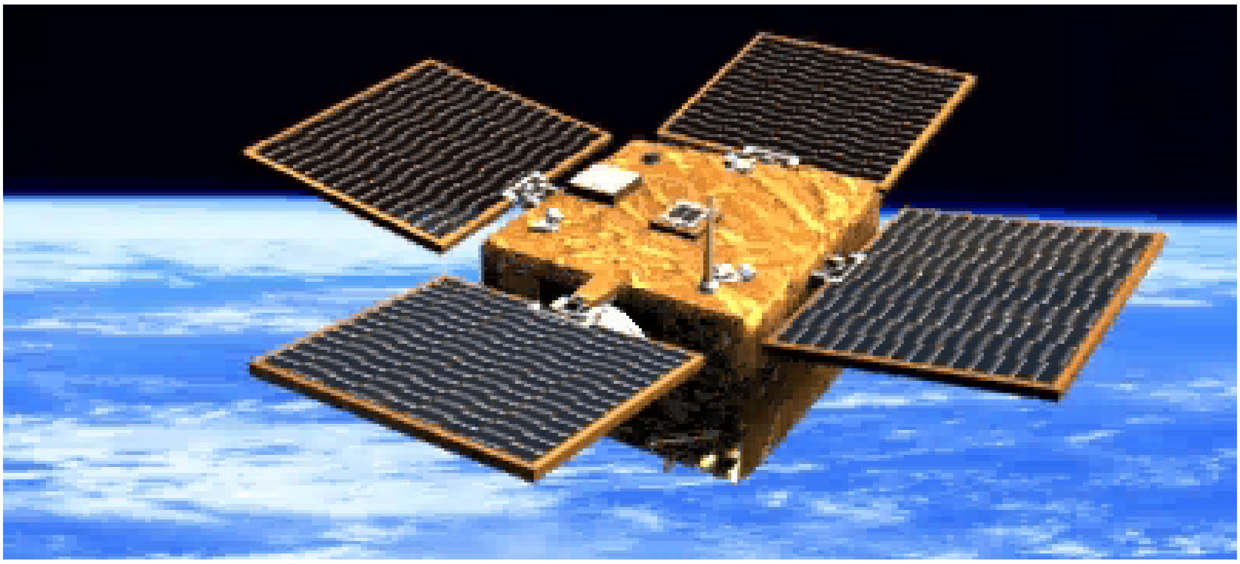
THE VICTORIA SATELLITE

FEASIBILITY STUDY AND COMMUNICATION PROTOCOL



Behzad Bahrami-Hessari **David Foo-Wooi Yap**

Master Degree Thesis
August 2002

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The Royal Institute of Technology (KTH), Stockholm, Sweden
Department of Physics

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August 2002

In association with:
AMSAT-SM

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Abstract

Satellites today provide society with everything from environmental scientific data to global telecommunications services. Satellite broadcasting and communications benefit people even in the most remote parts of our planet, we observe the state of our oceans and the health of our crops and forests, etc. The satellite era began with Sputnik 1 that was launched October 4, 1957, by the Soviet Union. This started the conquest of space between the United States of America and the formal Soviet Union, Russia. The interest for space rose among the people in the whole world. Through this the Radio Amateur Satellite Corporation known as AMSAT was formed on March 3, 1969. Through the 33 years of AMSAT history, there has been over 30 Amateur Radio satellites successfully launched into Earth orbit. Today, almost 20 of these satellites are still operational. Most of these satellites are used as relay in space or “store and forward” operations like PACSAT.

However, space activities are extremely demanding, not just in terms of technology, costs and management. Space missions have been huge and expensive programs taking many years to develop. However, this is no longer the only path into space. Advances in microelectronics have made small-scale space missions very affordable while still delivering impressive and valuable results. The development of **“smaller, faster, cheaper, better”** spacecraft now enables any country, or even a university, to build, launch and operate in orbit its own small satellite - bringing with it direct access to the advantages of space.

The Victoria satellite project is a common project between the Royal Institute of Technology and AMSAT. It is a continuation of HUGIN satellite project which was also conducted in the Royal Institute of Technology. Some devices from another satellite project called Munin has been used to reduce the time schedule and the complexity of the Victoria satellite project. The Victoria satellite is a nano-satellite, weight less than 10 kg and cost less than 1 million US dollars. It is explicitly designed to be an amateur technology demonstrator but mainly a satellite for education and for radio enthusiasts.

This thesis project is a feasibility study of the Victoria with the focus on the communication protocols and the communication subsystem of the satellite. Since the Victoria is an amateur satellite our preferred communication protocol is the AX.25 protocol. Work has been conducted on a simple overview and possible solutions to assemble the Victoria satellite. Preferred solutions surrounding the power supply, communication equipments, experiments and sensor needs have been proposed. A general calculation on the power budgeting of the satellite has also been made. Different solutions on how to send telemetry data to earth have been worked on. Future improvements and possible redundancy surveillance of the system has also been discussed.

Preface

This thesis project is carried out in the Royal Institute of Technology (KTH) with the purpose to write a protocol for a spin stabilised, sun-pointing satellite in a sun synchronous orbit. The project is called VICTORIA and is managed by AMSAT-SM in co-operation with KTH under the supervision of Professor Thomas Lindblad. The satellite will carry a camera to photograph the sunspots, a simple answering machine "Parrot" and a Slow Scan TV (SSTV) repeater for the radio enthusiasts. It will be an amateur technology demonstrator but mainly a satellite for education. Thus it will carry memory chips for studying single event upsets and a particle detector. The final goal is, of course, an autonomous intelligent detector system with maximum redundancy or/and adaptability that can be reconfigured at will.

In this thesis work, one question among others to be answered is to decide what information to be measured and sent to the control station on earth. A major part of the job will be to proof that the proposed protocol is the most optimised for this satellite and works for the transfer of wanted information. Another dimension of this work is to decide what type of sensors and other components to choose to make sure the information transfer will be sustainable and redundant.

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Notice: All sound wave files can be found on the Victoria Thesis CD.

Figure 1: A model of the Victoria satellite

Mission Statement

The VICTORIA satellite is a nano-satellite and as mentioned in the preface, a spin-stabilised, sun-pointing satellite in a sun synchronous orbit. From the perspective of AMSAT (Amateur Satellite Corporation), the satellite is mainly for educational use. It is believed that the facilities on the satellite should be interesting for youth and be able to stimulate their desire for more knowledge in the fields of physics, mathematics, engineering and space. Therefore the satellite will contain mainly 4 different experiments:

1. The Chipcorder "Parrot" for telemetry transmission in audio form.

2. The Slow Scan TV (SSTV) for image transmission in audio form.

3. A Camera for photographing sunspots.

4. The Particle Detector and Memory Chips (SEU) for measuring level of high ionising particles.

A Brief History

Satellites today provide society with everything from environmental scientific data to global telecommunications services, resulting in a multibillion dollar industry. Let us take a look back at the beginning of the satellites era to understand the Victoria satellite.

The Sputnik 1

The first satellite was launched October 4, 1957, by the Soviet Union. It was called Sputnik 1. This satellite orbited the earth once every 95 minutes and sent a continuous "beep, beep, beep" signal (Sputnik1 wave file). The satellite travelled up to 900 kilometres above the surface of the earth. The angle of inclination of its orbit to the equatorial plane was 65 degrees. [R.1]

The satellite had a spherical shape, 58 centimetres in diameter and weighed 83.6 kilograms. It was equipped with two radio transmitters continuously emitting signals at frequencies of 20.005 and 40.002 megacycles per second (wave lengths of about 15 and 7.5 meters, respectively). The power of the transmitters ensured reliable reception of the signals by a broad range of radio amateurs. The signals had the form of telegraph pulses of about 0.3 second's duration with a pause of the same duration. The signal of one frequency was sent during the pause in the signal of the other frequency. The figures below show how Sputnik 40 uses a technique called PPM-AM to transmit temperature telemetry. [Appendix]

RS-17 (Sputnik 40)

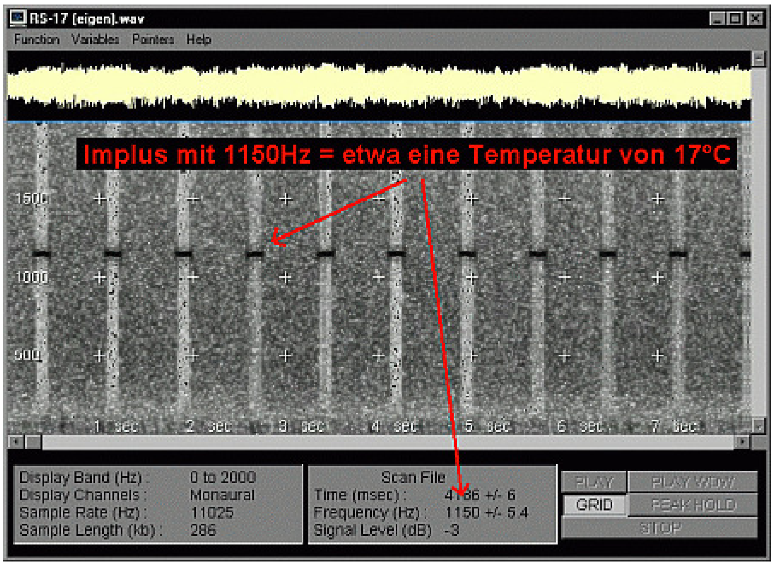


Figure 2: (Left) Signal recorded at time 10:10 UT, 24 September 2000. Listen to the signal (Sputnik 40 Real audio file). (Right) The Sputnik 40.

Hertz	Temperatur
179Hz	-38°C
273Hz	-30°C
440Hz	-20°C
634Hz	-10°C
830Hz	+ 0°C
1025Hz	+10°C
1200Hz	+20°C
1308Hz	+30°C
1405Hz	+40°C
1447Hz	+45°C
1483Hz	+50°C

The Explorer 1

Four months after the launch of Sputnik 1 the first U.S. satellite named Explorer 1 was launched. The U.S. launched its first satellite from Cape Canaveral (named Cape Kennedy 1963–73), Florida., on Jan. 31, 1958. The 14-kg cylindrical spacecraft, 15 cm in diameter and 203 cm long, transmitted measurements (Explorer 1 wave file) of cosmic rays and micrometeorites for 112 days and gave the first satellite-derived data leading to the discovery of the Van Allen radiation belts. [R.2]

Spectrogram of Signals from Explorer 1

Explorer 1, the first satellite ever launched by the U.S.A., had two RF frequencies, 108.0 MHz and 108.03 MHz. The builder of the satellite, the Jet Propulsion Laboratory, tracked the satellite from stations in California. The Explorer 1 Cosmic Ray Counter uses a Geiger tube to count the cosmic ray by applying a two-level voltage signal to a voltage-controlled oscillator having a centre frequency of 1300 Hz. The temperature at 730 Hz transmitted the temperature at the nose cone, while the 560 Hz showed temperature data at the skin of the satellite. All telemetry data are modulated in a technique called Frequency Division Multiplex Telemetry. [Appendix]

Listen to the recording of Explorer 1: (Explorer 1-telemetry wave file). This recording was made in Dallas, Texas on February 11, 1958. The analogue transmission results are sometimes difficult to read due to distortion and interference.

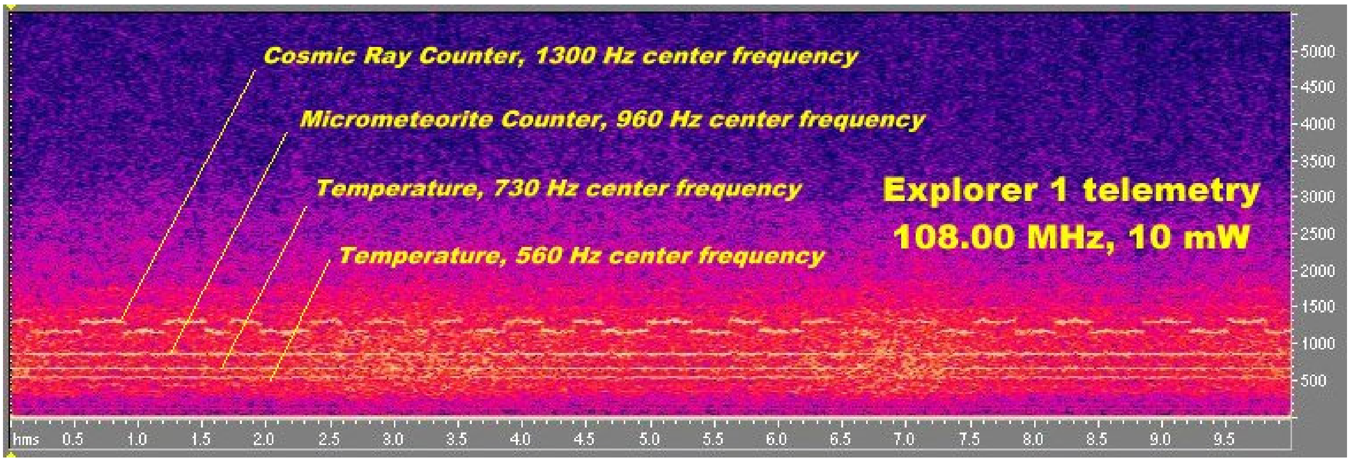


Figure 3: An example of Explorer 1 telemetry.

The First Amateur Satellite, Oscar 1

Orbiting Satellites Carrying Amateur Radio series started with OSCAR 1 that was launched December 12, 1961 by a Thor Agena B launcher from Vandenberg Air Force Base, Lompoc, California. OSCAR 1 was launched piggyback with Discover 36, a United States Air Force satellite. Orbit of a apogee of 372 km and a perigee of 211 km with inclination 81.2 degrees. The orbit has a period of 91.8 minutes. OSCAR 1 was the first of the phase I satellites. A group of enthusiasts in California formed “Project OSCAR” and persuaded the United States Air Force to replace ballast on the Agena upper stage with the 4.5 kg OSCAR 1 package. The satellite was box shaped with a single monopole antenna and battery powered. The 140 mW transmitter onboard discharged its batteries after three weeks. 570 Amateurs in 28 countries reported receiving its simple "HI-HI" Morse code (Oscar 1 wave file) signals on the VHF 2-meter band (144.983 MHz) until January 1, 1962. A temperature sensor inside the spacecraft controlled the speed of the HI-HI message. OSCAR 1 re-entered the atmosphere January 31, 1962 after 312 revolutions.

AMSAT

The Radio Amateur Satellite Corporation, as AMSAT is officially known, aims to foster Amateur Radio's participation in space research and communication. Since the start, other like-minded groups throughout the world have formed to pursue the same goals. Many of these groups share the "AMSAT" name. While the affiliations between the various groups are not formal, they do cooperate very closely with one another. For example, international teams of AMSAT volunteers are often formed to help build each other's space hardware, or to help launch and control each other's satellites.

The story of AMSAT actually begins in Australia. There, a group of students at the University of Melbourne had pieced together an amateur satellite that would evaluate the suitability of the 10 meter Amateur Radio band as a downlink frequency for future satellite transponders. It would also test a passive magnetic attitude stabilization scheme, and demonstrate the feasibility of controlling a spacecraft via uplink commands. Unfortunately, the completed satellite languished as launch delay followed launch delay. At about that same time, a group of Radio Amateurs with space-related experience in the Washington DC area met to form what initially became known as the East Coast version of the West Coast Project OSCAR Association. As a result of this meeting, AMSAT, The Radio Amateur Satellite Corporation, was born. AMSAT was later chartered as a 501(c)(3) educational corporation in the District of Columbia on March 3, 1969. Its aim was, and still is, to embrace and expand on the work started by Project OSCAR. The new AMSAT organization selected, as its first task, to arrange for the launch of OSCAR 5. After some modifications by AMSAT members, OSCAR 5 (later to be called Australis-OSCAR 5, or simply AO-5) was successfully launched on a National Aeronautics and Space Administration (NASA) vehicle. Previous OSCARs had all been launched using US Air Force rockets. The OSCAR 5 satellite performed nearly flawlessly.

The AMSAT members are widely spread around the world; AMSAT-North America alone has 7500 members. Through the 33 years of AMSAT history, there has been over 30 Amateur Radio satellites successfully launched into Earth orbit. Today, almost 20 of these satellites are operational. Most of these satellites are used as relay in space or “store and forward” operations like PACSAT. [R.3]

Analog and Digital Technology

The field of satellite design has undergone many changes since its inception at the dawn of the space age in the late 1950's. Figures 4 and 5 plot the beginning of life (BOL) dry masses and power budgets of many NASA science satellites that have already flown or are scheduled to launch. Both graphs follow similar trends. The sizes of scientific spacecraft continually grow from the late 1950's through the 1990-1991 time frames, when the trend reverses itself and spacecraft sizes begin to decrease. [R.4]

More satellite is using digital communication techniques instead of analog are because of several reasons.

1. Digital signals can more precisely transmit the data because they are less susceptible to distortion and interference.

2. Digital signals can be easily regenerated so that noise and disturbances do not accumulate in transmission through communication relays.

3. Digital links can have extremely low error rates and high fidelity through error detection and correction.

4. Multiple streams of digital signals can be easily multiplexed as a single stream onto a single RF carrier.

5. Easier communication-link security, easier implementation of the hardware and lower power usage.

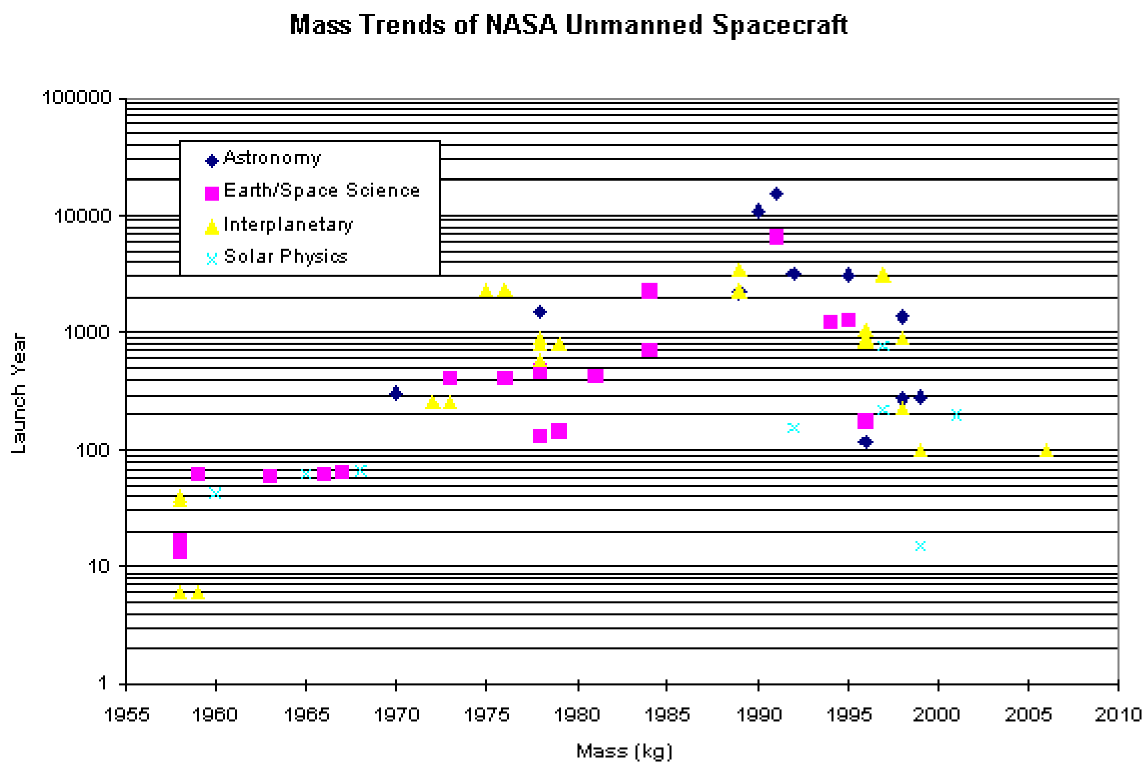


Figure 4: Dry Mass Trends of NASA Science Satellites.

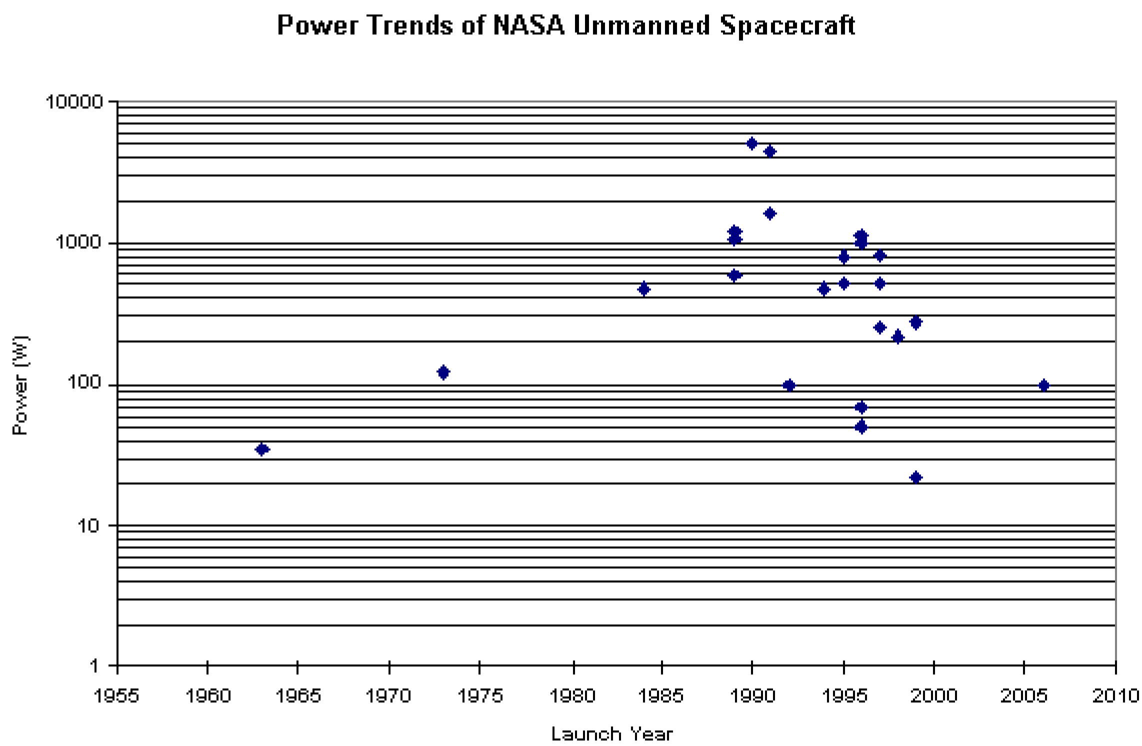


Figure 5: Power Trends of NASA Science Satellites.

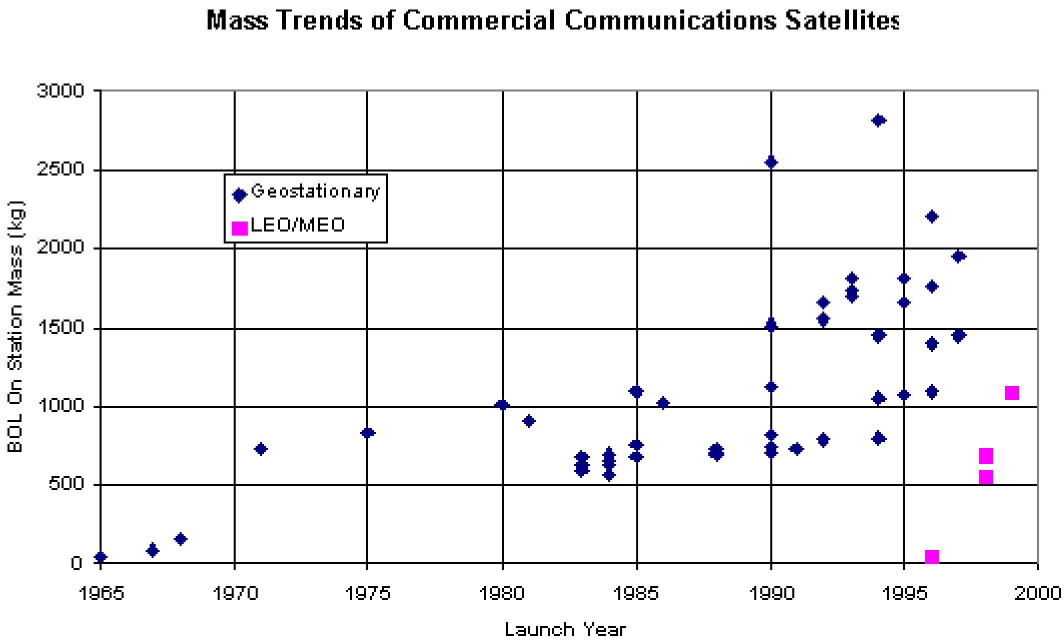


Figure 6: Mass Trends of Commercial Communications Satellites.

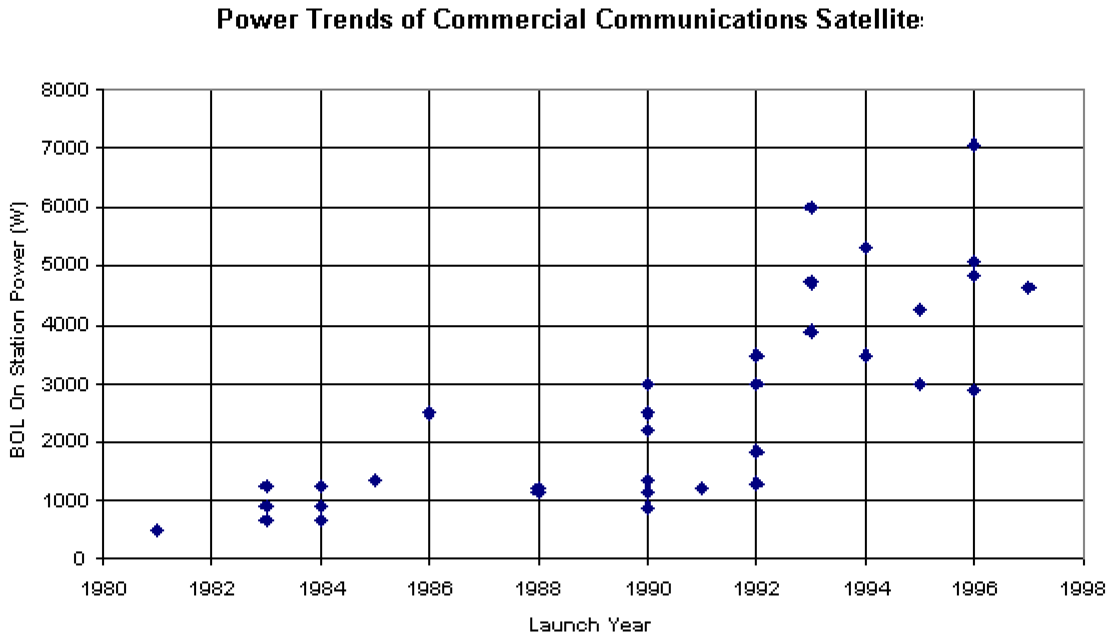


Figure 7: Power Trends of Commercial Communications Satellites.

Figures 6 and 7 illustrate how the BOL mass and power budgets for commercial communications satellites have changed over the same time period. In contrast to NASA's scientific spacecraft, communications satellites continue to grow in size.

Nanotechnology

Nanotechnology and micro electromechanical systems also hold the potential to revolutionize the field of satellite design. NASA science spacecraft continued to increase in size until the early 1990's, at which time the trend reversed itself and the average size of NASA science satellites continues to decrease today. Parametric cost models by the U.S. Air Force and the Aerospace Corporation for spacecraft clearly demonstrate that satellite cost is directly proportional to satellite mass; the lower the total spacecraft mass, the lower the cost. The limit to how small spacecraft can be designed and built is currently bound by how small electromechanical actuators can be constructed. Decreasing the size of these actuators, collectively termed as micro electromechanical systems (MEMS), are a field of intense research and development for both industry and academia.

Researchers believe that MEMS could be applied to data processing, communications, signal conditioning, power, and even individual sensors. Draper Labs has already developed a vibrating wheel gyro measuring one mille meter in diameter that could be used to sense satellite attitude and the Aerospace Corporation has developed a hydrogen sensor the size of a microchip. These so called "Nano-satellites" would be easily developed, semi-automated fabricated much like computer chips at reasonable unit costs, and would drastically decrease launch costs by allowing many satellites to be placed into orbit at once. Such architecture would be ideal for deploying large satellite constellations. "Nano-satellites" would still contain all of the typical satellite subsystems. Thus, nanotechnology reduces satellite size and cost by making all components smaller, while multifunctional structures achieve similar reductions in size and cost by using individual components to perform the functions of more than one spacecraft subsystem simultaneously. Limits on the practical reduction of satellite size do exist, however. These limits include power generation capability (proportional to solar cell surface area), power storage levels (proportional to battery size), radiation shielding, and the resolution requirements for optical payloads and communication antennae. Despite these limits, nanotechnology may in the near future drastically reduce the size of spacecraft and thus revolutionize how satellites are designed. The VICTORIA satellite is considered to be a nano-satellite, which means that it has all the benefits and problems related to a nano-satellite as discussed above.

The field of satellite design continues to evolve today as a result of the different forces affecting space mission design. Science satellites and commercial communications satellites have followed distinct trends dictated by the market, political environment, state of technology, and launch vehicle capabilities. While almost all satellites used to be custom designed subsystem by subsystem for each specific mission, the trends toward modular design make financial sense and are likely to continue. The extent to which low cost, high risk small satellite design is embraced by the conventional aerospace community depends on how successful multifunctional structure, nanotechnology, and distributed satellite systems turn out to be. As the evolution of satellite design continues the time to design, build, and test a new spacecraft; a process that only a decade ago took upwards of eight years and today can be done in less than three years, will continue to decrease. The continued increase in performance and decrease in cost of modern day satellites will help to insure that satellites continue to provide services for the benefit of all parties involved.

Description of the VICTORIA Satellite

General Information on the Satellite

Spacecraft name: VICTORIA

Launch

Date: N/A

Launch vehicle: A piggyback ride on a rocket yet not decided.

Orbital Parameters

General designations: The orbit chosen is a 600 kilometres (low altitude) circular sun synchronous orbit.

Apogee: 600km

Perigee: 600km

Inclination: 97.6˚

Operations

Co-ordinating group: AMSAT-SM, KTH

Schedule: The transceiver and the receiver of VICTORIA will be open for authorised experimentation. The 1269.90 MHz receiver will be scheduled exclusively for use by the control station and other authorised people. One radio module, the 437.75 MHz transceiver, may be used for engineering if the 1269.90 MHz receiver fails. Any unauthorised person who wishes to transmit a packet to the satellite must do so through the authorised people.

Spacecraft Description

Shape: Box with four solar panels in the directions of +X, -X, +Y and -Y.

Size: A square box with 20cm x 20cm x 20cm.

Mass: Less than 10-kilos at launch.

Stabilisation: Spin stabilised with the magnetic torque coils.

Subsystem Description

Telemetry: Telemetry data will be broadcast either via audio transmission or as Whole Orbit Data (WOD) via digital transmission.

Command System: Engineering up-link will put recorded messages or commands directly into the onboard computer memory.

Radio Modules: Two radio modules, where one will receive signals at 1269.90 MHz, the other will receive and transmit signals at 437.75 MHz. The radio-amateurs will use the 437.75 MHz for communications and experiments.

Antennas: The work on the antennas is proceeding and no information is available as this thesis project report is being written.

Solar Panels: There are 4 solar panels in the directions of -X, X, -Y and Y. The maximum output would be around 50W and the total surface area of the 4 solar panels is approximately 0.31 m^2. [R.5]

Battery Package: The batteries that will be used on the Victoria satellite are of Lithium Ion type and are manufactured by Duracel. The charger maximises the charging current to 0.5 Amps and the voltage to 12.35 Volts. The charger has an efficiency of approx. 80% and allows the supply voltage to be in the 15-25 Volts range, which should suite the solar panels. The battery pack has a capacity of 4200 mA at a nominal voltage of 12 Volts. The battery and the charger are currently under test. [Appendix]

Embedded Controller Card: This ECC is a radiation hardened UT131 model manufactured by UTMC Microelectronic Systems. The ECC includes a number of peripherals and memory mapped I/O devices. [Appendix]

A short list of the contains is as follows:

- 32 input A/D converter with a maximum 14bits resolution.
- An onboard 16bit, 16MHz microcontroller with the model name UT80CRH196KD.
- A user PROM of 64Kbytes and a SRAM of 64Kbytes.
- 1 RS232 debug port.
- A Low Power Serial Data Bus.
- Total radiation dose of 50K rads(Si).
- 4 user defined, variable speed, serial links for external communication.

Sun Sensor: The sun sensor is made by IRF, Kiruna and has a field of view of +/- 40 deg. It has 4 analogue outputs labelled alfa1, alfa2, beta1 and beta2 and yielding between 0 and +2, +2, -2 and -2 V, respectively. The axis's should be identified on the pertinent PCB and are required to calculate the direction. The resolution of the sun sensor is claimed to be 0.4 deg or better depending on the no of bits of the ADC. The sun sensor requires four OP-amplifiers, which will be mounted on an extra PC/104 PCB. It weights 68 grams and uses +12 and -12 volts. [R.6]

Magnetometer: The magnetometer selected is made by APS at Mountain View, CA. It has model no 533 and is a small fluxgate magnetometer of compact size (0.725" dia x 1.5" long" and only 18 g) and rugged construction. It is a complete 3-axis system and measures up to 1 Gauss with a sensitivity of 4 volts/Gauss. Operating at +/- 5 volts (30 mA each), it generates an output between –4 V and +4 V with a linearity of +/- 0.1%. The device is encapsulated in fibre glass/epoxy resin and has six no 28 gauge insulated wires. [R.7]

Camera: There are two cameras of choice, the Sony FCB-IX47P or the Sony XC-777. There is currently no final decision on which camera to use. [Appendix]

DC / DC Converter: The generated voltages are +/- 5V and +/- 12V. [R.8]

Temperature Sensors: The temperature sensors are of the model “A590” and can measure temperatures between -55C and +150C. It has a sensitivity of 1 micro ampere per Kelvin. The HARRIS Semiconductor company manufactures this temperature sensor. The sensor is a current output analog sensor. [R.9]

Magnetic Torque Coils: Victoria has an attitude control subsystem with the help of magnetic coils, which leads to a decrease in performance as well as a considerable reduction in complexity. However the attitude control subsystem will still consider reduction in development, in reliability concerns, and in safety issues. [R.10]

Separation System: A spring system using a wire to hold down the spring and a wire cutter that cuts the wire in time to release the springs, previously used in MUNIN satellite. [Appendix]

Components and System Status

The satellite contains a camera that will photograph the surface of the sun and send information about the sunspots back to the earth. In order to locate the sun in its orbit, the satellite has a sun sensor onboard. A magnetometer is also in place to read the earth magnetic field and in this way help control the satellite by the magnetic torque coils. The satellite also has a Particle Detector and a Memory Chips (SEU). There is a receiver and a transceiver onboard for engineering communication and for the use of radio amateurs. All these components and systems require a good monitoring system to check the correct functioning of the satellite.

We need to define the satellite as if it would be placed on the Cartesian co-ordinates with centre of the satellite at the origin. The satellite has the form of a box with four solar panels in every four direction.

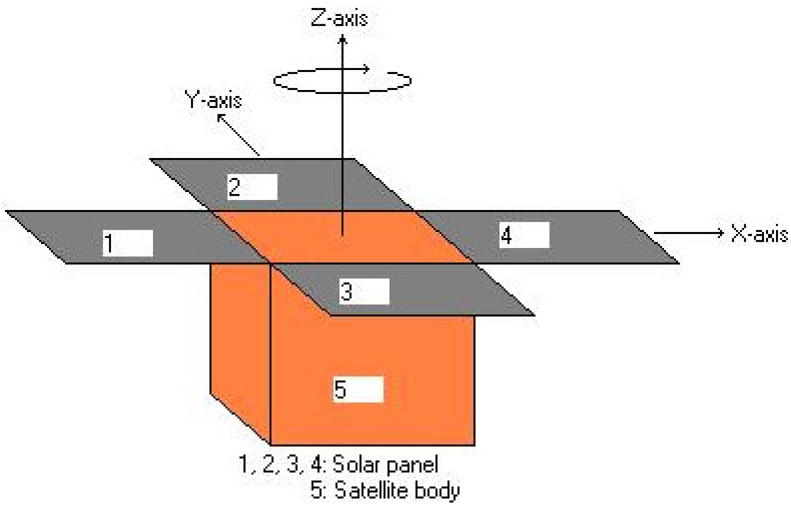


Figure 8: Victoria's axis structure

The contains of the satellite, at this moment, is as follows:

1. Four solar panels used in the satellite:
    - 1 solar panel in the direction of X-axis
    - 1 solar panel in the direction of –X-axis
    - 1 solar panel in the direction of Y-axis
    - 1 solar panel in the direction of –Y-axis
2. A battery package.
3. Three magnetic torque coils each in X-, Y- and Z-axis.
4. A power control unit.
5. A TNC.
6. A ChipCorder "Parrot".
7. A Slow Scan TV (SSTV).
8. A transceiver for use in the 437.75 MHz frequency.
9. A receiver for use in the 1269.90 MHz frequency.
10. A camera.
11. A sun sensor.
12. Two photo sensors.
13. Six voltage sensors.
14. Three temperature sensors.
15. Fourteen current sensors.
16. A magnetometer.
17. A particle detector.
18. A Memory Chip (SEU).
19. An Embedded Controller Card (ECC) containing the Central Processing Unit (CPU).

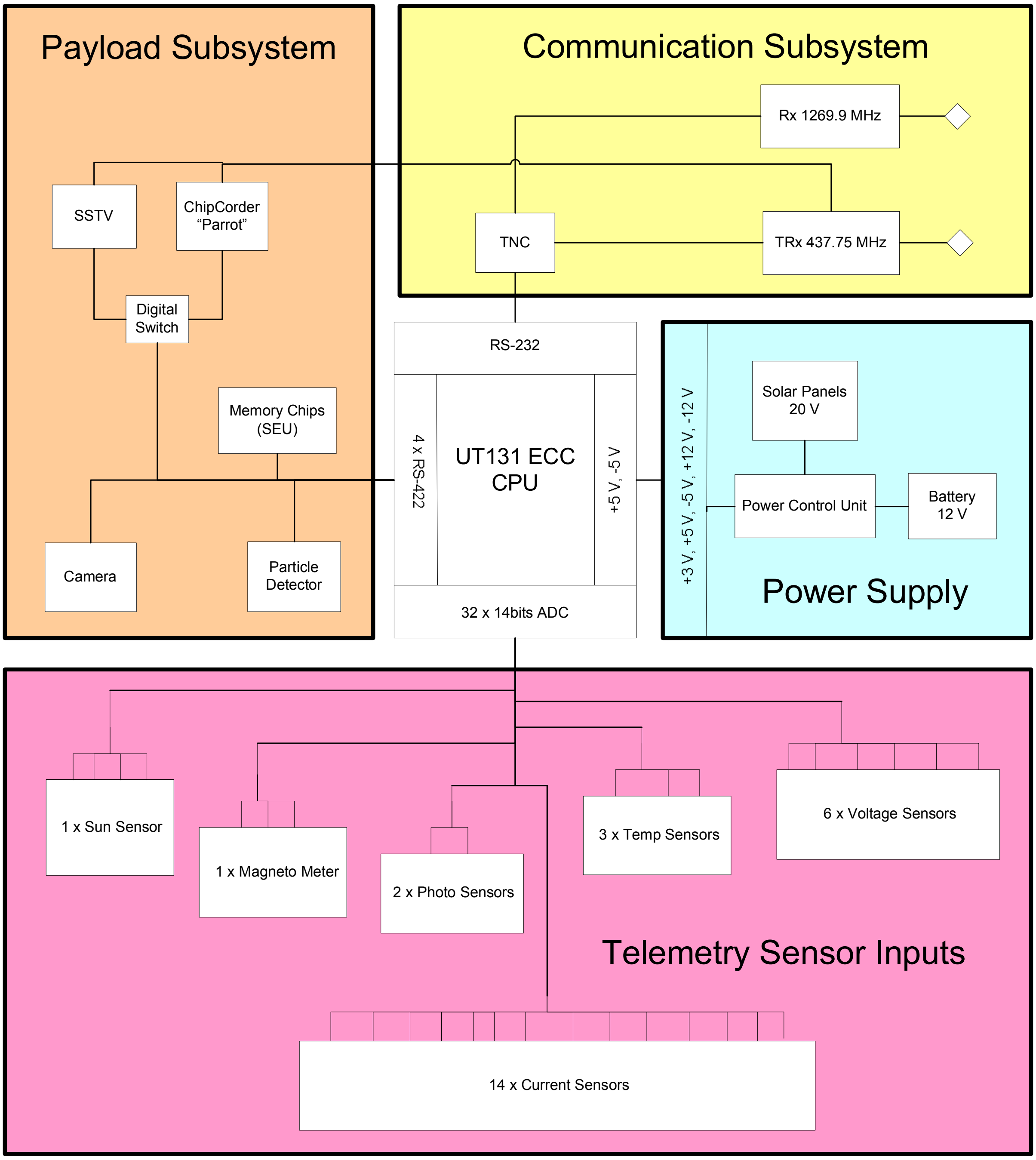


Figure 9: A block diagram of the components of the Victoria satellite.

Now we must have some sensors to check the system status of the satellite by measuring different data on its various components. The chosen sensors are as follows:

Temperature Sensors: We will use 3 temperature sensors (TS) in the satellite for monitoring the temperature inside and outside of the satellite, on both the shadow and sun side.

- 1 temperature sensor on the front panel: Z-axis.
- 1 temperature sensor on the rear panel: -Z-axis.
- 1 temperature sensor inside the satellite body on the battery package.

Photo sensors: We will use 2 photo sensors in the satellite to easier detect the direction of the sun. One sensor will be placed on one side, say in the direction of the X-axis, of the satellite and the other will be placed in the opposite direction of the sun sensor.

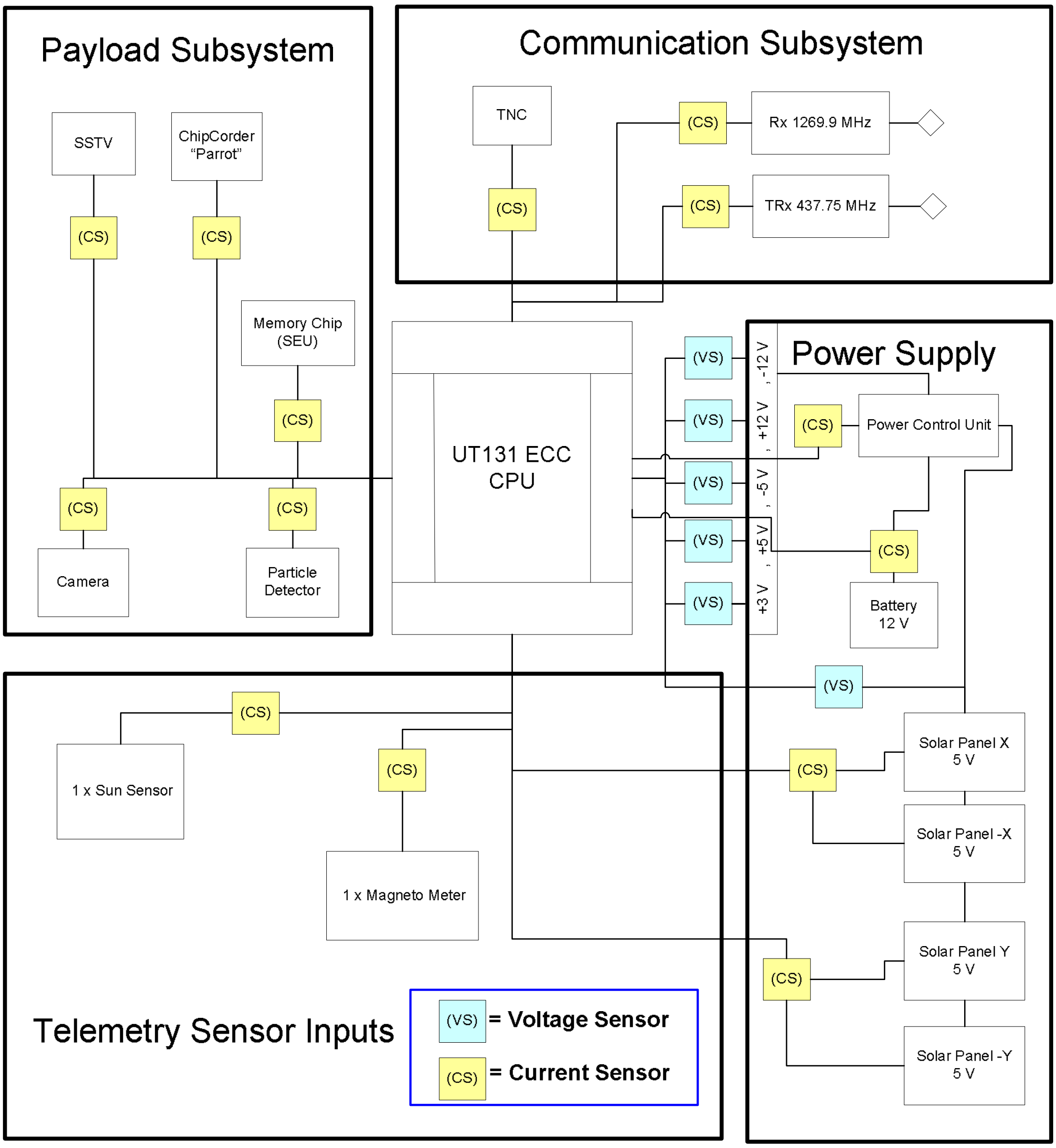


Figure 10: The sensor layer showing the layout of voltage and current sensors.

Voltage Sensors: We will use 6 voltage sensors (VS) to monitor the system status of the satellite. These will be placed on the power supply bus.

- A voltage sensor for measuring the +3V bus.
- A voltage sensor for measuring the +5V bus.
- A voltage sensor for measuring the -5V bus.
- A voltage sensor for measuring the +12V bus.
- A voltage sensor for measuring the -12V bus.
- A voltage sensor for measuring the total accumulated voltage on the solar panels bus, which should generate +20V.

Current Sensors: We will use 14 current sensors (CS) to monitor the system status of the satellite.

- 2 current sensors for each pair of solar panels for measuring the total current accumulated by 4 solar panels in 2 strings.
- 1 current sensor on the battery package.
- 1 current sensor on the TNC.
- 1 current sensor on the ChipCorder (Voice Transmitter/Parrot).
- 1 current sensor on the transceiver.
- 1 current sensor on the receiver.
- 1 current sensor on the camera.
- 1 current sensor on the sun sensor.
- 1 current sensor on the magnetometer.
- 1 current sensor on the particle detector.
- 1 current sensor on the SSTV.
- 1 current sensor on the Memory Chips (SEU).
- 1 current sensor on the power control unit.

Note that these sensors are measuring all the components onboard. If there is a need for having less current sensors we can give up measuring some components.

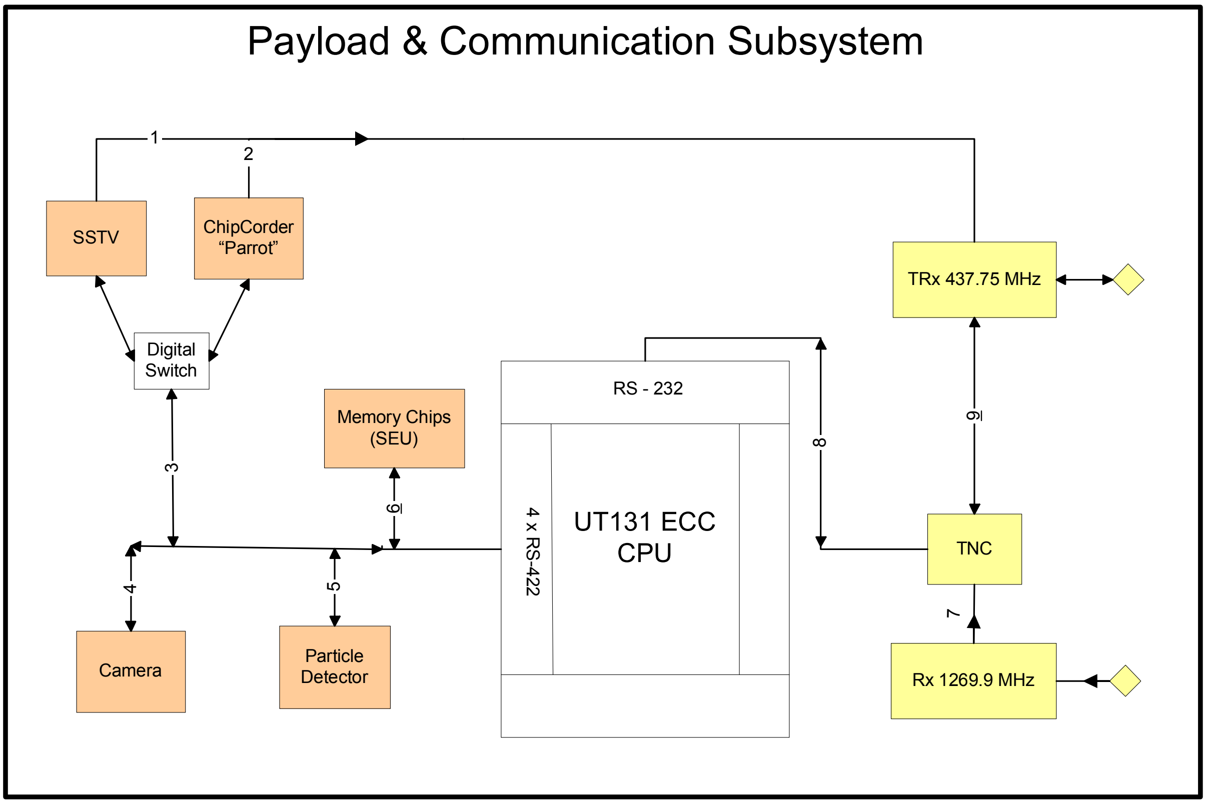


Figure 11: The data flow between the payload, CPU and communication subsystems.

1. Use during Broadcast Mode for transmitting SSTV image.
2. Use during Broadcast Mode for transmitting voice telemetry.
3. Update memory and control signal via the digital switch for SSTV and Parrot.
4. Download image to the UT131.
   Transmit the control signal from the CPU to the camera.

5. Download measured data to the UT131.
   Transmit control signal from the CPU to the Particle Detector.
6. Check (SEU) Memory Chips status from the UT131.
   Transmit control signal from the CPU to the Memory Chips.
7. Receiving command signals in AX.25 package format from the 1269.90 MHz receiver to the TNC.
8. Receiving disassembled AX.25 packages from TNC to UT131.
   Sending data to TNC for assembly in AX.25 package format.
9. Transmit AX.25 packages between the TNC and the 437.75 MHz transceiver.

Power Supply Subsystem

The power system generates energy, stores it in batteries for use during peak demand cycles and during orbit eclipse. It also controls the distribution of power to the required satellite parts and payload systems. The figure below is a simplified functional block diagram of the power supply subsystem. This figure shows the primary power system functional elements as well as the monitoring and switching circuits used in the generation and control of satellite power.

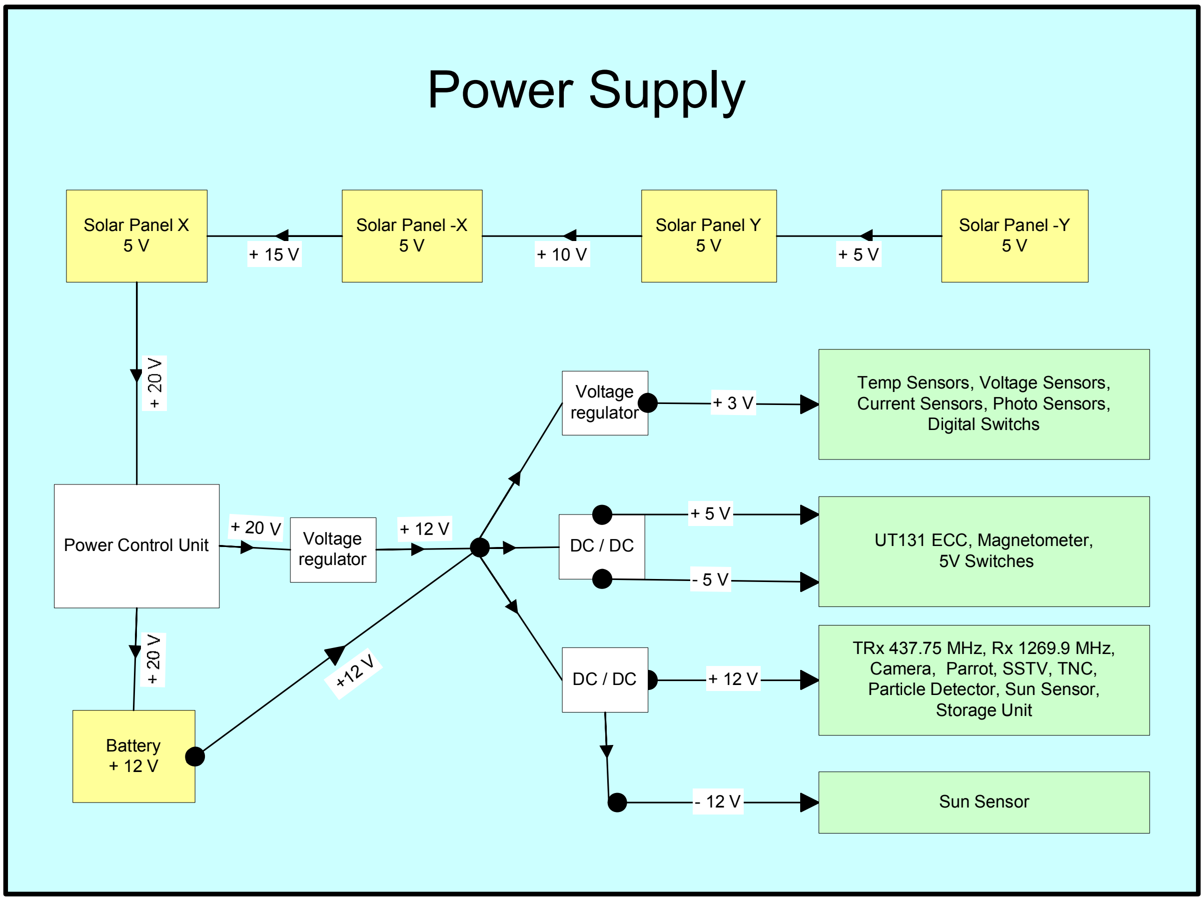


Figure 12: The power supply chart of the Victoria satellite.

Power is generated by body mounted solar panels. There are 4 rectangular solar panels, together containing 2 strings generating a total of 20 volts and 2.5 amperes. The strings consist of a number of silicon photovoltaic cells with an efficiency of approximately 10%-20%. Diode isolation of the individual array circuits from the bus should be used to prevent a failure in an array string from causing a failure of the entire power generation system.

Assuming one year degradation of 20% and a 30° solar angle of incidence, the solar cells should be chosen carefully and provide approximately >25% margin.

Energy required for peak loads and during the eclipse portion of the orbit will be stored in the battery packs. The power usage profile will probably produce an average battery depth of discharge of between <10%-20%. Only one battery is necessary for operation but two could be provided for redundancy; a one-time relay can be used to remove one battery from operation if it fails. The power budgeting is a very important part and future work could be assessed to study this further in detail.

Power Budgeting

Here we will just give a general statement of how the power usage of the satellite looks like as of today and decide some figures on the choice of solar cells. The following table is showing the major components of the satellite.

Component name	Voltage (V)	Current (A)	Power (W)	Weight (g)	Size WxHxD (mm)
ECC	+/-5	0.5	5	N/A	N/A
Sony FCB-IX47P	6 - 12	0.47 - 0.23	2.8	205	51.2 x 57.8 x 92.4
Sony XC-777P	12	0.19	2.3	75	22 x 22 x 89
TEKK KS-1000L	7 – 12	0.51 – 0.3	3.6	145	85 x 52 x 21
Receiver 1269.90 MHz	12	0.15	1.8	N/A	N/A
Battery charger	20	0.5	10	N/A	N/A
Sun sensor	+/-12	0.002	0.05	100	N/A
Magneto-meter	+/-5	0.02	0.2	18	N/A
Memory Chips (SEU)	N/A	N/A	N/A	N/A	N/A
SSTV	N/A	N/A	N/A	N/A	N/A
Magnetic torque coil	N/A	N/A	N/A	N/A	N/A
ChipCorder (Parrot)	N/A	N/A	N/A	N/A	N/A
Particle detector	N/A	N/A	N/A	N/A	N/A
TNC	N/A	N/A	N/A	N/A	N/A
DC/DC-converter	N/A	N/A	N/A	N/A	N/A
Battery (accumulated output power)	12	3.75	45	N/A	N/A

Table 1: The preliminary power budgeting of the Victoria satellite.

We see in the table that the total generated power needed to charge the batteries and run the satellite, based on the pinch of information that we currently have, would be about 23W. Note that much of the information, about some components power usage, is still missing. If we would want to guess the value, of the missing information and add it to the sum of power usage of the rest of the satellite, we would need approximately 37.5W. Since the solar panels usually get older and produce less power then it would be wise to have an extra energy buffer, of at least 25% of the nominal value of produced power by the solar panels, to make sure the satellite survives for a number of years. This means that our 37.5W is 75% of the nominal value, hence the nominal accumulated power would be (37.5 x 100)/75 which is 50W. This means that we need a total of 20V and 2.5A to produce 50W of power in the beginning of lifetime (BOL).

If we look at the existing solar panels, we see that the efficiency of the panels varies between 15% and 25%. For example the satellite cell named "SG-2x6" produces 0.5V and 0.5A with a size of 2.5x6.2cm. With this cell we would need to parallel-connect 5 cells to get 2.5A and serial-connect 10 of these rows-of-5-cells to get 5V. This would then represent one of our 4 solar panels which would consist of 50 cells. The size of each panel, using this cell, would therefore be $(0.025x0.062m^2)x50$ which is $0.0775m^2$. This is the area of one panel. All 4 panels together would have an area of $4x0.0775m^2$ which gives us $0.31m^2$. With a cost of US$12.5 for each cell the total cost of our 4 solar panels would be US$2500. We suggest a further study in power budgeting to be conducted to make available full detail and accurate information on this subject. [R.11]

The Experiments

These experiments will be integrated in such a way so to work all together with other subsystems, the transceiver and the receiver. It will be possible for the ground station to choose which of the experiments to run or shut down, also what type of message to send. The communication will be possible for the amateur-radio enthusiasts by using an antenna, a receiver, a computer equipped with soundcard and needed software.

Chipcorder "Parrot"

The satellite contains a ChipCorder / voice transmitter that will be of the type "parrot". This means that it works similar to an answering machine thus will transmit the voice telemetry or uploaded messages back to earth. The voice telemetry data will be such as temperature, voltages, currents and other sensors data. There is a prototype that is functional for a transceiver in the 437.75 MHz band but that also should work with a yet not tested receiver in the 1269.90 MHz band. For more details on this issue read the "Broadcast Mode" section.

The parrot works so that it sends voice telemetry during the times when the satellite is in broadcast mode. This sending will last for 30 seconds. The voice message could be either the voice telemetry of the satellite or a message that has been uploaded to the satellite via the control station. There is the possibility of having 8 minutes of sound on the "parrot", which gives us 16 different messages of 30 seconds each. The possibility of how to use these 30 seconds in other ways also exists. For instance, the messages could be 15 seconds each and the other 15 seconds could be used to send the telemetry.

After having sent the 30 seconds of voice message the parrot will not be transmitting anything for a period of 80 seconds or 60 seconds depending on what communication mode the satellite is using. It will be in standby for 80 seconds if the communication mode is half-duplex and 60 seconds if the communication mode is full-duplex. If we want to save battery power, then we could turn off the parrot during these 80 or 60 seconds by using a power switch. If we do not want to turn off the parrot at all, then it could simply be on standby mode during the non-transmitting time. The cycle will be repeated until the whole function is turned off or if a "wake up flag" is received.

Slow Scan TV (SSTV)

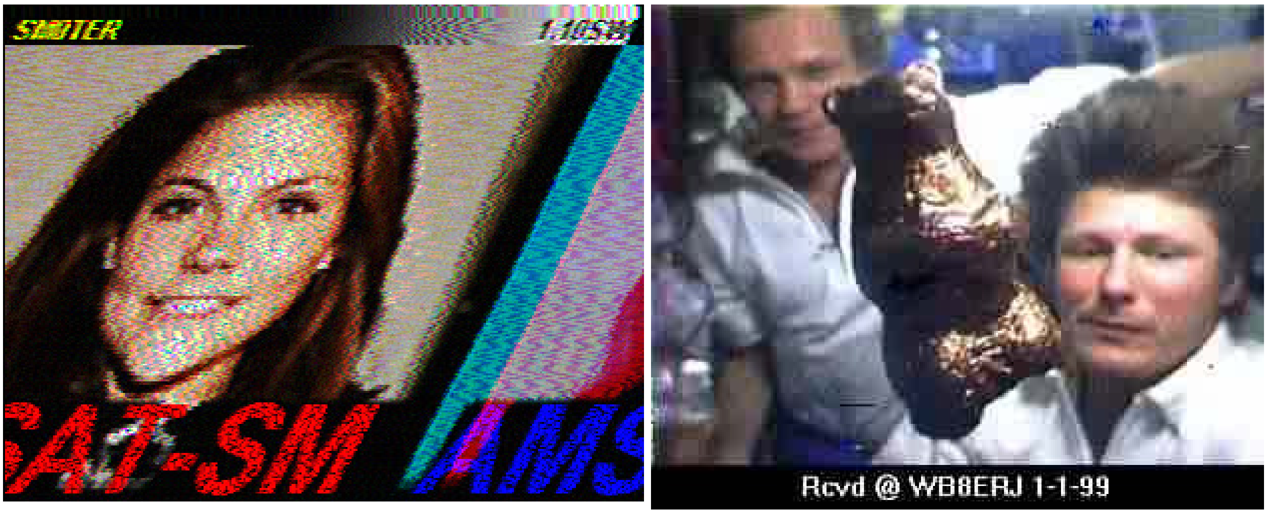


Figure 13: Two examples of SSTV images with different quality.

Slow Scan TV is a picture transmission mode developed and used by the Amateur community. While these signals are FAX-like in function they do not possess the scratching quality of the FAX signal. This will enable us to transmit a complete image in a time of 60 seconds. The chosen protocol for transmitting SSTV image is Martin M2, due to its performance. The images are of two different types. One is the image that the ground station uploads to the satellite and the second is image from the camera. These images are transmitted in audio format on the 437.75 MHz frequency. It means that the SSTV encodes each pixel of the picture to an audio wave. These waves represent different pixels in the picture and holds information about the colour of the pixel. When the sound wave is received it will be decoded back to pixels by using the proper software and the picture will appear. The time of transmission for the SSTV is 60 seconds. After the transmission of uploaded picture or the telemetry the SSTV will not be transmitting for either 40 seconds or 30 seconds. It will be in standby for 40 seconds if the communication mode is half-duplex and 30 seconds if the communication mode is full-duplex. During these periods of non-transmission the SSTV could be turned off to save battery power. If we wish to turn the SSTV off, we could arrange a timer and connect the timer to a switch shared by the SSTV and the Parrot. When the parrot is off, then the SSTV is on and when the SSTV is turned off then the Parrot is on, all of this by switching power between the SSTV and the Parrot using the timer. The cycle will be repeated until the whole function is turned off or if a "wake up flag" is received.

Camera

The digital camera will photograph the sunspots and download these images via the SSTV. Future work to integrate the camera with the satellite should be conducted. [Appendix]

Particle Detector and Memory Chips (SEU)

The particle detector is to measure some highly charged particles and reconfirm it together with the Memory-Chip that will indicate the SEU onboard, the data will send back to earth with the P2P Mode.

Single Event Upsets

Single Event Upset (SEU) is a change of state or transient induced by an ionizing particle such as a cosmic ray or proton in a device. This may occur in digital, analogue, and optical components or may have effects in surrounding circuitry. These are “soft” bit errors in that a reset or rewriting of the device causes normal behaviour thereafter. For example if a SEU has occurred, a single bit flip, while not damaging to the circuitry involved, may damage the subsystem or system (i.e., initiating a pyrotechnic event).

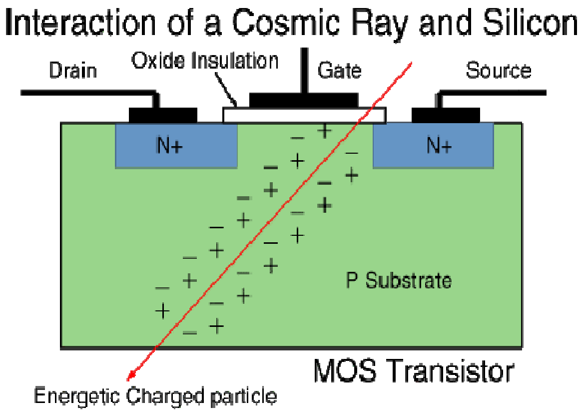


Figure 14: An example of how the SEU works.

The space radiation environment is highly variable. The SEU was discovered in space in 1975 at intervals and particularly when the spacecraft has its apogee over the South Atlantic, the memory of the microprocessor can be corrupted by a Single Event Upset (SEU). Often this affects a part of the memory that does not disturb the running of the CPU, but whenever an SEU is detected (most are flagged as a result of a checksum calculation), the microprocessor is rebooted. Occasionally, several hours, or days of data have been lost before this is done.

Communications

After initialization Victoria will conduct normal operations by remaining in a receive-only mode at all times, waiting for a “wake up flag” from a command ground station. After acknowledging the user, Victoria will begin the information-relay phase, during which the operator will be able to access Victoria’s WOD, log files, telemetry and system status. When the information-relay is complete, the user will log out and the station will send a request-to-disconnect command to end the session. Victoria will implement AX.25, which is a standard link-layer protocol used by amateur radio operators.

A point-to-point communications path for command stations over Victoria’s single physical communication channel is made possible by the use of AX.25, which embeds each message with a source and a destination address. In order to command the satellite Victoria, some access code will be needed. Victoria will allow the transfer of any format of file, including text and binary. Files may contain executable programs, graphics, images and encoded voice. Of course, due to storage limitations, there will still be limitations regarding file size, number of files, and length of time each file remains on Victoria.

Assuming a minimum usable elevation of 10° and a 28.5° inclination, low earth orbit (LEO), command ground station would have a maximum communications window of approximately 8 minutes with Victoria during each of its approximately 4 passes per day. In addition to an increase in the number of passes per day, higher inclinations also equate to longer orbital lifetimes.

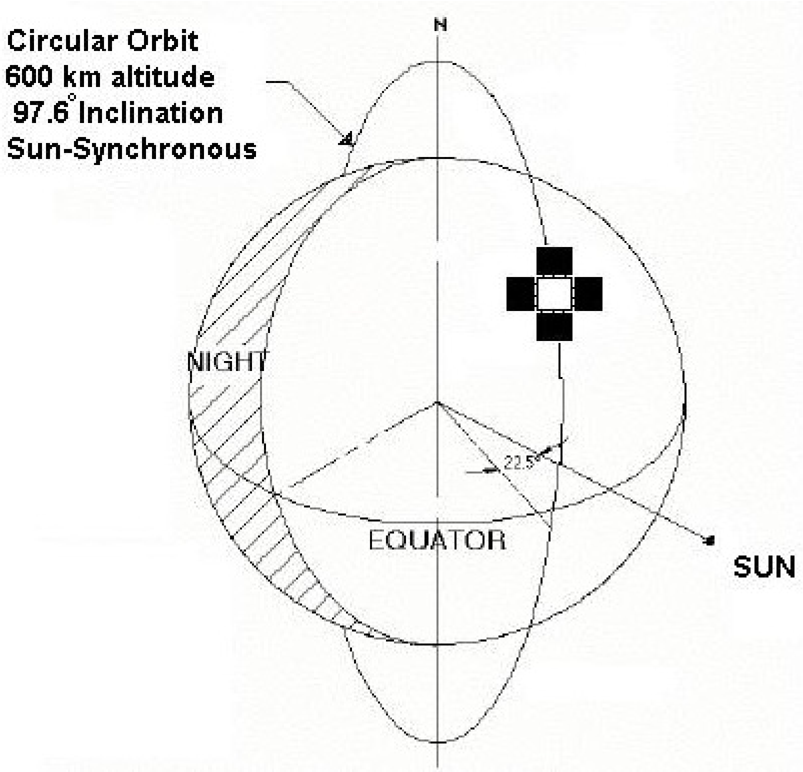


Figure 15: The orbit of the Victoria satellite.

The use of digital technology in the communications subsystem incurs numerous advantages. Digital technology uses less area on the satellite, reduces satellite power requirements, provides flexible data rates and is programmable. Additionally, the increased flexibility inherent in digital design allows for the future addition of multiple spreading codes and ease of adaptation to other systems. The case for a "Digital Broadcast Protocol" for use on Victoria is made and a suitable protocol is proposed. [Appendix]

Uplink and Downlink Frequencies

The chosen frequencies are 437.75 MHz uplink/downlink and 1269.90 MHz uplink. The reason to choose these frequencies is that they are not very commonly used, thus are not so crowded. Therefore the signal interference and disturbance will be lower. Because of the 1269.90 MHz frequency being used by several radar stations around the globe, we are prohibited from using this frequency for downlink transmission. To increase the redundancy of the satellite communication we suggest having 2 downlink radio modules, instead of one, which uses the same frequency of 437.75 MHz.

Choosing the Baud Rate

The decided communication speed, have been set to 9600 baud (9.6k bits/s). The reason for this is that 9600 baud is using the most common technique and the price range of the needed components is not too high. It would therefore ease wider use of the satellite for many amateurs. But there is a problem with a technology that is too common and that is the radio amateur "hackers" who block the frequency at which the control signal is being sent. Higher speed could give us some protection against "hackers" since it is not as easy-to-come-by and relatively cheap technology as 9600 baud is. The right transmitter is chosen by the signal power that needs to be sent from the satellite. This transmitting power is calculated from the quality of the signal, received by radio amateurs.

Encoded Command to Victoria

One other way to avoid attacks by "hackers" is to have the control signal that is sent on 1269.90 MHz coded. The messages sent to the satellite on this frequency is the most important, hence the proposal to have the message coded. This would make it difficult enough for the "hackers" and protect the satellite against unprofessional use without requiring too much processing power. Decision must be made on the choice of coding procedures.

Digital Transmission Frame

We use 512bytes block that allow us to send 4096bits of information per second. The reason to choose this size of package is that it is large enough to contain reasonable information that is transmitted in a relatively short time. If we would choose a larger package of for example 1024bytes the error bit rate would be too much which would result in a higher rate of messages containing errors. We can conclude that the package size of 512bytes is optimal since it is large enough for the information but small enough to be sent without too much error and in a reasonable amount of time.

The Communication Subsystem (COM)

The COM subsystem can work on half-duplex, which means it incorporates a single channel for both up-link and down-link. The up- and down-link do not occur at the same time. The subsystem can also work on full-duplex, which means it uses two different channels, one for up-link and the other for down-link. The up- and down-link can occur at the same time. Data rate will be 9.600 bits per second (bps) or faster maybe 38400 bits per second. The spacecraft will, during half-duplex, operate at a center frequency of 437.75 MHz in the amateur radio 70-cm band. When in full-duplex it will use the 437.75 MHz as down-link frequency and the 1269.90 MHz as up-link frequency. It will occupy a bandwidth of 230 kHz. The *Code of Federal Regulations* (CFR) places some restrictions on amateur radio spread spectrum, but at the same time amateur radio involvement provides a large user base. The reason to choose these frequencies is that they are not very commonly used, thus are not so crowded. Therefore the signal interference and disturbance will be lower. There is also a TNC involved which is the PacComm's Spirit 2.

TNC

TNC stands for "Terminal Node Controller" and is similar to the modem used when connecting to the internet. One difference is that the digital transmission the TNC is used to interface our terminal or computer into the Radio Frequency (RF) or wireless radio medium.

Inside the TNC there is some internal firmware called a “PAD”. The pad or “Packet Assembler/Disassembler” captures incoming and out-going data and assembles it into “packets” of data that can be sent to and from a data radio or transceiver. In our satellite communication sub-system the TNC will receive packages from the 437.75 MHz transceiver or the 1269.90 MHz receiver. These packages received will be disassembled to a data bit stream and assessed by the ECC, the onboard CPU and the correct process will be performed. In the same sense, the data destined for earth will be received by the TNC from the ECC. The data will be assembled in to AX.25 packets by using the specific protocol AX.25 version 2.2. The 437.75 MHz transceiver works as the downlink as well; all transmission will use this downlink both in Broadcast Mode and P2P Mode.

The TNC that is used in the VICTORIA satellite is a SPIRIT2 which supports, among others the KISS mode of AX.25, which we intend to use, and follows its procedures. It supports a communication speed of 9600 baud and higher up to 38400 baud, for satellite downloads, without dropped frames. This TNC also support full duplex connections because it has two separate filters for incoming and outgoing packets. This will ease the digital full duplex communication during P2P Mode. The frame transmitted by KISS is a complete AX.25 frame without the checksum or the HDLC (High-level Data Link Control) encoding. To know for sure that the received data stream is the correct data stream, and that there has not been any loss of bits, the TNC will compute the CRC and perform a HDLC encoding on transmission. On reception it is the task of the TNC to remove the HDLC encoding and validate the checksum before making the frame available to the host, which in our satellite is the ECC. The creating of package follows the version 2.2 of AX.25 protocol and our chosen TNC supports this protocol. For more details study the AX.25 protocol specification.

Modulation Format

The spacecraft digital information at 9600 bits/sec is first differentially encoded so that a message "1" is represented by a change in the data stream and a message "0" by no change. This data is then Exclusive-OR with its 9600 Hz clock to create Manchester coding. Finally this stream is passed through a gentle low pass filter (3 db point = 560 Hz) to restrict extraneous sidebands and then balanced modulated onto the RF carrier to create PSK.

Differential encoding is used, similar to packet radio systems, to ensure that channel and decoder polarity inversions are of no consequence; it's the changes that matter, not the absolute polarity.

Digital Control Subsystem (DCS)

The primary functions of the Digital Control Subsystem (DCS), which is also referred to as the Command and Data Handling (C&DH) Subsystem, are to:

- provide control and monitoring of the satellite system status
- provide control and operation of the COM
- gather, organize, store telemetry data and Whole Orbit Data (WOD)
- gather, organize the Particle Detector data and Memory Chips (SEU) data.
- gather satellite’s login request in a logfile

The DCS design implements both a multi-tasking operating system to provide Voice Telemetry, SSTV Image, Particle Detector Data, SEU Data and "pair and spare" technology to provide redundancy for space operations. The current DCS design consists of a UTMC 131 Embedded Controller Card and pre-programmed software in the UTMC 131’s PROM . The UTMC 131 Embedded Controller Card is selected because of its proven architecture, radiation tolerance, low power consumption, availability of development tools and capability of supporting a multi-tasking environment.

Launch and In-Orbit Operations

A sequence of events allows Victoria to separate from a launcher and enter its own orbit. The low weight and the small size of the Victoria satellite gives us the opportunity to design a very simple yet reliable separation system. The approach that we have chosen is based on the use of a steel wire to tie down the satellite to the launcher interface plate. The line will pull down the satellite at three points. The wire is tensioned by a spring. When the separation system will be activated a small pyro-guiliotine is used for cutting the steel wire. Three helical springs will push Victoria away from the launcher with a speed of 0.5-0.6 m/s and a maximum tip-off rate of 10 deg/s when the wire is cut. At the same time a circuit will be turning ON the Victoria and Victoria will enter the Launch Mode. Victoria is launched with minimal software and must undergo the Launch Mode, after testing the satellite and additional software have to be uploaded, before users with “level 1 access code” can begin to interact with the satellite. Once the operating system and other software tasks are uploaded from the command ground station, the satellite will attain full operation and can begin it Broadcast Mode. Victoria will broadcast voice telemetry and SSTV image if there is no request of a P2P Mode. If there is a request of Point to Point Mode, then Victoria will stop broadcasting and enter the P2P Mode.

Mode Status of the VICTORIA Satellite

How to define the mode status of the VICTORIA satellite is proposed as follows:

1. Launch mode; which means that all the experiments and communication onboard are shut down and only the needed sensors are active for guiding the satellite toward its sun-pointing position.

2. Normal mode; indicates a normal satellite system status and energy usage. In this mode, all the components and experiments are in use, unless manually shut off by the control station, using different level access keys. Victoria will remain in the Broadcast Mode when no request of a Point to Point Mode is made.

3. Safe mode; is the indication of problem with the power usage. When the satellite is in this mode, all the experiments are shut down. Victoria will remain silence with no broadcasting of voice telemetry and SSTV image, only command ground station with “level 2 access code” will be granted access to Victoria. Victoria will remain in this Safe Mode until the battery level has reached 60% of its capacity.

Launch Mode

After separation from the launcher, the Victoria will be in the Launch Mode. This mode means that all the experiments onboard are shut down and only the needed sensors are active for guiding the satellite toward its sun-pointing position. The list below shows the activity onboard the VICTORIA satellite:

ON	OFF
ECC	ChipCorder (Parrot / Voice transmitter)
TNC	Particle detector
Battery	CCD (Camera)
All the voltage sensors	SSTV
All the current sensors	
All the temperature sensors	
Sun sensor	
Magnetometer	
Magnetic torque coil	
Transceiver (437.75 MHz)	
Receiver (1269.90 MHz)	

Table 2: A list of active devices onboard the Victoria satellite during the launch.

1. The satellite is unloaded to orbit. Confirmation received from NORAD that the VICTORIA satellite is placed in the correct orbit.

2. Auto pilot (AP) is an automatic program, which will automatically be turned on after 20 minutes passed without the sun sensor, magnetometer, current sensors and the voltage sensors giving the valid value for a sun pointing system. The adjustments then made by the AP are:
   - Check the values of the sun sensor, magnetometer, temperature sensors, voltage sensors and the current sensors.
   - Use the received values to determine the current position of the satellite towards the sun.
   - Unfold the solar panels if not already unfolded.
   - Test if the solar panels are unfolded by checking the values of the current, voltage and temperature sensors.
   - Adjust the satellite to point toward the sun by using the magnetic torque coil.
   - Check the battery level.
   - Dependent on the battery level, go to preferred mode.

   This list will primarily show how the preferred mode is chosen:

Mode name	% of maximum battery power
Normal mode	100% to 41%
Safe mode	40% to 0%

   Table 3: The chosen satellite mode depends on the battery power.

   The above list is considered only when the solar panels do not produce enough power to run the whole satellite on the normal mode.

3. If the satellite is in normal mode, then check if the contact with the control station is stable. If so, then supervisor with access level 2 code will be able to test the satellite and its experiments onboard. The control station will receive the whole orbit data by logging in to the satellite and download the data. When everything is stable on board Victoria then the latest user interface of access level 1 code will be uploaded to Victoria. Afterward Victoria will be in the Broadcast Mode when no request of a P2P Mode is made.

Description of Communication Procedures

Auto Pilot

The radio modules will be used during the communication between the satellite and user. Every access requirement will follow the secure access procedure decided in the "Security of the satellite and signal transfer" section. Communication with these radio modules follows two techniques, called full-duplex mode and half-duplex mode. Here follows some diagrams about the satellite and its communication:

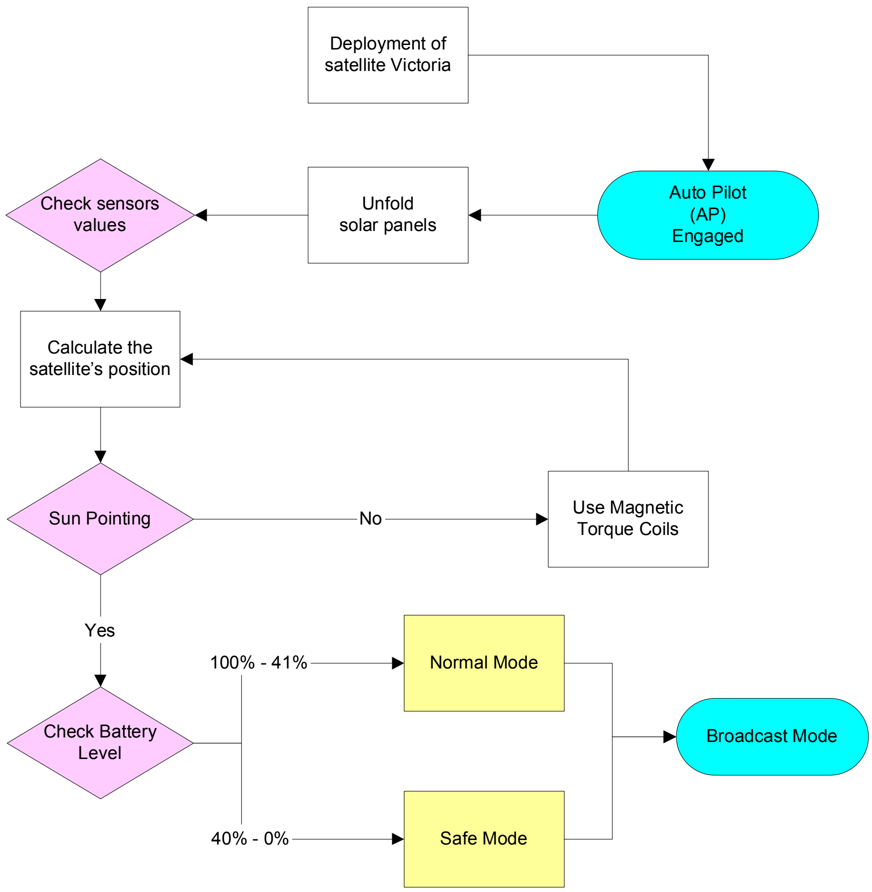


Figure 16: The Auto Pilot process.

The Auto Pilot will start approximately 30 seconds after separation from the launch vehicle. This will be the first time this procedure is running. Other than the first time, after approximately 20 minutes of no valid sensor information and no valid accumulated power from the solar panels, the onboard computer will give command to the "Auto Pilot" to start its operation. The reason to wait 20 minutes is that the LEO satellite will sometimes be in the earth shadow for approximately 16 minutes. The Auto Pilot operations start with the unfolding of the solar panels. The onboard computer will check the values provided by the sensors, then calculate the position of the satellite, by using some predefined measurements and compare it to the sensor values. Is the satellite sun-pointing? If no try to make it so by applying the calculation on the magnetic torque coil and use the coil to point the satellite towards the sun. Check the values once again. The loop will keep on checking the sensor information and use the coil if necessary, until the satellite is sun-pointing position. Then check the battery level, se the figure above. Dependent on the battery level, go to the correct satellite mode, and start broadcast mode. Observe that the ability to shut down the "Auto Pilot" is possible, if the ground station with "level 2 access code" wish do control Victoria manually.

Broadcast Mode

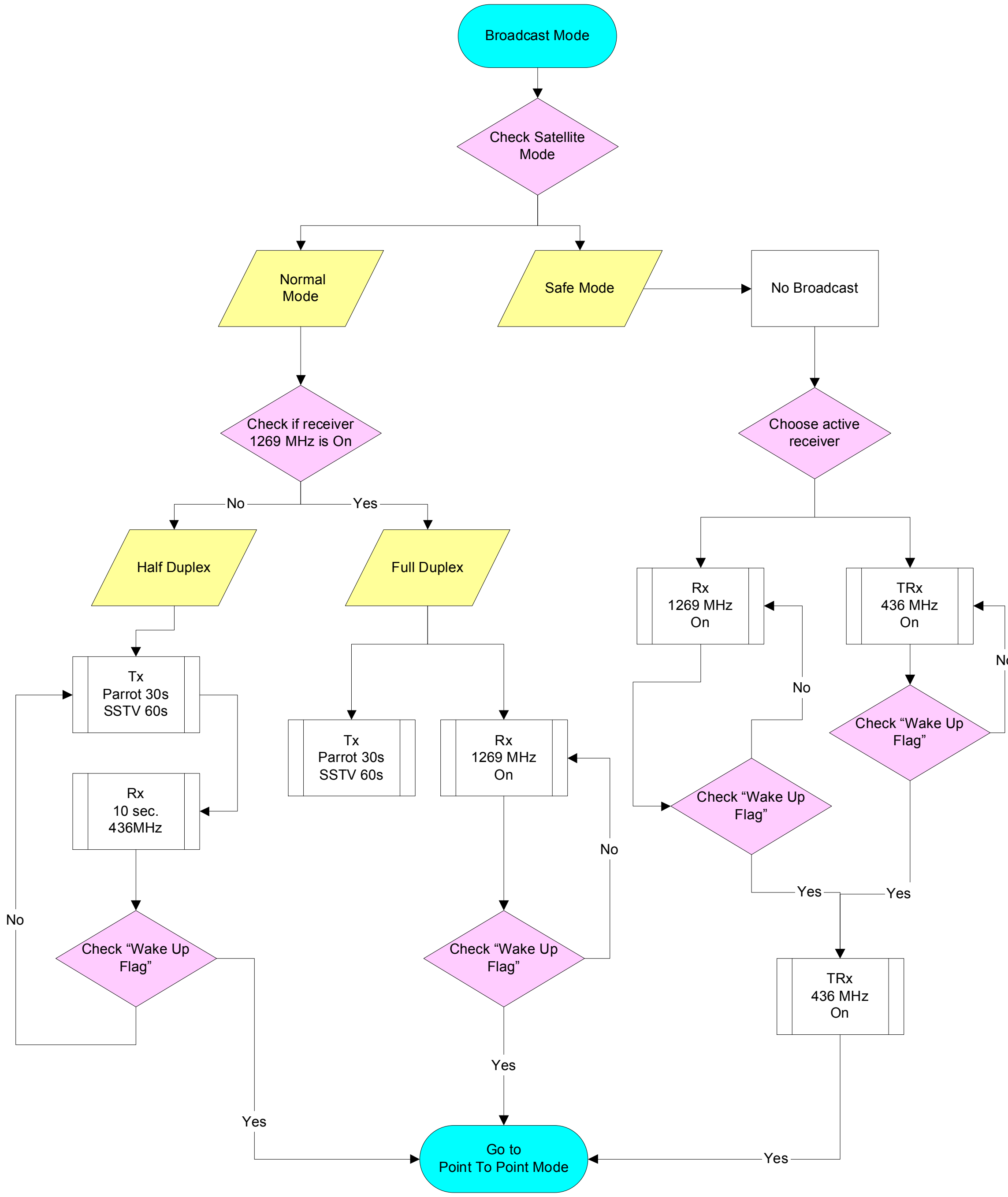


Figure 17: The process in Broadcast Mode.

The process of Broadcast Mode starts with checking the satellite mode. If the satellite is in safe mode, there will not be any broadcasting. Both the receiver and the transceiver will be in standby and only listen to command from ground station with "level 2 access code". If the 1269.90 MHz receiver is not out of function then it will be listening for "wake up flag" and commands to perform engineering tasks, since all the experiments are shut down during safe mode. The telemetry would be sent to earth on command as a WOD through the 437.75 MHz transceiver as the transmitter. This communication will happen in full-duplex mode. If the 1269.90 MHz receiver would be out of function, then the communication would be in half-duplex mode, with the 437.75 MHz transceiver as both the transmitter and the receiver.

If the satellite would be in normal mode, then by checking if any of the radio modules is out of function we would choose a duplex mode. In the normal mode, all the experiments are on, so there would be a broadcasting of voice telemetry and SSTV image. The request for communication would be either for full- or half-duplex mode. This means listening for "wake up flag" on the 1269.90 MHz and broadcast telemetry by the 437.75 MHz transceiver, if capable of full-duplex communication. If in half-duplex mode capability, then listen for "wake up flag" on the 437.75 MHz for 10 seconds and then broadcast voice telemetry for 30 seconds and SSTV image for 60 seconds. If the receiver detects the "wake up flag", regardless of satellite mode, the communication mode would change from broadcast mode to P2P mode.

Point to Point (P2P) Mode

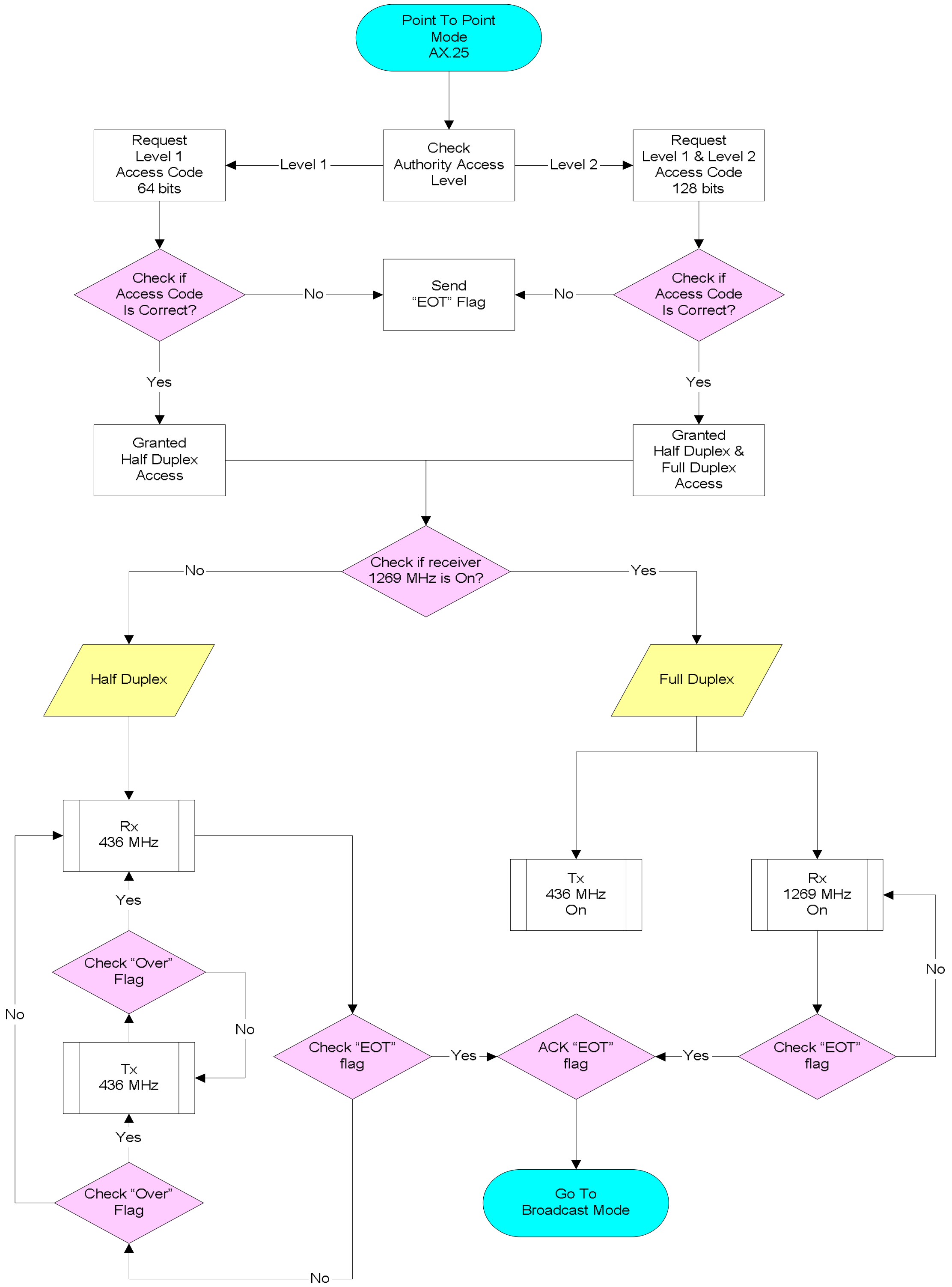


Figure 18: The process Point to Point (P2P) mode.

This P2P mode is more complicated than the Broadcast Mode, because there is a need for valid contact between the satellite and the ground station. When a “wake up flag” is received the satellite will determine the authority level of the client by checking the address field of the packet sent. If the client has level 1 authority the 64bit access code request will be sent and a 64bit answer will be received. If the client has level 2 authority then the 64bit level 1 request will be sent together with the 64bit level 2 request in a combined 128bit access code request. If the key is wrong then the connection will be closed down. When the correct access code is received the client will receive a granted duplex mode, which in turn grants access to some parts of the satellite. Level 1 authority grants half-duplex access and gives access to the experiments, while the level 2 authority grants full-duplex access and gives access to all manually controlled parts of the satellite. The 1269.90 MHz receiver will be checked to make sure that it is functional. If it works, then the connection will be in full-duplex mode. The 1269.90 MHz receiver would receive and the 437.75 MHz transceiver would transmit signals. When the receiver detects an "End Of Transmission" (EOT) flag, the P2P mode is over and the satellite would acknowledge the EOT flag and go to broadcast mode. If the 1269.90 MHz receiver would be out of function, then the connection would be in half-duplex mode. In this case, the receiver would receive signals and also listens for EOT and OVER flag. If no EOT flag was detected and no OVER flag either, then the receiver continues to receive data. If an OVER flag is detected then the transceiver will change its mode from receiving to transmitting and sends data until an OVER flag is detected and transmitted, when the mode will be changed back to receive. This continues until the whole connection is ended with an EOT flag where the P2P connection mode will be ended and the broadcast mode starts.

As a result of above diagrams, some specific rules regarding the satellite communication have been created, such as:

- The communication between the command ground station (control station) and the satellite will be on full-duplex mode, with uplink on 1269.90 MHz and downlink on 437.75 MHz. This mode uses the P2P AX.25 Connected Mode communication.

- The communication between other ground stations and the satellite is possible on half-duplex mode with uplink on 437.75 MHz and downlink on 437.75 MHz. Communication in half-duplex mode is not considered an option if not necessary.

- The 437.75 MHz transceiver can not be shut down. The 1269.90 MHz receiver can not be shut down.

- The 1269.90 MHz receiver on the satellite is always in the standby mode, ready to receive "wake up flag" signal from the control station. After each full-duplex connection the receiver will automatically go to standby mode.

- The 437.75 MHz transceiver is always transmitting voice telemetry and SSTV image using Broadcast Mode until a full-duplex connection is requested and the transceiver will go to P2P Mode instead. After each full-duplex connection the transceiver will automatically go to broadcast mode unless the satellite is in safe mode.

- During the period of Safe Mode, the transceiver on 437.75 MHz will not be transmitting any data using the broadcast mode. It will only be on standby mode to transmit on request.

- The half-duplex communication mode should automatically be on, if the receiver on 1269.90 MHz has a failure, thus it is out of function.

- After the end of any communication in half-duplex mode, the transceiver should go to broadcast mode only if the satellite is in normal mode. When a signal is received, the transceiver will establish contact.

- After the end of any communication in half-duplex mode, the transceiver should go to standby mode and not send any voice telemetry or SSTV image if the satellite is in safe mode.

- The half-duplex broadcast mode can consist of two stages. Stage one could be 30 seconds transmitting followed by stage two that could be 30 seconds receiving.

Security of the Satellite and Signal Transfer

The proposal for the satellite security and secure signal transfer is that the communication should be code based. It means that to be able to run the experiments on the satellite and to be able to close down parts of the satellite if necessary, one will need access to the satellite. This access is given by sending a key each time the satellite requests one. This communication process could be as in the following example between the ground-station (GS) on the 1269.90 MHz uplink and the satellite (S) on the 437.75 MHz downlink. The examples below show the two different authority levels.

GS: sends a wakeup signal ("level 1" authority information included).
S: sends acknowledge + level 1, 64bits key request (key number)
GS: sends level 1 key (key number)
S: acknowledge

GS: sends wakeup signal ("level 2" authority information included).
S: sends acknowledge + level 2, 128bits key request (key numbers.)
GS: sends level 2 keys (key numbers.)
S: acknowledge

This communication represents the high level of access to the satellite. For the access to control the very important parts of the satellite that are crucial to its survival, such as updating Victoria's software, the level 2 key is necessary. To control the experiments, such as shutting down the camera or the answering machine, there will be a level 1 key needed.

There will be 8 level 1 keys. Every level 1 key has 8 level 2 sub-keys. This gives us a total of 8 level 1 and 64 level 2 keys. Each key is different from the other, regardless of key level, with no visible pattern of similarity with other keys.

Each key is 64 bits long of which only 32 bits carry correct and crucial information for the key to be correct. These 32 bits also differ from key to key.

All these information will be programmed in the RAM of the ECC of the satellite. In this way the same information will be available to the satellite so that the satellite will know the correct answer to every key request.

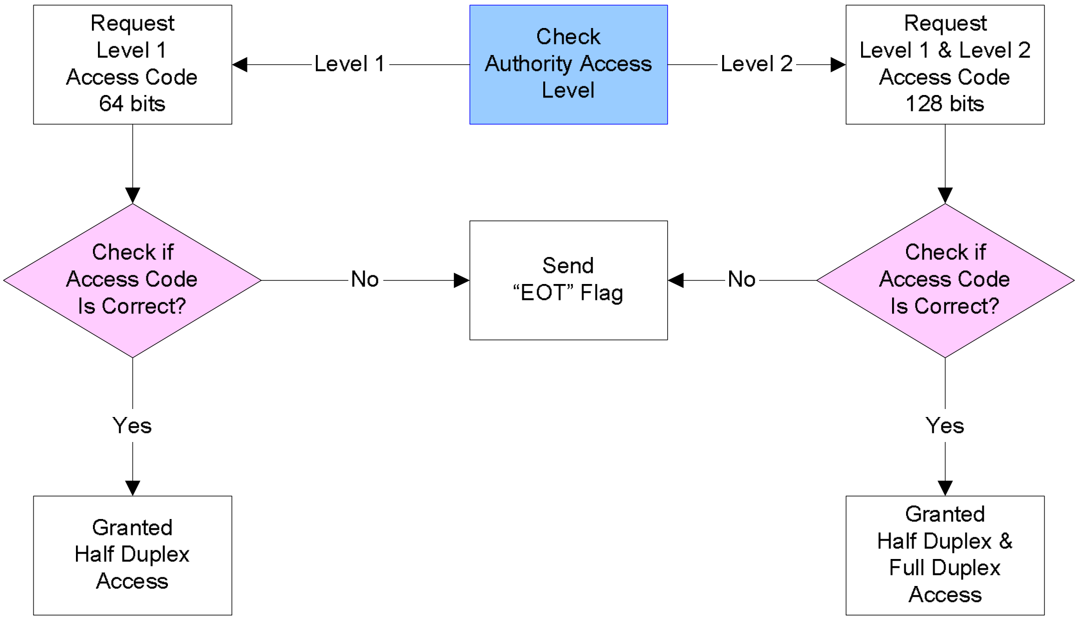


Figure 19: An example of a "login key request" process.

The Victoria Protocols

There exist different protocols for satellite communication. The two protocols of choice were CCSDS File Delivery Protocol, CFDP, and the AX.25 version 2.2, which is the most used protocol for amateur satellite communication. There are many differences between these protocols. The CFDP is new and used in a couple of satellites. The protocol is large and powerful, hence takes a long time to implement and requires more individuals working on it than perhaps the AX.25 protocol. So in comparison with the simpler AX.25 and with regard to the limited amount of time and manpower the choice became simple. The AX.25 has been used in different satellite projects since the 1980s and proved to work perfectly for small satellites similar to VICTORIA. It is also simple enough to be implemented by amateurs, as part of a thesis project. So we will be using the AX.25 protocol, version 2.2, in the VICTORIA satellite.

Amateur Packet Radio AX.25 Protocol

In order to provide a mechanism for the reliable transport of data between two signalling terminals, it is necessary to define a protocol that can accept and deliver data over a variety of types of communications links. The AX.25 Link- Layer Protocol is designed to provide this service, independent of any other level that may or may not exist. The AX.25 protocol is a data link layer protocol adopted by the Amateur Radio community from the International Telegraph and Telephone Consultative Committee (CCITT) X.25 data link layer protocol. This protocol will work equally well in either half- or full-duplex Amateur Radio environments.

Amateur packet radio AX.25 protocol is a communication technique that allows high speed and error-free digital data exchange. The amateur radio community has developed a data link layer protocol that fits within the seven layers Open Systems Interconnection (OSI) Reference Model. The data link layer is considered the second level of protocol that communicates with the physical level. This protocol layer is responsible for taking a transmission facility (such as a spread spectrum modem attached to a radio transmitter) and producing an error-free link. The data link layer structures the streams of bits into small blocks of data, called frames.

Frame Structure

Each frame is made up of several smaller groups, called fields. The standard Information Frame is shown in Figure 20. Note that the first bit to be transmitted is on the left side. The flag fields indicate the beginning and end of a frame. By using a technique called bit stuffing, this bit pattern never repeats within the frame. Amateur call signs are used in the address field to indicate the source and destination of a frame. The control and protocol identifier (PID) fields assist in identifying the type of frame being sent and controlling the connection. The information field contains up to 256 bytes of data. The frame-check sequence is a cyclic redundancy code (CRC) used to detect corruptions by the physical layer. There can be up to eight outstanding frames in a relay sequence. Thus, AX.25 frames are sent in bursts and can be acknowledged by the destination in small link-management frames, or with information frames that are sent back to the source. Currently, AX.25 is the most widely-used data link layer protocol for packet radio within the amateur community.

Information and Unnumbered information (UI) Frames:

Start Flag	Address Bits	Control Bits	Information no more than 2048 Bits	CRC Bits	Stop Flag
01111110	112-560 Bits*	8 Bits	8 PID Bits	16 Bits	01111110

Figure 20: AX.25 Information Frame, each field is made up of an integral number of bytes.

Use of AX.25 Protocol

A very simplified model of the functions performed onboard Victoria for processing AX.25 frames is provided in Figure 21. This figure is a modified flow chart with actions handled at the task layer denoted by the six-sided symbols. A task can be thought of as the WOD request, or other service. The frames that processes are a disconnect request, a negative acknowledgment, a request to connect, and a frame containing information for the CPU. When a ground station wishes to disconnect, acknowledges this automatically, and then informs the task that the disconnection occurred. CPU also handles the automatic retransmission of outgoing frames (frames that the task has sent to the ground station). This occurs when a ground station has a CRC error with a previously sent frame, and thus indicates this problem by sending a NACK frame. If an incoming frame indicates that a ground station desires a connection, the CPU is then responsible for accepting or rejecting the request and then sends the appropriate frame indicating the task's decision.

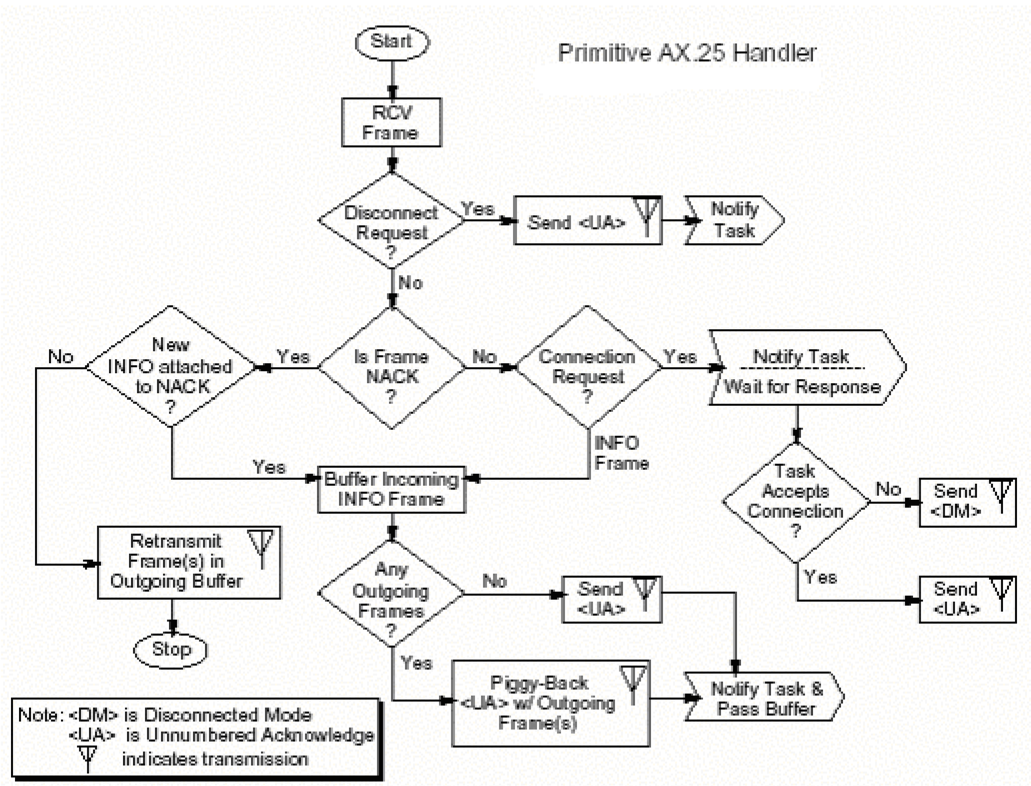


Figure 21: AX.25 frames processing interface.

When an incoming frame contains data destined for the CPU, the data will be first buffer. If there are any frames that required sending to the ground station, an acknowledgment of the incoming frame is placed within the outgoing frame using a method called piggy-backing. Otherwise CPU just sends an acknowledgment frame. Finally data will be notifies and passes the data to the CPU. The complete packet exchange protocol is well defined in ref. AX.25 protocol and will be implemented on Victoria.

Whole Orbit Data (WOD)

The UT131 can conduct Whole Orbit Data (WOD) surveys much like those supported by previous UoSAT onboard computers. The UT131 Housekeeping Integration Task will sample WOD survey with a sample rate of 1 second upward. The UT131 stores WOD in binary files with Victoria File Header. WOD files in the UT131 file store are using the following convention.

A specified telemetry point can be monitored at regular MA intervals and downloaded in a text block. Example:

```
+--------------------------------------------------------------+
|E Whole Orbit Data    Samples: 1    Captured Channel: #019B   |
|gggggg........................................................|
|.....................................;;;....;;................|
|..............    ...........;;...;;.....;.;.;.;;.............|
|..............................................................|
|.......................;;;...;;....wwwwww................gg....|
|.......                                                       |
|Start= 13:54:56 8465  #9FC0     Last= 13:59:32 8466  #A106    |
+--------------------------------------------------------------+
```

Notes:

1. Line 1: Samples: [n] specifies the sample interval in MA units (/256)
   Captured Channel: [n] specifies the telemetry channel number

2. Line 2 - 7: 384 sampled values. Range is 0-255, so some values will be unprintable as ASCII. Block is initialised with value 32, i.e. <space>

3. Line 8: Start= hh:mm:ss dddd #oozz   Last= hh:mm:ss dddd #oozz

   These give the day (dddd), time (hh:mm:ss), orbit number (#oo), and MA (#zz) when the capture program was initiated, and similarly for the last point. When the block is complete, "Last=" is replaced with "End ="

   Day means Amsat Day Number, and 0 = 1978 Jan 01. Time is UTC.
   Orbit number is in hexadecimal, and only its LS byte is given.
   MA is in hexadecimal.

4. Sampling actually occurs on an MA that is exactly divisible by Samples, i.e. when MA MOD SAMPLES = 0

Victoria's Ground Stations

Victoria's ground stations will be of 2 different kinds:

1. During the Victoria's Broadcast Mode those ground station with a setup like Figure 22 will be able to receive the Victoria's voice telemetry and SSTV image. Together the soundcard, a program named "EZ SSTV" and the PC, will work as a sound spectrum for decoding SSTV image. This type of ground station can only receive voice telemetry and SSTV images and NOT for transmitting any acknowledgements or commands to Victoria.

   The station includes a personal computer, sound card, speakers and receiving equipment. There are numerous software applications available providing user interfaces based on personal preferences. The decoding of SSTV image is handled while the ground station is in contact with the Victoria satellite.

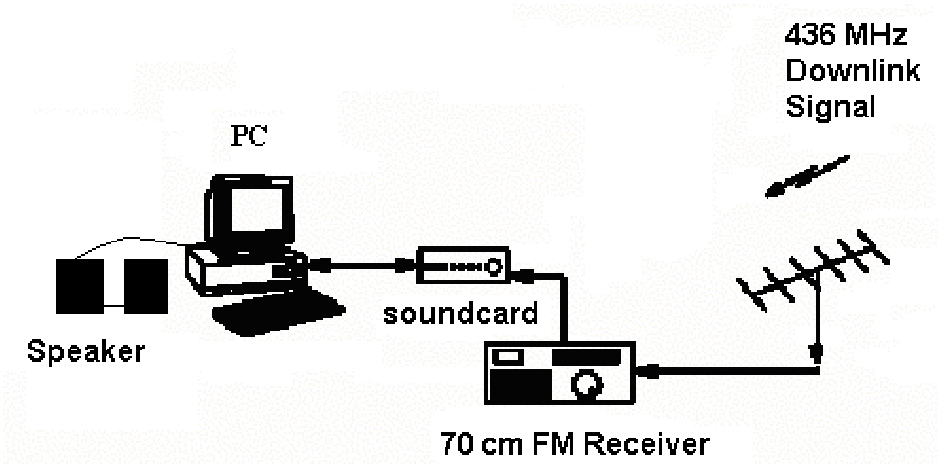


Figure 22: The setup for receiving Victoria's Broadcast Mode.

2. The Victoria's Point to Point Mode is for those command ground station with "level 1 access code" or "level 2 access code". The setup for this station will look like Figure 23. This station will be able to upload command to Victoria, update Victoria's software and download Victoria's particle detector and SEU data or WOD.

   In order to communicate with Victoria, a typical command ground station will include a personal computer attached to a TNC that controls a Victoria specific spread spectrum modulator-demodulator (modem), which controls the radio transmitter and receiver. The tracking system will acquire a rotor controller for guiding the antenna system. Later software will be providing for the PC for a simple-to-use user interface that includes telemetry & system status decoding, like Figure 24. The command ground station will be connected to the web services and those users that want to send some voice message or image to Victoria for later broadcasting is possible. But the message or image will be first filtered and later upload by a supervisor with a "level 2 access code".

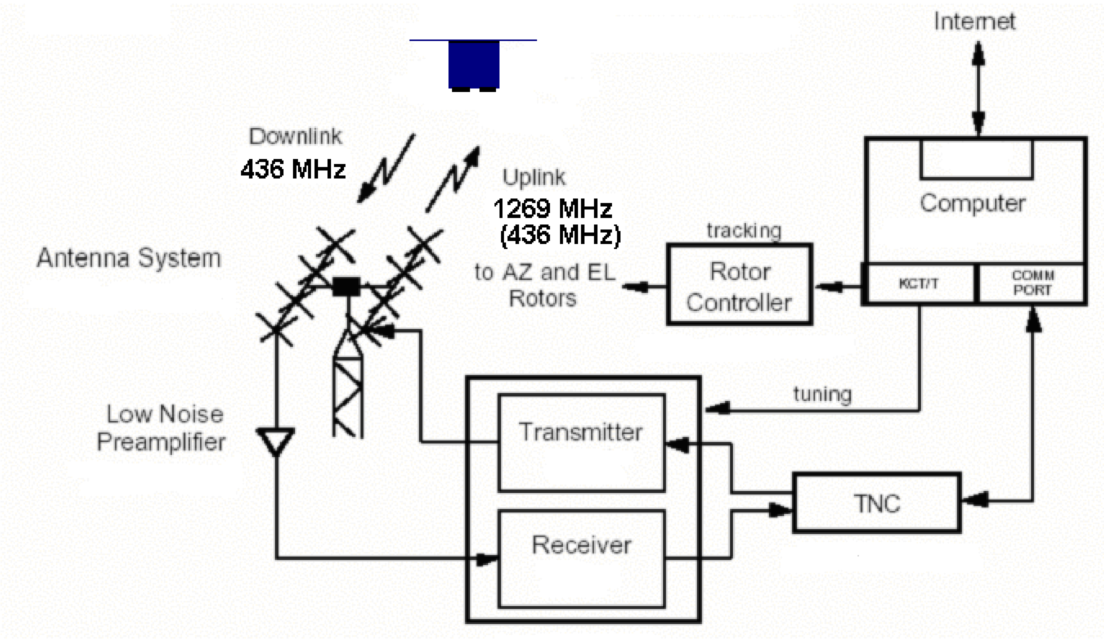


Figure 23: How a Victoria's Command Ground Station looks like.

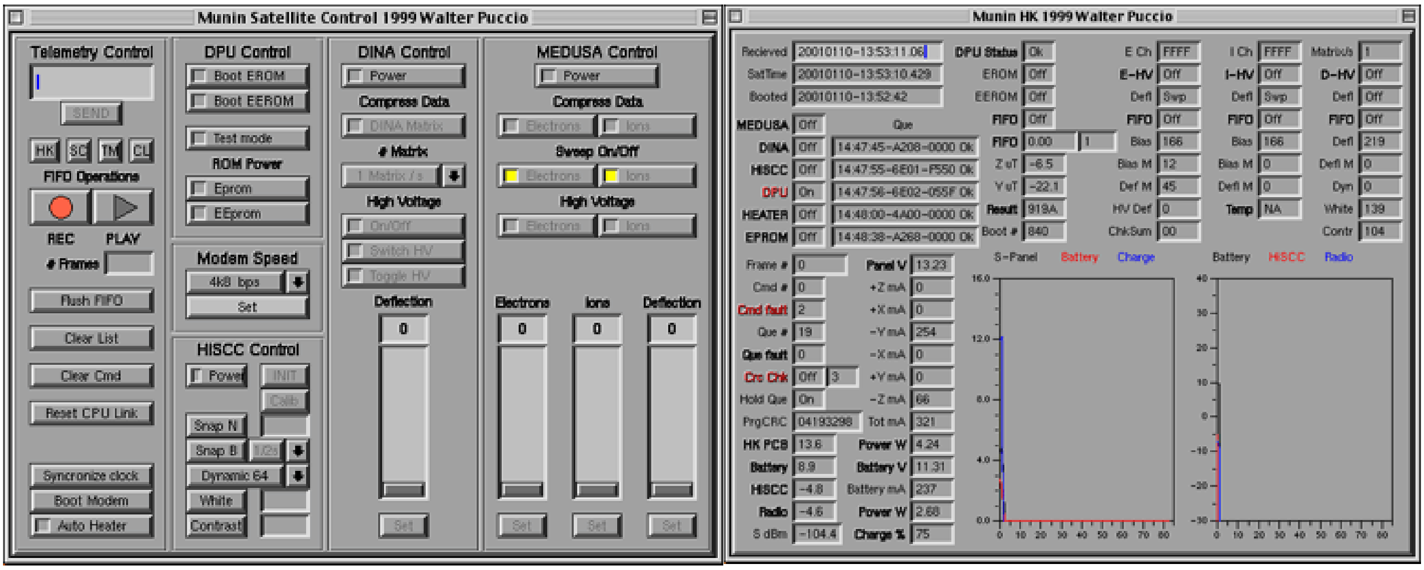


Figure 24: This is a how the command software and the system status of the Munin satellite looks like. The Victoria satellite will use a similar layout.

The software is programmed to calibrate the various instruments, switching ON/OFF the payloads and showing the system status onboard.

Control Station's Operations

The command ground station will perform satellite commands, update voice messages, update SSTV image, control an open loop tracking antenna, gather, display and archive telemetry data like WOD, Particle Detector Data and SEU Data. The telemetry will contain information concerning numerous items including:

• values for all on-board sensors
• satellite log file
• system status

Although any telemetry point can be downloaded to the command ground station, a minimal set of telemetry will be routinely gathered and stored by Victoria. This list of telemetry and the frequency with which the items are gathered can be modified via command ground command. The command ground station will also be used to command the spacecraft's subsystems, as they may need direct commanding from the ground to enable certain vital functions like battery discharging, modification of transmitter amplification or control changes to allow a redundant subsystem component to become operational for example in case of a break down of the 1269.90 MHz receiver (see "Different case studies" section). During the course of normal operations, Victoria will be in Broadcast Mode transmitting voice telemetry and SSTV image and it's always ready to change to P2P mode if a "wake up flag" is received. Preferably the command ground station will connect with Victoria within a time, thus enabling any necessary management and maintenance functions to be executed. The proposed software design allows Victoria and the command ground station to operate in conjunction to periodically free mass storage space by purging out-of-date log-files, WOD, payload data. Furthermore the command ground station will be able to reboot of the system and upload software to the spacecraft, giving Victoria the ability to correct software deficiencies and take advantage of new software.

Software Modifications

The ability to perform software modifications and upload new software modules after launch has been proven to be vital. Previous satellites have demonstrated that with the implementation of a simple and well tested boot process, satellite's software can be modified after launch. This feature is vital because not all of the spacecraft's operational scenarios can be forecast during the design process. This does not mean that attention to details is being ignored at this time. On the contrary, attention to all details in a more limited scope is being explored right now. At launch, Victoria may not have the entire user services implemented, but the Victoria's ground station will have the ability to upload a version of the software on-board the spacecraft. The boot process will consist of the minimum actions required to initialize the necessary hardware on Victoria so that the spacecraft is capable of communicating with the ground station. The communication will provide the capability to upload any software component desired, including the operating system.

Management and Maintenance

Management and maintenance of Victoria will be handled by the command ground station, located within Stockholm, Sweden. The hardware will be similar to other amateur radio stations like in Figure 23; most of the differences will be in the software and access code.

This ground station will be required to gather and archive telemetry from Victoria. This telemetry will contain values for all on-board sensors the whole orbit data WOD, log file of the Victoria's activities, information about on-board tasks and system status of the satellite. Victoria will be broadcasting general telemetry and SSTV image in audio form to any listener on 437.75 MHz. Commanding of the spacecraft is necessary to incorporate new software modules or to update the existing software. The subsystems of Victoria can be command from the ground station to force certain functions such as battery discharging, modifying transmitter amplification or forcing a redundant subsystem component to assume control. Victoria and the ground station will periodically free storage space by purging out-of-date log file and WOD. A command interface is also needed to communicate with a possible on-board experiment module.

Spacecraft Telemetry

Spacecraft telemetry is a popular item that amateur users receive from orbiting satellites. Current spacecraft telemetry will be available to any user who can receive on 437.75 MHz. The telemetry will be transmitted in audio form so that the users can listen to it. The voice telemetry will be broadcast with the Parrot when Victoria is in Broadcast Mode. This will make current telemetry available to any user who is currently listening but who doesn't have to connect with Victoria. Thus within the satellite's footprint region, several users will be able to receive current telemetry all at the same time. This service will also aid in the initial set-up of a Victoria's ground station to verify a communication link.

Choosing Telemetry Information

The telemetry information contains two parts. The first part is the system status information part containing a total of 32 channels. The second part is the digital status of the satellite, which gives us the information about the satellites functioning and different modes of the satellite. This second part is containing 16 channels.

We will choose telemetry information with regard to the measured information. This implies to all the sensors that can be seen in the table below. The information measured will be either sent directly, as voice telemetry, or stored on the memory, as WOD, and sent to earth dependent on the system status of the satellite. These system modes and their effect on the transmission of telemetry data are discussed in the section "Mode status of the Victoria satellite".

The telemetry could look like the tables below. The first table is that of telemetry status information.

Table one:

Channel	Name (Unit)
1	Temperature sun (C)
2	Temperature shadow (C)
3	Temperature inside (C)
4	20V bus voltage (V)
5	12V bus voltage (V)
6	-12V bus voltage (V)
7	5V bus voltage (V)
8	-5V bus voltage (V)
9	3V bus voltage (V)
10	Solar panels X and –X current (A)
11	Solar panels Y and –Y current (A)
12	Battery package current (A)
13	TNC current (A)
14	ChipCorder (parrot) current (A)
15	Transceiver current (A)
16	Receiver current (A)
17	Camera current (A)
18	Sun sensor current (A)
19	SSTV current (A)
20	Memory chips (SEU) current (A)
21	Power control unit current (A)
22	Magnetometer current (A)
23	Particle detect. current (A)
24	Photo detector satellite's rear
25	Photo detector satellite's side
26	Magnetometer output X
27	Magnetometer output Y
28	Magnetometer output Z
29	Sun sensor output X
30	Sun sensor output –X
31	Sun sensor output Y
32	Sun sensor output –Y

Table 4: First table of the telemetry of the Victoria satellite.

The second table is showing the digital (On / Off) status of the satellite.

Table two:

Channel	Function	"1"	"0"
1	Sat. launch mode	Yes	No
2	Satellite mode	Normal mode	Safe mode
3	Reset	Yes	No
4	Reciver 1269.90 MHz	On	Off
5	Transceiver 437.75 MHz	On	Off
6	Duplex Mode	Half-duplex Mode	Full-duplex Mode
7	Power control unit	Battery charging	Battery bypass
8	TNC mode	9600 baud	38400 baud
9	TNC	On	Off
10	Memory Chips (SEU)	On	Off
11	Sun sensor	On	Off
12	Magnetometer	On	Off
13	Particle detector	On	Off
14	Camera	On	Off
15	Digital switch	SSTV	Parrot
16	Battery switch	On	Off

Table 5: Second table of the telemetry of the Victoria satellite.

The information in the tables will be sent to earth during the P2P mode following the Victoria block structure. A thought is to first send the information about what functions that are "OFF" and then the functions that are "ON". This is because of the risk that the communication would be disrupted during passage. If the satellite would be in safe mode it could be a problem for the power consumption if the info about "OFF" functions did not get to the satellite in time.

Victoria Block Structure

Victoria block structure will be similar to AO-40 which can transmit two AX.25 blocks of 250 bytes each that equal one 500 bytes transmission block. Each AX.25 block is preceded by a synchronisation sequence and followed by a checksum (CRC). This will give us a total transmission block of 512 bytes, as described in the table below:

	bytes

Sync:	4 (#39 #15 #ED #30)
Block(total):	512
CRC:	2

A byte consists of 8 bits and is transmitted serially, MSbit first at a theoretical rate of 1200 bytes/s which is equal to 9600 baud.
Note: 50 Hz is the standard rate for an operating system clock and interrupts and could limit the transmission speed even though our CPU speed is 16MHz.

Victoria Block Contents

Blocks are identified according to the first byte of the block (followed by <space>, e.g. “E”, “A” etc.

1. A blocks carry 32 analog and 16 digital telemetry channels.

2. D blocks carry 32 analog and 16 digital telemetry channels.

3. E blocks carry historic data events like WOD. (see the section “Whole Orbit Data”)

Victoria Block Formats

A-Block format

```
+--------------------------------------------------------------+
|A HI, THIS IS VICTORIA yy-mm-dd  hh:mm:ss #nn                  |
| text messages                                                 |
|32 analog inputs                                               |
|aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa  |
|16 digital inputs                                              |
|ddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddd |
+--------------------------------------------------------------+
```

Notes:

1. "yy-mm-dd" is the UTC date.

2. "hh:mm:ss" is UTC time

3. "#nn" is the command number in hexadecimal.

4. "aaaaa" is 32 channels of 2 bytes each, of telemetry inputs from memory.

5. "ddddd" is 16 channels of 1 byte each, of system status from memory.

6. "text messages" is up to 52 bytes of ASCII plaintext. Use optional.

7. Blanks are #20.

D-block Format

D-blocks are in a format to allow transfer of long data files. This format has been devised to allow error free transfer of files in either upload or download mode. The file is split into blocks (or packets) which contain the minimum amount of housekeeping to enable the original file to be re-assembled.

To that end, the packet contains an Amsat block ID, file ID, total number of blocks in sequence, sequence number, byte count and checksum. This requires 12 bytes; the remaining 500 bytes are file data.

Thus a packet contains sufficient information for any D-block to be mapped into the output file, independent of the order in which the blocks are received.

The data content is arbitrary, but it is assumed that the mapping from source data to D-blocks will be essentially sequential. That is to say, the first block contains file bytes 0-499, the second 500-999 and so on. However this is only a convention, and alternative relationships are not proscribed.

Bytes	Information	Notes
0,1	"D " Block Identifier, i.e. #44, #20	1
2,3	File ID	2
4,5	Number of blocks in sequence, NB	3
6,7	Sequence Number, NS	4
8-507	500 data bytes, randomised	5
508,509	Number of bytes in this block, N	6
510,511	CRC checksum	7

Notes:

1. The Block Identifier is used as a distinguishing mark by telemetry display software or as an IPS command for uploads.

2. The File ID is two arbitrary bytes which identify the source material. These bytes might well be printable ascii values, e.g "JM", and perhaps be incorporated into the output filename, e.g. DUMP_JM.DAT Their use is optional, but recommended.

3. The number of blocks in a sequence is normally NB = (FileLength DIV 500)+1

4. Each D-block has a unique Sequence Number NS which takes values from 0 to NB-1. This tells you where to position the Data Bytes into the output file.

5. The contents of the data byte field would typically be 500 bytes from the source file, starting at offset NS*500. The data byte field is crudely randomised by EXORing each byte with the block position pointer. Thus the first data byte is EXORed with 0x08, the next with 0x09 and so on up to 0xFB.

6. The number of bytes in a block would normally be 500, with some other value for the last block in the sequence. For example, a file of 1024 bytes would be split into three blocks (NB=3) with N = 500, 500 and 24 bytes respectively.

7. The inner CRC checksum is optional since the block already had an outer checksum. However it might be useful for users of older 512 byte telemetry decoders where the outer checksum is discarded.

AMSAT P3 CRC Definition

```
 ------------------------
        M           L
        .---------------.
  +--<---|||||||||DATA
  |     '---------------'
  |
 (+)--------->-----+-------------->------------+-------->--------+
  |             |                     |              |
  |  .-------.   |   .-------.   .-----.    |    .---------.  |
  +-<-|||||<--(+)<--|||||<--||||<--(+)<--||||||<-+
     '-------'       '-------'   '-----'        '---------'
     <--------- M S B --------->   <--------- L S B --------->
```

CRC MSByte sent first, then LSByte.   (+) means "EXOR"

The initial value of the CRC register is hex FFFF

Note: that calculating a crc of a block that already includes a correct crc as the last 2 last bytes, results in a net crcc = 0 because 16 "0"s are input to the crc register!

The AMSAT CYC2 (x^16 + x^12 + x^5 + 1) definition is similar to, but not the same as, CCITT CRC16.

Scenarios and Improvements

Different Case Studies

When a radio communication system is studied, one finds many different strength and weaknesses in the system. By looking at the system from different point of views and through different scenarios we can enhance the redundancy and stability of the system. Here we will try to describe different scenarios to control the communication link between any ground station or the control station and the satellite.

Kick or Ban a User

The control station must have the authority to kick or ban a client if the client do not follow the regulations of satellite communication. For instance, think if a client wants to access an experiment, but has not the authority to do that. He will be asked to submit a key for access, which he does not have. So it is a good idea to have a list in the memory of the satellite about the people with authority to perform tasks. In this way the satellite will recognise the address of the sender, requests appropriate access key, and in case the sender gives a wrong answer to the request he will then be kicked and the connection will be closed. This scenario can be allowed to happen for a number of times, say three times, and after the third time kicked, the person will be banned from the satellite for a symbolic time, say 96 minutes, which is an approximate time for one sun-synchronous orbit. This banning of a client means putting the name of the client, which is in the address field of every transmitted frame, from the list of authorisation to the list of banned users. In this way the satellite will ignore the request for a connection by the banned client, since the banned name is in the address field. This process can happen manually, so that the control station can kick people who violate the agreements on the communication. If a full-duplex satellite connection is established between the satellite and a user, and the control station with the level 2 access key wish to disconnect that specific person, it will be possible. Approximately 20 people, within the footprint region of the satellite, can have simultaneous contact with the satellite even though the satellite does not use multiple access techniques. The contact is possible due to a very low chance that two people would send a signal that would get to the receiver in the exact same time. The command ground station, or authorised control stations, must never be banned due to engineering needs.

Lost Solar Panels and Decreasing Battery Power

This scenario could be the most important scenario for the control station. If, for any reason, battery power shows a decreasing trend and there is no sign of recovery, even when the satellite is not in the earth shadow, the satellite must go to lower battery use even though we know that the satellite will not survive such a scenario. The loss of battery power can depend on “power leakage” with old batteries. It can also depend on the low power provided by the solar panels, which can be damaged because of various reasons. If the speed of power leakage is greater than the theoretical speed of total power provided by all the solar panels to charge the batteries, then the satellite is doomed. If the speed of power leakage is less than the theoretical speed of total power provided by the solar panels, which charge the batteries, then a minimisation of power usage by the satellite might just help to balance the power consumption of the satellite or at least make the satellite survive a bit longer. A table could be created, and regularly updated, to monitor power consumption in the experiments and components that can be shut down. This could make it easier for an eventual automation of the power supervision and control. This information table could be sent to the control station as part of the telemetry.

Breakdown of the TNC

Having only one TNC reduces the redundancy of the Victoria satellite, if the TNC would be out of function then the whole satellite would be out of function since no connection would be possible to earth in any way. We therefor suggest having another TNC, which would be of the same model, to switch to in case the first TNC breaks down.

Breakdown of the 1269.90 MHz Receiver

If this receiver is out of function for any reason, and cannot be used again, the communication will be made in half-duplex mode, using the 437.75 MHz transceiver. All the issues concerning the communication will follow the regulations in the section "Description of communication modules".

Breakdown of the 437.75 MHz Transceiver

If the transceiver would, for any reason, be out of function, the satellite communication would be stopped and no further communication would be possible. This is because there is no other transmitter, than the 437.75 MHz transceiver, to transmit the signal to earth. Therefor we recommend having a second transmitter on the 437.75 MHz frequency to increase redundancy.

Breakdown of the Sensors

We determined several sensors that could be of importance for the attitude control and stabilisation of the satellite. These are the sun-sensor and the magnetometer that gives the information on how the magnetic torque coil should react for positioning the satellite correctly. If the sun-sensor is broken, then the values of the solar panels, photo sensors and perhaps temperature sensors could be used to determine the position of the satellite towards the sun. If the magnetometer fails, then there will not be any possibility to figure out the co-ordinates thus how to charge the magnetic torque coil so that it would point in the correct direction. We have therefore suggested using two magnetometers to be able to switch between them if one of them breaks down. If the other sensors, such as temperature sensors or photo sensors are broken there will not any direct impact on the satellites functioning, and therefore not important to have extra of them onboard.

Possible Future Improvements

Multiple Access Communication Techniques

Although the VICTORIA satellite will not be using multiple access techniques we find it interesting to mention this issue here. There are numbers of different multiple access techniques being used in various satellite systems today. These systems comprise of satellites for communication, mainly in commercial voice and data transfer between one satellite and many ground stations at once. The techniques used are called “Multiple Access” techniques. This means that the ground station must share the same satellite resources, mainly transmitter and receiver, with other clients. Multiple access techniques can also be used together in the same system. The problems facing communication in this way have been solved differently. See the appendix for more information on multiple access techniques of FDMA, TDMA and CDMA.

Budgeting the Energy

To save the accumulated energy of the solar panels stored in the batteries from being wasted, there is a need for a detailed study in energy budgeting. This means to be able to make an exact analysis, create a detailed map of the solar panels and register the most important components and experiments in the satellite as a detailed list. In case of energy shortage some applications can be turned off until there is sufficient energy stored to run them. These affected applications will be chosen from the mentioned list and follow the detailed conditions and rules designed by the responsible budgeting study group. The more important the component is for the satellites functioning, the less chance that it will be turned off. At the same time, the more power the component uses the more chance that it will be turned off. This could be shown in a more detailed “Importance vs. Power Usage” diagram to visualise the different components used.

Component and Circuit Blueprint

One could work towards a very detailed map of the components in a circuit board layer and put together the information on what extra components, such as diodes, shunts, signal amplifiers, etc., that are needed to fully integrate every small part of the satellite and its components together. The information could be used to produce a detailed blueprint of each satellite block and be used for later assembly of the satellite parts.

Temperature and Isolation

Victoria will have a passive temperature regulation because of the simplicity. Work could be conducted on a more detailed map of isolation due to the fact that Victoria will be sun-pointing most of the time. The work should consider the functionality of the experiments, specially the particle detector and SEU.

Appendix

The Radio Modules of the Satellite

There will be two radio modules in the satellite. One is the module receiving on the 1269.90 MHz band and the other is the transceiver that sends and receives data on the 437.75 MHz band. The decided speed is set to be at 9600 baud (9.6k bits/s). The reason for this is that 9600 baud is using the most common technique and the price range of the needed components is not too high. It would therefore ease wider use of the satellite for many amateurs. The transmitter can have a power output of up to 5 watts, but 2 watts would be enough. This gives us a couple of choices among different transmitters. These are the Tekk KS-1000L with 5 watts power output for the sending and receiving data on the 437.75 MHz band and the 1269.90 MHz (No name) receiver which will be used for data receiving at 1269.90 MHz.

Specification of 437.75 MHz Transceiver (Tekk KS-1000/1000L) [R.12]	**Specification of 1269.90 MHz Receiver (No name) [R.13]**
General Specifications: • FCC ID GOXKS-900/15.22.90 • Frequencies 450-470MHz (KS-1000) • 430-450MHz (KS-1000L) • Operating Temperature -30 to +60C • Voltage 9.6VDC (7.5 to 12.0) • Dimensions 85 x 52 x 21 mm • Weight 145g • RF Connector BNC/50 Ohms • Interface Connector 9 pin D	General Specifications: • Dimensions 80 x 170 mm • Weight < 150 g • Voltage between 11 – 13.5 V • Negative ground • RF Connector BNC/50 Ohms • Operating Temperature +10 to +30C • Frequency 1269.90 MHz • Current < 150 mA • Internally voltage stabilised
Transmitter: • Power output 2W @ 9.6VDC • Modulation Direct FM • Attack Time (TXD) 8ms • Audio Response Flat • Distortion % • Maximum data mod. 50mV for 3.5kHz deviation • Spurious Emissions & Harmonics <->60dBc	Receiver: • Sensitivity 0.35µV • Selectivity 60dB • Distortion < 1 dB • Receiver recovery 8ms • Audio output 750mV RMS • **No distortion filter if the incoming signal is low or missing**
Receiver: • Sensitivity 0.35µV • Selectivity 70dB • Spurious Rejection 60dB • Audio Response Flat • Distortion 5%	• **Detector for receiving FM- (Audio) and FSK-Signals (Data)** • **Output impedance 1 kOhms** • **1 audio output** • **Output adjusted with a trim-potentiometer**

• Receiver recovery 8ms • Audio output 750mV RMS • Current Drain 20mA <u>Connector:</u> • 1 - positive Volts • 2 - Ground • 3 - PTT • 4 - TXA • 5 - RXA • 6 - n/c • 7 - Ground • 8- RSSI • 9 - DCD <u>Transmitter Crystal Specifications:</u> • Holder HC-18/T Wire Lead • Mode of oscillation Fundamental • Load Capacity 32pF parallel • Series Resistance 20 Ohms • Driver Level 2mW • Holder Capacity 7pF max. • Operating Temperature -20C to +60C • Frequency Tolerance +/- 5ppm • Freq. Stability +/- 5ppm • Freq. Calculation (Fc/27) <u>Receiver Crystal Specifications:</u> • Holder HC-18/T Wire Lead • Mode of oscillation Third Overtone • Load Capacity 32pF parallel • Series Resistance 35 Ohms • Driver Level 2mW • Holder Capacity 7pF max. • Operating Temperature -20C to +60C • Frequency Tolerance +/- 5ppm • Freq. Stability +/- 5ppm • Freq. Calculation (Fo-21.4)/9	• **Frequency deviation between 100-3000 Hz rippel max. 1 dB.** • **Data output with TTL level ("0" 0 V and "1" +5 V.** <u>NOTICE!</u> For more information on the home made 1269.90 MHz receiver, please contact professor Thomas Lindblad at the Royal Institute of Technology or Olof Holmstrand at UHF Units AB.

Table 6: General information on the radio modules of the Victoria satellite.

Multiple Access Techniques

FDMA, Frequency Division Multiple Access

This technique is very common in radio communication since it relies on frequency separation between carriers. All that is required is that the ground stations to send their traffic on different frequencies and that the modulation should not cause the carriers to overlap. Since the Doppler effect is a usual phenomenon in satellite communication there will be a need for a "guardband" to avoid overlapping of carrier frequencies. The principle behind the FDMA is that every ground station is assigned a separate frequency on which to transmit. This assignment is either fixed for a time, or demand assigned (Demand Assignment Multiple Access, DAMA) responding to user request for service. A constraint in FDMA is that the sum of the bandwidths of the individual carriers cannot exceed the satellites available bandwidth. Here follows a list of strength and weaknesses of the FDMA.

+ Low complexity (old and verified technique).

+ Possible Demand Assignment Multiple Access.

+ Special signalling channels (for stations to request connections and to alert stations to incoming calls).

+ Transmission with no need for co-ordination or synchronisation between transmitter and receiver.

- Interference sensitive

- Guard band needed, 5% to 10% of channel signal (wasted bandwidth).

- LO Drift

- Doppler frequency shift (hence use of narrowband FDMA is not possible).

TDMA, Time Division Multiple Access

The communication in a TDMA network happens all in the same frequency, but at different time. It means that instead of dividing the frequency between different users, the time will be divided between users so that a connection between a user and a satellite is made for a short time. During this time the user will have the whole frequency band for its own communication. Data will be transmitted or received as a "burst" of information. This technique is very complex and requires good timing, but is possible to use in narrowband connections. Another variant of TDMA is called ALOHA that greatly simplifies the control of digital satellite networks, but we will not discuss it here.

+ Narrow band TDMA reduces the need for power and bandwidth.

- Time gap needed (lost time).

- Most appropriate modulation technique is digital, typically QPSK, which is also complex but needed since it is compatible with requirements of burst info.

- Compression and expansion of data is needed due to burst of information in a short amount of time.

- Co-ordination and synchronisation between transmitter and receiver needed.

- Complex technique.

CDMA, Code Division Multiple Access

This technique combines modulation and multiple access to achieve a certain degree of information efficiency and protection through the technique of spread spectrum communications. The basic concept is to separate or filter different signals from different users, not by using frequency or time, but by the particular code that scrambles each transmission. The basic approach is to use pseudo-random noise (PN) binary sequence, which is a computer-generated randomised sequence of bits designed not to be similar to itself in any way over any sequence. Each CDMA signal consist of the original data, protected by FEC which are digitally multiplied by the PN sequence and then modulated onto a carrier using either BPSK or QPSK. Multiple spread spectrum signals can then be transmitted on top of each other as long as the PN codes are not synchronised.

+ Secure transmission.

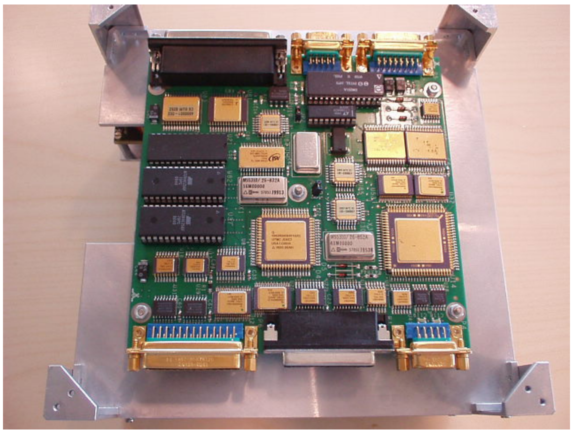
+ Reuse of Frequency.

+ Bandwidth efficient if considered sending multiple signals on top of each other.

- Complex technique.

- A high processing power is needed.

The Embedded Controller Card, UT131



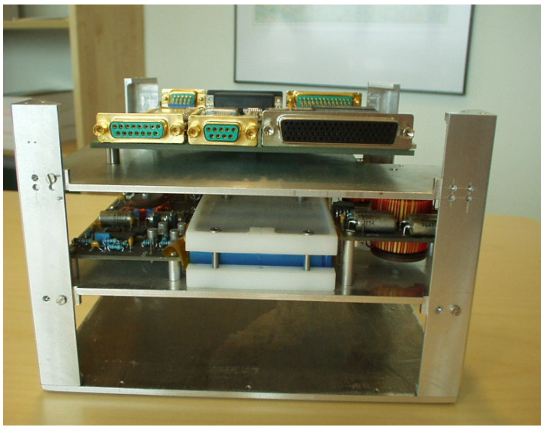


Figure 25: The ECC mounted on the structure of the Victoria satellite.

The Embedded Controller Card (ECC) has also limitation that needs to be considered. For example the supply requirements are as follows:

Description	Voltage	Tolerance	Current
V_{DD}	+5.0V	+/-5%	500mA[1]
V_{EE}	-5.0V	+/-5%	-10mA

Table 7: The power supply to the ECC.

1. The current on the 5-volt supply may increase based on the termination techniques used for the RS-485 transceivers and the RS-422 drivers/receivers, and with the serial communication duty cycle.

And the temperature specifications are:

Temperature	Minimum	Maximum
Operating temperature	-40˚C	+85˚C
Storage temperature	-65˚C	+165˚C

Table 8: The temperature specification for the ECC.

The ECC includes a number of peripherals and memory mapped I/O devices. A short list of the contains is as follows:

- A/D converter with 14-bit resolution, 32 analog input signals, ±3V bipolar signal voltage, DC to 41.5KHz, 11µs sample rate.
- A microcontroller with the model name UT80CRH196KD.
- A 64K byte user programmable PROM and a 64K byte on-board SRAM with EDAC.
- 1 RS232 debug port @ 19.5Kbaud with optional RS232 debug monitor.
- A 1Mbps Low Power Serial Data Bus with 8K words of RAM for connection to main CPU or other ECC.
- 4 user defined variable speed serial links, 4 @ 0 to 1Mbaud.

The ECC contains a microcontroller with the model name UT80CRH196KD. This MCS-96 compatible, 16-bit and 20MHz microcontroller is the core of processing power and functional capability of the ECC. The UT80CRH196KD controls all the peripheral activity, and maintains the flow of data through the ECC. The periphery functions that are controlled by the UT80CRH196KD include:

- A 14-bit A-to-D conversion of up to 32 analog input signals with a bipolar voltage range of ±3V.
- 32 low drive output discretes; or optional 16 high drive discretes and 16 low drive discretes.
- 4 multiplexed serial COM ports with programmable communication formats and baud rate.
- A Low Power Serial Bus running the MIL-STD-1553 bus protocol over a TIA/EIA-485 physical layer.
- An RS-232 serial debug port at 19.2Kbaud.

We have previously decided to have 64 measuring stations which is the maximum limit of our chosen protocol. But as we can see, the ECC-UT131 has a limit of 32 analog inputs. This means that our telemetry data that is gathered from the satellite will be limited to the information collected from 32 measuring stations. [R.14]

The Onboard TNC

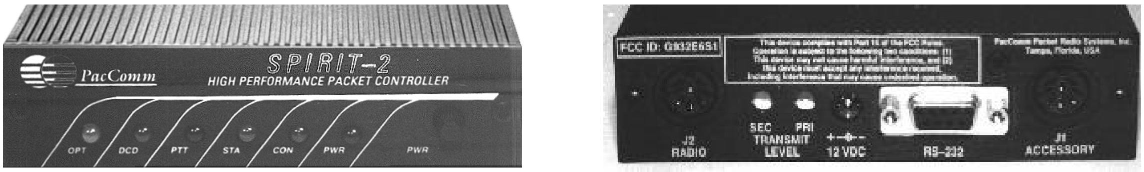


Figure 26: The SPIRIT-2 TNC.

The SPIRIT-2 is the ideal TNC for the modern (9600 BPS & faster) packet station & for BBS, satellite and Network use. It uses reliable, proven technology (G3RUH modem, TNC-2 CPU architecture) with large-scale programmable logic circuits for solid, reliable performance.

PacComm firmware uses TAPR style commands with PacComm extensions, including KISS and Personal Message System. 512kbit (64k Byte) EPROM with bank-switching circuit for TheNet or ROSE network firmware. No modifications required, just set jumpers. TNC-2 compatible design works with any TNC-2 EPROM. 64k of Personal Message System storage and large send and receive buffers. 9.8 MHz CPU clock speed and 10 MHz rated parts are standard. High Speed 16.67MHz CPU option. Terminal baud rates from 9.6 kb up to 57.6 kb for satellite file download without dropped frames.

G3RUH design modem with PLL demodulation for outstanding performance. Two independent modem transmit and receive filter sections. Radio baud rates from 4.8 kb up to 57.6 kb are supported. (64kb on special order.)

TNC Features

- Six LEDs. Power (red), Connect (green), Status (yellow), Push to Talk (red), DCD (green) and OPT (a multi-purpose dual colour LED).
- When used with the CoaxLAN, red and green indicate transmit and receive data on the LAN.
- Black anodised aluminium case; rugged, attractive, and RFI/EMI resistant.
- Extensive RFI/EMI filtering.

TNC Reliability

- Radio and serial port lines are extensively filtered against RF and noise effects.
- Major RS-232 and radio lines and power feed are protected against power spikes with on-board surge suppressers (Transorbs).

TNC Network

- TNC-2 EPROM compatible, TheNet X1, ROSE, and TEXNET ready, Processing power and modem performance for serious throughput.
- PacComm's CoaxLAN circuit is built in for easily inter-connecting multiple SPIRIT-2s in node stacks.

Chosen TNC Model

Satellite Model: 128k RAM. PacComm PMS Firmware. Modem filters for 9.6 and 38.4 KBPS. Other speeds upon request. [R.15]

The Onboard Camera

The chosen camera for the Victoria satellite is either the Sony FCB-IX47P or XC-777A/777AP.

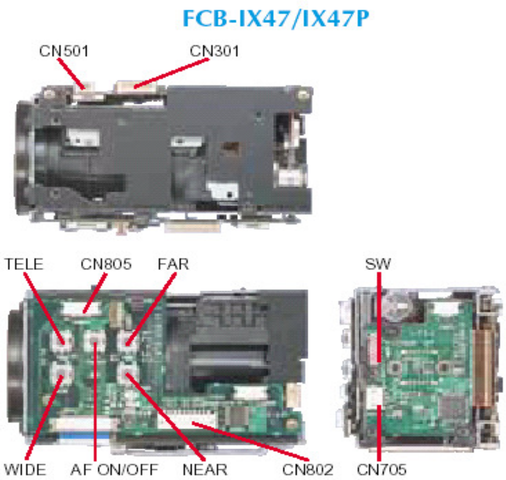


Figure 27: The Sony FCB-IX47P camera.

The FCB-IX47P has a specification as follows:

- H. Resolution: more than 460TVL
- Digital zoom: 4x (72x with optical zoom)
- Angle of view: approximately 40˚ (wide end) or approximately 2.7˚ (tele end)
- Min. working distance: 10m.m. (wide end) or 80m.m. (tele end)
- S/N ratio: more than 50dB
- Electronic shutter: 1/3 to 1/10000sec., 20 steps
- Gain: 3 to 18dB, 8 steps
- Battery: 6 months fully charged
- Video output: VBS:1.0Vp-p (Sync Negative) and Y/C
- Storage temperature: -20˚C to 60˚C/20 to 95%
- Operating temperature: 0˚C to +50˚C/20 to 80%
- Power: 6 to 12 Vdc/2.8W (active motors), 3.6W (active motors and IR LED ON)
- Weight: 205 grams
- Dimensions (W x H x D)(m.m.): 51.2 x 57.8 x 92.4

XC-777A/777AP

Figure 28: The Sony XC-777AP.

The XC777A/777AP has the specification as follows:

- Colour filter: Complementary colour mosaic
- Effective picture elements: 752(H) x 582(V)
- Lens mount: NF mount (can be converted to C mount).
- Horizontal resolution: 460TV lines.
- Minimum illumination: 4.5lx (F 1.2, AGC).
- Sensitivity: 2000lx F 5.6 (3200K, 0dB).
- S/N ratio: 46dB or more.
- Electronic shutter speed: 1/1000 second, 1/4000 second, FL.
- White balance: ATW, 3200K, 5600K, Manual (R.B).
- Power requirements: DC10.5 ~ 15V (typical 12V).
- Power consumption: 2.3W.
- Dimensions: 22(W) x 22(H) x 89(D) mm (excluding projecting parts).
- Weight: about 75g.

Due to the benefit of size, mass and power usage we suggest using the XC-777AP. [R.16]

Telemetry Files

This is the format that the Command Stations and the AMSAT Archive require. Log files stored in any other format cannot be processed and hence valuable data cannot be accessed. Files saved in the format below can be viewed using P3T's Replay.

1. Filenames: TYYMMDD.RAW or TYYMMDD.TLM

   T ← Indicates Telemetry File of all block types.

   YYMMDD ← Date of start of telemetry capture.

   .RAW ← for files that include all blocks captured, CRC OK, CRC BAD, CRC Unknown or combination thereof. Don't split capture into separate CRC OK and CRC bad files. RAW files should contain everything captured good or bad in the correct sequence. Only store complete blocks of 512 bytes, discard incomplete blocks.

   .TLM ← for files that include only blocks that are CRC OK

   Note: Only 1 file should be created per day, this avoid overwrites.

2. Files should contain the blocks in the order of capture, no filtering or sorting is recommended. Files should contain all block types, some blocks do not contain any time stamp, therefore adjacent A blocks are required to determine when a block was sent and in the case of the archive, where a block should be stored.

3. Each block is stored as 512 bytes, the checksum is not stored. No End-Of-Record or CRLF characters are placed between the blocks. 512 512 512...

4. The AO-40 CRC Calculation can be found here: http://www.amsat.org/amsat/ftp/satinfo/ao13/spec_crc.doc

5. If the block was captured on a 512 byte decoder then the CRC cannot be tested, in which case the block should be saved in the log file with bit 7 (MSB) of bytes 0 and 1 set to 1. Setting bit 7 of a byte is IPS for inverse video. With P3T replay if you see the first 2 two bytes of a block in inverse video then you don't know if the CRC is good or bad and hence the data may be good or maybe bad.

6. If the block was captured on a 514 byte decoder and the CRC tests OK, then the block is saved in the log file unchanged. If the block fails the CRC test then it is saved in the log file with bit 7 (MSB) of byte 0 only set to 1. With P3T replay if you see the first byte of a block in inverse video then you know that the CRC is bad. [R.17]

Separation System

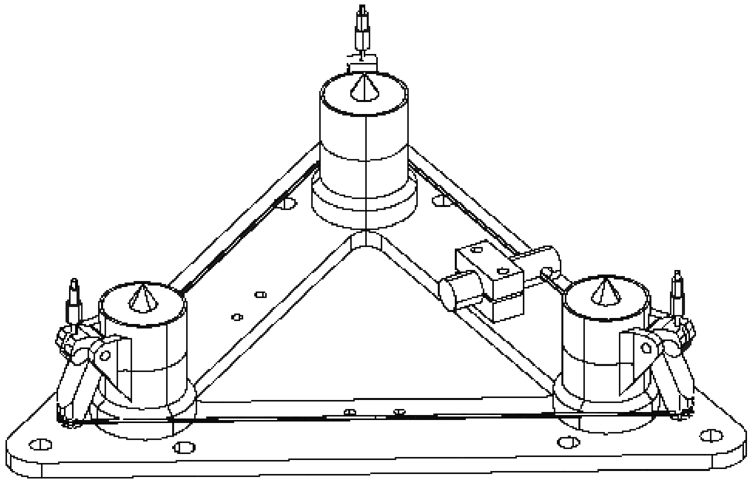


Figure 29: The separation system of the Victoria satellite.

The low weight and the small size of the Victoria satellite gives us the opportunity to design a very simple yet reliable separation system. The approach that we have chosen is based on the use of a steel wire to tie down the satellite to the launcher interface plate. The line will pull down the satellite at three points. The wire is tensioned by a spring. A small pyro-guiliotine is used for cutting the steel wire. Three helical springs will push Victoria away from the launcher with a speed of 0.5-0.6 m/s and a maximum tip-off rate of 10 deg/s when the wire is cut. [R.18]

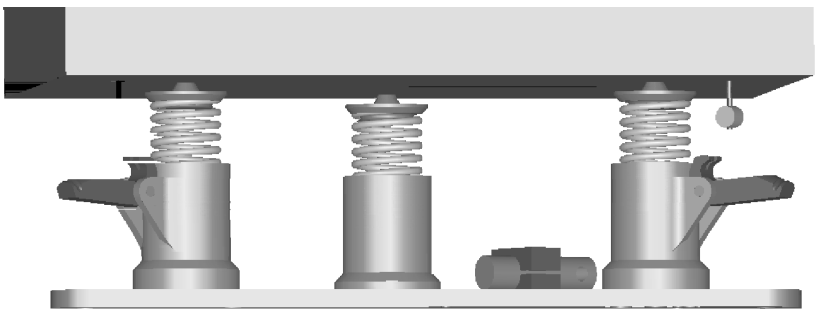


Figure 30: Side view of the separation system.

Victoria's Batteries

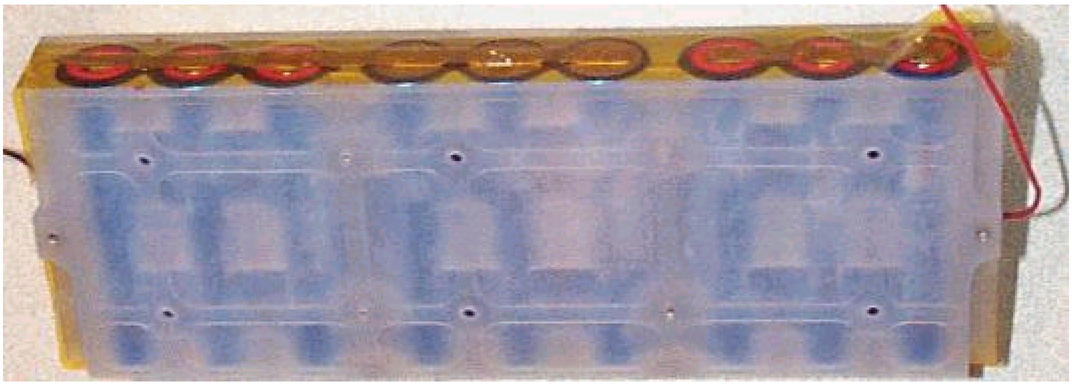


Figure 31: The battery package used in the Victoria satellite.

Description: The batteries that will be used on the Hugin satellite are of Lithium ion type and are manufactured by Duracel. The charger maximizes the charging current to 0.5 Amps and the voltage to 12.35 Volt. The charger has an efficency of approx. 80% and allows the supply voltage to be in the 15-25 Volt range witch suites the solarpannels. The battery pack has a capacity of 4200 mA at a nominal voltage of 12 Volt. The battery and the charger are currently under test. [R.19]

Satellite Signal Formats

PPM-AM Telemetry

This type of telemetry was used by many types of automated and piloted spacecraft launched by the Soviet Union. In this pulsed AM transmission 4 microsecond long pulses are transmitted every 80 microseconds. These pulses define words in the telemetry format. Within each such interval a word value pulse is transmitted. Its position in the 80 microsecond word interval defines the particular word value transmitted. Therefore the telemetry system is called pulse-position modulated amplitude modulation (PPM-AM). There is also a second mode of the telemetry system with word interval length equal to 96 microseconds.

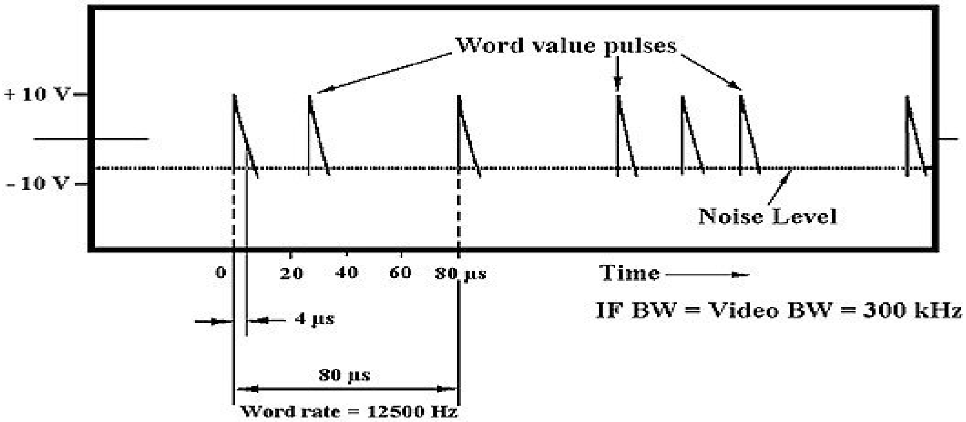


Figure 32: An example of the PPM-AM telemetry.

China 2 Telemetry on 19.995 MHz

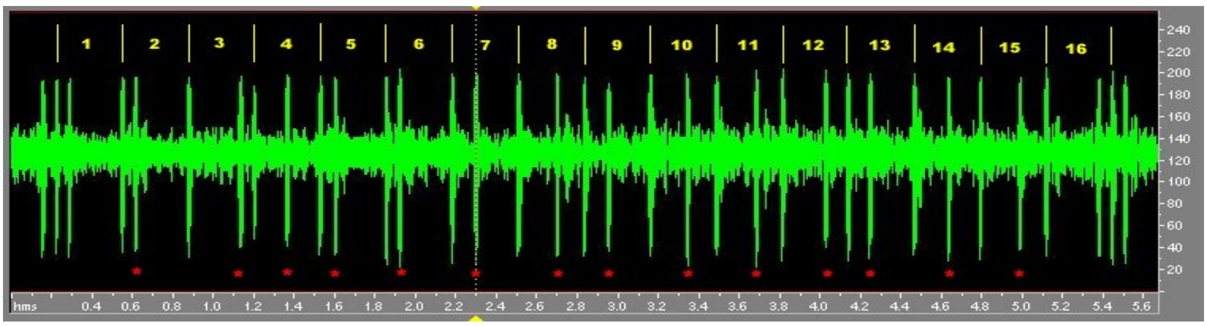


Figure 33: Another example of the PPM-AM telemetry.

The signal consists of a train of pulses. Some pulses define constant time periods (telemetry words) within which an additional pulse appears. The word length is 0.3125 sec. The position of this additional pulse (marked with a red dot in the picture above) within the word interval defines the measured value. There are 16 such word intervals in a "frame" that lasts 5.0 seconds. Two word intervals are use for synchronization, so 14 useful words are available in each frame. This type of telemetry is called PPM-AM (Pulse-Position Modulated Amplitude Modulation). The advantage with PPM-AM is that it requires very little power. The duty cycle of the transmitter is very low!

PDM Signal Format

This signal format was used for almost 30 years by many Soviet space vehicles. It was employed on shortwave transmitters operating close to 20 MHz. Especially in the CW-PDM mode (see below), this transmission method used very little bandwidth and could easily be heard far beyond the radio horizon due the "whispering gallery effect", i.e. the propagation of the signal through a duct between layers in the ionosphere. In fact on early Soyuz missions propagation around the world often occurred.

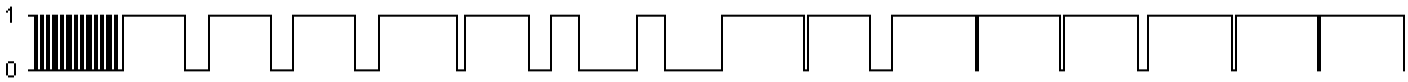
FSK-PDM

Frequency-shift keyed (FSK) with the "off" and "on" periods transmitted on two adjacent frequencies, approximately 1000 Hz apart. The telemetry frame consists of a train of rapid pulses followed by 15 words transmitted at a rate of approximately one word per second. These words are pulse-duration modulated (PDM). *Listen to Cosmos 929, FSK-PDM, 19.954 MHz, September 20, 1977 (228 kB, WAV)*

CW-PDM

A carrier (CW) keyed "off" and "on". The telemetry frame consists of a train of rapid pulses followed by 15 words transmitted at a rate of approximately one word per second. These words are pulse-duration modulated (PDM) by keying the carrier. *Listen to Cosmos 186 on 20.008 MHz, command-off at 1420 UT, October 30, 1967 (209 kB, WAV)*

When displayed on a pen-recorder these two signal formats look extremely similar. Below, an example of PDM telemetry is shown.



CW-PDM signals from Cosmos 140 on 20.008 MHz recorded on rev.5, February 7, 1967.

PCM-FM Telemetry

The Soviet/Russian telemetry system employed since the mid-70's is a rather normal PCM telemetry frame. The symbol rate is 256 kHz. The signal is frequency modulated on the carrier. The modulation index is quite high and the received signal spectrum has two distinct peaks about 125 kHz from the nominal carrier frequency. That is why a sharp buzzing sound is heard on a narrow-band FM receiver on 165.875 MHz and 166.125 MHz when listening to telemetry from modern Soyuz vehicles. This modulation system is also used by satellites in the Foton series, transmitting on 239.5 MHz. The image on the right shows the spectrum of the PCM-FM signal as picked up by a Nems-Clarke 2501A receiver and displayed on the accompanying Spectrum Display Unit 200-1.

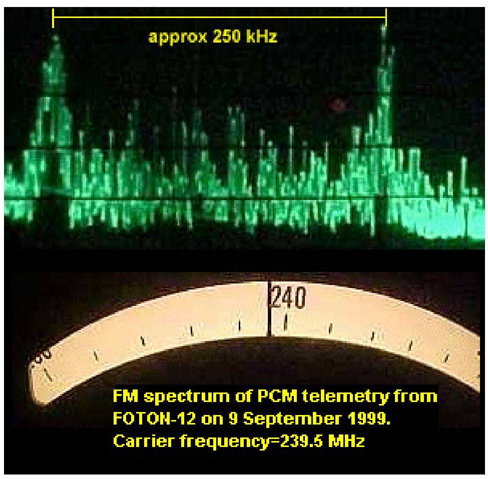


Figure 34: A PCM-FM telemetry.

Frequency Division Multiplex Telemetry

The basic operation of a frequency division multiplex telemetry system is illustrated in the figure below. The measurement signals from transducers modulate "sub-carrier" oscillators tuned to different frequencies. The output voltages from the sub-carrier oscillators are then summed linearly. The composite signal is used to modulate the downlink transmitter.

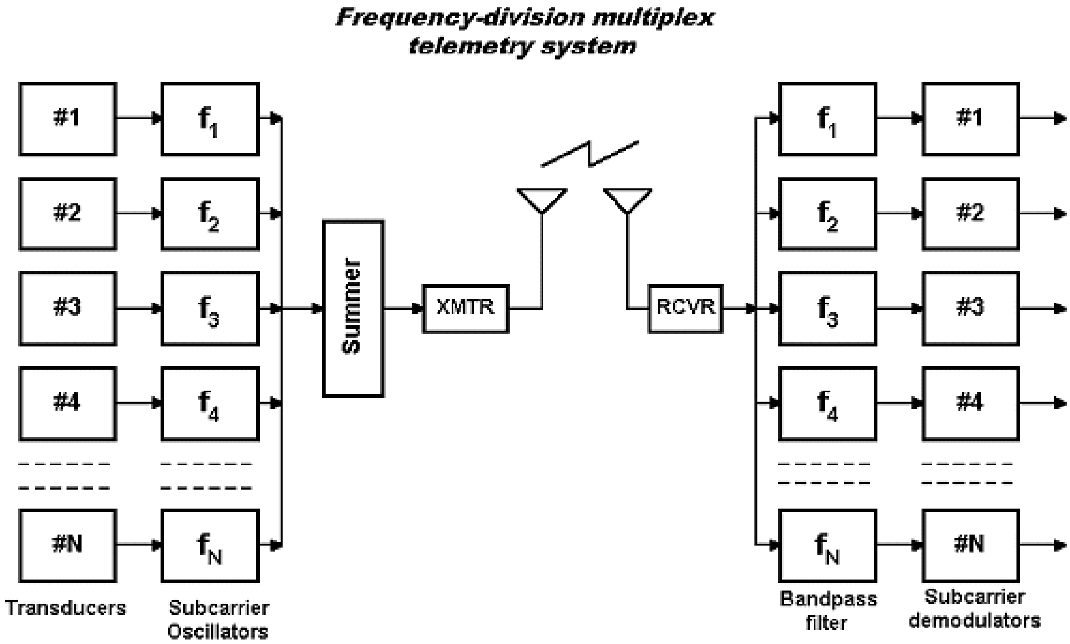


Figure 35: An example of a Frequency-division multiplex telemetry system.

In the receiving station the composite signal is available at the output of the receiver demodulator which is then fed to band-pass filters that are tuned to the centre frequencies of the sub-carrier’s oscillators. The outputs from the filters are the demodulated and the original transducer signals are recovered. All types of modulation can be used for both the sub-carrier oscillators and the prime carrier. The transmission system for frequency division multiplex systems is designated by first giving the modulation for the sub-carriers and then the prime carrier. Thus FM/AM would indicate a frequency-division multiplex system in which the sub-carriers are frequency modulated and the prime carrier is amplitude modulated by the composite sub-carrier signal.

The most commonly used frequency-division multiplex system is FM/FM it’s also known as the Inter-Range Instrumentation Group (IRIG) standards. The FM/FM standard established the centre frequency for sub-carriers and how much bandwidth each sub-carrier can occupy. The most noteworthy variants frequency-division multiplex systems used in addition to FM/FM are FM/PM and SS/FM (for Single-Sideband/FM). An FM/PM system was used in the early days of the U.S. space program, because phase-locked receivers were used to acquire and detect the main carrier. The early Explorer satellites and Pioneer probes used this system. However, the amount of information transmitted in these early systems was very limited. By using single-sideband sub-carrier signals much more data could be compressed in a narrow bandwidth and the SS/FM systems were used in early Saturn 1 flights.

In the early days of telemetry Analogue Time-Division Multiplex systems were used in conjunction with frequency division multiplex systems. A very common type of time-division multiplex was the Pulse-amplitude modulation (PAM) system. The output of the converter in such a system is a series of pulses, the amplitudes of which correspond to the sampled values of the input channels from the transducers. At the receiving station the process is reversed. The demodulator output from the receiver is passed through a de-converter that produces outputs corresponding to the sampled measurement signals. The pulse-amplitude waveform may take several forms as can be seen below. The principle difference lies in the duty cycle of the pulse. In the figure on the right the top diagram shows a 100% duty cycle system while the lower diagram shows a 50% duty cycle system. The length of time necessary to sample all channels is called the "frame time". In order to identify the channel corresponding to a sample at the receiving station, it is necessary to provide frame synchronization.

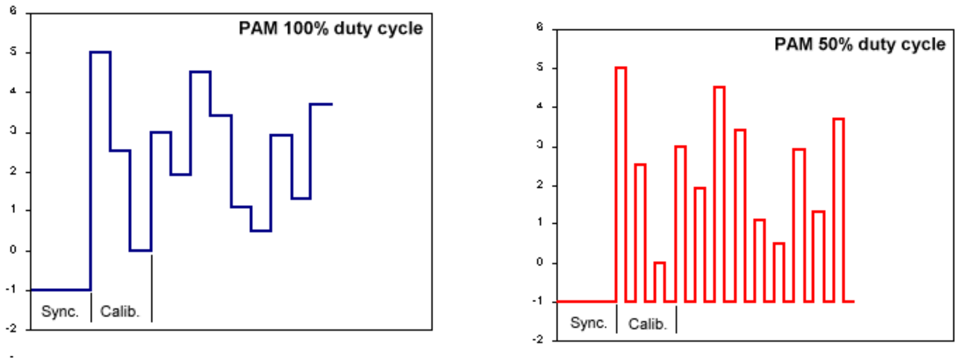


Figure 36: An example of 2 PAM duty cycles.

Explorer-7, Example of PAM/FM/AM

In real-life applications many sensors were multiplexed on each sub-carrier. Explorer-7 is a good example of this. This spacecraft was also called S-46 and it used a PAM/FM/AM system on 20 MHz and PAM/FM/PM system on 108 MHz. The 20 MHz system using PAM/FM/AM is shown in the figure below. Explorer-7 was launched on a Juno-2 rocket from Cape Canaveral on 13 October 1959 into an orbit at 556-1088 km with an inclination of 50.3 degrees. It transmitted on 19.9904 MHz for nearly 2.5 years. The choice of 20 MHz was very unusual for U.S. satellites. In this case this frequency was selected to permit reception of signals by radio amateurs as part of activities connected with the International Geophysical Year. The picture below shows a piece of the telemetry transmission from Explorer-7.

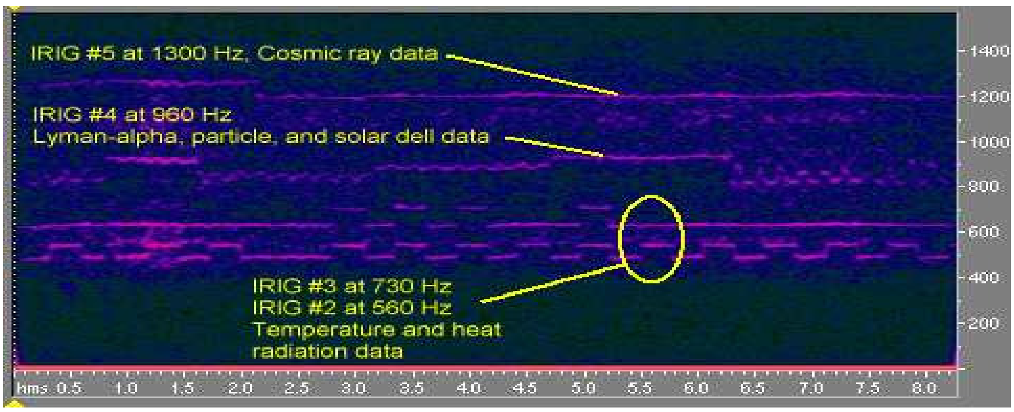


Figure 37: An example of the PPM-AM telemetry.

Victoria Digital Broadcast Protocol

Background

The case for a digital broadcast protocol for use on Victoria is made and a suitable protocol is proposed. In the proposed protocol, files of image and payload data are chopped into <UI> frames and repeatedly sent by the Victoria or on request. Each<UI> frame datagram contains enough information for ground station software to place the frame in the correct position in the appropriate file. Information indicating the type of file being received is also included in each frame.

Victoria is a generic term used to describe as an analogue and digital satellite with a mission for the Amateur Radio Service and KTH. Victoria will use the AX.25 frame as the basic link layer protocol, either in the full AX.25 connected mode or as unconnected <UI> frame datagram.

Victoria will have several types of data to send. Some of these are:

1) Broadcasting (send it once for reception by many) and point-to-multipoint messages. These are messages are not destined for Victoria as an endpoint, but are in transit between forwarding ground stations. These messages can be image, voice messages and payload data.

2) Real-time Telemetry. These are current spacecraft telemetry values, such as solar array power, internal temperature, etc.

3) Stored Telemetry. This is a file of one or more telemetry values stored over time, for example, the output of the solar arrays once a second over the last orbit. This is usually called ``Whole Orbit Data'' or ``WOD''.

4) Bulletins. These are items of general interest, orbit predictions, AMSAT News, etc.

Items 1), 2) and 3) above are primarily points for operations.

The other items are germane to this discussion. Both are data types that would be of interest to a large number satellite user’s people. Any time that more than one user is interested in the same information, it will generally make more sense to broadcast it rather than send the information separately to each individual.

Now assume that one wished to distribute on Victoria, an environment where time and spectrum are at a premium. Current terrestrial packet radio use is highly inefficient. If 100 people in southern Sweden want to read the 300k byte ARRL Gateway newsletter, they each log into Victoria and read it separately. This requires 30 MB of data to be sent. Because of packet overhead, collisions, ACKs, etc., the actual number of bytes sent and the total channel time is much higher.

Assuming a very optimistic average throughput of 9600 bits/second, it takes 7 hours of channel time to allow 100 people to get a copy. Taking the standard loaded of 18% of that 7 hours, that means 39 hours of channel time are required. Because there are 24 hours in a day, the inefficiency of the system is masked by the large amount of time and RF spectrum available. The Victoria is visible for about 14 minutes a pass, or about 60 minutes a day. It would then take 39 days to accumulate 39 hours of channel time, since even though the Victoria has multiple uplinks, it has only one downlink.

Even if we assume a much disciplined set of users who access the satellite one at a time, we can move the efficiency from 18% to nearly 95%, enabling Victoria to service the 100 users in 7 days. This is assuming the single downlink frequency is devoted to the activity of downloading files to individual users.

There are several conclusions that can be drawn from this. One is that a satellite is useless for dealing with a large number of individual users if they all want individual copies of the same file. It would be far better to broadcast a copy by the satellite. The conclusion is that if there is a way to send a single copy of "data" that could be seen by all 100 users at the same time, this will reduce both the load on the satellite. Since the satellite CAN see all 100 users in southern Sweden at one time, the solution is now clear.

A digital broadcast protocol for items of general interest is clearly desirable. In a broadcast mode, Victoria can transmit at least 2 Mb of data to a station in the mid latitudes in an average day. There is another advantage to a digital broadcast protocol, due to transmitting on one way, does not require a transmitter at the receiving site. The complexity of the ground station is reduced as the 70 cm antenna and a TNC are required to receive the broadcast.

The Victoria environment gives another encouragement to digital broadcast protocols, because the transmit- and receive-frequencies are on different bands, it is inherently full-duplex. Since Victoria will be the only transmitting station on the downlink, a major source of data-loss, and collisions with other stations is removed. Notice this only apply when the ground station is in the receive mode. When the link is good, there is no need for retransmissions, making the digital broadcast protocol more efficient than the normal ACK/Timeout AX.25 protocol.

Attributes of a Digital Broadcast Protocol

The AX.25 protocol, in its connected mode, makes the following guarantees:

- All bytes are received once, in the order they were sent, with no gaps.
- No bytes are received in error (within the limits of CRC16).

This means that the two stations can establish a connection and then send a file. When the expected number of bytes or an end of file marker is received the receiving station can assume that it received the entire file (or message) correctly. The general philosophy is that the sending and receiving stations work together to retransmit each frame (or small group of frames, 1-7) repeatedly until it is received correctly, before moving on to the next frame. The connected mode requires two-way point to point transmissions, and is not suitable for a broadcast protocol. But it's great when updating Victoria software or requesting the missing bits.

The unconnected mode <UI> of AX.25 makes these guarantees:

- Byte order is maintained within a frame only.
- No bytes in a frame are received in error (within the limits of CRC16).

One or more frames may be missing within a group of frames. Although some TNCs allow you to receive frames with CRC errors, you can receive no reliable indication that you have missed a frame. AX.25 does not provide frame sequence numbers in these frames. You can not know if the frame you have just received immediately follows the previously received frame, or if you missed some. Although on average, the Victoria's ground station will still get occasional dropouts from local conditions, polarity reversals due to the spacecraft's changing orientation, 70cm radar, etc. Loss of signal as the spacecraft goes over the horizon will also cause a loss of frames. All of this means that if you receive a file as a set of broadcast <UI> frames, AX.25 itself does not provide enough information to allow you to tell if the entire file has been received, or if it has gaps. A digital broadcast protocol must provide this missing information. The digital broadcast protocol would ride inside a standard AX.25 <UI> frame.

The ideally broadcast protocol will have the following attributes:

- Any frame, when received independently, can be placed in the proper location within the file to which it belongs.
- When all the frames have been received, the ideally way for a ground station is to tell that the file is complete. But this is not possible because during the digital broadcast mode Victoria will not be "listening" to any ACK from the ground station. Instead the software that the ground station use will try to puzzle up all the small transmitting frames back into the same file before it is transmitted.

Three rules can be derived from the above desires:

1) Each frame must contain a file identifier
2) Each frame must contain something that identifies this frame's position in the file.
3) The file must contain a special record that defines file attributes, particularly file size. Other items of interest would be the actual file name, creation date, etc.

File Transmission Frame Format

Frame Header

Each frame contains a frame header, which occupies the first 10 bytes of the frame. The structure of the frame header is as follows:

<flags>	<file_id>	<file_type>	<offset>
1 byte	4 bytes	1 byte	4 bytes

Frame

A broadcast frame consists of a header, data and a crc. The length of the header and data is of fix size. The broadcast frame is wholly contained within a standard AX.25 <UI> frame. A <UI> frame containing a broadcast frame uses a PID of 0xbb. A <UI> frame containing a broadcast frame uses a source address of the transmitting station and a destination address of QST-1.

The above rules define a frame structure that looks like this:

<flags>	<file_id>	<file_type>	<offset>	<data>	<crc>	<flags>
1 byte	4 bytes	1 byte	4 bytes	60 bytes	4 byte	1 bytes

Each field is discussed below.

<flags>

The flag field is a byte which defining the “start-bit” and the “stop-bit”.

<file_id>

At first glance, the simplest file id would be the actual name of the file. Since the Victoria file system permits 8 bytes of name and 3 bytes of extension, this would lead to 11 bytes of overhead per frame, or 4%. This is somewhat large, to overcome this problem Victoria assigns each created file a ``file number'', which is 4 bytes long and will uniquely identify the file. This unique number is used as the file_id in the broadcast protocol header. All frames which are part of the same file are tagged with the same file_id.

The receiving station will not know the actual name of the file until the file header record is received. This record could be transmitted more frequently than other records, increasing the chances that it would be available in any partially-received file.

<file_type>

If a partial file it is useful that some information on the file_type must be provided with each frame. Examples of file types are:

- ASCII text bulletins
- Images from CCD
- Stored telemetry
- Digitized voice
- Machine-ready Keplerian element updates

The file_type byte is the same byte which is found in the file header record in the file. File types are assigned and defined in a separate document.

<offset>

Each frame of broadcast data must contain the position in the file where the data come from. Each frame then contains an offset field.

To place a received data frame into a file, one need only:

```
seek((long) offset);
write(handle, data, frame_size);
```

While it is easy to insert the frame bytes into the file, it is much harder to know when all the bytes have been received. There are several methods; one is maintaining a list of holes in the file, much as some TCP/IP implementations do when reassembling IP packets.

The size of the offset field is important, too small and the size of broadcast files is limited, too large and the overhead for each file is increased. We've chosen 16 bits as a compromise between efficiency and maximum file size. This allows for files up to 0,4Mb.

<data>

This part of the frame is the file data with a fix length of 60 bytes. All frames in a particular transmission of a file should be the same length, to avoid having the receiver resize his bit map too often. The file_type can be used to tell what type of data is present.

<crc>

It is most likely that TNCs operating in KISS mode will be used to receive the UI frames which make up Victoria's broadcast. The link between the KISS TNC and the user's personal computer may be prone to errors caused by a lack of flow control. This is especially true when using high radio data rates such as Victoria's 9600 baud link. Although the AX.25 CRC assures that only correctly received frames will be passed on by the KISS TNC to the host computer, we are now not certain that the frame reaching the host computer is error free. If we process incorrectly received frames, even occasionally, files will be lost or corrupted.

Thus we must add some error protection to the broadcast frame. For this reason, we have chosen to append a 16-bit <crc> to the broadcast frame within the AX.25 UI frame data field. These 4 bytes <crc> will be calculated using the XMODEM's crc specification, which has been successfully and efficiently implemented on many microcomputers. The <crc> covers all data bytes in the AX.25 UI frame, including the broadcast frame header.

File Header

Clearly the 2 bytes file_type and the 4 bytes file_id cannot convey all of the information which a ground station needs to know about a file (e.g. time of creation, complete file name, file's size). This information is in a structure at the beginning of each file. The file header is 56 bytes that fit within one data frame and it is always at start of the file. The File Header will repeatedly send more often so that the ground station know what file it is receiving.

Binary Data

For greatest efficiency, all header information is coded in binary. This is new compare to previous amateur digital satellite philosophy. Currently, UO-9, AO-10, UO-11, and AO-13 transmit telemetry and bulletins in uncompressed ASCII. This was in part to make this information available to the widest possible audience. The audience was a late 1970 early 1980 audience, and was assumed to have only the modem and a terminal, with little or no computer assistance. Telemetry on all of the above satellites can be read in ASCII and decoded with pencil and paper. The amount of telemetry generated is small, and the broadcast data is bi-weekly bulletins.

Victoria is being designed for a 2000s environment. A new piece of hardware is required, either an external TNC, or an add-on card for your computer. In almost all cases, a computer is present at the ground station. The number of users who must deal directly with the raw data is reduced, perhaps to zero.

An increased of compressed data will lead to a downlink which is mostly binary anyway. Several ground station programs are planned or already available which will allow users to monitor the downlink and acquire the data. The plans are to make public domain source and shareware programs available for the PC, with proceeds going to AMSAT-SM.

Victoria Digital Broadcasting

Victoria is broadcasting to an unknown number of ground stations by using the unconnected <UI> frame mode of AX.25. The protocol can also be used in purely terrestrial applications. Each file that is to be broadcast is assigned a 4 bytes file_id. This number must be unique among all other files broadcast by this station. A station must be able to later match the file_id with the file if the station is to handle retransmission requests.

When a file is broadcast, it is broken down into frames. Each frame is identified with enough information so that the data can be placed in the proper location and in the proper file by a ground station. Each frame is sent within an AX.25 <UI> frame, and is totally contained within that <UI> frame.

The Victoria is using two protocols for transmitting of files.

1. Digital Broadcast Protocol for sending a few files repeatedly to every Victoria's ground station.

2. Point-to-Point AX.25 connected mode is a standard communication protocol for radio amateur users. This protocol will be use for the request retransmission of all or part of a file and updating Victoria's software and command list. Notice only those who acquire a valid access code will be granted access.

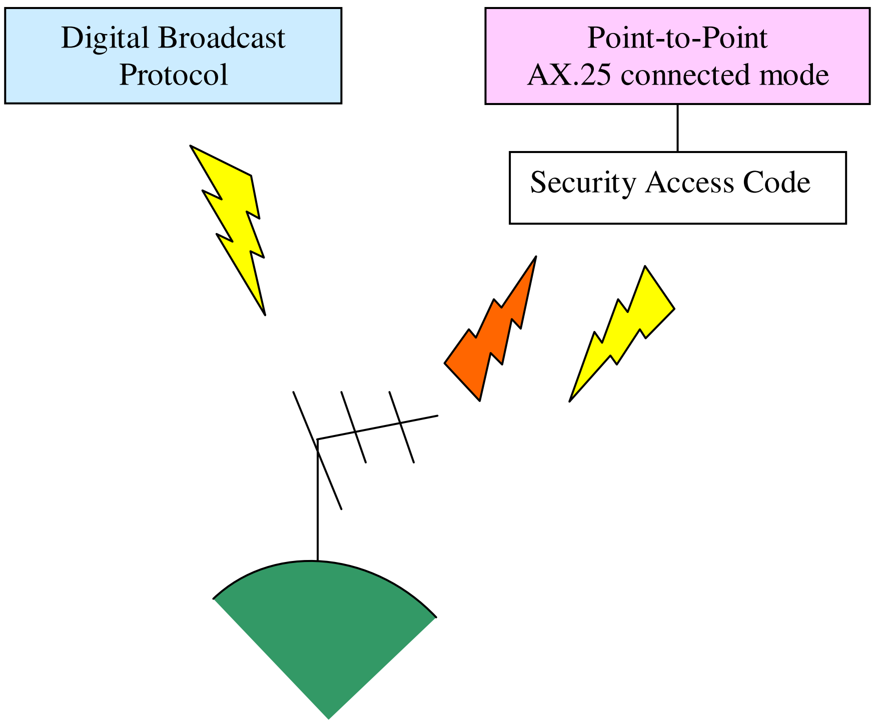


Figure 38: The Victoria satellite will use 2 different protocols.

During digital broadcast mode some files are repeatedly retransmitted enough times over several passes so that the likelihood of a station receiving all parts of the file at least once with no errors is high. There are only a few ground stations that are provided with access code.

They can request the transmission of certain frames to allow fills of missing data. The rest of the ground user with unauthorized code can only "listen" to the broadcast.

Each request to retransmit portions of a file is sent in a retransmission request frame that fit in an AX.25 connected mode. If more data is being requested than it will fit in one request, multiple requests may be sent. This protocol is intended to service retransmissions of already-broadcast files.

Only command stations with the right access code will be able to upload files to Victoria. All files will be broadcast based on a rotation order, i.e., broadcasting telemetry first, then image, then voice message and then the payload data. Since parsing binary data (the header) in the standard monitor mode of TNCs is non-trivial, we can assume that the KISS mode will be used to implement the ground program. Therefore the PID byte in the frame can easily be used to identify broadcast protocol frames. The exact value is 0xbb.

Ground users would run a program that monitors the downlink for frames. This program shall use the KISS mode of the TNC. As each frame was received, the <file_id> and <offset> field of the frames are used to build up an image of the file. Duplicate frames are discarded. Several files can be active at once. A utility program is provided to convert the received files into a usable form. It will display the contents of the Victoria's File Header record in received files. It can also generate a hole- list or bit-map as required, to send to Victoria and request retransmission of missing parts of the file, if the right access code is used.

Extensions

All files on Victoria can be divided into two groups: broadcast files which are sent with the broadcast protocol and point-to-point files which are sent using AX.25 connected mode. There is also a grey area: point-to-multipoint files, which are not of interest to all Victoria's ground stations, but might be of interest to more than one station in the Victoria's footprint. For instance, a "message" from a ground station that wants to broadcast to all Victoria's users will be able to if it has the right priority password. By using the broadcast mode after the first upload file from the ground station.

Because if users who does not receive the file completely while it is being broadcast can send a description of the missed data (hole-list) to the Victoria. Re-transmission requests for a particular file can come from many stations, but by the nature of the round-robin-broadcast, requests are not likely to be synchronized and cause a mass uplink collision. That is why only a few ground stations with the right password that can request of retransmitting of missing bits or uploading data to Victoria.

Incremental Decompression

Incremental decompression is the ability to decompress partial files. In the most general case, any frame can be decompressed independently of any other frame. It should be noted that the desire for incremental decompression has several deleterious effects.

Primarily it forces the use of non-optimal compression techniques. Some compression schemes, such as Huffman coding, require that a table be sent along with the file that provides deciding information. The file is not decodable without this table, so a partial file that did not include the table would be useless. To allow use of Huffman-style coding, files would have to be compressed with a small number of standard tables that can be encoded in the file type.

Many compression methods, including Huffman coding, turn a file into tokens of variable bit length. That is, a token will not necessarily be an integral number of octets long, whereas an AX.25 frame must be an integral number of octets long. An arbitrary frame can be decoded only if the start of the frame is also the start of a token and we know the number of meaningful bits in the frame.

Decompression of partial files is an area for further discussion. It shall be noted that the WO-18 image transmission format is a form of broadcast with incremental decompression, allowing even a single frame of the compressed image to be placed in it proper location on the display screen. But the Victoria's protocol will skip the incremental decompression due to the limited data volume for transmitting.

Digital Broadcast Ground Station

Nearly everything broadcast from Victoria will have several bytes of binary data in the front of each frame. This would make it difficult to monitor with just a TNC and terminal. A PC and proper program would be required in any case, so it is unlikely there will be any TNC-only stations. We also note that most of current fleet of spacecraft are already transmitting telemetry in raw binary form. Due to the difficulty of parsing binary data from the standard monitor mode of TNCs, only TNCs with the KISS protocol will be suitable.

Notice

B. Legalities within the Amateur Satellite Service
The use of the words ``broadcast'' and ``compression'' sometimes raise the hackles of certain members of the amateur community. ``Broadcast'' is mentioned in the Amateur Rules (Part 97 of the FCC regulations), and compression is sometimes equated with encryption.

Broadcast

To establish the bona-fides of a broadcast protocol:

97.113(d)(2) specifically permits information bulletins consisting solely of subject matter relating to amateur radio. The prohibited items are communications intended to be received directly by the public (1200/4800/9600 baud PSK HDLC should take care of that), or for newsgathering for broadcast purposes.

Compression

97.117 specifically permit the use of abbreviations or signals where the intent is not to obscure the meaning but only to facilitate communications. Compression using published algorithms to increase data throughput would thus be permitted.

Victoria File Header Definition

Background

A fix encoding method for Victoria file headers is described. These headers are supplied by the programs which send files to Victoria and by onboard programs which build files intended for downloading or broadcasting. Victoria's file headers are present in all files stored onboard. It's more efficient to send a file header just a few times than if the file header should send on every frame. Because the "information" of the file header will remain the same for the same file but not the file body.

Victoria is a file and message switch and a data generating device. Files may be generated by onboard processes such as telemetry- and system- programs, payload data, imaging cameras or uploaded messages. Files and messages will be sent and received by many nodes: individual user stations, command stations, and various onboard tasks. To ensure that these files can be properly identified and processed, each file stored on Victoria will begin with Victoria File Header (VFH).

The primary objectives of the Victoria File Header standard are to:

- Encode all header items in a standardized manner.
- Maintain complete separation between the file header and the file body.
- Provide for expansion through easy incorporation of additional header items.
- Minimized the transmitting data.

Victoria File Header System

Every Victoria file will start with the <Header start> byte. This flag is followed by the rest of the Victoria File Header (VFH). The VFH is terminated by a special <Header end> after which the file body begins on the next frame. A valid File Header contains all of the items of the VFH. All HEADER ITEMS are encoded using a fix format standard described in Section 2.

Victoria File Header:

<Header start>	<Header>	<Header end>

Victoria Header

All Victoria file header items follow a single format, simplifying both specification and implementation of the Victoria File Header. The format is:

flag	file_nr	file_name	file_ext	file_size	create_time	source	File_description	Header_checksum	flag
4	4	8	3	4	4	6	17	2	4

continue below

Table 1

The first two bytes of a Victoria file should always contain <0xaa> followed by <0x55> to confirm that the file contains a Victoria file header. The 0xaa 0x55 sequence must be followed immediately by all items of the Header. When preparing files for uploading to Victoria, ground stations must initialize header items as specified as the Table 1.

<file_id>

length : 4
data : unsigned long file_id

<file_nr> is a 4-byte unsigned serial number assigned to a file by Victoria when the file is created. This number uniquely identifies any file. Since the Victoria file system makes no different between files and images.

Initialization - Must be initialized to 0.

<file_name>

length : 8
data : char file_name[8]

<file_name> is the base name of the file as it is stored in the Victoria file system. If the name is shorter than 8 characters, it is extended on the right with ASCII spaces (0x20).

Initialization - Must be initialized to 8 ASCII spaces (0x20), allowing Victoria to choose its own name for the file.

<file_ext>

length : 3
data : char file_ext[3]

<file_ext> is a 3 character file name extension. If the extension is shorter than 3 characters, it is extended on the right with ASCII spaces (0x20).

Initialization - Must be initialized to 3 ASCII spaces (0x20), allowing Victoria to choose its own name for the file.

<file_size>

length : 4
data : unsigned long file_size

<file_size> is a 4-byte unsigned integer indicating the total number of bytes in the file, including the HEADER_FLAG, all HEADER_FIELD structures, and the file body.

Initialization - Correct <file_size> must be provided.

<create_time>

length : 4
data : unsigned long create_time

<create_time> is a 4-byte unsigned integer time-stamp telling when the file was created. This time-stamp counts the seconds since Jan 1, 2003.

Initialization - If <create_time> is initialized to 0, Victoria will set the time upon receiving the file header or when the system create the file. Otherwise Victoria does not alter this item.

<source>

length : 6
data : char source[]

Contain the ax.25 address of the station which uploaded the file. The SSID is not included in this address. If the callsign is less than 6 characters long, it will be filled to 6 characters by appending spaces (0x20) on the right.

Initialization - No initialization required.

<file_description>

length : 17
data : char file_description[]

The <file_description> item is an additional text that descripts the file a little bit plus the <file_type> values can describe the file body. For example, an uploading station might set the <file_type> to 0xff which stand for “image” and <file_description> says ``South of Africa”.

header_checksum

length : 2
data : unsigned int header_checksum

A 16 bit checksum formed by adding ALL bytes in Victoria File Header, including the leading 0xaa 0x55 sequence, into a 16 bit variable, ignoring overflow. This number is then stored as the <header_checksum>. The <header_checksum> is primarily intended to confirm correct header reception during file transfers.

Initialization - the <header_checksum> must be correctly initialized.

Header Termination

The end of the Victoria File Header, <Header end>, will be with the byte sequence <0x00 0x00>.

Header Summary

The VFH will be present on every Victoria file. When preparing to upload a file or message to Victoria, ground station software must create a valid VFH and insert it at the beginning of the file or message. The VFH defined above is designed for file transfer. It contains sufficient information to reliably upload and download Victoria files, including transfers spread over several satellite passes.

Victoria File Types

<file_type>

0x00	ASCII text file intended for display/printing.
0x01	Telemetry & Status
0x02	Voice message
0x03	Payload data
0x04	Victoria Whole Orbit Data
0x06	MS/PC-DOS .exe file
0x08	Keplerian elements NASA 2-line format
0x09	Keplerian elements AMSAT format
0xff	Image

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NOTICE:

More internet links can be found in the "victoriafinal-bookmark.htm" on the Victoria satellite's thesis project CD.