Innovative embedded sensors for power electronic modules: CAPTIF – ANR research project

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CAPTeurs innovants Intégrés et logiciels au cœur d'un dispositiF d'électronique de puissance

ANR-14-CE05-0044

Agenda

1. Main features of the CAPTIF project : partnership, context
2. Scientific and technical objectives
3. Main facts : what is expected ?
4. Organisation : deliverables, workpackages
5. Oustanding results : per WP
6. Conclusions

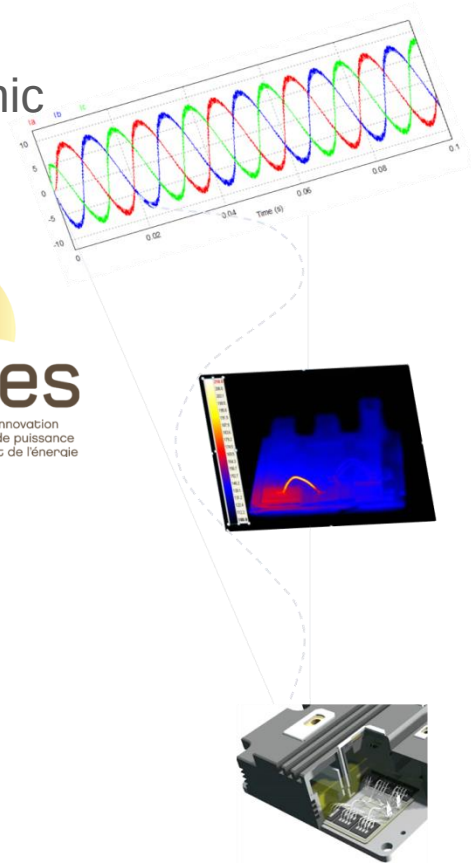
Partnership

CAPTeurs innovants **I**ntégrés et logiciels au cœur d'un dispositi**F** d'électronique de puissance.

Embedded innovative sensors and software in power electronic components.

Partnership :

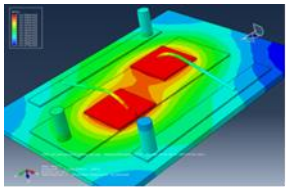
Laboratoire Génie de Production — ims — Nanolike NANO ENGINEERING — aPSI 3D — Primes Plate-Forme d'innovation Mécatronique de puissance et Management de l'énergie

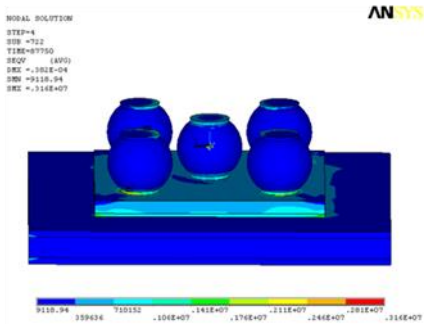


2 research laboratories,
3 industrial partners.
Starting time : 5/01/2015
Duration : 42 months
Letter of interest of AIRBUS.

Context

- New power devices : SiC, GaN…
- Efficiency : improvement of power electronics
- Behavioral study
  - Modeling and simulation,
  - Reliability,
  - Insight measurement.





- To be delivered :
  - Tools for integrated sensors,
  - Design of innovative sensors,
  - Integrated of sensors
  - Data processing technics,
  - Reliability comparison – embedded sensors into power modules.

Scientific objectives

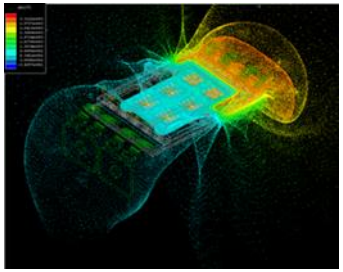
Improvement of the scientific skills in high integrated embedded systems:

- Multi scale power electronics integration;
- Multi physics design, model and characterization – simulation of thermo mechanical and electromagnetic challenges;

Key issues in overall 3D real–time behavior of mechatronic devices.

Optimize the availability of power electronic devices that match the following needs:

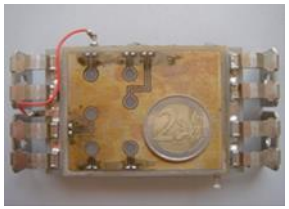
- Reliability and robustness;
- Monitoring and diagnosis of power devices health avoiding oversized devices – minimizing conventional protection for thermo mechanical and electromagnetic constraints.

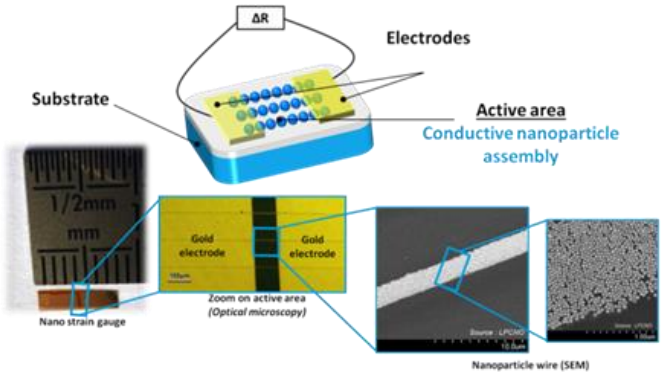


Technical objectives

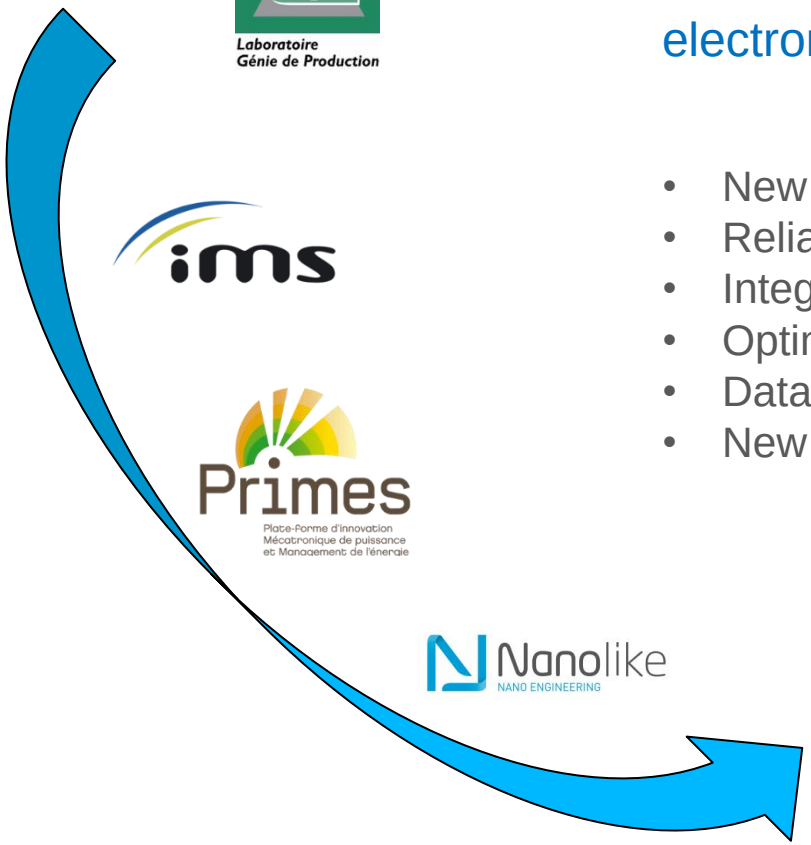
Design and integration of a sensor network:

- Temperature (based on the Nanolike‘s sensor technology)
- Strain gauge (based on the Nanolike‘s sensor technology)
- Electromagnetics Near-Field array (based on LGP‘s sensor technology).
- Virtual prototyping by Finite Elements Modeling of sensor based power modules:
  - Design optimization
  - Lifetime estimation under real mission profile of specific design;
- Data processing issued from the sensor network for:
  - Data packaging by transforming the physical treatment measures into data
  - Diagnosis and health status monitoring;
  - Overall system prevention.





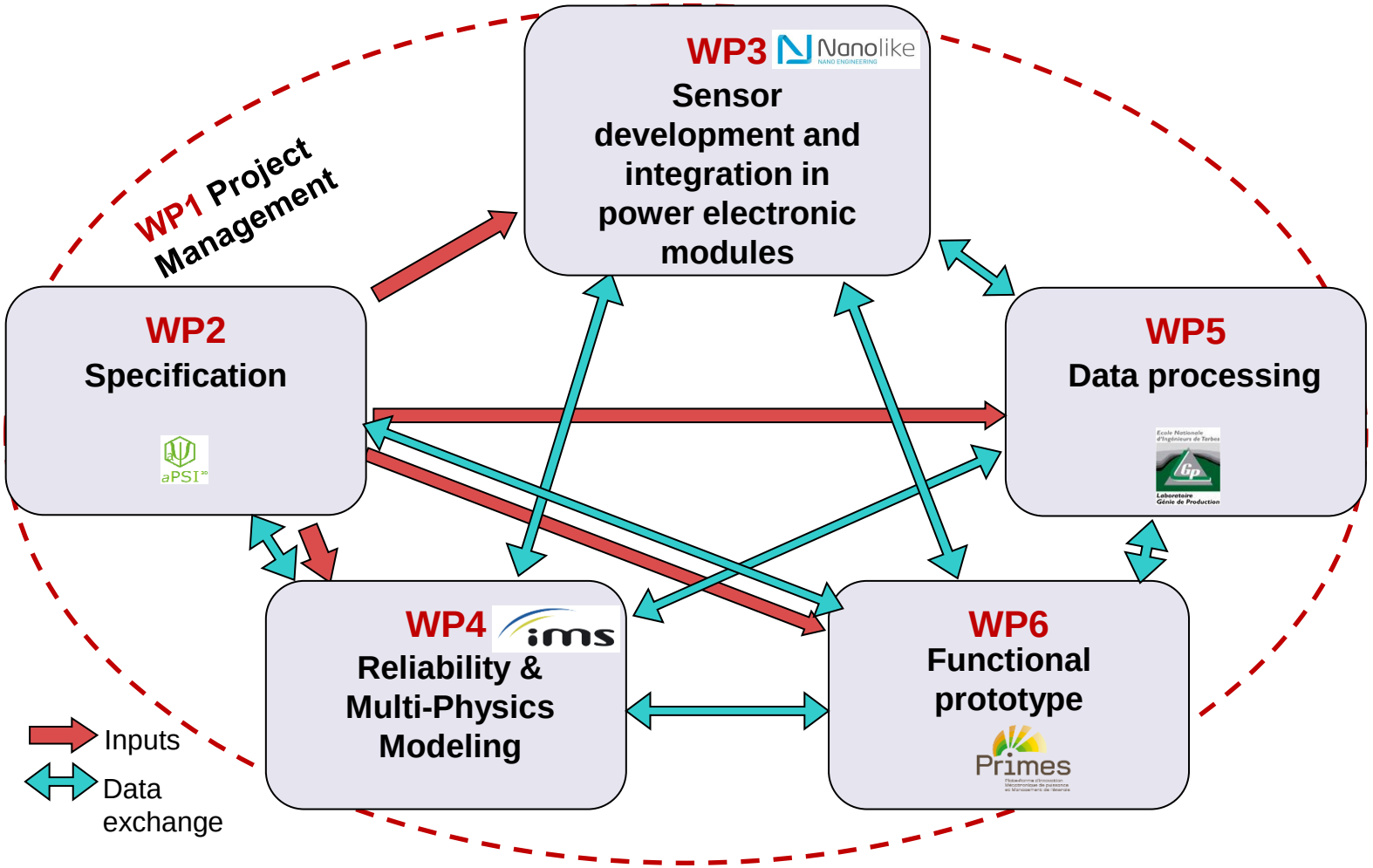
What is expected ?



From the idea to the higher power density of power electronic modules

- New ideas and processes for integrated power modules
- Reliability numerical modeling,
- Integrated set of sensors,
- Optimized modules and components,
- Data processing,
- New products and new markets.

Workpackages



Deliverables

WP3 Sensor development and integration in power electronic modules:

- Test report on nanoparticle-based sensors: strain gauges and temperature sensors
- Test report on electromagnetic field sensors study, design, spec, prototype validations.
- Design of output sensor data packaging board.
- Feasibility prototypes: elementary power electronics module with multiple integrated sensors.

WP4 Reliability & Multi-Physics Modeling:

- Multi-physics modeling and experimental data for sensors routing.
- Multi-physics modeling and reliability data for the contribution to design a health and self-monitoring power module.

WP5 Data processing:

- Supervision algorithms for power electronics devices.
- Functional device and the data processing: integration of the algorithms on the device.

WP6 Functional prototype:

- 3D Model of the power cell - Flowchart process Report - 20 functional prototypes.
- Electrical characterization Report.
- Reliability Report.

Temperature and strain sensors

Nanoparticle-based sensors

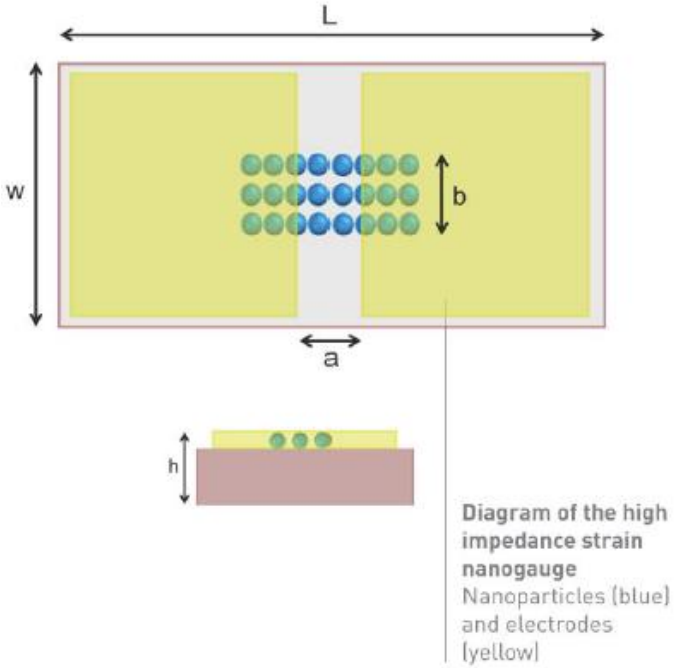
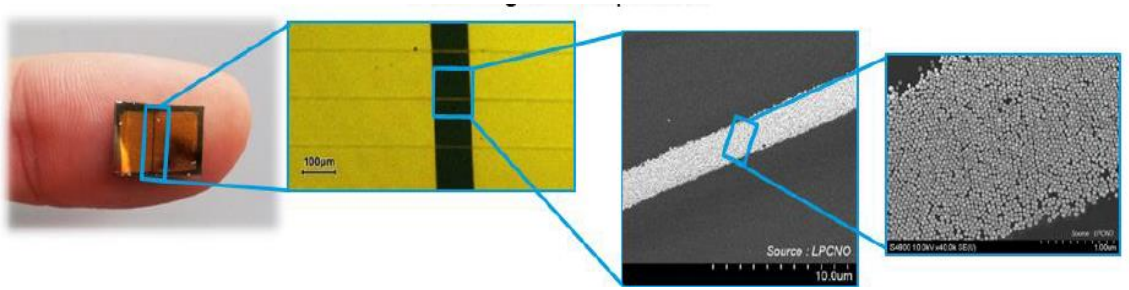
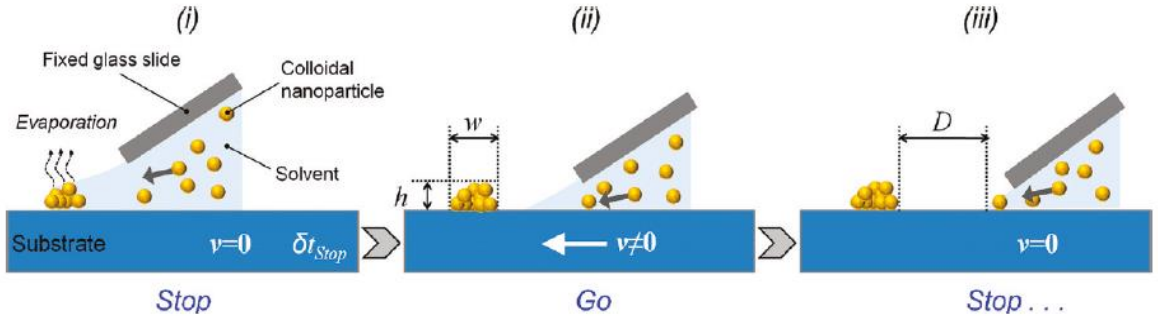


Diagram of the high impedance strain nanogauge
Nanoparticles (blue) and electrodes (yellow)

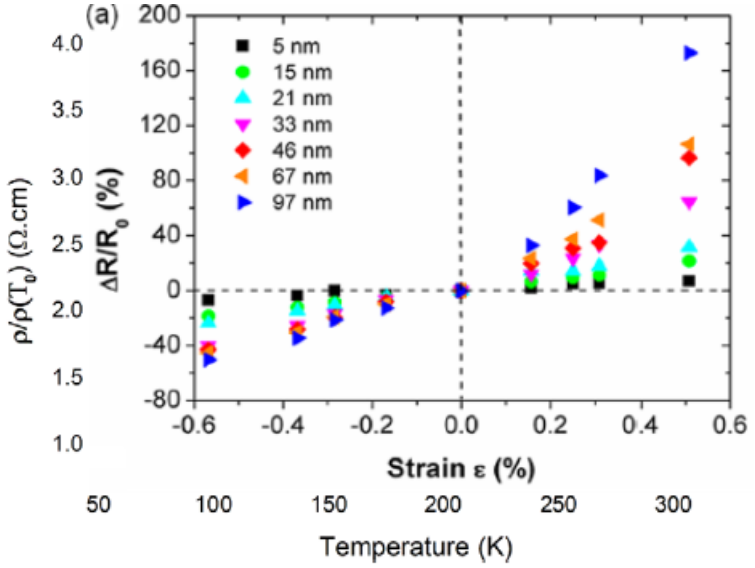




Nanoparticles, ligands, substrate ?

Temperature and strain sensors

Analysis for choice for Au nanoparticles



Following the possible ligands, the relative resistivity may vary !

Diameter of nanoparticles : compromise !

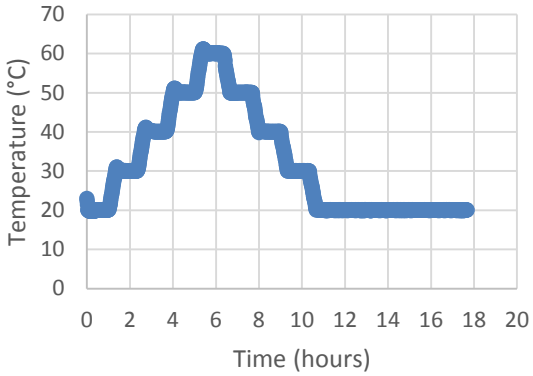
- $\sim 10^{\circ} nm$

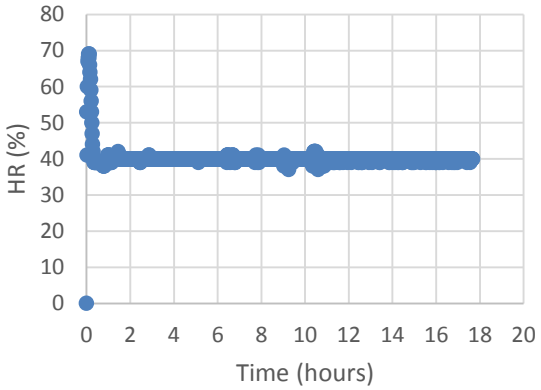
2 substrates : $Si0_2$ and Polyimide

Decision = compromise and possible processability

Temperature and strain sensors

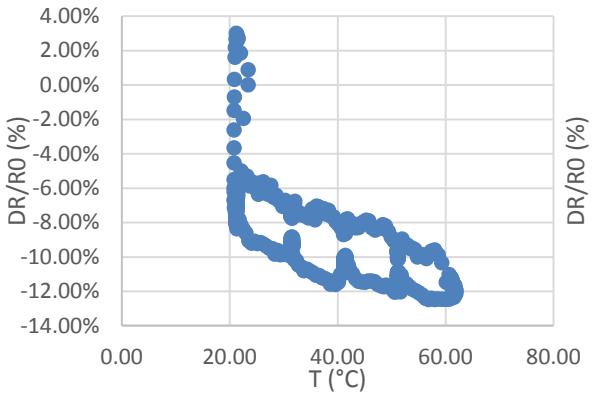
First steps for sensor characterization : preliminary tests

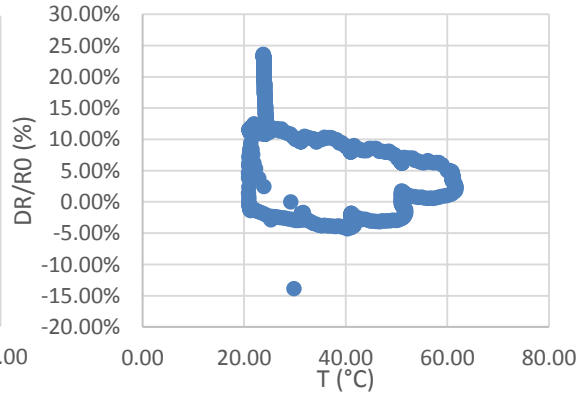




Temperature coefficient of gauge factor :

$$\frac{R_{T1} \_ R_{T0}}{R_{T0}} \cdot \frac{1}{T1 - T0}$$



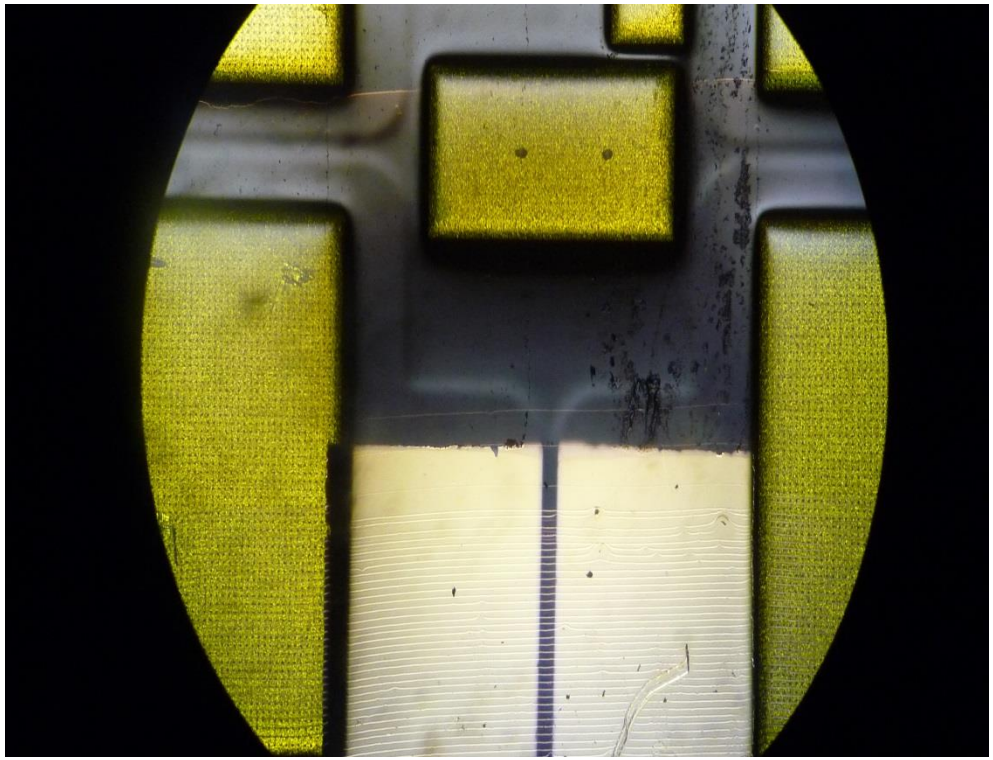


The repeatability was not insured !

- Pb identified and fixed
- A limited maximum temperature.

Temperature and strain sensors

First integration test on power dice - IGBT 650V/300A



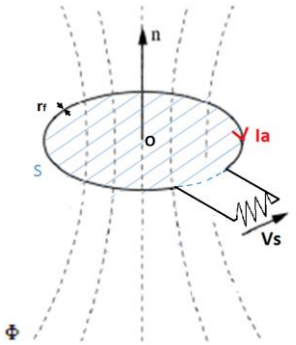
Operating area
400*400µm²

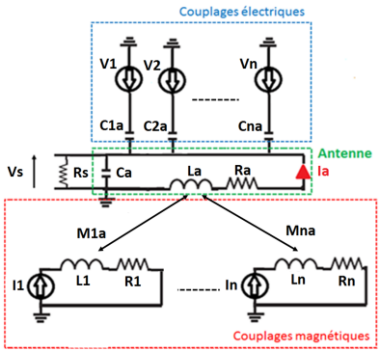
Zone identified;
Pasted sensors :
- Strain sensors
- Temperature sensors.

Integration test.

Coming next :
- Reliability survey of the integrated assembly
- Measurements.

Electromagnetic sensors



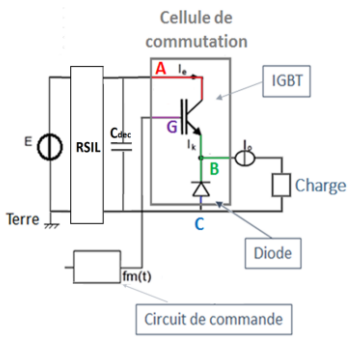


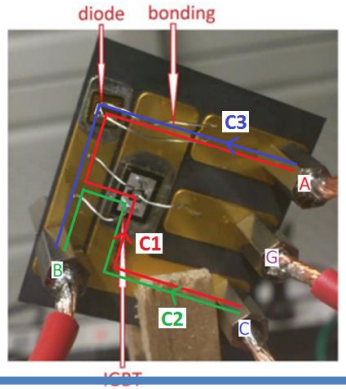
Study split as:

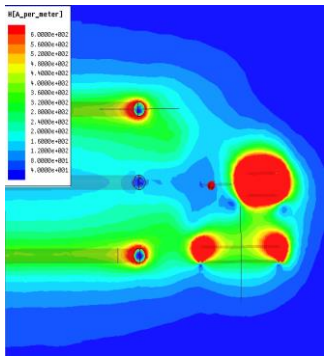
- Near field electromagnetic measure;
- Design of antennas for power modules;
- Characterization;
- Integration and validation.

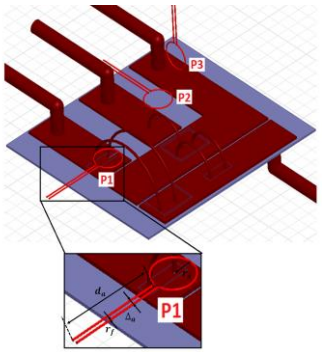
- Magnetic fields => near field assumption;
- Antenna position !
- Model the couplings.

$$e = -\frac{d\phi}{dt}, \qquad \phi = \iint_S \mu \vec{H}.\vec{n}\, dS$$







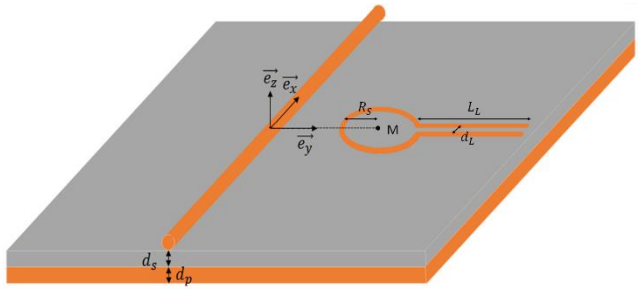


Current path flow => Several frequencies => Radiated $\vec{H}$ => antenna position

Electromagnetic sensors

Design of antennas for power modules

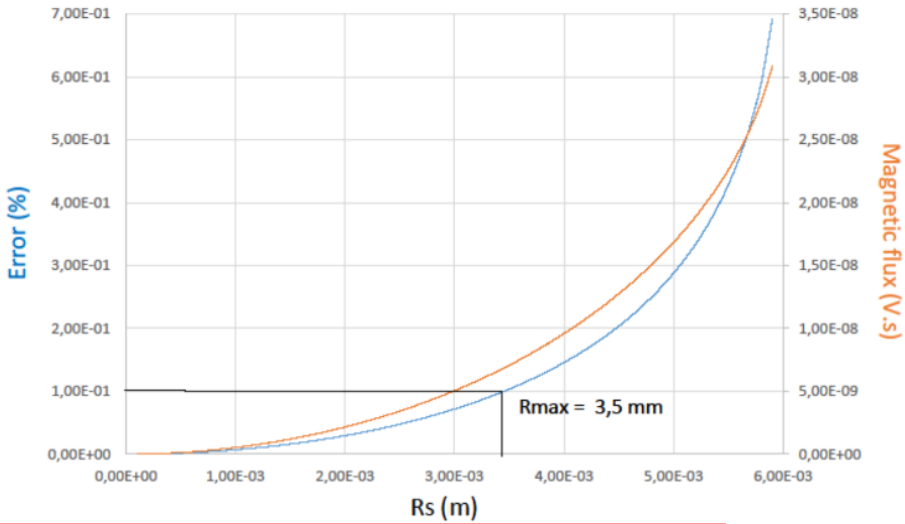
- A punctual receiver;
- No effect on the magnetic field distribution;
- Only the magnetic field;



- Study of the substrate constitution influence on the radiated field;
- Size and geometry of loop;
- Influence of the transmission line;

$$\phi = \mu * \int_{x=-R_S}^{R_S} \int_{y=y_M-\sqrt{R_S^2-x^2}}^{y_M+\sqrt{R_S^2-x^2}} H_z(y, z_M).\, dxdy$$

$$\varepsilon = \frac{\left(\phi - \mu S * H_z(y_M, z_M)\right)}{\mu S * H_z(y_M, z_M)}$$

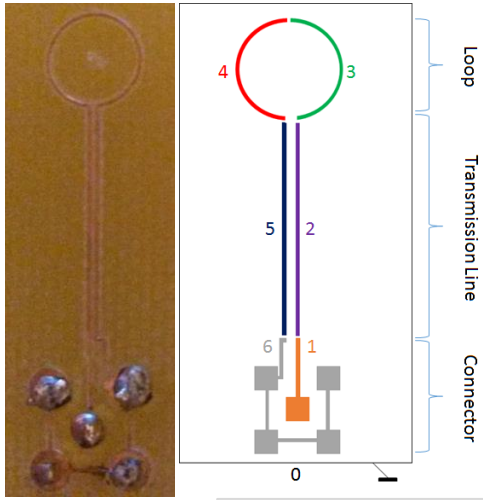


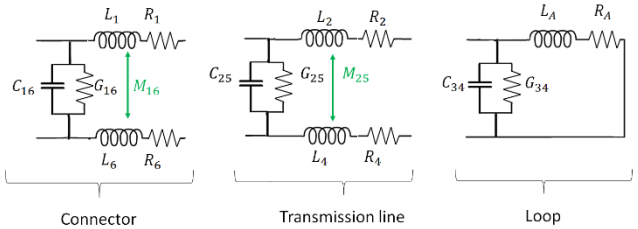
$1\ kHz < f < 1\ GHz$ antenna design and position

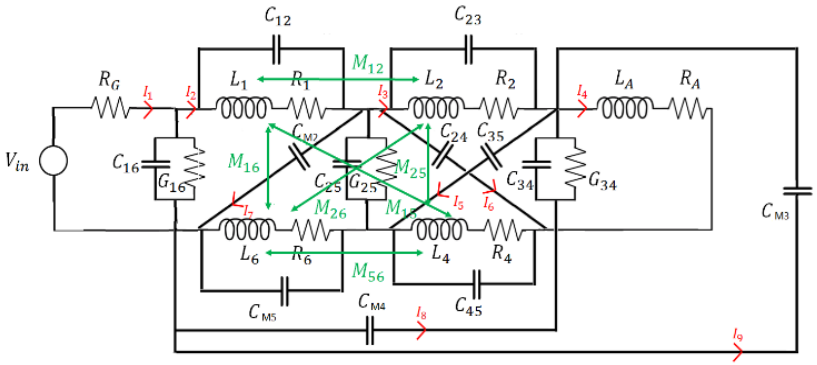
Electromagnetic sensors

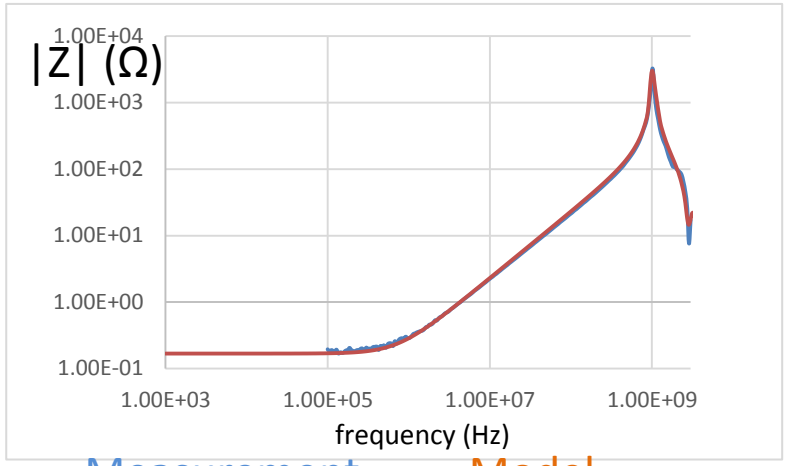
Characterization

- Isolated antenna;
- Transmission line;
- Connectors;
- Model and measures.







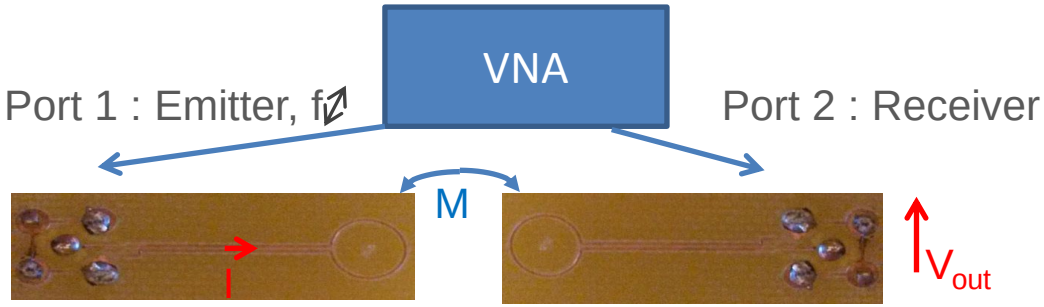


-- Measurement -- Model

Electromagnetic sensors

Characterization

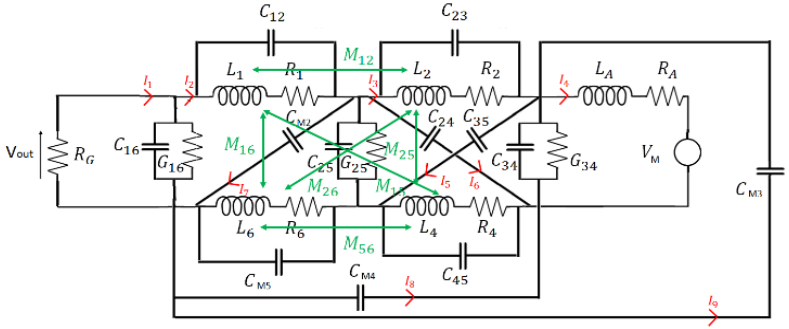
- Coupled antenna;
- Emitter: I ⇔ B;
- Receiver: V_m.

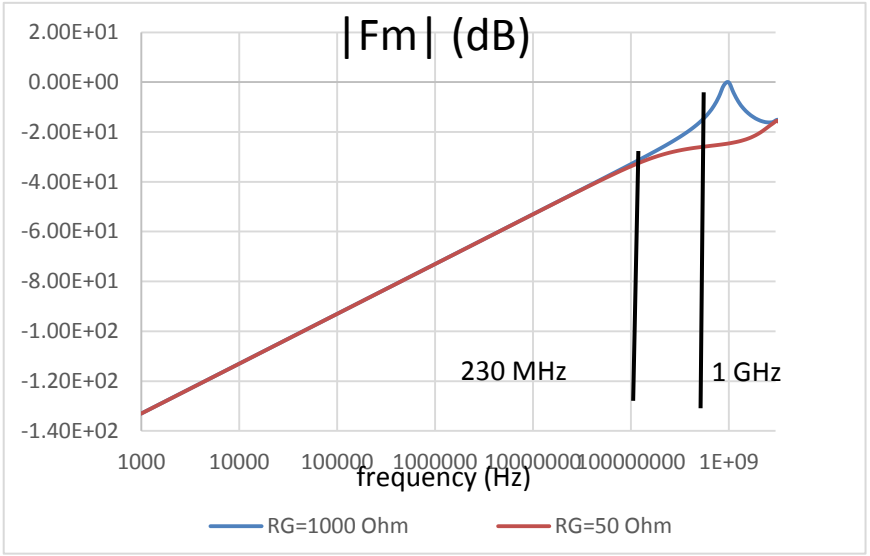


Antenna factor:

$$V_m = j\omega BS$$

$$F_m = \frac{V_{out}}{B}$$





Coming next :

- Measurements with the “simple” power module

Conclusion

Achieved:

- Nanoparticle-based sensors: strain gauges and temperature sensors;
- First attempt of integration;
- Electromagnetic field sensors study, design, first prototype validations.
- Design of output sensor data packaging board.

To be done:

- Improve reliability (measurement) of nanoparticle sensors;
- Increase their temperature functioning range;
- Functionalize them.
- End of testing electromagnetic sensors to entirely validate their coefficient factor.

Thank you.