ANDE AX.25 Satellite Network

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Abstract

ANDE is a follow-on digital communications payload to the highly successful PCSAT-1 [1] that was launched on 30 Sept 2001 and PCSAT2 that was launched on 26 July 2005 and recovered from the international Space Station on 2 July 2006. These satellites all use off-the-shelf standard AX.25 Packet TNC's for command, control and telemetry which greatly simplifies student payload design. ANDE, along with its companions of RAFT and MARScom are currently at Kennedy Space Center for integration with mission STS-116 currently planned for launch about mid December 2006.

These student built Amateur Satellite missions have taken advantages of synergisms in the Amateur Satelite Service, Student Education and experience, and science sponsors while operating within the rules of the Amateur Satellite Service[2]. MARScom is an experimental communications satellite for the Navy and Marine Corps Military Affiliate Radio System which is also operated by radio amateurs volunteers in that organization. All depend on the global network of Amateur Satellite Ground stations for recovering their downlink data and making it available to students worldwide.

Figure 1. The ANDE spacecraft during final tests at the Naval Research Labs in Washington DC. This photo shows the final tweaks of the antenna matching network to match the sphere to the 145.825 MHz operating frequency.

The ANDE Mission

The specific mission of ANDE is for observing the orbital decay due to the higher levels of the atmosphere. In this regard, ANDE is a perfect sphere with no external protrusions. To improve the ability of ground system to track it precisely, it has laser corner reflectors and its own lasers.

Because of its spherical surface requirements, the original ANDE mission indended to have no electronics since there could be no external antennas and no solar panels for power. But the Naval Academy came up with the concept for splitting the sphere in half and using an insulator disk so that the entire spaceframe could be used as an antenna. Then power could come from a very low power design driven from 112 "D" size lithium primary cells.

The digital communications mission implemented in PCSAT-1, PCSAT2, ANDE, RAFT and MARScom is a generic mission using the ubiquitous AX.25 protocol used in many of the satellites in the Amateur Satellite Service. The digital transponder provides real-time message, position, and status relay via satellite to a worldwide Internet linked amateur radio tracking system. Any amateur or university payload can support this mission by simply enabling the DIGIPEAT-ON function in any AX.25 compatible transponder (TNC). The users of such a relay system can be for Boats at Sea, remote environmental sensors[3], cross country travelers, expeditions, school projects, or any other users which are far from any existing APRS terrestrial digital network.

The AX.25 satellite downlink from this mission is fed into the existing worldwide Internet linked ground system by participating ground stations. Our ultimate objective is to have all such AX.25 satellites work together as a constellation of digital transponders to provide connectivity to everyone in the Amateur Satellite Service[4].

The Space segment of PCSAT/APRS had been demonstrated a number of times in space via MIR School tests[5,6], the Shuttle SAREX[7], the SPRE mission, AO-16, UO-22 and more recently via SUNSAT and ISS and PCSAT-1 and 2. Full details of each of these missions can be found at:

http://www.ew.usna.edu/~bruninga/pcsat.html
http://www.ew.usna.edu/~bruninga/pcsat2.html
http://www.ew.usna.edu/~bruninga/ande.html
http://www.ew.usna.edu/~bruninga/raft.html

http://www.ew.usna.edu/~bruninga/astars.html

AX.25 Digital Communications Protocol

An advantage of the AX25 protocol is that any node in the system can be used for relaying data between any other nodes. Thus, the TNC can not only provide the dedicated up and downlinks and command/control channels, but also serve as a generic relay for other applications on a secondary basis. Examples of TNC's on orbit are SAREX, SPRE, MIR, ISS, SUNSAT, OPAL, PCSAT-1 and 2, SAPPHIRE and STARSHINE-3. But PCSAT-1 was the first to use the TNC as the complete Spacecraft system controller with no other CPU's on board.

ANDE HARDWARE REQUIREMENTS

ANDE was designed around two KPC-3+ TNC's. These TNC's have all the latest APRS generic digipeating advantages as well as telemetry, command and control and can even cross route packets between ports and baudrates. By using standard off-the-shelf TNC hardware and FIRMWARE, on orbit risk was minimized due to the track record of thousands of identical hardware in use all across the country.

A dual redundant system was designed to assure mission completion using only these off-the-shelf components.

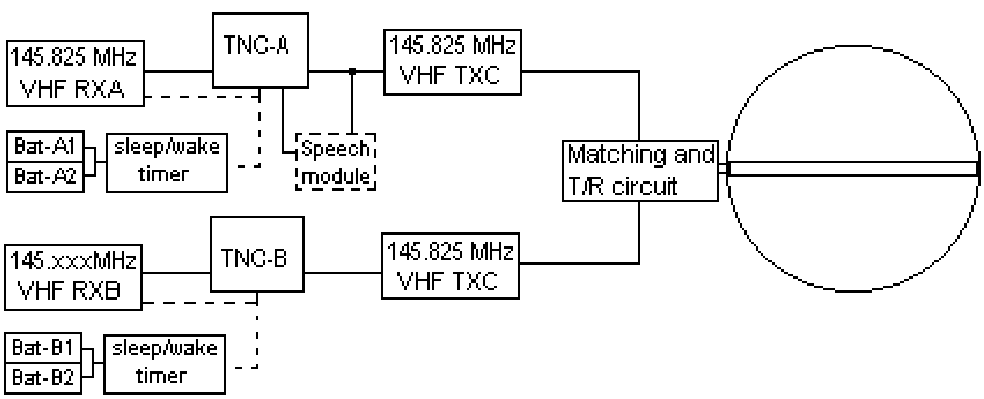


Figure 2. ANDE's dual AX.25 command and control system transponders based on KPC-3+ TNC's can also be switched into modes to support a packet-to-voice experiment. ANDE also carries a test-to-speech module as an added experiment in packet-to-speech communications. The sleep/wake timers save power by keeping everything including the receivers off when not in view of ground stations. Both transmitters feed the same spacecraft-shell/slot antenna system via a system of ¼ wave matching lines and PIN diode T/R arrangements. The lasers are not shown in this diagram.

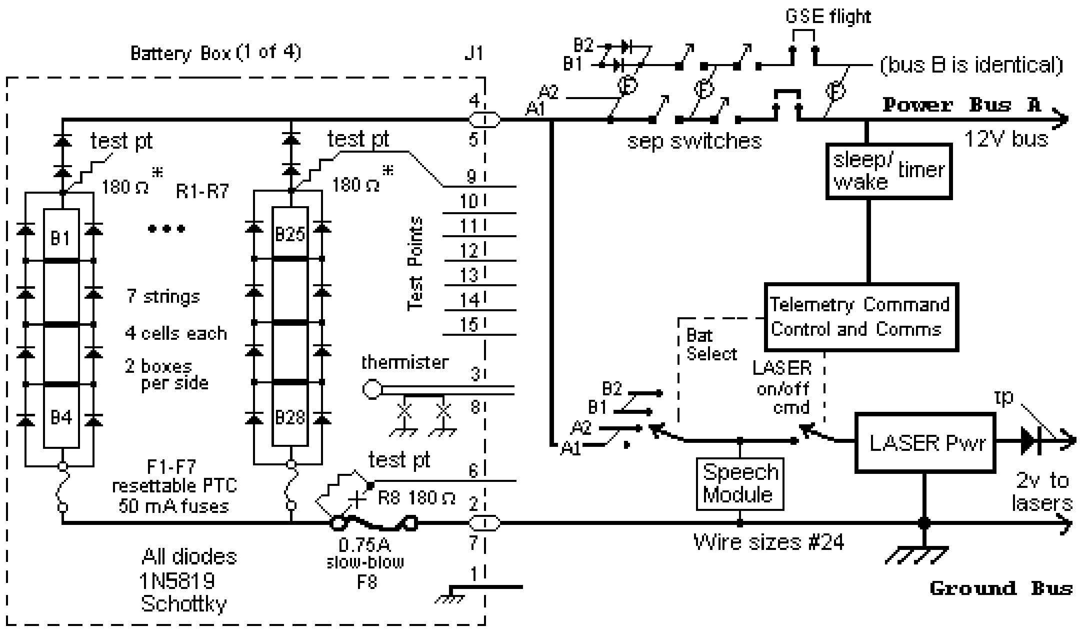
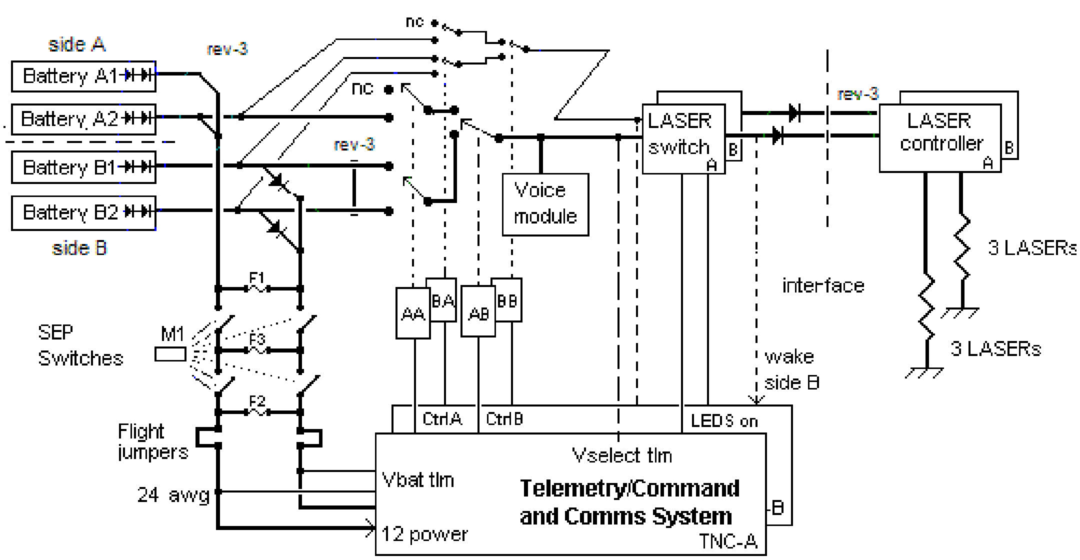


Figure 3. ANDE Battery System Schematic showing the one of the four parallel battry packs and the battery switching arrangement for the laser power system.



The TCC system is always redundantly powered by all battery strings. But the LASER load was to be separately powered from one battery pack at a time via RYA or RYB. But to get enough current, the A and B systems had to be paralleled. The C1-C3 lines are the 3 command switches per TNC controller.
A is primary, B is backup. All power system wiring is #24 awg.

Figure 4. ANDE Battery system consists of four battery packs of 28 cells each. These redundantly power the spacecraft system and transmitter, but they can be individually switched to power the lasers so that their berformance can be separately evaluated through the life of the mission as individual battery packs fade.

ANDE KPC-3+ Command and Control

The Kantronics KPC-3+ TNC as used on ANDE, has a serial comm port at 1200 baud and also 5 analog telemetry channels and three ON/OFF command bits. These features are sufficient to handle all of the Telemetry Command and Control for ANDE as detailed below.

ANDE Design for Space Station Deployment

ANDE will be carried to orbit on the Space Shuttle and as such it presented many design challenges in the areas of power, safety and thermal. The biggest concern was the 112 "D" cell Lithium primary cells connected in series parallel to provide the long mission duraiation (greater than one year) and the peak power needed for the transmitters. as shown in Figure 3.

Of particular note, however is the absolutely flat discharge curve of these Lithium cells. The curve does not begin to taper until more than 97% of the mission life was used up. This would give no warning to the life of the mission.

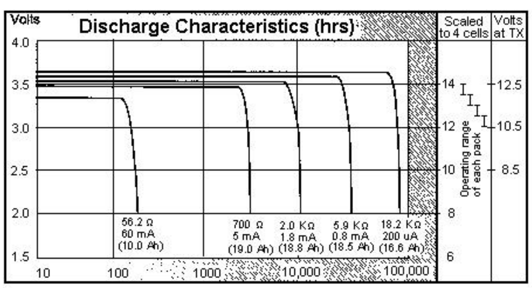


Figure 5. Lithium Primary Cells discharge curve.

To mitigate this, a power management scheme was devised to force an additional 0.5 voltage drop from the 3rd and 4th battery packs. This would provide a 0.5 volt taper from the initial life voltage where mostly the 1st and 2nd battery packs would carry the load. As the mission progressed we could detect the 0.5 long term voltage drop in telemetry and anticipate the end of life. With this knowledge, we could plan our operating load to match.

ANDE Spacecraft Design

The ANDE spacecraft has no solar panels and no external antennas. We were able to get a ride inside the hollow perfectly spherical aluminum spacecraft by splitting the shell into two halves and using the shell as an antenna at 2 meters and by using 112 "D" cell lithium batteries.

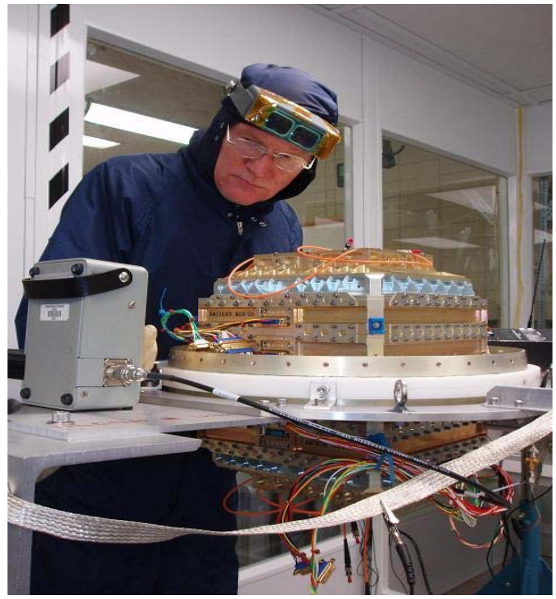


Figure 6. The photo above shows the identical top and bottom stacks. Each stack consists of two battery trays and then a Comm tray and topped by a smaller laser module.

This photo shows the final SWR tweaks to bring the hemispheres into resonance. The antenna actually is more of a slot antenna formed by making 18 of the 36 bolts that connect the two halves be conducting and 18 of them being insulating and feeding the insulated half in the middle.

The black and anodized paint scheme is to make the spacecraft visible to high power telescopes and the small laser reflectors are for tracking by the Maui Laser tracking station. ANDE also has 6 orthogonal lasers that we can turn on from the ground to aid in visibility to telescopes.

ANDE / ASTARS BACKGROUND

ASTARS, the APRS Satellite Tracking and Reporting System evolved through a number of existing and previous satellite experiments. First was **1200 Baud PSK ASTARS** called TRAKNET [11] at the 1998/99 AMSAT conferences, using AO-16, LO-19 and IO-26. But these required specialized modems.

Photo 7. Chas Richard, W4HFZ's mobile APRS Satellite capability (including HF.

Then space station MIR carried a packet experiment using **1200 Baud AFSK**, which *any* TNC could do and this brought satellite APRS to just about everyone[6] and SAREX[7]. A week long experiment via MIR using the new Kenwood TH-D7 [5] resulted in over 55 stations with 2-way hand-held message communications.

In the year 2000, **9600 BAUD ASTARS** using UO-22 and SUNSAT and the new Kenwood 1200/9600 baud TM-D700 APRS data mobile radio were successful. In 2001 PCSAT-1 was launched and then PCSAT2 in 2005. AO-51 was finally enabled for APRS digipeating (9600 baud) in the spring of 2006.

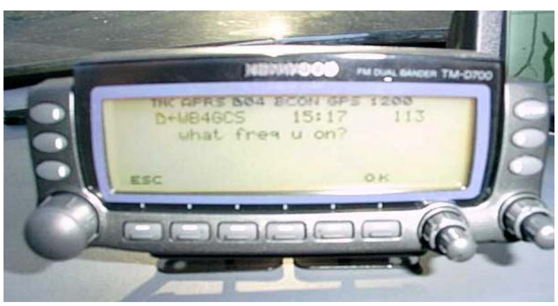


Figure 8. The front panel APRS message capability of the Kenwood D700 radio. Messages can be up to 64 characters in length.

PCSAT and the INTERNET

Like our PCSAT-1 and PCSAT2 satellites, ANDE capitalizes on the connectivity of the Internet by linking together multiple downlink sites to provide a tremendous gain in reliability through space and time diversity reception. The Internet allows a few stations, called SAT-Gates (Satellite IGATES) to combine all packets heard into the existing worldwide APRS infrastructure for delivery to any APRS operator anywhere in real time.

FAILSAFE RESET

To save power and also to provide immunity from a SEU or other lockup condition in space in these commercial off-the-shelf TNCs, ANDE gets a power-up cold boot every 16 seconds to check for channel activity. If it hears any ground stations, it will remain awake for the next minute to support communications. But at LOS, after 1 minute, it will go back into the power-saving on/off cycle.

TELEMETRY

ANDE uses the APRS five channel Telemetry format used in the Kantronics family of TNC's with an added 20-to-5 hardware multiplexer to allow telemetry to read as many as 20 analog values and 5 status bits transmitted in four consecutive telemetry packets.

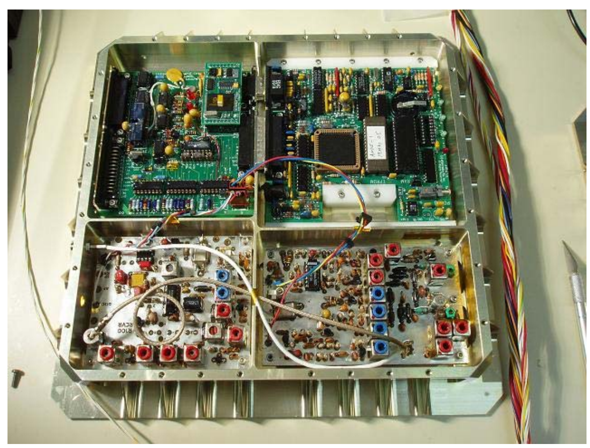


Photo 9. The KPC-3+ TNC system with Hamtronics TX and RX inside the ANDE comms tray.

LINK BUDGET

The primary driver of this APRS Satellite design was to deliver messages to handhelds and mobiles with only whip antennas. For this, the downlink needed to be at least 12 dB stronger than most existing digital satellites. ANDE accomplishes this with a 2m downlink (+9 dB over UHF.

Also, the digital trasnponder operates at a low transmit duty cycle so it is easy to power relatively high power transmitters. The Amateur Satellite user population only covers 10% of the earths surface and with the low duty cycle of the ALOHA style of APRS operations, less than 4% of ANDE's average transmit power budget is required for AX.25.

The VHF link budget on the uplink is also suitable for low power devices and other experiments. There are several student projects using stand-alone tracking devices or data collection buoys or remote WX stations such as the one built by Ronald Ross, KE6JAB in Antarctica [3].

SAT-GATE OPERATIONS

Although Mobile-to-mobile and HT-to-HT communications work well, the more useful application is linking these packets to any other APRS station worldwide through the network of many volunteer ground stations. They feed every packet heard into the APRS-Internet system (APRS-IS).

OMNI NO-TRACK SAT-GATES

Setting up a SATgate is trivial requiring nothing more than a normal packet station and omni antenna running any APRS software with Igate capability. Even without the map features of conventional APRS, the ALOGGER program by Bill Diaz provides a background data capture and SATgate capability as well. Even though a vertical whip will not provide horizon-to-horizon coverage, each such station simply contributes their packets to the same worldwide stream as all the other Igate receivers. The combination results in over a 99.96% chance of capturing every packet over the USA! Just a few such stations even if they only have a 60% chance of decoding each packet, combine to a probability of 98%. If the original packet is replicated TWICE, then this probability becomes 99.96%! A Certainty!

CONCLUSION

Everything is going wireless. And Ham radio HT's and especially the TH-D7 HT with built-in APRS capability give ham radio operators a satellite messaging capability in the palm of their hands. This satellite capability should be a major driver for future amateur satellite and educational missions.

AX.25 transponders on 145.825 MHz are ideal for extending Amateur Satellite digital services to mobile and handheld users because of the availability of not only the off-the-shelf end user mobile and handheld fully integrated data radios but also the off-the-shelf spacecraft design demonstrated by PCSAT-1 and PCSAT2 and the future missions of ANDE, RAFT and MARScom

Combining this with the Internet as a global resource for exchanging data worldwide suggests a unique opportunity throughout the world where the infrastructure exists to extend worldwide amateur communications to mobiles in areas where it doesn't exist.

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