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Producing a Live HDTV Program from Space

By
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"Wouldn't it be cool if we could downlink live HDTV from space?"

The obvious answer to that question from a 1999 meeting of the NASA Digital Television Working Group was yes, but none of the attendees thought it would take so long to happen. Finally, on November 15, 2006, the first-ever live high-definition television (HDTV) broadcasts from a spacecraft were conducted, one in Japan by the Japan Broadcasting Corporation NHK and the other in the United States (US) by the Discovery Channel.

The path to these first HDTV downlinks from the International Space Station (ISS) was arduous and involved many detours along the way.

By the year 2000, NASA had flown HDTV camcorders on three Space Shuttle missions: STS-95, STS-93 and STS-99. All three flights of these camcorders were accomplished with cooperation from the Japanese space agency (then known as NASDA and now known as JAXA). The cameras were large broadcast-standard cameras provided by NASDA and flight certified by both NASA and NASDA. The high-definition video shot during these missions was spectacular. Waiting for the return of the tapes to Earth emphasized the next logical step: finding a way to downlink the HDTV live from space.

Both the Space Shuttle and the International Space Station (ISS) programs were interested in live HDTV from space, but neither had the resources to fully fund the technology. Technically, downlinking from the ISS was the most effective approach. Only when the Japanese broadcaster NHK and the Japanese space agency expressed interest in covering a Japanese astronaut's journey to the ISS did the project become possible. Together, JAXA and NHK offered equipment, technology, and funding toward the project. In return, NHK asked for a live HDTV downlink during one of its broadcast programs. NASA and the ISS Program sought a US partner to broadcast a live HDTV program and approached the Discovery Channel. The Discovery Channel had proposed a live HDTV project in response to NASA's previous call for offers. The Discovery Channel agreed to provide additional resources. With the final partner in place, the project was under way.

Engineers in the Avionics Systems Division at NASA's Johnson Space Center (JSC) had already studied the various options for downlinking HDTV from the ISS. They concluded that the easiest way was to compress the HDTV so that the resulting data stream would "look" like a payload data stream. The flight system would consist of a professional HDTV camcorder with live HD-SDI output, an HDTV MPEG-2 encoder, and a packetizer/protocol converter. The converter would format the video into a fiber-

optic interface with a data stream formatted for the data distribution system of the ISS. On the ground, the data stream would be automatically routed to the Marshall Space Flight Center, where ISS payload data is processed. The MSFC Payload Operations Information Center (POIC) would strip the headers off of the data stream and provide an ASI stream for decoding, monitoring, recording and further distribution. Several tests were conducted in 2002, including a simulation using JSC's Electronic Systems Test Laboratory to simulate the data stream from the ISS. After adjusting some buffers at the POIC, the system worked perfectly. The hardware was stowed in the mid-deck and Multi-Purpose Logistics Module (a module that carries racks and supplies to and from the Space Station) in preparation for the Space Shuttle mission, STS-114. Then on February 1, 2003, disaster struck in the form of the Columbia accident.

A few weeks after the accident, it became obvious that a year or more might elapse before another Space Shuttle could be launched. A principal investigator for the project felt that the best way to process and distribute video on the ISS was as internet protocol (IP) video instead of the payload data method selected. He wrote a short white paper recommending that the lag between flights be used to develop a more elegant system for the downlink project, one that could be a precursor for future upgrades to the permanent video processing system on the ISS, one that transformed the video streams into IP video and that had onboard recording capabilities like a digital video recorder. He pitched the change to the partners at NASA JSC, JAXA, NHK, and the Discovery Channel. Everyone agreed to the change and the project underwent a major revamp, including a new name: the Space Video Gateway (SVG).

The Space Video Gateway

To downlink HDTV as IP from the ISS meant using a HDTV camera with live HD-SDI output, an encoder, an IP packetizer, and a protocol converter (Figure 1). The interface to the downlink system on the ISS is fiber-optic, so the final output of the system would have to be converted to light. On the ground a capability was needed to reverse all of the processing and get back to HD-SDI or the DVB-ASI signal for decoding.

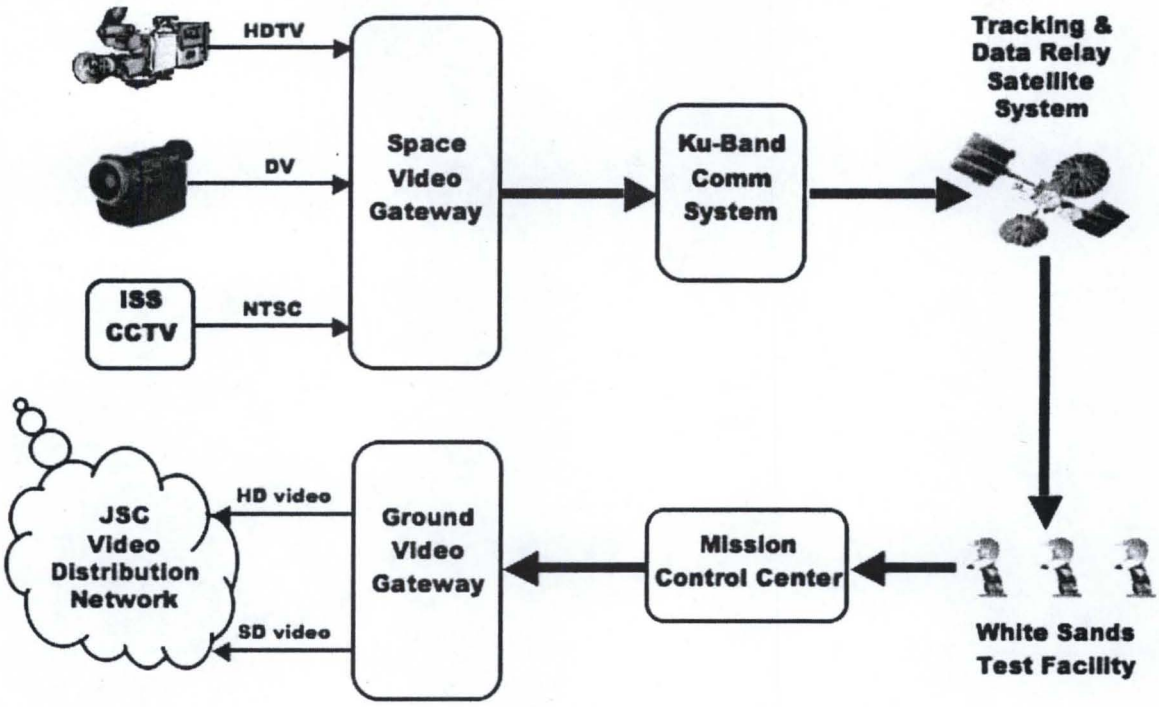


Figure 1: Basic concept for the Space Video Gateway.

The camera was a relatively easy problem to solve. One partner, JAXA, agreed to provide a Sony HDW 750 HD camera that has a built-in HD-SDI output. NASA would then certify the camera for use aboard the ISS.

Solving the encoding and data stream processing proved to be much more challenging. Ideally, all of the functions would be combined into one unit or device. Volume and stowage area on the Space Station are extremely limited. Adding multiple boxes with cables and power cords for an HDTV downlink system was not an option.

To develop, test, and fly the SVG encoding and data stream processing system, JSC engineers quickly realized that the options involved leveraging existing hardware, whether commercial off-the-shelf (COTS) items or already-developed hardware that was purpose-built for the ISS. We selected an existing IP packet-to-satcom protocol converter known as the orbiter communications adapter (OCA) to process the IP video so it could flow into the existing ISS high data rate downlink. The OCA has been used since 1994 to provide connectivity between the onboard Space Shuttle and ISS local area networks with the Mission Control Center; using it for SVG was a low-risk option. Historically, the OCA had been hosted on laptop computers running the Microsoft Windows operating system, so the SVG team was constrained to using Windows-compatible COTS hardware. This choice also allowed control of the SVG by flight controllers in the Mission Control Center, who would simply log on to the SVG via remote desktop software. Crew time is extremely constrained on the ISS: allowing ground personnel to completely control the SVG made it more operationally flexible than a standard ISS payload.

Another element of the SVG system was the HD MPEG-2 encoder: the HDTV Xpress from LSI. When the SVG concept was first developed in 2004, the HDTV Xpress was the only PCI-based encoder that was both Windows-compatible and could encode both 720p60 and 1080i30 with 4:2:2 chroma subsampling. The DVB Master from Computer Modules served as the final element of the SVG video processing capability, the ASI-to-IP converter (Figure 2). An SD capture card with an open source MPEG-2 encoder from Digital Rapids was included for processing the existing ISS NTSC video.

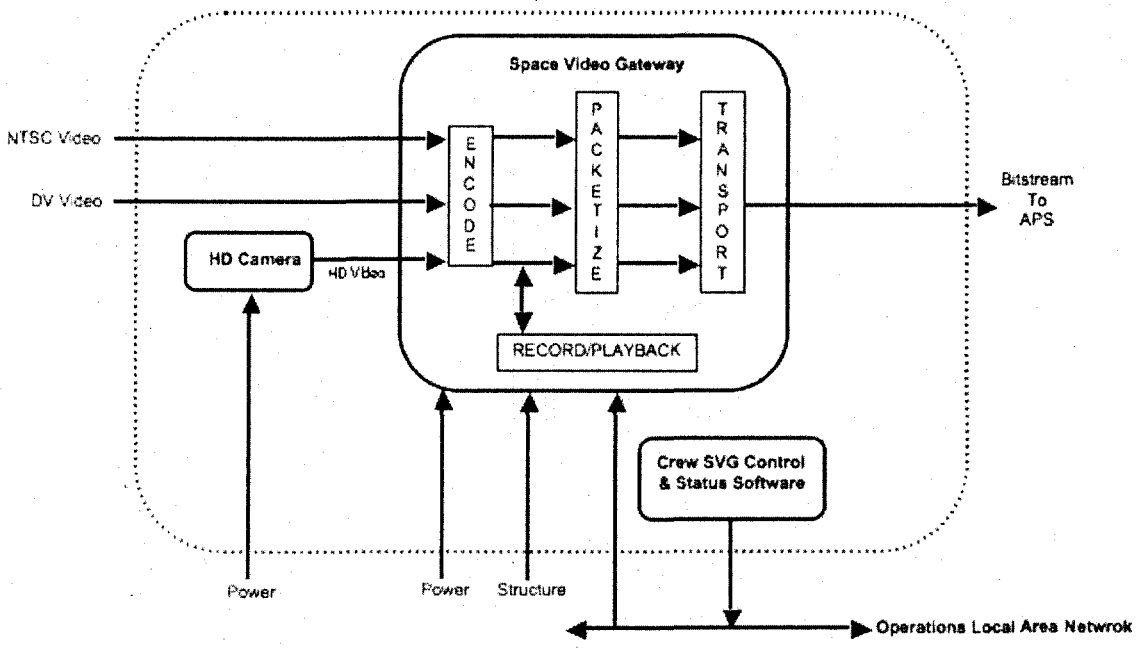


Figure 2: Configuration diagram for the in-flight video.

With the video processing and protocol converters selected, all that remained was to find a host computer that was small, had substantial processing speed, and was DC-powered. We chose a small rack mount server and so integration began in earnest. The SVG involved seven different software applications as well as a variety of hardware drivers that were integrated to provide the entire video processing and control functions. Existing ISS DC power supplies were selected to power both the SVG and the Sony HDW 750.

The Ground Video Gateway

To convert the SVG video back from OCA protocol, a Ground Video Gateway (GVG) was developed to reverse-process the flight data stream. The ISS data stream is received at Mission Control via NASA's Tracking and Data Relay Satellite System and White Sands Test Facility ground station. There it is converted back to fiber-optic and fed into another OCA. The OCA outputs the IP video to either a DVB Master for high-definition or to a Stradis decoder for standard-definition, both of which are housed in the GVG (Figure 3). The GVG used four different software applications. The output ASI, as well

as the SD-SDI from the GVG, was then picked up by JSC's video distribution system for distribution to JAXA and the Discovery Channel as well as local viewing at JSC (utilizing a JAXA-provided HD decoder).

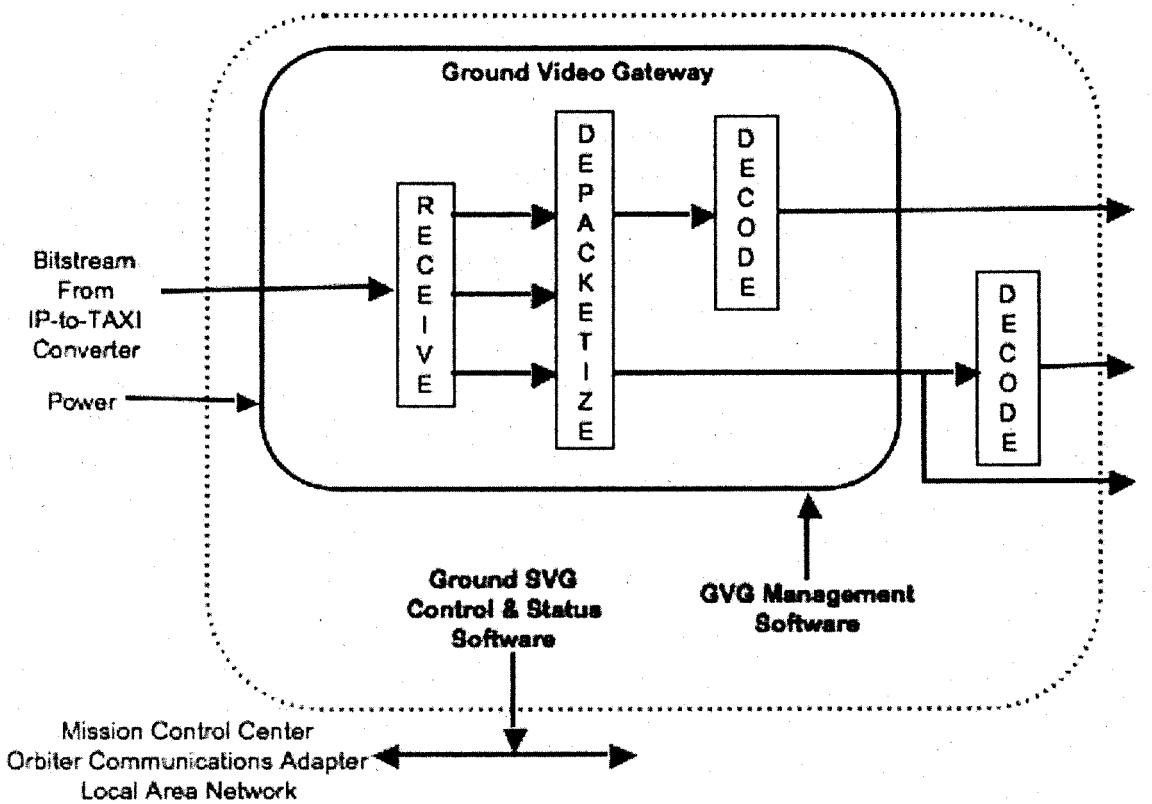


Figure 3: Basic concept for the Ground Video Gateway.

Producing the Event

In the summer of 2006, the SVG system had been through testing and flight certification by NASA. It was finally ready to be transported via the Space Shuttle to the International Space Station, where producing the momentous first HDTV downlink would occur. Identifying a Shuttle flight and establishing a realistic timeframe for production was the overall job of the NASA HDTV Mission Manager, whose responsibilities were analogous to those of an Executive Producer in the network television world.

The decision process by which any hardware is assigned to a Shuttle flight is complex and is always a matter of weighing difficult priorities. The first opportunity for the SVG system to fly was missed because other flight hardware took priority. The basic hardware, including the SVG, the Sony HDW 750 camera without lens, and the ancillary accessories weighed about 32 lbs. Flying any cargo on a Shuttle costs NASA approximately ten thousand dollars per pound. Thus, the ticket to space for the SVG system amounted to nearly $320,000.

The next available Shuttle flight (STS-115) was scheduled to launch in September 2006, but had practically no weight margin. The SVG hardware competed against 30 other items that needed to be flown to the Space Station. The HDTV Mission Manager obtained a high-priority clearance for the SVG to be flown. The ISS Program was committed to fulfill its obligations with the commercial partners and to further technology on the ISS. So the SVG at last launched from Earth onboard the Space Shuttle Atlantis on September 9, 2006.

Once the SVG was transferred to the ISS, it was temporarily stowed with other cargo in the ISS airlock waiting for the downlink to be scheduled. The ISS Increment Manager, responsible for managing all crew activities onboard the ISS, warned that the sooner the live HDTV downlinks could be accommodated by the commercial partners, the better the chances of getting the events scheduled. The increment, which began with the September 2006 launch of the crew to the ISS on a Russian *Soyuz* capsule and would conclude with the departure of the crew the following April, would only get busier. The crew onboard was getting ready to perform several complex extra-vehicular activities, or space walks. Russian visiting vehicles, such as *Soyuz* and *Progress*, would soon dock to the ISS and another Shuttle would also pay a visit, These activities meant an extremely busy crew with limited time to execute the live HDTV downlink. The availability of communication passes, because of Ku-band antenna blockage on the ISS, would also diminish as the increment progressed. So, we had to make progress—and quickly—towards this high-definition television event.

The HDTV Mission Manager, working with the mission team, identified an opportunity for the live downlinks two weeks after the SVG was transferred to the Space Station. Unfortunately neither the Discovery Channel nor NHK felt that they could develop a high-quality program that would do justice to that first historic HDTV downlink from space. They required adequate time to develop scripts, storyboards, and most importantly, to promote the programs in their respective markets. Since flying the SVG hardware had been quite a challenge and uncertain until the last minute, no advance preparations could be made for the live commercial programs. The first window of opportunity for the HDTV downlinks was declined. At this point, the SVG team was facing a delay of six months or more for the long-awaited television broadcast from the ISS.

The HDTV Mission Manager, the Discovery Channel, and NHK were unwilling to accept another delay of this magnitude. During a series of crucial planning teleconferences, the commercial partners committed to executing high-quality live programs, including scripts, storyboards, promotional campaigns, on-air talent in the US and Tokyo that had to be ready to air by the middle of November 2006. The HDTV Mission Manager pledged to make the live downlink happen and set out to convince the key decision makers on the mission team of the new timetable. Since the broadcast affected the resident cosmonauts and their activities, even the Russian flight team was involved in the discussions.

The requirements for the downlinks called for at least twenty minutes of uninterrupted Ku-band downlink from the ISS. Due to its position in orbit, and partial blockage of the onboard Ku antenna, the Space Station had few, long periods of steady communication. Very few twenty-minute time blocks were available. The schedule of the Space Station crew added further complexity. The agreement with the commercial partners stated that both of the downlinks had to occur on the same calendar day. Obviously, the crew had to be awake for the events; with a 14-hour time difference between Tokyo and the US East Coast, the only solution was to hold the NHK downlink first. NHK wanted their program to air during Japan's evening prime time, which is early morning in the United States. The Discovery Channel agreed to produce a mid-morning show.

While reviewing future crew timelines in early October, the HDTV Mission Manager identified a 30-minute Ku-band communication pass on November 15, about 30 minutes after the crew wake up call. It would accommodate the NHK request for their prime-time program. Another communication pass a few hours later would satisfy the requirements of the Discovery Channel. Having identified these time windows, we needed an additional downlink opportunity to test the onboard HDTV equipment. First, the ISS crew had to destow and unpack the SVG, the Sony HDW 750 camera, and the ancillary accessories; configure all of it to the ISS communication system; and power it up to ensure that all would work properly after the rough ride to space. This activity had to be coordinated with personnel in Mission Control, who would command the SVG from the ground once it was powered up. The downlinked signal, video, and audio would have to be tested end-to-end to make sure they were within SMPTE standards.

The HDTV Mission Manager initially met with quite a bit of resistance when requesting the identified downlink windows. Preparation activities for a critical space walk would have to be re-planned to accommodate the HDTV downlinks. Also, preparing for the downlinks involved more than the equipment test and three downlinks. The time-consuming activities that lead up to a production, including tidying up the Station area that would serve as the on-orbit TV studio, reading the scripts, rehearsing the program, and blocking the scenes per the storyboards. A perturbation of a few minutes to the crew schedule can mean hours of re-planning, so this request for the HDTV downlinks was substantial. In the course of the discussions, the HDTV Mission Manger stressed the importance of this event from a public relations perspective, the spirit of the partnership, and the historic significance to the television and broadcast industry. With such convincing rationale, NASA's mission and increment managers decided that this first live HDTV downlink from the ISS was worth rescheduling crew activities and the additional work to the flight team. And so the "go" for live HDTV from the ISS was in place.

Producers, directors, script writers, talent and technicians at NHK, the Discovery Channel and the Johnson Space Center had their work cut out for them. NASA offered both commercial partners high definition B-roll footage that had been recorded onboard the ISS and during Space Shuttle flights over the last eight years. This footage was used to build intros and background material for the high-definition programs. Initially, production concepts involved moving from module to module within the Space Station and showing command posts, window views, toilets and other areas of the orbiting

outpost. However, trying to do too much was risky and not worth the potential production difficulties. Eventually, the partners agreed to keep the broadcasts simple and to the point.

Both live events would be anchored from television studios. NHK approached the program from a scientific point of view. In Tokyo, several hosts in a virtual studio set discussed microgravity, science, and physics and showed every day life on the ISS to a live studio audience (Figure 4). Aboard the ISS, the Commander demonstrated experiments during the live HDTV downlink and proved the science concepts being discussed. The downlink portion from the ISS conducted in English was translated simultaneously for the Japanese audience.

Photo courtesy of NHK

Figure 4: The set, complete with a computer graphic of the ISS, for NHK's live high-definition broadcast from the ISS.

The Discovery Channel built their show around the historic event that would mark the first live HDTV downlink from space (Figure 5). This approach safeguarded against unexpected delays in the downlink. The host opened the program by discussing the advantages of deploying high-definition television in space operations and pointing out how far the television industry had advanced since the early days of space exploration when only fuzzy black and white television images were available. The transmission of that day's high-definition television signals would mark a new era in digital television from space. Some 10 minutes into the live program, the ISS transmitted a high-definition television image. Behind the Discovery Channel host, the audience saw a sharp ISS in-cabin view. With the American public as a witness, the ISS Commander Michael Lopez-Alegría was ready to start the first live high-definition interview from space. Not only

did the broadcast air live on Discovery HD Theater, but it was also displayed live on the huge Times Square JumboTron in downtown Manhattan.

Photo courtesy of the Discovery Channel

Figure 5: Live broadcast of the Discovery HD Theater program in New York's Time Square.

But how was the actual production handled onboard the ISS and at the Johnson Space Center? At JSC, the Mission Operations Directorate Photo/TV group trains the crew to use hardware and writes procedures for crews to follow when setting up camera and recording equipment aboard the ISS. The Photo/TV staff trained European Space Agency astronaut Thomas Reiter to set up and operate the Sony HDW 750 camera and to configure the SVG. The procedures for the initial test of the system called for the step-by-step power up, set up, and test procedures, which included white and black balancing of the camera. The program audio to be transmitted was set up via a hand-held microphone plugged into the camera. Approximately six months before the actual event, Thomas Reiter received his training. Once the real downlinks were scheduled, the Photo/TV group sent Thomas the specific technical and production procedures for review. A space-to-ground audio conference was held ahead of time to answer questions, discuss the production for the event, and go over the storyboards. Thomas Reiter's outstanding camera work during the events was recognized with a NASA-wide "Videographer of the Year" award.

The actual event producer was provided by NASA's Public Affairs Office or PAO. This organization has produced hundreds of live interviews onboard the ISS and the Space Shuttle for news organizations, educational organizations, politicians and VIPs world-wide. Just as live remote or field TV interviews are anchored from a news studio, PAO handled these HDTV events with the ISS. The Discovery Channel and NHK established phone links to send their program audio from their studios to the PAO Audio Control Room, which in turn patched the audio to the ISS ground-to-space audio link used by the Mission Control to talk to the crew. During the actual events, Mission Control handed over communications to the studio hosts in Tokyo and on the US East Coast.

The audio signal from the ISS was embedded in the HDTV downlink. Due to the MPEG-2 video compression, and several satellite and fiber network relay links, a delay of about four seconds occurred between the audio uplink from Earth and the audio downlink from the Space Station. This delay was well-known in advance by both commercial partners, NHK and the Discovery Channel, and they were prepared to handle this nuisance—something that would be essentially invisible to television viewers.

The downlink signal from the ISS was routed to the Video Control Center at JSC, where downlinked signals from spacecraft and institutional video can be processed, recorded, duplicated, archived and distributed. Both commercial partners (NHK and the Discovery Channel) agreed to receive the live DVB-ASI signal at an established demarcation point.

NKH contracted with a commercial fiber carrier to transmit the signal from JSC to their New York studios and from there to Tokyo. The interface between NASA and the fiber company was established at the Video Control Center.

The Discovery Channel opted for a different path. Two HDTV uplink trucks were moved to the JSC satellite uplink area, where newscasters and production companies establish uplink facilities during missions or other important events. The DVB-ASI signal was routed from the Video Control Center to the demarcation point in the satellite uplink area. The uplink trucks picked up the signal and beamed it in parallel over two transponders to the Discovery studio for the live program.

Summary

As of the writing of this paper, the Space Video Gateway remains onboard the ISS. Much has been learned that will be useful for designing future upgrades to the US segment of the ISS video system as well as plans for the next generation of crew spacecraft, the vehicle known as Orion.

Prior to this project, the largest synchronous IP stream ever downlinked from the ISS was only 6 megabits per second (Mbps). The HDTV IP stream was over 30 Mbps, with no glitches. This demonstrated a capability for downlinking large data streams via IP that payloads on the ISS could use also.

Tests of the SVG's standard-definition MPEG-2 encoder were mixed. Live video streams had macroblock problems and sync audio was never decoded successfully. Since the SDTV portion of the SVG's capability was considered a less critical function of the project, no further tests are scheduled to allow troubleshooting. It is assumed that a dedicated hardware encoder like the HD MPEG-2 encoder used in the SVG would not have had any problem functioning properly.

During the next two years plans are to replace the HD MPEG-2 encoder card in the SVG with a HD MPEG-4 encoder card. MPEG-4 Part 10 is one of two codecs chosen for video on NASA's Orion spacecraft. NASA would like to accumulate more spaceflight experience and thus compare quality and bitrate performance with what MPEG-2 produced.

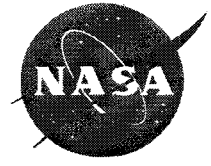
Radiation damage to CCD sensors continues to be a significant issue. In the short time between the launch and the use of the Sony HDW 750 camera, the CCDs suffered significant damage resulting in hundreds of colored dots in the picture. By January 2007, the camera was so damaged no further HD downlinks have been attempted. Upcoming flights may have new HDTV cameras onboard and will offer further opportunities for live downlinks.

The biggest hurdle to permanent use of HDTV on spacecraft is this issue of radiation damage to image sensors. CMOS sensors should be significantly less susceptible to radiation damage than CCDs. Samples of different commercial sensors, both CCD and CMOS, are planned for stowage on an upcoming flight to the ISS. The sensors would be left on board for at least three months and then returned. Once returned they would be tested by their manufacturers for pixel damage. Once that data is available, actual cameras would be flown to confirm results. Since space is limited and the cost to fly hardware is so high, HDTV will continue to be a rare capability on human-rated spacecraft until the cameras are proven to last several years without requiring replacement. The ISS has at least one external analog NTSC camera that has been operating in space six years.

The goal is to have the next human steps on the moon, currently planned for late next decade, to be watched live in HDTV back here on Earth. Much has to be accomplished between now and then. The SVG project was NASA's first major step towards this reality of live HDTV for the next steps in exploration.

MSFC-521-PRESENTATION

National Aeronautics and Space Administration



Producing a Live HDTV Program from Space

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SMPTE 2007 Technical Conference

Background and History

- Original system stowed on Shuttle poised for flight when Columbia Accident occurred
- Delay in Shuttle flights provided opportunity for new IP based system that would look more like what was planned for future spacecraft or upgrades to the ISS video system
- JAXA (Japanese Space Agency), NHK, and Discovery Communications Inc. all agree to partner with NASA for upgrade to the project

The Space Video Gateway

- New system requirements

  HD MPEG-2 encoder capable of 4:2:2 and 4:2:0, 720P and 1080i encoding

  SD MPEG-2 codec

  IP packetizer

  Fiber Optic output compatible with ISS communications system

  On-board tapeless recording with streaming playback or file based output

  HD SDI, SDI, and composite NTSC input

  Camera with HD SDI output

  Embedded audio

Space Video Gateway Implementation

- Crystal computer chassis chosen as platform for system

  LSI HDTV Xpress HD MPEG-2 encoder

  Digital Rapids Hardware/Software SD encoder

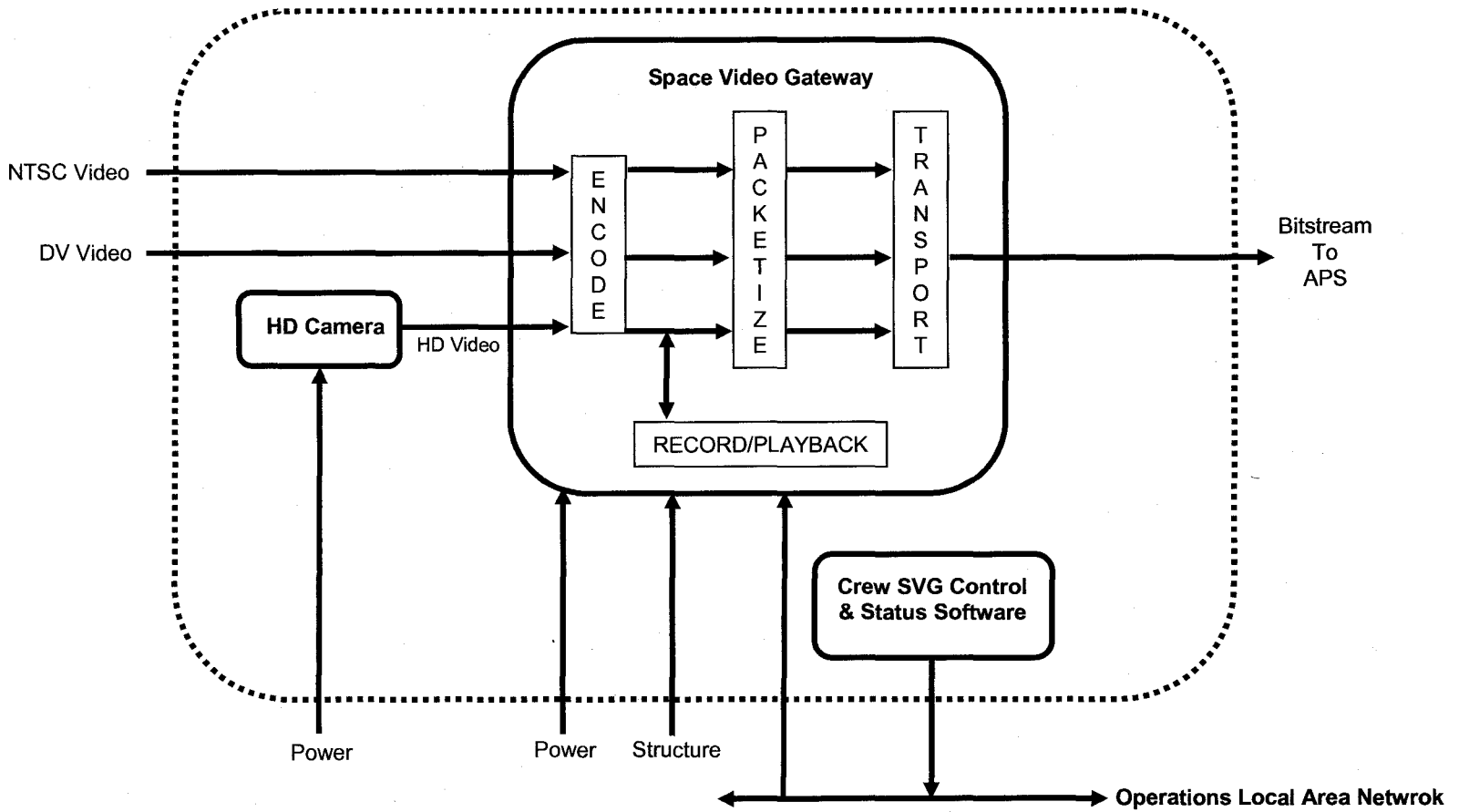
  NASA/JSC built Orbital Communications Adapter for IP packetization and format conversion to fiber optic output

  Windows Operating System

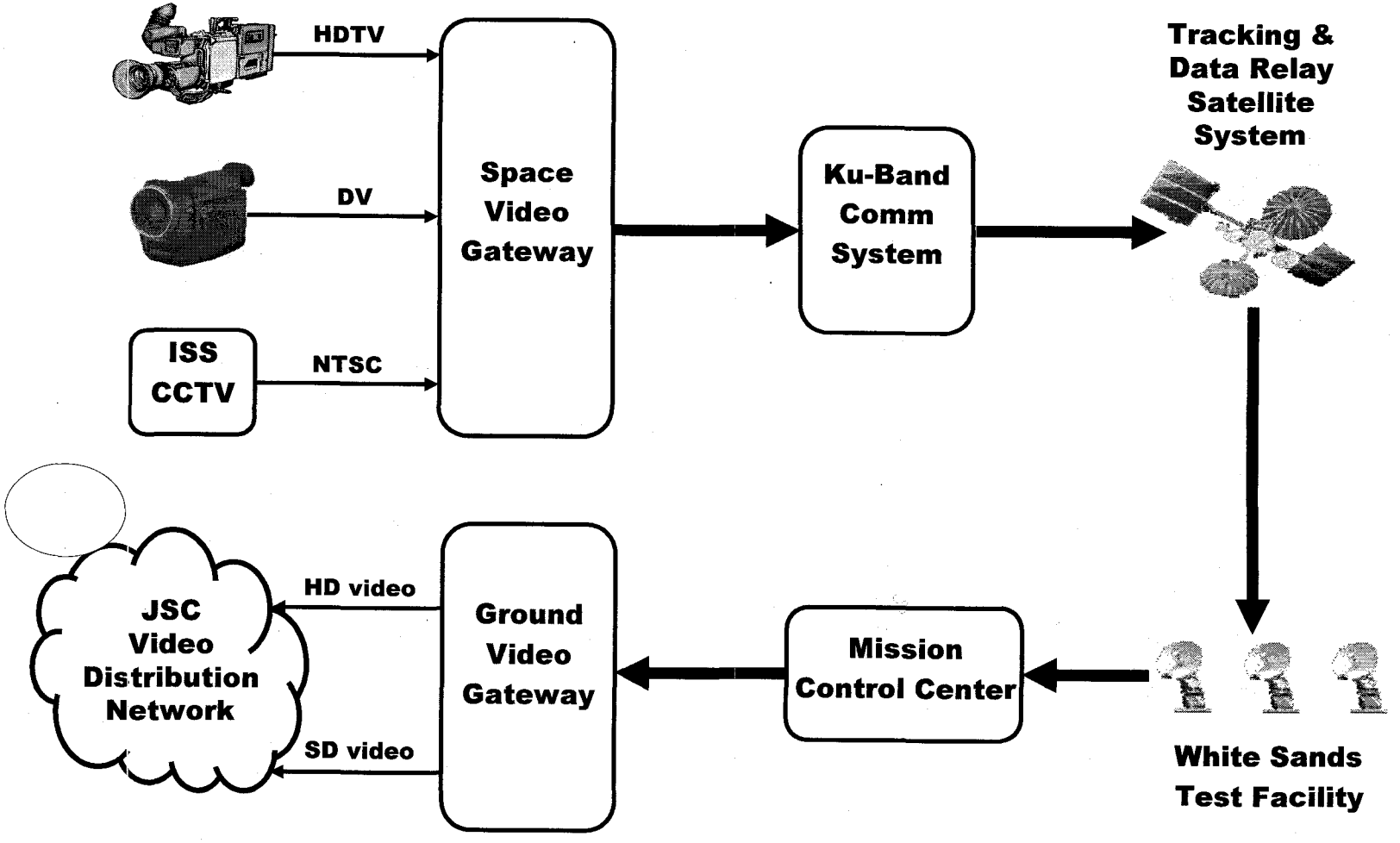
    » JSC software implementation for ground command and control

- JAXA/NHK provided Sony 750 HDCAM camera system

Flight System Data Flow



Overall System Data Flow



The Ground Video Gateway

- ISS downlink includes telemetry, voice and other data…
- Ground Video Gateway identifies video signal from other data and reverses data processing

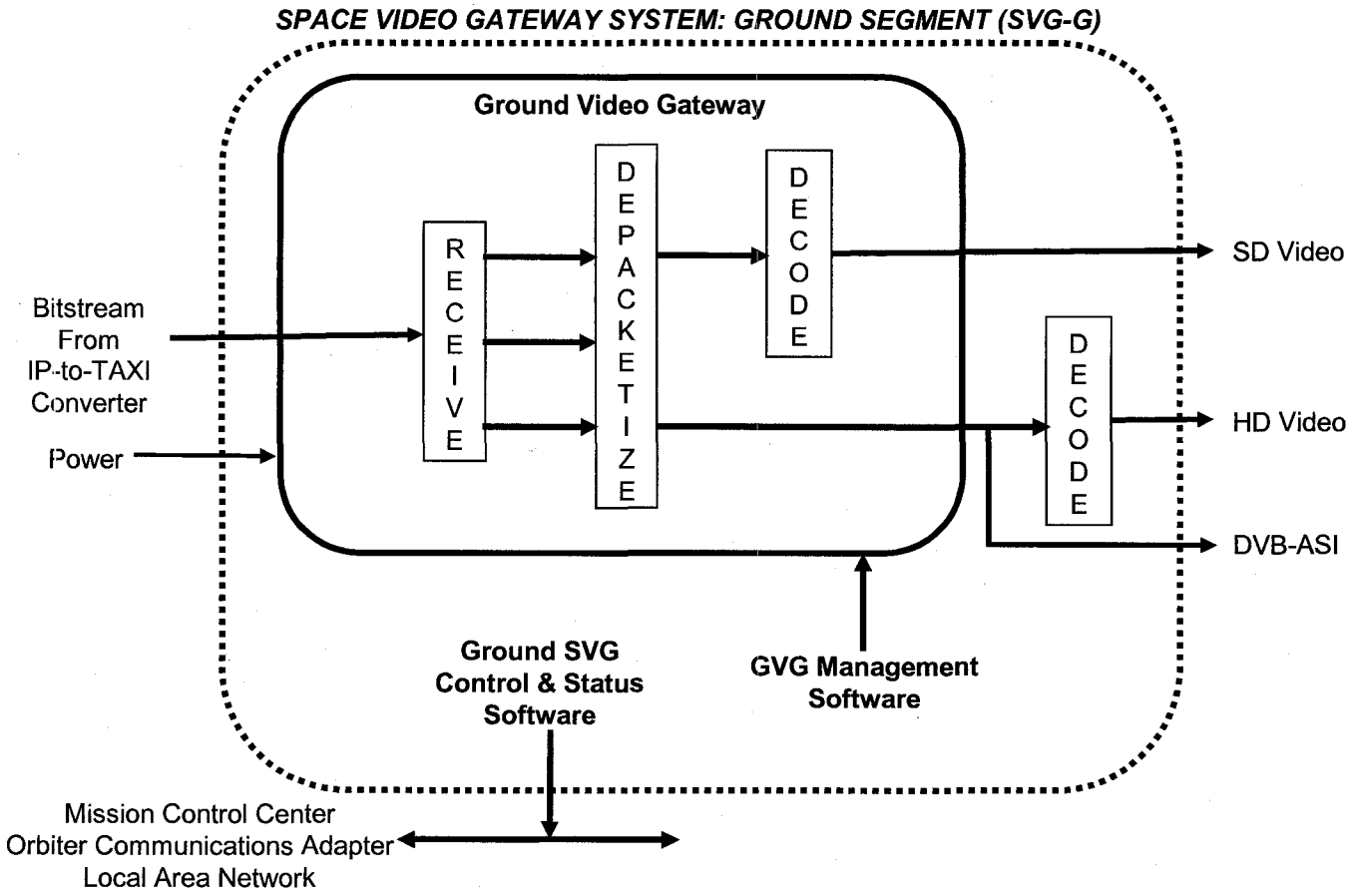
  Depacketize IP stream

  DVBASI with embedded audio
- DVBASI stream routed to distribution amplifier

  Decoder to provide HD SDI

  Also able to provide DVBASI to partners for routing

Ground Video Gateway Signal Flow



Producing a Live HD event on the ISS

- First challenge… Get the hardware flown!

  Finally able to get storage space for ride to ISS on board Space Shuttle Atlantis, September 9, 2006

- Next challenge… Timeline for downlinks

  Astronaut time

  Downlink opportunities

  - » Orientation of ISS for Ku downlink
  - » Limited to 20 minute blocks of time

  Coincident with broadcast times in Japan and US

  Finally able to schedule test downlink and production downlinks

  - » Production downlinks scheduled for November 15, 2006
  - » NHK downlink first, DCI second

Producing the Show

- Live TV with the ISS astronauts

  Keep the scripts simple

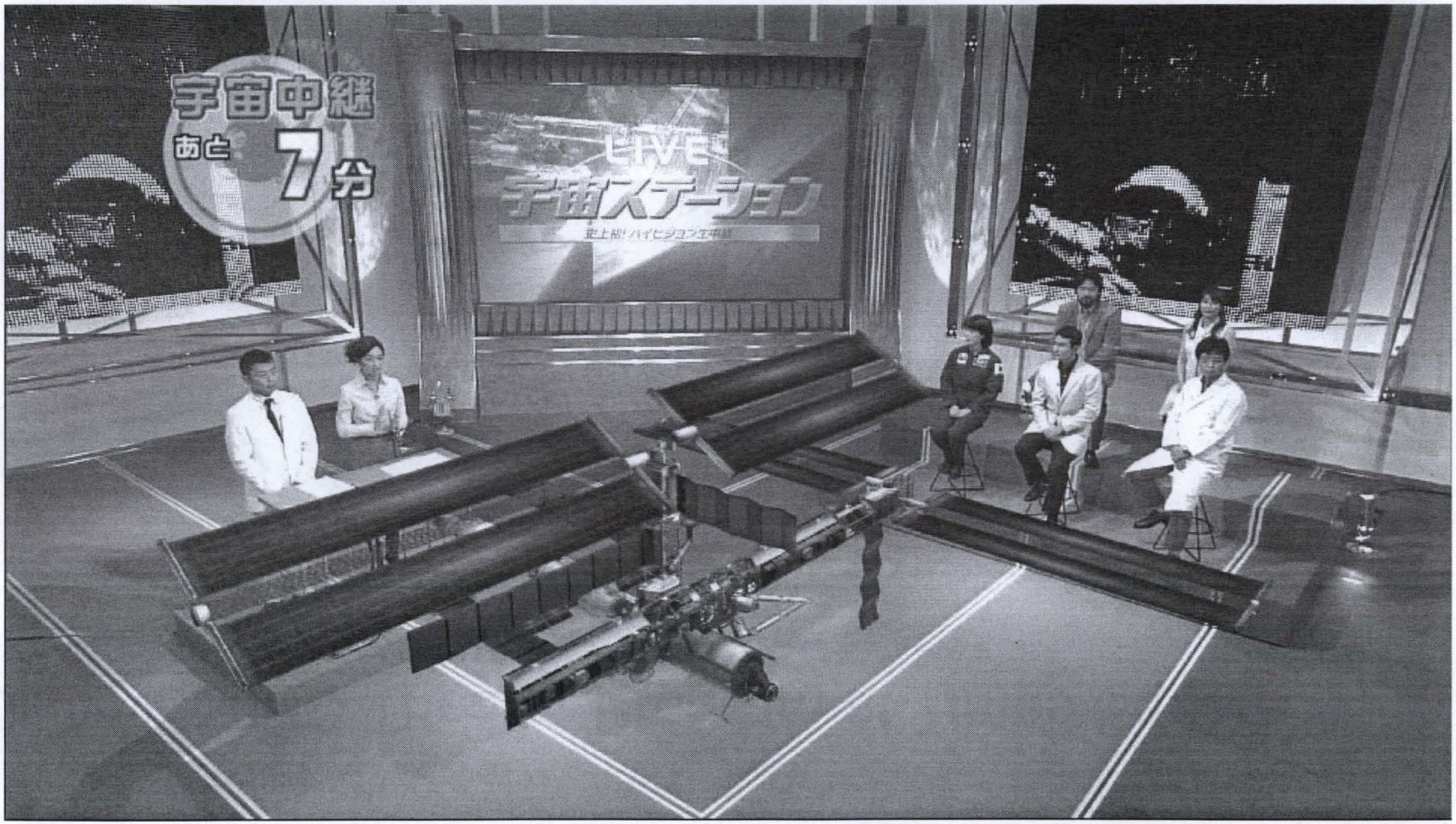
  Camera views limited to US Lab and view out Lab window

- HD encoded @ 30 Mbps 4:2:2 long GOP MPEG-2 with embedded audio
- NHK and DCI provided with DVBASI and HD SDI at JSC for distribution

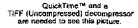
  Both broadcasters relied on HD SDI fiber optic links to their production facilities

- NHK's program centered around what it was like to live on the ISS
- DCI's program was about the historic live HD video itself

NHK Program Set with CG ISS



Discovery HD Theater Program at Times Square



Lessons Learned and Next Steps

- Radiation damage to imaging sensors remains biggest hurdle to permanent HD system on orbit
- Proved concept of large synchronous IP streams from ISS communications system
- Proved concept of recording on hard drives for streaming downlink later
- Proved capability of using remote desktop to control a flight PC from the ground
- Next steps

  Fly additional HD cameras with HD SDI output

  Test CMOS and other CCD sensors

  Change out MPEG-2 card for MPEG-4 Part 10

  Test packetization protocols for next spacecraft (Orion)