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6. AUTHORS Michael Steer			5d. PROJECT NUMBER		
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			5f. WORK UNIT NUMBER		
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14. ABSTRACT The vision of SIAMES was to study the interaction between RF fields and electronic circuits, with the ultimate goal of rapid and accurate extraction of system, functional, and device information from external stimulus and monitoring of electronic systems. Basic research was performed in the following areas: (1) Determining the general limitations on the information that can be extracted remotely from general categories of circuits and systems; (2) Formulating theories and computational models for predicting the most effective probe field combinations and					
15. SUBJECT TERMS Circuit-Field Interaction, Behavioral Modeling, Passive Intermodulation Distortion, Co-Site Interference					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Michael Steer
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 919-515-5191

## Report Title

### Standoff Inverse Analysis and Manipulation of Electronic Systems - Final Report

#### ABSTRACT

The vision of SIAMES was to study the interaction between RF fields and electronic circuits, with the ultimate goal of rapid and accurate extraction of system, functional, and device information from external stimulus and monitoring of electronic systems. Basic research was performed in the following areas: (1) Determining the general limitations on the information that can be extracted remotely from general categories of circuits and systems; (2) Formulating theories and computational models for predicting the most effective probe field combinations and signal analysis methodologies for general categories of circuits and systems; (3) Designing optimal search, sensor management, and signature extraction techniques; (4) Validating the phenomenology through measurements on a limited but useful assortment of canonical electronic systems.

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**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)

<u>Received</u>	<u>Paper</u>
2011/10/31 1  6	Jonathan Wilkerson, Peter Lam, Kevin Gard, Michael Steer. Distributed passive intermodulation distortion on transmission lines, IEEE Transactions on Microwave Theory and Techniques, (05 2011): 1190. doi:
2011/10/31 1  7	Christopher_Saunders, Jie_Hu, Carlos_Christoffersen, Michael_Steer. Inverse singular value method for enforcing passivity in reduced-order models of distributed structures for transient and steady-state simulation, IEEE Transactions on Microwave Theory and Techniques, (04 2011): 837. doi:
2011/10/31 1  2	John Kosinski, W Devereux Palmer, Michael Steer. Unified understanding of RF remote probing, IEEE Sensors, (12 2011): 3055. doi:
2011/10/31 1  4	Jie Hu, Justin Lowry, Kevin Gard, Michael Steer. Nonlinear radio frequency model identification using a hybrid genetic optimizer for minimal user intervention , IET Microwaves, Antennas & Propagation, (01 2012): 0. doi:
2011/10/31 1  3	Wonhoon Jang, Nikhil Kriplani, Aaron Walker, Michael Steer. Behavioral modeling of power amplifier asymmetry in the time domain, International Journal of Numerical Modelling, (01 2012): 0. doi:
2011/10/31 1  1	Christopher Saunders, Michael Steer. Passivity enforcement for admittance models of distributed networks using an inverse eigenvalue method, IEEE Transactions on Microwave Theory and Techniques, (01 2012): 0. doi:

**TOTAL: 6**

**Number of Papers published in peer-reviewed journals:**

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

<u>Received</u>	<u>Paper</u>
2011/10/31 1  8	Nikhil Kriplani, Stephen Bowyer, Jennifer Huckaby, Michael Steer. Modelling of an Esaki tunnel diode in a circuit simulator, Active and Passive Electronic Components, (02 2011): 1. doi:
2011/10/31 1  5	Jie Hu, Kevin Gard, Michael Steer. Calibrated nonlinear vector network analyzer without using a multi-harmonic generator , IET Microwaves, Antennas & Propagation, (05 2011): 616. doi:

**TOTAL: 2**

Number of Papers published in non peer-reviewed journals:

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**(c) Presentations**

Number of Presentations: 0.00

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

<u>Received</u>	<u>Paper</u>
2011/10/31 11:09	Christopher Saunders, Michael Steer. "Reduced-order modeling for co-simulation of circuit and electromagnetic interactions," , Proceedings of the XXX General Assembly of the Union of Radio Scientists International. 2011/08/15 00:00:00, . : ,

**TOTAL: 1**

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

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

<u>Received</u>	<u>Paper</u>
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**TOTAL:**

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

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**(d) Manuscripts**

<u>Received</u>	<u>Paper</u>
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**TOTAL:**

Number of Manuscripts:

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**Books**

<u>Received</u>	<u>Paper</u>
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**TOTAL:**

**Patents Submitted**

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**Patents Awarded**

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**Awards**

M. Steer, Distinguished Educator Award, IEEE Microwave Theory and Techniques Society, 2011

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### Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	Discipline
Joshua Wetherington	0.50	
Jie Hu	0.50	
Christopher Saunders	0.50	
<b>FTE Equivalent:</b>	<b>1.50</b>	
<b>Total Number:</b>	<b>3</b>	

### Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

### Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Edward Delp	0.20	No
Andreas Cangellaris	0.20	No
Michael Steer	0.25	
<b>FTE Equivalent:</b>	<b>0.65</b>	
<b>Total Number:</b>	<b>3</b>	

### Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

### 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

<u>NAME</u>
<b>Total Number:</b>

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**Names of personnel receiving PHDs**

NAME

Jie Hu

**Total Number:**

1

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**Names of other research staff**

NAME

Nikhil Kriplani

**FTE Equivalent:**

**Total Number:**

PERCENT SUPPORTED

0.50

**0.50**

1

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**Sub Contractors (DD882)**

1 a. University of Illinois - Urbana - Champaign

1 b. Office of Sponsored Programs

1901 S. First Street

Champaign IL 61820

**Sub Contractor Numbers (c):** 2005-0725-02

**Patent Clause Number (d-1):** 37 CFR Part 401

**Patent Date (d-2):**

**Work Description (e):** Electromagnetic Modeling in Support of Methodologies for Standoff Inverse Analysis and Manipu

**Sub Contract Award Date (f-1):** 7/1/2005 12:00:00AM

**Sub Contract Est Completion Date(f-2):** 6/30/2011 12:00:00AM

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1 a. University of Illinois - Urbana - Champaign

1 b. Grants & Contracts Office

Office of Business & Financial Services

Champaign IL 618207406

**Sub Contractor Numbers (c):** 2005-0725-02

**Patent Clause Number (d-1):** 37 CFR Part 401

**Patent Date (d-2):**

**Work Description (e):** Electromagnetic Modeling in Support of Methodologies for Standoff Inverse Analysis and Manipu

**Sub Contract Award Date (f-1):** 7/1/2005 12:00:00AM

**Sub Contract Est Completion Date(f-2):** 6/30/2011 12:00:00AM

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1 a. Purdue University

1 b. Sponsored Program Services

Purdue University

West Lafayette IN 479072114

**Sub Contractor Numbers (c):** 2005-0725-01

**Patent Clause Number (d-1):**

**Patent Date (d-2):**

**Work Description (e):** Remote Examination & Manipulation of Electric & Electronic Devices Using Inverse Evaluation of

**Sub Contract Award Date (f-1):** 7/1/2005 12:00:00AM

**Sub Contract Est Completion Date(f-2):** 6/30/2011 12:00:00AM

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1 a. Purdue University

1 b. Sponsored Program Services

610 Purdue Mall

West Lafayette IN 479072040

**Sub Contractor Numbers (c):** 2005-0725-01

**Patent Clause Number (d-1):**

**Patent Date (d-2):**

**Work Description (e):** Remote Examination & Manipulation of Electric & Electronic Devices Using Inverse Evaluation of

**Sub Contract Award Date (f-1):** 7/1/2005 12:00:00AM

**Sub Contract Est Completion Date(f-2):** 6/30/2011 12:00:00AM

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**Inventions (DD882)**

## Scientific Progress

Research accomplishments addressed the following areas:

- Determination of the general limitations on the information that can be extracted remotely from general categories of circuits and systems.
  - Formulation theories and computational models for predicting the most effective probe field combinations and signal analysis methodologies for general categories of circuits and systems.
  - Design of optimal search, sensor management, and signature extraction techniques.
  - Validation of the phenomenology through measurements on a limited but useful assortment of canonical electronic systems.
- The work focused on phenomenology and understanding fundamentals. The more than 100 papers produced over the duration of the project go into detail.

NC State University Report Prepared by Michael Steer

Summary:

Work at NC State University focused on completing fundamental studies, writing papers and writing dissertations. The majority of the phenomenological investigations were completed in the first three years of the project. We have explored a number of fundamental issues that address remote classification. Time-frequency effects. We are looking at the response of filters and RF front ends to RF pulses. We are looking at filters on their own and at co-site interference. Passive intermodulation distortion (PIM). We have determined that PIM is the source of fundamental limitations in high power transmitters. We have shown that PIM is primarily a thermal effect and is described by fractional calculus. An example of problems that occur as a result of thermal PIM is that a two-tone signal applied to an antenna will result in third-order intermodulation products. A sequence of three papers are being written on the topic.

Purdue University Report Prepared by Bill Chappell

Summary:

The work at Purdue focused on the understanding of passive intermodulation (PIM) in order to mitigate the effect of PIM in fielded systems. To this end a method was developed that determined that coaxial connectors produce PIM due to the current passing through them. This allowed us to develop a process for designing matching networks to reduce current in the PIM source thereby reducing the distortion it creates.

Purdue University Report...Prepared by Edward J. Delp and Saul Gelfand

Summary:

Forensic characterization of a wireless device was developed. Forensic characterization allows determination of the type of device, make, model, configuration, and other characteristics based on observation of the signal that the device produces. The unique characteristics of the device are known as device signatures or device fingerprints. For our experiments we focused specifically on the unique features introduced by the filter component of the RF front end.

University of Illinois Report. Prepared by Andreas C. Cangellaris

Summary:

Over the project period efficient methodologies and computer algorithms were developed for the numerical calculation of the transient response of electromagnetic systems exhibiting multi-tone behavior, or involving the analysis of wave phenomena and electromagnetic responses that are governed by highly disparate time scales.

## Technology Transfer