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This document serves as the final report for the Department of Defense (DoD) Research and Education Program for Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI) Equipment/Instrumentation Grant (W911NF-14-1-0042). This final report will described the instrumentation and the integration into the academic and research programs. All instrumentation has been procured, delivered, and integrated into the laboratories at Morgan State University (MSU) Clarence M. Mitchell Jr. School of Engineering (SOE)

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Report Title

Final Report: Test and Evaluation Enhancements for Cognitive Radio Technologies

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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)

Received Paper

TOTAL:

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:

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

Received Paper

TOTAL:

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

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

Received Paper

TOTAL:

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

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

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

Technology Transfer

Department of Defense (DoD)
Research and Education Program for Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI)
Equipment/Instrumentation Grant
(W911NF-14-1-0042)

TEST & EVALUATION ENHANCEMENTS FOR COGNITIVE RADIO TECHNOLOGIES

Final Report

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PURPOSE

This document serves as the final report for the Department of Defense (DoD) Research and Education Program for Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI) Equipment/Instrumentation Grant (W911NF-14-1-0042). This final report will described the instrumentation and the integration into the academic and research programs. All instrumentation has been procured, delivered, and integrated into the laboratories at Morgan State University (MSU) Clarence M. Mitchell Jr. School of Engineering (SOE).

INSTRUMENTATION

The primary objective for the instrumentation was to enhance our test & evaluation (T&E) capabilities for non-linear and time-domain analysis of communication components and systems. We procured the following instrumentation:

- **50-GHz GHz PNA-X Network Analyzer**

  The Agilent PNA-X Microwave Network Analyzer will be used to characterize the components, sub-systems and systems for noise, non-linear behavior, power, and impedance performance up to 50 GHz.

- **Digital Signal Analyzer**

  The digital signal analyzer will be used to identify spectral content of wide-bandwidth RF signals and analyze transient physical phenomena of various components, subsystems and systems. The oscilloscope offers 8 GHz true analog bandwidth that delivers the lowest noise floor and jitter measurement floor ensuring superior measurement accuracy.

Working with the vendor and applying additional university discounts, we were able to procure an additional piece of instrumentation within the allocated funding to further enhance our capabilities for high-speed digital signal analysis and functionality:

- **AXIe-based Logic Analyzer Module**

  The logic analyzer module provides high-speed time-domain analysis of digital signals in support of digital firmware design. The module consist 136-channels with 12.5 GHz timing zoom, 1.4-GHz State and 2 Mb memory depths.

LABORATORY INTERGATION

The instrumentation was integrated into two laboratories in support of the academic and research concentrations for RF/microwave engineering and communication systems. SOE has implemented an open-access laboratory philosophy across its graduate and undergraduate laboratories. General laboratory and instrumentation oversight is based on several

concentrations and research programs. The instrumentation was integrated into the following laboratories:

- **Communication System Integration Laboratory**: Focus of the multidisciplinary design and integration of software-defined radios, cognitive radios, and other embedded systems.
  - **8-GHz, 40-GSa/s Digital Signal Analyzer**
  - **136-Channel, 1.4-GHz State High-Speed Logic Analyzer**
  - CAD SW: Matlab/Simulink, Agilent ADS & SystemVUE, Ansoft HFSS, Altium
  - 6-GHz VNA, Spectrum Analyzers, Signal Generators, Noise/Power Characterization
  - 7-GHz Vector Signal Generator w/ Arbitrary Waveform Functional

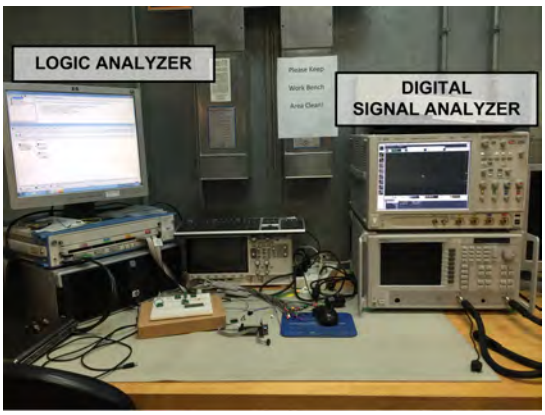

Figure 1: Communication System Integration Laboratory

- **High-Frequency Characterization Laboratory:** Focused on the high-speed characterization of RF/microwave components and sub-systems.
  - **50-GHz PNA-X Network Analyzer**
  - 50-GHz 8510C Network Analyzer with On-Wafer Probe Station
  - Signal Generators, Noise/Power Characterization
  - Device Characterization and Modeling Software

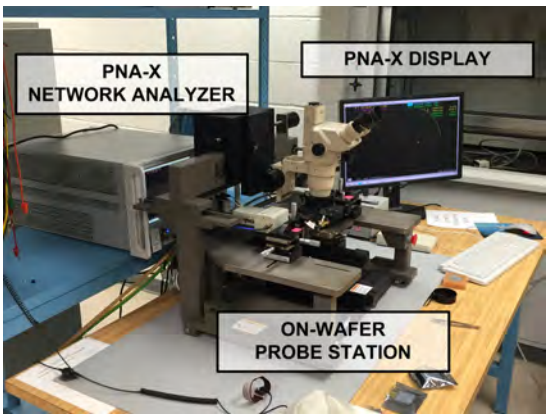

Figure 2: High-Frequency Characterization Laboratory

In addition to the direct integration of the instrumentation within the above laboratories, the following laboratory will be impacted by the enhanced T&E capabilities:

- **Embedded System Design Laboratory:** Focused on the firmware and software development of embedded systems.
    - 10 REDHAWK Development Systems
    - CAD: Xilinx Vivado/ISE, Mentor Graphics ModelSim, Matlab/Simlink
    - Development Platforms: Kintex KC705, Zynq ZC706, Zedboard, Spartan SP601

RESEARCH IMPACT

This instrumentation had a direct impact on the following DoD-funded projects:

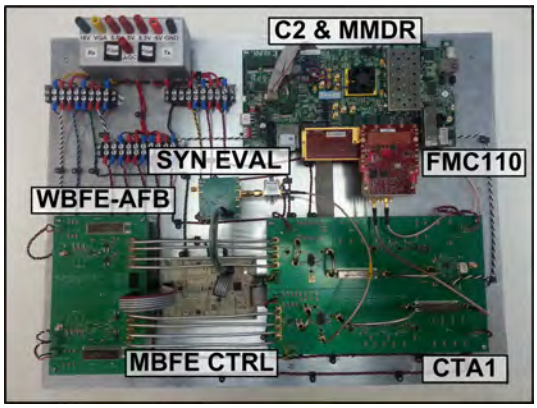

Figure 3: MBMM SDR Hardware Platform

Center of Excellence for Tactical and Cyber Technologies (CETACT) has been awarded a $2.2-million Broad Agency Announcement (BAA) contract (W900KK-12-C-0048) released by the U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI). The contract is for the development of a multi-band, multi-mode SDR (MBMM) platform in support of research objectives of the Spectrum Efficient Technology (SET) Test Science & Technology (S&T) and Test Resource Management Center (TRMC)/Office of Secretary of Defense (OSD). During the performance period of this grant, we developed a hardware platform composing of several integrated subsystems as shown in Figure 3. It consists of the wide-band front end with an adaptable filter bank (WBFE-AFB) board, the channel tuning (CTA1) board; the synthesizer evaluation (SYN EVAL) board, the multi-mode digital radio (MMDR) subsystem, and configuration and control (C2) subsystem with the multi-band front-end controller (MBFE CTRL). The C2 and MMDR subsystems are implemented using state-of-the-art system-on-chip (SoC) technology, which consist of a highly integrated ARM processor with advanced programmable logic. The instrumentation was used during the T&E phase. As a result of this work, we were awarded Phase 3 for full prototype development.

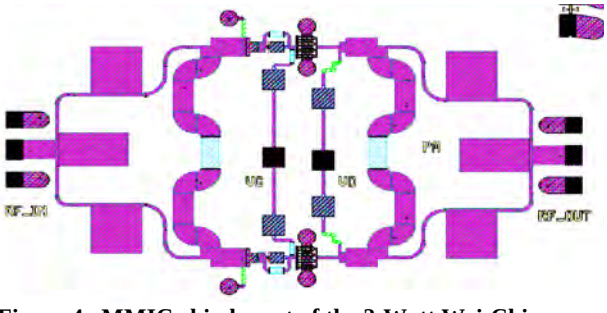

Figure 4. MMIC chip layout of the 2-Watt Wei-Chi power amplifier.

Center of Microwave, Satellite, and RF Engineering (COMSARE) has been awarded $277.2K (N00014-13-1-0335) from the Office of Naval Research to develop an efficient linear 10-Watt GaN power amplifier that incorporates novel on-chip planar power combiner architecture with harmonic suppression. This grant has been used to support the advancement of wide band-gap semiconductor microwave and millimeter wave circuits. The procured PNA-X has been configured to operate with the

Cascade Microtech on-wafer probe test station for on-wafer characterization and measurement of GaN HEMT devices and circuits. To date, we have developed a 2-Watt driver amplifier as shown in Figure 4. The final MMIC chip has been submitted and the fabricated chip is ready for testing.

ACADEMIC IMPACT

The instrumentation has been used to train an initial small audience (~ 6 participants) of student and professional researchers during the summer of 2014. The PNA-X is targeted to be integrated into the following academic courses that will expose over 25 undergraduate and graduate students, annually beginning Fall 2015:

- *Automated Measurements, Devices & Systems* - This course will consider microwave active circuits utilizing semiconductor devices. Students will be introduced to the fundamentals of high-frequency measurements and the latest techniques for accuracy enhanced microwave measurements. Automated network analyzers and high-speed wafer probes are used in conjunction with state-of-the-art calibration techniques.
    - Graduate Enrollment: 10

- *Introduction to Microwaves* - This course deals with electromagnetic wave types, transmission lines and waveguides, Smith Chart, S-parameters, and passive components associated with microwave signals and circuits.
    - Undergraduate Enrollment: 10
    - Graduate Enrollment: 10

- *Microwave System and Components* - This course provides the practical aspects of microwave systems and components. An overview of communication and radar systems is followed by detailed analysis of key components. Topics include linear and nonlinear characteristics of individual components and their relationship to system performance.
    - Graduate Enrollment: 10

- *Active Microwave Circuit Design* - This course will provide a brief overview of Smith Charts and transmission line theory, microstrip lines, and impedance matching. It will introduce power, gain equations, stability considerations, and solid state microwave circuits such as amplifiers, oscillators, active mixers, attenuators, and frequency multipliers.
    - Graduate Enrollment: 10

STEM OUTREACH

MSU believes that investment into the STEM pipeline enhances its holistic approach for the integration of academic and research activities. As a result, this instrumentation has been used to support the following STEM outreach program:

- Pre-Accelerated Curriculum in Engineering (PACE)

PACE is a six-week transitional summer program for in-coming STEM freshmen that give students a significant advantage in both academic and personal development. Academically, the program reinforces fundamental subjects that will increase the probability of a successful freshman year. Students take physics, chemistry, mathematics, English, critical thinking, and computer science. Also, students take part in a research rotation program in which they participate in the Summer Research Symposium. For personal development, this on-campus program allows students to become acclimated to college life, and bond with peers, tutors and professors, which assist them in their first-semester matriculation.

During the summer of 2014, approximately 25 pre-freshmen PACE students participated in demonstrations that showed how the PNA-X is used to make on-wafer device measurements. Students were able to measure a device's DC characteristic current-voltage behavior and display the results in a software computer-aided extraction tool, ICCAP. Undergraduate and graduate students gave technical talks that provided an overview of their research project results.