SOLAR CELL POWER SYSTEM FOR ADVENT (1)

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ABSTRACT

The Advent Communication Satellite will derive its electrical power from the sun by means of silicon solar cells. Energy storage required for operation while in the Earth's shadow will be provided by nickel-cadmium batteries. Unclassified aspects of orbit imposed conditions, mechanical design considerations, and cell connection are discussed.

In September 1959 the Missile and Space Vehicle Department of the General Electric Company was selected by the Department of Defense to develop a Communication Satellite. This vehicle will be used in a network of satellites placed in orbit around the Equator travelling at speeds equal to the Earth's rotation. These satellites will be at approximately 20,000 nautical miles altitude and will provide continual communication coverage over nearly all the Earth.

The vehicle will be positioned so that its antenna will be continually oriented toward the Earth by means of the attitude control system. The electrical power for the vehicle will be drawn from the Sun and converted to electricity by silicon photovoltaic cells. The tens of thousands of cells required will be distributed over one side of two paddles deployed on each side of the vehicle. Fig. 1 shows a possible configuration. These paddles will be free to rotate with respect to the vehicle (about the X axis) to maintain continuous alignment to the sun. Because slip rings are not desirable the vehicle will be flipped once each orbit to re-orient the paddles for the next orbit. This maneuver will take place at high noon and will involve rotation about the Z axis only. Energy storage during the non-illuminated portions of the orbit will be accomplished by Ni-Cd batteries. For the particular orbit chosen the maximum dark period is 75 minutes and is a modified sinusoidal shape

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as shown on Fig. 2. This same figure also shows the long periods of illumination which occur. Under these cycling conditions a battery depth of discharge of 65% is felt to be practical. In Volume III of the American Rocket Society Astronautics Series in the chapter on Electrochemical Cells, Mr. Schulman discussed the charging and overcharging problems resulting from the orbit.

The paddles are a series of laminations: the mount-honeycomb, the back adhesive which bonds the cells to the honeycomb, the solar cell, the front bonding layer to hold the glass and the so-called cover glass and its associated optical filters. These elements are shown on Fig. 3.

The paddle design work may be divided into sub-areas for analysis. The thermal problem of single crystal silicon is well known and may simply be stated that as temperature rises power output decreases. The illuminated temperature affects the electrical power output. The shadow temperature determines the stress due to thermal coefficients of expansion.

The charged particle radiation influences the design. The paper (3) by Snyder and Karcher points out the quantity and energy level of particles to be encountered and the effects upon solar cells.

Our studies indicate that 70 mils of fused silica will be required to provide adequate mass for reducing ambient electron energy to 145 Kev, the threshold of tolerance for silicon cells. This mass required for protection applies not only to the front of the cells, but to the back as well. The P layer is shielded from the back by the approximately 20 mils of N type silicon and by about 1 mil of lead-tin solder. The balance of the required shielding must be provided by the structure. Our studies show that the requirements for shielding demand a heavier structure than only the mechanical requirements would indicate. In other words the design is not limited by the structure weight - it is limited by the shielding mass requirements. Based upon these masses and the desire to hold the illuminated temperature at 100°F, the shadow temperature is estimated to be -200°F with no active temperature control.

The electrical circuit for connecting the many silicon cells is important. Enough cells must be series connected to produce the required voltage. At 25°c. approximately 70 cells are required in series to produce 28 volts. Figure 4 shows typical voltage - current curves and the effect of temperature. In addition the cells must be paralleled to generate the required current. The resulting matrix, therefore, is the system power source. There are two extreme methods by which the required interconnections may be accomplished. Case 1, see Figure 5A,

(3) Solar Cell Power Systems for Space Vehicles - printed elsewhere in this volume.

produces power by means of paralleled strings of series connected cells. For this case, the only paralleling connections are at the ends of the strings. Case 2, see Figure 5B, represents the extreme case of the maximum number of paralleling interconnections.

Our study of the optimum connection method was based upon the following: (1) 28 volts system, (2) cell efficiency 10% or above, (3) probability of failure between 50% open circuit - 50% short circuit and 90% open circuit - 10% short circuit, and (4) five series connected in a shingle, as shown in Figure 3, with no parallel connections within the shingle. The study was programed to determine the power loss per failure versus the number (N) of strings with all shingles paralleled as shown in Figure 5C. Each power source would then be composed of a number of N string groups tied together.

The curve shown in Figure 5D is the result of the analysis. When N=1 case 1 previously discussed is established. In this case an open circuit causes the power loss of 70 cells - a high power loss per failure. When $N=\infty$ case 2 exists. A failure by short circuit causes the power loss of all cells paralleled to the failed cell. The curve then is the result as N varies from 1 to infinity. Because of the steep slope where N=3 it is recommended that N=3 be chosen. This will minimize the power loss so that one or two failures will not have an extreme effect.

To further insure maximum reliability the total array of solar cells and energy storage batteries are further divided into independent units each feeding the main lines. Based upon the particular classified loads and their duty cycles, four parallel array-battery elements will be used.

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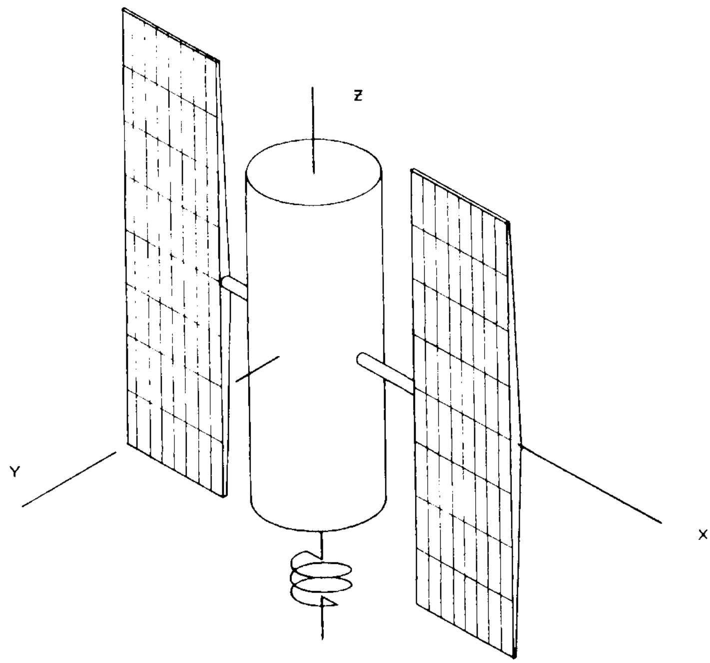


FIG. 1 POSSIBLE VEHICLE CONFIGURATION

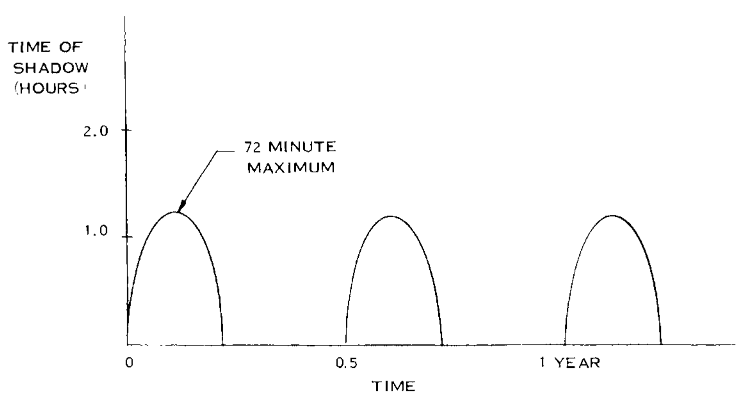


FIG 2 SHADOW PERIODS

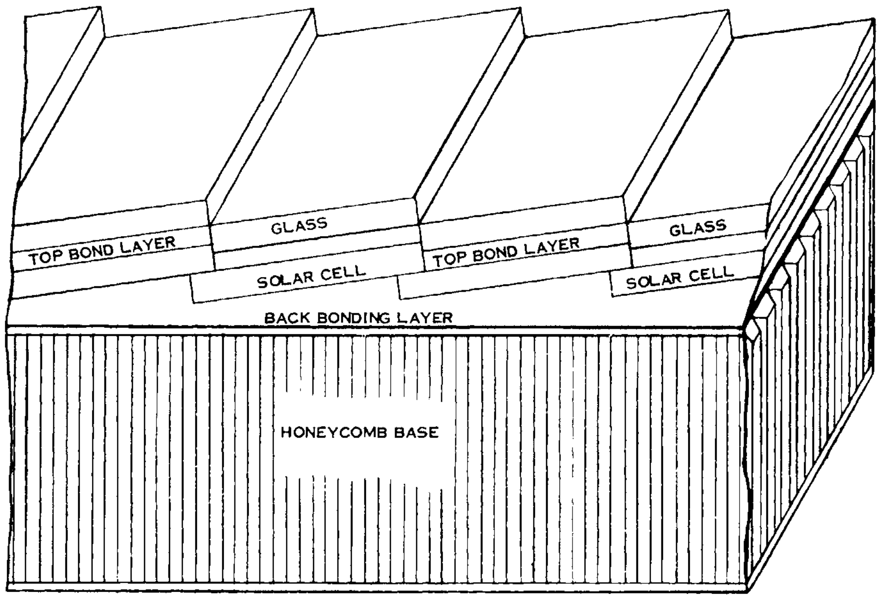


FIG. 3 EXPLODED VIEW OF PADDLE SEGMENT

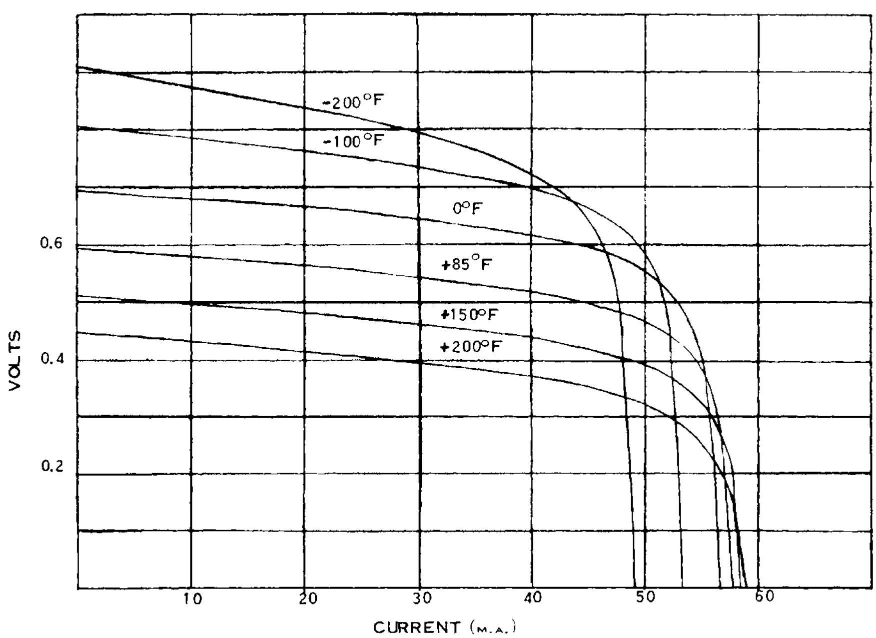
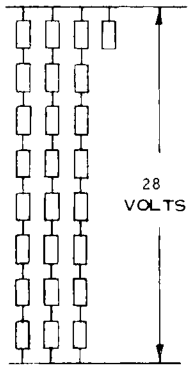
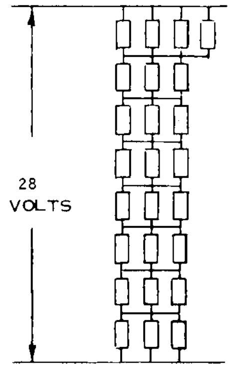


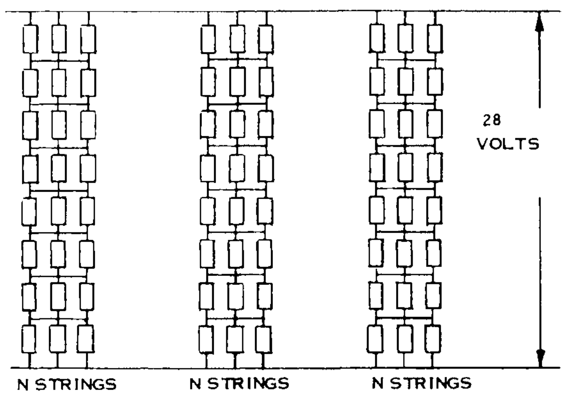
FIG. 4 V-I CURVE vs TEMP. SOLAR CELL CHARACTERISTICS vs TEMP.



SERIES STRINGS OF SHINGLES
FIG. 5A



STRINGS PARALLELED BETWEEN SHINGLES
FIG. 5B



ARRAY CONNECTION
FIG. 5C

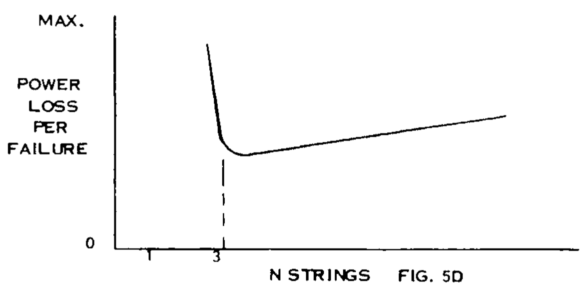


FIG. 5D