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# SATELLITE COMMUNICATIONS RESEARCH PROGRAM

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## Final Report

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Research grant was designed to investigate research related to the use of low-power, high-performance radio systems for achieving high data rate spacecraft communications. There are a wide variety of new satellite missions and components that are being created based on a new class of satellites called CubeSats. These CubeSats are often flown in a Low Earth Orbit (LEO) and are usually less than 10 kilograms in mass. Their low size, mass and limited lifetime will mean that, often, inexpensive commercial communication electronics can be utilized for flight. COSMIAC developed two CubeSats for delivery to NASA in 2013/2014 and all of that proposed research built upon lessons learned from these two satellites and involved testing and characterization of existing radio systems.

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## Summary

This was a three year activity for a total dollar amount of approximately $450,000. The University of New Mexico (UNM) proposed to perform extended research related to the use of low-power, high-performance radio systems for achieving high data rate spacecraft communications. There are a wide variety of new satellite missions and components that are being created based on a new class of satellites called CubeSats. These CubeSats are often flown in a Low Earth Orbit (LEO) and are usually less than ten kilograms in mass. Their low size, mass and limited lifetime will mean that, often, inexpensive commercial communication electronics can be utilized for flight. COSMIAC is a leader in this area of communication, research, development, and has multiple satellite communications terminals operating 24 hours a day providing real world communications to on orbit assets.

## Introduction

COSMIAC has been in existence for approximately ten years and consists of approximately 15,000 square feet of office space and laboratories located on three floors. COSMIAC is a Tier-2 Research Center at UNM that is devoted to the use of microprocessors, communications radios, and microcontrollers in education, training and in LEO satellite development. COSMIAC has multiple ground and communication systems for preparing and conducting this type of research.

The team at COSMIAC used the provided funds to complete three major research goals:

1. Explore a variety of radio and ground station systems from different vendors for robustness.
2. Develop test frames and platforms for use in testing the radios.
3. Publish results.

## Methods, Assumptions and Procedures

Differing activities are occurring in the frequency world related to nanosatellites that have necessitated the need for the team to slightly change the research focus, stay within the scope of work and still provide research that is relevant to the global nanosatellite community. The National Aeronautics and Space Administration (NASA) recently had a nanosatellite that was scheduled for launch that experienced having their amateur frequency satellite transmitter license denied. The overarching licensing process involves two steps. The first is the amateur frequency coordination process with the International Amateur Radio Union (IARU) and the second is the Federal Communications Commission (FCC) approval of the license. In the past, most federal agencies have not been authorized by IARU guidelines to be able to obtain IARU coordination (thus FCC licensing) however, waivers have always been granted. This denial to NASA has potentially caused the cancellation of the launch and mission. This is a major change for the nanosatellite community and could affect many future missions in that all inexpensive and easily obtainable nanosatellite radios are no longer going to be viable options for any mission that has any federal funding as part of its composition (for example, NASA provides parts) as the receipt of any federal funds (or parts) disqualifies the organization from utilizing the amateur bands.

**Goal 1. Explore a variety of radio and ground station systems from different vendors for robustness**

**Figure 1. National Instruments USRP-2920**

The team procured several different radio systems for testing and implementation. The first is the National Instruments (NI) model 2920 Software Defined Radio (SDR). The 2920 (shown in Figure 1) is based on the highly succesful Universal Software Radio Peripheral (USRP) platform that was completely open source. USRP (and the Ettus Corporation) created a system for performing SDR activities based on reconfigurable platforms. The SDR is configured at the time of use to utilize different modulation schemes, data rates and frequencies. It has a tunable center frequency from 50 MHz to 2.2 GHz covering a wide variety of different frequency bands. It also has up to a 20 MHz baseband I/Q bandwidth streaming at 25 MS/s for host-based processing with the National Instruments LabView software.

**Figure 2. RTL-SDR Communications System**

In coordination with the Air Force Research Laboratory's Small Satellite Program (SSP), we have been able to gain access to various waveforms and other information that has allowed us to utilize the USRP platforms to perform analysis on the various frequencies of interest to the nanosatellite communities in an attempt to be able to see where interference patterns could occur in the Albuquerque area and to be able to perform modifications to the different frequencies, data rates and modulation schemes that would permit more successful transmission and reception of satellite to ground communications as well as with the uplink path.

**Figure 3. COSMIAC Roof Antenna System**

In addition, the team has obtained multiple of the RTL-SDR platforms (shown in Figure 2). These small platforms are extremely powerful for analyzing the available frequency spectrums to allow for a better monitoring of interference patterns. They were used to investigate frequencies between 50 MHz and 2.5 GHz. The team combined the RTL-SDR with the onsite antennas (the 900 MHz antenna is shown on the left hand side of Figure 3). The G-5500 antenna rotator shown on the antenna mast allows for rotation of the antenna in azimuth as well as in elevation for investigating the entire local area. This system is routinely used to satellite tracking.

What became obvious in the second year of this funded research is that the amateur radio frequencies are becoming obsolete for the nanosatellite community. As such, COSMIAC is moving to higher and less congested frequencies. One activity in this area is the potential acquisition of a Unified S-Band (USB) antenna and tracking system. This system would transmit using our available USRP systems at 2.1. GHz to space and receive from space at 2.2 GHz. USB will be where many spacecraft will perform in the next several years. Weight loading analysis was performed on this capability for installation on the COSMIAC roof of a three meter spun cast aluminum dish assembly.

During the third quarter of the grant, the team continued preparations for the operations to support the purchase of the Unified S-Band system for COSMIAC's roof. However, with the continued delay in passing the federal budget, this purchase of the roof dish has been delayed. What the team has done instead is to spend more time in developing the frames and mounts for the dish system so that when it is delivered, it will be quicker and easier to install. Based on wind loading and analysis of the past 12 months of wind data, it is envisioned that approximately 2,220 lbs. of bricks (on other ballast) will be required to stabilize and hold down the system. Time was devoted to analysis of mounting screws (or other retaining bolts) into the roof to hold the system in place but this was discarded due to the unique treatments that have been installed on the roof to prevent leaks. Instead, the team will utilize a not-penetrating roof mount with a protective membrane to mitigate damage to the roof.

In addition, extensive work was continued in the areas of USRP waveforms during the second year for interfacing to new systems for testing the ability to encrypt the different waveforms. The new Global Positioning System (GPS) waveforms one of great interest to COSMIAC

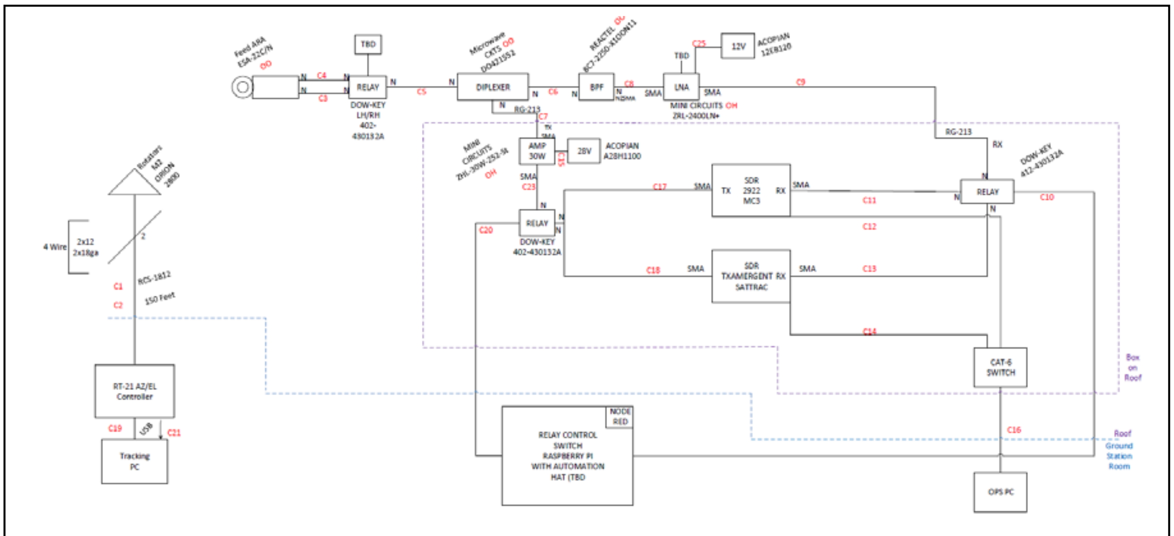


**Figure 4. COSMIAC 3-Meter Dish Configuration**

since GPS equipment will be changing in the near future.

Work was also accomplished in the areas of design for providing configuration for the three-meter dish system. This work involves configuring the system to work with two different radio systems. The first is the Ettus Corporation's model 2922 radio system and the second is the Amergent Sattrac modem system. The system design (shown in Figure 4) was necessary to provide a complete understanding of the various components but also was an excellent training area for students that were new to satellite communications. The complete documentation package included the visual diagram shown in the picture above. This led to three other documents. The first was a parts list. This list of parts was tied directly to the visual display. It also contained the Internet links to the various parts and the associated documentation related to datasheets so as to provide teams coming after COSMIAC to have a complete turnkey system for future satellite ground systems designs. Additionally, a cabling diagram was created. This document provided the detailed specification on all cables utilized in the system. Items that where detailed included cable types, connectors, pin configurations, lengths and other considerations to allow the ability for other organizations to benefit from this design.

**Goal 2. Develop test frames and platforms for use in testing the radios**

The initial effort on this goal involved the development and use of Radio Frequency (RF) systems to test nanosatellite communications capabilities. This involved the purchase, construction and installation of 900 MHz antennas for the COSMIAC ground station on the roof of the building. The desired capability is to be able to transmit and receive between COSMIAC and the Air Force Research Laboratory (AFRL) for testing of the various radio systems to see if it is possible to close the link for RF strength and signal quality to allow for satellite integration and future testing. Since this test produced positive results, the team proceeded with interconnecting research type radios for testing and analysis.

Work was performed in the areas of building the infrastructure for performing testing in the 900 MHz range and above. What the team determined was that it was not reasonable to be able to receive signals from space using the purchased 900 mHz antenna and what was required was an additional amplifier. This amplifier has been received, installed and tested. Two filter assemblies were utilized. The team investigated filtering systems which could be utilized to increase the ability to perform this type of operations and communications within an urban environment. The first filter was a high pass filter to block all frequencies below 900 MHz. The second was a low pass filter to restrict the higher frequencies. The addition of the amplifiers and filters have allowed the team to able to communicate with the Montana State University CubeSat currently in orbit.

**Figure 5. Testing Waveforms**

During the second quarter of the grant, the team was provided with an excellent opportunity to test hardware and related algorithms. AFRL's Small Satellite Program created and delivered the Satellite for High Accuracy Radar Calibration (SHARC) CubeSat. It operates at approximately 900MHz with differing waveforms. Figure 5 shows the test configuration used at COSMIAC to test with the SHARC spacecraft during integration and test. One of the surprising discoveries was that the team was able to receive from the COSMIAC ground station when AFRL was broadcasting from several miles away on base. This allowed the team to be able to provide real time feedback on the effects of differing algorithms on signal to noise ratio and bit error rate degradation. To perform this analysis, the team purchased a higher quality preamplifier that would allow for 18dB of gain in the receive signal. This amplifier (at 900 MHZ) is far superior to the ones previously utilized at 450 MHZ. The team has so far tested the amplifier (shown in the far left of figure 4) in a laboratory environment. It was then relocated to the COSMIAC roof and installed in a weatherproof box on the antenna frame thus providing higher quality receive capabilities. The team has also purchased satellite tracking software (described later) that will allow the tracking of SHARC and other nanosatellites when in orbit.

During the third quarter of the grant, the team finished all mounting and testing of communications equipment on the roof and routed all associated cabling through the access ports in the ceiling to allow for supporting and testing of future satellite missions including SHARC as they become available. The team installed the Ham Radio Deluxe (HRD) software for antenna tracking and testing. The HRD package is used to track antennas by utilizing the two line elements provided by a launch provider after separation from the rocket. Testing for the complete receive system is done by tracking the sun during the day. This allowed the team to be able to “tweak” the controllers to ensure they are tracking properly. The sun provides an excellent spectrum source for the system to track and to ensure the antennas are pointing where they should. In addition, the team also investigated different ways to more appropriately develop for a concept called the Enterprise Ground System (EGS). The term EGS has multiple meanings for multiple organizations but what is desired is the capability for ground systems to be less reliant on rigid design architectures. As such, a real EGS system will allow satellite developers to be able to bring their system to the ground station architecture and utilize a paradigm such as that developed for applications on cellular phones. As part of this activity, the cosmos software package was obtained and systems were created to provide mock communications infrastructure for nanosatellites.

During the fifth quarter of the grant the team obtained a 900 MHZ resource for on orbit testing of communications systems. The AFRL SHARC mission launched from the International Space Station (ISS) became a great testbed. As part of this grant, the team has worked with on base AFRL teams to create a downlink capability for SHARC for research endeavors. Although not the primary ground station for this mission, the capability has provided the ability to monitor and work on decryption of RF and data signals from the SHARC mission.

Additionally, the team is also began work on the Resilient Network Advanced Testbed (RESINATE). This testbed will involve the creation of a wide range of interconnected RF systems for testing new modulation schemes and will focus in the 4400MHz bands of interest. COSMIAC’s activities involved research of the various antennas and radio systems to provide “best” choice in terms of cost and functionality.

**Goal 3. Publish results**

COSMIAC took eight faculty and students to the SmallSat Conference in August, 2016 to begin to publish the information associated with this research. The paper to describe the activities was not accepted but COSMIAC team took the opportunity to brief conference attendees from AFRL, NASA Glenn, NASA Ames and NASA Goddard Centers on the research being accomplished. Communications is becoming more and more complicated and all these organizations are looking for ways to accomplish real world missions in an increasingly small (and congested) frequency spectrum. More and more organizations are looking for the information that is being developed through this research.

During the second quarter of the grant, COSMIAC's presentation was accepted at the 2017 Ground System Architectures Workshop (GSAW). The GSAW presentation and poster session occurred the final week in February 2017. The presentation was staffed through Public Affairs for general release. The presentation covered the topics related to big data analytics, RF analysis and ground station support associated with EGS. The team also evaluated submitting to the SmallSat Conference for 2017. The topic of the conference in 2017 was "Small Satellites, Big Data" which aligned perfectly with the communications and data research currently being accomplished under this grant.

**Results and Discussions**

The team achieved the original objectives as well as going into other areas of investigation that were of interest to the space community as more and more spacecraft activities are looking to use SDR assets for satellite development and an orbit operations. The outcome is that excellent advances have been made in the areas of reconfigurable communication for space.

The team met established goals. There were no cost overruns on this activity.

**List of Acronyms**

(AFRL) Air Force Research Laboratory

(FCC) Federal Communications Commission

(GSAW) Ground System Architectures Workshop

(HRD) Ham Radio Deluxe

(IARU) International Amateur Radio Union

(LEO) Low Earth Orbit

(NASA) The National Aeronautics and Space Administration

(RF) Radio Frequency

(SDR) Software Defined Radio

(SHARC) Satellite for High Accuracy Radar Calibration

(UNM) University of New Mexico

(USRP) Universal Software Radio Peripheral

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