I/UCRC Executive Summary - Project Synopsis		Date: April 8, 2013
Project Title: **All-optical embedded fiber-optic up/down-links for motor controller**		
Center/Site: NSF I/UCRC for Embedded Systems, SIUC site		
Principle Investigator: M. R. Sayeh		**Type: Continuing**
Tracking No.: (CES office to input)	**Phone :** (618) 453-7066	**E-mail :** sayeh@siu.edu
		Proposed Budget: $ 50,000

Abstract: (250 words max) This proposed project is to design, build, and test all-optical embedded fiber-optic links connecting the controller electronics in a benign environment (70 °c) to the power-electronic switches in a harsh location (125 °c).

Problem: This project addresses the issues and solutions concerning an all-optical bi-directional linkage of the power switches (PS) and sensors which are embedded in a harsh environment to the control/gate drives (CD) electronics in a benign environment.

Rationale / Approach: PS controlling a high-power motor usually operates in high temperature in the range of 125 °c. The CD electronics running the PS plate, functions best when it is embedded in a cooler environment below 70 °c. Thermal isolation of PS and CD plates requires a costly cooling system beyond the motor system design requirements. One solution is to physically separate the two plates about 20 m from each other. Due to the high EM interference in the PS side, a fiber-optic link connecting the two plates will be a practical choice.

Novelty: The optical isolation of the high-temperature power switches from the control/gate drives will enhance the performance and cost-effectiveness of the state-of-the-art high power motors. The embedded optical links will provide a high-temperature tolerant, EM interference free, and light-weight linkage. Applying an artificial neural network to the link will reduce the noise and nonlinearity due to high temperature environment.

Potential Member Company Benefits: The optical sensors and links can benefit industries, in particular Hamilton Sundstrand, where isolation of embedded electronics from harsh environments with factors including high temperature, high EMI, high pressure, and high stress/strain, is essential.

Deliverables for the proposed year: A report with the detail design, build, and test results of the fiber-optic links will be given.

Milestones for the proposed year: Design the up-link according to the industry specifications. Build the up-link where the detector is in the harsh environment. Test the up-link for noise and nonlinearity. If needed, apply the back-error propagation network for reduce the unwanted disturbances. Repeat the above for the down-link with the exception of replacing the detector with LED.

Progress to Date: **THIS SECTION TO BE UPDATED IN JANUARY**

Estimated Start Date: August 15, 2013	**Estimated Knowledge Transfer Date**: May 2014

Center for Embedded Systems (CES)
Request for Proposals Template – YEAR 5

DUE: Monday, April 8, 2013, by 5 p.m.

TITLE:	**All-optical embedded fiber-optic up/down-links for motor controller**		
PI:	M. R. Sayeh	**EMAIL:** sayeh@siu.edu	**TEL:** (618) 453-7066
DEPT:	Electrical and Computer Engineering	**SCHOOL:** Southern Illinois University Carbondale	

ABSTRACT: (250 OR FEWER WORDS)

This proposed project is to design, build, and test all-optical embedded fiber-optic links connecting the controller electronics in a benign environment (70 $^{\circ}$c) to the power-electronic switches in a harsh location (125 $^{\circ}$c).

PROBLEM:

This project addresses the issues and solutions concerning an all-optical bi-directional linkage of the power switches (PS) and sensors which are embedded in a harsh environment to the control/gate drives (CD) electronics in a benign environment.

RATIONALE:

PS controlling a high-power motor usually operates in high temperature in the range of 125 $^{\circ}$c. The CD electronics running the PS plate, functions best when it is embedded in a cooler environment below 70 $^{\circ}$c. Thermal isolation of PS and CD plates requires a costly cooling system beyond the motor system design requirements. One solution is to physically separate the two plates about 20 m from each other. Due to the high EM interference in the PS side, a fiber-optic link connecting the two plates will be a practical choice.

APPROACH:

Knowledge gained from the preliminary phase of this research is applied to the current proposed research. The use of optical sensors is not possible when the temperature exceeds 85 ^{o}c due to extreme reduction of the Faraday and Pockels effects [1, 2]. The light-triggered SiC power transistors are very inefficient requiring 0.5 mJ energy to switch [3]. The SiC MOSFET power transistors [4] requires external power source where EMI and other noises can enter the power switches. So the only viable solution to the optical link is to use high-temprature LEDs and photodetectors.

The proposed bi-directional fiber-optic link is shown in Fig. 1. Since the input of the down linkage is situated in the harsh environment (PS side), a high-temperature LED as light source is used. Due to their noisy/nonlinear nature, we propose to apply a neural-network style processing technique [5] to the signal received from the down-link LED.

The up-link, which connects CD to PS, is a simple fiber-optic link with a light source (LED) modulated with a control signal with bandwidth in the range of 100 KHz. The light signal enters the fiber (multi-mode type) of about 20 meter length; the output of the fiber is terminated into a high-temperature photodetector converting the light signal to the electric signal capable of tuning on the exciter drive. In case the photodetector signal has nonlinearity or noise due to the high-temperature environment, a neural-network processing will be applied.

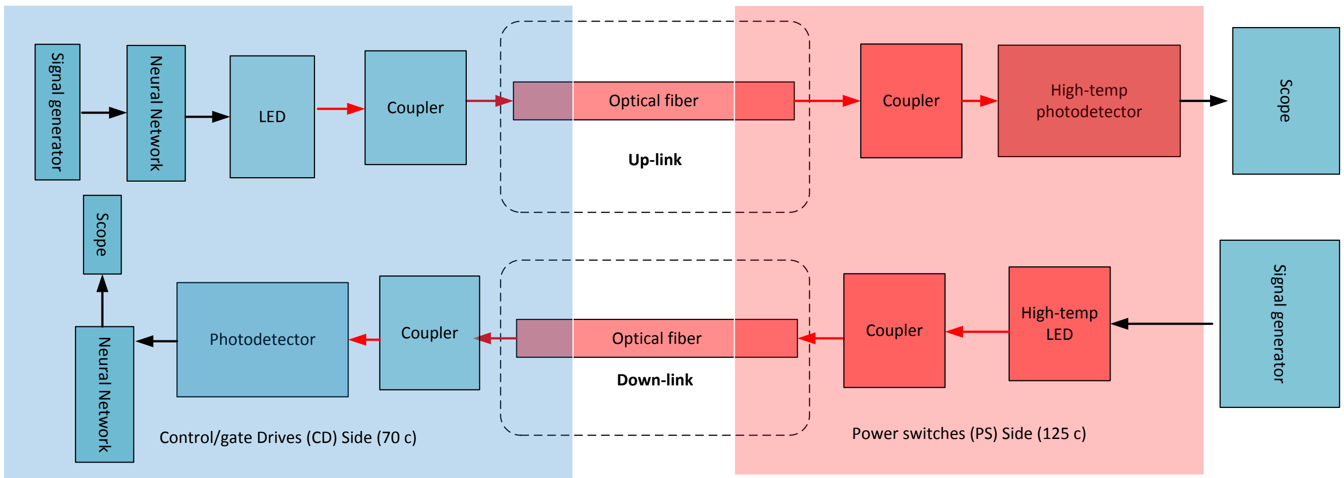

Figure 1. The proposed bi-directional smart optical link.

The proposed tasks are:

1. Design the up-link according to the industry specifications. These specifications include but not limited to: power needed for turning on the exciter drive; temperature variations; total link power consumption/loss; tolerances on SNR and bandwidth; and packaging dimensions.
2. Build the up-link where the detector is in the harsh environment.
3. Test the up-link for noise and nonlinearity. If needed, apply the back-error propagation network for reduce the unwanted disturbances.
4. Design the down-link according to the industry specifications. These specifications include but not limited to: temperature variations; total link power consumption/loss; tolerances on SNR and bandwidth; current and voltage sensory measurement ranges; and packaging dimensions.
5. Build the down-link where the LED is in the harsh environment.
6. Test the down-link for noise and nonlinearity. If needed, apply the back-error propagation network for reduce the unwanted disturbances.

NOVELTY:

The optical isolation of the high-temperature power switches from the control/gate drives will enhance the performance and cost-effectiveness of the state-of-the-art high power motors. The embedded optical links will provide a high-temperature tolerant, EM interference free, and light-weight linkage. Applying an artificial neural network to the link will reduce the noise and nonlinearity due to high temperature environment.

POTENTIAL BENEFITS TO INDUSTRY MEMBERS:

The optical sensors and links can benefit industries, in particular Hamilton Sundstrand, where isolation of embedded electronics from harsh environments with factors including high temperature, high EMI, high pressure, and high stress/strain, is essential.

DELIVERABLES:

A report with the detail design, build, and test results of the fiber-optic links will be given.

TIMELINE/MILESTONES: (PER QUARTER)

Task/Quarter	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
Task 1	X			
Task 2	X			
Task 3		X		
Task 4			X	
Task 5			X	
Task 6				X
Report				X

TECHNOLOGY TRANSFER:

Given the terms and conditions of the Center, the results of the study will be disseminated through publications in IEEE conferences and journals, in particular, IEEE Embedded Systems Letters. Outcome of the research project will also be distributed to undergraduate/graduate level courses and laboratories related to Photonics, Fiber Optic Communications, and Embedded Systems.

BUDGET:

The total project expense is at **$115,936** which includes $50,000 from the industry through the NSF I/UCRC for Embedded Systems. Detail is shown below.
Industry Contribution: **$50,000** = $17,867 (PI salary & fringe benefits for one month), $20,253 (an Ph.D. student salary & PCF @ 50% for 12 months), and $9,880 (equipment), $2,000 (travel)
SIU Match: **$65,936** = ($18,255 on indirect cost waiver and $47,681 on Ph.D. student tuition waiver)

BIBLIOGRAPHY: (ATTACH IN IEEE CONFERENCE OR JOURNAL FORMAT)

[1] G. Y. Chen, T. Lee, R. Ismaeel, G. Brambilla, and T. P. Newson, "Resonantly enhanced Faraday rotation in a microcoil current sensor," *IEEE Photonic Technology Letter*, Vol. pp, No. 99, pp. 1-1, 2012.

[2] F. Pan, X. Xiao, Y. Xu, and S. Ren, "Optical AC voltage sensor based on two Bi4Ge3O12 crystals," *IEEE Transactions on Instrumentation and Measurement*, Vol. 61, No. 4, pp. 1125-1129, 2012.

[3] F. Zhao and M. M. Islam, "Optically activated SiC power transistors for pulsed-power application," *IEEE Electron Device Letters*, Vol. 31, No. 10, pp. 1146-1148, 2010.

[4] T. Sarkar and S.K. Mazumder, "Photonic compensation of temperature-induced drift of SiC-DMOSFET switching dynamics," *IEEE Power Electronics Letters*, Vol. 25, No. 11, pp. 2704-2709, 2010.

[5] S. Haykin, *Neural networks, a comprehensive foundation, 3rd Edition*, Prentice Hall, New Jersey, 2009.

PI INFORMATION: (ATTACH 2-PAGE CV)

Mohammad R. Sayeh
Professor
Department of Electrical and Computer Engineering
Southern Illinois University Carbondale
Carbondale, Illinois 62901-6603
Phone: (618) 453-7066, Fax: (618) 453-7972 E-mail: sayeh@siu.edu

A. PROFESSIONAL PREPARATION

College/University	Major	Degree	Year
Oklahoma State University	**Electrical Engineering**	B.S.	1981
Oklahoma State University	**Electrical Engineering**	M.E.	1982
Oklahoma State University	**Electrical Engineering**	Ph.D.	1985

B. ACADEMIC/PROFESSIONAL APPOINTMENTS

- Asst./Assoc./Professor 1986-present
  Department of Electrical and Computer Engineering, Southern Illinois University Carbondale, Carbondale, Illinois, 62901

- Visiting Assistant Professor 1986
  Oklahoma State University, Stillwater, Oklahoma,

C. PUBLICATIONS MOST CLOSELY RELATED TO PROPOSAL

- M. Tafazoli, N. Davoudzadeh, and **M. R. Sayeh**, "All optical asynchronous binary delta–sigma modulator," (2013) *Optics Communications,* Vol. 291, pp 228-231.
- **M. R. Sayeh** and S. Azeemuddin, "Effect of Various Parameters on Working of All-optical Schmitt Trigger," (2011) *Optik,* Vol. 122, No. 21, pp 1935-1938.
- B. Regez, **M. R. Sayeh,** A. Mahajan and F. Figueroa, "A Novel Fiber Optics Based Method to Measure Very Low Strains in Large Scale Infrastructures," (2009) *Measurement*, Vol. 42, pp. 183-188.
- **M. R. Sayeh** and J.W. Park, "Spinning-top Dynamics of Photorefractive Grating," (2008) *Optics Communications*, Vol. 281, No. 8, pp. 2309-2315.
- J. Cheng, **M. R. Sayeh** and M. R. Zargham, "Lorentzian-Based Model for Clustering," (2007) *Intelligent Engineering Systems Through Artificial Neural Networks*, Vol. 17, Editors: C.H. Dagli, A. L. Buczak, D. L. Enke, M. J. Embrechts, and O. Ersoy, ASME Press, pp. 513-518.
- **M. R. Sayeh** and A. Siahmakoun, "Nonlinear Dynamics of Two-wave Coupling Process," (2004) *Optics Express*, Vol. 12, No. 13, pp. 2999-3010
- **M. R. Sayeh** and A. Siahmakoun, "Analytical Solution for Nonlinear Dynamics of Photorefractive Gratings," (2003) *OSA Trends in Optics and Photonics Series*, Vol. 87, pp. 306-312.
- R. Athinarayanan, **M. R. Sayeh**, and D.A. Wood, "Adaptive Competitive Self-organizing Associative Memory," (2002) *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans*, Vol. 32, No. 4, pp. 461-471.
- **M. R. Sayeh** and R. Marusarz, "Neural Network Based Multi-mode Fiber Optic Information Transmission," (2001) *Applied Optics*, Vol. 40, No. 2, pp. 219-227.
- **M. R. Sayeh**, L. Gupta, D. Kagaris, R. Viswanathan, and B. Chung, "Multiplexed Fiber-optic Strain Sensors for Distributed Sensing," (2000) *Distributed Optical Fiber Sensors and Measuring Networks,* Edited by Y.N. Kulchin, SPIE Selected Papers, Vol. 47-53.

D. SYNERGISTIC ACTIVITIES

Technical reviewer:

- NSF, 1991-present; IEEE Transactions on SMC, 1989-present;
- IEEE Journal of Quantum Electronics, 1992-present.

Society membership:

Phi Kappa Phi, Eta Kappa Nu, Optical Society of America

University:

- Senator, University Senate, 2008-2009
- Member, College Ph.D. Committee, 2007-2009
- Member, University Doctoral Fellowship Review Board, 2006-present
- Member, University Outstanding Dissertation Committee, 2006-present

Research Activities:

- Optical Delta-sigma Modulator 2001- present
- Photorefratcive Optics 1986 – present
- Neural Networks: Theory and Application to Image Understanding and Fiber Optic Sensors, and Optical Implementation of Associative Memories, 1986 - present

Patents:

- "Binary Delta-Sigma Modulators," with S. Siahmakoun from Rose-Hulman Institute of Technology, US Patent: 7,355,538, April 8, 2008.
- "Optical Strain Sensor," with A. Mahajan, B. Regez, and F. Figueroa, under preparation through NASA.

Grants:

- "Low-power Terahertz Optical A/D Converter," PI: M.R. Sayeh, sponsored by US Navy/ONR, 2006-2008, amount: $507,000.
- "Terahertz Optical A/D Converter (TOADC): Decimation Module," PI: M.R. Sayeh, sponsored by US Navy/ONR, 2004-2005, amount: $64,000.
- "Photorefractive Continuous-Time Delta-Sigma Modulator," PI: M.R. Sayeh, sponsored by Rose-Hulman Institute of Technology/ONR, 2003, amount: $17,000
- "Real-time Modeling of Flexible Structures for Health Monitoring and Control," Co-PIs: M.R. Sayeh, F. Pourboghrat, and M. Daneshdoost, sponsored by the Materials Technology Center and Coal Research Center, and Graduate School at SIU-C, 2001-2002, amount: $37,500

E. COLLABORATORS AND OTHER AFFILIATIONS

Collaborators: R. Athinarayanan, Purdue University, Lafayette, IN; S. Dhali, Old Dominion University, Norfolk, VA; A. Siahmakoun, Rose-Hulman Institute of Technology, Terra Haute, IN; C. Hatziadoniu, L. Gupta, D. Kagaris, R. Marusarz, R. Viswanathan, and M. Zargham, Southern Illinois University, Carbondale, IL.

Graduate and Postdoctoral Advisors

- Ph.D. Advisor: H.R. Bilger, Oklahoma State University, Stillwater, OK

Thesis Advisor and Postgraduate Scholar Sponsors over the Last Five Years:

- Total Number of Graduate Students advised: 40, Ph.D. Students advised: 8
- Total Number of Postdoctoral Scholars Sponsored: 0