# Aerospace Structure Health Monitoring using Wireless Sensors Network


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# Toulouse – Aerospace City

# Outline

- Objectives and specifications for greener and safer aircrafts
- Structure Health Monitoring System Requirements
- Proposed solutions
  - **Robust Communication Architecture**
  - **MAC layer and clock synchronization**
  - **Ultra Wide Band Impulse Radio Transmission**
  - **60GHz Nanometric CMOS circuits**
  - **Flexible substrate integration**

# Long term objectives for aeronautic systems

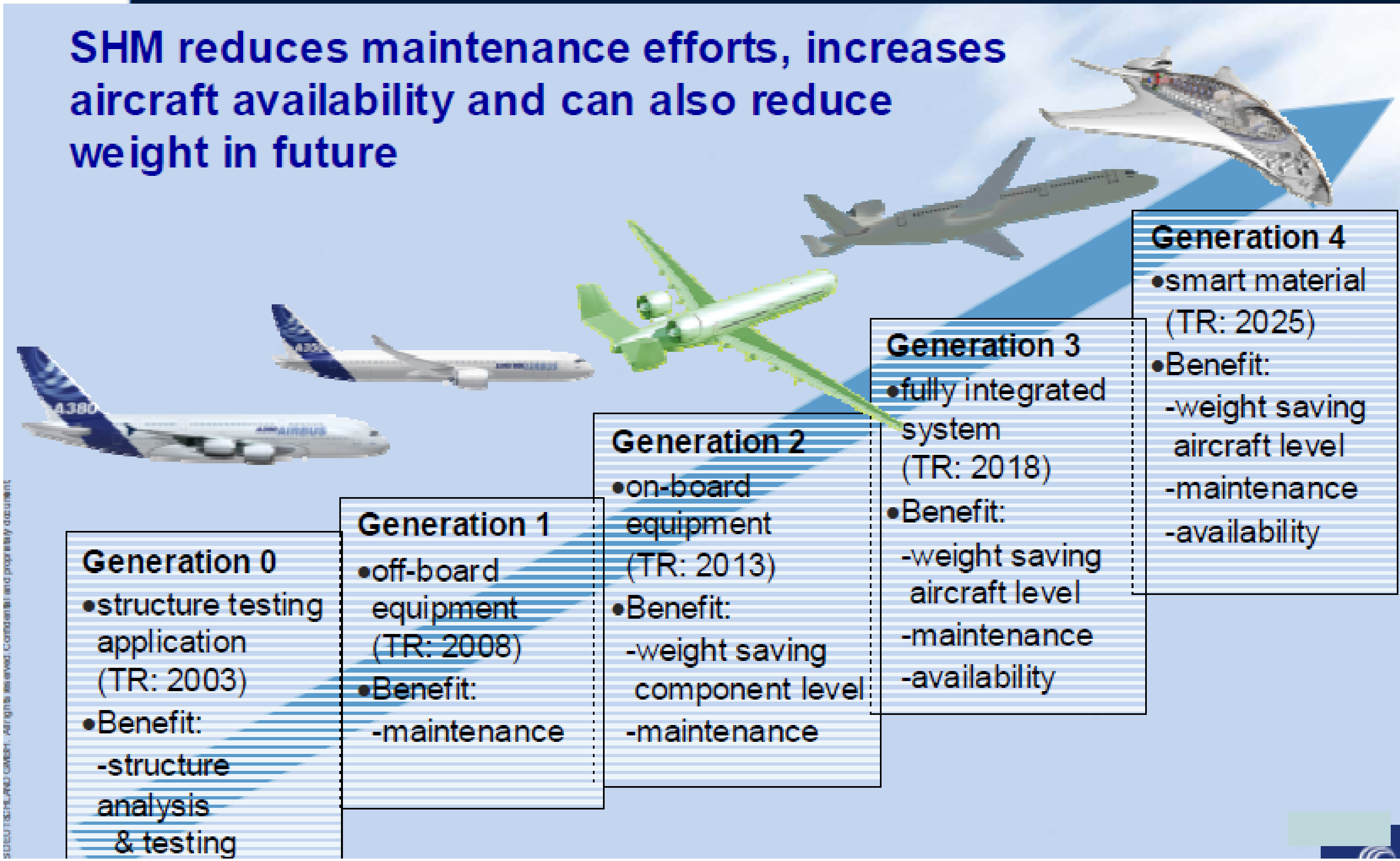
- **Eco-efficiency**
  - **Greener systems**
  - **Lowest carbon emissions**
  - **Less weight**
  - **Higher performance**
  - **Cost efficiency**
  - **Passenger comfort**

- **Safer aircrafts**
- **Time to market**

**Global system challenge → Global system solution**

# Structure Health Monitoring

# Structural Health Monitoring stepwise approach




Copyright H.Rosner – "Smart structures contribution to Airbus aircraft eco-efficiency", IWSHM , Stanford 2009

# Hard landing problem

- Goals: Reduce aircraft schedule interrupts by:
  - **Reducing number of false reporting hard landings**
  - **Aiding the maintenance process**


- Current process
  - **Pilot initiate inspection**
  - **Large number of false reports**

- Process with structure health monitoring
  - **Pilot initiate inspection**
  - **Flight parameters and structure health monitoring sensor information will be used to predict load information in critical structure areas**
  - **Recommended maintenance action**
  - **Aid maintenance process**

# Structure health monitoring benefits

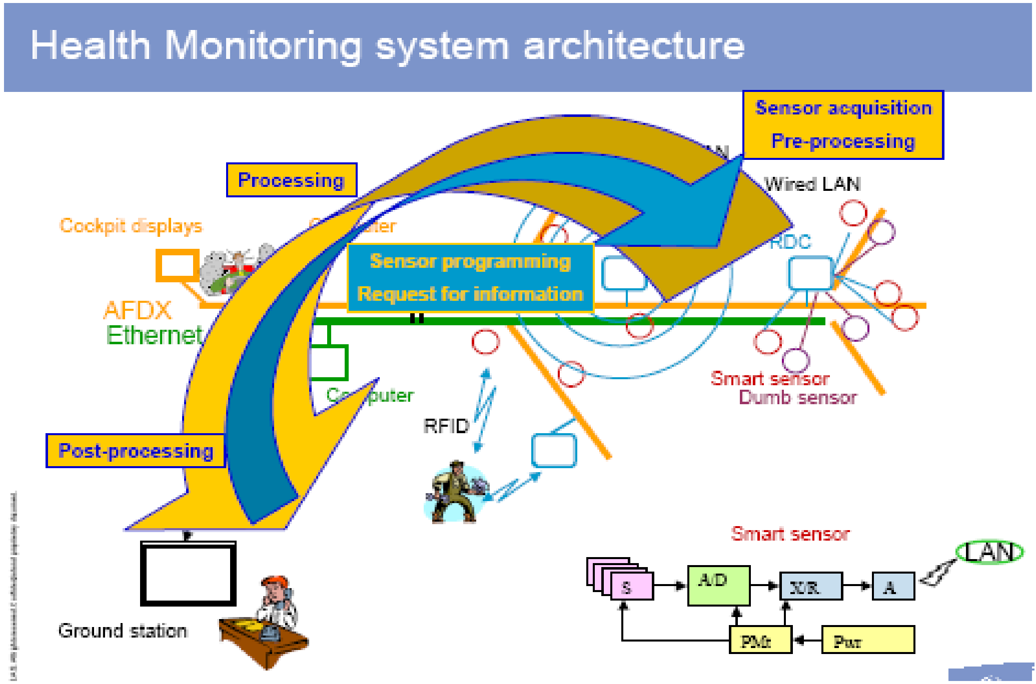
- Reduce maintenance effort
- Increase aircraft availability

- Component history record
- Predictive diagnosis

- Wired : weight problem

and time deployment problem

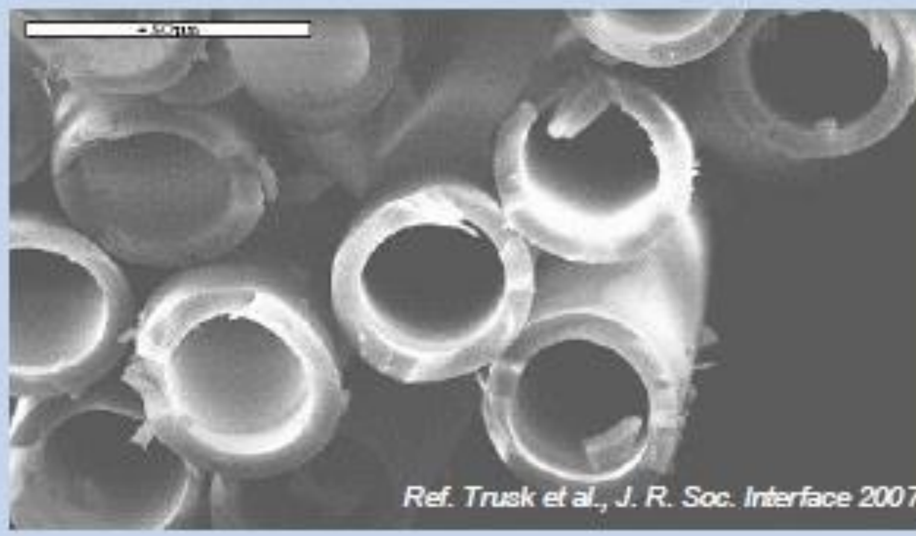
- Green systems : wireless



# Far future

- **In the far future – smart materials, composite materials → self –healing !**

Vascular system for healing resin in sandwich structures




**Self-healing ability in visionary aerospace composites is able to reduce the inspection efforts and provide rapid repair**

# New requirements → new solution needed

- **<u>New requirements:</u>**
- **Very high number of sensor communicating nodes, different kind of sensors**
  - High number of nodes in some small areas → high interferences → **60GHz communications enabled by nano-metric CMOS technology**
- **Ultra–low power nodes → autonomy needed up to several years**
- **Measurements synchronization**
- **Safety and security**
- **Small size → high integration**

Rethinking the hardware-software system

- **Hardware reconfigurable solution**
- **Energy efficiency (energy/bit)**

- <u>Problems to use COTS:</u>
- Medium numbers of nodes
- Low and medium data rate
- Not real-time systems
- Without clock synchronization
- Not enough autonomy
- Not enough integrated

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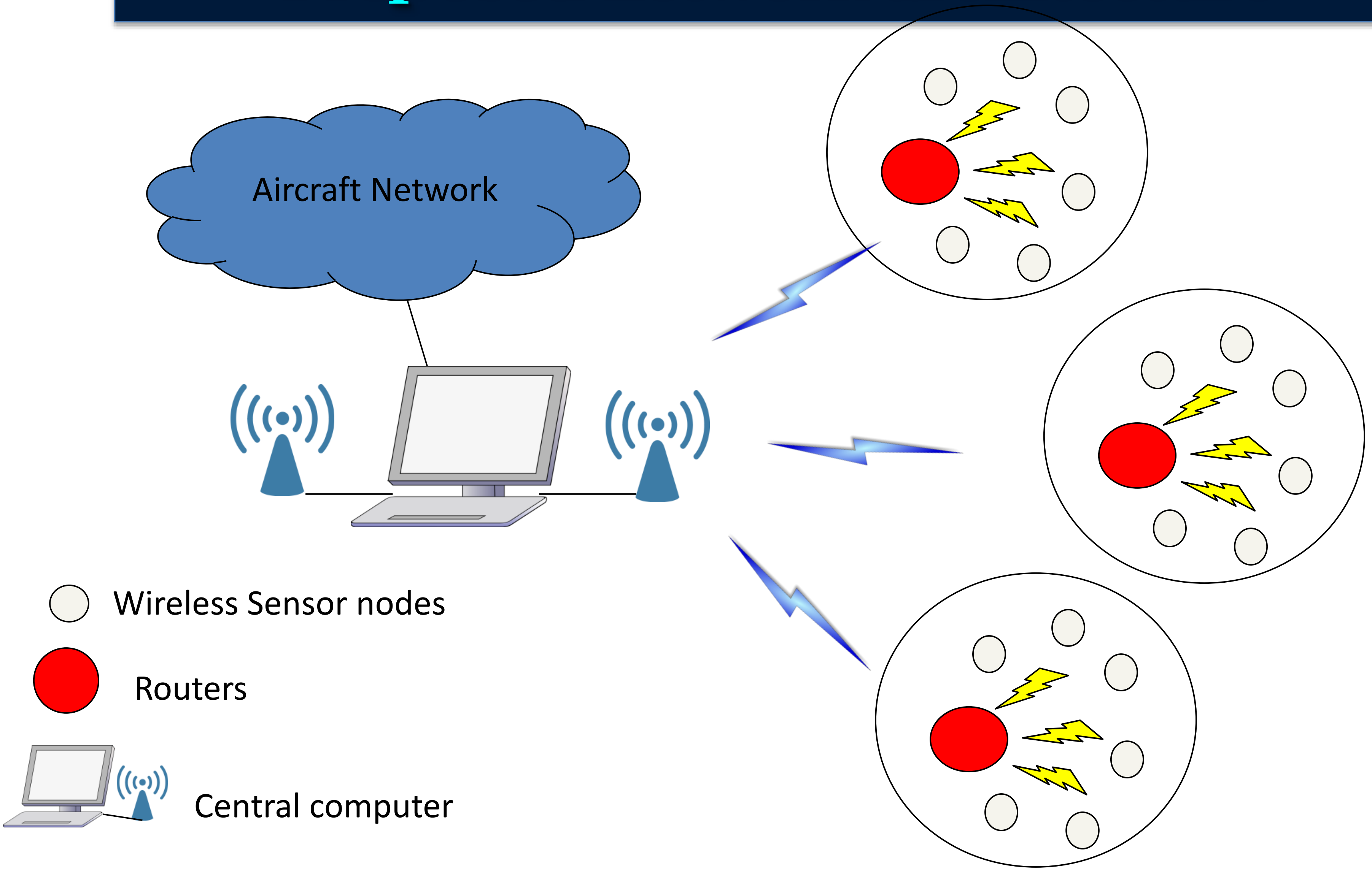
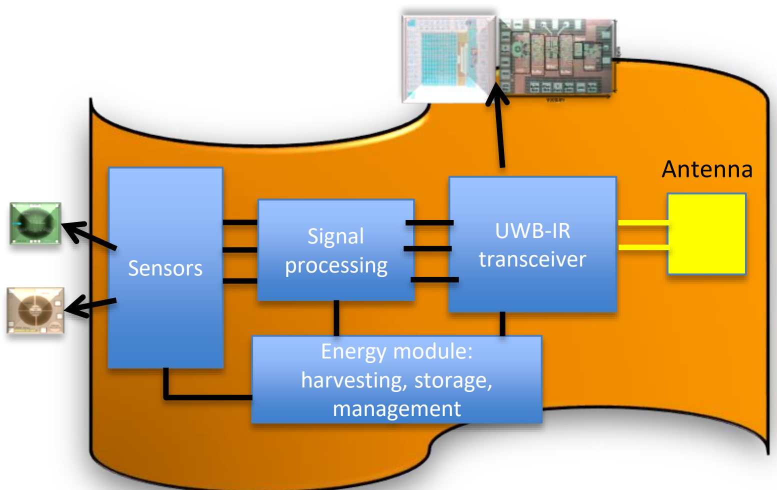
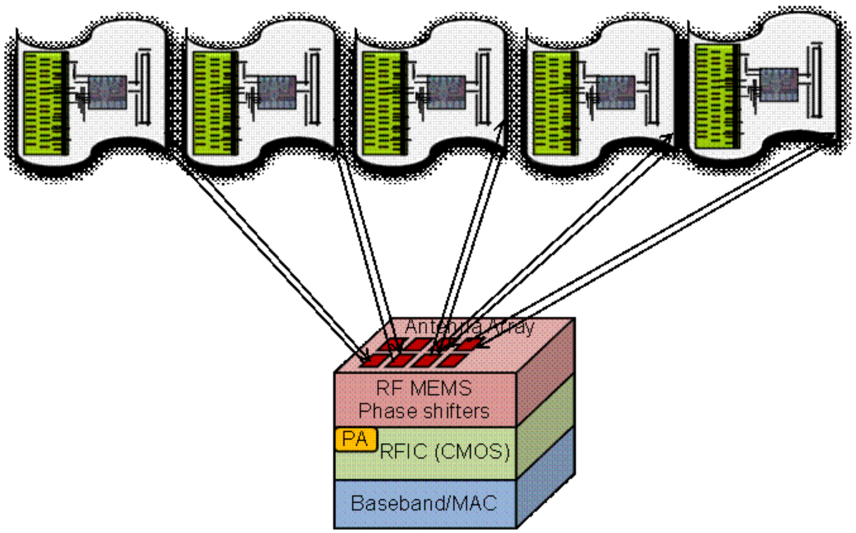
# Proposed network architecture



# Network architecture

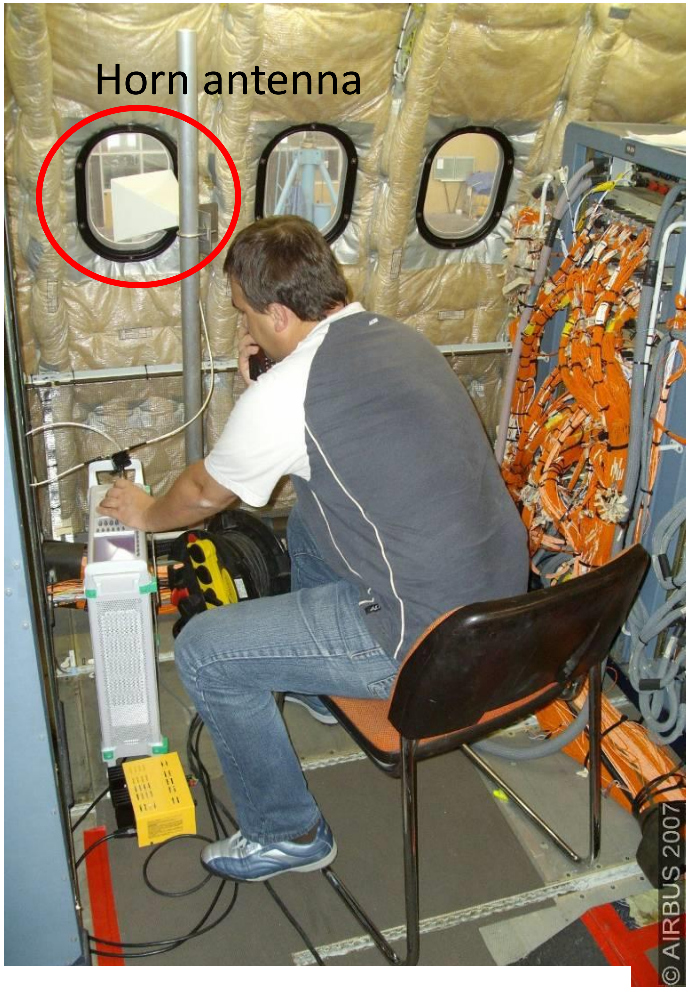
- Flexible substrate architecture for the nodes
  - Low power transceiver integrated on flexible substrate together with the sensor and the antenna
- 3D integration with smart antenna for the routers in SHM applications




ANR NanoInnov – NanoComm Project

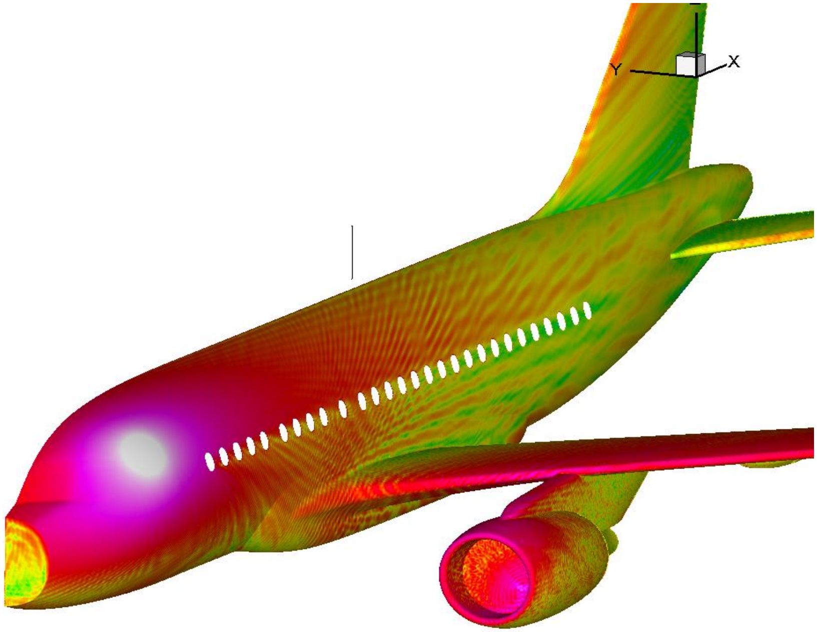
# Radio link characterization on the aircraft wings

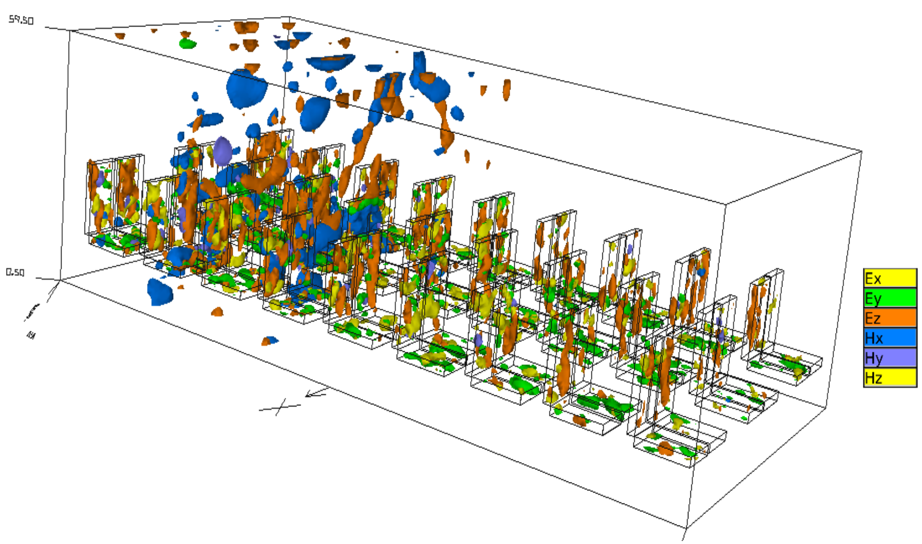




**Channel Model : Close to ground propagation !**

# Radio link propagation simulation inside the future composite aircraft

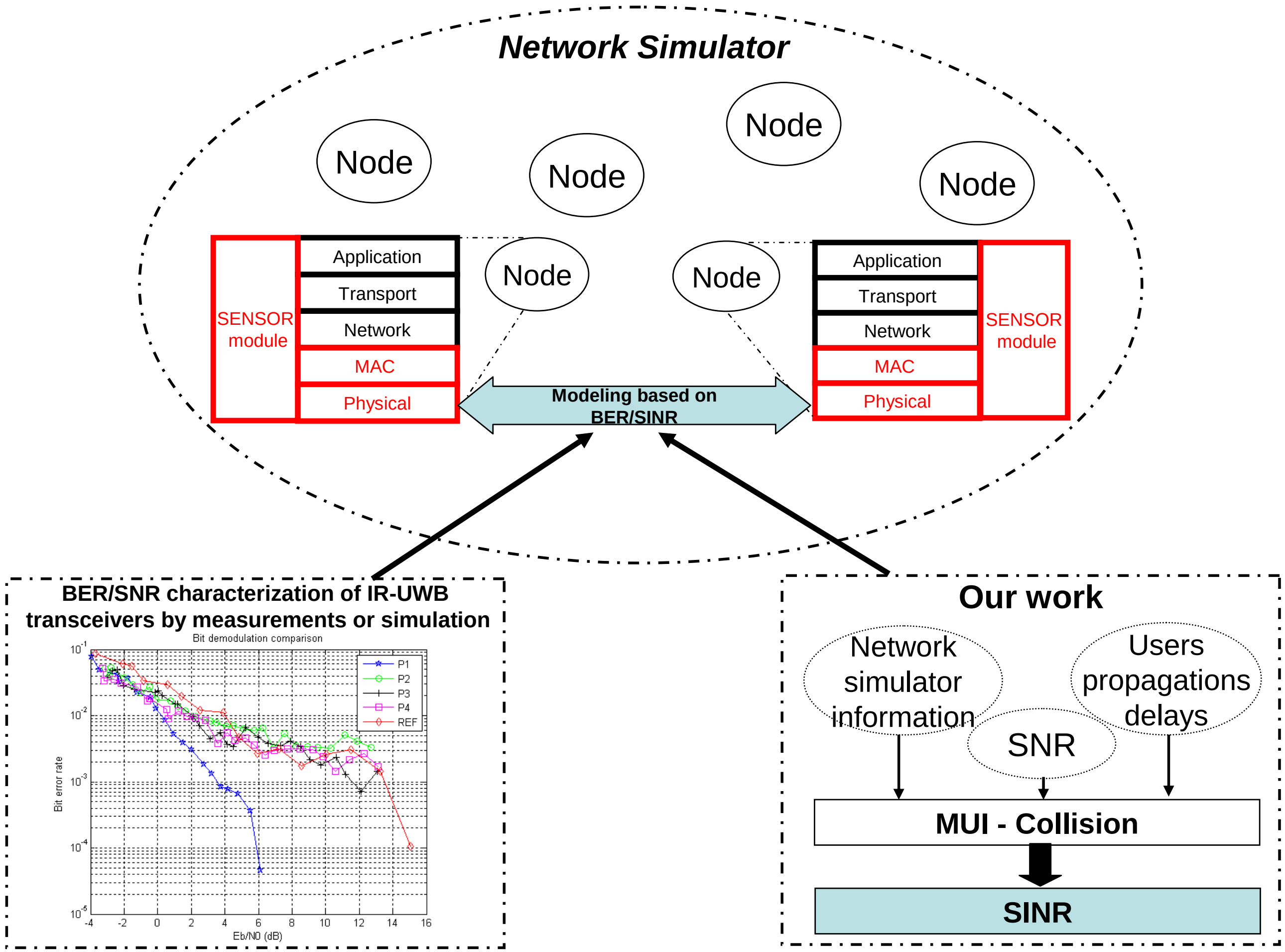

- Work in collaboration with Airbus
- Electromagnetic simulations
-Take into account the windows, chairs, the passengers



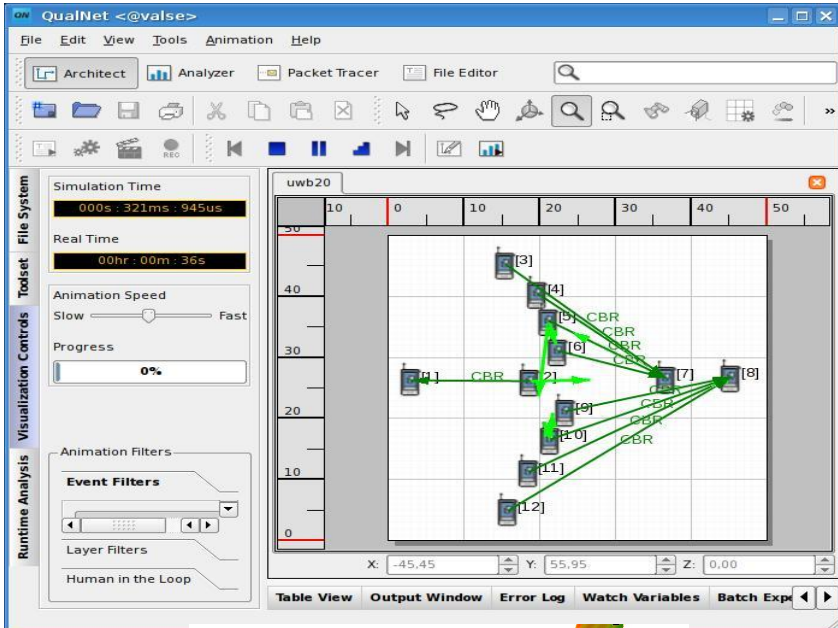
# WSN simulateur structure

- Rigorous modelling of IR-UWB PHY using BER/SNR



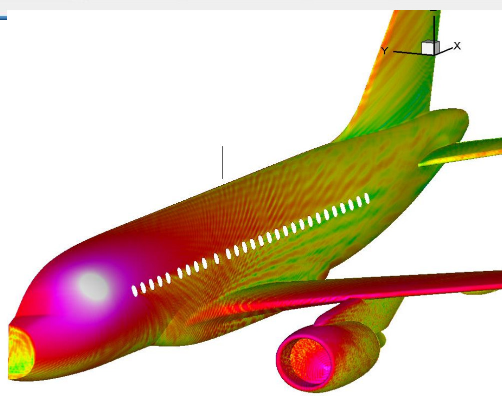

A Lecointre et al, Performance Evaluation Of Impulse Radio Ultra Wide Band Wireless Sensor Networks, Proc of IEEE MILCOM 2009, Octobre 2009

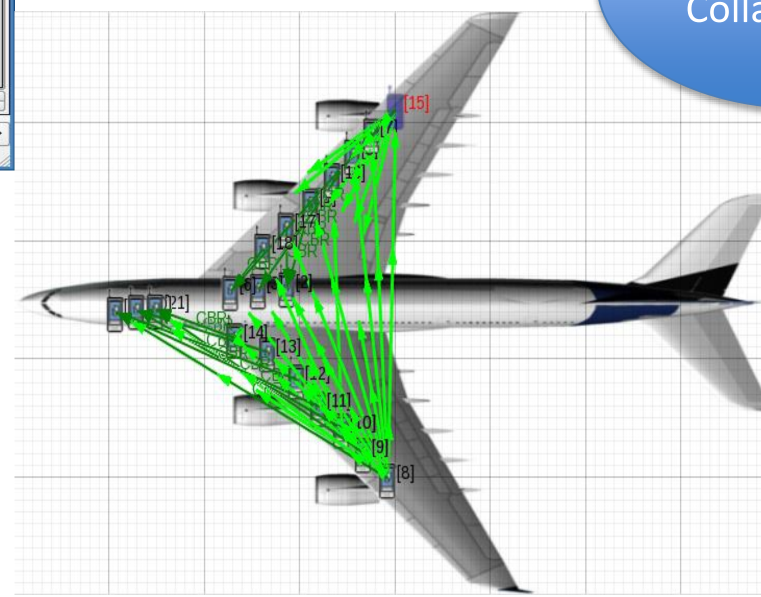
# Example : Aircraft SHM simulation




- ❖ Qualnet software
  - ❖ Packet tracer
  - ❖ 3D visualisation tool
  - ❖ Directive antenna
  - ❖ **Establish best network topology**

Airbus Group Collaboration





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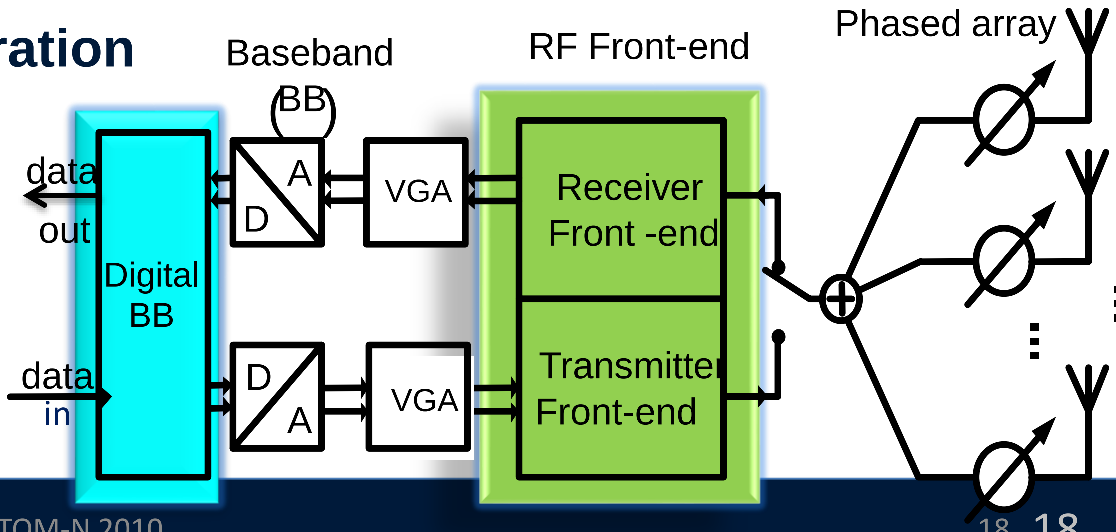
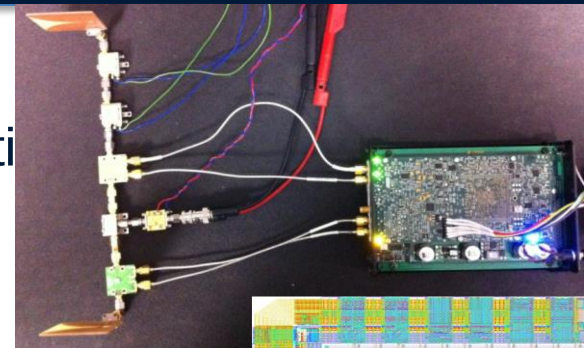
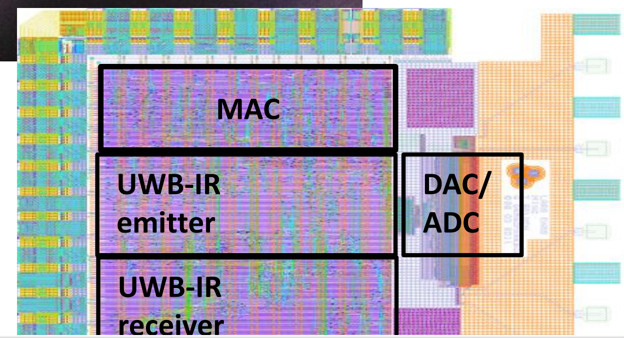
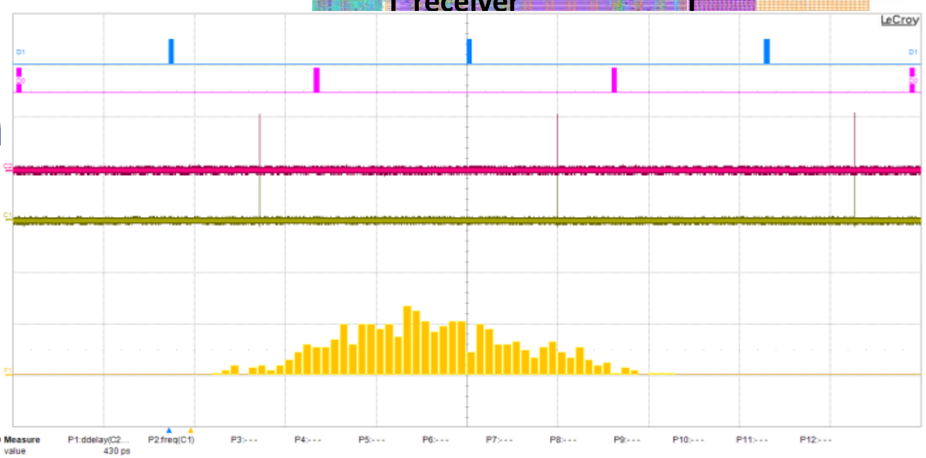


# MAC layer and clock synchronization

- Support high data rate
- Support real-time constraint (deterministi MAC)
- Include new service : precise clock synchronization
- FPGA prototype developed
- Energy efficient ASIC prototype developed including :
  - **TDMA MAC layer**
  - **UWB-IR transceiver ( emitter and receive**
  - **Fast DAC/ADC → power consumption to optimized further**
  - **Energy/bit: 100 pJ/bit**
  - **Clock synchronization precision < 1 ns**
    - **State of art: MIT (prof. Chandrakasan) →**
    - **IEEE PTP wired protocol– 50 ns**

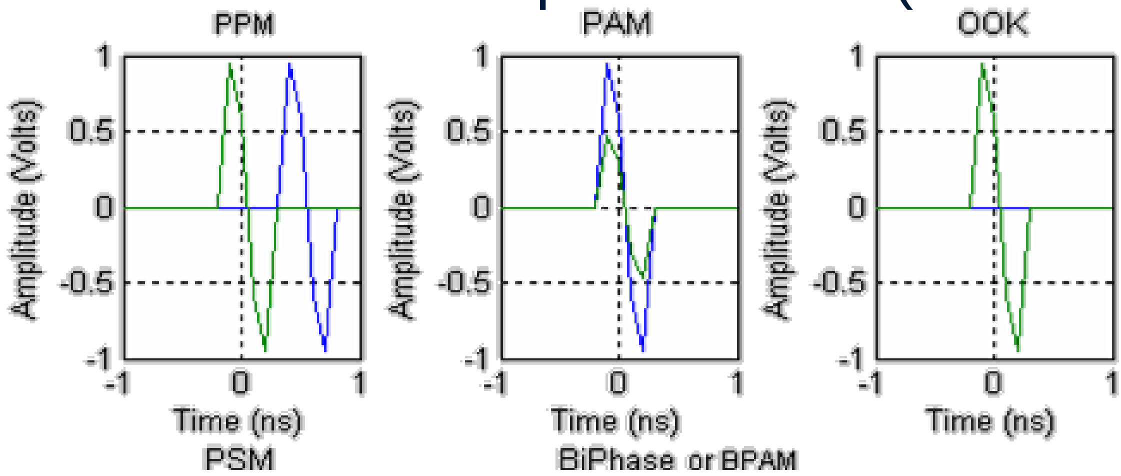




# UWB-Impulse Radio - Promising Technique for Energy Efficient WSN

- Using Ultra Wide Band-Impulse Radio (UWB-IR)




  - **Low power transmission : very short pulse**
  - **Short transmission range and high directivity →Low interferences between nodes**
  - **High number of communicating nodes in a small area**
  - **Fine temporary resolution → Localization**

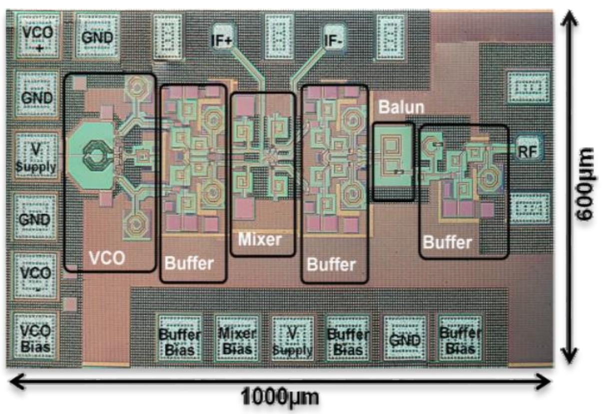
- Design approach : Mostly Digital

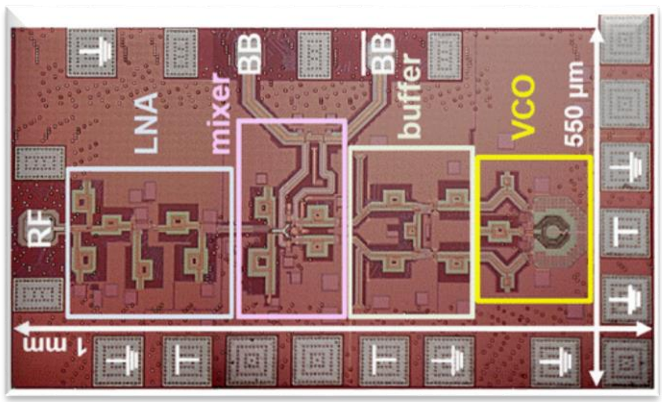
**Toward low power and low complexity transceiver able to be powered by energy harvesting**

# RF front-end @ 60GHz

- CMOS 65 nm ST Microelectronics technology

IEEE RFIC



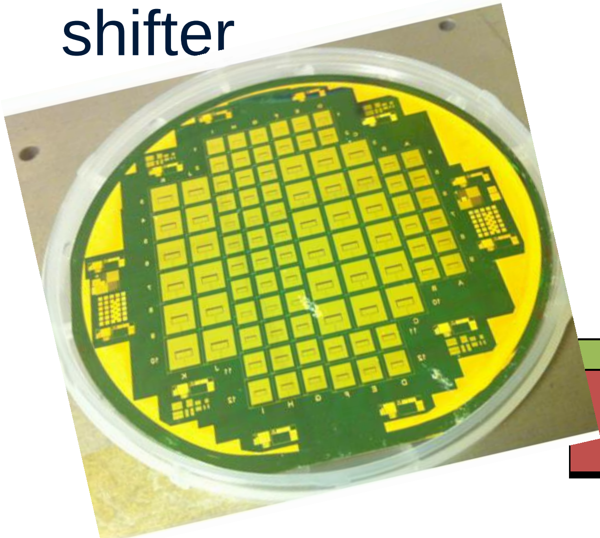

- Emitter
  - **Power consumption: 53 mW**
  - **Conversion gain > 5dB**
  - **Bandwidth: 10 GHz**

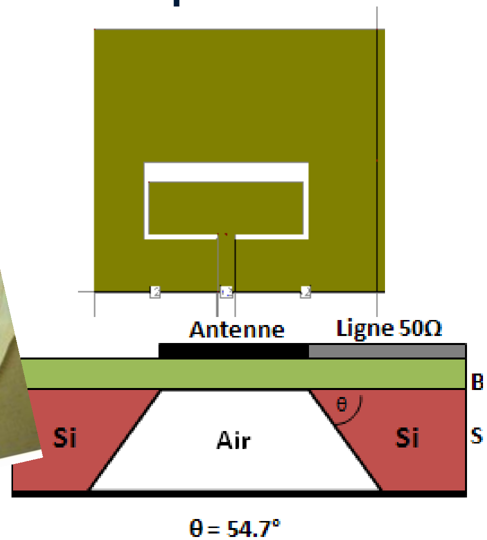
- **Receiver**
  - **Power consumption : 43 mW**
  - **Conversion gain : 30dB**
  - **Bandwidth :5 GHz**

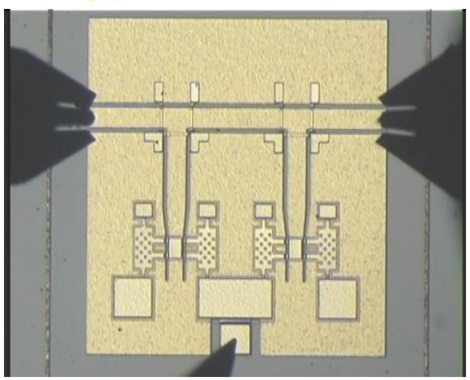
- Complete system (MAC – UWB-IR and RF front-end) transmission validated from
  - **30 cm - singe patch antenna without PA**
  - **up to 10 m – array antenna and PA (designed by IMS Bordeaux)**

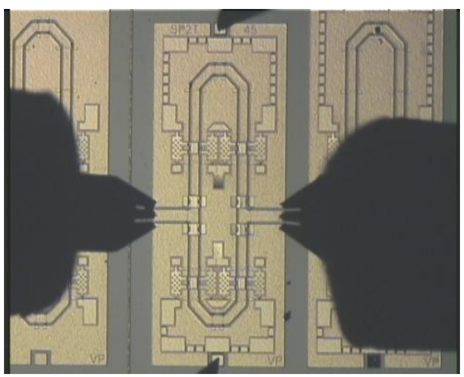
# Antenna

- Silicon integrated smart antenna with MEMS phase-shifter

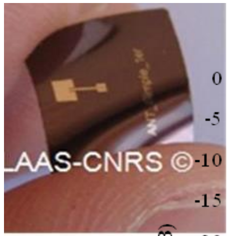


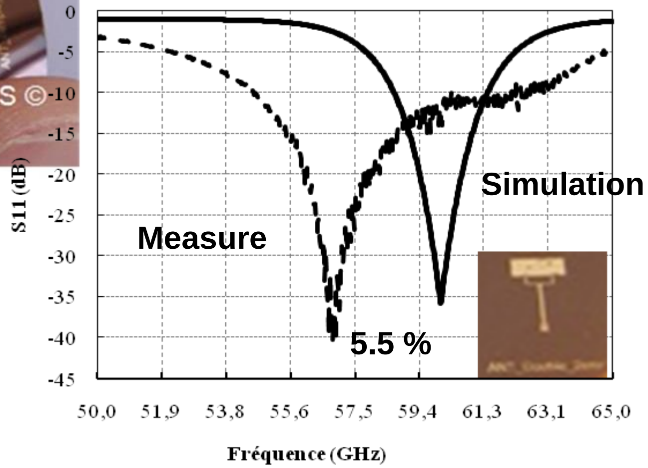


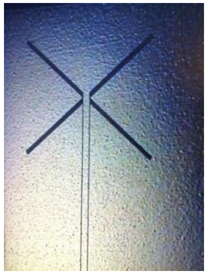


- **Antenna on flexible substrate**
- **Patch @ 60GHz**



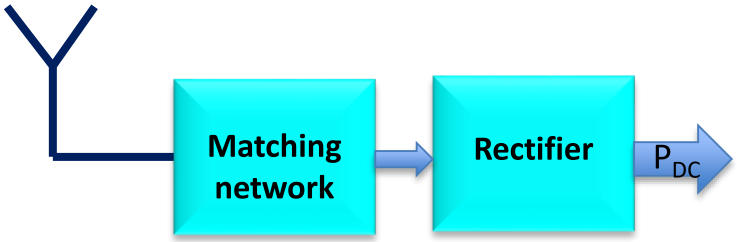



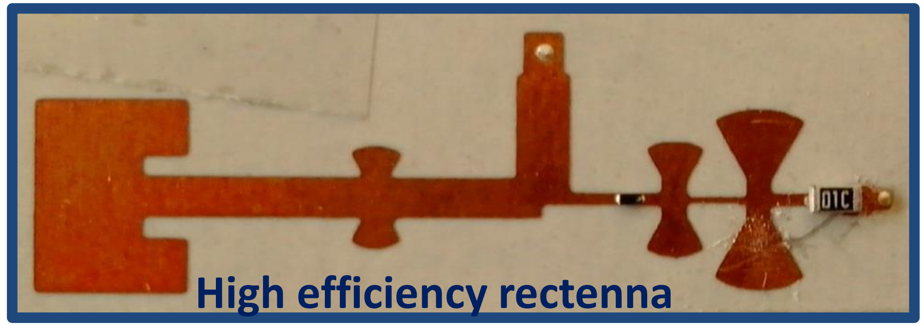

- **Cross-dipole slot antenna**



# EM Energy Harvesting

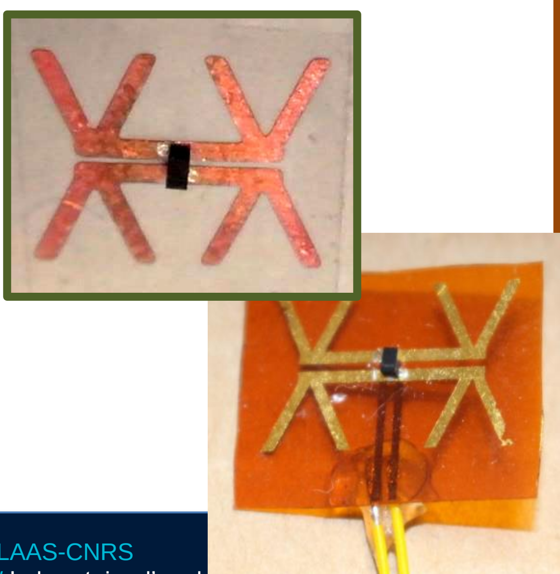
- **Objective:** powering (by harvesting the spill-over loss of microwave antennas) autonomous wireless sensors for structure health monitoring

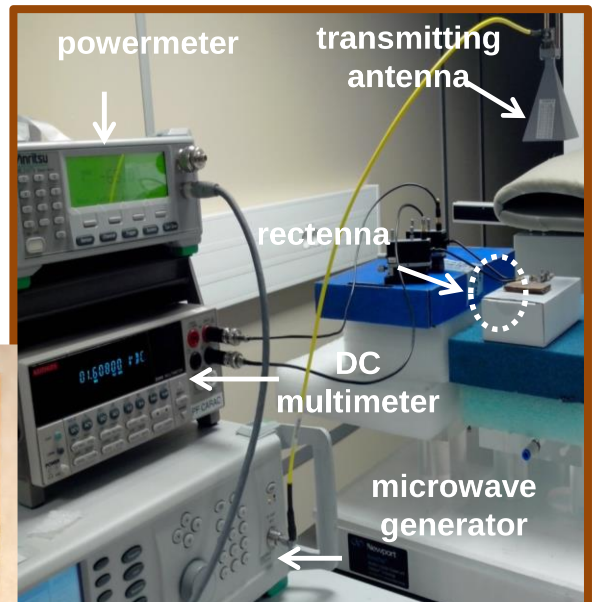


High efficiency rectenna

**Ultra-compact (2.5 cm$^2$) & broadband K-band rectenna**



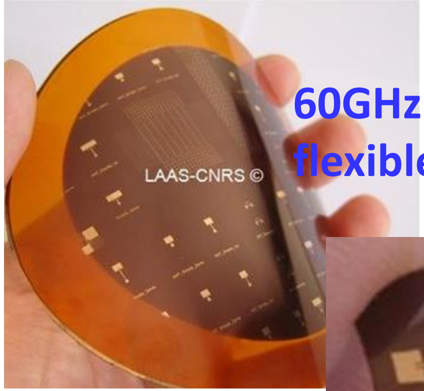



**Setup for rectenna caracterisation**

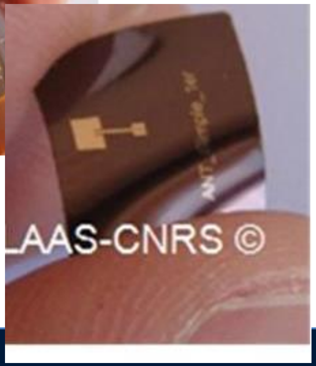
**DC harvested power – up to 2 mW for an $E_{field}$ = 80V/m**

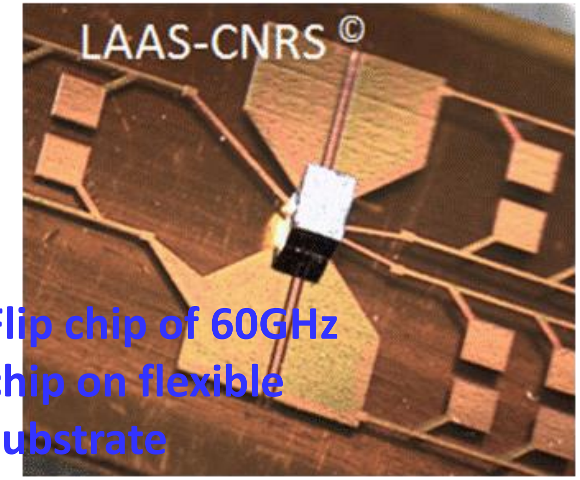
# Flexible substrate integration

- Objective: complete sensor communicating node integration on flexible substrate.
- 1st step : flexible substrate choice → Kapton for RF/microwave
- Challenge : flip-chip technology for microwaves chips
- Challenge : High efficiency antenna with wide bandwidt
  - **Prototype : patch antenna**
  - **Protoype : cross-dipole slot antenna**




**60GHz antenna on flexible substrate**




**Flip chip of 60GHz chip on flexible substrate**

- **$R_{Bump}$ ~ 15 mΩ**
- **RF loses $< 1$ dB**

**Major advantage of flexible substrate integration : facility to deploy the WSN nodes for any application**

# Conclusion

- WSN for SHM as enabler for safer, greener aircrafts:
  - **SoC Architectures – heterogeneous integration on flexible substrate integration for communicating nodes**
  - **Impulse radio UWB emitter on ASIC developed → very low power**
  - **60GHz architectures on ASIC**
  - **Measurements synchronization**
  - **Energy harvesting**
  - **Demo on You Tube:**

**https://youtu.be/f1-i81rY-js**

# Thank you for your attention !