ADVANCED SOLAR CELL POWER SYSTEMS FOR SPACE

by

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As space missions have become more sophisticated, the demands for electrical power have increased. All too often the percentage of payload weight allowed for the power system is tightly restricted or even reduced. Today, the average unmanned spacecraft has allotted between 20 and 25% of its weight for the power system.[1] They have ranged from as little as 9% to as much as 44%.

Missions such as the Pioneer sun probe and oriented satellites like the new Radio Astronomy Explorer (RAE) and the Applications Technology Satellite (ATS) will develop solar array temperatures in excess of 70 to 90°C. To meet the power requirements of these and similar missions and stay within the permissible weight limits, improvements in the solar cell array design are necessary. Some of the methods used to reduce weight and to withstand the severe thermal stress which were adopted between the design of the Interplanetary Monitoring

Platform (IMP) A and the new lunar anchored IMP-D are discussed in the following paragraphs.

The IMP series of satellites, shown in Figure 1, is intended to assess the Project Apollo radiation hazard, study the solar flare prediction capability, measure solar/terrestrial relationships, and record the relation of magnetic field to the sun's particle fluxes in cislunar space. IMP-A attained an apogee of about 106,000 nautical miles and a perigee of nearly 200. IMP-D is intended to orbit the moon with an apogee of 1600 to 5400 nautical miles and a perigee from 270 to 800.

Table 1 shows a comparison between the IMP-A and IMP-D solar cells and cover glasses. The greatly improved radiation-resistant 2 x 2 cm N/P configuration is used on IMP-D as well as a much thinner solderless cell. This decreased the cell weight for an equivalent 4 cm^2 cell area from 0.46 to 0.30 gram. The stronger titanium-silver contacts are also used to better withstand the thermal stresses associated with the lunar orbit where temperatures are expected to range from +40°C to well below -100°C, two or three times in 24 hours. This compares with

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+25°C and -90°C for IMP-A which eclipsed in the earth's shadow once every 4-1/2 days.

The radiation environment is expected to be quite a bit less severe for IMP-D than IMP-A, which has permitted a relaxation of the cover glass thickness from 12 to 6 mils. IMP-A showed a 25% degradation in its power generating capability in exactly one year of space life. If N/P cells were used, this probably would be observed after about 10 years. To insure maximum transmissivity of the cover glass, IMP-D will use 7940 type fused silica instead of microsheet 0211. The same antireflection and blue filters will be employed on IMP-D as on IMP-A. There is insufficient evidence of any benefits of using a red filter to justify the added cost for this coating at this time.

Prior to the selection of 2 x 2 cm cells for the IMP-D satellite, extensive ground environmental tests were performed to establish acceptability. The advantages sought in using the larger cells were the inherently fewer cells, interconnections, cover slips, and lower cost per unit area of active surface. Figure 2 shows a mechanical test paddle with 2 x 2 cm cells and 3 x 3 cm silicon blanks. This paddle is designed to meet all the mechanical requirements of shock, vibration, acceleration, temperature, vacuum, etc., for the expected launch conditions of the Thrust Augmented Delta booster and the expected orbital life of one year. Should 3 x 3 cm cells eventually become competitively available, there is hope these can also be used for such missions with further reduction in the number of solar cells, cover glasses, interconnections, and cost.

Reduction of cell thickness is an obvious way to save weight, but there are certain limits to which one may go. First, the thinner the single crystal wafer becomes, the higher the breakage rate. Also, as the cell thickness is reduced below 12 mils, the electrical properties of the cell begin to suffer appreciably. Figure 3 shows the results of a study made by Wolf & Ralph[2] on the effects of solar cell thickness on short circuit current. Assuming a cell with a minority carrier lifetime of 6 microseconds, it is seen that a reduction in I_{SC} by 2 to 3% can be expected at air mass zero for a 12 mil thick cell and as much as 8 or 10% when reduced to 8 mil thickness. As can be seen from the figure, this is considerably more severe than one would expect theoretically.

Significant improvements in the paddle substrate construction have also contributed to a more favorable weight density in the IMP-D spacecraft. Figure 4 shows a cutaway view of the paddle. The aluminum honeycomb is covered with two 0.0015 inch thick epoxy-impregnated Fiberglas sheets which act as an insulated substrate for the paddle. Next, an expanded silver metal mesh conductor is laid down directly beneath where the solar cell modules are to be placed. This innovation acts as the return path to the prime converter for the solar cell current. Also, it is distributed over a region equal to the solar cell active area, thus neutralizing any stray magnetic fields which might otherwise be induced when using conventional wiring.

Another two-ply layer of 1.5 mil epoxy-impregnated Fiberglas is placed over the expanded metal mesh; then the cells are bonded to this layer with RTV-40 adhesive. Connections from the ends of the solar cell modules to the silver mesh are made by penetrating through the two upper layers of Fiberglas and soldering.

A comparison between the properties of the IMP-A and IMP-D paddles is shown in Table 2. Even though the paddle area on IMP-D is 1.2 ft.^{2} per side larger than on IMP-A, the paddle weight is 0.4 lb. less. IMP-D will generate 45 watts per paddle face compared with 33.6 for IMP-A at 30^{o}C and normal incidence. Thus, the IMP-D weighs 1.3 lb./ft.^{2} on one side or 0.15 lb./ft.^{2} counting both sides of the paddle. While the efficiency of the cells has changed very little over the last two years, giving about 9.3 to 9.4 watts/ft.^{2} of illuminated surface, the IMP-D will produce 7.3 watts per pound of paddle, while the IMP-A developed only 5.1. This is a 43% improvement in performance per unit weight.

Developments are currently under way in attempts to further reduce the weight density of solar paddles. One of the most recent is the wrap-around 2 x 2 cm solar cell which delivers 5% more power than the conventional device because of the additional active area formerly covered by the bus bar.

In many missions, very thin cover glasses of 1 to 3 mils would be suitable. Handling conventional cover glasses of this thickness is presently prohibitive from a breakage standpoint. Integral cover glasses, now in early stages of development, appear to be feasible and should indeed represent a weight savings in future space applications.

Welded interconnections between cells and modules offer promise of the complete elimination of the solder now used and should increase the operating or peak temperature to which solar cells may be subjected. This, also, is expected to permit a more reliable and rugged connection.

Dendrite webs are now being produced in widths of 1 cm by many centimeters long. With present semiconductor technology, strips of series-connected solar cells, 30 cm or more in length, developing several volts per unit, should become available and applied as needed. Many interconnections would be further eliminated.

The research and development performed over the last year and a half has permitted the reduction of paddle weights from 1.8 lb./ft.^{2} to 1.3 lb./ft.^{2} Counting total active area (both sides of the paddle), this reduces from 0.9 lb./ft.^{2} to 0.65 lb./ft.^{2} Thus, oriented panels under 3/4 lb./ft.^{2} can now be built to withstand the rigors of launch and space. Further developments presently under way should make further reductions possible in the near future.

REFERENCES

1. Balent, R., Heathco, C.W., N.A.A. Atomics International, AI-64-207, "Standard U.S. Launch Vehicles and Space Nuclear Power Systems," Sept. 21, 1964

2. Wolf, M., Ralph, E.L., "Effect of Thickness on Short Circuit Current," 4th Annual Photovoltaic Conference, Cleveland, Ohio, June 2-3, 1964

IMP SOLAR CELL PHYSICAL CHARACTERISTICS

	IMP-A&B	IMP-D
Cell Type	P/N	N/P
Cell Size (cm)	1 x 2	2 x 2
Cell Weight (gm)	0.23	0.30
Cell Thickness (mil)	20 (including solder)	12.5 (solderless)
Contacts	Ni plated	TiAg
Cover Glass Type	0211	7940
Cover Glass Thickness (mil)	12	6
Coatings	Blue & AR	Blue & AR

Table 1

SOLAR PADDLE CHARACTERISTICS

	IMP-A&B	IMP-D
Paddle Area One Side ($ft.^2$)	3.6	4.8
Paddle Weight (lbs.)	6.6	6.2
Power Output One Side, AMO (watts)	33.6*	45.0*
Paddle Weight/Area ($lb./ft.^2$)	1.8	1.3
Paddle Power/Area ($watts/ft.^2$)	9.3	9.4
Paddle Power/Weight (watts/lb.)	5.1	7.3

*at 30°C

Table 2

DEVELOPMENTS UNDER WAY

TO FURTHER IMPROVE

SOLAR CELL SYSTEMS

A. Wrap-Around Cells

B. Integral Cell Covers

C. Welded Interconnections

D. Webbed Dendrites

Table 3

FIGURES

SUBJECT CATEGORIES FOR GODDARD JOURNAL

(To be used for classifying all NASA publications, journal articles, and other papers for inclusion in the Goddard Journal.)

Part A - Space Sciences

A 1. Astronomy and Astrophysics
A 2. Celestial Mechanics and Geodesy
A 3. Solar Physics
A 4. Ionosphere and Radio Physics
A 5. Fields and Particles
A 6. Planetology
A 7. Planetary Atmospheres
A 8. General (subjects not clearly belonging in any of categories 1-7)

Part B - Space Technology

B 1. Projects and Programs
B 2. Space Dynamics and Control Systems
B 3. Spacecraft and Subsystems
B 4. Vehicle Technology
B 5. Sounding Rockets
B 6. Sensors
B 7. General Electronics
B 8. Environmental Testing
B 9. Tracking Systems
B 10. General (subjects not clearly belonging in any of categories 1-9)

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