

Establishing a Real-Time Video Link to Antarctica

On November 24, 1992, NASA engineers implemented a real-time video link between McMurdo Station in the Antarctic and the continental United States. The problems encountered and the solutions developed in establishing a network in a harsh and isolated environment provide valuable insights into the conditions space explorers will encounter in planetary exploration. These efforts have enabled subsequent breakthroughs in technology applications, education, and telepresence.

Mark León

On November 24, 1992, NASA Science Internet (NSI) engineers implemented the world's first real-time video link between McMurdo Station in the Antarctic and the Continental United States; this link was also the first real-time video transmission accomplished from such a low latitude. The effort, which built upon NSI's existing Antarctic high-speed data communications infrastructure, was a response to last-minute requests from major television networks for live coverage of the National Aeronautics and Space Administration's (NASA) Mars analog experiments in Antarctica. To meet broadcast requirements for bi-directional video, NSI employed laser, microwave, and satellite communication links, as well as a variety of video codecs and multiplexers. NSI implemented several different network configurations within a short period of time to accommodate requirements for both live broadcasts and scientific experimentation with a remotely operated vehicle. The problems encountered and the solutions developed in establishing a communications network, in a harsh and isolated environment equipped with World War II vintage equipment, provide valuable insights into the conditions space explorers will encounter in planetary exploration. These ground-breaking efforts have enabled subsequent breakthroughs in technology applications, education, and telepresence.

NASA Science Internet engineers at NASA Ames Research Center (ARC) in California have implemented four different communication configurations in the Antarctic to date: one was part of NSI's original Three-Year Plan; one was the result of an urgent request by the ABC network, NASA, and the National Science Foundation (NSF); and two arose as a result of accomplishing the second requirement.

NSI's Three-Year Plan included initiation of a 56-Kb/s data link for Internet service in the first year, 1991, with an increase to 128 Kb/s in the second year. When the repositioning of a satellite from inclined to geosynchronous orbit achieved bit error rates of 10^{-8} at 768 Kb/s, plans to increase bandwidth for telepresence applications and compressed video were accelerated. The increased bandwidth performance indicated that proof-of-concept testing at McMurdo Station could be accomplished in 1992 instead of 1993.

An experiment simulating operation of a Remotely Operated Vehicle (ROV) was therefore conducted in July 1992, and in November, ABC presented an urgent request to use the video circuit for a live broadcast for "Night Line" and "Good Morning America" 15 days hence. Because of the short deadline, NSI engineers worked around the clock to implement the requirement. The effort to establish the bi-directional real-time video link is described herein.

Background

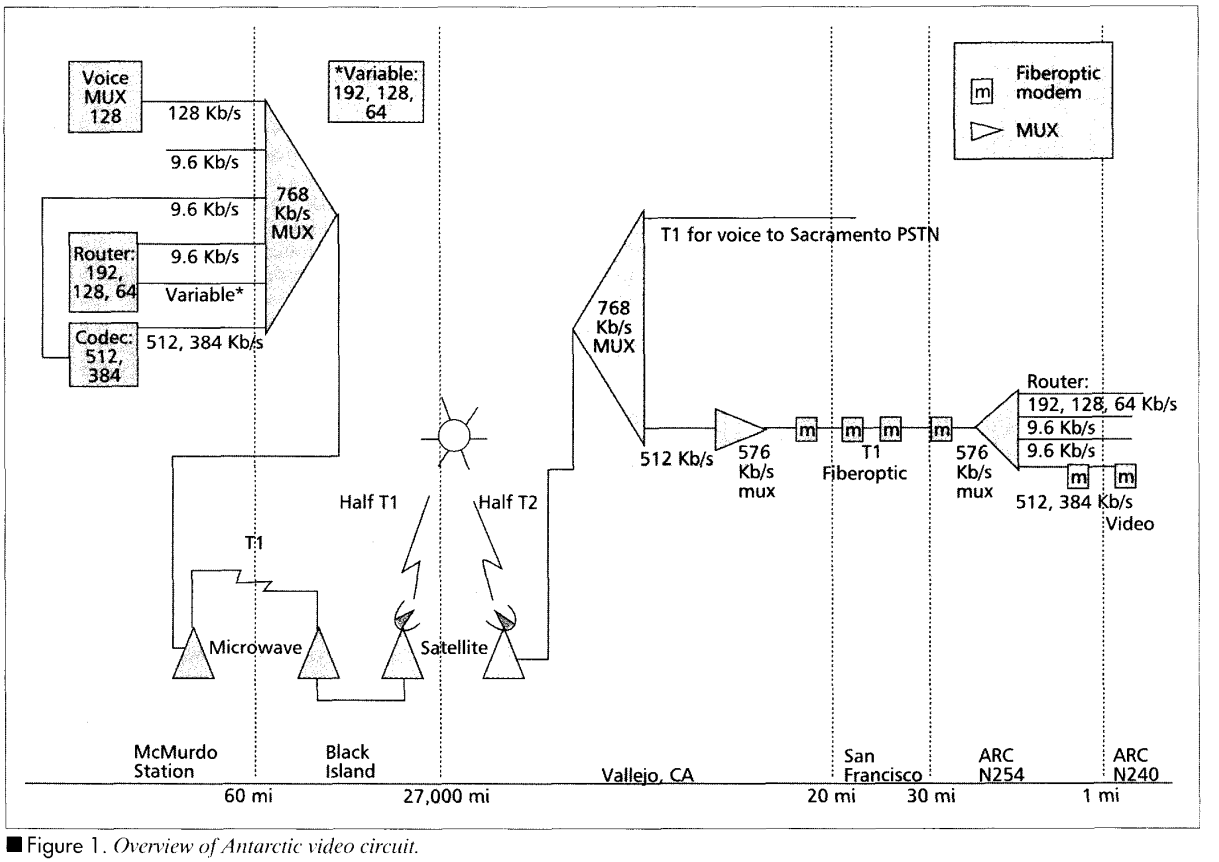
In 1990, NSI engineers met with the National Science Foundation (NSF) to pose NASA's Antarctic communication requirements for '91, '92, and '93. At that time, NSI envisioned high bandwidth requirements to support compressed video for the purpose of returning vision from a robot exploring beneath the Ross Sea Ice Shelf. NSF did not, however, include NSI's requirements in its bid for a communications implementation due five years later, in 1995.

As a result, NASA developed its own Three-Year Plan. The first year of the plan, 1991, included requirements for 56 Kb/s of data for Internet service; the second year involved higher bandwidth, also to support data; and the third year was to involve yet higher bandwidth for telepresence applications and compressed video.

In 1991, NSI had a link to IntelSat 177 East, which had an inclined orbit of 3°. This link pro-

MARK LÉON is deputy project manager for the NASA Information Infrastructure Technology and Applications Project at Ames Research Center and deputy program manager for the NASA IITA K-12 Program.

0890-8044/95/$04.00 1995 © IEEE

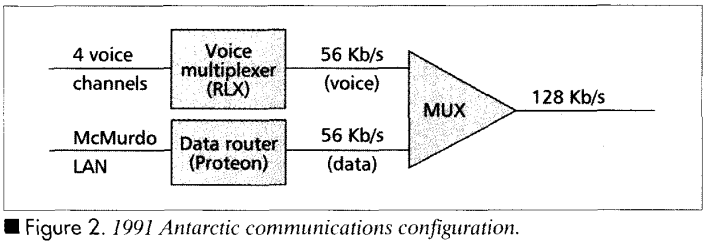


■ Figure 1. *Overview of Antarctic video circuit.*

vided approximately six hours of dedicated real-time connectivity between McMurdo Station and the Sylmar Tracking Station in California. However, because the satellite was in an inclined orbit, it was difficult to keep a lock on. Its average bit error rate of 10^{-7} dropped sharply to 10^{-4} as it entered the horizon prior to setting. Many problems were experienced with this particular implementation, including outages of several hours at a time without good explanation. The service was run in its entirety for only about two-and-a-half weeks of the originally planned two months. The difficulties NSI experienced in establishing the satellite link were exacerbated by the conditions in Antarctica, and in Black Island and McMurdo Station, specifically. This link, however, provided the infrastructure which would be used in 1992.

In the 1991 configuration, the entire 128-Kb/s circuit was channeled through the multiplexer (MUX) into a voice multiplexer (RLX) for four voice channels, and into the data router (Proteon) for 56 Kb/s of data (Fig. 2). This particular implementation was jointly funded by NASA and NSF.

The 1992 configuration was originally planned to be much like that for 1991, and in 1993, NSI planned to upgrade to higher bandwidths to provide compressed video. The compressed video would be used to return video from the ROV underneath the frozen lakes in the Taylor Valley and to allow operation of the ROV remotely from ARC. What actually occurred differs considerably from the original plan.



■ Figure 2. *1991 Antarctic communications configuration.*

Satellite Move

After the experiences in 1991 with the inclined satellite, it became evident to NSI engineers that a geosynchronous satellite would be required. By organizing a contract with ComSat through IDB/STARS, an inclined satellite was moved from 177° East to 180° East, and a geosynchronous satellite was moved from 180° East to 177° East. By switching the two, NSI gained access to a satellite with much greater capability. NSI used an LNB with an ultra-high gain step on the antenna assembly to communicate with this satellite, a configuration which is much more powerful than what is normally used. On the down-link we received a 42.5 db signal-to-noise (S/N) ratio.

After moving the satellites and establishing the link to the receiving stations at Vallejo, California and Black Island, Antarctica, NSI was able to get bit error rates of 10^{-8} operating at a total bandwidth speed of 768 Kb/s. From Black Island

to McMurdo Station, NSF employed a T1 microwave link operating with a bit error rate of 10^{-10}.

This preparation established the infrastructure for subsequent communications at McMurdo Station. As a result of having additional bandwidth available, NSI decided to advance the testing of a full-motion video link, originally scheduled for 1993, to 1992 in preparation for the telepresence objective. NASA performed a swift procurement of video codec/s, infrared lasers, and other communications equipment required to perform the basic test at McMurdo Station.

ROV Simulation

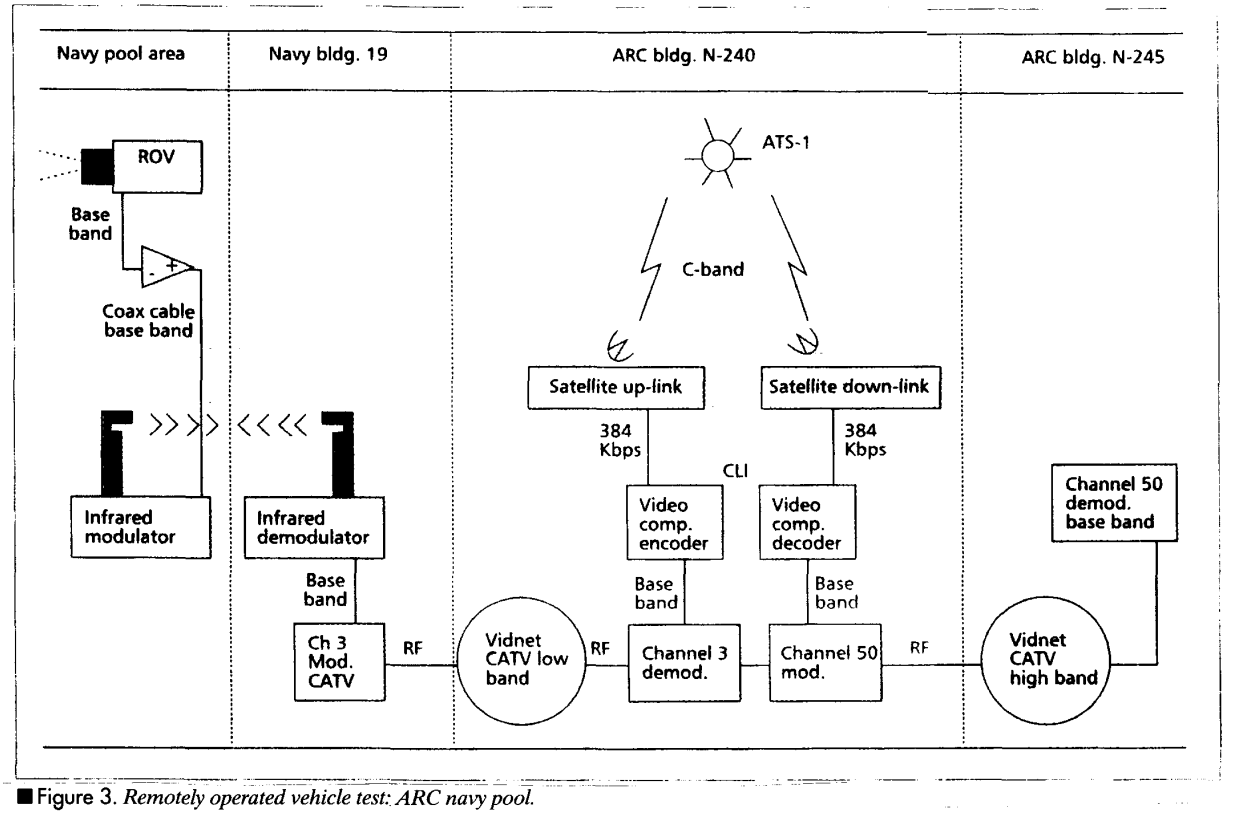
In July 1992, NSI simulated video transmission from the ocean under the frozen Ross Sea Ice Shelf by placing the ROV in the Navy pool at ARC (Fig. 3). Base-band amplifiers were used to send a signal to the roof of the pool house, and IR lasers and a cable TV network then brought the video to the NASA ARC ground station. Next, SatCom F2R was used in loop-back mode to send the signal back to ARC. From there it was distributed to the researchers' location so that they could get a sense of the video quality and time delay which would be comparable to the signal coming from Antarctica. The video signal they saw was being compressed at 384 Kb/s, utilizing a Rembrandt video codec made by Compression Labs, Inc. (CLI). This video codec equipment was inferior compared to the CLI CTX plus planned for actual deployment to Antarctica.

New Urgent Requirements — November 1992

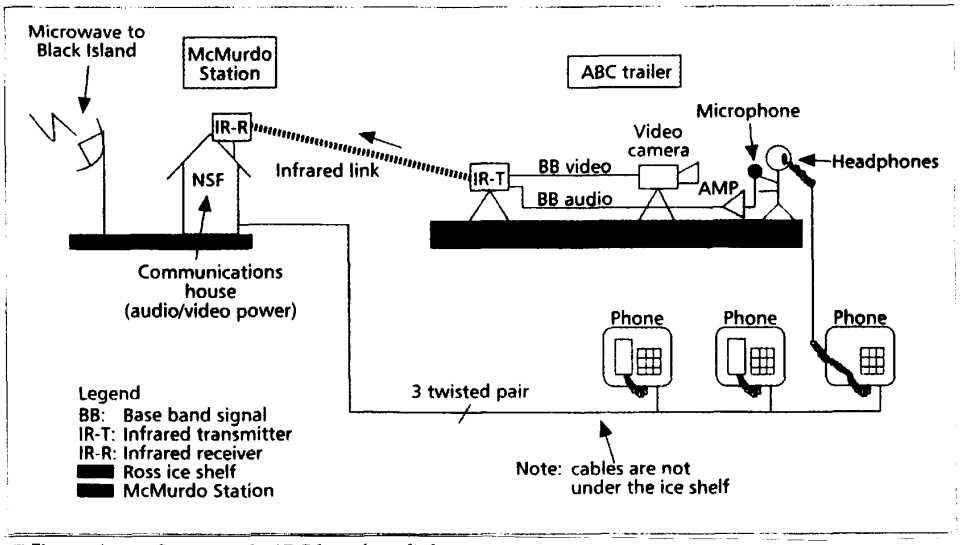
On November 9, 1992, I received a call from the ABC network requesting use of NSI's video circuit for a live broadcast from Antarctica back to the ABC national news network for their "Night Line" and "Good Morning America" programs on November 24 and 25, respectively. Our engineering team thus began working around the clock to prepare for an "all-or-nothing" mission. One of our engineers, Roxanne Streeter, had been sent earlier to Antarctica to support the ROV experiment; this new requirement, however, made it necessary for me, as a design engineer, to travel to Antarctica to modify the design so that ABC could use it for the video broadcast, and also to design audio into the original circuit.

I worked 15 hours on Veteran's Day to secure as much equipment as I could before leaving ARC. However, because of the last-minute request, we did not have enough time either to procure or to send all of the additional equipment we would need for Antarctica, nor did we have enough time to do the additional engineering designs necessary to achieve broadcast quality. Worst of all, we were going down to install high-technology equipment in vastly outmoded circumstances, with no Radio Shack for thousands of miles. We had no guarantee that the broadcast would work since this type of link had never been done before.

Last minute, inadequate planning caused other



■ Figure 3. *Remotely operated vehicle test: ARC navy pool.*



■ Figure 4. *Configuration 1: ABC broadcast link.*

unexpected problems beyond those concerning equipment. Just before I left for Hawaii, I learned that I had been given incorrect information on the customs forms needed to transport equipment through New Zealand, and that customs agents there would not let me catch my connecting flight to Christ Church, the staging base to Antarctica, until my paperwork was in order. My wife had to go to NASA in the middle of the night to get the correct forms and fax them to me in Honolulu so I could make the flight to New Zealand.

Seven days after the initial request, on November 16, I finally deployed to Antarctica. The flight seemed interminable in the spartan cargo plane, but after losing one day crossing the date line and surviving a bout with food poisoning, I arrived November 20. After only one hour's sleep, I proceeded to work around the clock to get the link up and running for the November 24th full-motion live broadcast for ABC's "Night Line." Nineteen-to-22-hour work days were normal, and though tiring, were made somewhat easier because of the 24 hours of sunlight every day during the austral summer. Since it was impossible to make scheduled mealtimes, I had to rely on coworkers to bring food out to the work site.

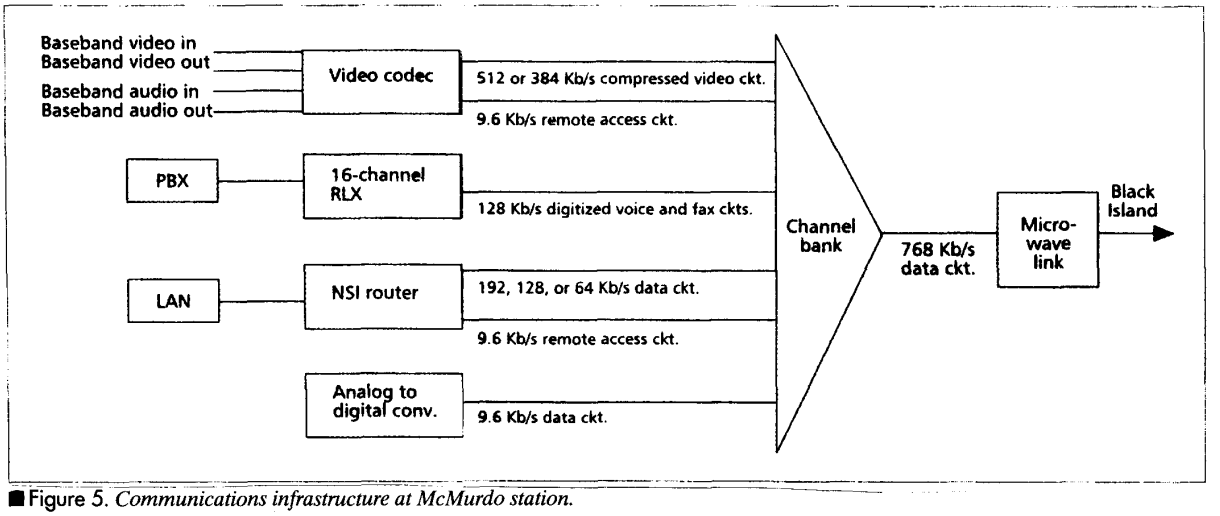
Tuning the infrared laser equipment was too awkward in my bulky gloves, so I often removed them, which caused my skin to stick to the controls and rip off in the cold.

Problems, Makeshift Implementation, and Configuration Breakthrough

The network configuration, which we engineered to accommodate ABC's request for a live broadcast, is shown in Fig. 4.

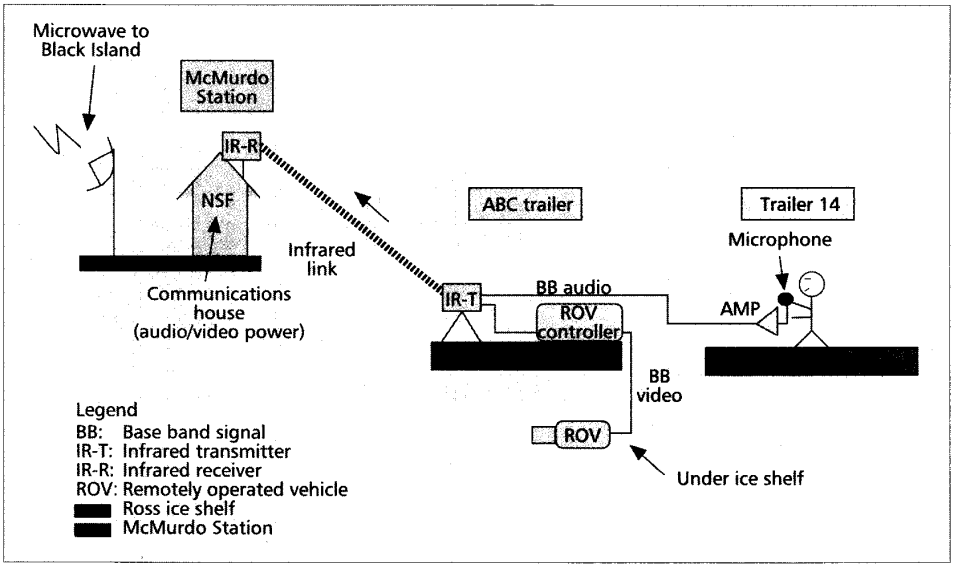
Lack of Resources

The most serious problem we faced was the lack of time to adequately plan a task of this complexity, since detailed planning is essential if parts are to be available at remote areas such as McMurdo Station. We faced a serious lack of resources to implement the task, ranging from audio connectors to interface cables, and even to wrong circuit boards.



■ Figure 5. *Communications infrastructure at McMurdo station.*

This eight-minute oculation happened seven minutes before "Good Morning America" was to go live, and although it cleared up in eight minutes, the ABC staff was somewhat frantic.



■ Figure 6. *Configuration 2: ROV link.*

The most serious problem was the lack of a 768 Kb/s interface card to connect the T1 microwave link from Black Island to the half-T1 channel bank at McMurdo Station. So I had hand-carried a 768 Kb/s card to Antarctica to replace the defective part (Fig. 5). From that point on, we began deploying IR laser, video codec, etc.

Harsh Environment

The extreme cold and wind of the Antarctic environment presented unexpected problems in achieving our mission. Black cables would melt their way into the ice, then as the temperature dropped, freeze over, making it difficult to move them. Tuning and stabilizing the delicate infrared laser equipment to transmit the signal was too awkward in my bulky gloves, so I often removed them for tuning, which caused my skin to stick to the controls and rip off in the cold.

Equipment Isolation

The power supply in Antarctica is severely limited. Because of the general lack of power, we were using two different phases of electricity in the same building. Unfortunately, it was not made clear to us that multiple phase sources were being used until it was too late. We would use all of the current on one breaker, then go to the other. However, any connection between some pieces of equipment without an isolation transformer produced a two-phase delta of 120 degrees. In the power cycle, the potential difference of about 60 V between the two points produced 60 V shocks. We had to do a lot of equipment isolation, resulting in burned out boards, physical shocks, and short tempers.

Oculation Period

The sun orbits low on the horizon, so at one point between the IR transmitter and the IR receiver it overcomes the transmission signal for about 8 minutes out of every 24 hours. This eight-minute oculation happened seven minutes before "Good Morning America" was to go live, and although it cleared up in eight minutes, the ABC staff was somewhat frantic. Even though I had tested it, I did not know how much the sun's position changes with respect to rotational aspects — which could change a few minutes a day. I could only move the equipment a certain amount in any direction because the sun had to be in the right spot for the camera. The oculation period is the only timeslot when, because of the low-look angle, no signal can be received. The set up was good for "Night Line," but for "Good Morning America" it was very close (actually a matter of luck). Later, when there was more time, I did a statistical analysis to determine the oculation period of the sun.

Unacceptable Audio Signal

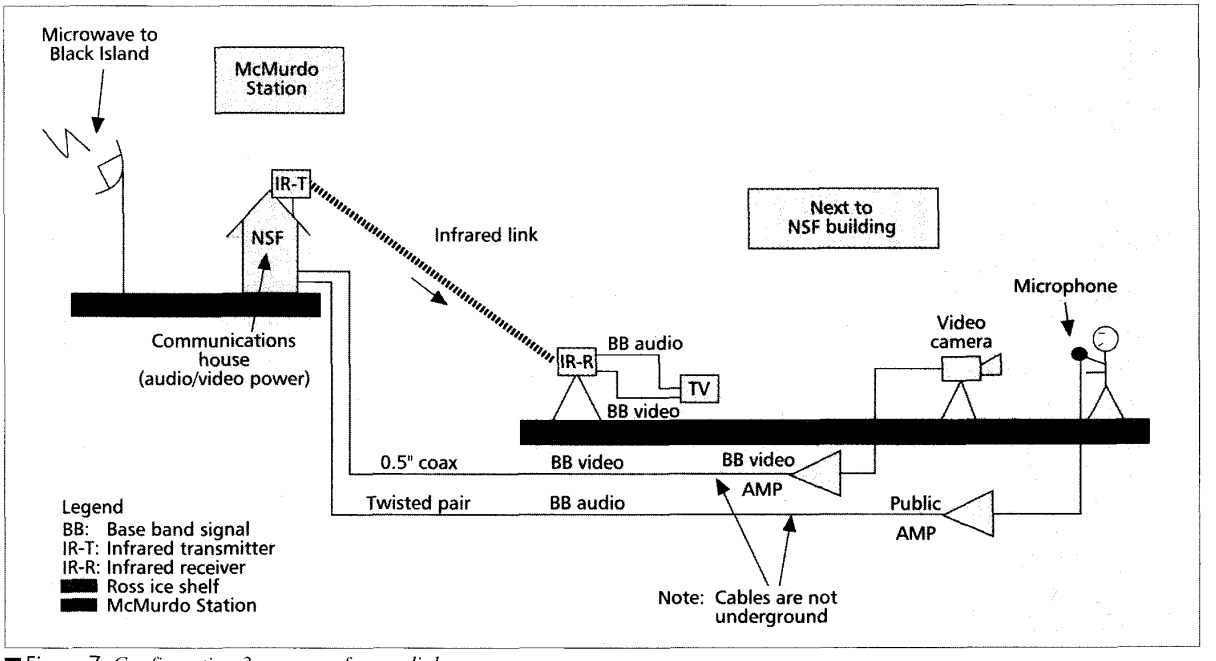
The video codec box we had at McMurdo caused an audio problem for ABC, because while other video codec boxes had been recalled because of unacceptably high audio output, the one they had at McMurdo had not been recalled. I had to attenuate the audio signal by 15 dB so that it would be within the normal acceptable audio ranges for ABC. We had no indication that its signal was too hot until the signal reached New York. I backtracked it to the output of the video codec and discovered that I had to internally insert a 15 dB pad; I found this out when there were only 14 minutes of satellite time remaining in which to solve the problem. Since there was nothing available to use there, I finally lifted something from the ABC sound man that would work.

Video Codec (CLI) Interfaces

In the process of interfacing the video codec boxes, a blocking processor on the CLI blew out. I was able to replace it only because I had taken redundant boards down.

Dealing with a Large Number of Demarcs

NSI had to interface with seven different groups to get from Antarctica to ARC, including: the communication trailer on the ice; the fire house (the location of the communication hub); Black Island



■ Figure 7. *Configuration 3: press conference link.*

personnel: Vallejo, California; San Francisco Telecom; Building 254 at ARC; and Building 240 at ARC. One demarc would put something in loop-back mode, and it was impossible to figure out where it was looping. From the McMurdo standpoint, if there was a big time delay, it was obvious that it was on the other side of the satellite; if there was not a big time delay, it had to be in Antarctica. Loop backs, which are useful for testing, cause a logistical coordination problem.

Motion Compensation

The channel bank MUX receives 768 Kb/s of data and distributes it to various channels (Fig. 5). When I learned that NSI would be required to do an ABC broadcast, I upgraded the preplanned video segment from 384 Kb/s to 512 Kb/s, because although each gives the same resolution, there is better motion compensation and therefore faster tracking at 512 Kb/s.

Nonstandard Interfaces

Another problem concerned the interfaces necessary to get the video codec to talk to the channel bank. The channel bank had a V.35 interface while the video codec had an RS 422 interface. I changed the CLI interface to a V.35. In addition, the CLI had a special V.35 design. With the help of Marshall Space Flight Center and ARC engineers, I had to physically rebuild the V.35 interface to get the devices to communicate.

The video codec was set up with the primary video of 512 Kb/s, but it also had a remote access port so that researchers at ARC could control it with a 9.6 Kb/s remote access board. During the Antarctica encounter, NSI engineers at ARC remotely controlled that 9.6 Kb/s port with a local terminal, since otherwise they would have been forced to use a difficult control interface.

A 128 Kb/s circuit also led from the channel bank to a 14-channel voice/2-channel fax multiplexer (RLX) which provided the voice and fax circuits for McMurdo Station. These 16 channels tied directly into McMurdo's PBX. Further, in the initial configuration, 64 Kb/s of data went to the NSI router, which was the data channel providing Internet connectivity to the rest of the world. The router then connected to the McMurdo local area network. The router also used an additional 9.6 Kb/s out-of-band access channel.

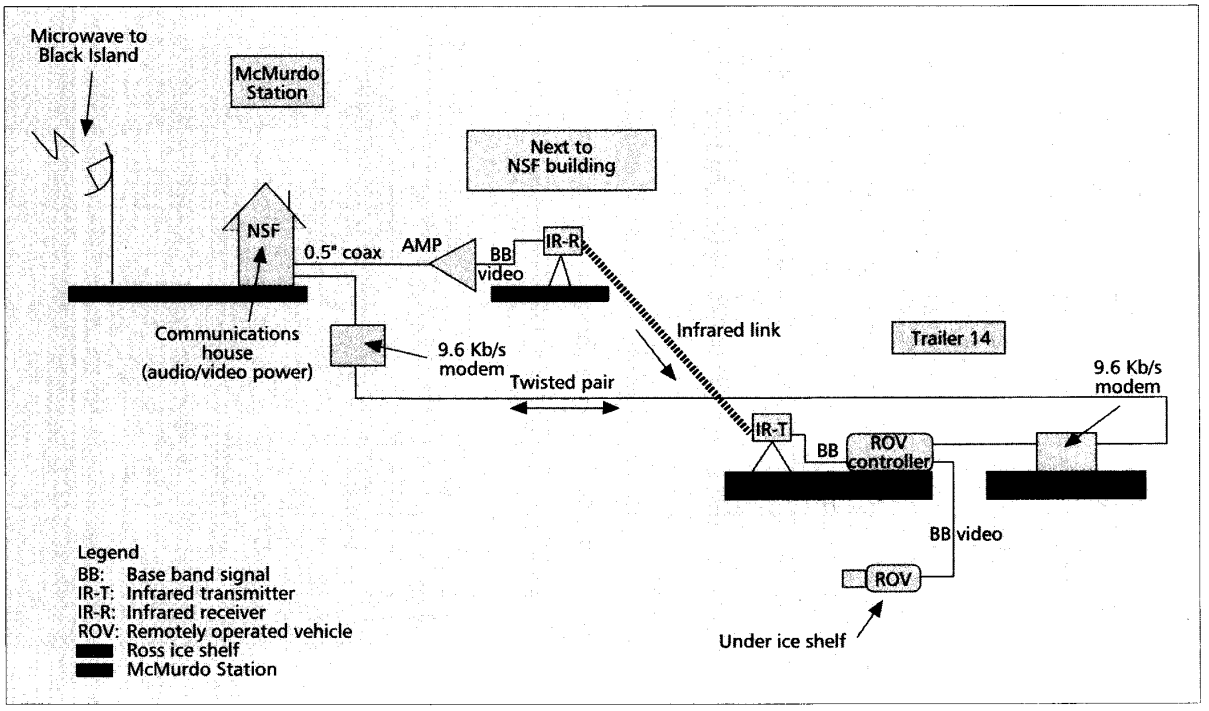
Following the ABC event, NSI proceeded to repeat its scheduled ROV test, as shown in Fig. 6.

After we were successful with the initial configuration, we were called upon to engineer a number of different configurations throughout this entire experiment (Fig 5).

Additional Breakthroughs

ARC held a bidirectional video press conference between ARC and Antarctica, which allowed the press to see and talk to reporters at McMurdo Station. Several TV stations and newspapers were involved. For the two-way press conference, nearby access was required to receive the channel coming from ARC. However, since the ABC broadcast was to be conducted out on the ice, we had to find a way to get both video and audio signals out to the broadcast site from the receiving station where the video codec (CLI) was located. Therefore, we ran a baseband video and audio signal from the NSF building to the site of the video conference using audio and video amplifiers, twisted pair, and 1/2-inch coaxial cable as mediums of transport. This was another very successful milestone in establishing communications in hostile environments.

Further, in spite of planning, critical components are often either missing or unobtainable. On a stop-over in New Zealand, it took me almost until midnight to locate the special computer board essential for the completion of the complicated



■ Figure 8. *Configuration 4: ROV telepresence link.*

link. On another occasion while in Antarctica, I had to redesign an audio circuit. Because of the World War II vintage equipment in the Antarctic, I had to engineer from scratch several of the critical links to facilitate the transmissions.

Connectors

The audio level was too low for the press conference coming from Antarctica, so I had to amplify it. I shanghaied a 1950s PA system they had at McMurdo, which was used by an entertainment group. The connectors were not compatible, so I shoved large paper clips into the holes, and soldered alligator clips to the dissected XLR jack (three-pronged). Another problem with the connectors was that they could not be laid on the ice because they would melt the ice and subsequently get water in them.

Cold Solder Joints

When you are sitting on a –20° surface trying to solder something, the slightest breeze will turn it into a cold solder. The solution is to have a hair dryer on while soldering to keep the air around the solder warm. A good solder is essential for a homogeneous bond or poor connectivity will result. If the outside of a bond cools too fast, it will break connectivity and produce high resistance.

Cable Isolation

Because the preparations were so rushed, NSI had a 60 Hz hum (power cycle) during the press conference. This was because the video, audio, and power cables were wrapped inside the conduit going to the roof of the fire house. This implementation was the result of a rushed job. The 60 Hz on the power cable induced 60 Hz on both the video and the audio cables, although the interference is significant only on the audio. We were not able to isolate the 60 Hz hum because we couldn't separate the cables which should have been isolated or shielded to begin with.

Telepresence Experiment Moved up from '93 to '92

The mission of the entire NSI Antarctic operation has always been to support the communication requirements for Mars Analog research. We were to have provided telepresence support in 1993, but when Carol Stoker of the Exobiology/Mars Analog Project at ARC saw what had been done for the broadcast and press conference, she asked whether or not we could go ahead with support for a telepresence experiment instead of waiting until 1993.

Therefore, I analyzed the McMurdo configuration and decided that one of the existing 9.6 Kb/s data circuits could be reconfigured to meet that requirement. Two of the 9.6 Kb/s circuits were being used for remote control of the video codec and the NSI router. Since these circuits are meant only for secondary access for control of the equipment, NSI engineer Roxanne Streeter disabled the NSI 9.6 Kb/s out-of-band circuit and borrowed a couple of 9.6 Kb/s modems from people at McMurdo, using the phone lines that NSI had used for the ABC broadcast. ABC had needed three sets of twisted pair to communicate with the producer, the camera man, and the audio man, each of whom had his own head set. Streeter took one of those twisted pairs, hooked it to a modem, used RS 232 interface to plug into the 9.6 Kb/s circuit, then was able to get it out to the trailer, and from the trailer, plug in the RS 232 to the outputs of the remote control for the ROV.

Additional problems with DTE and DCE interfaces and with signal inversion were all overcome.

After the ABC broadcast, we moved the laser to point at the ROV hut (Bldg. 14). This was the same configuration as the ABC broadcast, but instead of using the input from the cameras, it used input from the ROV. Video quality for the ROV experiment was not as good as that for the ABC broadcast. The 25 dB S/N ratio on the baseband signal coming from the ROV was inferior; 65 dB S/N ratio is standard for broadcast quality. Even though we had designed the system to operate at a 50 dB S/N ratio, the system was limited to the poorest link, which in this case was 25 dB. The main reason for the drop in video quality is that their communications medium utilizes video going over 1000 ft of twisted pair, which has substantial attenuation causing signal loss.

Thus, on Friday, December 5, 1992, NASA accomplished its first telepresence application. This event marked a historical first when a researcher at ARC experienced moving through the water, hundreds of feet under the Ross Sea Ice Shelf in the Antarctic, as though he were on the back of the robot. This was accomplished by fitting the researcher with a virtual reality headset; with each movement of his head, the tracking cameras on the robot moved and transmitted the images directly to him.

Conclusion

As a direct result of the NSI's ground-breaking efforts in November 1992, several historical breakthroughs have occurred, not only in technology applications, but in historic "firsts" for education and telepresence. For example, NASA has provided remotely operated telepresence applications as demonstrated in the National Air and Space Museum in December 1993, in which students were able to wear stereovision virtual reality helmets and guide a robot and its arm operating beneath the frozen surface of the Ross Sea at the bottom of the planet. We were able to send back high quality video compression algorithms at half-T1, we were able to send back freeze-frame video from the South Pole, we have recently sent back live video from places like the remote Dry Valleys in Antarctica, and we will soon be sending back live video from the South Pole. These are all the direct result of technology applications that were implemented in the winter of 1992. This technology is not unique; it is turn-key technology — self-contained systems sold by a vendor which and used intact by the customer. The unique and unprecedented aspects were NASA's rigor and the innovative fashion in which this historic first was implemented at a time when it was thought to be technically unfeasible. As technology advances, several issues must be addressed.

Interoperability

The equipment described in this article must be more universally interoperable if it is to be more widely utilized. Industry needs to develop interoperability standards for equipment and interfaces so that if a card in a codec fails, for example, or if an interface fails, it can be successfully replaced from a similar vendor. However, until standards are agreed upon and resolution at those standards is acceptable for dynamic applications, that will not be possible. Existing standards are too low in resolution to support these types of applications—industry standards for interoperability in image quality and frame rate are so low that we are still forced to use proprietary solutions. Clearly the success of a specific vendor will not be based on a single user like NASA but will be based on its ability to integrate and interoperate with other equipment.

Multiplexing

Requirements are growing for technology that can integrate voice, data, and video. Until off-the-shelf technology can ensure a superior mean time to failure (of several thousand hours) for self-contained pieces of equipment such as routers that could handle data muxing internally, we will have to use proprietary equipment in Antarctica. The direction technology is currently taking is to make compressed data in the form of voice and video readily available over the Internet. Therefore, rather than having a router that would incorporate data or video muxing, industry should continue to develop packet video software and packet audio software that run over TCP/IP. These softwares will command the market when the wide area network backbones mature to speeds of 2 Gb/s. Proprietary solutions will become obsolete.

Biography

MARK LEON received a B.S. in electrical engineering from San Jose State University and is working toward an M.B.A. at Santa Clara University. He is currently deputy project manager for the NASA Information Infrastructure Technology and Applications Project at Ames Research Center, Moffet Field, California, and deputy program manager for the NASA IITA K-12 Program. During his tenure as Engineering Manager of the NASA Science Internet, he designed and implemented the first audio/video link to Antarctica. His e-mail address is: leon@nsipo.nasa.gov.

The equipment described in this article must be more universally interoperable if it is to be more widely utilized.