PICSAT: a Satellite Demonstrator

By Andy Russell, G0VRM * and Luke Church †

TO MOST people, setting up an amateur radio station to operate routinely through packet satellites sounds at best challenging and, in the worst case, expensive. However, a project being run successfully at a secondary school in Hull is doing just that and going one stage further by designing and building their own working 'satellite'.

The 'satellite' is a working model being used to introduce the PIC microcontroller into the 'Electronics Products' GCSE course at St Mary's College, Hull. It is based conceptually on the systems of the APRS satellite, PCsat, and makes use of two PIC microcontrollers and analogue components already covered in the curriculum. Its purpose is to transmit data on the performance of its solar cells and batteries in a format compatible with the APRS packet radio network, thus allowing the experiment to be monitored by the students from home via the Internet.

An amateur radio satellite ground station will be set up at the school and operated by students during National Science Week, which runs from 8 to 15 March. This will enable the students to track and monitor PCsat in orbit, and try their hand at sending and receiving greetings messages using PCsat and the packet transponder on the International Space Station (ISS). These provide opportunities to introduce amateur radio as a viable medium for science and technology to an audience of future engineers, scientists and potential radio amateurs.

* 126 Boothferry Road, Hessle, E Yorkshire HU13 9AX. E-mail: g0vrm@rsgb.org.uk

† St Mary's College, Cranbrook Avenue, Kingston-upon-Hull HU6 7TN. E-mail: luke_church@hotmail.com

GCSE students at work at St Mary's College, engaged in the task of measuring the voltage developed by PICSAT's solar cells.

THE BEGINNINGS

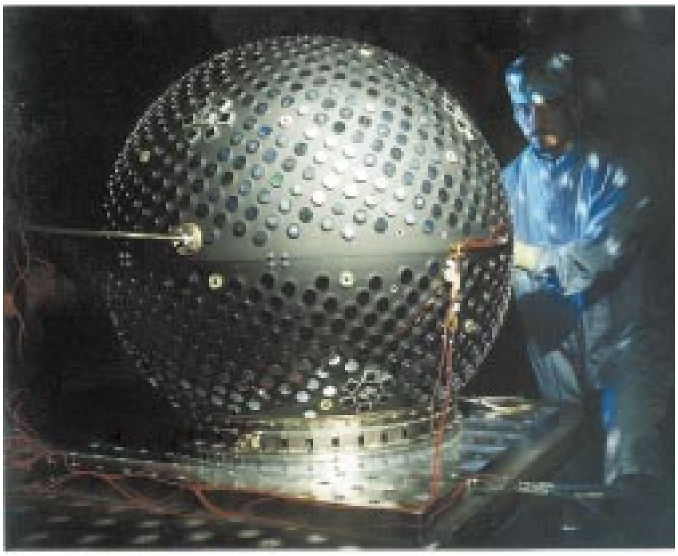
THE PROJECT BEGAN as a discussion between the two authors, (a sixth former at St Mary's College in Hull, and an engineer from BAe Systems, already working with the school as part of 'Ambassadors in Schools' - a scheme designed to promote engineering within schools). The starting point was a question on how information could be obtained on satellite design to assist with a project to construct a Space Mission Simulator, a project linked with the Hungarian Astronautics Society Magyar Asztronautikai Társaság - MANT.

This question did not remain unanswered for very long, as the author had been busy investigating the workings of PCsat in readiness for its launch. It is of relatively simple design, and technical information is publicly available from the Internet. Furthermore, telemetry data can be easily obtained using the simple equipment and its format is again well documented. Access to this live data was considered to be an extremely valuable asset for the development of the Space Mission Simulator.

Following further discussions with the school, it was agreed that a project to design a working satellite model would make an excellent education liaison project, encompassing many disciplines relevant to the curriculum (eg system design, telecommunications, electronics, physics, information technology and project management), and also include technical challenges suitable for the age ranges involved (14-15-year-olds).

The satellite is conceptually based on the design of PCsat and supported by observations from it. It is the first satellite to be launched which is dedicated to serving the Automatic Position Reporting System (see the panel).

Probably the first questions that come to mind are: what exactly is APRS, and, how can something as complex as the internal workings of a satellite be simplified so that it can be explained to and understood by the target audience of electronics students? The sidebar on the fol-



Starshine before its launch, showing some of the 1500 mirrors (polished by students world-wide) designed to reflect the sun's light. Also shown are the clusters of solar cells which power the on-board electronics.

lowing page helps to answer these questions. [Readers are also reminded of the article 'APRS - An Introduction', featured in the December 2000 *RadCom*, p18 - *Ed]*

PCSAT

PCSAT, OR the ***Personal Communications*** satellite, was designed and built by Midshipmen at the US Naval Academy, Annapolis, Maryland under the supervision of retired US Navy Commander Bob Bruninga, the inventor of APRS, with the primary mission of extending this network to the far corners of the globe.

This is fulfilled by providing a digipeater that can be operated by remote handheld and mobile radio users. Its secondary use is to downlink packets directly onto the US APRS frequency – this is restricted to authorised 'special events' such as the recent US Navy/Army football run, where the position of the ball was relayed via satellite.

Despite world events, it was successfully launched at 0240UTC on 30 September 2001 from Kodiak in Alaska, after several abortive attempts due to technical difficulties (not least the weather!). It was successfully deployed into a low-earth orbit at an altitude of 500 miles with an inclination of 67.1°, providing a footprint of approximately 5,000 square miles. On the same launch was Starshine, a NASA-sponsored project to provide a visible satellite that could be tracked by students – the mirrors being polished by schools across the US (see the photo).

PCsat differs from previous amateur satellite experiments in that it was designed to operate with a worldwide network of stations linked via the terrestrial APRS network. During the early days of its life, a 'Launch Information Network' of volunteer ground stations was set up to assist the Naval Academy ground station by relaying signal reports and captured telemetry data.

Other notable features of PCsat are: An on-board GPS receiver that will be used to enable ground stations to determine its availability without having to resort to satellite tracking software, although it may not be routinely enabled due to the significant amount of the available power it consumes. It also has an LED array used to dissipate excess electrical power – these high-brightness red LEDs may be switched on during a night-time pass to make PCsat visible from earth with a pair of binoculars.

USING PCSAT

PCSAT IS PROBABLY one of the easiest of the amateur radio satellites through which to operate; anyone who has worked the packet transponder on the Space Shuttle, MIR or the International Space Station (ISS) has already made the first step and has the necessary experience and equipment.

PCsat can work exclusively on the 2m satellite allocation, where the effects of the satellite's Doppler shift and the ionosphere (such as Faraday rotation), are less pronounced than on higher frequencies. It is based on standard packet radio hardware and was designed with the mobile or handheld user in mind; hence it can be used without having to resort to the large antenna arrays and azimuth-elevation rotators normally associated with satellite operation.

It operates by simply retransmitting any packet that it successfully decodes containing, within the path, either its own call sign (**`W3ADO-1`** on 2m) or the generic alias **`APRSAT`**. It substitutes the call sign **`W3ADO-1*`**, indicating that the packet has been digipeated. Although it has an on-board mailbox and stores emergency status bulletins, it does not normally operate in 'store-and-forward' mode.

However there are far more features available than just this simple 2m digipeater. The original design catered for the requirements of two user networks: a network of low-power handheld transceivers operating on 148.825MHz at 1200 baud; a network of mobile transceivers and base stations with higher powers and antenna gains in their favour, using uplinks of 435.250MHz and downlinks of 145.825MHz at 9600 baud.

Table 1 shows some of the possible routes through the system, selected by using the appropriate path. For example, **XBAUD** allows a cross-baud contact to be made between the 9600 baud and 1200 baud networks – useful if the 2m uplink channel is busy.

Transmitter	Power	Uplink	Path	Downlink	Receiver
Handheld (TH-D7)	5W	145.825MHz 1200 baud	APRSAT `W3ADO-1*`	145.825MHz 1200 baud	Handheld (TH-D7)
			XBAUD `W3ADO-2*`	145.825MHz 9600 baud	Mobile (TM-D700)
Mobile (TM-D700)	50W	435.250MHz 9600 baud	APRSAT `W3ADO-2*`	148.825MHz 9600 baud	Mobile (TM-D700)
			XBAUD `PCSAT-2*`	145.825MHz 1200 baud	Handheld (TH-D7)
Base Station	50W	435.250MHz 9600 baud	XBAUD `W3ADO-1*`	145.825MHz 1200 baud	Handheld (TH-D7)
			APRSAT `W3ADO-2*`	145.825MHz 9600 baud	Mobile (TM-D700)
Legacy Packet	50W	145.825MHz 1200 baud	APRSAT `W3ADO-1*`	145.825MHz 1200 baud	Legacy Packet

Table 1: Available routes through PCsat's digipeater, selected by using the appropriate path.

To avoid conflict due to over-use, it is essential that the current operating procedures are followed, these are posted on the PCsat website and are frequently updated - A rule of thumb for base stations is to aim to get your APRS position/status report relayed through the satellite *once only* during its pass - leaving time for others.

PCSAT HARDWARE

THE PRIMARY and secondary missions of PCsat are performed by duplicate systems, as shown in **Fig 1**, made up of two Kantronics KPC-9612+ packet controllers operating independently. Full use is made of the available radio ports of the KPC-9612+, one being configured to operate at 1200 baud (normal AFSK) and the other at 9600 baud (G3RUH-compatible frequency shift keying).

System 'A' is dedicated to the primary mission of extending the APRS network operating on the ITU satellite allocation of 145.825MHz, whereas System 'B' is used

WHAT IS APRS?

THE AUTOMATIC Position Reporting System (APRS) is a system designed to relay messages such as position reports, status information, one-line text messages, weather information and a whole series of other items in real-time using packet radio as the transmission medium.

Packet radio operates digitally by breaking down the messages to be sent into segments called 'packets', each encapsulating the original message, together with additional information such as the addresses of the sender and receiver, routing information, data flow and error-correction information. The resulting data stream is converted into a pair of audio tones, representing the binary '0's and '1's, which are then frequency-modulated onto a carrier (the process being known as Audio Frequency Shift Keying – AFSK).

APRS messages are simply 'broadcast' onto a network, subsequently to be received, decoded and checked for errors by the recipient. This method does not use the usual back-and-forth coordination to ensure complete transmission of the message, it is simply repeated several times.

To extend the range of transmission beyond normal line-of-sight reception, ***digi***tal re***peaters*** (digipeaters or 'digis' for short) are set up to relay any packet they hear, containing a generic routing address. This network has grown over recent years, so that it now almost extends nationwide. In those areas served by an Internet Gateway (IGate), the coverage is extended continent-wide.

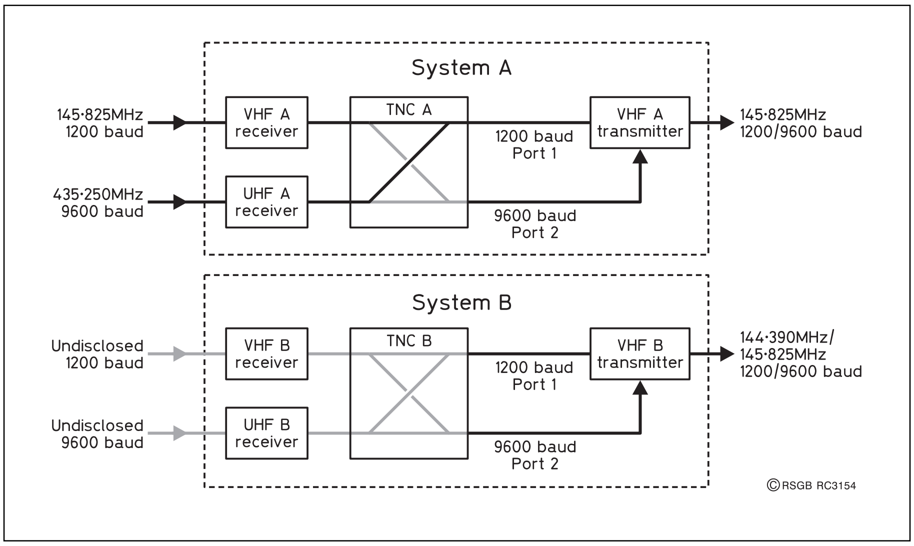


Fig 1: PCsat's duplicate radio systems based on the Kantronics KPC-9612+ packet controller, satisfying the requirements of both world-wide digipeater coverage and linking into the US APRS network.

to downlink reports from 'Special Events' onto the US APRS frequency of 144.390MHz, little used outside of the US and Australia.

Under low-power conditions, the systems are automatically switched to into 'Safe Mode', sharing the batteries, cross-connecting the downlink transmitters and switching to 145.825MHz. This configuration ensures that the satellite can be recovered from a failure of one of the transmitters by reconfiguring it to operate in a limited capacity. Similarly, all four of the receivers are active, allowing an uplink to be made in the event of one of the receivers failing.

REMOTE CONTROL AND TELEMETRY

ALL THE FUNCTIONS of interfacing to the mission electronics and the acquisition and transmission of the system data are performed entirely by existing features of the Kantronics KPC-9612+ packet controller, which supports remote control and telemetry.

Commands sent to the packet controller from the ground station are used to switch digital outputs on and off remotely. These output lines control the various systems of the satellite and also report back their current status. The telemetry circuits are responsible for remotely measuring the conditions of the on-board systems using transducers built into the satellite power systems allowing these currents, voltages and temperatures to be measured. However as the Kantronics KPC-9612+ has only four available analogue inputs, these must be multiplexed (switched) and transmitted in sequence.

Telemetry packets (**Fig 2**) are normally transmitted automatically at one-minute intervals so, over a four-minute period, an assessment of the status of all the systems can be made. However, to gain a further insight into the detailed operation, it is perhaps a good idea to read the relevant portions of the manual, downloadable from the Kantronics website as an Adobe Acrobat pdf file.

Software to convert the raw transmitted data into meaningful units that can be displayed and logged has been written by Roger Barker and is available either as a stand-alone application or as a plug-in for *UI-View 32*.

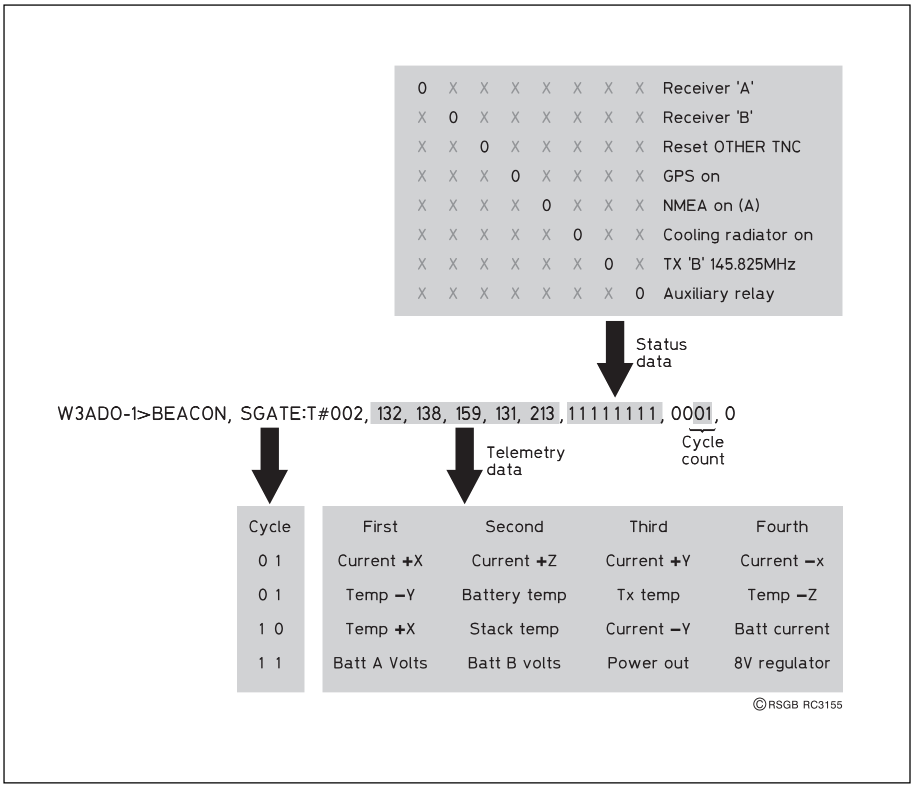


Fig 2: De-scrambling a typical PCsat telemetry packet shows the measured data from its onboard systems, the status and sequence number

STARSHINE 3

THE STARSHINE SATELLITES are part of an all-volunteer project, with headquarters in Monument, Colorado, to measure the effects of atmospheric drag, a phenomenon causing the orbits of all low earth orbit satellites to decay and eventually burn up in the earth's atmosphere. The satellites are designed to be tracked by students worldwide and consist of a hollow aluminium sphere covered in small reflective mirrors designed to catch the sun, the 1500 or so required for each satellite being polished by schools around the world (see the photo).

Starshine 3 was launched aboard the same Kodiak Star mission as PCsat. The launch vehicle deployed PCsat (and two other payloads) at an altitude of 500 miles and then finally descended to approximately 300 miles to deploy Starshine 3.

The solar cells visible on the surface of Starshine 3 are used to power a telemetry system, transmitting packets on the performance of the integrated solar cells and lithium batteries at one-minute intervals at 9600 baud on 145.825MHz, the same frequency as the PCsat downlink.

To allow the participants to predict when Starshine 3 sightings are likely to occur, on-line predictions (complete with star charts), customised for any location, are available from Heavens-Above, a website specialising in visible sightings of satellites. Little else was known by the authors about the internal workings of the Starshine telemetry circuits at the time of launch, this has since been published on the web and is surprisingly based on the PIC 16F876 microcontroller - the detailed operation being beyond the

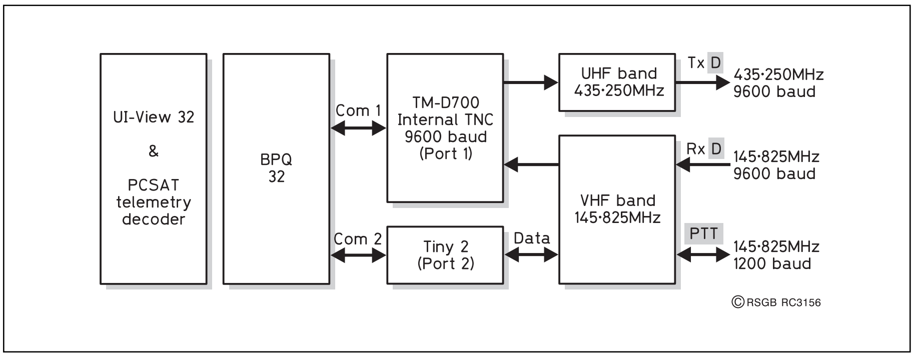


Fig 3: The authors' configuration, allowing simultaneous monitoring and operation at both 1200 and 9600 baud, using one Kenwood TM-D700E dual-band transceiver.

understanding of the student audience.

GROUND STATION

THE AUTHOR'S ground station was hastily set up to monitor PCsat's 1200-baud

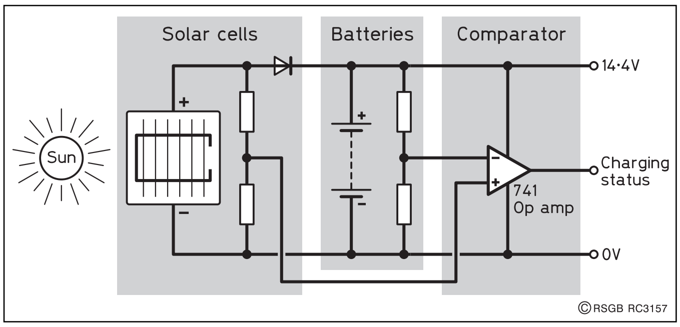


Fig 4: Simplified telemetry circuit designed and built by the students to determine if the solar cells are supplying charging current to the NiCd batteries aboard 'PICSAT}.

telemetry during the weeks before the scheduled launch, making use of a Kenwood TM-D700E dual-band transceiver which could be operated either with the shack computer (using *UI-View 32*) or simply left to monitor the activity using its internal APRS terminal.

As the interest broadened to include the students, it was felt that the ability to monitor both the 1200- and 9600-baud VHF downlinks from PCsat simultaneously would be useful to the project (also enabling Starshine 3 to be monitored). After several days of experimenting with Kenwood's Memory Control Program (MCP-D700), a configuration was eventually found where its internal TNC could be persuaded to operate in a mode where 9600-baud data are received on the VHF band and transmitted on the UHF band - the auxiliary data input socket on the transceiver body being active only on the selected band. **Fig 3** illustrates the system.

With the Kenwood TM-D700E configured to operate at 9600 baud, all that was required was to connect a 1200-baud Tiny 2 into the auxiliary socket. The final configuration was done on the shack computer, setting up *BPQ-32* to enable *UI-View 32* to communicate with both the TNCs operating on their own COM ports.

'PICSAT'

GOING BACK to our theme of education, the students were given a presentation outlining the Kodiak Star mission and its payloads, PCsat and Starshine. They were asked to consider what rigours the payloads would have to endure from launch to deployment and in what environment these would eventually operate. They were presented with the challenge of designing their own working satellite model over the coming months, based on the material covered in their GCSE Electronics coursework.

The group, many of whom had not encountered the PIC microcontroller before, were surprised to find out that such a small component as an 18-pin chip could be programmed in the classroom to handle the complex functions they were talking about and were surprised when shown the TAPR PIC Encoder (PIC-E) circuit, assembled and programmed (in 'C') by the authors, transmitting APRS position reports from a GPS onto a laptop.

Their first step, which defines the direction of their project, was to establish the mission that their model will perform. The following represent some of the less zany (and therefore more achievable) suggestions:

- Measuring and reporting the environmental conditions.
- Measuring and reporting the satellite's position with GPS equipment.
- Sending a greetings message in Morse code using LEDs (surprised us!).
- Taking pictures using a digital camera (although no thought was given to the complexities of transmitting the images).

All their suggestions can be suitably simplified, and easily achieved in the classroom environment using the PIC. An example is a circuit, used to provide an indication to the system that the batteries are being charged by the solar cells, shown in **Fig 4**.

In operation; when the solar cell voltage is greater than the battery voltage, the current generated is used to charge the batteries – the diode in the circuit both prevents the batteries from discharging back through the solar panel and provides a measurable voltage drop. The voltages are scaled down using potential dividers and then compared by the operational amplifier, providing an input for the PIC. Similar comparator circuits using a Zener diode may be used to indicate if the batteries are fully charged or near full discharge – the appropriate action is programmed by the students, such as shutting down the system.

'PICSAT' will use two PIC 16F84 microcontrollers, the first being used both to control the satellite and to continuously monitor the status of the solar cells, and onboard battery voltages, temperatures etc, outputting data in the form of serial data. This part will be designed, built and programmed by the students. The PIC encoder and a low-power 433MHz module will handle the complexities of encoding and transmitting the serial data into APRS-compatible packets which are then filtered and gated onto the APRS network.

Thanks to the APRS network, the students are able to display telemetry data from PCsat, Starshine and 'PICSAT' at home on their computers - without needing any radio equipment! This is done by using *Alogger*, a read-only Internet APRS client designed to log selected packets to disc, and written by Bill Diaz, KC9XG. This can be downloaded from the Starshine website.

To conclude the project, a simplified version of the Space Mission Simulator will be set up in the classroom, using incandescent lamps and a time switch to simulate the cycling from daylight to darkness - the eventual aim of their completed satellite being to endure the rigours of the MANT Space Mission Simulator. ♦

WWW.

PCSAT	**http://web.ew.usna.edu/~bruninga/pcsat.html**
User contract	**http://web.ew.usna.edu/~bruninga/pcsat/contract.txt**
KPC-9612+ User Guide	**www.kantronics.com**
UI-View	**www.packetradio.org.uk**
Starshine	**www.azinet.com/starshine/**
Heavens Above	**www.heavens-above.com/**
Tucson Amateur Packet Radio	**www.tapr.org/tapr/html/Fpice.html**