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THE MAGSAT POWER SYSTEM

The Magsat power system was required to generate, store, and condition energy for use by all spacecraft systems. It consisted of a solar cell array, a rechargeable battery, redundant battery charge regulators, and several converters, inverters, and regulators to condition power for use by Magsat loads.

SOLAR CELL ARRAY

An array of silicon solar cells mounted on four deployable panels generated electrical power for the Magsat spacecraft. Each panel consisted of two interhinged, curved segments that were designed to be folded inside the rocket heat shield and restrained against the side of the base module during launch by a thin-wire despin cable. After the spin-stabilized last rocket stage was fired, a special purpose timer activated pyrotechnic devices that released the despin weights and cables. This action caused the spacecraft to despin while simultaneously allowing deployment of the spring-loaded panels. The deployed panels formed a planar cruciform array, with the long axis of each panel perpendicular to the spacecraft B axis.

Each of the eight array segments was a curved, lightweight, aluminum-honeycomb structure approximately 64 cm long by 36 cm wide. Two of the eight segments flown were from another spacecraft program and had 2 by 2 cm silicon solar cells on both sides. The remaining six segments were of more recent manufacture and had 2 by 4 cm, high-efficiency silicon solar cells on one side only. All segments were configured with two circuits of 57 series-connected cells in order to permit effective recharge of the spacecraft battery.

Opposing panel pairs in the array could be independently rotated about their common axis, if desired, by ground command. Rotation to any angle from 0° (the normal value at deployment) to 90° could be effected. A separate synchronous motor drive was employed aboard the spacecraft to perform this function for each axis. The feature could have been used to optimize power generation by the array if the spacecraft had assumed some anomalous attitude.

The Magsat attitude control system was designed to maintain the B axis of the spacecraft nearly perpendicular to the sun-synchronous orbit plane. This resulted in relatively close alignment of the sun-earth line and the B axis of the spacecraft, and full orbit sunlight illumination throughout most of the mission lifetime. Therefore, the power generated by the solar array was largely a function of the angle ψ between the +B axis of the spacecraft and the sun-earth line. Figure 1 illustrates the prelaunch predicted power available at the battery as a function of this angle.

BATTERY

The spacecraft battery consisted of 12 series-connected 8 A-h (ampere-hours) nickel-cadmium cells operating at a nominal voltage of 16.7 V. The battery supplied energy to meet brief demands in excess of the generating capability of the solar array and operated the spacecraft during transient phases of orbit acquisition and attitude adjustment. It also sustained operation of the spacecraft during periods of solar eclipse that occurred late in the mission lifetime.

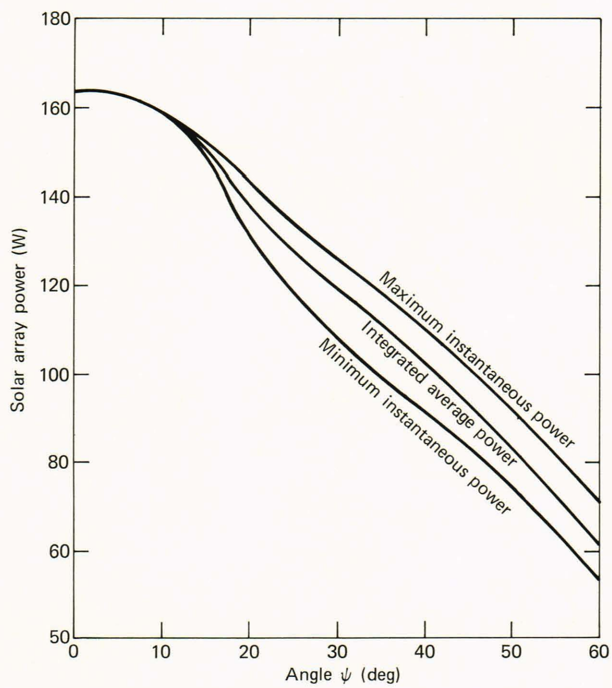

Fig. 1—Power output of the Magsat solar array as a function of angle ψ between the +B spacecraft axis and the sun-earth line. Variations in instantaneous array power output illustrated here result from array shadowing by both the base and instrument modules. These losses were evaluated with the assistance of a 3/8-scale model of the spacecraft.

BATTERY CHARGE CONTROL

Since the Magsat battery was to be exposed to extended periods of continuous overcharge, considerable design effort was expended to provide a charge control system that would permit rapid recharge of a depleted battery and would limit overcharge to levels that were electrically and thermally acceptable. The power system therefore incorporated a lightweight shunt regulator of special design to dissipate excessive solar array power as heat (up to a maximum of approximately 120 W) on three externally mounted radiator panels.

The dissipative shunt regulator and its control element were fully redundant. The inputs to the control element were bus voltage, battery temperature, and a voltage proportional to battery current. Depending on the operating mode selected (either fixed-rate trickle charge or voltage-limited charge), the controller exercised active elements in the regulator to shunt unwanted battery current. The electronic elements (shunt drivers) were mounted on an external panel on the +B axis of the spacecraft. The resistive elements were distributed on external radiators mounted on the sides of the base module. The selectable voltage limit charge control characteristics are shown in Fig. 2.

We anticipated that ground controllers would primarily employ shunt regulator No. 1 in the voltage-limited mode to permit rapid recharge of a depleted battery while limiting maximum battery voltage to a conservative value. The trickle charge mode, a viable one for noneclipsed orbits, was considered a secondary operating mode. The trickle charge limit for both shunt regulators was 250 mA.

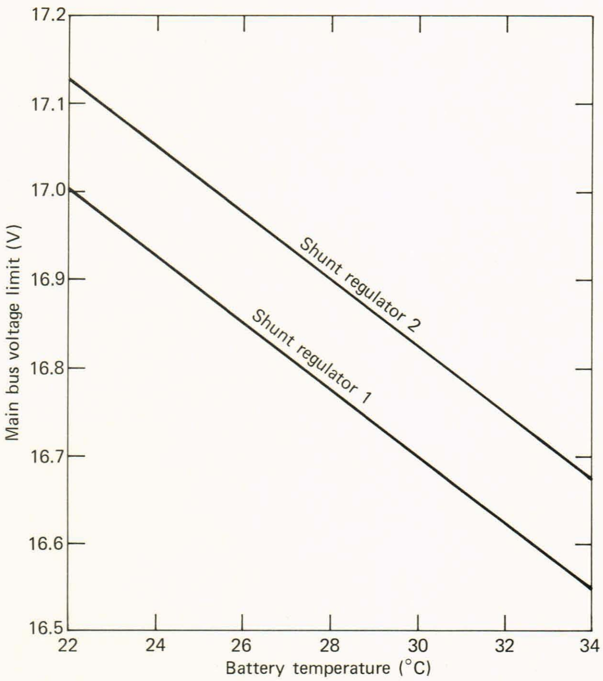

Fig. 2—Voltage limit of the Magsat main bus as a function of battery temperature.

A block diagram of the subsystem is shown in Fig. 3, and its salient characteristics are provided in Table 1.

Table 1

POWER SYSTEM CHARACTERISTICS

Power available	120 to 163 W, average
Main regulator capacity	4.0 A, maximum
Unregulated bus voltage	18.6 V, maximum 16.7 V, nominal 15.0 V, minimum expected (circuit breaker actuates at 13.2 V)
Regulated bus voltage	13.5 V ± 2%
Charge control system	Redundant shunt regulator provides trickle charge and/or temperature compensated voltage limit. Shunt capacity: 120 W
Battery	12 series-connected 8 A-h cells. Battery cell manufacturer: SAFT America, Inc.
Solar cell array type	Four panels in rotatable coplanar pairs. Each panel consists of two interhinged segments.
Number of cells	1824, 2 × 2 cm 1368, 2 × 4 cm
Solar cell type	Centralab 10 Ω-cm, Si, N/P cells, 2 × 2 cm, and Spectrolab 10 Ω-cm, Si, N/P cells, 2 × 4 cm
Number of cells in series	57
Coverglass type	6 mil microsheet with antireflective filter applied by Optical Coating Laboratories

SYSTEM OPERATION UNDER ABNORMAL CONDITIONS

The Magsat power system was designed to accommodate malfunctions within the spacecraft automatically. A low-voltage sensing system, acting as a circuit breaker, controlled all commandable relays that supplied power to noncritical loads. If the main bus voltage fell below 13.2 V (which indicates a depleted battery), the system automatically took remedial action as indicated in the box on the next page. Ground controllers were required to reset the desired spacecraft power system configuration and to reenable the system to function by command, upon recovery from an undervoltage fault.

ORBITAL PERFORMANCE

The Magsat power system performed satisfactorily. The output power of the solar array exceeded

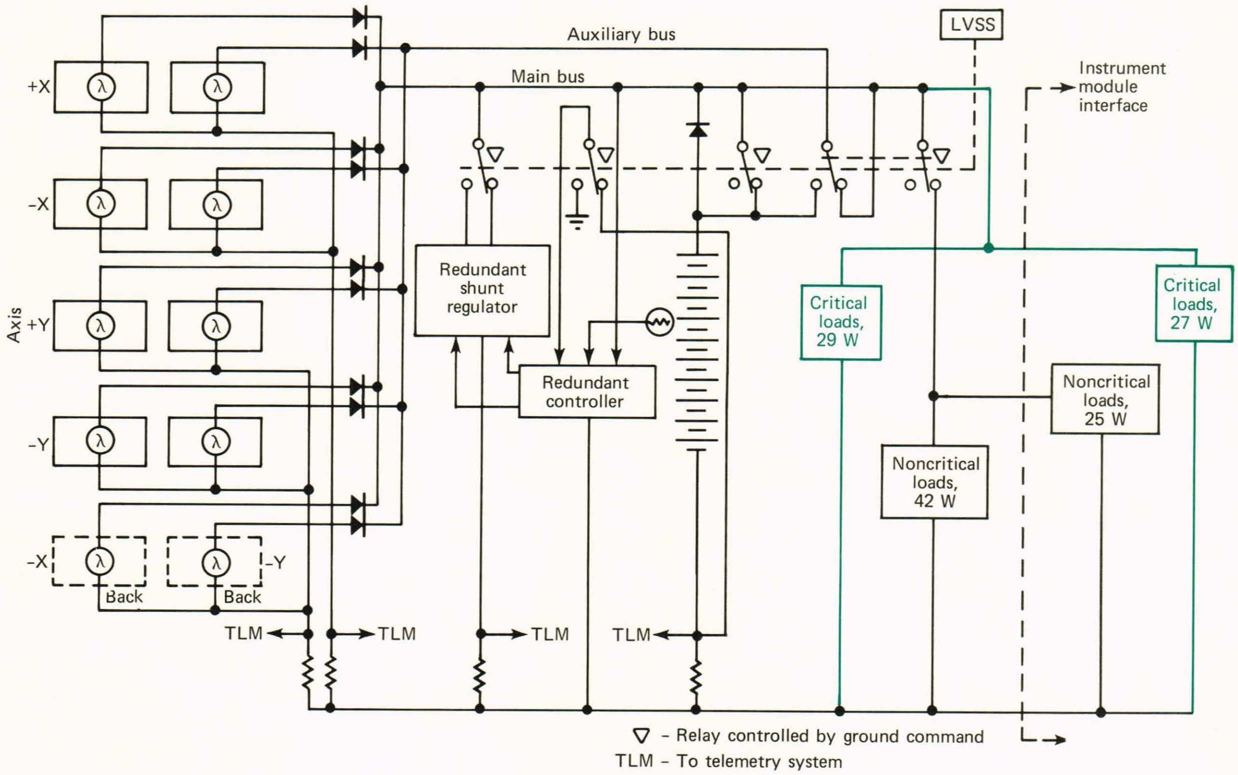

Fig. 3—Block diagram of the Magsat power subsystem. The loads are divided into critical and noncritical categories. Critical loads are defined as those that are essential to mission success and that must be powered continuously. The critical power system loads are the command system, selected attitude control system elements, and instrument module thermal control. All loads derive power from the main power bus. The solar array is equally divided between the main bus and an auxiliary bus that is normally connected to the main bus when the noncritical loads are powered.

the predicted value by approximately 10%. This was attributable to the seasonal increase in solar illumination intensity at the time of observation, panel illumination enhancement from earth albedo, and sunlight reflections from the highly reflective thermal control surfaces of the base and instrument modules onto the solar panels. We believe that reflections are the principal contributor to array power enhancement.

The orbital operating temperatures of elements in the Magsat base module were somewhat higher than anticipated. In an attempt to minimize temperatures in the base module, the battery had been primarily operated in the OR mode with the battery diode not bypassed. OR mode operation, as the term suggests, permitted either the solar array or the battery (or both) to supply power to the main bus through their respective "one-way" blocking diodes. System operation in the OR mode prevented the battery from being charged but had the positive effect of reducing internal power dissipation in the base module by approximately 5 W, thereby lowering temperatures. The battery was discharged briefly during recovery of tape-recorded data, and continuously by internal self-discharge mechanisms. As a result the battery required periodic recharge in order to maintain the necessary reserve capacity to meet anticipated storage demands and to cover contingencies.

In order to recharge the battery in orbit while operating in the OR mode, the battery diode was typically bypassed for one orbital revolution every

Actuation of the Low-Voltage Sensing System

Main bus voltage drops below 13.2 V:

Cause 1—Insufficient solar array generating capability (most probably attitude related).
Cause 2—System electrical overload.
Cause 3—Shunt regulator overload.
Cause 4—Battery failure.

System Response:

Action 1—Noncritical loads are turned off to conserve power.
Action 2—The auxiliary solar array is connected directly to the battery to effect a rapid battery recharge. The battery is simultaneously ORed to the main bus as a power source by the battery diode.
Action 3—The controller of the shunt regulator is automatically switched to the voltage limit mode.
Action 4—Shunt regulator 2 instead of 1 is switched on (Fig. 3). This also permits the main bus to achieve the slightly higher voltage limit.

If the low voltage condition results from cause 1 or 2, action 1 will be helpful. If it results from cause 3, action 4 is helpful. If it results from cause 4, action 2 will be helpful. In the case of cause 1, actions 2 and 4 will help restore the battery to a charged condition and permit the determination of the particular subsystem causing the overload.

fifth day. Figure 4 illustrates the telemetered battery performance data obtained during recharge on Day 316, 1979. Small step jumps in the data are attributable to the granularity of a digital telemetry system. Relatively large perturbations in initial battery charge currents were caused by load variations that occurred as heaters were automatically switched on and off to maintain selected instrument module temperatures. The battery charging current was tapered as the selected instrument temperature was reached. The battery charge regulator was activated; it shunted excess current to maintain the appropriate bus voltage throughout the remainder of the charge period.

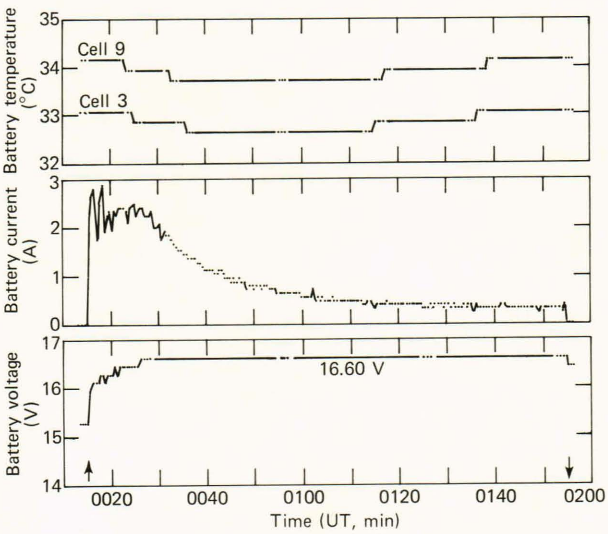

Fig. 4—Magsat battery 100 minute charge profile, Day 316, 1979.

Particularly noteworthy in Fig. 4 is the change in Magsat battery cell temperature during recharge. During the early part of the charge cycle, the temperatures of cells 3 and 9 dropped because of the endothermic nature of the chemical reactions taking place during recharge. During the last 40 minutes of the charge cycle, temperatures began to rise, indicating the onset of overcharge.

All telemetered performance parameters of the Magsat power system were nominal, including load currents and converter output voltages. The main bus voltage was closer to 16.5 V than to the predicted 16.7 V. This was a direct result of the somewhat higher than nominal operating temperature of the base module.

A significant loss in battery capacity was observed late in the Magsat mission lifetime. This loss is believed to be attributable to sustained high temperature operation. As a result of this capacity loss, operation of the spacecraft proved somewhat problematic during periods of solar eclipse; selected loads had to be switched off briefly during these periods in order to reduce the electrical load imposed on the battery.