WIRELESS VIDEO SYSTEM FOR EXTRA VEHICULAR ACTIVITY IN THE INTERNATIONAL SPACE STATION AND SPACE SHUTTLE ORBITER ENVIRONMENT

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Abstract - The Wireless Video System (WVS) provides real-time video coverage of astronaut extra vehicular activities during International Space Station (ISS) assembly. The ISS wireless environment is unique due to the nature of the ISS structure and multiple RF interference sources. This paper describes how the system was developed to combat multipath, blockage, and interference using an automatic antenna switching system. Critical to system performance is the selection of receiver antenna installation locations determined using Uniform Geometrical Theory of Diffraction (GTD) techniques.

I. INTRODUCTION

The WVS supports assembly of the ISS by providing real-time video from astronauts during Extra Vehicular Activity (EVA) to video monitors in the Space Shuttle Orbiter (SSO) and the Mission Control Center (MCC). The functional block diagram shown in Figure 1 includes the Crew Compartment, Payload Bay, and EVA Mobility Unit (EMU) RF Camera Assembly (ERCA). The Crew Compartment Assembly provides control and monitoring of the system performance. This assembly is composed of two separate components. One is a panel interface (Wireless Video Interface Box - WIB) used by the crew for providing control inputs to and receiving video, telemetry, and status from the Payload Bay Assembly and ERCA. The other component is a Payload General Support Computer (PGSC) that contains the software used for monitoring and configuration control. Command and telemetry generated at the PGSC is transmitted via a RS-422 serial data link to the WIB.

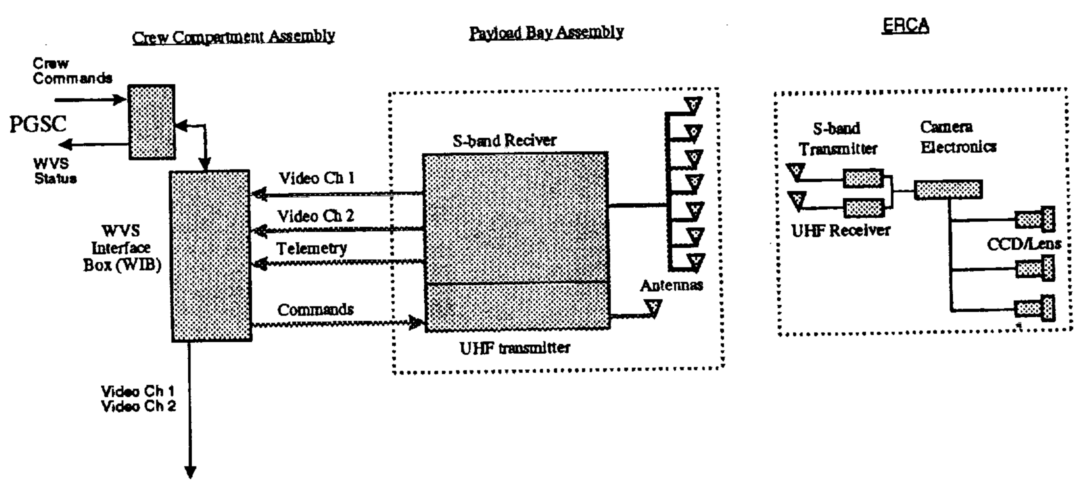

Figure 1.- Overall block diagram of the Wireless Video System (conceptual).

The Payload Bay Assembly consisting of the radio transceivers and antennas serves as the hub and is used for video, command, and telemetry signal routing. The ERCA provides the video input signal and accepts commands from the Crew Compartment Assembly via the Payload Bay Assembly. The ERCA has three video cameras, an S-band transmitter for sending video to the payload bay receiver, and a UHF receiver for receiving commands from the ISS or SSO. The S-band transmitter uses frequency modulation (FM) to transmit National Television System Committee (NTSC) compatible composite video to the receiver at a range of up to 300 feet. On the ISS structure and in the SSO payload bay, Quad S-band patch antenna assemblies are mounted for reception of the composite video RF signal. The receiver automatically selects the Quad patch antenna assembly with the strongest received signal. The placement of these S-band receiving antennas is critical to the system performance in terms of coverage and received video quality. The UHF transmitter provides command and control data to the ERCA at 9600 baud using Gaussian Minimum Shift Keying (GMSK) modulation. The S-band equipment, UHF transmitters, and receivers are commercial off the shelf (COTS) equipment modified for ISS and SSO environment.

II. ISS WIRELESS ENVIRONMENT

Multipath and Blockage

The ISS wireless environment is unique due to the nature of the ISS structure shown in Figure 2. The ISS consists of various truss segments, solar panels, thermal radiator panels, and modules for laboratories and crew accommodations. As the astronauts on EVA move over the ISS structure, multipath becomes a major issue in the design. A system of selectable S-band antennas ensures that the antenna with the strongest received signal gets connected to the receiver. S-band antennas are placed throughout the ISS structure and the SSO payload bay. The locations are selected based on GTD modeling and simulation. In this technique, a structural model of the ISS and SSO is developed to describe the major structural components that impact RF signal blockage and reflection. Source geometry statements specify the location of the transmitting antenna and the emitter characteristics such as frequency, generating function, and orientation. A received signal path is specified over which GTD computes the received signal levels including the direct, reflected, and diffracted electromagnetic fields from the transmitter source. GTD modeling provides a method for estimating the received signal strength and interference signal power levels at various locations throughout the ISS and SSO structures. The modeling was used to compute the RF coverage and assess the interference effects.

Interferometer Effects

Two S-band transmit antennas will be mounted on opposite sides of the EVA helmet. This arrangement will cause an interferometer region to exist. Multipath and the interferometer region will tend to degrade the received signal. The Quad patch antenna will protect against the multipath effects. Thus protection against the interferometer region is desired. By utilizing a spatial diversity scheme, the Quad patch antennas were mounted throughout the payload antenna. The spacing of these antennas will combat the interferometer region and multipath effects.

RF Interference & System Compatibility

Due to scarcity of communication bandwidth, the S-band and UHF frequencies were selected adjacent to other RF sources. The interference sources are located on the ISS, SSO, Low Earth Orbit (little LEO) Satellites and ground-based transmitters. Selecting a frequency for the S-band and UHF link which will coexist with all interferers poses a major design challenge. The ISS includes modules and laboratories built by International Partners including Russia, Japan, France, Germany, Italy, Canada and ten other countries. These modules have UHF and S-band systems which do not fall under the authority of the United States (U.S.) Federal Communications Commission (FCC). No common set of guidelines is established ensuring spectrum emission compliance. ISS systems which are known to have an interference and compatibility problem with other systems are modified in hardware before deployment if possible. In cases where hardware modification cannot be performed, operational workarounds are implemented. For example, WVS which operates at 2.41 GHz and 2.47 GHz carrier frequencies falls within the 2.40-2.48 GHz hopping bandwidth of the wireless local area network (LAN) which operates inside the ISS

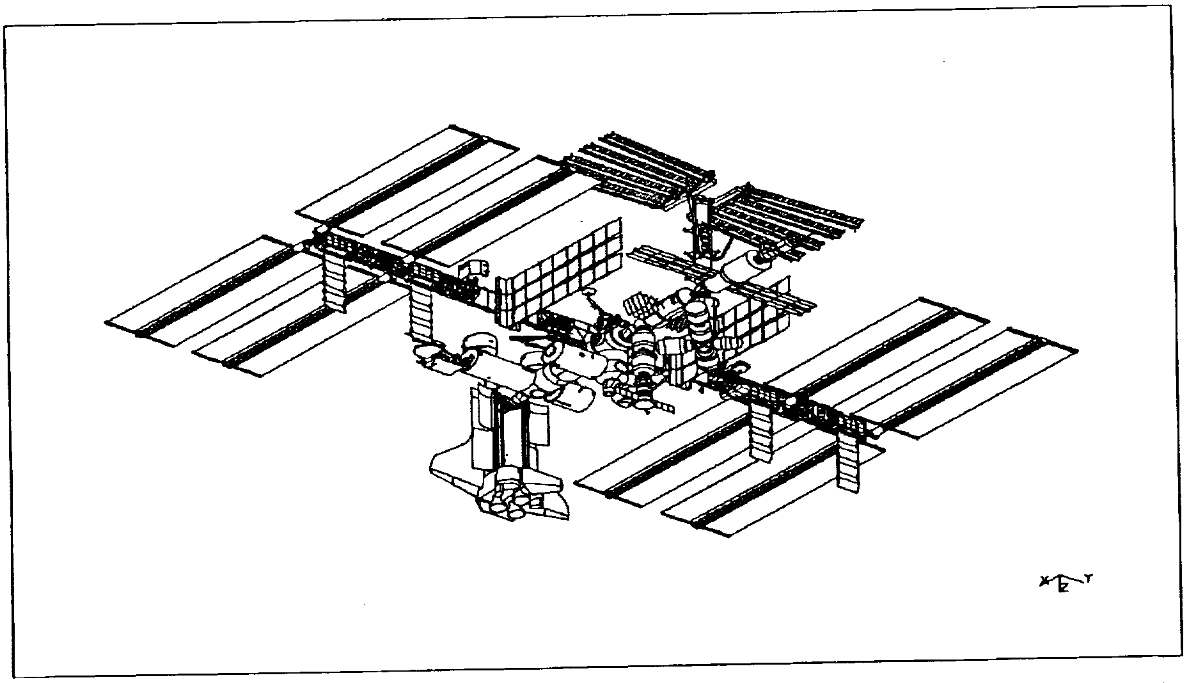

Figure 2. ISS Structure

laboratory module. To support concurrent operation of the WVS and wireless LAN, it is necessary to install RF shielding in the laboratory module windows and implement an operational workaround which maintains a minimum separation between the WVS and wireless LAN transceiver. Sometimes an operational work around is the only solution for interference and compatibility problems. For example, the Russian Space Agency operates a global timing system (GTS) at 400.1 MHz which interferes with the UHF command link at 400.2 MHz. During an EVA using WVS, GTS will not be operational.

III. RECEIVER ANTENNA SWITCHING

Quad S-band Patch Antenna Assembly

The ability to automatically select the S-band receiver antenna which has the strongest received signal power level without distorting the received video signal is what distinguishes the WVS from typical wireless video systems. The receiver design has the capability to automatically switch among eight antenna assemblies. Each antenna assembly consists of a Quad S-band patch antenna (four patch antennas per assembly), input filtering, internal cables, and a low-noise amplifier (LNA). The LNA installed within each antenna assembly reduces the overall system noise temperature at the receiver input. The automatic antenna selection algorithm is implemented in the receiver where cables from the eight patch antenna assemblies are connected. The receiver performs the antenna selection during the composite video horizontal and vertical blanking pulses such that no observable distortion can be seen on the video monitor.

Automatic Antenna Switching

The nominal mode of operation for the receiver is to automatically switch to the S-band antenna with the strongest received signal power level. The automatic switching mode combats multipath fading since an S-band receiving antenna which has cancellation due to multipath will usually not be selected by the switching algorithm. In most cases, the automatic switching algorithm will provide quality video reception in spite of structural blockage, multipath, and reflections. The EVA helmet has an S-band antenna mounted on each side, so that the astronaut may have to only slightly rotate or translate his position enabling selection of an S-band antenna which will improve the video signal reception. The automatic switching algorithm can support good video reception even in the presence of in-band interference sources as long as the interference power does not cause the switching algorithm to select the wrong receive antenna. When the received signal-to-noise ratio (SNR) variations at the receiver are consistent with variations in total received power, the antenna switching algorithm will make the correct decision and not switch to the antenna receiving the strong interference. For example, when the wireless LAN hops within the WVS bandwidth, the undesired interference signal does not confuse the antenna switching logic as long as the SNR varies consistently with the changes in total received power.

Manual Antenna Switching

Manual antenna switching is required whenever an interference source exists which causes the automatic switching algorithm to incorrectly select a receiving antenna which has strong received interference power. Failure of the automatic switching algorithm occurs when a transmitter antenna operating at the S-band carrier frequency radiates directly on S-band antenna. For example, the Russian Space Agency (RSA) Functional Cargo Block (FGB) hosts the S-band Komparus system which operates at 2.367 GHz with spectral components which cause interference in the 2.40-2.48 GHz band. If the Komparus omni antenna radiates, the antenna switching algorithm must be placed in manual mode to avoid selecting a S-band antenna that is in line-of-sight (LOS) with the Komparus omni transmitting antenna.

IV. ANTENNA DESIGN CONSIDERATIONS

Antenna design plays an important role in minimizing multipath effects and enhancing the system performance. Due to assembly and maintenance tasks, astronauts can possibly be anywhere around the ISS. To provide a broad coverage area for an astronaut, an omnidirectional antenna will be required. Currently, the most commonly used omnidirectional antenna designs are monopole (whip), microstrip patch, and helix. Unlike ground communications in which the users orientation is usually known (normal to the ground), the astronaut orientation is unknown and can be arbitrary. Any misalignment between transmitting and receiving antennas will result in a polarization mismatch and hence reduction in system performance. Multipath (reflections and diffractions) causes polarization shift which further complicates the polarization mismatch issues. To avoid potentially severe polarization loss due to the misalignment of linear antennas, circular polarization is essential to ensure good performance in the multipath environment. The whip or monopole antenna is discarded due to its linear polarized nature. Patch and helix antennas with proper feed can provide a circular polarized omnidirectional pattern. Limited real estate on the astronaut helmet requires that patch antennas be used. Both UHF command and video links will have patch antennas mounted on the helmet. The S-band video link employs an antenna diversity technique for combating the multipath environment. The S-band antenna assembly on ISS has six S-band Quad antennas on each transceiver box. The antenna with the strongest signal strength will be selected automatically. There is limited real estate for a transceiver box to accommodate six Quad patch antennas. The patch antenna design was selected because of its low profile and ability to be mass produced. There is a UHF transmit antenna on each transceiver box on the ISS and one antenna in the SSO payload bay. Good axial ratio is required to utilize a polarization discrimination technique to minimize in-band interference with the little LEO satellites. The patch antenna axial ratio performance is quite sensitive to the feeding network design. It is very difficult to achieve good axial ratio beyond 70-80 degrees from boresight. Helix antennas by nature are a very good circular polarized antenna design. Good axial ratio for helix antennas can extend beyond 90 degrees from boresight. Good coverage requires a broad beamwidth. A helix antenna provides the broadest beamwidth omnidirectional pattern. Thus, a ½-turn resonant ½ wave quadrifilar helix antenna has been selected for the UHF transmit antenna..

V. CONCLUSION

The ISS environment is unique due to the nature of the ISS structure and the multiple RF interference sources. The antenna switching algorithm mitigates multipath and interference from adjacent and co-channel RF sources. In cases where degradation cannot be avoided, operational workarounds are required. Using spatial diversity, multiple antennas, and operational workarounds, WVS will provide quality coverage for ISS assembly.