AMATEUR RADIO ON THE INTERNATIONAL SPACE STATION— PHASE 2 HARDWARE SYSTEM

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INTRODUCTION

The International Space Station (ISS) ham radio system has been on-orbit for over 3 years. Since its first use in November 2000, the first seven expedition crews and three Soyuz taxi 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.

Early on, the Amateur Radio on the International Space Station (ARISS) international team devised a multi-phased hardware development approach for the ISS ham radio station. Three internal development Phases---Initial Phase 1, Mobile Radio Phase 2 and Permanently Mounted Phase 3 plus an externally mounted system, were proposed and agreed to by the ARISS team.

The Phase 1 system hardware development which was started in 1996 has since been delivered to ISS. It is currently operational on 2 meters. The 70 cm system is expected to be installed and operated later this year.

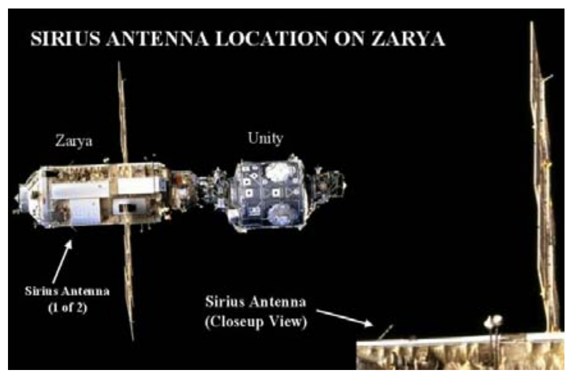
Since 2001, the ARISS international team have worked to bring the second generation ham system, called Phase 2, to flight qualification status. At this time, major portions of the Phase 2 hardware system have been delivered to ISS and will soon be installed and checked out.

This paper intends to provide an overview of the Phase 1 system for background and then describe the capabilities of the Phase 2 radio system. It will also describe the current plans to finalize the Phase 1 and Phase 2 testing in Russia and outlines the plans to bring the Phase 2 hardware system to full operation.

HAM RADIO EQUIPMENT SPECIFICS

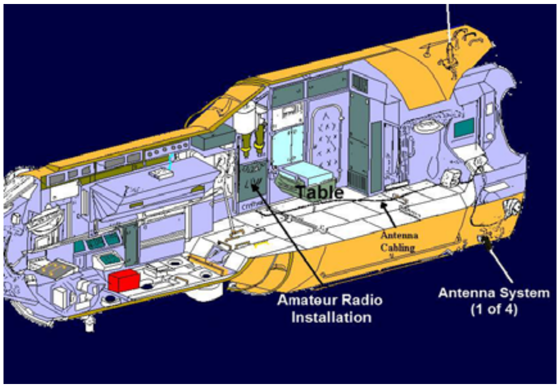
Ham Station Location

The ISS Ham radio equipment will reside in two locations inside the ISS and at least 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 2 meter portion of the Phase 1 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

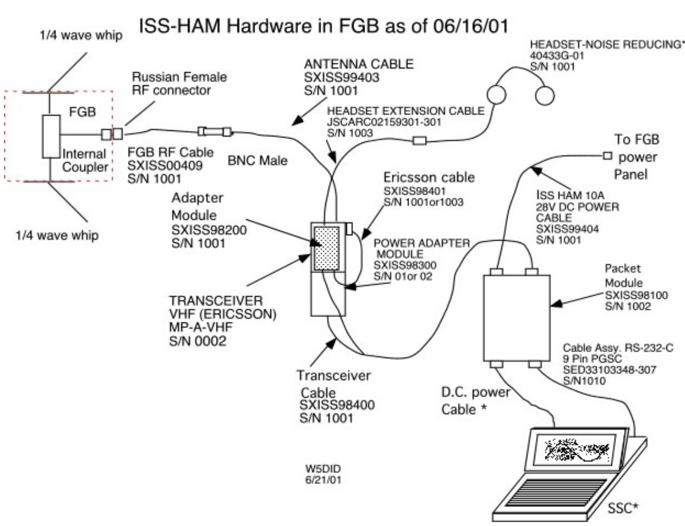
The ARISS team's vision of supporting several different international users at the same time on separate frequency bands and different modes (voice, data, television, etc) requires several different antenna systems. The ARISS-Russia team, led by Sergej Samburov, RV3DR,



ARISS Hardware in Service Module
Figure 2

provided this foundation through the installation of four ham radio antenna feedthrough ports on the Russian Service Module. With these antennas in place, the primary location of the ham station will reside inside the Russian Service Module (SM) named Zvezda. The ham station will be installed near the SM dining table. See figure 2. Simultaneous multi-band operations can be conducted with these two (SM and FGB) station locations.

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 the crew to communicate with Earth-bound radio amateurs



ISS Ham Phase 1 System in the FGB
Figure 3

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.

Phase 1 Hardware Overview

The ARISS team has developed all the hardware elements for the Phase 1 radio system. These hardware elements have been flown to ISS on three Shuttle flights. The Phase 1 system supports voice and packet (computer-to-computer radio link) capabilities. Packet radio has several capabilities including an APRS 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.

The Phase 1 ham radio system was developed primarily in the US. However, extensive testing and coordination with the ARISS-Russia team was required since it is installed in the ISS Russian segment. The initial portion of the Phase 1 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 MP-A transceivers for 2 meters and 70 cm, a power adapter, an adapter module, an antenna system, a packet module, a headset assembly, and the required cable assemblies (see figures 3, 4 and 5).

This configuration can be operated in the attended mode for voice communications and either the attended or automatic mode for packet communications.

Ericsson Radio
Figure 4

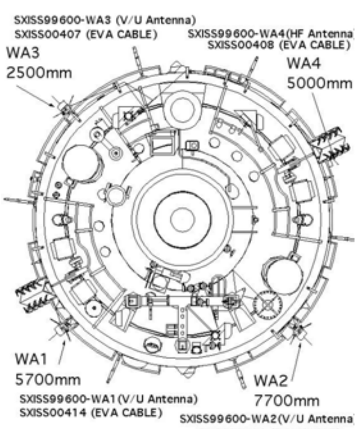
Additional ARISS Phase 1 hardware was deployed during two additional Shuttle flights to ISS. This

Phase 1 Hardware
Figure 5

hardware included an additional Packet Module on the STS-105 Discovery flight on August 10, 2001 (see Figure 6), and additional cables and modules to support simultaneous 2 meter and 70 cm operation on the STS-108 Endeavour flight on December 5, 2001. Details of the Phase 1 system are described in reference 1.

Antenna Assemblies

In 2002, a set of four antenna systems, developed by the ARISS team, were deployed during three Russian EVAs. These antennas will support the Phase 1 and Phase 2 systems in the Service Module. 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 to the four antenna feedthroughs located on the outside of the Service Module.



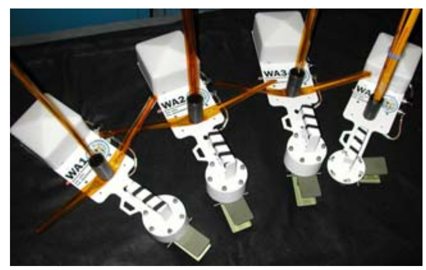
Antenna Location from
End of Service Module
Figure 7

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 7. Three of the antennas (WA1-WA3) include a

Phase 1 Packet Module
Figure 6

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 8.



Antenna Systems WA1-WA4
Figure 8

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 by EVA (space walk) in January 2002 and the two down-looking (Nadir) antennas, WA1 and WA2, were deployed by EVA in August 2002.

Antenna installation EVA procedure development and training was led by Sergej Samburov from Energia with support from the ARISS-USA team.

PHASE-2 HARDWARE SYSTEM

Phase 2 Hardware Overview

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 two Ericsson radio systems already on-board the ISS as part of the Phase 1 system. Combined, the Phase 1 and Phase 2 system will provide more capabilities for the crew and permit simultaneous, multi-mode operations by more than one crew member.

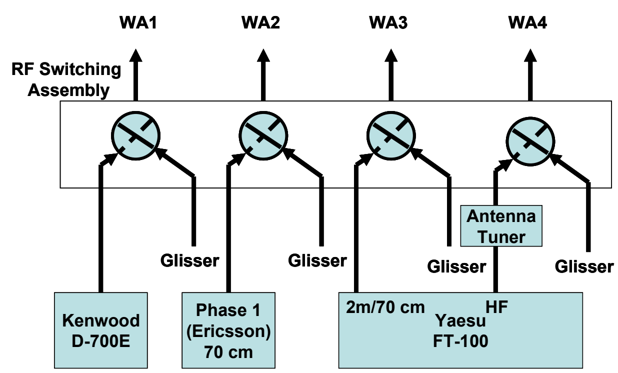
The Phase 2 development is a joint Russian, U.S. and Japan activity. Development was led by Russian team member Sergej Samburov, RV3DR. The Russian team was responsible for certifying the hardware for flight and providing the ride on the Progress launch vehicle. The Japanese team provided (donated) the Kenwood radios to the ARISS team and made specific hardware and firmware modifications to the radio system to prepare it for flight. The USA team, in conjunction with the Japan and Russian team, developed the Program Memory software that provides a powerful system with a very user-friendly interface for crew.

One of the two radios qualified for flight is a Kenwood TM-D700 radio. This radio supports 2 meter (144-146 MHz) and 70 cm (435-438 MHz) transmit/receive operation and L-band uplink operation. This radio provides a higher output power capability (10-25 Watts) than the Phase 1 radio system 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 FT-100. 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 on 2 meters and 70 cm.

The entire set of Phase 2 hardware consists of the Kenwood and Yaesu radios, an RF tuning unit for the Yaesu radio system, interconnecting signal and RF cables, two specially developed Energia power supplies, a power distribution assembly developed by the USA team, a computer and the 70 cm Phase 1 hardware system. These will be mounted on a Velcro-backed table. See figure 9. These radio systems will be connected to the four Service Module antenna systems through a Russian developed antenna switching system. See figure 10. A schematic of the hardware configuration is shown in figure 11.

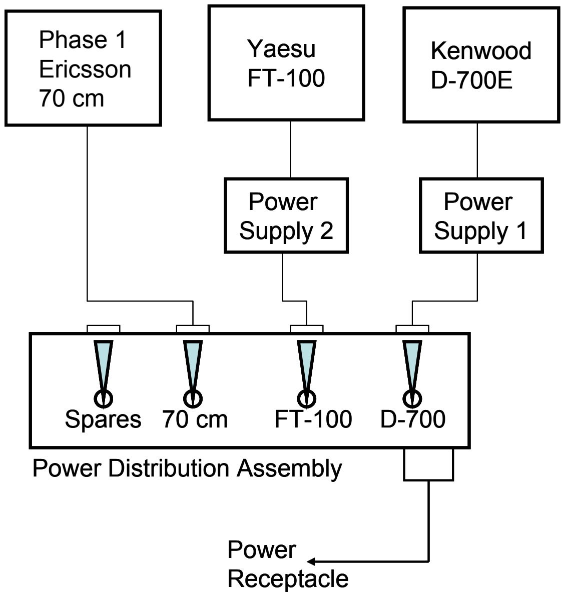
Phase 2 Hardware Housed in
Velcro Table
Figure 9



RF Layout of ISS Ham Radio Systems
Figure 10

Kenwood D-700 Specifics

The ARISS and Kenwood teams agreed that the Kenwood European model radio, D-700E, would



Power Distribution Schematic
Figure 11

be used for flight and ground operations. This radio was already certified by the Russian team.

Several modifications were made by the Kenwood Japan and Kenwood Moscow (Bermos) teams to prepare this radio system for flight. These included:

1) Developing a special Memory Control Program (MCP) to support reprogramming of the radio in the USA, Japan and Russia to ARISS specifications
2) Changing the packet radio default parameters, as specified by the ARISS team, in EEPROM memory
3) Enhancing the "repeater mode" of the radio system
4) Replacing the power cable and the microphone and control head cables with flight cables to allow certification of the hardware to the Russian requirements.
5) Reducing the maximum power output of the radio to 25 watts
6) Replacement of the 6-pin data connector with an 8-pin connector. One of the additional pins on this connector supports an 8 V DC output capability.
7) Incorporating a channel designator for the front panel as the default instead of the frequency information.

The architecture of the radio interface to the crew was carefully crafted by the USA and Japan team to make the D-700 a powerful radio system with a simple user interface. A set of 5 default options, or Programmable Memories, were embedded in the D700 to support ISS operations. See figure 12. The advantage of these five Program Memories (PM's) are that they can be restored with a two-button key press by the crew at any time. With the two hundred different frequency channels, the nearly one hundred TNC parameters, and the variety of applications for this radio on orbit, the default configurations are absolutely critical to being able to maintain communications with the crew under all conditions. These five configurations reduce operations to these fundamental configuration baselines:

Kenwood D-700
PM1 Crew Display
Figure 12

PM1: Voice Operations (mono band)
PM2: Voice Operations (cross band/repeater)
PM3: APRS/Packet and BBS operations
PM4: Attached PC and packet operations
PM5: Emergency Voice and alternate 9600 baud Packet Operations.
PM-off: No defaults. This mode is for knowledgeable licensed crew member's experimentation

The PM's remember the following types of parameters for the radio:

- Default Channel for LEFT side and RIGHT side of radio
- Which side of radio the Microphone and PTT will activate
- Which side of the radio the TNC will RECEIVE and on which side it will Transmit
- The function of the several “soft keys” on the radio front panel

While the MCP program stores all 200 frequency channels in the radio, the PM’s do not store any combination of channel frequencies other than the initial two defaults for the left and right side of the radio. This means, that once a PM has been selected by the crew, this only configures the radio to a known default pair of channels. The crew member can still tune to any channel after that. Thus, with a push of two buttons and a rotation of the main dial, the crew member can operate on multiple modes and different frequency pairs. While this architecture offers the ultimate in flexibility (millions of combinations), it also provides a user-friendly interface of the five PM’s to always return the radio to a known initial state.

Each of the 200 memory channels can support separate TX and RX frequencies, offsets, and PL or CTCSS tones. The D700 is a dual radio system and although it only supports two channels at a time, it is very important to remember that each channel consists of both a displayed RECEIVE frequency and a separate TRANSMIT frequency. Thus, at any time, there can be up to four frequencies involved in radio operations. Since the Microphone and PTT (for voice) can be using one channel and the TNC can be using the same or the other channel, or even can transmit on one channel and receive on the other, there are many conventional (e.g. simplex, split) and non-conventional (e.g. crossband, repeater, CTCSS-enabled command uplink digital channels, etc) ways to use these combinations for ARISS.

Yaesu FT-100 Specifics

The ARISS technical team working on the Yaesu project has specified several modifications to the Yaesu radio system to prepare it for flight. These modifications include:

1. Replacing the power cable and the microphone and control head cables with flight cables to allow certification of the hardware to the Russian requirements.
2. Reducing the maximum power output of the radio to 25 watts
3. Replacing the PVC RF cables and connectors on the back of the radio with SMA connectors. Attached to these are Teflon coated RG-142 antenna cables with N connectors
4. Tuner cable replacement with flight cables
5. Replacement of 6-pin data connector with an 8-pin connector. One of the additional pins on this connector supports a 12 V DC output capability.

Since the FT-100 supports HF operation and the WA4 antenna is a single 2.5 meter vertical the ARISS team felt that it would be best to supply a tuner with the radio to minimize SWR concerns and optimize signal output. See figure 11. The ARISS USA team is working closely with the Yeasu team to modify their existing FT-100 auto-tuner for ham radio operations on ISS.

Development of the Yaesu system is on-going, but is expected to conclude in early November 2003.

Power Distribution Assembly

One of the primary issues in a household is sufficient and easy access to electrical receptacles. A similar issue exists on ISS. There just aren’t enough receptacles where you need them. With the 3 radio systems being installed in the Service Module (Phase 1 70 cm, Phase 2 Kenwood and Phase 2 Yaesu), the need for electrical receptacles for the ISS ham radio system could become a major issue.

The power distribution assembly, see figures 11 and 13, resolves this problem and several other potential issues on ISS. The power distribution assembly allows the ISS ham system in the Service Module to be plugged into only one ISS receptacle. It also provides a power shutoff capability via switches and circuit breaker protection for each radio system. This not only provides an addition level of safety but also provides an additional shut-down feature that is critical for satisfying the ISS EVA safety requirements. With the power distribution assembly, there will be no need to plug and unplug ISS Ham items due to insufficient receptacles. Thus, this assembly serves to reduce wear and tear on the power cables, improving system safety.

Power Distribution Assembly
Figure 13

The Power Distribution Assembly is being developed by the USA team with strong support from the Russian team. While the unit will be fabricated in the US, several of the parts, particularly the electrical connectors, are Russian supplied. The current plan for the Power Distribution Assembly is to fabricate the flight unit, certify it for flight in the US and in Russia and then fly it on-board the next space shuttle. Since the Yaesu system will not be deployed until the Spring of 2004, this development and delivery schedule appears to make sense.

Power Converters

Two fully redundant, flight certified power converters were developed by the Russian Energia team and were supplied to the ISS Ham team for use as part of the Phase 2 radio system. These power supplies convert the 28 VDC ISS power to 13 VDC for use by the Kenwood and Yaesu radio systems. Since the power converters are fully redundant, the ISS ham team will have adequate power capabilities for all the radio systems even if one of the power converters fail.

Power Converter
Figure 14

Phase 2 Delivery, Testing and Checkout

The final version of the flight MCP software was delivered to the Russian team by the USA team on July 17, 2003. Just prior to this, the Kenwood Japan team delivered the final firmware load to the Kenwood Japan (Bermos) team for installation into the D-700 radio. The Bermos team and the ARISS-Russia team, led by Sergej Samburov, completed the hardware and software modifications to the radio system in late July and readied the Phase 2 hardware system for flight. The initial set of Phase 2 hardware, including the Kenwood D-700 radio, interconnecting cables, power converters, and RF switching system were delivered to the Baikonur Cosmodrome in Kazakhstan in early August. The Phase 2 hardware was launched on the Progress 12P rocket on August 29, 2003 and docked with the ISS on August 31. The Velcro table is already on-board ISS and is awaiting equipment installation.

The Phase 2 equipment is currently “yellow tagged” meaning that we need to accomplish some additional tests prior to on-board hardware integration and testing. A series of tests are being planned for early November, 2003 at the KIS facility (Service Module engineering model equivalent) located at Energia in Korelev (Moscow area) Russia. The Russian and US team will be conducting tests in this Service Module equivalent to validate that the Phase 2 and 70 cm and 2 meter Phase 1 systems are compatible with the other electrical systems on the Service Module. We will also conduct some RF testing with the flight-identical antenna systems and the Phase 1 and Phase 2 hardware. Once these tests are successfully completed, the yellow tag can be removed and hardware installation can begin.

The current plan is for Mike Foale and Alexander Kaleri to install the Phase 2 and Phase 1 70 cm hardware on Expedition 8. The plan is to perform hardware installation and checkout in mid to late November 2003.

The remaining Phase 2 hardware, including the Yeasu radio system is planned to be launched on the Progress 14P flight that is planned for January 2004.

FUTURE HARDWARE DEPLOYMENTS

Follow-on Phase 2 Hardware

Two future projects are envisioned to improve the capabilities of the Phase 2 system. These include the development of the tuner for the Yaesu radio system and the certification of a Standing Wave Ratio/Power meter. These two projects will be developed and flight certified by the US team and flown on a future shuttle flight.

SSTV

In the near future, a Slow Scan Television (SSTV) system will be deployed on ISS. 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-MG 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 flown on Progress flight 14P in January 2004.

CONCLUSIONS

The ARISS-international team, with help from Kenwood and Yaesu, have developed the ISS Phase 2 ham radio system. The Kenwood system is currently on-orbit and will be soon operational on ISS. The team expects that the Yaesu system will be operational in Spring 2004. This multi-national development effort presented many challenges to the team. Despite these challenges, the tremendous teamwork and optimistic spirit resulted in an outstanding new capability on ISS that we expect to set the standard in space for years to come.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the tremendous support, teamwork and volunteer spirit of the ARISS-International team in making this hardware system come to fruition. Technical, financial and administrative support by the ARISS member organizations--the AMSAT organizations and IARU organizations (ARRL in the USA) continue to be crucial to the success of the program. Also special recognition is in order to NASA, Energia, Kenwood, and Yaesu. The ARISS team continues to be indebted to them for all their in-kind contributions and support. Together we are pioneering the new frontiers of amateur radio and educational outreach.

DEDICATION

This paper is dedicated to the memory of Roy Neal, K6DUE. Roy’s tireless pursuit to make amateur radio on human spaceflight missions a permanent capability was an inspiration to us all. We feel privileged to have realized his vision on ISS during his lifetime. We have more solidly cemented that permanence with the delivery of the Phase 2 hardware system. Our thoughts and prayers are with you old buddy.

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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 or http://www.rac.ca/ariss