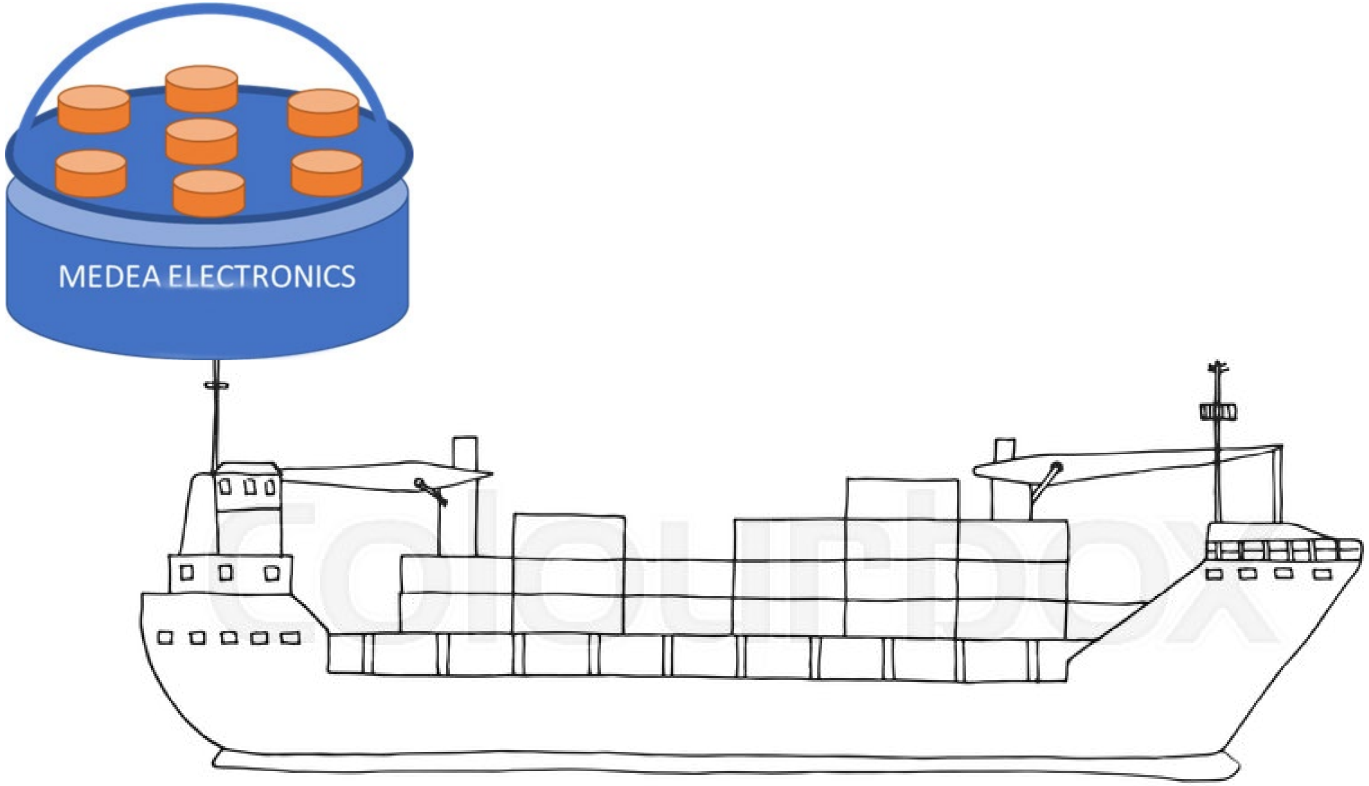
MEDEA

MultifrEquency Digital BEamforming Antenna

NAVISP-EL2-0101
ESA Contract No. 4000137690/22/NL/ND



FINAL PRESENTATION
30/01/2024

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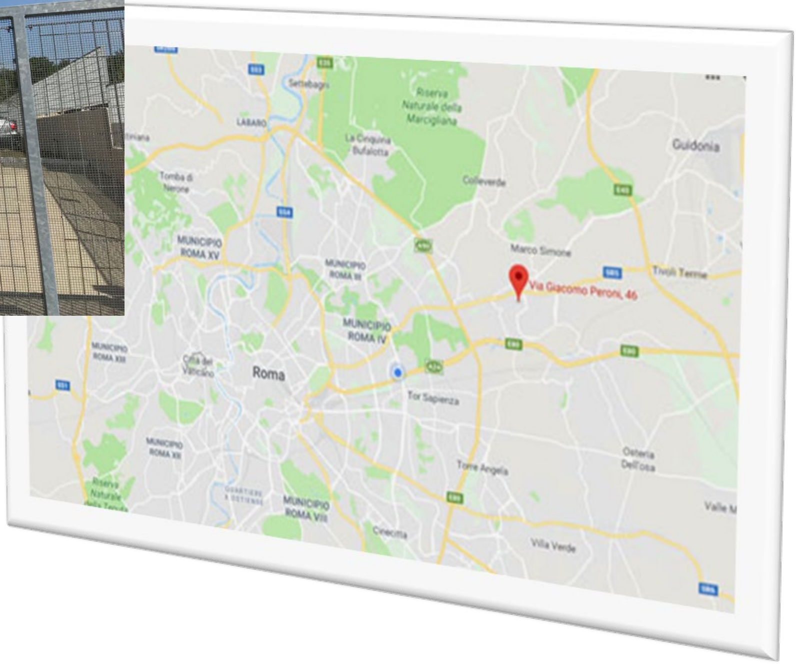
ST4I Company - 1

ST4I - Space Technologies for Innovation is an Italian SME based in Rome – Tecnopolo Area



ST4I Company - 2

ST4I was founded in September 2018. ISO9001:2015 certified

ST4I interest is in technological opportunities characterized by low TRL recommending innovation substantiated by credible solutions.

Products target: design and development of on-board and on-ground components, equipment and S/S. ST4I role is addressed to conceptual, architectural design, tradeoffs and detailed design as well as in supporting prototyping and AIT, including qualification aspects. Point of excellence in ST4I is the aptitude to propose innovative RF architectures involving conducted and radiating structures as well as the extreme sophistication and quality of the associated electromagnetic analyses and optimization. Strong background is present.

MEDEA Program

Kick-off Meeting: 02.05.2022
Final Review: 03.11-2023

Electronic antenna terminal for EGNSS applications focused on maritime utilization - Letter of Support from FUGRO

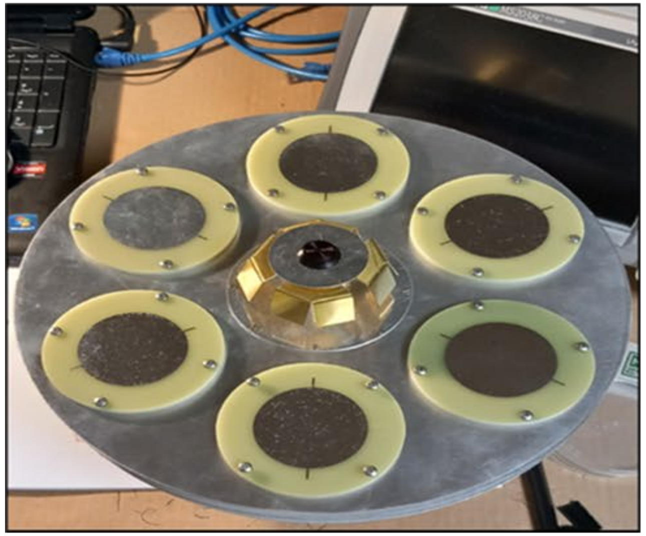
New generation GNSS antenna - Letter of Interest from TELESPAZIO

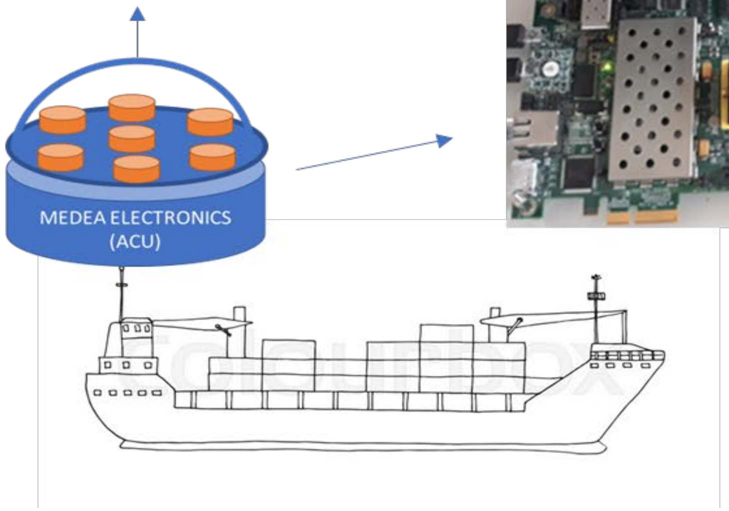
Program Objective Activities: unit system detailed design, algorithms verification through simulator, test results on demonstrators. To assess and approve system detailed design for implementation.

MEDEA

MEDEA PROJECT

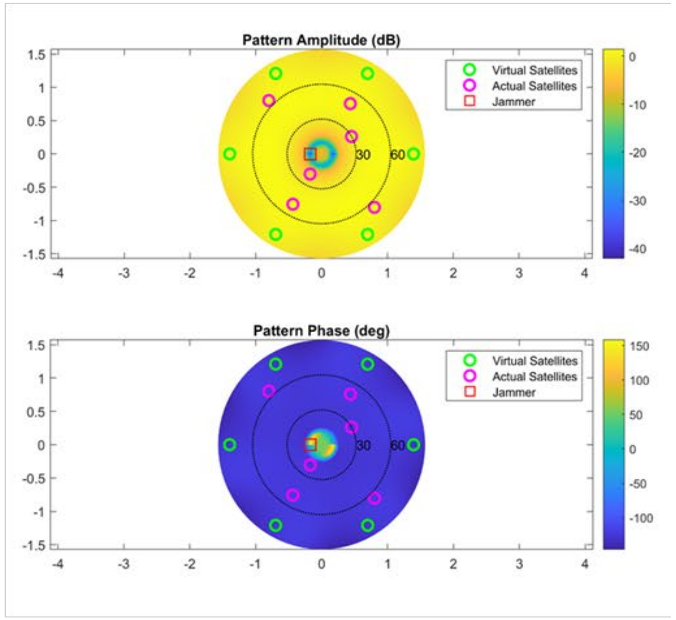
RADIATOR ARRAY





ANTENNA CONTROL UNIT DEMONSTRATOR

NEW BLIND INTERFERENCE MITIGATION ALGORITHMS



Abstract

- MEDEA project consists of the design of a EGNSS multifrequency/multi-radiators digital antenna

- It is currently capable to mitigate interfering signals by digital Beam Forming in L1/ E1 BW.

- MEDEA is not just an antenna but can be considered an “applique” that embeds several features and functions that improve the integrity of the receiver to which it is connected.

- MEDEA is conceived to be characterized by a high degree of flexibility and versatility so that it can be adapted to the needs of specific user and embed algorithms deigned from the customer.

- MEDEA full development design is composed of two phases, the first one here presented includes the development of critical items.

Introduction and Context

The enormous expansion the use of satellite positioning, navigation and timing in our daily activity, in professional and security applications leads to consider the development of EGNSS receivers and equipment with high level of quality, accuracy and outmost integrity. The MEDEA idea born from the needs and requirements identified in several application and service sectors that request antennas capable to provide higher integrity keeping performance.

A key element that nowadays affects the integrity is related to the EM interferences because the spectrum is becoming more and more congested and contested. Interferences can be unintentional or intentional and often are unexpected and unpredictable.

It is also worth to mention the spoofing subject characterized by different levels of complexity and it should be accounted in the design of high integrity applications.

There are several ways to protect the receiver PNT computation from interference, but the most important component relays for sure in the antenna.

Many antennas are available on the market with different levels of complexity and cost. The present ST4I design was able to conjugate high effectiveness versus interference, low cost and high integrability with existing receivers.

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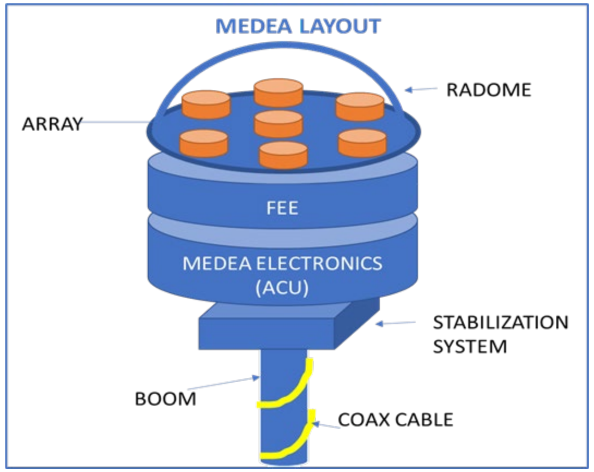
PRODUCT RATIONALE

MEDEA is a EGNSS multifrequency, array digital antenna totally covering the two BWs from 1150 up to 1290 MHz and 1539 to 1610 MHz, including INMARSAT BW.
Presently it is capable to mitigate interfering signals by digital beam forming in L1. Planned upgrading will be able to simultaneously mitigate two sub BWs as in L2/E6 BW.



It is not just an antenna but it embeds features and functions that improve the integrity of the receiver to which it is connected.

MEDEA is characterized by a high degree of flexibility and versatility so it can be adapted to the needs of specific user and it embeds algorithms designed from the customer. It can be configured as antenna or integrity terminal with different degrees of complexity.

Initially the maritime applications requirement coming from our sponsor FUGRO were used to tailor the design requirement. This implied one single interface to ship electronics and sealed packaging.

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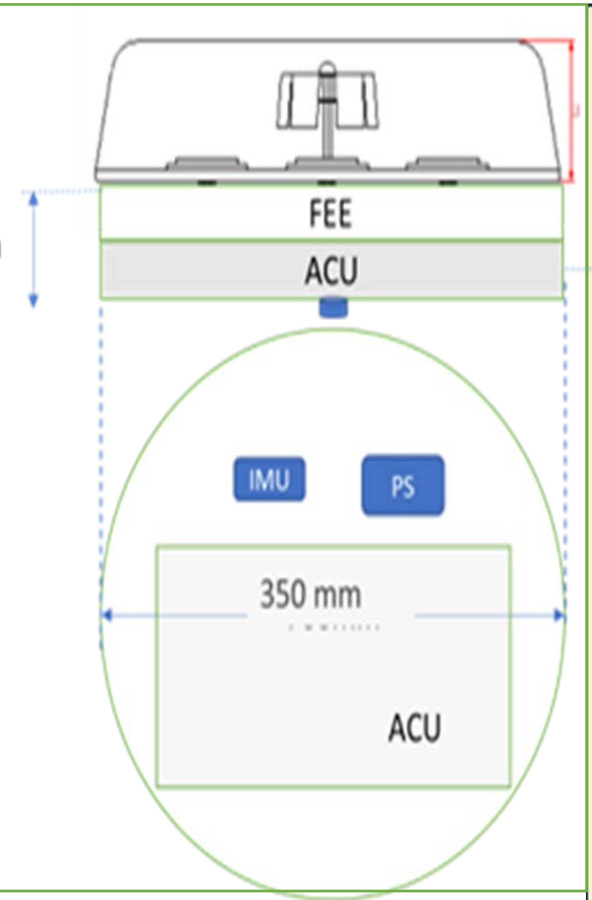
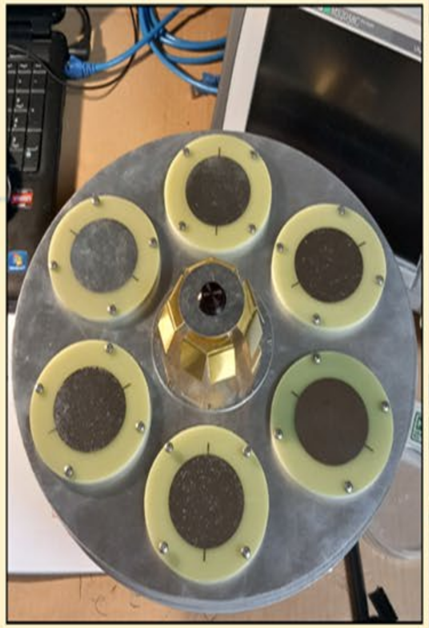
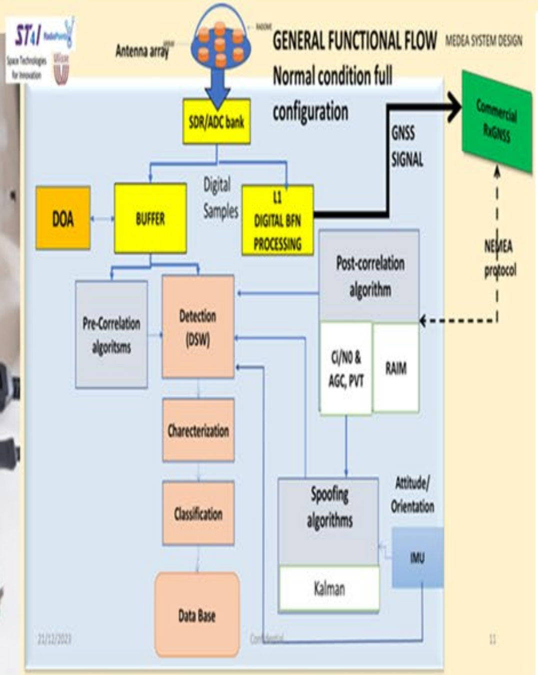
Product Description



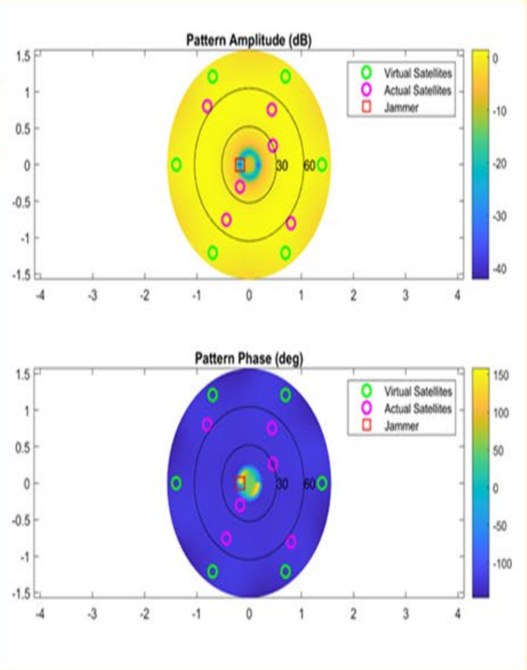


RADIATOR ARRAY

ANTENNA CONTROL UNIT DEMONSTRATOR



MEDEA OPERATIONS



NEW BLIND INTERFENCE MITIGATION ALGORITHMS

SYSTEM DESIGN: FUNCTIONAL BLOCK DIAGRAM

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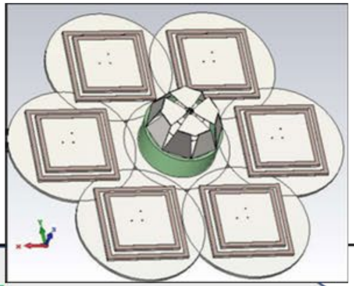

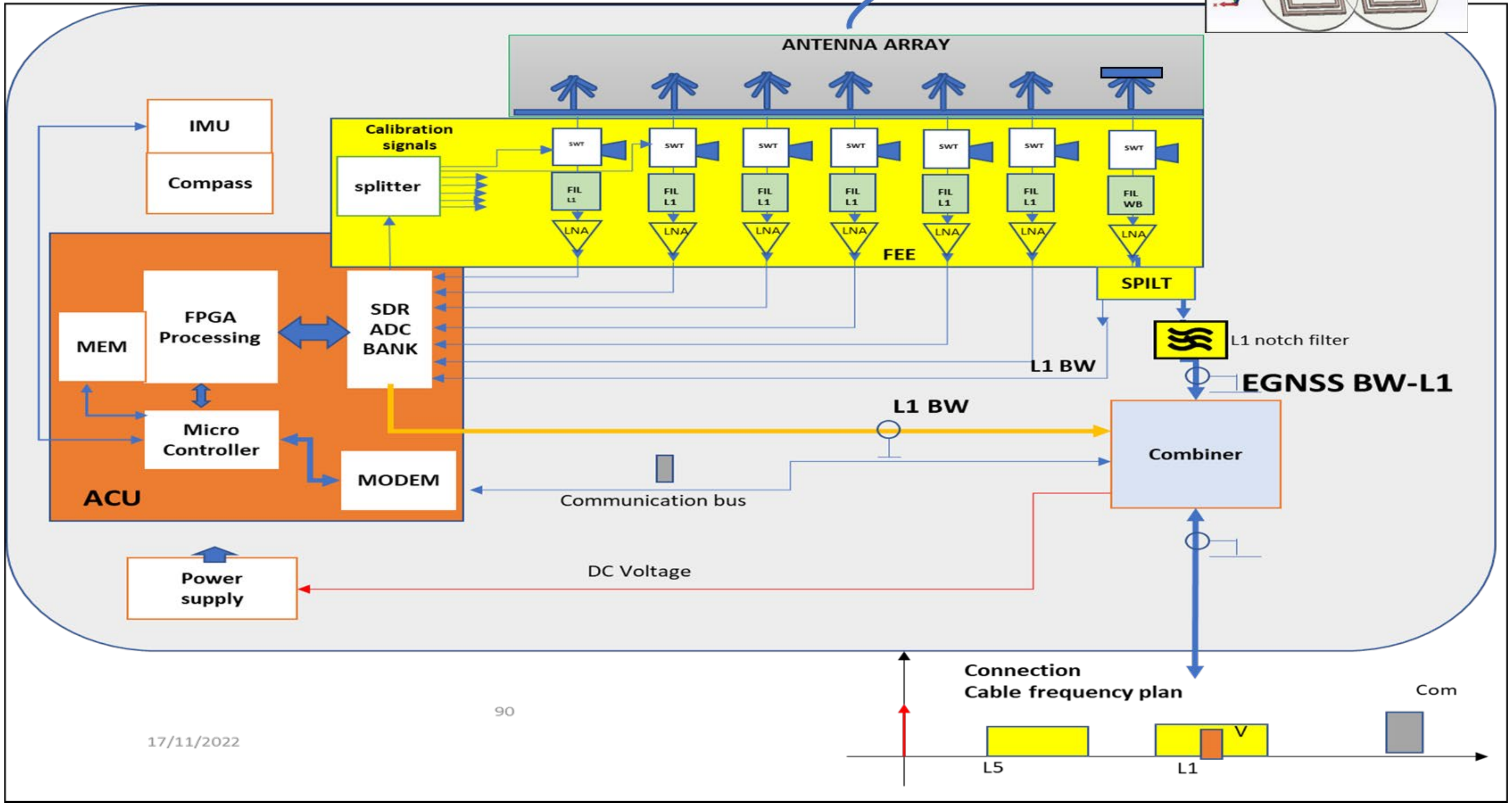

System design: MEDEA Decomposition

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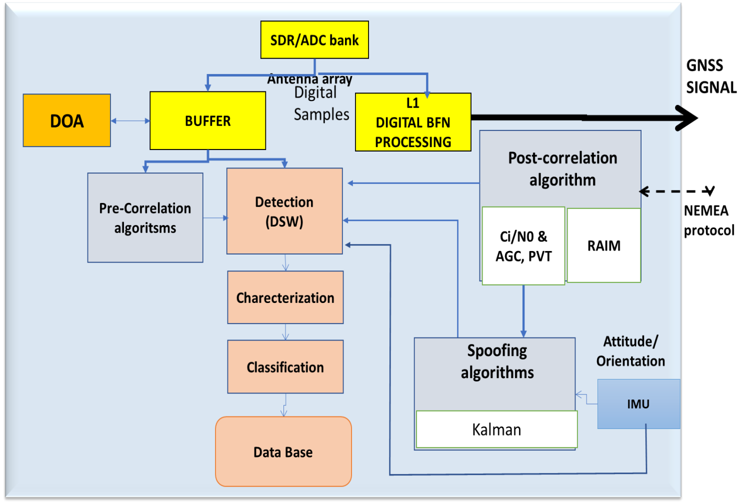
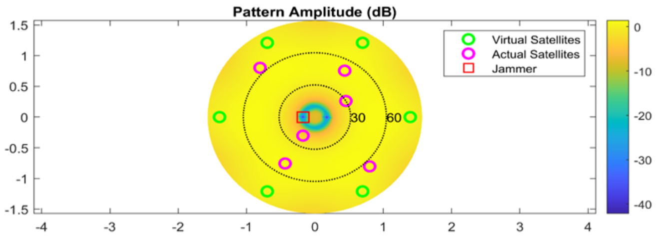
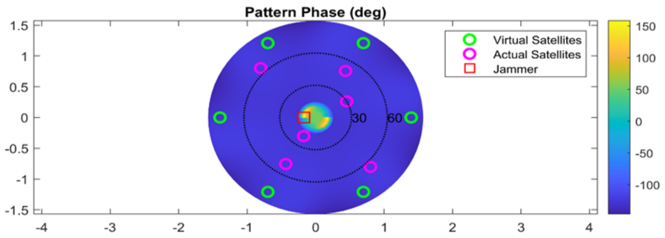
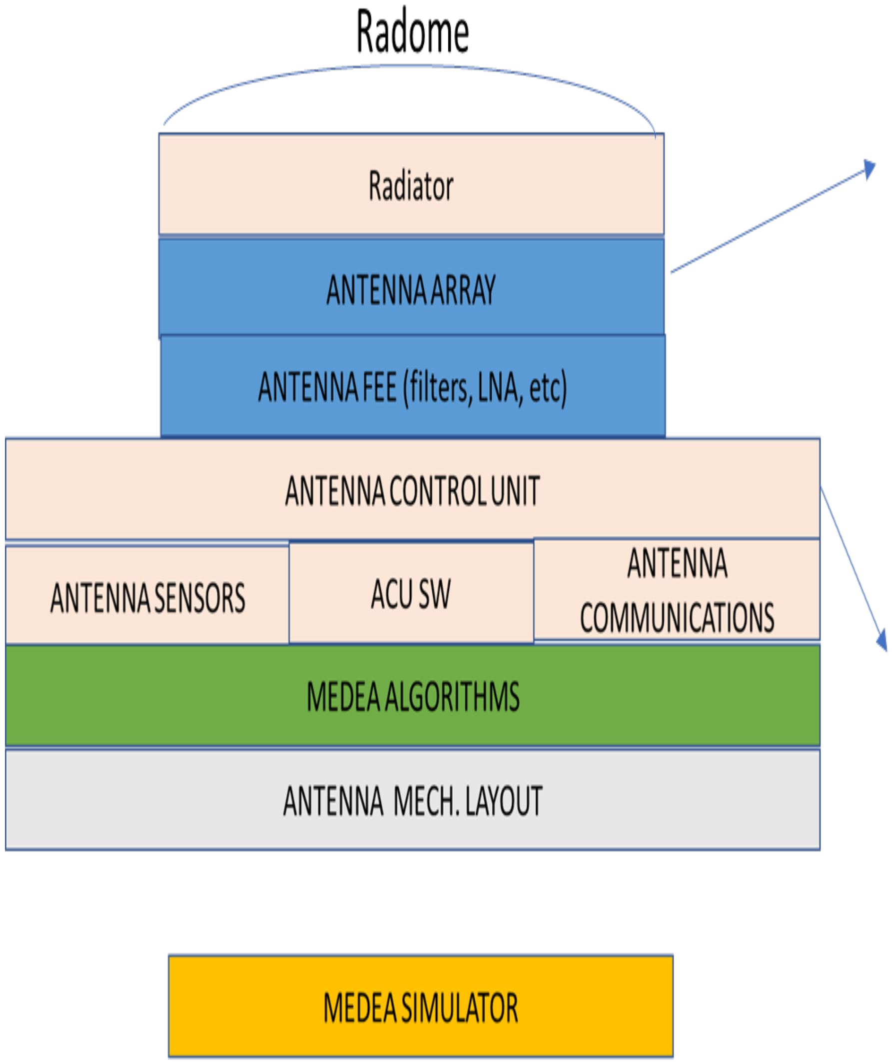
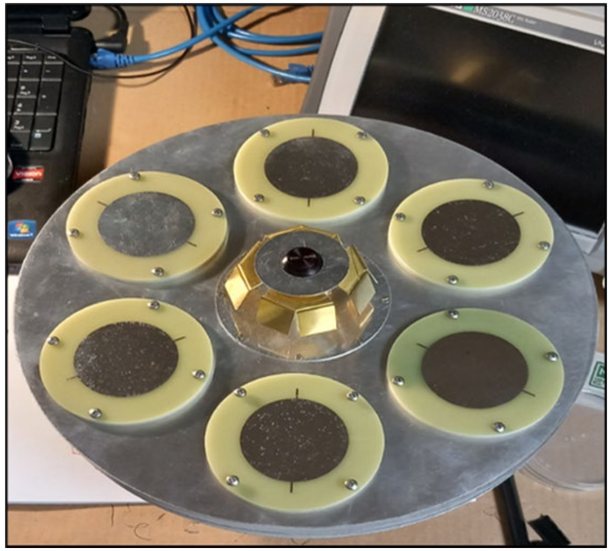






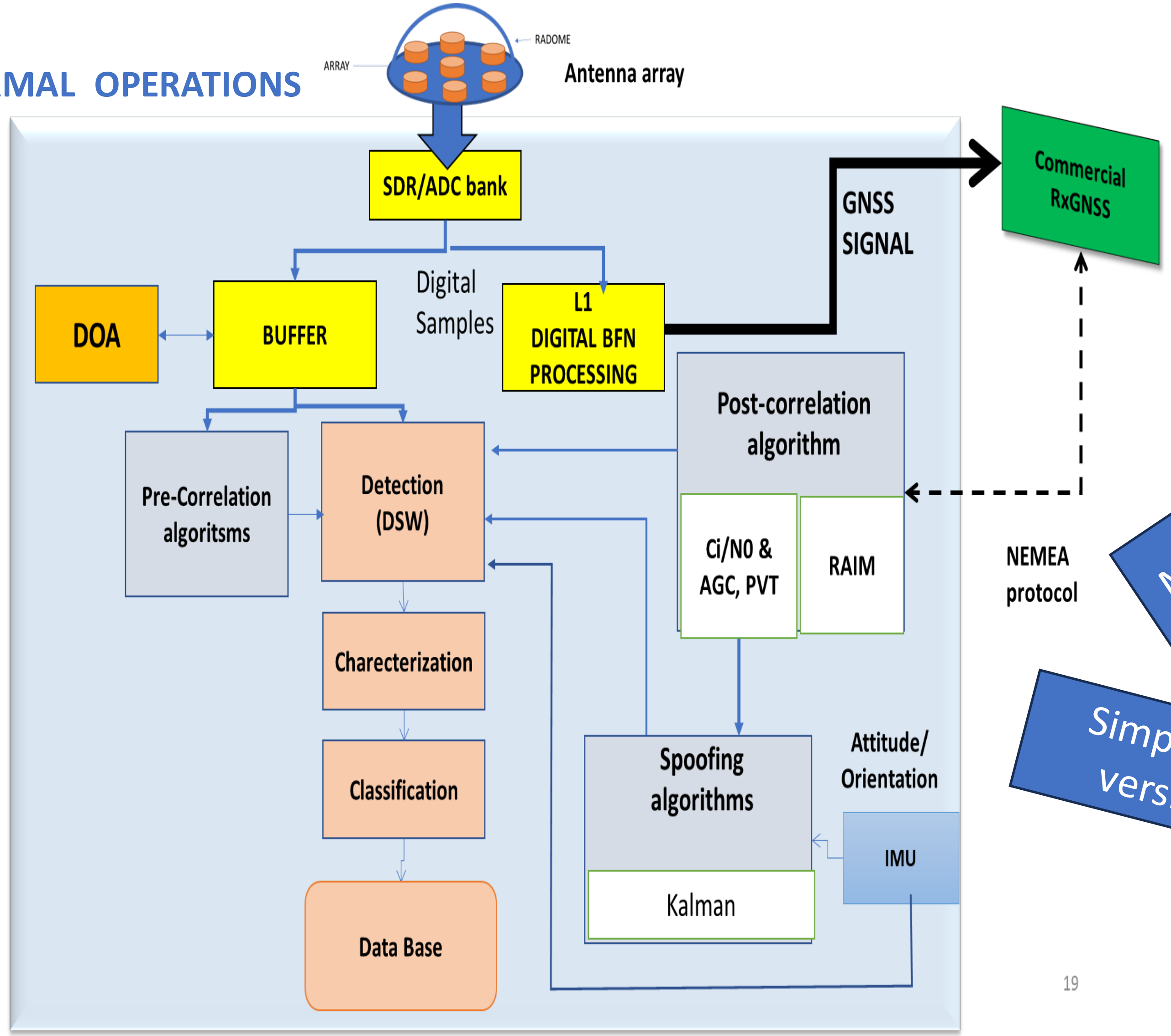


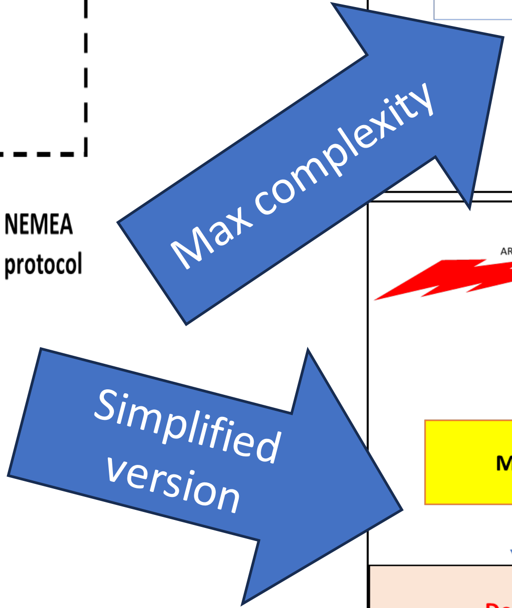


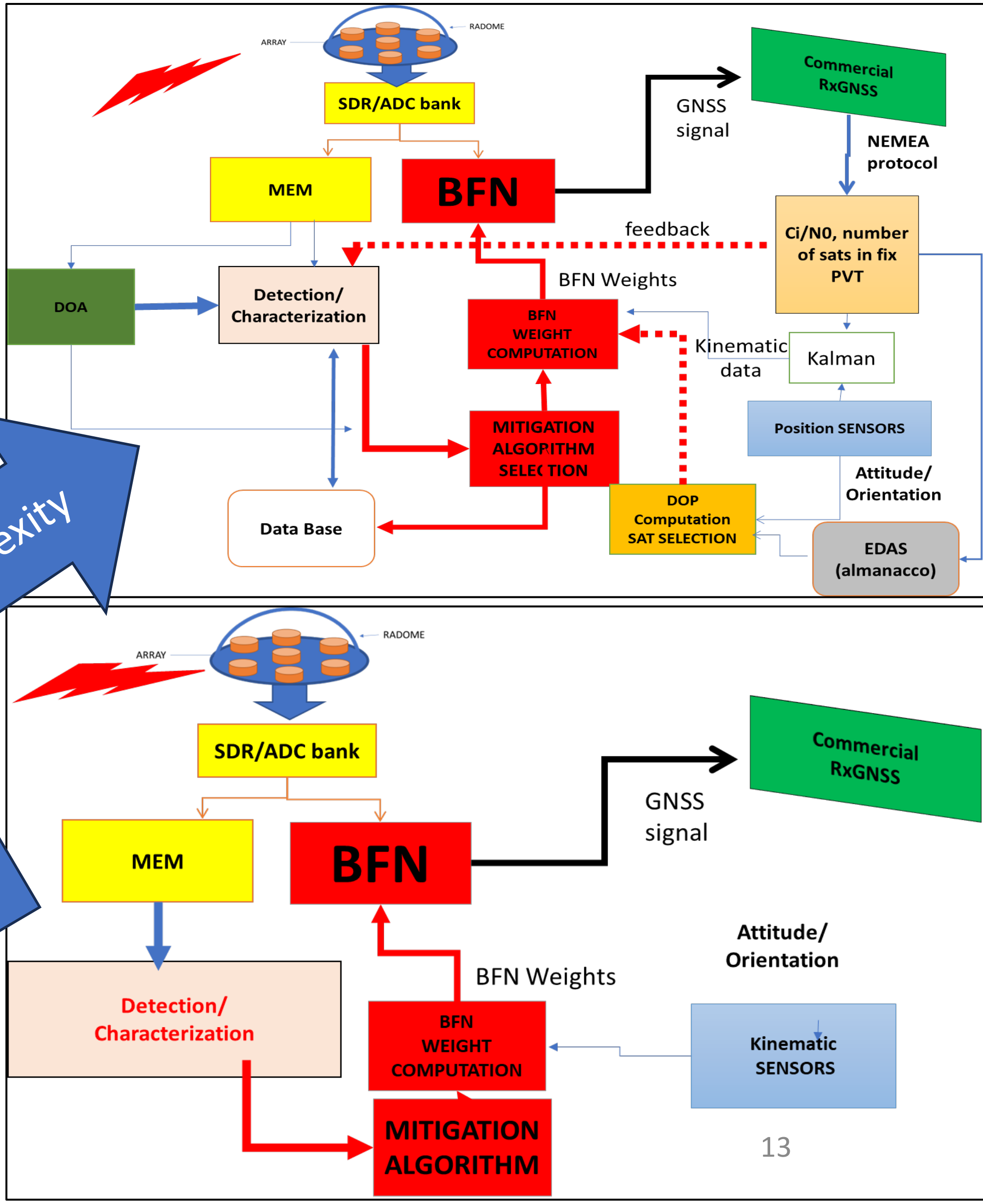
MEDEA OPERATIONS

UNDER ATTACK OPERATIONS

NORMAL OPERATIONS







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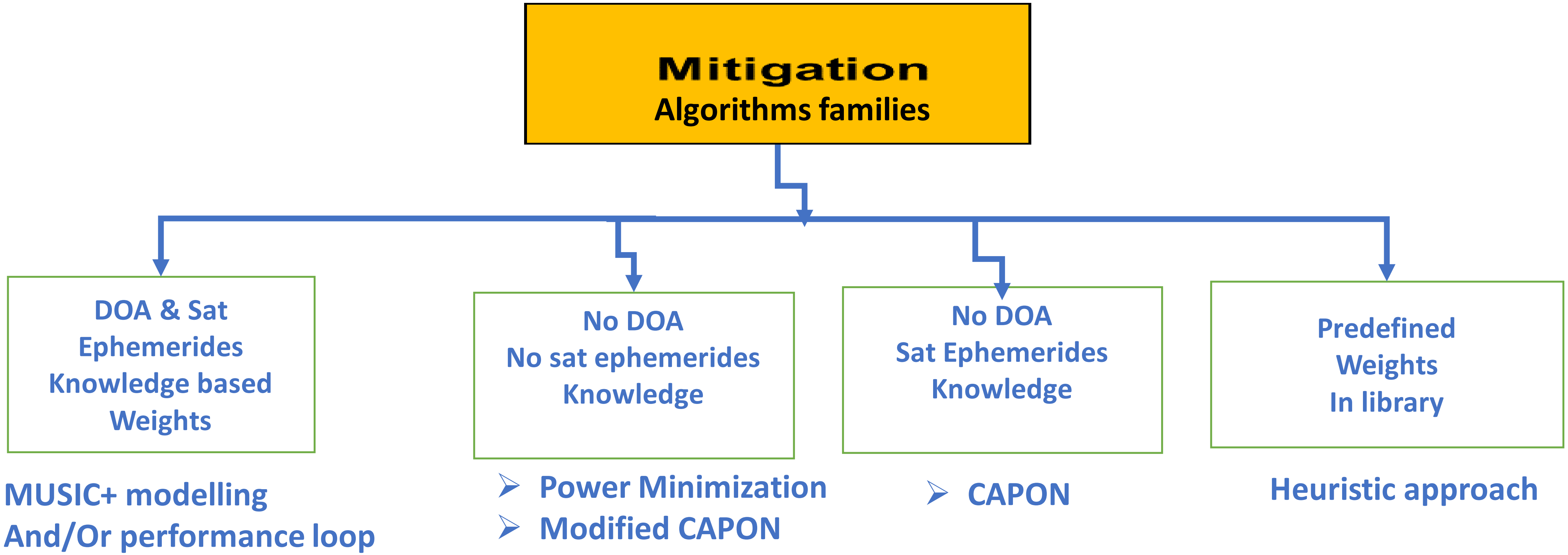
EXPLORATION OF ALL MITIGATION ALGORITHMS FAMILIES



MEDEA DESIGN CAN INCLUDE MORE MITIGATION ALGORITHMS THAT ARE SELECTED ACCORDING TO CUSTOMER NEEDS OR EFFECTIVENESS VS SPECIFIC ENVIROMENTS OR DISTURBS.

A KEY ELEMENT IN THE ALGORITHM SELECTION WAS ITS CAPABILITY TO MINIMZE THE IMPACTS VS THE POSITION ACCURACY

BEAMFORMING ALGORITHM SELECTION

Proposed beamforming algorithm: Hybrid CAPON/CAPON-2 solution

The CAPON algorithm can be implemented taking in input:
Option #1: the real directions of satellites (when we can assume that the attitude of the antenna platform is known with a good accuracy and also the knowledge of the DoA of satellites is good and updated constantly);
Option #2: FIXED steering vectors stored in the antenna system (in this case the algorithm becomes CAPON-2)

By comparing the performance of CAPON and CAPON-2 over several scenarios (i.e., position of the jammer), the average performance of CAPON-2 are better than CAPON. In particular:

- The amplitude gain of the resulting pattern is always larger than 22 dB which is better than the one achieved with CAPON
- The standard deviation of the phase of the resulting pattern is in most scenarios under 3 deg.

CAPON-2 guarantees:

- Robustness to different type of errors such as errors in the DoA estimation or knowledge of satellite directions/ship asset, errors in the calibration;
- Good «nulling» performance
- Controlled phase bias introduced by the beamformer

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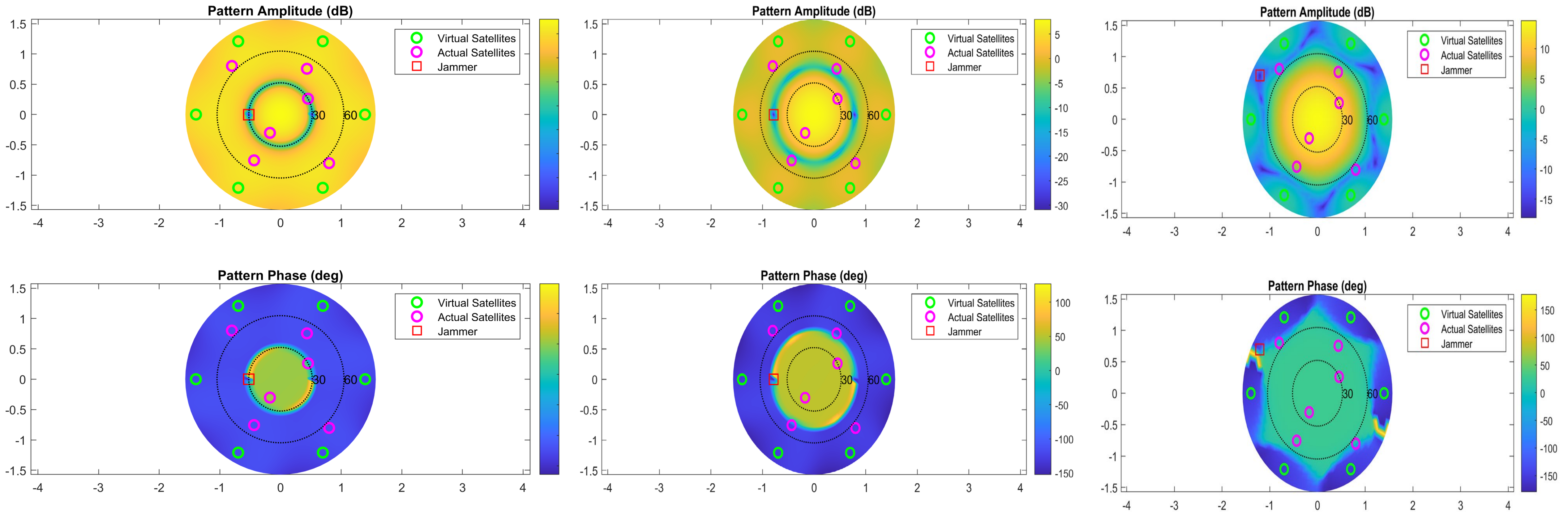
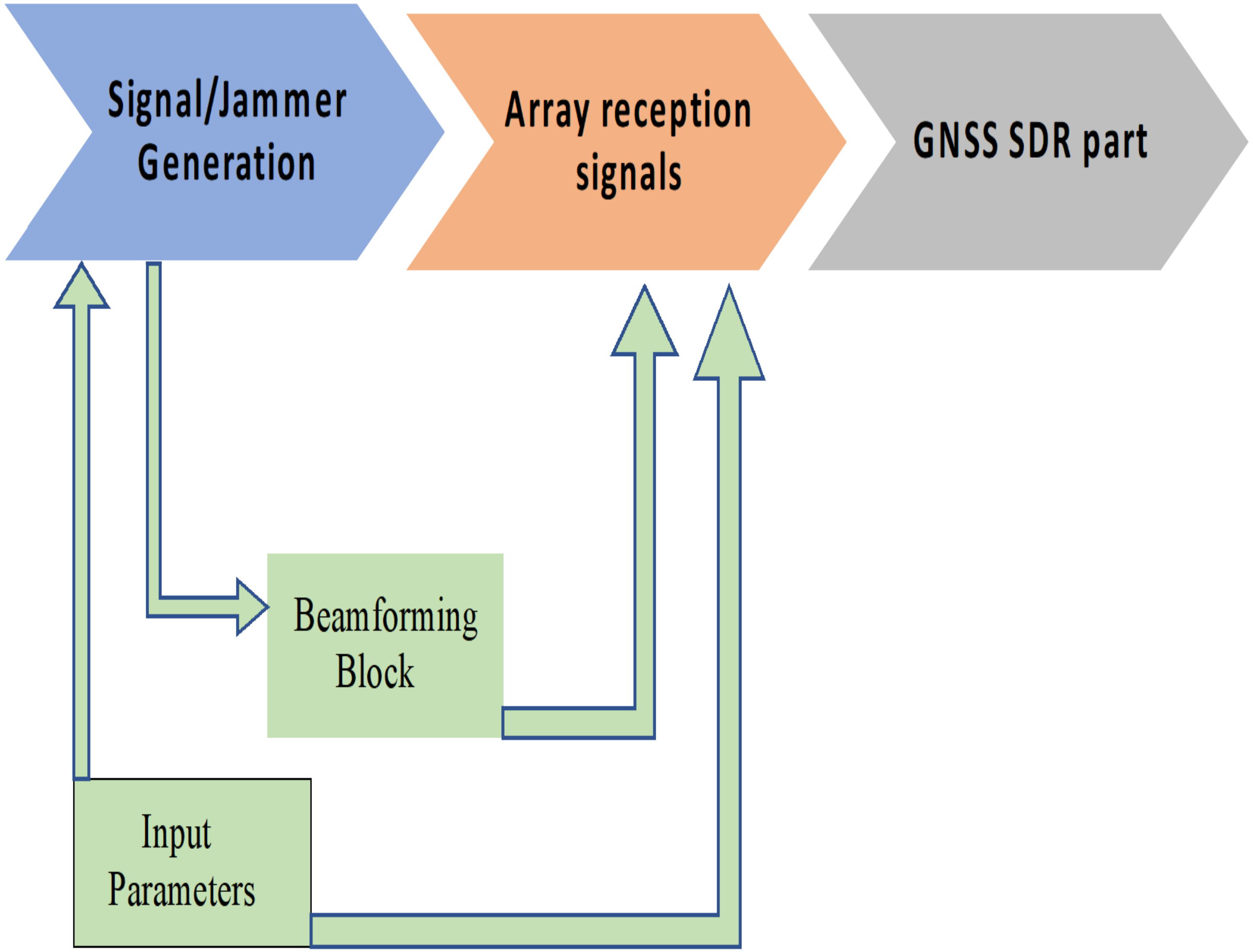
CAPON-2 ALGORITHM RESULTS



MEDEA DESIGN SUPPORTED BY SYSTEM SIMULATOR



Generate of the signals transmitted by Ns GNSS satellites

Generate signal generated by one jammer

Combine them using the real embedded antenna pattern

Generate beamforming weights and apply them

The combined received signal is sent in input to the KAI Borre SW GNSS receiver to check the performance in terms of acquired satellites and other outputs such as: PLL discriminator output, DLL discriminator output, cross-correlation output.

It could take as an input also real “acquired signals”

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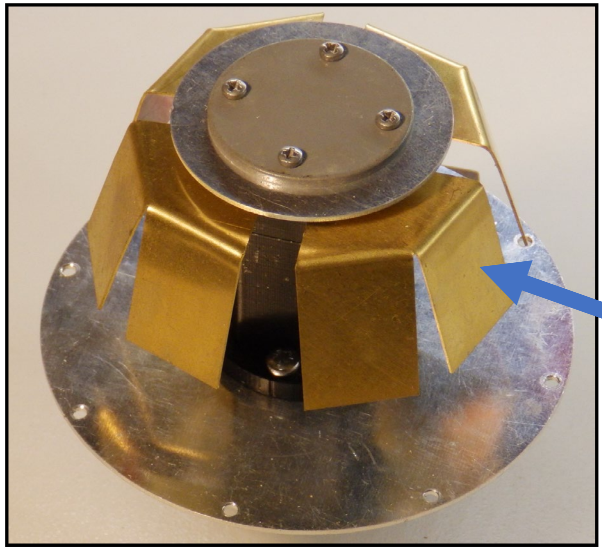
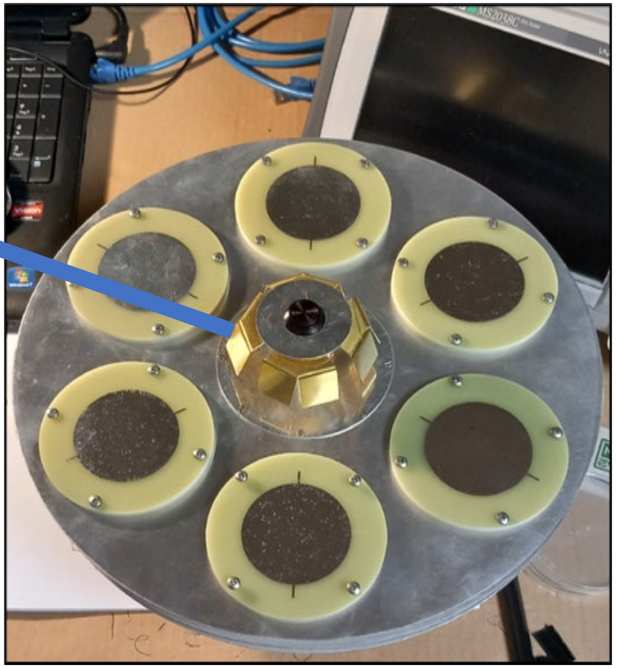
MEDEA Antenna Array Design





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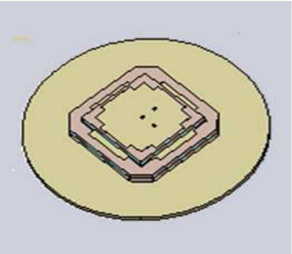
Antenna Array Design Process

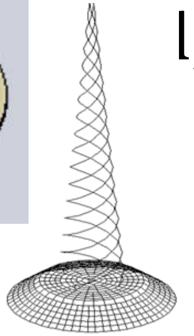
•***Development of the activity…***

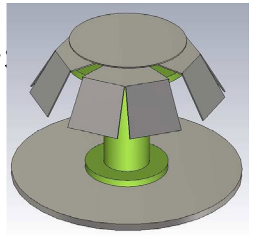
•Optimization of Antenna **central element:** critical requirements (coverage, XPD, GD…).

•Optimization of Antenna **Array**: critical requirements (coupling, flexibility for nulling…)

- Shape (planar, conformal), number of elements, centra l optimized)



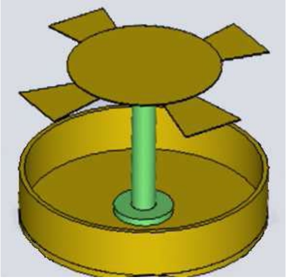




- Feeding architecture (multidirection, wide coverage…)

-***Baseline architecture:***

- 7 elements (flexibility for freedom degree)
- Planar (due to PCV stability between nav and nulling)
- Central element deeply optimized, outer ones dedicate to mitigation



- outer elements with low-profile, large coverage

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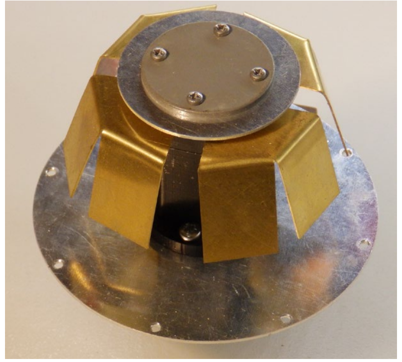
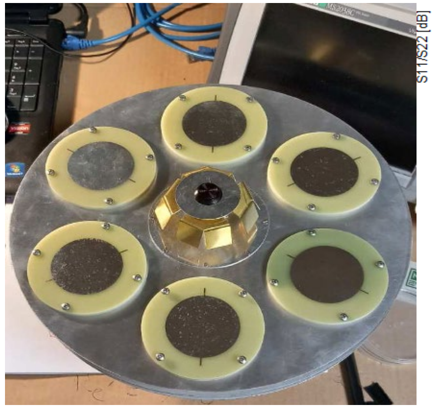
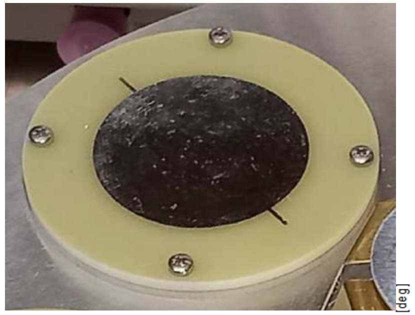
ANTENNA ARRAY RESULTS - 1

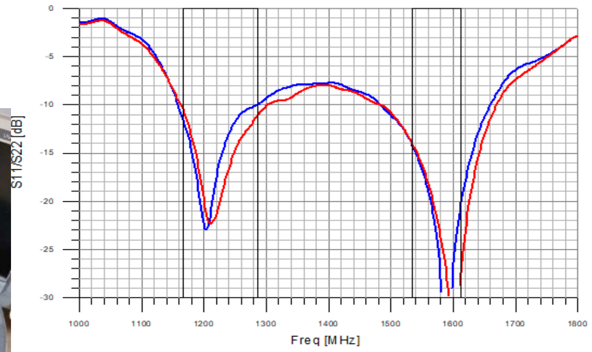
•***Results of breadboarding and complete antenna***

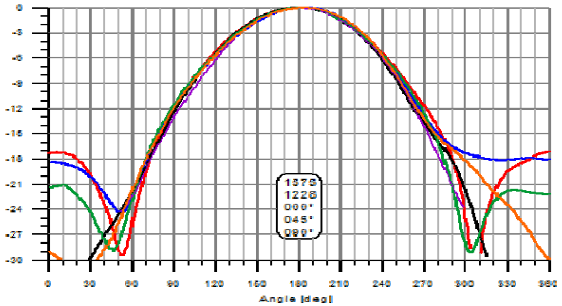
- Matching
- radiation patterns
- other parameters…
- Multilayer patch characterization

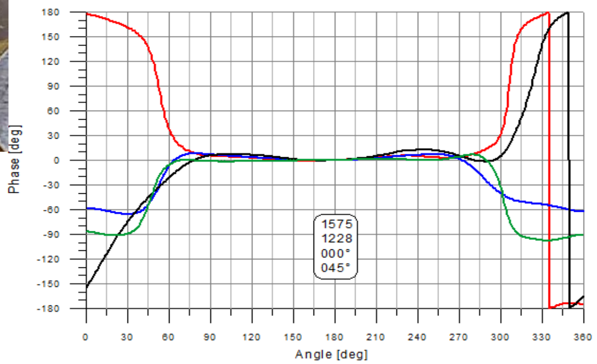












- Discussion of the polarization principles for the jamming mitigation.
- Analysis of technical solutions to allow limited complexity and cost…

Antenna Array Results - 2

•***Other parameters results…***

• Analysis of all the performance w.r.t. requirements values:

- Wide band behaviour of the central element (matching)
- coverage, with direct measurement of C/No for a breadboard
- Patterns, axial ratio, Group Delay, Phase Centre displacement, back radiation…

- Analysis of further development: wide band behaviour of central element and dual band optimization for side elements, with limited gemetrical details tuning.

ANTENNA CONTROL UNIT: SYSTEM ARCHITECTURE

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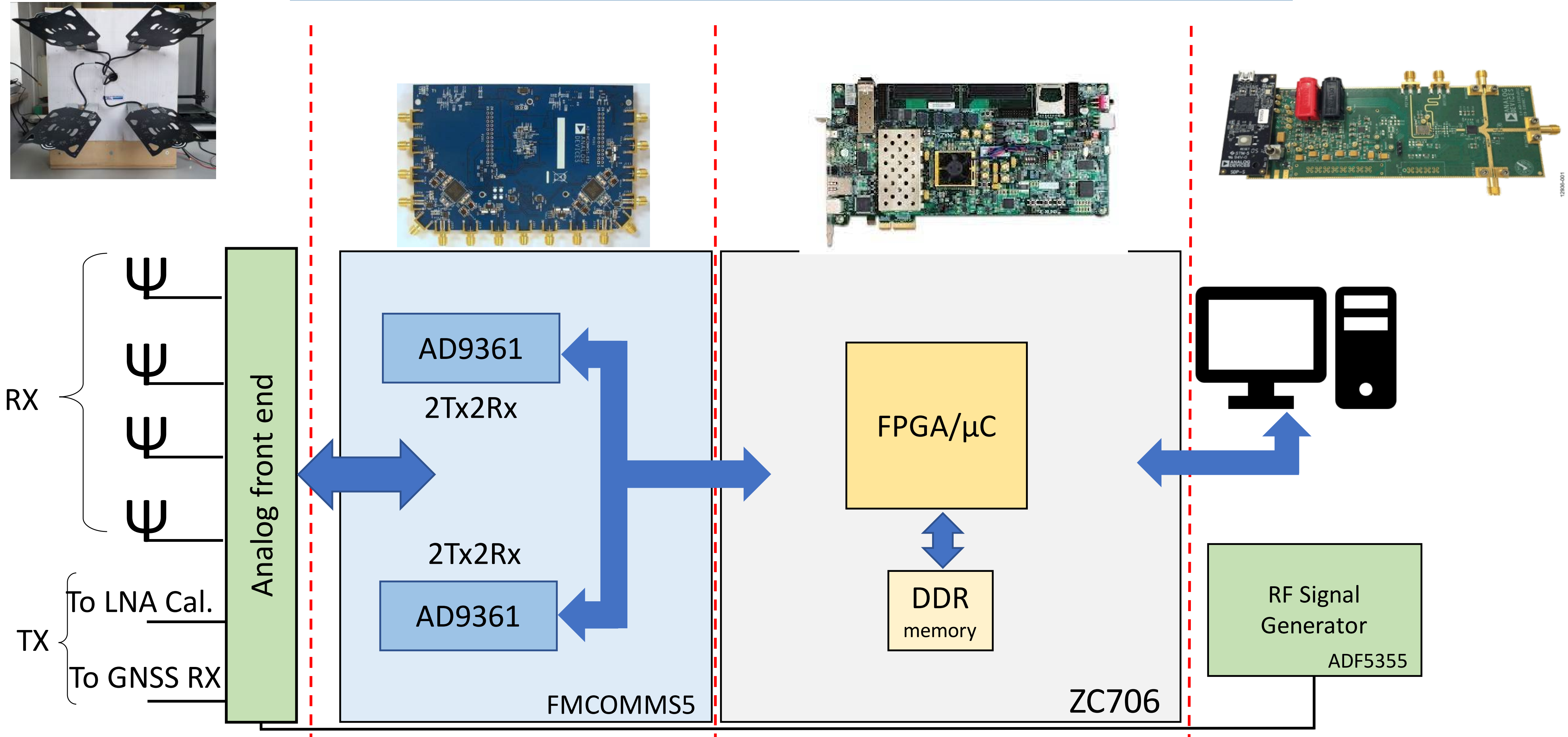

Antenna & analog front end

A/D & D/A conversion

FPGA & µ controller
DDR for signal storage

PC
Ethernet communication

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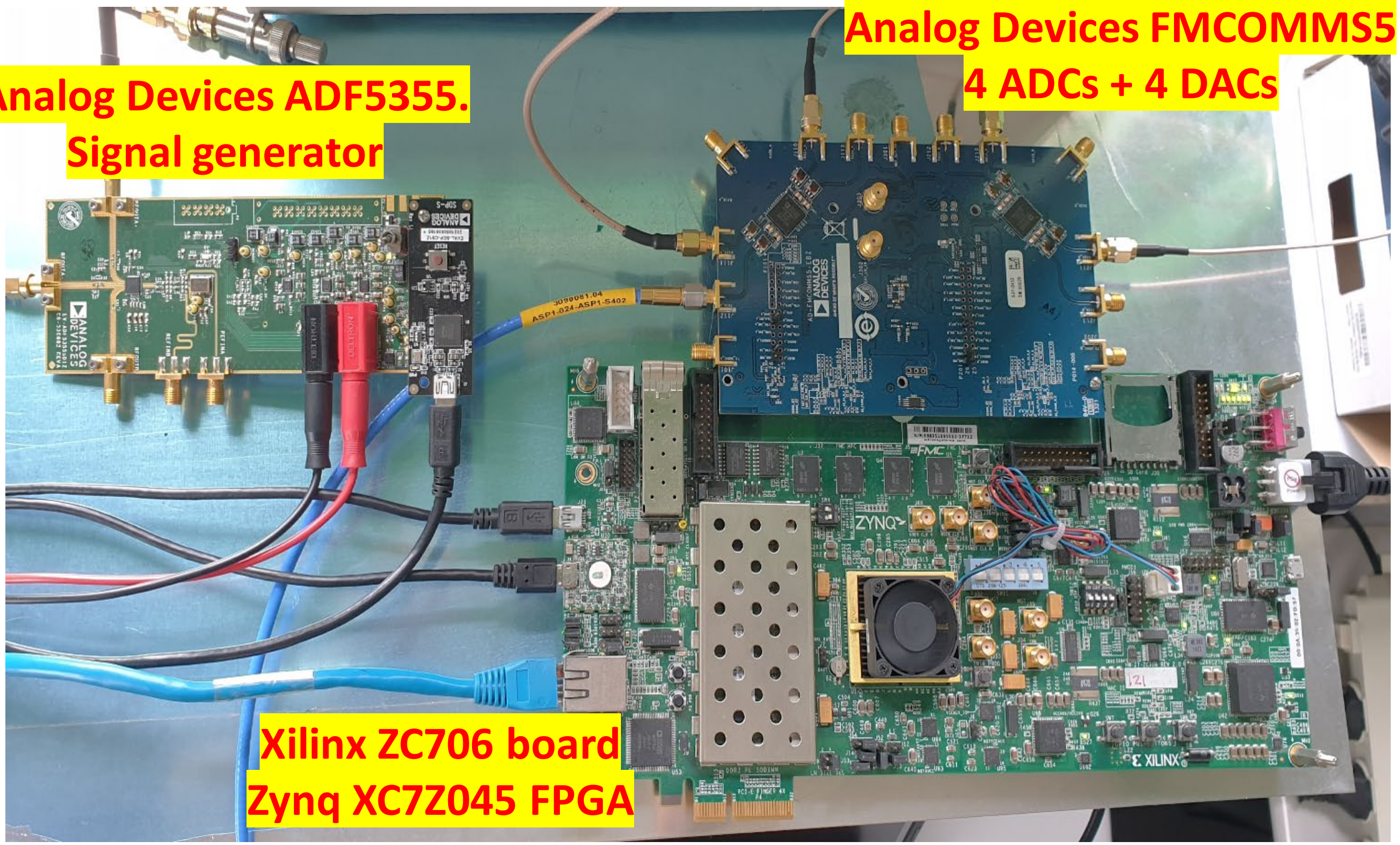
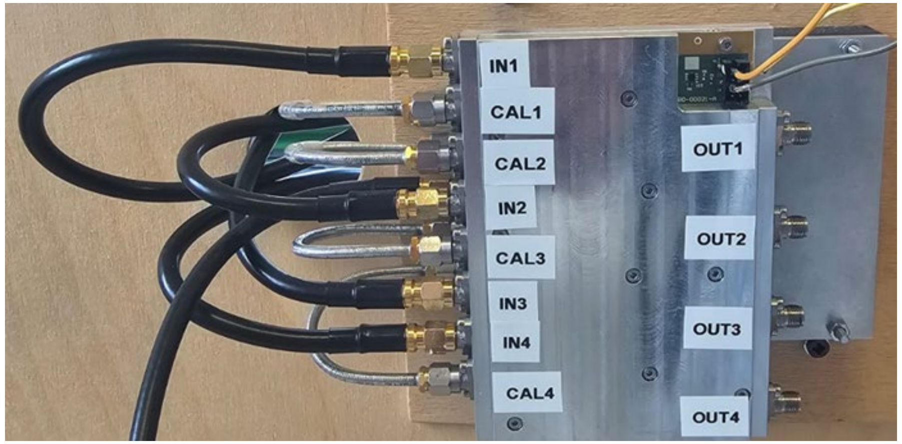
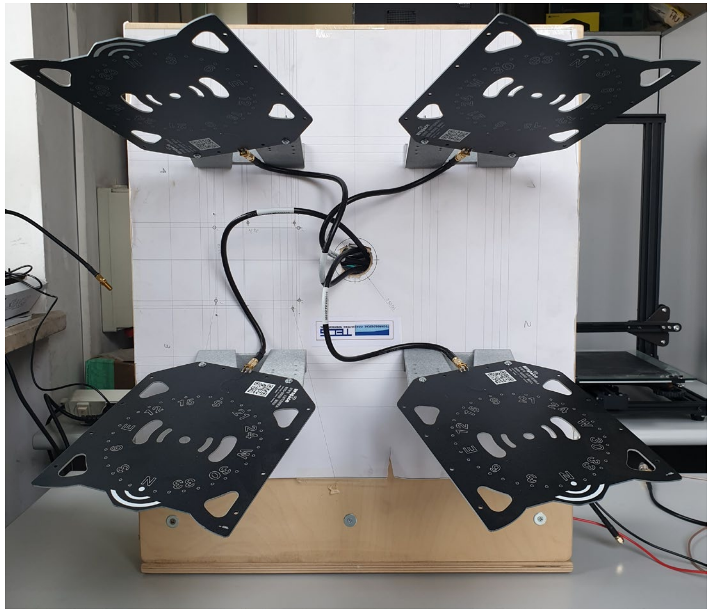
Antenna Control Unit: ACU Breadboard

The main subsystems composing the ACU breadboard are the listed in the following:

1. Xilinx Zynq-7000 SoC ZC706 Evaluation Kit (FPGA + Microprocessor)
2. AD-FMCOMMS5-EBZ evaluation board (Transceivers TX/RX)
3. ADF5355 Evaluation Board (Microwave Wideband Synthesizer with integrated VCO)
4. LNA + ANTENNAS gain is 34dB







ANTENNA CONTROL UNIT: BEAMFORMING & ANTI-JAMMING TEST

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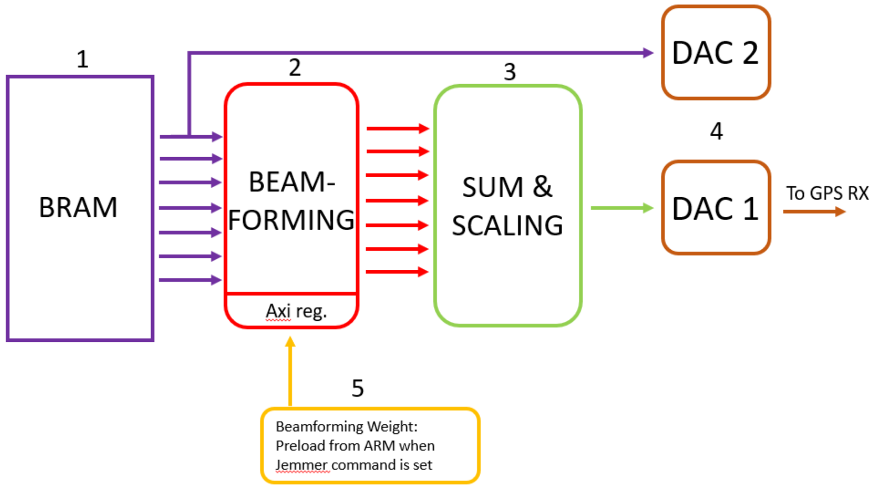
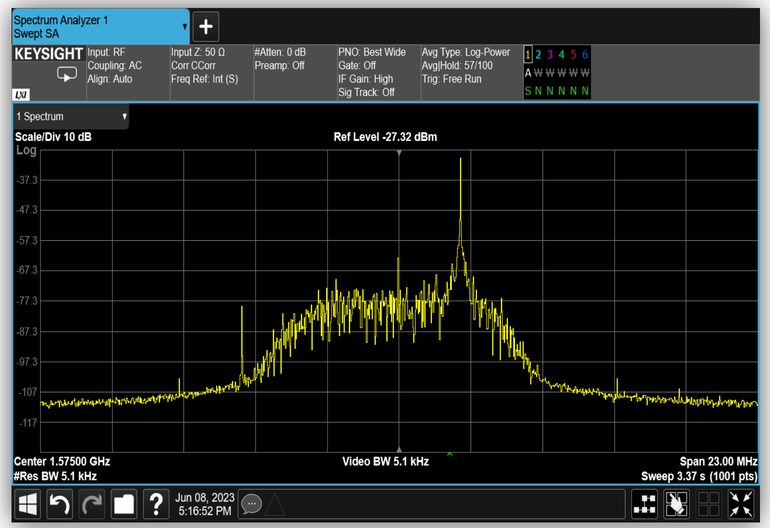
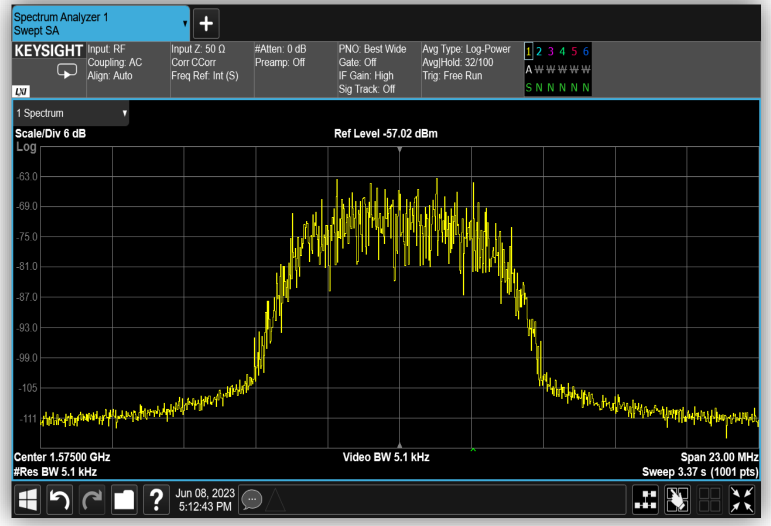
Goal: Demonstrate the correct functioning of the beamforming implementation and the algorithm for weight calculation.







Description

1. The signal provided as an example of 7 channels plus a jammer is stored in RAM and cyclically read to emulate the 7 channels.
2. Block that performs beamforming of the 7 channels using the weights of the CAPON algorithm.
3. Sum of the signals after beamforming.
4. The input signals of the beamforming and the output signal are placed on two DACs for certificating the correct operation.
5. Weight calculation (implementation of the 7-channel algorithm) in software, loading of weights in beamforming.

Weight calculation takes approximately 100ms to execute.

MEDEA Competitive Features

- High adaptability to different applications and users (civil or government).
- Whole EGNSS and IMMARSAT BW's when in normal operations.
- Mitigation capability in two GNSS sub BWs (future MEDEA 2.0, current design only L1/E1)
- New Beam Forming algorithm (CAPON 2) capable to get inference mitigation and minimize impacts in terms of performance reduction (let's think to antenna phase centre variation).
- Antenna array design embedded with SDR receivers and digital beam forming that allows the capability to mitigate interfering signals and simultaneously select and look at up to 5 GNSS satellites with optimum DOP identified by a specific algorithm that uses a stored almanac produced by the on-board receiver.
- Integration of several integrity functions such: interference detection, localization and classification, anti-spoofing, DOP computation optimization. RAIM/ABIA can be also added.
- Internal calibration of Rx chains
- Integration of kinematic sensors (IMU, others) and GNSS Rx for improved resilience against EMI
- High level of programmability and upgradability of the algorithms based on FPGA design arrangement.

ST4 RadioPoints Ulisse

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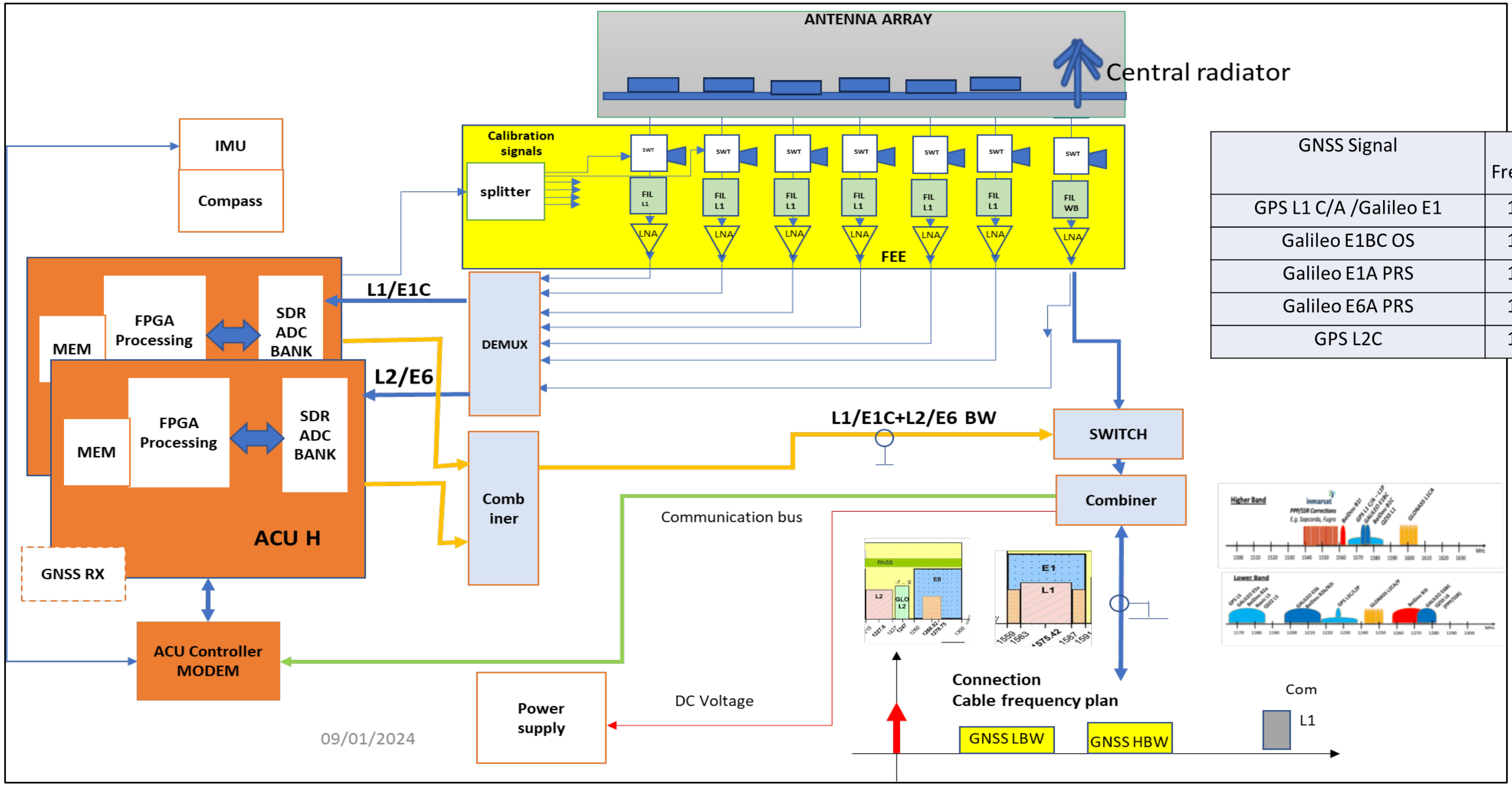
Next development phase currently proposed to ESA

Two frequency BWs can be controlled in MEDEA 2.0 assessment design



GNSS Signal	Carrier Freq. [MHz]	Modulation	Bandwidth [MHz]
GPS L1 C/A /Galileo E1	1575.42	BPSK(1) /BOC(1,1)	5
Galileo E1BC OS	1575.42	CBOC(6,1,1/11)	14
Galileo E1A PRS	1575.42	BOCcos(15,2.5)	40
Galileo E6A PRS	1278.75	BOCcos(10,5)	40
GPS L2C	1227.60	BPSK	1

PRODUCT ON THE MARKET

MEDEA product is addressing the sector of :

- Maritime navigation
- Integrity monitoring stations
- High integrity applications

As user case of maritime navigation the following specific characteristics (see GSA report) are of interest:

- Autonomous navigation, including collision risk modelling;

- Resilience requirements.

- Multi-system control;

- Spoofing resistance;

ST4I Growth and Opportunities

The future of vehicle paradigm will be for sure based on autonomy and high integrity navigation operations. This will happen in all the fields: automotive, rail, airspace, maritime. So new capabilities should be embedded in the future class of PNT equipment that may also include different position technologies such video and signal of opportunity.

In the above contest the market of CRPA antennas is growing driven by new applications in the transport sectors and maritime, rail and trunks. But not only integrity monitoring station may be deployed in critical areas to support SoL application and services and protect assets and people.

Indeed, the new international political evolutions have led to new awareness about the importance of resilience in the communication and navigation applications both for civil and defence services.

Benefit working with ESA

NAVISP-2 program allowed ST4I the detailed design of MEDEA as an electronic antenna terminal for EGNSS applications focused on maritime utilization and to demonstrate the concept and its key-performances.

Fully cooperative interaction with ESA allowed ST4I to focus the effort on the MEDEA key-requirements and to fit as well the expected overall system unit performance, also through the support of experimental verification of the critical items.

MEDEA project evolution will certainly take benefit of such interaction.

Program Follow-On: MEDEA complete terminal implementation and verification.

CONCLUSIONS -1

MEDEA Project development phase has demonstrated the capability to implement the product requirements according to the User expectations. The whole set of the design critical items have been developed and successfully proved. Next PRODUCT finalization phase would result in the complete realization of the MEDEA proto unit. The Market appears ready to introduce new effective antenna units to cope with Integrity Requirement.

MEDEA Additional Applications to be further addressed in the next phase

- RAIL
- Road Transportation and Automative
- Manned Aviation
- DRONES and RPAS/UAS including ground stations for accuracy /integrity augmentation and traffic control
- Integrity Monitoring Station & Emergency Response

CONCLUSIONS -2

ST4I thanks FUGRO for the received sponsorship as well as for the availability to discuss and address actual requirements for maritime applications.

ST4I thanks TELESPAZIO for the received sponsorship.
Next phase will be initially devoted to focus on potential common opportunities based on MEDEA development.

ST4I thanks ASI and ESA on the received support for this specific MEDEA development opportunity.