MICROSAT: A New, Small Satellite Bus Concept

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The Radio Amateur Satellite Corporation of North America (AMSAT-NA) is pioneering a new, small satellite bus concept known as "Microsat." The product is roughly a nine inch cube, exclusive of antennas, with five sub-assemblies. Four are standard: radio transmitter(s), radio receiver(s), power system, and onboard computer. The fifth module is reserved for payload or special application hardware. Design goals dictate that the cost of the satellites and the cost and complexity of ground terminals be minimized. Satellite software is also standardized. Applications can be prototyped on common personal computers. The four development Microsats will be in the Amateur Radio Service. They have payloads that include an FM voice transmitter, a TV camera, electronic mailboxes, a microwave transmitter, and a beacon transmitting Morse Code.

INTRODUCTION

For nearly three decades, groups of amateur radio operators in North America have participated in the development, launch, and operation of relatively small and inexpensive communications and scientific satellites. In cooperation with amateurs in the United Kingdom, the Federal Republic of Germany, and other countries, thirteen such payloads have been developed and orbited to date. A comparable number of similar satellites have been provided by other countries, particularly the Soviet Union and Japan.

Workers on these projects have traditionally been motivated only by the desire to play a significant part in producing or using satellites, not by considerations of markets, funding, grants, proposals, customers, or executive direction. The engineers therefore experience considerable freedom in determining everything about projects from the broad issues to small implementation details. These satellite efforts are quite large by amateur radio standards, but are rather small when compared to conventional satellite development programs.

By and large, this approach has led to meaningful and successful facilities for use in the amateur radio service and has demonstrated or spun off inexpensive, advanced techniques and technologies into various fields of engineering. The emphasis is on actual performance rather than perceived feasibility or large scale finance.

Such contributions are one important reason for the existence of the amateur radio service and the radio amateur satellite service.

The approach has also placed the developers in positions of unique opportunity, the ability to obtain free, excess payload space on a rocket launch being one example.

There are advantages and disadvantages to using amateur radio frequencies for space missions, prototype or otherwise. Among the advantages is that it is comparatively easy (though not trivial or guaranteed) to get an allocation within amateur spectrum, particularly for an experimental or proof-of-concept project. Among the disadvantages is that it is illegal when using amateur spectrum for any of the direct radio operators to receive any compensation or to have any pecuniary interest at all. It is not allowed, for example, to bill or charge users for the communications service rendered or scientific data obtained. Fund raising is handled through voluntary donations but services are provided freely to all qualified participants.

It is not intended, however, that any or all future satellites in the Microsat series necessarily involve amateur radio. As we will see below, the Microsat bus has many potential applications in commercial, academic, and scientific realms.

THE MICROSAT SYSTEM BUS

After years of building satellites one by one, doing a full engineering development, prototype, and flight model on each one, it was realized that satellite systems had many components in common and that a defined, modular approach could save considerable effort. The result of this refinement in approach is the Microsat.

Spacecraft busses ordinarily meet at least four basic equipment requirements: power management, communications with controllers, control and/or sequencing mechanisms, and payload functions. The Microsat bus is a modular design conceived with exactly these requirements in mind. The complexities of inter-module communication are minimized. In the interest of simplicity, internal redundancy is also minimized. Due to the low cost and small size of Microsats, redundancy is achieved by orbiting multiple identical or similar copies of the same spacecraft.

The Microsat bus is composed of five aluminum frames formed into a composite stack held together with stainless steel tie bolts. There is no other mechanical structure aside from these modules. Dimensions of the stack are 230 X 230 X 213 mm (9 X 9 X 8-3/8 inches). High efficiency solar cells are assembled onto four solar panels which are installed onto the four sides of the frame stack assembly. Additional solar cell assemblies are mounted on the top and bottom of the spacecraft.

Figure 1 is an exploded view of the mechanical structure provided by Microsat draftsman Dick Jansson, amateur callsign WD4FAB.

The five frames of a baseline Microsat are arranged in the following way.

Module 05:	VHF FSK AX.25 Receiver, four channels
Module 04:	Payload - TSFR (This Space For Rent)
Module 03:	Power Module
Module 02:	Flight Computer
Module 01:	UHF BPSK AX.25 Transmitter, one channel

This arrangement is modified easily as required by mission constraints.

Transmitter.

The prototype UHF transmitters send digital information using Binary Phase Shift Keying (BPSK) at 1200 or 4800 bits per second, selectable. The design is a fairly straightforward oscillator - multiplier chain. Due to launch slips, it has been possible to include dual transmitters on the original four Microsats giving some measure of redundancy.

Receivers.

The prototype VHF receiver boards contain four complete receiver strips each. The channels are nominally set to different frequencies. The receivers detect digital information which has been Frequency Shift Keyed (FSK) at 1200 or 4800 bits per second. Channels may be independently commanded to each rate or can be constructed to automatically select between rates depending on the data captured in the RF uplink.

The transmitters and receivers use the "connected," error correcting, AX.25 protocol under direction from the flight computer. Systems with baud rates up to 56.8 thousand bits per second are planned for future versions of Microsat.

Antennas.

Refer to Figure 2.

Antennas are mounted on the top and bottom near the transmitter and receiver. In the baseline prototype, a VHF whip (for 145.9 MHz) of "carpenter's tape" type material is mounted on top and feeds the spacecraft receivers. Four elements of a UHF canted turnstile (for 437.1 MHz) extend from the bottom.

Power Management.

The power modules are slightly larger than the others in order to allow space for battery cells. This system receives power from the solar panels and down converts it from 22 volts to the main bus voltage of 10 volts. A 5 volts regulated supply is also included. A Battery Charge Regulator (BCR) is used to properly maintain the battery state.

Solar arrays consist of 20 identical sub-panels referred to as "clips." Each clip contains 20 high efficiency solar cells measuring 20 mm X 20 mm (0.79 inch X 0.79 inch). Five of the six cube surfaces contain four clips each. The -Z or bottom surface contains four ten cell "half clips."

This module contains eight 6 amp-hour NiCd battery cells which are of adequate capacity to assure proper operation during eclipse periods. Commercial grade cells are carefully matched and qualified before assembling each spacecraft battery.

General Purpose Computer.

Each Microsat contains a general purpose microcomputer for command and control purposes and for digital data management. The computer is responsible for ensuring that all spacecraft functions are properly carried out. It performs the following sorts of tasks:

- o Battery-charge regulator set-point control
- o Telemetry measurement or calculation and conversion
- o Transmitter power level selection and scheduling
- o Command reception and decoding
- o Telemetry packet or data initiation
- o AX.25 protocol implementation, transmit and receive
- o A variety of payload functions and options, discussed below
- o "Watchdog" operation to reset the computer if no commands are received in a certain period or to reduce transmitter power output if the battery voltage becomes unacceptably low.

This computer is a custom design based on an NEC V-40 microprocessor. Three primary memory areas are supported. For executable image storage, 256K bytes of RAM are implemented with Error Detection And Correction (EDAC) hardware employing twelve bits per byte, eight data bits and four check bits. A 2K byte ROM boot loader is non-volatile and provides a means of safely restarting the flight computer from a hard reset. Applications or payload data are stored in a nominal two megabytes of RAM which is accessed in half megabyte switched memory banks. Up to six additional megabytes of RAM may be accessed as a serial-interface mass storage medium (RAM-disk). Half megabyte memory banks may be individually powered down in order to conserve spacecraft power when the memory is not in use.

Running at about 5 MHz, this computer is comparable to an IBM-XT in performance and storage capabilities.

A single 8 bit analog to digital (A to D) converter in the computer measures voltages on a pair of bus lines reserved for analog measurements. This provides the means for the flight computer to monitor operating parameters throughout the spacecraft for telemetering and operational purposes.

Onboard programs are managed by the Quadron Multi-tasking operating system which looks similar to MS-DOS to each of the running applications. This approach is used in order to greatly simplify ground based software development on existing PCs.

Use of such a powerful flight computer allows unprecedented opportunities for statistical and scientific data collection along with some degree of onboard data reduction.

Standard AART

Each module in each Microsat, except the flight computer itself, is attached to an Addressable Asynchronous Receiver/Transmitter (AART). This is a simple, standardized CPU-to-module interface for command (both discrete digital and analog multiplexer) data by the use of a three wire bus (transmit, receive, and common) which uses ordinary ASCII communications at 4800 bps. An identical PC board is used in each module (aside from the Flight Computer Module) to provide these command functions.

The inter-module electrical interface is a 25 wire bus. Each AART board provides the mechanical mounting for the DB25 connector on each module. Wires on the bus include power supply voltages, the analog pair to the A/D converter, various discrete control lines and mission specific signals, and the 4800 bps AART data.

Thermal Characteristics

The Microsats are designed specifically for low earth orbit operation. Spacecraft coatings are designed to minimize heat inputs from the sun, earth, and earth reflection radiations. The objective is to keep the spacecraft temperatures low (in the -5 C to +5 C range) in order to promote as high an efficiency from the solar cells as is possible. Long lifetime of the NiCd storage cell batteries is also enhanced by the lower temperatures.

The thermal controls can be adjusted for different payloads in different orbits.

Attitude Control.

Microsat attitude is controlled by a passive magnetic and photon pressure technique. Permanent magnets are mounted in the spacecraft parallel to the Z axis. In orbit, these tend to align themselves with the local magnetic field of the earth. In polar orbit (where the prototypes are to be tested) the field lines enter the earth near the poles and are parallel to the surface near the equator. Tracking this pattern, the Z axis of each satellite rotates twice per orbit, about once every 50 minutes or 0.02 RPM.

Supplementing this rotation of the Z axis is a rotation about the Z axis. The UHF transmitting antenna (turnstile) elements are each painted black on one side and white on the other. Net torque from solar photon pressure produces this second rotation. Its rate is on the order of one RPM and is regulated by magnetically lossy hysteresis rods mounted on the spacecraft baseplate (in the X-Y plane).

These combined rotations combine to give all faces of the satellite exposure to the various environments experienced, the earth, the sun, and deep space. This allows the temperatures within the satellites to moderate. It also regulates radiation damage to the solar cell clips. There is also an effect on the presentation of the radio antenna patterns although it is not anticipated that this effect will cause serious problems with digital data flow.

This discussion of the bus has dealt mostly with the prototype Microsats. The payloads of each are described below. The modular approach and flexible construction make it possible to adapt the flight ready subsets of the package to a variety of situations. For instance, AMSAT has been approached by parties interested in using transmitter, receiver, and computer modules in support of projects for which power, stabilization, and bus construction are already determined.

GROUND SEGMENT

Along with the goal of making the space segment simple and inexpensive, another goal of the Microsat program is to facilitate simple, inexpensive ground terminals.

Command or user ground terminals for these satellites are easily constructed from commercially available equipment at a cost of about three thousand dollars. Amateur radio operators, being the thrifty Americans that they are, have been known to build up perfectly adequate stations for a total cash outlay of just a few hundred dollars.

For a dedicated service, i. e. one in which access per channel is controlled and coordinated, Microsats will be accessible with very modest ground terminals. Demonstrations of such terminals where all the parts, including antennas, fit into a brief case have been made.

The four initial Microsats are intended for general access by amateur radio operators and because of uplink competition for the four channels, transmitting requirements are expected to be more stringent. Nevertheless, Steve Roberts (amateur call N4RVE), the builder and operator of the "Winnebiko," is equipping his low mass, power sensitive station for bicycle-mobile Microsat access and expects a reasonable level of success.

In the amateur radio service, the first four missions will be greeted by a few thousand terminals spread around the world. As each payload function becomes well known, their popularities are also expected to increase, particularly in the special interest areas that each one addresses.

Prototype Applications

The four original Microsat payloads are designed to carry out three primary missions and several secondary experiments.

The simplest conceptually is the Digital Orbiting Voice Encoder, Project DOVE, sponsored by BRAMSAT, the Amateur Radio Satellite Corporation of Brazil. The TSFR module on DOVE contains circuitry producing and allowing selection between three forms of audio for transmission. Unlike the BPSK digital format transmitted on UHF by the other three Microsats, this satellite is intended to transmit programmed audio on narrow-band VHF (145.825 MHz) for educational purposes. Sound is digitized on the ground either in straight analog to digital conversion or using a Votrax format and uplinked as digital data by control stations. Either of these formats may be played back by the satellite digital to analog (D/A) or Votrax circuits. The third downlink option is an Audio Frequency Shift Keying (AFSK) modulator for digital transmissions on the narrowband circuit.

Two of the Microsats will be used primarily as "pacsats" or packet radio bulletin boards. The term "packet radio" describes utilization of digital modulation and AX.25 protocol for the purpose of virtually error free data communication. These satellites will behave like dial up telephone bulletin boards with the added feature that their extreme mobility (the intended orbit sees every point on the surface of the earth four or more times per day) allows automatic forwarding of electronic mail between ground based systems everywhere. Satellite capable amateurs will also use the pacsats for individual electronic mail exchange. Pacsats do not require any additional hardware in the TSFR module space, they only require special software in the onboard computer.

The pacsat - Microsat sponsored by The Radio Amateur Satellite Corporation of Argentina (AMSAT - LU) will feature a special TSFR experiment provided by the amateurs of Argentina. This experiment will transmit telemetry in a specially modified Morse code so that amateurs anywhere, regardless of equipment (aside from the need for a UHF receiver) will be able to participate in use of the satellite.

The pacsat - Microsat sponsored by The Radio Amateur Satellite Corporation of North America (AMSAT - NA) will have in its TSFR slot an experimental BPSK transmitter operating in the amateur S-band around 2.4 GHz.

The fourth of the original Microsats is sponsored by Weber State University of Ogden, Utah. It carries several educational - scientific experiments in its two extra modules. The stack is rearranged so that these two can be on top. The most impressive of these experiments is an off-the-shelf TV camera which has been rebuilt and qualified for spaceflight. Color pictures will be digitized and transmitted to the ground in compressed computer files. The other experiments include a magnetometer, a micrometeor impact detector, and an amateur L-band (1.265 GHz) receiver for direct uplink of standard color TV pictures.

These applications are just the first of many possibilities for the Microsat bus. They demonstrate the flexibility and potential power of the modular, nearly assembly-line approach to spacecraft construction.

FUTURE APPLICATIONS

The Microsats are intended to demonstrate cost effective satellite technologies for budget customers like small companies, agencies, or educational institutions.

Potential applications include remote data gathering. Platforms in equatorial regions could uplink about 2 megabytes per day per channel (non real time) to one of the current Microsats in polar orbit, two or three times more from polar regions. If choice of orbit is possible, higher average data rates can be supported from any latitude. Data can then be pre-processed, reduced, and/or compressed if desired by the powerful onboard computer before downlinking to a fixed station.

Any small experiment (that can fit into 9 X 9 X 1 inches) can be flown in the TSFR space. This can include one or more of several possible small science payloads even including smaller micro-gravity apparatus. Such possibilities are demonstrated aptly by the Weber State Microsat.

The potential for use of the Microsat bus in small experiments of this type or Microsat modules in grander schemes is limited only by the imagination.

LAUNCHES

An unfortunate by-product of the now demonstrated popularity of small satellites which use otherwise empty space inside launcher farings is the fact that launching authorities are beginning to catch on and to charge appropriately for the space. The cost of launching the first four Microsats will be about half of their construction value, and this is only an introductory price. Future launches of such small objects are likely to cost much more. Nevertheless, it is still possible with Microsat technology to construct a mission with two or three satellites, obtain a launch at going rates, and set up an adequate number of ground stations for something less than a million dollars, at least an order of magnitude less than the cost of comparable services in the recent past.

Miniaturization, clever planning, and imagination make this possible.

ORDER FORM

For more information about any aspect of the Microsat project, contact:

AMSAT - North America
P. O. Box 27
Washington, DC 20044.

ACRONYMS

A/D	Analog to Digital
AART	Addressable - Asynchronous Receiver Transmitter
AMSAT	Amateur Radio Satellite Corporation
AX.25	Amateur X.25 (protocol)
BCR	Battery Charge Regulator
BPSK	Bi Phase Shift Keying
BRAMSAT	Amateur Radio Satellite Corporation - Brazil
CPU	Central Processing Unit
D/A	Digital to Analog
DOVE	Digital Orbiting Voice Encoder
EDAC	Error Detecting And Correcting
FSK	Frequency Shift Keying
IBM	International Business Machines
MS-DOS	MicroSoft Disk Operating System
NEC	National Equipment Corporation
NiCd	Nickel Cadmium (battery type)
PC	Personal Computer
RAM	Random Access Memory
RF	Radio Frequency
TSFR	This Space For Rent (payload)
TV	TeleVision
UHF	Ultra High Frequency (300 - 3000 MHz)
VHF	Very High Frequency (30 - 300 MHz)

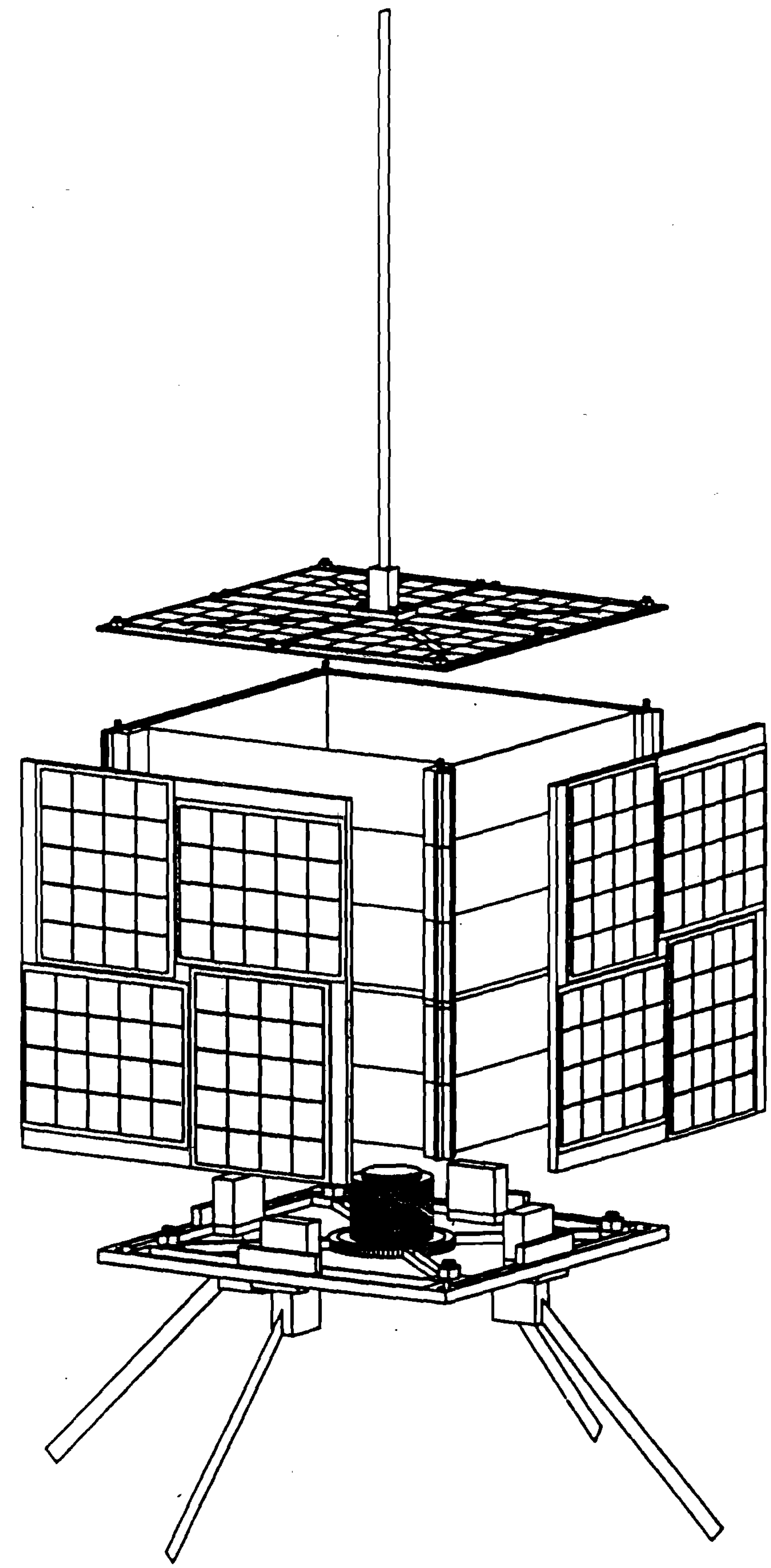

Figure 1. Microsat Structure, Exploded View.
(courtesy of Dick Jansson, WD4FAB)

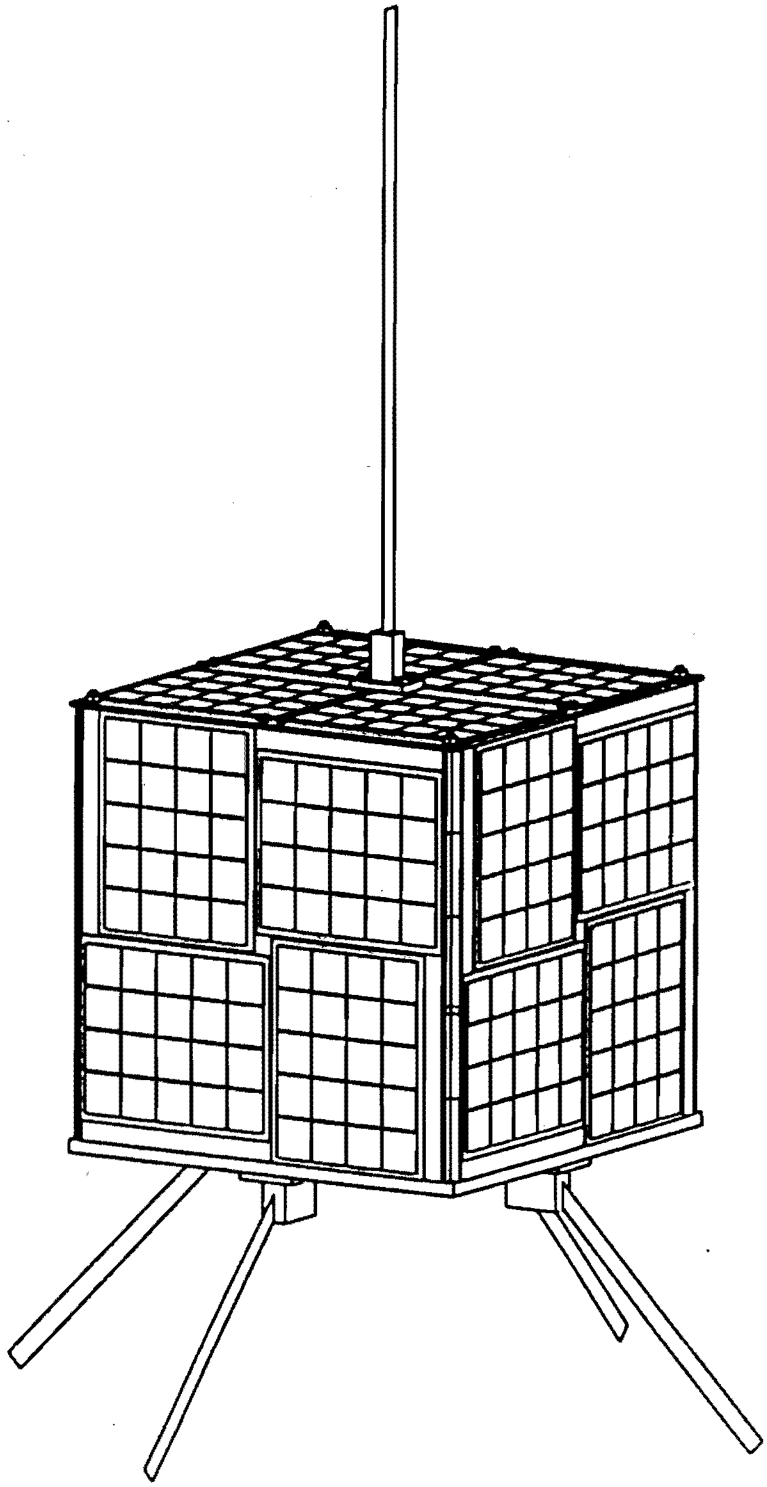

Figure 2. Microsat Structure.
(courtesy of Dick Jansson, WD4FAB)