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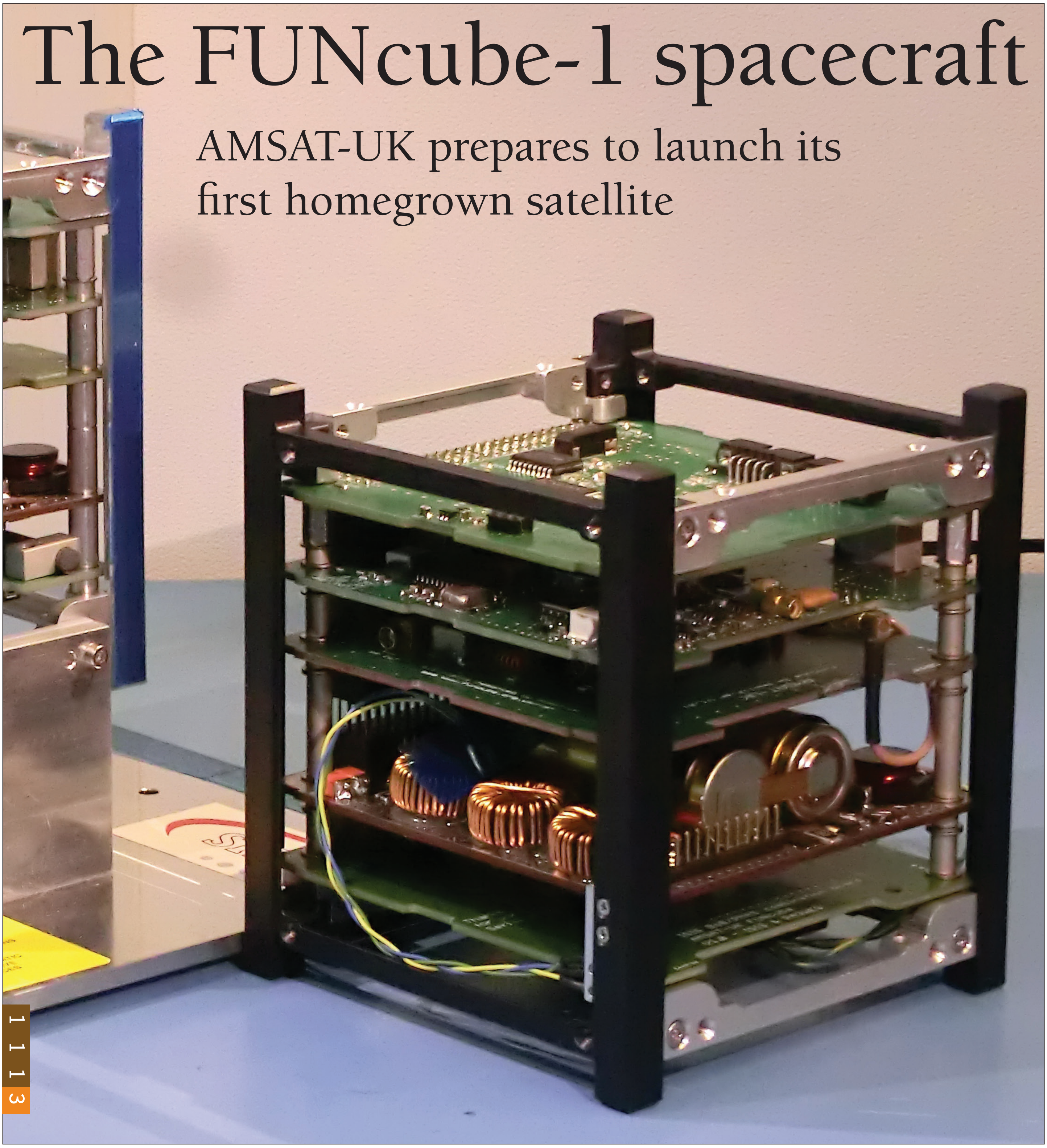
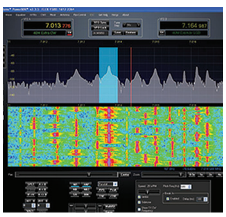
The FUNcube-1 spacecraft

AMSAT-UK prepares to launch its first homegrown satellite





Software Defined Radio

Learn the characteristic signatures of signals in the waterfall display

British medals in Poland

UK successes at the 19th IARU Region 1 ARDF Championships

Peter Hart Review

G3SJX gets his hands on the long-awaited Hilbering PT8000A HF-2m transceiver

Graham Shirville, G3VZV ◆ e-mail: g.shirville@btinternet.com

FUNcube-1

A new spacecraft from AMSAT

BACKGROUND. The first earth orbiting satellite was Sputnik, launched by the USSR in 1957. The first earth Orbiting Satellite Carrying Amateur Radio (OSCAR) was launched just four years later, in 1961. Since that time, more than 70 OSCAR spacecraft have achieved orbit, in addition to more than 30 Radio Sport (RS) satellites from the USSR/Russia [1]. Some ten years ago, a specification was developed for a new, very small, cost effective spacecraft. These are called CubeSats, have a mass of less than 1.3kg and overall dimensions of approximately 100 x 100 x 100mm (called 1U). The idea was to provide a standard to enable university development teams to be able to actually fly their spacecraft at a 'reasonable' cost.

A number of commercial companies around the world have now set up to supply some of the standard parts, subsystems and platforms needed for these missions [2].

These CubeSats can also be produced in double or triple formats; but even the 1U size is capable of providing a reasonable science return within the constraints of mass and volume described – and with less than 1.5 watts of DC power averaged over a typical sun synchronous orbit.

THE FUNCUBE-1 SPACECRAFT. AMSAT-UK has contributed to many of the OSCAR projects in past years, both technically and financially, but have not, up until now, been in a position to create a complete spacecraft themselves. With the advent of CubeSats, coupled with a significant bequest received via the Radio Communications Foundation, this has now become possible and FUNcube-1 is the result.

This 1U satellite has a 70cm to 2m (UHF/VHF) linear transponder and also has a telemetry data transmitter for educational outreach to schools and colleges. It has been designed to create an educational facility, which is intended to enthuse, excite and educate young people about radio, space, physics and electronics. It will also support other educational Science, Technology, Engineering, Maths (STEM) initiatives.

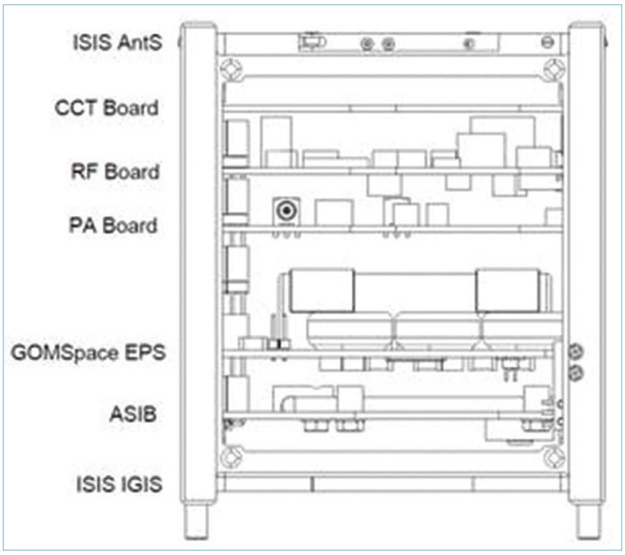


FIGURE 1: The satellite is made up of seven boards stacked into a standard ISIS 1U CubeSat structure.

The target audience has been planned to be students at both primary and secondary levels and the project has included the development of a simple and cheap 'ground station' operating on VHF frequencies in the Amateur Satellite Service. This is the already famous FUNcube Dongle SDR receiver [3].

The satellite is intended to operate autonomously in 'educational' mode when it is in sunlight and in 'amateur' mode when it is in eclipse. Educational mode provides a 300mW 1200bps BPSK downlink with some 54 channels of telemetry from the housekeeping system, a Material Science Experiment and nine 'Fitter' messages. Each of these can be up to 200 characters and new messages can be uploaded after launch.

The telemetry will provide information about

- On board temperatures – both internal and external, to show the effects of solar radiation.
- Voltages and currents flowing from the solar arrays and to/from the battery.
- Specific temperatures from external metal strips that have different finishes to provide an enhanced demonstration of the 'Leslie's Cube' experiment. (One of the traditional demonstrations of how objects emit heat).
- Whole Orbit Data for orbit illumination/eclipse demonstrations.
- High Resolution data for attitude and spin rate determination.
- More advanced demonstrations relating to antenna radiation patterns and levels of solar radiation. Long term effects of radiation on microcircuits and other subjects would also be possible.
- Integration into the maths and physics curricula at primary and secondary levels.
- Demonstrations of radio communications and the 'Doppler effect' at schools.

When the satellite is in eclipse, ie during local night, when it is assumed that schools will no longer be open, the satellite will switch to provide a 20kHz wide linear UHF/VHF transponder for radio amateurs to use. As the power consumption in this mode is somewhat lower than when in educational mode, this will help the power budget and reduce the depth of discharge of the battery.

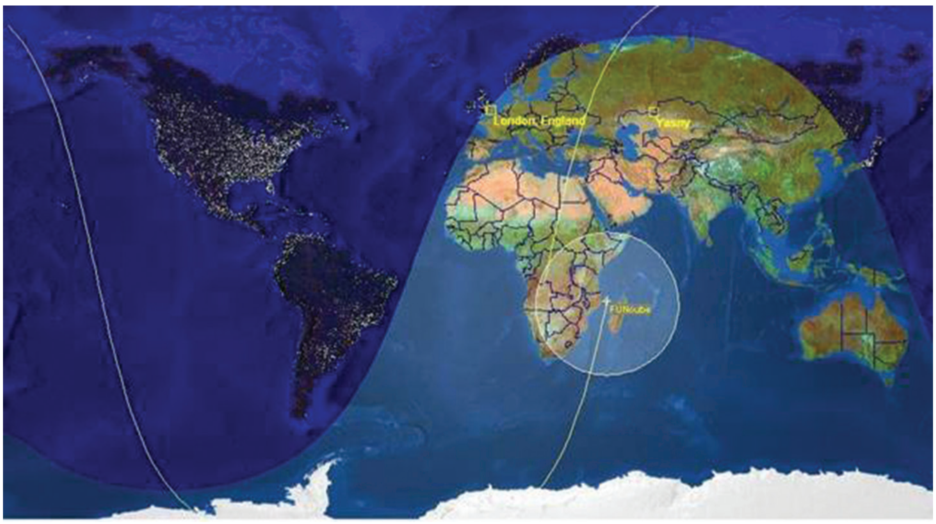


FIGURE 2: The first signals will be heard in southern Africa, then the first orbit passes over Antarctica and the Pacific.

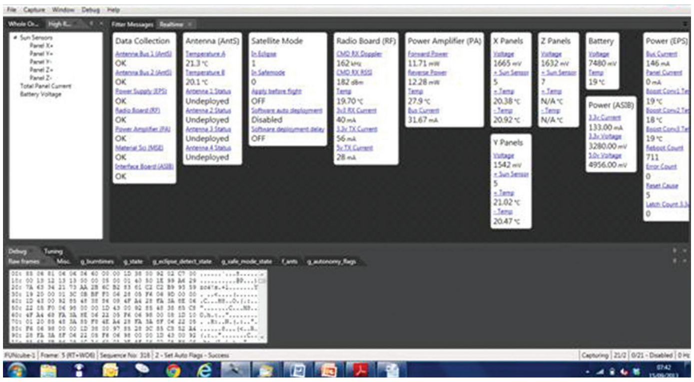


FIGURE 3: The Dashboard display.

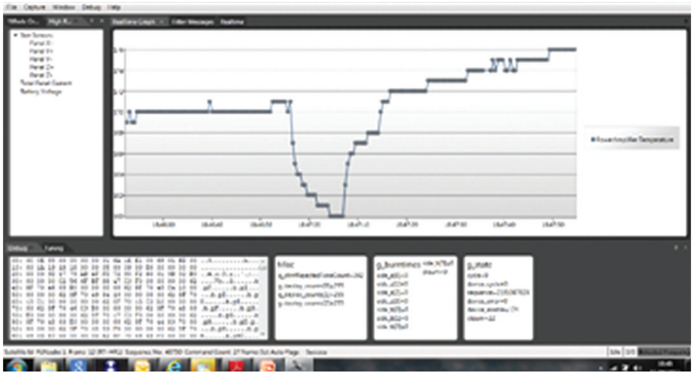


FIGURE 5: A Dashboard display showing a temperature graph

The satellite is expected to be in eclipse for approximately 35 minutes in an orbit of approximately 95 minutes in total. The type of orbit being planned is near a polar near sun synchronous type and, at any location on the Earth's surface, the spacecraft will provide three orbital passes during the local daytime and three orbital passes during the local night in every 24 hour period.

THE PROJECT. The project started back in 2009 with a team of experienced volunteers from AMSAT-UK working in collaboration with AMSAT-NL in the Netherlands. It was agreed that AMSAT would develop and build the specialist sub-systems required and would purchase a number of standard parts to enable a complete spacecraft to be produced as quickly as possible and with the least risk. A contract for the supply of these parts together with the provision of system integration and testing services was signed with ISIS-Innovative Solutions in Space BV who are based in Delft in the Netherlands.

During the project, the team, which comprises less than ten members, has met at 'face to face' technical meetings over weekends on numerous occasions and has held Skype conference calls every Sunday evening for three years. It has also exchanged many thousands of e-mails! In addition, individual team members have made many trips (without cost to AMSAT) to ISIS BV in Delft to make use of their test facilities and we are indebted to ISIS for their support and forbearance. We must additionally thank RAL Space at Harwell who kindly provided thermal vacuum and vibration test facilities to verify the performance of the FUNcube-1 Engineering Model.

FIGURE 4: The FUNcube Dongle.

THE SATELLITE IN DETAIL. The satellite is made up of seven boards stacked into a standard ISIS 1U CubeSat structure.

Figure 1 shows a cutaway drawing of the final stack. Externally each face has a solar panel to ensure the maximum possible power is available for the spacecraft. The main physical interface between the boards is the CubeSatKitBus connector and commands and data are transferred using an I^2C data bus. The boards have a PC/104 form factor.

The AntS subsystem: This is the 'top' board and contains the antennas, their deployment mechanism and matching harness. It is a commercial product from ISIS. There is a dipole for 435MHz reception and another one for 145MHz transmission. The board contains redundant systems for releasing the antennas autonomously soon after separation from the launch vehicle or, if necessary, by ground command.

Command, Control & Telemetry (CCT) Board: This is a bespoke board provided by AMSAT-UK and is an intentionally uncomplicated on-board controller using a low power Freescale microcontroller and a Xilinx programmable logic device (CPLD). This board decodes telecommands received from the ground and collects, stores and formats all the telemetry for transmission on the 145MHz downlink. It also applies the forward error correction coding that improves the robustness of the downlink signals. Additionally it provides an interface with the AntS board and the four thermistors used for the Material Science Experiment (MSE). The DC power consumption of the CCT board averages just 13mW.

RF Board: This bespoke board, provided by AMSAT-NL, contains the 435MHz receiver that is used for both commanding and the transponder uplink. The transponder section down converts the 20kHz passband to an IF of around 10.7MHz and this is then up converted to the final downlink frequency at 145MHz. The board includes a conventional AGC system that has over 40dB of gain control and a decay time of around two seconds. Additionally the board also provides six channels of telemetry.

PA Board: This board, from AMSAT-UK, provides the final 145MHz amplification using a Mitsubishi MOSFET. The design includes extensive harmonic filtering that prevents the third harmonic from the transmitter causing desense to the 435MHz receiver. This board also provides four channels of telemetry.

EPS Board. This is the on board power supply sub system (Electronic Power System) and is a commercial product from GOMspace in Denmark. It includes a lithium ion battery of two cells having a 2600mAh capacity, MPPT (Maximum Power Point Tracking) control of the six solar panels, battery charging and switched regulated outputs at 3.3V and 5V. It also provides abundant telemetry via an I^2C data bus and includes various I^2C and timer watchdogs to enable the power bus to be rebooted if needed. Thermal control within a 1U CubeSat is always challenging and the most important issue is to try to ensure that the battery never operates below 0°C. The only on board equipment that dissipates any significant heat is the PA, so it is for this reason that these two boards have been placed next to each other.

The ASIB Board: This AMSAT Special Interface Board incorporates the components of a standard ISIS passive magnetic attitude control sub-system – a magnet and two hysteresis rods – and it provides a power distribution interface and current/voltage monitoring sensors. Additionally, it includes ADCs to interface sun sensor and solar panel temperature sensors to the I^2C bus and acts as a break-out board from the CubeSatKitBus to the IGIS below.

IGIS Board: This is the bottom board and is a standard product from ISIS. It provides a connector for battery charging before flight and enables the vital ABF (Apply Before Flight) plug to be inserted at the launch site. Without this plug being present the satellite will not function!

Solar Panels: Each of the 6 solar panels incorporates two 28% efficient triple junction solar cells that have special cover glass for enhanced radiation resistance. These are standard CubeSat Solar panels, again from ISIS. One of the panels has been modified to accept the inclusion of two projecting metal strips. These 70 x 4 x 3mm aluminium strips are mounted externally and incorporate a thermistor to measure temperature. One strip

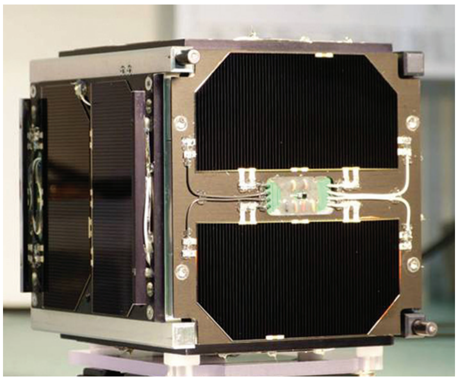


FIGURE 6: FUNcube-1 flight model in the lab.

is matt black whilst the other has a highly polished, reflective surface. As the satellite enters eclipse, heat energy will be lost by radiation at different rates. Temperature data, taken once a minute for the previous 104 minutes, can be displayed graphically to show the difference characteristics of the metal samples.

CubeSat Structure: The whole satellite is built around a 1U structure from ISIS. Again a modification has been made in that two sides are silver anodised and two sides are the usual black anodised. Thermistors have been fitted and they will also provide data for thermal demonstrations.

LAUNCH AND EARLY OPERATIONS (LEOPS). After many delays that have been outside the control of AMSAT, we finally managed to identify a launch opportunity early this year and AMSAT-NL signed a contract with ISL BV to broker the launch and provide the required coordination services. This has also been funded by voluntary donations received from many individuals and from a number of AMSAT groups from around the world.

At the time of writing (late September) it is expected that FUNcube-1 will be placed into orbit with more than twenty other objects on DNEPR launch vehicle from Yasny in Russia on 21 November. The satellite will be released from the POD on the launch adapter approximately 16 minutes after liftoff and deploy its antennas and activate the transmitter 10 minutes later. The satellite will initially be in Safe Mode and will transmit its 1200bps BPSK telemetry signal at approx 30mW. This is intended to be a very low power mode but should be easily heard and decodable by any station having a steerable Yagi with more than 9/10dBi gain. A circularly polarised array will provide the most reliable signals but linear antennas will also perform adequately.

It is anticipated that the first signals will be heard by stations in southern Africa; after that, the first orbit passes over Antarctica and the Pacific. It is likely that the next reception reports will not be available until the satellite is approaching Hawaii.

After a full checkout of the onboard systems that will, hopefully, only take a week or two, FUNcube-1 will be placed in its normal operation schedule – educational telemetry downlink when in daylight and amateur transponder operations at night. This schedule may be modified by ground command if required during holidays or for special events and, if the power budget is not satisfactory, it will be possible to command the satellite into 'receive only' mode for occasional eclipse periods to fully recharge the battery.

THE GROUND SEGMENT. It is planned that, when more precise information has been gained after launch, a follow-up article will be published that will give more detailed operational guidance for amateurs who wish to make use of the transponder or who wish to receive the telemetry and perhaps become involved in supporting the educational outreach opportunities. In the meantime, here are some guidelines.

To predict when the satellite will above your horizon, pre-launch Two Line Elements (TLEs) will be provided and these can loaded into any of the many tracking/prediction programs [4].

The telemetry downlink uses 1200bps BPSK. Full details of the downlink format can be found on the FUNcube website [5]. When operating at full power, the satellite signals should be sufficiently strong that they can be received using an omnidirectional antenna such as a turnstile. This is one of the design requirements for the project to enable easy reception by schools.

To receive this telemetry, any SSB receiver that covers 2m, or an SDR receiver with suitable software will be suitable. Either type of FUNcube Dongle will work directly with the *Dashboard* telemetry decoding software described below.

The *Dashboard* software will be available before the launch date from the FUNcube website [5]. In addition to working directly with a FUNcube Dongle, this software will accept audio via a sound card. The *Dashboard* will display the real time telemetry, graphs of the Whole Orbit and High Resolution data, the Fitter messages and debug information. It can be configured to capture the incoming data in real time or from recorded audio or IQ files. When connected to the internet, the

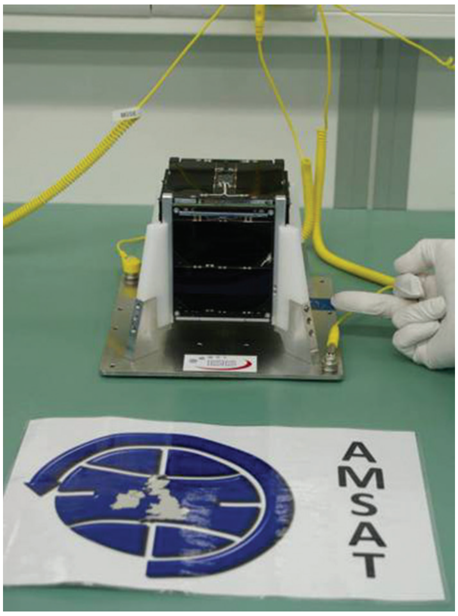


FIGURE 7: FUNcube-1 waiting to placed in its POD.

Dashboard will also upload your telemetry data to our central Data Warehouse server.

Presently the Dashboard software only works in the Windows environment, however the software source files are being made available to encourage other writers to 'roll their own'. Our only request is that you ensure that the software is able to correctly upload the received telemetry to the Data Warehouse.

When the transponder is active and the spacecraft is operating in amateur mode, it will require an uplink 435MHz SSB transmitter with approximately 10 watts of power to a steerable 10dBi Yagi. The transponder inverts the signal to reduce the effects of Doppler shift, so please transmit using LSB on 70cm and receive using USB on 2m. In any event, please do not transmit a signal that results in your downlink being any stronger than the telemetry downlink on 145.935MHz.

For all the latest, up-to-date information about FUNcube-1 you should consult the www.funcube.org.uk website and join the funcube yahoo group [6].

THE FUTURE. As a follow-on to FUNcube-1, the AMSAT team has also been working on FUNcube-2. This is a sub-system on UKube-1, a 3U CubeSat that is sponsored by the UK Space Agency. Our sub-system, which has almost identical functionality to FUNcube-1, has been specially included to provide the main educational outreach for their mission. UKube-1 is now scheduled to launch in early 2014.

FUNcube-1 Frequencies

	Downlink	Uplink
Transponder:	145.950-145.970MHz (USB)	Transponder 435.150- 435.130MHz (LSB)
Telemetry:	145.935MHz	

WEBSEARCH

[1] http://en.wikipedia.org/wiki/OSCAR
[2] www.cubesatshop.com/
[3] www.funcubedongle.com/
[4] http://tinyurl.com/l6vpb5l
[5] http://funcube.org.uk/working-documents/
[6] http://uk.groups.yahoo.com/group/FUNcube/