EPS, Battery And Solar Panels For Cubesats

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DOCUMENT CONTROL

Issue	Date	Section	Description of Change	Reason for Change
A	28/04/08	All	First Draft	

CONTENTS

1 INTRODUCTION

This document outlines the technical, price and schedule proposal for the power system electronics and battery for a CubeSat.

More specifically, this document covers the following:

1. 1U CubeSat Power Board.
2. 3U CubeSat power board.
3. 1U CubeSat battery; 1.25Ah – 2.5Ah. (also daughter board to the 3U battery)
4. 3U CubeSat battery; 1.25Ah - 3.75Ah.
5. SIX 1U flight panels with two EMCORE large area cells
6. SIX 1U flight panels with 24 TASC cells
7. SIX 1.5U flight panels with two EMCORE large area cells
8. SIX 1.5U flight panels with 24 TASC cells
9. SIX 3U flight panels with SIX EMCORE large area cells
10. SIX 3U flight panels with TASC large area cells

2 TECHNICAL PROPOSAL

This section describes the technical specifications of the proposed electrical power system and battery.

3U Electrical Power System

Power from each of the solar array sections are transferred to the bus via battery Charge Regulators (BCRs), operating independently to enable optimum power transfer from panels/array sections with individual differing characteristics. The BCR sets the array voltage at the maximum power point, ensuring the available energy from the array is fully utilised.

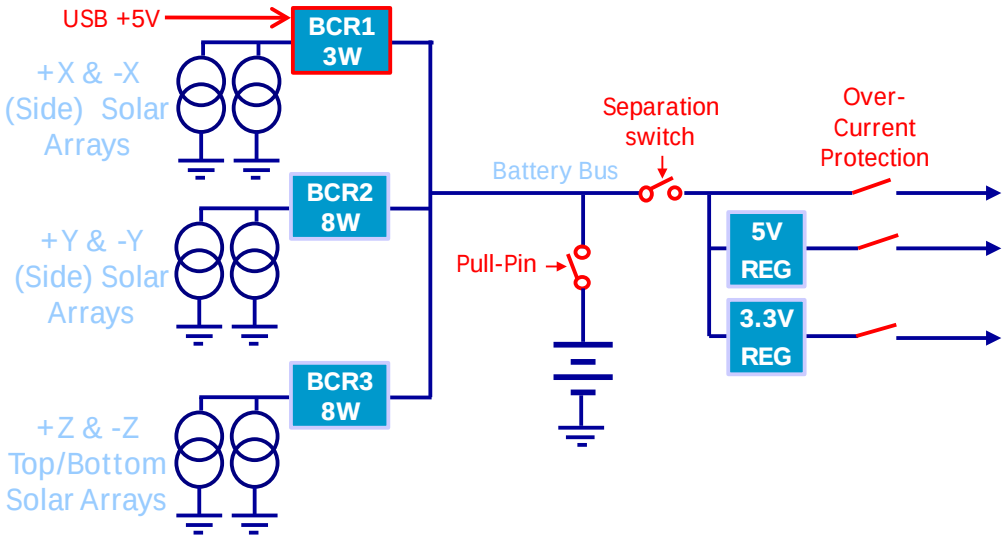


Figure 1 Power System Block Diagram

BCR Power Stage Design

The BCR uses SEPIC regulators as main converter stage. The efficiency of each unit at full load is greater than 90%. Each BCR operates at a frequency of approximately 250kHz. The BCR will remain with its de-rated limits for an input voltage of 20V and an output voltage of 10V. There are 3 BCRs in total; BCR 1 is rated at 3W and BCRs 2 and 3 are rated at 8W.

Autonomy and Redundancy

The BCRs are self-sustaining and do not rely on power from the battery for their operation. This means that the BCRs can supply charge to the battery when the solar arrays are illuminated and irrespective of the state of charge of the battery.

Peak Power Tracking Method

The CubeSat EPS Peak Power Tracker actively monitors the characteristics of the solar array and sets the BCR input voltage to the maximum power point of the array

Charge Method

The BCR uses a taper charge method. The system works on the basis that, when the battery voltage is below the pre-set End of Charge (EoC) or Float

voltage, the BCR operates in PPT mode, acting as a current source to the battery bus. Once the EoC or Float voltage is reached, the BCR regulates its output at this voltage and allows the BCR input voltage to drift from the maximum power point.

5V and 3.3V Regulator

The 5V and 3.3V regulators both use a simple BUCK regulator as the main converter stage. The efficiency of each unit at full load is approximately 90%. Full Load on the 5V regulator is an output current of 1.2A and the 3.3V regulator is 1A. Each regulator operates at a frequency of 150kHz. The regulators will remain with its de-rated limits for an input voltage of 10V and an output voltage of 6V.

Bus Protection

Three main buses are supplied to the rest of the spacecraft for distribution via dedicated over-current protection switches. The switches prevent damage to the power system due to a short circuit after the connector and can never be switched off for more than a few milliseconds at a time.

Telemetry and Telecommand

The Telemetry and Telecommands interface is provided via an I2C digital interface. There is an I2C interface per 3U board.

There is a single telecommand reset the three voltage buses to the rest of the spacecraft.

There are telemetries available for solar array voltage, temperature and current; battery voltage temperature and current; and bus current.

Quiescent Power Consumption

As each BCR is self sustaining, not only is the unit power consumption taken into account in the efficiency figure, the power consumption of the entire system is expected to be below 0.1W.

Mass and Mechanical Configuration

The mass of each 3U power board is 75g and is contained on a single PC/104 card compatible with the CubeSat Kit.

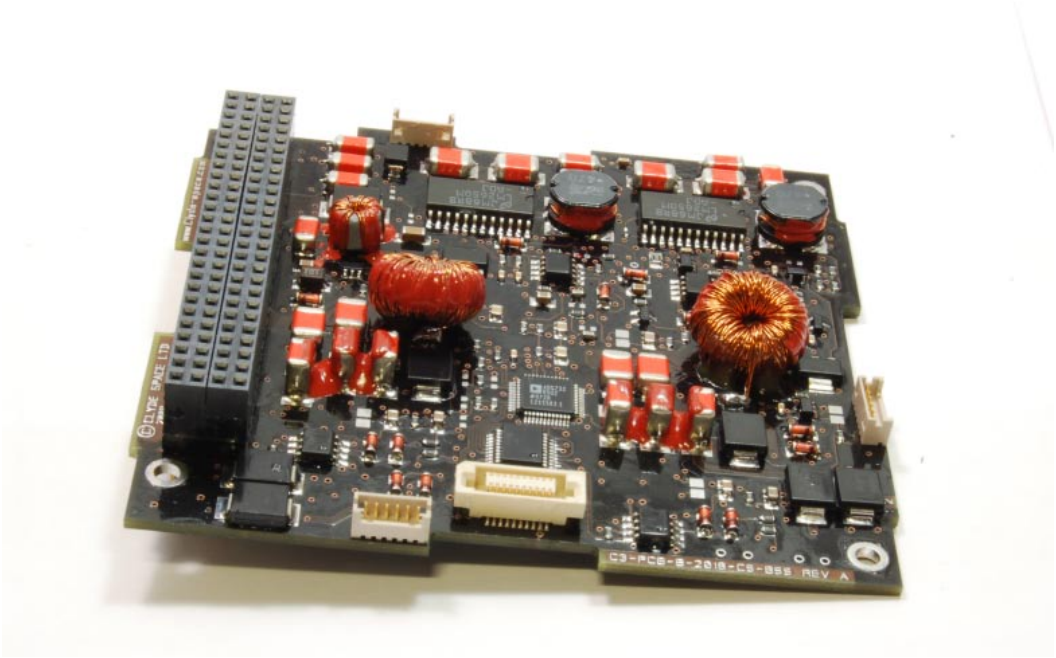


Figure 2 3U CubeSat Power unit

Schedule

The Flight 3U CubeSat EPS boards are made to order and on a 2 month lead-time.

1U Electrical Power System

Power from each of the 6 solar array sections are transferred to the bus via dedicated BCRs, operating independently to enable optimum power transfer from panels/array sections with individual differing characteristics. The BCR sets the array voltage at the maximum power point, ensuring the available energy from the array is fully utilised.

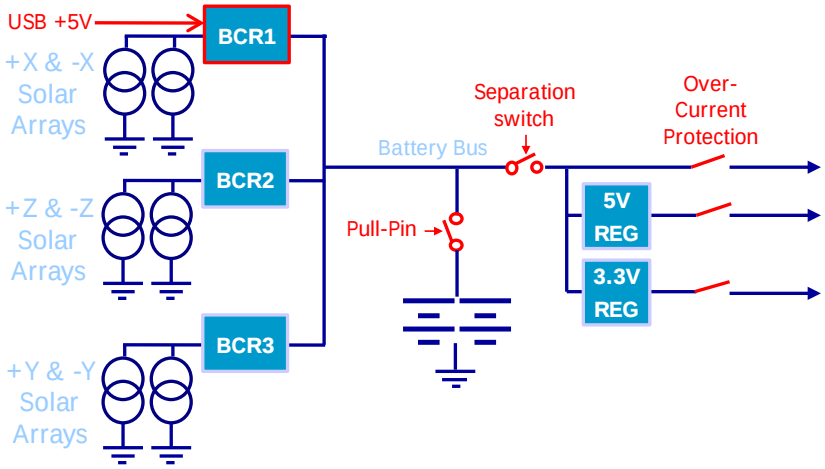


Figure 3 1U Power System Block Diagram

The functionality of the 1U power board is identical to that of the 3U with the exception of having Three 3W BCRs and the ability to integrate the battery as a daughter board.

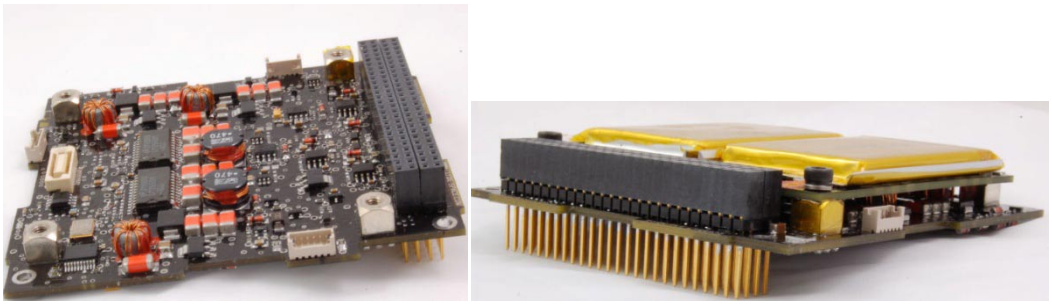


Figure 4 1U CubeSat Power System without (left) and with (right) battery daughter boards

Mass and Mechanical Configuration

The mass of the system 80g and is contained on a single PC/104 card compatible with the CubeSat Kit.

With a single lithium polymer battery in place the height from the top surface of the PCB is 13mm. With two batteries in parallel, the height of the system from the top surface of the EPS PCB is 21mm.

Schedule

The 1U power module is currently available on a 4 week turn around.

Battery System

A commercial Lithium Polymer cell has been selected by Clyde Space for use with our CubeSat EPS in a space application. Prior to selecting this cell it had undergone a number of tests to verify its performance in a space environment. These tests were as follows:

- Capacity at C/10 under vacuum.
- Radiation up to 500krad.
- DPA
- Capacity at -10C, 0C, 20C and 40C
- Resistance
- Self Discharge
- Missions Scenario Tests
- EMF vs SOC
- Cycling Tests at reduced pressure (15-20mbars) - 30% DoD, C/2 Charge/Discharge; capacity check ever 50 cycles; >5000 cycles obtained.

Clyde Space is currently performing further analysis and qualification of our cell under and ESA contract. This contract involves life tests as well as cell characterisation.

1U Battery

The 1U battery board has two series cells are mounted flat, side-by-side on a PCB that can be mounted as a daughter board on the 1U Power board or the 3U Battery board.

Each Battery board has: an integrated, thermostatically controlled battery heater; battery current telemetry; cell balancing and over current protection (N.B. not using a PTC); battery voltage telemetry; cell voltage telemetry. Each daughter battery unit weighs 62g.

3U Battery

The 3U battery board has two series cells are mounted flat, side-by-side on a PC104 sized, CubeSat kit compatible PCB. Two additional, two cell battery daughter boards can then be integrated with this main PCB to increase the capacity. The maximum battery size per 3U battery board is a 2s3p (2 series cells per string and 3 strings in parallel). The capacity of each 2s3p is 3.75Ah at a maximum voltage of 8.2V.

As with the 1U battery, each Battery board has: an integrated, thermostatically controlled battery heater; battery current telemetry; cell balancing and over current protection (N.B. not using a PTC); battery voltage telemetry; cell voltage telemetry. The 3U battery PCB (PC104) weighs approximately 80g.

In addition, the 3U battery has an optional 12V line (BOOST converter from the battery voltage) that can supply up to 300mA and a 50V line that can supply up to 1mA. The battery board also has its own I2C telemetry and telecommand node (telelcommand is to disable the thermostat activation of the heater)..

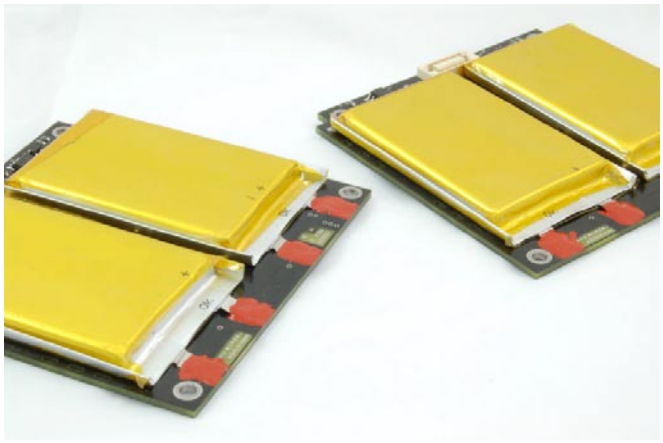


Figure 5 Battery Daughter Boards; 1.25Ah at 8.2V

Workhorse Battery

We strongly recommend that you also purchase a workhorse battery. The workhorse battery should be used during general ground testing of the spacecraft and swapped out for the flight battery for Environmental test and (of course) launch. The reason for this is because Lithium ion batteries suffer from irreversible capacity fade with use; therefore most people use an additional battery to preserve the condition of the flight battery.

Solar Arrays

The solar arrays use multilayer PCB with a space rated polymide (Kapton) covered front face with tracking to the solar cell terminations.

We have specified panels with large area cells and with TASC cells. The large area cells have coverglass and come from the cell manufacturer in CIC format (with solar cell, coverglass and interconnects). The TASC cells do not have coverglass, but we protect the silver metalisation with coverglass adhesive. The TASC cells are only suitable for mission lifetimes up to one year.

Magnetorquer Specifications

The solar panels have integrated magnetorquer coils. The table below details the characteristics of magnetorquers coils as designed by Clyde Space for another mission:

Table 1 Clyde Space Magnetoquer Specifications

	Magnetorquer Properties			
Current Intensity	0.1 A			
Copper wire resistivity	1.68e-8 Ohm·m			
Voltage	5V (split across two identical panels on opposite spacecraft sides)		5V	
per	**Per 3U Side**	**Per 1.5U Side**	**1U Side**	**Top**
Average Effective Area (mm^2)	54x205	92x57	67x57	67x57
Perimeter (mm)	518	348	248	248
Wire cross section (mm^2)	533e-4	391e-04	391e-04	391e-04
Number of turns per layer	28	31	31	31
Number of turns total	290	373	373	373
Maximum PCB thickness (mm)	2.4	2.4	2.4	2.4
Magnetic Dipole Momentum ($A·m^2$)	**0.345**	**0.188**	**0.188**	**0.188**

Flight Panel Performance

The following table summarises the performance of the flight panels.

Panel Type	1U Side/ Top 3U Top	1U Side/ Top 3U Top	1.5U Side	1.5U Side	3U Side	3U Side
Type	ATJ	TASC	ATJ	TASC	ATJ	TASC
Junctions	Triple	Triple	Triple	Triple	Triple	Triple
String Length	2	2	3	2	6	6
No. of Strings	1	13	1	19	1	14
BOL Voc at Min Temp	5.95V	5.88V	9.04V	5.88V	18.09V	17.63V
BOL Vmpp at Min Temp	5.41V	5.35V	8.16V	5.35V	16.33V	16.04V
BOL Vmpp at Max Temp	3.98V	3.92V	5.93V	3.92V	11.87V	11.77V
BOL Vmpp at 28C	4.60V	4.27V	6.90V	4.27V	13.80V	13.62V
BOL Power at Min Temp	2.29W	2.41W	3.52W	3.53W	7.28W	7.80W
BOL Power at Max Temp	1.83W	1.92W	2.70W	2.81W	5.56W	6.22W
BOL Power at 28C	2.04W	2.15W	3.07W	3.14W	6.32W	6.95W

Table 2 Estimated Panel Performance (note, a seventh ATJ cell can be fitted to the 3U side panel if using the full 3U length for the panel).

Solar Array Schedule

Flight Panels: The schedule for delivery of the panels is dictated by the lead-time on the solar cells from EMCORE. Typically, it takes 3 months to get an export license from the USA, but it can be a lot quicker depending on the location of the customer. Once we have the cells, it will take only 2 weeks for us to perform cell laydown and deliver the panels.

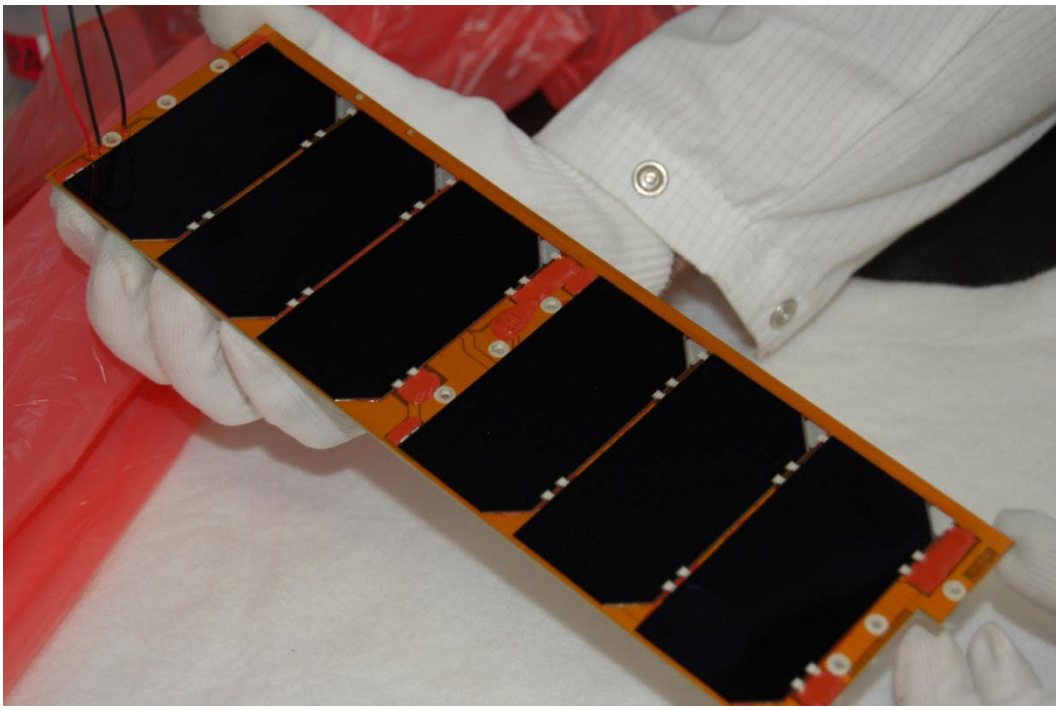


Figure 6 3U Solar panel for a 3U CubeSat. EM Panel for INTA's OPTOS Mission

3 PRICE PROPOSAL

	USD
1. Electrical Power System **ONE** 1U CubeSat power board. ***SUBTOTAL:***	***$2,900***
2. Electrical Power System **ONE** 3U CubeSat power board. ***SUBTOTAL:***	***$5,100***
3. Battery **ONE** 1U CubeSat battery; 1.25Ah, 8.2V. (also daughter board to the 3U battery) ***SUBTOTAL:***	***$910***
4. Battery **ONE** 3U CubeSat battery; 1.25Ah, 8.2V. ***SUBTOTAL:***	***$1450***
5. FM 1U Solar Arrays **SIX** flight panels, each with two EMCORE large area cells ***SUBTOTAL:***	***$20,500***
6. FM 1U Solar Arrays **SIX** flight panels, each with 24 TASC cells ***SUBTOTAL:***	***$14,000***
7. FM 1.5U Solar Arrays **SIX** flight panels (FOUR 3U Side Panels and TWO Top/Bottom Panels), each side panel with SIX EMCORE large area cells and each Top panel with 2 EMCORE cells. ***SUBTOTAL:***	***$24,500***
8. FM 1.5U Solar Arrays **SIX** flight panels (FOUR 3U Side Panels and TWO Top/Bottom Panels), each side panel with 38 TASC cells and each Top panel with 24 TASC cells. ***SUBTOTAL:***	***$18,000***
9. FM 3U Solar Arrays **SIX** flight panels (FOUR 3U Side Panels and TWO Top/Bottom Panels), each side panel with SIX EMCORE large area cells and each Top panel with 2 EMCORE cells. ***SUBTOTAL:***	***$34,500***
10. FM 3U Solar Arrays **SIX** flight panels (FOUR 3U Side Panels and TWO Top/Bottom Panels), each side panel with 84 TASC cells and each Top panel with 24 TASC cells. ***SUBTOTAL:***	***$25,500***

Clyde Space Terms and Conditions of Sale can be found in Section 7 of this document.

4 RELEVANT EXPERIENCE

ATSB Malaysia

Clyde Space has designed and produced the power system electronics and solar arrays for a 3U CubeSat for ATSB in Malaysia. The power system consists of Peak power Trackers, voltage regulators and bus protection circuitry. The solar panels use high efficiency, large area solar cells for the side panels and 2x2cm TJ solar cells on the Bottom and 2x4cm SJ GaAs cells on the Top panel.

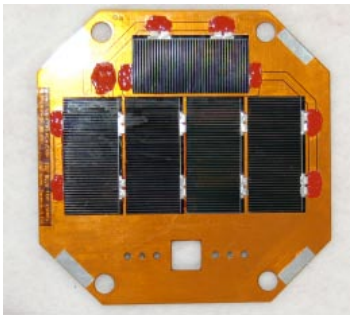


Figure 7 ATSB Top Solar Panel

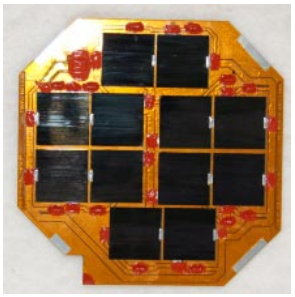


Figure 8 ATSB Bottom Solar Panel

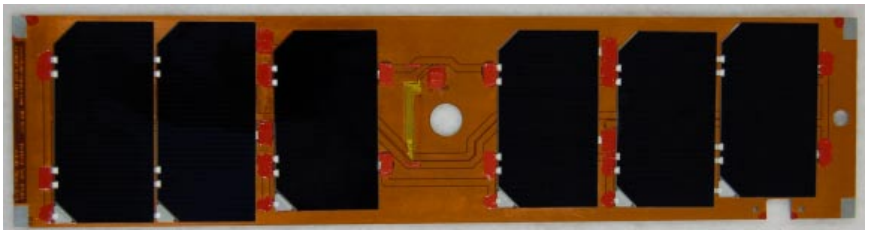
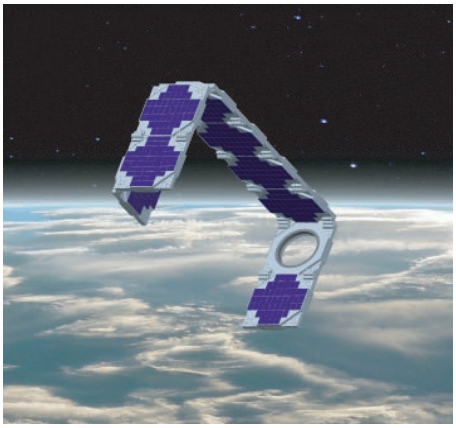
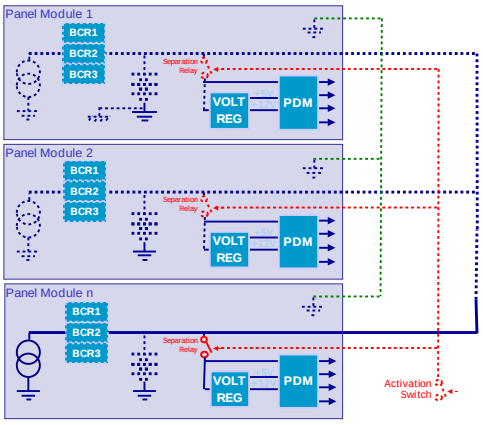


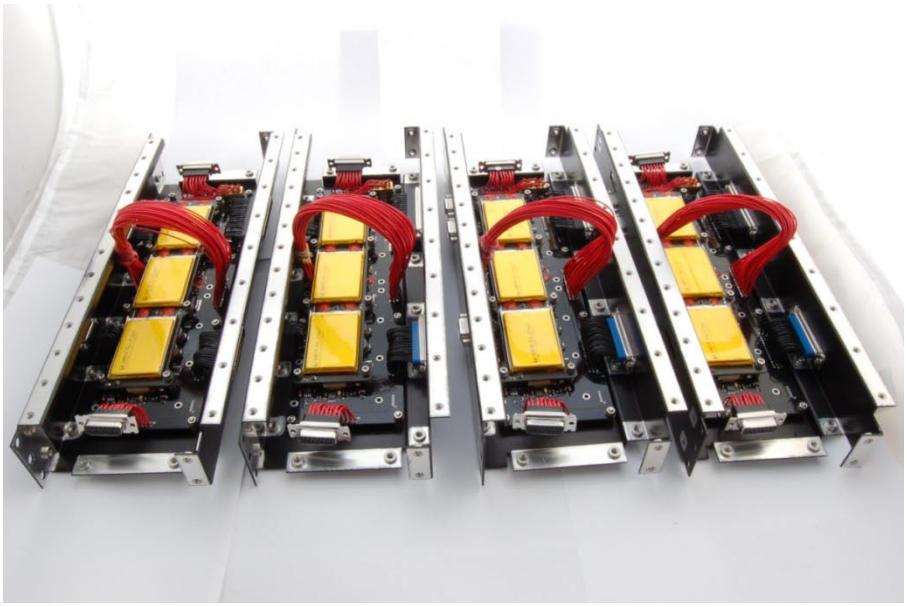
Figure 9 ATSB Side Panel

SOHLA Japan

Clyde Space has developed and is in the process of building the solar panels, battery and power system electronics for SOHLA's highly innovative PETSAT small satellite platform. The power system has been designed to provide an efficient, reliable system that is also highly modular. The figures below show the spacecraft configuration and the power system simple block diagram.





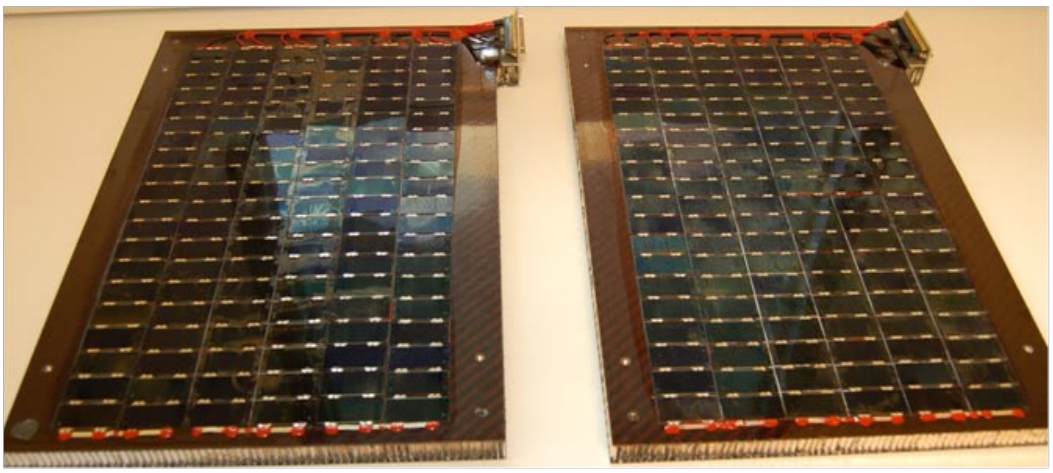


SunSpace

In 2006, Clyde Space recently two 24W solar arrays to SunSpace in South Africa. The solar arrays used bare, single junction GaAs cells from ENE in Belgium. Clyde Space were responsible for the integration of the interconnects on the solar cells, the laydown of the cells on the solar panel and the final wiring of the panel.

Clyde Space has specially produced jigs and vacuum plates to enable us to screen print adhesive to the backs of the cells and then safely lay the cells on the panels. The screen print process ensures that the thickness of the adhesive is even and controlled. The panels are cured in a vacuum bag to ensure good bonding between the cells and the panel.

The pictures below show the final solar panels as produced for SunSpace.



The following are testimonials from Sunspace following delivery of their solar arrays:

'On technical issues where clarity and support was needed, it was handled rapidly, concisely, enthusiastically and generously.

I certainly support the notion of endorsing Clyde Space for services delivered to Sunspace. I would like to commend them for their apt delivery on the stringent terms provided to them on our request.'

5 PAPERS AND PRESENTATIONS

The Clyde Space team has presented several papers on small satellites and small satellite power systems at various international conferences. The papers of most note are as follows:

- 'Commercial Nickel Cadmium Batteries For Space Use: A Proven Alternative for LEO Satellite Power Storage', Craig S. Clark, Martin Day and Alan Hill, Fifth European Space Power Conference, ESA, 21-25 September 1998, Tarragona, Spain.
- 'From Concept to Launch. Faster, Better, Cheaper Spacecraft Engineering', Craig S. Clark, Space Power Workshop, 20 – 22 April 1999, Long Beach, CA.
- 'The Design and In-Orbit Performance of the Power System of Surrey's First Nanosatellite (SNAP-1)', Craig S. Clark, Space Power Workshop, 20 – 22 April 2001, Redondo Beach.
- 'Successful Design Practices for Use of COTS in Spacecraft', Craig S. Clark, 5th European CMSE Conference, 17 – 19 September 2001, Nice, France.
- 'A Universal Power System Architecture: One Topology for Earth and Planetary Orbits', Craig S. Clark, 6th European Space Power Conference, 6 – 11 May 2002, Porto, Portugal.
- 'Power System Design and Performance on the World's Most Advanced In-Orbit Nanosatellite', Craig S. Clark and Kevin W. Hall, 6th European Space Power Conference, 6 – 11 May 2002, Porto, Portugal.
- 'A Versatile Power System: Scalable From 50W LEO To 2kW GEO, Craig S. Clark, Alejandro Lopez-Mazarius and Alan H. Weinberg, 1st International Energy Conversion Engineering Conference, 17 - 21 August 2003, Portsmouth, Virginia.
- 'The Design and Performance of a Power System for the Galileo System Test Bed (GSTB-V2/A)', Craig S. Clark, Alan H. Weinberg and Antonnio Garutti, 7th European Space Power Conference, 9- 13 May 2005, Italy.
- 'Non-Sequential Power Bus for LEO Applications', Peter Alcindor and Craig S. Clark, 7th European Space Power Conference, 9- 13 May 2005, Italy.
- 'Plug n Play, Reliable Power Systems for Nanosatellites', Craig S. Clark and Alejandro Lopez, 20th Annual AIAA/USU Conference on Small Satellites, 14- 17 August 2006, UTAH.
- 'Power System Challenges for Small Satellite Missions', Craig S. Clark, 4S Symposium, Chia Laguna, Sardinia, 25 - 29 September 2006.
- 'Evaluation of Lithium Polymer Technology for Small Satellite Applications', Craig S. Clark and Evelyne Simon, 21st Annual AIAA/USU Conference on Small Satellites, 13- 16 August 2007, UTAH.

6 OTHER CLYDE SPACE PRODUCTS

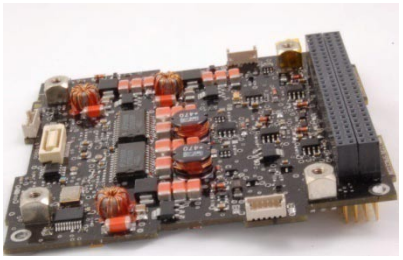
CubeSat Power System

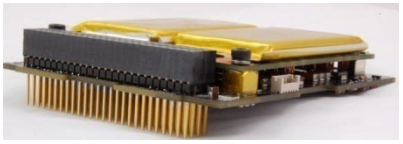
Main Features

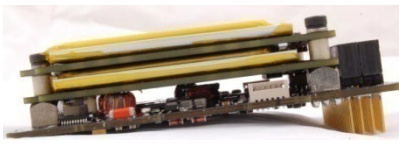
- CubeSat and CubeSat Kit compatible.
- 3.3V, 5V and Raw Battery buses are provided.
- Flexible design: different solar cell types/string lengths.
- Modular design: Parallel operation compatible – modules are stackable for 2U and 3U CubeSat use.
- 6 channel Maximum Power Point Tracking.
- Lithium Polymer battery with integrated heater.
- Analogue telemetry and digital status lines.
- Bus over-current and battery under-voltage protection.
- USB battery charger.
- Compatible with dead launch via separation switches.

Applications

- CubeSat and CubeSat Kit satellites.
- Nanosatellites with a power requirement from 1W to 20W orbit average power.
- Low power terrestrial micro-renewable applications.







Small Satellite Solar Panels

MAIN FEATURES

- Space compatible solar arrays for small satellites.
- Our approach is to apply space manufacturing techniques, using space components and adhesives, but employing a small satellite approach to documentation. This enables us to produce a quality product on a strict budget.
- Our manufacturing processes are flexible and can be applied to a range of solar cells types: silicon, single junction GaAs, Multi-junction GaGas. And solar cell sizes; 2x4cm up to 4x8cm cells.
- Our flexible approach enables us to turn around completed solar panels in very short timescales; the solar arrays for ZA-002 were turned around in less than 5 weeks from order.

APPLICATIONS

- Cubesats, Nanosatellites and Microsatellites. Panel power levels from <1W up to 100W.

TRACK RECORD

- ZA-002 - Satellite for South Africa.

Small Satellite Batteries

MAIN FEATURES

- Lithium ion, Lithium Polymer and Nickel Cadmium space batteries available.
- The Clyde Space team has extensive experience in the application of commercially available battery cells to space.
- Commercial cells must undergo a stringent set of qualification tests before being selected for use on a space application:
    - Tests include: Vacuum compatibility, DPA, Radiation, Capacity, Self-discharge, Mission, Resistance, EMF vs SOC.
- The use of commercial cells not only reduces the system cost, but also significantly reduces lead-times for delivery.

APPLICATIONS

- Cubesats, Nanosatellites and Microsatellites. Capacities from 1Ah up to 10Ah and battery voltages from 4.2V to 40V.

TRACK RECORD

- CubeSat Power.

NanoSat Power System

MAIN FEATURES

- Non-sequential, modular interface to solar arrays; Permits different cell types/string lengths per interface.
- Effective maximum power point tracking system.
- Battery bus 7 – 10V (can be increased) / 5V regulated.
- Max currents: Battery bus = 10A / 5V bus = 3A.
- Compatible with NiCd, NiMH, Li-ion and Lithium Polymer battery systems.
- Resetable over-current latching power switches.

APPLICATIONS

- Small satellites with a power requirement from a few watts to 20W orbit average power.
- Rovers and UAVs utilising a solar array/battery system.

TRACK RECORD

- SNAP-1* (Launched on COSMOS ‘00) and FalconSat-2*.

This subsystem is based on designs licensed from Surrey Satellite Technology Limited (SSTL). Subsystems for the missions marked '*' were developed and manufactured by SSTL alone. Clyde Space is wholly responsible for the development and manufacture of its subsystems and equipment.

SmallSat Power System

MAIN FEATURES

- Non-sequential, maximum power point tracking, modular interface to solar arrays; Permits different cell types/string lengths per interface.
- Battery bus 16 – 35V and 5V regulated.
- Max currents: Battery bus = 15A / 5V bus = 2A.
- Compatible with NiCd, NiMH, Li-ion and Lithium Polymer battery systems.
- Resetable over-current latching power switches.

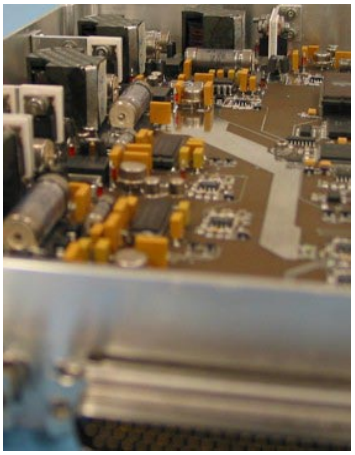
APPLICATIONS

- Small satellites with a power requirement from 20W to 300W orbit average power.
- Suitable for LEO and interplanetary environments.

TRACK RECORD

- Over 20 missions in various configurations, including: Cerise* ('95), Clementine* ('99), PICOSat* ('01), ALSat-1* ('02), BILSAT*, UK-DMC* ('03) and TOPSat* ('05).

This subsystem is based on designs licensed from Surrey Satellite Technology Limited (SSTL). Subsystems for the missions marked '*' were developed and manufactured by SSTL alone. Clyde Space is wholly responsible for the development and manufacture of its subsystems and equipment.



CommSat Power System

MAIN FEATURES

- Generates a fully regulated bus in sunlight and eclipse.
- Three domain control ensures smooth transition between operational modes and that the battery charge is according to solar array power margin.
- Modular design to easily adapt to required power level.
- Radiation tolerant at component level to 100krad.
- Regulated 50V bus (±1%). Battery bus 28 – 38V.
- Max currents: 50V bus > 40A. Battery bus > 40A.
- Designed to ESA-PSS-02-10 Power Standard.

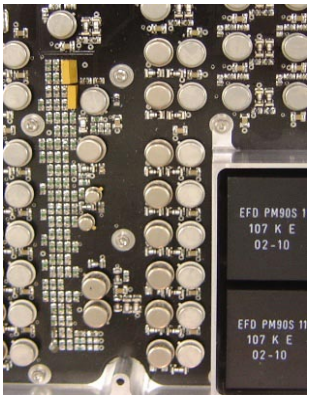
APPLICATIONS

- Small to medium sized satellites with a power requirement from 300W to over 2.5kW.
- Suitable for all mission environments on spacecraft with fixed aspect/sun tracking solar arrays.

TRACK RECORD

- GIOVE-A* (AKA 'Galileo System Test Bed-V2/A') for ESA.

This subsystem is based on designs licensed from Surrey Satellite Technology Limited (SSTL). Subsystems for the missions marked '*' were developed and manufactured by SSTL alone. Clyde Space is wholly responsible for the development and manufacture of its subsystems and equipment.



7 TERMS AND CONDITIONS OF SALE OF GOODS AND RELATED SERVICES

1. FORMATION OF CONTRACT

a. All quotations, offers and tenders are made and all orders are accepted subject to the following conditions. Except as otherwise provided in these conditions, all other terms, conditions or warranties whatsoever are excluded from any contract between the Seller and the Buyer unless expressly accepted in writing by the Seller.

b. If there is a conflict between these conditions and any other terms of the Seller's quotation, offer, tender or acknowledgement of order, such other terms shall prevail.

c. Quotations shall be available for acceptance for a maximum period of 30 days from date of issue and may be withdrawn by the Seller by written or oral notice to the Buyer at any time prior to the Seller's acceptance. Acceptance will only be effective where it is made on the attached Seller's Quotation signed by an authorised representative of the Seller and posted or delivered to the Buyer.

d. If any statement or representation has been made to the Buyer by the Seller or its officers, employees or agents (other than in the document(s) enclosed with the Seller's quotation or acknowledgement of order) upon which the Buyer wishes to rely it shall only be entitled to do so if the statement or representation is attached to or endorsed on the Buyer's order and then only if the Seller subsequently confirms in writing to the Buyer that the Buyer is entitled to rely on the statement or representation.

e. Prices are quoted by the Seller on the basis of the limitations of liability set out in these conditions. The Buyer shall be entitled to request the Seller to agree a higher limit of liability and the Seller may then quote a revised price taking account of any increased insurance premium to be borne by the Seller.

f. Unless specifically agreed to the contrary all commercial terms shall be interpreted in accordance with INCOTERMS current at the time the order is accepted.

2. PRICES

a. Unless otherwise agreed in writing, all prices are quoted net ex-works exclusive of VAT. If the Seller agrees to deliver the goods otherwise than at its premises the Buyer shall pay all packaging, transportation and insurance costs and other charges incurred by the Seller in making or arranging such delivery.

3. PAYMENT

a. The Seller shall be entitled to submit its invoice with its delivery advice note or at any time afterwards except that where delivery has been postponed at the request of, or by the default of, the Buyer, the Seller may submit its invoice at any time after the goods are ready for delivery or would have been ready in the ordinary course but for the Buyer's request or default.

b. Where goods are delivered by instalments or services performed in stages, the Seller may invoice each instalment or stage separately and the Buyer shall pay such invoices in accordance with these conditions.

c. No disputes arising under the contract nor delays, otherwise than due to default by the Seller, shall interfere with prompt payment in full by the Buyer.

d. If the Buyer shall default in payment, the Seller shall be entitled, without prejudice to any other right or remedy, to do all or any of the following:

i. to suspend all further deliveries and the performance of services under this Agreement and under any other contract or contracts between the Seller and the Buyer then current, without notice, in which case any delivery dates specified in Seller's Quotation or otherwise agreed in writing shall, at the option of the Seller, be postponed by a period of time equivalent to the period of time of such suspension;

ii. to claim interest under the Late Payment of Commercial Debts (Interest) Act 1998, together with any statutory debt recovery costs;

iii. to serve notice on the Buyer requiring immediate payment for all goods supplied and services rendered by the Seller under this and all other contracts with the Buyer whether or not payment is otherwise due;

iv. to sue for the price of the goods and services even though (in the case of the goods) title may not have passed to the Buyer.

4. DELIVERY

a. Unless otherwise agreed in writing, delivery of the goods shall be given and taken at the Seller's premises.

b. Unless otherwise agreed in writing expressly in the Seller's Quotation, time for delivery and completion of the services is given as accurately as possible but is not guaranteed. The Buyer shall have no right to damages or to cancel the contract for failure for any cause to meet any delivery or completion time stated nor shall the Buyer be entitled to make, or to purport to make, time for delivery of the essence of the contract.

c. The date for delivery or completion of the services shall in every case be dependent upon prompt receipt of all necessary information, final instructions or approvals from the Buyer.

d. Failure by the Buyer to take delivery of or to make payment in respect of any one or more instalments of goods delivered or services partially performed in accordance with the contract shall entitle the Seller to treat the contract as repudiated by the Buyer either in whole or in part.

e. The Seller will endeavour to comply with reasonable requests by the Buyer for postponement of delivery of the goods or completion of the services but will be under no

obligation to do so. Where delivery or completion is postponed, otherwise than due to default by the Seller then, without prejudice to all other rights and remedies available to the Seller, the Buyer shall pay all costs and expenses, including a reasonable charge for storage and transportation so occasioned.

f. Section 32(2) of the Sale of Goods Act 1979 shall not apply. The Seller shall not be required to give the Buyer the notice specified in Section 32(3) of that Act.

g. The Buyer shall be solely responsible for obtaining all import authorisations and paying any import duty.

h. Without prejudice to Condition 4.7, and notwithstanding the provisions of Condition 4.1, the Seller will not be liable for any delay in delivering, or failure to deliver the goods where such delay or failure occurs as a result of the UK Government Export Control Organisation (or any replacement organisation from time to time) delaying the grant of, or refusing to grant any required export authorisations.

5. PACKING

a. Packaging supplied by the Seller, unless otherwise agreed in writing expressly in the Seller's Quotation, is intended to provide adequate protection in normal conditions of transit of expected duration.

6. RISK AND TITLE

a. Risk shall pass to the Buyer (so that the Buyer is then responsible for all loss or deterioration of the goods or for any damage occurring) at the time when the goods leave the premises of the Seller.

b. Title to the goods shall only pass to the Buyer if the Buyer has paid to the Seller all sums (including any default interest) due from it to the Seller under this contract and under all other contracts between the Seller and the Buyer including any sums due under contracts made after this contract whether or not the same are immediately payable.

c. The Seller may recover goods in respect of which title has not passed to the Buyer at any time and the Buyer irrevocably licences the Seller, its officers, employees and agents to enter upon any premises of the Buyer, with or without vehicles, for the purpose either of satisfying itself that Condition 6.4 below is being complied with by the Buyer or of recovering any goods in respect of which title has not passed to the Buyer.

d. Until title to the goods has passed to the Buyer under these conditions it shall, if the Seller so requires, store the goods separately from other goods and shall ensure that they are clearly identifiable as belonging to the Seller. During such time as the Buyer possesses the goods with the Seller's consent, the Buyer may in the normal course of its business sell or hire the goods as principal but without committing the Seller to any liability to the person dealing with the Buyer.

7. CANCELLATION

a. Cancellation will only be agreed to by the Seller on condition that all costs and expenses incurred by the Seller up to the time of cancellation and all loss of profits and other loss or damage resulting to the Seller by reason of such cancellation will be paid forthwith by the Buyer to the Seller.

b. Goods returned to the Seller without the Seller's written consent will under no circumstances be accepted for credit.

8. VARIATIONS

a. No variations to the goods or services required by the Buyer shall be binding on the Seller unless agreed by the Seller and the Buyer in writing, including, as part of such agreement, any change to the contract price arising in consequence of the variation to the goods or services. If the Seller shall vary the goods or services in accordance with the Buyer's requirements without agreement having been reached as to the consequential change in the contract price, the price shall be varied by reference to the extra costs incurred by the Seller in making the variation plus an appropriate profit margin.

b. If the Seller agrees to any such variation any dates quoted for delivery and completion of services shall be extended accordingly.

9. SPECIFICATION

a. Unless otherwise agreed in writing expressly in the Seller's Quotation, the Seller reserves the right to alter the dimensions or composition of the goods supplied to conform to applicable standards or laws or otherwise within reasonable limits having regard to the nature of the goods.

b. The information contained in the advertising, sales and technical literature issued by the Seller including any illustrations, performance details, examples of installations and methods of assembly and all other technical data in such literature are for general guidance only. No such information or data shall form part of the contract unless the Buyer shall have complied with Condition 1.4 relating to statements and representations and the Seller shall have given the confirmation referred to in that Condition.

10. DEFECTS APPARENT ON INSPECTION

a. The Buyer shall only be entitled to claim (and then subject to Conditions 12 and 13) for shortages or defects in the goods as supplied which are apparent on visual inspection if:-

i. the Buyer inspects the goods within three working days following the date of their arrival at its premises or other agreed destination; and

ii. a written complaint specifying the shortage or defect is made to the Seller (and, where the Seller has arranged transport for the goods in accordance with a specific contractual obligation to do so, to the carrier) within seven working days of delivery in the event of shortage, defect, or non-delivery of any separate part of a consignment, or within [fourteen] working days of the notified date of despatch in the event of non-delivery of a whole consignment or (if applicable), within such shorter period as the carrier's conditions require; and

iii. the Seller is given an opportunity to inspect the goods and investigate any complaint before any use of or alteration to or interference with the goods.

b. The Buyer shall only be entitled to claim in respect of defects apparent on visual inspection of services performed by the Seller if a written complaint is made to the Seller within fourteen working days of completion of performance of the services and the Seller is given the opportunity to inspect the services performed and to investigate the complaint.

c. If a complaint is not made to the Seller as provided in this Condition 10, the goods shall be deemed to be in all respects in accordance with the contract (subject only to Condition 11) and the Buyer shall be bound to pay for the same accordingly.

11. DEFECTS NOT APPARENT ON INSPECTION

a. The Buyer shall only be entitled to claim (and then subject to Conditions 12 and 13) in respect of defects in the goods supplied or services performed which are not apparent on visual inspection at the time of delivery or completion of performance if:-

i. a written complaint is sent to the Seller as soon as reasonably practicable after the defect is discovered and subsequently no use is made of the goods or alteration or interference made to or with the goods before the Seller is given an opportunity to inspect the goods and services performed in accordance with Condition 11.4; and

ii. the complaint is sent within 12 months of the date of delivery of the goods or completion of the performance of the services or, in the case of an item not manufactured by the Seller, within the guarantee period specified by the manufacturer of such item.

b. The Buyer shall not be entitled to claim in respect of any repairs or alterations undertaken by the Buyer without the prior specific written consent of the Seller nor in respect of any defect arising by reason of fair wear and tear or damage due to accident, neglect or misuse nor in respect of any goods to which alterations have been made without such consent or to which replacement parts not supplied by the Seller have been fitted.

c. The Seller shall not be liable for (and the Buyer shall indemnify the Seller against claims arising from) loss or damage suffered by reason of use of the goods after the Buyer becomes aware of a defect or after circumstances have occurred which should reasonably have indicated to the Buyer the existence of a defect.

d. The Seller may within 28 days of receiving a written complaint inspect the goods and services as performed and the Buyer, if so required by the Seller, shall take all steps necessary to enable it to do so.

12. GUARANTEE

a. Unless otherwise agreed in writing expressly in the Seller's Quotation, the sole and exclusive warranty of the Seller, is that goods manufactured by the Seller and sold to the Buyer will at the time of delivery be constructed of sound materials and be of good workmanship and that all services will be performed in accordance with good practice.

b. The Seller guarantees, in the case of goods or services being found to be defective in workmanship and/or materials, that it will as soon as reasonably practicable and at its sole option either repair or rectify such defective goods or services or deliver replacements or credit the Buyer with the price of the defective goods or services provided that:-

i. the alleged defect arises within the period of 12 months from the date of delivery of the goods or completion of the performance of the services;

ii. a written complaint is sent to the Seller in accordance with the provisions of Conditions 10.1.2 or 11.1.1 and no use has been made of the goods thereafter and no alterations made thereto, or interference made therewith, before the Seller has been given the opportunity to inspect the goods; and

iii. any defect is found by the Seller on its inspection to be due solely to defective workmanship or materials.

c. The Seller shall not be liable for any claim:-

i. in respect of any repairs or alterations undertaken by the Buyer without the prior specific written consent of the Seller;

ii. in respect of any defect arising by reason of fair wear and tear or from damage due to misuse;

iii. for loss or damage suffered by reason of use of the goods after the Buyer becomes aware of a defect or after circumstances which should reasonably have indicated to the Buyer the existence of a defect.

d. If the Seller does so repair or rectify the goods or services or supplies satisfactory replacement goods or issues a credit the Buyer shall be bound to accept such repaired or replacement goods or rectified services or the credit and the Seller shall be under no liability in respect of any loss or damage whatsoever arising either from the initial delivery of the defective goods or performance of services or from the delay before the defective goods or services are repaired, rectified or replaced or the credit is issued.

e. The Seller will not accept returns of allegedly defective goods unless it has issued prior consent in writing to the Buyer.

f. All goods which pursuant to specific agreement are to be returned to the Seller must be shipped prepaid by the Buyer. The Seller shall pay the costs of the return of repaired or replacement goods to the Buyer.

g. This warranty is intended solely for the benefit of the Buyer. All claims must be made by the Buyer and not by any other person, firm or company who may have possession of the goods.

h. In the case of goods not manufactured by the Seller:

i. the Seller gives no assurance or guarantee whatsoever that the sale or use of the goods will not infringe the patent, copyright or other industrial property rights of any other person, firm or company; and

ii. the liability of the Seller shall be limited to the guarantee (if any) which the Seller receives from the manufacturer or supplier of the goods.

i. Unless otherwise agreed in writing expressly in the Seller's Quotation, the Seller does not warrant the fitness or suitability of any goods supplied for any particular purpose or application and the implied warranties and conditions contained in Sections 13, 14 and 15 of the Sale of Goods Act 1979 (as amended) and Sections 3, 4 and 5 of the Supply of Goods and Services Act 1982 and any other condition or warranty implied by trade custom or usage are expressly excluded.

13. EXCLUSION OF LIABILITY

a. Subject to Condition 12, the Seller shall be under no liability to the Buyer for any loss, damage or injury, direct or indirect, resulting from defects in design, materials or workmanship or otherwise (and whether or not caused by the negligence of the Seller its employees or agents) other than liability for death or personal injury resulting from the Seller's negligence;

b. Subject to Condition 12, the Seller shall have no liability for any indirect or consequential losses or expenses suffered by the Buyer, however caused, and including without limitation, loss of anticipated profits, goodwill, reputation, business receipts or contracts, or losses or expenses resulting from third party claims.

c. [The Seller's aggregate liability to the Buyer whether for negligence, breach of contract, misrepresentation or otherwise shall in no circumstances exceed [the cost of the defective, damaged or undelivered goods which give rise to such liability as determined by the net price invoiced to the Buyer] in respect of any occurrence or series of occurrences.]

14. CONFIDENTIAL INFORMATION AND INTELLECTUAL PROPERTY RIGHTS

a. All drawings, documents, confidential records, computer software and other information supplied by the Seller, whether produced by itself or a third party, are supplied on the express understanding that copyright is reserved to the Seller (or the third party) and that the Buyer will not, without the written consent of the Seller, give away, loan, exhibit or sell any such drawings, documents, records, software or other information or extracts from them or copies of them or use them in any way except in connection with the goods in respect of which they are issued. In addition, any design right or copyright created in relation to the goods will vest in the Seller where the goods are commissioned by the Buyer, whether or not for a separate fee.

b. All claims for alleged infringement of patents, trade marks, registered designs, design right or copyright received by the Buyer relating to the goods must be notified immediately to the Seller. If requested by the Seller, the Seller shall be entitled to have conduct of any proceedings relating to any such claim in such manner as the Seller thinks fit and the Buyer will provide to the Seller such reasonable assistance as the Seller may request. The cost of any such proceedings will be borne by the Seller.

c. If any allegation shall be made against the Buyer to the effect that the supply of such of the goods as are manufactured by the Seller infringes the intellectual property rights of any third party or the Seller has reason to believe that any such allegation is likely to be made, the Seller may at its option and expense modify or replace the goods so as to avoid the infringement (but without adversely effecting the overall performance of the goods), or obtain for the benefit of the Buyer the right to continue to use the goods, or repurchase the goods at the contract price as reduced by a reasonable provision for depreciation. If the Seller pursues any of such options, the Buyer will have no rights or remedies against the Seller arising directly or indirectly out of the alleged infringement. Furthermore, on no account will the Seller be liable for consequential or other indirect loss, loss of profits or wasted expenditure which arises in consequence of an infringement or alleged infringement of intellectual property rights relating to the goods.

15. CUSTOMER'S DRAWINGS

a. The Buyer shall be solely responsible for ensuring that all drawings, information, advice and recommendations given to the Seller, either directly or indirectly by the Buyer or by the Buyer's consultants or advisers, are accurate, correct and suitable unless, and then only to the extent that, the Seller agrees in writing, to accept responsibility. Examination or consideration by the Seller of such drawings, information, advice or recommendations shall not of itself limit the Buyer's responsibility.

b. The Buyer shall indemnify the Seller from and against all actions, claims, costs and proceedings which arise due to the manufacture of goods or performance of services by the Seller being in accordance with drawings or specifications provided by the Buyer if such drawings or specifications are inaccurate or contain design defects or if they infringe or are alleged to infringe a patent, copyright, registered design, design right or design copyright or other right of any third party.

16. INSOLVENCY

a. If the Buyer shall become bankrupt or shall be deemed to be unable to pay its debts for the purposes of Section 123 of the Insolvency Act 1986 or shall compound with its creditors or if a resolution shall be passed or proceedings shall be commenced for the administration or liquidation of the Buyer (other than for a voluntary solvent winding up for the purposes of reconstruction or amalgamation), or if a receiver or manager shall be appointed of all or any part of its assets or undertaking or if the Buyer shall suffer any similar difficulties pursuant to the laws of any other country, the Seller shall be entitled to cancel the contract in whole or in part by giving written notice to the Buyer, without prejudice to any other right or remedy available to the Seller.

17. FORCE MAJEURE

a. The Seller shall be under no liability for any failure to perform any of its obligations under

the contract if and to the extent that the failure is caused by act of God, governmental restriction, condition or control or by reason of any act done or not done pursuant to a trade dispute, shortages of labour or materials or breakdown of machinery or any other matter (whether or not similar to the foregoing) outside the control of the Seller.

18. SPECIALS AND FREE ISSUE MATERIALS

a. Unless otherwise agreed in writing expressly in the Seller's Quotation, the Seller does not guarantee the suitability of materials or the design of goods made specially to the Buyer's requirements and differing from the Seller's standard specifications even if the purpose for which the goods are required is known to the Seller.

19. CONSUMER PROTECTION ACT 1987 (THE "ACT")

a. In circumstances in which the Seller supplies goods to the Buyer for incorporation with, or use ancillary to, any composite or other products to be produced, manufactured, processed or supplied by the Buyer or a third party then:

i. the Buyer shall forthwith on demand produce for inspection by the Seller copies of all written instructions, information and warnings to be supplied by the Buyer in relation to the composite or other products, provided that such inspection or right to inspect shall not of itself constitute acceptance or approval on the part of the Seller of such instructions, information or warnings; and

ii. the Buyer shall indemnify, reimburse and compensate the Seller for all losses and damages (including costs, expenses and charges for legal actions in which the Seller may be involved) which the Seller may incur, or have to bear, if any claim or claims shall be made against the Seller, pursuant to the Act or otherwise, relating to the composite or other products in circumstances in which the goods supplied by the Seller are either (i) not the defective part of the composite or other product, or (ii) are only rendered the defective part or became a defective product by reason of acts or omissions of the Buyer or a third party (including without limitation the supply of defective free issue materials), or (iii) are only rendered the defective part or became a defective product by reason of instructions or warnings given by the Buyer or other supplier of the composite or other products or (iv) are supplied in accordance with a specification or drawings furnished by, or on behalf of, the Buyer.

b. For the purposes of Condition 19.1 only, the word "defective" shall be interpreted in accordance with the definition of "defect" contained in Part 1 of the Act.

c. The Buyer acknowledges that it is under a duty to pass on to its customers all instructions, information and warnings supplied to it by the Seller with the goods.

20. ASSIGNATION

a. The contract is entered into between the Seller and the Buyer as principals and the Buyer shall not be entitled to assign the benefit or delegate the burden of it or of any interest in it without the prior written consent of the Seller. The Seller shall be entitled to sub-contract the whole or part of its obligations under the contract and to assign its interest in the contract.

21. ECONOMIC AND MONETARY UNION

a. Unless otherwise agreed in writing expressly in the Seller's Quotation, the occurrence or non-occurrence of an event associated with Economic and Monetary Union will not of itself discharge the contract, or entitle one party unilaterally to vary or terminate it.

22. THIRD PARTY RIGHTS

a. A person who is not a party to this Agreement (a "third party") shall have no rights whether in contract or at law to enforce any of these conditions. Any right or remedy of a third party which exists or is available otherwise at law is not affected.

23. LAW AND JURISDICTION

a. The parties agree that any disputes arising or in any way connected with the subject matter of this Agreement (whether of a contractual or tortious nature or otherwise) shall be subject to the laws of Scotland and in the case of proceedings issued against the Seller shall be subject to the jurisdiction of the Scottish courts only.

b. The schedule to the Uniform Law on International Sales Act 1967 shall not apply to the contract.