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SOLAR ARRAY REGULATORS OF EXPLORER SATELLITES XII, XIV, XV, XVIII, XXI, XXVI, XXVIII, AND ARIEL 1

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ABSTRACT

This paper describes how the solar array regulators of the various spacecraft differ in design to accommodate the different requirements of nickel cadmium and silver cadmium batteries.

The Ariel I satellite contains two nickel cadmium batteries, one of which is in a standby condition. To protect the main battery from overcharging, both voltage and current limiting are incorporated in the solar array regulator. The voltage limiting "tracks" the battery temperature characteristics, and the temperature-sensitive current limiter protects the battery against thermal "runaway." A novel battery selector circuit automatically selects the better of the two battery packs and trickle-charges the standby battery.

Explorers XII and XIV contain a silver cadmium battery pack. The solar array regulator utilizes a simple single-level voltage limiter and is designed to regulate approximately 30 watts.

In the Explorers XV, XVIII, XXI and XXVI, the experiment power requirements and the power capabilities of the solar array are significantly increased. As a result, the voltage limiting solar array regulator is redesigned to regulate up to 100 watts at 19/6 volts.

In the Explorer XXVIII spacecraft, silver cadmium type batteries are used. The charge control system uses a "two-level" solar array voltage regulator. The higher limiting level is set for the full charge voltage of the battery pack. A current sensor combined with a Schmitt trigger trips the regulator to open circuit voltage when the charge current diminishes to C/100, where C is the rated capacity of the cells. This method is especially desirable if the satellite is exposed to long sunlight periods, thus minimizing the possibility of cell unbalance. Although a shunt-type regulator is used in the above-mentioned satellites, the charge control methods are equally adaptable to the series-type regulators.

CONTENTS

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INTRODUCTION

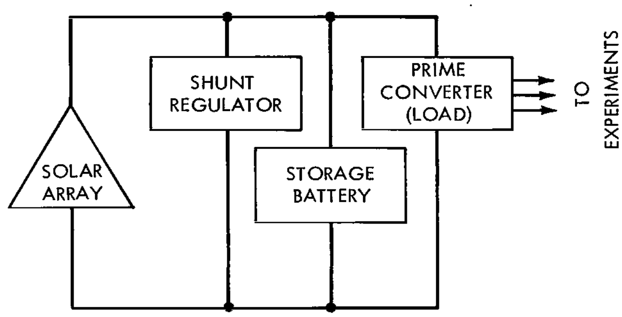

Figure 1—Block diagram of a typical satellite power system.

One of the prime sources of spacecraft electrical power is a bank or array of silicon solar cells. These cells convert solar energy to electrical energy for use while the spacecraft is illuminated. They also charge storage batteries which supplement the solar array during shadow or eclipse periods. Figure 1 is a block diagram of such a satellite power system. The shunt regulator (solar array regulator) diverts all excess power when the battery voltage reaches a predetermined level. This excess power is dissipated in power resistors located on the solar paddle arms which are thermally isolated from the main body of the spacecraft. Momentary load demands in excess of the solar array capability are met by using the supplementary power stored in the battery. Various regulated voltages required by the spacecraft experiments are provided by the prime converter.

Solar Array

The solar array itself is composed of a number of light-sensitive silicon solar cells. Individual cells are connected in series to yield the desired voltage level. A sufficient number of these series circuits are connected in parallel to yield the desired current capacity. The solar array is constructed of a number of solar cell panels, each containing series-parallel groups of cells and connected to the solar bus through isolation diodes to prevent loading of the bus in case of an electrical fault.

Solar Array Regulator

The purpose of the solar array regulator (Figure 2) is to prevent the solar bus voltage from becoming excessive and overcharging the battery. This is accomplished by comparing the solar

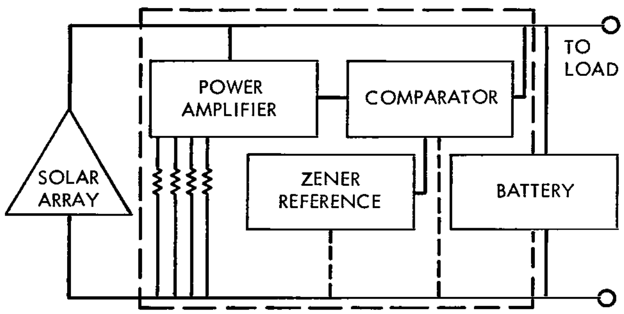

Figure 2—Block diagram of a solar array regulator.

bus voltage to a reference zener diode in order to develop an error signal. When the bus voltage reaches a preset threshold, the error signal from the comparator is amplified and fed to the power amplifier. In response to this signal, the power amplifier shunts current to the power-dissipating resistors, thus loading the bus until the system voltage is reduced to the desired level.

Storage Battery

The storage battery supplies power to the spacecraft during eclipse periods and supplements the solar array power when necessary. When there are no magnetic restrictions, nickel-cadmium cells are generally used because of their high current and continuous overcharge capabilities. When magnetic restrictions are imposed by on-board equipment, silver cadmium cells are generally used.

Prime Converter

The various voltage levels required by the satellite experiments and other circuitry are supplied by the prime converter. Converter power is supplied from the solar array/battery bus.

ARIEL 1 POWER SYSTEM

The power system in the Ariel 1 satellite employed nickel-cadmium batteries (Gulton Industries, type VO-6HS, hermetically sealed) rated at 6 ampere-hours capacity. This type of cell can accept continuous overcharge and provide long life when operated in the expected temperature range of -10° to +40°C. The system had two battery packs for redundancy, each with ten cells in series. The standby battery received a trickle charge as long as excess current was available.

Figure 3 is a diagram of the Ariel 1 satellite solar array regulator and battery switching circuit. Design specifications are presented in Tables 1 and 2. The regulator employed both voltage and current limiting. The voltage regulator was designed with a negative temperature coefficient to permit regulation at higher voltages at colder temperatures. The current regulator also had a negative temperature coefficient, and limited the current by overriding the voltage regulator. Both limiting circuits employ the same shunt power dissipating circuit. The battery selector circuit selects the "better" of the two battery packs. Nickel cadmium cells exhibit a voltage upswing at the end of charge in nominal room temperature and in cold temperatures. Voltage limiting is adequate at these temperatures, but in high temperatures (30°C and above), voltage limiting becomes critical and unreliable. For this reason, current limiting was incorporated into the regulator.

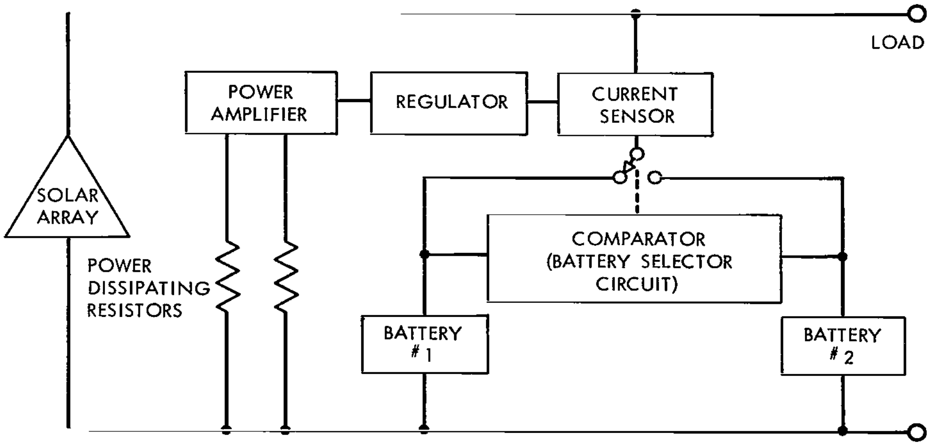

Figure 3—Ariel 1 solar array regulator and battery selector circuit.

Table 1

Ariel 1 Voltage Limiter Specifications.

Temperature	Regulating Voltage
-10°C	14.2 to 14.5 volts
25°C	13.85 to 14.15 volts
50°C	13.6 to 13.9 volts

Table 2

Ariel 1 Current Limiter Specifications.

Temperature	Current
-10°C	≥ .8 amperes
25°C	.6 to .8 amperes
50°C	< .6 amperes

Voltage Limiting

The circuit diagram of the voltage regulator is shown in Figure 4. Diodes CR1 through CR4 were selected to provide the negative temperature coefficient as dictated by the specifications. The voltage across the four reference diodes is amplified by Q1 and Q2. The output of Q2 drives the two power dump transistors Q8 and Q9. Resistors R19 and R20 were selected so that at maximum dump power the major portion of the power was dissipated in them rather than in the transistors. These dump resistors and dump transistors, located on the solar paddle arms, radiate the heat generated by the excess power into space rather than into the spacecraft.

Current Limiting

The current limiter comprises a current transformer T1 and transistors Q2 through Q9 (Figure 4).

A voltage from a portion of the zener reference string is applied to the base of transistor Q4. Transistor Q4 is operated in a common base configuration with, and is the voltage source for, a magnetic core multivibrator composed of Q6, Q7, and the current transformer T1. The frequency of this self-oscillating multivibrator depends on the volt-second characteristics of the current

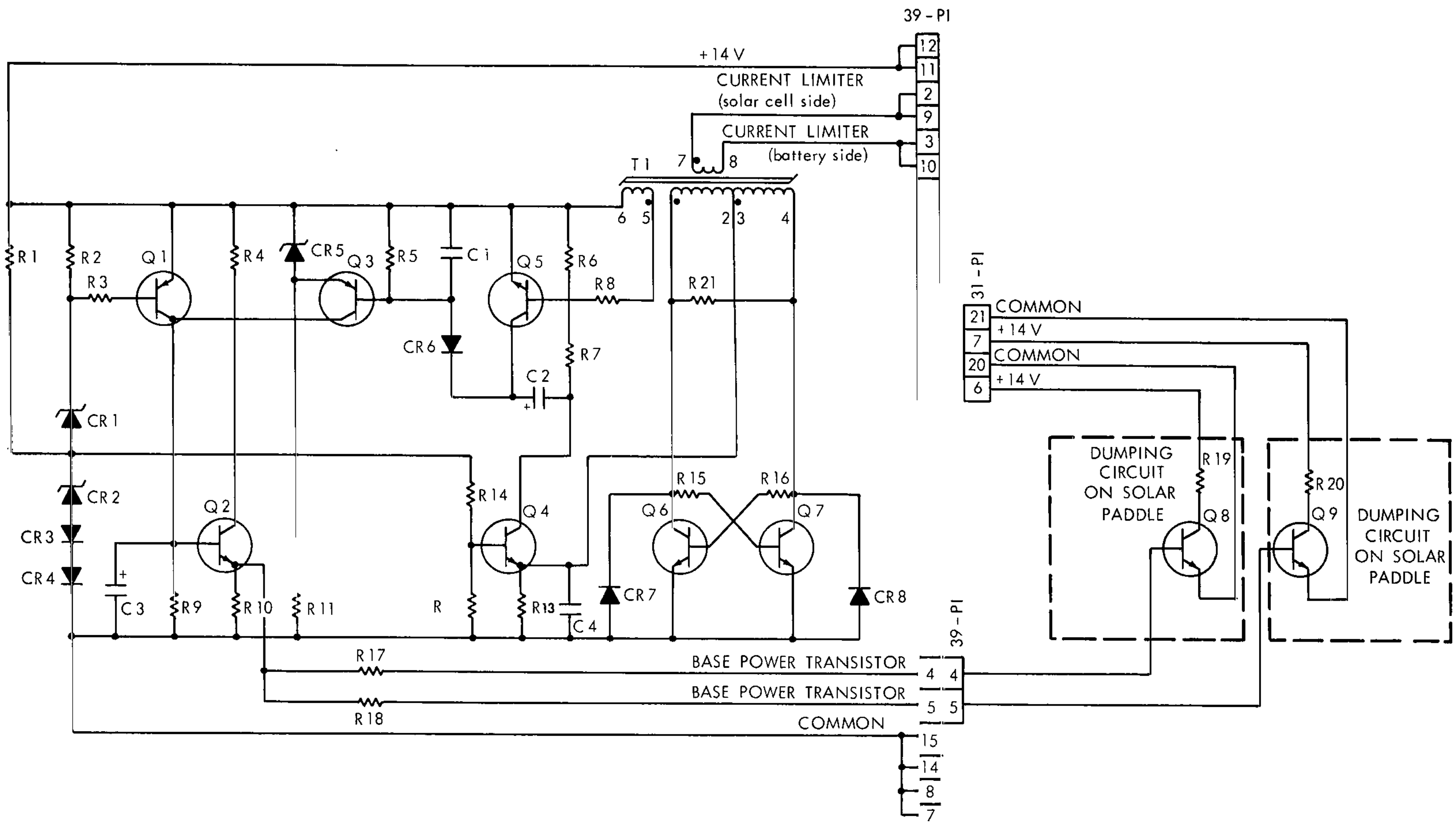

Figure 4—Schematic diagram of Ariel 1 solar array regulator.

transformer core. For zero current through the current sensing winding (terminals 7 and 8 of T1), Q6 and Q7 draw identical collector current during opposite half-cycles of the multivibrator. Capacitor C4 suppresses the transient spike during switching of the two transistors. Therefore, the current through Q4 is a dc current. As a current flows through windings 7 and 8 to the battery, the reflected current aids the current of Q6 and opposes that of Q7. Thus, the collector current of Q4 is an ac current directly proportional to the current being sensed. The Q4 collector current develops a voltage across resistors R6 and R7 whose ac component is coupled by C2 to CR6 and collector Q5. CR6 and Q5 act as rectifying diodes in a voltage doubler configuration along with C1. Transistor Q5 also performs the function of making the current sensing unidirectional, and thus senses only the charge current. The potential on C1, which is directly proportional to the battery current, is compared to zener diode CR5. If it exceeds the CR5 reference voltage, Q3 starts to conduct. This in turn causes Q2 to conduct and turns "on" the dump transistors Q8 and Q9, thus lowering the bus voltage as necessary to maintain this charge current level.

The resistors R6 and R7 are sensistors and exhibit a positive temperature coefficient. Thus, as the temperature increases, the resistance of R6 and R7 increases, thereby developing a higher ac voltage. This causes the voltage on C1 to increase with temperature and consequently causes the current limiter to regulate at lower current levels at the higher temperatures.

The electrical I-V characteristics of the solar array voltage regulator are shown in Figure 5. Figure 6 is a composite curve of the temperature characteristics of the voltage regulator and the current limiter; the design specifications are also indicated. It will be noted that at cold temperatures no upper limit is specified on the current regulator. At these temperatures the battery exhibits a voltage upswing, making the voltage regulator the primary means of regulation. At the higher temperatures an upper limit (selected as a safe continuous over-charge rate) is specified for the battery current limiter. In this mode of operation (at 30°C and above), current limiting is the primary means of regulation.

Battery Selector Circuit

A battery selector circuit (Figure 7) incorporated in the Ariel 1 satellite power system automatically selects the "better" of the two battery packs for system operation. Only one battery is connected to the system at a time, the selection of which depends on the potential difference between the two batteries. Should the battery in the circuit drop in potential to 0.8 volt less than the standby battery, the switching circuit would select the battery with the higher potential.

The relay shown in the schematic (Figure 7) is a DPDT latching type. Resistor R3 is connected from the solar bus to the bases of transistors Q5 and Q6. If the battery selector switch is in the position shown, then battery B1 is connected to the solar bus and to the load. Assuming negligible current in R3, the base of Q5 is at the same potential as battery B1 while its emitter is back-biased by the voltage divider network consisting of R1 and R8. Resistors R2 and R9 are selected so that, if battery B1 drops in potential to 0.8 volt below battery B2, Q6 starts to conduct. The conduction of Q6 is amplified by Q8, which in turn trips the relay to select battery B2.

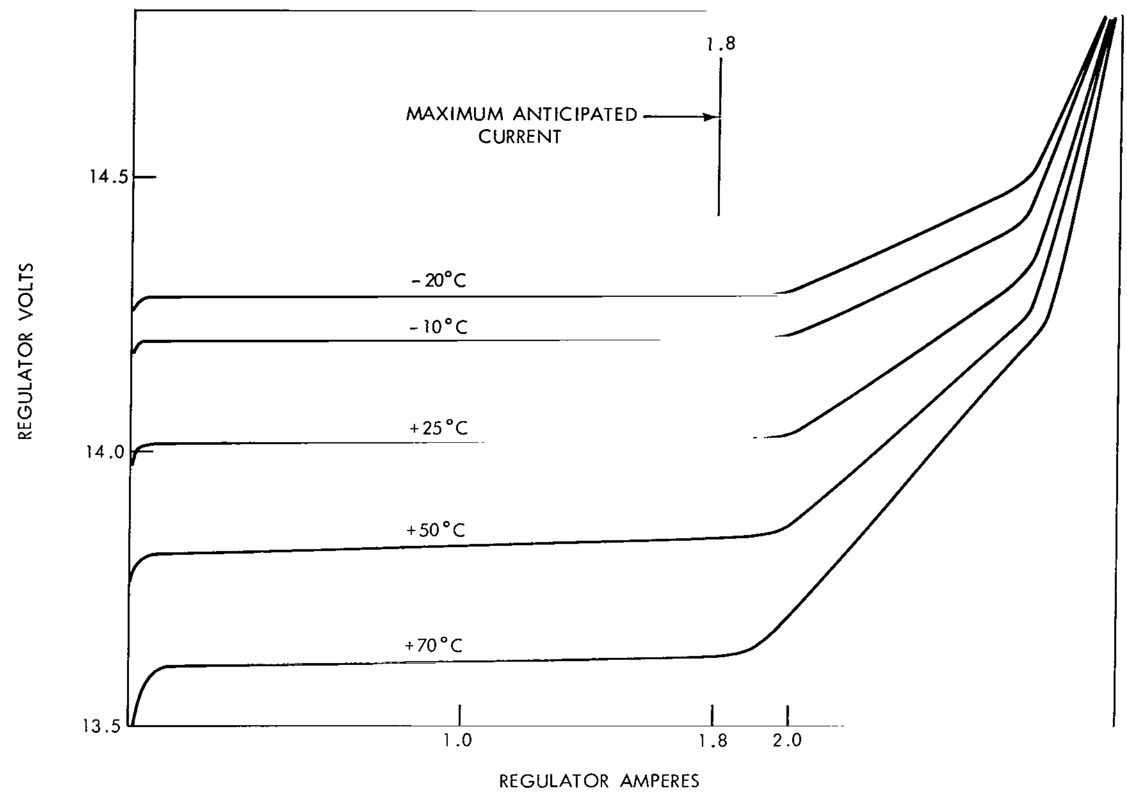

Figure 5—I-V characteristics of Ariel 1 solar array regulator.

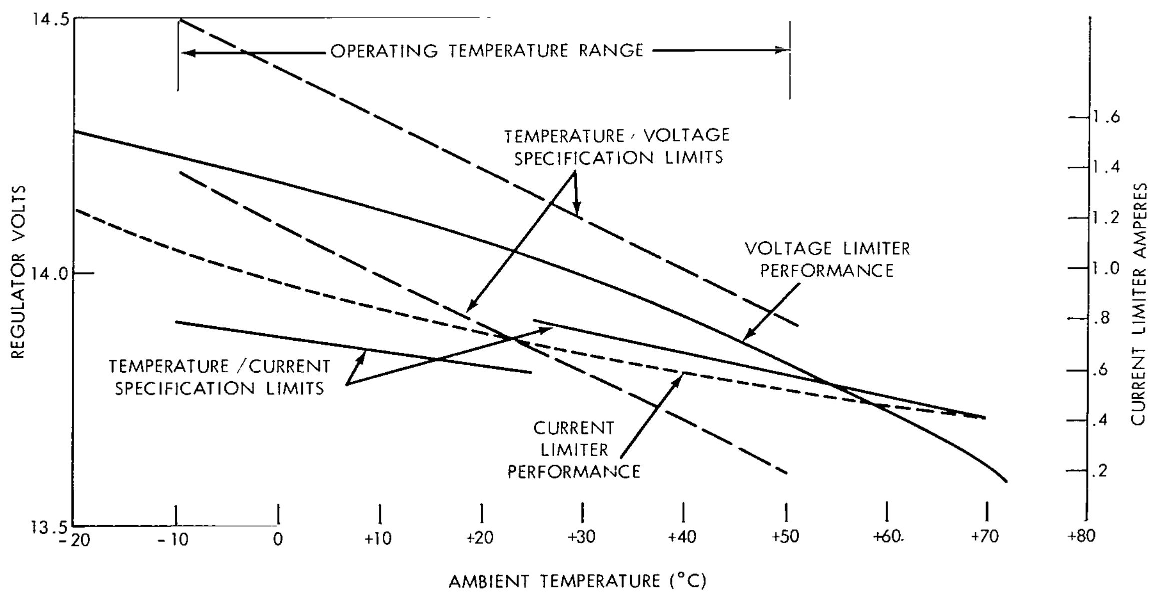

Figure 6—Temperature characteristics of Ariel 1 voltage regulator and current limiter.

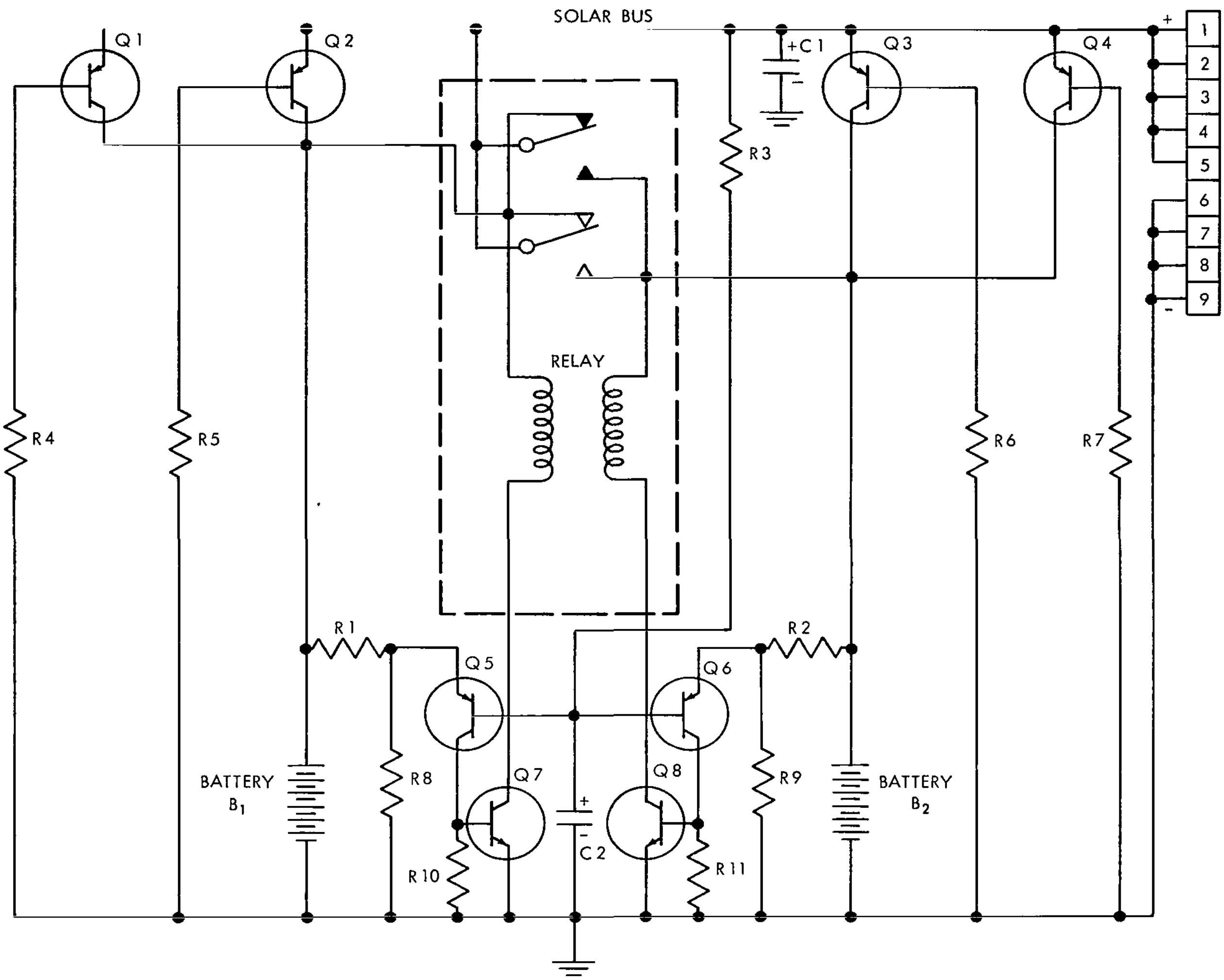

Figure 7—Schematic diagram of the Ariel 1 battery selector circuit.

Trickle Charge of the Standby Battery

Transistors Q1 through Q4 (Figure 7) permit the trickle charging of the standby battery. These transistors were selected on the basis of good temperature characteristics and a high ratio of forward-to-reverse beta. They maintain a relatively constant beta within the anticipated operating temperature range. The trickle charge current is a function of the beta of the transistors and is given by:

$$I_{trickle} = \text{Beta} \times I_b \text{ per transistor} ,$$

where R4, R5, R6, and R7 determine I_b. The trickle rate was set at approximately 20 ma or 10 ma per transistor. Laboratory tests indicated that this was sufficient to eventually recharge a discharged battery and more than sufficient to maintain the fully charged state. Two transistors were used in parallel for redundancy and also to minimize the power dissipation in the individual transistors. Capacitor C2 prevents tripping of the current by line transients.

EXPLORERS XII AND XIV SOLAR ARRAY REGULATOR

The power system in the Explorer XII and XIV satellites employed a battery pack composed of 13 Yardney type YS-5 silver-cadmium cells in series rated at 5 ampere-hours capacity. The solar paddles were capable of supplying up to 1.5 amperes peak current at 19.6 volts. The open circuit voltage of the solar paddles was on the order of 30 volts. The solar array regulator was designed to meet or exceed the following specifications:

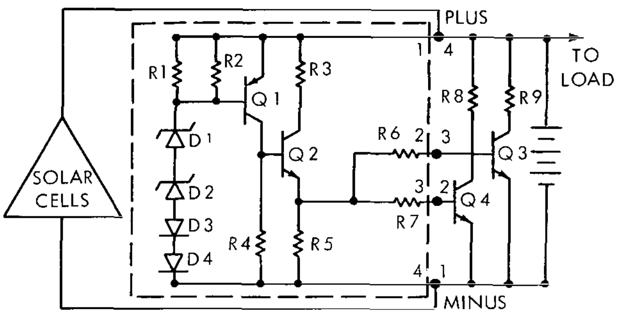

Figure 8—Explorers XII and XIV solar array regulator.

Voltage limiting:

19.5 volts ±0.1 volt

EXPLORER XII

19.6 volts ±0.1 volt

EXPLORER XIV

Current range at specified voltage:

0.1 to 1.5 amperes

Operating temperature:

-10°C to +50°C

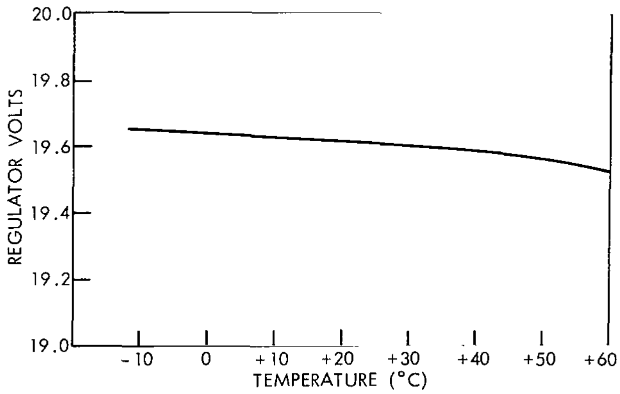

Figure 9—Explorers XII and XIV solar array regulator temperature characteristic.

Figure 8 shows a schematic of the solar array regulator. Diodes D1 through D4 compose the reference diode string. No voltage adjustment was provided, since these diodes were selected for the desired voltage level. Also, since the batteries themselves have negative temperature coefficients, the diode string was selected for a slightly negative temperature coefficient (Figure 9).

When the solar bus voltage is below the regulating voltage, all transistors (Figure 8) are in the "off" state. As the bus voltage increases, the diode string starts to conduct, causing Q1 to conduct and thus turning Q2 "on." Q2 causes Q3 and Q4 to conduct. Conduction of Q3 and Q4 loads down the system voltage as necessary to maintain the desired voltage level. The power dissipating resistors R8 and R9 are, as in the case of Ariel 1, mounted exterior to the spacecraft on the solar paddle arms to radiate the excess power into space.

Figure 10 shows the I-V characteristics of the regulator, which in this instance can regulate approximately 1.8 amperes as compared to the specification requirement of 1.5 amperes.

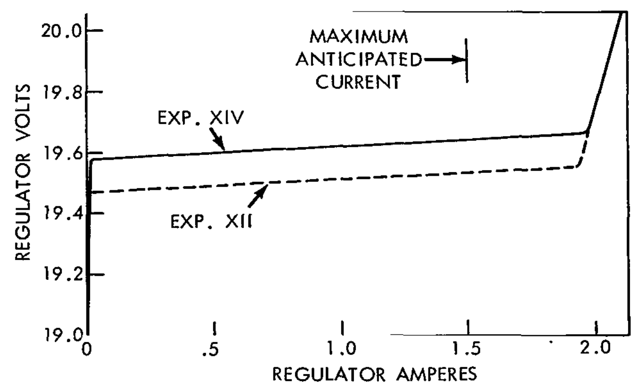

Figure 10—Explorers XII and XIV solar array regulator I-V characteristics.

EXPLORERS XV, XVIII, XXI, AND XXVI SOLAR ARRAY REGULATOR

In the Explorer XV, XVIII, XXI, and XXVI satellites, the experiment power requirement and the power capabilities of the solar array were increased as compared to the earlier satellites. As a result, the solar array regulator was redesigned to regulate up to 100 watts at 19.6 volts. The new design utilizes a differential amplifier because of the ease of voltage adjustment and excellent temperature stability. Figure 11 is a schematic diagram of this regulator.

The voltage of the reference zener D1 is compared to the voltage of the resistor divider which consists of the upper leg R3 and the lower leg R4, R5, and R6. The lower leg is composed of three resistors for ease of adjusting the regulator voltage. Should temperature compensation be required, one or more of these resistors could be temperature-sensitive. In practice it was found that no temperature compensation was necessary if the reference diode was a temperature-compensated type.

If the voltage impressed across the regulator is less than 19.6 volts, transistor Q2 conducts and transistor Q1 is cut off. Thus, transistors Q3 through Q8 are all turned off. As the system voltage increases and the base voltage of Q2 approaches that of Q1 (when the bus voltage reaches 19.6 volts), Q1 starts to conduct and Q2 decreases its conduction. The conduction of Q1 is amplified by Q3 and Q4 which drive the four dump transistors Q5 through Q8. The dump transistors are connected in an emitter-follower configuration and drive the power dissipating resistors, equally distributing the dissipated energy. The conduction of the dump circuit loads down the solar array bus to maintain the desired regulated voltage.

Figure 12 illustrates the I-V characteristics of this regulator. The circuit exhibited excellent regulation and temperature stability. Regulation was maintained to ±1% from 20 ma to 5.7 amperes at 19.6 volts. The temperature stability of voltage regulation was within ±1% from -20°C

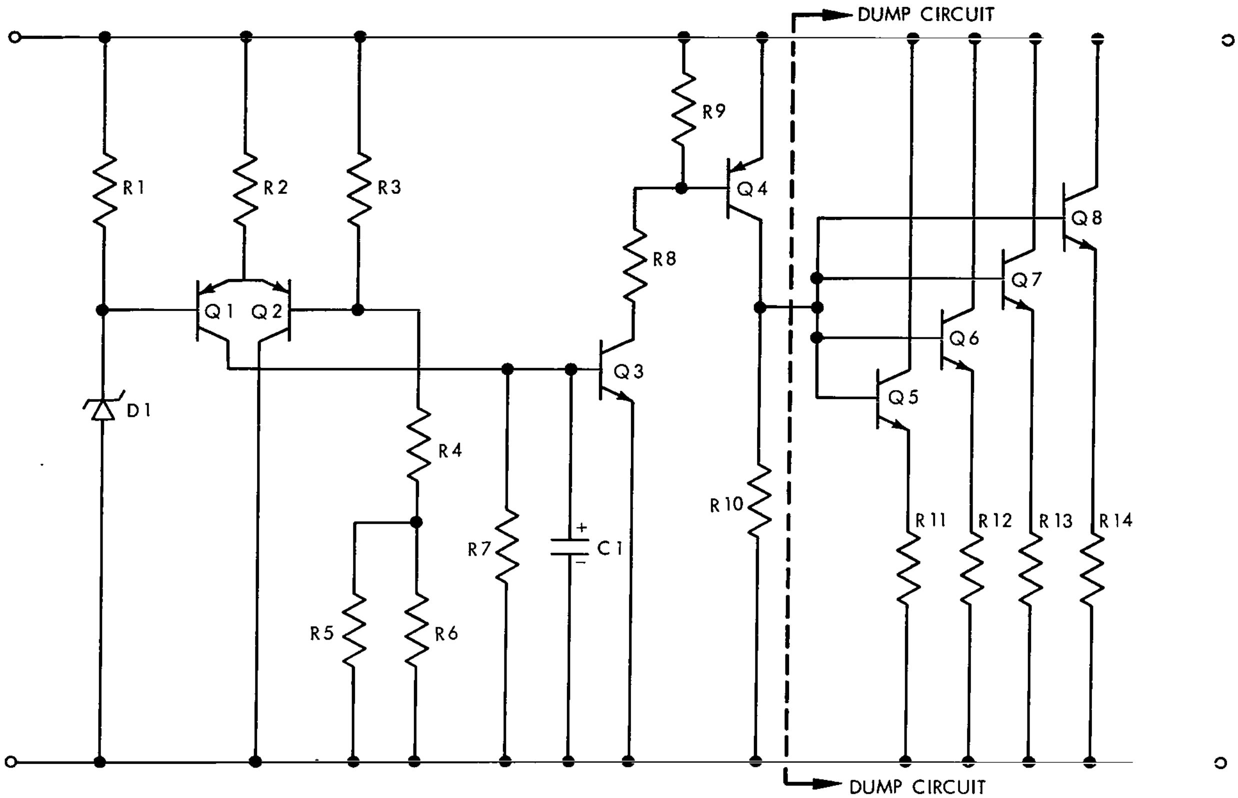

Figure 11—Explorers XV, XVIII, XXI, and XXVI solar array regulator.

to +60°C. The current drain in the standby mode was less than 10 ma. (The standby mode is defined as solar array bus voltages below 19.0 volts.)

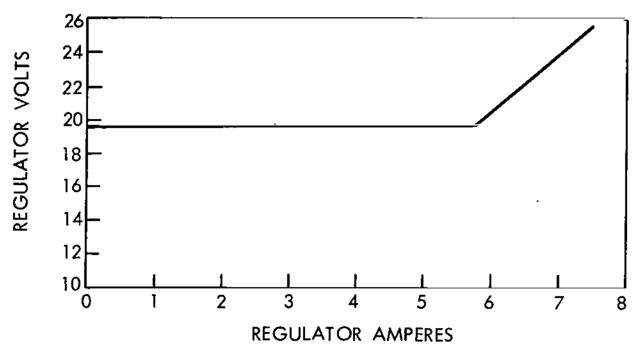

Figure 12—Explorers XV, XVIII, XXI, and XXVI solar array regulator I-V characteristic.

EXPLORER XXVIII TWO LEVEL SOLAR ARRAY REGULATOR

The Explorer XXVIII satellite employed basically the same type of regulator as was used in the Explorer XVIII satellite, but with the addition of a low voltage turn-off feature and a two level regulation scheme. The purpose of the two level operation was to diminish the possibility of cell unbalance in the battery pack. If a battery is charged to 19.6 volts and held at that voltage for a prolonged period, the cells tend to unbalance. This is due to the difference in the cell capacities and their internal leakages. The cells with the greater leakage will drop in voltage, those with lower leakage will rise in voltage. An undesirable gas pressure, resulting from excessive voltage, can occur on the higher voltage cells. However, if the voltage is reduced to approximately open circuit voltage, this condition does not arise.

Turn-Off Circuit

To conserve as much power as possible during eclipse periods, a turn-off circuit is incorporated in the solar array regulator. This circuit (Figure 13) is composed of transistor Q7, resistors R18, R19, and zener diodes CR2 and CR3. The zener diodes were selected to turn off transistor Q7 when the system voltage drops below 17 volts, as it would during eclipse. When Q7 is off, the source of drive for all the transistors is removed and the circuit is disabled. Thus, the regulator consumes no power during eclipse. As the system voltage increases, Q7 is the first transistor to conduct. This connects the differential amplifier to the circuit for normal operation.

Two Level Regulation

The differential amplifier compares the zener voltage (CR1) to the voltage divider composed of the upper leg R3 and the lower leg R4, R5, and R6. These resistors were selected for regulation at 19.6 volts. Turning on Q6 adds an additional resistor network in parallel with R3 and thus alters the regulating voltage to the 18.6 volt level. Switching between these two regulating levels is accomplished by a signal from the spacecraft's performance parameter circuit, which senses the battery charge current and converts it to a voltage for monitoring purposes. This voltage is fed to a schmitt trigger which is set to trip when the battery charge current falls below 50 ma, indicating a good state of charge. The schmitt trigger then supplies a voltage signal, turning on Q5, which turns on Q6, placing resistors R15, R16, and R17 in parallel with R3 to alter the regulating voltage to the 18.6 volt level. Capacitors C3 and C4 prevent the circuit from switching too rapidly, thus eliminating a rapid step function from occurring on the solar array bus. Level changes take approximately 3 seconds.

Whenever the batteries are in a discharged state, as during a long period of shadow, it is desirable that the solar array regulator remain in the 19.6 volt operating mode to provide the most charge. Therefore, should the batteries discharge to 12 volts, an undervoltage circuit turns off the spacecraft power, disabling not only the experiments but also the performance parameter circuit. Thus the schmitt trigger cannot be activated to switch the solar array regulator into the 18.6 volt mode unless; (1) the satellite has been turned on by the undervoltage timer and (2) the battery charge current has fallen below 50 ma.

Figure 14 illustrates a test setup using the two level regulator. A power supply was connected through a recycle time to the battery and the two level shunt regulator. A current sensor in series with the battery supplied a signal to the two level regulator when the battery current dropped below 50 ma. The recycle timer was set to switch to the power supply for 10 minutes and to the load for 10 seconds. The purpose was to determine whether there are adverse effects on the two level regulation scheme under pulse load conditions.

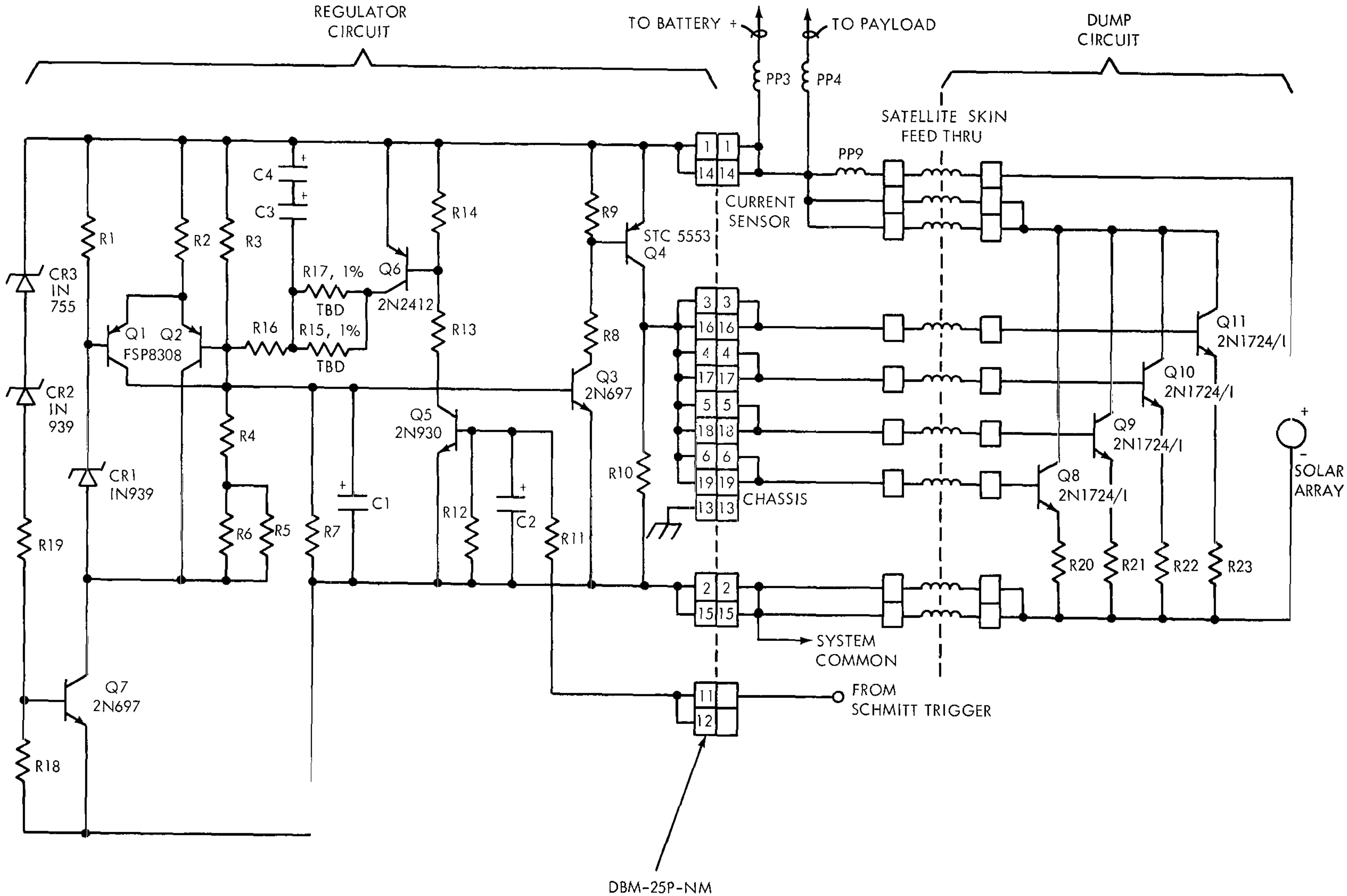

Figure 13—Explorer XXVIII two level solar array regulator.

Figure 15 illustrates the start-of-charge characteristics with a constant current, constant potential source. The battery charged at a 2 ampere rate to a charge of approximately 2.2 ampere-hours, at which time the battery potential reached 19.6 volts. At this point the current started to decrease, dropping to approximately 1.2 amperes. This current continued to diminish until approximately 6 ampere-hours had gone into the battery. At this time the current had dropped to 50 ma. Figure 16 illustrates the battery charge curves after approximately 6 ampere-hours of charge. It will be noted that after a 10 second load the regulator resets to the 19.6 volt level until the current diminishes to 50 ma and then switches to the 18.6 volt level. Figure 17 is an expanded curve of the battery voltage versus battery current taken 24 hours after the voltage started tripping to the 18.6 volt level, at which time the circuit had achieved a stable mode of operation. It will be noted that the charge ampere-hours is approximately 120% of the discharge ampere-hours. This is a very satisfactory recharge.

Figure 18 illustrates the I-V characteristics at both levels of the two level regulator. The voltage is within ±1% from 10 ma to 5

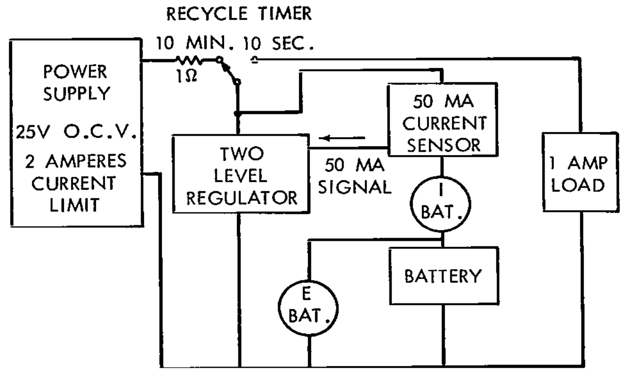

Figure 14—Explorer XXVIII two level regulator test setup for pulsed load conditions.

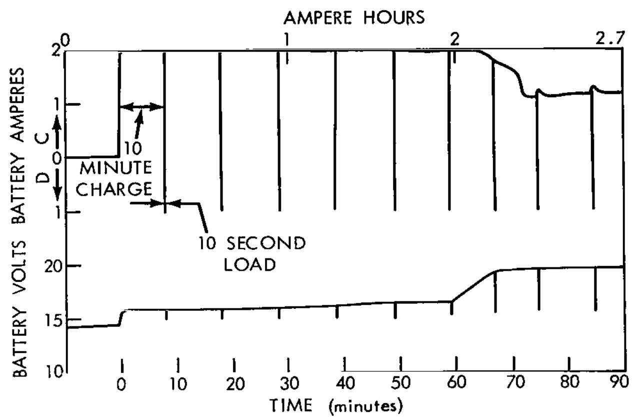

Figure 15—Explorer XXVIII two level solar array regulator start-of-charge characteristics.

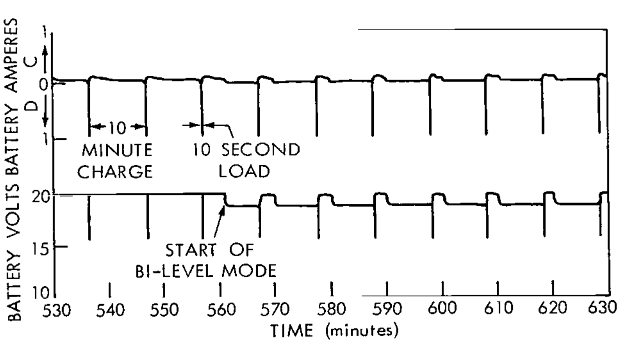

Figure 16—Explorer XXVIII two level solar array regulator characteristics after approximately 6 ampere-hours of charge.

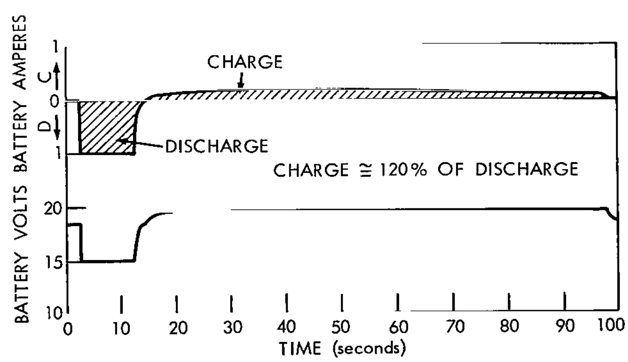

Figure 17—Explorer XXVIII two level solar array regulator characteristics after approximately 24 hours of stable mode operation (expanded time scale).

amperes for temperatures ranging from -10°C to +55°C at either the 19.6 or the 18.6 volt level.

SUMMARY

Charge control of nickel cadmium batteries by voltage limiting alone is inadequate because of their negative temperature coefficient. This problem was overcome by incorporating current limiting into the voltage limiting circuit. Both the voltage and current limiting circuits presented possess negative temperature coefficients.

One of the main difficulties encountered with silver cadmium battery packs maintained at full charge voltage for prolonged periods is a tendency to unbalance (due to the variations in the internal leakages of the cells). The utilization of a two-voltage-level regulation scheme eliminates this problem.

The shunt-type regulator is utilized in all the scientific spacecraft described. This particular type of regulator has the advantages of simplicity, reliability and rapid dynamic response to transient loading. The major deficiencies of this circuit consist of a slight reduction in efficiency and the necessity for dissipative elements to radiate surplus power into space without raising the temperature of the payload. All of the circuit techniques described have been applied in regulators that have been successfully flown in one or more satellites.

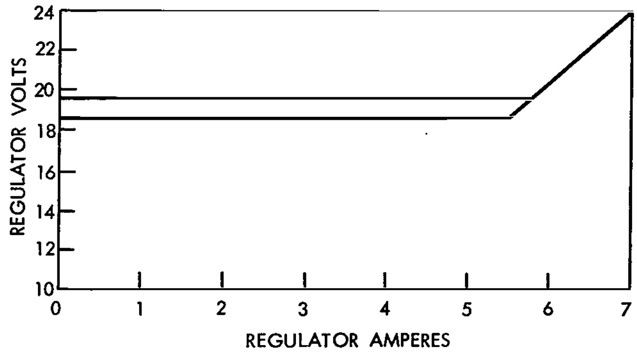

Figure 18—Explorer XXVIII solar array regulator I-V characteristics.

ACKNOWLEDGMENTS

The author wishes to express his appreciation for the assistance, throughout the Explorer projects, from the many groups at GSFC whose efforts have aided in obtaining the information presented here. Special gratitude is expressed for the outstanding cooperation of Leo J. Veillette.

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National Aeronautics and Space Administration
Greenbelt, Maryland, September 16, 1966
120-33-08-16-51

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Appendix A

Spacecraft Nomenclature

The eight satellites considered here have been known by several designations. For clarification, these designations are listed below.

Post-Launch Designation	Pre-Launch Designation	Alternate Designation
Ariel 1	Ariel 1	S51, UK-1
Explorer XII	S3	
Explorer XIV	S3A	
Explorer XV	SERB	S3B
Explorer XXVI	EPE-D	S3C
Explorer XVIII	IMP-A	IMP-1, S74
Explorer XXI	IMP-B	IMP-2, S74-A
Explorer XXVIII	IMP-C	IMP-3, S74-B

Appendix B

Parts Lists

Table B1

Ariel 1 Battery Charge Regulator Parts.

Part	Description	Part	Description
R1	4.7 k	CR3	Diode SG22
R2	selected, nominal 200 ohms	CR4	Diode SG22
R3	100	CR5	zener 1N746
R4	220 ohms, 2 w	CR6	Diode 1N462
R5	20 k	CR7	Diode 1N462
R6	680 ohms, .25 w	CR8	Diode 1N462
R7	680 ohms, .25 w	Q1	2N1132
R8	36 k	Q2	2N1049
R9	2 k	Q3	2N1132
R10	390	Q4	2N718
R11	7.5 k	Q5	2N718
R12	10 k	Q6	2N718
R13	20 k	Q7	2N718
R14	selected, nominal 10 k	Q8	2N1724
R15	20 k	C1	2.2 mfd, 35v
R16	20 k	C2	10 mfd, 35v
R17	100	C3	10 mfd, 35v
R18	100	C4	.47 mfd, 30v
R19	Dalohm RH25, 10 ohm ww, 25 w	T1 :	core 51418-1D magnetics inc
R20	Dalohm RH25, 10 ohm ww, 25 w		1-2 1500 turns #39 HF
R21	10 k		3-4 1500 turns #39 HF
CR1	zener, selected 1N1520-1N1524		5-6 1000 turns #41 HF
CR2	zener, selected 1N1520-1N1524		7-8 4 turns #20 HF

NOTE: All resistors carbon composition ±5% unless otherwise specified.

Table B2

Ariel 1 Battery Selector Circuit Parts.

Part	Description	Part	Description
R1-R2	200 ohms, 1w	C2	47 mfd, 35v
R3	1k, 1w	Relay	SL11DM Potter & Brumfield
R4-R5-R6-R7	39k, 0.5w	Q1-Q2-Q3-Q4	2N1654
R8-R9	6.3k, 1w	Q5-Q6	2N863
R10-R11	2.2k, 1w	Q7-Q8	2N1480
C1	82 mfd, 50v		

Table B3

Explorers XII and XIV, Solar Array Regulator Parts List.

Part	Description	Part	Description
R1	selected, sensistor	R9	20 ohms, 50w Dalohm ±1%
R2	selected, sensistor	D1	zener, selected 1520-1524
R3	270 ohms, 2w 5%	D2	zener, selected 1520-1524
R4	2.2k	D3	1N629
R5	620	D4	1N629
R6	100	Q1	2N1132
R7	100	Q2	2N1049
R8	20 ohms, 50w, Dalohm ±1%	Q3-Q4	2N1724/I

NOTE: All resistors carbon composition ±5% unless otherwise specified.

Table B4

Explorers XV, XVIII, XXI, and XXVI Solar Array Regulator Parts.

Part	Description	Part	Description
R1	10k .25w, RN-65B 1%	R13	13 ohms 50w, Dalohm RH50 1%
R2	2.67k	R14	13 ohms 50w, Dalohm RH50 1%
R3	selected nom. 1k, .25w, RN65B 1%	D1	1N935
R4	select nom. 500Ω, .25w, RN65B 1%	Q1-Q2	FSP-24 Fairchild
R6	select nom. 500Ω, .25w, RN65B 1%	Q3	2N1482
R7	1k, .5w, cc 5%	Q4	STC5553 Silicon Transistor Corp.
R8	3k, 1w, cc 5%	Q5	2N1724/I
R9	500, .25w, cc 5%	Q6	2N1724/I
R10	1.8k, 1w, cc 5%	Q7	2N1724/I
R11	13 ohms, 50w, Dalohm RH50 1%	Q8	2N1724/I
R12	13 ohms, 50w, Dalohm RH50 1%	C1	5 mfd, 15v

Table B5

Explorer XXVIII Solar Array Regulator Parts.

Part	Description	Part	Description
R1	10k, 1/4w, RN-65B 1%	C1	68μf, 20v Tant.
R2	2.67k, 1/4w, RN-65B 1%	C2	0.1μf, 75v, 350D
R3	3.83k, 1/4w, RN-65B 1%	C3	350μf, 15v, 136D
R4	1.96k, 1/4w, RN-65B 1%	C4	350μf, 15v, 136D
R5	Select, 1/4w, RN-65B 1% Nom. 1.1k	CR1	1N939
R6	Select, 1/4w, RN-65B 1%	CR2	1N939
R7	1k, 1/4w, Carbon Comp. 5%	CR3	1N755
R8	3k, 1w, Carbon Comp. 5%	Q1-Q2	FSP8308
R9	510Ω, 1/4w, Carbon Comp. 5%	Q3	2N697 or 2N2658
R10	1.8k, 1w, Carbon Comp. 5%	Q4	STC5553
R11	2k, 1/2w, Carbon Comp. 5%	Q5	2N930
R12	20k, 1/2w, Carbon Comp. 5%	Q6	2N2412
R13	30k, 1/2w, Carbon Comp. 5%	Q7	2N697 or 2N2658
R14	20k, 1/2w, Carbon Comp. 5%	Q8-Q11	2N1724/I
R15	Select 1/4w RN65B Nom. 17k		
R16	15k, 1/4w, RN-65B 1%		
R17	Select		
R18	10k, 1/2w, Carbon Comp. 5%		
R19	1.5k, 1/2w, Carbon Comp. 5%		
R20	13Ω, 50w, Dalohm NH-50 1% Non-Inductive		
R21	13Ω, 50w, Dalohm NH-50 1% Non-Inductive		
R22	13Ω, 50w, Dalohm NH-50 1% Non-Inductive		
R23	13Ω, 50w, Dalohm NH-50 1% Non-Inductive		

NASA-Langley, 1967 —— 3

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