UNIVERSITY OF SPLIT
FACULTY OF ELECTRICAL ENGINEERING, MECHANICAL ENGINEERING AND NAVAL ARCHITECTURE

Training School on Ground Penetrating Radar for civil engineering and cultural heritage management

Building a cheap GPR prototype with graduate students - the experience of the University of Split

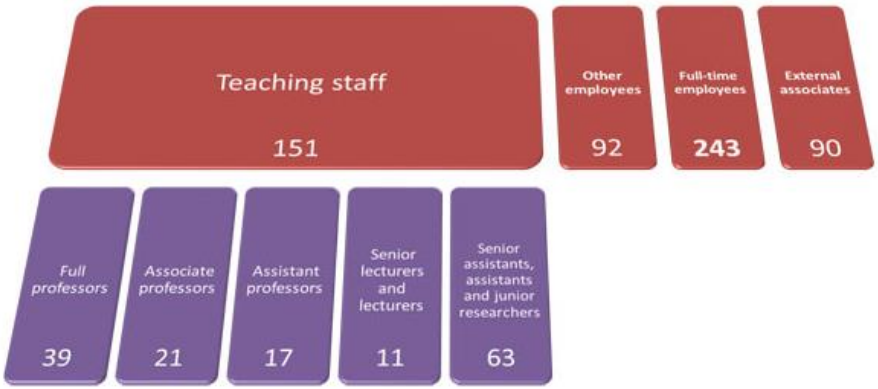
Maja Škiljo, Phd.
University of Split, FESB
Research group for electromagnetic compatibility and numerical methods in electrical engineering

Roma, Italy, May 14-18, 2018

University of Split

Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture

- *approximately **2700** students and **240** employees*



Conferences:

SpliTech 26-29 June 2018

Workshop on Applications of GPR Radar

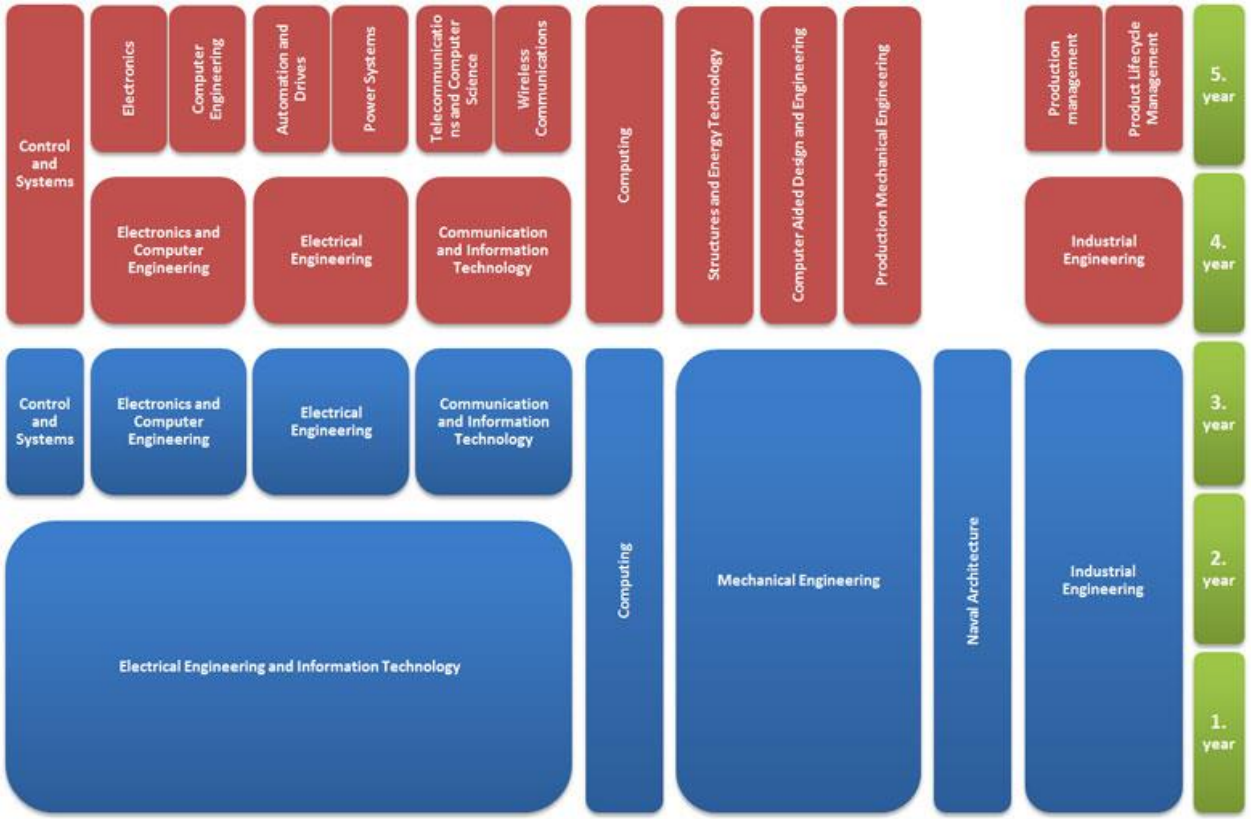
SoftCOM

September 13-15, 2018, Split - Supetar, Croatia

University of Split, FESB

- This university education comprises undergraduate, graduate and postgraduate studies, or is often referred to as a model 3+2+3:

- undergraduate university study,
- graduate university study,
- postgraduate university study.



Electromagnetic Compatibility and Numerical Methods in Electrical Engineering

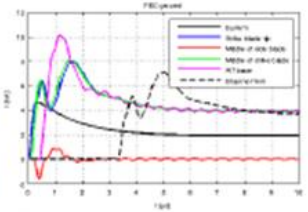
GROUP LEADER

Dragan Poljak

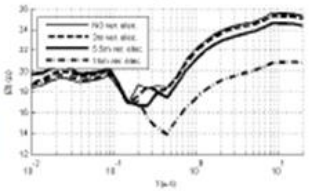
Full Professor

A research Group for Electromagnetic Compatibility (EMC) and Numerical Methods in Electrical Engineering at the Department of Electronics, with the University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split deals with an advanced computational electromagnetics and related applications in areas of EMC, antennas and propagation, human exposure to electromagnetic fields magnetohydrodynamics and plasma physics.

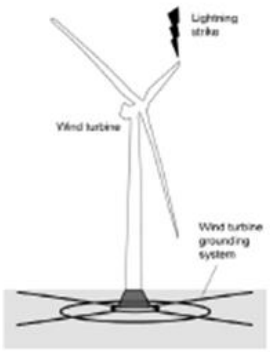
The group has established 2 research laboratories: Lab for EMC and Numerical Methods in Electrical Engineering and Lab for Antennas and EMC.



Current waveforms at different points of WT for PEC ground



Transient impedance for different lengths of additional vertical electrodes



Wind turbine subjected to a lightning strike

THE GROUP AT A GLANCE

Activities of the Group for EMC and numerical methods in engineering can be divided in following areas of fundamental and applied research areas:

FUNDAMENTAL RESEARCH

Advanced formulations in electromagnetics

The group main activity is a development of advanced formulations in electromagnetics (classical electromagnetic field theory) based on several space-frequency and space-time differential, variational, integral and integro-differential equations, respectively. Of particular interest are topics related to antenna theory, three-dimensional scattering, transmission line models and magnetohydrodynamics.

Advanced numerical methods in engineering

Of particular interest is a development of several efficient schemes of Finite Element Methods (FEM), Boundary Element Methods (BEM) and Finite Difference Methods (FDM) for the solution of various types of differential and integral equations, respectively. Several research codes and user friendly software packages have been developed.

Radio-channel modeling

Channel models for various frequency bands have been analyzed. Besides the classical wide-band modeling based on deterministic methods and channel statistics as in mobile networks, of special interest are the narrow-band radio-channels for transmission of power and the development of spherical mode theory (SMT) based channel models.

APPLIED RESEARCH

Electromagnetic compatibility of thin wire structures

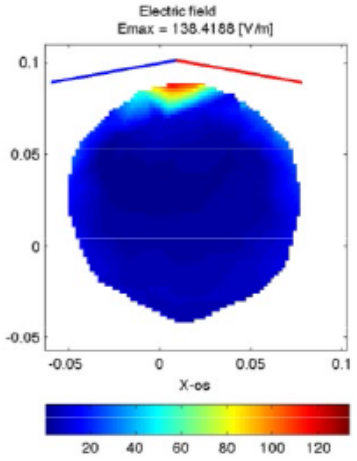
Various antenna and transmission line models for antenna systems, overhead wires, lightning channel, lightning rods and buried cables have been developed in either frequency or time domain. These models are based on related systems of integral equations. The corresponding equations of interest have been solved via originally developed numerical methods based on Finite Element Methods (FEM), Boundary Element Methods (BEM) and Finite Difference Methods (FDM).

Analysis and design of grounding system

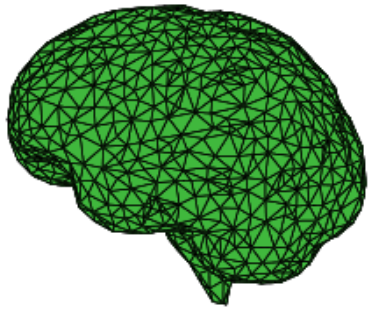
Stationary and transient analyses of realistic grounding systems of highly complex geometries placed in inhomogeneous media have been carried out with a particular emphasize to wind turbine grounding systems being highly vulnerable to lightning strikes. Namely, to reduce potential damage that may occur due to lightning strike, it is necessary to design an efficient lightning protection system, with a particular emphasis on accurate electromagnetic modeling.

Human Exposure to electromagnetic fields

Many techniques of incident field dosimetry and internal electromagnetic-thermal dosimetry methods have been used to assess human exposure to electromagnetic fields from extremely low (ELF) to microwave range. A number of human body models from simplified canonical geometries to anatomically based realistic representations have been developed. In particular, some dosimetry methods for the analysis of biomedical applications of electromagnetic fields have been developed.



Electric field distribution in the model of a human brain



The brain model

Wireless power transmission

Analysis of wireless power transmission to moderate distances by electrically small antennas (ESAs) has been carried out with special attention to the possibilities of decreasing transmission frequency and antenna size. It has been proven by means of spherical mode theory antenna model (SMT-AM) that the radiation efficiency is a decisive factor for achieving the best transmission performances. Hence, the methods of increasing the radiation efficiency of ESAs while maintaining proper antenna impedance and mode ratio have been developed. The power transmission to multiple receivers and the adjustment related problems are to be dealt with thoroughly.

INTERNATIONAL COLLABORATION

The Group has established contacts and developed a long-term active cooperation with many international research groups. The most intensive on-going collaboration is achieved with the following institutions:

1. Université Blaise Pascal, Clermont-Ferrand, France (EMC of antenna systems and transmission lines)
2. Wessex Institute of Technology, Southampton, UK (modeling of human body exposed to electromagnetic fields)
3. Technische Universität Ilmenau, Ilmenau, Germany (TMS)
4. Ecole Polytechnique Fédéral de Lausanne, Lausanne, Switzerland (grounding systems)
5. Otto-von-Guericke Universität Magdeburg, Magdeburg, Germany (aced formulations in electromagnetics)

Forms of collaboration include joint research work, publishing scientific and professional papers, writing of bilateral and multilateral project proposals, etc.

HIGHLIGHTS

In last two years the Group was involved in one international, one bilateral project and one professional project. There were one PhD Viva in the period from the beginning of 2012 to the end of 2013, M. Cvetkovic. (December/2013).

In last the period 2012-2013 several advances were achieved in modeling of complex wire configurations related to EMC problems (antennas, lines, cables, lightning channel, grounding systems), human exposure to electromagnetic fields and biomedical applications of electromagnetic fields.

Of particular importance were EMC aspects of the analysis and design of wind turbines (WTs). Sophisticated models pertaining to WT struck by lightning, grounding systems for WTs and EMI impact of WT's for radar systems have been developed.

Furthermore, realistic modeling of the human eye and brain, respectively has been undertaken based on the corresponding boundary integral equation methods.

The radio-channel models based on SMT-AM for wireless power transmission have been investigated and efficient ESAs design for the purpose has been considered.

The Group has developed and upgraded several research codes:

- SoAPLinCS (Software for the Analysis of Power Line Communications Systems)
- STAGE (System for Transient Analysis of Grounding Electrodes)

Note: These codes can be considered to be extensions of the TWiNS (Thin Wire Numerical Solver) code developed by early 2009 and published in UK and USA together with the related book.

- TrAnSolBS (Transient Analytical Solver for Buried Structures)
- SoHuBraD (Software for Human Brain Dosimetry)
- RSD (Diffraction Loss Calculations by Approximate Methods)

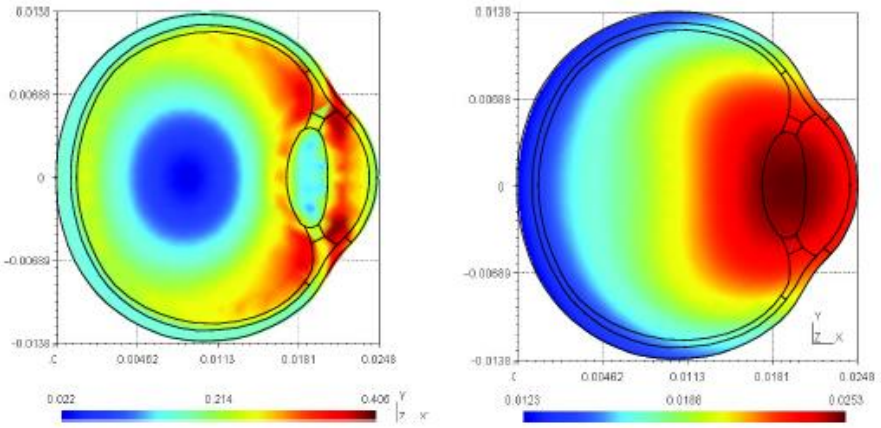
The intensive on-going group activities deal with magneto-hydrodynamic based fusion related research activities. In particular, significant efforts of the group are devoted towards the solution of current diffusion equation and Grad-Shafranov equation for plasma equilibrium in tokamak.

SELECTED REFERENCES/ PUBLISHED PAPERS, BOOKS, MONOGRAPHS, ETC.

The results having come out of the last 2 year period are documented in various publication. Some selected references are given:

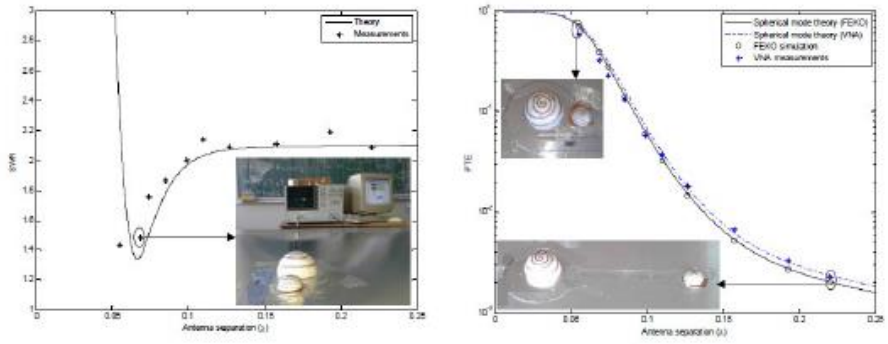
JOURNAL PAPERS (CC, SCI, SCI EXPANDED) (8)

1. Antonijevic, Sinisa; Poljak, Dragan. **A Novel Time-Domain Reflection Coefficient Function: TM Case.** *// IEEE Transactions on electromagnetic compatibility.* PP (2013), 99; 1-7
2. Cavka, Damir; Poljak, Dragan. **On the Evaluation of Input Impedance and Transient Impedance for Grounding Electrodes Using Antenna Theory.** *// COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering.* 32 (2013), 6; 2045-2062
3. Šesnić, Silvestar; Poljak, Dragan. **Antenna model of the horizontal grounding electrode for transient impedance calculation: Analytical versus Boundary Element Method.** *// Engineering analysis with boundary elements.* 37 (2013); 909-913
4. Šesnić, Silvestar; Poljak, Dragan; Tkachenko, Sergey V. **Analytical Modeling of a Transient Current Flowing Along the Horizontal Grounding Electrode.** *// IEEE Transactions on electromagnetic compatibility.* PP (2013), 99; 1-8
5. Škiljo, Maja; Blažević, Zoran. **Spherical helices for resonant wireless power transfer.** *// International Journal of Antennas and Propagation.* 2013 (2013), Article ID 426574; 1-12
6. Čavka, Damir; Poljak, Dragan; Dorić, Vicko; Goić, Ranko. **Transient analysis of grounding systems for wind turbines.** *// Renewable energy.* 43 (2012); 284-291
7. Poljak, Dragan; Drissi, Khalil El Khamlichi. **Electromagnetic Field Coupling to Overhead Wire Configurations: Antenna Model versus Transmission Line Approach.** *// International Journal of Antennas and Propagation.* 2012 (2012); 1-18
8. Poljak, Dragan; Shoory, Abdolhamid; Rachidi, Farhad; Antonijević, Siniša; Sergey, Tkachenko. **Time-Domain Generalized Telegrapher's Equations for the Electromagnetic Field Coupling to Finite Length Wires Above a Lossy Ground.** *// IEEE Transactions on electromagnetic compatibility.* 54 (2012), 1; 218-224



SAR and temperature increase in the eye due to EM wave with power density 10 W/m2 at: f=1 GHz.

Measurements of wireless transmission between different spherical helical monopole antennas at 163 MHz vs. theory and numerical simulations: standing-wave ratio (left) and power transmission performances (right) for 50-Ω vector network analyser loading



Our Research group courses

(some of them…)

- Human exposure to electromagnetic field
- Numerical methods in communications
- Fields and waves in electronics
- Electromagnetic waves
- Electromagntic fields
- Electromagnetic ecology and dosimetry
- Radiocommunications
- Radars
- Mobile communications
- Electromagnetic compatibility
- Measurements in wireless systems
- Wireless energy transmission systems
- …

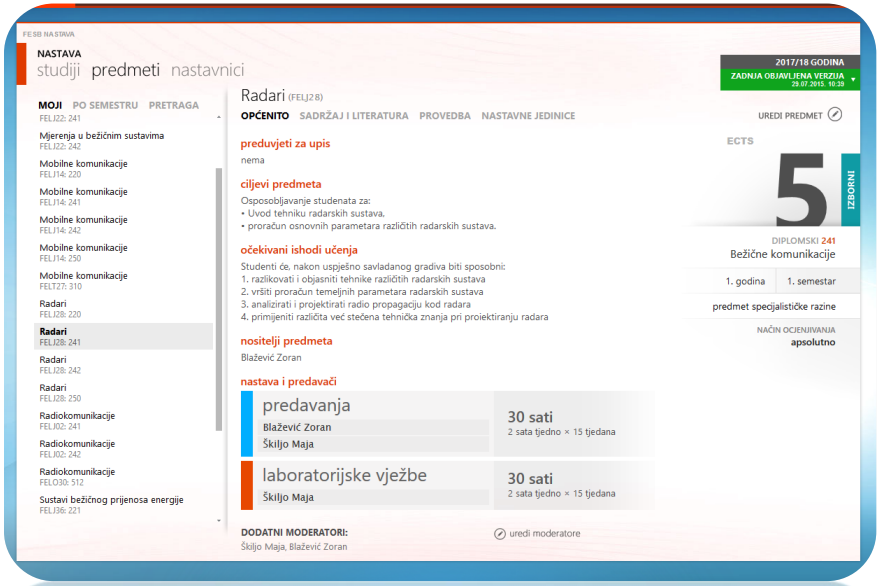
Radars 2017./2018.:

24 students from graduate studies:

- Electronics and Computer Engineering,

- Communication and Information Technology, and

- Computing



Motivation

- A low-cost frequency modulated continuous wave (FMCW) GPR for educational purposes is developed within the framework of COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar„.
- During the Action TU1208 a lot of free resources was developed and given, which is very practical and convenient for educational use, e. g. books, journal papers, free software, case studies and open database with various useful GPR data sets.
- Also, MIT Lincoln Laboratory sponsored a radar short-course with goal to increase student interest in RF electronics, antennas, radio propagation and signal processing- cheap laptop-based FMCW synthetic aperture radar (SAR).

Goals

- To build a GPR in one semestar based on two free resources:

1. V. Ferrara, M. Chizh and A. Pietrelli, „Guide to building a GPR prototype for educational use", Warsaw, Final Conference of Cost Action TU1208, in Warsaw, Poland
2. Gregory Charvat, Jonathan Williams, Alan Fenn, Steve Kogon, and Jeffrey Herd. RES.LL-003 Build a Small Radar System Capable of Sensing Range, Doppler, and Synthetic Aperture Radar Imaging. January IAP 2011. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

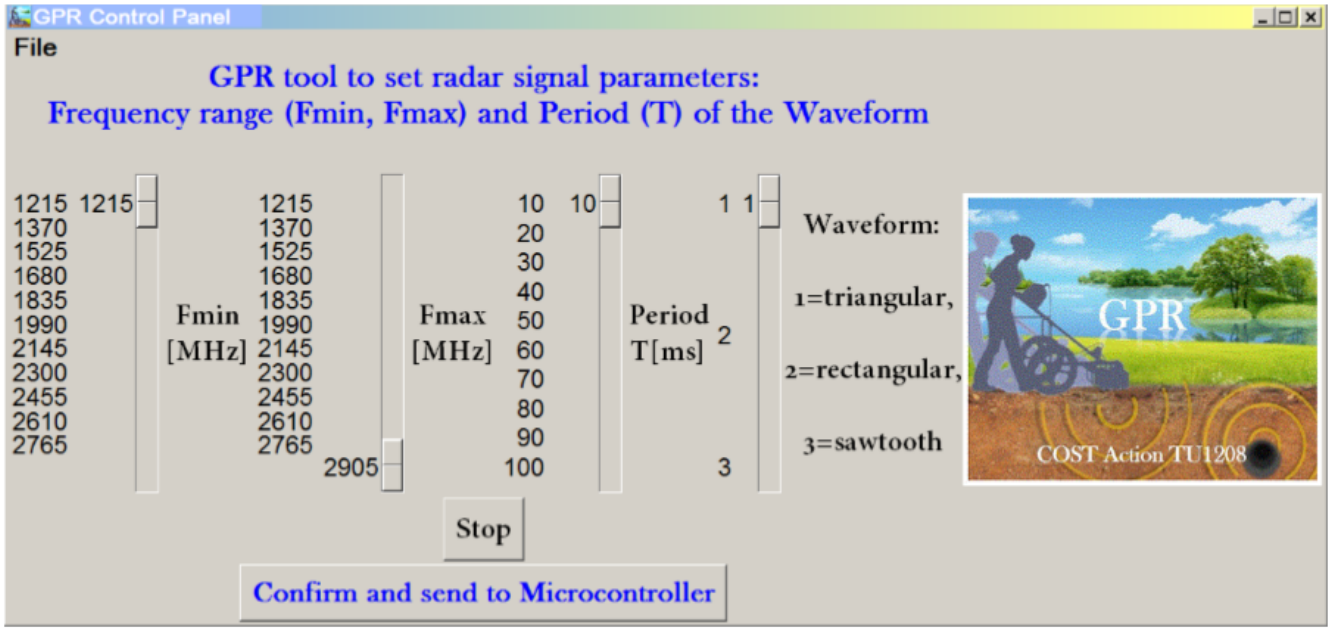
- Cooperation of students from different programmes
- Project based course?

Building a cheap GPR prototype

- Graphical user interface (GUI) is developed during Short-Term Scientific Missions: Years 4 & 5 of COST Action TU1208
- Python software program and firmware for microcontroller
- This provides flexibility in further development of GPR where the firmware can remain unchanged while all modifications can be done in the software.

V. Ferrara, M. Chizh and A. Pietrelli, „Guide to building a GPR prototype for educational use", Warsaw, Final Conference of Cost Action TU1208, in Warsaw, Poland

Building a cheap GPR prototype



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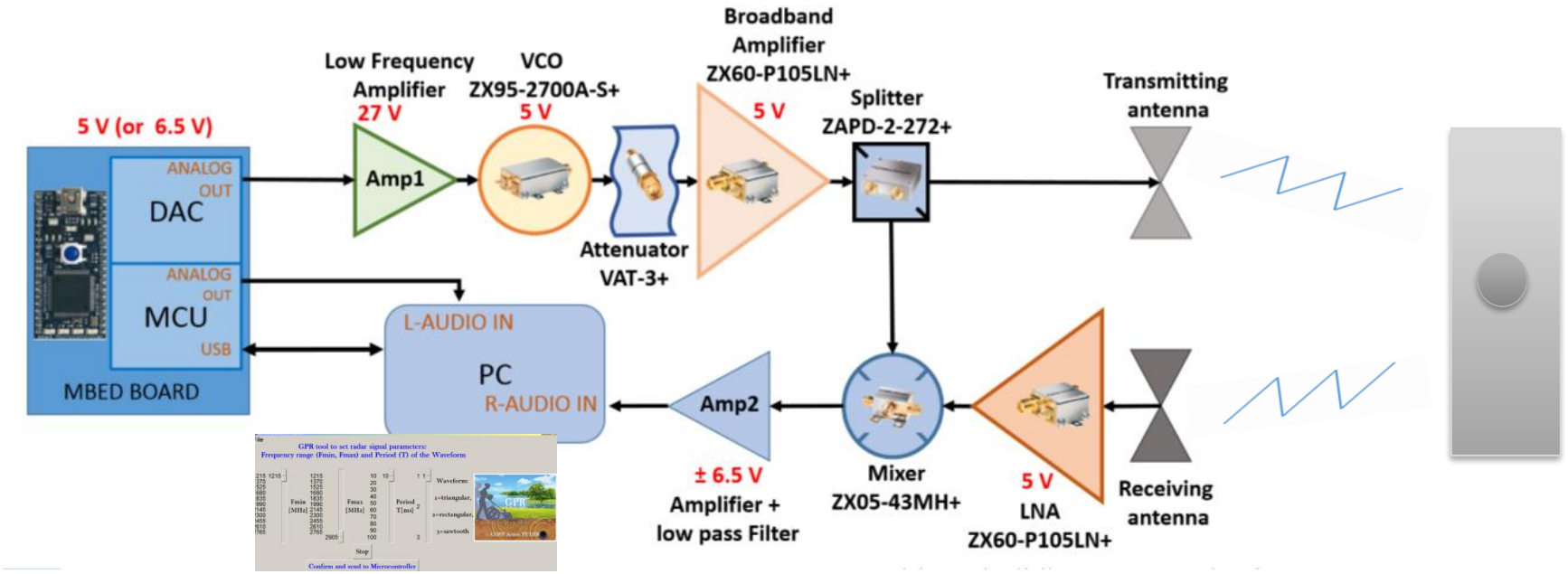

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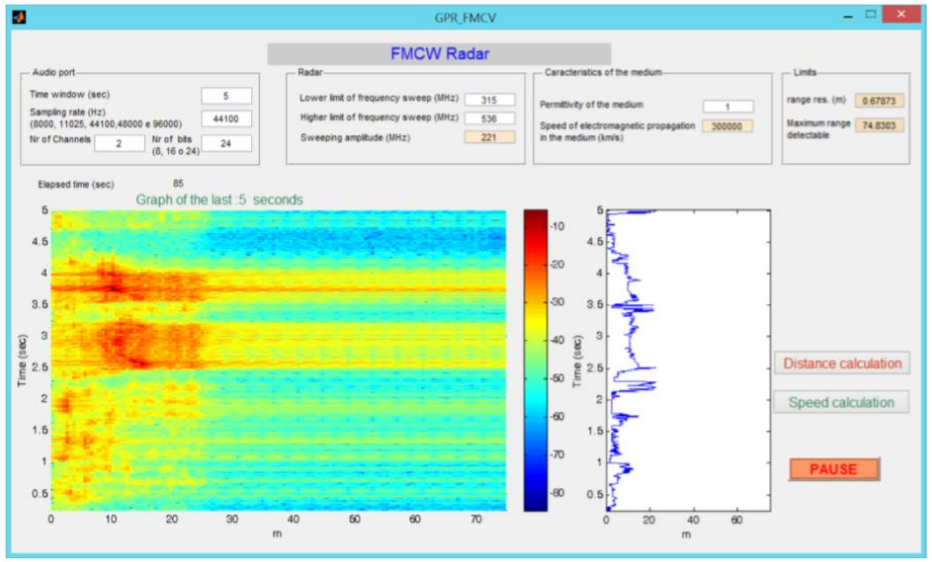
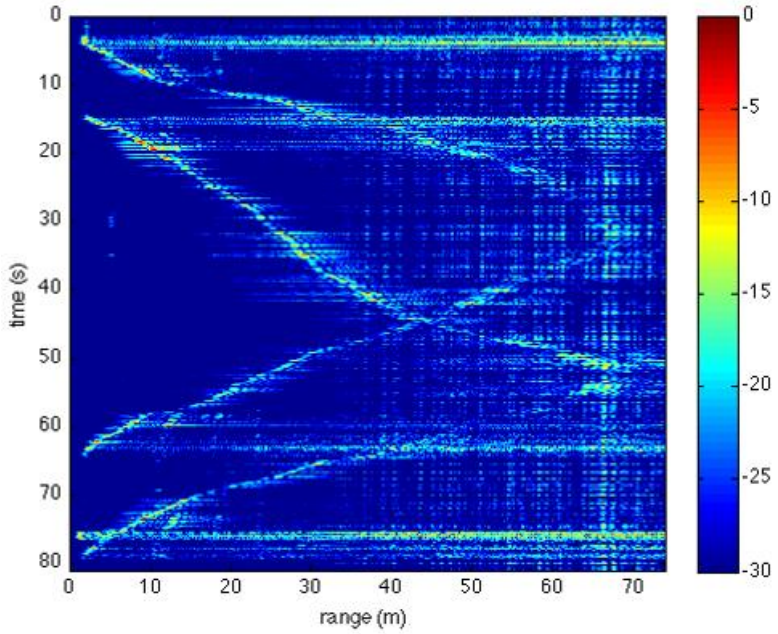


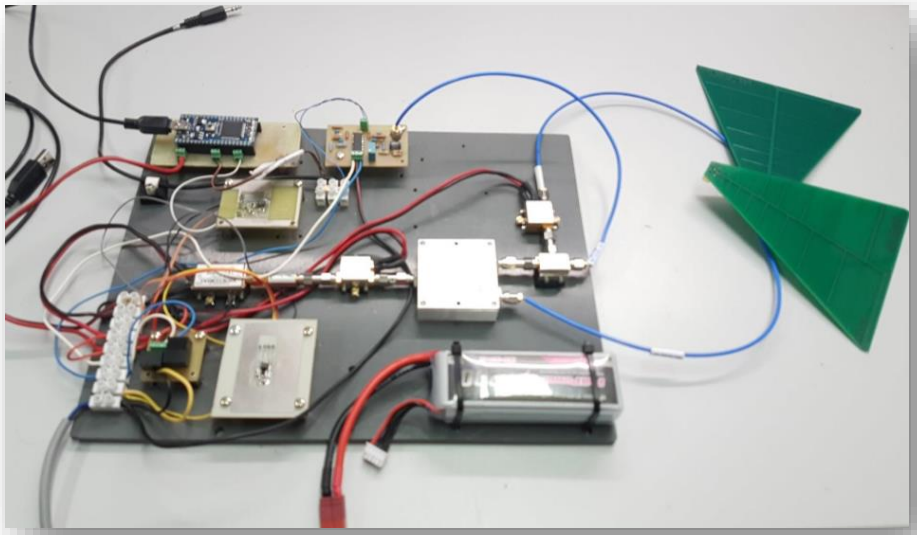


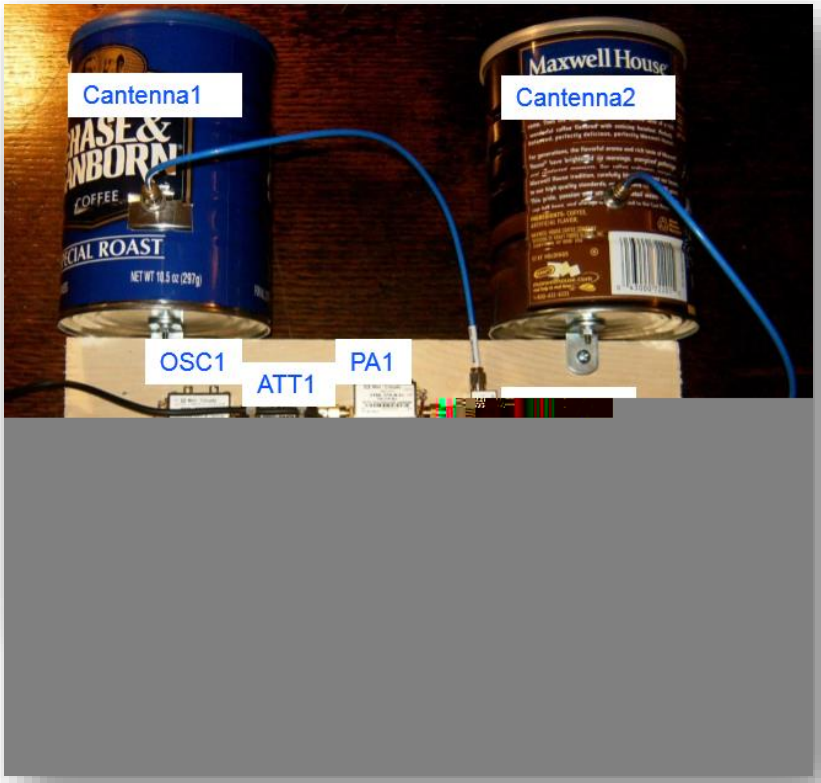
2 targets walking in the woods

V. Ferrara, M. Chizh and A. Pietrelli, „Guide to building a GPR prototype for educational use", Warsaw, Final Conference of Cost Action TU1208, in Warsaw, Poland

Gregory Charvat, Jonathan Williams, Alan Fenn, Steve Kogon, and Jeffrey Herd. RES.LL-003 Build a Small Radar System Capable of Sensing Range, Doppler, and Synthetic Aperture Radar Imaging. January IAP 2011. Massachusetts Institute of Technology: **MIT OpenCourseWare,** https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

Building a cheap GPR prototype





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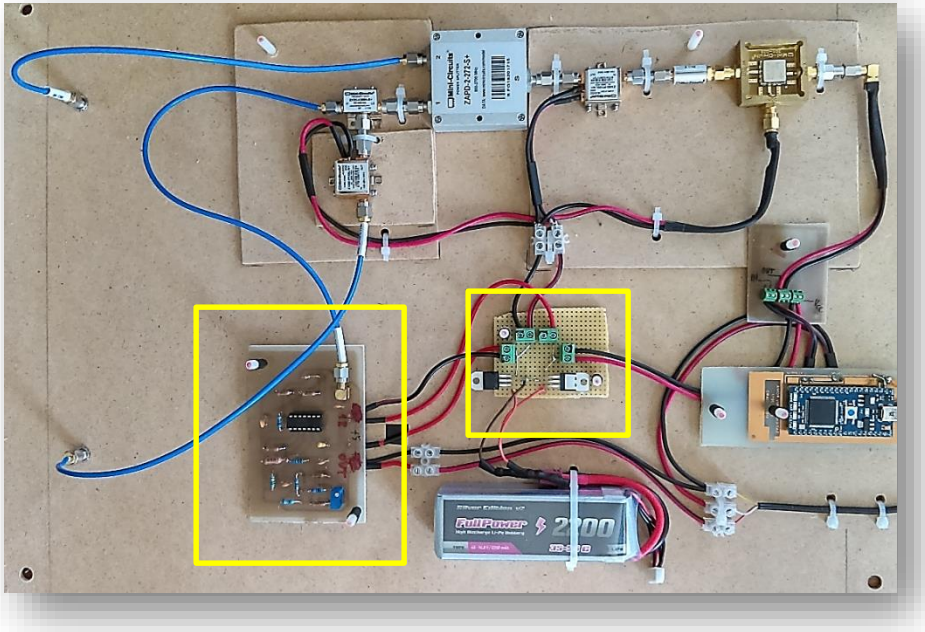

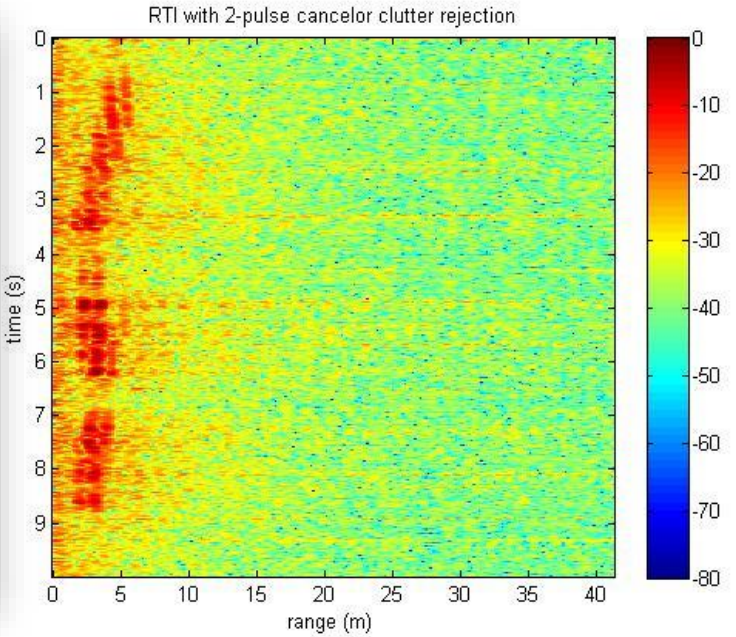

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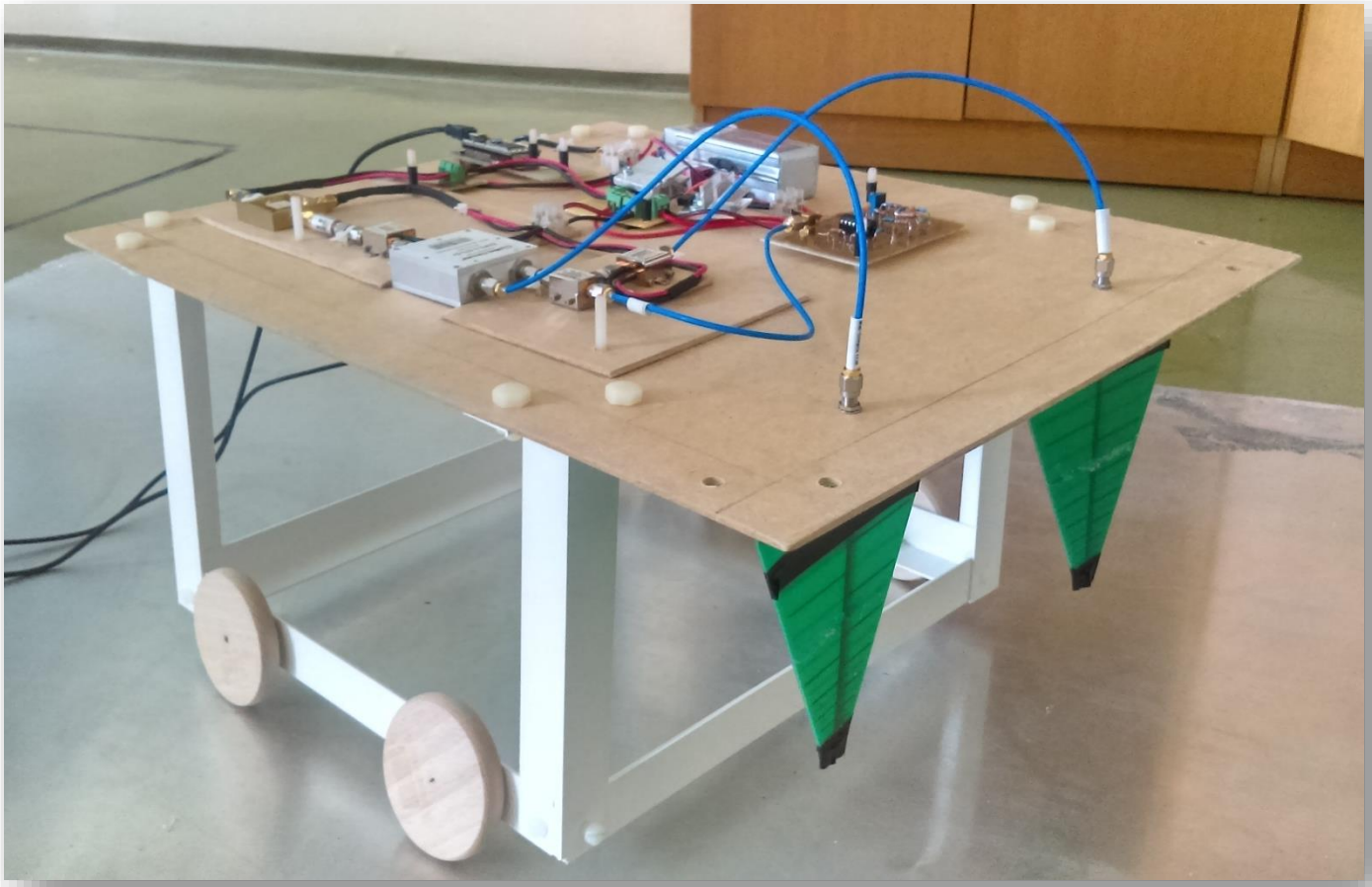
Building a cheap GPR prototype



GPR antenna design

-GPR antennas operate in harsh environment near the ground and the second antenna.

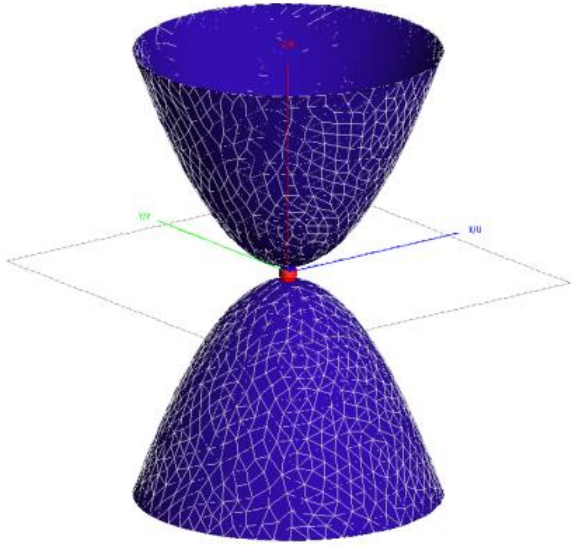
-They are required to transmit and receive fast transient signals with a large frequency bandwidth with negligible distortion.

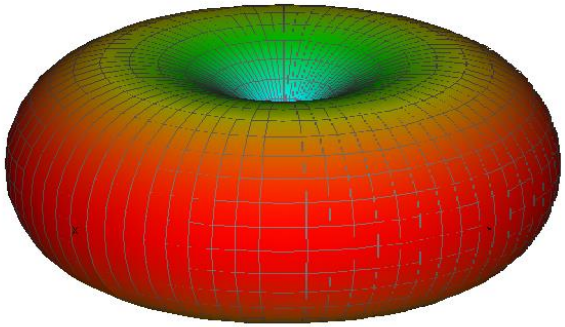
-Compact, light weight, small-size and low-cost.

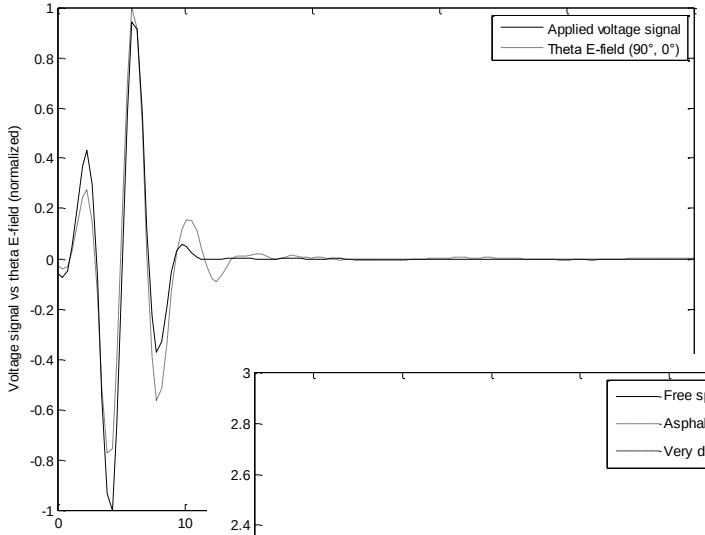
-Our goal: to find and analyze the antenna design that covers the entire frequency bandwidth od the FMCW GPR prototype, achieves high directivity, small size and low cost.

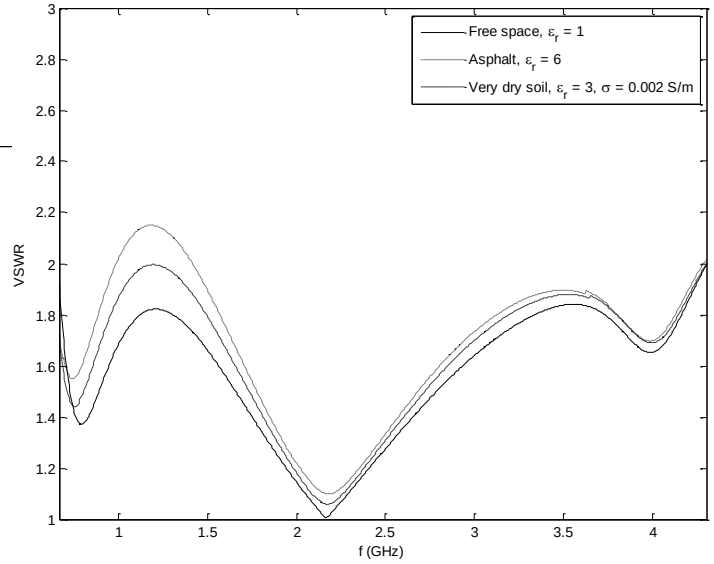
GPR antenna design

- Parabolic bicone antenna (previous work)



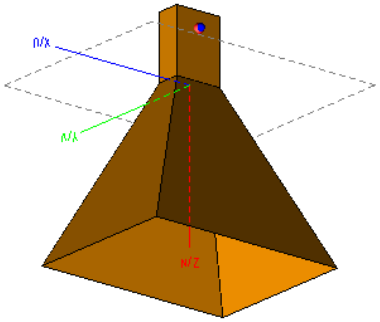


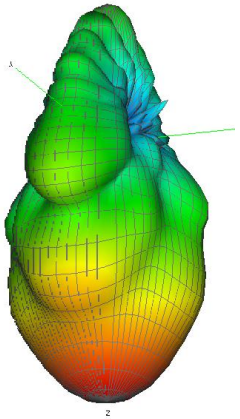


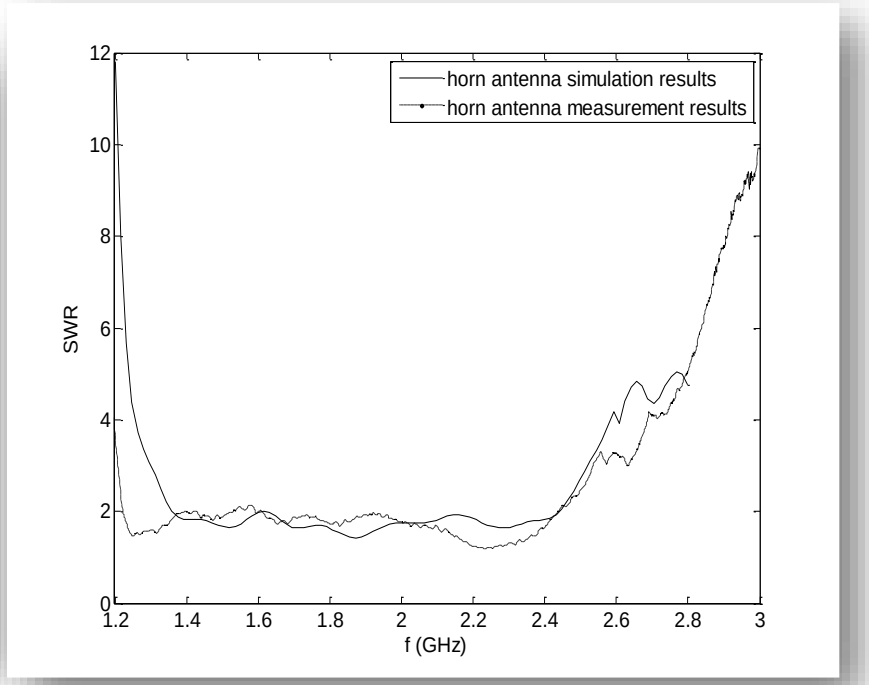


GPR antenna design

- Horn antenna

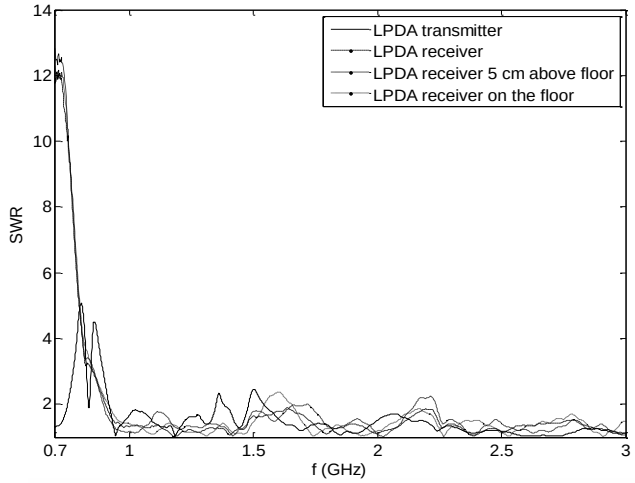


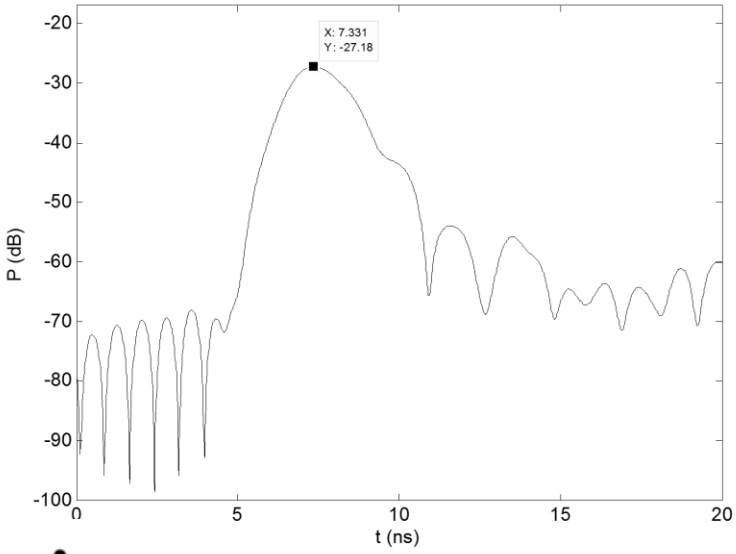


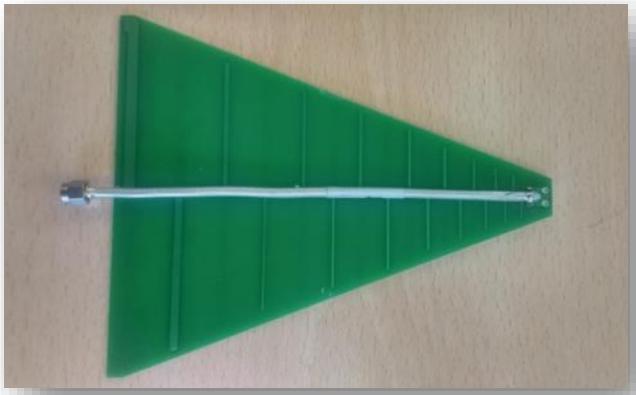


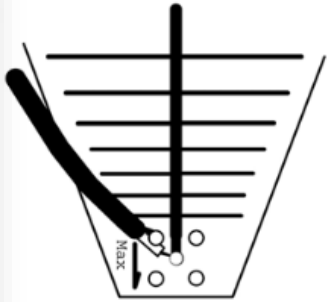
GPR antenna design

- LPDA- log-periodic dipole antenna array



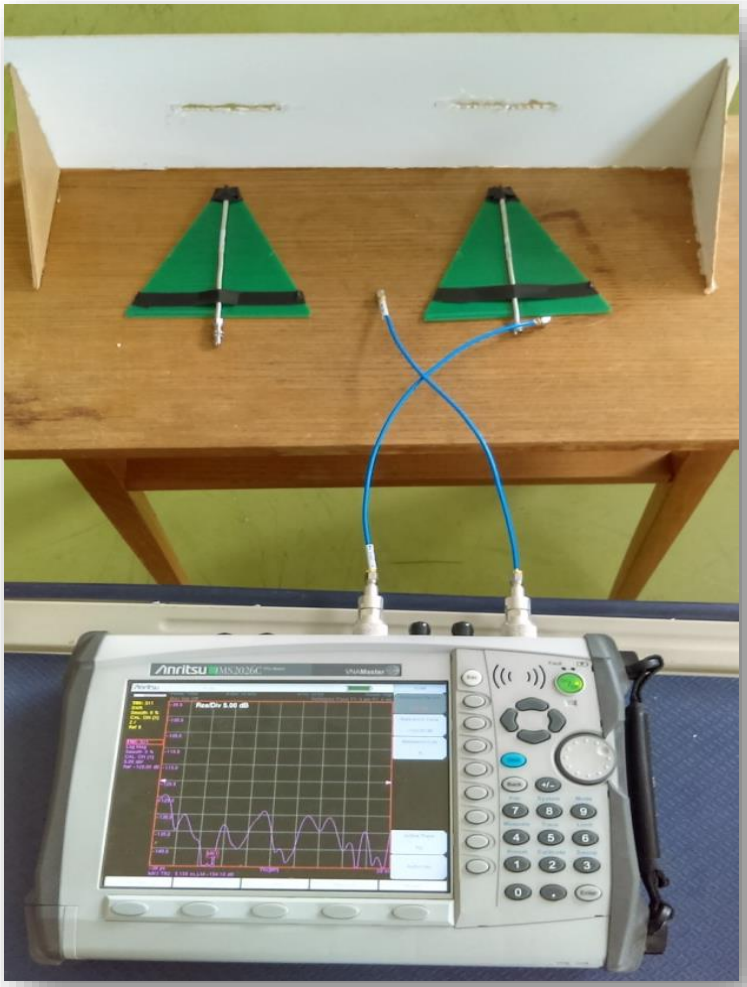


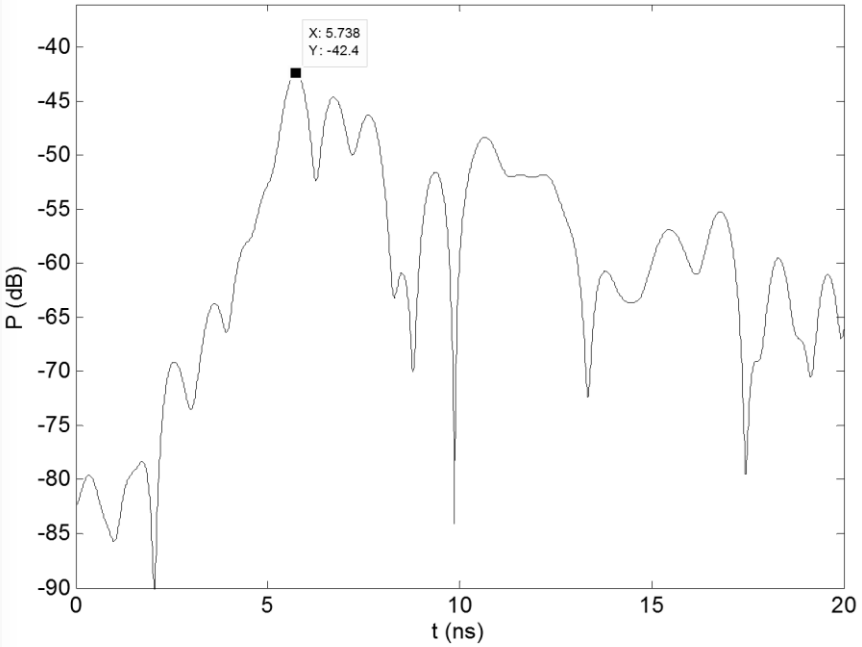




$$a_{FS}\,(\mathrm{dB}) = 32.5 + 20\log f\,(\mathrm{GHz}) + \\ +20\log d\,(\mathrm{m}) - (G_{RX} + G_{TX})$$

GPR antenna design

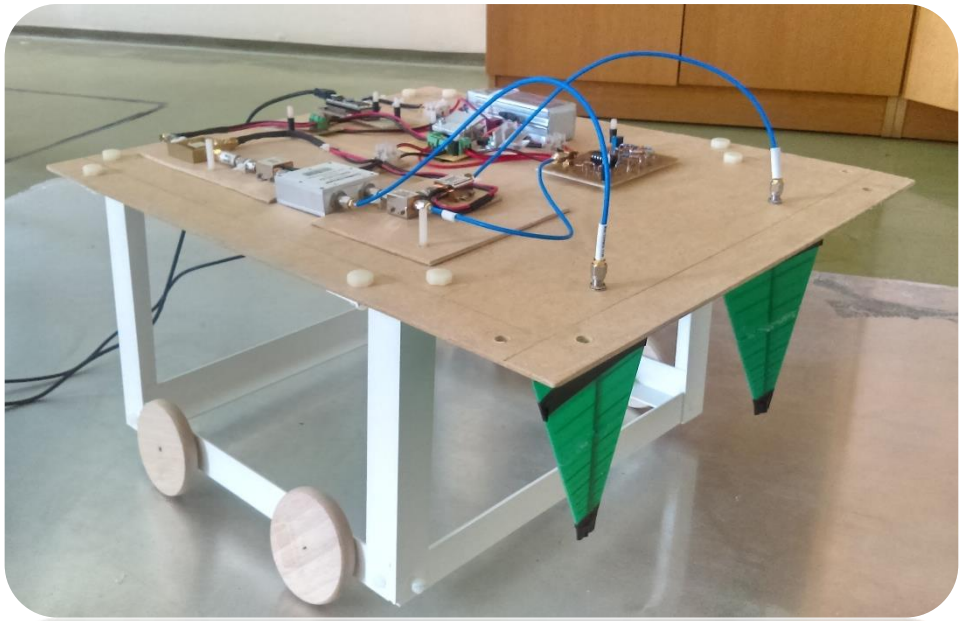




Conclusion

- Building a FMCW GPR prototype for educational purpose is not a straightforward task.
- Students and professors need to have a certain background in various fields: programming, electronics, antenna design, numerical modeling, radio wave propagation and signal processing.
- We continued the work on the GPR prototype focused on antenna design, beacuse our field of research is related to antennas and propagation.
- *Future work:*
  - *next academic year: signal processing and antenna design*

Thank you for your attention!



SAPIENZA
UNIVERSITÀ DI ROMA