CMOS / SiGe BiCMOS |
| ADC/DAC | CMOS + NLTL acceleration |
| Power Amplification | GaN |
| Digital Control | FD-SOI CMOS |
| Packaging | Heterogeneous chiplet integration |

## Main Technical Pillars

### 1. Broadband RF Front-End Design

- Broadband MMICs
- Distributed broadband matching
- Tunable RF subsystems

### 2. Analog-Hybrid Beamforming

- Beamformer IC evaluation
- Small-scale phased arrays
- Beam steering experiments

### 3. Antenna Array Integration

- Compact FR3 antenna tiles
- RF/antenna co-design
- OTA measurements

### 4. Wideband ADC/DAC Investigation

- High-speed conversion concepts
- NLTL-assisted techniques
- Wideband RF interfacing

# Thank You!

**Democritus University of Thrace (DUTH)**
**Department of Electrical & Computer Engineering (DECE)**
**Microwaves Laboratory (MWLab)**

## Modular FR3 RF Front-End Testbed

Contact

- **Georgios A Kyriakou, Professor, Director of the Microwaves Laboratory, gkyriak@ee.duth.gr**
- **Theodoros Kaifas, Assistant Professor, tkaifas@ee.duth.gr**

Open for Collaboration

FR3-RFTB aims to contribute to the development of practical and scalable FR3 RF Front-End technologies for future European 6G ecosystems.

We welcome discussions with:

- industrial partners,
- research organizations,
- semiconductor ecosystem stakeholders,
- SNS and Chips JU aligned initiatives.

### Areas of Collaboration

- RFIC/MMIC design
- Beamforming ICs
- Antenna arrays
- Mixed-signal systems
- Packaging and integration
- OTA validation
- AI-assisted radio functions