"Multi-Magnetometer Methods for Magnetic Dipole Modelling (AO/1-7463/13/NL/GLC)"

Ακρωνύμιο: AO/1-7463/13/NL/GLC
Δράση: ICT-……
Ημ. Έναρξης **1/9/2014**

Ιστοσελίδα:

Διάρκεια:24 months

Προϋπολογισμός Συνολικός: **249.463,00€**
ΕΜΠ: 46.380,00€
Ρόλος ΕΜΠ: Συντονιστής Έργου/ συμμετέχων
Επιστημονικός Υπεύθυνος: Χ.Καψάλης
Nikolaos-Antonios Livanos / EMTECH

Βαθμολογία πρότασης:

Background

In various exploration missions, magnetometer-carrying spacecrafts aim to reveal the structural composition of planets and to study the complex interactions between the solar wind and the planetary environments. Magnetic field levels are usually extremely low making the need for "magnetically clean" spacecraft. Magnetic cleanliness is based on identification of subsystems and components with potential contribution to magnetic field emissions, equipment (unit) level measurements at Mobile Coil Facilities (MCF), for characterization and acceptance and system level either by simulation or in large magnetic facilities for final testing. These facilities use a small number of magnetometers and employ rotational measurements to obtain a magnetic signature around an Equipment Under Test (EUT). Disturbances of the ambient field during the test can require several repetitions. In the frame of this activity the rotation shall be completely replaced by an increased number of fixed magnetometers. A typical Mobile Coil

Facility is shown in
Figure 1. The aim of this project is to increase reproducibility of test results by a reduction of measurement sensitivity to environment variations occurring during the test. The activity shall strive in parallel also to reduce considerably required test time and necessary operator expertise.

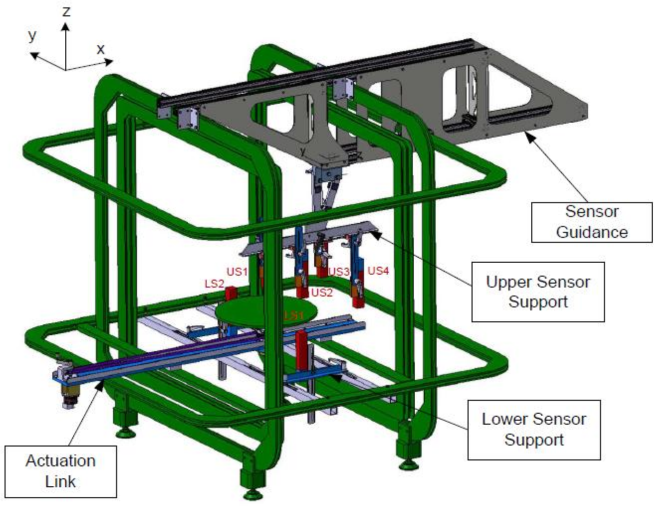


Figure 1. Bartington MS Series magnetometer (square section type)

Scope - Consortium

The first principal activity of this work is to study different possible multi-magnetometer test setups with the following targets: To obtain a snapshot of the magnetic field and its gradient for a unit while keeping measurement time below 1 second. To identify the optimum number and position of magnetometers and the parameters affecting the reproducibility of test results. To reveal possible additional capabilities the use of gradiometer configurations was also exploited. The pros and cons of possible resultant setups have been examined in a trade-study that optimizes instrumentation, hardware (mechanical and electronics) and software implementation while meeting project requirements.

The second principal activity is the design, implementation and operational/performance verification of the new, multi-magnetometer, facility. The desired solution has two major targets:

- To reduce total measurement time so as to avoid influence of ambient field variations compared to the current turntable mechanism. In general, the measurement sequence of: Ambient B-field measurement (AMBbefore) – EUT snapshot field measurement (EUT) - Ambient B-field measurement (AMBafter) should be performed as fast as possible to reduce effects of ambient field variation to the snap-shot EUT magnetic field measurement result.
- To make the new multi-magnetometer test facility operate with desired accuracy, resulting in better quality measurements and helping the modeling algorithms to produce better results. The new system shall be verified for its performance and accuracy against given requirements.

The implementation of the proposal is based on a consortium of two contractors. One new and upcoming company interested in consulting and development of real-time embedded systems and software, and a university laboratory interested in high-technology research, form a complete team that includes all the desired resources. More specifically the consortium consists of the following contractors:

- ***NIKOLAOS & MARINOS LIVANOS OE – EMTECH***; a Greek company involved in embedded systems and software design and development, manufacturing products for the domains of Energy Systems and Automations, Space and Ground Segment Software Applications, and Medical Devices.
- *Wireless and Long Distance Communications Laboratory* ***(WLDCL) of the National Technical University of Athens (NTUA)***, with domains of specialty the theoretical and experimental research on telecommunication topics, emphasizing on subjects such as Electromagnetic Compatibility, Antennas, Radiation Effects, Wireless Links and Propagation and Biotechnological issues.

Objectives of the Activity

The activities that were carried out under this project contain but are not be limited to the following:

a) Study possible multi-magnetometer setups, which reduce measurement time below 1 s.

b) Possible setups allow obtaining a "snap-shot" of the magnetic field or gradient signature of a unit.

c) The study focuses on

  i. optimum number of magnetometers,

  ii. optimal locations for minimum uncertainty, and

  iii. maximum reproducibility of results.

d) The combination of individual magnetometers to gradiometer configurations is included in the study.

e) A trade-off analysis identifies and weighs the advantages and disadvantages of possible setups.

f) Test cases that were considered as a minimum are shown in Figure 2.

g) The requirements for hardware and software implementation of useful methods were defined with special attention on requirements on magnetometers.

h) Potential setups allow precise displacement of EUT to obtain gradient information

The scope of this project is to provide the analytical results of the study of different possible multi-magnetometer test setups for obtaining a snapshot of the magnetic field, identifying the optimum number of magnetometers and their position and revealing possible capabilities that can arise by gradiometer configurations. A trade off analysis is also included which identifies advantages and disadvantages of different configurations by means of measurement time, optimum number and type of sensors (magnetometers or gradiometers), magnetometer location to reduce measurement uncertainty and reproducibility of test results.
The present work is output of the study of several proposed multi-magnetometer test setups targeting to realize the innovative facility for Magnetic Dipole Modelling for

spacecraft magnetic cleanliness, which is based on snap-shot magnetic field measurements.

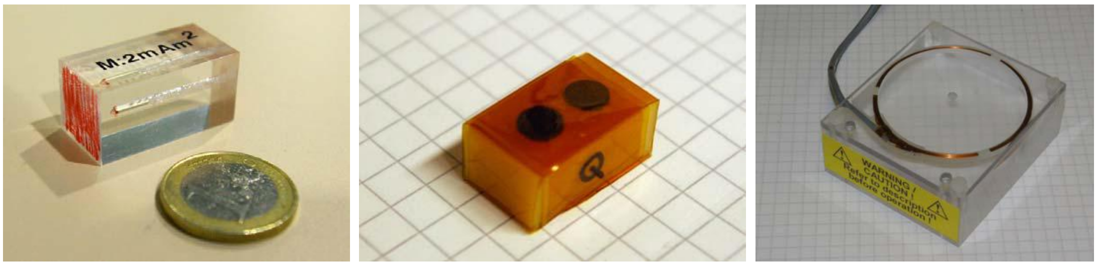


Figure 2. Magnetic dipole, Magnetic quadrupole and Magnetic coil used in the Test Cases

Main objective of the activity is the implementation of methods to use multiple magnetometers for measurements of the magnetic field from an EUT. The measured magnetic field then is modelled by multiple equivalent magnetic dipoles. Such multiple dipole models will be later used to extrapolate the magnetic field at larger distances, i.e. at the location outside the spacecraft where the sensitive measuring equipment (magnetometers) is placed.
The main steps of the work are to:

- Study possible multi-magnetometer setups to perform a "snap-shot" of the magnetic signature for an EUT and perform trade-off to select optimal setups.
- Develop software with a graphical user interface to solve the discrete inverse problem of finding the minimum number of magnetic sources able to cause the measured magnetic signature.
- Build a prototype facility as proof-of-concept including mechanical and electrical hardware as well as software.
- Verify the resulting magnetic dipole models with a set of a-priori known magnetic sources.

The present activity has the aim to perform an instant "snap-shot" of the magnetic signature of an Equipment Under Test (EUT). It will result in a final proof-of-concept implementation of a Multi-Magnetometer Facility (MMF).

Results of AO/1-7463/13/NL/GLC

The analysis involves results of the study and the trade-off of multi-magnetometer setups. The software development was built on existing MCF-MAGNET code and allows the use of multiple magnetometers as required for the identified optimal setups. As a proof-of concept, a prototype facility shall implement at least one optimal setup with complete instrumentation, data acquisition and software. The proper implementation shall be verified by known DC magnetic sources. Several configurations of magnetometers were used for the analysis; indicative setups are depicted in Figure 3 - Figure 6.

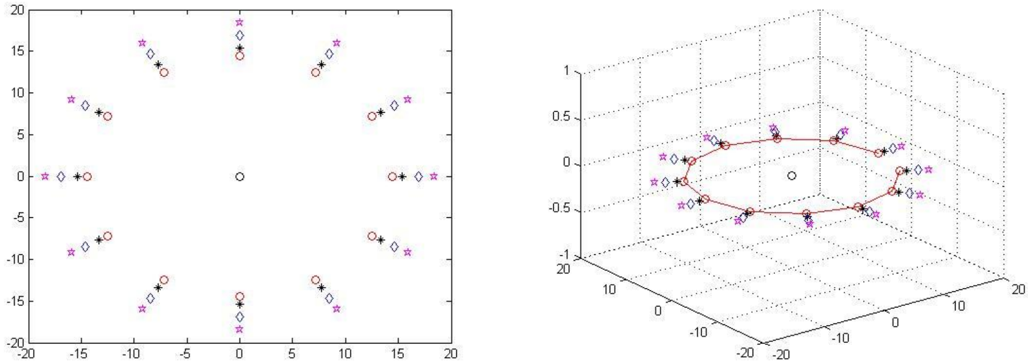


Figure 3. Setup 1 – magnetometers placed in a circle around the EUT (left – top view and right – side view)

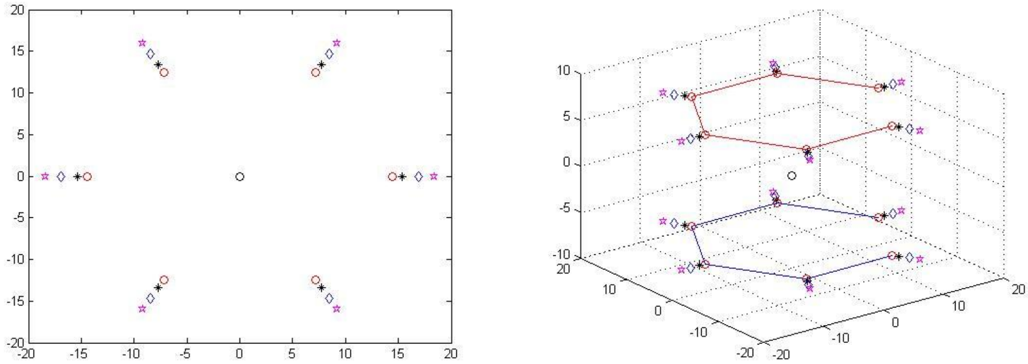


Figure 4. Setup 2 – magnetometers placed in two circles above and below the EUT (left – top view and right – side view)

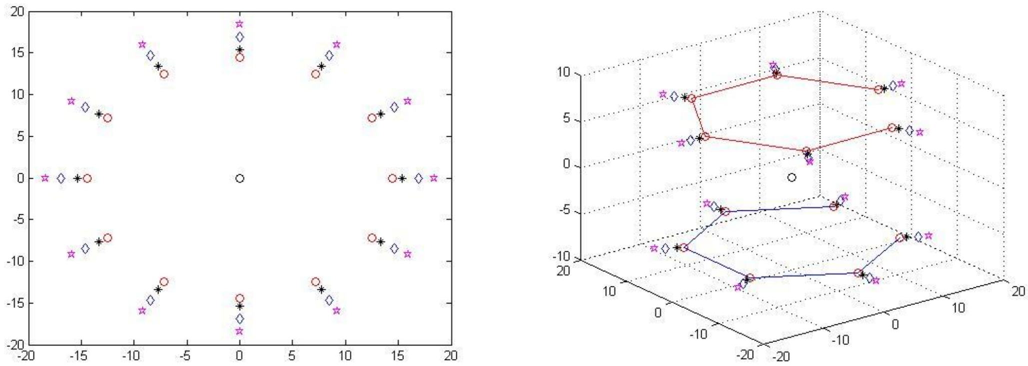


Figure 5. Setup 3 – magnetometers placed in two circles above and below the EUT at different angles (left – top view and right – side view)

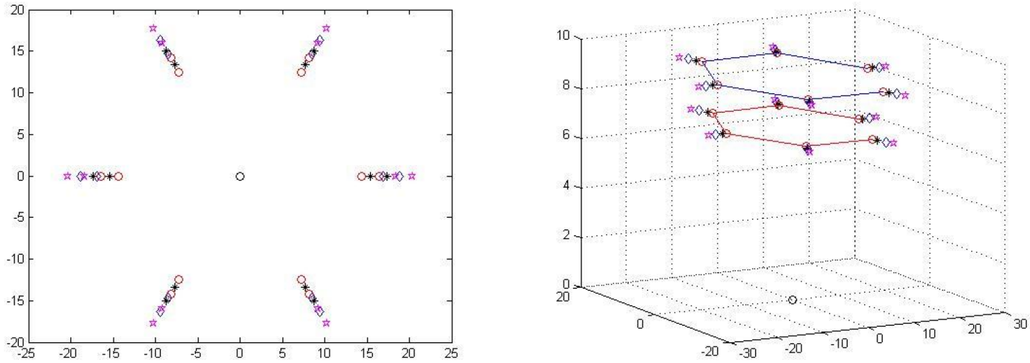
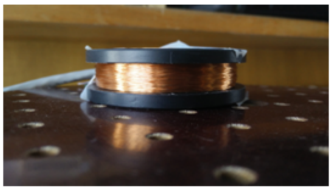


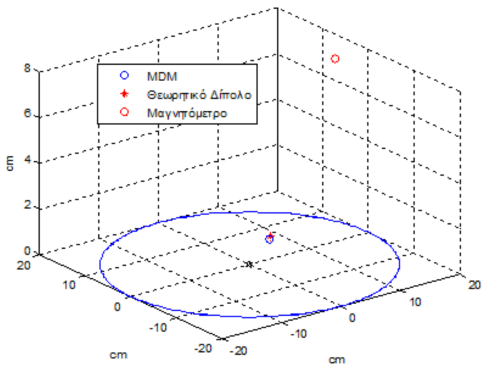
Figure 6. Setup 4 – magnetometers placed in two circles above the EUT at different radii (left – top view and right – side view)

Moreover, the verification of these setups was carried out by known DC magnetic sources. For instance, one of the magnetic sources that were used for verification purposes is a magnetic coil. The parameters (position, magnetic moment) of the current – fed coil can be predicted with the use of various optimization algorithms, such as Genetic Algorithms (GAs) or Particle Swarm Optimization (PSO), as shown in Figure 7.



MDM

x (cm)	1.9418
y (cm)	-1.8811
z (cm)	1.1168
m_x (mAm^2)	-0.8327
m_y (mAm^2)	-0.3005
m_z (mAm^2)	-20.5158



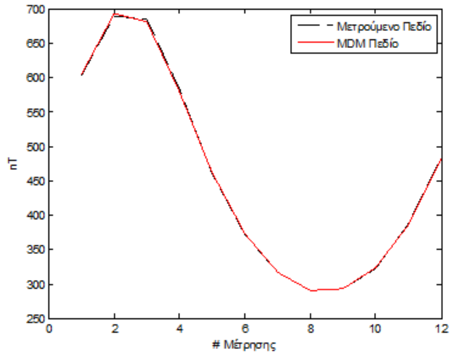


Figure 7. Prediction parameters of a current – fed coil

A jig configuration that was preliminary used for measuring the magnetic signature of several magnetic sources is shown in Figure 8. It is worth mentioning that the jig facility is at the premises of NTUA and currently operating during the present stage of the project; besides, it will remain as property of the Wireless and Long Distance Communications Laboratory (WLDCL) of the **National Technical University of Athens** (NTUA).

Adjust height of magnetometers

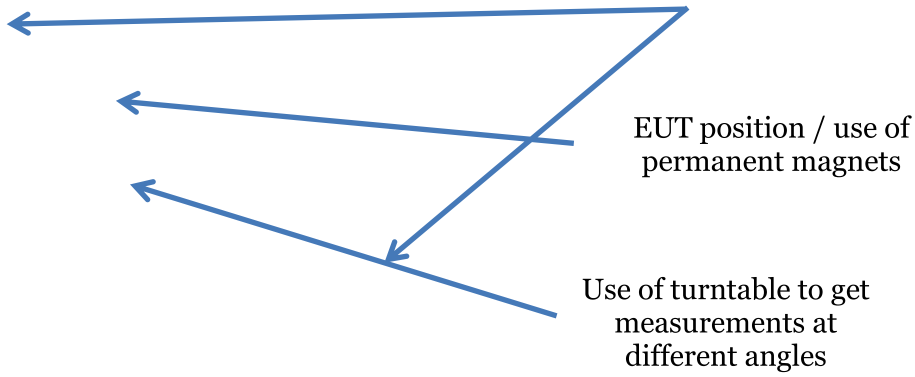


Figure 8. Jig Configuration for measuring the magnetic signature of an EUT

Furthermore, the simulation analysis, modeling and preliminary measurements performed by WLDCL will result in a final proof-of-concept implementation of a Multi-Magnetometer Facility (MMF). The mechanical drawings of the final MMF are shown in Figure 9 and Figure 10. Evidently, the final facility operated with 12 magnetometers using setup 2 of Figure 4, which was concluded to be the most efficient setup during trade – off analysis, but is easily extendable to also configure setups 1 and 4.

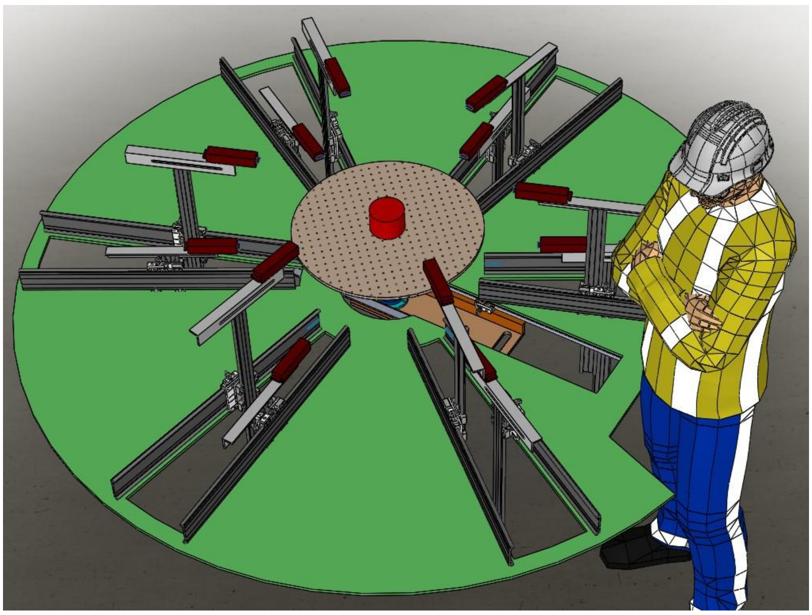


Figure 9. Configuration setup for measuring the magnetic signature of an EUT (top view)

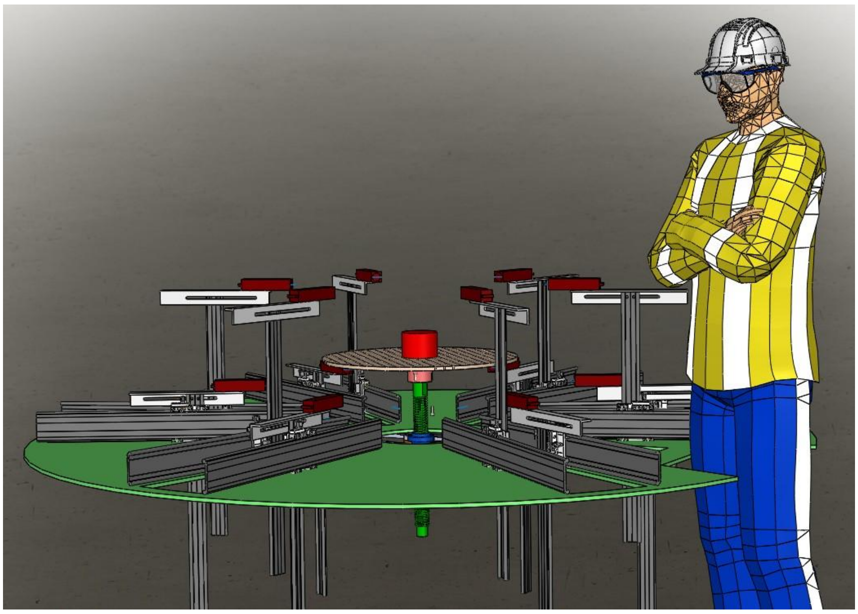


Figure 10. Configuration setup for measuring the magnetic signature of an EUT (side view)

Finally, it should be noted that at later stages of the project – October 2016 – the MMF prototype facility will be transported at the premises of ESA – ESTEC headquarters in Noordwijk, Netherlands, complementing the existing MCF facilities for measuring the magnetic signature of equipment mounted on the spacecrafts in recent and upcoming space missions (e.g. LISA Pathfinder, JUICE, THOR, etc.).

In the frame of ESA contract 4000111736/14/NL/GLC on Multi- Magnetometer Methods for Magnetic Dipole Modelling, prof. Capsalis and personnel of WLDCL visited the Clean Room and the Mobile Coil Facility at the premises of ESA – ESTEC in Noordwijk, Netherlands (Figure 11).

Figure 11. Outside the clean room of ESA – ESTEC's headquarters in Noordwijk, Netherlands.

Indicative Publications

- Kapsalis, N. C., Kakarakis, S.-D. J. and Capsalis, C. N., "*Prediction of multiple magnetic dipole model parameters from near field measurements employing stochastic algorithms*", Progress In Electromagnetics Research Letters, Vol. 34, 111-122, 2012.
- Kakarakis, S.-D. J., Kapsalis, N. C. and Capsalis, C. N., "*A Semianalytical Heuristic Approach for Prediction of Eut' s Multiple Dipole Model by Reducing the Number of Heuristics*", IEEE Transactions on Electromagnetic Compatibility, Vol. 57, No.1, pp.87-92, Feb. 2015.
- Spantideas, S. T., Kapsalis, N. C., Kakarakis, S.-D. J. and Capsalis, C. N., "*A Method of Predicting Composite Magnetic Sources Employing Particle Swarm Optimization*", Progress In Electromagnetics Research M, Vol. 39, 161–170, 2014.
- S. Spantideas, S.-D. J. Kakarakis, N. C. Kapsalis, , and C. N. Capsalis *"Theoretical Methods for Studying Distance and Frequency Scaling for AC Magnetic Fields in Satellite Missions",* IEEE Transactions on Magnetics, vol. 52, no. 4, pp. 1-5, April 2016.
- Zacharias, P. P., Chatzineofytou, E. G., Spantideas, S. T., and Capsalis, C. N.: "*Distance Scaling Method for Accurate Prediction of Slowly Varying Magnetic Fields in Satellite Missions*", Geosci. Instrum. Method. Data Syst. Discuss., doi:10.5194/gi-2015-47, in review, 2016.
- S. Spantideas, N. C. Kapsalis, S.-D. J. Kakarakis and C. N. Capsalis *"A Novel Technique for Accurate Extrapolation of Complex Magnetic Sources",* ESA Workshop on Aerospace EMC, Valencia, Spain, under publication.

Αποτελέσματα του …Project… για το ΕΜΠ/Σχολή

Για παράδειγμα:

i. δημιουργία/ανάπτυξη καινούριας ερευνητικής περιοχής: **Μαγνητική καθαρότητα σε διαστημικές αποστολές.**
ii. ονόματα έμπειρων/μεταδιδακτορικών ερευνητών που συνεισέφεραν/ υποστηρίχθηκαν
iii. υποψήφιοι διδάκτορες που υποστηρίχθηκαν: τίτλοι διατριβών **Σαράντης – Δημήτριος Κακαράκης: Ανάπτυξη Μεθόδων Μέτρησης και Ανάπτυξη Αλγορίθμων Μοντελοποίησης και Ανάλυσης Μαγνητικής Συμπεριφοράς Συσκευών για Επίτευξη Μαγνητικής Καθαρότητας σε Διαστημικές Αποστολές.**
iv. αριθμός άρθρων σε περιοδικά και συνέδρια: **6**
v. διπλώματα ευρεσιτεχνίας
vi. βραβεία: **Θωμαΐδειο Βραβείο για τα έτη 2013 – 2014 για 3 δημοσιεύσεις σε επιστημονικά περιοδικά που περιλαμβάνονται σε έγκριτες βάσεις δεδομένων (π.χ. Scopus, Science Citation Index Expanded).**

vii. αξιόλογος νέος εξοπλισμός

viii. νέες συνεργασίες με ερευνητικούς φορείς και βιομηχανία:

1. **Συνεργασία με την EMTech, μέλος του Space Cluster της Ελλάδας.**
2. **Συνεργασία με την Ευρωπαική Υπηρεσία Διαστήματος (ESA).**

ix. περιθώρια για καινοτομία ως αποτέλεσμα έργου

x. κάτι ιδιαίτερο που πρόσφερε, π.χ. Πειράματα ερευνητών της Σχολής στο εξωτερικό, φιλοξενία και πειράματα απο ξένους ερευνητές στη Σχολή