UNIVERSITY-BASED NANOSATELLITE MISSIONS AND GROUND OPERATIONS AT MOREHEAD STATE

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The Space Science Center (Department of Earth and Space Sciences) at Morehead State University (MSU), Morehead, KY (USA) engages undergraduate students in the development and operation of nano- and microsatellite systems to provide real-world engineering opportunities and training experiences. The Space Science Center operates several ground stations, including low-bandwidth VHF/UHF systems and a 21-meter diameter, full motion, parabolic dish antenna system, to support these and other university-based small satellite missions. The MSU 21-m Space Tracking Antenna is capable of providing telemetry, tracking, and command (TT&C) services for a wide variety of space missions. The 21-m has the capacity to track satellites in low earth orbit (LEO) with extremely low transmission power, as well as satellites at geostationary, lunar, and Earth-Sun Lagrangian orbits. The system currently operates at L-, S-, C-, X- and Ku-bands. The instrument is primarily operated by undergraduate students who work in the associated laboratories to gain hands-on training in RF systems and techniques. The 21-m is also used as a test bed for advanced RF systems developed by faculty and collaborators, and has been employed in a growing portfolio of satellite missions including serving as the primary ground station for KySat-1, a secondary ground station for EduSat, and as the primary high-bandwidth ground stations for Radio Auroral Explorer 2 (RAX2) and the Cosmic X-Ray Background NanoSatellite (CXBN) missions. The system has also been employed in the testing and calibration of the NASA Lunar Reconnaissance Orbiter synthetic aperture radar (mini-SAR) at X- and S-bands. The team is in the process of upgrading the system to incorporate automated operations and to become Space Link Extension (SLE) compliant. This paper describes the current nanosatellite missions managed by the Space Science Center and the ground operations components of these missions (including the challenges and constraints imposed by the university-based non-commercial structure), all of which are

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designed to train undergraduate students as the next workforce in support of the ground operations and satellite development industries.

Nomenclature

21- m	=	21-Meter (Space Tracking Antenna)
CCSDS	=	Consultative Committee for Space Data Systems
CXBN	=	Cosmic X-Ray Background Nanosatellite
G/T	=	figure of Merit: gain over system temperature
HPBW	=	half-power (3 dB) beamwidth
IOAG	=	Interagency Operations Advisory Group
LEO	=	low Earth orbit
SLE	=	Space Link Extension
T_{sys}	=	system temperature

I. Introduction

The Space Science Center at Morehead State University is emerging as a center for research and student education in nanosatellite technologies and space mission operations. Faculty and staff with extensive experience in space systems design and operations have assembled in Morehead Kentucky, in the Eastern U.S. to establish this research and development center for small satellite technologies. In addition, to the R&D efforts, the Center offers unique degree programs, a B.S. in Space Science (an engineering technology program that trains students for careers in space technologies and applications), and a B.S. in Astrophysics (a physics program that trains students for careers as research astronomers). The main goal of the Space Science degree program is the production of graduates who have developed basic competencies and real-life experience in space systems engineering. The program places emphasis on astronautics, focusing on satellite design and development – particularly in the areas of satellite systems and ground station operations and related ground station technologies. The B.S. in Space Science is one of only five such undergraduate programs in the U.S. The Center is also an integral partner in Kentucky Space, is a non-profit consortium of private and public universities, companies, and other organizations with the goal of designing and leading innovative space missions within realistic budgets and objectives.[14]

The Center's facility is a $16 million, 45,000 ft.^{2} building with state-of-the art laboratories that include: an electromagnetic anechoic chamber, a space systems development laboratory, a class 10,000/1,000 clean room for spacecraft assembly and integration, a spacecraft verification laboratory, and an astrophysics lab. The centerpiece instrument is a 21-meter (m) antenna system which is an integral part of a rigorous research program in radio astronomy and also serves as aground station for satellite mission support as well as a test bed for advanced satellites communications systems. In 2006 the 21-m university-based full motion antenna system was brought on-line by faculty and students of the Space Science Center. Since then, the MSU 21-m Space Tracking Antenna has been engaged in a research program in astronomical observations-- primarily of active galactic nuclei and supernova remnants). As a ground station, the 21-m provides telemetry, tracking, and command (TT&C) services for the small satellite community. The 21-m ground station has the capability of tracking small satellites with low power transmission in low Earth orbit (LEO), geostationary orbits (GEO), lunar orbits, and potentially Earth-Sun Lagrangian points. The 21-m high gain antenna currently operates at L-band, S-band, high C-band Ku-band, with a low C-band feed under development.

The 21-m is the primary ground station for the Morehead State University Space Science program, which has produced a series ofuniversity-based microsatellites and cubesats. In general, Cubesats[15] (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. The 21-m also serves as the primary

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[14] Kentucky Space is supported by the Kentucky Space Grant Consortium and developed out of the programs of the Kentucky Science and Technology Corporation

[15] 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

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).

In addition to its service as a small satellite ground station and radio telescope, the 21-m serves an active laboratory for students engaged in research and training in space science, electrical and mechanical engineering, telecommunications electronics, software development, fundamental research in astrophysics, and space systems operation and protocol. The instrument is largely operated by undergraduate students who work and manage the associated laboratories to achieve hands-on training in RF systems and techniques. Specifications for the 21-m, its RF and mechanical performance characteristics are described herein along with a discussion of the use of the instrument in undergraduate research and training. A discussion of the current and planned small satellite missions managed by the Space Science Center is provided.

II. Current Small Satellite Missions

A. Small Satellite Missions

Faculty and students of the Morehead State University Space Science Center have developed a series of nanosatellites including Kysat-1 and KySat-2 with the Kentucky Space program, EduSat with the University of Rome that was launched from Russia on a Dnepr rocket in August 2011, TechSat-1, a tech-demo satellite for the U.S. Space and Missile Defense Command with commercial partners including Radiance Technologies and Honeywell International, and the Cosmic X-Ray Background Nanosatellite (CXBN). All of the satellite systems were designed, built, tested and validated in the Morehead State Space Science Center, primarily by undergraduate students. These students also participated in on-orbit operation of these smallsat missions. Engaging engineering students in the system design (mechanical, electronic and software), pre-flight validation and testing, and operation of these small spacecraft provides invaluable experience, and at the same time, allows the university to conduct cost-effective science and technology demonstration missions with this technology.

B. CubeSats

CubeSats are "loaf of bread" or smaller-sized nanosatellites that have become the defacto world-wide standard for small satellite technologies. CubeSats are 10 x 10 x 10 cm (or by 20 or 30 cm in length) satellites that weigh under 1 kg per unit. The CubeSat form factor has become the de facto standard for 1 kg pico-class satellites worldwide. The CubeSat first was developed by Bob Twiggs (then at Stanford University) and Jordi Puig-Suari (California Polytechnic University) in 1999.[16]

The evolution of micro/nanotechnologies and microelectronics, in particular the availability of small but powerful microprocessors, microcontrollers and MEMs devices, has facilitated the development of these inexpensive ($100,000 to $1,000,000) highly capable small satellites that are now being flown by NASA, the U.S. Department of Defense, aerospace companies and universities around the globe. CubeSats, including those developed at Morehead, are used for a wide variety of applications ranging from tactical defense to scientific research (including astrophysics research and Earth phenomena and resource monitoring) to practical applications ranging from communications to relaying data from ground sensors. CubeSats are considered "disruptive technology" by the world-wide aerospace industry because they can provide some of the same services as conventional satellites at a fraction of the cost and with short development times.[17]

CubeSats are typically launched as secondary payloads. 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. As many as 14 CubeSats have been launched on a single launch vehicle. Developers envision flying constellations of CubeSats with scientific, defense-related, and Earth-observing sensors and payloads. The capabilities of CubeSat technologies will be greatly expanded when the challenges of formation flying and inter-satellite communications have been overcome allowing the deployment of CubeSat constellations.

In 2012, there is a growing number of CubeSats currently on-orbit and scheduled for launch—these satellites typically operate in the VHF, UHF, and S–band frequency regimes. While most universities can establish

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[16] 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.

[17] A. Soojung-Kim Pang and Bob Twiggs, "Citizen Satellites: Sending Experiments into Orbit Affordably", Scientific American, February 2011.

VHF/UHF tracking stations (as these are based on well-understood amateur radio technology), few universities can establish high-gain S-band stations owing to the prohibitive cost and complexity of these systems. However, the onset of these satellite missions has established the need for S–band capabilities. Toward that end, Morehead State University developed S–band capabilities allowing MSU to participate in CubeSat missions as a ground node for tracking, telemetry and telecommand. The 21-m system, along with MSU's other ground assets, support a variety of CubeSat missions, both currently on-orbit and planned, including serving as the primary Earth station for CXBN, KySat-2, UniSat-5, and Eagle-1, each of which is briefly described below.

C. KySat-2

KySat-2 is a 1U (10 x 10 x 10 cm) cubesat designed primarily as a test bed for the KySat standard bus with a concept of operations of outreach to K-12 students across Kentucky. KySat-2 is under development by the Kentucky Space program, which is a collaborative effort of public and private partners throughout the state of Kentucky focused on small satellite development and access to space for small payloads. The Kentucky Space consortium was formed 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. Kentucky Space includes KSTC, the University of Kentucky, Morehead State University and other Kentucky public universities, including the Kentucky Community and Technical College System, and Belcan Corporation serving in a consulting role.

KySat-2 is a replacement for KySat-1 which was launched in March 2011 as a secondary payload on NASA's Glory Mission. The launch vehicle failed to place Glory, KySat-1 and the other secondary payloads into orbit. KySat-2 is a direct replacement for KySat-1 (shown in Figure 4) having the same mission objectives, same subsystems (but upgraded) and the same concept of operations.

The primary goal of the KySat-2 project is education and public outreach (E/PO). The satellite system is designed and intended to be accessible to pre-college students and the amateur radio community. Contacts can be made with the satellite utilizing inexpensive amateur radio equipment. Students can receive data and telemetry from the satellite and upload audio and text files that can be downloaded by students at other schools. Students can also download low resolution images taken by the satellite's imaging system and "command" the satellite (via an authorized operator scheduled over the Internet) to take pictures and send data at specified times.

A low resolution camera for education/public outreach (E/PO) is the primary "payload" on-board KySat-2. A secondary payload is a broad-band S-band radio that has limited flight heritage. Data and telemetry collected by the amateur radio community and pre-college students will be posted on the world-wide APRS system. Additionally, data and images from the satellite will be posted on the Kentucky Space website. The Kentucky Space website will also have a portal that can be used to issue commands to the satellite (i.e. take a low-resolution picture of the Earth, upload text data for broadcasting later in the orbit, request telemetry, etc.). A major purpose of KySat-2 is to excite students about space science and engineering by allowing them to interact with a live spacecraft on orbit.

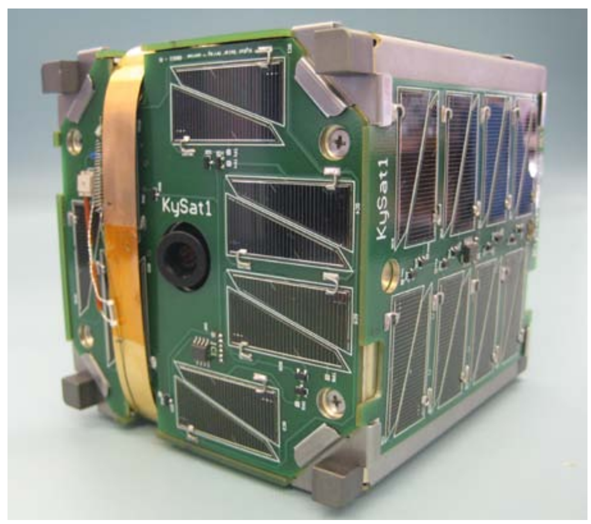

Figure 1. KySat-2 CubeSat *Under Development is an Updated Version of KySat-1 (shown above) that was lost during a failed launch attempt on a Taurus A from Vandenberg Air Force Base in 2011*

D. Cosmic X-Ray Background Nanosatellite

A university-based partnership led by the Space Science Center at Morehead State University (MSU) has developed a 2-U CubeSat bus that is applicable to a wide variety of missions including science missions (to which the bus is most well suited), technology demonstrations, and communications applications. A prototype, the Cosmic X-Ray Background NanoSatellite (CXBN) was built in 2011 and accepted by NASA's ELaNa program for a flight opportunity in 2012. CXBN's mission is to make improved measurements of the X-Ray background (in the 30-50 keV range) with a detector system based on a Cadmium Zinc Telluride array. These measurements have the potential to provide insight into underlying physics of the early universe. MSU was responsible for engineering, fabrication and testing of the spacecraft subsystems. The payload (X-Ray detector) was designed by colleagues at Little H-Bar Ranch and built by Black Forest Engineering. Partners from Lawrence Livermore National Laboratory and Noqsi Aerospace also contributed to the mission. CXBN features many unique systems, including sun sensors, a star sensor system, a distributed C&DH system utilizing 4 MSP430 microprocessors, and a deployable high power solar array. MSU will also provide ground operations for the mission utilizing the 21-Meter Space Tracking Antenna and other ground assets that include amateur-radio derived VHF/UHF Yagi systems.

The concept of operations (conops) is characterized by a sun-pointing, spinning spacecraft (1/6 Hz) in LEO with a non-equatorial inclination. The mission addresses a fundamental science question that is clearly central to our understanding of the structure, origin, and evolution of the universe by potentially lending insight into both the high energy background radiation and into the evolution of primordial galaxies, while testing an innovative 2-U bus that is adaptable to a variety of other mission profiles. CXBN is scheduled for launch from Vandenberg Air Force Base in August 2012 on a U.S. Department of Defense mission.

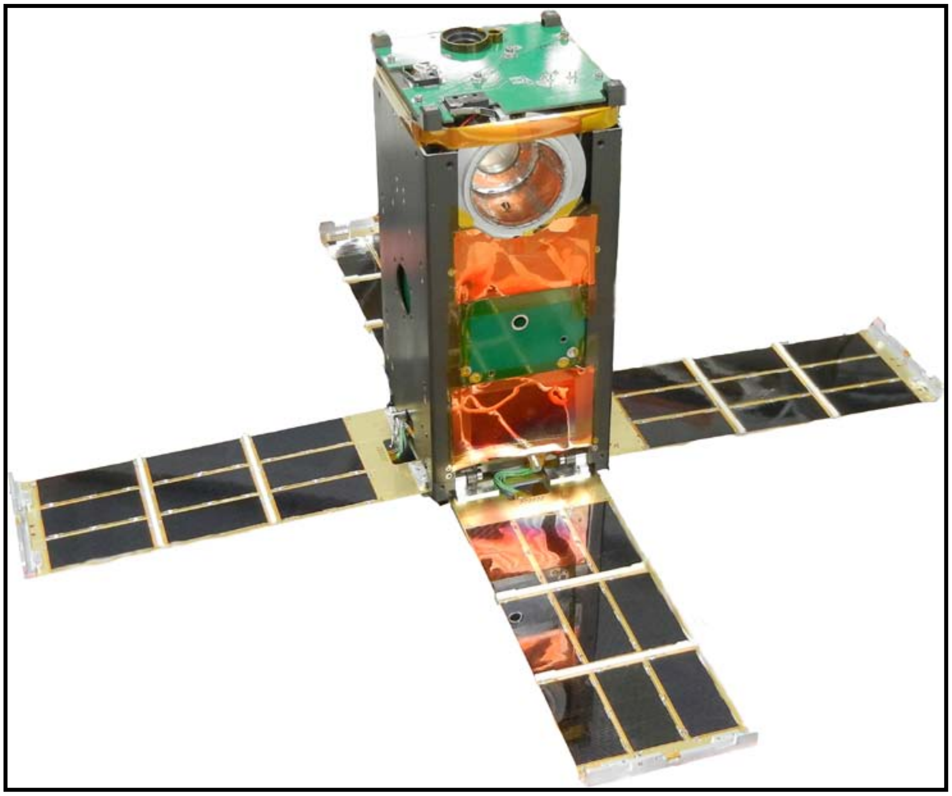

Figure 2. Cosmic X-Ray Background NanoSatellite (CXBN) *was developed in 2011 by the Space Science Center at Morehead State University. CXBN is scheduled for launch in August 2012 and will measure the diffuse X-ray background emission from the Big Bang.*

III. Planned Missions

A. MicroSatellite: UniSat-5

UniSat-5 is the sixth satellite developed by the Astrodynamic Group of the University of Rome "La Sapienza" (GAUSS) group. The GAUSS group is composed of students and professors from the School of Aerospace Engineering. The team is managed by Ph.D. and graduate students with the support and supervision of professors. UniSat-5 is a partnership between the GAUSS group and students and researchers from the Space Science Center of Morehead State University who are developing several of the spacecraft subsystems in collaboration with the Italian partners. UniSat-5 is a civilian scientific microsatellite whose primary mission is to test home grown research equipment in the space conditions, create heritage for follow-on missions, and provide hands on experience and training for university students. The satellite, entirely manufactured by university students and researchers with custom-developed and commercial off-the-shelf components, will carry four principal payloads:

1. GlioSat, a space biomedical experiment with the goal of investigating the combined effects of microgravity and ionizing radiation on Glioblastoma cells behavior, led by the GAUSS group with the support of IRCCS research center and Space Science Center at Morehead State University;

2. A stand-alone system for high definition digital imaging, whose purpose is to observe Earth's surface, as well as space debris *in situ*. It is composed of a camera, a telescope, C-band & S-band transceivers;

3. Morehead-Roma FemtoSatellite Orbital Deployer (MRFOD), a student-built technology demonstrator which will result in the ejection of two-femtosatellites called PocketQubs (defined below) proposed by Professor Robert J. Twiggs. The femtosatellites Eagle-1 (designed by MSU students) and QBScout-1 will be ejected from UniSat-5 using an orbital deployer (MRFOD) which is similar to a smaller version of the PPOD, but has unique innovations, including a "sled" design that the femtosats are mounted to that eliminates the requirement for extreme mechanical precision in the exterior dimensions of the femtosats;

4. GAUSS CubeSat Deployer System, a student-built technology demonstrator which will allow the deployment of a 1UCubeSat. The system designed by GAUSS will allow the in orbit injection of the first cubesat designed by university students from Peru: PUCP-SAT-1.

UniSat-5 is scheduled for launch in September 2012 as a secondary payload on a Russian-Ukrainian Dnepr launch vehicle from the Yasny launch base (Orenburg, Russia). The satellite will be inserted into a 700 km sun-synchronous orbit. The femtosats will be ejected at perigee, one month after deployment of UniSat-5.

B. FemtoSats: Eagle-1

A new satellite standard was proposed in 2009 by Professor Robert Twiggs (now at Morehead State University) for a satellite even smaller than the CubeSat, a femto-class satellite called PocketQub™. This Femto-class satellite is a 5 cm cube weighing under 400 grams. The PocketQub leverages the CubeSat standard and miniaturization of modern electronic systems. PocketQubs will ultimately have a wide range of applications including:

- Network Nodes
- Sensor Systems
- Satellite Constellations
- Inexpensive, Redundant, Spatially Organized

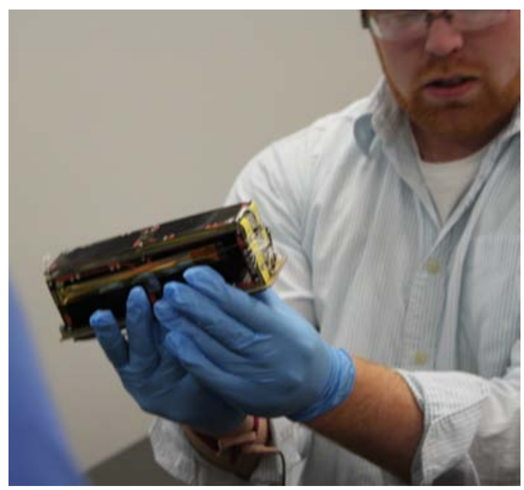

Figure 3. QubScout PocketQub Femto-satellite *being inspected by a Morehead State University Student.*

The Eagle-1 spacecraft is designed to provide a component test-bed for various spacecraft technologies, primarily among them being a de-orbit system that also increases the spacecraft radar cross section. To support this goal, the Eagle-1 spacecraft contains a number of components, such as a commercially available unrestricted 8 bit microcontroller and basic electronic components. Eagle-1 uses the bus, power systems and radio that equal one PocketQub Unit (PQU). The de-orbit system developed at Morehead State uses 0.5 PQU in stowed configuration and expands to facilitate disposal by re-entry. The de-orbit system deploys a PCB and copper substrate-based structure that greatly increases the spacecraft's surface area serving to reduce the spacecraft's ballistic coefficient allowing atmospheric drag at relatively low altitudes (under 300 km) to rapidly de-orbit the system and, at the same time, increases the radar cross-section making the cube more easily detected by space surveillance radar.

IV. Ground Operations

A. University-Based Ground Operations

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 down-linking 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 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 moderately to highly inclined orbits. The gain and RF sensitivity are appropriate to support a robust niche radio astronomy research program. The basic performance characteristics (aperture, dynamics, and radio frequency) are provided below for the currently operating frequency regimes..

Figure 4. The Morehead State University Space Science Center 21-m Space Tracking Antenna, Morehead, KY *(Lat: 38° 11 30.773 N, Long: 83° 26 19.948 W) U.S.A.*

Table 1.0 21-M Performance Characteristics

FEATURE	PERFORMANCE
Antenna Diameter	21 Meter
Optics	Prime Focus
F/D Ratio	0.363
Receive Polarization	RHCP,LHCP,VERT,HORZ
Travel Range	AZ +/- 275 degrees from S 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 Beam (0.028 deg RMS L-band) (0.005 deg RMS Ku-Band)
Pointing Accuracy	<= 0.01 deg rms

B. Operational Capabilities: LEO, MEO, GEO, Lunar and Beyond

The 21-m is a very capable instrument, having pointing and tracking specifications capable of supporting space assets in a wide range of Earth orbits, sufficient aperture (and therefore gain) to support missions to the Moon and the inner solar system, and excellent surface accuracy (RMS surface deformations)—good enough to support Ku missions and potentially even Ka band missions (using techniques that illuminate only the interior, highest accuracy surface of the dish).

C. **Operating Frequency Regimes and Feeds**

The antenna design allows for interchangeable feeds. Currently, Morehead State University has four different feed systems, L-band, S-Band, high C-band and Ku-band, with a low C–band system under development. One of the goals of the 21-m program 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 experimental feeds at S–band and High C–band developed by Microwave Engineering and Manufacturing Corporation (MEMCO) of Frederick, MD, USA. The frequency ranges for each of the feeds are provided below.

Table 2.0 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	2.0 GHz	2.5 GHz
High C-Band	7.0 GHz	7.8. GHz
Ku-Band	11.2 GHz	12.7 GHz

The typical feed design incorporates a series of front-end low noise amplifiers and filters followed by common intermediate frequency (IF) stages of 160 and 70 MHz. Down conversions are accomplished using frequency specific, interchangeable tuners. Tuning is accomplished by changing the local oscillator frequency with a frequency synthesizer. Calibration of astronomical signals is provided by an ENR noise source, which itself is calibrated relative to accepted radio frequency flux density calibrators. All feed 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. Most of the feeds are designed to support both missions of the 21-m antenna.

Measured performance characteristics of the L-band, S-band, High C-Band Ku-band system made in situ on the instrument are provided in Table 3.0. The G/T values are measured at various elevations. The Ku–band measurement is over the entire band so the average frequency is used in the G/T.[18] L–band specifications are at 1.4 GHz and Ku–band specifications are at 11.2 GHz. System temperature is calculated at 40^{o} elevation.

Table 3.0 Radio Frequency Performance in Operational Regimes

Radio Frequency (RF) Performance Criterion	Performance Parameters			
	L-Band	S-Band	High C-Band	Ku-Band
Frequency	1.40 GHz	2.4-2.7 GHz	7.1-7.6 GHz	11.2 GHz
Antenna Gain	47.80 dBi	52.8 dBi	62.0 dBi	65.50 dBi
System Temperature, T_{sys}	25 K	215K	215K	70 K
N_o	83.8 K	-175dBm/Hz	-175dBm/Hz	139.0 K
G/T at 5^{o} Elevation	28.6 dBi/K	29.5dBi/K	38.7dBi/K	44.1 dBi/K
HPBW	0.62^{o}	0.37^{o}	0.13^{o}	0.08^{o}

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 radio astronomy measurements) have been implemented on the 21-m system.

D. System Upgrades

The 21-m system is being upgraded to automate operations and to become Space Link Extension (SLE) compliant. A feature of the project is collaboration with Johns Hopkins Applied Physic Laboratory (APL) to upgrade the 21-m Space Tracking Antenna and associated systems to insure the required level of performance for compatibility with NASA's Near Earth Network (NEN) and to ultimately become a non-governmental ground asset of the Interagency Operations Advisory Group (IOAG). Compatibility, in this respect, is defined as having compatible back-end instrumentation, software systems, and mission operation and systems development protocol, to insure seamless

[18] 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

interoperability with NASA elements. One goal of this system is to develop the capability to serve as an ad hoc component of the NASA NEN (and to implement data and communications standards defined by the Consultative Committee for Space Data Systems (CCSDS) for spaceflight. The resulting system (hardware, software, and protocol) will provide supplementary capabilities to existing systems to insure adequate performance to meet NASA and IOAG mission requirements for ground station needs. The current upgrade effort will result in:

- Development and implementation of a flexible back-end GSE instrumentation Adaptation of the NEN software system for operation of the MSU 21-m Tracking Station
- Implementation of data and communications standards that are SLE compliant and consistent with the CCSD standards for space systems
- Adaptation of a Systems Development Protocol that is aligned with industry engineering standards
- Complete remote operations capabilities

These upgrades will be implemented and demonstrated in September 2012.

D. Remote Operations

The upgraded system will facilitate remote operation of the 21-m from the Mission Operations Center (MOC) at Morehead State University (located 0.6 km from the ground station) and by "remotely-located" customers. The upgrade to remote operations will be accomplished by implementing an optical fiber link between the antenna the MOC for data and control connectivity. The RF signal from each feed will be downconverted to a common 70 MHz IF which will be sent to the MOC via the fiber link. Antenna control will be accomplished by implementing a software system based on the NEN software suite that will remotely operate the antenna control unit. Antenna electrical and mechanical functions including motor drives, blower motors, stow pin, and electrical panels will be controlled by installing switched relays at the antenna base which will be controlled by the software system.

Figure 5. The Mission Operations Center *at the Morehead State University Space Science, Morehead, KY,U.S.A.*

A major feature of the remote operations will be an upgrade to Space Link Extension compatibility. SLE protocol follows CCSDS standards that define how to transport forward link (uplink) and return link (downlink) data across a wide area network and then onto the satellite. The SLE protocol is used between a control center (in this case a remote user/customer) and a ground terminal (modem/antenna) at another location (in this case the MSU 21-m). Gateways on each edge must implement the SLE protocol between the modem and FEP. The upgraded system architecture of the 21-m front-end (Figures 6 and 7) incorporates a modem, a high rate digitizer and a software defined telemetry, tracking and command digital signal processor (front-end). The modem performs the bit-synchronization, demodulation, and decoding. The front end processor performs bit-synchronization, data processing, and provides the SLE protocol compliance. The digitizer system will be used for experiments that need to directly digitize the 70 MHz IF signal and then save to disk for post processing.

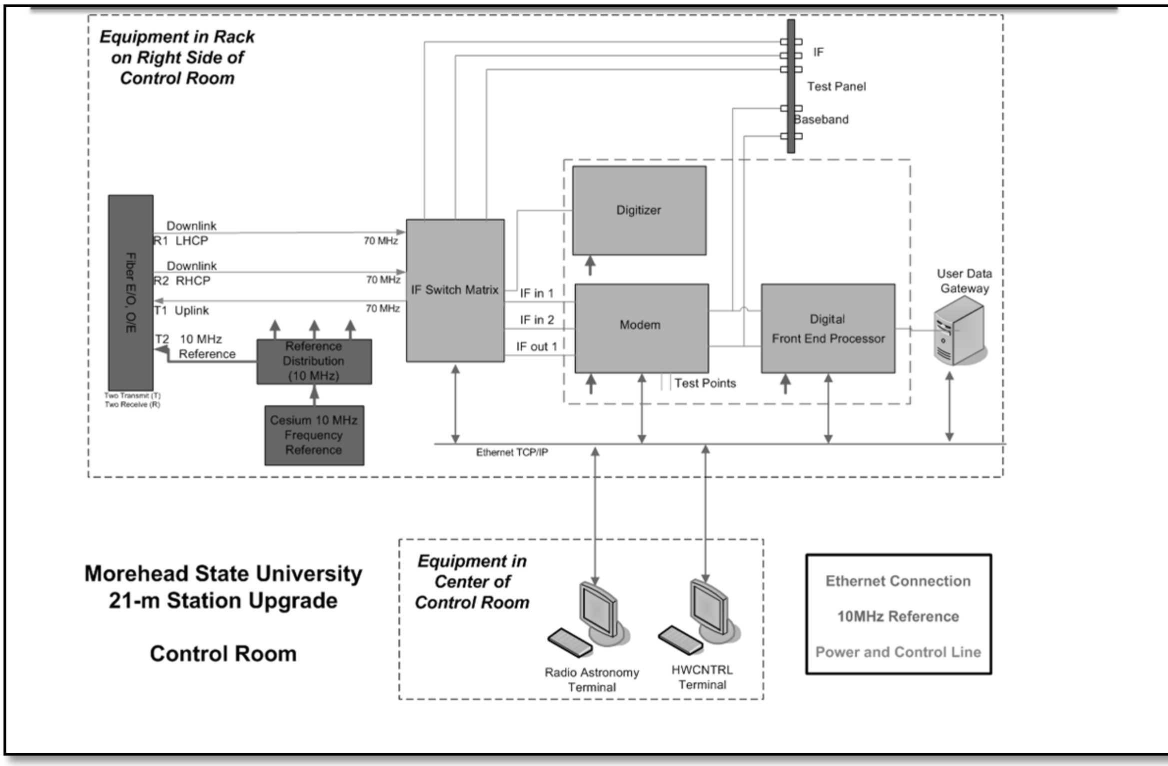

Figure 6. Block Diagram of the 21-m Digital Signal Processing Architecture

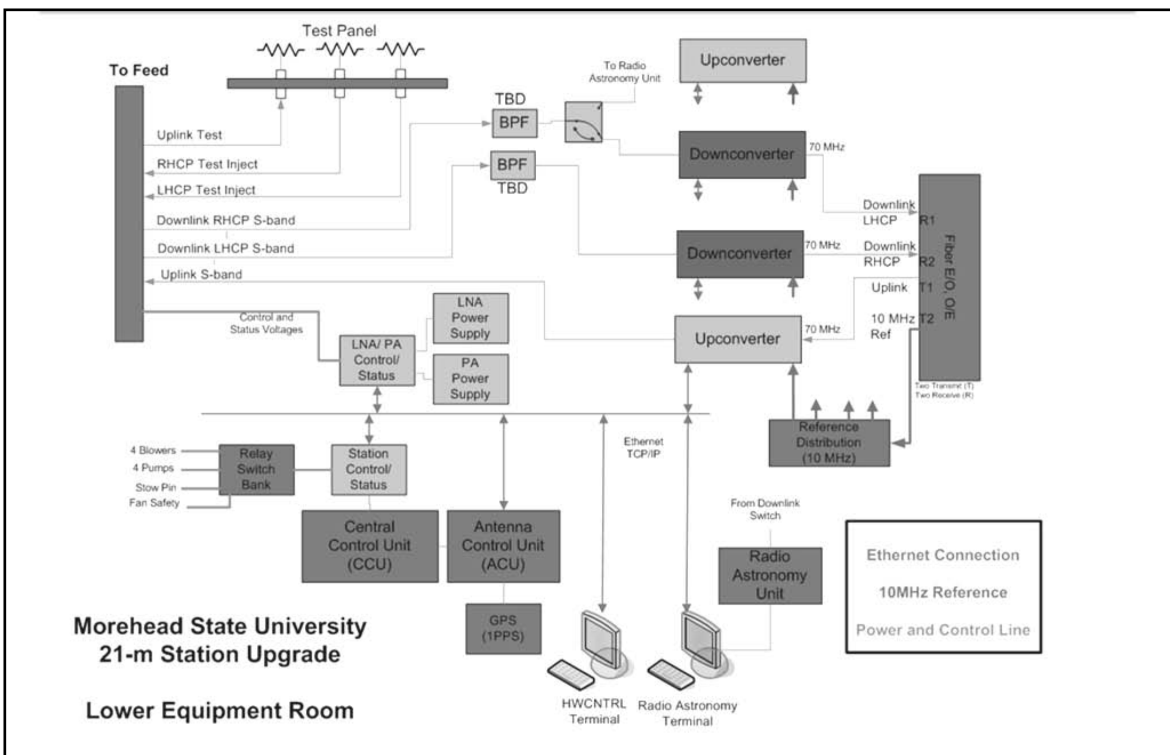

Figure 7. Block Diagram of the 21-m IF, Front-end Processor and Remote Operations Architecture

V. Conclusions

A versatile 21-m full-motion parabolic antenna system has been developed at Morehead State University that serves as an ground station for satellite mission support, a radio telescope for astronomical research, and a test-bed for RF and signal processing systems. Four RF feed systems (L-band, S–band, C-band, and Ku-band) are currently in operation. Upgrades of the RF and control systems are currently underway to facilitate remote and autonomous operation of the 21-m and to bring the system into compliance with SLE data and communication protocol. The 21-m is available to a variety of users (scientific, government, and commercial space) for telemetry, tracking, and command services.

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