SMPTE Meeting Presentation

Engineering a live UHD program from the International Space Station

Rodney Grubbs

NASA

Sandy George

SAIC

Written for presentation at the

SMPTE 2017 Annual Technical Conference & Exhibition

Abstract. *The first-ever live downlink of Ultra-High Definition (UHD) video from the International Space Station (ISS) was the highlight of a "Super Session" at the National Association of Broadcasters (NAB) Show in April 2017. Ultra-High Definition is four times the resolution of "full HD" or "1080P" video. Also referred to as "4K", the Ultra-High Definition video downlink from the ISS all the way to the Las Vegas Convention Center required considerable planning, pushed the limits of conventional video distribution from a space-craft, and was the first use of High Efficiency Video Coding (HEVC) from a space-craft.*

The live event at NAB will serve as a pathfinder for more routine downlinks of UHD as well as use of HEVC for conventional HD downlinks to save bandwidth. A similar demonstration was conducted in 2006 with the Discovery Channel to demonstrate the ability to stream HDTV from the ISS.

This paper will describe the overall work flow and routing of the UHD video, how audio was synchronized even though the video and audio were received many seconds apart from each other, and how the demonstration paves the way for not only more efficient video distribution from the ISS, but also serves as a pathfinder for more complex video distribution from deep space.

The paper will also describe how a "live" event was staged when the UHD video coming from the ISS had a latency of 10+ seconds. In addition, the paper will touch on the unique collaboration between the inherently governmental aspects of the ISS, commercial partners Amazon and Elemental, and the National Association of Broadcasters.

Keywords. *NASA, live UHD video, ISS, International Space Station, HEVC, High Efficiency Video Coding*

Introduction

In 2015, NASA launched the first Red Dragon digital cinema camera to the International Space Station (ISS), ironically, aboard a SpaceX cargo vehicle called Dragon. Red Digital Cinema had responded to a NASA Research Announcement and signed an agreement to provide cameras for the US National Lab. The National Lab is part of the U.S.-operated portion of the International Space Station. The Red cameras are now considered "core" cameras for users of the National Lab for science and research, and crew members can also use the camera to capture life on board the ISS as well as views of the Earth and the exterior of the ISS.

During the 2016 National Association of Broadcasters (NAB) Expo in Las Vegas, NASA imagery specialists met with Red officials, including CEO Jarred Land, to discuss future cameras and capabilities. The question was posed, "Wouldn't it be cool if we used the Red camera as an Ultra-High Definition (UHD) camera for a live feed from the ISS? Maybe we could do that as a demonstration at the next NAB." Jarred answered with an enthusiastic "yes", and thus began the planning that led to the first-ever live UHD downlink from a spacecraft, which was featured during a Super Session at the 2017 NAB called "Reaching for the Stars: Connecting to the Future with NASA and Hollywood."

Numerous steps were required to make this live UHD demonstration happen: Identifying the hardware that would be needed onboard the ISS; certifying the hardware for space flight; testing the flight hardware with ground systems; launching the hardware to the ISS; testing the system to confirm ISS to ground capability; determining the architecture to distribute live UHD from NASA's ground reception site to the Las Vegas Convention Center; building and testing the end-to-end distribution; and finally, executing the live program.

The Hardware for Flight

After the NAB meeting with Jarred and the Red team, Red's engineers set about providing NASA with a camera configuration that would enable live UHD output. The primary component to enable this capability was their REDCAST module. That module would provide four live 3G-SDI 1080P @ 29.97fps outputs. Next, an encoder was needed. Red already had a relationship with Elemental, so NASA began working with Elemental's Senior Director of Field Operations-Federal, Barry Lauer. Elemental was in the early stages of developing a software-based H.264 UHD encoder, but NASA needed a hardware solution because there were no computers on-board the ISS that could handle the processing power needed for software encoding of UHD video. With expanded downlink capacity from the ISS, 30 - 40 Mbps streams were now possible. Eventually, Elemental came up with a combined hardware/software solution that uses H.265 encoding. Subsequently, Red provided NASA with a camera system in September 2016 for testing and certification; one that included both a REDCAST module and a computer outfitted with Elemental's encoding software.

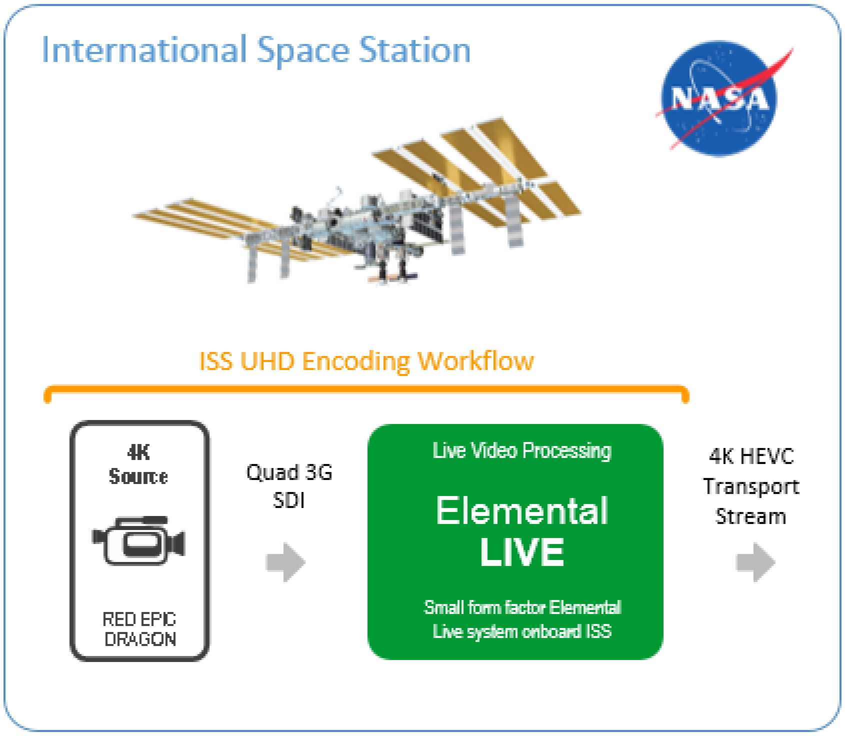

Figure 1. Live UHD workflow on the International Space Station.

Flight Certification of the Hardware

Everything flown in space has to be certified for use in that environment. In this case, the hardware would be used inside the cabin of the ISS and operated by the astronauts, so we conducted a verification program that essentially proves the hardware will cause no harm to the crew or the vehicle. Electronic equipment is certified not to create issues such as electromagnetic interference and off-gassing with critical vehicle communications and electronics. Batteries and chargers are verified to be safe during operation, are protected against over-charging, and verified not to overheat during operations and charging. All certification was performed by NanoRacks, a company that provides commercial services for payloads on the ISS. It may sound counter-intuitive, but this flight certification process doesn't verify whether the system works properly. That requires an additional step - system testing.

System Testing

Before launching the system to the ISS and developing procedures for the astronauts to follow, an end-to-end system test was conducted to make sure we could create Ultra-High Definition Video that would stream successfully through the ISS avionics and communications system. The ISS is equipped with a communications system that provides for live downlink of IP data streams. High definition video streams from H.264 encoders are routinely transported as UDP MPEG2 Transport Streams through the system to a multiplexer that combines them with all the other data and communications traffic streaming from the ISS. From the ISS, this data is transmitted via a Ku-band transmitter across a fleet of geo-synchronous Tracking Data and Relay Satellites to a ground station at White Sands, New Mexico. From White Sands, the data is routed to the Johnson Space Center (JSC) near Houston, Texas and the Marshall Space Flight Center in Huntsville, Alabama. JSC has a lab where the ISS and data relay system can be simulated, and that lab allowed for a full test sourcing from the Red Camera outfitted with the REDCAST module to the encoder, ISS communications system, data relay, and then decoding and monitoring. A BrightSign 4K1142 Media Player decoded the H.265 compressed video. With just a bit of tweaking, the system worked well and provided us confidence that a live transmission for NAB could be accomplished.

Figure 2. Testing the Red Epic Dragon with REDCAST module and Elemental Flight Encoder at Johnson Space Center's Sonny Carter Test Facility.

A few challenges were revealed from testing. Latency for the decoded UHD signals was measured using an LED timer in the camera's field-of-view and was found to be about 5 seconds. In addition, the Red camera with RECAST module could not embed audio, so it would have to be provided from a conventional HDTV camera feed. However, HD video with embedded audio from the ISS has a latency of roughly 1 second. As a result, it was decided that for a live transmission, the ISS HD video (decoded to HD-SDI with embedded audio) would be routed to JSC's Audio Control Room. There the audio would be extracted, processed through delay units, and routed back to be embedded with the decoded UHD video.

Launch and Space-to-Ground System Testing

Getting the new Red camera, REDCAST, and encoder flown to the ISS in time for testing and utilization for NAB meant launching everything on the next available ride to the ISS. That happened to be a Japanese Cargo Vehicle dubbed Kounotori-6, scheduled for launch on December 9, 2016. To meet that schedule, everything was hand-carried on a flight to Japan and stowed on the launch vehicle shortly before liftoff.

Once on-board, JSC's Dylan Mathis (co-Principal Investigator for the Red Camera) arranged for an end-to-end test of the flight and ground system. There had been some discussion of doing a demonstration in conjunction with the Super Bowl that was held in Houston in February 2017. While it was decided not to pursue a UHD downlink at that time, the test on January 17, 2017 was successful. AWS/Elemental loaned NASA a BlackMagic Teranex AV embedder to marry the uncompressed UHD video with the delayed audio. The quality was spectacular and gave AWS/Elemental confidence to pursue a live demonstration during the 2017 NAB Show, so planning began in earnest.

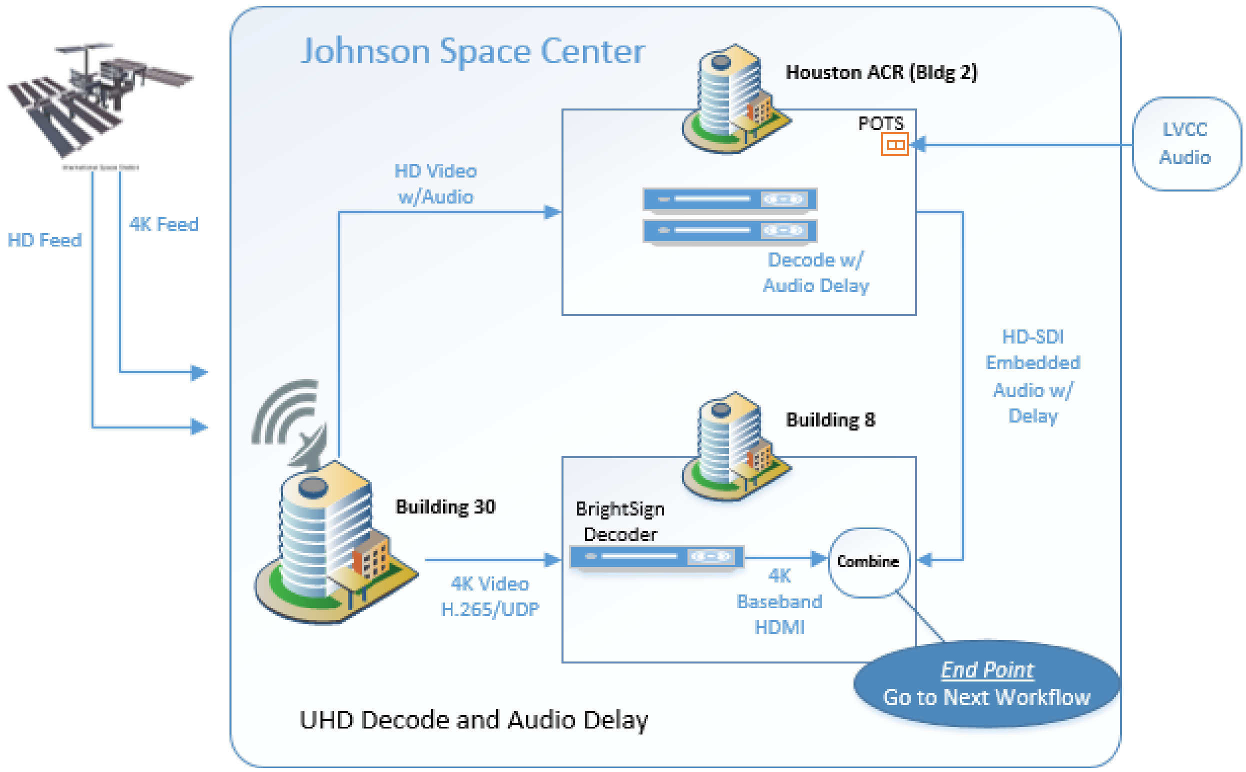

Figure 3. ISS to JSC Work Flow.

Architecture for the Live Show

Now that the ISS-to-ground live UHD link was proven, the challenge was how to route the UHD video with synchronized audio from JSC to the Las Vegas Convention Center. NASA's television infrastructure for live HD transmissions utilizes the Agency's wide-area-network to link compressed HD video from NASA centers to Encompass' satellite teleport in Atlanta, Georgia. Encompass provides the live uplink to NASA's leased C-band transponder for full-time NASA TV distribution as well as housing the playout server for recorded content and live streaming distribution for web feeds. Ideally, NASA wanted to use that same architecture to distribute the live UHD from the ISS to the Las Vegas Convention Center. A recording was made of the live UHD downlink test and that recording was used to test distribution to Encompass across the NASA TV architecture.

Initially, not all of the required equipment was readily available to test the transmission chain, so NASA and AWS/Elemental conducted tests on each individual segment. The first step was to play the ISS pre-recorded video with an added audio test tone into the Elemental Live encoder at JSC that was connected to a NASA TV Cisco switch. The signal was successfully received at NASA's Marshall Space Flight Center (MSFC) and Goddard Space Flight Center (GSFC). The next step was to receive the signal at Encompass in Atlanta from NASA's Atlanta-based network gateway, routing the signal via IP to an encapsulator and modulator which prepared it for satellite uplink. NASA conducted the first uplink test of this signal on the Galaxy 17 KU-band satellite and was able to receive it at MSFC and GSFC to prove the viability of the system design. At MSFC, the received test signal was added to the local cable distribution system and viewed on a 4K display monitor with extracted audio in the test lab. After this successful test step, the test was repeated with a downlink satellite truck provided by Roberts Communications from their facility in Las Vegas.

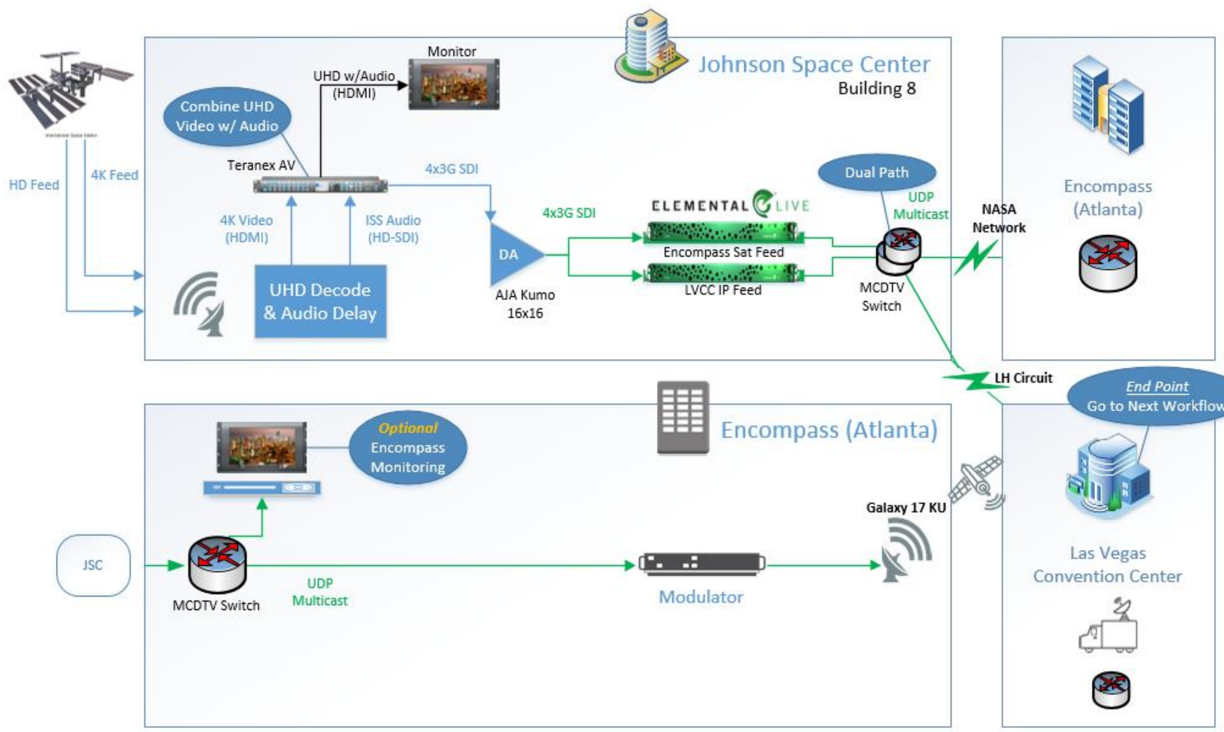

Figure 4. Work Flow from ISS to the Las Vegas Convention Center.

On March 24th, a simulated end-to-end test was conducted using the ISS pre-recorded video with the newly-installed audio embedder at JSC. The downlink truck was parked at an assigned location for the upcoming event and arrangements were made for direct fiber to be installed from the truck location into the LVCC communications center that provided the connection into the actual LVCC event room. LVCC staff installed a media converter to change the optical fiber signal to the required copper media format for the interface equipment located in the event room. The signal was then distributed via decoders for dissemination to Elemental's IP Streaming infrastructure and to a local projector. Live streaming out of the Elemental LIVE encoder, utilizing an internet connection provided by the LVCC, was not achieved during this testing phase due to some required software updates and limited satellite time availability. It was a serious challenge to temporarily install all the required equipment at the LVCC and be ready to test in less than two hours.

Another test was scheduled the next day and was successful with the simulated configuration. An additional test was conducted using NASA's Houston Audio Control Room (ACR) for the audio configuration, which successfully simulated the audio delay that would be present in the actual UHD stream from the ISS. The long audio delay (10 seconds) was challenging in that most audio delay processors are not designed to process such a large delay interval.

The last test was an actual live feed from the ISS, conducted on April 17th to configure and verify all systems before conducting a lip-sync test with an ISS astronaut. The ISS astronaut team set up the encoding configuration onboard and verified the system configuration. This test was successful all the way from the ISS through NASA's network to Encompass for uplink and downlinking from the satellite truck at LVCC. A fiber connection was made into the LVCC network to the event room's decoding equipment and the signal was distributed to large-screen projectors, with audio routed through an audio board and video routed through a Blackmagic UHD live switcher. The program was also fed to the Elemental LIVE encoder, which streamed the 4K signal to the internet. The Blackmagic UHD live switcher could also switch to on-site LVCC cameras so the team could view the temporary configuration in the LVCC room. Audio was also tested and lip-sync was verified from the ISS to the Houston ACR and onto the LVCC. This test was successful and proved direct live interaction with the astronauts was possible, even with a round-trip latency of ten seconds.

Redundancy was very important to the NASA and Elemental team, especially for such an exclusive special event. Back-up encoders, Cisco switches, and other necessary equipment were installed or were already implemented in the NASA TV system. However, redundancy for the transmission segment between the ISS and JSC was not practical. While conducting all these tests, the NASA & AWS/Elemental teams created a secondary circuit between JSC and the LVCC. This allowed the LVCC to fully function as a NASA point-of-presence site within the NASA TV system. Each Cisco switch at JSC had an encoder connected and used a multicast address which allowed Encompass, NASA centers, and the LVCC to each receive the signal and decode it. This design also made troubleshooting and verification of the signal at each segment possible. The circuit was promptly established via Metro E and by using Cox Communications in Vegas for the last mile connection.

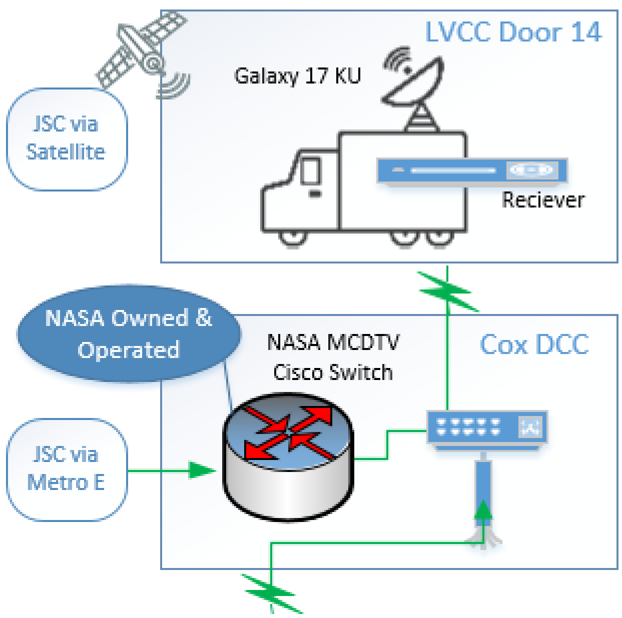

Figure 5. Redundant signal reception at the Las Vegas Convention Center.

The Program

AWS/Elemental facilitated the production of the fully-switched live UHD program at the LVCC. Together with NAB, they provided the projectors and switching capability to present the live

UHD downlink from the ISS on large screens, using Boxer 4K30 projectors from Christie Digital to display the state-of-the-art video content.

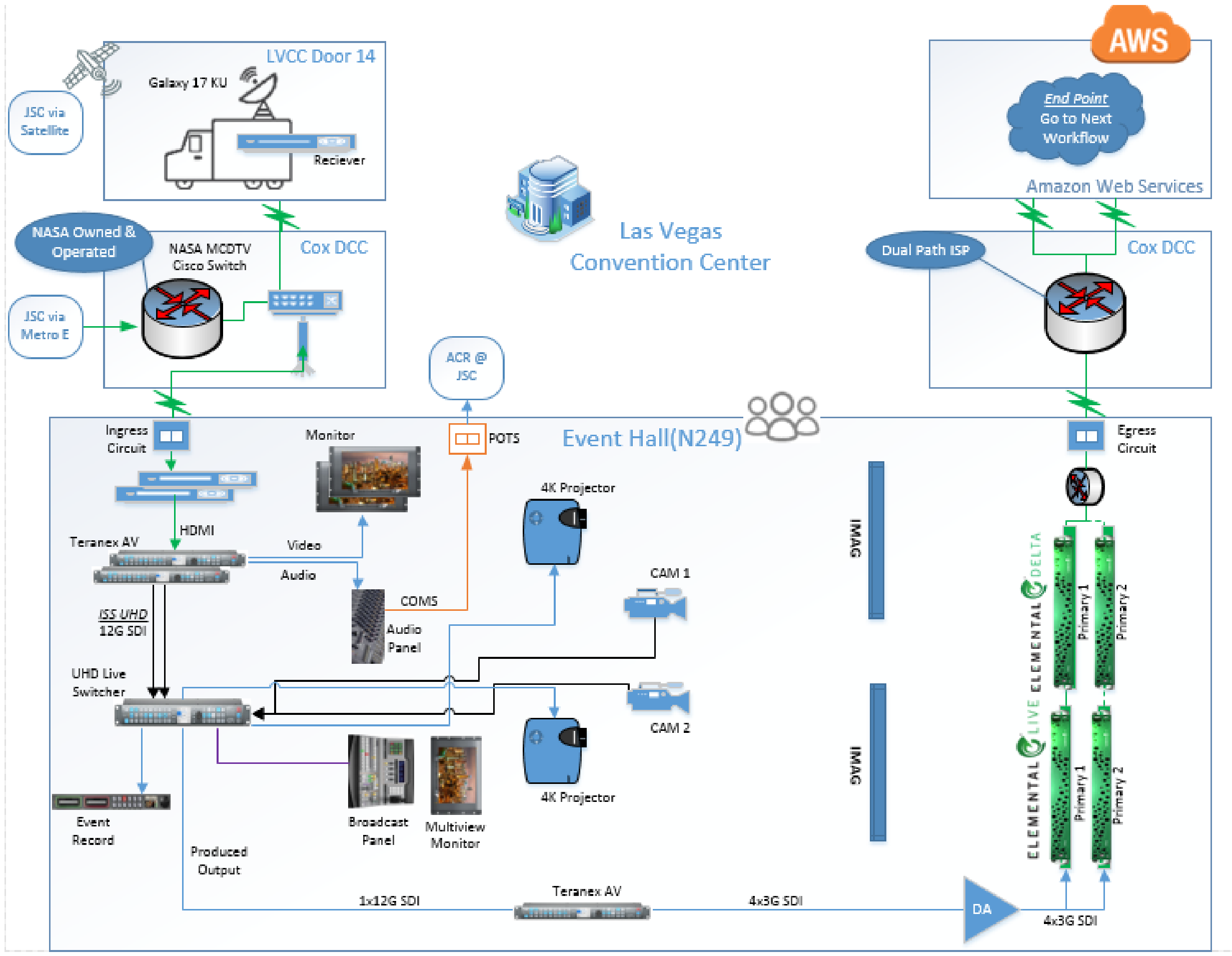

Figure 6. Las Vegas Convention Center Live Program Configuration.

Choreographing the program for the live audience at the LVCC was challenging. As described earlier, there was a ten-second round-trip delay between audio communications to the ISS crew onboard the ISS and their responses using UHD video with embedded audio. AWS/Elemental's Sam Blackman hosted the show and was already used to the delay from testing the week before. NASA provided a communication link from the LVCC to JSC audio control that included the host audio as well as queue audio.

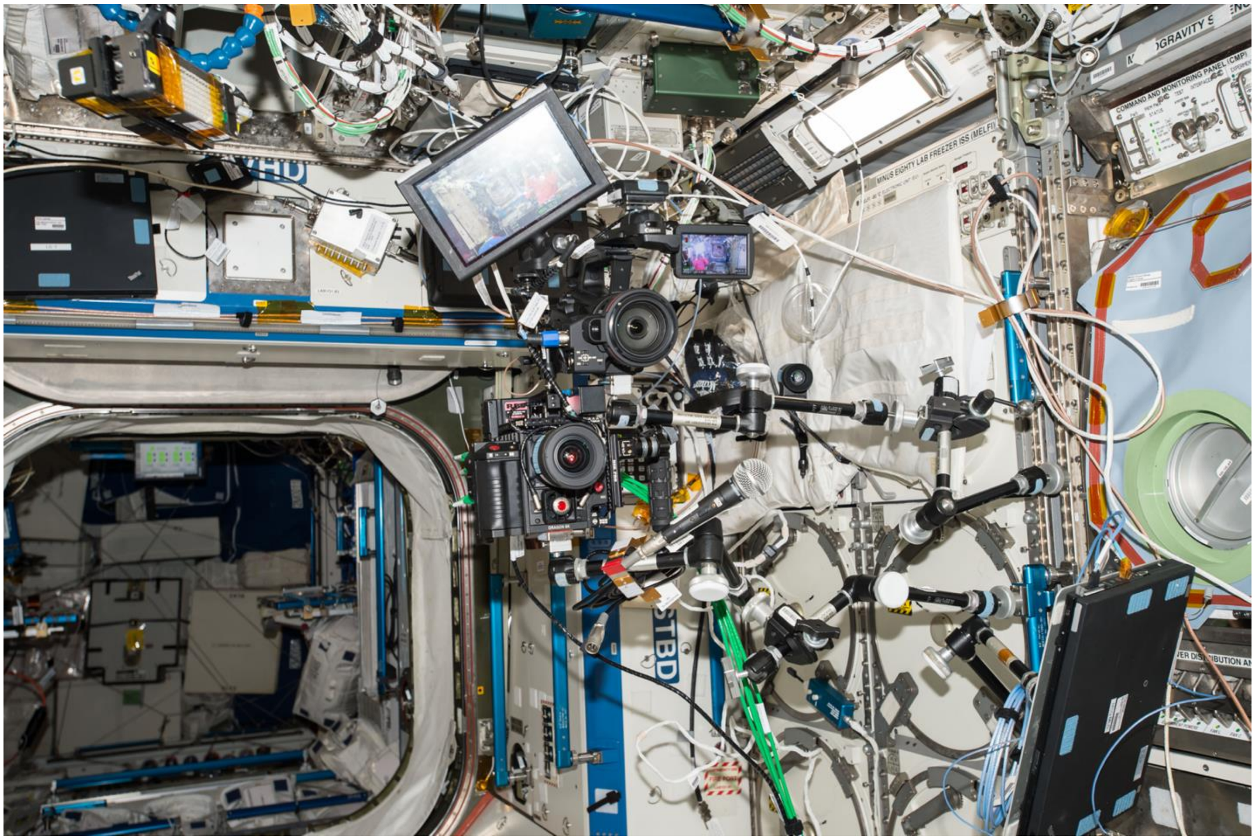

Figure 7. Camera configuration on-board the ISS. The Red Dragon camera with REDCAST module sits below a Canon 305 HD camera that was used for audio.

The final circuit configuration for the live event (with redundant features) was identical to the last tested circuit configuration. As part of the live event, a Houston ACR specialist joined the audio team in Las Vegas to coordinate between the LVCC, Houston ACR, and the ISS. During the event, the entire team of talented engineers and producers monitored all circuit locations to ensure optimal performance and quality assurance for the first live UHD transmissions from space.

What's Next

In 2006, NASA demonstrated live HDTV from the ISS in joint project with the Japanese Space Agency and the Discovery Channel. Within just three years, live HDTV downlinks from the ISS became routine. Time will tell whether UHD downlinks become routine or are reserved for special presentations. Higher spatial resolution, high dynamic range, and more efficient encoding such as the H.265 format all provide much better imagery to document science experiments and to fire the imaginations of the public.

Looking forward; as NASA plans to extend a human presence beyond low Earth orbit - perhaps to the Moon and Mars – available bandwidth for video transmissions from spacecraft will become limited and more efficient video encoding will become crucially important. Cameras with 360 ° field-of-view, like many commercial virtual reality cameras available today, could provide the functionality of a pan-tilt camera system with reduced mass and no moving parts. It’s likely that these cameras would have sensors with at least 4096x2160 pixels to provide higher-resolution detail and better stitching of multiple camera feeds. Development of these future technologies for use in space has already begun with the demonstration of live UHD transmissions at NAB 2017.

Acknowledgements

System drawings courtesy AWS/Elemental, Barry Lauer. JSC testing image courtesy Brian Kelly, JSC Test Engineer.

Thanks to Dylan Mathis, JSC, for editing and verification of content.

Standards

SMPTE, ST 292, Bit-Serial Digital Interface for High Definition Televsion

H.265/MPEG-H, High Efficency Video Coding.

H.264/MPEG-4 Part 10, Advanced Video Coding

UDP, User Datagram Protocol, RFC 768

MPEG-2 Transport Stream, MPEG-2 Part 1, Systems ITU-T Rec. H.222.0