RECEIVER DEVELOPMENT FOR ROOFTOP CONCENTRATOR APPLICATIONS

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ABSTRACT

Rooftop concentrator modules require low cost receiver assemblies that satisfy the requirements of good thermal dissipation and dielectric standoff whilst still meeting a product warranty of 20 years. This paper describes the development of receiver assemblies for the rooftop mounted Heliotube™ module and their associated performance and reliability. The impact of material choice on dielectric/thermal performance is discussed and compared with experimental data before and after accelerated testing.

HELIOTUBE™

At low concentration ratios, the receiver assembly of a concentrating photovoltaic panel (CPV) can share many of the characteristics of conventional flat panel technology. However, the increased intensity at the cell requires improved thermal management to maximize power output whilst still maintaining the dielectric standoff needed to meet the safety requirements of UL1703.

In the Heliotube™ concentrating trough shown in Figure 1, the receiver assembly is bonded to a reflective trough that combined with a linear Fresnel lens completes the hybrid optic assembly.

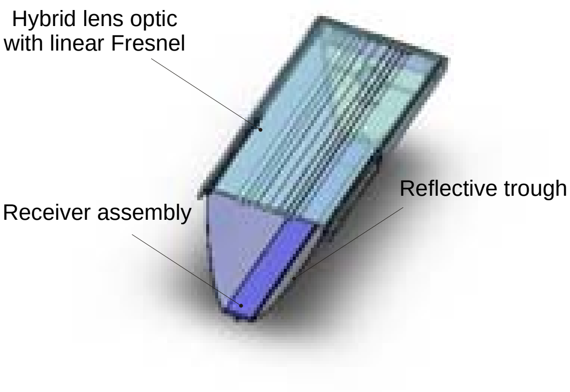


Figure 1. Heliotube concentrating photovoltaic trough

RECEIVER CONFIGURATION

A range of receiver configurations was evaluated based upon a 4 cell test vehicle which, whilst shorter than the 14 cell receiver used in the Heliotube™ module, would share the same process parameters and materials. The design was largely based on conventional flat plate module manufacturing techniques and materials: EVA encapsulant, Tefzel cover, and ribbon wire interconnection, with the addition of an aluminum substrate acting as structural support and heat spreader.

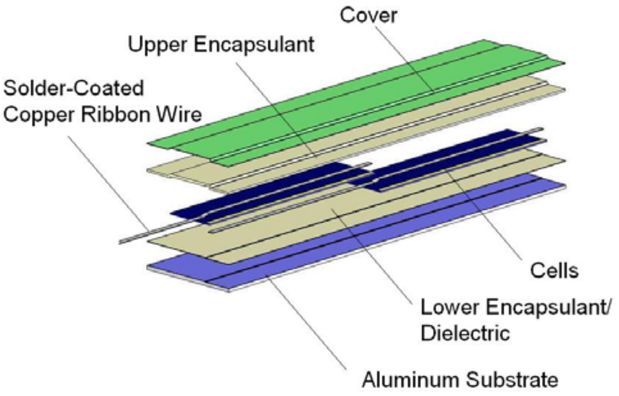


Figure 2. Exploded detail of receiver construction

The main areas of departure from flat plate module technology were the lower encapsulant/dielectric layer and the aluminum substrate. Conventional modules use a second thick layer of EVA and usually a thick layer of Tedlar (PVF) or PVF/PET laminates [1]. However, to meet the thermal requirements of a concentrating module, new materials or combinations of materials are needed. A number of different material options were evaluated based on their thermal and dielectric performance.

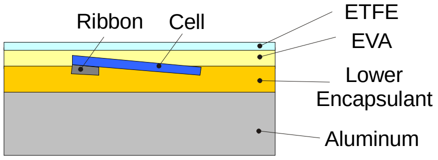
In addition to the choice of photovoltaic cells, the reliability and performance of the receiver was influenced by three areas that were evaluated in detail:

- Substrate design
- Encapsulant/Dielectric System
- Upper Encapsulant/Cover

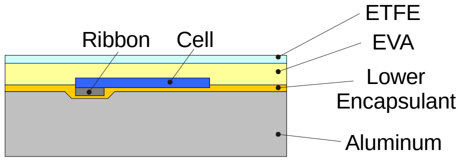
Substrate Design

The purpose of the aluminum substrate is primarily to spread the absorbed heat over a larger area to minimize the thermal resistance between the cells and the carrier/trough bond line. Secondly, it functions as a carrier that assists in handling and bonding to the trough.

The simplest design would obviously be a thin flat strip. However, if the lower encapsulating layer becomes thin (approaching the thickness of the interconnecting ribbon wire), there is increasing motivation to contour the substrate to the profile of the cell and ribbon wire. A contoured substrate will decrease the thermal impedance between substrate and the cell as well as reduce the chance of cell breakage as shown in Figure 3. Two groove configurations were evaluated: a square-sided groove (GRV-1) and a contoured groove (GRV-2)



(a) Thick lower encapsulant with flat substrate



(b) Thin lower encapsulant with contoured substrate

Figure 3. Conceptual illustration of substrate contouring

Encapsulant/Dielectric System

The material between the aluminum substrate and cells must perform three functions:

1. Complete encapsulation of the cell for environmental stability.
2. Electrical isolation of the cell from the substrate.
3. Provide a low-thermal-resistance path between the cells and the substrate.

As the thickness of the layer increases, it becomes easier to satisfy the first two requirements but at the expense of the third. A number of solutions were investigated which generally fall into three categories:

a) Materials that satisfy encapsulation and dielectric requirements simultaneously (usually materials with a porous dielectric standoff through which encapsulant can flow, such as fiberglass or glass beads impregnated into an encapsulant sheet),
b) Direct treatment of the aluminum with a dielectric layer (a fluid coating which is cured, for example) and subsequent encapsulation with EVA,
c) Solid sheets of dielectric material which are bonded directly to the aluminum in a process step prior to cell encapsulation (these materials must be stable at encapsulation temperatures).

A summary of the different materials evaluated is given in Table 1.

Dielectric material	Thickness (mm)	Thermal Conductance (W/m^2K)	Predicted dielectric strength (V)
Silicone with fiberglass Bond Ply LMS	0.1625	5500	3500AC
EVA with fiberglass	0.45	560	-
Powder Coating Series 49, REL 9016	0.125	1600	3000
Liquid Coating Polane-S Polyurethane	0.0625	3200	2300
Aluminum Oxide Epoxy 343 A-B	0.1	>10,000	3000
PET film Mylar OL13	0.025	6100	8000
PET film Melinex 301H	0.02	6100	6400

Table 1. Thermal properties of dielectric materials

Only the two fiberglass-impregnated materials provided both encapsulation and dielectric resistance. For the rest of the dielectric materials encapsulation was provided by a 0.2mm thick layer of EVA.

Upper Encapsulant/Cover

Conventional flat plate modules typically use a tempered glass superstrate as the final protective cover. Whilst this is an option for the Heliotube receiver, a Tefzel coverlay was evaluated for this purpose. In addition to withstanding environmental exposure over a 20 year period, the receiver must also be able to satisfy the cut and push test requirements of UL1703.

PERFORMANCE AND RELIABILITY TESTING

The overall test sequence for the 4 cell receivers is shown in Figure 4 based on a reduced version of the test sequence specified in UL1703 for flat plate modules.

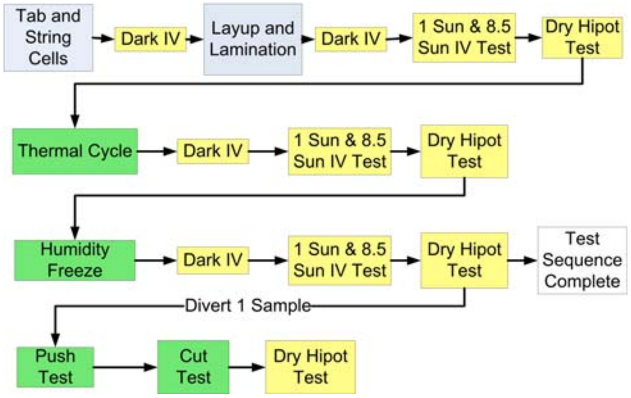


Figure 4. Process flow for receiver design testing

IV-Curves

All IV curves were measured using a Keithley 2420 SourceMeter (bipolar power supply), and four-point measurement. Dark IV curves were taken to 3A forward bias. One sun and concentrated sunlight IV curves were recorded at GreenMountain's rooftop testing facility.

Insolation was measured using an Apogee PYR-S pyranometer, and ambient temperature measurements were recorded using type K surface mount thermocouples. IV data was normalized for insolation, but not for temperature since temperature was controlled during a single test sequence using a water cooled thermal chuck.

High Potential Test

Receivers were tested according to UL1703 using a QuadTech Sentry 30 HiPot tester. The voltage was ramped from 0-2200V over 5 seconds and then held at 2200V for 60 seconds. The threshold leakage current for a failure was set to 10μA.

Thermal Cycle and Humidity Freeze

Environmental tests were conducted at Quanta Labs in Santa Clara, CA. The profiles used were modified and abbreviated versions of those used in UL1703. Table 2 shows a comparison of the cycles used with those recommended in UL1703. Thermal cycle and humidity freeze are two of the most demanding tests which the receiver must withstand. Analysis of the design indicated that the cycle times could be shortened due to the much reduced thermal mass and path length for moisture absorption. However, these cycles will still be less severe than those expected in UL testing and additional future testing of the preferred design was recommended.

	Thermal Cycle (TC)		Humidity Freeze (HF)	
	UL1703	Acc.Test	UL1703	Acc. Test
Number of Cycles	200	50	10	10
Cycle time (hours)	3-6	1	24	12
Total time (days)	25-50	2	10	5
Ramp time (mins)	60	15	60	60
High temp soak time (mins)	60	15	1200	540
Low temp soak time (mins)	60	15	60	60
Humidity	n/a	n/a	85%	85%

Table 2. Comparison of environmental tests performed with UL1703 environmental tests

TEST RESULTS

Grooved substrates

Exposure of the receivers to temperature cycling and subsequent humidity freeze revealed the sensitivity of the design to the contour of the groove. GRV-1 which had a square sided groove showed considerable degradation believed to be caused by microcracks induced by the edge of the recess during expansion and contraction. In contrast, a radiused groove, GRV-2, exhibited excellent performance throughout the tests.

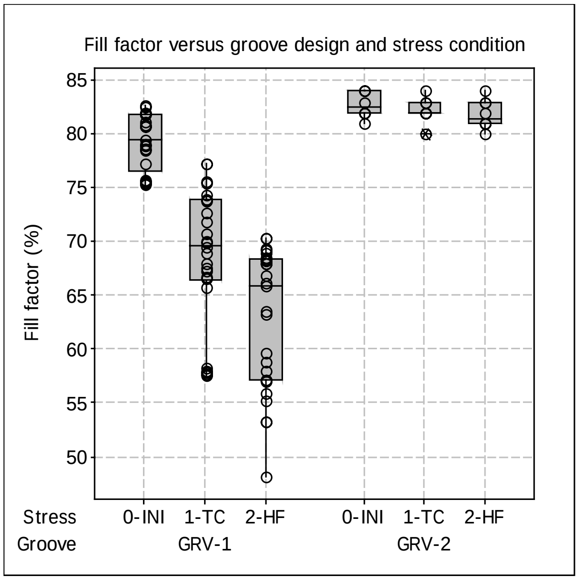


Figure 5. Receiver performance versus substrate design

Thermal Resistance

Thermal resistance of each configuration (defined as the rise in temperature of the cells relative to the substrate under concentration) was estimated by measuring the open circuit voltage (V_{oc}) as a function of time from initial exposure of the receiver to sunlight until it reached thermal equilibrium. Based on the temperature coefficient for V_{oc} for the cells of 2.225mV/C, provided by the cell manufacturer, and the difference in the values of V_{oc}, the temperature rise under concentration was determined. A comparison of the measured thermal resistance for different material configurations as a function of reliability stress is shown in Figure 6.

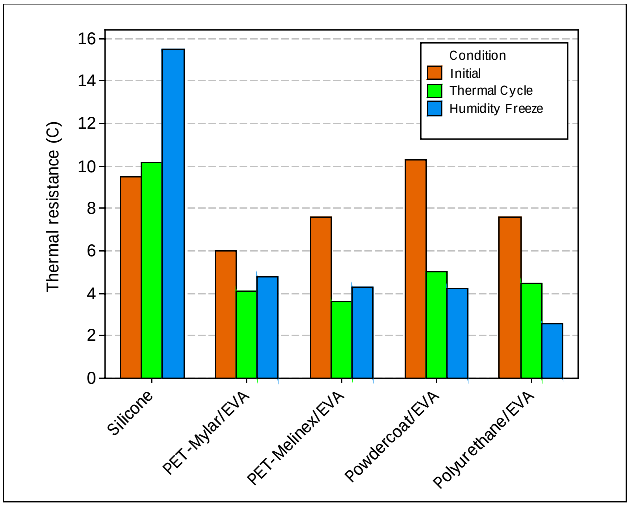
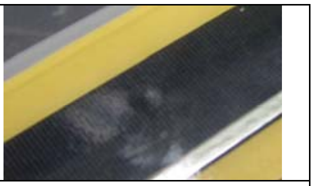


Figure 6. Thermal resistance versus dielectric material

Push and Cut Test

The cover material of EVA/Tefzel was found to successfully pass the 4lb and 20lb push tests of Ul1703 as shown in figures 6 and 7. Cut tests induced no critical damage to the test vehicle resulting in no weakening of the dielectric properties and hence the safety of the system.

	
Figure 6. Result of 4lb push test.	Figure 7. Result of 20lb push test.

Performance Summary

A summary of the performance of the different dielectric materials is shown in Table 3 indicating that the PET/EVA dielectric\encapsulation provided greater than 2200V dielectric strength with a thermal resistance of approximately 5C.

Dielectric material	Measured cell temp rise [±1C]	Measured dielectric strength after humidity freeze [±100V]	Adhesion strength after humidity freeze [N/mm]	ΔFF after humidity freeze (%)	Comments
Silicone with fiberglass Bond Ply LMS	15	Shorting	1-10	-	Fail (shorting)
EVA with fiberglass	-	Shorting	N/A	N/A	Fail (Shorting)
Powder Coating Series 49 REL 9016	4	1100	>10	-1.5	Fail
Liquid coating Polane-S Polyurethane	5	1100	>10	-3	Fail
Aluminum oxide epoxy 343 A-B	N/A	1200	>10	N/A	Fail (Outgas observed)
PET film Mylar OL13	5	>2200	1-5	-2	Pass
PET film Melinex 301H	4	>2200	5-10	-1.5	Pass

Table 3. Performance comparison for different materials

CONCLUSION

The thermal, dielectric and reliability performance of a range of different receiver configurations has been evaluated. Based on the test results summarized in Table 3, the proposed design of a grooved substrate with a PET/EVA dielectric layer is expected to produce the required power output and survive environmental stressors without significant degradation.

REFERENCES

[1] Handbook of Photovoltaic Science and Engineering, A. Luque and S. Hegedus, 2005

[2] UL 1703 Standard for Flat-Plate Photovoltaic Modules and Panels (Third Edition)