Modular Shielded Solar Panels Made Using Low Cost Lamination Process

Theodore G. Stern
DR Technologies, Inc.
7740 Kenamar Court, San Diego, CA 92121
858-6778-1230
tstern@drtechnologies.com

ABSTRACT
A modular, laminated solar panel approach has been demonstrated which uses high efficiency cells and allows application to a variety of smallsat footprints without customizing each application. The module design includes a contiguous integral shield which protects the solar cells more effectively from a variety of space environments, and also provides electromagnetic cleanliness to protect sensitive instruments from solar array generated EMI. The laminated approach also provides significant cost reduction by incorporating self-tooling and reducing the number of steps and processes needed to assemble a solar panel from individual cells. Modularity leads to standardization, which allows process controls and inherently improved reliability. A number of alternative cell and module sizing approaches were considered to meet the needs of smallsats which often have small and discontinuous surface areas available for solar cell strings. The modular laminated solar panel provides a means of obtaining reliable, efficient panels for smallsats at an acceptable cost.

INTRODUCTION
Smallsat power systems are often faced with a challenge in providing a high-performance, high-reliability solar power source. Current approaches to space solar arrays use relatively large solar cells with areas exceeding 25cm² per cell. When strings of these cells are connected in series are needed to provide appropriate voltage to the spacecraft, the limited area available on each potential sun-facing surface often leads to complex arrangements that drive cost and risk.

The modular approach that is described here uses current cell technology and space qualified materials with the objective of applicability to a wide variety of spacecraft power needs. A key aspect of the modular design reduces the cost of solar panels by adapting the transparent shielding layer and the printed circuit layer with features to assemble solar cells into completely connected and wired panels using lamination. Features built into the layers position the Cell-Interconnect (CI) assemblies, solder pre-forms and wiring connections, allowing a one step process for “glassing,” stringing, laydown and wiring. This eliminates the most costly labor and schedule intensive elements of conventional solar panel assembly. The laminated, broad-area encapsulation approach has been used for years in terrestrial solar panels, but never applied to spacecraft arrays because of mass considerations.

Standardizing the solar array modules allows us to implement production line approaches, including automation, which overcomes the labor intensiveness and reliability concerns which drive space solar array designs towards larger cells. The ability to choose smaller cells allows modules which can be fit onto much smaller spacecraft surfaces, and also allows the use of “co-products,” the remnant high efficiency photovoltaic cells that can be fabricated from material that is left when large rectangular solar cells are fabricated from round wafers.

LAMINATED MODULE DESIGN
We started with the space qualified high efficiency solar cells with welded interconnects and integral diodes, however, there was no coverglass or adhesive used. The elimination of the coverglass and its bonding process saves considerable cost and schedule. The solar cell–interconnect (CI) components were individually placed into a specially designed shield molded with a ‘waffle’ pattern. The shield is fabricated from a durable space qualified transparent material using a tool designed to form pockets for each CI as shown in Figure 1. This allows the transparent shield material to also act as a placement tool for achieving cell and string alignment.
assembly costs and schedule time. While some of these tasks can overlap, others (especially procurement of coverglasses) have lead times of up to 20 weeks. By eliminating the coverglass and glassing step, and performing the wiring, stringing and laydown in a single step, we anticipate reducing the cost of a solar panel by 30%, and the schedule time from 16-24 weeks to less than 8 weeks. Even this schedule can be reduced to near instant delivery if sufficient market penetration allows the standard module to be pre-made and sold through distributorships.

MODULARITY STUDY

We conceived a general approach to encapsulating cells into an integrated module, and studied module sizing for optimum mass and cost. Figure 3 shows the general approach we conceived for integrating modules into an array. The approach uses pre-populated solar array panels, and integrates them into a composite frame which is fabricated from typical structural l-beam and box-beam members. By pre-populating the array modules and requiring only that the frame be designed and built to the shape factor desired by the application, the cost and schedule of developing a typical solar array is significantly reduced.

We started with a kilowatt size deployable panel and performed a modularity trade-off, using a finite-element analysis model to evaluate how scale-up of the module sizes affects mass. The model considered a baseline panel structure having overall dimensions of $2 \times 2\text{m}$ (80 x 80"), and assembled from identical modules. The modules varied in size between 25 X 50cm, 50 X 50cm, 50 X 100cm and 100 X 100cm (~ 10 x 20", 20 x 20", 20 x 40", and 40 x 40").

The model boundary conditions fixed the panel at the four corners and middle of the panel. The model was analyzed to determine the first mode and the maximum panel deflection under 30g acceleration normal to the panel. By varying the module size and determining the
corresponding weight we see there is an inflection point wherein increasing the module size yields less of a weight savings. Figure 5 shows this occurs at a module size of approximately 20x20" (50 X 50cm = 2500cm²).

Figure 4. Solar Panel Analysis Model with 50 X 50cm modules in a 2m X 2m panel.

We determined that the 50 X 50cm (20" X 20") module provides a good mass trade-off, a convenient manufacturing size, and a reasonable power building block size (such a module would form a building block generating between 40 and 80W per module depending on cell type and orbit). The design showed an overall mass effectiveness as well. With 28.5% state-of-the-art solar cells and an 85% packing factor, the 4m² panel incorporating 0.25m² modules projects a specific power of 97W/kg.

Figure 5. Mass of a solar panel as a function of module size for different frame configurations.

MODULARIZING FOR SMALLSATS

While the optimum size for a modular panel of kilowatt capability is on the other of 50 X 50cm, for smaller spacecraft, this size may be larger than even the largest available area for either body mounted or deployed arrays. For this reason we looked at the approach to achieving smaller cell sizes. Immediately we were faced with the problem of achieving a small module when 10-20 cells in series are typically needed to achieve spacecraft voltage requirements, and each cell has a size of >25 cm². The approach we decided upon makes use of “co-products.”

We looked at two typical co-products that are remnants typically available after high efficiency cell production from CVD growth on germanium wafers. In one approach, the annulus of the wafer is used, avoiding the last 0.5mm around the edge to assure that the wafer quality is good. This approach, shown in Figure 6, provides at least 2 small cells from area in each wafer that would otherwise be thrown away.

Figure 6. Co-products of a typical rectangular cell production produces cells of ~6cm² area.

The second approach arises from the use of trapezoidal shaped cells in some spacecraft applications. The production of such cells leaves small triangular remnant areas, which can be fabricated into cells like those shown in Figure 7.

Figure 7. Triangular co-products from trapezoidal cells have an area of ~2.5cm² each.

Using these cell sizes, we were able to construct modules of much smaller dimensions. The 20-cell modules that we conceived in this study, shown in
Figure 8, could be viewed as encapsulated high voltage solar cells, which could be bonded onto any size panel, with lead wires being the only remaining interconnection requirement.

![Figure 8. Smaller modules using co-products can be assembled with ~125cm² and ~50cm² module sizes.](image)

Using these smaller modules, we completed an application study to determine if improved packing factor can be achieved with smaller modules. We looked at a variety of body mounted and deployable solar panel configurations. We found that, especially for smaller body-mounted applications which may have complex keep-out zone geometries. As an example, the spacecraft side panel of Figure 9 had very poor packing factor with conventional cells, but using the 50cm² module with triangular cells, we were able significantly improve on this.

![Figure 9. Smaller modules (shown as rectangles) are able to achieve high packing factor on body panels with complex keep-out zones (shown hash marked).](image)

CONCLUSIONS

An encapsulated solar panel module made using lamination techniques has many benefits for cost, schedule and reliability, mostly as a result of the ability to use production techniques for automation and quality improvement. The complexity and risks associated with unique and customized solar panel designs for every new application along with the cost and problems of qualification are avoided with this approach. In addition, the ability to make smaller modules that provide appropriate end-of-life voltages allows improved packing factor on smaller available surfaces typical of smallsats, which may include complex keep-out zones that interfere with string continuity. These smaller modules, which may use low-priced solar cell co-products, may be especially beneficial to the needs of smallsats.

**Acknowledgements**

This research was sponsored in part under an SBIR from the NASA Glenn Research Center, Contract No. NNC06CA69C, “Affordable High Performance Electromagnetically Clean Solar Arrays.”

**References**
