

## ARISS Contact at Hawthorne Brook School

November 29<sup>th</sup>, 2005 was the culmination of two months of intense preparation for an ARISS contact between the International Space Station and Hawthorne Brook Middle School in Townsend.

The middle of September the Nashoba Valley Amateur Radio Club had been contacted with a request to provide radio communications for the event by Steven Best VE9SRB (contact for the previous club) and Marilyn Richardson N1CSH (the teacher) at Hawthorne Brook School. They had been involved in the original application in April 2002 for a space station contact. The club that had signed up on the original application was no longer able to support the event. After some brief discussions and a club meeting poll NVARC decided to support the event. The kids after all had already been waiting three and one half years for this to happen.

From that point on it was a scramble to assemble the required two satellite stations for the contact. Not having been involved in the original application we had a lot to learn.

It is important to keep track of what has been done and what needs to be done. Devote a notebook to the project. Take notes when talking to the mentor. Make lists of equipment and sources. Record measurements such as cable lengths, distances at the site, and make sketches. Having all your information in one place will save time.

Ralph KD1SM and Stan KD1LE immediately made a site visit to the school to check out the grounds. This first visit was to get the general layout, determine where we could place antennas, and see where the classroom was with respect to where we could place antennas. This was done on a weekend so it was strictly an external assessment. Another visit took place to check out the classroom and see what access would be like for putting antennas on the roof. We also looked more closely at the adjacent athletic field and the basketball court near the classroom. Drawings were made of the site. The original application listed no obstructions but knowing something of the terrain we had concerns. The obvious omission was the tall and heavy tree cover directly south of the school. If the pass were to the south and less than a sixty degree elevation we would be shooting through the dense pine trees. The plus side was that anticipated ISS passes were expected to have Acquisition of Signal (AOS) in the southwest which was over the athletic field and Loss of Signal (LOS) in the southeast where the trees would be farther away and thinner. These were the optimum places since a high ridge runs east-west on the north side of the school. It is very important to verify the horizon limits of the site by reviewing either topographical maps or a computer program to do terrain profiles. A satellite spends a significant portion of the total pass time near the horizon. This means that avoiding obstacles such as heavy tree cover or hills is critical to maximizing the total pass time. Little did we know at the time that even some distant hills that were below the tree line would have an impact on the RF horizon. In the next few days Ralph did several iterations of what our horizons would be trying to look at some worst cases depending on where AOS and LOS were.

During the interior school survey we found that the school had a membrane roof and access was from the opposite end of the building via an internal ladder. This would make it difficult to move any significant equipment to the roof. The roof lacked any structures that could be used to secure antennas. The roof was also only 22 feet high so considering the risk of roof damage and the difficulty of putting equipment up there for the limited height gain we chose not to use it. Since we were already concerned about the hills and trees we decided it would be worthwhile to exercise another option we had. Several of the club members jointly own a 100 foot tower trailer. It is pictured later in this paper. Using the tower trailer we could put antennas near the tree tops by extending it only 75 feet. This would keep the antennas out of the wind and minimize the number of guys sets needed. This height would significantly reduce the loss from the trees. It would also have a small but beneficial effect on the horizon. We needed a good place to set up the tower

and decided to use the paved basketball court right outside the classroom. This was approximately 125 feet from the building so our cables would be long. One concern was that with a contact late in November snow might limit the access to the outside areas where we wanted to put antennas. The basketball court was on a security road around the school and was plowed when it snowed so access could be assured. On the basketball court we could only guy the tower to either the basketball net posts or trees that were much farther away. Not knowing how sturdy the metal poles were we decided to use the trees for guy points. To protect the trees nylon slings were used to wrap around the trees. The steel guy wires would hook to a steel ring on the slings.

We also had a lot to learn about the NASA requirements for the equipment used. A review of the original application and several other sources revealed more of the specifics. This included a primary station consisting of; a radio, power amplifier, large circular polarized antenna, rotator system, emergency power, some audio amplifier system, and lots of cables. The secondary station could be similar but a vertical antenna was all that was expected. The reason for the two stations is redundancy. By the time you get to the actual contact many hours of time have been invested and expectations are high. Unlike a random contact or even a scheduled contact a failure in this event is final. There are no second chances. When planning the stations we kept them totally independent. No single failure should result in a failed contact. We also didn't consider any piece of equipment functional until it was tested assembled into the complete system. Running all of the equipment at the same time in one place is the only way to be sure there are no interactions or noise problems.

Once the school contact was approved by NASA a mentor from the ARISS organization was assigned. That person contacted us weekly giving ideas, encouragement, and checking on our progress. I suspect his input to NASA is critical in getting final assignment and approval. As time progressed he asked fewer questions as I think he was convinced we knew what needed to be done. There are several important mileposts in the process. The school is approved and given a list of possible weeks three months in advance. It was shortly after this that we were asked to help. This step happened about 3-1/2 years after the initial application was filed. The school chooses a few weeks based on the school schedule with consideration for holidays, vacations, etc. With about a month to go NASA comes back with the week you get. You receive pass information for each day which includes the time of the pass and the maximum elevation. It is up to you at this point to analyze the passes for where AOS and LOS will be. But the decision again is made by the school based on their previous criteria and now adding lunches and class movements. Our preference was to stay away from Monday since it would be difficult to get into the school on Sunday for setup. This is important because one of the requirements or at least a preference is that the station be set up 24 hours prior to the contact so that it can be checked out. The school replies with a list of the days in the preferred order. That is, the school assigns an order preference to the days. What that does to our planning is not insignificant. On the first preferred day (Wednesday) the pass had a 44 degree maximum elevation and went to the north of the school which meant a longer pass and our rotators needed to be north centered (stops in the south). The next preferred day (Tuesday) the pass was 38 degrees, which was lower and went to the south of the school. This put our LOS path through the heavy pine trees and into a nearby hill and required our rotators to be south centered (stops in the north). In order to have the rotator track the ISS uninterrupted it cannot run into the stops. This means for a pass to the south of your location the rotator azimuth stop should be in the north and opposite for the north pass.

After looking at what radios might be acceptable it was decided to use a satellite type radio. Bob W1XP had a Yaesu FT-847 which would fit the bill. The satellite radios have the advantage of finer frequency steps than a mobile type radio. This would be better for adjusting to Doppler shift. It also had VFO tracking features that made CW and SSB contacts easier. Our intention was to make as many contacts in advance of our scheduled school QSO as time permitted to check out every part of the system. To make operation and programming easier it was decided to use two of the same radios. After sending out an all-club email we located three more of the same rig.

When we started assembling the second station Hank Lane KB1JLA supplied the second rig. Once we received the primary and secondary frequency matrix with the Doppler shift frequencies we programmed the primary station radio using sequential memory locations. Use of sequential memory locations rather than the VFO makes it easier to write instructions for the operator who watches the clock and tunes the radio by hand. We also included the packet and voice frequencies the ISS uses. While there is only one downlink frequency there are primary and secondary uplink frequencies. These are unpublished frequencies to prevent interference with the school contacts. Each matrix had a series of frequencies to account for Doppler shift. Programming the second radio was easy because the FT-847 has cloning capability. With regard to the secondary frequency its use was not initially clear. During our preparations NASA was drafting the procedure for its use. The bottom line is the astronaut making the contact is the only person who can initiate a change to the secondary frequency and that affects uplink frequencies only.

To improve the radio performance NASA recommends a power amplifier with a receive preamp. We used two different model Mirage (now MFJ) 160 watt amplifiers both with preamps. The amplifier used on the primary station required 50 watts of drive for 160 watts out and the amplifier for the secondary station required 10 watts of drive for 160 watts out. This difference was due to what was available and not a conscious choice. Each amplifier had an advantage. On battery power we could not get 50 watts out of the FT-847's. This meant we could only get a little over 100 watts out of our primary station amp but we didn't have to worry about exceeding the rated drive power for the amplifier. Since the secondary station amp required only 10 watts input, and the radio was running on 13.8 volts, we could deliver full drive power and get full output power. The disadvantage was that with a 50 watt capable radio there was the risk of damaging the amplifier if the radio power was inadvertently turned up too high.

Amateur equipment, such as an amplifier, is rated for Intermittent Commercial Service (ICS) or Intermittent Commercial and Amateur Service (ICAS). Not knowing how our use would compare to the rating so we assumed key down for an extended length of time. Mirage recommends adding cooling for amplifiers in heavy use. We added a screened cover and two twelve volt cooling fans to cool the heatsink of the primary amplifier. The fans had no controller and were plugged into the twelve volt power source when we set up. In use the amplifier never got warm. A Bird wattmeter was placed at the output of each system to monitor power output.

One challenge is the requirement to run on emergency power. We chose to run on a deep cycle 12 volt battery for the primary station and amplifier. This was an easy choice since the radio and amplifier ran on 12 volts. While the radio and amplifier operate on 12 volts they are actually designed to run on 13.8 volts which results in the lower power outputs mentioned above because the battery is approximately 12.5 volts in use. The battery system included a six amp charger that kept the primary station battery fully charged. The radios and amps were directly connected to the station power source which was the deep cycle battery for the primary station and the Astron 35A power supply for the secondary station. We had a 300 watt inverter that we could use to power either rotator from the battery if we had a power failure.

All of the other equipment (rotator interface, speakers) was wired to use Anderson Powerpole connectors. These were connected to a Powerpole distribution box powered from an auxiliary 17 Ah gel cell battery.

During testing we had run the station for several weeks with and without the charger on the battery. The secondary station ran from an Astron 35 amp power supply.

As equipment was collected it was set up with the designated station. The stations were set up on adjacent tables in one of the member's garage. As each piece was put into place additional requirements were identified. We left each day with a list of items we needed to build or get. We had a radio, amplifier, power meter and antenna switch to be connected. The first task was to build a number of quality coax jumpers and power cables for each station.

The available antennas needed to be repaired, some elements replaced, matching cables built, and the antennas tuned and checked out. The antennas we had to work with were a KLM 2M-22C 22 element antenna and a KLM 2M-14C 14 element antenna. Both are circularly polarized antennas. The 22 element antenna was to be the primary station antenna and was comparable to what others had used. The 14 element antenna was to be the secondary antenna. The antenna repair work was completed by mid October. With the upgrade of the antenna for the secondary station from a vertical to the 14 element we decided to keep the vertical antenna option and connect it to the primary station via a coax switch. The idea was that if we had a catastrophic problem with the primary station we would switch to the secondary station which had the next best antenna. If we only had an antenna problem with the primary station once the contact started we could switch to the vertical by throwing the switch and complete most of the contact. Switching to the secondary station could then be done when convenient to maximize the contact. The 14 element antenna would be better than the vertical when the ISS started dropping low on the horizon.

Coax is critical with the weak signals you are trying to receive at the start and end of a satellite pass. RG-8 types are the absolute minimum. Never use RG-58 coax as the losses are too high. Higher quality cable is better and cable such as LMR-400 which we used is preferred. One tradeoff, besides price, is the LMR-400 is not very flexible and should be rolled and unrolled carefully. Rolled into coils with a four foot diameter is reasonable. It should not be twisted or bent sharply. We expected to need 250 foot runs from the primary antenna on the basketball court and the secondary antenna in the field off the southwest corner of the school to the classroom. These are long runs so good coax is especially important. The vertical antenna was connected with RG-214. One problem is the cabling from the antenna to below the rotators. It needs to be flexible to move with the rotation and hang nicely below the antenna. This is especially important for the AZ-EL rotator since it moves in two axes. A compromise was to use a section of RG-142A/U, which is more flexible and has reasonable loss, to a point below each rotator where we transitioned to the LMR-400 cable.

Software was obtained to track the satellites and International Space Station. The software we used was NOVA which costs approximately \$60. Some practice was required to understand the program, learn to update the KEPS, and synchronize time. You need to set up the software with the location you will be operating from and the satellites you want to track. The latitude and longitude of the school was checked against the application numbers and our own GPS readings. Most programs like NOVA have the option of automatically updating KEPS and setting computer time if the computer is connected to the Internet. We updated the KEPS and clock regularly and particularly the day before the contact. The software was installed on two identical laptop computers, one for each station.

A Yaesu 5400 AZ-EL rotator system was available but untested. Cabling had to be made to test the system. First a six foot cable was built to test the rotator and controller. We set up the rotator inside with some plastic pipe simulating the antenna. With this setup we tested the rotator and controller interface on simulated passes.

For accurate aiming, computer control of the azimuth and elevation of the primary antenna was needed. Having computer control eliminates one worry during the actual pass. A computer interface and software was obtained. This is separate from the satellite tracking software mentioned above. The interface we used is by EA4TX and the software ARSWIN comes with it. The software for the rotator interface accepts data from the NOVA satellite tracking program (and several others) to point the antennas in the correct direction. Calibration of the system to synchronize the position and feedback from the controller is necessary. This requires manually driving the rotators to the end points and telling the software where they are.

One important consideration is the rotator stops. The normal rotator configuration is to have the azimuth stop set at north and most controllers are configured to show this on their display. If the

satellite is to pass to the north of your location the rotator will run into the stop. At this point it will have to rotate fully around to continue tracking the satellite. This may result in a loss of signal for 50 seconds or more which is unacceptable in a nine minute pass. Once the pass is known the rotator should be physically oriented and calibrated with the stop in the proper position (north or south) so that you have continuous tracking for your pass. The mast for the rotator on the tower has two clevis pins that hold it in place in a tube. To change the rotator from north centered to south centered was easily accomplished by pulling the pins and rotating the mast which turned the rotator exactly 180 degrees. For the controller and software we used there is a setting in the software for north or south centered rotation. A second consideration is whether the elevation rotator had a range of 90 or 180 degrees. Some software can take advantage of this. In a pass that goes directly overhead the elevation rotator can just track right overhead without any azimuth rotation. This only helps in a direct overhead pass. We used a standard TV rotator on the secondary station antenna. It has the same issue with the stops as the AZ-EL rotator above. Calibration is simply running it from end to end. If it needs to be set up north centered it also needs to be physically rotated 180 degrees. A template disc with the center cut out and marked with 360 degrees was made to sit over the TV rotator control knob. This could be rotated as needed to compensate for whatever physical orientation the TV rotator was placed in.

Another tracking issue is when the system will actively drive the rotators. By default our system did not track below the horizon. This was selectable. If AOS is at zero degrees elevation and the rotator control is not active until a satellite is above zero degrees then the antennas will be rotating to the proper position while you are trying to call the ISS. Depending on the hardware and software the solution may be to set tracking to start several degrees below the horizon or simply to manually position the antennas at the AOS azimuth and zero degrees elevation prior to the contact.

Using the G5400 AZ-EL rotator and computer interface for the primary station the antenna system was set up on Stan's roof for cabling and debugging. Of particular interest is properly dressing the coax from the antenna to the boom and then to the mast below the rotator so it can freely move as the antenna rotates in both azimuth and elevation. Besides getting tangled or caught at this level the loops may get caught on the tower itself.

The secondary antenna had a wider beamwidth which made using only an azimuth rotator practical. This allowed fixing the secondary antenna at an elevation angle which would still cover the range of elevation angles we needed. The normal mast to boom bracket is made to hold the antenna horizontal. We needed a bracket that would allow the antenna to be set at other than a horizontal elevation. This would be a compromise elevation between the horizon and the ISS maximum elevation. Stan fabricated a two plate mast to antenna bracket that allowed the antenna to pivot and be set at elevations of 0, 15, 22.5, 30, and 37 degrees. This would allow a reasonable compromise setting once we knew the maximum elevation for our pass. When we knew the maximum would be 38 degrees we decided to set the antenna at 30 degrees. This antenna was also set up on Stan's roof.

For testing purposes a code key was installed on the primary station. It was used to make contacts on satellites where CW was an appropriate mode. On the ISS packet is the alternate mode. A TNC and computer were connected to the primary station. When the astronauts are not using the FM radio to make contacts it is connected to a packet system. Contacts are made by monitoring transmissions of other stations through the packet repeater. There is no direct connection between stations in this mode.

The primary station was completed more than three weeks before the contact. We still only knew the week and not the day of the contact. But we started testing equipment by making packet QSO's through the ISS packet system on nearly a daily basis as passes were available. Ultimately more than fifteen packet QSO's were made through the ISS with a variety of continental US stations. We also made several contacts using other satellites to test systems. We made comparisons of the signal strength on the various antennas. We found the 22 element

yagi to give about one S unit better signals than the 14 element. We also found the vertical to be very usable once the ISS was well above the horizon. At low elevations the yagi antennas were significantly better than the vertical antenna. Once we were satisfied with the systems and frequency programming the second radio was programmed using the cloning capability.

At this time Bob and Stan made another visit to the site. Using several methods we measured the height of the trees to confirm our estimates. This would be a factor when we decided how high we would raise the tower. We decided to use the center of the basketball court for the tower and primary antenna. We also decided to place the secondary antenna and vertical in the field off the southwest corner of the school. This gave maximum clearance from the school building and trees. This was important since the antenna was at ground level and depending on the pass may have to shoot over the school. We then took measurements of the distances for coax and rotator cable runs. We also measured for the guy wires for the tower. With this info and available material we decided we would make two 250 foot LMR-400 cables to be used with the yagi antennas. The vertical would be connected using 140 feet of RG-214. Extension cables were made for both rotators. The AZ-EL rotator used two six conductor cables and was extended to 260 feet. The smaller azimuth rotator used three conductor cable and was extended to 200 feet. Rotator cables for such long runs need to be at least #18 gauge. Often this cable comes in 100 foot lengths. This creates a problem of too many connectors for reliable service. The cables we started with were a 66 foot length of twelve conductor and four 100 foot pieces of six conductor cable we borrowed that had connectors. The six conductor wire is used for sprinkler systems and is readily available and relatively inexpensive. Unfortunately this wire is solid conductor. In a fixed use this may be acceptable but it doesn't work well with connectors. This set of wires put 16 connectors in the control to rotator path. We found this to be unreliable. For the highest reliability the cables should have the minimum number of pieces with the fewest connectors. The weekend before the contact we disassembled the rotator cable and hard wired all but the four end connectors.

The adjustable guys we use with the tower are only 35 feet long but have hooks on both ends and a turnbuckle built into one end. Using the measurements we made at the school extension cables were built with fixed loops in each end to fit each instance. The guys needed to be as much as 130 feet long. Six different cables were made and labeled for length. A diagram was drawn up for proper installation at the school.

We made another visit to the classroom and decided that the preferred arrangement would be to set up the two stations on a laboratory bench that ran the along the windows. There was ten feet of bench on each side of the classroom separated by a ten foot air handler. One station would be on each bench separating the equipment and operators. This would give us access to the windows where antenna and rotator cables would come in. It would also put all the interconnecting coax and power cables on the bench so there would be nothing to trip on. With students, operators, visitors and the media there are a lot of people moving around during the contact so keeping wires out of the way is critical. The other decision was to place the microphone, actually the two microphones, between the two stations. This put the radio equipment out of the way but up front. With the two microphones side by side in the center we only needed to change to the other microphone to switch to the secondary station. This required building two ten foot rig to microphone cables. Since we were concerned about RF interference these were made of shielded twisted pair wire.

Over the course of the two months the prospective date had narrowed from a list of weeks in November and December to the last week in November. With a week to go we received news the contact would be November 29<sup>th</sup> at about 1:24 PM. The good news was we now had the date and time. The bad news was the pass was now going to come up in the northwest where we knew there was a significant hill and set in the southeast. Ralph KD1SM set to work again computing the horizon elevation angles where we expected AOS and LOS. To our dismay we found that with the new AOS bearing of 298 our acquisition elevation angle would be near three degrees. The LOS bearing of 142 meant Meetinghouse hill, a small but close hill, in the southeast would now be a

problem and cause LOS at an elevation just under 3 degrees. With this information we estimated the total length of the contact. This would be less than if the land were flat horizon to horizon which is the time calculation the program gives. After a few adjustments to the calculations we estimated that the 9 minute 44 second pass would be more like 9 minutes. This information was passed on to Marilyn so she could plan the students question and answer time.

Marilyn had printed each student's question on a strip of paper that was eventually laminated. After talking with the mentor we suggested the students practice with Marilyn and that their question crib sheets include the word "over" so they would not forget it during the real contact. They would have several practice sessions prior to our coming in to do a rehearsal. The word "over" is expected by the astronaut and forgetting it will cause a delay in the astronaut's response. With us attempting twenty questions from twenty students in nine minutes every second counted so it was important the student rotation and questioning proceed briskly. The other item was the calling procedure for the ISS. The suggested calling procedure was found on one of the ARISS sites. For us it would look like "NA1SS NA1SS this is N1CSH Hawthorne Brook over". The protocol is the ground station starts calling the ISS about one minute prior to the expected AOS. That way as soon as the astronaut can hear you the contact can start and no time will be wasted.

The week before the contact Bob and Stan practiced with the students. Using the actual radio and microphone setup they transmitted to a local handheld and tape recorder. After all the students asked their questions which now included the word "over" the tape was played back so they could hear how they sounded and if they needed to speak louder or make other adjustments. That process was repeated several times. One thing we had to decide was who would key the microphone. Originally the teacher thought she should do it. Our preference was that we (Bob) would do it. The person keying the microphone is in charge and would have to handle switchover in case of a failure. The way it ended up the teacher keyed for the initial calls until we made contact. Then Bob took over keying the microphone for all of the student contacts. This kept Marilyn free to monitor the queuing of the students at the microphone and to monitor the time. The students were seated in question order. With practice they were able to keep a queue of five students in line at the microphone so there were no gaps. We did find RF interference on the handheld inside the school. This was not seen on the rigs using outside antennas.

Since the space station is moving through space at about 17,000 miles an hour there is a Doppler shift of the radio waves traveling between the space station and the ground station. At two meter frequencies this shift can be as large as plus or minus 3.3 kHz. This is a total of 6.6 kHz for a near overhead pass of the space station. The exact amount of shift and the distribution with time is a function of the path geometry between the space station and the ground station. This in turn is a function of the orbit and is different for every pass. At plus or minus 3.3 kHz the distortion to an FM signal is minimal. This we confirmed with testing using typical two-meter radios. The question was should we do anything about the Doppler shift during the pass. Originally it had been thought that the radio used would allow the operator to just adjust the receive frequency to keep the signal centered in the discriminator using the front panel tuning indicator. This only works for the received frequency as it is not possible to track the transmit frequency in this mode with the chosen transceiver. The transmit frequency is normally tracked by the receiving station but in this case our adjustments also had to make up for the fact the ISS cannot adjust for Doppler. In the end we decided to construct a table of the offset frequencies verses time. This series of offsets was then applied to the down link frequency and the three uplink frequencies.

The distribution of the Doppler shift is unique to the specific pass of the space station. It is best to determine the Doppler shift verses time from the specific orbit pass. To do this we used a tracking program that reads out the Doppler shift during the satellite pass. We set the computer date and clock forward to simulate the pass and read out the frequency shift every thirty seconds of the pass. This shift plus or minus was then added to the downlink and three base frequencies (one primary and two secondary). To reduce the number of steps the time-frequency matrix was

based on one KHz frequency shift increments. When this was done we had seven receive and seven transmit frequencies in each table.

The frequencies were loaded into memory with the lowest frequency in memory number 30 and the highest in memory number 36. The next group, based on the first alternate uplink frequency was loaded in 40 to 46 and the last group in 50 to 56. This way if we were required to change to one of the alternate uplink frequencies it was only necessary to switch to the proper bank of memories and continue to change memories based on the clock time. By design unused memory locations are skipped when stepping through the locations. In the above set up moving from memory location 36 to 40 is only one step if the locations in between are empty.

Using the above information a table of actual time in 30 second increments was prepared that specified the last digit of the memory to be used. Using clock time the radio operator adjusted the frequency by stepping through the memories. Since the pass was nine minutes it had eighteen 30 second increments but only seven frequencies so depending on the portion of the pass you were on one frequency for from one to several time increments.

A change was not required every 30 seconds but it could be easily determined what memory should be in use based on the time. Most of the Doppler change occurs when the space station is nearing the point of closest approach and this is the time that the antenna pointing is changing rapidly also. For this reason the station that was manually tracking the spacecraft had two operators. One operator made adjustments in azimuth to keep the antenna on target. The second operator made radio memory changes based on time to track the Doppler shift. The primary station with the automatic antenna tracking had only one operator who tracked the Doppler. By using identical transceivers not only were we able to easily clone the memories but also only one piece of equipment was required to be learned by the operators.

Another problem was audio distribution and a desire to record the event. We chose to use regular computer speakers that were powered by 12 volt wall warts. We built new cables with Powerpoles to run the speakers directly from our 12 volt power sources. Fixed level audio is commonly available from radios at a port used for the digital modes. The level at this port is too low to drive the speakers directly. Bob built two audio preamps so the speakers could be driven by the fixed audio output of the rigs. The preamp had its own level adjustment. This made the speaker audio level independent of the rig volume control which might need to be adjusted by the operator if he were wearing headphones. Cables were built to interface the audio preamp to the radio which were DIN at the radio to 1/8 mono phone plug at the preamp. This arrangement isolated the rig audio from other uses. These amplifiers were independently powered by internal nine volt batteries. The original requirement was only to have audio in the classroom which would only have the 20 students asking questions and some visitors. A simple PA system using a pair of computer speakers satisfied this requirement. We did not provide amplified uplink audio in the classroom as it didn't seem necessary and would have created a feedback problem. It is important to test the audio system to be sure no RF is getting into the system. Larry KB1ESR put together a mixing and distribution system that he thought would satisfy the requirements. Having a second amplified output from the preamps would have been better to feed the speakers and audio distribution system separately. This needs to be done in an isolated manner to avoid interaction which may cause a disruption of the primary mission audio.

The Audio support for this ISS contact can be described as in keeping with the redundant theme that NASA thrives on. The challenge is keeping in mind that your flexibility will be tested in the field with many changes. Other people's equipment (the School's) will want an output for a public address system in two other classrooms. Make sure that it is a buffered output of Line level value. We suggest seeking out the school's Music teacher and querying Him/Her on the subject of available support audio equipment.

The backup is easy to describe so let's do this first.



An Olympus Digital Voice recorder (VN-4800 PC) was placed on the podium setup to handle the two transmitting Microphones. The VN-4800 will record for two hours at its high quality setting and is voice activated. The output of this recorder is in two forms. Audio and a digital wav file. The wav file has a time tag so one must set the time reasonably accurately the day of the event. The wav file was transferred to a PC and coupled with the Cassette Audio later on a CD. This unit performed very well recording the transmitted questions from the room and hearing the received audio with some room sounds added. Having a time tagged audio recorder is a very useful tool. Start this recorder at T-45 minutes and relax. The teacher did a dry run on the 20 questions and recording this event is a must! After the dry run, play some back so that everyone will hear that it is being recorded. That includes yourself.

The Primary recording system consisted of -

JVC Cassette Deck (Model TD-W309), with VU level set meters

Radio Shack Stereo Sound Mixer board (Model SSM-60) also with VU level set meters

Two vintage 3M microphones, semi directional.

Creative 3 piece speaker system of 18 watts audio power

Kenwood TH-D7 hand held radio



The connections are as follows. Microphone 1 and 2 to the respective inputs of the mixer board, secure the # 1 microphone to the microphone used to drive the transmitter (uplink audio). The # 2 microphone is pointed in the direction of the receiver speaker as a backup to the direct connection between the receiver and the mixer board (downlink audio).

From the preamplifier box constructed by W1XP a line was run to the mixer board input labeled line # 1 (downlink audio). Set this line input level with a squelch break test from the main receiver. Agree with the radio operators to not drastically change this level set. This line level drives the recorder and the class room amplifiers! Start this recorder at T-15 minutes.

The Kenwood HT was used to pickup uplink audio as a backup to the #1 microphone above. Connect the HT receiver speaker output jack to the input of line # 2 on the mixer board. Again break the squelch set on the TH-D7 to obtain a level set on the VU meters. A test transmission to this receiver should now be accomplished. No attempt was made to track the transmit frequency as it was shifted to correct for Doppler shift at the ISS. It was set to the center uplink frequency. The receiver was near saturation anyway.

Have plenty of tape on hand and keep your eye on the level set. Most of all watch the young ones have the event of a lifetime!

After the event is over (including the post track euphoria) the playback should be done ONLY after the record enable snaps have been removed from the cassette. Do not even rewind! Protect first then Enjoy.

The week before the scheduled event both stations, all the antennas, and all the peripheral equipment were assembled. On the weekend before the event we scheduled a training session to go over last minute details and have everyone assigned a role. Gary K1YTS, Joel W1JMM, Bob W1XP, Stan KD1LE, and Larry KB1ESR made the meeting. As a plus there was an actual pass of the ISS so we could track in auto and manual, compare received signals on both stations, and try to make a few packet QSO's. As the ISS approached antennas were positioned. When the ISS came over the horizon at AOS we expected to hear packet bursts. Much to our surprise and pleasure we heard voices. We quickly switched from the packet uplink frequency to the voice uplink frequency which was already programmed into the radios. Bill McArthur, the astronaut we would talk to in the school contact, was making contacts as he came up the east coast. One of those contacts was to the Naval Academy. During that QSO he wished them good luck at the upcoming Army Navy football game but said he would be rooting for Army. As he worked stations Stan KD1LE called and after a few tries was acknowledged. On closing Stan mentioned we would be the calling station for next Tuesday's school contact which he acknowledged. A number of additional stations made QSO's and as the ISS neared the horizon Joel W1JMM made several calls which were answered. We weren't sure Bill repeated the callsign correctly but we hoped so. Joel subsequently sent for an ARISS QSL for the QSO. He received a confirming QSL a week later.



Without notice on the day of the event the audio requirements expanded to providing audio to two adjacent classrooms. The challenge was to provide uplink and downlink audio to the adjacent rooms without creating feedback in the middle room where the students were asking their questions. The middle room would only have downlink audio so the students could hear the astronaut's replies. Additional audio equipment was supplied by the music teacher for the two adjacent classrooms. Larry KB1ESR supplied audio signal to the new systems from his mixer and recorder set up.



Above is the primary station with the packet computer on left (closed), rotator control and interface under the speaker and the radio with packet TNC on top. The power amplifier is on the right with the screen cover supporting two cooling fans. Stan KD1LE operated this station.



On the left side of the primary station was the tracking computer with software to track the space station and the controller interface software to pass tracking information to the controller interface.



Courtesy KB1ESR

Above is the secondary station with tracking computer, rotator control, radio, and power amplifier. Joel W1JMM and Les N1SV operated this station. Based on a paper table of time vs. azimuth bearing Les and Joel kept the 14 element yagi aimed at the ISS should we need to switch. Since this antenna was ground mounted its horizon was higher than the tower mounted 22 element antenna. This would have resulted in a shorter available pass time if we had had to switch to it.



Courtesy W1JMM

Above (L-R) Larry KB1ESR, Gary K1YTS, and Les N1SV setting up equipment in the classroom. The audio equipment and microphones for both stations are near Larry on the table covered with the green cloth. Since both stations were kept fully ready to operate it would only have been necessary to change which microphone was keyed in case of a failure of the primary station. One audio connector would have to be changed to connect the secondary station audio to the distribution system for the other classrooms. The primary station is off to the left and the secondary station is behind Gary and Les.

The projection screen on the right is set up to display the SatScape tracking program. We used this so everyone in the room could see where the space station was. It took a third laptop, the SatScape program, and an LCD projector to make this happen. SatScape had the advantage of being able to fill the full screen. Keeping this system independent was in line with our preference not to connect auxiliary systems to the primary station equipment. It also allowed us to position the projector anywhere without running wires across the room.



Above is the primary antenna for the contact. The 432 antenna on the right was not used for the contact. It was used during testing since we made contacts through other satellites. Since it balanced the weight on the rotator and kept the system "as tested" we chose not to remove it. The antennas were set up the day before the contact by Stan, Gary, and Joel. The classroom is on the second floor to the left of the greenhouse. The driveway between the basketball court and the school is used for school security checks by police. This meant cables needed to be rolled up after testing Monday afternoon and redeployed Tuesday morning. An eight foot anti-climb shield is wrapped around the tower starting eight feet up. It is nearly clear so it is difficult to see in the picture. Snow fence was placed around the trailer to discourage visitors.

The main antennas were removed from the elevation boom and attached to the tower trailer for transport. All of the cables were left connected. This kept all of the connections, service loops, and fittings exactly as they had been during our testing. The antennas were positioned vertically before the tower was lowered so they were horizontal when the tower was down. Returning the antennas to the boom and aligning them horizontally put them exactly back where they were.



Courtesy KD1LE

The backup antennas arrived ready for deployment. The secondary yagi was transported assembled with its coax and rotator cable rolled and attached to the tripod. The base for the yagi was on wheels so it could be quickly rolled into the field. The vertical used a tripod base and a ten foot mast and was assembled on site.



Courtesy W1JMM

Above is the backup cross polarized antenna with an azimuth only rotator. The antenna was set at a fixed elevation. The antenna system was mounted on a wheeled base. Cables were kept connected to the antenna and rotator and coiled on the cart ready for quick deployment. This setup required an operator to monitor the time and manually make azimuth adjustments.

After the practice contacts on Sunday the equipment was taken down including the cables, accessories, microphones, etc. It was packaged plastic storage containers labeled as primary station one or secondary station so that all of the parts would end up in the right place at the school and avoid confusion.

We had arranged for the classroom to be available from noon on Monday so we could bring in equipment and set up. We used several carts to move boxes from the school loading dock to the classroom. After we moved all the equipment to the classroom half the team worked on the antennas and half set up the two stations. Participating were Joel W1JMM, Stan KD1LE, Bob W1XP, Larry KB1ESR, and Gary K1YTS. We had hoped to at least listen for an ISS pass after we set up but they were earlier in the day than we were ready. We planned on four or more people to set up and an equal number or more on the next day for the final setup and contact.

Tuesday morning we arrived around 10:00 AM and continued set up and testing. The crew was composed of Larry KB1ESR, Bob W1XP, Dick KB1MBR, Stan KD1LE, Gary K1YTS, Les N1SV, and Joel W1JMM.

Cables were re-run to the primary antenna and rotator as we did not leave them across the driveway overnight. The secondary antennas were set up and cables run. While checking out the tracking and calibration of the primary rotator there was confusion as to whether the rotator was in fact set up south centered (stop on north). It seemed to be north centered. The actual problem was that in the calibration the antenna is run from end to end in both elevation and azimuth. When calibrating for elevation the antenna was left in the 180 degree elevation position which makes it seem to be in the opposite centering. Returning the antenna to zero degree elevation solved the problem.

Ninety minutes before our pass everything was set up. Since there was a pass around noon Bob started sending CQ on the packet frequency the space station uses. During the pass a message came back from the ISS "are you the station for the school QSO today?" Bob replied "roger we're just checking out the system". The reply came back from the ISS "good luck." Now Bob, Stan, Les, and Joel were manning stations one and two. Larry was set up at the sound distribution system. Richard and Gary helped by manning a video camera and the SatScape system.

After that exchange everything was set and we only had to wait. There was time to pose for pictures as did Marilyn and her crew of 20 students below.



Marilyn Richardson N1CSH (L) and her 20 student questioners.

We had discussed how or if we should try to do some basic Amateur Radio promotion. We never came to a conclusion as to how or if we could do it. We did consider that there might be some dead time prior to the contact after everyone was in place. Joel and Bob volunteered to be prepared to do a short five minute talk if needed. Joel prepared a discussion of where we would pick up and lose the ISS and how fast it traveled. At AOS the ISS was at three degrees elevation and was roughly over Bismark North Dakota. At LOS the ISS was about 1450 miles east of Miami Florida. Bob prepared to talk about how his interest in space motivated him to pursue a career in engineering and that he actually worked on equipment used in space and on the Space Shuttle. We ended up with time and both presentations were given once everyone was assembled.



Courtesy KD1LE

About ten minutes prior to the expected AOS Marilyn gave an introduction to the students and visitors. Behind the students are various members of the press and the School Principle.



Courtesy KB1ESR

Above Marilyn is ready to call the ISS. Marilyn had attended NASA Space Camp and is wearing her "official" jumpsuit. After calling "NA1SS this is N1CSH" for the third time Bill McArthur replied "hear you loud and clear". With a brief comment Marilyn turned the microphone over to Bob and the students. Bob keyed the microphone for each student after Bill completed his answer of the previous question.

Nineteen students were able to ask their questions though only 18 answers were heard by the students. As the space station went lower on the horizon the signal started getting noisy. The last student asked her question but we heard no reply. At this point Marilyn thanked Bill and led a group "Thank You" from the students after which she signed off. Though we could not hear Bill he apparently heard us till the end.

Knowing we had restricted horizons at both AOS and LOS we made every effort to understand and maximize our contact time. The original flat earth pass time both from NASA and from our software was approximately nine minutes and forty four seconds. Our adjustment to the time based on the horizons put the contact at nine minutes even. Our AOS was within a few seconds of our expected time as was our LOS.

After the contact was completed Larry replayed the audio for the students.

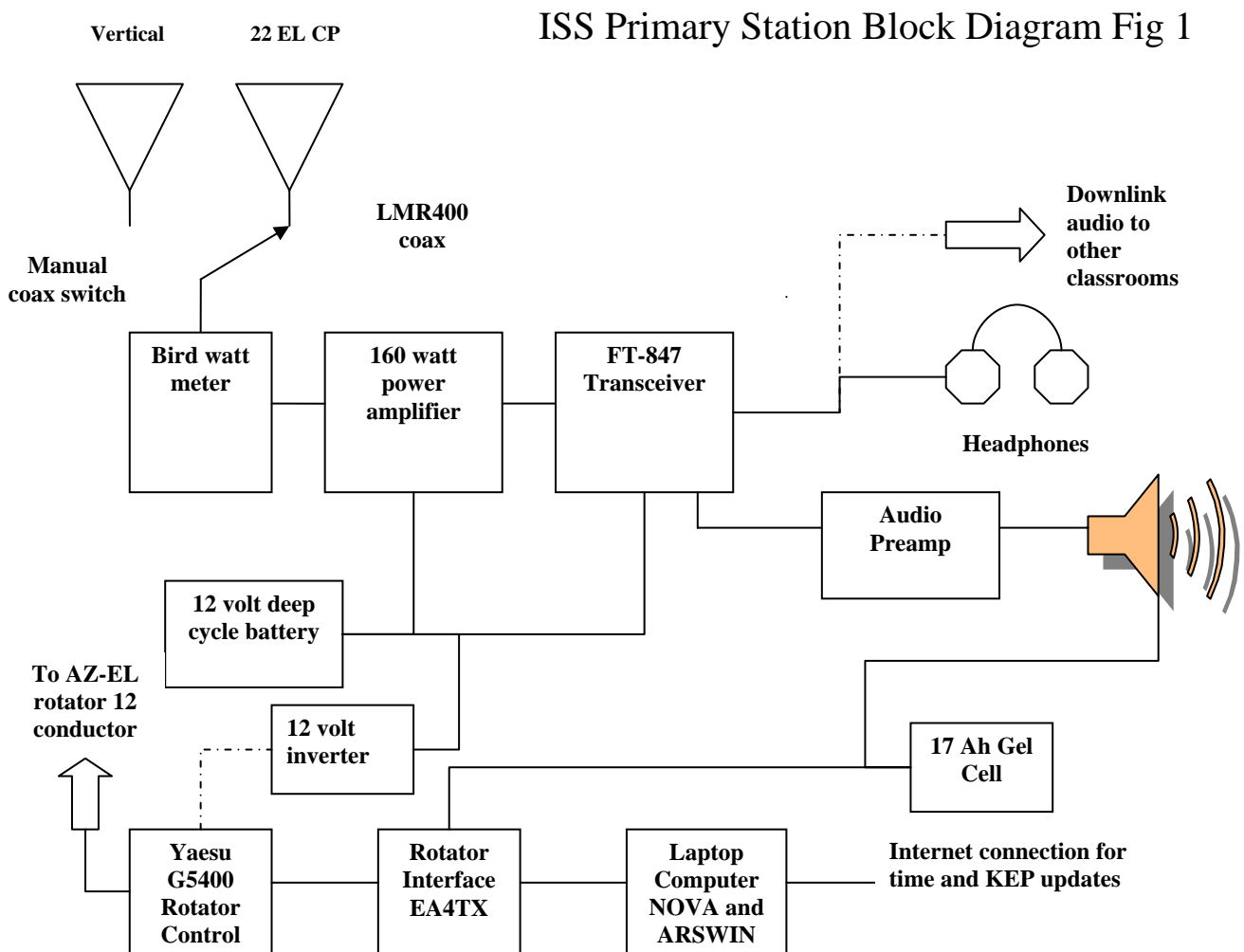


The school provided a pizza lunch after the event. After everyone had calmed down we started packing up. It took a while to pack all the equipment and take down the antennas but considering it took two days to set up the two hours to take down was not bad.

Video from the contact was played in the school library and given to Townsend Cable Access TV for editing. All press releases for the event were handled by the school. Articles were published in the Worcester Telegram and Gazette, The Community Journal, and the Groton Landmark. There were online articles at the ARISS and ARRL Websites. It was also included in the ARRL Letter.

### Ground Station Block Diagram

A block diagram of the primary ground station is shown in figure 1. The secondary station is shown in figure 2. The ground station consisted of two independent stations, a primary station and a back up station. Each station has its own antennas.



The primary station has a 22 element circular polarized yagi on a 100 ft crank up tower mounted on a trailer. This antenna uses computer controlled azimuth/elevation (AZ/EL) tracking. As a back up antenna for this station a vertical antenna was mounted on a tripod. A manual coax switch could select either the yagi antenna or the vertical antenna.

With the exception of the rotator control box, all of the equipment in the primary station was operated off a 100-amp hour deep cycle 12-volt battery. It was planned to power the rotator control box from a 12-volt to 120 volt AC inverter so that the station would be totally independent of AC power, but the consideration of possible noise generated by the inverter caused us to only have the inverter standing by. The computer used for the tracking of the antenna in azimuth and elevation was a laptop with an internal battery back up. This gave us complete operation capability independent of the AC power lines. Since the battery voltage was lower than the normal 13.8 volts of a battery under charge the maximum 160 watt power output of the power amplifier was reduced to only 100 watts but this should be and was adequate for the contact.

The FT-847 transceiver was followed by the 50 watt in / 160 watt out power amplifier. This power amplifier also had an internal low noise receiving preamplifier. This is a worthwhile addition to improve the signal to noise ratio of the received signal. If the power amplifier used does not have such a built in amplifier an alternative is to add a separate receive preamplifier.

The antenna output port of the power amplifier is connected to a Bird power meter so that the output power can be monitored. An indication of abnormal power output can save valuable time in switching to the back up station. The Bird power meter also provides a quick way to check the antenna SWR for reassurance that the antennas are connected and functioning properly. The output of the power meter is connected to the antenna switch so that a vertical antenna can be selected if problems with the primary antenna or tracking equipment/software develop.

The AZ/EL rotator used on the 100 ft crank up tower required a 12-conductor control cable. Because the only possible location for the 100 ft tower trailer was on an outside basketball court, we needed about 250 feet of control cable and RF cable. The school is located on a heavily forested lot. Because of the heavy tall trees surrounding the school we felt we needed to place the antennas 50 to 70 feet in the air in order to provide good coverage at acquisition of signal (AOS) and out to loss of signal (LOS). Luckily we had a 100 ft trailer mounted crank up tower available. But because of the long control cable requirement we had to look for a source of control cable. At this length the wire needs to be at least #18 AWG. We borrowed some sprinkler system control wire and soldered the 100 ft lengths together to make up the required cable, using four six conductor cables to make up each of the required 12 conductor cables.

The RF cable is also required to be about 250 ft long. Again we were able to borrow several long lengths of LMR 400 cable. This low loss cable is not as good as larger hard line but it was much easier to work with. Especially when hanging it off the side of the crank up tower. There were no other good antenna location options available. On top of that the horizon has some natural obstructions at both the AOS and LOS azimuth.

For antenna tracking we used a laptop computer running Nova software. An interface card between the computer and the rotator control box was obtained from EA4TX. This card digitizes the position indicator voltages from the rotator and compares the present position against the required position. Based on program settings for accuracy the interface closes the proper rotator control switch to drive the motor circuit to reduce the error. This allows tracking the space station from horizon to horizon totally under control of the tracking computer. The rotator used was a Yaesu G5400. The antenna used was a KLM 22 element circular polarized yagi mounted on an eight-foot fiberglass boom. This boom is mounted through the elevation rotator. Two pieces of telescoping fiberglass were used for stiffness. The coax feed line was routed off the back of the antenna and looped back to the rotator to keep it out of the circular polarized antenna field as much as possible. A KLM 432 yagi was mounted on the opposite end of the fiberglass boom.

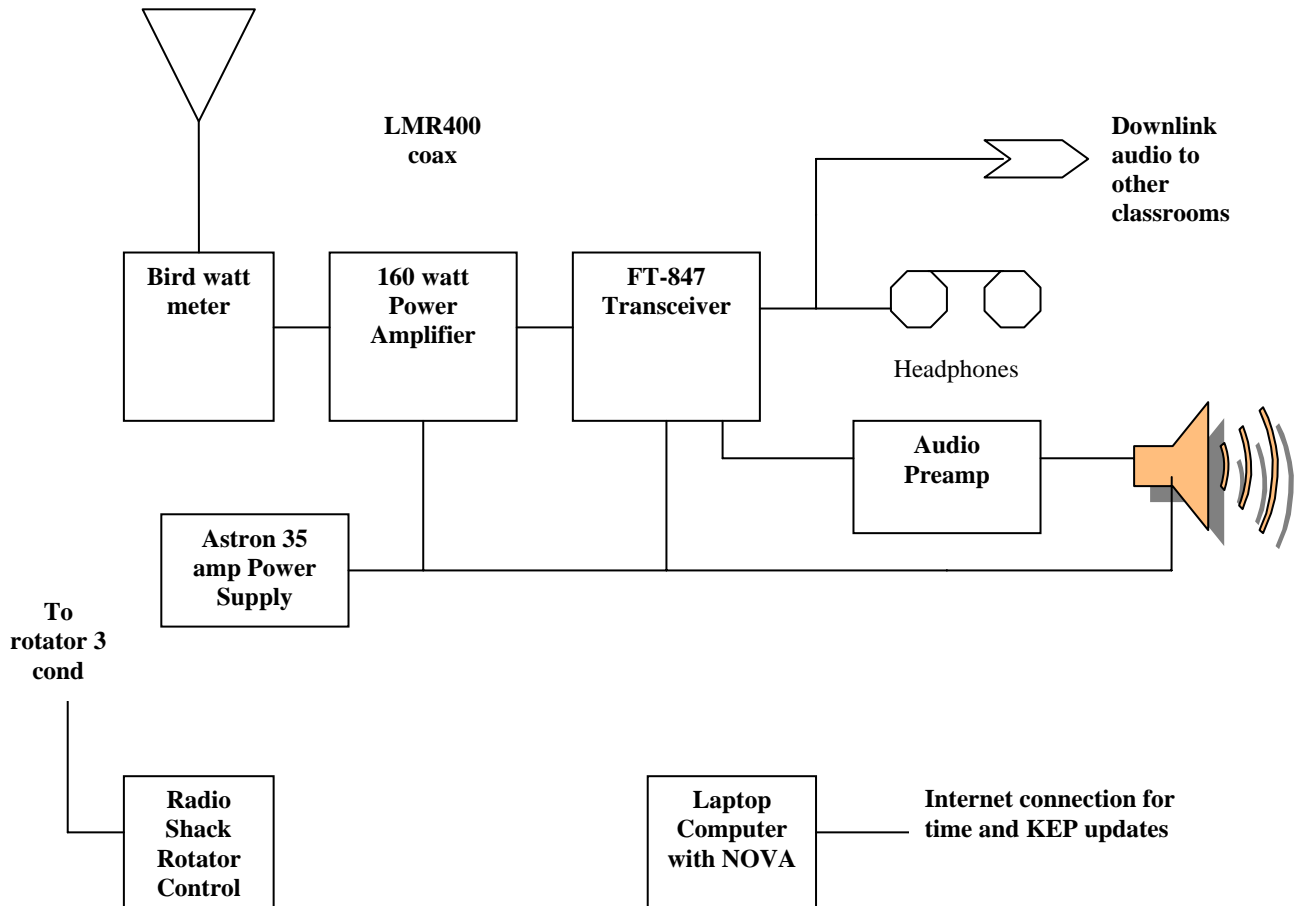
This antenna was used to work UHF up and VHF down satellites for system evaluation during station assembly and check out. It was left on the boom as a counter balance to the 144 yagi.

The primary station was rounded out with an audio system that consisted of a standard Yaesu desk microphone and an audio speaker system that consisted of an audio preamplifier that took the fixed level of receive audio out of the back of the FT-847 and amplified it for use with a pair of large computer speakers. This extra audio gain was necessary to raise the low level of the fixed audio output from the FT-847. With this addition the computer speakers powered from the 12-volt battery were more than capable of providing enough audio for the classroom. There was also an additional audio feed provided for two additional classrooms. Uplink audio was obtained from a two-meter hand held tuned to the uplink frequency. This was to provide audio for the additional classrooms where the students questions could not be heard directly. An audio mixer board (not shown in the block diagram) was used to mix these two audio signals for the external classrooms.

The backup station was set up much the same as the primary station.. The antenna was a 14 element circular polarized KLM yagi. This antenna was mounted at a fixed elevation on a small tripod. This tripod was mounted on a plywood base with four wheels so it could be easily positioned in an athletic field next to the school. The antenna was only movable in azimuth with a small TV rotator. The tracking for this antenna was done by manual control of the azimuth rotator. A second laptop computer provided the azimuth information. Two operators were used for the backup station; one operator controlled the antenna tracking and other operator making the Doppler frequency adjustments to the radio.

The back up station was powered from a 35 amp, 13.8volt power supply. A 160watt power amplifier followed the transceiver. This power amplifier was also equipped with a low noise receiving pre amplifier. An output power meter was provided in the antenna line of this station.

The microphone for the back up radio was the same type as the primary station. The two microphones were placed side by side on an elevated tabletop so the students could ask their questions while standing in front of the microphones. The push to talk switch was operated by one of the radio operators standing next to the microphones. To switch the uplink radio from primary to secondary it was only necessary to press the push to talk switch on the other microphone. This allowed for rapid switching from the primary to the backup station if required. To switch to the backup station on receive it was only necessary to turn up the speaker audio. The operators using headphones monitored the back up station audio. This rapid change is the advantage of two complete stations but only if carried through to this extent. With a contact that lasts less than ten minutes there is no time to change plugs or turn things on with out loosing a good deal of the time available. As they say, "this is rocket science". After waiting three and a half years for the opportunity to talk with the astronauts, you don't want to have some small (or major) failure cause disappointment for the students. This is why we set the two stations up before hand and checked them out. Everything went well, as we expected, but we were pleased all the effort had paid off. The excitement on the students' faces is compensation enough.



One subject that was never resolved to our satisfaction is which callsign should be used for the contact. We ended up using the teacher's callsign as was on the initial application. We believe the callsign used should be the one representing the organization doing the local work to make the contact possible.

After the event NVARC donated copies of *Now You're Talking* to Marilyn for her classroom and the school library.

Larry printed a photograph of each student at the microphone for them to keep. He also printed photographs of the group for Marilyn.

Marilyn had custom tee shirts for the students and other participants and gave a shirt and an ARISS patch to each of the NVARC members who participated. At our January club meeting Marilyn presented us a framed signed picture of the students.

Although not every student received a reply or got to ask a question they were all excited about the contact. There was an immediate discussion by our group about what could have been done differently to have lengthened the contact. The obvious problem was the location. If the hills could have been avoided 40 seconds might have been gained. This would have allowed all 20 questions and answers. Since there isn't much choice when it comes to the site it is important to

understand its limitations early so that expectations are realistic. Our feedback from stations further south along the track was that Bill could always hear us. The problem was that with the lower power from the ISS we could not hear him. Any improvements would have to address this fact. Since we had made an effort to have good antennas and coax only a few options were identified. One was to move the amplifier to the tower or base of the tower. Since the receive preamp is in the power amplifier this could result in a few db improvement. It does add a complication of adding a remote power supply and without a person stationed there it would be difficult to monitor performance. Adding a preamp at the antenna would be much more work because it would need a T/R switch. The second possible improvement would be to get a second 2M-22C antenna and use them as a stacked array. This could make a 3 db improvement in both transmit and receive. Another possibility is to remote the antenna and station to a better location. This would diminish the feel of a radio contact which is not desirable.

The current version of this document is available at [www.n1nc.org](http://www.n1nc.org) under the ARISS section.

#### Acknowledgements

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