dti

ELECTRA-SLATE

Final Report

CONTRACT NUMBER: S/P2/00468/00/REP

URN NUMBER: 05/1308

dti

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ELECTRA-SLATE

Final Report.

30th September 2004.

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Contractor

ICP Solar Technologies UK Ltd

Prepared by Malcolm Lane.

The work described in this report was carried out under contract as part of the DTI New and Renewable Energy Programme. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI.

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EXECUTIVE SUMMARY

1. Objectives of the Work.

The potential for use of roofs in the UK for generating PV electricity has been recognised in previous studies (Ref. ETSU S/P2/00277/REP The potential market for PV building products)

There is a definite and growing market for a solar product, which can be roof mounted for use in domestic power production applications in the developed world. Existing products are available in other European countries to meet this need, and the market is set to grow with the implementation of plans to use renewable energy to meet the Kyoto requirements. However no such package has been developed in the UK by a UK manufacturer with a product that so closely resembles the building product which it will replace and be commercially attractive to the rest of the world.

The building industry is known to be conservative, and more likely to embrace a product, which is recognisable, and does not require a PV specialist to install it. It was felt that the building industry was not likely to change its methodology without substantial support. Therefore the objective of the project was to create a tile (Electra-Slate) that appears physically and dimensionally to conform with a standard pattern, but is designed in a way that any roofer could install the device with total safety on an existing truss, rafter, felt and batten construction roof without additional training and supervision.

The UK roofing market in 1998 had a turnover of £491 million, with slate accounting for 13% of that market. This is a growing market as slate returns to being more fashionable for roofing structures. It is also apparent that many large volume producers of kiln fired roof coverings are now re-producing successfully the aesthetics of Slate in concrete tile formats in order to reduce the materials costs to the consumer whilst maintaining the desirable aesthetic appearance of a Slate roof structure.

A proposal to take and improve upon the design of Intersolar original design of the “Electra-slate” solar roof slate using thin film silicon was produced in 2003 by two companies who have extensive experience in the field of solar power, ICP Solar Technologies and PV Systems.

The proposal aimed to finalise the design of a PV roof-slate for the UK market, which would be simple to install by any roofer, robust for site handling, visually similar to slate, and suitable for distribution through normal builders merchants.

The proposal was accepted and the project commenced in October 2003 (this followed on from the project started by Intersolar Group Limited), ending in October

2004. Further qualification work will carry on after this date with the product expecting to reach full production in the second half of 2005.

The primary developmental objectives of the proposal were:

1. To research a novel 3 head multi laser concept to allow a reduction of laser from 20 time mins to 2 mins per plate on a common bed with precise alignment to maximise the active surface area of the plate

2. To research a polymer/mould combination that will function as a connector, be suitable for mass production injection moulding, and yet pass the accelerated IEC61646 tests.

3. To research a material/process combination that will allow an innovative fixing method to reduce the historical production costs associated with holes drilled in glass.

2. The Collaborators.

The companies participating in this proposal brought together all the skills and experience required to prove the concept, improve upon the existing design and achieve a product definition capable of volume production on a commercially viable basis.

ICP Solar Technologies as the lead Collaborator has significant experience in the Industrial translation of solar deposition methodology and volume production of commercial products for a global market. ICP purchased the IPR and physical assets of the Intersolar Group in 2003, and having retained a lot of the experience and knowledge gained under the Intersolar group has been able to improve upon the former designs whilst employing the reaches of the global arms of ICP to achieve cost effective solutions to the project briefs.

EETs (PV Systems) have a celebrated track record of both large and small-scale PV installations with balance of system equipment integration. Their expertise in the roofing installation and system integration, being key to the success of translating the project brief into an all-encompassing system that meets the needs of the product and installation in line with standard roofing practise.

Exitech's addition to the team complements the programme with their industry-recognised expertise on Laser systems and associated technology. Their ability to design and prove a cost effective prototype Laser system being key in achieving the complicated and closely toleranced laser scribing required on the product and in doing so reduce the time taken to achieve the laser patterning.

3. Primary Conclusions, Outcomes and Recommendations

The design specification of the Electra-Slate has been finalised and prototype parts produced to prove the concept in both installation and manufacturing. The desired manufacturing costs of the product can be achieved with conversion to a large scale manufacturing set up and with throughout capable of achieving the success of a product line that has significant commercial potential.

Fundamental changes to the Solar Technology employed within the product definition have been embodied. The Dual junction device planned for inclusion into the final product specification is being researched and developed under ICP's other DTI sponsored programme Capacity Ten 7.

This dual junction device technology when optimised will be paramount to the success of the Electra-slate as it removes a lot of the technology barriers Intersolar suffered during the development of ES1 and 2. It provides approximately double the open circuit voltage of a single stacked cell, thus helping the system to fall more comfortably into working voltage regions more readily addressed by Inverter manufacturers world-wide. It also has an improved power degradation factor reducing light induced (Steabler Wronski effect) cell degradation from a factor of approximately 33% to 20% over the lifetime of the cell structure.

The cells used for the prototypes produced during the project enable proving of the E-Slate manufacturing system, interconnection and integration remits of the project, but with a power output being lower then it would commercially be viable to qualify the product to. This fact has prevented ICP from being able to send production prototypes to ISPRA for full IEC 61646 Qualification within the project time-scale as originally planned.

One of the Capacity Ten 7 Project outputs is the manufacture of a prototype large area chamber of a design such that the limitations of the closed holder set as to be found currently on ICP's trials development unit are eradicated. It is envisioned that once the new chamber is installed in December 2004 that consistent and optimised dual junction cells will be produced. Some of those cells will then be installed in a set of prototype E-Slates that will be sent for full IEC qualification with a view to be having these results known to the company in late 2005.

In Summary

i) A Laser system has been developed that will replace the need for 4 separate laser systems taking in excess of 20 minutes processing time.

ii) A 2-part connector was developed within ICP -with - the female being on the Electra-slate and the male being on the wiring loom

iii) An Effective system of mounting the Electra-Slate with out the need for drilling holes in the Electra-Slate has been developed using commercially available hooks and established that hooks were available in sizes ranging from 60mm to 160mm increasing in length in 10mm increments. The availability of these hooks thus enabling the 600 * 300mm slate definition to be installed in all of the various geographical regions and associated pitches of roof structures in that area.

iv) A path for Future Development

The outputs of the project will enable ICP to undertake post qualification production of the Electra-Slate in order to achieve a profit line within two years after the completion of the project. ICP will utilise the intervening time between submission for IEC 61646 qualification and successful results of such qualification to conduct investigative marketing and strategic planning for entry into the global market place. Plans to partner with large-scale roofing product manufacturers and System integrator's will be brought into action and ICP will look to establish a mutually beneficial collaboration between these groups to support the launch of the Electra-Slate product.

Figure A. Early Prototype Electra-Slates on Welsh Slate roofing Structure.

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Introduction.

The UK was one of the first countries to identify the specific potential for building-integrated photovoltaics (BiPV) following a project commissioned by (the organisation then known as) ETSU in the early 1990's. This identified the suitability of building roofs and facades for accommodating PV arrays.

In considering ways of exploiting this potential, Intersolar Group (the original concept creators) believed that the optimum approach would be to develop PV elements as close as possible to standard building products. This would enhance the appearance, compared to traditional solar modules 'bolted on' to the building (as practised in most countries at the time). It would also enable the products to be introduced through the existing building industry channels, rather than requiring a separate sub-contract to a specialist PV system installer.

This approach led to certain design features, which have been fundamental to the Electra-Slate concept to this day, in particular:

a) The configuration of the unit to a standard size and shape, virtually identical to roofing slates already in use
b) The appearance of the unit to be virtually indistinguishable in colour and texture from a standard slate
c) The relatively high voltage output from each slate, to obviate the need for both series and parallel connections on the roof (if all units can be simply parallel connected to achieve system voltage, no special electrical expertise is required of the roofer)

It was requirement (b) above, which led the company to work first on an equivalent slate, because this has a colour and appearance that can be readily emulated using an amorphous silicon solar plate. However the company also entered into collaboration with the Swiss company Atlantis, using a similar approach for roofing tile, and this acted as a useful proof of concept.

Atlantis were already involved in a similar device using crystalline silicon cells, but were impressed by feature (c) above – the potential to increase the voltage to levels, which were uneconomic using individual cells due to the series interconnection costs. The monolithic interconnections in amorphous silicon are, of course, produced by laser scribing as part of the production process, so have very little associated cost.

The first DTI-supported Electra-Slate project enabled Intersolar Group to prove that the design was practicable and to demonstrate the three key features above. An installation on the Track 2000 building in Cardiff was successfully undertaken and the Electra-Slates were virtually indistinguishable from the synthetic slates, which made up the rest of the roof.

Fig B. Initial Fixings Track 2000

Fig C. Track 2000 Installation completed.

The product was selectively introduced to a wider audience and extremely well received, particularly due to its appearance. It became specified for a number of roofs on Persimmon Homes' Clapham Folly development near Bedford.

Fig D. Clapham Folly First Fixings.

The responsible Planning Officer was particularly impressed with the appearance of the product and enthusiastic about specifying it for a broader range of new-build projects. The first house there was successfully installed, but the rest of the programme was affected by Intersolar's liquidation.
At the same time the need to reduce production costs, in particular by speeding up the laser isolation process and reducing separation, was identified, and that led to the specification for the present project.

Fig E. Clapham Folly Work in Progress.

Fig F. Completed to ridge Level. View from Elevated Position.

4.0 Development of Multi Laser system.

4.1 Background to the Specification

A key aspect of the proposed product is that production requires significantly decreased laser isolation line separation compared to the ICP standard solar pane in order to maximise the available surface area of the active cells, potentially increasing production costs and time of process. For the cost sensitive domestic solar PV market, this is highly undesirable and the development of a suitably effective laser patterning system was therefore one of the key challenges of the project.

To address this challenge, Exitech Limited, who has extensive expertise and experience of the development of large area, advanced laser scribe systems, are collaborators on the project. The initial project plan proposed that Exitech should develop a free standing, self contained unit capable of meeting the diverse range of materials / layout options trials that might be required by the Electra-Slate project, in particular the development of a novel 'multi-head' system capable of scribing the anticipated 3 material layers requiring patterning.

Following initial discussions between ICP and Exitech, it had been recognised that the system also needed to have large area and 'production requirements definition' capabilities: i.e. the ability to process large area/multiple substrates and to test 'relaxation' of some capabilities (e.g. lower spec scribe accuracy) with a view to defining an optimum later production system. I.e. the system was to provide a 'proving tool' to support the definition of cost effective production laser systems for use on the wide range of products that ICP might wish to make and to highlight any opportunities for improvement – technical and cost – or constraints. However, note that the Electra-Slate project laser is not itself intended to be a production system, as this was outside the financial scope of the project. Instead, the system development was to focus on providing the versatility to conduct a wide range of scribing trials on a range of materials combinations.

Accordingly, the following Target Performance Specification defines the overall requirements that were to be targeted by the Exitech development of the laser scribe system. The direct project goals and those relating to definition of a later production process are addressed by this specification.

4.2 Form of the Specification

The requirements were defined, so far, as were possible, in terms of the performance required of the system. These had been based on the known current design and anticipated likely future developments. The slate design is not included directly in this specification, but has been referred to by PQL, ICP and Exitech in formulating the requirements.

4.3. Performance Requirements: Laser Cutting Capabilities

The laser heads should be capable of performing the following tasks (with appropriate minor reconfiguration or process parameter adjustment).

4.3.1 The system must be able to pattern the 'standard' thin film device structure used in various ICP products: this comprises a glass substrate, patterned Transparent Conducting Oxide (TCO, typically tin oxide or indium-tin oxide), patterned hydrogenated amorphous silicon (a-Si:H) based layers, and patterned top metal contact (aluminium). This requires the following capabilities.

4.3.2. The system must be able to ablate cleanly a TCO layer on polished and textured glass substrates. Typical TCO thickness is expected to be 200 – 600nm, though up to 1000nm is possible. The laser must cut through the glass, with a process speed of 600mm/sec

4.3.3 In particular, the system must be able to ablate cleanly the LOF[1] tin oxide coated glass product, which is thought to include a very thin silica layer within the tin oxide coating, The performance criteria is an isolation value either side of the cut of greater than 1 meg/ohms before the substrate has been cleaned.

4.3.4 The system must be able to ablate cleanly the hydrogenated amorphous silicon (a-Si:H) based materials, ranging from wide bandgap a-SiC (or oxide)

[1] Libbey Owens Ford.

to narrow bandgap a-Si:Ge, on the above TCO / glass combinations, without measurable damage to the TCO. Typical a-Si thickness is 500 – 1500 nm, depending on the a-Si structural combination used. The laser must cut through the glass, with a process speed of 600mm/sec

4.3.5 The system must be able to ablate cleanly the aluminium layer overlying the a-Si based layers, by cleanly ablating the a-Si layers if necessary, without measurable damage to the TCO. Aluminium thickness is expected to be 200-300nm. The laser must be able to cut through the glass, with a process speed of 600mm/sec

4.3.6 The system must also be able to ablate a series of disconnected holes (or a continuous line) through the Si:H based layers above, to permit later good interconnect of the lower and upper contact materials and ablation must be adequate to ensure that the panel electrical performance is not compromised by inadequate removal of material after the product has been heated to 100C for 12hrs.

4.3.7 All the above laser ablation processes must be achieved without 'fusing' the materials such as to degrade panel electrical performance, in particular accidental partial or full interconnection of the top and bottom contact materials must be avoided.

4.3.8 The laser system must be readily re-configurable to provide laser cuts of width up to 0.1mm, for both the continuous scribe lines and interconnect 'vias' . The beam spot shape must also be readily alterable to give rectangular (desirable) or circular cuts (intended for the continuous scribe lines and 'vias' respectively).

4.3.9 The laser system must be able to produce isolation lines, ablating all 3 material as defined above, without causing shorts between the 3 materials. The width of the line must be up to 0.5mm in width, with isolation above 1mega/ohms @500mm/sec

4.4. Performance Requirements: Patterning Capabilities

The above functions are to be capable of being uniformly applied across the full panel area as follows:

4.4.1 A 'standard' ICP panel of nominal size 930 by 330mm (both dimensions plus/minus 1mm) will need to be patterned over the full area. With the same quality of cut from side to side and from top to bottom.

4.4.2 The maximum active surface area taken between and including the Aluminium scribe line and the TCO Scribe line must be no more than 0.5mm.

4.4.3 The laser machine must be capable of scribing up to 60 line sets in both X & Y axis.

4.4.4 The spacing between each set of line must be variable from 5mm to 30mm in both the X & Y axis.

4.4.5 The spacing between each set of scribe lines must be variable across the plate.

4.4.6 The isolation line as described in (2.9) above must be able to isolate product and produce a border 1mm in from the edge for products ranging in size from 20mm in the y axis (width) and 20mm in the x axis (length) , to a single isolation line 1mm in from the edge of the full plate. It should also be possible to produce various sized-isolated products from one full plate.

4.4.7 The system must be designed, with a control system so the beam can be 'interrupted' during the scribing process. To provide discontinuous laser scribe lines (where required) in order to optimise the patterning process to maintain stage (substrate) translation and therefore throughput speed. This is specifically for the edge isolation requirement as described in (3.6) above and for the a-Si scribe line where the scribing line needs to start 12mm in from the end of the substrate.

4.4.8 The laser patterning layouts will be fully programmable and allow for 'interrupt' of the laser beam.

<u>4.5 Performance Requirements: General Capabilities</u>

4.5.1 The system is to have the capability for auto location via a three-point location system as presently used on ICP's production laser systems. I.e. three pneumatic driven cams pushing against 3 bearings. The system must also include a method that pushes the glass up from the jig to allow easy access to the edges, so the substrate can be removed.

4.5.2 The system should include in-process visual monitoring and inspection.

4.5.3 The system should auto-alert operators to unmanageable misalignment errors (e.g. panel positional errors) or system failures, to minimise production loss.

4.5.4 The system should be targeted at providing 95% availability if used in a Production environment.

4.5.5 The system should be designed for easy loading and unloading of the plate by the operator, with an auto sequence from loading to unloading. The sequence is as follows:

i.) Table moves to loading/unloading position
ii.) The 3 pneumatic cam pushers release the glass and extraction switched on.

iii) The 2 pneumatic glass-raising pushers, raise the glass to allow removal
iv.) The access door (hatch) opens
v.) The substrate is removed by hand
vi.) The next substrate is loaded
vii.) The sequence button is activated. Health and safety issues means it needs to be designed so you can not have one hand on the button and one hand in the way or a sensor within the door closing operation.
viii.) Door closes (these should be sliding doors that are pneumatically driven).
ix.) Glass raising pushers go down.
x.) Cam pushers locate substrate and extraction switched on
xi.) Table move to start position.
xii.) Laser scribing program is activated
xiii.) Laser scribes the substrate
xiv.) Laser program complete
xv.) Table moves to loading/unloading position

4.6. Health and Safety, Environmental Requirements

4.6.1. The system shall be manufactured and operated in accordance with all relevant Health and Safety Legislation. Exitech Limited shall be responsible for ensuring that the system includes all relevant and required interlocks, key switches and other precautions to prevent inadvertent unauthorised or incorrect unsafe operation of the system. Exitech shall provide required training and operation manuals and procedures to ICP personnel or their contractors to allow those persons to safely and effectively operate the system, including patterning redefinition and programming.

4.6.1 The system shall include a filtered extract system to remove dust and debris generated during the laser cutting process. Must catch 99.999%

4.6.2 The system should include facilities for nitrogen cleaning assist (of debris / dust removal) during the laser cutting process.

4.6.3 The system shall be designed to sound environmental principles in order to minimise waste power consumption and environmental impact of generated by-products of the processes.

4.6.4 The systems must be CE marked.

4.7. Outline of the Baseline Exitech System

The following details the key performance characteristics of this baseline system:

4.7.1 The lasers used will be standard high power q-switched Nd:YAG units; two heads will be available with the unit, operating at 1064nm ('red') and 532nm ('green'). In conjunction with the relevant power, repetition rate, focus and other process variables available for control of the laser operation, this will provide full capability for controlled and selective patterning of the required materials layers. It is expected that this will meet the essential requirements for the project and provide a sound basis for development to meet the more ambitious targets.

4.7.2 The laser system must have an auto sequence from the loading to the unloading of the substrate.

4.7.3 Laser beam width and profile will be readily reconfigurable to meet the essential project requirements.

4.7.4 The laser patterning layouts will be fully programmable and allow for 'interrupt' of the laser beam to provide discontinuous laser scribe lines (where required) in order to optimise the patterning process to maintain stage (substrate) translation and therefore throughput speed.

4.7.5 The system will include an optical auto-alignment system to allow accurate and repeatable multi-layer patterning. This will readily meet the essential accuracy requirements of the project.

4.7.6 System s speeds of up to 600mm/s

4.7.7 Being based upon an existing production tool, the system will meet all health and safety and environmental requirements of the specification.

4.8. Typical laser pattern

Note that the amorphous silicon cut starts inside the Tin oxide scribe line and the isolation cut requires an 'interrupt'.

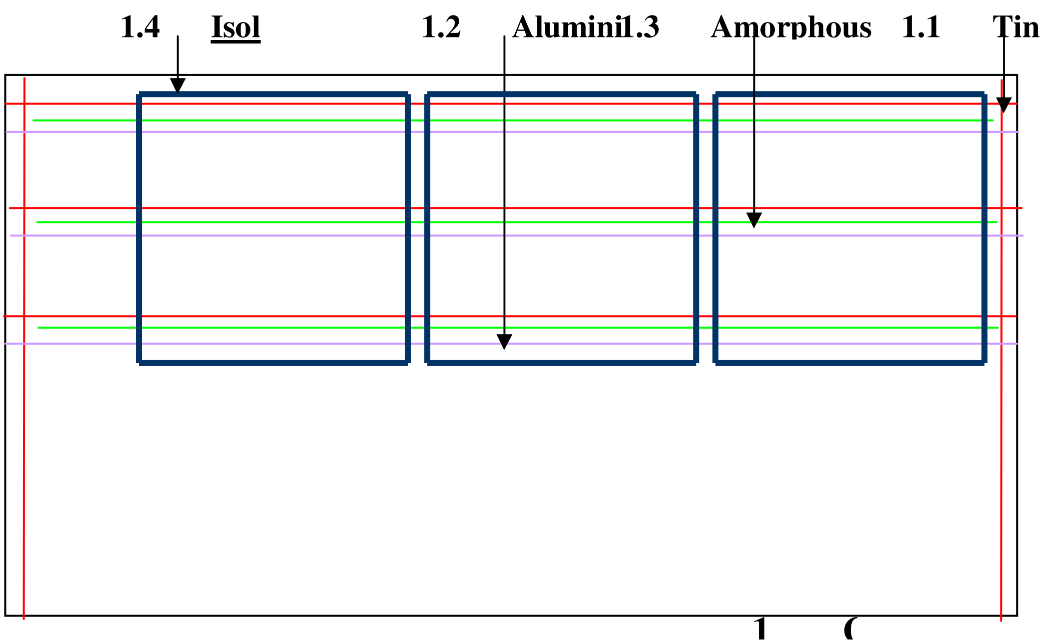


Fig G. Typical Isolation Pattern.

Briefly, the laser operations are:

- Layer 1 consists of the laser scribing with an infrared laser of the ITO insulation lines of the solar cell, and the complete removal of the ITO in 2 bands at the short sides of each panel.
- Layer 2 consists of the laser processing (with a green laser) of interconnect holes in the a-Si layer.
- Layer 3 consists of the scribing of isolation lines in the top metal layer, with the same green laser.
- Layer 4 consists of a final isolation scribe of 2 mm wide around all four edges of the panel, removing all ITO, silicon and metal. This is done with the 1064 nm wavelength laser.

<u>4.9 General machine characteristics</u>

The laser tool built for the Electra-Slate project is a member of a family of existing laser tools designs, designed specifically for laser patterning of ITO, silicon and metal thin films on thin glass and other substrates, using single or dual x-y galvanometer scanners combined with x-y flatbed stages. The tool design can accommodate panels up to 0.33 m × 0.93 m in size, but can be upgraded with a larger chuck if required of size 0.66 m × 1.30 m.

4.9.1 Scribing process

The tool scribes the lines not with a stationary focused laser beam and fast x-y stages movement and beam splitters, but instead with an x-y galvanometer scanner and flat-field focus lens. This device is capable of scanning the laser spot at speeds of up to 5 m/s over an area of approximately 100 mm × 100 mm. The motion of the x-y stages (which can be comparatively slow) is synchronised with the galvanometer scanner and the laser firing pulse generator. The advantage of this method is that there is no longer a need for very fast large x-y tables and complex laser beam splitting. The tool has two lasers, (infrared and green), and two completely separate beam lines and x-y galvanometer scanners, one for each laser.

4.9.2 Control software and process

The tool features an optical height sensor, which measures the thickness of the plate prior to the scribing process, and brings the laser focus to the correct height before scribing is commenced.

The tool also features an inspection camera with microscope objective which allows precise alignment to marks that are written in the ITO layer in two of the corners of the glass sheet, during the same process that cycle the scribe the lines in the ITO (layer 1 process). A fully automated routine stores images of the marks into the computer, recalls these when the plate is put back onto the machine for the layer 2 process and aligns the layer process lines. The same happens again for layer 3. In this way it is possible to locate the 3 lines in ITO, Si and very close together. Currently ICP’s separation of Isolation lines spans some 3mm. By being able to reduce this span to less than 1 mm we gain approximately 10% plus gain in active cell area.

The control software is written in a modular form using a special scripting facility is available to write bespoke patterns for any layer using simple G-code commands. It is possible to upgrade the machine with software (such as AlphaCam) to be able to handle CAD files directly and generate G-code automatically.

All relevant processing parameters can be controlled, such as: scribing speed, separation between ITO, α-Si and metal scribes, cell size (i.e. separation between each group of ITO/α-Si/metal scribes), isolation line width. There are also a number of different possible layouts, ranging from simple single cell configuration to multiple 'Electra-Slate' panels. The pages within Appendix B. give an overview of the control software by means of screen capture images of some of the control software interface.

Below you can see an overview of the Electra-Slate tool, with operator panel (right) and control cabinet (background, right). The laser power supply and extract unit are located to the left behind the main tool enclosure.

Fig H. Electra-Slate Laser Tool in Enclosure cabinet.

View inside the tool. Visible are the two lasers (extreme left and right), chuck on x-y stages with loaded panel, and two scanner heads.

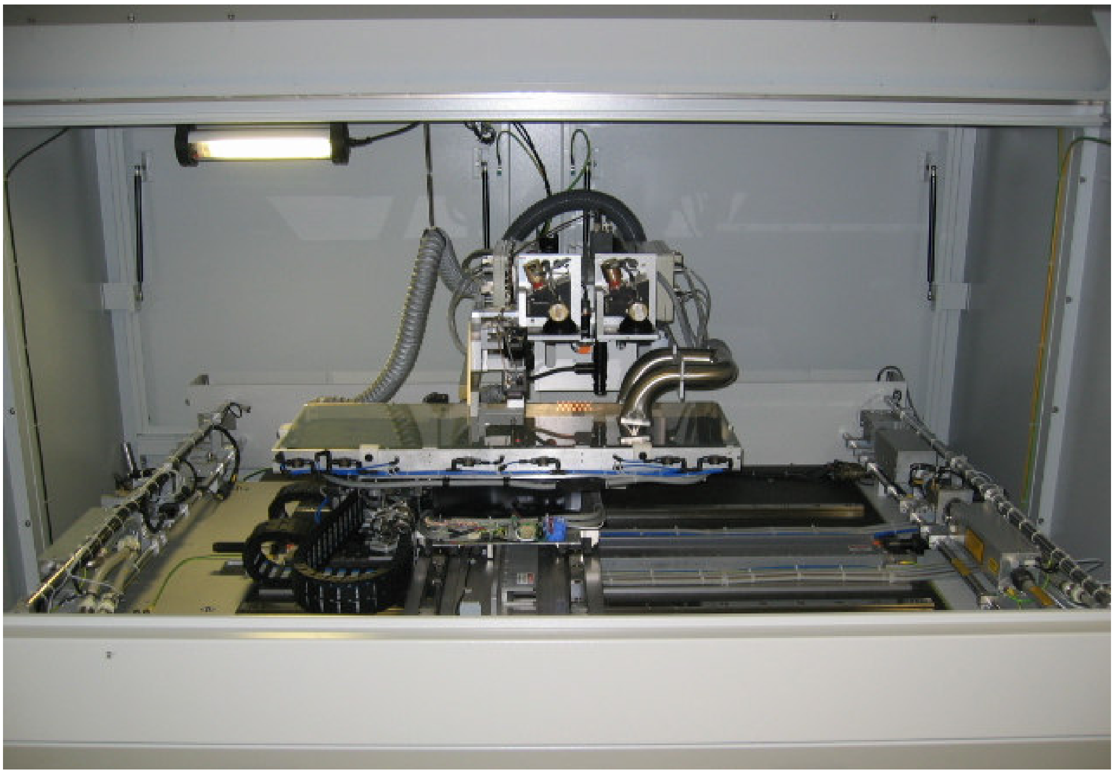


Fig I. View Inside Enclosure.

View inside the tool with scanners. Visible are the two lasers (extreme left and right), chuck on x-y stages with loaded panel, and two scanner heads.

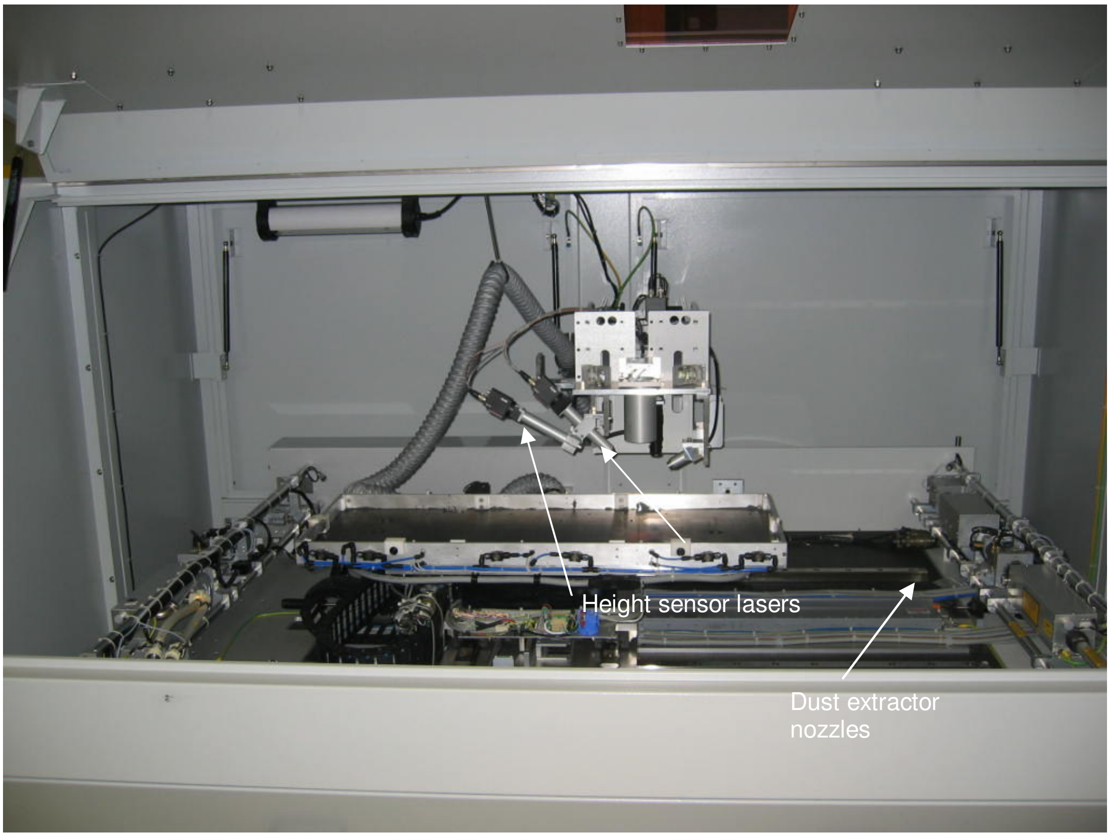


Fig J. View inside the tool with fixed lens.

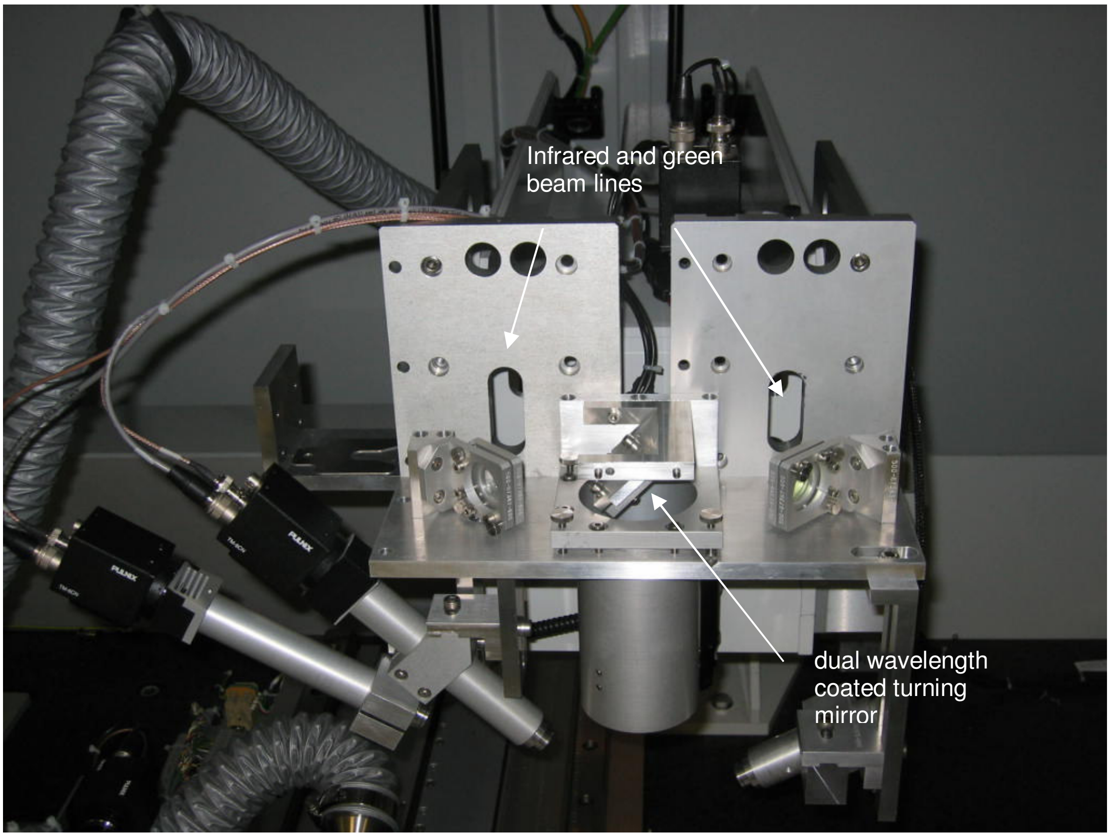
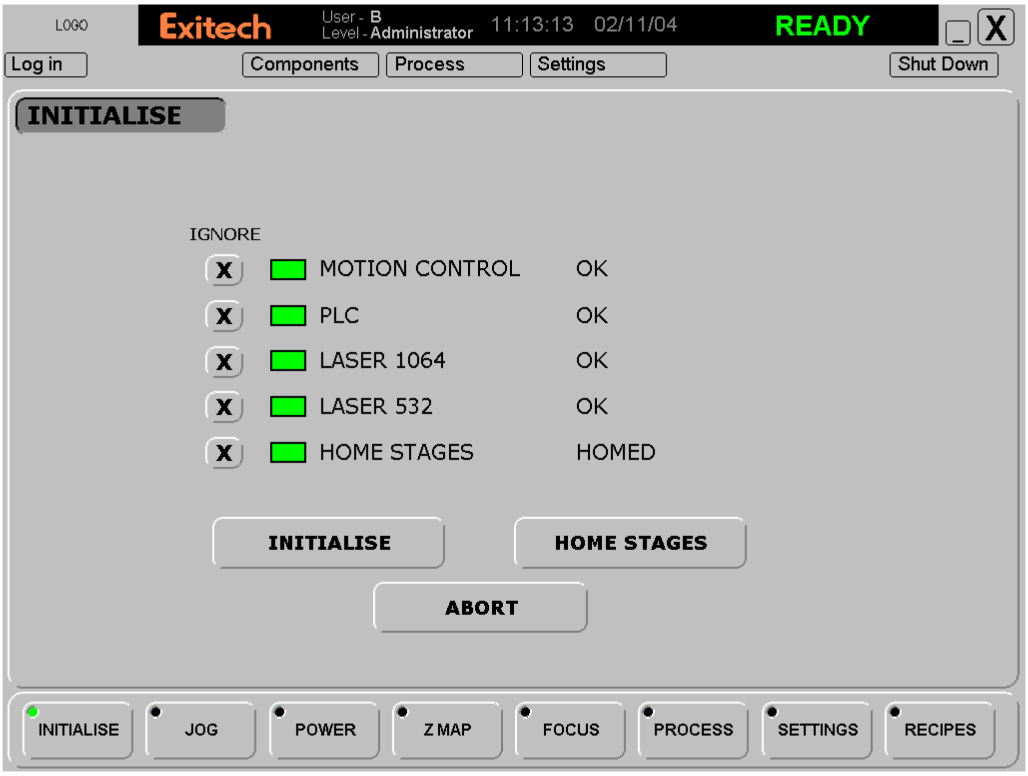
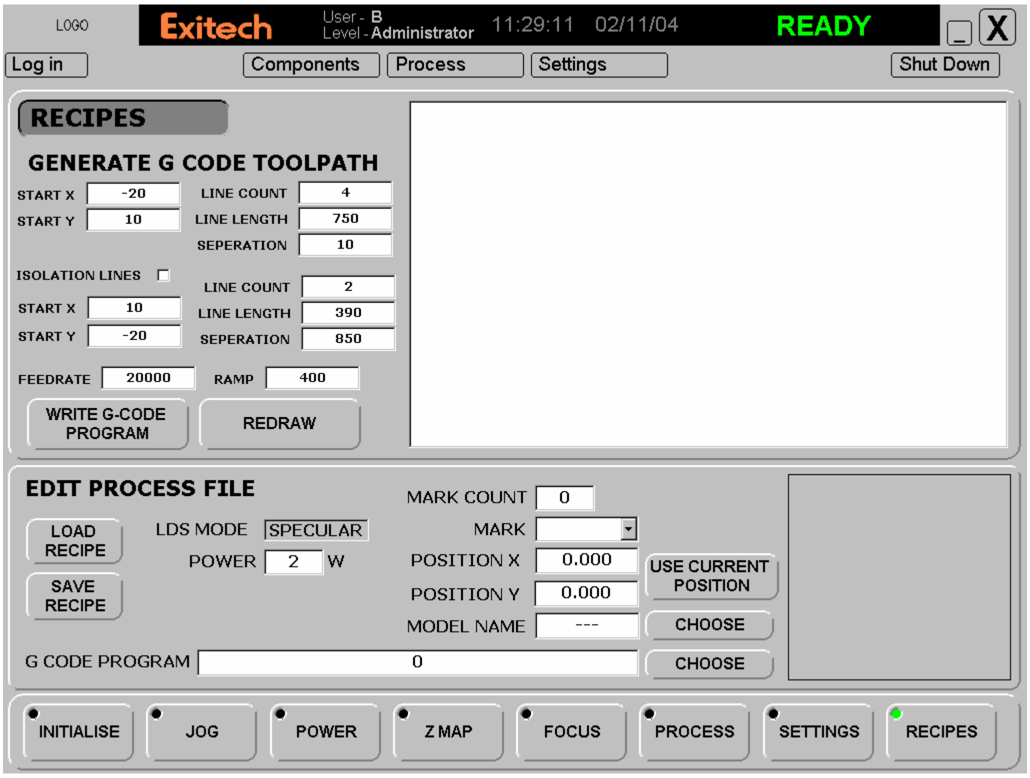


Fig K. Close-up of modified machine with fixed lens.

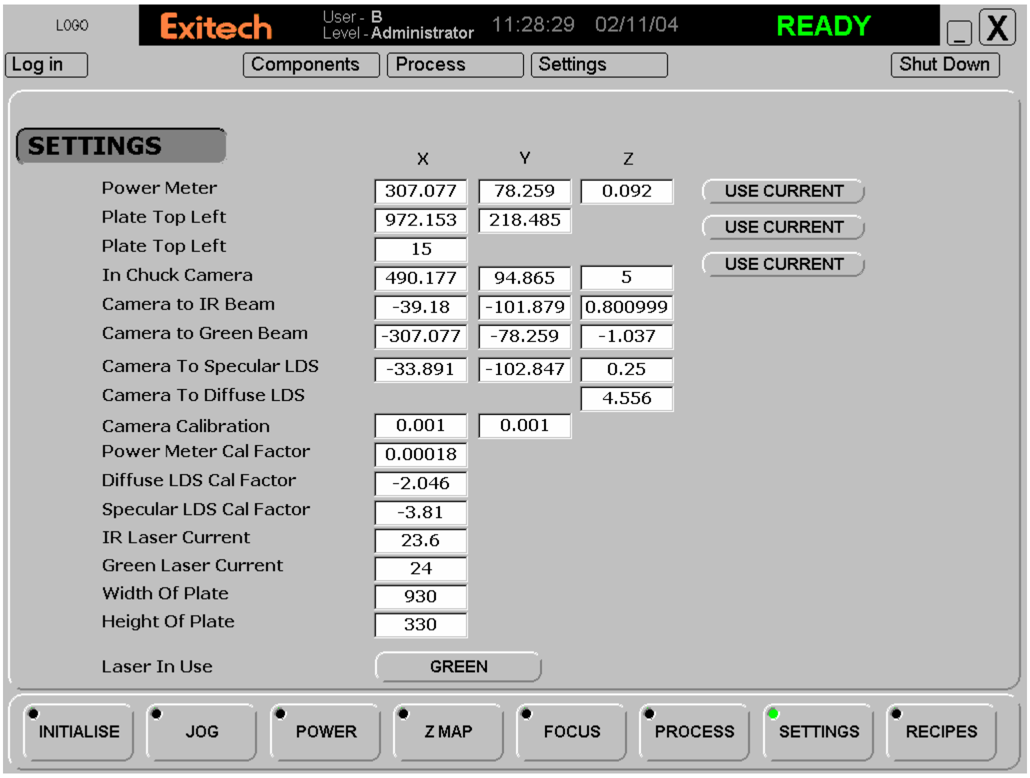
Software screen shots of software for use with fixed lens

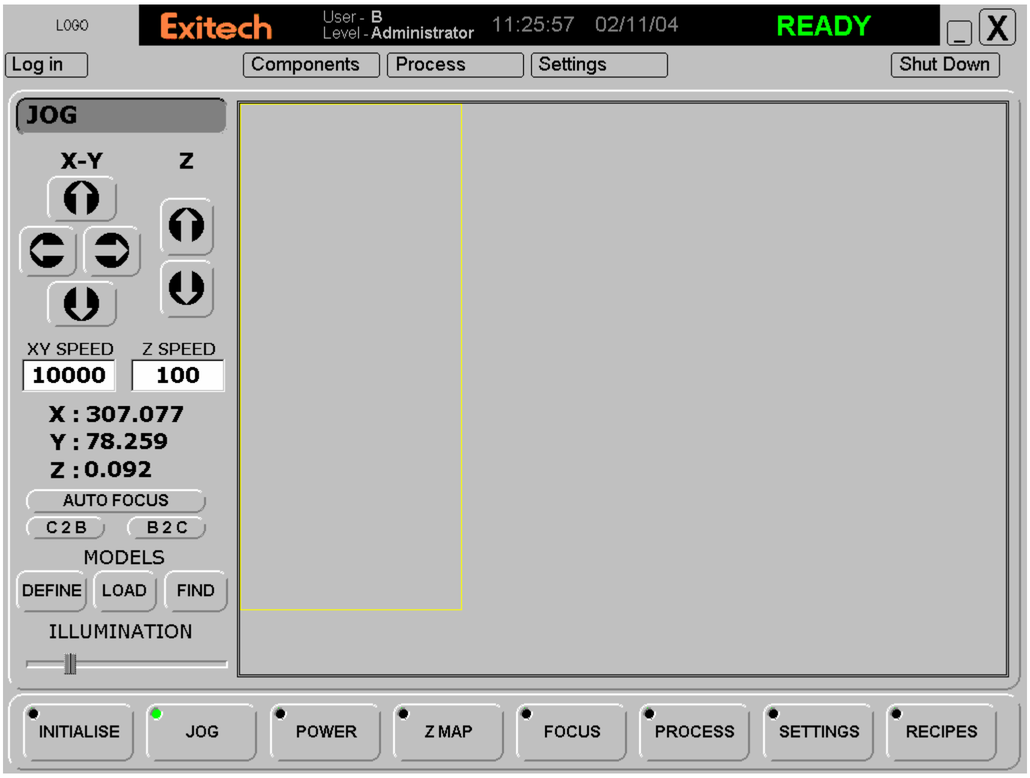


Top level menu of the control software. The four buttons on the left column initialise the tool (top button) and carry out each of the four scribe ‘layers’.

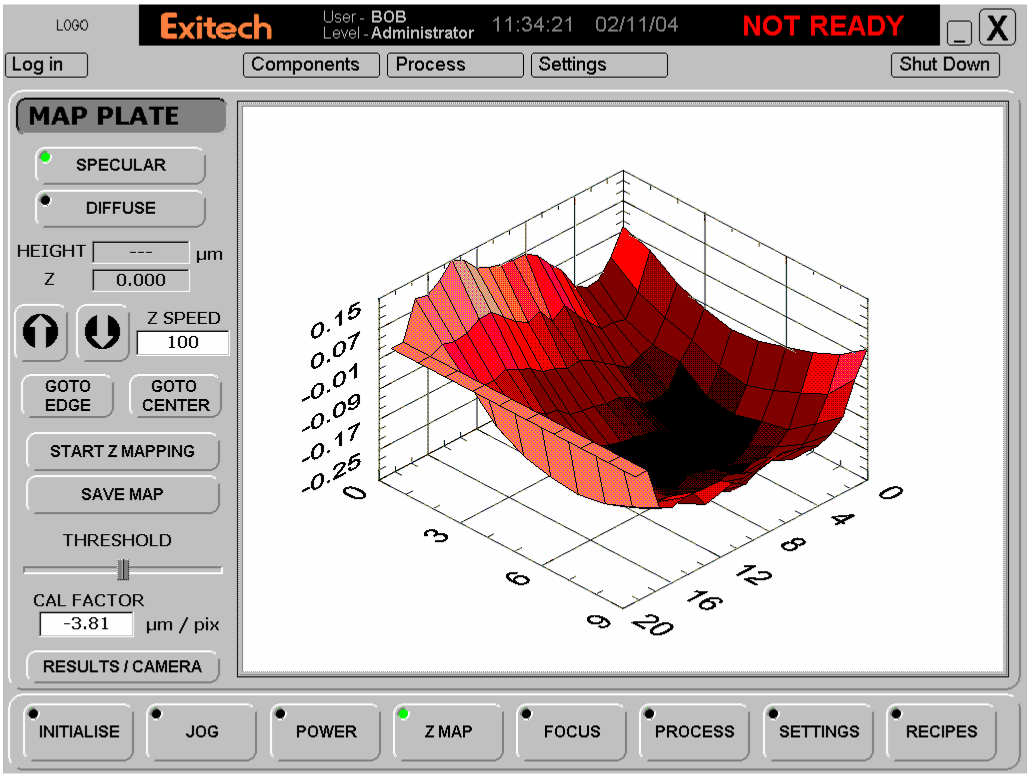


Recipe screen for laser tool path generation

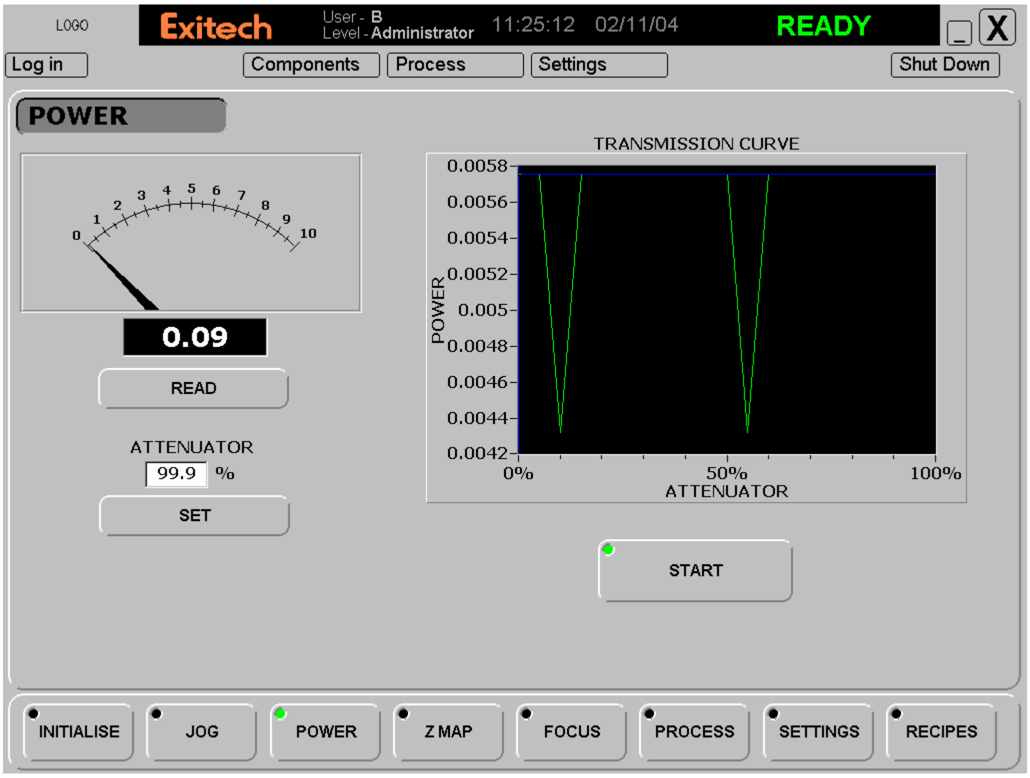




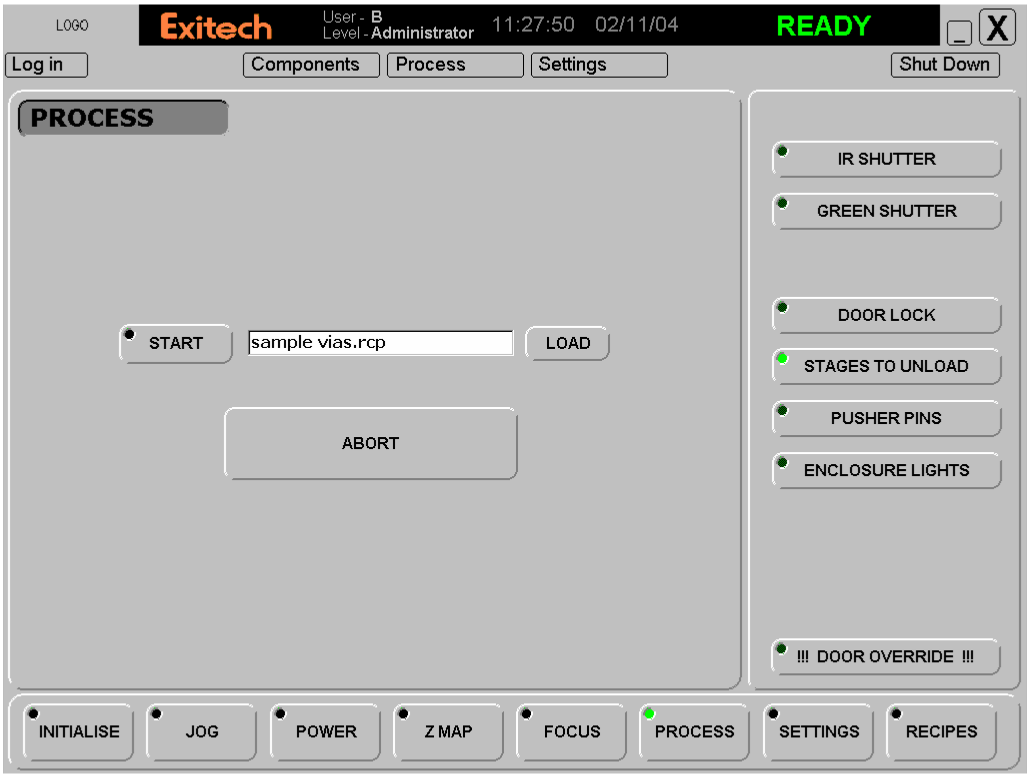
Jogging screen



Screen for height sensor and height profile mapping

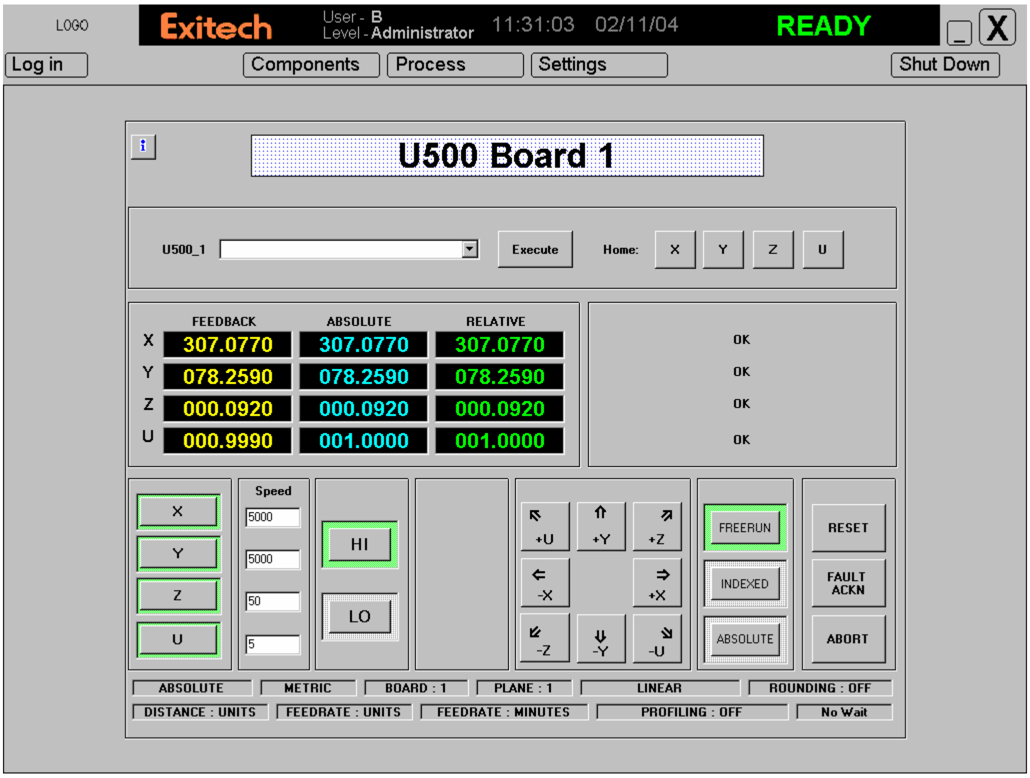


Screen for calibrating power meter and attenuator settings, and setting of laser power for process

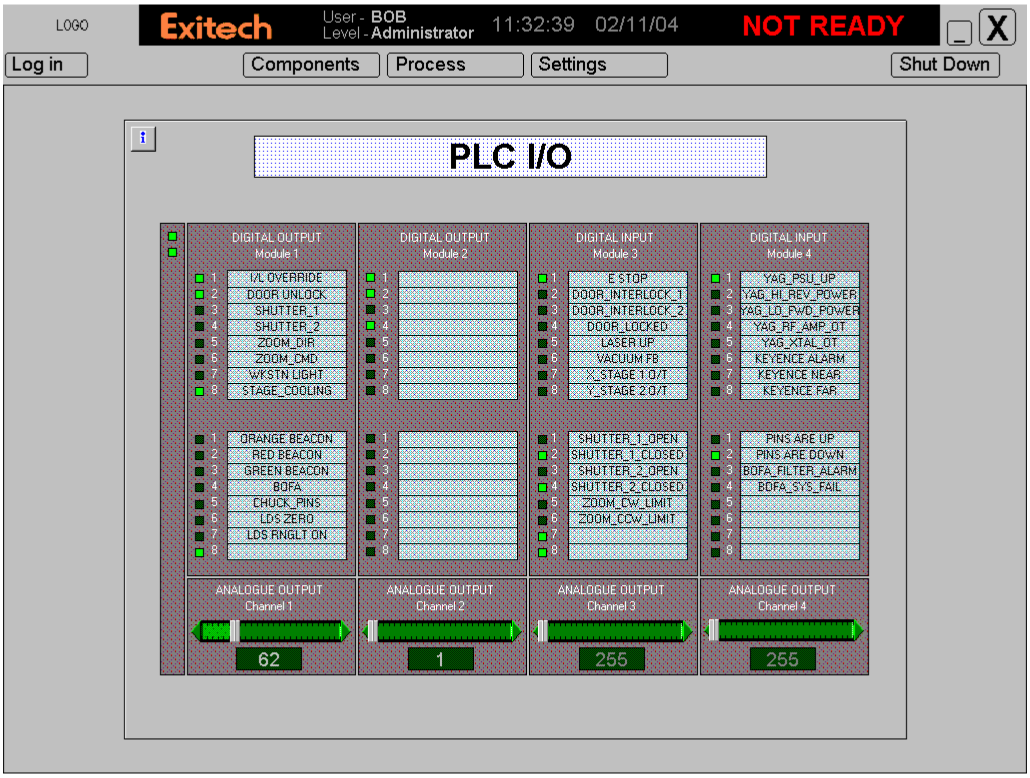


Screen for running process.

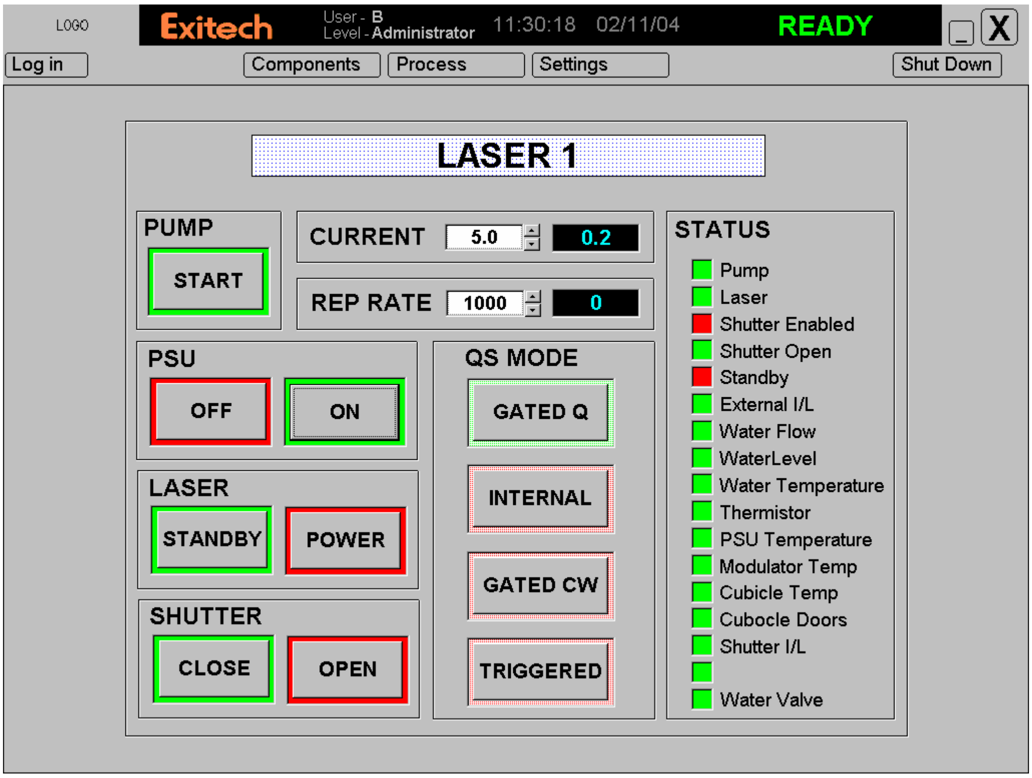
Screen for automated finding and setting of laser focus.



Screen for direct motion controller access (Aerotech Unidex 500 board)



Screen for direct PLC control



Screen for laser control. There separate screens for the infrared laser (laser 1) and the green laser (laser 2).

4.9.4 System Test and commissioning.

A series of Tests were specified by ICP in order to prove the capability of the tool when compared to the specification. The tests were primarily designed around producing patterns on active plate that would both prove the materials handling capability and Laser scribe effectiveness.

All processes took place with the active layer away from the laser, facing down onto a box-section chuck, which collects the debris through an extractor unit. The laser beam therefore traverses the glass first, before ablating the material.

4.9.5 Layer 1: TCO scribe.

Full panels were provided with LOF TCO, and isolation line scribing tests conducted in order to establish processing quality and processing speed. Quality is primarily determined by electrical isolation across a scribe, using an ohm meter.

The TCO scribe requires the use of the 1064 nm wavelength (near-infrared) fundamental mode Nd:YAG laser. When focused, the laser spot is approximately 40 μm which will limit the maximum process rate to about $12x10^3$ mm/min, given the maximum laser pulse repetition of 10 kHz and the minimum required spot overlap in order to form a continuous line.

There is, however, significant excess laser power for such a small spot size, there being enough power to move the work piece out of focus by about 1 mm, thereby increasing the effective spot size to approximately 200 μm, and therefore increasing the processing speed to 60x10^3 mm/min, which is well above the required rate of 30x10^3 mm/min. Average laser power under these conditions is 15 W onto the work piece. Isolation values of over 20 Mohm were achieved, which are acceptable.

Figure L. shows a typical example of a fast TCO scribe, produced with an out-of-focus spot and with high resistivity (> 20 Mohm).

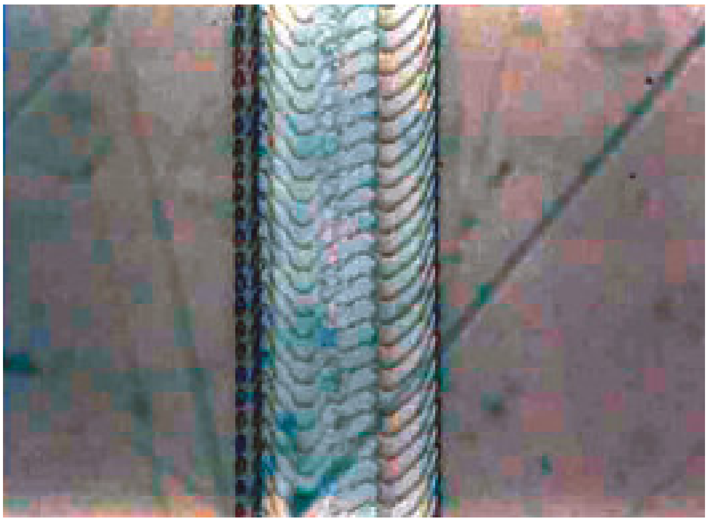


Fig L. TCO Scribe.

4.9.6 Layer 2: α-Si interconnect vias.
Full panels were also provided with a functional α-Si layer LOF TCO for via drilling tests. The functionality of the vias cannot be tested at Exitech, although visual inspection with a microscope gave a good indication of the functionality, by assessing the . α-Si removal in transmitted light (the TCO being transparent, but not the α-Si).

The via drilling process requires the use of the frequency doubled, 532 nm wavelength (green, visible) Nd:YAG laser. The process takes place through the glass and the TCO layer, both of which are highly transparent to the green light and therefore suffer no damage.

The trials were conducted with a 2 mm aperture in from of the focus lens. This results in a more precisely defined, larger laser spot on the work piece but has however the consequence of a loss of laser power on the work piece compared with simple focusing. The loss is about 50%.

When focused, the laser spot is also approximately 40 μm which yields a maximum process rate to about 36x10^3 mm/min at an interconnect pitch of 60 μm, which is acceptable.

Continuous interconnect lines can also be scribed, but at a lower speed depending on the pulse overlap. At an overlap percentage of 33% (i.e. the next pulse covers one-third of the previous pulse) the processing rate is reduced to approximately 27x10^3 mm/min.

Figure 2 shows a typical example of a continuous interconnect scribe, produced at a scribe speed of $10x10^3$ mm/min and a laser power of 0.8W on the work piece.

Interconnects produced on the tool at Exitech were assessed by ICP Solar and found to be acceptable.

4.9.7 Layer 3: aluminium isolation scribe

Full panels were also provided with a functional aluminium layer on top of the α-Si and TCO for via drilling tests. The functionality of the scribes can be tested at Exitech, using an ohm meter as for the TCO scribes.

The process parameters for the aluminium isolation scribe are identical to those needed for the interconnects in layer 2. The explanation for this is that the α-Si and aluminium layers are both very thin (< 100 nm). The laser hits the α-Si layer, which ablates and simply takes the aluminium with it.

Good isolation values were obtained under the same conditions as the continuous interconnect lines of layer 2. The achieved scribe speeds of up to $27x10^3$ mm/min are below specification, the prime reason being low laser power due to the 2 mm aperture. If the aperture is removed, the laser power on the work will double, resulting in a 40% increase in spot size and hence a 40% increase in scribing speed, bringing it within acceptable range.

Layer 4: isolation scribe through layers 1, 2 and 3

The same panels as for layer 3 were used to carry out scribing tests of wide isolation lines through all previous layers. These scribes were tested with a 'Megger' test device to test for good electrical isolation at high voltage (2 kV).

This process requires the use of the 1064 nm fundamental mode Nd:YAG laser, under conditions that are very similar to those of layer 1. This is because the laser ablates the TCO, taking the α-Si and aluminium layers with it. This is an efficient process, given that the TCO is approximately 70% transparent to the laser radiation, while the combined Al/ α-Si layers absorb the remaining radiation fully and therefore ablate very efficiently.

Wide isolation lines (up to several mm wide) are produced by scribing multiple lines close together, and acceptable isolation values have been obtained.

The tool has been shown to be capable of the basic machining requirements of the four process layers, at the required speed. In trials carried out in conjunction with ICP the results have proven the tool to be capable of meeting the specification laid down by ICP Solar Technologies at the outset of the project.

5.0 Develop Moulding Techniques for Higher Specification Materials.

When the concept of the Electra-Slate was evolving the Intersolar group looked at various options for interconnection of the slates to the balance of system equipment based upon the then definition of 12v dc single junction amorphous silicon active area of the slate. The fundamental connection of these plates required that the slates be connected in parallel strings, such that the individual voltages of the slates were kept within the ELV directives for connection of DC voltage systems. Thus the current of the individual slates being added to provide a maximum power output from a string of Slates.

The rational behind the Electra-Slate 1 was that it should be a product that is easy to handle and easy to fit. It should be no more complicated to install than a standard roof slate.

To this end the inter-connecting mechanism was designed to be an integral part of the tile thus making it almost impossible for technically untrained personnel to wrongly connect the system.

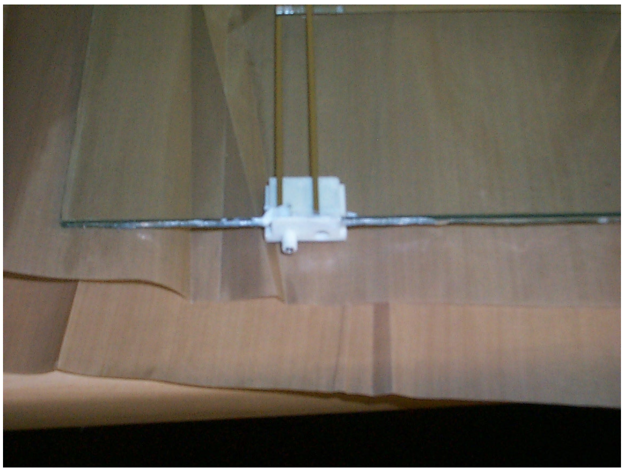


Fig M. Prototype Connector

The connector design on the original Electra-Slate performed this task well. It was fixed to the slate in such a manner that it made connection as simple as placing and lining up the slates with each other and then giving a gentle sideways push to mate the two connectors. It also served to keep the alignment of the slate rows.

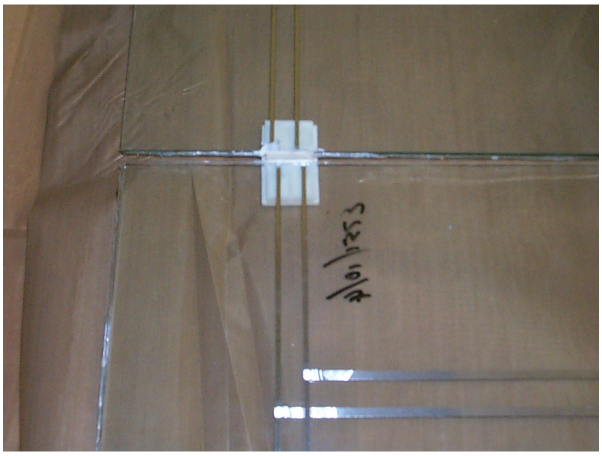


Fig N. Prototype Connector Mating.

The connectors were soldered to the internal wiring bus and then glued to the slate. Finally they were sealed with a silicone compound. This design of Slate was used for a demonstration roof system implemented with Persimmons homes as pictorially shown in Figures D, E and F.
However, review of the manufacturing process and installation feedback from the roofing contractors showed that the design did have significant drawbacks.

1. The internal wiring required during production of the slate was time consuming and therefore added to cost.
2. The connectors proved susceptible to damage from knocks and cracking whilst on site and during installation.
3. In the event of a single slate element needing replacement a whole string of the tiles would have to be uncovered and lifted to enable one slate to be replaced.
4. The numbers of connections made were unnecessary, plus if one connection were lost through individual failure the whole string of Slates would also be rendered inoperative.

Outside of the demonstration roofing trial, Intersolar also submitted the product for ISPRA qualification to IEC 61646. Testing of the Product through accelerated Life time tests indicated that the connectors were prone to yellowing in colour, cracking and deformation of the terminal connections. This proved to be a major part of the product failure at these tests.

Intersolar had as a result a radical re-think about the interconnection methodology. Electra-Slate 2 was designed with automation in mind, such that it was desirable to re-design the connector assembly whilst retaining the functionality and ease of use of the original Slate design.

During project meetings a number of important decisions were made.

To reduce lay-up time and complication the internal bus wiring would be removed and the bus would instead run within the body of the new connector.
If it became necessary to remove the slate from a row, for any reason, it would be desirable for the connector to remain in place thus retaining the electrical integrity of the string.

The new connector assembly would be two-piece consisting of a small connector box fitted to the back of the slate, and the main body which plugs into the box. The tapes from the plate will be laid internally within the laminate and then emerge from a hole cut in the backing glass. The small connector box was to be fitted over the hole, the tapes are fixed to internal connections within the box and then the connector is glued to the glass.

The main assembly, which contains the bus connections, plugs into the small box and is held in place by clips. The body was to be fixed to the glass using a double-sided tape. This, allied with the clip design, would allow easy disconnection when the slate was pulled away.

In the original connector design circular pins and receptacles were used. The new design, initially, utilised a blade type connector. Intersolar believing that this type would be easier to fabricate including the internal bus bars.

The connection box on the slate back has two male pins fitting into two female on the main body, the reasoning being that if the slate is removed the sockets remaining on the main connector will be less prone to moisture ingress.

The resulting proposed design of the interconnecting Busbar Housing and connector box were per below:

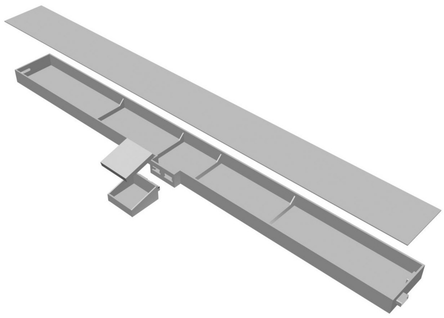


Fig O. Prototype Housing Model

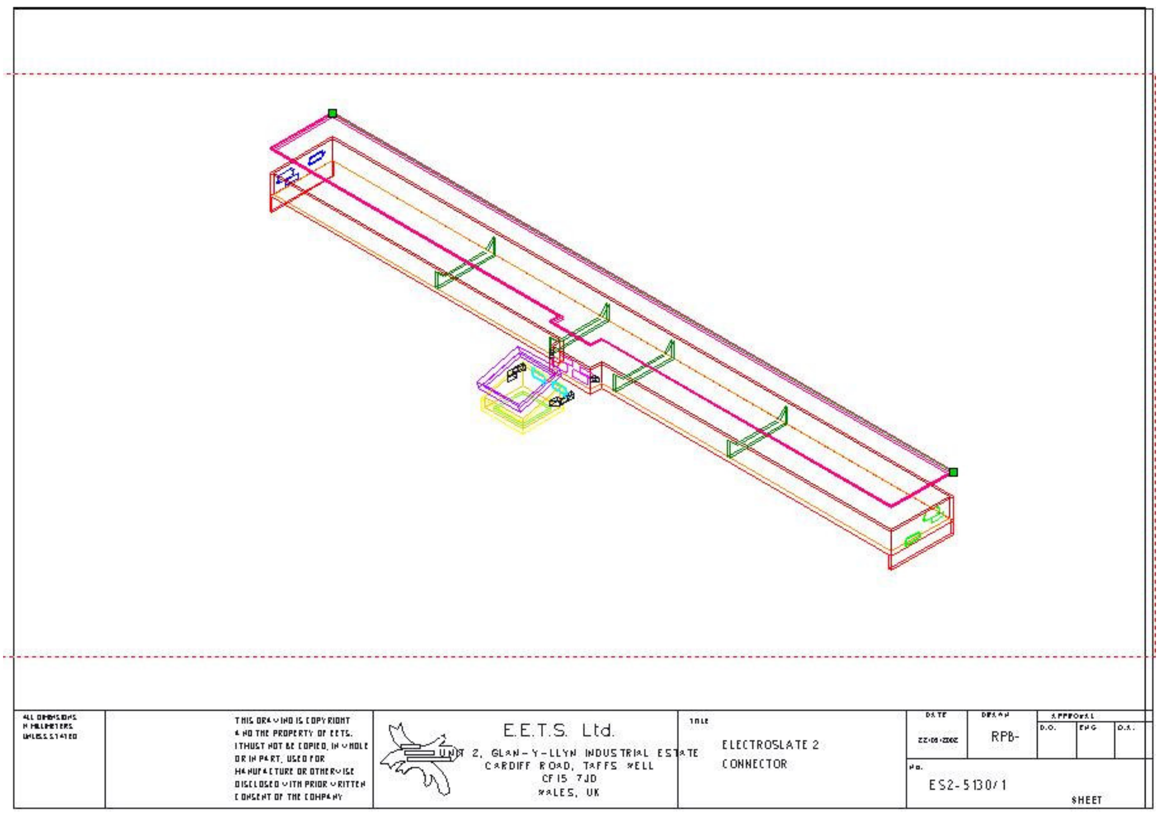


Fig P. Line Drawing Housing Model

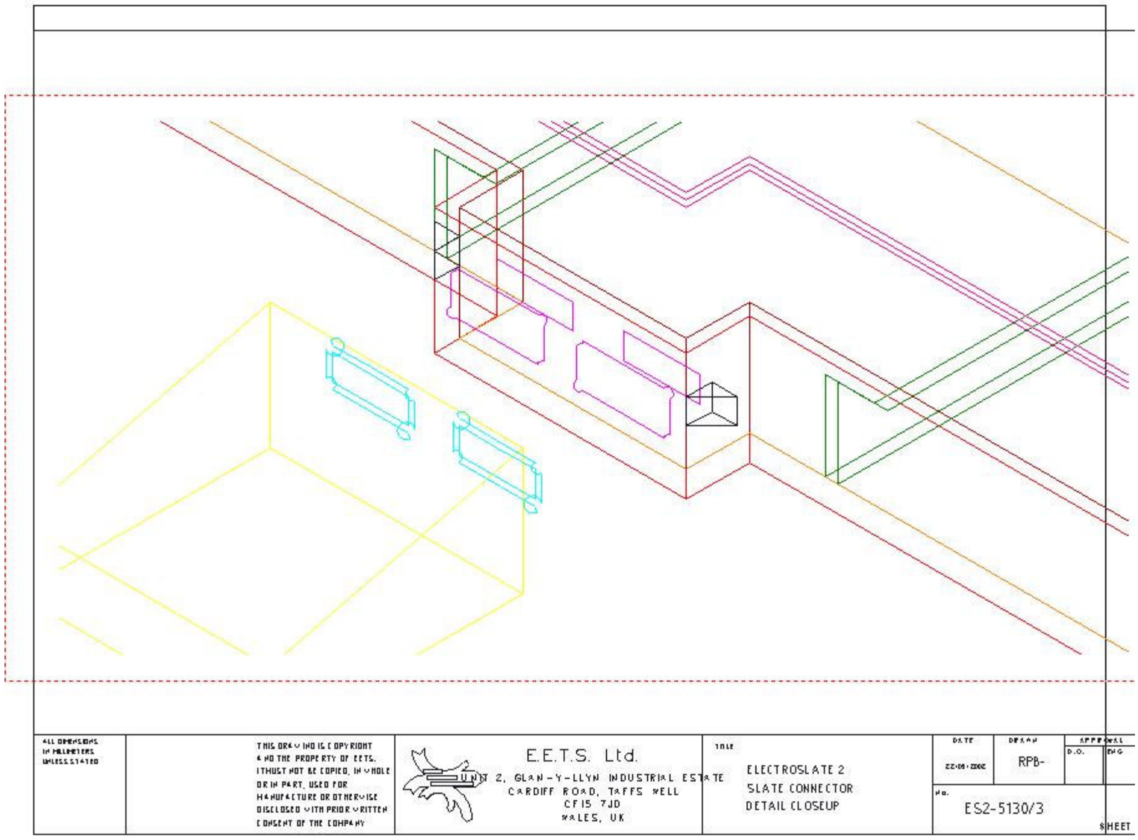


Fig.Q. Housing / Connector Mating Prototype

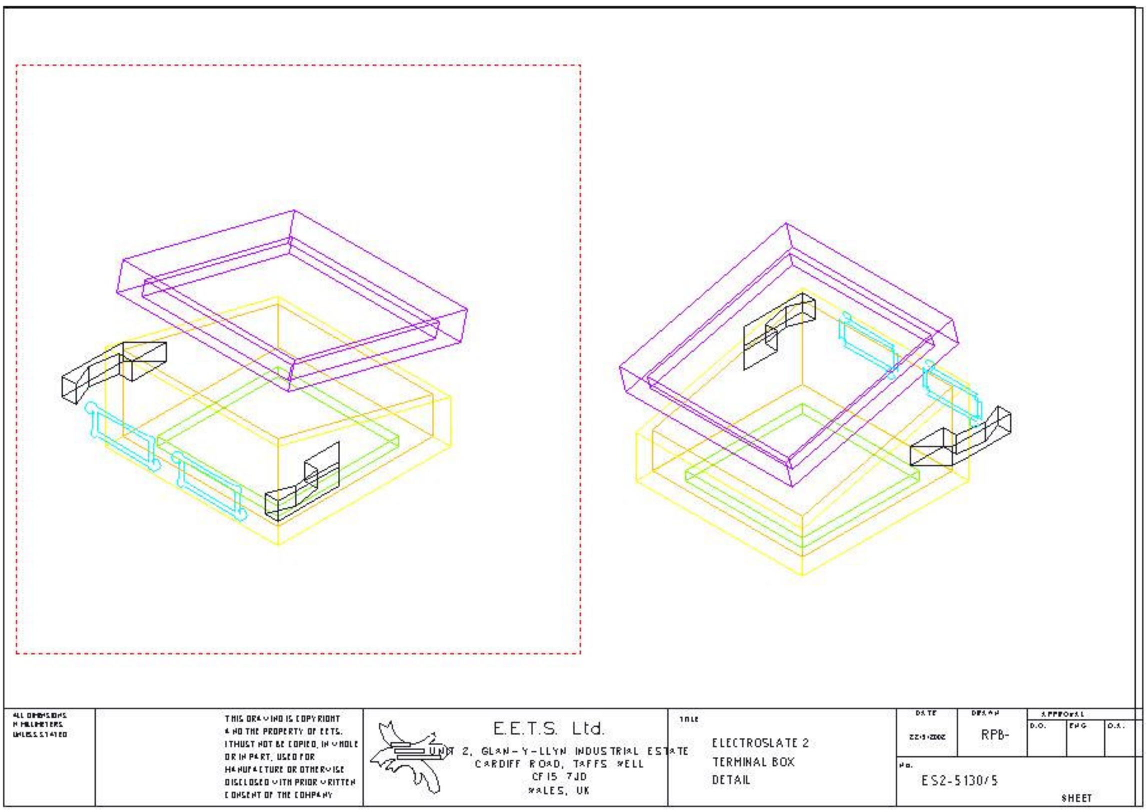


Fig R. Prototype Connector Box. (exploded)

Although some rapid Prototyping was carried out at Cardiff University the resulting prototypes still had inherent drawbacks that the company felt needed further research and testing work carried out upon. It was at this point that Intersolar decided that an outside perspective on the solution was required and turned to UK based injection moulding specialist.

This company specialises in the automotive sector specifically over-moulded connectors, which is a very tough environment for power connectors to operate in. They had as a result the industry knowledge for large scale manufacturing of connectors for tough environments and at that time brought about a rapid design and prototyping phase to the project.

Initial Prototype Connector Boxes were designed (as shown fig S.) in order to meet the re-designed specification of power collection from within the slate.

Fig S. Initial Integrated Connector Prototypes

The fundamental busbar interconnection method remaining as it had been previously. Testing was undertaken to ensure viability and robustness of the terminations.

The first set of trials carried out simply looked at the conductive properties of the conductive ink-foil-connector interfaces. The results of which showed an acceptable resistance value of 0.2 ohms if the surface was clean or a knife-edge contact was made, if not the resistance could be as high as 4 ohms. This led them to conclude that the best way forward was to design the connector with a knife edge contact. Having completed this test they set up a bench test so they could cycle the contacts between -15c and +100c to establish whether the contact breaks down. The set up of this test is shown below. The results of the test indicating that this method required augmentation of the knife edge contacts required by either use of a conductive adhesive or Soldering, as at temperatures of 100 degrees the thermal expansion of the materials could lead to intermittent contacts.

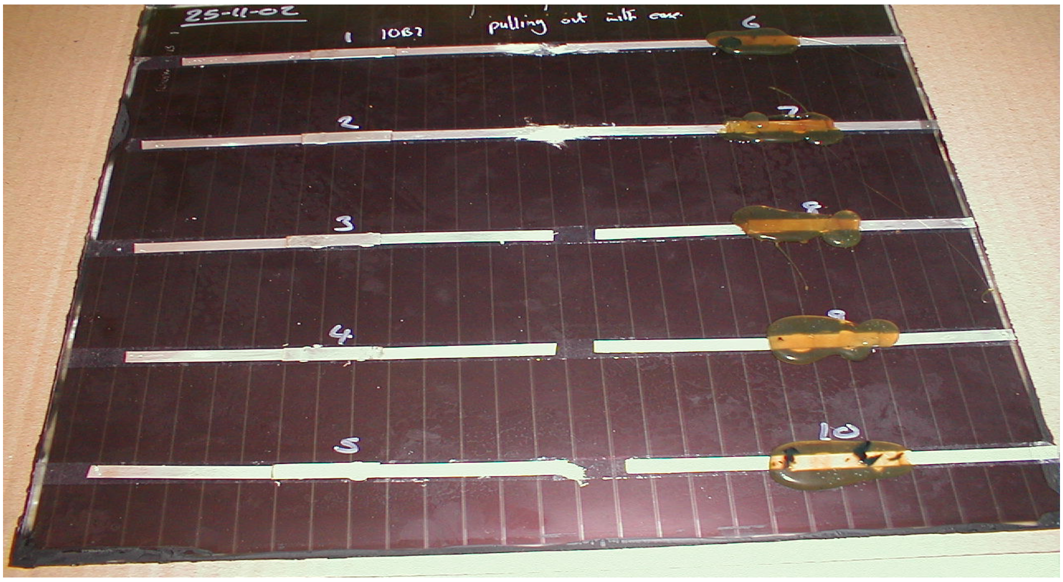


Fig T. Contact Trials

Fig U. First ES III Prototype

Further trials were then set up to establish that there was good adhesion of the plastic to the glass during lamination and that the hole was sealed. To test this they mocked up a connector and laminated it onto the back of the glass. Contact was made through the hole drilled in the backing glass. This showed very good adhesion to the top of the glass and down the sides of the hole and the principle of EVA lamination adopted as the preferred method of connector box installation.

Unfortunately at this point in the development cycle The Intersolar Group went into liquidation and the project work stopped in approx. December 2002.

5.1 Project Continuation under ICP Solar Technologies (UK) Ltd.

In April 2003 just after ICP purchased the assets of the Intersolar Group a proposal was presented to the DTI for re-instigation of the Electra-Slate project. ICP believed that the original goals and expectations given in the Intersolar project proposal still rang true and presented ICP with the opportunity to take this product from the drawing board into full and profitable large-scale manufacture.

In October 2003 ICP received final confirmation that the project proposal had been accepted and all contractual issues that had arisen had been resolved. ICP fully reviewed the project outputs under Intersolar and instigated a few fundamental changes to the design.

1. The Busbar designs as had been, were shelved. ICP has an Asian subsidiary that has access into the very competitive world of injection moulding. This opened up the opportunity to gain cheap prototype parts in short time without costly tooling pricing and long lead times as being advised in the UK. As a result, the fixed and moulded Busbar assembly gave way to a flexible loom type arrangement with connections incorporated along its length. This type of design lends itself to the use with the E-slates, by virtue of its simplicity, robustness and ease of connection into marshalling and balance of system equipment.

2. The design of the on slate solar panel connector although retained in principle was modified to incorporate a user friendly connection method that could be utilised by anyone without specialist training or additional fixings to the roof or baton structure.

ICP looked at the design of the connector as it stood and re-opened discussions with the UK injection moulding Company as to making changes to the design of the connector box.

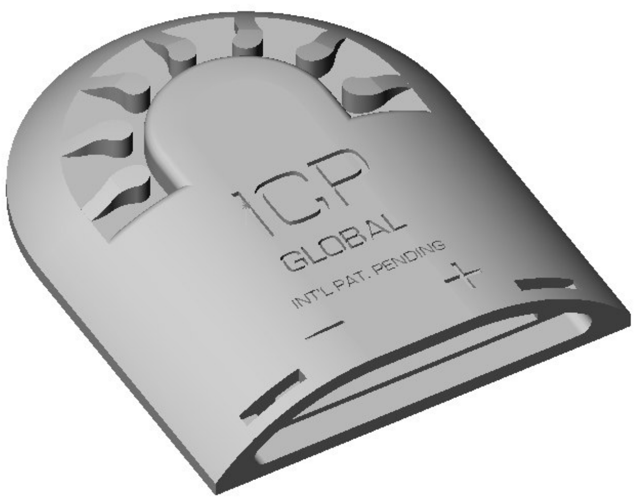
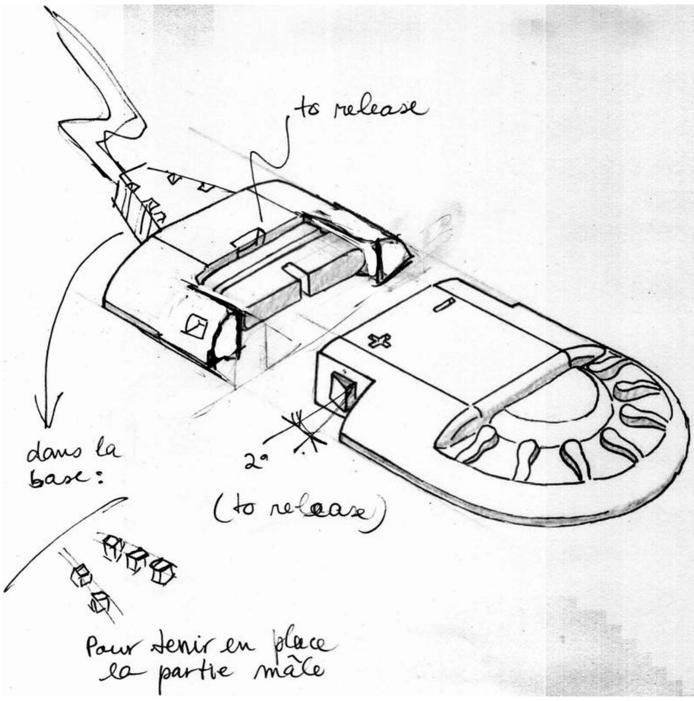


Fig V. ICP Integrated Connector box Prototype.

As discussions progressed the concept of the connector box evolved with input from the collaborative partners and their contacts in the roofing industry. The design remit to provide both a slate connection method but to marry this to a Male connector that could lend itself to incorporation into a loom and possible further system expansion.



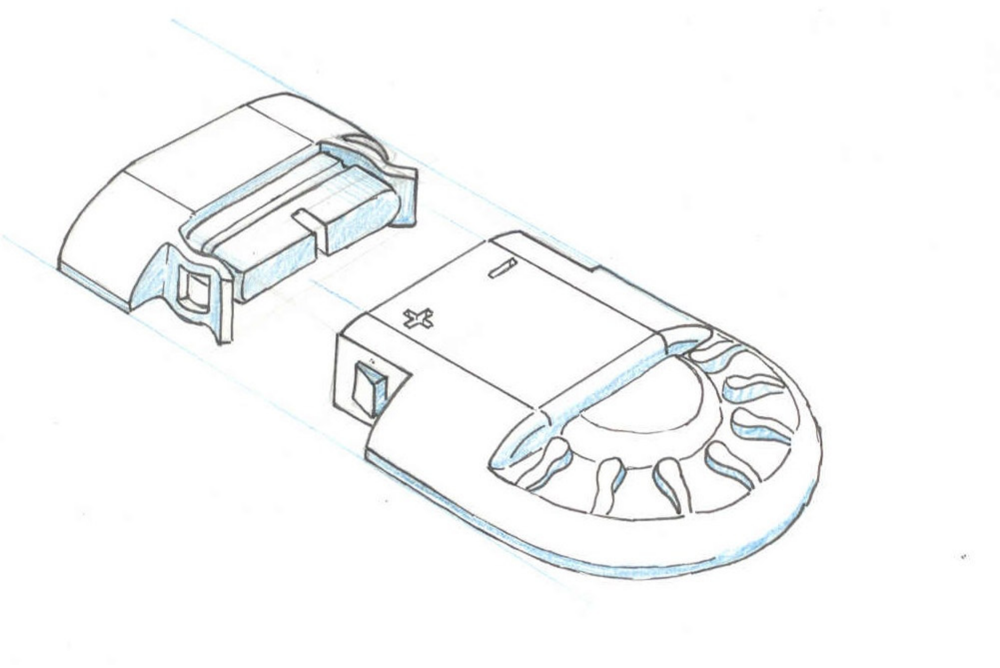


Fig W. ICP Design improvement Sketch.
Fig X. Further Development Sketch

As the design phase reached it's conclusion and tenders were put out for tooling and piece part costs, it became apparent to ICP that the costs of using the UK company Waldon for series tooling would be considerably more expensive than utilising the opportunities afforded by ICP's Asian arm.

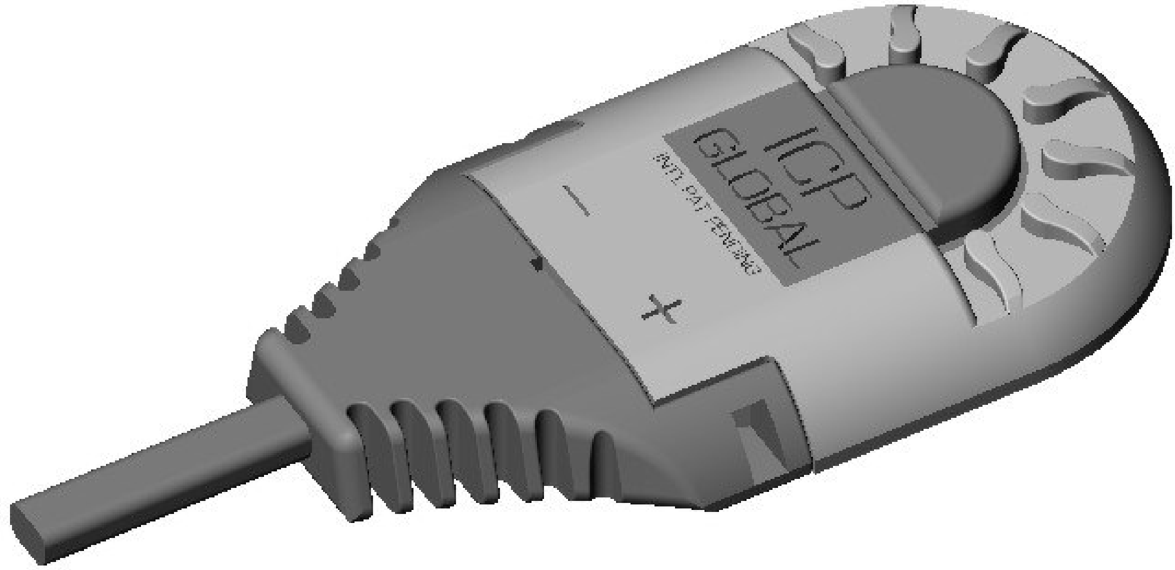


Fig Y. Final Design ICP Integrated Connector assembly.

During final quotation stage for series tooling for the above detailed connector box and male plug definition, the UK company were seen to be considerably more expensive then their Chinese counterparts for series tooling with the piece part prices being comparable to UK quoted costs across all stipulated volumes. A difficult decision was therefore made to continue development and sampling with the Chinese vendors.

With samples of the connector boxes in house ICP began re-visiting the method of busbar connection within the connector box. The intent of the Intersolar group had been to utilise a conductive adhesive compound to augment the connections to the aluminium busbar tape and thus reduce reliance upon abrasive soldering methods.

Exhaustive trials with potentially suitable compounds did not provide a satisfactory joint which proved to be reliable enough to provide a robust electrical joint that could be introduced into a product with a planned 20 year warranty.

The connector box had been specifically designed to allow access to the contacts for electrical connection so that the eventual adhesion/soldering process could be carried out. The type of soldering currently employed by ICP with Aluminium busbars is of the abrasive type method without the use of a flux.

This soldering method would not work with the tin plated contacts of the connector box and the aluminium busbars of the slate. Thus a suitable flux had to be found to undertake such a method of connection of the power carrying conductors.
After a series of trials with various flux samples, an aggressive flux readily commercially available was identified that would allow the fusing of the two materials of aluminium and tin-plate using a conventional tin lead solder.

Exhaustive trials have been carried out mirroring the tests conducted by Intersolar and the results indicate a strong and reliable connection that can reasonably be expected to last the planned life time of the product, regardless of the naturally occurring environmental conditions placed upon the product in service.

6.0 Development of Busbars and interconnections.

The Electra-slate will be operated at a voltage under that specified in the EU Low-Voltage Directive 1973.

Article 1 of the directive states: For the purposes of this directive ‘electrical Equipment’ means any equipment designed for use with a voltage rating of between 50 and 1000V for alternating current, and between 75 and 1500V for direct current.

Since the DC voltage of Electra-slate is under 75V even in the lowest temperature conditions, the consequence of this is that there are no stringent requirements for the double insulation and isolation, and earthing of the system.
The connection method employed therefore needed to meet a few basic criteria:

1. Allow the use of the Male plug definition partnering the connector box as employed upon the Electra-Slates.
2. Since the SELV requires no particular protection, the main requirement for the connections is that they are protected from mechanical damage, and from condensation.
3. As these components are fitted within the building envelope, they therefore do not require weather protection / UV protection.
4. The mating of Male plug and Connector box must be positive so that mis-connection is very difficult to achieve, and that the connector and male plug cannot be connected incorrectly (i.e. wrong way round) via the use of a polarised plug mating surfaces.
5. The material employed must not consist of any PVC material so as to prevent its use in commercial or domestic dwellings to meet fire regulations for fire spread and toxicity.
6. The method of interconnection should lend itself to transportation and storage on site in a convenient packaging arrangement.
7. The connection method must also be employed by persons working at height and must therefore be easy and quick to install without the need for introduction of specialist equipment or training.

As the Electra-Slates are designed to be connected in parallel as the working voltage of the system is provided individually by each slate, the system lends itself to a simple interconnection method.

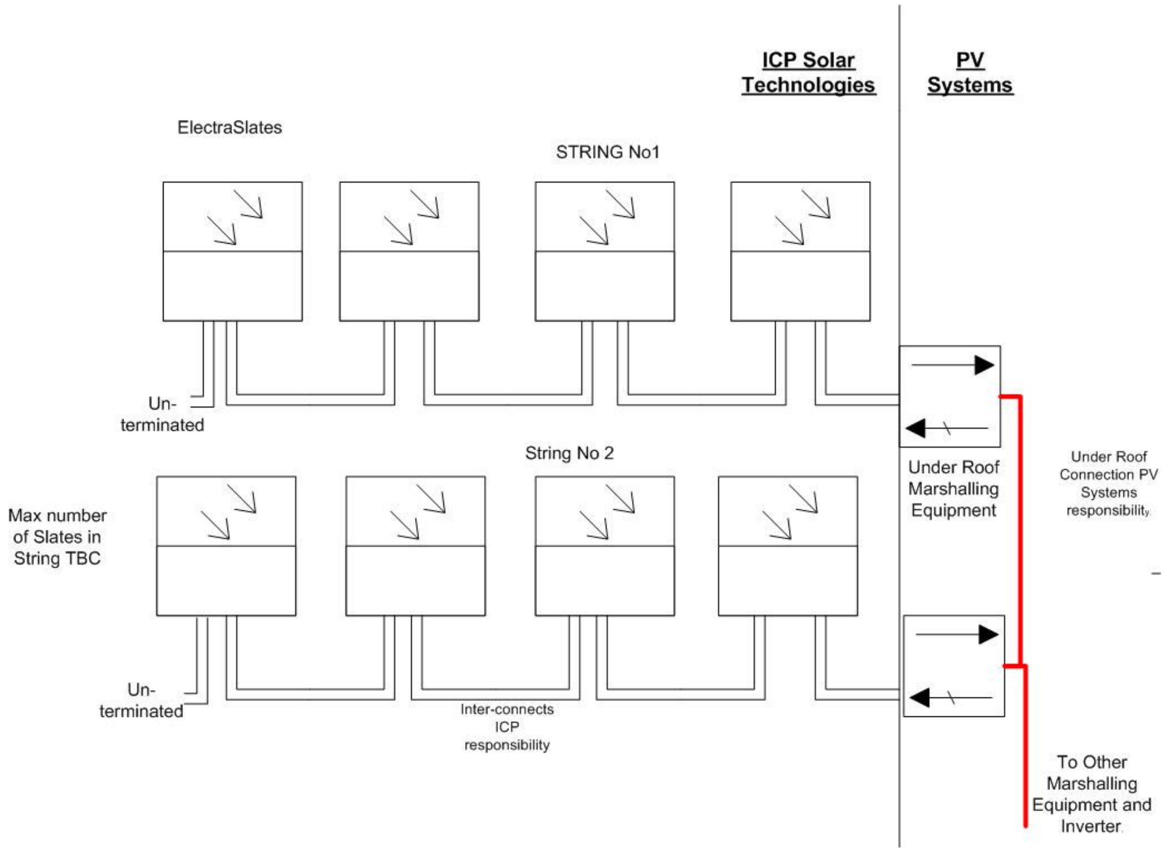


Fig Z. Basic Block interconnection Methodology

The string cables are to be provided with the Electra-slates, and are provided with positive and negative connections. These are sized to cope with the maximum number of slates in one row, e.g. 50 slates at 0.13A = 6.5A. The cable size selected overrates the cable, just because it needs to be stronger to resist site handling and manipulation in installation. The parallel interconnections being afforded by the splitter boxes along the loom length.

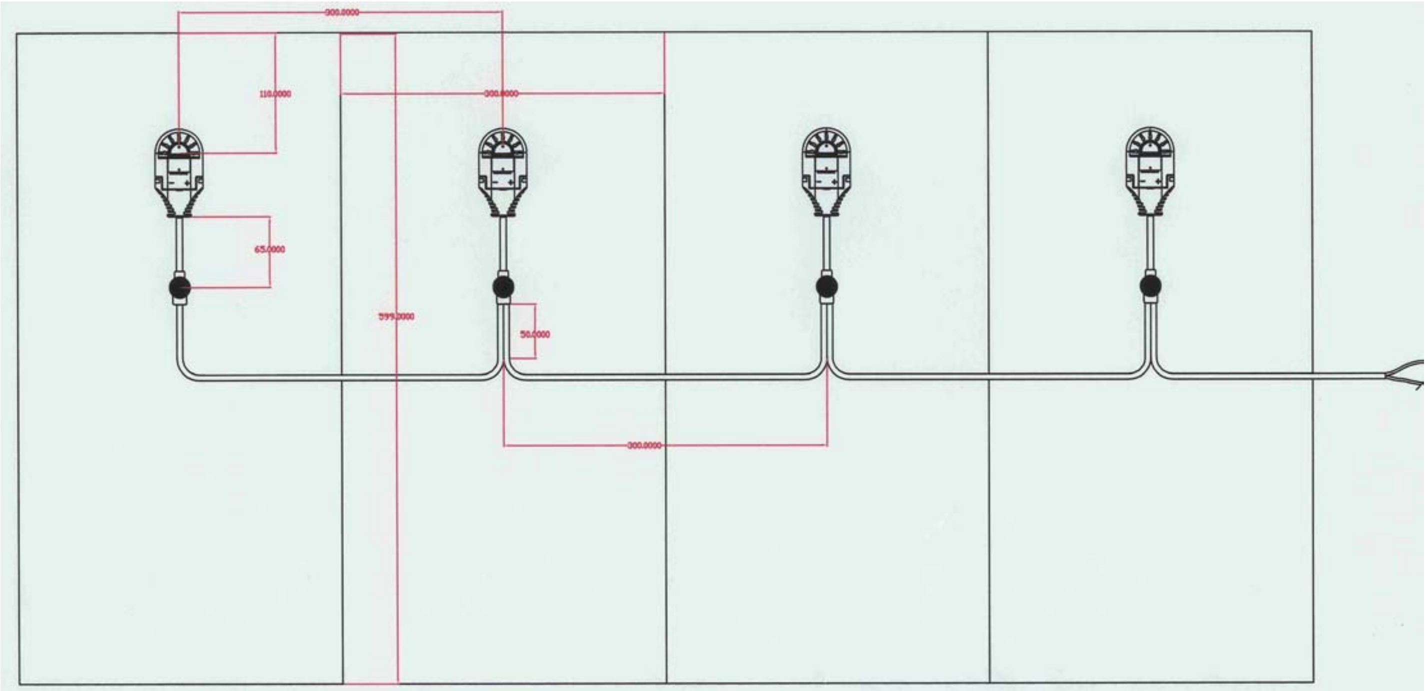


Fig AA. Interconnection Methodology

In the event of one slate becoming defective and a zero current /voltage being seen at the output of a slate, the string remains completely operative with only the consequent power loss of the individual defective slate.

The final material chosen for the loom was of a male plug constructed from PE thermoplastic with the cable sheathing of a PU material, both of which meet the applicable UK wiring and building regulations. The seal against moisture ingress into the connector box and the slates construction is afforded on the Male plug by the use of two silicon rubber o-rings that ensure a tight seal against the inside walls of the slate connector box fore and aft.

Initial samples of the Male plugs and splitter boxes on a loom were procured and installation tests carried out at ICP and our collaborative partners EETs.

Fig AB. Initial Prototype Loom

The following areas of weakness were highlighted.

1. The size of the overmoulding on the splitter boxes was not substantial enough for cable manipulation. Thus the conductor sheathing covers were visible at the entry of the splitter box. This is undesirable as it may act as to provide a moisture ingress path into the splitter assembly.

2. The length between the Male plug and the splitter box is such that it can catch upon the upper edge of the slate under installation.

Both issues were addressed via a temporary definition in the final prototype loom prepared for the projects Demo roof section.

In the interests of expediency it was not possible to have to tooling completed to the approved design for the new splitter and receive the loom in time for completion of the projects demo roof section. This change has now been actioned and future requirements for the loom will have splitter boxes per design below. The length between the splitter box and the Male plug was also been increased by a further 10 mm to avoid the interference problem seen on the first prototype.

Fig AC. Final Design Electra-Slate Connection Loom.

The cable ends once a string has been completed and connected are passed into the roof space where they are terminated at the Balance of system marshalling equipment.

Fig AD. Connection to Marshalling Equipment.

The function of this item is to connect together in parallel all the incoming strings and to provide a single DC output to the inverter. It will provide environmental protection for the connections inside, and must protect against damage and physical contact with electrically live components.
Under the wiring regulations (BS 7671) for separated extra low voltage installations (SELV) 411-02-09 states that there is no requirement for protection if the voltage is under 60V DC ripple-free.
SELV systems must use a plug/socket that is dimensionally incompatible with all other systems in the vicinity.

6.1 Connectors

The string connectors are rated to 8A and are standard units. Since there is no requirement for touch protection these will be ¼" spade sheathed crimp connectors, which have the advantage of being cheap and easily available, and are also available in colours to suit positive and negative.

The Main DC to inverter connections are for cable up to 10 mm2 depending on the number of slates in the system. Thus they can be a standard push on connector for lower numbers of slates, but should be a ring terminal for the larger cable sizes.

7.0 Development of Fixing Methodology.

Intersolar had over the lifetime of their part of the Electra-Slate project had many discussions regarding fixing methods of the slates.

Drilling holes in the slates during manufacture was considered to both a) expensive and b) a source of weakness. The possibility also existed that the slate may suffer damage during installation because of the necessity to hammer nails through the holes. This was borne out by the Clapham folly and Track 2000 Installations where a number of slates were cracked during installation via the use of roof nails. Although site visits to both installations some four years on have shown these cracks have not caused any de-lamination of the product or electrical failure of the individual cells. The cracks were undesirable in a finished product designed to be easily installed.

In an effort to ascertain the feasibility of other methods it was decided to manufacturer a number of samples and fix them to a trial roof assembly at the PV Systems factory. The slates used were of the old 500x300 pattern, but the methods employed would have easily transferred to the 600x300 current definition.

The first sample was a slate with a Triwall Tedlar strip of dimension 450x40mm laminated through the centre on the normal hole fixing line per below.

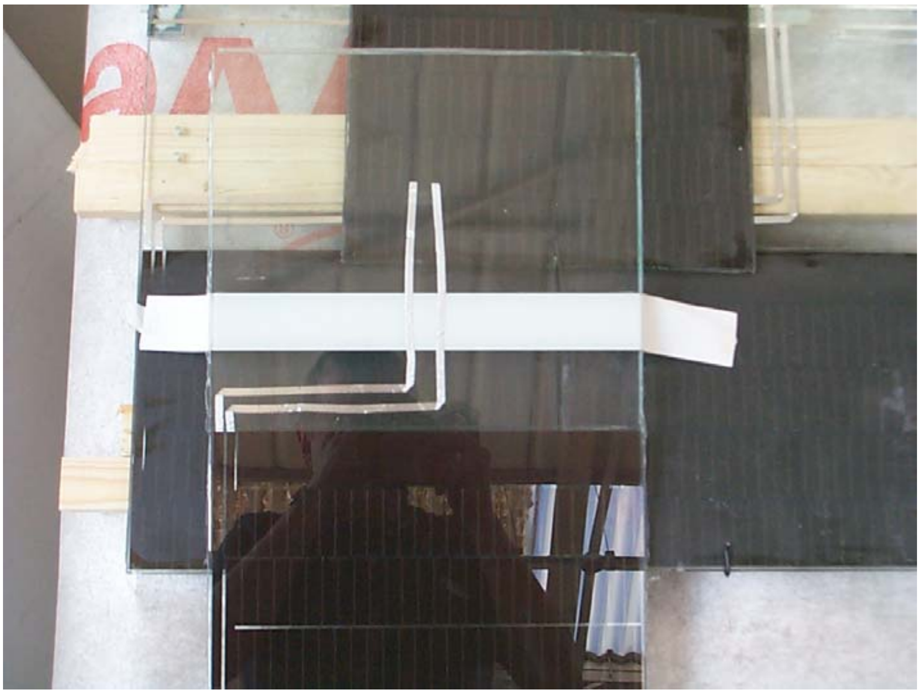


Fig AE. Fixing Trial 1.

The second trial conducted was with the Tedlar laminated on each side per below.

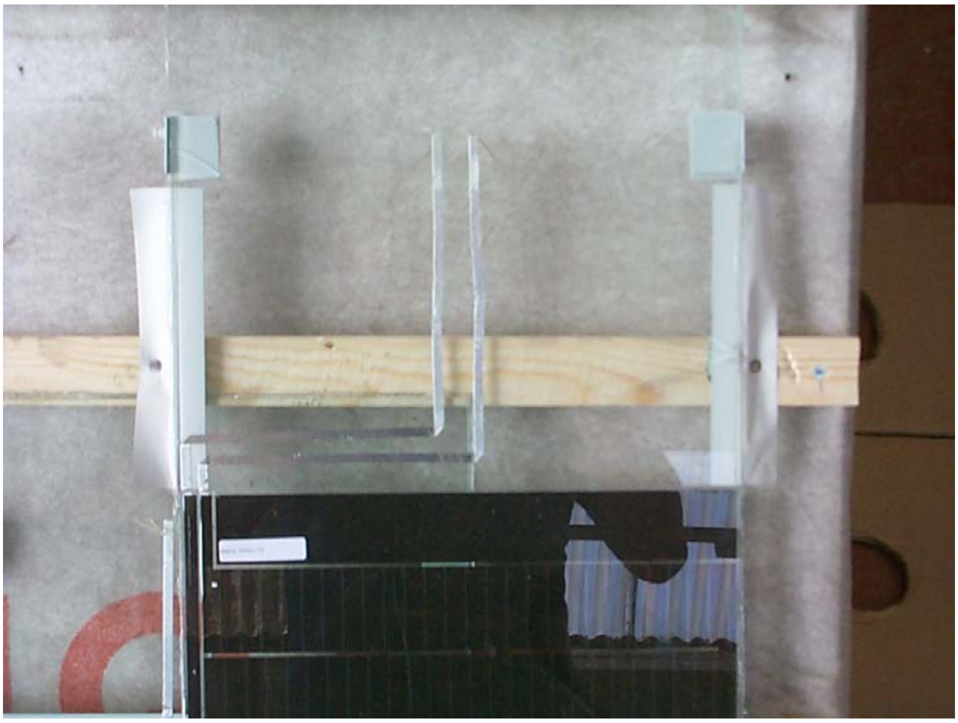


Fig AF. Fixing Trial 2.

The third trial was intended as a compromise using tape laminated into the top of the slate, to prevent slipping, and a clip, to be designed, to hold the slate to the roof .

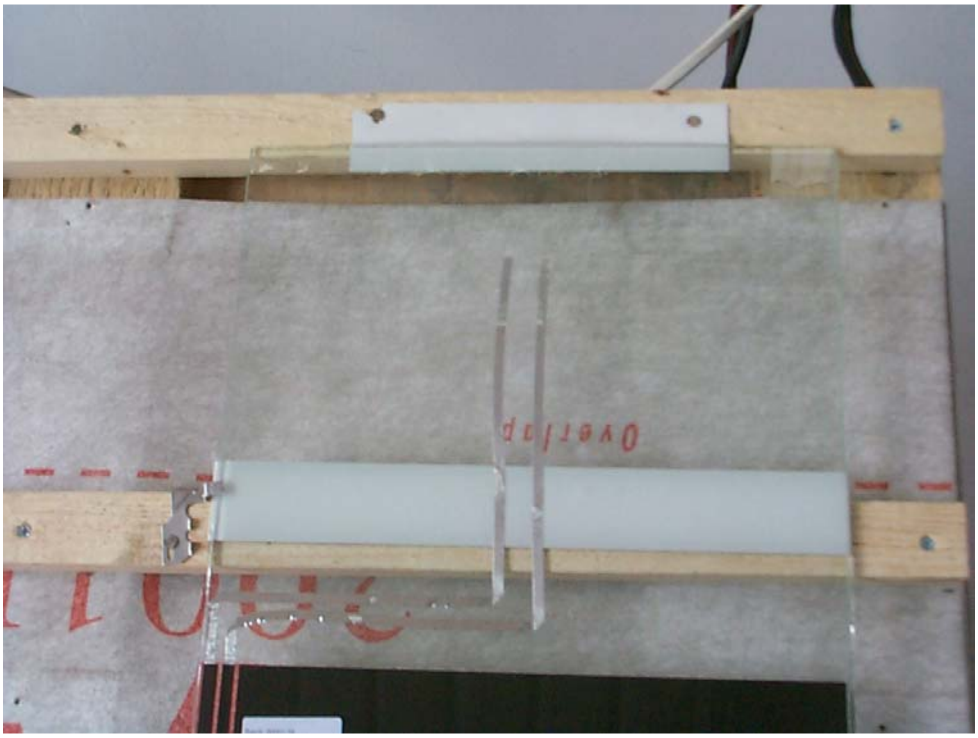


Fig AG. Fixing Trial 3

The fourth trial was the use of a 'standard' slate hook (picture 4).

Fig AH. Fixing Trial 4.

10 samples of the type 1 slate were manufactured and six were fitted to the test structure per below.

Fig AI. Fixing Trial Test Rig.

The extreme right-hand slate, simulating the first slate in a row, had the material nailed to the roofing batten on both sides.

The fixing principle was that the next slate to the left would be plugged into the first slate, and then the material on its left side would be nailed to the batten. This would then be repeated to the remainder of the row.

The assumption was that the electrical connector would provide positioning and support on the right side, the material giving the fixing on the left.

The results of this trial indicated that:

a) the material used for the test would not have sufficient resistance to tear forces, but more importantly
b) There was a strong possibility of lateral movement of the slate to the left. Even allowing for the weight of other slates in rows above, the fixing method was not strong enough. It was the opinion of the test group that other types of material used would probably not prevent the sideways movement. Only by using a rigid plastic might this be prevented. As an incidental comment it was found that damage to the slate may still occur with a poorly aimed hammer when trying to nail close to the slate.

One sample each of types 2 and 3 were produced, primarily as discussion points and demonstrators.

Type 2 would almost certainly suffer from the same movement as type 1 while the material on type 3 was not strong enough to resist even relatively light downward tearing motions of the type which may be found when working on a roof.

Finally was the section utilising the slate hook. It had been advised to the Intersolar Group in the early days of the Electra-slate project that slate hooks were not desirable and little used in the UK.

However discussions with a roofing contractor advising the group on roofing practise indicated that the use of hooks was actually more common than had been thought. Further investigations since have shown that the clip method of installation is even more commonly used in European building practise than originally thought.

Two samples were sent to PV Systems, the first of a type that clips over the batten, the second is a version that nails into the batten.

Original discussions had voiced two concerns over the use of hooks i.e. would the output of the slate be affected because of shading by the hook and might not the hook physically damage the slate in storm conditions.

Tests with slates in sun showed no discernible difference in output with or without the hook in place.

Although only 3 slates were placed in position for the test, the results were viewed as extremely positive and promising. The slate was easy to fit, suffered little stress during fixing but still offered mechanical strength. The opinion was taken that, as this method is a recognised industry standard then it would be one less hurdle for the product to take in acceptance.

It was decided that a sample of 12 slates would be sent to McAlpine for fixing on the test roof at the quarry in North Wales. McAlpines would determine the most suitable batten gauge and obtain the correct hooks.

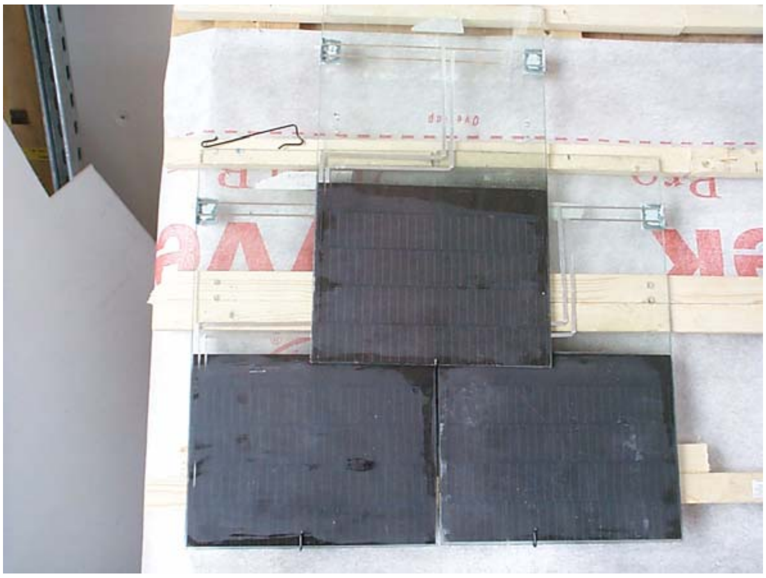


Fig AJ. Fixing Trial Final Definition.

Post installation of the tiles on the McAlpine test roof an unscheduled Hurricane force storm passed over the North Wales site.

Fig.AK. McAlpine Test Roof.

Inspection of the photo will demonstrate the force of the storm in that the lead flashing on the apex of the roof has been lifted and bent over the top of the roof structure. Post storm inspection of the Electra-slates indicated that no damage was apparent to the products under test.

The final decision taken by ICP at the re-start of the projects was that the project progression should be continued on the basis of using slate hooks to install the product to the roofing structure.

This identified the need to fully establish briefs for the use of the hooks requiring detailed investigation into current building regulations and practice. This work led to the need to carefully consider the slate installation practise in relation to at least five variables within the commercial and domestic roofing sector.

These variables are principally:

i.) The pitch of the desired installation roof.
ii.) The relative exposure to elements determined by the geographical location of the proposed site and whether the installation would be considered as being at a moderate or severe exposure risk.
iii.) The required Headlap of the slates to meet local regulations
iv.) The baton gauge required dependant upon the above factors and the size of the slate being installed.
v.) The commercially available hooks to be used in the installation.

ICP and PV Systems reviewed the commercially available hooks and established that hooks were available in sizes ranging from 60mm to 160mm increasing in length in 10mm increments. The availability of these hooks thus enabling the 600 * 300mm slate definition to be installed in all of the various geographical regions and associated pitches of roof structures in that area.

Headlap requirements were seen to range from 45mm to 100mm again dependent upon geographical location and pitch of roof. The headlap basically being considered to be the minimum overlap of the slates to ensure water ingress is not apparent into the roof structure by the action of capillary spread.

Roof pitches were seen to range from 22 degrees to 75 degrees although the local planning regulations and building planning applications were usually the driver to establishing this design specification.

The baton gauge is a result of consideration of the above factors, the slates must span at least three batons over their length to meet building regulations, thus as the pitch and headlap parameters were considered and a final value of baton spacing and required clip length could be reached.

The other important point to note here is that as the Headlap and consequent baton spacing also have an effect on the active area of the slate that would be covered under the overlaying slate. This obviously has the effect of changing the available area of active cell and thus the relative power output of each slate. This factor also then determines the number of slates required to achieve a system specification of either 1 or 2 KW* (*refers to a typical domestic application only)

PV Systems produced within the project a calculation formula to ensure that for system design specification purposes information input regarding the above detailed factors would provide a design specification of baton gauge, hook length and exposed area of the slate. This formula will be used for the purpose of system design and specification upon the commercial launch of the Electra-Slate product.

The demonstration roof section was installed using fully the clip methodology and is reported on later in this report.

8.0 Pre Competitive Development of Manufacturing Capability.

From the outset of the concept of "Electra-Slate" The physical attributes of the tile have remained fundamentally unchanged. The Project outputs and the progress of ICP in establishing the basic structure and process of producing the slate has however been revised and in some areas improved upon from the original concept.

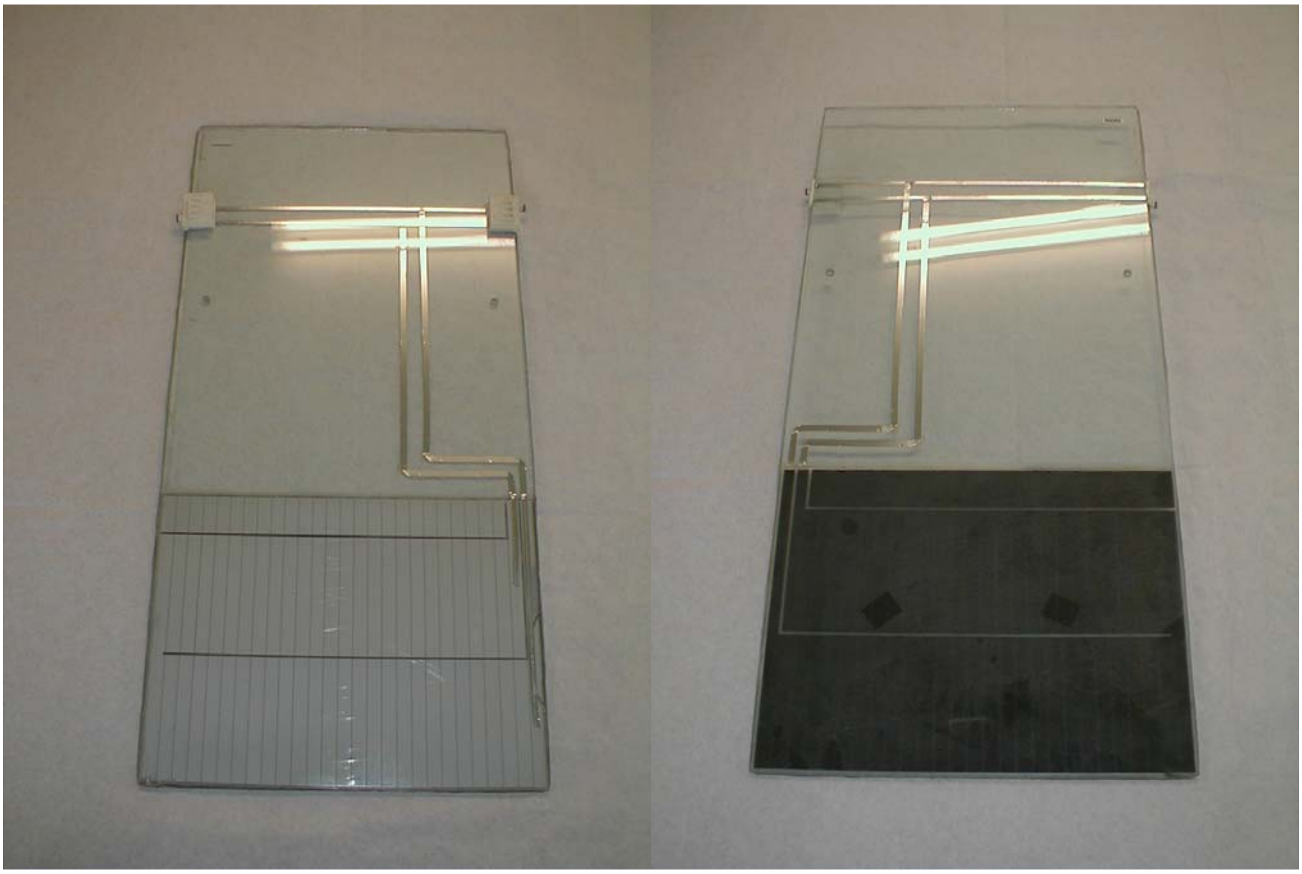


Fig AL. Electra-Slate II.

The slates still remains a glass laminate, constructed from three individual pieces of glass and dry laminated into the final article, but there the revisions become apparent. The appearance has changed, the size and output of the active solar plate has changed, as has the technology used in the solar cells themselves. The method of power collection from the cells and distribution of that power to the balance of system equipment is also fundamentally revised and improved upon.

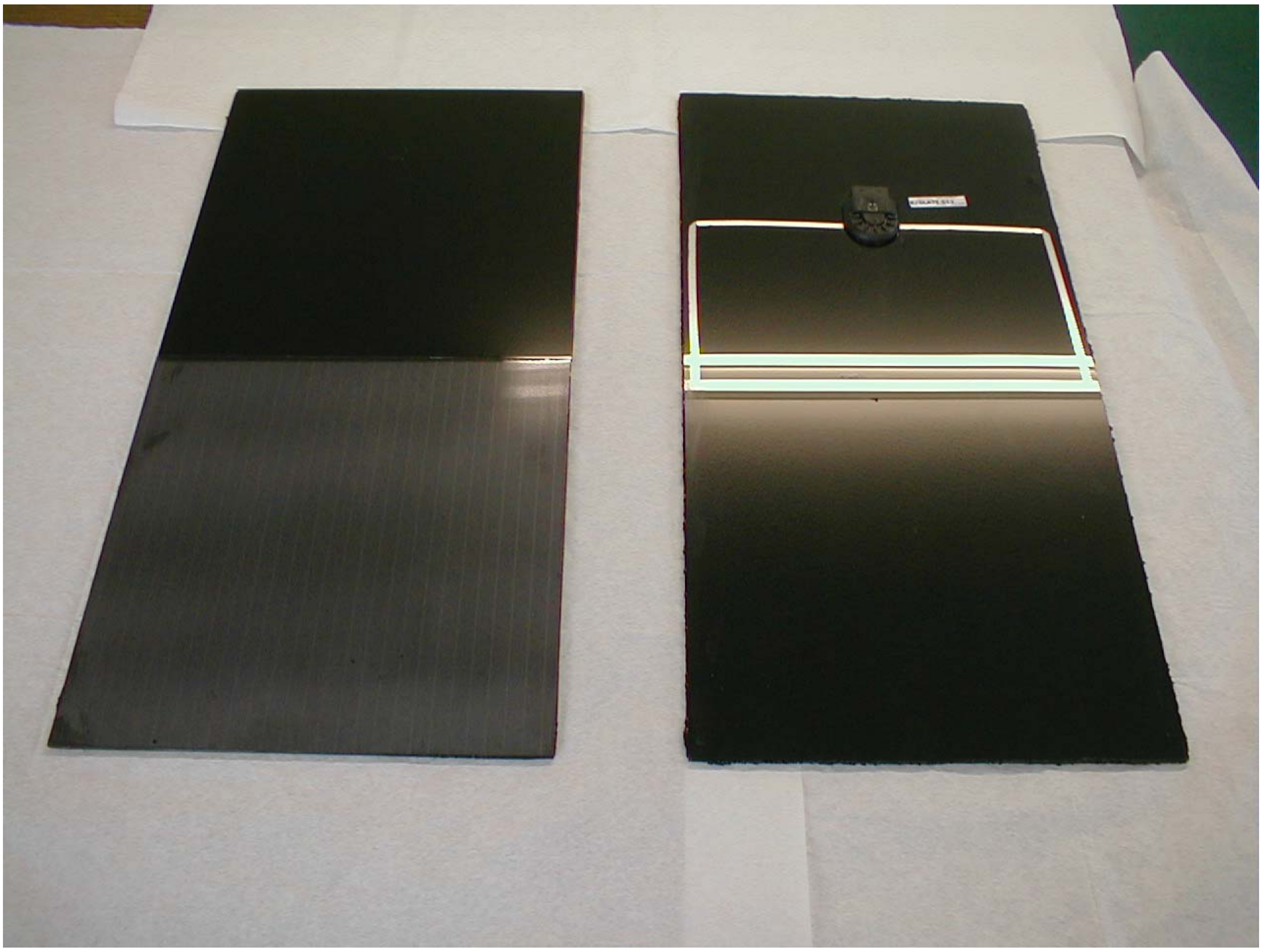


Fig AM. Electra-Slate III

The effects of the ICP introduced changes act as to reduce the costs of manufacture, make the Slate even more commercially viable with higher power output (thus reducing the number of slates required to achieve the required system output) and to have introduced a bespoke on-slate connector that is married up to the interconnection system by design.

However with all these changes to the product definition the Electra-slate roof can be still be installed by the general roofing industry without any specialist knowledge and equipment, utilising current standard roofing practise for mounting via the use of standard size slate hooks.

8.1 Slate Construction and Process Set-up.

In the original Intersolar product, the backing glass used in the slates construction was 3 mm float glass, today this is still the same. Many prototype ES have been constructed in 2.3mm backing glass over a number of years as test pieces, specifically as production of the core product line at ICP moved to use the same thickness glass. However the advantages to be gained by the additional strength of the thicker glass were overriding in the decision for inclusion in the final product specification.

ICP Intends to market the product with a Power performance and manufacturing warranty that may be in excess of 20 years. It must therefore have full confidence in the slate's robust construction to endure such a length of time at the hands of the elements.

8.2 Backing Glass.

Three basic sections of glass are used in the slates construction, a full Backing sheet of 3mm Float glass dimensions 600* 300mm, a 3mm active glass plate of dimension 300 * 300mm and a another backing glass section of the same dimension in 3mm glass.

All the glass sections incorporated into the Slates are processed prior to laying up of the E-Slate sandwich construction however the backing glass is treated separately to the active glass sections.

Once constructed and laminated the E-slate needs to be handled not only by ICP operators for post processing, testing, cleaning and packing but also by the roofing contractor who would be installing the slate system. It is necessary therefore to ensure the glass laminate is safe to handle. This requires the use of ICP's existing edge grinding equipment to ensure all sides of the backing glass sections are safely edged.

Fig AN. ICP Glass Grinding Line.

It is not possible to edge grind the active cell content of slate, as the process will destroy the cell structure of the plate. The issue of sharp edges on the glass of the active cell is addressed by the post processing stage of the Electra-slate.

The backing glass is then washed and dried in ICP's existing washing facilities.

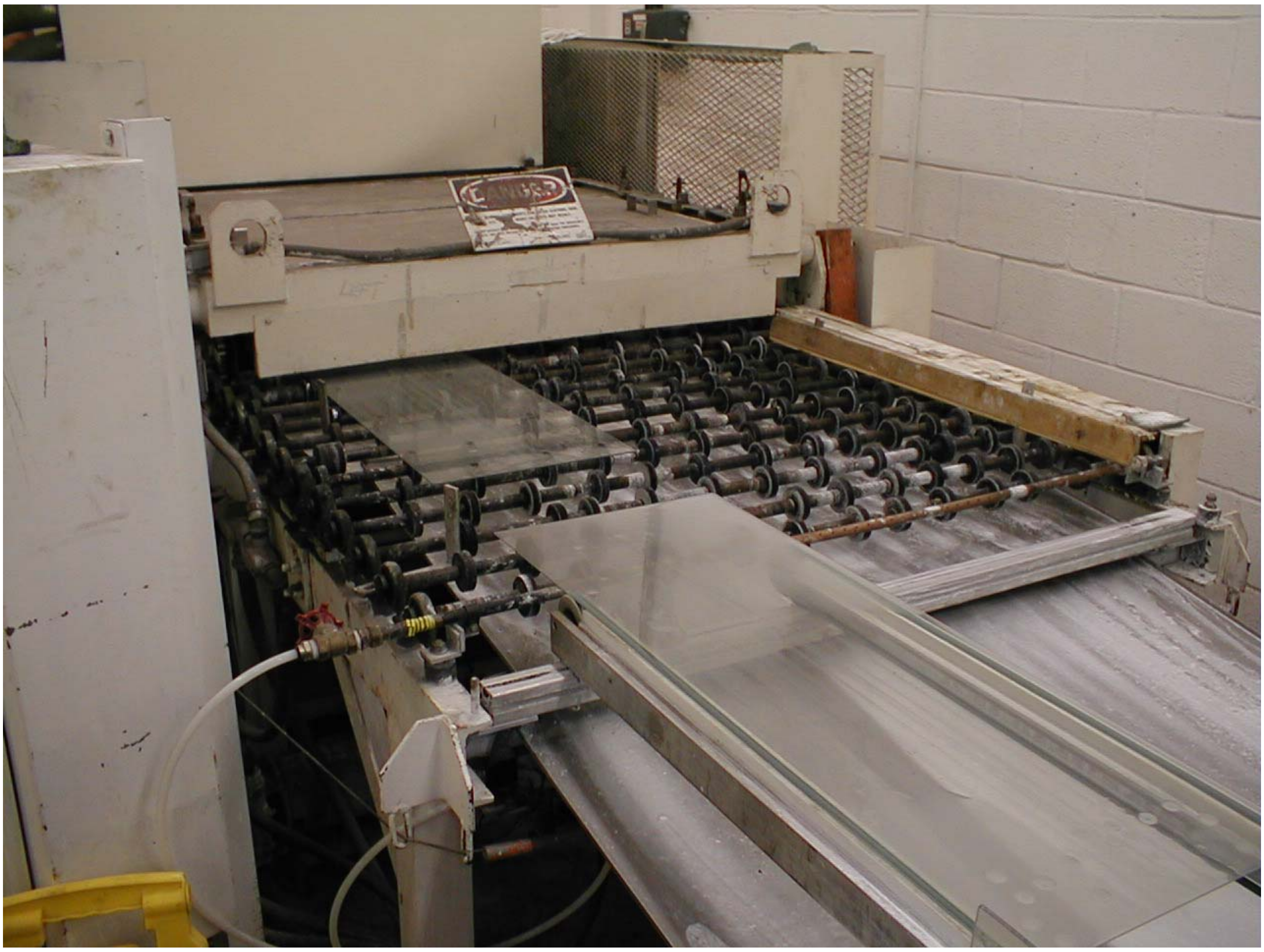


Fig AO. Glass Washing Line.

Part of the fundamental changes employed on the Electra-slate product is the need to take power from the slate via the use of the purpose designed on slate integral connector assembly.

In order to install the connector assembly a hole must be drilled into the 600 mm * 300mm backing glass section.

This process must be accurate, repeatable and give a low rise of breakage in process. When ICP purchased the assets of the Intersolar Group and re-initialised production at the Bridgend plant the projects were re-applied for in April 2003. However ICP had identified the need to continue the development of the Electra-slate and as such purchased outside of the project budget a purpose specified drilling machine to meet this manufacturing need, and before the Project re-start approval was granted in October 2003.

The drill is capable of drilling the required hole in 2.3mm and 3mm sheets at a throughput of 1 sheet per 45seconds. It is possible to increase the speed of throughput, but trials have indicated that this leads to excessive wear of the diamond drilling heads and increases proportionally the amount of breakage's seen.

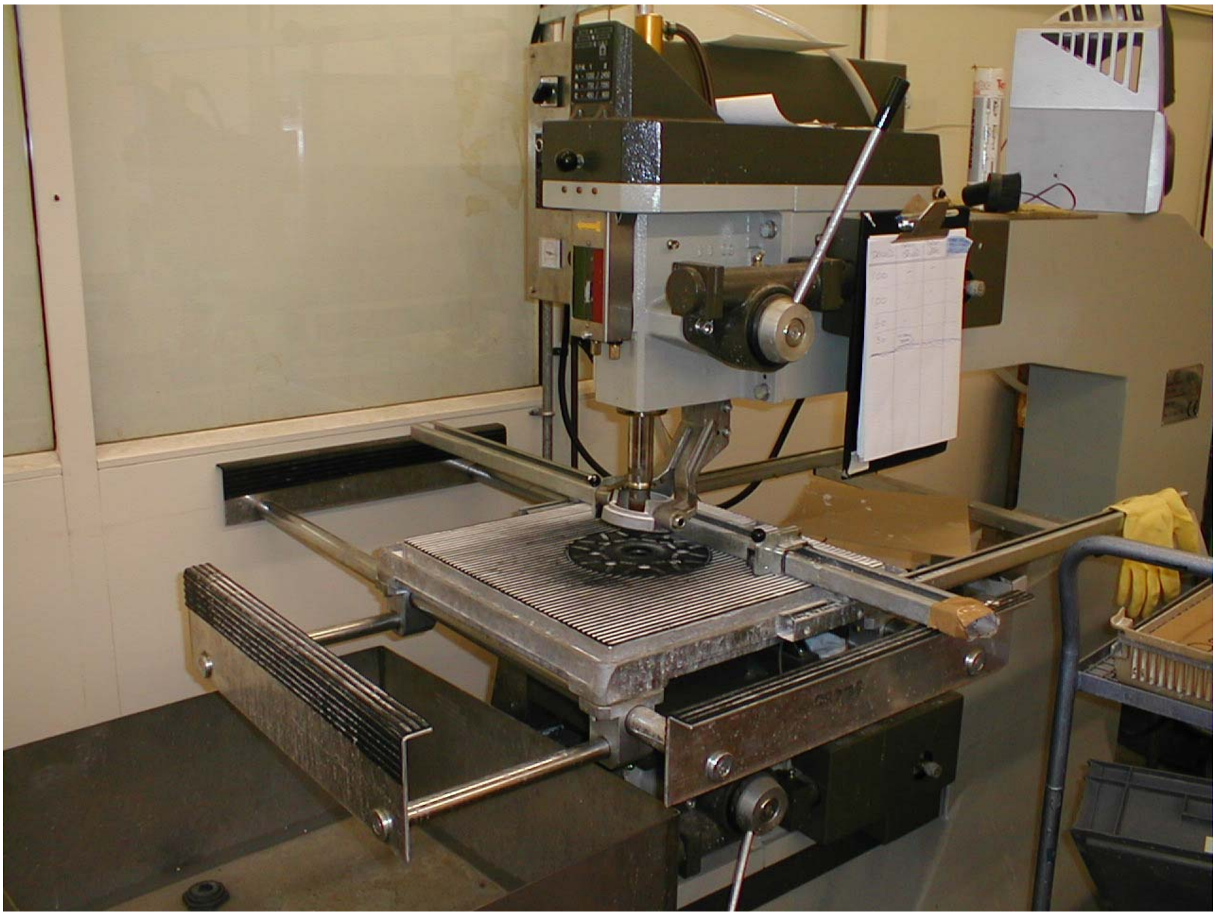


Fig AP. Glass Driling Machine

Once the drilling action has been completed the glass is washed again to remove any debris. The backing glass is then transported and stored ready for construction lay-up of the slates.

8.3 Active Area Solar Cells.

The process employed by ICP for creation of the Solar cells is outside of the remit of this report, but for clarity is best described by the process flow diagram shown below.

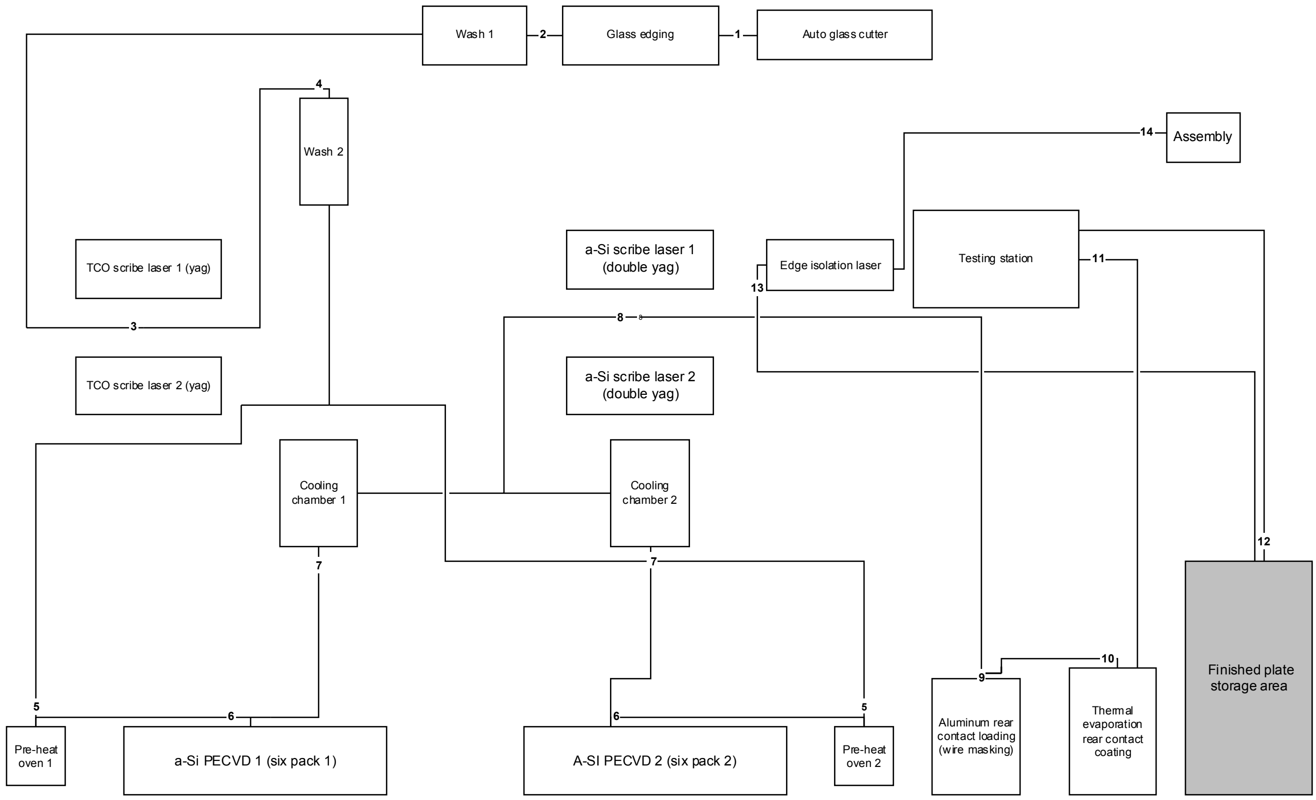


Fig AQ. ICP Process Flow Diagram

ICP is currently limited to deposition onto glass substrate 930mm * 330mm. It is therefore possible
to gain multiple active area plates from the full size active plate. Once the Solar deposition process is completed the glass is cut to gain multiple active plates from the full plate. This is cost effective use of the full plate with only minimal amounts of active plate lost in length and width depending upon the number of active areas required.

Fig AR. Automated Cutting Line

The active glass area of the E-slates has fundamentally changed. In the original concept ES1 single junction amorphous silicon plate was utilised. However the working voltage of the active area was 12v DC and this presented problems during trials in finding an inverter system that was capable of tracking efficiently at these low levels of working voltage.

A fundamental change was actioned under ES2 by the introduction of a complex laser pattern and busbar arrangement to take the working voltage of each slate to 24v DC with an initial output of 2 Watts.

However during ISPRA IEC 61646 Qualification testing, the product failed as a result of plate power failures and the integrated connectors deforming under test. Before Intersolar was able to re-design the E-slate to overcome these difficulties the group of companies went into liquidation.

When ICP re-started the Projects in October 2003 fundamental changes were actioned. The integrated connection method was fundamentally revised plus the active area of the slate was revised in both technology and size.

ICP within the Capacity Ten 7 Project is developing an equipment set and methodology of Dual junction device deposition. In its most basic form the tandem A-si deposition process essentially stacks two PV photodiodes one on top of the other as a continuos film. Tandem cell deposition is a lot more complex and demanding than the above suggests and is far less tolerant of process variation and potentially more expensive to run unless carefully optimised. ICP is still developing and optimising this technology under Capacity Ten 7.

The decision to make the Electra-Slate from this technology opened up various advantages to ICP.

1. Individual Cell voltage is approximately doubled.
2. Individual Cell current is approximately halved.

3. Substantially less light induced degradation is apparent.
4. Stabilised Power is increased in comparison to single junction devices.

It can be drawn from the above statements that as Power output in Watts is a function of Voltage (V) and current (I) (P=V*I) that the power output of a dual junction device is approximately the same as a single junction device, but that the working voltage is doubled and the stability of the device is greatly enhanced.

Consequently the active area of the slate could be increased to 300mm * 300m without the loss of active cell area found on the ES2 by virtue of the complex laser and busbar patterns.
Thus the slates fundamental dimensions were changed to use active glass of 300mm square.

The benefit offered by this change to active area is that an open circuit voltage of 38-40Vdc is apparent on each slate and therefore a working voltage of 32 – 36v DC is achievable in circuit under MPP load.

This working voltage enables the product to still meet the SELV directives on DC power supplies and regulation, but also moves the operating voltage of the Slate system into an efficiency region more easily covered by the range of commercially available inverters thus removing the need to specify specific products. This enables the inverters to be purchased off the shelf thereby reducing any associated costs with the need to specify specific products that operate in the lower voltage regions.

Giving a theoretical stabilised Power output of 4 watts per slate also reduces the final system installation costs by reducing the number of slates required to make a rooftop 1KW system.

Ie. 1 kW Rooftop System @ 2 w per slate = 500 Slates required.

1 kw Rooftop System @ 4 watts per slate = 250 Slates required.

It follows therefore that with a full plate of 930mm * 330mm three active area slates can be produced with a total wastage of only 30mm in length and width.

The Electra-Slate Product that will be sent for Full ISPRA / TUV qualification will be wholly based upon the Dual junction device as the active area of the Slate. This sets out ICPs commitment to the product utilising the dual junction technology being afforded under the sister project of Capacity Ten 7.

Once cut to size the active plate needs the aluminium Busbars to be ultrasonically bonded to the collection cells. In preparation ICP have made mechanical and software modifications to the in house bonding equipment to be able lay the tapes down accurately within the collection cell areas and leave approximately 300mm over length on the tails for connection to the integrated connector assembly.

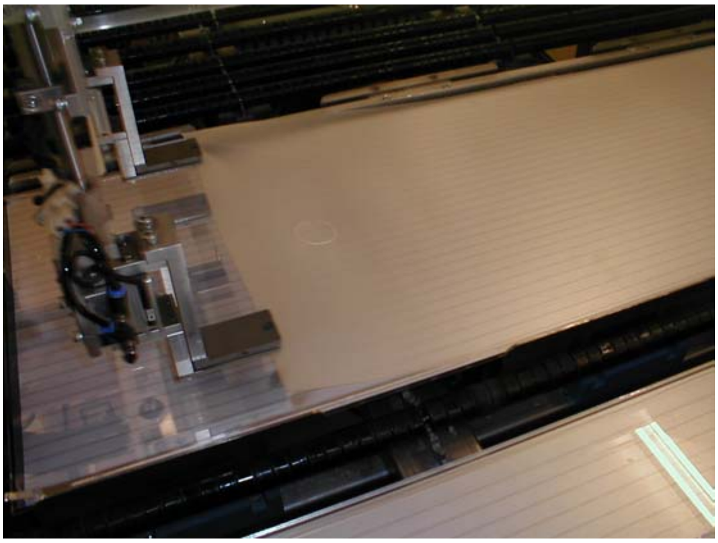


Fig AS. ICP’s ultrasonic Bonding equipment.

8.4 Slate Lay-up (pre Lamination).

All the component glass parts are now prepared for construction of the “sandwich”. The final article required to complete this bill of materials is the EVA sheet used within the laminator to bond the glass together into a lamination thereby providing the environmental protection required by the product.

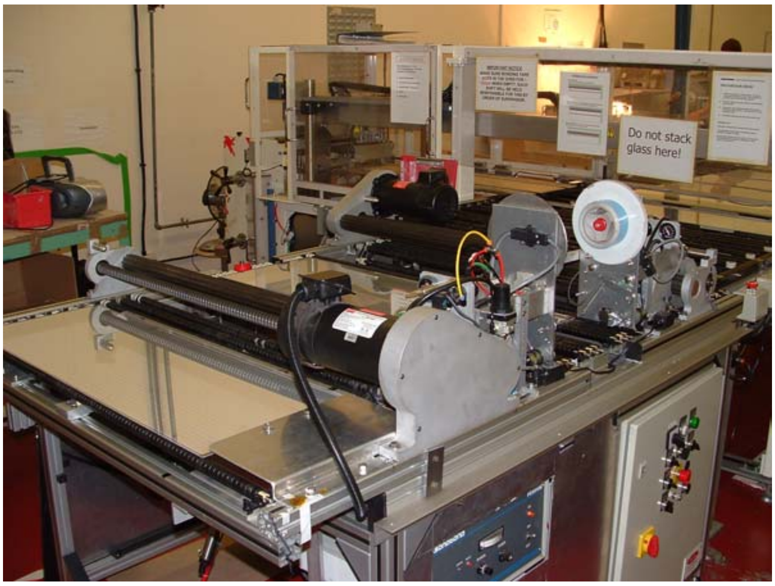


Fig AT. _Automated EVA Cutting line.

ICP have in operation at the Bridgend plant an automated EVA sheet cutting line. Both mechanical and software modifications were required to the unit in order to be able to cut the EVA to the desired length and to punch out the required hole in the EVA. This hole when placed onto the backing glass acts as to line up with the same diameter hole as processed into the 600mm backing glass section.

Historically ICP has used Clear EVA for the ES project and installs to date however some aesthetic issues with the use of the clear EVA needed to be overcome in the final product definition. Close inspection of the below photograph will show that a small gap between the Slates is apparent post installation and therefore the glass that can be seen was reflective and clear.

Fig AU. ES2 Install visible Glass

This clear region can be see from ground level and can also reflect sun light if the suns position happens to be in the right azimuth relative to the slope and direction of the roof. This reflection could possibly be undesirable to other residents in the locale of the install and needed to be eradicated as a possible issue.

ICP have taken the decision to utilise Black EVA for this product as this not only overcomes the clear glass region issue, but also serves to darken the whole appearance of the E-slates bringing them even closer to matching the surrounding natural slate. The Black EVA is however slightly more expensive then the clear EVA in use at ICP currently on their consumer product line and will initially be procured in lower volumes. However as a spin off ICP are evaluating the use of Black EVA across it's complete commercial product line as it also serves to reduce cosmetic rejection of plate with slight manufacturing marks.

Fig AV. ES3 install Black EVA.

The individual glass sections are laid up on a horizontal surface. A black EVA sheet is laid between them with the automated pre-cut hole for the connector box void. The busbar connections from the collection cells on the solar plate are fed through the laminate EVA sandwich construction to meet the on-slate connector position located centrally in the non-active area of the slate construction.

In recent years the fundamental convention for producing the Electra-slates was to adhere the connector box onto the glass as part of the lamination process. As the Slate is a three-glass construction with the front of the slate being two pieces and the connector box being located on the back face, a method of jigging for lay-up and a system of load spreaders was required.

The glass sandwich could in this configuration only be placed into the laminator with connector box upper most (ie two front glass faces facing down) in a jigging tray assembly. A series of load spreaders was also required in order to prevent the diaphragm from causing the slate to crack under press hold conditions.

The design of Load spreaders was simple and relatively cheap to produce, they also performed adequately in trials. However the need for jigging of the slate lay-up for introduction into the laminator proved to be fraught with difficulties as the EVA released from the construction during lamination acted as to stick the "hot" Slate to the carrier tray and thus require more work to remove from the tray and clean the tray ready for the next cycle.

It became necessary for a re-think of the lamination process to be undertaken. During a trip to the Paris Photovoltaic Conference in early summer 2004 a new product was being demonstrated. This new product seemed to meet all the requirements of ICP in being able to post process the connector to the slate after lamination. The product being designed and tested to meet IEC 61646 criteria was a distinct advantage as ICP could be confident the material would not breakdown during the Environmental qualification testing process and ultimately in long life service.

The other dis-advantage to the use of the tray carrier assembly was that the ICP laminator could only accommodate four slates in any given run. Significant numbers of test samples also indicated a slightly higher than usual failure rate of the slate through stress cracking was apparent. This rise in rejections was attributed to the use of load spreaders and could have been further addressed by modification of the design. This however also introduced the possibility of reducing the gel content analysis of the Eva due to heat-sinking effect of the load spreader make up material.

After extensive trials with the new adhesive product the decision was taken to introduce the E-slate to the laminator without the connector box being installed. This released ICP form the constraints of having to use complicated tray carrier assemblies and load spreaders. It also enabled 6 Slates to be loaded into the laminator (plus spacers) in any given run thus improving the throughput capability by a factor of 50%.

The Laminator at ICP is a large unit capable of significant throughput, however it has a fixed time for the process to be undertaken. All the production remits of the Electra-Slate are designed to fit this cycle time as closely as possible in order to ensure that the whole operation can be run by one operator from loading to post processing of the laminates when completed.

Fig AW. ICP's Lamination Equipment.

Post lamination processing of the Electra-slate it is necessary to install the connector box to the laminate construction and make the power connections within the connector box.

Equipment purchased with the specification of the Adhesive supplier has enabled the task of con box attachment to be undertaken effortlessly and with a minimal time requirement.

Fig AX. Dispensing Equipment.

Costs implicated with the use of the new product have shown the method to be very cost effective as each slate uses only approx. 2.8ml of the adhesive per slate and thus approx. 100 slates can be produced from one cartridge.

The associated cost per unit would be reduced even further by the use of a heated pail system of dispensing, however the volumes required in order to justify the initial equipment cost are unlikely to be seen until full scale production is launched late Summer 2005. Based upon predicted volumes the payback time for the cost of the heated pail system would be some two years assuming the system cost remains as quoted. This cost is outside of the remit of this project budget.

Completion of ICP's processing of the slate with its current equipment set is actioned by the termination of the aluminium busbars inside the connector box. Trials of many sorts of electrical joint augmentation were carried out with varying degrees of success. However the decision taken is to keep the soldering process employed through the trials stage. This provides and extremely robust joint that cannot be effected by any thermal expansion seen within the slate construction when in service.

Once connected the integrated connector cap is installed and the void in the plug is filled under pressure with an Electrical grade of Silicon RTV to “pot up” the connector assembly and prevent any potential for moisture ingress into the slate assembly.

8.5 Slate Finishing.

It is necessary to remove the reflective face of the active glass on the ES so as to produce a product that closely resembles natural slate and to reduce any surface reflection from the slates when in situ.

Trials have been conducted with a specialist UK supplier of Wetblasting equipment with a view to specification of an automated blast system where the desired finish is achieved and the slate is washed to remove blast debris and dried ready for despatch.

Sample testing of slates produced with the desired finish has enabled ICP to evaluate the consequent reduction in power output of each Slate required for IEC Qualification.
However the indicated cost of such a system above is outside of the budget remit for this project.

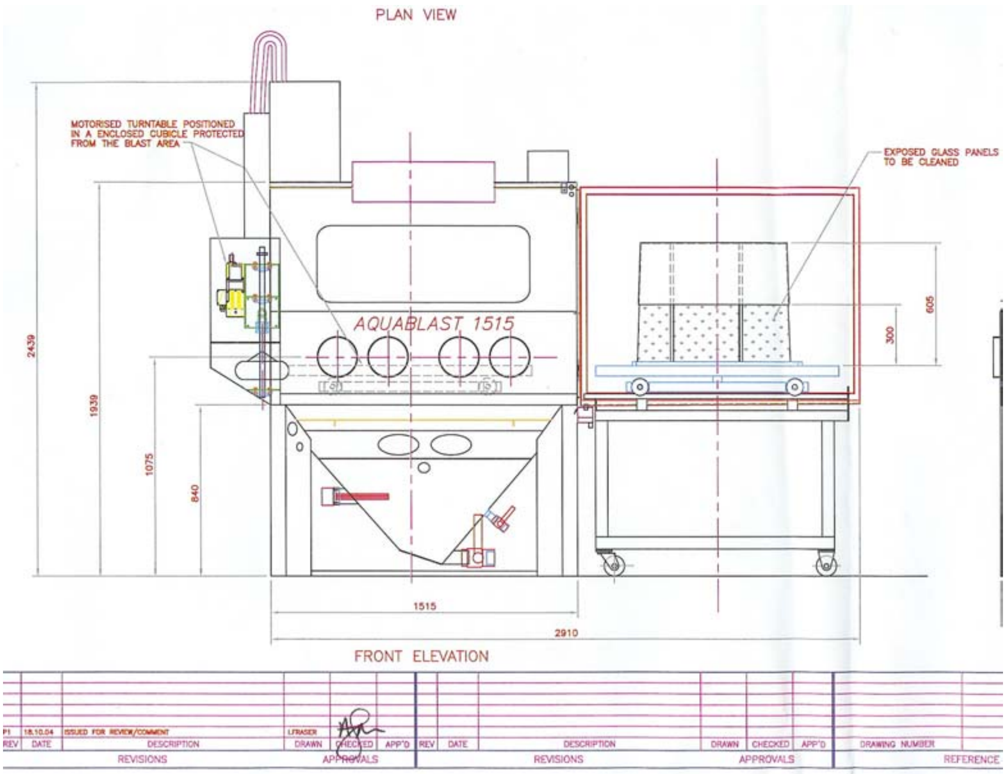


Fig AY. Proposed Equipment Set.

An alternative means of achieving the required finish has been found and trialled within the project. This does have a cost implication to the product in the short term, as the process must be sub-contracted to an outside agency. However once the product has cleared qualification successfully ICP will gear up for large-scale volume which will include equipment as above.

9.0 Demonstration Roof Section.

9.1 Roof Sub-structure

The roof section employed of trial used a good quality membrane (Tyvec in this case, but any high spec membrane would be suitable) fixed to the rafters under standard battens of 35mm x 19mm section. The battens were spaced at 250mm (called the batten gauge) as per UK standards.

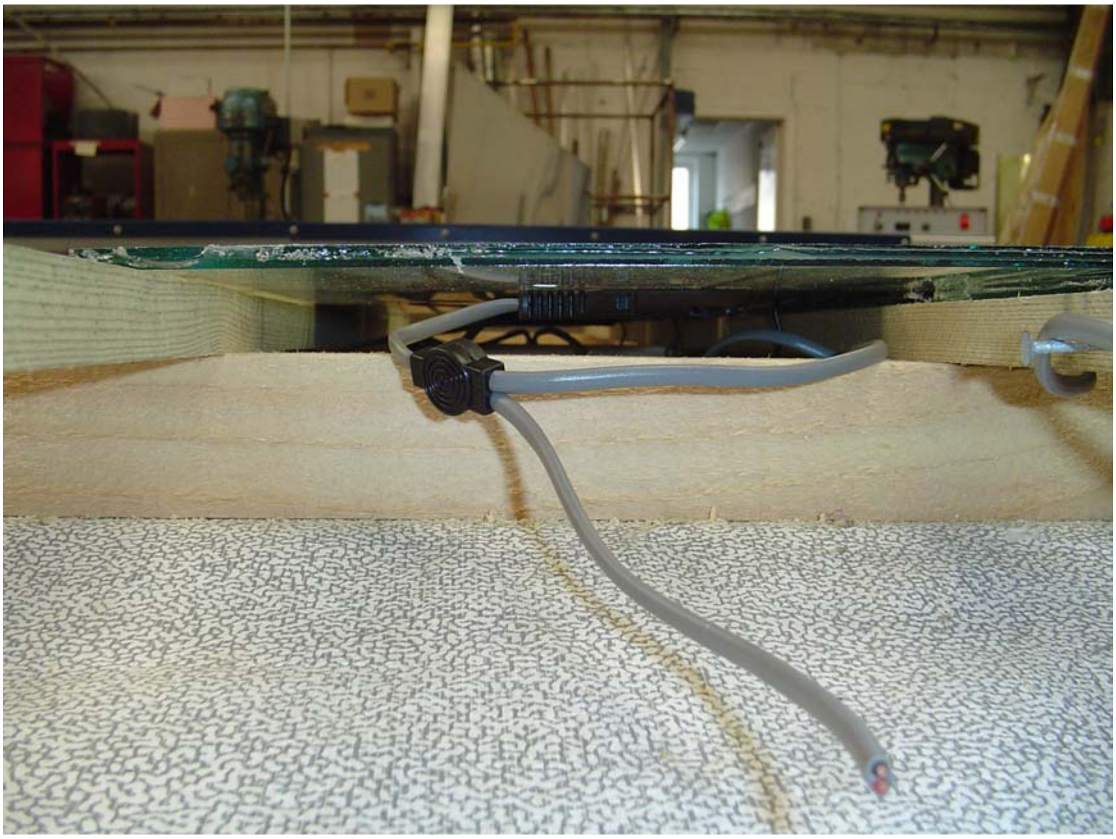


Fig AZ. Roof Substructure.

9.2 Slates Layout

The batten gauge was chosen as being representative of most of the UK for a medium slope of roof. This condition would cover the majority of roofs in the UK. The slating was started at the bottom row in the centre, in accordance with normal industry practise. The E-Slate wiring looms were laid out below each batten and cut to the length of the row of active slates that were to be installed on that level. It is clear that the layout of the Electra-slates must be clearly defined by the designed in advance of the installation, so that the looms can be fitted to the correct length. It is also necessary from the point of view that the electrical design has to end up with equal length strings. This level of prior layout is not normal in slating, where the details are worked out upon the roof as the installation proceeds.

Fig BA. Slate Layout.

9.3 . Attachment of Slates

The hook attachment method for the Electra-slate is discussed in Section 7.0 earlier in this report and although it is only currently found on a small percentage of UK roofs. The technique is common in other European countries.

The roofer has to place the hooks on the battens, in the gaps between the row below.

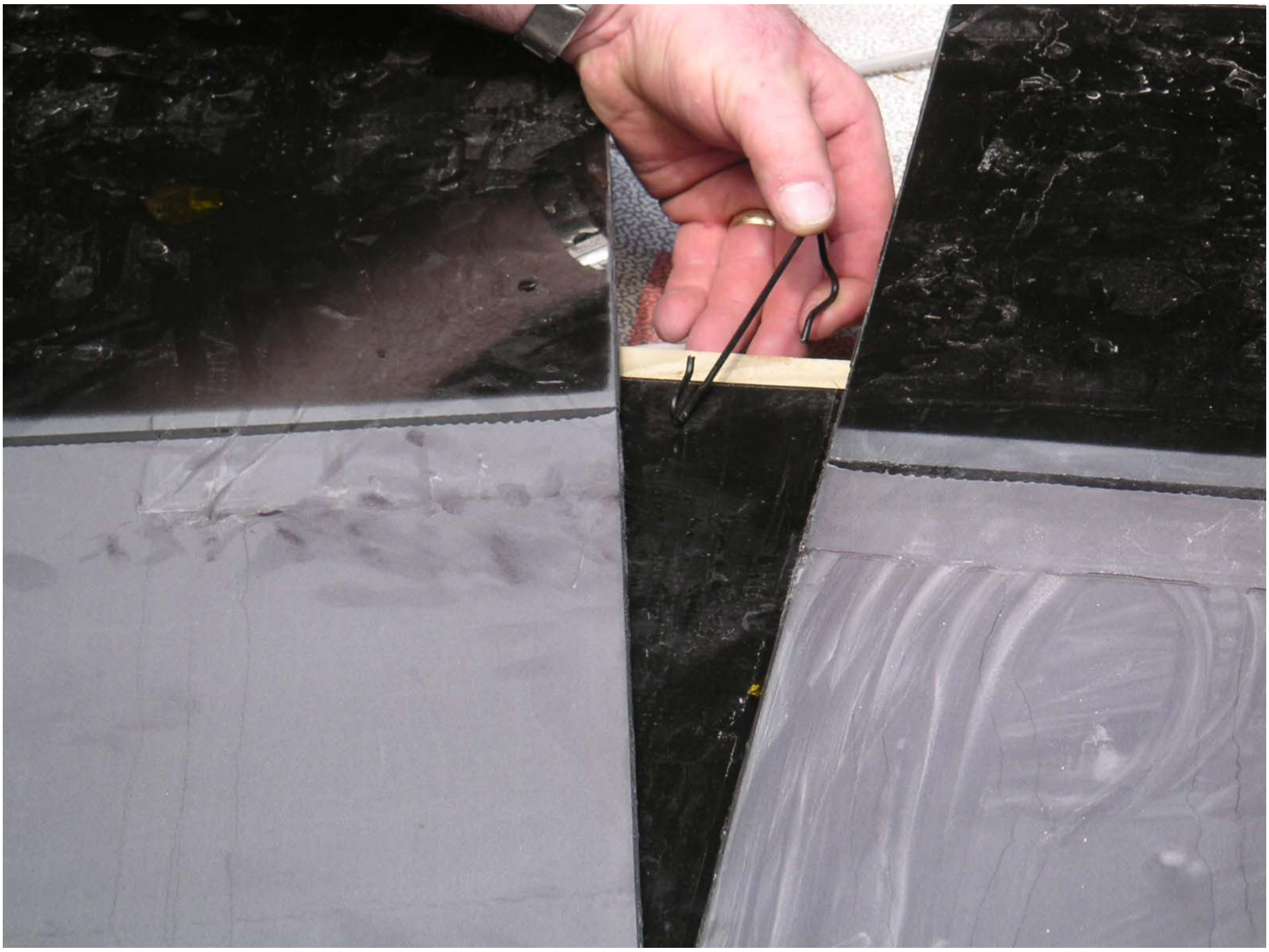


Fig BB. Hook installation.

The clips employed for the demo roof section were standard 125mm types and specified to match the pitch and baton spacing employed on the roof section.

For Installation the roofer is required to plug in the male plug from the loom connection into the integrated connector box installed on the E Slate before lowering the slate onto the plane of the roof and sliding it down into the clip of the hook.

Fig BC. Demo Roof Installation work in progress.

This part of the process was the most unusual for the roofer and required some practise to gain a reasonable speed of work. As the slates are being placed above another row, up a diagonal edge, the roofer has to lean over the slates, grasp the connector, balance the next slate on his knee on edge, align and push in the plug.

After approximately 20 or so slates the roofer felt that a task that had initially seemed impossible, was now achievable.

9.4. Electrical interconnections

The maximum numbers of slates in a string is limited by 2 parameters

- The current capability of the Loom
- The reverse current survivable by a shaded slate

The cable that has been used for the loom is capable of 8A, which is sufficient for 50 times the short circuit current of the final slate specification. Maximum I/sc is approximately 154ma. This gives a max s/c for a string of 50 at about 7.7A. Impp at this time is approximately 120ma yielding a maximum operating current of 6A.

The reverse current capability was established by test, and was found to be .05 Amps at the MPP voltage of 28v. This rises to 170mA at 45v, the theoretical maximum o/c voltage. If we assume that the whole string of 50 were shaded and that the rest of the roof is supplying current whilst standing at 45v, then a possible fault current of 8.5A could flow in the string. This is an unlikely scenario so therefore the maximum number of slates in one string remains at 50 limited by the cable capacity.

Fig BD. Under Slate Connection.

9.5 Interface with standard Slates

Where the end of a row of active slates occurs, there is usually a need for at least one standard slate at the end. This allows half slates to be cut to form a verge, or angled cut slates to be used at a valley. The cable loom is taken through the membrane behind the last active slate, and so does not form a barrier to normal roofing practise thereafter.

Fig BE. Interface with Standard Slates

9.6. String Interconnections – Marshalling box

When laying out the roof the cable loom is cut to the required length. The 'start' end is sealed using a 'twist and seal' end cap.
A lead-out cable of appropriate length is attached to the remaining end using two twist and crimp connectors. The resultant joint should be sealed using self-fusing silicone insulation tape. If it becomes necessary to extend a cable loom then the above jointing method may be used.
The lead-out cable is passed into the roof void under an overlap flap of the waterproof membrane.
The string cables are fed into the terminating box in the roof void. The terminating box contains string connection terminals, string fuses and a DC rated isolation switch. Where the cable enters the marshalling box it passes through a gland plate and is fixed into positive and negative screw terminals. Each terminal pair is fitted with a LED. When connecting the individual strings the LED will illuminate to indicate correct polarity and available voltage.
The positive line of each string passes through a fuse rated at 8 amps and thence to the DC isolator.

Fig BF. Marshalling Box..

9.7 Inverters

A high current DC cable from the marshalling box is attached to the input terminals of the inverter via glands.
The output from the inverter, following standard PV installation conventions, then passes via an AC isolation switch to the building grid.

Fig BG. Inverter connection.

The Inverter selected for the demo system was the Sunny Boy 1100LV. This type proving to be most suitable for the Electra-Slate system as it is capable of use with systems from 800w to 1600w and is the ideal solution to a system with relatively low input voltage.

In the event of a larger system than 1600w being installed on any given roof the number of Inverters attached to the system would be increased accordingly.

The 1100LV provides for the following specifications:

- Single Phase 230v 50 Hz.
- Maximum Input Voltage 60v Dc Max.
- PV Voltage Range MPPT (Vpv) 23.8 v to 60V.
- Maximum Input Current 56A.
- Max Efficiency 92%
- Size (W) 434mm x (H) 295mm x (D) 214mm
- Weight 28 kg.
- Short circuit protection
- Meets Grid Conformity EN 61000-3-2.
- Meets Low voltage regulations EN50178, EN60146 part 1-1.

- Meets CE conformity.
- IP65 Integrity.
- Easily commercially available.

Please refer to the below drawing 5159103 for a schematic layout of the balance of system components.

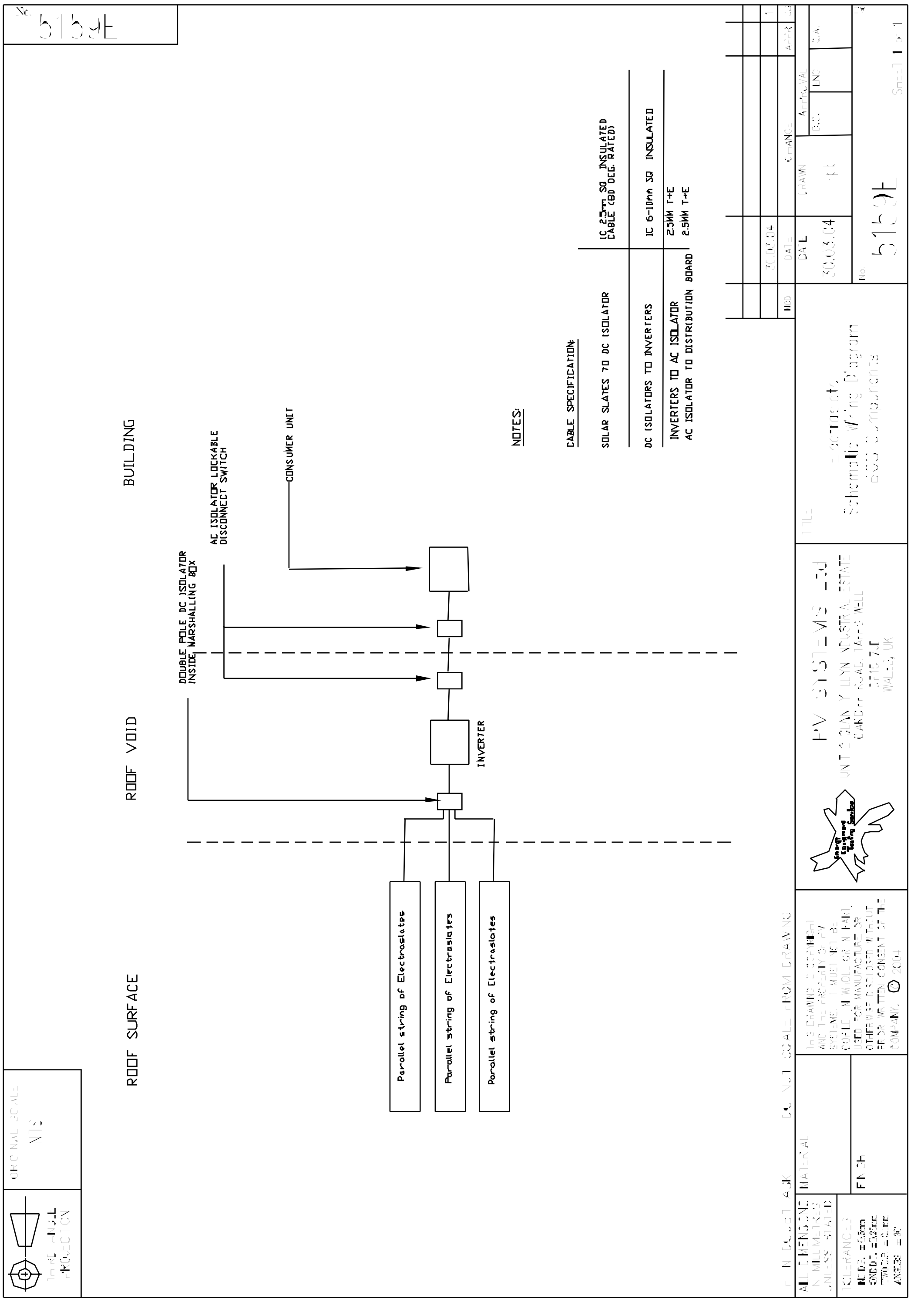


Fig BH. Balance of System Schematic

9.8 System Test.

The demo roof was tested outdoors in full natural sunlight, normally incident on the surface. The radiation level at the time was measured using an ESTI calibrated standard reference cell.

Fig BI. Roof Section under Test

A connected string of 55 slates was created in order to prove interconnection capability. The end cable was attached to a meter in short circuit mode and the output measured.
The array achieved an output of 7.17A at 1034W/m2. This equates to 6.93A at standard conditions of 1000W/m2.

The array was left in this condition for a period of 2 hours and inspected at the end of that time. The temperature of the slates and attached components gave rise to no observable changes in the cable or connector condition.

The roof was sprayed with water to simulate a rain shower. The output of the panels was monitored during the drying out period, but no significant effects were noted. The visual appearance changed from a shiny ‘glassy’ effect when wet to a grey ‘slate’ looking roof when dry.

10.0 PROJECT CONCLUSIONS

Fig BJ. Demo roof Section Completed.

The above Photograph of the demo roof section demonstrates the aesthetic appeal of the Electra-slate product in its similarity to natural slate. In order to prove this statement one natural slate has been intermingled with the Electra-slates on the demo section above. It can be seen that it is difficult to distinguish this natural slate from the surrounding Electra-Slates.

The use of the Slate hooks has proven to be a convenient method of fixation to the roof structure, with the roofer providing positive feedback to their use. The slates are not suitable for walking on, as in essence they are glass laminates. However this would not hinder a roofer in their use. Further market studies and feedback from the roofing Industry will be undertaken in the months before ICP launch the product commercially.

The one area where not being able to walk on the roof would slightly impede a user would be in the unlikely event of a slate needing replacement through electrical failure or breach of the roof structure via storm damage and the like. This would necessitate the use of a roof ladder to span the affected area in order to facilitate replacement.

However we cannot assume that all users would employ this method and may walk on the slates. Unlike natural slate however if a single unit is cracked from such use, it will not disintegrate and fall to the ground representing a health and safety issue.

This is a virtue provided by the fact that the slate is of a laminate construction and will maintain it's structural integrity in the event of cracking or impact damage.

Tests were conducted to establish how easy or complicated it would be to remove a slate and replace. Much as a normal roofing specialist would replace a natural slate, the slates that sits directly above the effected unit are lifted slightly with a suitable implement. Then the effected unit would be pushed up to release it from the clip and then slipped downwards to remove it from the roof structure raising it in the process to ensure the integrated connector clears the baton it sits behind.

The length on the loom between male connections is specifically designed to enable enough cable to be come clear of the structure of the roof to effect a removal of the loom plug, discard the damaged slate, replace it with new and re-install in the reverse of the removal procedure.

The testing conducted to prove interconnection capability has proven the fundamental design of the Slate integrated connector and string loom operates effectively with minimal losses over a large string of the E-Slates. All the balance of system equipment is of size capable of fitting through an aperture of 0.4 x 0.6 mtrs which is considered to be the standard loft hatch to be found in most UK properties. Thus the system will meet the needs of the physical limitations that maybe apparent in an installation in the UK domestic housing market.

The system also lends itself to the use of a consumer monitoring system such as the sunview user display such that the consumer is capable of monitoring the performance from an installed roof array for a small additional cost.

Feedback from roofers involved in the previous installations of the prototype Electra-Slates under Intersolar had commented that the glass laminate could tend to be sharp in the corners and on some edges of the slate itself. ICP have countered this feedback by ensuring that the sections of backing glass employed in the slate are edge ground pre lamination into the final product. It is not possible however to edge grind the active plates section of the slate as this will normally "kills" the plate with contamination falling into the laser isolation channels cut in the active material of the cells. It cannot also then be washed for the same reason.

The effect however of the shot blasting undertaken on the product in order to achieve the non reflective finish in a completed laminate acts as to blast of any sharp edges of the active area. Feedback from the roofer employed to undertake this installation was that he had no concerns about handling the product and did not find any issues with the slate edges.

In summary the Electra-Slate has proven the concepts behinds it intended use. ICP have in place the facilities, equipment and trained personnel to manufacture in medium volume with the intent to upscale our capability in readiness for commercial launch of the product in 2005.

It is relatively easy to install and has proven that a roofer without any special training is able to install the roof part of the system, the fixation methodology has proven to work well within standard roofing practise and the interconnection system meets the design criteria and performs as anticipated.

It is also noteworthy that the aesthetic appeal of the Electra-slates has been improved by changes made to the construction of the Electra-slate from earlier prototype models of the product.
ICP is confident that the Electra-slate is a robust and cost-effective means of introduction into the world of grid connected PV roof generation systems where a slate roof style is the preferred roofing definition.

Following closure of the DTI sponsored Project ICP will continue to review the product definition against feedback being collated from within the roofing Industry in readying it for final IEC 61646 qualification. ICP plans to undertake submission for qualification later this calendar year once fully optimised dual junction solar cells are made available to the project. We are also planning to undertake further building product related trials such as Fire spread testing and demo installations during the nine months of the qualification period that IEC 61646 will take to achieve.