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Final Report: Highly Efficient Wireless Powering for Autonomous Structural Health Monitoring and Test/Evaluation Systems

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Stavros Georgakopoulos

5d. PROJECT NUMBER

5e. TASK NUMBER

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Florida International University
10555 West Flagler, EC 2441

Miami, FL 33174 -1630

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14. ABSTRACT
Autonomous sensors with simultaneous wireless powering and communication will play significant role in future Structural Health Management (SHM), and Test & Evaluation (T&E) systems for military assets by: (a) reducing the expensive and time consuming installation and maintenance of wired sensors/devices, and (b) increasing the limited lifetime of battery-operated wireless sensors/devices. The scientific objective of this work is to improve the efficiency, range, and safety (in terms of EMI/EMC and signature) of wireless powering of sensors using the recently discovered method of Strongly Coupled Magnetic Resonance (SCMR). This project supports the DoD

15. SUBJECT TERMS
Wireless Power Transfer, Structural Health Monitoring, Test and Evaluation

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Stavros Georgakopoulos
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Report Title

Final Report: Highly Efficient Wireless Powering for Autonomous Structural Health Monitoring and Test/Evaluation Systems

ABSTRACT

Autonomous sensors with simultaneous wireless powering and communication will play significant role in future Structural Health Management (SHM), and Test & Evaluation (T&E) systems for military assets by: (a) reducing the expensive and time consuming installation and maintenance of wired sensors/devices, and (b) increasing the limited lifetime of battery-operated wireless sensors/devices. The scientific objective of this work is to improve the efficiency, range, and safety (in terms of EMI/EMC and signature) of wireless powering of sensors using the recently discovered method of Strongly Coupled Magnetic Resonance (SCMR). This project supports the DoD mission by leading to discoveries that will transform the development of: (a) intelligent and efficient diagnostics and prognostics, and (b) lightweight and safe airborne structures with extended service life as well as reduced fuel and maintenance costs. Also, our research is expected to have significant impact to other important technologies for the Air-Force and DoD, such as, smart runways, nano-satellites, smart skins for hypersonic vehicles, autonomous portable devices, integrated circuits, and embedded sensors. In this report, we describe our progress during the third year of our grant.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
08/29/2014	1.00	Olutola Jonah, Arvind Merwaday, Stavros V. Georgakopoulos, Manos M. Tentzeris. Spiral resonators for optimally efficient strongly coupled magnetic resonant systems, Wireless Power Transfer, (03 2014): 0. doi: 10.1017/wpt.2014.3
TOTAL:	**1**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received		Paper
TOTAL:		

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper
07/27/2016	29.00 . Miniaturized Strongly Coupled Magnetic Resonant Systems for Wireless Power Transfer, 2016 IEEE Antennas Propagat. Society Internat. Symp. 27-JUN-16, Fajardo, Puerto Rico. : ,
07/27/2016	30.00 . Misalignment Study of Cylindrical SCMR Wireless Power Transfer System, IEEE Antennas Propagat. Society Internat. Symp., Fajardo, Puerto Rico, Jun. 26- Jul. 1, 2016. 26-JUN-16, Fajardo, Puerto Rico. : ,
07/27/2016	31.00 . Analysis and modeling of Conformal Strongly Coupled Magnetic Resonant devices, 2016 IEEE 17th Annual Wireless and Microwave Technology Conference (WAMICON). 11-APR-16, Clearwater, FL, USA. : ,
TOTAL:	**3**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received		Paper
07/26/2016	23.00	Elad Siman Tov, Kun Bao, Stavros V. Georgakopoulos. Backscattering modulation using strongly coupled magnetic resonance (SCMR) antennas, 2015 IEEE Antennas Propagat. Society Internat. Symp., Vancouver, BC, Canada, Jul. 19-25, 2015. 19-JUL-15, Vancouver, BC, Canada. : ,
07/27/2016	5.00	Hao Hu, Stavros V. Georgakopoulos. Wireless power transfer through strongly Coupled Electric Resonance, 2013 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting. 07-JUL-13, Orlando, FL, USA. : ,
07/27/2016	20.00	Kun Bao, Hao Hu, Stavros V. Georgakopoulos. Design considerations of conformal SCMR system, 2015 IEEE Wireless Power Transfer Conference (WPTC). 13-MAY-15, Boulder, CO, USA. : ,
07/27/2016	18.00	Daerhan Daerhan, Hao Hu, Stavros V. Georgakopoulos. Misalignment study of two Strongly Coupled Magnetic Resonance systems, 2015 IEEE 16th Annual Wireless and Microwave Technology Conference (WAMICON). 13-APR-15, Cocoa Beach, FL, USA. : ,
07/27/2016	22.00	Kun Bao, Elad Siman Tov, Stavros V. Georgakopoulos. Conformal SCMR system with multiple resonators, 2015 IEEE Antennas Propagat. Society Internat. Symp., Vancouver, BC, Canada,. 17-JUL-15, Vancouver, BC, Canada. : ,
07/27/2016	21.00	Hao Hu, Shun Yao, Kun Bao, and Stavros V. Georgakopoulos. Misalignment Insensitive WPT with Conformal SCMR Systems, 2015 IEEE Antennas Propagat. Society Internat. Symp., Vancouver, BC, Canada, Jul. 19-25, 2015.. 19-JUL-15, Vancouver, BC, CA. : ,
08/29/2014	2.00	Olutola Jonah, Stavros V. Georgakopoulos. Optimized helix with ferrite core for wireless power transfer via resonance magnetic, 2013 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting. 07-JUL-13, Orlando, FL, USA. : ,
08/29/2014	3.00	Olutola Jonah, Stavros V. Georgakopoulos, Manos M. Tentzeris. Multi-band wireless power transfer via resonance magnetic, 2013 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting. 07-JUL-13, Orlando, FL, USA. : ,
08/29/2014	4.00	Olutola Jonah, Stavros V. Georgakopoulos, Shun Yao. Strongly coupled resonance magnetic for RFID applications, 2013 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting. 07-JUL-13, Orlando, FL, USA. : ,
08/29/2014	6.00	Olutola Jonah, Stavros V. Georgakopoulos, Manos M. Tentzeris. Orientation insensitive power transfer by magnetic resonance for mobile devices, 2013 IEEE Wireless Power Transfer Conference (WPTC). 15-MAY-13, Perugia, Italy. : ,

08/29/2014 7.00 Stavros V. Georgakopoulos, Hao Hu. Analysis and design of broadband Wireless Power Transmission system via conformal Strongly Coupled Magnetic Resonance,
2014 IEEE 15th Annual IEEE Wireless and Microwave Technology Conference (WAMICON). 06-JUN-14, Tampa, FL, USA. : ,

08/29/2014 8.00 Kun Bao, John Gibson, Hao Hu, Stavros V. Georgakopoulos. Printable and Conformal Strongly Coupled Magnetic Resonant systems for wireless powering,
2014 IEEE 15th Annual IEEE Wireless and Microwave Technology Conference (WAMICON). 06-JUN-14, Tampa, FL, USA. : ,

08/29/2014 10.00 H. Hu, S. V. Georgakopoulos. Optimal Design of Conformal Strongly Coupled Magnetic Resonant Systems,
30th Annual Review of Progress in Applied Comput. Electromagnetics, Jacksonville. 23-MAR-14, . : ,

08/29/2014 11.00 S. V. Georgakopoulos,, O. Jonah, D. Daerhan, M. M. Tentzeris. Novel Highly-Efficient and Misalignment Insensitive Wireless Power Transfer Systems Utilizing Strongly Coupled Magnetic Resonance Principles,
IEEE 64th Electronic Components and Technology Conference (ECTC). 27-MAY-14, . : ,

08/29/2014 12.00 S. V. Georgakopoulos, H. Hu. Analysis and Design of Conformal SCMR WPT Systems with Multiple Resonators,
IEEE Antennas Propagat. Society Internat. Symp., Memphis, TN, Jul. 6-12, 2014.. 06-JUL-14, . : ,

08/29/2014 13.00 H. Hu, S. V. Georgakopoulos. Design of Optimal and Broadband Conformal SCMR Systems,
IEEE Antennas Propagat. Society Internat. Symp., Memphis, TN, Jul. 6-12, 2014. 06-JUL-14, . : ,

08/29/2014 14.00 S. V. Georgakopoulos, D. Daerhan, S. Yao, O. Jonah. Misalignment-Insensitive Wireless Power Transfer Via Strongly Coupled Magnetic Resonance Principles,
IEEE Antennas Propagat. Society Internat. Symp., Memphis, TN, Jul. 6-12, 2014. 06-JUL-14, . : ,

08/29/2014 15.00 D. Daerhan, H. Hu, S. V. Georgakopoulos. Novel Topologies of Misalignment Insensitive SCMR Wireless Power Transfer Systems,
IEEE Antennas Propagat. Society Internat. Symp., Memphis, TN, Jul. 6-12, 2014. 06-JUL-14, . : ,

08/29/2014 16.00 J. Gibson, K. Bao, H. Hu, S. V. Georgakopoulos . Wireless Charging for Li-Ion Battery Using a Printable Conformal SCMR,
IEEE Antennas Propagat. Society Internat. Symp., Memphis, TN, Jul. 6-12, 2014. 06-JUL-14, . : ,

TOTAL: **19**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

1. Georgakopoulos, S., Bao, K., Miniaturized Highly Efficient Wireless Power Transfer Elements Using Multiple Layers of Resonators and/or Tunable Capacitors, USPTO Utility Patent Application Serial No. 14/802,794 (filed on 07/17/15).

2. Georgakopoulos, S., Misalignment Insensitive Wireless Power Transfer with Cylindrical, Spherical and Conical Transmitter and Receiver Elements, USPTO Utility Patent Application Serial No. 15/084,836 (filed on 03/30/16)

Patents Awarded

Awards

Dr. Georgakopoulos received the FIU President's Council Worlds Ahead Faculty Award in Sept. 2015. This award is the highest honor that FIU extends to a faculty member to highlight the contributions of individuals who excel in every aspect of their work, including teaching and mentorship, research and service.

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Hao Hu	1.00	
Daerhan Liu	1.00	
Bao Kun	0.02	
FTE Equivalent:	**2.02**	
Total Number:	**3**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Stavros Georgakopoulos	0.21	
FTE Equivalent:	**0.21**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Our research work has achieved the following:

1. Development of optimal broadband or multiband conformal SCMR Wireless Power Transfer (WPT) elements that have been validated through comparisons with simulation models and measurements of working prototypes.

2. Development of a novel SCMR WPT system with cylindrical symmetry that exhibits reduced misalignment sensitivity in the azimuth planes compared to standard SCMR systems. Our results have been validated using simulation models and measurements of working prototypes.

3. Development, analysis and optimization of miniaturized conformal SCMR WPT systems using multi-layer resonators and capacitance tuning

4. Development of optimal SCMR systems that can simultaneously transmit power
and data thereby eliminating batteries.

This project has enhanced the research training of the following students:
1. Three Ph.D. students were supported by this grant

2. Provided materials and mentorship on a Senior Design project that involved the design and development of a Hydration Level Monitoring system that is wearable and wirelessly charged. All the team members graduated in May 2016 and are successfully continuing their carreers:

a. Karina Quintana joined Boeing in CA as a Flight Test Engineer
b. Adolfo Martinez joined Boeing Research & Technology in SC as an Electrophysics Engineer
c. Alain Anton accepted a summer Internship at MIT Lincoln Laboratory and will puruse a Ph.D. degree in Electrical Engineering at UC Berkeley
d. Junior E. Theogene joined Northrop Grumman as a Electronics/Hardware Engineer
e. Meilyn Planas joined Florida Power and Light as an IT System Administrator

3. This project has enhanced the teaching training of one Ph.D. student that have assisted Prof. Georgakopoulos in his curriculum development efforts for antenna and RF Design courses. Specifically, the students assisted in the development of training materials (manuals, videos and exercises) for electromagnetic simulation software.

Also, Prof. Georgakopoulos, has attended and presented in the annual T&E program review organized by Dr. Kendra, who is the AFOSR PM for this grant.

Technology Transfer

Dr. Georgakopoulos founded Innovelix, Inc. to pursue the commercialization of the WPT technologies that have been developed by the research of this grant.