

A University-Based Ground Station: The 21 m Antenna at Morehead State University

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The Space Science Center (Department of Earth and Space Sciences) at Morehead State University (MSU), Morehead, KY (USA) operates a 21 meter diameter, full motion, research quality, parabolic dish antenna system, built under contract for MSU by Vertex-RSI, one of the premier fabrication corporations for high gain antennas. This system, referred to as the MSU 21 m Space Tracking Antenna, is engaged in ongoing research programs in radio astronomy and is also capable of operation in a satellite ground station mode, providing telemetry, tracking, and command (TT&C) services for a wide variety of satellite systems. The 21 m is used as a test bed for advanced RF systems developed by the faculty, students, and collaborators. This system has the capability of tracking fast moving, low transmitting power small satellites in low earth orbit (LEO), as well as satellites at geostationary, lunar, and potentially Earth-Sun Lagrangian orbits. Currently configured for operation at L-band and Ku-band, with feeds being implemented at S-band and X-band and near term plans for the development of a C-band system, with others planned. The instrument also serves as an active laboratory for students engaged in research and training in space science, electrical and mechanical engineering, telecommunications electronics, astrophysics, and space systems operation. The instrument is largely operated by undergraduate students who work in the associated laboratories to achieve hands-on training in RF systems and techniques. The instrument serves as the primary Earth station facility for the Kentucky Space Program which develops and operates small satellites (cubesats and other picosats) for education and workforce development. Cubesat (1 kg pico-class satellites) programs offer outstanding education and training experience at low cost. They have evolved into a highly flexible and useful platform, having been flown by numerous universities, NASA, and a number of aerospace companies. The 21 m supports the small satellite community and in particular cubesat programs. In addition to providing ground operations support for small satellite programs, the 21 m is currently engaged in a rigorous scientific program in fundamental research (radio observations of microvariability in active galactic nuclei (AGNs) and observations of transient events, (i.e. radio afterglow of Gamma Ray Bursts) and applied research (RF systems development). Current ongoing missions supported by the 21 m include the Kentucky Space program orbiting satellite (KySat-1), scheduled for launch in November 2010 as secondary payload on NASA's Glory mission, and suborbital missions typically flown on sounding rockets from NASA's Wallops Flight Facility (Wallops Island, VA). Additional missions include supporting ongoing testing and calibration of the NASA Lunar Reconnaissance Orbiter (LRO) Mini-RF instrument, a space-based synthetic aperture radar, among others.

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Nomenclature

| | | |
|-----------|---|---|
| $21\ m$ | = | 21 Meter (Space Tracking Antenna) |
| G/T | = | figure of Merit: gain over system temperature |
| $HPBW$ | = | half-power (3 dB) beamwidth |
| $LHCP$ | = | left hand circular polarization |
| $RHCP$ | = | right hand circular polarization |
| T_{sys} | = | system temperature |

I. Introduction

A university-based full motion 21-meter class antenna system was developed and brought on-line in 2006 by faculty and students of the Space Science Center within the Department of Earth and Space Sciences at Morehead State University (MSU), Morehead, KY (USA). The MSU 21 m Space Tracking Antenna is engaged in a rigorous research program in radio astronomy and also operates in Earth station mode, providing telemetry, tracking, and command (TT&C) services for the small satellite community. The 21 m also serves as a test bed for advanced RF systems developed by the faculty, students, and collaborators. The 21 m ground station has the capability of tracking small satellites with low power transmission in low earth orbit (LEO), and out to geostationary orbits, lunar orbits, and potentially Earth-Sun Lagrangian points. The 21 m high gain antenna is currently operating at L-band, and Ku-band, with S-band and high C-band feeds developed and bench-tested and a low C-band feed system under development. The instrument also serves as an active laboratory for students engaged in research and training in space science, electrical and mechanical engineering, telecommunications electronics, and astrophysics, and space systems operation. The instrument is largely operated by undergraduate students who work in and manage the associated laboratories to achieve hands-on training in RF systems and techniques. The instrument is a primary laboratory of the Kentucky Space program which develops and operates small satellites (cubesats and other picosats) for education and workforce development. Cubesats⁷ (1 kg pico-class satellites) programs offer outstanding education and training experiences and have evolved into a highly flexible and useful platform, having been flown by numerous universities, NASA, and a number of aerospace companies. The 21 m supports the small satellite community and in particular cubesat programs. In addition to providing ground operations support for small satellite programs, the 21 m is currently engaged in a rigorous scientific program in fundamental research (radio observations of microvariability in active galactic nuclei (AGNs) and observations of transient events, (i.e. radio afterglow of Gamma Ray Bursts) and applied research (RF systems development). The 21 m currently serves as the primary Earth station for the Kentucky Space program orbital and suborbital missions, and as a supporting calibration source for NASA's Mini-RF instrument on the Lunar Reconnaissance Orbiter (LRO).

The ground station provides a unique educational tool that serve as an active laboratory for students to have hands-on learning experiences with the intricacies of satellite telecommunications and radio astronomy. This major research instrument provides a state-of-the art laboratory for researchers and students in astrophysics, satellite telecommunications, engineering (including electrical, mechanical, and computer architecture), and software development. Specifications for the 21 M, its theory of operation, RF characteristics, and current missions are described herein along with a discussion of the use of the instrument in undergraduate research and training.

II. 21 M System Specifications

The MSU 21 Meter Space Tracking Telescope was designed with a dual purpose of observing astronomical objects such as quasars and supernova remnants and supporting satellite missions by tracking, telemetry and telecommand. The 21 M is equipped with L-Band, S-Band, low and high C-Band, and Ku-band feeds that are used to support both missions.

The system was designed with appropriate gain, drive speeds and pointing and tracking precision to provide the capability to track LEO satellites in inclined orbits. The gain and RF sensitivity are appropriate to support a robust

⁷ H. Heidt, J. Puig-Suari, A.S. Moore, S. Nakasuka, R.J. Heidt, "CubeSat: A new Generation of Picosatellite for Education and Industry Low-Cost Sace Experimentation," 14th Annual USU Conference on Small Satellites, August 2000

radio astronomy research program. The basic performance characteristics (aperture, dynamics, and radio frequency) are provided below for the currently operating frequency regimes (L-band and Ku-Band) and bench-test values (and expected/theoretical system performance values) for the S-band and high C-band feed systems.



Table 1.0 21 M Performance Characteristics

| FUNCTION | PERFORMANCE |
|-----------------------------|---|
| Antenna Diameter | 21 Meter |
| Receive Polarization | RHCP,LHCP,VERT,HORZ |
| Travel Range | AZ +/- 275 degrees from due South (180 deg) EL -1 to 91 degrees POL +/- 90 degrees |
| Velocity | AZ Axis = 3 deg/sec EL Axis = 3 deg/sec POL Axis = 1 deg/sec |
| Acceleration | AZ = 1. 0 deg/sec/sec min EL = 0.5 deg/sec/sec min |
| Display Resolution | AZ/EL = 0.001 deg POL = 0.01 deg |
| Encoder Resolution | AZ/EL = 0.0003 deg (20 Bit) |
| Tracking Accuracy | <= 5% Received 3 dB Beamwidth (0.028 deg RMS L-band) (0.005 deg RMS Ku-Band) |
| Pointing Accuracy | <= 0.01 deg rms |

Figure 1.0 The Morehead State University Space Science Center 21 M Space Tracking Antenna, Morehead, KY
(Latitude: 38° 11' 30.773 N, Longitude: 83° 26' 19.948 W) U.S.A.

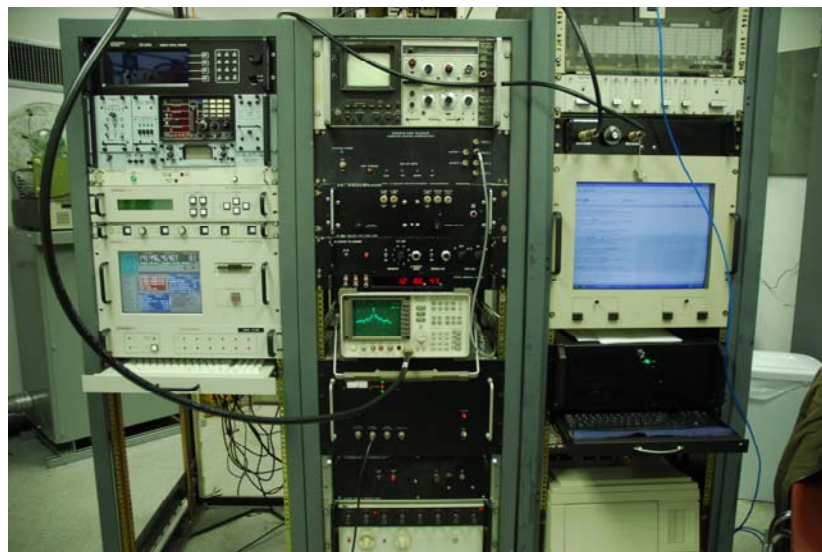


Figure 2.0 The Morehead State University 21 M Space Tracking Antenna Control Room (Lower Equipment Room 2010)

III. Theory of Operation

A. LEO to Lunar Capabilities

The 21 m has the capability to track satellites from “LEO to Lunar” orbits and beyond. The 21 meter system has a drive system that is capable of tracking LEO satellites at an altitude of 350 nautical miles and a maximum elevation angle of 77°. The primary challenges of this requirement are azimuth drive speeds and the development of controlling software. The secant elevation coordinate transformation factor from the cross-El to the Azimuth plane is often referred to as the "Keyhole effect". A solution to ameliorate this effect is based on compensating azimuth drive speeds and accelerations at Keyhole and compensating via software strategies. To handle 350 NM passes with minimal link breakage up to 77° elevation, a field weakening algorithm (and circuit) is employed to enable the azimuth axis to slew up to a velocity of greater than 3°/s. The system has sufficient gain and sensitivity to track satellites in lunar orbit, Earth-sun Lagrange points, the asteroid belt and nearby planets (given sufficient spacecraft transmit power).

The 21 m system is operated using the antenna control unit (ACU) and may also be (ultimately) controlled remotely from the mission operations center at Morehead State University via optical fiber link. The ACU or remote control unit (RCU) can operate the 21 m in a variety of drive modes to facilitate execution of both the Earth station and radio astronomy missions. Basic drive modes and a brief explanation of each are provided in Table 2.0.

Table 2.0 21 M Antenna System Drive Modes

| MODE | EXPLANATION |
|---------------|---|
| Steptrack* | Self Peaking Algorithm |
| Optrack | Orbit Determination and Pointing Algorithm |
| NORAD Track | 2 Line Element Set |
| INTELSAT | Position calculated from INTELSAT position parameters |
| Table Track | Track on Preloaded Table, Position & Time |
| GEO Designate | Command LAT/LONG on Geo-synchronous Arc |
| Star Track | Stored Star Trajectory |
| Memory Track | Tracking backup mode follows stored trajectory |
| Monopulse* | Nulling out of CFE provided XEL and EL error signals |
| Rate Offset | Used in conjunction with Star Track Mode |

IV. Radio Frequency Characteristics

The antenna design allows for interchangeable feeds. Currently, Morehead State University has three different feed systems, L-band, S-Band, and Ku-band, with high and low C-band systems under development. One of the goals of 21 meter is to be capable of as many diverse tasks as possible to help capitalize on its potential. A key element of this strategy is to provide operation in as many frequencies regimes as possible for radio astronomy observations and several bands for satellite mission support. To accomplish this, the feed system must be either broadband (which is not very efficient) or different feeds must be installed. Toward this end, the Space Science Center at Morehead State University has either developed or acquired feed systems in the RF bands mentioned above. These include commercially-produced feeds (L-band and Ku-band developed by Vertex RSI (General Dynamics) of Richardson, TX, U.S.A. and C-band developed by Chaparral Communications, Inc., San Jose, CA, U.S.A.) and experimental feeds (S-band developed by the Space Science Center at Morehead State, and High C-band developed by the Johns Hopkins Applied Physics Laboratory). The frequency ranges for each feed are provided below.

Table 3.0 21 M Antenna System Radio Frequency Operating Regimes

| Radio Frequency (RF) Band | Bandwidth | |
|---------------------------|-----------|----------|
| | Low End | High End |
| L-Band | 1.4 GHz | 1.7 GHz |
| S-Band | 2.2 GHz | 2.5 GHz |
| High C-Band | 7.0 GHz | 8.0 GHz |
| Low C-Band | 4.8 GHz | 5.0 GHz |
| Ku-Band | 11.2 GHz | 12.7 GHz |

Basic schematics of the L-band and Ku-band feed design are outlined below in Figure 3.0. Both feeds consist of a horn, coupler, ortho-mode transducer (OMT), low noise amplifier (LNA), and noise control source (test inject) with heater which is encased in insulation. Down conversions are accomplished using frequency specific, interchangeable tuners. Tuning is accomplished by changing the local oscillator frequency with a frequency synthesizer. Calibration of the astronomical signal is provided by an ENR noise source, which itself is calibrated relative to accepted radio frequency flux density calibrators. The X-band and C-band systems are composed of a feed horn antenna, a preamplifier/amplifier and housing, mounting and fixturing, a down converter system and associated cabling of required components. The S-feed design is based on a circular aperture, cylindrical waveguide with a mathematically-defined stepped metallic septum that induces circular polarization. This design provides for waveguide resonators that contain a left hand circularly polarized wave used for radio astronomy continuum work and a right hand circularly polarized wave that will be used for satellite communications. This single feed design supports both missions of the 21-M antenna.

A variety of down conversion schemes are available along with a wide variety of back-end receiver systems, including satellite telemetry receivers, demodulators, bit and frame synchronizers (for satellite telemetry systems) and detectors, IF processors, A-D converters, and data acquisition systems (for the radio astronomy systems). The 21 m system is extremely flexible based on the variety of front-end feeds and back-end receiver systems (and combinations thereof) that can be implemented.

Measured performance characteristics of the L-band and Ku-band system made in situ on the instrument during 2007 and 2009 are provided in Tables 4.0 and 6.0. Expected values based on the performance of bench-tested components and theoretical calculations (especially for systems-level performance indicators) are provided for S-band and C-bands in Table 5.0.

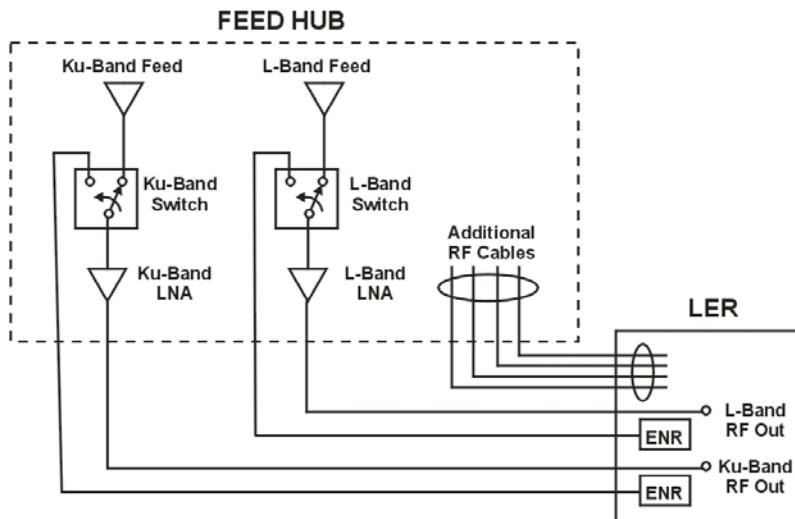


Figure 3.0 RF Block Diagram

Table 4.0 Radio Frequency Performance at L-Band and Ku-Band

| Radio Frequency (RF) Performance Criterion | Measured Parameters | |
|---|---------------------|------------|
| | L-Band | Ku-Band |
| Frequency | 1.40 GHz | 11.2 GHz |
| Antenna Gain | 47.80 dBi | 65.50 dBi |
| LNA Temperature | 25 K | 70 K |
| System Temperature, T_{sys} | 83.8 K | 139.0 K |
| G/T at 5° Elevation | 28.6 dBi/K | 44.1 dBi/K |
| HPBW | 0.62° | 0.08° |

L-band specifications are at 1.4 GHz and Ku-band specifications are at 11.2 GHz. System temperature is calculated at 40° elevation.

Table 5.0 Radio Frequency Performance Expected at S-Band and C-Band

| Radio Frequency (RF) Performance Criterion | Theoretical Parameters | |
|---|------------------------|-------------|
| | S-Band | High C-Band |
| Frequency | 2.4-2.7 GHz | 7.1-7.6 GHz |
| Antenna Gain | 52.8 dBi | 62.0 dBi |
| System Temperature, T_{sys} | 215K | 215K |
| N_0 | -175dBm/Hz | -175dBm/Hz |
| G/T at 5° Elevation | 29.5dBi/K | 38.7dBi/K |
| HPBW | 0.37° | 0.13° |

Table 6.0 Measured G/T Vales at L-Band and Ku-Band

| Measured G/T Values | | | |
|------------------------------------|---------------|---------------|---------------|
| Receiver | 45° Elevation | 30° Elevation | 10° Elevation |
| L-Band at 1.42 GHz ⁵ | 30.5 dB/K | 30.3 dB/K | 29.7 dB/K |
| L-Band at 1.70 GHz ⁵ | 32.0 dB/K | 31.9 dB/K | 31.2 dB/K |
| Ku-Band avg 11.95 GHz ⁷ | 45.9 dB/K | 45.7 dB/K | 45.4 dB/K |

Measured G/T values at varied elevations. The Ku-band measurement is over the entire band so the average frequency is used in the G/T.⁸

V. Current Missions

A. Small Satellite Missions

The primary aspects of mission operation services for which the 21 m Earth station are utilized in Earth station mode include satellite tracking and associated scheduling, command sequence generation, uplink and downlink commanding, science instrument control, satellite housekeeping, orbit tracking, modeling trajectories, management of downlinking activities including science and telemetry data acquisition, storage, archiving, and distribution. Scheduling and commanding of the satellites are carried out by ground station personnel that include a significant student workforce component. The 21 m is primarily utilized in servicing university-class space missions, including CubeSats.

⁸ Antenna Verification Measurements: Vertex-RSI 21 m L-Band and Ku-Band Space Tracking Antenna with TwoPort Linear Polarized Feed Horn, J. Atwood, M.Combs, M. Ennis, R. Kroll, J. Kruth, T. Pannuti, 2007

B. CubeSats

The CubeSat form factor has become the de facto standard for 1 kg pico-class satellites worldwide. The CubeSat first developed by Bob Twiggs (then at Stanford University) and Jordi Puig-Suari (California Polytechnic University) in 1999.⁹ CubeSats are defined in size and mass as 10x10x10 cm³ and 1 kg or under respectively per unit. Up to 3 units satellites (3-U) can be deployed from the standard orbital deployment system called the P-POD (Poly Picosatellite Orbital Deployer) developed at the California Polytechnic University. There are large numbers of satellites currently on-orbit and scheduled for launch that operate in the S-band ISM region. The onset of these satellite missions has established the need for an S-band feed. S-band capabilities will allow MSU to participate in satellite missions as a ground node for tracking, telemetry and telecommand. The 21 M system will support a variety of CubeSat missions, including serving as the primary Earth station for KySat-1.

C. KySat-1

KySat-1, Figure 1, is, 1-kg satellite following the CubeSat standard developed by the Kentucky Space consortium. Kentucky Space (formerly KySat) is a consortium of 6 Kentucky Universities¹⁰ and was formed in 2006 under the leadership of the Kentucky Science and Technology Corporation (KSTC) a private nonprofit corporation committed to the advancement of science, technology and innovative economic development in Kentucky. The goal of Kentucky Space is to design and lead innovative space missions within realistic budgets and objectives and to train students in the dynamics of spacecraft design, construction, testing and operation as a means of extending science and technology education, R&D, innovation and economic development in Kentucky. Kentucky Space projects involve an ongoing series of satellite design, fabrication, testing and operation— each with increasing scope and complexity.

KySat-1 is the flagship mission of Kentucky Space to date.¹¹ The primary mission of KySat-1 is educational outreach to both university students who are designing the satellite and to K-12 students and teachers to incorporate into lesson plans to give the opportunity for hands-on learning in the Science, Technology, Engineering, and Math (STEM) disciplines. The outreach payload includes a low-resolution camera and a relatively high powered (for CubeSats) UHF/VHF radio to allow satellite communication from small portable ground stations that can be easily set up on a playground or parking lot of a school. KySat will also carry a communications payload, a commercial 2.4 GHz high-speed transceiver, which will be tested for feasibility of use in a space environment as well as the in-situ optimization of several parameters.

In 2008, the KySat-1 CubeSat was down-selected by NASA in a competition among universities in the United States for a launch on NASA's first effort to carry student built satellites as secondary payloads, the Educational Launch of Nanosatellites (ELaNa) Mission.¹² KySat-1, along with CubeSats from the University of Colorado and Montana State University are manifested as secondary payloads on NASA's Glory mission which is scheduled for launch in November 2010.

⁹ H. Heidt, J. Puig-Suari, A.S. Moore, S. Nakasuka, R.J. Heidt, "CubeSat: A new Generation of Picosatellite for Education and Industry Low-Cost Space Experimentation" 14th Annual/USU Conference on Small Satellites. August 2000.

¹⁰ Partners in Kentucky Space include: University of Kentucky, University of Louisville, Morehead State University, Murray State University, Western Kentucky University, the Kentucky Community and Technical College System, Kentucky Space Grant Consortium, Kentucky Science and Engineering Foundation, Kentucky Council on Post-Secondary Education, Kentucky Science and Technology Corporation, and the Belcan Corporation.

¹¹ G. D. Chandler, D. T. McClure, S. F. Hishmeh, J. E. Lumpp, Jr., J. B. Carter, B. K. Malphrus, D. M. Erb, W. C. Hutchison, III, G. R. Strickler, J. W. Cutler, R. J. Twiggs, "Development of an Off-the-Shelf Bus for Small Satellites," IEEEAC paper #1365, IEEE Aerospace Conference, Big Sky, Montana. March 2007.

¹² D. M. Erb, T. Clements, J. E. Lumpp, Jr., B. K. Malphrus, , Kentucky Space: A Multi-University Small Satellite Enterprise, 23rd Annual AIAA/USU Conference on Small Satellites, 2004



Figure 4: KySat-1 CubeSat in a P-POD

D. NASA's Lunar Reconnaissance Orbiter (LRO)

The 21 M Space Tracking Antenna is currently engaged to perform Earth-Based calibrations of LRO's Mini-RF instrument, a synthetic aperture radar. LRO was launched on June 18, 2009 and after a four day transit entered a circular polar orbit approximately 50 km (31 miles) around the Moon. LRO's composed six scientific instruments are providing key data sets to enable NASA's return to the Moon. One of six instruments on-board LRO, is the Radio Frequency Technology Demonstration (Mini-RF)—an advanced synthetic aperture radar that operates at both 2380 and 7140 MHz frequencies. The Mini-RF project is managed and operated by the Johns Hopkins University/Applied Physics Laboratory. It is used to image the poles of the moon and search for water ice in permanent shadow regions. In addition, it serves as a technical demonstration of a unique miniaturized dual use RF instrument (radar and communications).

In order to infer science products from the radar data collected with the Mini-RF instrument, a series of calibration activities are being planned with the 21 m Space Tracking Antenna at Morehead State University. This ground station is being used in calibrate both transmit and receive paths of the LRO Mini-RF instrument at 7140 MHz. This is accomplished by configuring the MSU 21 m ground station with a transmitter (Tx) system, that will uplink a 50 Watt circular polarized signal to Mini-RF, as shown in Figure 5.0, and a digital receiver system that samples a transmitted Mini-RF signal in an alternating time synchronized pattern.

The purpose of the LRO calibration experiments are to:

- Characterize the axial ratio of the LRO Mini-RF transmitted signal
- Determine Polarization Characteristics of Mini-RF's receive system
- Confirm beam center pointing of the Mini-RF antenna

Calibration has already been performed for Mini-RF's 2380 MHz operations using NRAO's 100 m Green Bank Telescope (GBT) located in West Virginia and 300 m Arecibo Radio Telescope (ART) in Puerto Rico, for Mini-RF's transmit and receive system measurements, respectively. In order to support Mini-RF's 7140 MHz radar calibrations, a different ground station solution is required because the telescopes at ART or GBT cannot be configured to uplink an RF signal to Mini-RF. The ART telescope can only be configured to receive a Mini-RF's transmission but accurate pointing of its 0.01 degree (3-dB) beam-width is a concern. The telescopes on the GBT campus cannot support any uplink experiments because it is designated a RF quiet zone. The Morehead State University (MoSu) 21 M Space Tracking Antenna is ideal for this calibration because a custom feed system and RF test-bed equipment can easily be developed and integrated into the ground station. The 21 m reflector diameter and high surface accuracy provides sufficient antenna gain in order to characterize Mini-RF expected -20 dB cross-polarized signal, which is used to determine the axial ratio of LRO Mini-RF transmitted signal.

With the radiation pattern, signal parameters, and EIRP of the 21 M precisely known, the spacecraft antenna and receiver systems known (having been empirically measured pre-flight), and the link characteristics between the Earth and the LRO numerically modeled, the signal received by the LRO's Mini-SAR can be precisely calibrated.

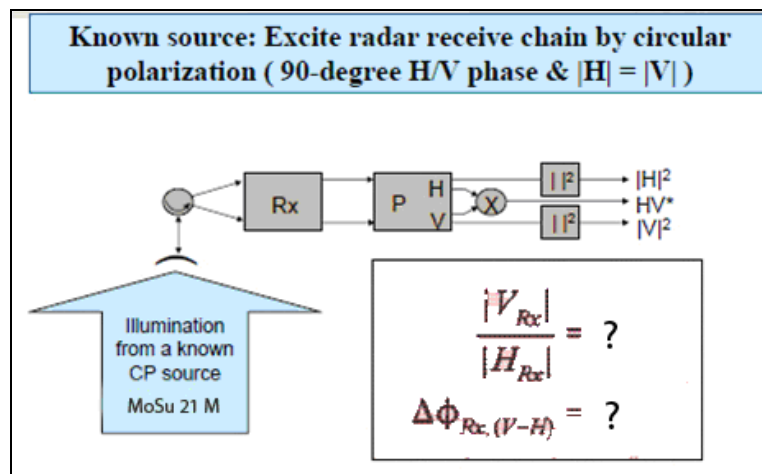


Figure 5.0 LRO C-band Calibration Experiment Schematic

Tracking a satellite on orbit around the moon (ca. 350,000 km away) with a pencil beam generated by the 21 m antenna at X-band and producing a transmit EIRP of precise power and frequency to meet the LRO experimental requirement, all within a 15 minute window, will be nontrivial. The 7140 MHz calibration test-bed system has been designed, fabricated, and bench-tested and is ready for Earth-based calibration experiments to begin in May 2010.

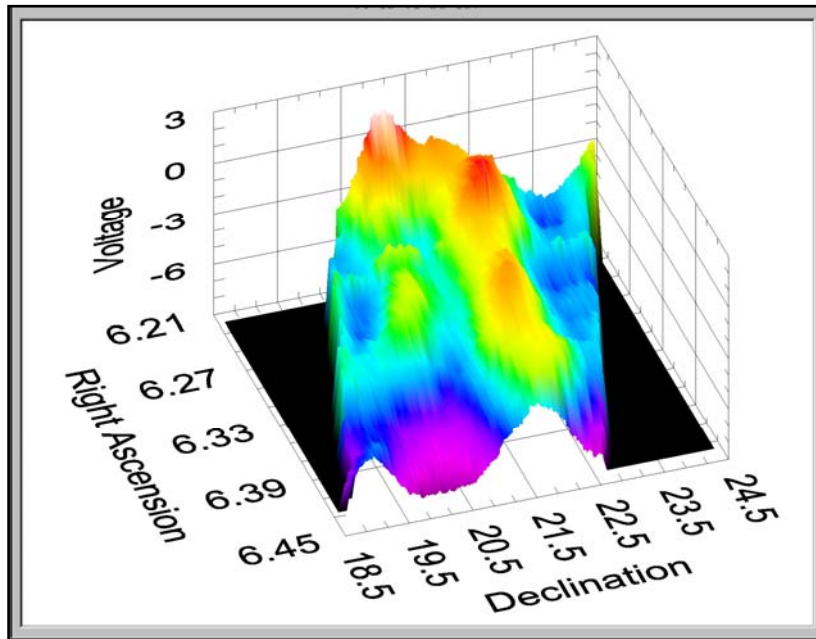
E. Radio Astronomy Research

The 21 m is considered to be a medium-aperture telescope where apertures of radio telescopes have been generally categorized by a ratio of the aperture diameter to the incident wavelength. At L-Band, the ratio of the aperture diameter of the Antenna to the incident wavelength exceeds 100 while at higher frequencies this ratio becomes 1000 or higher. Medium-aperture telescopes such as the Antenna have many advantages as active laboratories and as research instruments for both students and faculty members. Medium-aperture centimeter-wave instruments like the Antenna can produce significant scientific contributions: for example, while time on large-aperture instruments is generally heavily subscribed for phenomenon-specific observations, medium-aperture telescopes can devote time to long-term monitoring campaigns, sky surveys, and event-specific phenomena such as supernovae, gamma-ray bursts and apparitions of comets. In this respect, the Antenna stands to produce a lasting legacy of crucial datasets at multiple frequencies to the entire astronomical community.

Radio astronomy research projects include:

- long-term monitoring campaigns (AGNs)
- sky surveys (Dynamic Mapping of HI in the Milky Way)
- transient phenomena (supernovae and GRBs)

Maps of the spatial distribution of RF emission associated with astronomical objects are produced by raster scanning across the field of view and producing a map of the RF intensity distribution field by integrating the entire post-detection frequency band of 6 MHz into a single, integrated channel map (0th moment map). An image of the velocity field (1st moment map) and an image of the velocity dispersion (2nd moment map) can also be produced. Analysis of these maps of the phenomena in “velocity space” allows astronomers to calculate the kinematics of the system and thereby derive the dynamics, then infer the energetics, and virial masses, along with other insights into the underlying physics of these systems. An example of a 0th moment map showing the spatial distribution of radio emission from a supernova remnant (3C 157) is shown below. The detail seen in this image demonstrates the sensitivity and resolution of the 21 m.



VI. Facilities Management and Undergraduate Programs and Research

The management strategy for the 21 m system, which is essentially a university laboratory, is to utilize experienced and well-trained faculty and staff who primarily work with undergraduate students that comprise the bulk of the technical staff. A “mentor-mentee” approach is taken with respect to the undergraduates, requiring that upperclassmen provide training for successors. This peer training model perpetuates the program objectives and demonstrates the Center’s commitment to undergraduate research, while providing a cost-effective approach, and outstanding experience for the students.

A major objective of the Center is to help students develop a wide array of skills specifically including analog and digital electronics, electrical engineering, interfacing and automation, antenna testing and measurement, wireless and microwave electronics, computer programming, data reduction, numerical modeling, and image processing. Students are exposed to the intricacies of scientific research via immersion in research and development projects in these areas. The benefits to students are based upon a hands-on approach to learning concepts in space science and its related engineering support. Students are provided design and research challenges (in new and existing courses, directed research opportunities, senior theses, and undergraduate research assistantships) and are allowed to pursue their own solutions. Problem-solving abilities and research design skills are cultivated by this approach.

Morehead State University offers two degree programs that target the production of a workforce for space mission operation and for the astrophysics community, including a B.S. in Space Science and a B.S. in Physics with an Area of Concentration in Astrophysics. The B.S. in Space Science is essentially an engineering technology program that trains students for careers in space technologies, processes, and applications. The main goal of this program (which is one of distinctively few such programs nationwide) is to prepare its graduates for professional opportunities in space science, whether their interest lie in astrophysical research or in applied technologies such as space systems development or satellite tracking and telemetry. Graduates are competitive for positions with NASA, aerospace corporations, research facilities, colleges, planetariums, and observatories. The B.S. in Physics, Area of Concentration in Astrophysics focuses on observational astrophysics. Undergraduate researchers are involved in research radio and X-Ray observations of AGNs, gamma ray bursts, and Blazars as well as in scientific instrument development. The program is designed to prepare students for a career in astronomy and related space sciences. Graduates from this program have breadth of physics knowledge, laboratory and observational experience and skills, and adaptability, the marketable tools of new and exciting professional careers in astrophysics and related space sciences.

An underlying philosophy of the Space Science program is related to a systems engineer approach to R&D. It is commonplace for the undergraduate to have some understanding of how a particular device may fit into a system,

but at the same time to lack a clear concept of the overall goals of that system. It is considered a key talent to be able to understand the role of the elements in the overall system and to realize the “big picture.” The ability to start with requirements and to design a system to meet specific goals of technical performance, economic constraints, form and fit is very valuable and relevant to commercial sector needs. The Space Science program is based on this philosophy of a systems-level approach to engineering and technology.

VII. Conclusions

A versatile 21 m full-motion parabolic antenna system has been developed at Morehead State University that serves as an Earth station for satellite mission support, a radio telescope for astronomical research, and a test-bed for RF and signal processing systems. Three RF feed systems (L-band, S-band Ku-band) are currently in operation with a two additional feeds (X-band and C-band) under development. Extensive measurements indicate that the 21 m systems at L-band, S-band, Ku-band are working to the specifications and expectations. RF performance characteristics, in particular, compare very favorably to specified and theoretical values. Scientific results have been obtained at all frequency regimes.

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¹⁻⁶ Author Affiliations

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