Figure 1. Meeting at SpaceQuest, February 8, 2002. This photograph was taken during a joint meeting of the project team and the AMSAT-NA executive committee with SpaceQuest on February 8, 2002. Shown, clockwise from the left, are Linda Jacobsen (SpaceQuest), Art Feller W4ART (AMSAT-NA Treasurer), Rick Hambly W2GPS and Dick Daniels W4PUJ (AMSAT OSCAR E project team), Dino Lorenzini KC4YMG (SpaceQuest), Robin Haighton VE3FRH (AMSAT-NA President), and Keith Baker KB1SF (AMSAT-NA Executive Vice President). In attendance but not shown is Mark Kanawati N4TPY (SpaceQuest).

AMSAT OSCAR-E
A New LEO Satellite from AMSAT-NA

Rick Hambly, W2GPS (w2gps@amsat.org)

AMSAT-NA has embarked on the construction of a new Low Earth Orbit (LEO) satellite that will be called AMSAT OSCAR-E, or "Echo" until it achieves orbit and receives the next sequential OSCAR number. Keith Baker KB1SF was referring to this satellite when he introduced a new "MICROSAT-class project" in the Apogee View column of the March/April issue of *The AMSAT Journal*.

Notice that with this satellite AMSAT is returning to the practice of designating LEO satellites by sequential characters. This was last done for AMSAT OSCAR-D, which became AMSAT OSCAR-8 after launch and commissioning. AMSAT didn't use letters for the first four Microsats and the Phase 3 series started again with "A".

It has been 12 years since AMSAT-NA built and launched the original Microsats in 1990, and 8 years since AO-27 was launched in 1993. AMSAT OSCAR-E will put AMSAT-NA back in the satellite business while providing an improved companion for AO-27, which has been very popular with hams for the past 8 years, but is getting old. Space and power are available for one or more optional payloads that will be provided by AMSAT volunteers.

The AMSAT OSCAR-E project team is led by Dick Daniels, W4PUJ and includes Tom Clark, W3IWI and Rick Hambly, W2GPS. Oversight of the project team is provided by the AMSAT-NA executive committee and the Board of Directors. The core of AMSAT OSCAR-E will be built by SpaceQuest, Ltd. a company that is owned and staffed largely by AMSAT-NA members including Mark Kanawati, N4TPY and Dino Lorenzini, KC4YMG.

Figure 2. A mockup of AMSAT OSCAR E in front of an original AMSAT Microsat

The remainder of this article will be divided between an overview of the core satellite systems and descriptions of candidate optional payloads. (The information in this article borrows heavily from "Microsat Mission Study Report" by Mark Kanawati, N4TPY, commissioned by AMSAT-NA and submitted by SpaceQuest, Ltd. to AMSAT-NA on January 9, 2002.)

AMSAT OSCAR-E: Core Subsystems

In the decade since AMSAT-NA built the Microsats, SpaceQuest has made many improvements to the Microsat concept. AMSAT OSCAR-E's core subsystems closely resemble those of the original Microsats but show the benefit of years of development and technology advancements.

The subsystems that make up the core elements of AMSAT OSCAR-E are:

- The physical structure
- Attitude control
- Central processor hardware
- Spacecraft flight software
- Power generation and distribution
- Command and control – ground station and satellite
- A basic set of receivers, transmitters and antennas
- Space for optional payloads

The satellite with just this set of subsystems will have an impressive array of functions including FM voice operation (EasySat), 9600 bps data channel(s), and a multi-band receive capability.

AMSAT OSCAR-E is a Microsat class spacecraft weighing approximately 10 kg. The spacecraft consists of five solid aluminum trays, each with four walls and a bottom stacked to form approximately a 10-inch cube structure. A top cover is provided for the top tray. Six solar panels attach to each of the six sides for power generation. Additionally, several antennas protrude from the top and bottom surfaces. Figure 2 is an example of what the AMSAT OSCAR-E structure might look like, although the antennas will be quite different. Note the similarity to AMSAT's original Microsats, as shown by the full size model in the background. These original Microsats were AO-16, DO-17, WO-18, and LO-19. They were followed by the descendents of that legacy, including IO-26, AO-27, MO-30, and SO-41.

Internally the spacecraft consists of a various electronic subsystems including:

- 4 VHF receivers,
- 2 UHF transmitters,
- 6 modems,
- Flight computer,
- RAM disk,
- Batteries,
- Battery charger and voltage regulators,
- Wiring harness,
- RF cabling,
- RF switching and phasing networks,
- 56 channels of telemetry, and
- Magnetic attitude control.

Figure 3 shows a conceptual block diagram of the AMSAT OSCAR-E spacecraft. The items enclosed in dashed lines are not a part of the basic AMSAT OSCAR-E mission, but are under consideration as secondary payloads.

Physical structure

AMSAT OSCAR-E's overall structure consists of a stack of five machined aluminum modules. Each module measures approximately 9.5 inches x 9.5 inches. The height of each module is adjustable up to a total of 9.5 inches. The nominal useful internal area is approximately 8 inches x 7.5 inches. Each module houses a different spacecraft subsystem.

Modules are interconnected by RF cables and a wiring harness carrying power, inter-module data, telemetry, and control signals. Four machined rods running the height of the spacecraft are used to bolt the assembly together. Figure 4 shows a photo of a typical Microsat structure.

AMSAT OSCAR-E employs a passive thermal control system and has no on-board propulsion. Almost all of the satellite's surface area is covered by solar cells. Some surface area is required for antenna mounts and launch vehicle interfaces. The remaining surface area is covered with thermal absorbing and reflective tape to balance the spacecraft's thermal behavior.

A separation mechanism needs to be designed to adapt the satellite to a particular launch vehicle. Finalizing the separation mechanism will await selection of a launcher although one version already exists for the Russian Dnepr launcher due to SpaceQuest's previous use of that launch vehicle. Dnepr is a de-militarized Russian ICBM.

A standard commercial shipping container will be used to transport the AMSAT OSCAR-E to the launch site.

Attitude control

The basic AMSAT OSCAR-E passive attitude control system consists of two permanent magnets that align the satellite's vertical axis with the Earth's magnetic field, four hysteresis damping rods that control the satellite spin rate, and reflective/absorptive tape that cause the satellite to rotate about its Z-axis as a result of solar photon pressure. This simple, no-power technique has been demonstrated to work well on several previous Microsat missions. The solar-induced spin averages out the thermal load on the satellite, while the permanent magnets allows one end of the satellite to point generally towards the earth.

The many advantages of this simple passive attitude control system are offset by one significant limitation. The permanent magnets cause the satellite to make two rotations per orbit resulting in one face favoring the Northern Hemisphere and the opposite face favoring the Southern Hemisphere. The Earth-pointing direction is on the order of ±20 degrees in the temperate zones, varying with orbital inclination.

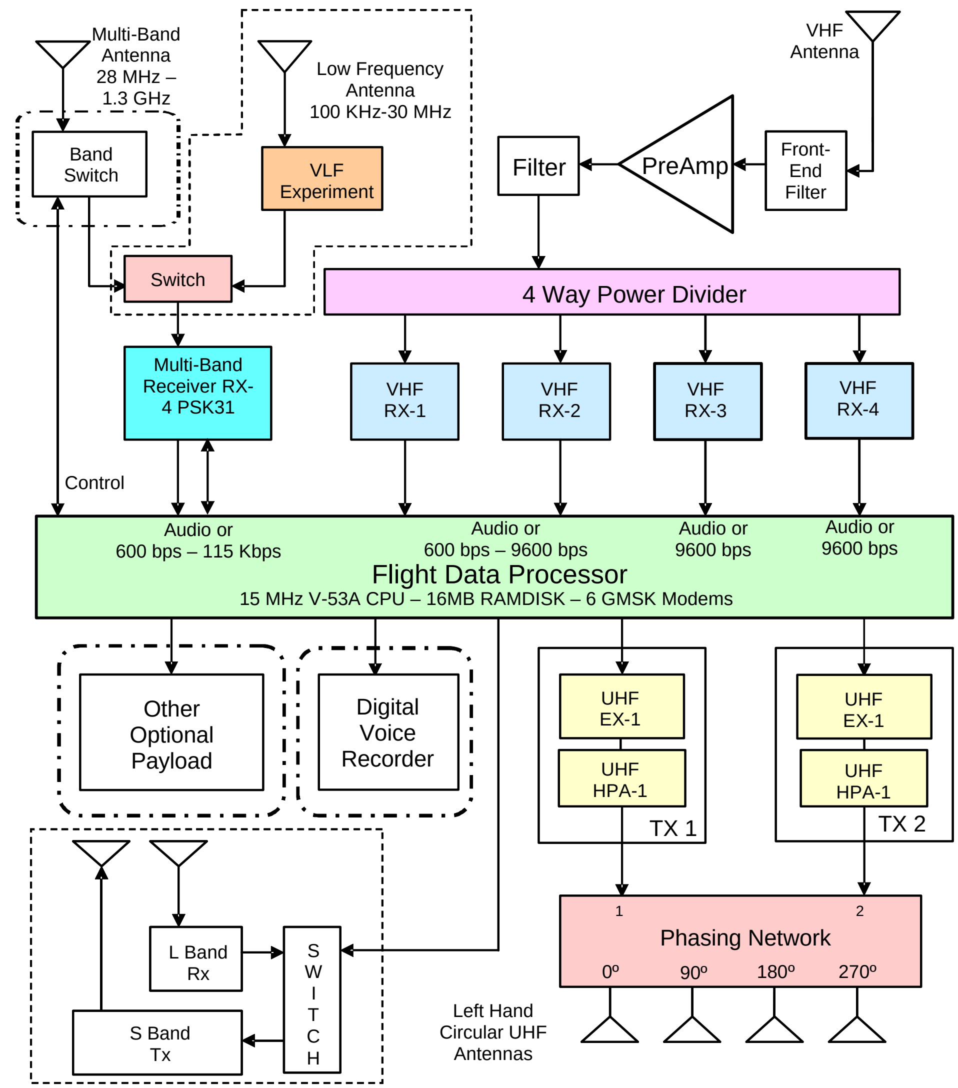

Figure 3. Conceptual Block Diagram of the AMSAT OSCAR-E Spacecraft

Central processor hardware

AMSAT OSCAR-E includes an Integrated Flight Computer including the central processor unit (CPU), random access memory (RAM), RAMDISK, and modems. All of these functions are incorporated on a single, multi-layer, both-sides-populated PC board.

The CPU is a flight-proven, low-power NEC V53A processor. This processor first flew in 1993 on AO-27, and has flown on a number of LEO missions since. It is based on an x86 core and runs the Spacecraft Operating System (SCOS), also flight proven on numerous spacecraft. See Figure 5.

The processor is clocked at 29.412 MHz, running the bus at 14.7456 MHz. This yields three times greater processing throughput and three times faster interrupt response than previous missions using this processor.

The boot ROM uses a standard CMOS EPROM running a variant of the Microsat Boot Loader (MBL). The EPROM is divided into two sections, alternately mapped into memory space with each RESET command. Thus, if a partial failure of the EPROM occurs, the satellite operating system can still be booted. This

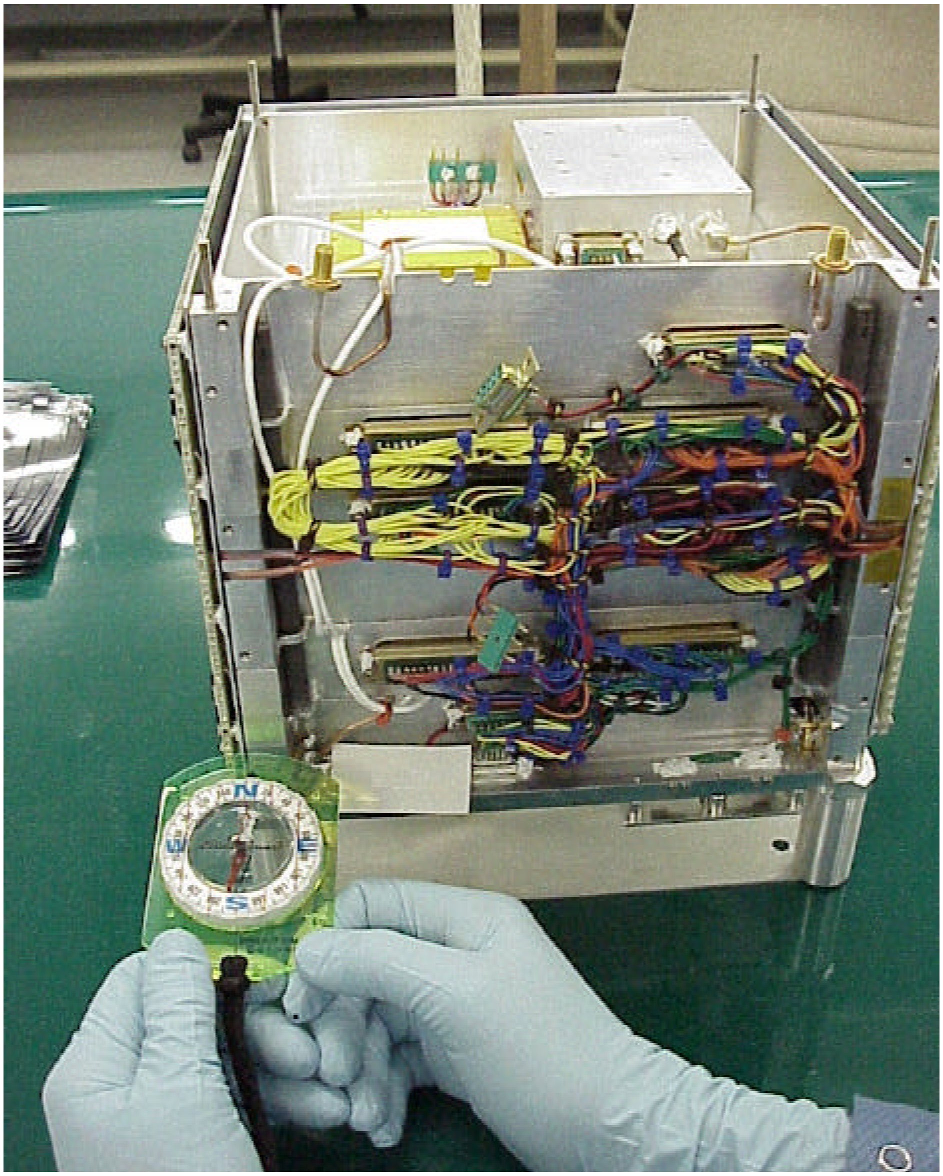

Figure 4. Typical Microsat Structure

technique has been flown successfully for several years.

The main memory system is error-detecting and correcting (EDAC) using bit-wise triple mode redundancy (TMR). TMR allows the safe use of wide-word memory, in this case 512Kx8 static RAM (SRAM) chips. The overall EDAC memory size is one (1) megabyte. A portion of this memory space is remapped to allow the boot read-only memory (ROM) to occupy the highest memory addresses.

A RAMDisk consisting of 16 megabytes of serial-accessible static memory are provided for bulk storage of data. This memory has no hardware error correction mechanism, so error control must be handled in software. This technique has successfully been used since the Microsats launched in January, 1990.

A 16 megabyte NAND-Flash memory is included for rapid re-booting of the operating system and application tasks after RESET. This is modeled after the successful FLASH operating system image reload facility of IHU-2 aboard AO-40.

Six (6) GMSK modems are included. At least one will be fixed-rate for primary command and control of the spacecraft. Each modem is attached to a dedicated multi-protocol serial port based on the NEC 72001 SCC. Two of the modem uplink channels are fitted with firecode detectors to provide ground-commandable RESET regardless of the state of the CPU. The variable-rate modems can go as slow as 600 bit/s and as fast as 115.2 kbit/s. The uplink and downlink data rates are set independently. Two (2) of the modems are DMA-capable, the other four (4) are interrupt-driven only. Care must be exercised to ensure the CPU is not overloaded with interrupts during mission planning and general spacecraft operation.

Up to eight (8) open collector N-channel FETs provide power switching control (low side switching) and several bits of 3.3V CMOS-level I/O are included. A pair of SPI ports is available for command and control functions to various modules in the satellite.

Approximately 56-channels of telemetry will be gathered on board AMSAT OSCAR-E. Eight-channel telemetry boards with 10-bit analog-to-digital converters are located in four of AMSAT OSCAR-E's trays. A Serial Peripheral Interface (SPI) bus links the telemetry boards to the central processor. Twenty-four telemetry channels are built into the Battery Control Regulator (BCR) board. The telemetry includes:

- All of the solar panel voltages, currents and temperature,
- Battery voltages, currents, temperature and charge polarity;
- BCR regulated voltages and currents;
- Temperature of the receiver, transmitter, central processor, and switching regulators;
- Multi-band receiver signal strength indicator; and
- The high-power amplifier output and reflected power on both transmitters.

A dedicated SPI bus is used to channel the telemetry from the BCR and the individual telemetry boards to the central processor.

Spacecraft Flight Software

The boot loader provides the minimal set of functions required to verify the satellite health and load the operating system. The boot loader runs on the initial power up, and whenever a software or hardware reset occurs. Because it resides in permanent memory and cannot be changed after launch, the boot loader is simple, robust and proven.

The boot loader provides the capability to:

- Send acknowledge beacons
- Upload new software
- Download memory locations
- Peak and Poke memory and I/O
- Load software from FLASH or error-detecting and correcting memory (EDAC), and
- Execute operating system by command or timer

The Spacecraft Operating System (SCOS) has been used on all of the Amateur Radio Microsat projects to date. The operating system and the housekeeping task are contained in EPROM and are moved into RAM for execution by the boot loader. In addition to detailed telemetry reporting, the housekeeping functions include control of the power system, transmitters and receivers. If needed, it can also support minimal attitude control. As was the case for the boot loader, the operating system and minimal housekeeping task are unchangeable after launch. However, updated versions of these programs can be uploaded and executed after launch. In order to be robust and proven, this version of the housekeeping is kept as small as possible. The list of off-the-self programs that execute as tasks include:

- Memory file manager (M-FILE) from Surrey Satellite Technology Ltd (SSTL),
- PACSAT File Transfer Level 0 (FTL-0) from SSTL,
- Transmitter Scheduling and Power Monitoring from SpaceQuest, and
- Supervisor Task Loader and Monitoring from SpaceQuest.

The Mission Software provides complete control over all aspects of the satellite, including experiments and attitude control. This software can be loaded into FLASH from the ground after launch, which allows for flexible development and deployment of new software. The

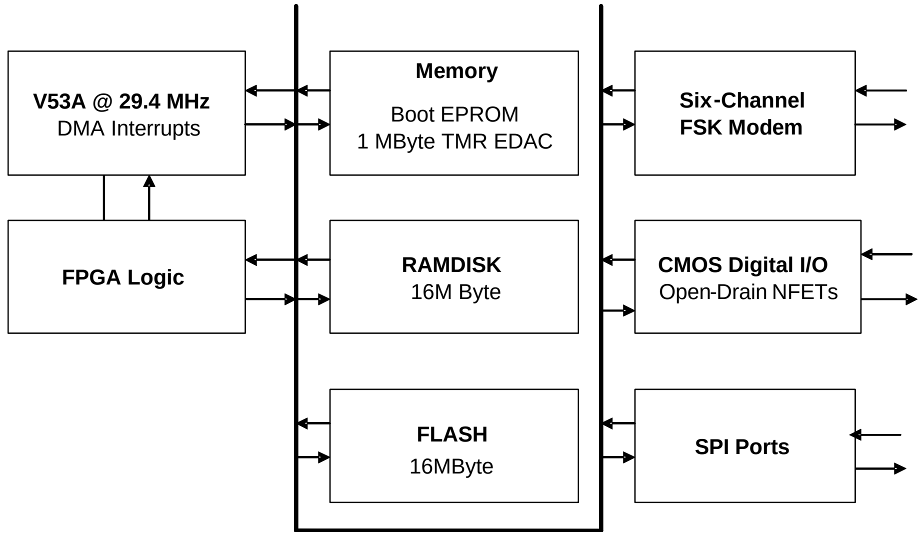

Figure 5. AMSAT OSCAR-E Central Processor Unit

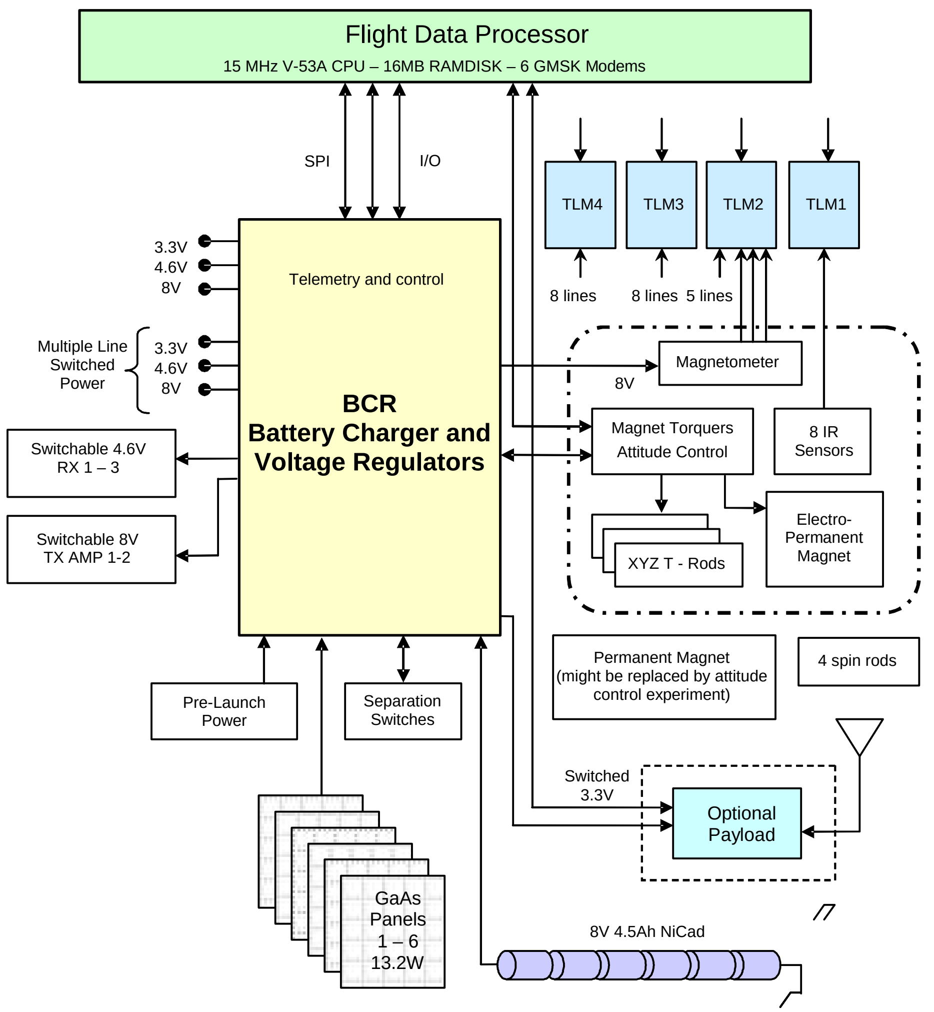

Figure 6. AMSAT OSCAR-E Power, Telemetry and Attitude Control Block Diagram

complete set of software should include:

- Multitasking Spacecraft Operating System (SCOS) from BekTek
- Advanced Task Supervisor
- TX and RX muxing and control
- Telemetry monitoring, storage and reporting
- RAMDISK management and PACSAT protocol
- Scheduling for regional satellite access
- Magnet torquer and IR attitude control
- Optional experiment control
- Addition experimental tasks, such as the digital recorder

Power generation and distribution

The AMSAT OSCAR-E Power Subsystem consists of a Battery Control Regulator (BCR), GaAs solar panels, matched flight cells, voltage regulators and a power activation switch. A block diagram of the power subsystem is shown in Figure 6.

The Battery Control Regulator (BCR) provides a power control system designed by SpaceQuest for small satellites. Its function is to convert solar panel power to system power, and manage battery charge and protection. The BCR takes power from solar panels with necessary restraint so as not to draw too much current and lose panel efficiency. The main converter on the BCR uses this solar panel power to charge the system battery, with similar restraint so as not to overcharge the battery. The battery charge system sets maximum charge voltage according to cell temperature, to maximize charge storage while avoiding overcharge and cell heating. The charge regulator is also prevented from reducing solar panel voltage below a preset voltage, to maximize panel output power. The maximum battery charge voltage set point and the minimum solar panel voltage set point can be adjusted by external computer control. The battery charge regulator is a switching design with a measured efficiency of 89 percent.

The BCR is designed to operate autonomously, with CPU supervision for fine-tuning of default parameters. The BCR will safely manage battery charge during the critical period after separation and before ground operators establish control. On-board software can then fine-tune the solar panel and battery charge limit set points for maximum performance with minimum attention.

Six GaAs Solar Panels, which are mounted on all six sides of AMSAT OSCAR-E, produce a bus voltage of approximately 16 volts. The cells have not been selected yet but the minimum efficiency will be 19% and cells with efficiencies up to 28% are available. The choice depends on their price and availability at the time the solar panel decision is made.

The battery configuration is six NiCd cells at 4.4 Ah each with a nominal battery voltage of 8 V dc depending on temperature and charge state. These matched batteries have been flown successfully on previous Microsat missions and are well-characterized on orbit.

The BCR provides multiple switched 8-V lines for both transmitters and other high power applications. There are also 3.3-V and 4.6-V switching regulators, capable of over 250 mA output each, with multiple switched and unswitched outputs.

Separation-switch circuitry is included on the BCR to turn all systems off while the satellite is mounted on the rocket. An external connection port is provided with two levels of separation switch override to safely charge satellite batteries and test the satellite while it is mounted on the rocket.

Command and control – ground station and satellite

The Bootloader Command and Control application communicates with AMSAT OSCAR-E's bootloader to allow the user to upload necessary code changes, or to load and execute the operating system and tasks. This program will need to be rewritten for AMSAT OSCAR-E. The current version of this software runs under DOS.

The Housekeeping Command and Control program communicates with each of the tasks onboard the satellite. It must be customized to support each additional task. Its primary use is to configure the satellite. The housekeeping command and control software is also currently DOS based.

The Telemetry Gathering and Reporting program is a standalone Windows application that will need to be developed for downloading and displaying satellite health information. This application would monitor a serial port, listening to the telemetry downlink and whole earth data files.

A basic set of receivers, transmitters and antennas.

The VHF antenna consists of a very thin quarter-wave (18-inch) vertical whip mounted in the center of the top surface of the spacecraft. This piano-wire antenna connects to the spacecraft with a standard SMA connector, and has been flown on several previous Microsat missions.

The antenna feeds the low insertion loss bandpass filter prior to entering the GsAsFET Low Noise Amplifier with a noise figure of less than 1 dB and a gain of 18 dB. Additional filtering is accomplished by a second bandpass filter. A four-way power divider channels the incoming signal into four VHF receivers

Four miniature VHF FM SpaceQuest receivers are used for both command & control and for user links. Each receiver consumes less than 40 mW and weighs less than 50 gm. Typical sensitivity is –122 dBm. The receiver's IF bandwidth can be configured prior to flight at either 15 kHz or 30 kHz, based on data rate requirements. They are capable of passing either analog or digital data up to 14.4 kbit/s. All of the receivers are fed directly into GMSK modems on board the Flight Data Processor. These receivers have flown successfully on several low-earth orbiting spacecraft.

AMSAT OSCAR-E has two SpaceQuest UHF FM transmitters that have been flown on several previous Microsat missions. Each transmitter contains a PLL-based exciter and a Motorola high-power amplifier. The unique characteristics of this design include its small size, low mass, high efficiency, on orbit adjustable output power from 1 to 12 watts and its nominal operation is at 7.5 volts. Analog or digital data rates up to 56 kbit/s and beyond are possible.

The overall gain of the UHF power amplifier is 39 dB, generating up to 12 watts of RF output with a single carrier at more than 60% efficiency excluding the 2mW exciter. Both transmitters can be operated at the same time into a single antenna system. High power on the UHF downlink is needed to offset the extra path loss at UHF frequencies balancing the VHF uplink. High downlink power will also permit transmissions at higher data rates and/or enable true hand-held voice or data operation. The high efficiency reduces the heat generated and absorbed in the spacecraft and increases the useful life of the transmitter. The measured output of the UHF high power amplifier at 40 °C is shown in Figure 7.

AMSAT OSCAR-E has a UHF Turnstile Antenna that is fed by SpaceQuest's hybrid antenna phasing network consisting of a strip line circuit that provides the appropriate quadrature phase and amplitude to each of four output antenna ports with less than 0.5 dB of insertion loss.

AMSAT OSCAR-E: Candidates for Optional Payloads

The following are brief abstracts describing the optional payloads under consideration for the AMSAT OSCAR-E mission. Other outstanding proposals have been suggested but were rejected in the first cut by the project team for a variety of factors including feasibility, value to the Ham community, cost, power budget and risk. It is almost certain that more cuts will have to be made because it is not possible to support all the remaining payloads on a single satellite the size of AMSAT OSCAR-E.

1. *Advanced Data Communications for the Amateur Radio Service (ADCARS):* This payload supports the proposal by KA9Q and others for applying digital encoding techniques to improve communication links and bandwidth utilization. This system would use a wide-band TDMA single frequency data link to support multiple simultaneous users and modes (voice, data, video, telemetry, etc.). The downlink will be S-band, due to the bandwidth requirements. The uplink will be L-band if the single frequency TDMA wide-band uplink is implemented.

2. *L-Band/S-Band Communications System:* This payload, proposed by KA0ESA of AMRAD, describes a capability similar to that required to support the ADCARS experiment.

3. *GPS Receiver:* This payload was proposed by W3IWI and W2GPS. Unfortunately the NASA PiVoT GPS receiver that we had hoped to carry will not be available. If a receiver of the right size and low power requirement can be found, this payload will be re-considered.

4. *Active Magnetic Attitude Control:* This experiment has the potential for significantly improving the stabilization of the spacecraft. Several possible attitude control system (ACS) configurations will be investigated. The simplest ACS concept is to replace the permanent magnets with semi-permanent electromagnets. While physically passive, electronics are required to polarize and condition the magnetic rods. Another more involved ACS concept is to use three miniature torque rods for attitude control and a magnetometer for attitude determination.

5. *Audio Recorder Experiment*

This experiment, proposed by KK7P, will provide the capability for recording and playing back any audio channel. It is particularly useful in recording data from the Multi-band receiver to support the low frequency experiment.

The ADCARS experiment team has recognized that, with minimal changes, the hardware for the Audio Recorder Experiment could also serve the ADCARS needs for computing resources.

6. *Low Frequency Receiver:* This experiment, proposed by AMRAD, uses the LF capability of the on-board multi-band receiver to study LF propagation phenomenon from the unique observation point above the ionosphere, particularly at 136 kHz.

The receiver and antenna whip are already on the spacecraft but a new E-field antenna interface amplifier and antenna switching hardware will need to be designed if this project is to be supported.

7. *APRS:* This payload will provide a generic APRS digipeater to support and encourage mobile and handheld satellite digital communications. The target ground system assumes a user with a 9600-baud integrated TNC/Radio with an omni antenna, either an HT or a mobile. The spacecraft simply digipeats all UI packets addressed via the paths of APRSAT, RELAY or WIDE. The spacecraft digipeater does call sign substitution like all APRS digipeaters and substitutes its own call after it digipeats the packet.

While it is not optimal for portable and mobile users, incorporating an APRS capability in the spacecraft can be done within the spacecraft basic bus, requiring no additional hardware if 9600 FSK is used with VHF uplink and UHF downlink. The downlink will have to share bandwidth with spacecraft telemetry and other data downlinks. Some switching capability in one of the receivers may be required.

The implementation of APRS that is being considered would also allow for a *store-and-forward* mode, where copies of APRS packets are saved until the satellite is in range of a known APRS Internet Gateway station, when the APRS data can be downloaded at high speed on an encoded data link for high reliability.

8. *PSK-31:* Proposed by WB4APR, transponding using the PSK-31 technique can be accomplished using the communications capability of the basic spacecraft bus. Uplink would utilize 10 meter SSB reception through the multi-band receiver. Downlink would be via one of the UHF transmitters.

9. Multi-band Receiver/Antenna: Proposed by SpaceQuest, this receiver has already been tested in space and can provide a receive capability over a wide range of frequencies from LF through L-band. The development of the antenna is challenging and it is currently unclear if the broadband antenna would be optimized for LF/HF (through 30 MHz) or for VHF/UHF (10 meters through UHF) or both. A separate antenna will be provided for L-band.

10. High Efficiency Solar Arrays: Included in the SpaceQuest proposal to AMSAT, the additional power that would be made available for the experiments would clearly benefit the experiments. Efficiencies of up to 28% might be achieved using a combination of *flexible cells* with a new mounting and substrate design invented by SpaceQuest.

11. Robust Telemetry Link: This experiment would demonstrate the value of using FEC and interleaving encoding techniques to improve telemetry reception by ground stations. This technique was developed by KA9Q and others for AO-40, where it is now being considered for implementation.

Summary

The core elements of AMSAT OSCAR-E are under construction now by SpaceQuest. The AMSAT OSCAR-E project team is working to finalize plans for the optional payloads.

There is the possibility that a launch opportunity might arise before the optional payloads could be ready. If this happens it is conceivable that the spacecraft would be launched as an *EasySat* only, with few, if any, optional payloads. However, it is considered likely that AMSAT OSCAR-E will be the first in a series of new low-cost LEO satellites, each to carry optional payloads of interest to the AMSAT community.

AMSAT OSCAR-E will be a step forward in the evolution of Microsat technology, with better receivers, higher power transmitters, and new operating modes. The user community will see a strong set of features from the basic satellite, even before optional payloads are added. These include:

- Analog operation including FM voice.
- Digital operation including high speed APRS.
- Higher downlink power.
- Multiple channels using two transmitters.
- Can be configured for simultaneous voice and data,
- Has a new multi-band, multi-mode receiver.
- Can be configured with geographically based personalities.
- Has a dual circular UHF antenna that maintains its circularity over a wide range of squint angles.

For those with an interest in the technical infrastructure of the satellite there are significant improvements in AMSAT OSCAR-E:

- Faster and more capable IHU processor.
- Higher data rates on downlinks.
- Autonomous, self-healing, high efficiency power management system.
- Upgraded, highly capable, software package.
- Store and forward with continuous monitoring and geographically defined data forwarding.

These are only partial lists of new and improved capabilities. Notice that there are some tantalizing items in these lists that have not been explained in this article. They will be explored in future articles. AMSAT OSCAR-E is expected to be a very popular satellite.

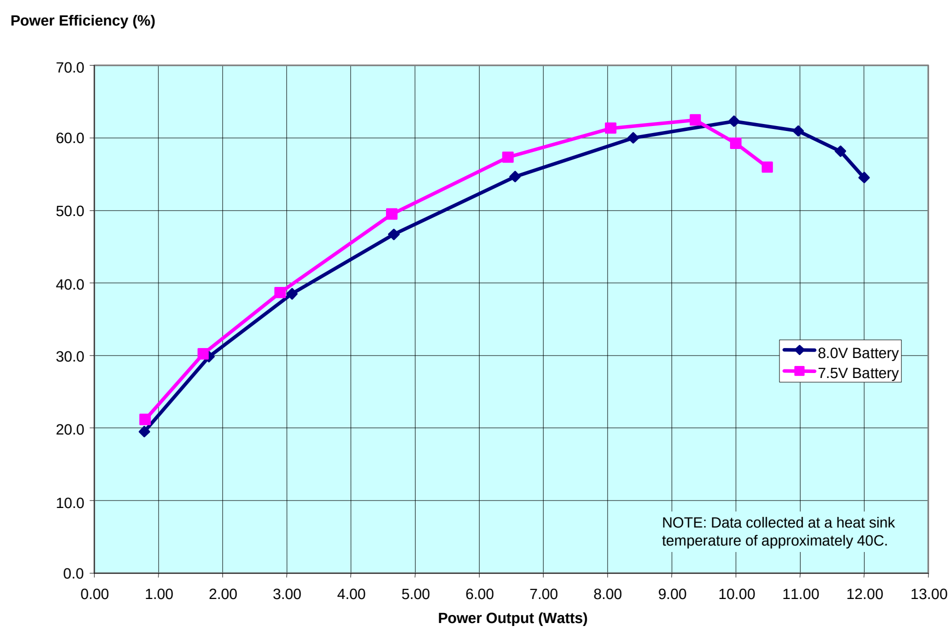

Figure 7. UHF Amplifier RF Power Output vs. Efficiency