AMATEUR RADIO ON THE INTERNATIONAL SPACE STATION— THE FIRST OPERATIONAL PAYLOAD ON THE ISS

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ABSTRACT

As astronauts and cosmonauts have adapted to life on the International Space Station (ISS), they have found amateur radio and its connection to life on Earth to be a important on-board companion and a substantial psychological boost. Since its first use in November 2000, the first five expedition crews have utilized the amateur radio station in the Functional Cargo Block (also referred to as the FGB or Zarya module) to talk to thousands of students in schools, to their families on Earth, and to amateur radio operators around the world.

This paper will discuss the development, qualification, installation and operation of the amateur radio system. It will also discuss some of the challenges that the amateur radio international team of volunteers overcame to bring its first phase of equipment on ISS to fruition.

INTRODUCTION

Prior to the development of the ISS, both the Russian and U.S. space agencies saw the significant benefits for having an amateur radio (ham radio) system on-board their vehicles. On Mir, the ham radio system served as a significant crew psychological boost for long duration missions as well as an emergency communications backup capability. In the U.S., the National Aeronautics and Space Administration (NASA) endorsed the education outreach and human spaceflight awareness capabilities that amateur radio on the Space Shuttle provided. Early in the development of ISS, NASA requested that an international consortium of ham radio teams come together and develop and operate a coordinated amateur radio system on the ISS. In 1996, an international organization called ARISS (Amateur Radio on the International Space Station) was formed to coordinate the construction and operation of amateur radio equipment on ISS. ARISS consists of a delegation from 9 countries including several countries in Europe as well as Japan, Russia, Canada and the USA. The organization is run by volunteers from the national amateur radio organizations from each of the nine countries and the international AMSAT (Radio Amateur Satellite Corporation) teams from each country.

ARISS represents a melding of the volunteer teams that have pioneered the development and use of amateur radio equipment on human spaceflight vehicles. The Shuttle/Space Amateur Radio Experiment (SAREX) team enabled Owen Garriott to become the first astronaut ham to use amateur radio from space, talking to hundreds of radio amateurs and heard by thousands during the STS-9 space shuttle mission in 1983. Since then, amateur radio teams in the U.S. (SAREX and MAREX) Germany, (SAFEX), and Russia (Mirex) have led the development and operation of amateur radio equipment on board NASA's Space Shuttle, Russia's Mir space station, and the International Space Station.

Through ARISS, the ham radio community and others can talk to the astronauts and cosmonauts on-board ISS. The primary goals of the ARISS program are fourfold: 1) Educational outreach through crew contacts with schools, 2) Improving crew morale through random contacts with the Amateur Radio public and scheduled contacts with the astronauts' friends and families 3) ISS-based communications experimentation and 4) Promoting international good will. To date, over 70 schools have been selected from around the world for scheduled contacts with the orbiting ISS crew. Ten or more students at each school ask the astronauts questions during the 10 minute orbital pass at the school location. Thousands of students participate in the school events each year. The nature of these school contacts embodies the primary goal of the ARISS program -- to excite student's interest in science, technology and amateur radio.

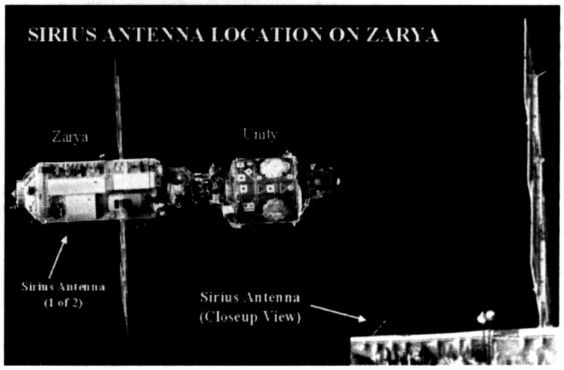
The ARISS team has developed various hardware elements for the ISS amateur radio station. These hardware elements have flown to ISS on three Shuttle flights and one Progress flight. The initial educational outreach system supports voice and packet (computer-to-computer radio link) capabilities. Packet radio has several capabilities including an Instant Messaging-type system and a Bulletin Board System that allows radio amateurs to store and forward messages and allows the orbiting crew to send e-mail to all hams or to individuals.

In addition to the hardware elements flown on the Shuttle and Progress, the ARISS team supported Extra-Vehicular Activity (EVA) training, planning and operations to install four ham radio antenna systems.

HAM RADIO EQUIPMENT SPECIFICS

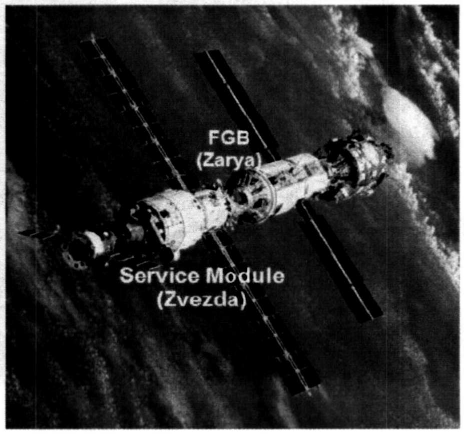
Ham Station Location

The ISS Ham radio equipment will reside in two locations inside the ISS and one location outside the ISS. 2-meter (144 MHz) operations will primarily be conducted inside the Functional Cargo Block (FGB), named Zarya, using antennas that supported docking of the FGB with the Russian Service Module. These antennas, designed for use near the 2-meter band, (see figure 1) no longer support docking and can be used by the ARISS team permanently. This is the current location of the ISS ham radio station. The FGB radio system represents a minimal capability that allows the ARISS team to support school group contacts and packet communications on one band, the 2-meter band.



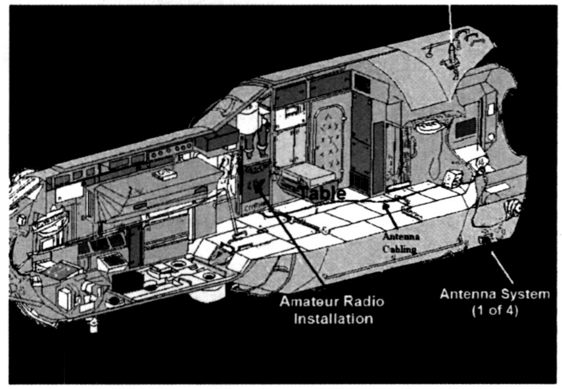
FGB 2 Meter Antenna Locations
Figure 1

The ARISS team's vision of supporting several different international users at the same time on separate frequency bands and different modes (voice, data, television, etc) requires several different antenna systems. The ARISS-Russia team provided this foundation through the installation of four ham radio antenna feedthrough ports on the Russian Service



Service Module and FGB
Figure 2

Module. With these antennas in place, the primary location of the ham station will reside inside the Russian Service Module (SM) named Zvezda. See figure 2. The ham station will be installed near the SM dining table. See figure 3. Simultaneous multi-band operations can be conducted with these two (SM and FGB) station locations.

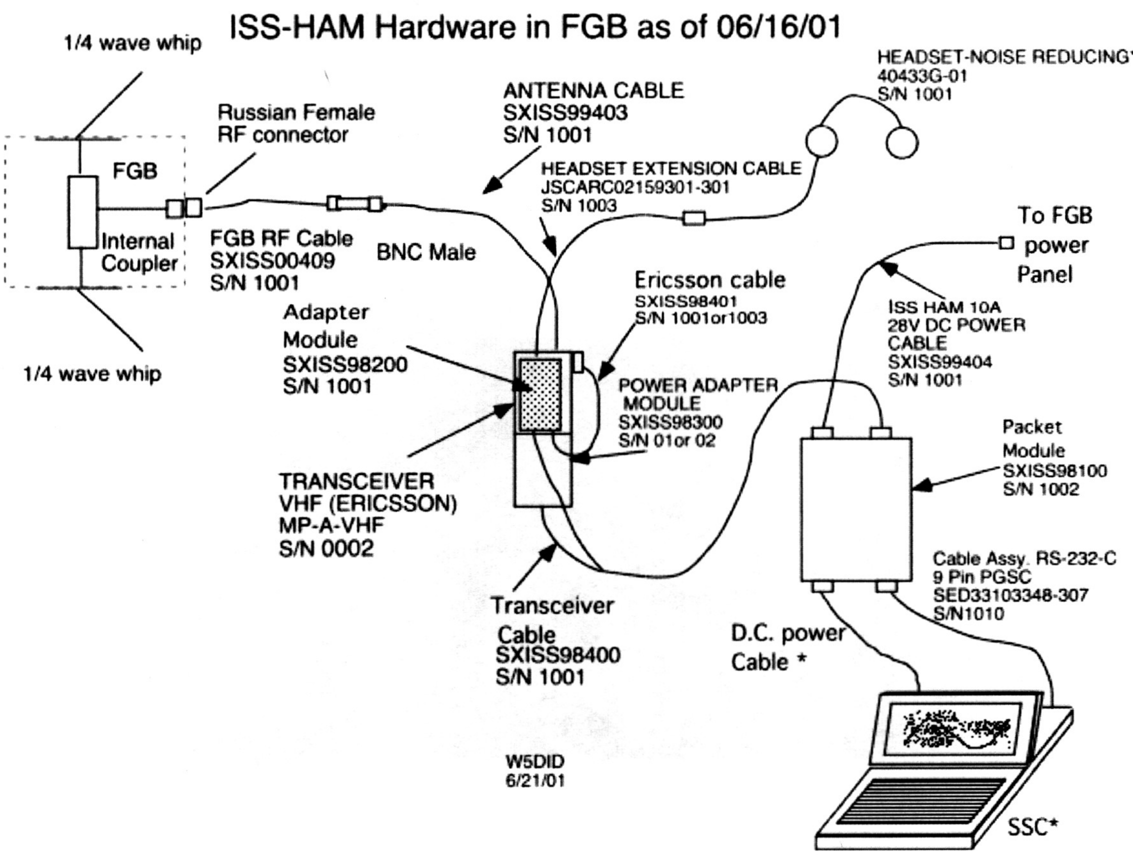


ISS Ham Hardware Location in Service Module
Figure 3

The ARISS team is also working with the international space agencies to install externally-mounted amateur radio equipment on the ISS. This hardware will enable to crew to communicate with Earth-bound radio amateurs and school students using handheld systems that can be moved throughout the ISS. It will also support communications experimentation that will enable students and radio amateurs to receive telemetry data from ISS.

Hardware Overview

Development of the ISS ham radio equipment was led by an internationally based set of volunteers primarily from AMSAT. The AMSAT team has developed and flown over 40 satellites since 1961. They were also instrumental in the development of the ham radio equipment that flew numerous times on the Space Shuttle (SAREX) and on Mir (Mirex).



ISS Ham Hardware Configuration in the FGB
Figure 4

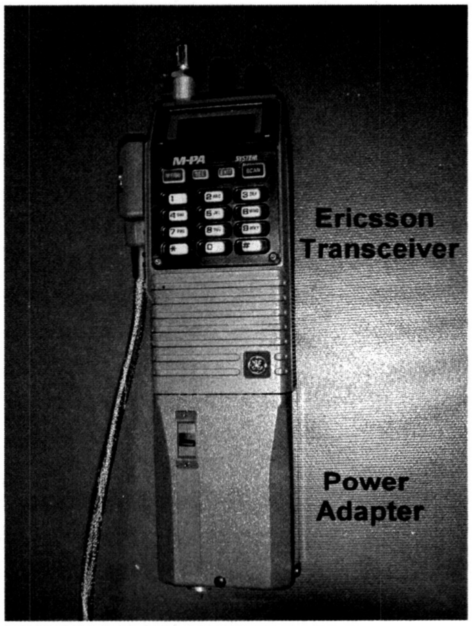
The ham radio equipment was developed by modifying commercial off-the-shelf hardware for permanent spaceflight use. The USA team received safety certification support from Orbital Sciences Corporation. By utilizing several members of NASA Goddard's Hubble Space Telescope safety certification team during their "down time", the ARISS team was able to complete its safety certification in a lower cost (albeit slower) manner than having a dedicated safety certification team. Hardware validation and safety certification testing was performed at test facilities in the USA and in Russia. Our test facilities were located at the NASA Goddard Space Flight Center, the NASA Johnson Space Center, and the NASA White Sands Missle Range in the USA and at the Khrunichev Corporation and RSC Energia Corporation in Russia.

Initial Hardware System

The initial ISS Ham radio system was launched on-board the STS-106 Space Shuttle Atlantis mission on September 8, 2000. This system consists of two hand-held Ericsson transceivers, a power adapter, an adapter module, an antenna system, a packet module, a headset assembly, and the required cable assemblies (see figures 4 and 5). The ham radio station is capable of operating in either the voice or data (packet) mode with amateur stations within line-of-sight of the ISS. This configuration can be operated in the attended mode for voice communications and either the attended or automatic mode for packet communications. The function of each of the components that comprise the initial ISS Ham radio station is summarized below:

Photo of Flight Hardware
Figure 5

Hand-held Ericsson (M-PA Series) Transceivers – There are two transceivers on board: A VHF radio that receives and transmits FM voice or packet radio signals in the 2-meter (144 to 146 MHz) Amateur Band, and a UHF radio that receives and transmits FM voice or packet radio signals in the 70 centimeter (435-438 MHz) Amateur Band. Both radios are Ericsson (M-PA) series commercial grade radios. These radios look identical in size and features, but are specially tuned to support the different bands. Each radio transceiver receives 7.5 VDC from the ISS through a DC/DC power converter located in the power adapter. Up to 5 Watts of output power is available on any one of 64 possible channels. See figure 6.



Transceiver & Power Adapter
Figure 6

a. **Power Adapter** – The Power Adapter consists of a specially developed 12 V to 7.5 V DC/DC power converter that converts the 12 VDC received from the power supply in the packet module to 7.5 VDC that powers the transceiver. A 12.0-to-7.5 Switching Mode Voltage Regulator is built into a standard, polymeric Ericsson Battery casing. The power adapter snaps onto the base of the transceiver in place of the battery pack interface (see figure 6).

b. **Adapter Module** - Provides a means of interconnecting the ISS Ham transceiver with the supplied headset assembly, as well as, a standard crew personal tape recorder (see figure 7). It also provides the audio interface to the packet module and will become the primary interface with the Slow Scan Television (SSTV) hardware.

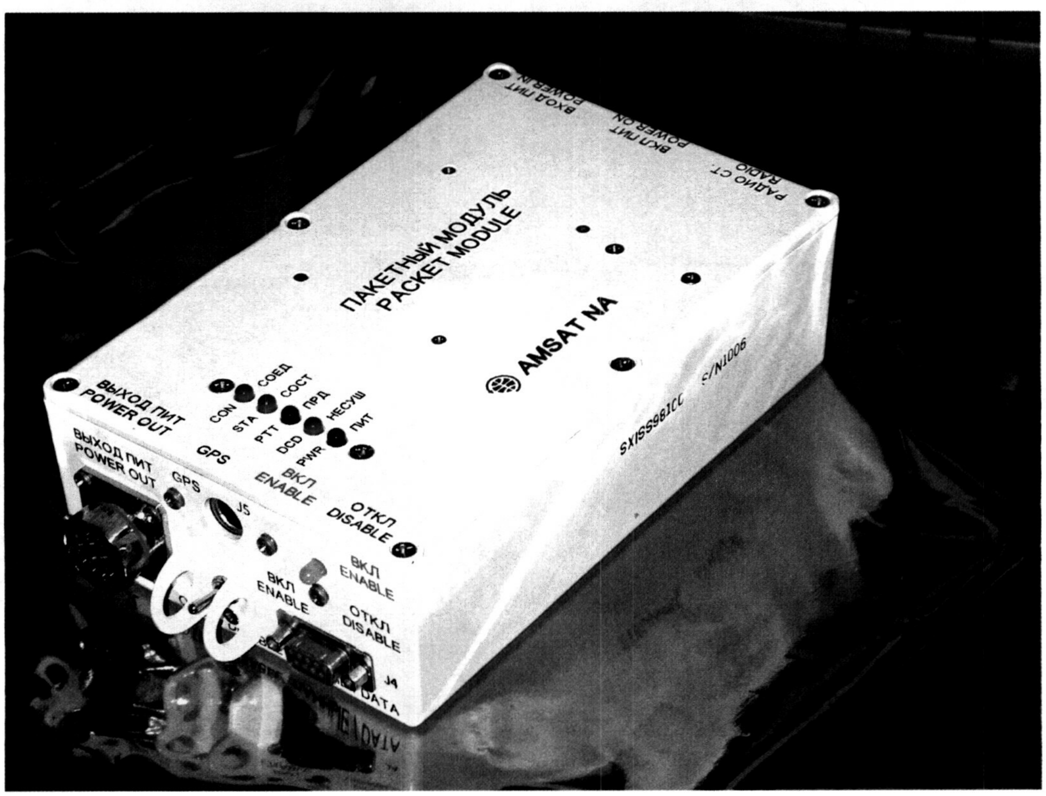
Adapter Module
Figure 7

c. **Computer** – an IBM Thinkpad A22P computer, left on the ISS by taxi crew member Mark Shuttleworth, was connected to the packet module by Expedition 5 crew member Valery Korzun. This computer serves as a data terminal for packet radio operations. It will also serve as the video and software interface for the SSTV system that is planned to be deployed in the near future.

d. **Packet Module** – The packet module contains the primary power supply for the radio station. A maximum of 3 amps of current at 28 V can be provided to the various elements that make up the ISS Ham system. Embedded in the packet module is a PacComm Picopacket Terminal Node Controller (TNC). See figure 8.

e. **Headset assembly**: A David Clark aviation-type headset, similar to that used on several shuttle missions, was configured for the ISS ham radio station. See figure 9.

f. **Cable interfaces**: Several interface cables were specially developed to provide power,



Packet Module
Figure 8

Headset Assembly
Figure 9

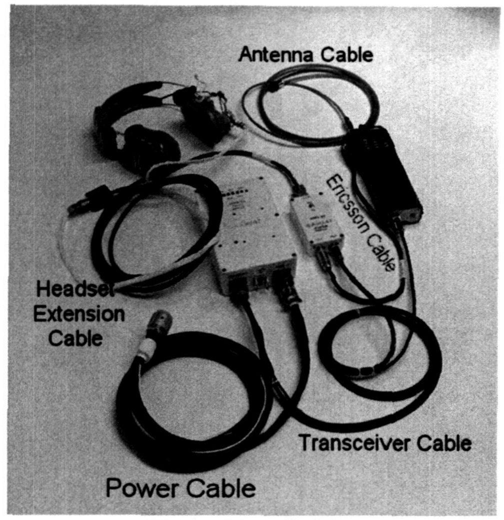
signal and RF connections between the antennas, radios, headset, packet system and computer. These interconnecting cables are depicted in the graphic (figure 4) and the picture (figure 10).

Follow-on Hardware Deployments

Additional ARISS hardware was deployed during two additional Shuttle flights and one Progress flight to ISS. This hardware included an additional Packet Module on the STS-105 Discovery flight on August 10, 2001, four Service Module antenna systems on the STS-108 Endeavour flight on December 5, 2001 and the Antenna cable clips on the Progress 6P flight on November 26, 2001. Specifics of this equipment are described below.

Additional Packet Module

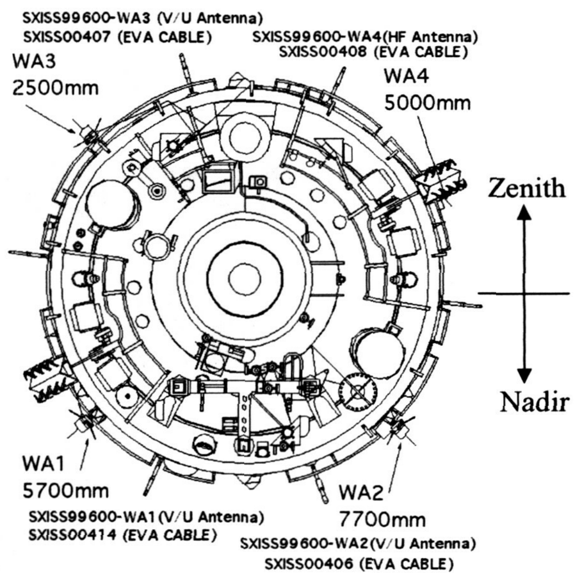
An upgraded packet module with new capabilities was stowed on the ISS in August 2001 and installed at the FGB radio station on February 21, 2002. The new Packet Module includes a specially developed Read Only Memory (ROM) with standard ISS Ham defaults, Russian and USA labels, a new battery, and extended memory (up to 1 megabyte). Since the packet module serves as the power supply for the station, the ARISS team has decided to leave both packet modules on-board ISS. This will allow the simultaneous use of the two radio systems, 2-meter and 70 cm, in the FGB and the Service Module respectively.



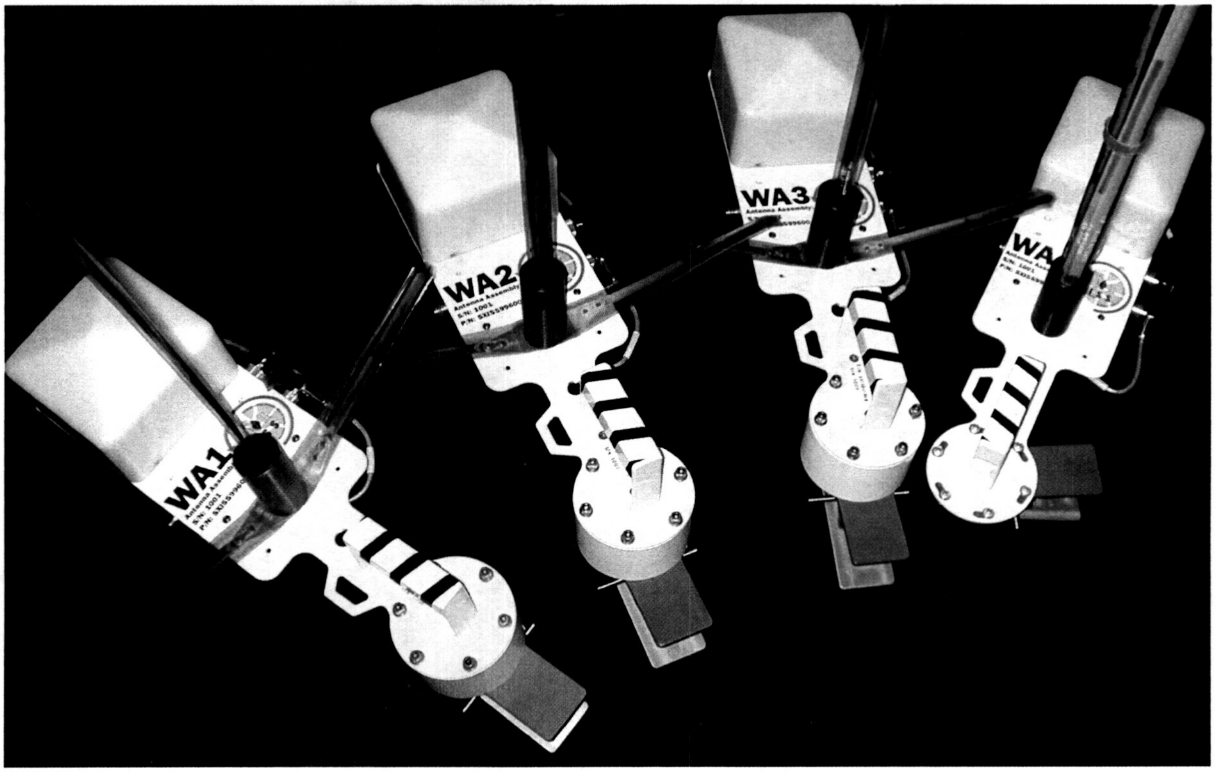
Equipment Cables
Figure 10

Antenna Assemblies

In 2002, a set of four antenna systems, developed by the ARISS team, were deployed during three Russian EVAs. Once checked out, the specially designed antenna assemblies will permit operations on HF (20 meters, 15 meters & 10 meters), VHF (2-meters), UHF (70cm), and the microwave bands (L and S band) These antennas also permit the reception of the Russian Glisser EVA video signals (2.0 GHz). This dual-use (Ham/EVA video) capability is the primary reason the ARISS team received access



Antenna Location View from End of Service Module
Figure 11

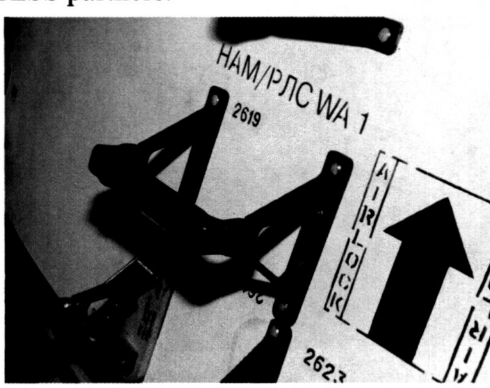


Antenna Systems WA1-WA4
Figure 12

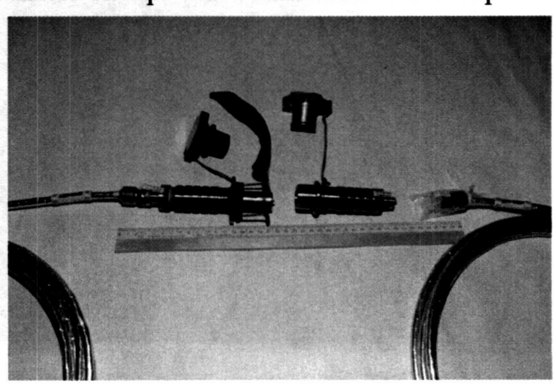
to the four antenna feedthroughs located on the outside of the Service Module.

A total of four antenna systems were developed to get maximum use of the antenna feedthroughs. These were installed around the periphery of the far end of the Service Module. See figure 11. Three of the antennas (WA1-WA3) include a VHF/UHF flexible tape antennas. WA4 includes a 2.5 meter flexible tape HF antenna. The antenna systems were developed by the U.S., Italian, and Russian ARISS partners.

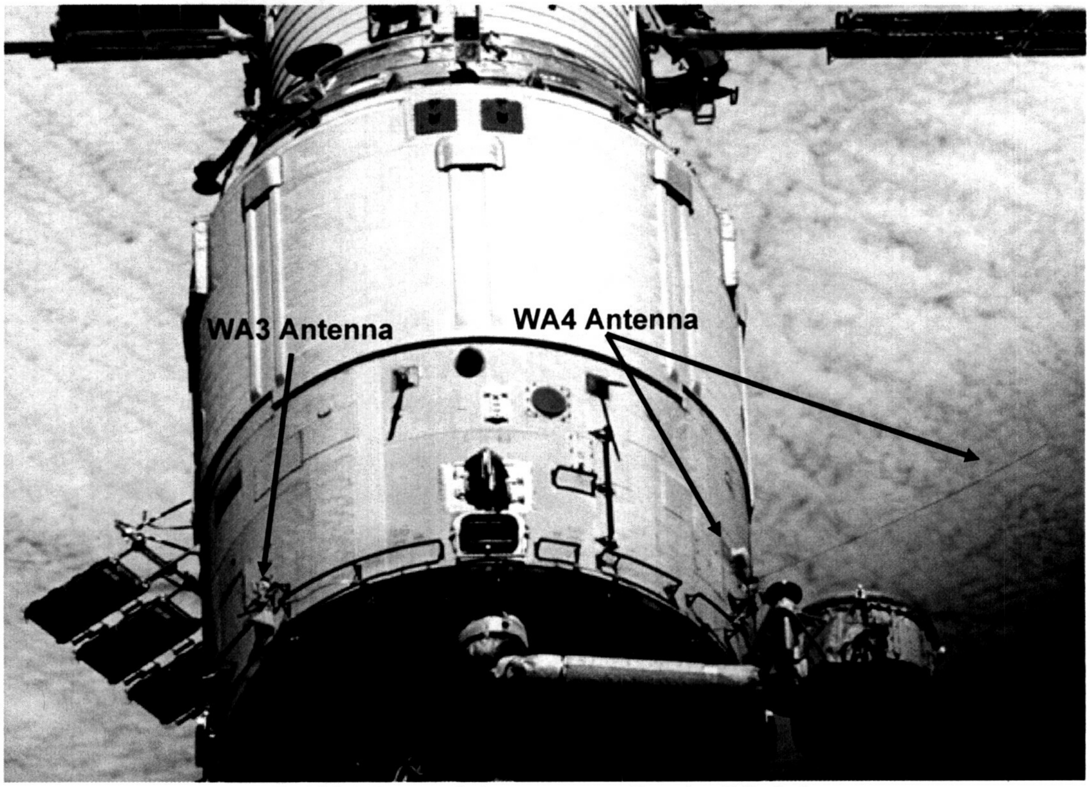
Each antenna assembly consists of a mounting plate, spacer, a black striped handle, a Russian handrail clamp, an orange-colored VHF/UHF (or HF) metal flexible tape antenna with black delrin mounting collar, an L/S band flat spiral antenna with a white delrin radome cover, a diplexer (mounted underneath the plate) and interconnecting RF cables. See figure 12. The antennas will be mechanically mounted on Russian handrails, illustrated in figure 13, using the green-colored Russian "clothespin type" handrail clamp. RF connection is accomplished



Antenna Handrail WA1
Figure 13



Russian EVA Connectors
Figure 14



Zenith Mounted Antennas on Service Module
Figure 15

using 4 feedthroughs that have a special EVA connector attached. See figure 14.

The antenna systems were launched on the Space Shuttle Endeavour flight on December 5, 2001. The two up-looking (zenith) antennas, WA3 and WA4, were deployed in January 2002 and the two down-looking (Nadir) antennas, WA1 and WA2, were deployed in August 2002. The WA3 antenna was deployed by Yury Onufrienko and Carl Walz during the first Expedition 4 crew EVA on January 14, 2002. The WA4 antenna was deployed on January 25, 2002 by Yury Onufrienko and Daniel Bursch. On August 26, 2002, Expedition 5 crew members Valery Korzun and Sergei Treschev completed the installation of the final two antennas (WA1 and WA2). An on-orbit view of the two zenith mounted antennas, WA3 and WA4, is shown in figure 15.

The two Expedition crews performed extensive training of the antenna installation in the Russian Hydrolab water tank located at the Gagarin Cosmonaut Training Center (GCTC) in Star City Russia. See figure 16. Antenna installation on-orbit procedure development and training was led by Sergej Samburov from Energia (also an ARISS-Russia team delegate) with support from the ARISS-USA team.

EVA Training for Antenna Installations
Figure 16

FUTURE HARDWARE DEPLOYMENTS

In the near future, a Slow Scan Television (SSTV) system and a next-generation (Phase 2) radio system will be deployed on ISS. These systems will provide more capabilities for the crew and permit simultaneous operations by more than one crew member. Other equipment, to be installed inside and outside the ISS, is currently being formulated, but won't be developed until their operation and use have been negotiated with the space agencies. The following describes the equipment expected to be deployed on ISS in 2003.

SSTV

The SSTV system for the ISS ham radio station is currently in development. This system will consist of a software interface, developed by the MAREX-NA team and a hardware interface, developed by the AMSAT-NA hardware team. Prototype hardware and software systems have been developed and the flight system fabrication has started. The SSTV system will allow digital still pictures to be uplinked and downlinked in both crew-tended and autonomous modes. The ARISS team expects the SSTV system to be operational on ISS sometime in mid-2003.

Phase 2 Hardware

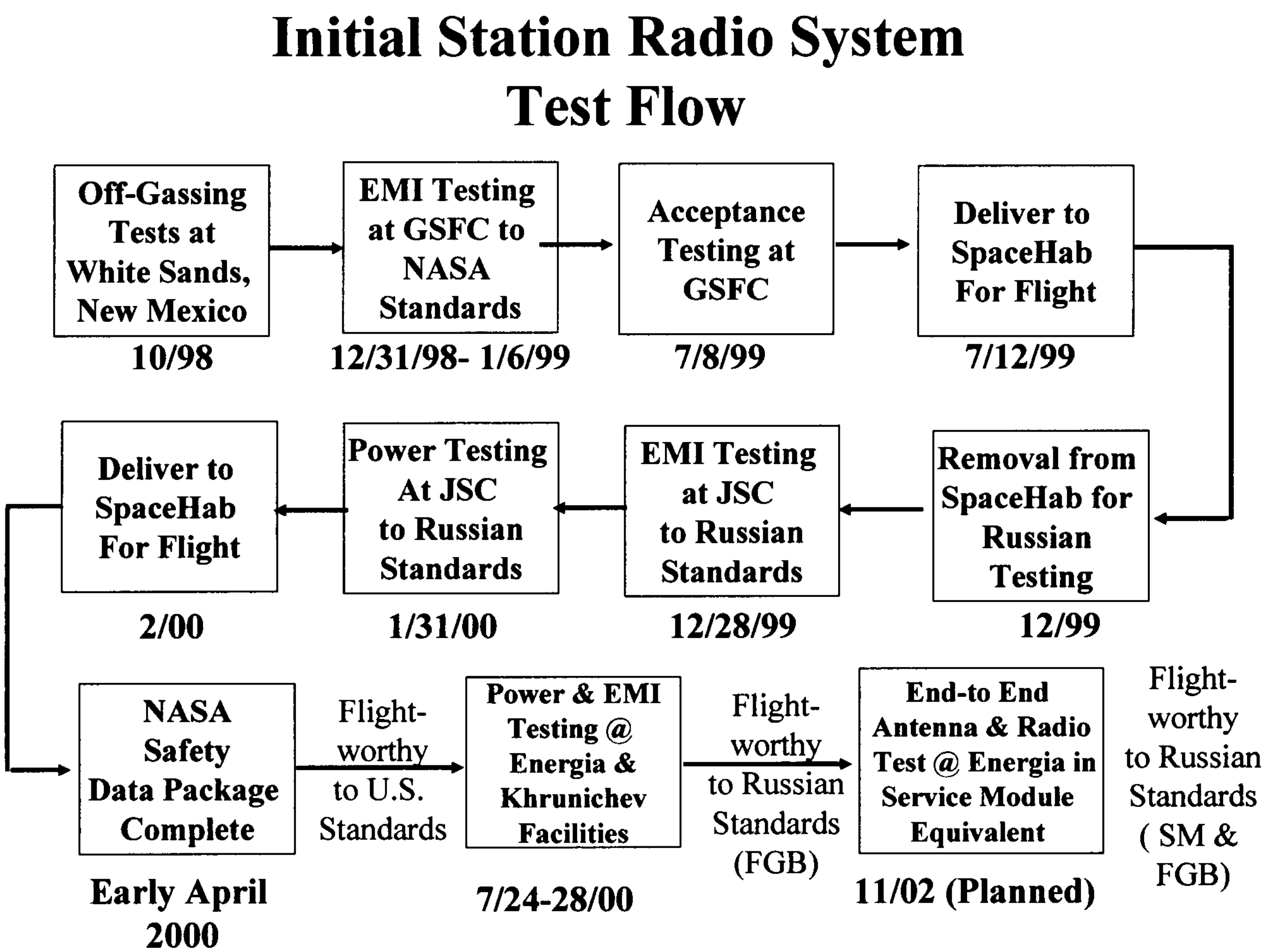
The Phase 2 hardware system is expected to exploit the new antenna systems installed on the Service Module. Two new radio systems will be installed as part of Phase 2. These systems will augment the 2 Ericsson radio systems already installed as part of the initial system. The Phase 2 development is being led by the ARISS-Russia team. One of the two radios currently being qualified for flight is a Kenwood TM-D700 radio. This radio supports 2 meter (144-146 MHz) and 70 cm (435-438 MHz) operation. This radio provides a higher output power capability (35-50 Watts) and can support FM and packet operations. The higher power capability should allow nearly horizon-to-horizon signal reception using simple hand-held radios or scanners.

The other radio is a Yaesu FT100. This radio system will permit operation in the high frequency bands. Of particular interest is performing ionospheric propagation experimentation using the WA4 (high frequency) antenna and this radio. This radio also supports higher output power capabilities.

CHALLENGES

It has been said that when developing a project that the more interfaces required to complete that project, the more difficult, time consuming and expensive the project will be. This is acutely true when one considers an international venture where the different cultures and challenges encountered can seem to get in the way of progress.

After the first ARISS International Partners meeting in 1996, the team walked away from the meeting "cautiously optimistic" that we would be able to develop, deploy and operate an integrated ham radio system on the ISS. It was a good thing the volunteers involved in the hardware development and deployment had no idea of the significant challenges that faced them. The challenges that this international team endured were immense. We were the first payload to fly on ISS and no one—USA's NASA or the Russian Space Agency—really knew how we should be qualified. We repeated several flight qualification tests up to four different times to satisfy all the different organization's requirements—the Shuttle, the USA ISS team and the Russian ISS team requirements. Figure 17 depicts the testing performed to qualify the ARISS hardware. A couple of weeks prior to the September 2000 launch of the initial ISS Ham radio hardware, an additional stumbling block surfaced. The issue this time was that all the Russian EMI testing requirements were not completed. This issue was resolved through a test in Russia and the equipment was deemed worthy to be used in the FGB. The team is currently resolving certification issues to install and use the 70 cm radio in the Service Module. An end-to-end test is planned at Energia in late 2002 to certify the use of the Service Module antennas and Ericsson radios.



ARISS Test Flow
Figure 17

We also had to overcome the cultural difference hurdles that result from working as a fully integrated international team. At the onset, we all tried to "force" our individual cultures on the other teams. We quickly learned that to effectively work together, we must first understand each other's culture and then respect that culture as we worked together as a team. It was tough in the beginning but, over time, we have come to understand each other. This has allowed ARISS to be successful and work effectively as a team.

Communication within the international team continues to be a challenge, but not insurmountable. The significant differences in language between the 9 member countries pose difficulties in ensuring that there is consensus between the international partners. In an effort to minimize communications breakdowns, the Russian and USA teams who have hardware that will be flown on their vehicles have teleconferences twice a month. These teleconferences, with interpreters on-line, help to synchronize the ARISS activities being performed in the USA and Russia. We also have monthly ARISS teleconferences with the entire team on-board as well as face-to-face ARISS international meetings twice per year.

E-mail has also helped make team communication easier, but it has its drawbacks. The ARISS team has been continually plagued with the prevention of e-mail traffic reaching its destination due to Internet filtering and blocking as a result of the proliferation of Internet hackers and spammers. The team's access into the NASA and Energia team members, in particular, have been effected by this. These

communications blockages slow down the ability to complete the hardware development tasks at hand and communicate effectively.
The ARISS team continues to get great support from the international space agencies and contractors. However, the volunteer nature of our work, at times, conflicts with the space agency's specific demands for immediate information as part of a flight critical system. The volunteer team's organizational structure is set up to facilitate getting critical information in a timely basis to the space agencies to meet their flight critical requirements.

Because we are an integral part of ISS, our team, at times, gets immersed in some international space agency issues. For example, when Dennis Tito, the first tourist to ISS, requested the use of our equipment during his stay on ISS, we worked with NASA, Energia and Mr. Tito's team to ensure that ARISS fulfilled the ISS international agreements and served Mr. Tito. In this case, some of the agreements were being heavily negotiated very close to the launch of the Soyuz, putting our team in an awkward situation. In the end, Mr. Tito was very pleased to use the ARISS equipment to talk to his family. The success of this activity and many others is a testament of the close, working relationship that members of our international team have with the space agency and Energia managers.

CONCLUSIONS

The ARISS-international team developed the first payload to become certified to fly on the ISS. Similar to the pioneers of old, this volunteer team faced significant hurdles along the way. They successfully and methodically overcame each issue to pave the way for future amateur radio endeavors on ISS. The hardware team's success on ARISS is a testament to their tenacity, international teamwork and drive to make amateur radio a permanent fixture on the International Space Station.

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For more information on the ARISS program, you are welcome to visit the ARISS web page at: http://ariss.gsfc.nasa.gov