WEBERSAT OPERATIONS AND EXPERIMENT RESULTS

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Abstract:

WEBERSAT, a 27 pound LEO satellite launched by the Ariane 40 on January 21, 1990 into an 800 Km polar orbit, carries several inexpensive payload experiments that were developed as a learning experience for engineering students at Weber State College. The experiments include a color CCD camera, a CCD light spectrometer, video flash digitizer, 1.26 GHz NTSC video uplink, micro-impact sensor, and optical horizon sensors.

Operational command and control of the spacecraft and its payloads is performed by students in the School of Technology, from a ground station located on the WSC campus. Here, the students and their advisors monitor on-board systems, plan and execute experiments, and observe test results.

This paper describes the satellite experiments, ground station requirements, and experiment results as of this date.

INTRODUCTION

WeberSat is a small, yet sophisticated satellite now available for experimental and educational use by interested groups and individuals. It is one of four "MicroSats" developed by the Radio Amateur Satellite Corporation (AMSAT), in cooperation with the Center for AeroSpace Technology (CAST) at Weber State College. WeberSat was launched from Kourou, French Guyana aboard ESA's Ariane 40 vehicle on January 21, 1990. It is WSC's second major satellite project, and involves undergraduate students, faculty, and industry advisors from many disciplines.

The 27 pound, 9" x 9" x 12.5" satellite is in an 800 Km, sun-synchronous, polar orbit with a period of 100.7 minutes. Four to six passes per day are visible from the ground station at WSC.

Like the other MicroSats, WeberSat is an amateur radio satellite capable of store-and-forward message handling, and uses the amateur packet (AX.25) protocol for all data transmissions. WeberSat differs from its three cousins in that it contains a number of experiments in an extra "attic" module. (See Figure 1.)

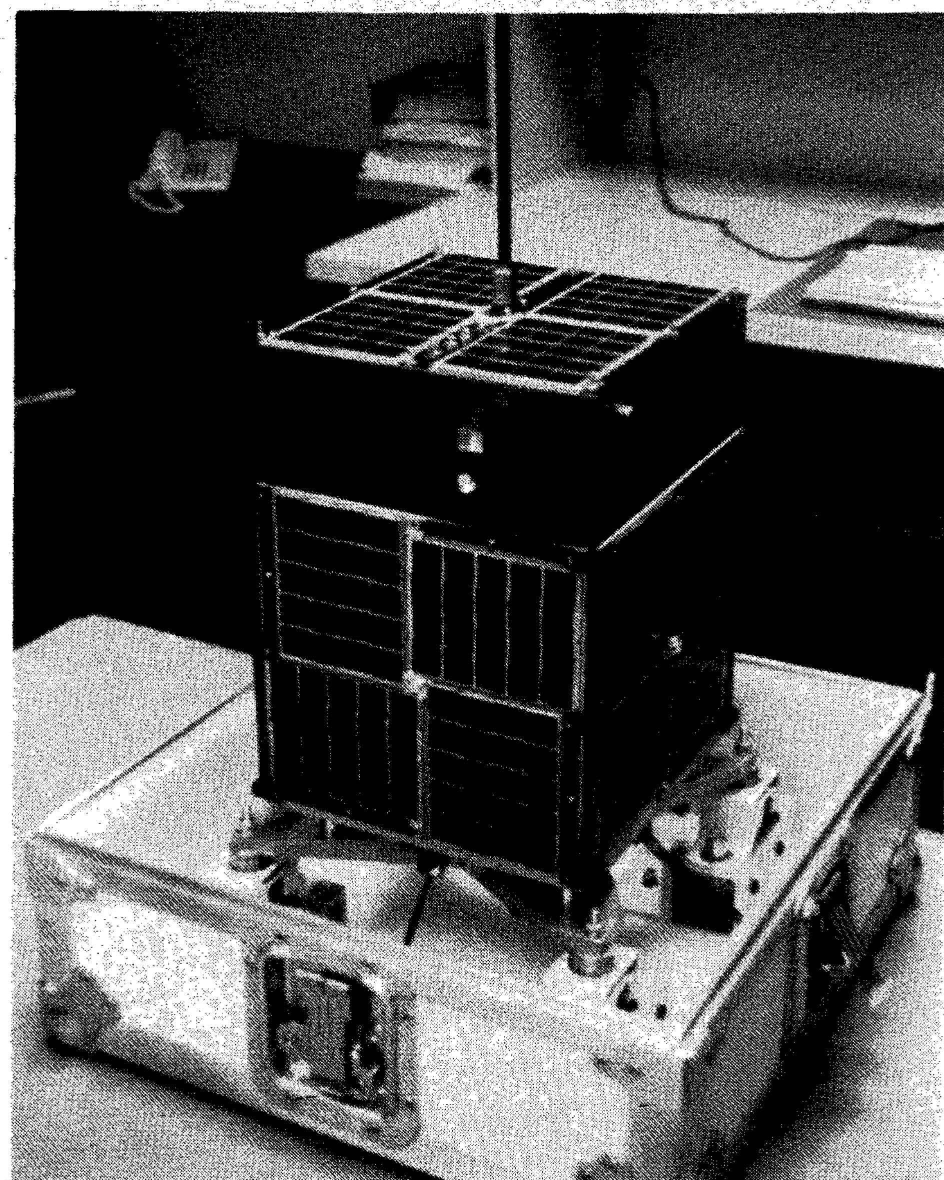

Figure 1: WeberSat

EXPERIMENTS

As shown in Figure 2, the satellite has six sections vertically stacked, which communicate through an onboard local area network. The top, or "Attic" modules contain various experiments, including:

Micro Meteor Impact Sensor
L-Band Video Uplink Receiver
Horizon Sensor
CCD Color Camera
CCD Light Spectrometer
Video Flash Digitizer.

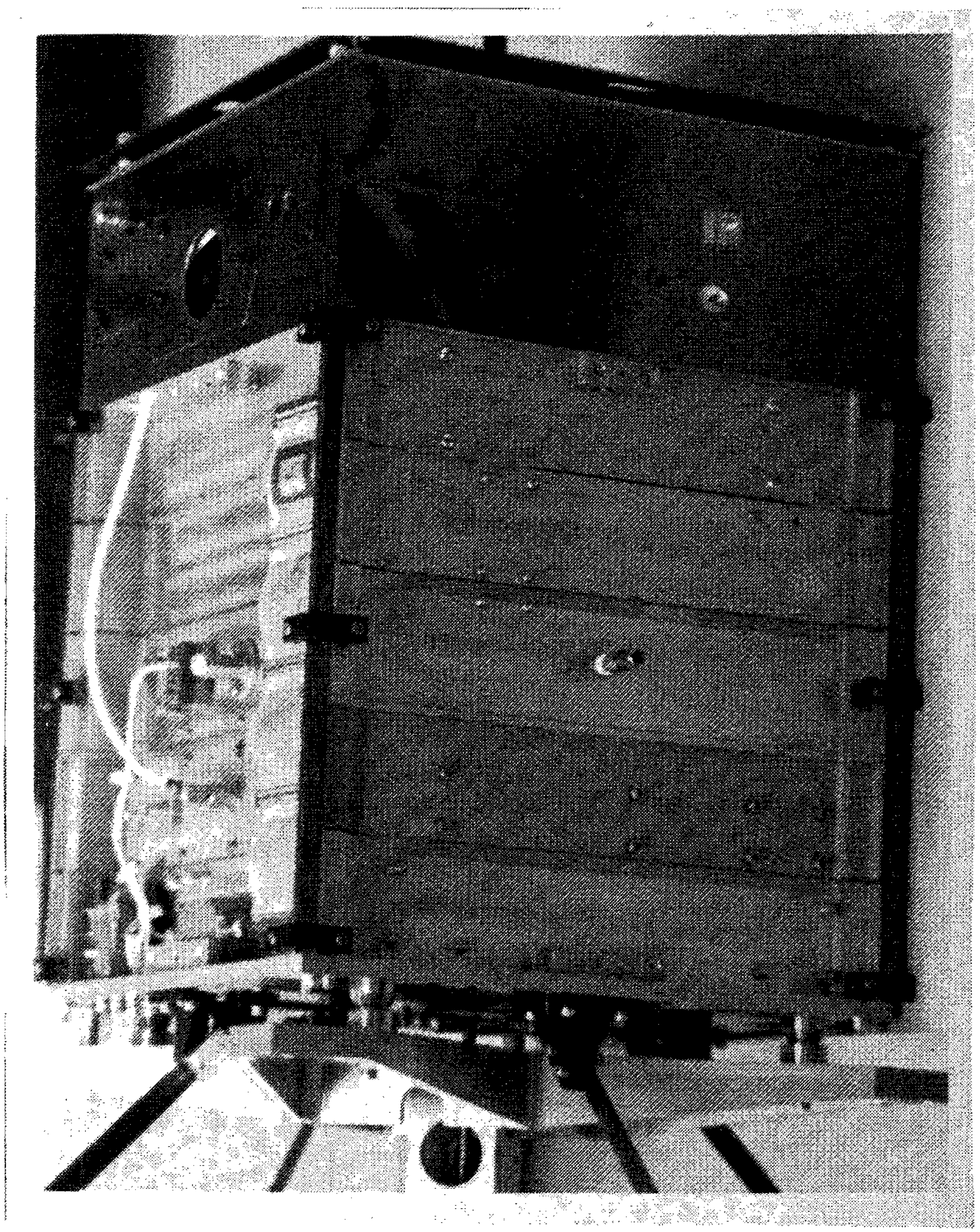

Figure 2: WeberSat's Modular Construction

Impact Sensor

The impact sensor was designed and built by students at Brighton High School in Sandy, Utah, with assistance from the Zevex Corporation of Murray, Utah. It can detect small vibrations caused by micro-meteor impacts, or on-board events such as opening and closing of the camera iris, and thermal stress.

The detector is a 6 x 1.25 inch piezoelectric strain gauge, mounted on the +Y surface of the satellite. When acceleration of the sensor occurs, voltage pulses are generated and summed. The resulting voltage is sampled by an analog to digital converter, and translated into a digital value ranging from 0 to 255 (0 to FFh). This value is reported in the telemetry data.

A second, identical sensor is mounted inside the attic module, perpendicular to the external sensor. This detector feeds the count circuit in such a way as to inhibit a count from being recorded if the whole frame flexes, as it might during a thermal event. Strikes of moderate intensity may cause a portion of the structure to ring (produce a damped oscillation). This results in a greater pulse count if the impact was not large enough to trigger the second sensor.

This configuration does not provide quantity or magnitude data directly, but when sample period, rate of change, and environment factors are accounted for, inferences about relative magnitude or quantity can be made.

L-Band Video Uplink

WeberSat's 1.26 GHz NTSC video receiver permits ground stations to uplink, store, and re-transmit a single frame video picture.

The uplink signal is received by one or both of the quarter wavelength antennas mounted on the + & - X surfaces of the spacecraft. The 1.26 GHz amplitude modulated signal is converted down to 45.75 MHz, amplified, and detected. The resulting composite video signal is directed to an Analog Data Multiplexer, where it can be selected for digitization and storage. The latter process is also used in handling camera and spectrometer signals.

Users of this feature will need to generate a signal with a high effective radiated power (ERP). Pre-launch testing indicated the following system sensitivity:

-127 dBm:	Some effects seen on CRT.
-112 dBm:	Recognizable image on CRT.
-97 dBm:	Readable fine print images on CRT.
-87 dBm:	Fully quieted picture on CRT.

L-Band Uplink Continued...

Assuming no antenna gain on the satellite, and free space attenuation of 153 to 164 dB, it would require 500 to 1000 watts ERP to produce recognizable images. Over 2.5 KW ERP would be required to produce high quality pictures.

This system can also be used to experiment with other signals in addition to composite video, such as radar, or to measure antenna radiation patterns and atmospheric attenuation effects.

Horizon Sensor

The horizon sensor is composed of two photodiodes aimed through holes in the wall of the attic module. The holes limit the field of view (FOV) of each photodiode to 11 degrees, and are aligned to produce a total FOV of 22 degrees centered perpendicular to the +X axis (same as the camera). Sensor 1 is closest to the outside edge of the surface, and is adjusted inward toward the center. Sensor 2 is closest to the camera lens, and is aligned with the outside edge. The FOV's cross about 1 foot from the spacecraft, but do not overlap at infinite range. Given these characteristics and WeberSat's 800 kilometer orbit, only the earth subtends an angle large enough to illuminate both sensors simultaneously.

Since WeberSat's attitude is uncontrolled, except for passive magnets on the Z axis, the horizon sensor is used to aid in directing the camera and spectrometer, and helps to determine the spin rate of the spacecraft. Restricting availability of the camera, spectrometer, and flash digitizer power to periods when the earth is in view of the sensor also helps to conserve limited battery power.

CCD Color Camera

WeberSat's CCD color camera is a modified Canon CI-10 with a 25mm lens and automatic iris. It has 700 x 400 pixel resolution. The following changes were made to the basic design in order to make the camera spaceworthy:

1) Replaced iris range control potentiometer with a programmable potentiometer to accommodate widely varying brightness levels.

2) Added a 10.7 MHz digitization clock, phase-locked with the 3.579545 MHz color reference.

3) Replaced focusing mechanism with a fixed focus support.

4) Replaced aluminum electrolytic capacitors with solid tantalum capacitors.

CCD Camera Continued...

Camera output signals, composite video, red, green, blue, and the 10.7 MHz digitization clock are fed to the flash digitizer, where they are processed for storage in the spacecraft computer RAM.

Camera control commands are stored and executed via the on board computer. The command information includes desired shoot time, horizon sensor constraints, and iris settle-in delay. The on board software also controls the iris potentiometer setting, and the time-out delay for the horizon search. Uploaded command information can be routinely varied for each picture as desired.

However, actual software changes are more complex due to the extensive simulations required to insure safe operation.

On power-up, the camera draws a surge current of three amperes. This quickly drops off to the nominal value of 360mA at 10 volts. As this is normally the power budget for the entire spacecraft, the camera remains on only as long as necessary to complete the programmed photo sequence. This is insured by software and firmware safeguards.

WeberSat's camera system has received the most attention of all the experiments to date. It has provided interesting data, and a few surprises which will be discussed in the Results section of this paper.

Spectrometer

The purpose of the spectrometer is to measure the spectrum of sunlight reflected from the atmosphere in order to determine the exact composition of the atmosphere in particular places and times. This data might be used to study changes in the concentration of gasses, such as ozone or carbon dioxide.

The spectrometer measures the chromatic content of light passing through a narrow slit in the -Y surface of the satellite. The light is focused by a lens onto a diffraction grating, then onto a 5Kx1 byte CCD sensor array. The array converts the spectral data to a waveform that is flash digitized by the same circuit used by the camera. The spectrometer covers the band from 200mu to 1000mu.

Flight software is not yet available for the spectrometer.

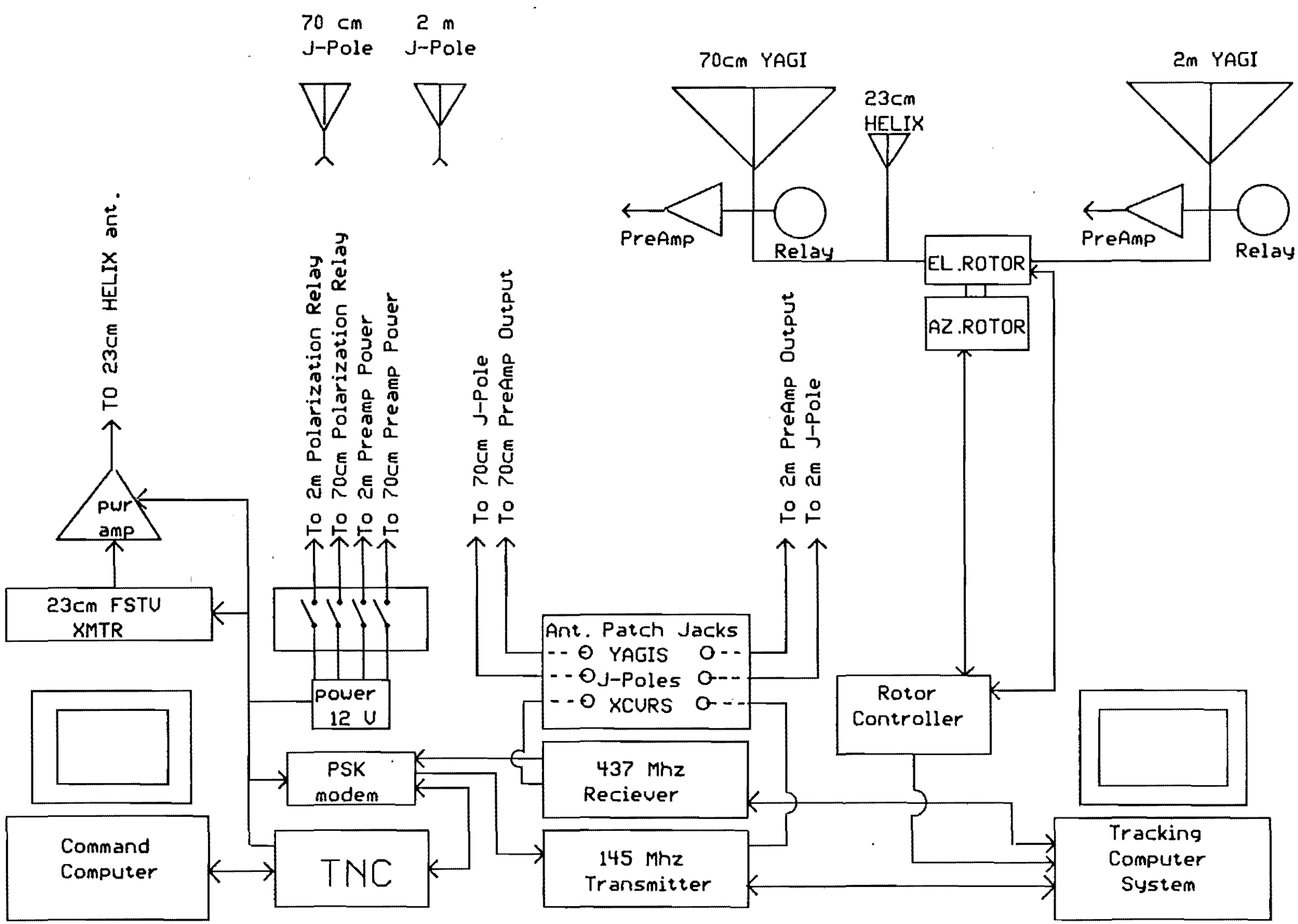

Figure 3: WeberSat
Ground Station Block Diagram

Flash Digitizer

The flash digitizer unit is common to WeberSat's three video experiments. Analog signals from the camera, spectrometer, or L-band receiver are converted at 50ns per sample into an 8-bit digital format, then stored in RAM for transmission. The unit allows computer control of data array size, analog data channel, phase, and trigger source, making it capable of handling a multitude of data types and sources. Video compression algorithms are also available to maximize efficient use of memory, while minimizing required transmission time.

The digitizer is interfaced to the 2Mb bank switched RAM by direct memory access (DMA), allowing up to 12 still video images of 166K pixels each to be stored for download. Pixel luminance values, represented by 8-bit binary numbers, appear as extended set ASCII characters in the serial data received by the ground station terminal.

Other Sensors

Other sensors located throughout the spacecraft provide important data about temperature, current, voltage, and power levels; information used to determine and regulate the operating conditions aboard the satellite. This data is transmitted periodically between data packets from other experiments.

GROUND STATION HARDWARE

The Weber State ground station is equipped to communicate with WeberSat and other amateur radio satellites. This section is a technical description of the Weber State ground station.

This system (figure 3) has two transceivers, an L-band transmitter, two computers, a 1200 baud phase shift keyed (PSK) modem, terminal node controller (TNC), power supplies, antennas and several command, control and support software programs.

The ground station has three basic functions: tracking the satellite, receiving and transmitting data, and decoding information from the satellite.

Tracking

Tracking the satellite is one of the most important functions of the ground station. If the antennas are not pointing in the proper direction, severe difficulty in communicating with the satellite would result. The tracking system is composed of an IBM XT computer which is linked to an azimuth and elevation rotor system though two software programs:

Kansas City Tracker and Quiktrak. Quiktrak calculates the position of the satellite and provides this information to Kansas City Tracker which aims the antennas at the satellite when it comes in range.

Receive System

The receive system is composed of a 435 Mhz, 40 element, cross polarized yagi with a gain of 15.2 dB, connected to a 24 dB preamp. This is connected to a 70 cm all mode transceiver which receives the signal from the antenna, then passes it to the 1200 baud PSK modem which locks on to the signal and compensates for Doppler shift. The modem compensates for Doppler shift by comparing the received audio frequency to its internal clock, and sending pulses out to the receiver's frequency control circuit as needed. After frequency lock is established, the PSK modem converts the phase shift keyed signal into voltage levels. The PSK modem sends the voltage levels to the TNC which converts the level type packet format to RS-232 serial data. The signal is then fed into the serial port on the command computer, where the data is collected and saved by a WSC software package called "Capture". It is later translated into its final form by various decoding programs depending on the experiment.

Transmit System

The transmit system is composed of the command computer, TNC, PSK modem, 2m transceiver and a 22 element cross, polarized yagi with a gain of 13 dB.

When a command needs to be sent to the satellite, it is first composed and saved on the command computer until the satellite is in range. When the command is sent it is converted from RS-232 to packet level by the TNC. It is then fed into the PSK modem which converts it into phase shift keying, then on to the 2m transceiver where it is transmitted via the 2m antenna up to the satellite.

L-Band Video Uplink

The L-Band link from the ground to the satellite consists of several components. First a computer, camera, or a VCR, provide the video information to be sent to the satellite. The video is sent to a transmitter, then to an amplifier and on to either a dual helix antenna or a Loop Yagi antenna via 100' of 7/8" hard line.

The dual helix design from an economic stand point seemed to be a suitable choice for an antenna. With 20 turns each, it is feasible to obtain 17 dB of gain as well as circular polarization. Another benefit is that the existing rotor system could be used. After construction and testing, the antenna with some adjustments gave approximately 12 dBi of gain and was apparently linearly polarized. It was then clear that there must be a better choice. A loop Yagi with 21 dBi of gain was donated to the college by Down East MIcrowave, and this is what is used at present.

The communications link has several gain and loss factors. There is a 47 dB gain from the amplifier, a 3.2 dB loss in the hard line, and a 21 dB gain from the Loop Yagi antenna. At 821 Km from the surface of the earth, the atmospheric loss from the horizon to zenith is 163.6 dB to 153.5 dB respectively. Thus, the total power at the satellite with the existing system from the horizon to zenith is -104.3 dBm to -93.5 dBm. Obviously there is room for improvement on the L-Band ground station. Planned improvements include a more powerful amplifier, and a 10'parabolic dish for an antenna.

GROUND STATION SOFTWARE

The operation of the ground station requires several command, control, and support software programs. These programs are responsible for command transmission, data collection, tracking, decoding and the execution of the on board experiments.

Tracking Software

Tracking and orbit prediction of the satellite requires several different software systems which interact with each other, and with experiments on board the satellite. The tracking portion of the ground station is one of its most important functions. The ground station uses a tracking program called Quiktrak to accomplish this task. Quiktrak uses a set of Keplerian elements to calculate the position of the satellite at any given time during its orbit. Quiktrak builds a table of the satellite's position and the Doppler shift, and stores them for use by two other programs: Kansas City Tuner and Kansas City Tracker. Quiktrak also uses these values to construct a map of the pass area, and to simulate where the satellite will be during any given time during the pass. Quiktrak also can project where the satellite will be during future passes. This function is a great asset since WeberSat's camera is programmable and can be commanded to take pictures at any point in its orbit. By plotting the orbit path with this program, ground station operators can pick prime locations for picture taking.

Quiktrak calculates the table for the position of the satellite and Doppler shift, but it cannot aim the antennas or compensate for Doppler by itself. Therefore, Quiktrak is mated with Kansas City Tracker and Kansas City Tuner which interface the tracking computer to the rotor system, transmitter and receiver via an add-on PC board in the XT. These programs read the calculation table for the position of the satellite and the Doppler shift from Quiktrak.

Communication Software

Receiving data from and sending information to the satellite requires several software and firmware programs. Receiving accurate data from the satellite requires the TNC's firmware to be set into KISS mode and some kind of data collection program to be present on the command computer. KISS mode is a pass all mode where all characters are passed including null and control characters. In standard packet protocol the null and special characters are stripped out. Almost any modem program will work for data collection as long as it does not strip off any of the null or control characters. For example, Procomm will act like it is properly collecting data, but in reality it is stripping out null characters and will prevent data from being decoded properly. Weber State's ground station uses a program called "Capture" which collects all the data it receives without eliminating null and control characters.

Data Decoding Software

Currently the Weber State ground station is using two different decoding programs: Weberware and Decode. Both of these programs were written at Weber State by WSC students and faculty members.

Decode sorts and converts normal telemetry data, and the telemetry from the Whole Orbit Data transmissions, from ASCII files to a readable format.

Weberware extracts the picture information from the raw data files captured in KISS mode. It takes this information and displays it in either a gray or false color format. At this point, the operator has the option to enhance the detail of the picture by adjusting the brightness, contrast and false color pallets. Weberware has the ability to generate a picture in true color if 90 percent or more of the picture information has been collected. After the picture has been fully captured and decoded it can be printed on a standard dot matrix printer.

EXPERIMENT RESULTS

CCD Camera

The CCD color camera has successfully taken several pictures since launch. The field of view from the 800km orbit is about 150 miles on the earth. This narrow view has made it difficult to define land masses accurately Cloud formations, however, are clearly visible.

Efforts are still being made to take pictures over easily identifiable targets such as small island clusters.

Impact Detection

The impact sensor has been recording events that would indicate impacts from micrometeorites and dust. Thermal expansion stress has also been occasionally observed. The value given for an impact is between 0 and 256, depending on the magnitude of the hit. A magnitude of 16 is considered a minimum reading for an impact. If an impact magnitude is greater than 256, the reading may not be usable because the value will go past 256 and start from zero again. Iris movement in the camera also has been verified with corresponding impact readings at the time of the movement. Electrical noise and voltage fluctuations have been observed to cause a small change in the impact count. These effects are filtered out by comparing changes in 5 and 10 volt bus values to the variations in impact count.

Digitizer and Video Uplink

The digitizer is also capable of capturing picture data from the ground station 1.26 Ghz uplink. At the present time, WSC ground station does not have sufficient antenna gain to provide the spacecraft with a readable picture signal. The only results to date are snow with some diagonal patterns, indicating the satellite is receiving a weak signal. Efforts are progressing to erect a dish antenna capable of increasing the uplink gain.

Horizon Sensor

As previously stated, the horizon sensor was designed to detect when the +X axis is aligned with the earth, thereby allowing the satellite to determine the proper time to take a picture. The sensor does allow detection to take place, but readings seem to indicate that the base level is higher than expected. It appears that the sensor may sometimes be fooled by reflections in the cylinders housing the photodiodes. This problem arose because the cylinder walls were not darkened to prevent such an occurrence. After initial testing, it seems that the sensor is working well enough to allow pictures to be taken in the general direction of the earth.

Whole Orbit Data

Standard telemetry data consists of information from 66 voltage, current, temperature, and other sensors located throughout the spacecraft. Values are sampled and transmitted every 10 to 60 seconds. This real-time mode allows data to be collected only while the satellite is in range of a ground station.

Whole Orbit Data (WOD) allows up to six telemetry channels to be sampled at a rate ranging from 1 to 12 samples per minute. A maximum of 2275 data samples may be collected and stored in RAM for transmission on command. The run time of the collection is determined by dividing the maximum number of samples by the sample rate.

WOD collection has proven to be very useful in determining what actually transpires aboard the spacecraft. The first analysis performed from this data was an attempt to verify the existence of thermally induced impact events. To aid in analyzing the impact sensor data, the effect of thermal stress and other factors needed to be determined. Several solar panel current outputs, thermisters, and bus voltages were monitored along with the impact sensor. This experiment demonstrated that few sensor readings could be attributed to thermal creaking, however, erroneous readings could be induced by unusually sudden voltage changes on the 5 volt bus.

WOD has also been used to calculate WeberSat's spin rate and direction. This was accomplished by gathering array current data and measuring the time between peaks.

One obvious advantage of WOD collection is the ability to record events that occur outside the range of the ground station. A recent example of this is the July 22, 1990 solar eclipse over Siberia. When the satellite passed over the area, penetration of the shadow was indicated by a sudden decrease in array current.

EDUCATIONAL ASPECTS

The educational aspects of using satellites as teaching tools are numerous. Building a satellite requires the unification of many different talents and disciplines which eventually impact on each other. For example, thermal considerations affect the materials selected for the structure as well as the design itself. Size constraints affect the surface area available for the solar cells, which has impact on the power available for the spacecraft. The power available for the satellite determines how many experiments can be flown and how many can be executed at one time. This presents the students with exciting and challenging engineering problems and adds a real world dimension to their other assignments.

Educational Aspects Continued...

Students are involved in nearly all phases of the construction and operation of the satellite. This gives them hands on experience in designing systems and circuits as well as building and testing prototypes, developing software, and performing functional and environmental stress testing. Students also execute experiments, retrieve and evaluate the data from these experiments, monitor the status of the satellite and develop procedures and documentation for running the satellite.

PUBLIC SCHOOL INVOLVEMENT

The educational benefits of the WeberSat program are not strictly limited to the college level. The WeberSat program involves students on the Elementary, Jr. High, and High school levels in various ways. During the design and construction stages, students at Brighton High School developed the micro meteorite impact experiment for WeberSat. After the launch of WeberSat, students from Jr. High and High schools were invited to join a program that allows them to come in and participate in WeberSat operations during a pass. After the pass they are invited to remain for a short lecture on what went on during the pass or a related subject, given by one of the faculty or student members of the ground station team.

Educators and students are encouraged to submit proposals for experiments to be executed on board WeberSat. To help these experimenters, CAST has developed a WeberSat users handbook which describes the on board experiments, project history and ground station requirements. This exposes students to science, engineering, astronomy, radio, computers and teamwork. To involve students on the Elementary level, CAST gives lectures, presentations and demonstrations of ground station activities. These programs will hopefully encourage students in the lower grades to become interested in science and technology.