Nanoelectronics for Electric Vehicle Intelligent Failsafe PowerTrain (MotorBrain)

Coordinator: Infineon Technologies AG (Germany)

SC 6 – TORQUE SENSOR DEVELOPMENT

OBJECTIVES:

- concept development, design, simulation and realization of a torque sensor demonstrator

TEAM

National Institute for Research and Development
for Microtechnologies – IMT Bucharest (IMT)

Dr. Gabriel MOAGĂR-POLADIAN
Phys. Cãtãlin TIBEICĂ
Phys. Eng. Victor MOAGĂR-POLADIAN
Eng. George BOLDEIU

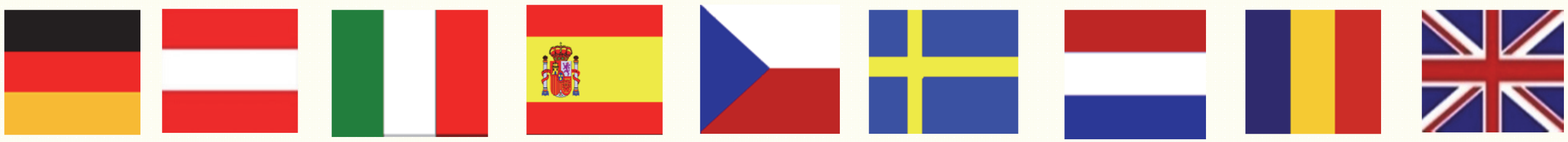
Infineon Technologies Romania (IFRO)

Eng. Răzvan-Cătălin MIALŢU
Eng. Marian BĂNCUŢĂ

Nanoelectronics for Electric Vehicle Intelligent Failsafe PowerTrain (MotorBrain)

Towards Horizon 2020 Societal Challenge: Smart, green and integrated transport

Participating countries:



DE AT IT ES CZ SW HL RO UK

After EC Review Meeting (Year 2) → project proposed for "ENIAC Innovation Award"

TORQUE SENSOR - TEAM RESPONSIBILITIES

IFRO:

- **Supply Chain SC6 leader**

IMT:

- **Deliverable Responsible**: D3.12 - Delivery of physical transducer for torque sensor
- **Deliverable Responsible**: D4.15 – Torque sensor Transducer Demonstrator (including magnetic sensor and electronics)
- Responsible of the Romanian team (IMT+IFRO) on administrative matters (contact with authorities)

Supply Chain 6 - to develop a torque measurement concept

- the innovation will focus on novel concept of magnetic source and magnetic sensor interaction.
- the concept will be checked and validated using advanced analysis and simulation techniques and will be concluded with the manufacture of a demonstrator.

MOTOR BRAIN

eniac JOINT UNDERTAKING

TORQUE SENSOR - PARTNERS IN SC6 AND COLLABORATORS

TECHNISCHE UNIVERSITÄT DRESDEN — component testing for component validation

Infineon — torque measurement sensor device

IMT — torque sensing apparatus

The University Of Sheffield. — fault tolerant machine architectures

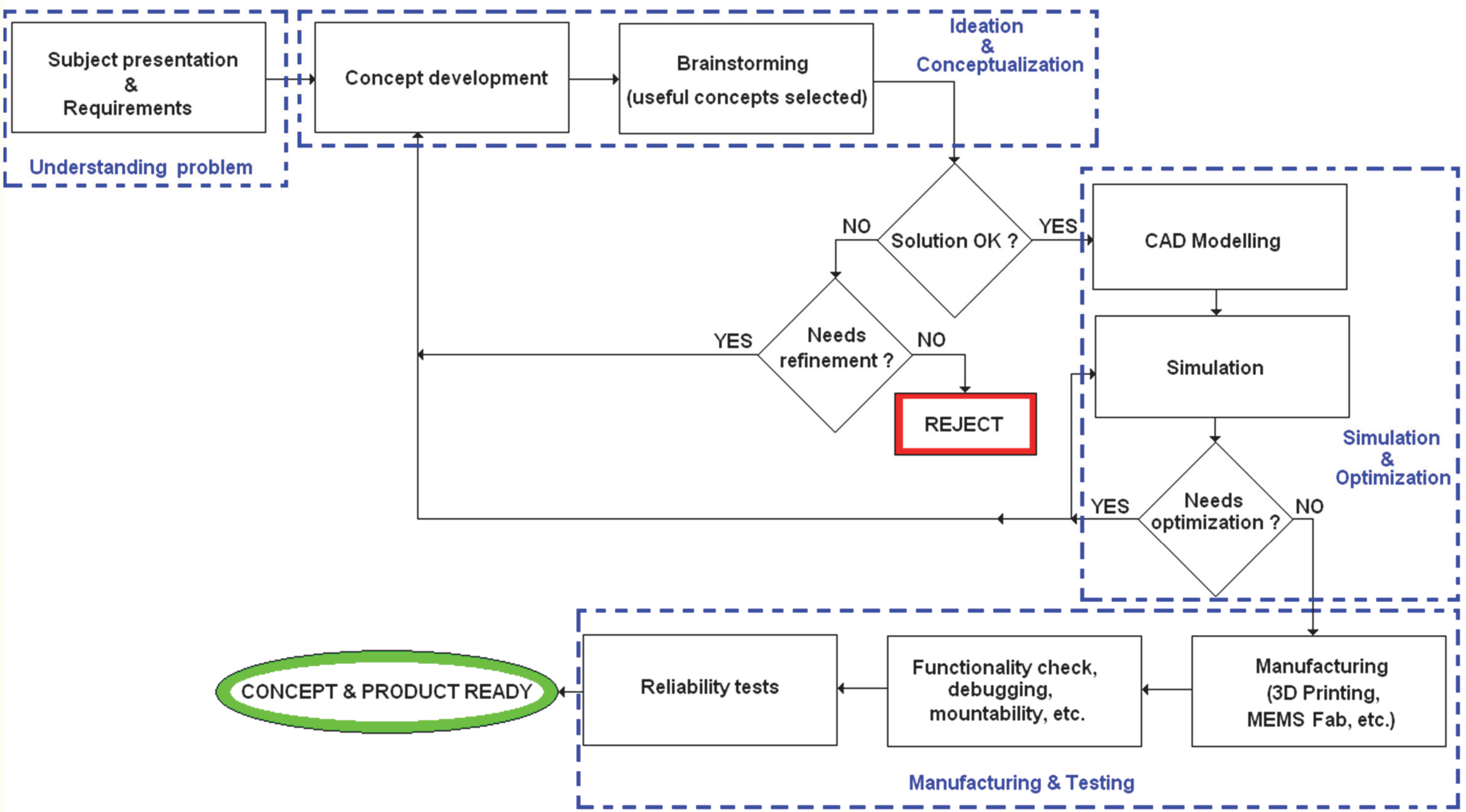
data converters

TORQUE SENSOR REQUIREMENTS

- Torque range: max. 300 Nm
- Measurement accuracy : 1 % (3 Nm)
- Rotation speed: 10.000 rpm
- Maximum temperature: $+180^{0}$ C

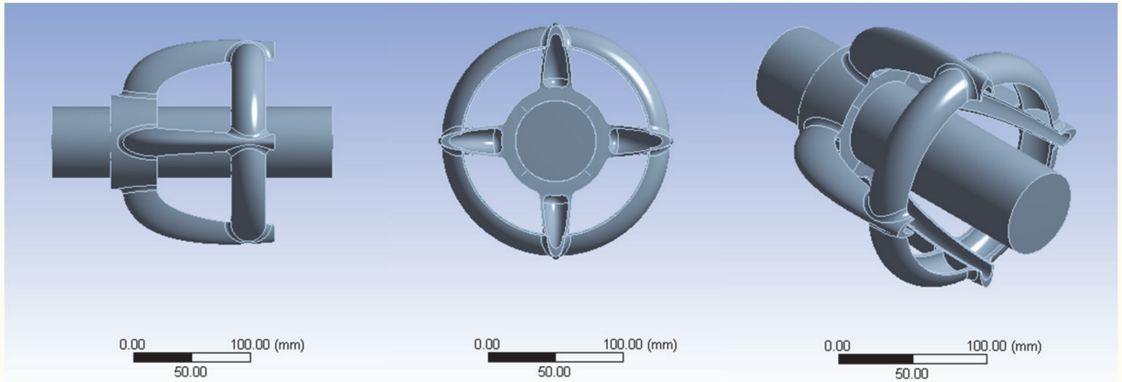
- Be able to measure both static and dynamic torque
- Redundancy
- Linearity
- Discrimination between:
    - torque and angular acceleration
    - torque and shaft elongation
    - torque and shaft bending
- It must not be influenced by the surrounding electromagnetic noise
- Temperature, vibrations, mechanical stresses must not influence the torque measurement
- Be as small as possible
- Be based on magnetic sensors as those developed by Infineon Technologies Romania

TORQUE SENSOR ENGINEERING APPROACH

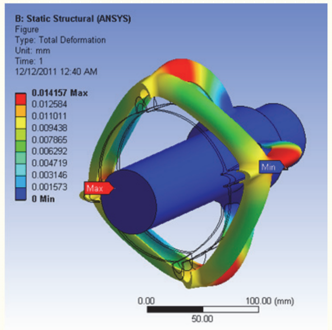


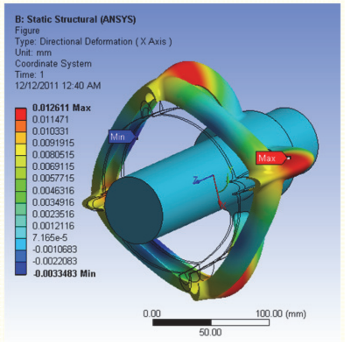
TORQUE SENSOR CONCEPT DEVELOPMENT – Initial structure

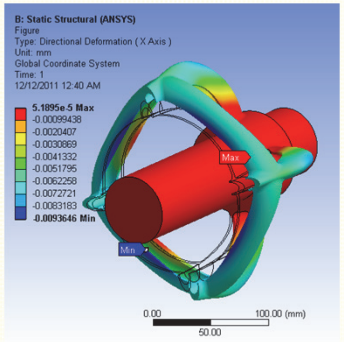
- we started from the principle “all-on-the-shaft”
  → all the components (transducer, sensors, etc.) mounted on the shaft
  → the energy supply / signal extraction acquired by capacitive means

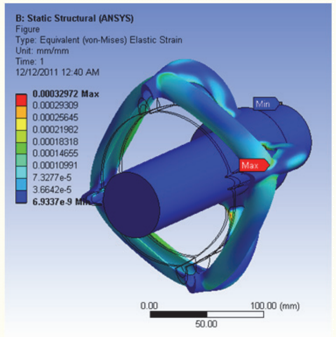


The initial transducer structure. Left: lateral view of half of the transducer; Center: axial view of half of the transducer; Right: izometric view of half of the transducer.



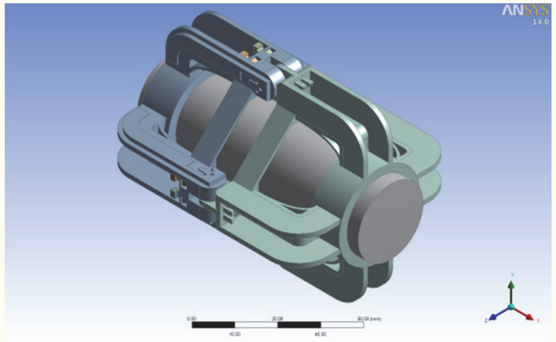




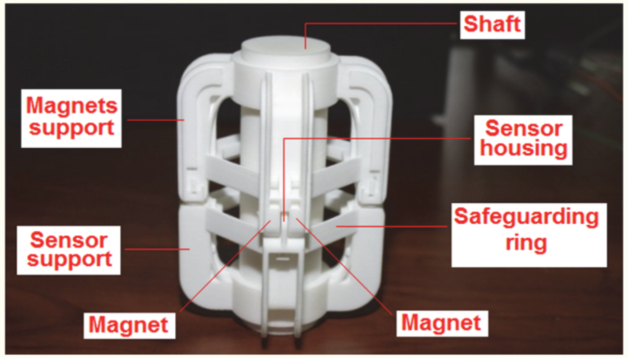


Simulation results for the initial transducer (half part). Far left: Total deformation due to centrifugal force; Left: Radial deformation under centrifugal force; Right: Axial deformation under centrifugal force; Far right: Relative elastic deformation under centrifugal force.

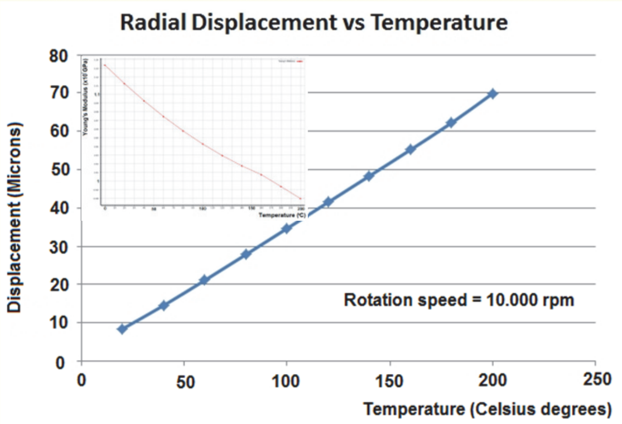
TORQUE SENSOR CONCEPT DEVELOPMENT – Improved structure



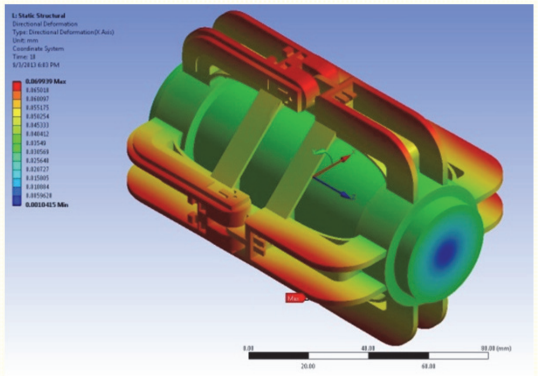
The optimized geometry of the torque sensor



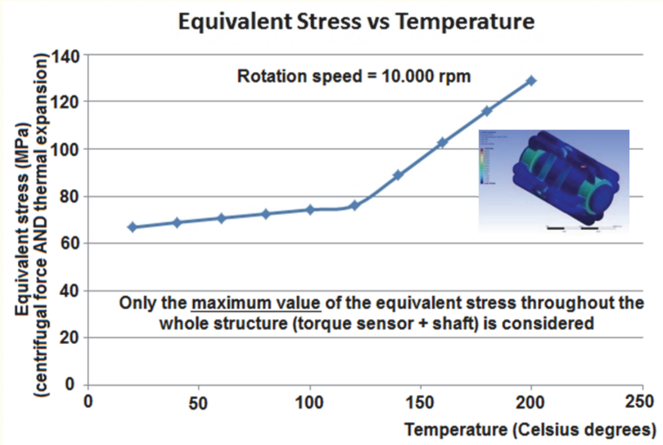
Beta version of the torque sensor (sensor part) made by Selective Laser Sintering of polymer (polyamide PA2200)



The effects of centrifugal force and thermal expansion are considered.



Radial displacement at 10.000 rpm rotation speed and a temperature of 200^0 C



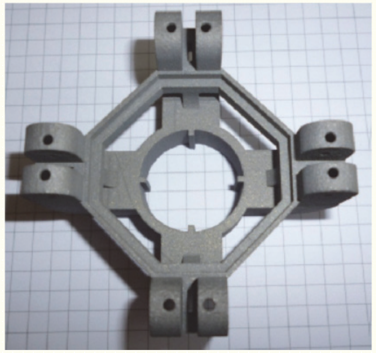
The effects of centrifugal force and thermal expansion are considered.

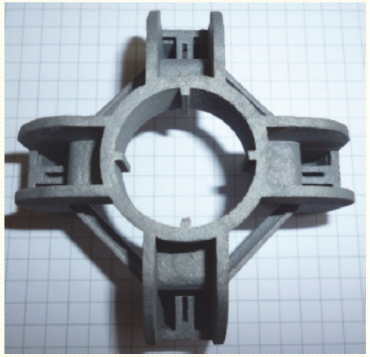
First resonance frequency (eigenmode):

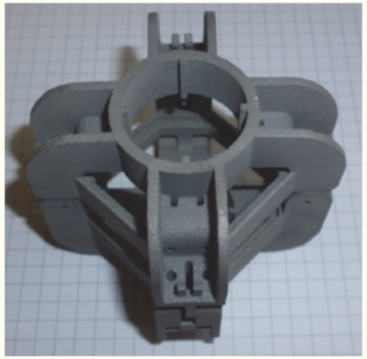
- 2794,700 Hz @ 20^0 C, 10.000 rpm
- 2635,60 Hz @ 200^0 C, 10.000 rpm

ALL REQUIREMENTS ARE FULFILLED !

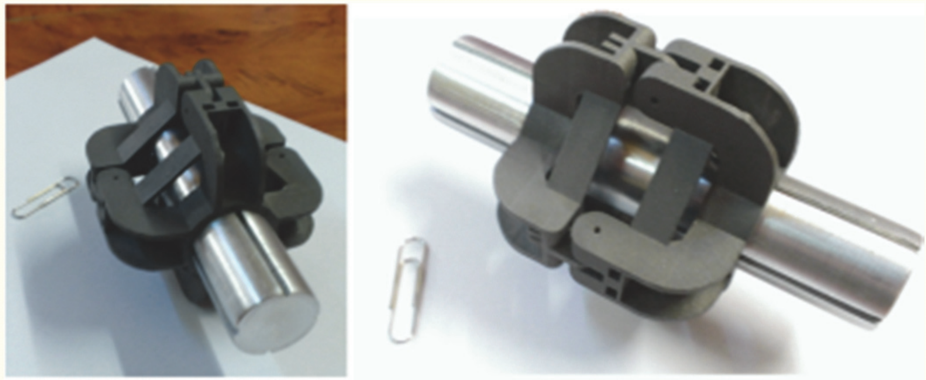
TORQUE SENSOR - FINAL (METAL) VERSION







The metal parts after post-processing (support structures removal and shotpeening (the part containing the magnets).
Far left: photo of the magnet containing part; Left: photo of the magnetic sensor containing part;
Right: photo of the assembled parts; Far right: photo showing the real size of the parts.



Torque sensor mounted on a metallic shaft (not final shaft)

Metal parts were made by order at EOS GmbH by using DMLS (Direct Metal Laser Sintering) on a M280 machine

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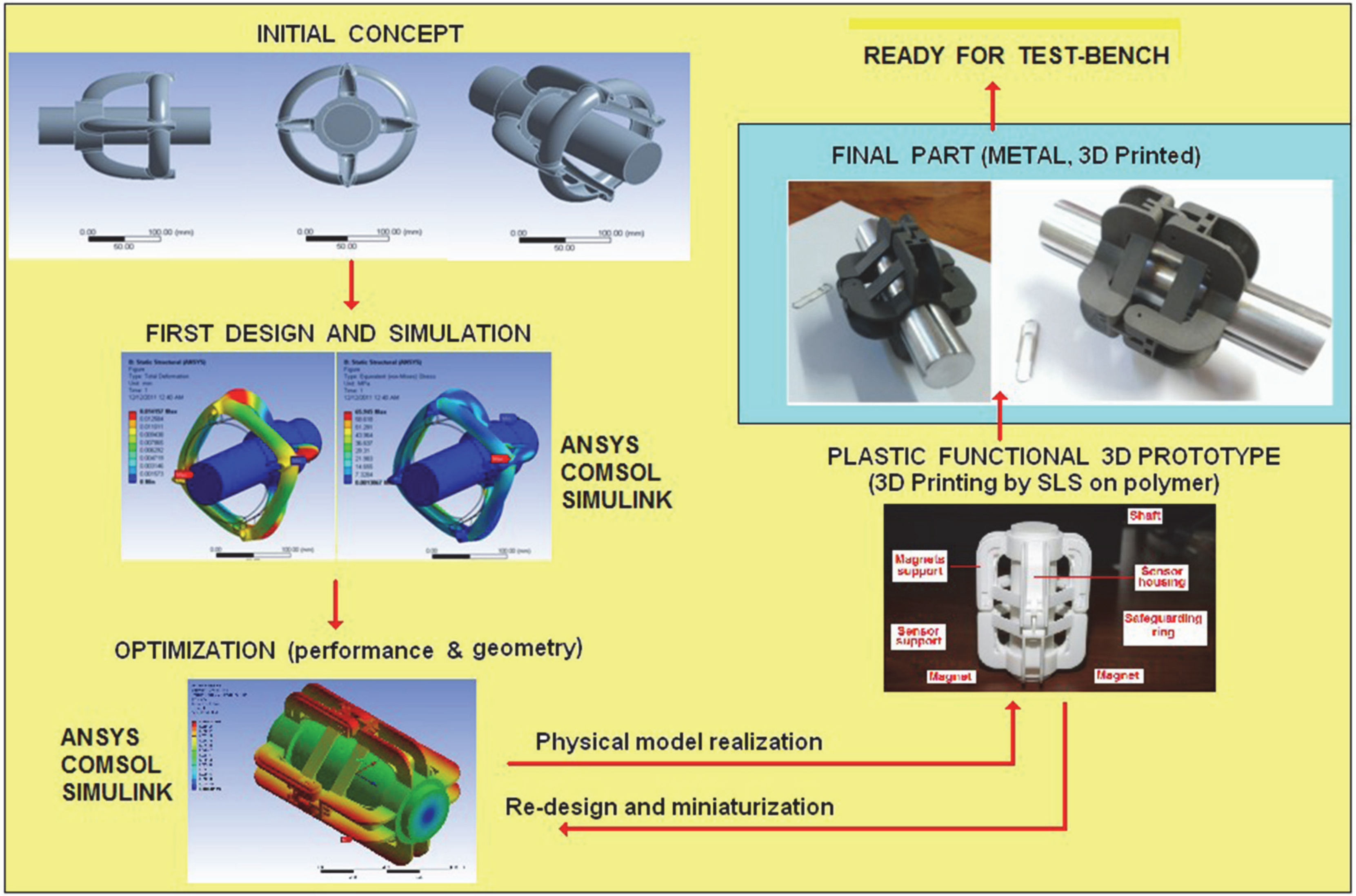
eniac JOINT UNDERTAKING

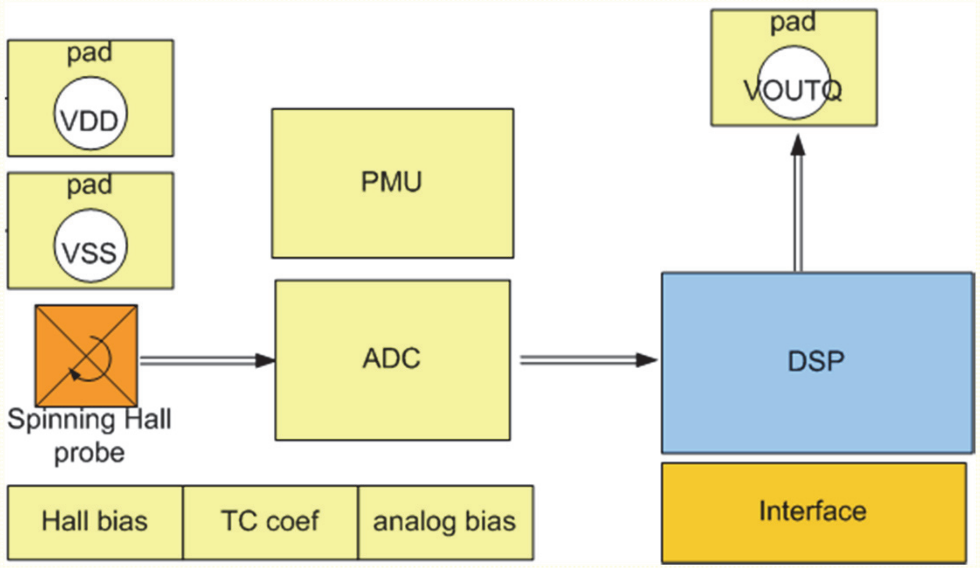
TORQUE SENSOR - WORK SCHEME



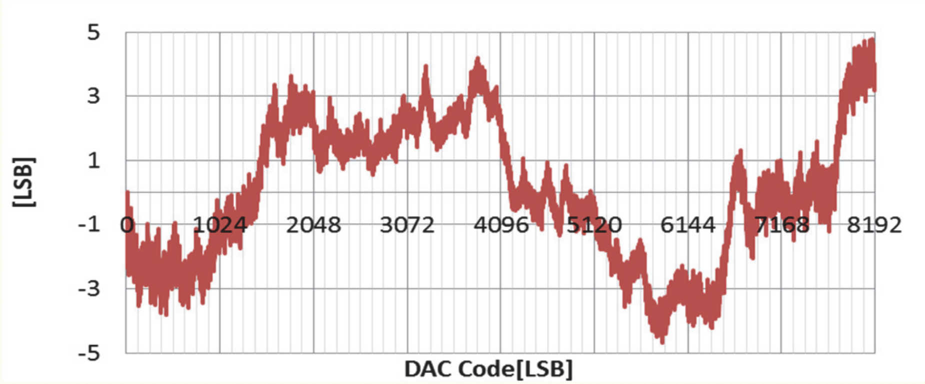
= infrastructure existing at IMT

= infrastructure not existing at IMT

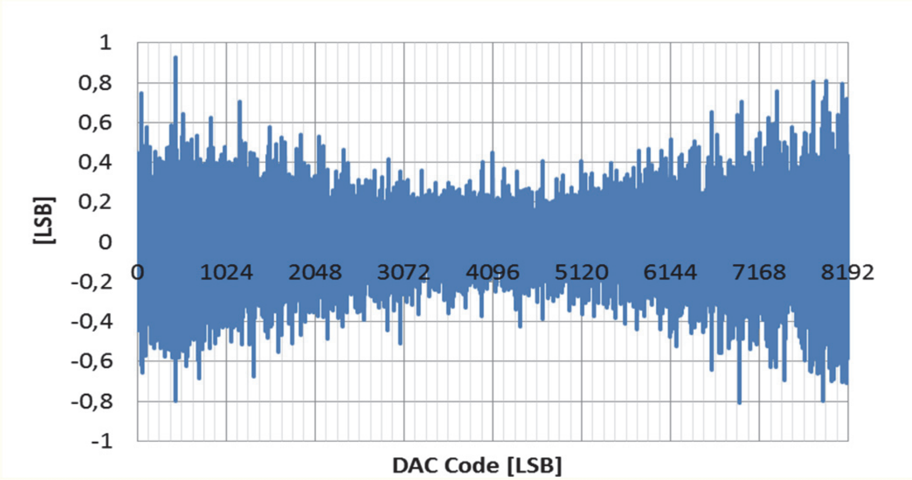
TORQUE SENSOR - MAGNETIC FIELD SENSOR



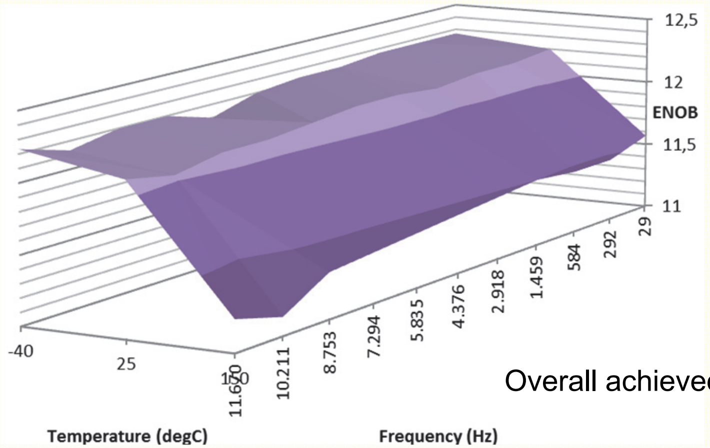
Architecture of developed linear magnetic sensor



Integral Non-Linearity measured under 5 LSB (an equivalent ENOB of 11 LSB)

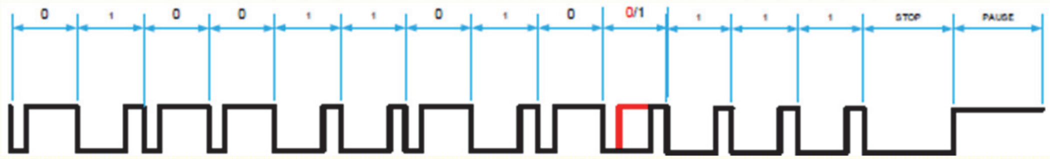


Differential Non-Linearity measured under 1LSB

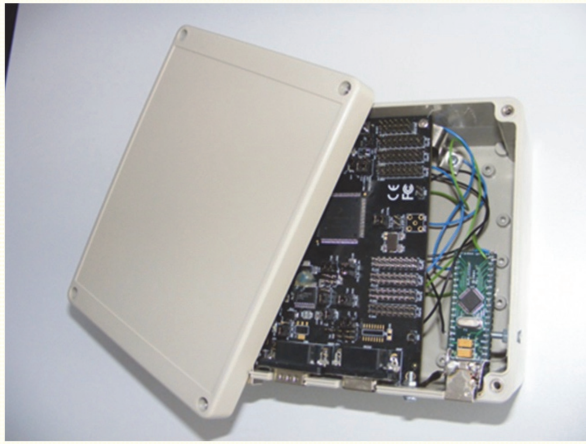


Overall achieved performance for conversion (ENOB)

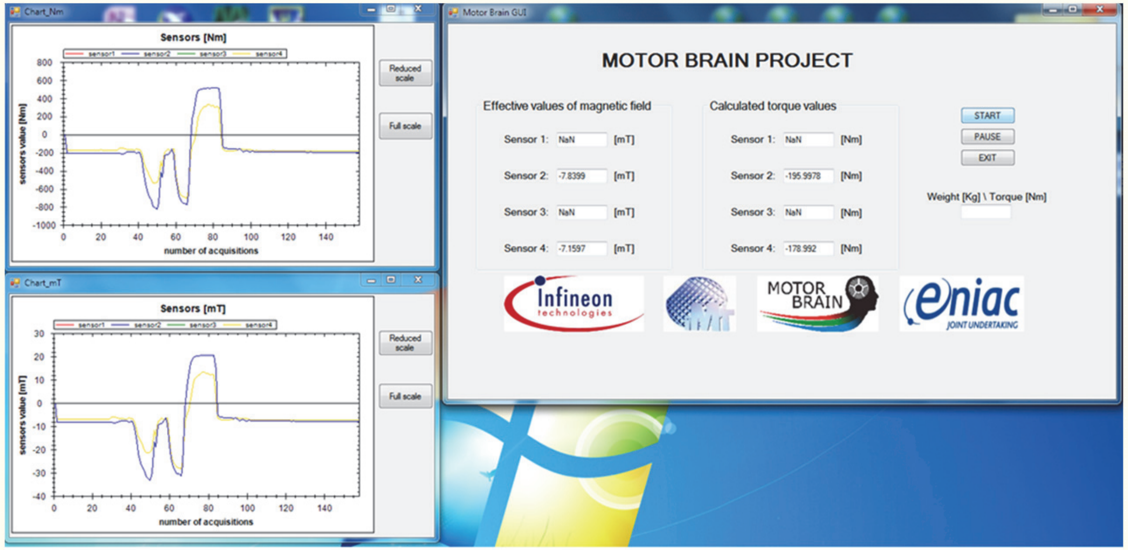
TORQUE SENSOR - ELECTRONICS AND SOFTWARE INTERFACE



Implemented protocol for digital transmission of torque information PWM (Pulse-Width Modulation)



Hardware developed for reading information provided by multiple magnetic sensors located on the torque sensing mechanical transducer



Software application developed for reading information provided by multiple magnetic sensors located on the torque sensing mechanical transducer

TORQUE SENSOR
- OTHER TYPES OF TORQUE SENSORS CONSIDERED IN THE PROJECT -

The main effort was directed toward the torque sensors based on magnetic field sensor.

However, IMT has also approached two other methods of sensing:

- an optical torque sensor which has the ability “to amplify” the torque angle (up to 10x)
  → simulations performed with an optical software showed that the 1 % accuracy is easily achievable.
  → it does not suffer from angular acceleration or shaft elongation.

- a nanostructure based torque sensor
  → we have performed its first simulations

TORQUE SENSOR - SUMMARY OF RESULTS

Main achievements for the torque sensor

Parameter	Initial / Targeted value	Actual value
Torque range	0 – 300 Nm	0 – 300 Nm
Torque measurement accuracy	1 % full-scale (3 Nm)	1 % full-scale (3 Nm)
Maximum rotation speed	10.000 rpm	10.000 rpm
Maximum working temperature	180^0 C	200^0 C
Redundancy	At least 2x	4x
Intrinsic linearity	Prefered	Achieved

Integration results

Integration topic	Status
Integration of mechanical part and magnetic field sensors	Proven
Accuracy of the realization of the metal part version	+/- 50 microns

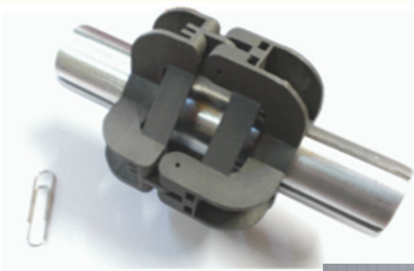
Verification results for the torque sensor

Target	Achieved/Achievable
Torque sensor working as devised	Yes
Integration of the mechanical and magnetic field part proven	Yes
Redundancy checked	Yes
Size reduction	Yes, for metal version
Intrinsic linearity of the torque sensor checked	Yes

Comparative view of achievements

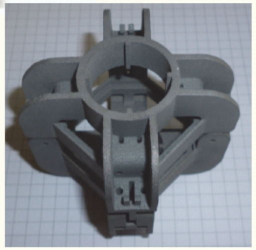
Achievement topic	Status
Functionality	Proof-of-concept demonstrator made of polymer show functionality according to the design
Rotation speed	Simulation results (ANSYS Multiphysics v. 12.1) indicate very good stability at 10.000 rpm and 200^0 C
Compared to state-of-the-art	a) Redundancy b) Intrinsic linearity c) Intrinsic compensation of temperature variation, mechanical stress and surrounding EM fields (devised, designed)

ENIAC PROJECT - SUCCESSFUL COLLABORATION BETWEEN ACADEMIA AND INDUSTRY

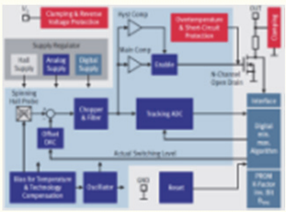


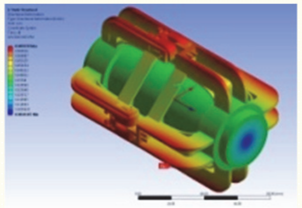
Industry
(magnetic field sensor)

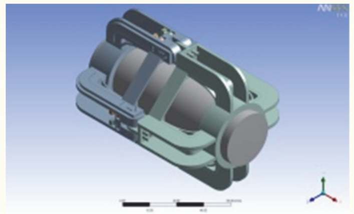
demonstrator



Academia
(concept, design & realization of the transducer)







Infineon Technologies Romania

National Institute for R & D in Microtechnologies
IMT-Bucharest

Work flux & Cooperation - Romanian Team

TORQUE SENSOR - RESULTS DISSEMINATION

Launch of the **European Framework Programme for Research and Innovation "Horizon 2020"** in Bucharest on 4th of October 2013

The European Commissioner for Research, Innovation and Science, Mrs. Máire Geoghegan-Quinn tested the model of the torque sensor at the booth of the MotorBrain project

Mars Curiosity rover © NASA

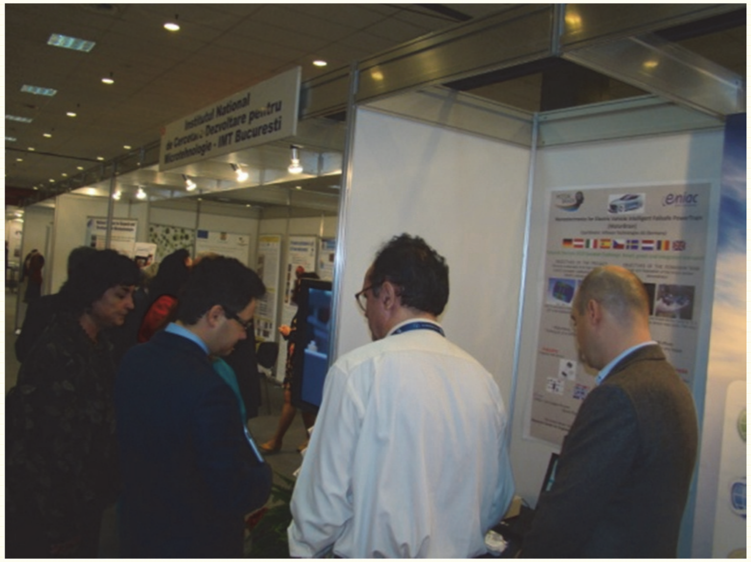
TORQUE SENSOR - RESULTS DISSEMINATION

Launch of the **European Framework Programme for Research and Innovation "Horizon 2020“**in Bucharest on 4th of October 2013

Discussions at the booth of the MotorBrain project with Professor Susan-Resiga – head of the Research Center for Engineering of Systems with Complex Fluids from Timişoara Polytechnical University, Romania

TORQUE SENSOR - RESULTS DISSEMINATION

Participation at the Annual Romanian Research Exhibition 2014, Bucharest, Romania, 15 – 18 October 2014 – MotorBrain project have had a dedicated booth



Visit of Dr. Mihnea Costoiu – Romanian Ministry of Research – at the MotorBrain booth.

Visit of Dr. Tudor Prisecaru, Secretary of State at the Romanian Ministry of Research, at the MotorBrain booth.

Presentation of the Romanian team work within the MotorBrain project with the occasision of Special Meeting "20 years of IMT"

TORQUE SENSOR - ACKNOWLEDGEMENTS

The IMT-Bucharest and IFRO teams thanks the following partners for their contribution and support:

- Dr. Reiner Jon (IFAG) for his permamnet commitment and availability to solve any of the problems that appeared, as well as for his highly efficient project coordination

- Prof. Alfred Hoess (HAW) for his patience and understanding when working with the project partners and for its efficacity to deal with the great amount of administrative issues

- Dr. Peter Lucas (TUD) for his kind support at the beginning of the work when we needed to define sensors parameters and sensor requirements

- The team from IMA (Czech Republic) for their efficient collaboration with IFRO

- Dr. Heike Lepke (HAW) for her work regarding the creation of an easy-to-navigate project webpage

- WP3 (Dr. Luca Buratti) and WP4 (Dr. Yves Burkhardt) leaders for their WorkPackage coordination work

- The Management teams from IMT and IFRO for their permanent support during the project run

TORQUE SENSOR - ACKNOWLEDGEMENTS TO ROMANIAN AUTHORITIES

The IMT-Bucharest and IFRO teams **thanks** the following staff of the **Romanian authorities** :

- **Mrs. Speranţa RÂŞAN**

- **Conf. dr. Ioana FĂGĂRĂŞAN**

for:

- competent management of the ENIAC programme
- permanent commitment and availability to solve any of the problems that appeared
- excellent support and communication

GOING FURTHER, IN NEW PROJECTS

One project (ENIAC) ended … and IMT and IFRO were invited to join a new EU project under the ECSEL Programme auspices:

Integrated Components for Complexity Control in affordable electrified cars – 3CCar

The project runs during 2015 – 2018 and is coordinated by Infineon Technologies AG (Germany)

There are **51 partners** from **EU and Taiwan**, comprising the whole palette from academia (universities and research institutes) to industry (SMEs as well as big corporations)

The proposed 3Ccar project will provide according to its mission 3C novel Integrated **C**omponents for **C**omplexity **C**ontrol in affordable smart electrified cars. Complexity control, complexity reduction and translation into semiconductors will be the next level of energy efficiency in transportation systems.

TEAM

National Institute for Research and Development for Microtechnologies – IMT Bucharest (IMT)

Dr. Gabriel MOAGĂR-POLADIAN
Phys. Cătălin TIBEICĂ
Phys. Eng. Victor MOAGĂR-POLADIAN
Eng. George BOLDEIU
Eng. Dragoş VÂRŞESCU
Eng. Niculae DUMBRĂVESCU

Infineon Technologies Romania (IFRO)

Eng. Flavius CHILOM
Eng. Emanuel STOICESCU

The objectives of the 3Ccar project are divided into six objective groups:

1. Competitive advantage through more complex semiconductor-based systems
2. Cost reduction of the automotive components
3. Control of complexity by architectures allowing new partitioning
4. Reduction of vehicle’s maintenance costs
5. Push more electric vehicles on the roads (replacement for combustion cars)
6. Reduce mobility’s environment footprint

Activities of the Romanian partners:

- Dealing with thermal management issues (IMT)

- Temperature measurements inside electric batteries (IFRO)

- Customized encapsulation for SoC by using 3D Printing techniques (IMT and IFRO)

- Support partner for micromirror MEMS integration and demonstration (IMT under the coordination of VTT)

IMT activities:

- **<u>Task T2.2 leader</u>**: Thermal simulations to design the structure for thermal management (**<u>IMT</u>**, Daimler, AVL,TNO) **(already reported)**

- **<u>Task T6.15 leader</u>**: Test of encapsulation structures and thermal insulation tests (**<u>IMT</u>**, IFRO, TNO)

- **Responsible of deliverable**: D2.2 – Report on thermal simulations and thermal management
- structure **(already reported)** (IMT, Daimler, AVL,TNO, + *IFAG as a suplimentary contributor*)

- **Responsible of deliverable**: D6.15 – Test of encapsulation structures and thermal insulation

- Participation in Task T5.5 - MEMS integration and demonstration (**<u>VTT</u>**, IMT, Okmetic, VIF)

- Participation in Task 7.1: Dissemination (**<u>MB</u>**, all partners contribute)

- Participation in Task 7.2: Exploitation (**<u>MB</u>**, all partners contribute)

- Participation in Task 7.3: Standardization (**<u>MB</u>**, all partners contribute)

IFRO activities:

- Participation in Task 1.7: Definition of the requirements for the on board charger platform and of the specifications of the power modules used to build the charger. (Triad, TOED, IFEVS, IFAG, Siemens, STmicro, IFRO)

- Participation in Task 2.3: Simulation and modelling of the components of the battery system (UNIPI, AVL-SFR, FhG-IPA, IFRO, TNO)

- Participation in Task 3.5: Technology Development for Embedding Power modules (IFAG, IFRO)

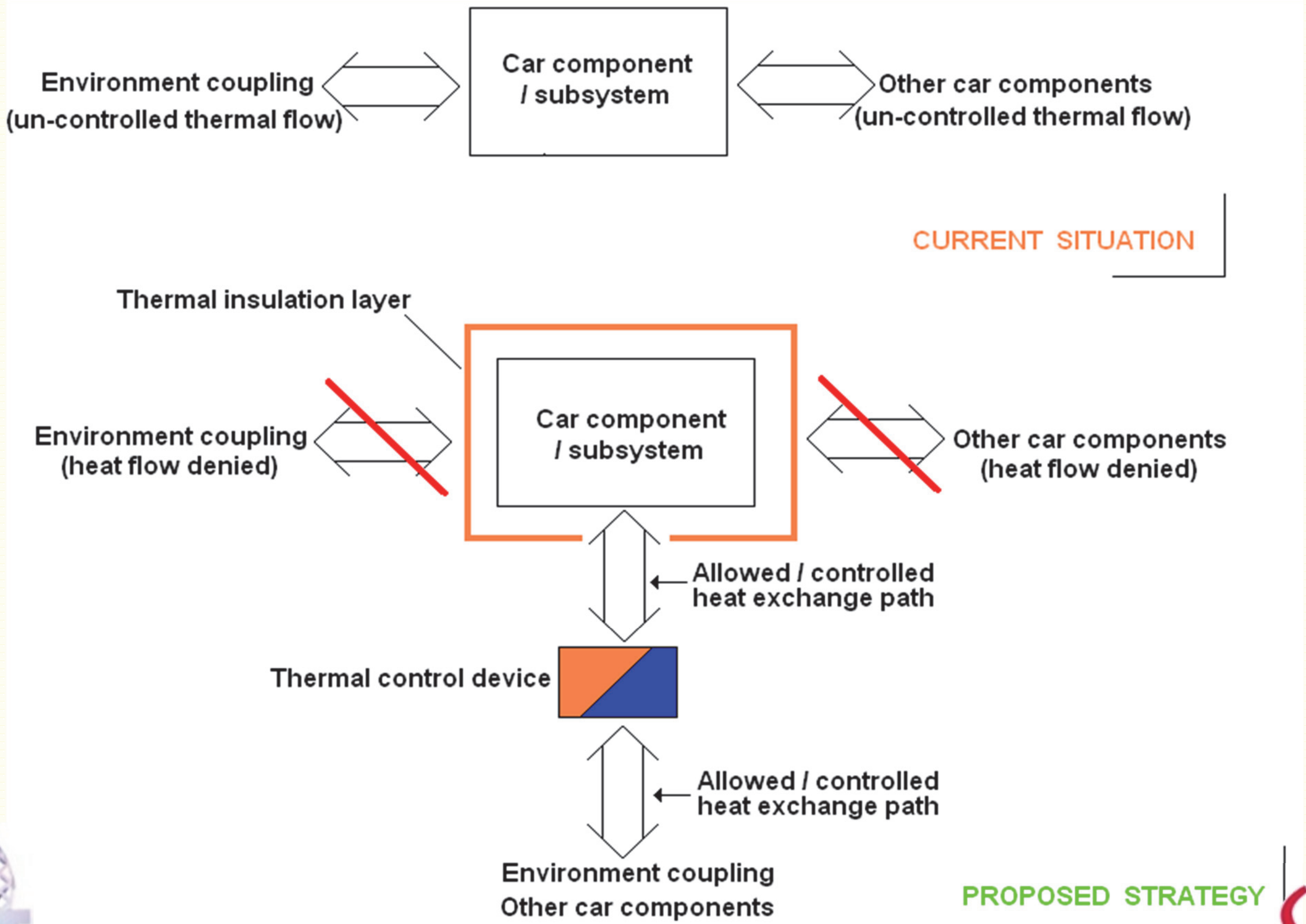
- Participation in Task 6.15:Test of encapsulation structures and thermal insulation tests (IMT, IFRO)

- Participation in Task 7.1: Dissemination (MB lead, all partners contribute)

- Participation in Task 7.2: Exploitation (MB lead, all partners contribute)

- Participation in Task 7.3: Standardization (MB lead, all partners contribute)

RESULTS OBTAINED

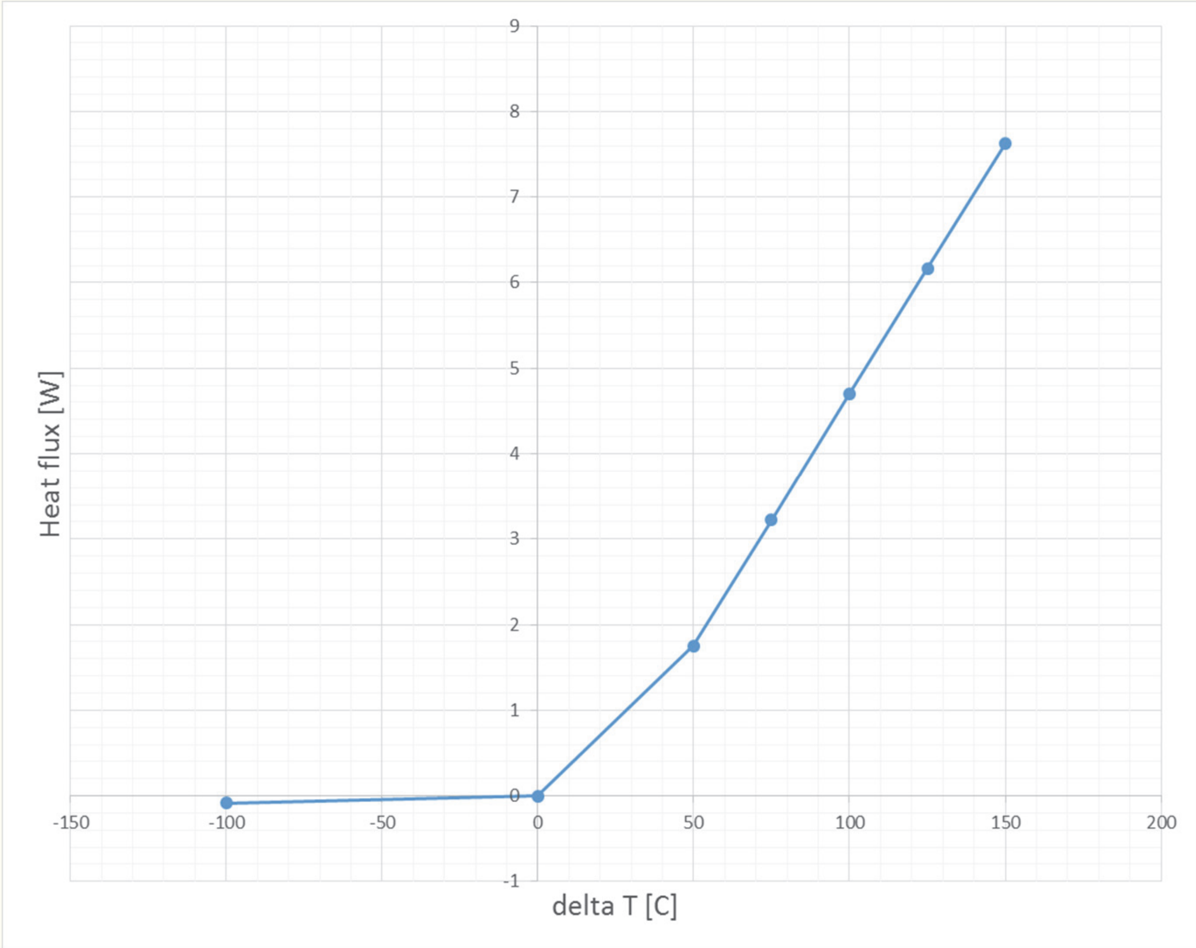


The scheme showing the proposed strategy for thermal management

RESULTS OBTAINED

IMT has conceived and simulated:

- A structure for thermal diode
- A thermal switch



Thermal diode characteristics of the simulated device

RESULTS OBTAINED

The parameters of the version 2 of the thermal switch

Parameter	Value	Units
Dimensions [xyz]	1x1x1	[cm^3]
Thermal resistance ON	0.5	[K/W]
ON/OFF ratio	1106	[-]
Maximum working temperature	100	[$^\circ C$]
Switching time	1	[s]
Power consumed in switching	1.5	[W]

EVALUATION REPORT FOR T2.2 MADE BY DAIMLER

Score the deliverable from 1 to 5 on each criteria below: 5 = Excellent, 4 = Very Good, 3 = Acceptable, 2 = Poor, 1 = Unsatisfactory, 0 = not addressed, NA = Not applicable			
General evaluation and comments		**Score**	**Comments and instructions for improvements**
Each partner's contribution is clearly indicated and in balance with the allocated resources.		4	Very clear
The scope of the work is relevant.		5	
The reasoning and logic are of high quality and convincing		4	
Related activities have been identified and taken into account.	inside **3Ccar**	5	
	outside **3Ccar**	5	
The results meet the objectives of the Task and WP.		5	
The deliverable is in appropriate form and well presented: executive summary gives a good overview of achievements; appropriate length; easy to read illustrations & tables.		5	
Compliance with requirements andspecificationsis clearly described.		4	
Industrial exploitation of results is clearly described.		5	
Potential impacts are clearly described.		5	
Other comments.			Much work and a lot of good results
Overall recommendation	Min score	**X**	**Comments and instructions for improvements**
Acceptable without any changes	3	3	
Acceptable with minor revisions	**2**		
Acceptable after major revisions	**1**		
Reject	**0**		
Return the filled form to the Coordinator			

ECSEL JU

3CCAR

CONCLUSIONS REGARDING PARTICIPATION IN THE ENIAC PROGRAMME

- Succesfull design and demonstration of the torque sensor based on magnetic field sensing (IMT)

- Succesfull magnetic sensors developed within the project
  → it entered the commercial level (IFRO)

- Romanian team was responsible for:
  - one supply chain (IFRO) √
  - two deliverables (IMT) √

- Romanian team behaved very well in MotorBrain
  → IMT and IFRO were invited to join a new ECSEL project:
  → 3CCar

IMT

infineon