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ON THE DESIGN OF CPC PHOTOVOLTAIC SOLAR COLLECTORS

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DISCLAIMER

ON THE DESIGN OF CPC PHOTOVOLTAIC SOLAR COLLECTORS*

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ABSTRACT

Two new photovoltaic solar collectors have been designed, built and tested. A substantial improvement in performance has been achieved in that they produce more electrical power and use significantly less photovoltaic material per unit area than the present state-of-the-art flat panel arrays. A reflective style Compound Parabolic Concentrator (CPC) optical system was used for one collector, and a dielectric style (DCPC) optical system was used for the other collector to concentrate sunlight onto custom designed photovoltaic solar cells. For these two panels only periodic angular adjustments are required, which eliminates the need for two-axis tracking.

A modular design of individual sub-units containing an array of series and parallel circuits allows a user to select a variety of operating conditions. The dielectric CPC panel can provide a peak voltage selected from the range of 6V to 120V d.c., in steps of 6V, and a peak current from the range of 23A to 1.15A, in 1.15A increments, respectively. The modular design also allows rapid replacement and repair of individual sub-units. The mechanical assembly was designed to withstand a very heavy load of 250 Kg/m^2.

The reflective CPC photovoltaic panel is 1.22m by 1.22m, requires thirty-six adjustments per year, and delivers 97 peak watts under 1 kW/m^2 of direct insolation. The dielectric CPC panel is also 1.22m by 1.22m, but only requires ten adjustments per year, and delivers 138 peak watts under 1 kW/m^2 of direct insolation. The net energy conversion efficiency over the entire dielectric CPC panel, including the frame, was 10.3%. The design considerations for these panels are summarized in this paper.

INTRODUCTION

The design and development of solar collectors which produce both heat and electricity is influenced by many factors. Ordinarily, the cost, quoted in dollars per watt, is the dominant design consideration. Since the cost of producing photovoltaic cells is the major cost in collector manufacturing, it is obvious that the amount of photovoltaic material should be reduced. However, deciding when to stop attempting to reduce the amount of photovoltaic material is a complex function of the expected future costs of the material, its packaging, and the efficiency of the cells operation. Each of these cost factors are, in turn dependent upon a wide variety of other conditions, usually quite unrelated to the physical or technical limitations of collector design.

One basic principle for the design of photovoltaic solar collectors should be to develop a durable, maintenance free product. The best design, from the user's viewpoint, is one that will last forever, and require no maintenance. Certainly, collectors which require two axis mechanical tracking equipment, must withstand extreme wind pressure, and maintain positioning to ± 0.5 degrees are poor candidates to meet these desired objectives. However, from a manufacturer's viewpoint, the repair and replacement activities can be rather profitable. This contridiction must be resolved in the users favor, if the implied and promised advantages of solar photovoltaic power are to be realized. In the spirit of attempting to develop a maintenance free collector, the use of the most durable materials and design is required.

MECHANICAL DESIGN

The mechanical design of these collectors is based on the desire to produce a device that could withstand a very heavy static load of 250 Kg/m^2. In addition, torsion, bending, vibration, and sheer forces were computed and a structural frame was assembled which would resist impacts and pressure from any direction. In particular, a metal border was provided surrounding the panels so that it could be rested on any corner or edge without damaging the panel. The self supporting frame has a variety of mounting holes to permit flexibility in attaching the collector to a base, and for adjustments of its tilt angle. Both collectors used essentially the same design for the support frame. In order to meet the time constraints for the construction of the panels, only standard aluminum channels, L's, and T's, were used; no attempt was made at reducing the weight of the frame and collector modules.

Acrylic (polymethyl-methacrylate) was used to form the dielectric CPC troughs, and for the covers of the reflective CPC modules. This material has shown resistance to damage from severe wind, rain, hail, ice, and snow storms as well as resistance to

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degradation from ultraviolet radiation. An extended sandstorm would probably craze the surface, however, if a more resistant coating is applied, then damage from sandstorms may be reduced. Several coatings may be applied if the local conditions require anit-abrasive, anti-reflective, or anti-static treatment. Futhermore, acrylic is easily mass produced using injection molding techniques. Casting techniques, using an optically clear epoxy which is resistant to ultraviolet degradation, provide a manufacturing method and material for large panels which is also easily mass produced.

The mechanical structure is based on a modular design. The dielectric CPC panel consists of 20 modules arranged in a 4 by 5 array, and the reflective panel consists of 16 modules, arranged in a 4 by 4 array. The modular design was chosen to simplify the development of several prototype minipanels, before a manufacturing commitment was made for a complete panel. It also allowed for the many presentations of the collector to a wide audience. In addition, the modular construction allowed several individuals to simultaneously assemble, and test easily handled units.

ELECTRICAL DESIGN

Figure 1 illustrates the photovoltaic solar cells developed for these panels. The nominal dimensions of the cells were specified as 0.284 cm wide, 2.570 cm long, and 0.0305 cm thick. The minimum acceptable solar power conversion efficiency was 12%, at 28°C when illuminated at 1 W/cm^2 (equivalent to ten suns) with an AM1 (or equivalent) solar spectrum. The base layer is p-type and the diffused surface layer is n-type. Two cells are shown, one having grid fingers connected to the metalization pattern (shaded), and one without grid fingers. The performance of these two cells was not significantly different, due to the low concentration of sunlight.

The same solar cell assembly was used for both the dielectric and the reflective CPC panels. Kovar was used as the heat sink material, in order to match the coefficient of expansion for the silicon. The Kovar heat sinks were plated with silver and solder, and served as the rear electrical contact for the diodes. The heat sinks were soldered to circuit sheets for the reflective panel, and to small buss bars for the dielectric panel. Each cell was tested and binned, before they were assembled into arrays. Each array was again tested, before the optical components were attached. Nine cells were wired in parallel to form one row of a dielectric CPC module, and ten cells were wired in parallel to form one row of a reflective CPC module. Having nine or ten cells in parallel provides a substantial improvement in reliability over the usual designs which ordinarily have one string of diodes in a simple series arrangement, where if one diode opens, the entire panel is worthless. Twelve rows were wired in series to complete a module which would be capable of charging a 6V battery.

The modular design permitted various combinations of modules to provide a selection of voltage and current combinations. One disadvantage of the modular approach is that full use of the illuminated surface of the panel is not achieved. For a commercial panel this disadvantage should be minimized, but for the experimental prototypes we developed it was not an important consideration.

Several solar cell and heat sink assemblies were designed that could be readily manufactured using automatic assembly equipment. Many variations are available in the cell-sink assembly for semiconductor wafers, ribbons, tubes, sticks, slices and chips. The cost of manufacture, assembly, and testing determines the configuration of concentrator, cell, and heat exchanger. If the cost of high efficiency solar cells continues to decline, then the design must reflect the rising relative cost of other materials, inventory costs, shipping, repair, and marketing limitations. The CPC shape allows many variations in the concentration, and hence the amount of photovoltaic material needed to produce electricity.

THERMAL DESIGN

The thermal design is the basis for all solar collectors. The design objective is usually the highest possible collection efficiency consistent with a useable quality (temperature) of heat. For flat plate photovoltaic collectors the thermal aspects are often considered to be of secondary importance, however for concentrating collectors the heat is available at higher temperatures and hence will have more uses.

The present collectors are designed to maintain the solar cells at a minimum temperature in order to eliminate the need for any active cooling equipment. An extended surface heat sink was selected to provide less than 6°C temperature rise between the cells and a 60°C ambient, under a 1 Kw/m^2 insolation.

The dielectric CPC panel receives a total of 1,254 W (or 4,270 Btu/hr.) of which approximately 10% is converted to electricity, about 20% is rejected from the front surface, and about 70% is available at the rear surface for heating. If the air flow across the rear heat exchanger is controlled, then various temperatures may be obtained. A primary goal should be to develop a collector that will provide electricity and heat for a residence in the amounts, and at the time, each is needed.

PERFORMANCE

Figure 2 gives the characteristic current, voltage curve for an average dielectric CPC module. The module is 27.4 cm by 22.9 cm, has an open circuit voltage of 7.76 volts, a short circuit current of 1.21 amps, and a peak power of 7.01 watts.

Figure 3 presents a comparison of the power obtained from an array of photovoltaic cells without a concentrator, and with the dielectric CPC attached to the solar cells, both curves are for 1 Kw/m^2 of direct insolation.

Figure 4 illustrates the performance of the dielectric CPC panel having 20 modules. One row of four modules were wired in parallel, and five rows were wired in series, to obtain this particular curve.

Figure 5 gives the characteristic current, voltage curve for the reflective CPC panel. This panel was composed of 16 reflective CPC modules, and had a power conversion efficiency of 9.64% over its active area.

Figure 6 provides a comparison of the output power for the reflective CPC modules, with and without the concentrators.

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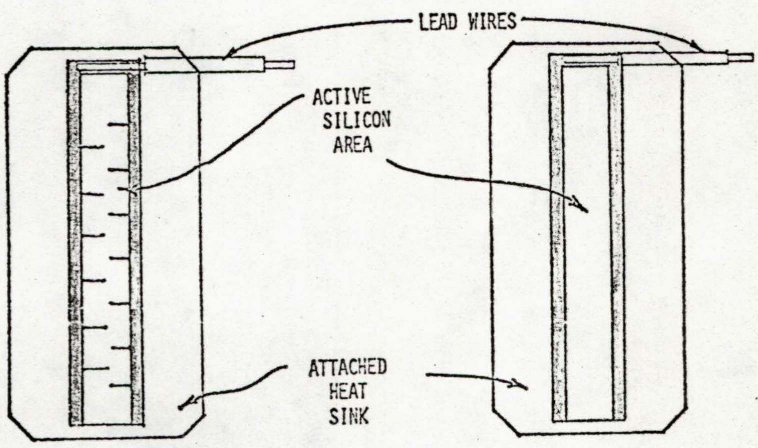

FIGURE 1. PHOTOVOLTAIC SOLAR CELLS

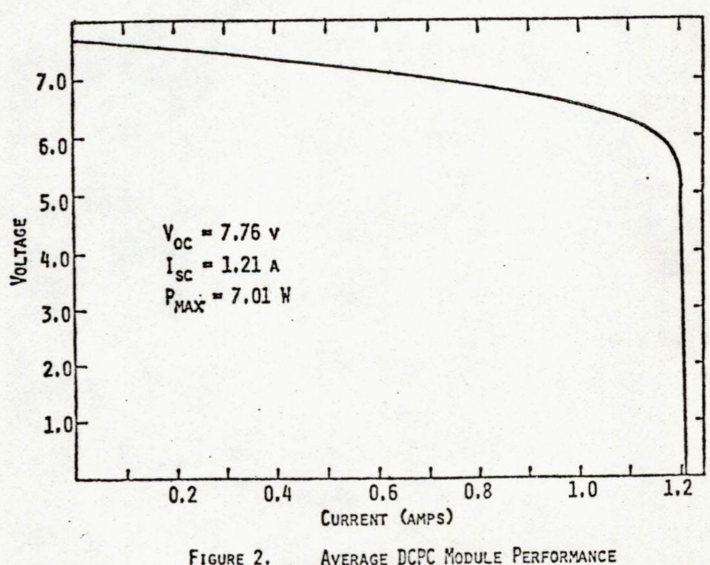

FIGURE 2. AVERAGE DCPC MODULE PERFORMANCE
(SCALED TO 1 kW/m^2 DIRECT)

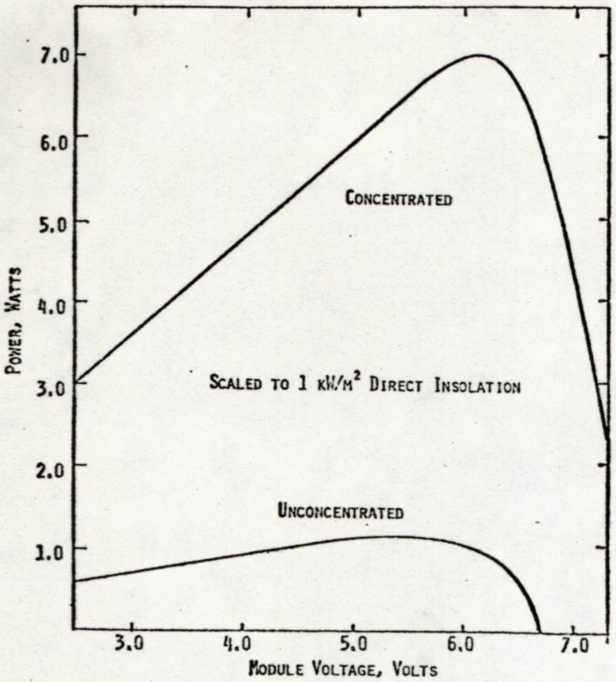

Figure 3. Average DCPC Module Power Curves

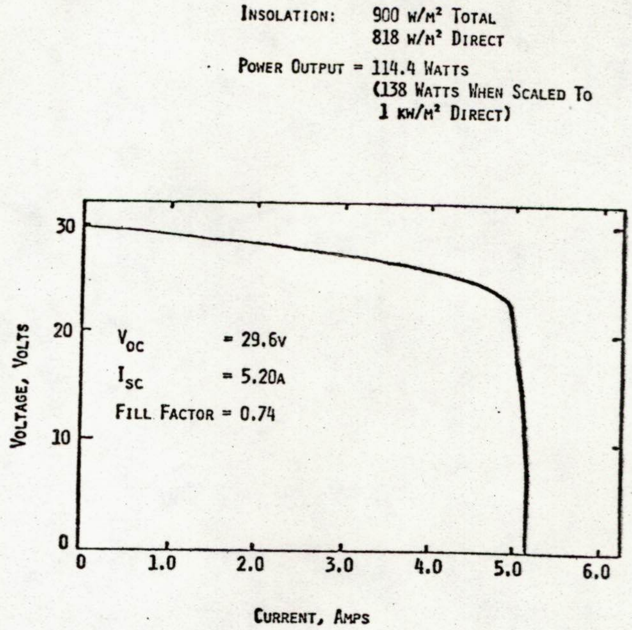

Figure 4. Performance Curve for DCPC Panel

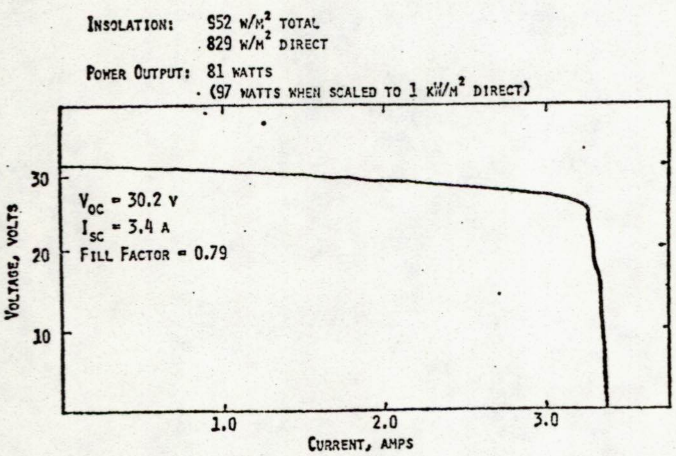

Figure 5. Performance of CPC Panel

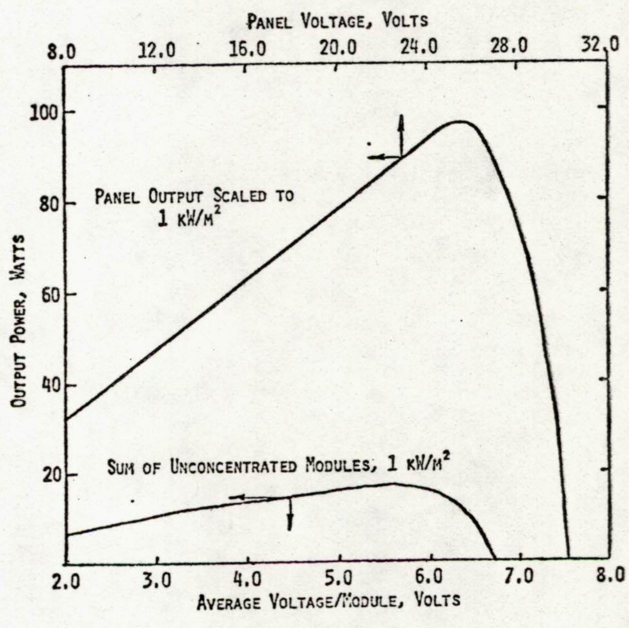

Figure 6. CPC Panel Output Power