1.1 MULTI-FUNCTION RF SEEKER BASED ON 3D PHASED ARRAYS (LIzARd)

PROJECT DURATION: 24 months

Company Name	Web site	Nationality (UK / Fr)	Organisation Type
Université de Bretagne Occidentale (UBO)	http://www.univ-brest.fr	Fr	University
Cranfield University	http://www.cranfield.ac.uk	UK	University
Thales Optronique S.A.	http://www.thalesgroup.com	Fr	Industry

1.1.1 Configuration control

Rev – First issue

1.1.2 Scope

In the LIzARd project, we propose to use novel 3D-shaped conformal antenna solutions for RF seekers to investigate and assess the resulting benefits in detection and classification performance. We also propose to exploit the additional degrees of freedom offered by the new antenna design to add new functionalities to the seeker. These will allow the use of a single sensor to carry out multiple tasks such as radio-altimetry, proximity activation and proximity fuze.

1.1.3 Background and Project Description

Background:

Current RF-Seekers use mechanical steerable antennas. In order to reduce the cost of the mechanical system and to improve significantly the performance of the missile seeker, we propose to replace the mechanical antenna components with an electrically controlled 3D antenna array. This will result in a much more robust antenna which will be capable to steer much faster and significantly more accurately than existing solutions. The proposed antenna will also provide an increased coverage as a result of flexible beam steering in all directions. The objective of the PYRANA project was to carry out an analysis of the performance of 3D antennas for RF-Seeker applications and to investigate and develop unique and bespoke antenna designs suitable for this application. The COBRA project is analysing potentialities of 3D manufacturing technologies in order to fabricate the 3D antennas.

In this new project, LIzARd, we propose to use the developed 3D shapes and the novel antenna solutions to investigate and assess the advantages in detection and classification performance of the new 3D RF Seeker. We also propose to exploit the additional degrees of freedom offered by the new antenna design and add new functionalities to the seeker that will allow the use of a single sensor to carry out multiple tasks such as radio-altimetry, proximity activation and proximity fuze. Another project, funded by the DGA and Dstl, which supports a PhD student for three years will contribute to LIzARd (Figure 1)

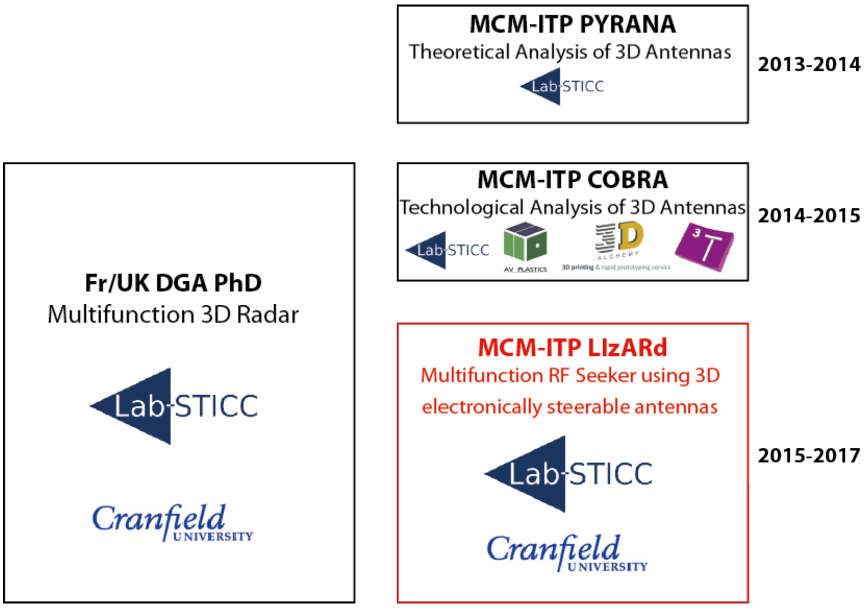

Figure 1: LIzARd project

Project Description:

Once achieved, the COBRA project will give information about the technological degrees of freedom in terms of 3D design in the short and medium term. A tool, allowing polarization and optimization will be also initiated. LIzARd will initially focus on the enhancement of this tool and then on its use for the optimization of the chosen prototype antenna with respect to the 3D monopulse technique (developed in COBRA and LIzARd). As shown in Figure 2, the polarization must be the same for all antennas in the received surface when the seeker is in transmit mode. As the number of antenna elements may be a key parameter, a specific tool has to be used to configure the orientation of each antenna element as a function of the shape. This optimization will be verified by electromagnetic simulations, which will take into account the feeding antenna network.

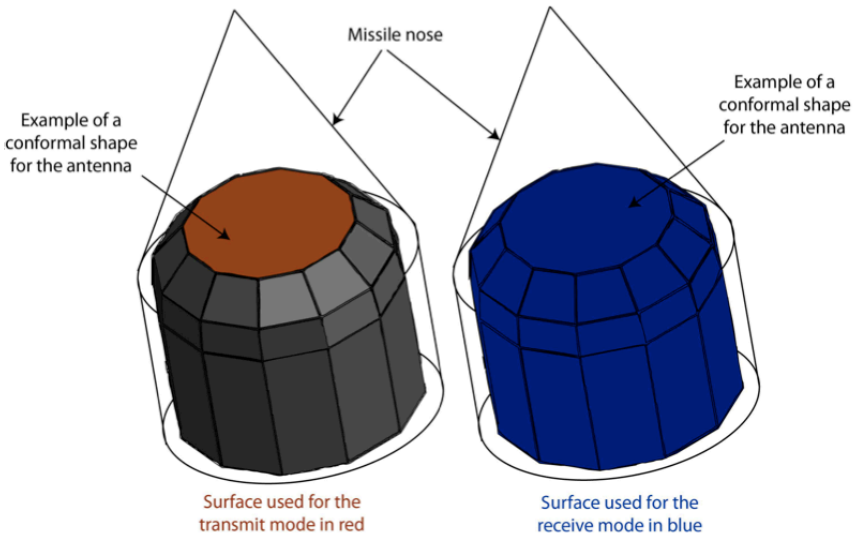

Figure 2: Example of the 3D antenna concept developed in PYRANA and COBRA

The Lab-STICC is a UMR CNRS laboratory of Information and Communication Science and Technology and is a partnership between universities and engineering schools (**Université de Bretagne Occidentale (UBO)**, Université de Bretagne Sud (UBS), Telecom Bretagne, ENSTA Bretagne and ENIB). It unites three poles working within one central theme: “From sensors to knowledge”.

The three poles are as follows:

- MOM: microwaves optoelectronic and materials;
- CAC: communications, architecture and circuits;
- CID: knowledge, information, decision.

The Lab-STICC team, who is involved in LIzARd, is specialized in microwave components and antenna design (Yves Quéré, Christian Person, Eric Rius). The Lab-STICC will be able to metallize 3D plastic objects by the development in the laboratory of a 3D Selective Metallization Equipment. The Lab-STICC owns equipment to measure the performance of the designed antennas up to 170GHz. Electromagnetic simulation of 3D conformal antennas and 3D antennas needs important computing. The Lab-STICC has a HPC cluster optimized for some commercial electromagnetic softwares, such as HFSS from Ansys (with HPC simulation license). With this, electromagnetic simulations can be carried out with up to 256 cores and more than 2T RAM in parallel.

Cranfield University is a post-graduated only University and one of the top research intensive universities in the UK.
The Research Excellence Framework 2014 (REF) has assessed that 81% of the research at Cranfield University is world leading or internationally excellent. In Cranfield’s Unit of Assessment (Aeronautical, Mechanical, Chemical and Manufacturing Engineering), the number of world leading or internationally excellent outputs has more than doubled from 2008 and we have ranked second only to Imperial College London, in terms of research power.

Cranfield University is at the forefront of Defence and Security and our partnership with the UK’s Ministry of Defence (MOD) offers a unique gateway for teaching, research and consultancy. We utilise a unique set of capabilities, expertise and facilities to deliver practical solutions that make a real difference to the lives of military personnel and civilians across the world.

Dr Alessio Balleri and Dr Nabil Aouf are respectively a radar lecturer and a reader within the Centre for Electronic Warfare. The Centre for Electronic Warfare is Cranfield's focal point for research, education and consultancy into electronic attack, electronic protection and electronic warfare support. Our capabilities are widely respected within the defence and security sector, serving an extensive range of students, clients and organisations.

1.1.4 Exploitation Strategy

The LIzARd research project proposes to experimentally demonstrate conformal antenna capacities for RF Seekers and to investigate their capacity to intricate other RF sensing functions, starting with the radio-altimeter function and also the RF proximity sensors.

The LIzARd research project is supported by a strong and unique expertise on several 3D printing innovative techniques applied to radiofrequencies. This project deeply investigates the conformal antenna aspect: realization, radiating patterns and feeds as well as their exploitation in track and pursuit radar modes and extra-functionalities.

Once the concept proven, to further enhance the maturation of conformal antennas for RF Seekers, we will need to address the active parts of the sensor, namely the Transmit / Receive (T/R modules) function. To fully benefit of conformal antenna concepts, we shall develop full 2D T/R modules in flat configuration (known as “Tile” shape modules) ,compliant with the mesh of antenna arrays in Ku band. This development corresponds to a major technological step that shall be pulled through EDA / PEA / TDP initiatives.

1.1.5 Technical Maturity Development Strategy

The table below summarises the possible technical requirements that this technology would need to meet in order to become exploitable in a missile system. A risk assessment has been carried out in order to identify the key technical challenges for the technology and to develop a research strategy focussed upon exploitation.

Future Technical Requirement	Risk	Technology maturation strategy
Mass/Volume	2	Mass and volume assessment of this disruptive technology is part of the evaluation of the project
Electrical/Power	1	Postponed to higher TRL programs with active conformal antenna demonstration
Temperature	1	Potential issues shall be detected within this project
Storage, Design life	1	Potential issues shall be detected within this project
Cost	1	Conformal antenna radiating structure cost shall be stand-alone assessed.
Rain, Sand, Dust, Salt Mist, Fluid Contamination, Humidity	1	Postponed to higher TRL programs with active conformal antenna demonstration
Vibration/Shock/Acoustic Noise	1	Postponed to higher TRL programs with active conformal antenna demonstration
EMC/Lightening/ESD	1	Postponed to higher TRL programs with active conformal antenna demonstration
Logistical burden, Maintainability, Availability	1	Postponed to higher TRL programs with active conformal antenna demonstration
Reliability or Safety	1	To be addressed in parallel, notably regarding whiskers on metallic parts produced by additive manufacturing
Manufacture/handling/transport/ Disposal	1	Manufacturing capacities have been investigated within COBRA. Evolution of industrial capacities shall be followed.
Survivability, stealth	0	
Concepts of use, mission planning	1	Postponed to higher TRL programs with active conformal antenna demonstration
Political, standards, regulations	0	

Technical risk of technology meeting future requirements

0. Not applicable. This technology will not need to meet these requirements.
1. This technology will need to meet these requirements, but a reasonable argument can be made today as to why this is low risk (technical challenge low or read across from other technologies).
2. This technology will need to meet these requirements, but its performance is not known, or technically challenging.

1.1.6 Work Package Description

Figure 3 and Figure 4 describe the organization of the work-packages for the LIzARd project. WP0 is dedicated to the management of the project, WP5 is dedicated to the dissemination of the results, and WP6 is focused on the System Level Assessment. Overall we propose four work-packages for the technical part of the project: WP1, WP2, WP3, and WP4. WP1 is dedicated to the 3D antenna analysis in terms of Design and Technology. WP2, WP3 and WP4 investigate and assess the benefits and advantages in terms of detection and classification performance of the new 3D RF Seeker. Prototyping will be done on the work-package WP3 and WP4.

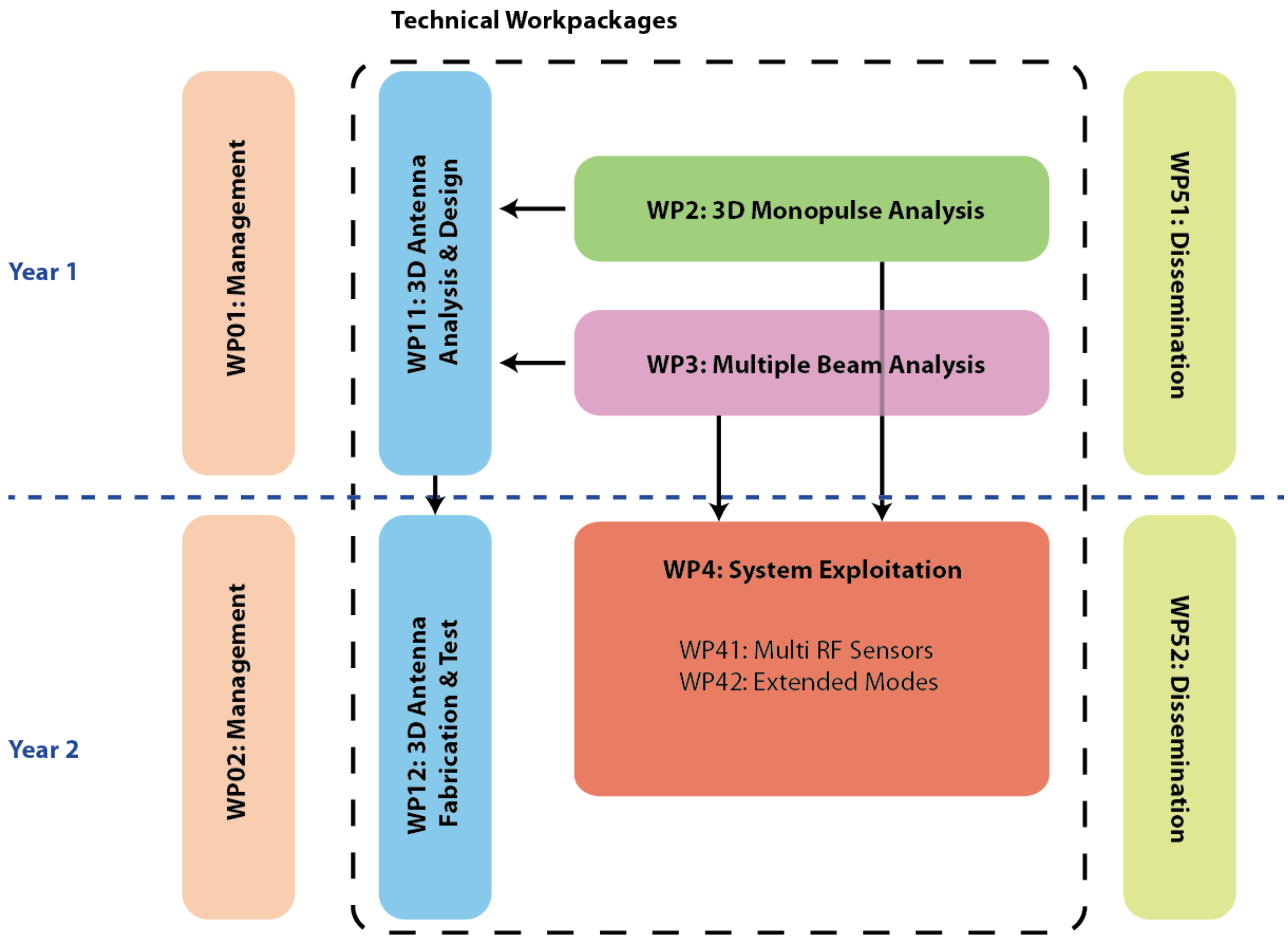

Fig. 3: Overview of all work packages and their interactions.

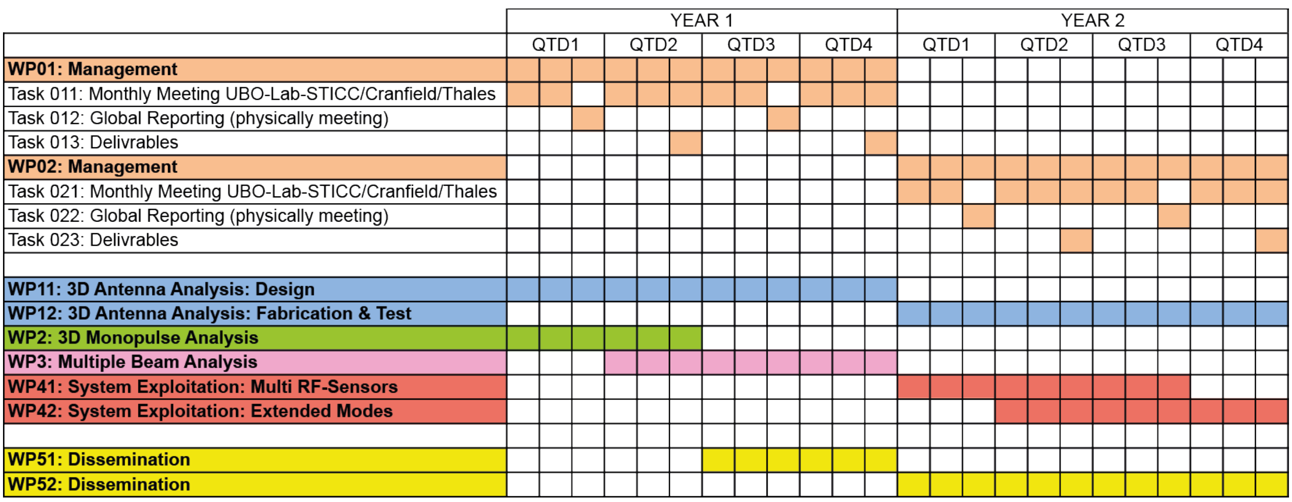

Fig. 4: Gantt chart (time dependence between work packages will be describe below).

1.1.6.1 WP0 Management (Lab-STICC / UBO)

WP01: MANAGEMENT	
RESPONSIBLE: Y. QUERE (LAB-STICC/UBO)	**Start dates:** t0 **End date:** t0+12

OBJECTIVES:

To ensure efficient project coordination in order to achieve the project objectives.

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TASKS:

- **T011: Meeting between the leader of the project and Thales (t0 to t0+12)** –Monthly meeting will be held with Thales and a short report of ten lines will be delivered.
- **T021: Global reporting (t0+3 and t0+9) –**Two face-to-face meetings will be held in the UK.

T031: Global deliverables (t0+6 and t0+12) –Lab-STICC/UBO and CRANFIELD will deliver the two technical reports.

WP02: MANAGEMENT	
RESPONSIBLE: Y. QUERE (LAB-STICC/UBO)	**Start dates:** t0+12 **End date:** t0+24

OBJECTIVES:

To ensure efficient project coordination in order to achieve the project objectives.

TASKS:

- **T012: Meeting between the leader of the project and Thales (t0+12 to t0+24)** –Monthly meeting will be held with Thales and a short report of ten lines will be delivered.
- **T022: Global reporting (t0+15 and t0+21) –**Two **face-to-face** meetings will be held in the UK.

  T032: Global deliverables (t0+18 and t0+24) –Lab-STICC/UBO and CRANFIELD will deliver both technical reports.

1.1.6.2 WP1 3D Antenna Analysis (Lab-STICC/UBO)

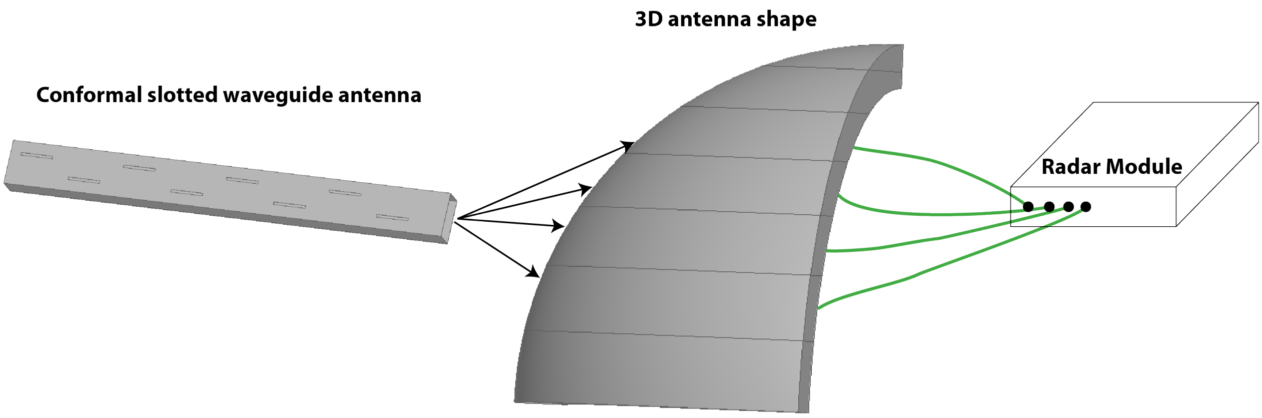
WP11: 3D Antenna Analysis: Design	
RESPONSIBLE: Y. QUÉRÉ (LAB-STICC/UBO) CONTRIBUTORS: LAB-STICC/UBO, CRANFIELD AND THALES	**Start dates:** t0 **End date:** t0+12

WP2 and WP3 will analyze the performance of the 3D monopulse and of the multi beam techniques using ideal antenna elements and without considering the complexity of the feeding network and the technology. The criteria against which performance is assessed will be agreed with Thales at the beginning of the work package.

Objectives **– In parallel with WP2 and WP3, this work package will analyze and design 3D antenna configurations. The feeding network complexity and the technological feasibility will be discussed. We will focus also on the possibility to mix several antennas within the same shaped surface and the feasibility to use the same antenna for the different functions. An antenna prototype will be design for the WP12. This prototype will be a 3D slotted waveguide antenna.**

WP12: 3D Antenna Analysis: Fabrication & Test	
RESPONSIBLE: Y. QUÉRÉ (LAB-STICC/UBO) CONTRIBUTORS: LAB-STICC/UBO, THALES AND CRANFIELD	**Start dates:** t0+12 **End date:** t0+24

Objectives **– Using the results of WP11, an antenna prototype will be fabricated and tested. Interesting results from COBRA project indicate that 3D metal printing could be a great candidate for the fabrication. Radiation patterns will be measured in several scan angle configurations.**



1.1.6.3 WP2 3D Monopulse Analysis (Lab-STICC/UBO)

WP2: 3D Monopulse Analysis	
RESPONSIBLE: Y. QUERE (LAB-STICC/UBO) CONTRIBUTORS: LAB-STICC/UBO AND CRANFIELD	**Start dates:** t0 **End date:** t0+6

The monopulse beams will be controlled purely electronically and a much higher precision and robustness can be achieved as a result of the 3D shape. In addition to this, the properties of the monopulse beams can be diversified during a mission and as a function of the specific task. The criteria against which performance will be assessed will be agreed with Thales

Objectives **- investigate how the monopulse properties, robustness, coverage, precision, and resulting monopulse performance vary as a function of the beam steering angles when the 3D antenna is used, and carry out a comparison with existing techniques.**

1.1.6.4 WP3 Multiple Beam Analysis (Cranfield)

WP3: Multiple Beam Analysis	
RESPONSIBLE: A. BALLERI (CRANFIELD) CONTRIBUTORS: CRANFIELD, LAB-STICC/UBO AND THALES	**Start dates:** t0+3 **End date:** t0+12

By using the 3D antenna as a co-located MIMO system (or virtual array) and by using suitable orthogonal waveforms the novel 3D seeker will be capable of generating multiple simultaneous beams. This can potentially allow the seeker to operate in a multifunction mode. The criteria against wich performance will be assessed will be agreed with Thales ath the beginning of the WP.

Objectives **- Design novel waveforms with suitable cross-corelation properties to allow orthogonality and show that simultaneous target detection over multiple beams is feasible. The developed waveforms performance will be experimentally assessed with a basic prototype (Fig. 5).**

Basic Prototype **- a virtual platform in the modulation band to test the new functionalities based on separated antennas**

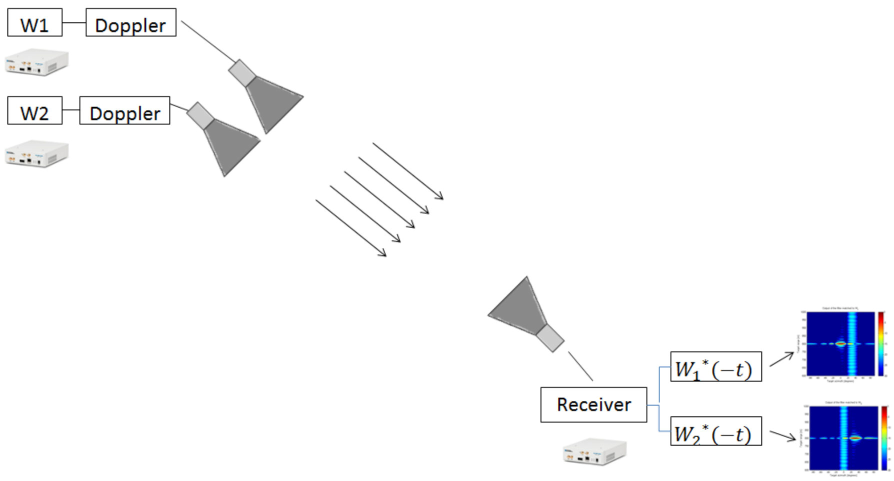


Figure 5: The Year 1 Prototype using separated antenna to test 3D monopulse and Multi-beam techniques

1.1.6.5 WP4 System Exploitation (Cranfield)

WP4: System Exploitation	
RESPONSIBLE: A. BALLERI (CRANFIELD) CONTRIBUTORS: CRANFIELD, THALES AND LAB-STICC/UBO	**Start dates:** t0+12 **End date:** t0+24

WP41: Multi RF-Sensors (T0+12 to T0+18)

The use of multiple beams will allow the seeker to carry out multiple functions simultaneously. In particular, the increased angular coverage will allow the transmission of a dedicated beam in the direction of the ground. This offers the opportunity to use the seeker as a radar altimeter when necessary. The criteria against wich performance will be assessed will be agreed with Thalesat the beginning of the WP.

Objectives - **Assess the properties of the 3D antenna beam at very high azimuthal/elevation angles when they are used in combination with waveform diversity. Apply these characteristics in combination to those of an altimeter and demonstrate the altimeter performance under these configurations.**

WP42: Extended Modes (T0+15 to T0+24)

The use of dedicated multiple beams will allow an increased dwell time on the targets which will result in the collection of additional information at a higher resolution, an increased prosecution time over a wider angular window, and ultimately will provide better classification performance. The criteria against wich performance will be assessed will be agreed with Thales at the beginning of the work package.

Objectives - **Take target measurements using the gain characteristics generated by the novel 3D antennas in the project PYRANA and assess and analyse classification performance as a function of dwell time and target aspect angle. These properties will also offer improved robustness against jammers.**

Prototype **- a virtual platform in the modulation band to test the new functionalities including radiating pattern of antennas based on EM simulations or measurements (Figure 6)**

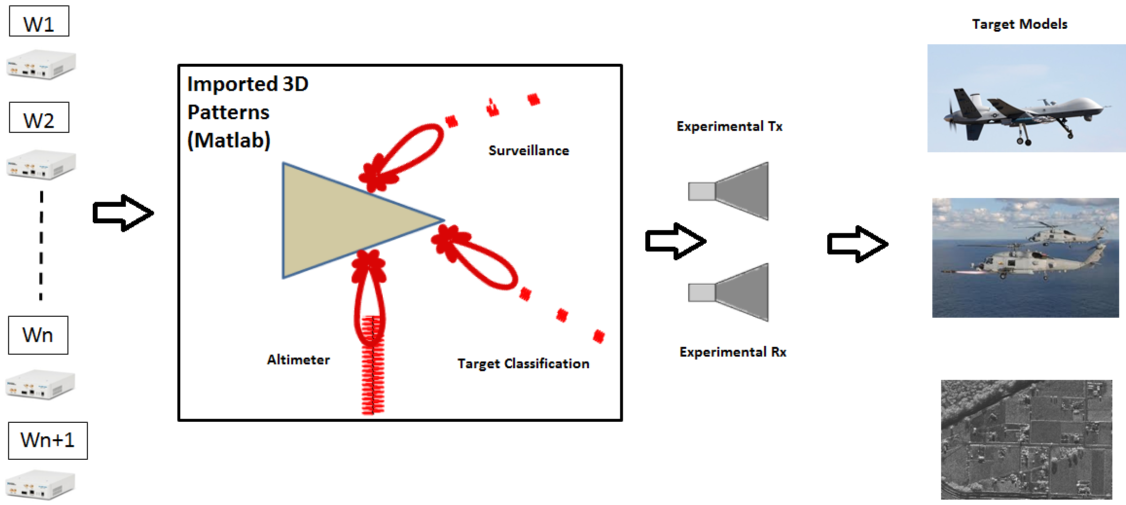


Figure 6: The year 2 prototype using 3D optimized antenna to test 3D monopulse, Multi-beam, classification and altimetry

1.1.6.6 WP5 Dissemination (Lab-STICC/UBO)

WP51: Dissemination	
RESPONSIBLE: Y. QUERE (LAB-STICC/UBO) CONTRIBUTORS: LAB-STICC/UBO, THALES AND CRANFIELD	**Start dates:** t0+6 **End date:** t0+12
OBJECTIVES: ***To analyze the strategy of communications, publications and patents.*** **TASKS:** • **MCM-ITP Workshops–**All partners have to prepare a presentation. • **Publications and Patents (t0+6 to t0+12) –**The strategy of publication or patents will be discussed every monthly meeting.	

WP52: Dissemination	
RESPONSIBLE: Y. QUERE (LAB-STICC/UBO) CONTRIBUTORS: LAB-STICC/UBO, THALES AND CRANFIELD	**Start dates:** t0+12 **End date:** t0+24
OBJECTIVES: ***To analyze the strategy of communications, publications and patents.*** **TASKS:** • **MCM-ITP Workshops–**All partners have to prepare a presentation. • **Publications and Patents (t0+12 to t0+24) –**The strategy of publication or patents will be discussed every monthly meeting.	

1.1.6.7 WP6 **System Level Assessment:** (THALES)

WP6: System Level Assessment	
RESPONSIBLE: THALES CONTRIBUTORS: LAB-STICC/UBOAND CRANFIELD	**Start dates:** t0+22 **End date:** t0+24
OBJECTIVES: ***To assess the achieved maturity and refine the exploitation path of this concept.*** **TASKS:** • **Assessment of improvements provided by this concept and translated in system benefits with the implication of MBDA** • **Assessment of future accessible improvements as well as current limitations and constraints of this concept and its related technologies applied to the harsh environment of the missile.**. • **Refine roadmap of future research to be carried.**	

For the application to RF Seekers, LIzARd research project contributes to 50% in the maturation step from TRL3 to TRL4. The demonstration aims to reach TRL4 for the antenna concept and its radiation properties.

1.1.7 Conference demonstration

The prototypes realized in WP11, WP3 and WP42 will be used as demonstrators. These prototypes will be available for workshops, roadshows and ITP conference.

Videos will be also done to illustrate the technological processes and the technical results of each workpackages.

1.1.8 Programmatic Risks and Opportunities

Risk or Opportunity	Probability	Potential Impact	Action to Mitigate / Benefit
Exploitation at system level of disruptive methods for accurate angular measurements	average	Inadequate characterisation	Close work with Thales on the criteria definition with early implication of MBDA
Possible Delay in WP3	average	Delay of WP4	WP4 can use simulated results instead of measurements
Availabity of real target measurements on time	low	Delay of WP6	Use target models in WP6

1.1.9 Partners and Organisation

Team member	**E-mail**	**Organisation, address, phone**	**Experience**
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Vincent CASTEL	vincent.castel@telecom-bretagne.eu	UBO / Lab-STICC 655 Avenue du Technopole, 29200 Plouzané, FRANCE	Technologies (Materials, Selective Metallization, Component Integration)
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1.1.10 Deliverables and Milestone Plan

Milestone Number	Description	Delivery Date	ITP Category
1	Year 1 Interim Report	T0+6	B
2	Year 1 Final Report	T0+12	B
3	Year 2 Interim Report	T0+18	B
4	Year 2 Final Report	T0+24	B

Table 1.1-1 Milestone plan

1.1.11 Background Intellectual Property (IP)

List the background the background intellectual property that is expected to be contributed by each organization involved in the project.

1.1.12 References

[1] Conformal Array Antenna Theory and Design, Lars Josefsson, Patrik Persson. Allard

[2] Guifu Zhang; Karimkashi, S.; Lei Lei; Kelley, R.; Meier, J.; Palmer, R.; Futon, C.; Doviak, R.J.; Zahrai, A.; Zrnic, D.S.; Al-Rashid, Y., "A cylindrical polarimetric phased array radar concept — A path to multi-mission capability," *Phased Array Systems & Technology, 2013 IEEE International Symposium on* , vol., no., pp.481,484, 15-18 Oct. 2013.

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[4] Hizal, A., "Wide angle scanning conformal phased array on a spherical surface," *Phased Array Systems & Technology, 2013 IEEE International Symposium on*, vol., no., pp.259, 266, 15-18 Oct. 2013.

[5] MCM ITP PYRANA and COBRA projects

[6] ANR ATOMIQ project

[7] ANR ASTRID COCORICO project

[8] Lilin Guo; Hai Deng; Himed, B.; Tan Ma; Zhe Geng, "Waveform Optimization for Transmit Beamforming With MIMO Radar Antenna Arrays," Antennas and Propagation, IEEE Transactions on, vol.63, no.2, pp.543,552, Feb. 2015.

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