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Le RADAR : un senseur pour les drones notamment pour la fonction détection et évitement

- Game Of Drones -

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Radars for RPAS

1. RPAS Synopsis
2. Focus on Sense and Avoid Cooperative and Non Cooperative sensors
3. What type of RADAR
4. MIDCAS
5. Conclusions & perspectives

1. RPAS synopsis

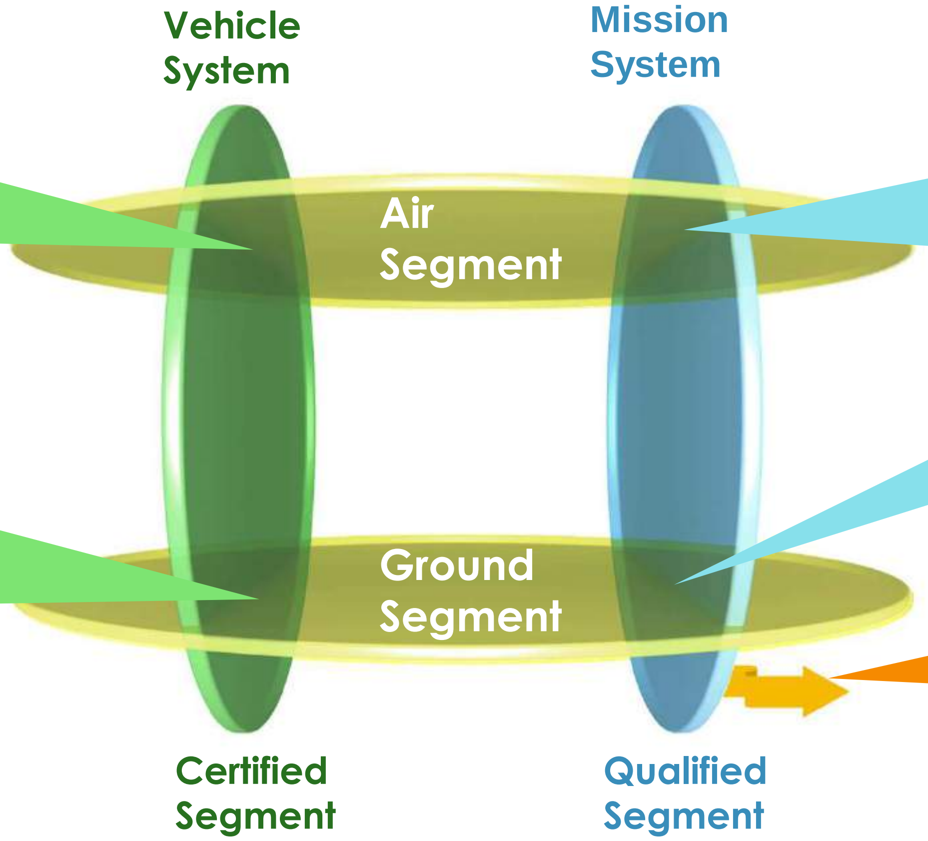
RPAS is a complete SYSTEM

- UAV is limited to aircraft platform only , which the airborne part of the complete system. Nowadays the focus is on the complete system.

- **UAS :** Unmanned Aircraft Systems or **RPAS:** Remotely Piloted Aircraft System.

- For example the system certification includes the following topics :
  - The Aerial Vehicle (Drone)
  - The ground control station(s)
  - Data links
  - The Operators (including the pilots)

1. RPAS synopsis



- Airborne Platform
- Avionics
- Fly computer
- C2 / Vehicle Communication
- Sense & Avoid function

- Vehicle Command & Control
- ATOLS
- C2 communications
- RADAR ATOLS or Safety Pilot

- Payloads E/O IR, RADAR, RESM COM INT
- Crypto
- Mission computer
- Operators
- Mission communication

- C2 communications
- Command & Control
- Network
- Operators

- **C4I**
- **Dissémination**
- **Exploitation 2ème niveau**

2. Focus on Sense and Avoid

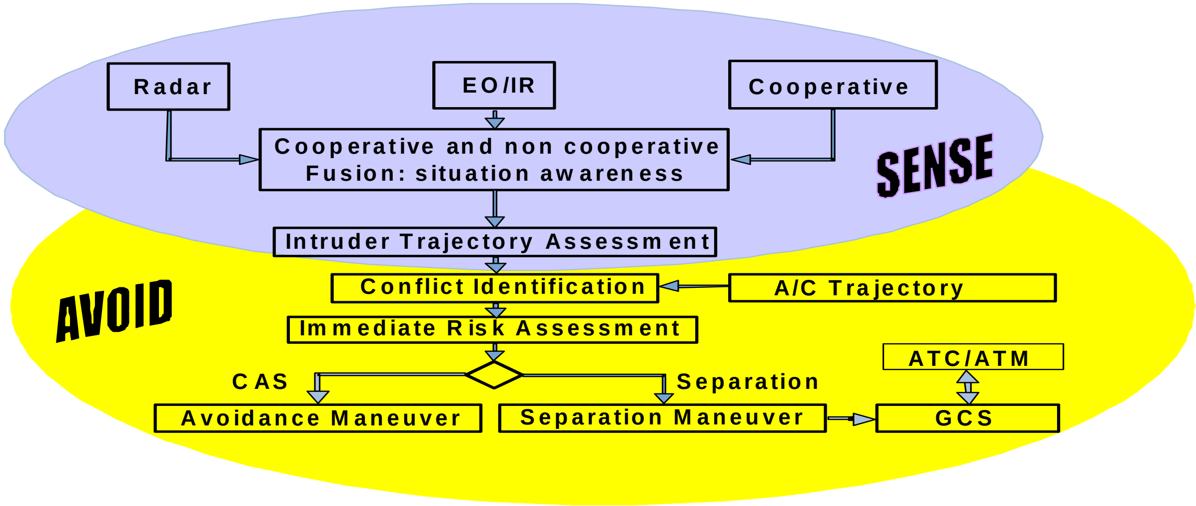
Cooperative and

Non Cooperative sensor

Why and what is “Sense & Avoid

It is a system that replaces the Pilot' eyes in the cockpit.

- **Safety and reliability are the watchwords. To do that, parallel sensors are fused.**
- **Sense function:**
  - Situation Awareness.
  - Trajectories prediction.
- **Avoid function:**
  - **In normal operation:** Traffic Separation with Man in the loop **(SEP)**;
  - **Emergency operation:** Automatic Collision Avoidance **(CAS)**.



The different Sensors Involved in S&A

Cooperative sensors:

- These are mainly transponders or squitter messages receivers:
    - The transponders send a request for an answer from a potential intruder
    - The squitter messages are unsolicited. **The message receiver onboard the own ship is the co-operative sensor**.
- But a cooperative sensor cannot be used alone for safety reasons:
    - **All Aircraft are not equipped, and the integrity of transmitted data must be checked.**

Autonomous sensors:

- Radar is an essential <u>active</u> sensor for Sense and Avoid, indeed:
    - **<u>Radar is "all weather", day and night</u>.**
    - It provides basically **Direction, Closing velocity and Distance of targets**.
    - **So, it provides itself all "Sense" tasks (and also the avoid task).**
- A complementary autonomous sensor can be a passive E/O one.
    - In favourable conditions, **to enhance the angle measurements**.

Passive E/O Sensor

E/O sensor alone may provide some avoid functions:

- It provides accurate angular measurements, but it is not "all weather"
- It may detect targets on a collision course criterion: $\frac{d\theta}{dt} \approx 0$
- It may assess the Time to Go (accuracy is questionable)
  - From the growth rate of a target image at short/medium range unless a very high-Res. Optical sensor system is used (>6000 pixels in H for a 5m target @ 5nm),
  - From the angle variation rate at short/medium range.

E/O sensor is unable to provide itself a situation awareness:

- Neither range nor velocity

E/O sensor can only be used with other sensors to do that:

- With radar, to enhance the angular accuracy through data fusion,
- With a co-operative sensor , to check the integrity of the received data.

E/O sensors alone may provide Avoidance function at "short or medium" range but never itself the Sense function.

Co-operative Sensor: ADS-B

ADS-B (Broadcast):

- Stand for:
  - **Automatic**: no interrogation is needed to start the squitter coming from surrounding aircraft/intruders.
  - **Dependent**: It relies on other aircraft/intruders navigation and broadcast means.
  - **Surveillance**: Automatic surveillance and traffic coordination.
- An ADS-B equipped aircraft automatically broadcasts:
  - Its position/velocity and ID. at a 2 Hz rate.
  - Geodesic position is derived from GPS.
  - Barometric altitude comes from anemometric sensors.
- An ADS-B receiver on board the own ship provides localizations:
  - Which are much more accurate than any other autonomous sensor;
  - Available “All weather” and at long range.

The main issue with ADS-B (or similar co-operative systems) is to check the integrity of received data

3. What type of RADAR?

mm Wave RADARS

Foreword:

- In airborne applications, MMW radars are mainly used for short range application, when available space and weight are the key factor.
- Since the performance in terms of range do not reach what is obtained in lower bands, this technology is mainly intended for tactical or smaller UAVs.
- Compared to EO sensors, Radars have two main advantages:
  - **It provides directly 4D measurements (Range, Doppler, Azimuth, Elevation)**
  - **This is a (relatively) "all weather" sensor.**

mm Wave RADARS

The main problem of using mm W for radar application close to the sea level:

- Strong attenuation due to O^2 and H^2O
- Strong attenuation in case of rain

The second problem is the cost of technologies:

- R.F. power sources
- E-Scan antennas

MMW bands which are allowed for Radar applications:

- Ku band: around 16 GHz (BW: 3 GHz)
- Ka band: around 35 GHz (BW: 1 GHz)
- V band: 77-81 GHz currently allowed for car Radars and discussed for helicopters
- W band: 94 GHz

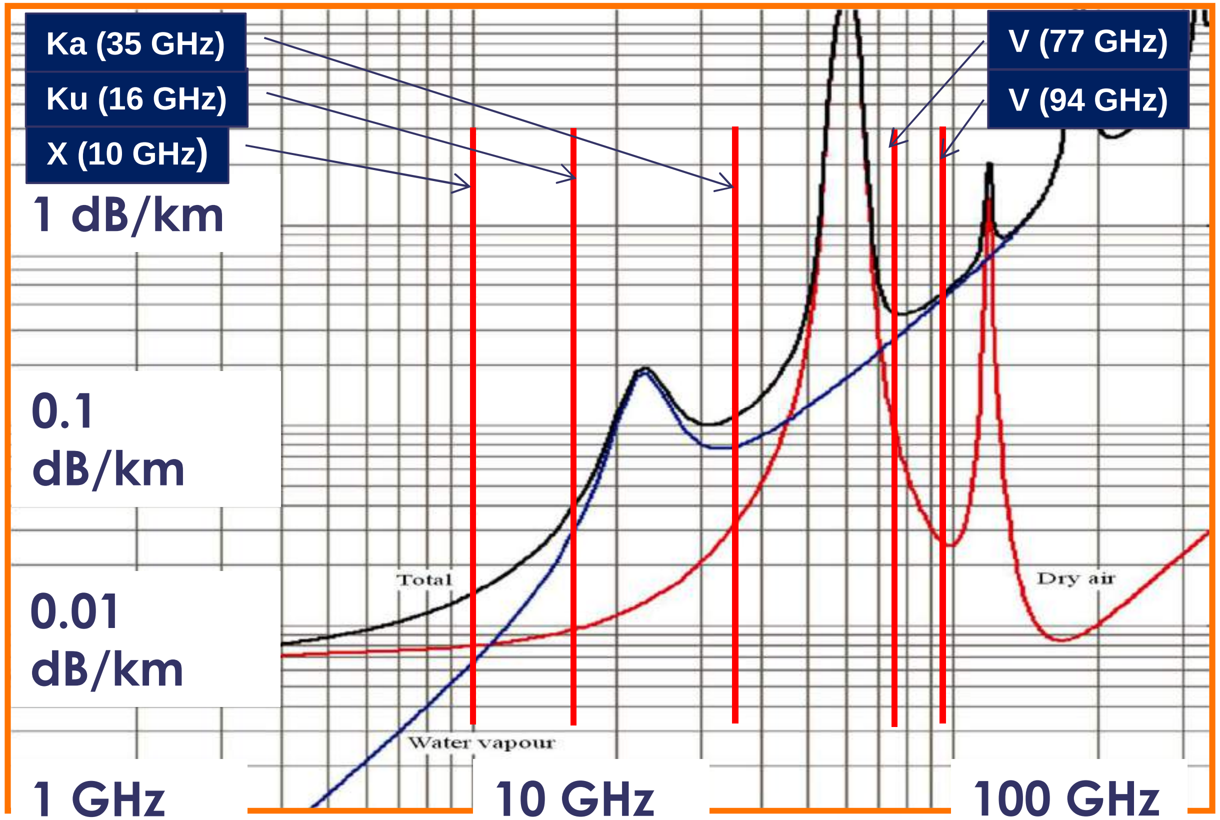
Possible Radar bands, gaseous attenuation

Range for 10 dB, two ways:

- **X band: > 250 km**
  - 10 GHz
- **Ku band: 125 km**
  - 16 GHz
- **Ka band: 50 km**
  - 35 GHz
- V band: 13 km
  - 77 GHz (car radars)
- W band: 12 km
  - 94 GHz

10 dB of attenuation can be seen as the limit of "economical use" of a given band.

One way attenuation



Possible Radar bands

For detect and avoid the maximum range of “reasonable” use is:

- **X Band (10 GHz): no significant limit**
  - But it is a centimeter wave band !
- **Ku Band (16 GHz): 30 to 100 km depending on weather conditions**
  - 60 – 100 km with no or light rain
  - Reduced to about 30 km with moderate rain
- **Ka Band (35 GHz):**
  - 15 – 50 km with no or light rain
  - Reduced to about 5 km with moderate rain
- **V & W Bands (77 & 94 GHz):**
  - 5 – 10 km with no or light rain
  - Reduced to about 2 km with moderate rain

Millimeter wave band (≥ Ka) are dedicated to short range radar applications (< 5-50 km)

Radar for Sense & Avoid: Two approaches

1) High safety approach:

- Would be for the insertion of UAVs in the general air-traffic
- High safety needs redundancy and “all weather”, night and day:
  - Various sensors (co-operative or not), including radar, are merged.
  - **Each sensor shall be able to carry out itself the task in a degraded mode**
- The radar must scan every few seconds a large angular range.
- Millimeter wave > Ku band are not appropriate for such a scan mode

2) “Low cost” non cooperative approach:

- Autonomous collisions avoidance in special air-traffic conditions
- Possible solution:
  - Detection and angle measurement by E/O sensors
  - Confirmation and ranging by a radar in starring mode.

Millimeter wave radar (35 GHz) are interesting only for the 2nd approach

Radar Design - Operating Band, Architecture Enablers

- **Up to S (even C band), the angular accuracy is not fulfilled with a “reasonable” overall size of the antenna system**
- **Wavelengths in Ka band and above are too much weather sensitive.**
  - So, operating frequencies in X or Ku band are a good tradeoff.
  - Moreover, many “COTS” are available in X-Band.
- **Both the required angular accuracy and the angular coverage:**
  - Make unrealistic mechanical scanning (too high rotation rate);
  - Make problematic “pure” E-SCAN (too short dwell time).
  - Full “classical” E-SCAN is also a costly solution.

DBF-based methods are convenient and cost effective for wide angular coverage systems in X or Ku bands.

Radar design – MIMO radar

Transmission and Vertical localization use a fixed vertical array:

- Directive in Elevation;
- Non directive in Azimuth;
- Vertical localization through Space Coloring on transmit.

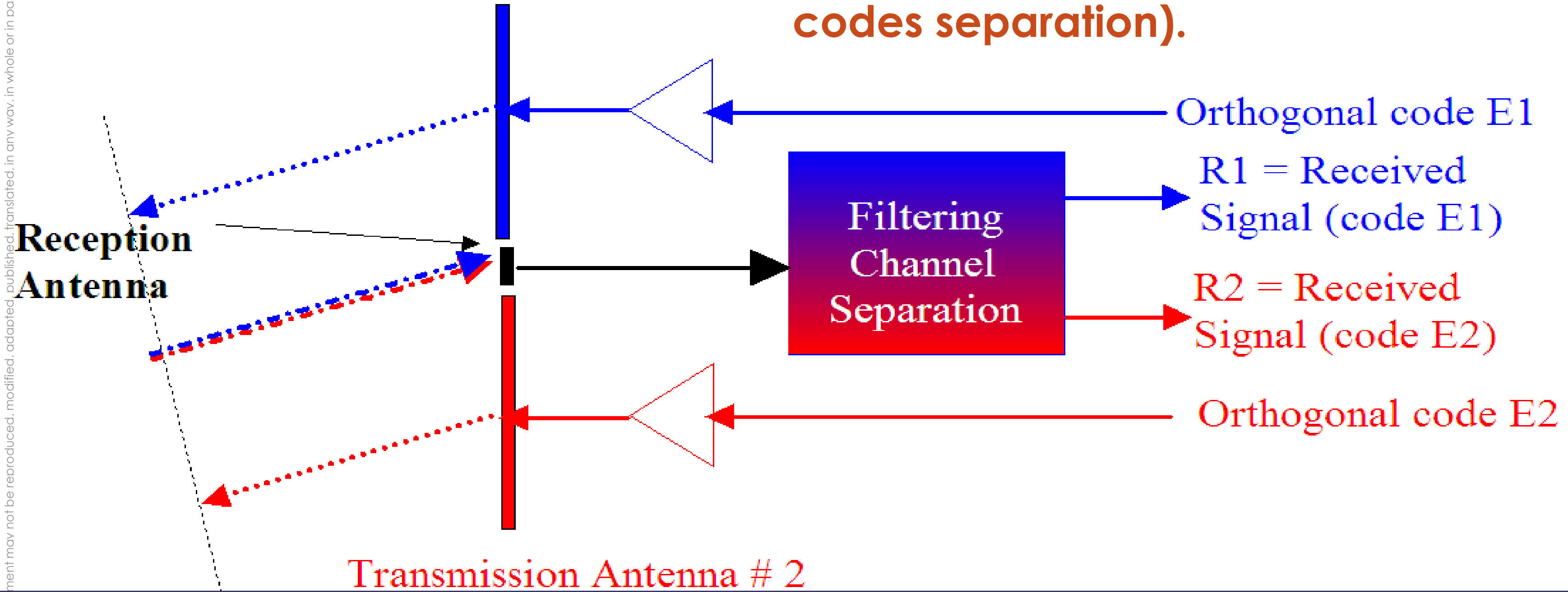
Reception and Horizontal localization use fixed horizontal array:

- Horizontal localization thanks to DBF;
- Receiving array pattern covers exactly the Elevation domain.

A cost effective solution is thus composed of 2 perpendicular separate arrays (T&R) implementing coherent MIMO principles.

Space Coloring Waveforms: “Mono-pulse” on Transmit”

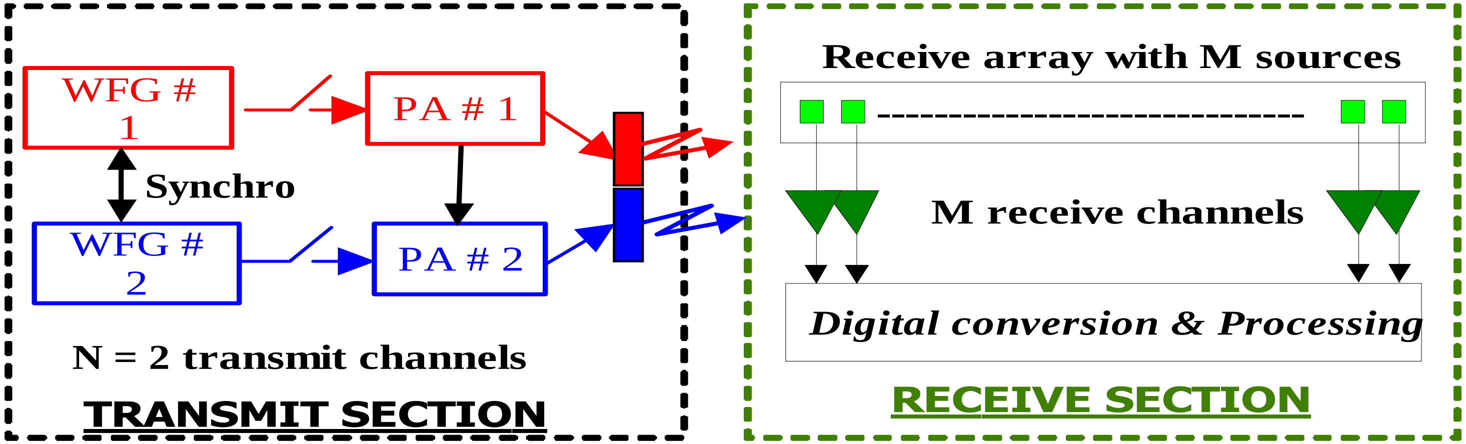
- Two “equivalent (Σ, Δ) channels” can be formed after filtering on receive (orthogonal codes separation).



Equivalent elevation “Monopulse” with only one horizontal array on receive.

Initial radar architecture

- **One linear array on receive: DBF in Azimuth (El. Coverage:±15°);**
- **One "small" vertical linear array on transmit (El. Coverage:±15°);**
  - Azimuth coverage: Wide (several tens of degrees)
  - Each half antenna radiates an orthogonal code with the other.

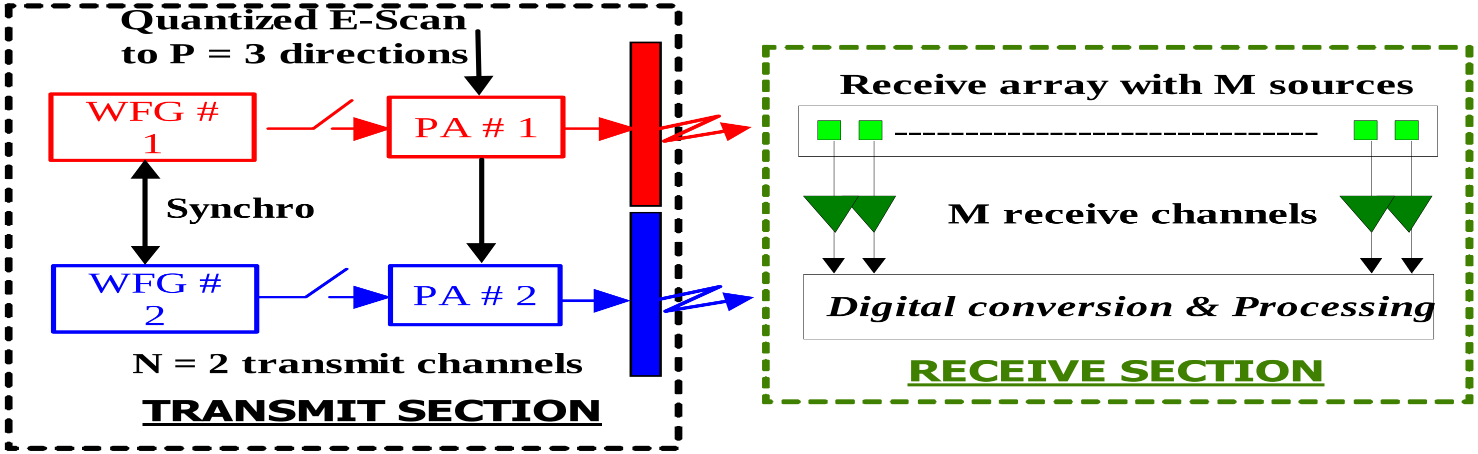


Lack of elevation selectivity ⇒ strong ground clutter

Small transmission antenna ⇒ Lack of accuracy in elevation

2^{nd} step: Improvement of Elevation Selectivity

- **Same receiving array & processing on receive (El. Cov.: ±15°);**
- **One "large" vertical linear array on transmit (El. Cov.: ±5°);**
  - ⇒ Additional quantized E-Scan on transmit (3 states) is required;
  - ⇒ Ground clutter reduction due to "narrow" elevation beam at transmission ;



Quantized E-Scan to P = 3 directions

WFG # 1

PA # 1

Synchro

WFG # 2

PA # 2

N = 2 transmit channels

TRANSMIT SECTION

Receive array with M sources

M receive channels

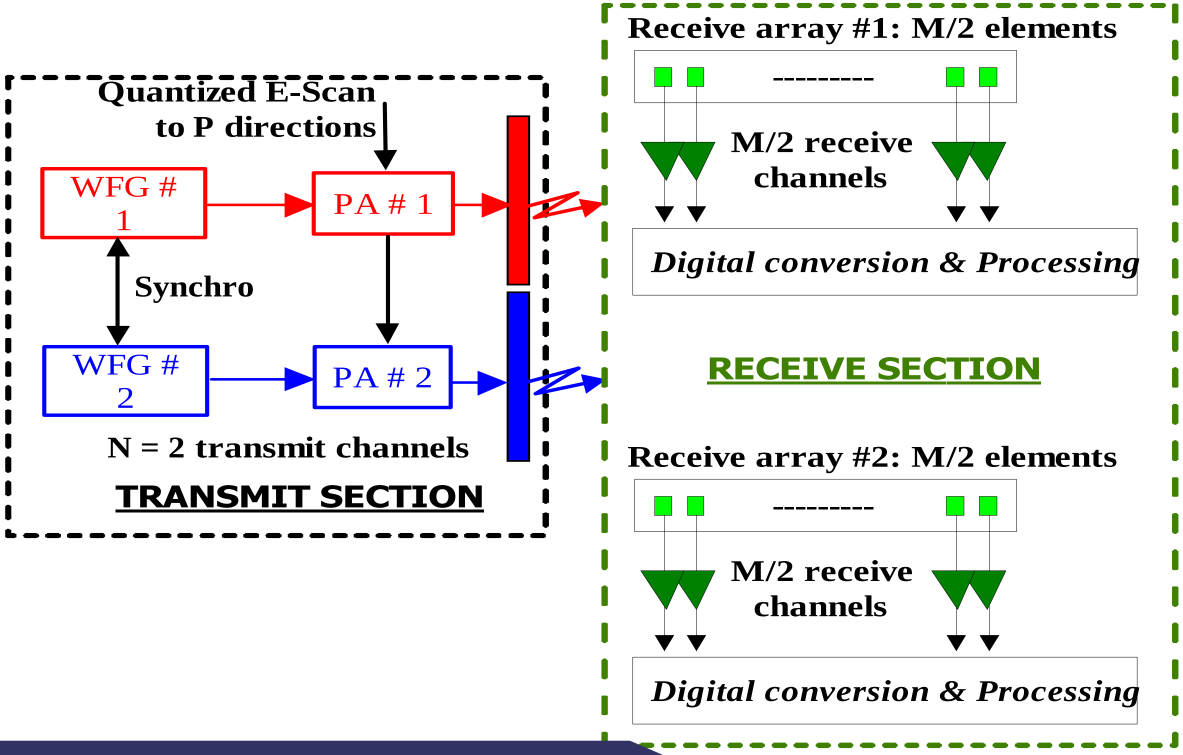
Digital conversion & Processing

RECEIVE SECTION

Better elevation selectivity ⇒ Ground clutter reduction;
Better accuracy in el. BUT does not meet requirements.

3rd step: Improvement of Elevation Accuracy

- **Same transmitting section as in 2nd step.**
- **Receiving array is split into two parts.**
  - The two parts form an accurate interferometer;
  - Interferometer is angle ambiguous in Elevation;
  - Ambiguities are removed thanks to Space Coloring on transmit.



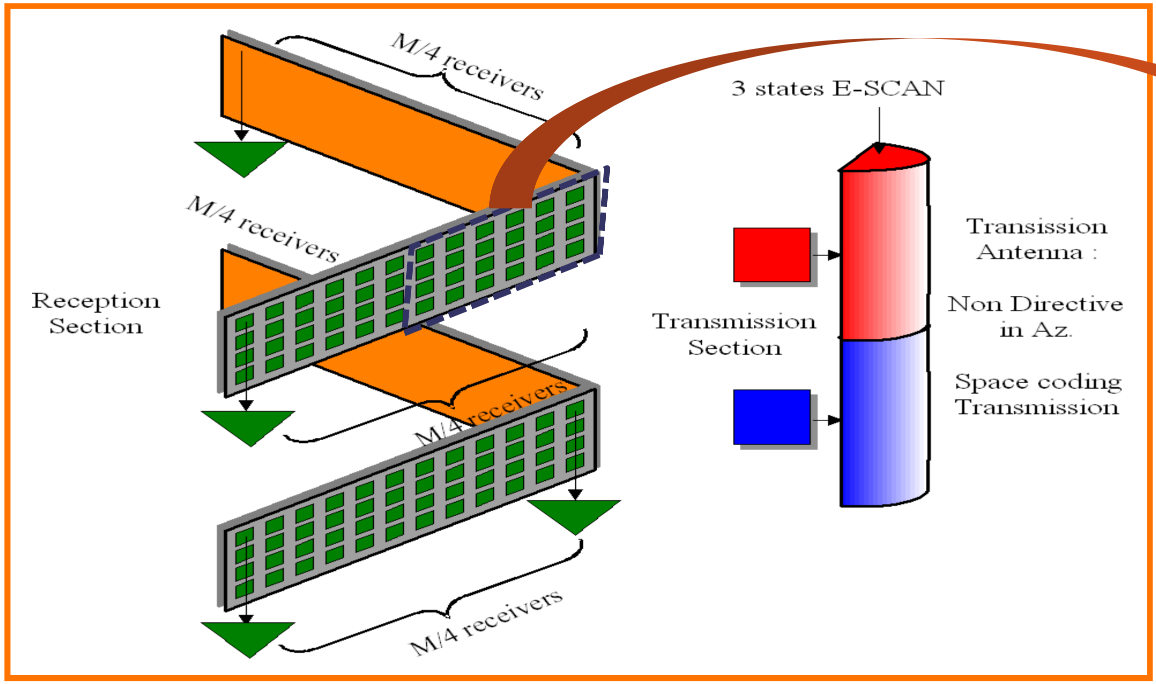
Excellent accuracy in el. : the proposed architecture meets the requirements.

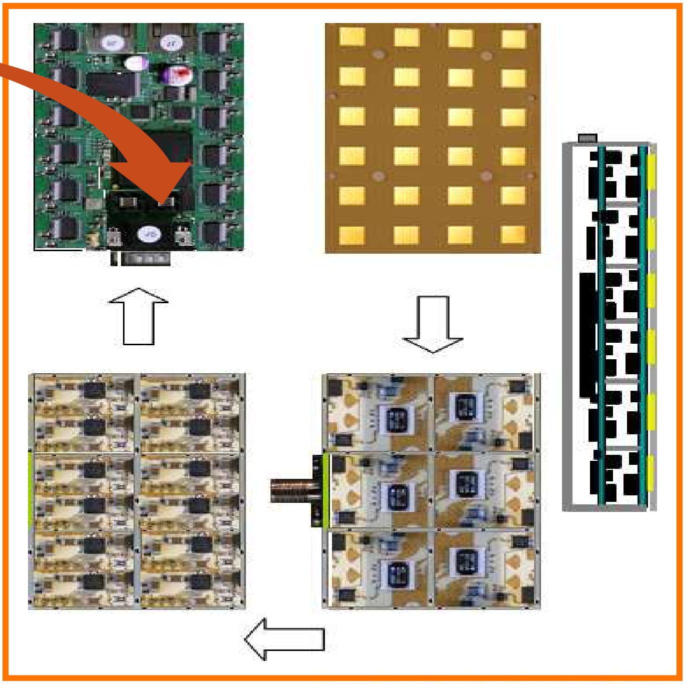
Radar for Sense & Avoid

Wide angular coverage, fast refresh rate radar:

- Use of Digital Beam Forming for fast refresh rate
- Unrealistic above Ku band due to technologies and cost of actives antennas

Mock-Up of a tile Building Block at reception:





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MIDCAS

MIDCAS main objectives

The MIDCAS project is designed with focus on 3 main tracks with high level of interaction and interdependency:

- Progress on Standards for D&A
- Design of a generic D&A function to be tested in simulations
- Design of a D&A Demonstrator to be tested in manned and RPAS flights

MIDCAS Project

EDA is the contracting agency for the MIDCAS project on behalf of the contributing members (CM)

- Sweden (lead)
- Germany
- France
- Italy
- Spain

EDA

European Defense Agency

With an industry consortium of 10 partners from the 5 nations

SAAB
AleniaAermacchi A Finmeccanica Company
DIEHL BGT Defence
DLR
AIRBUS DEFENCE & SPACE
ESG
indra
SAFRAN Sagem
Selex ES A Finmeccanica Company
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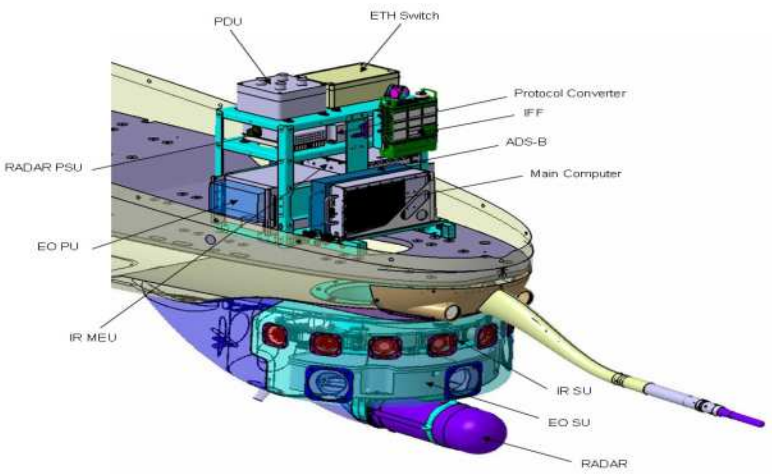
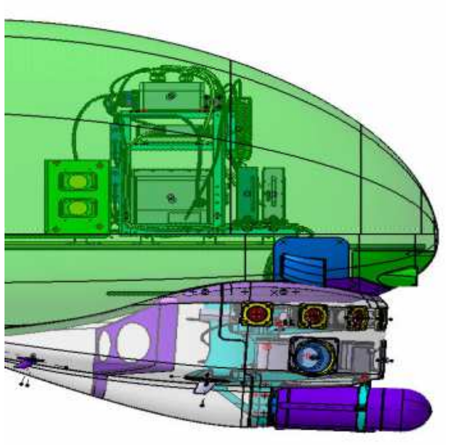
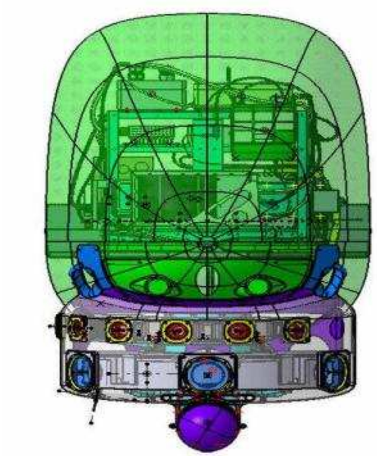
Project started in Sep. 2009 and will end in Sep. 2015

MIDCAS Architecture Description: Sky-Y Implementation







RPAS Flight Test Campaign: Overall Results - Sense

Several runs dedicated to performance of sensors. Best sensors combination, based on stability of track provided by Data Fusion function (velocity vector, heading) have been:

- Best combination of Coop. & Non Coop sensors [Best (NCS+CS)]:
  - **ADS-B + EO** (in the first CA/TRA testing phase)
  - **ADSB+RADAR+EO** (in the second CA/TRA testing phase)
- Best combination of only Non Coop. sensors [Best (NCS)]:
  - **RADAR + EO**

Typical Sensor tracking performance in flight:

- **ADS-B:** over **15 NM**
- **Radar:** around **5 NM (8000-9000 m)**
- **EO:** ranging from **8- 5 NM (15000-8000 m)**

MIDCAS Flight test summary

- Different sensors and sensor combinations evaluated
- Cooperative and Non-cooperative scenarios
- Traffic Avoidance and Collision Avoidance
- Variation of scenario setup with Head-on, Beam and Overtaking cases
- Fully automatic maneuvers performed for a variety of scenarios incl Non-cooperative sensors only

➔ In total 107 scenarios performed in 10 flights with real intruder

6. Conclusions and perspectives

- **The “Sense” task is the system performance driver.**
  - High accuracy at long range.
- **Radar is mandatory for safety and “all weather Sense” operation.**
  - **All aircraft are not equipped with co-operative means** such as TCAS or ADS-B and the co-operative data must be checked for integrity.
  - However, E/O devices and co-operative sensors can greatly enhance the situation awareness accuracy through data fusion.
- **A static Radar solution in X-band has been described.**
  - It provides a wide Field Of View thanks to a facetted array.
  - It is based on Digital Beam Forming and coherent MIMO principles.
- **The future: Prototype and In-flight trials of the proposed system:**
  - Expected in MIDCAS Phase 2.

QUESTIONS