ROUTING AND ACTION

MEMORANDUM

ROUTING

TO:(1) Network Sciences Division (Ulman, Robert)

Report is available for review

(2) Proposal Files Report No.: -REP Proposal Number: 68815-NS-REP.1

DESCRIPTION OF MATERIAL

CONTRACT OR GRANT NUMBER: W911NF-16-1-0466

INSTITUTION: University of New Mexico Albuquerque

PRINCIPAL INVESTIGATOR: Sudharman Jayaweera

TYPE REPORT: Final Report

DATE RECEIVED: 12/1/17 5:10PM

PERIOD COVERED: 8/15/16 12:00AM through 8/14/17 12:00AM

TITLE: Final Report: A Wideband Autonomous Cognitive Radio Development and Prototyping System

ACTION TAKEN BY DIVISION

(x) Report has been reviewed for technical sufficiency and IS [x] IS NOT [ ] satisfactory.

(x) Material has been given an OPSEC review and it has been determined to be non sensitive and, except for manuscripts and progress reports, suitable for public release.

(x) Perfomance of the research effort was accomplished in a satisfactory manner and all other technical requirements have been fulfilled.

(x) Based upon my knowledge of the research project, I agree with the patent information disclosed.

Approved by SSL\ROBERT.J.ULMAN on 12/4/17 8:01AM

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13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Sudharman Jayaweera
UU	UU	UU	UU		19b. TELEPHONE NUMBER 505-277-1078

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RPPR Final Report
as of 04-Dec-2017

Agency Code:

Proposal Number: 68815NSREP

Agreement Number: W911NF-16-1-0466

INVESTIGATOR(S):

Name: Balu Santhanam
Email: bsanthan@unm.edu
Phone Number: 5052771611
Principal: N

Name: Christos Christodoulou Ph.D.
Email: christos@unm.edu
Phone Number: 5052772436
Principal: N

Name: Gregory Heileman
Email: heileman@unm.edu
Phone Number: 5052774011
Principal: N

Name: Sudharman K. Jayaweera
Email: jayaweera@unm.edu
Phone Number: 5052771078
Principal: Y

Name: PhD Manel Martinez-Ramon
Email: manel@unm.edu
Phone Number: 5052773008
Principal: N

Name: Rafael Fierro
Email: rfierro@ece.unm.edu
Phone Number: 5052774125
Principal: N

Name: Ramiro Jordan
Email: rjordan@ece.unm.edu
Phone Number: 5052772412
Principal: N

Name: Wennie Shu
Email: shu@ece.unm.edu
Phone Number: 5052771433
Principal: N

Organization: **University of New Mexico Albuquerque**
Address: 1700 Lomas Boulevard NE, Suite 2200, MSC01 1247, Albuquerque, NM 871310001
Country: USA

DUNS Number: 868853094
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Report Date: 14-Nov-2017
Date Received: 01-Dec-2017
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Title: A Wideband Autonomous Cognitive Radio Development and Prototyping System
Begin Performance Period: 15-Aug-2016
End Performance Period: 14-Aug-2017
Report Term: 0-Other

Submitted By: Sudharman Jayaweera
Email: jayaweera@unm.edu
Phone: (505) 277-1078

Distribution Statement: 1-Approved for public release; distribution is unlimited.

RPPR Final Report
as of 04-Dec-2017

STEM Degrees: **STEM Participants:**

Major Goals: The requested equipment will expand our on-going research towards developing prototype wideband autonomous cognitive radio systems for several important applications leading to following benefits:
1. Support collaborative research, development and prototyping of self-learning, real-time reconfigurable cognitive radio devices and networks among faculty and students at the Department of Electrical and Computer Engineering at UNM. Make the equipment available for other areas of research within the ECE including robotics networks, autonomous vehicular networks and W/V and millimeter wave band research.
2. Support both graduate and undergraduate engineering teaching and training through the use of the requested equipment in hands-on laboratory courses and projects and, in particular in senior design capstone projects.
3. Support the development of cognitive and software-defined radio (SDR) systems by local hi-tech small businesses as they seek to commercialize technologies developed in collaboration with regional universities, in particular UNM, and federal labs via SBIR, STTR and other programs.
4. Support outreach to local high schools through summer internship programs at the ECE department and lab demonstration visit invitations in order to get students be aware of the potential of STEM fields so that they are excited about pursuing STEM education and careers. Moreover, expand the UNM's on-going partnership with the AFRL's La Luz Academy for attracting high school students to STEM areas and work with the UNM's
recently established STEM Collaborative Center.

Accomplishments: The funds were used to assemble a Wideband Autonomous Cognitive Radio Development and Prototyping System (WACR Development and Prototyping System) consisting of three infrastructure modules (a Network Spectrum Analyzer, a Vector Signal Generator and a Rapid Printed Circuit Board (PCB) Fabrication Unit) and a Software Defined Radio (SDR) testbed made of several USRP SDR (Universal Software Radio Peripheral Software Defined Radio) platforms.
The capabilities developed under this award has already had an impact on the cognitive radio research at the UNM in several ways, including new research funding opportunities, new research directions and validation avenues for graduate students, increased collaborations with the industry and new recruiting opportunities.

Training Opportunities: Nothing to Report

Results Dissemination: The equipment is being used in several projects. We will acknowledge the support from this award in future publications that may use these equipment for experiments.

Honors and Awards: New contracts secured during the project period:
1. C. Christodoulou (PI), “Wideband Autonomous Cognitive Radios for Networked Satellites Communications”, Phase II STTR Award Subcontract. Prime Contractor: Bluecom Systems and Consulting LLC, 11/01/16-10/31/18 ($753K), NASA Shared Services Center, Stennis Space Center, MS 39529-0001.
2. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou “Cognitive Radios and Reconfigurable Antennas for Mobile Platforms”, 02/01/17-12/31/17 ($100K), Honeywell FM&T.
3. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou “Wideband Autonomous Cognitive Radios (WACRs) for Spectrally-efficient and Agile Multiband/Multimode Communications”, 12/01/16-11/30/19 ($500K), Army Research Laboratory (ARL).
4. C. G. Christodoulou (Principal Investigator), “Advanced Components for Electronics in space”, 02/01/2017-02/30/2022, ($7M), Air Force Research Laboratory (AFRL).
5.

Existing contracts that continued during the project period:
1. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou (co-PI) “Spectrum-agile Cognitive GPS Operation Through Dynamic Spectrum Awareness”, 08/01/16-05/31/17 ($50K), Air Force Research Laboratory (AFRL) Collaboration Program – Sensors, Subcontract from Clarkson Aerospace (Prime Contractor).
2. S. K. Jayaweera (Principal Investigator), “Cognitive Communications for SATCOM”, Space Vehicles (RV) University Grants Program, 04/26/16-04/25/17 ($150K), Air Force Research Laboratory (AFRL), Kirtland AFB, Albuquerque, NM.
3. C. G. Christodoulou (Principal Investigator), “Deployable Modular Antennas for Small Satellites”, 03/30/2015-1/30/2018, ($447K), Air Force Research Laboratory (AFRL).
4. C. G. Christodoulou (Principal Investigator), “Terrestrial Link Experiment for the Characterization of Rain Attenuation and Depolarization at V/W Bands”, 8/30/2016-5/31/2020 ($1,931,267), Air Force Research Laboratory (AFRL).

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Sudharman Jayaweera
Person Months Worked: 1.00
Funding Support:
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

FINAL PROJECT REPORT

PROJECT TITLE: A WIDEBAND AUTONOMOUS COGNITIVE RADIO DEVELOPMENT AND PROTOTYPING SYSTEM

Principal Investigator: Sudharman K. Jayaweera
Contract Number: W911NF-16-1-0466
Type of Report: Final

Communications and Information Sciences Laboratory (CISL)
Department of Electrical and Computer Engineering
University of New Mexico
Albuquerque, NM 87131

1. Abstract

This equipment award was aimed at funding to equip the cognitive radio laboratory (http://cognitive-radio.ece.unm.edu/) at the ECE Department of University of New Mexico with a Wideband Autonomous Cognitive Radio Development and Prototyping System that will augment the its on-going research program in cognitive radios with development, prototyping and testing capabilities. The requested equipment will expand the on-going research into developing a prototype of wideband autonomous cognitive radio system resulting in following benefits:

The funds were used to assemble a Wideband Autonomous Cognitive Radio Development and Prototyping System (WACR Development and Prototyping System) consisting of three infrastructure modules (a Network Spectrum Analyzer, a Vector Signal Generator and a Rapid Printed Circuit Board (PCB) Fabrication Unit) and a Software Defined Radio (SDR) testbed made of several USRP SDR (Universal Software Radio Peripheral Software Defined Radio) platforms.

The capabilities developed under this award has already had an impact on the cognitive radio research at the UNM in several ways, including new research funding opportunities, new research directions and validation avenues for graduate students, increased collaborations with the industry and new recruiting opportunities.

2. Summary

In this final project report we list details of all items of equipment acquired using the funds from this award. These were used to assemble a Wideband Autonomous Cognitive Radio Development and Prototyping System (WACR Development and Prototyping System) consisting of three infrastructure modules (a Network Spectrum Analyzer, a Vector Signal Generator and a Rapid Printed Circuit Board (PCB) Fabrication Unit) and a Software Defined Radio (SDR) testbed made of several USRP SDR (Universal Software Radio Peripheral Software Defined Radio) platforms.

The University of New Mexico project team has been working on various aspects of cognitive radio technology several years. In the following sections, we will briefly describe how the equipment acquired under this award has been used to support and advance these existing research as well as to secure new sponsored research projects. Many of these projects have also been through Department of Defense (DoD) agencies and thus are aligned with research of interest to DoD.

3. Items of Equipment Acquired Under this Award Scope

The following is a list of major equipment items acquired using the fund from this award:

1. 50 GHz FieldFox Microwave Analyzer (Keysight Technologies), Cost: $80,611.20.
2. PSG vector signal generator (Keysight Technologies), Cost: $224,050.56.

3. Universal Software Radio Peripherals (USRPs) - 2953R (National Instruments), Cost: $19,790.28.
4. LPKF ProtoLaser S4 (LPKF Laser & Electronics), Cost: $144,975.00.

4. Sponsored Research Contracts on Cognitive Radios Received by the Project Team Members

New contracts secured during the project period:

1. C. Christodoulou (PI), “Wideband Autonomous Cognitive Radios for Networked Satellites Communications”, Phase II STTR Award Subcontract. Prime Contractor: Bluecom Systems and Consulting LLC, 11/01/16-10/31/18 ($753K), NASA Shared Services Center, Stennis Space Center, MS 39529-0001.
2. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou “Cognitive Radios and Reconfigurable Antennas for Mobile Platforms”, 02/01/17-12/31/17 ($100K), Honeywell FM&T.
3. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou “Wideband Autonomous Cognitive Radios (WACRs) for Spectrally-efficient and Agile Multiband/Multimode Communications”, 12/01/16-11/30/19 ($500K), Army Research Laboratory (ARL).
4. C. G. Christodoulou (Principal Investigator), “Advanced Components for Electronics in space”, 02/01/2017-02/30/2022, ($7M), Air Force Research Laboratory (AFRL).
5.

Existing contracts that continued during the project period:

1. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou (co-PI) “Spectrum-agile Cognitive GPS Operation Through Dynamic Spectrum Awareness”, 08/01/16-05/31/17 ($50K), Air Force Research Laboratory (AFRL) Collaboration Program – Sensors, Subcontract from Clarkson Aerospace (Prime Contractor).
2. S. K. Jayaweera (Principal Investigator), “Cognitive Communications for SATCOM”, Space Vehicles (RV) University Grants Program, 04/26/16-04/25/17 ($150K), Air Force Research Laboratory (AFRL), Kirtland AFB, Albuquerque, NM.
3. C. G. Christodoulou (Principal Investigator), “Deployable Modular Antennas for Small Satellites”, 03/30/2015-1/30/2018, ($447K), Air Force Research Laboratory (AFRL).
4. C. G. Christodoulou (Principal Investigator), “Terrestrial Link Experiment for the Characterization of Rain Attenuation and Depolarization at V/W Bands”, 8/30/2016-5/31/2020 ($1,931,267), Air Force Research Laboratory (AFRL).

Pending contracts:

1. S. K. Jayaweera (Principal Investigator) and C. G. Christodoulou "Cognitive Radios and Reconfigurable Antennas for Mobile Platforms", 11/01/17-12/31/18 ($150K), Honeywell FM&T.
2. C. G. Christodoulou (Principal Investigator), "High Gain, High Frequency, Circularly Polarized Planar Antenna Arrays for Space Applications", NASA.
3. C. G. Christodoulou (Co-Principal Investigator), "Multi-disciplinary investigation of the mammalian inner ear as a radio-frequency antenna, demodulator, and transduce", DARPA/NM Consortium.

Proposals on cognitive radios in preparation by the Project Team contracts:

1. S. K. Jayaweera (Principal Investigator), C. G. Christodoulou, M. M. Ramon, "Cognitive Radios", DARPA RFMLS program.

5. Current Research that Benefits from the Acquired Equipment

Following sub-sections detail briefly the on-going cognitive radio research at the University of New Mexico that make use of the acquired equipment.

5.1. Cognitive Radios and Reconfigurable Antennas for mobile Platforms

This research is aimed at using cognitive radio technology to achieve reliable and robust communications among mobile platforms in highly dynamic communications networks made of both mobile and static nodes. The long-term objective of this project is to develop a complete communications solution for mobile platforms based on cognitive radio technology [1-3]. Specifically, the project consists of following objectives:

- Objective 1. An assessment of anticipated communications infrastructure available in the continental United States (US) in the next 5 - 20 year timeframe.
- Objective 2. A model of a conceptual cognitive radio and configurable antenna system providing primary and backup data and voice communications between mobile land vehicles anywhere in the continental U.S. and a designated command center also within the continental US.
- Objective 3. Demonstration of a laboratory prototype simulation that implements the developed model of objective 2.

The project is executed under three tasks where each is focused on achieving individual objectives identified above:

- Task #1: Making an assessment of anticipated communications infrastructure available in the continental United States (US) in the next 5 - 20 years timeframe.
- Task #2: Developing a model of a conceptual cognitive radio and configurable antenna system that provides primary and backup data and voice communications between

mobile land vehicles anywhere in the continental U.S. and a designated command center also within the continental US.

- Task #3: Demonstrating a laboratory prototype simulation that implements the model developed in Task #2.

5.2. Wideband Autonomous Cognitive Radios for Networked Satellites Communications

Wideband Autonomous Cognitive Radios (WACRs) are radios that have the ability to sense state of the RF spectrum and the network and self-optimize operating mode in response to this state [1, 4, 5]. In this project, the University of New Mexico partners with Bluecom Systems and Consulting LLC, an Albuquerque R&D company, to design and develop such WACRs. The developed modular architecture consists of a cognitive engine, a Software-defined radio (SDR) platform and a reconfigurable RF front-end. Key module that makes the radio a WACR is the cognitive engine that acts as the brain of the system. Once fully-developed, these radios are expected to help exploit the full potential of autonomous and intelligent communication networks in applications ranging from first-responder/emergency/public safety communications, autonomous systems and drones to many other military communications.

5.3. Wideband Autonomous Cognitive Radios (WACRs) for Spectrally-efficient and Agile Multiband/Multimode Communications

The focus of this project is to develop technological solutions to the spectrum encroachment problem that also addresses some of the long-existing limitations of current Test & Evaluation (T&E) practices at test ranges. The targeted solution is to develop spectrally agile cognitive communications techniques that take advantage of spectrum knowledge. The success of this project will allow future T&E systems to be able to support multi-band messaging/communication for data capture, command and control and health/status monitoring. Moreover, due to its inherent ability to be spectrum-aware and spectrally-agile in response to the perceived status of the spectrum, future T&E approaches based on the proposed WACR technology will have the ability to manage a greater number of test assets and operations while also improving spectral efficiency and allowing flexible and adaptive sharing of critical test information and status.

Thus, the objective of this project is to develop a wideband autonomous cognitive radio architecture to achieve network-, user- and spectrum-aware communications that addresses limitations in current T&E practices as well as has the potential to greatly enhance the success of various defense and space mission types. Proposed WACRs are autonomous radios that can self-configure the mode of operation in response to the given state of the overall system made of the radio, spectrum and the end-user [1, 4, 5]. To achieve the envisioned overall goal, the project is divided in to following tasks:

- Task 1: Defining a Wideband autonomous cognitive radio architecture suitable for T&E applications leading to an efficient an improved future network.
- Task 2: Design and development of a spectrum knowledge acquisition framework suitable for T&E application at test ranges.
- Task 3: Design of a cognitive engine and developing spectrally agile cognitive communications protocols for efficient multi-mode operation.
- Task 4: Design and development of real-time reconfigurable RF antennas suitable for T&E applications.
- Task 5: Demonstration of cognitive communications in an HITL WACR system.

5.4. A Software Defined Frequency Reconfigurable Meandered Printed Monopole

In this research a frequency reconfigurable meandered monopole antenna was designed, fabricated and tested. The antenna was designed to cover specifically the bands from 700 MHz -1000 MHz and 2.1 GHz - 2.4 GHz for cognitive radio applications. The reconfigurability in these two bands is achieved through the appropriate integration of two PIN diodes. The control of these two diodes is software enabled through a graphical user interface. Figure 1 depicts the shape of the meander antenna that can resonate at 800 MHZ and 2.4 GHz based on the appropriate activation of the embedded witches. Figure 2 show the two cases and how the antenna can be tuned around these two frequency bands. Figure 3 shows the radiation patterns at 3 different frequencies.

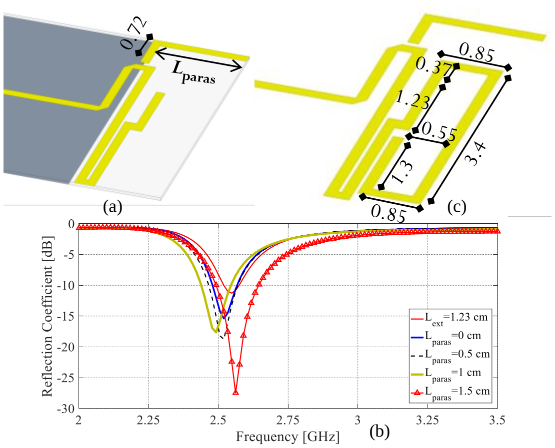

Fig. 1(a) The addition of the parasitic L-shaped element, (b) The effect of L_{paras} on the antenna's matching, (c) The further extension of the radiating element to operate in the lower-band range.

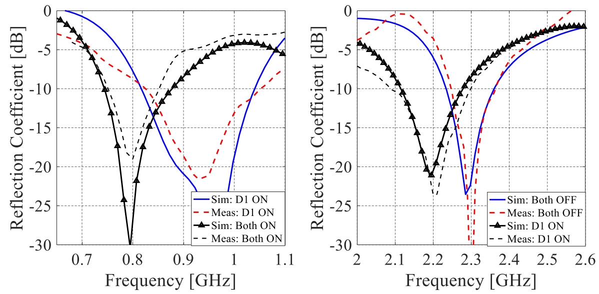

Fig. 2 The change in the antenna's reflection coefficients in the lower and upper bands when biasing the two integrated PIN diodes

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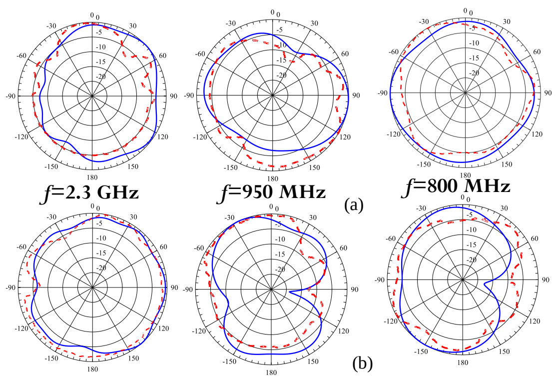

Fig. 3 The simulated (solid line) and measured (dotted line) normalized antenna radiation patterns at three different frequencies in the (a) XY,

5.5. Design of an Antenna Diversity System

In this research, the design of a radiating system that is composed of two diversity antenna structures is presented. Each diversity antenna structure is composed of four elements that operate over a different span of frequencies with a directive gain pattern. Two elements are aligned along the x-axis while the others two are placed along the y-axis to provide orthogonal polarization between the various radiating elements. A set of four curved dipoles constitute the first diversity structure while the second diversity structure is composed of four straight dipoles. The novelty of the presented work is based on the compact integration of the two antenna structures. Each structure is appropriately designed to actively shape the gain pattern of the other structure while at the same time enhancing the isolation levels. Figure 4 shows the schematic of the antenna geometry, Figure 5 shows the S11 performance, and finally Figure 6 depicts the actual fabricated antenna.

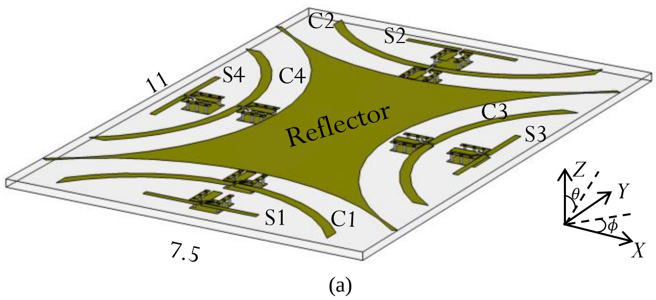

Fig. 4 The final antenna structure after the integration of the printed parasitic element

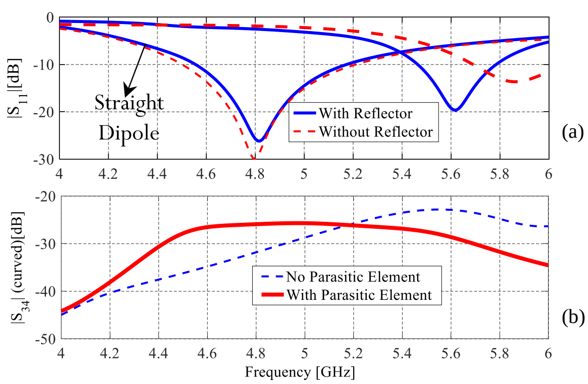

Fig. 2(a)The effect of the printed parasitic reflector on the reflection coefficient of both radiating structures, (b) The change in the isolation between C3 and C4.

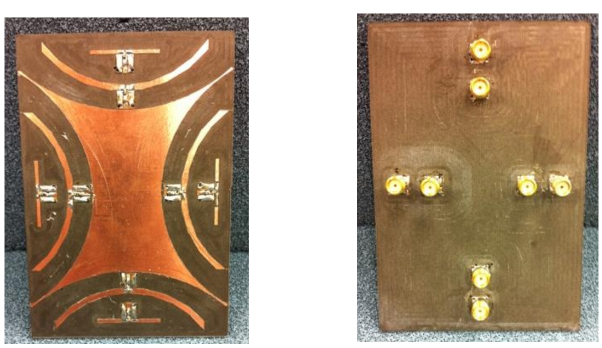

Fig. 3. The top and bottom layer of the fabricated prototype.

5.6. Liquid Crystal Antenna Design

In this research, a liquid crystal antenna that can be tuned to various frequencies for cognitive radio applications was designed and developed. The main radiating element is a microstrip patch antenna truncated on two of its corners to produce circular polarization as shown in Figure 7. More specifically, the overall antenna is composed of three different layers.

- Top Layer: Substrate where the Patch and the feed are printed.
- Middle Layer: LC cavity and the Substrate working as a structural support.
- Bottom Layer: Ground Plane.

The substrates used are Rogers Duroid 5880 with a thickness of 0.13 mm and an LC cavity height of 0.13 mm. antenna.

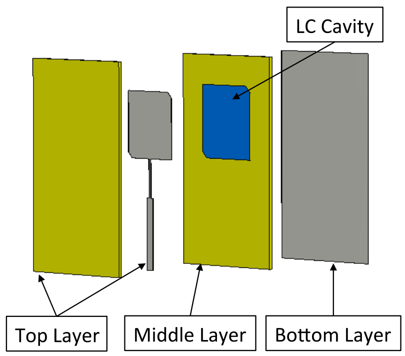

Figure 7. The layout of the entire microstrip antenna with its 3 layers.

The fabricated prototype and the approach used to inject the liquid crystal in the antenna cavity, under the metallic patch, is depicted in Figure 8.

Figure 2. Fabricated microstrip antenna with liquid crystal injection mechanism.

Figure 3 shows the measured S11 parameter for the fabricated antenna for various biasing conditions of the liquid crystal. The bias applied varied from 0 to 60 dc Volts. Overall, the antenna can be exhibits a very good input impedance from 26 to 32 GHz.

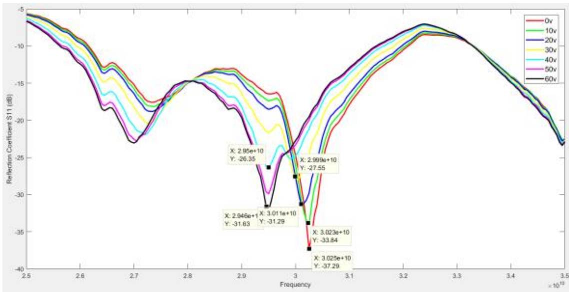

Figure 3. Measured input reflection coefficient.

6. References

[1] S. K. Jayaweera, Signal Processing for Cognitive Radios, 1st ed. New York, NY, USA: John Wiley & Sons Inc., 2014.
[2] J. Mitola III and G. Q. Maguire, Jr., “Cognitive radio: making software radios more personal,” IEEE Personal Communications, vol. 6, no. 4, pp. 13 –18, Aug. 1999.
[3] S. Haykin, “Cognitive radio: brain-empowered wireless communications,” IEEE JSAC, vol. 23, no. 2, pp. 201–220, Feb. 2005.
[4] S. K. Jayaweera and C. G. Christodoulou, "Radiobots: Architecture, Algorithms and Realtime Reconfigurable Antenna Designs for Autonomous, Self-learning Future Cognitive Radios", University of New Mexico Technical Report, EECE-TR-11-0001, Mar. 2011.
[5] S. K. Jayaweera, Y. Li, M. Bkassiny, C. G. Christodoulou and K. A. Avery, Radiobots: The autonomous, self-learning future cognitive radios, IEEE Intelligent Sig. Proc. and Commun. systems (ISPACS’2011), Chiangmai, Thailand, Dec. 2011.