NICKEL CADMIUM CHARGE CONTROL CONCEPTS

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ABSTRACT

APL has used several different types of charge control systems on their spacecraft. Some have used dissipative shunts to get rid of the excess solar array power; some have used non-dissipative shunts and some have used a hybrid system. Although they have all worked reasonably well, there are tradeoffs to be made between the impact on the thermal design caused by the dissipative devices and the generation of conducted emissions caused by the switching of non-dissipative devices.

INTRODUCTION

The primary function of a spacecraft battery charge control system is to provide sensible limits of battery discharge, recharge and overcharge to prevent undue stresses within the battery. In most cases this means that the charging current from the solar array must be reduced after the battery has reached 'full charge'. This leads to some interesting thermal problems, not just for the battery, but for the entire spacecraft.

SAS A/B

Figure 1 shows one of the early attempts to solve this problem at APL on the Small Astronomy Satellites (SAS) A and B. These satellites were small, using a single battery of eight 6 ampere hour cells to sustain a 30 watt load through a 36 minute eclipse which recurred every 96 minutes (a 300 nmi equatorial orbit). The Low Voltage Sensing Switch was set at 1.1 volts per battery cell (8.8 volts) to preclude excessive discharge which could result in the reversal of a low capacity cell.

For such a small battery the instantaneous variation in the array power was large (40 to 100 watts). This led to the need for correspondingly large shunts driven by a sophisticated Charge Regulator and Monitor (CRAM) system. CRAM monitored the bus voltage, the battery current and the battery temperature. It had a voltage limiter that limited the bus voltage in accordance with a voltage - temperature curve whether the battery was on the line or not. It also had an electronic coulometer that both monitored and controlled the battery recharge in parallel with the voltage limiter. There were four commandable percent returns: 105%, 110%, 125%, and 'monitor only' or infinite return.

Figure 2 shows a typical charge, discharge profile. The electronic coulometer counted down to a value indicative of the ampere - minutes discharged. During recharge it counted back at a slightly different rate depending on the percent return that was selected. After about 90 to 95% of the charge was returned, the voltage limiter would start to reduce the battery charge rate in order to limit the bus voltage to the value required by the V-T curve. When the coulometer was satisfied (110% return for the case of figure 2), then the battery trickle charge rate was reduced to a preset trickle charge rate of C/20 (300 ma). This resulted in a corresponding drop in the bus voltage.

Aside from these gradual changes in the bus voltage, the bus was relatively quiet, with little or no noise or conducted emissions being generated by the charge control system. This was true even without the battery on the line (Solar Only Mode) and was primarily due to the use of linear shunts.

Returning to figure 1, we see two groups of linear shunts; one internal and four external. The reason for an internal linear shunt was to provide internal heat if requested by a properly located thermistor. This was done over the protests of the thermal designer since the heat was provided during a short period at the end of sunlight after the battery was charged. For this reason and because the shunt driver can be relatively heavy, this concept is not recommended and has not been used on subsequent APL spacecraft.

The external shunt was divided into four parallel units, one mounted on each of the four solar panels and was designed with a total capacity of 120 watts (30 watts each) so that the system could function even if one shunt were lost. Referring to figure 3, we can see that the shunt resistor(s) must be designed to accept all the available power of 30 watts each. This was accomplished by placing a distributed resistor under the solar cells on each of the four solar panels covering an area of 1.4 ft^2. The shunt drive transistors, however, could not be distributed. We see from figure 3 that they experienced a peak power dissipation of Pmax/4 when shunting about one-half their maximum current. This is about 7-1/2 watts, an acceptable power level, but not ideal for long life. Indeed on SAS-A, we did experience failures of the shunt drive transistors within a year. This was found to be due to a defect in the transistor which was corrected on SAS-B by replacing the transistor with one of a different manufacture.

SAS-C

Due to a near doubling of the power on SAS-C, the charge control system was expanded to include digital shunts (see figure 4). The solar array was divided into 24 equal, parallel segments; each with a shorting transistor controlled by CRAM. The linear shunt could then be sized to have slightly more capacity than one of the digital shunts. Although the shunt drive transistor still had to be designed for 9 watts power dissipation, it was placed in a benign environment inside the spacecraft since there was only one of them.

Any abrupt change in the power balance was accommodated by the linear shunt. If it became saturated (or empty), then the digital shunts were shorted (or opened) sequentially until the power imbalance could be accepted by the linear shunt. SAS-C was also designed to operate without a battery (Solar Only). Since the battery was one of the few non-redundant items on the spacecraft, it was thought that we should at least be able to operate during the sunlit portion of the orbit in the event that the battery failed. An Active Ripple Filter (not shown) was employed to reduce bus transients when switching digital shunts without a battery on the line.

AMPTE/CCE

The charge control concept of a recent APL satellite, AMPTE/CCE (The Active Magnetospheric Particle Tracer Explorers/Charge Composition Explorer), is shown in figure 5. This is the first charge control system at APL to use a microprocessor, an RCA 1802. The figure shows one side of a two battery system for simplicity. The actual array power, shunt power and load are double those shown. The coulometer has no control function in this system, but is simply a monitor. Also, there is no linear shunt, but only a shorting transistor for each solar array segment. The transistors used in this case are MOSFETS IRF130 with a very low saturation resistance, which further reduce the power dissipation.

This system is simpler and of lower power dissipation than its predecessors, but it does result in some additional bus noise as shown in figure 6. Also, this system does not have any 'Solar Only' capability.

OPEN PROGRAM

Figure 7 shows still another charge control concept. One that is being proposed for three satellites for the OPEN (Origin of Plasmas in the Earth's Neighborhood) program and which will make extensive use of a microprocessor. At first glance, the much higher power levels of 470 to 800 watts from the solar array would seem to dictate another digital (non-dissipative) system. However, there is a strong desire to have very low conducted emissions on these satellites, a requirement that has forced us to re-think the linear shunt.

Sixteen linear shunts with a capacity of 25 watts each will accept the entire 800 watts from the array. The distributed resistors can once again be placed on the solar panels under the solar cells. To reduce the power in the shunt driver package, each of the shunts will be driven sequentially in tandem. That is, only one drive transistor will be allowed to operate at the maximum power dissipation point. All other energized shunts will have been driven to saturation. With this type of design, aided by the use of MOSFETs, the maximum power in the driver package can be contained to approximately 10 watts. This design should provide us with a quiet bus and allow us to once again consider the use of the 'Solar Only' mode.

V-T CURVES

Although the electronic coulometer has proven to be a very good charge control method, the simple voltage limiter has also proven to be very effective. Using an empirically developed transfer function, the voltage versus temperature (V-T) curve, the voltage limiter causes actuation of the shunts to keep the battery voltage below the level defined by this curve. Figures 8 through 10 show the V-T curves that were used for the SAS and AMPTE satellites. The more recent satellites have used more than one V-T level which can be selected by ground command. The reason for this is to provide flexibility. If the power dissipation is too high for a given thermal condition, it is possible to switch to a lower curve which will result in a lower battery overcharge rate. Also, when the battery charge voltage increases with age, it is possible to switch to a higher V-T curve in order to charge the battery.

ACKNOWLEDGEMENTS

The Author wishes to acknowledge that a large number of people were involved in the design and test of these power systems. However, the contributions of the following three people were major:

Mr. Arthur F. Hogrefe--Design of the CRAM II and III charge control systems for the SAS satellites.
Mr. Stanley Mantel--Design of the battery charge regulator (BCR) for the AMPTE satellite.
Mr. Walter E. Allen --Power system design for the AMPTE satellite.

REFERENCE

Sullivan, Ralph M.: Design and Test of the SAS-A Power System. Applied Physics Laboratory TG 1106, 1970.

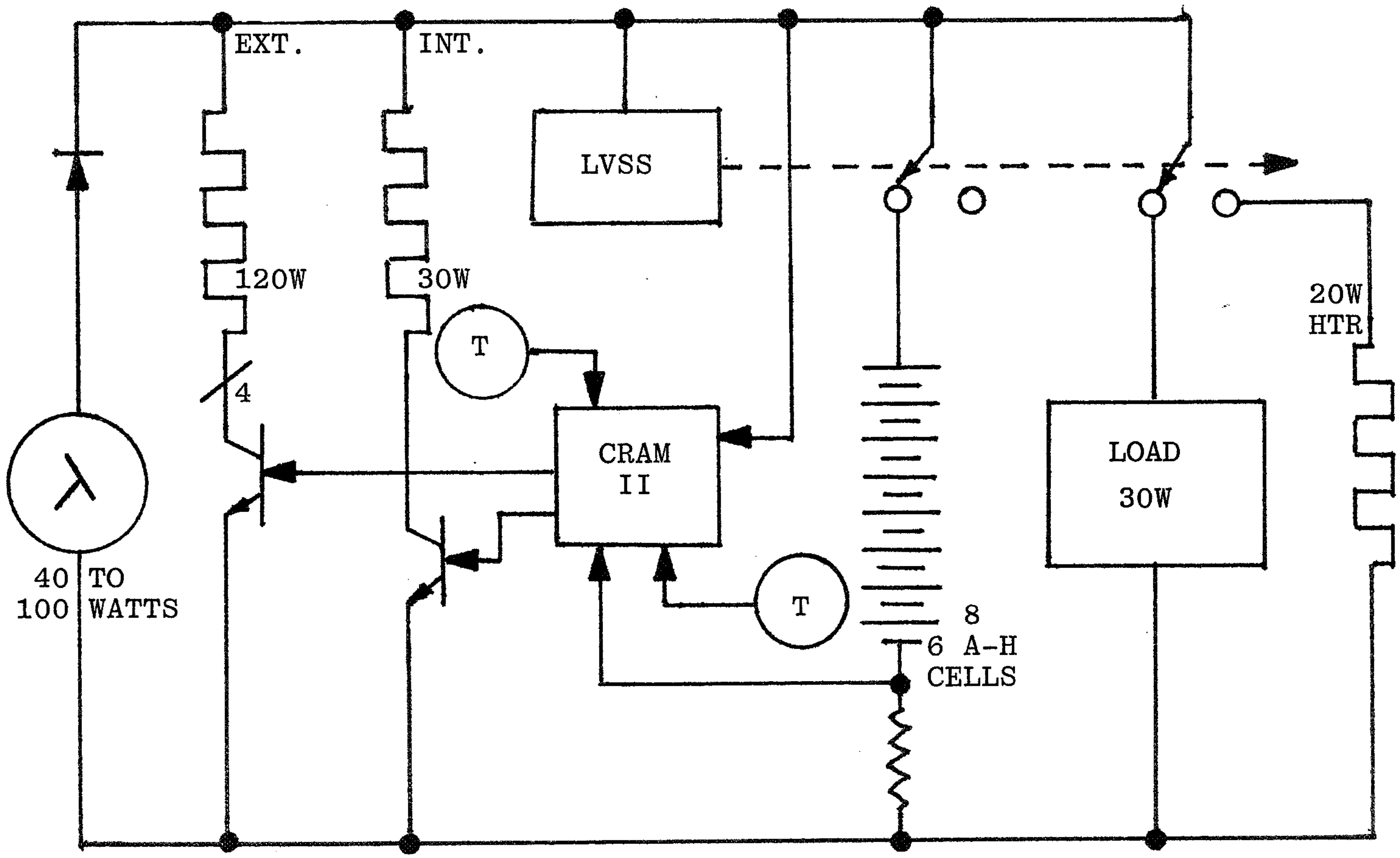

Fig. 1 SAS A/B POWER SYSTEM (1969)

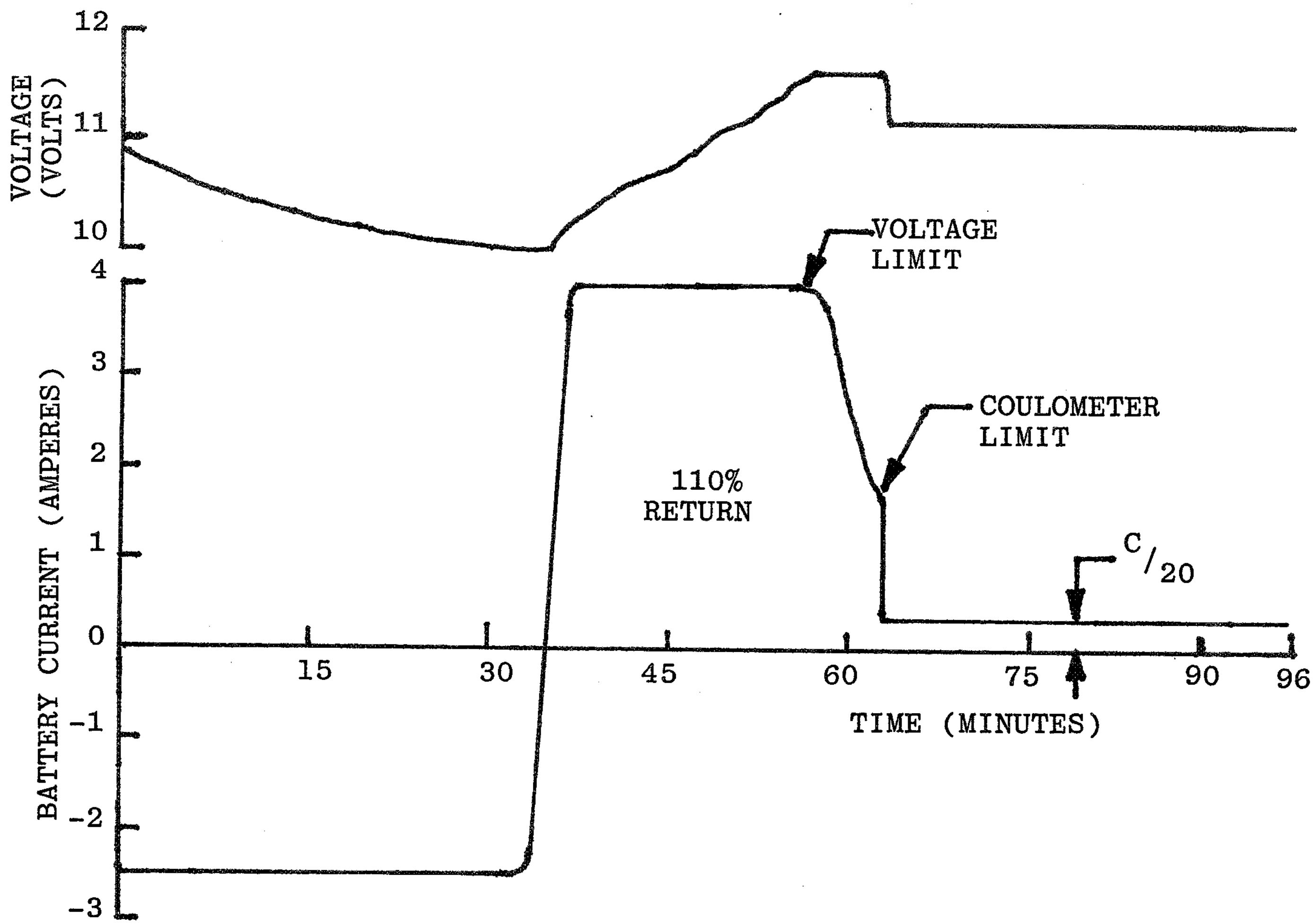

Fig. 2 SAS A/B CHARGE/DISCHARGE PROFILE

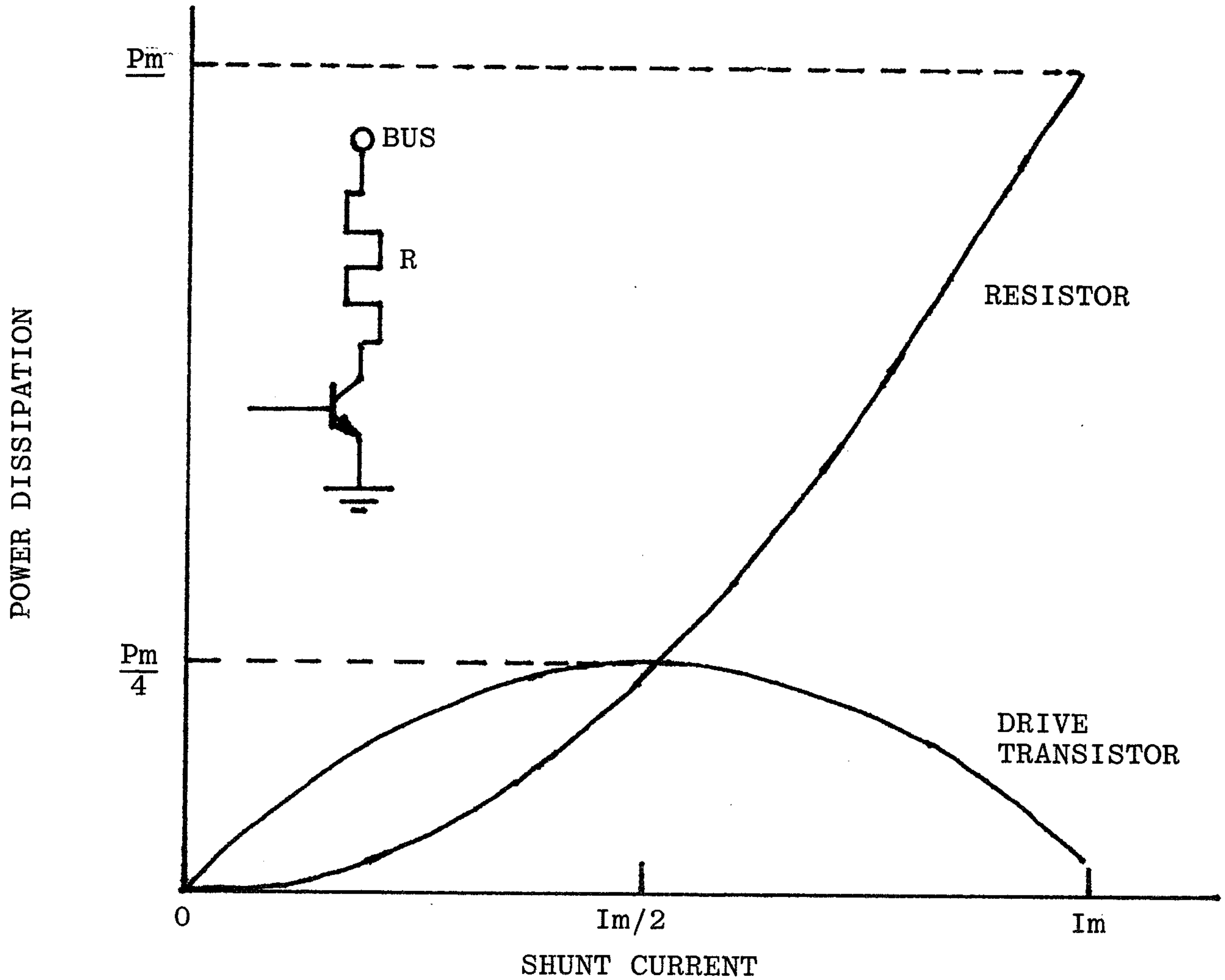

Fig. 3   POWER DISSIPATION IN EACH SHUNT ELEMENT

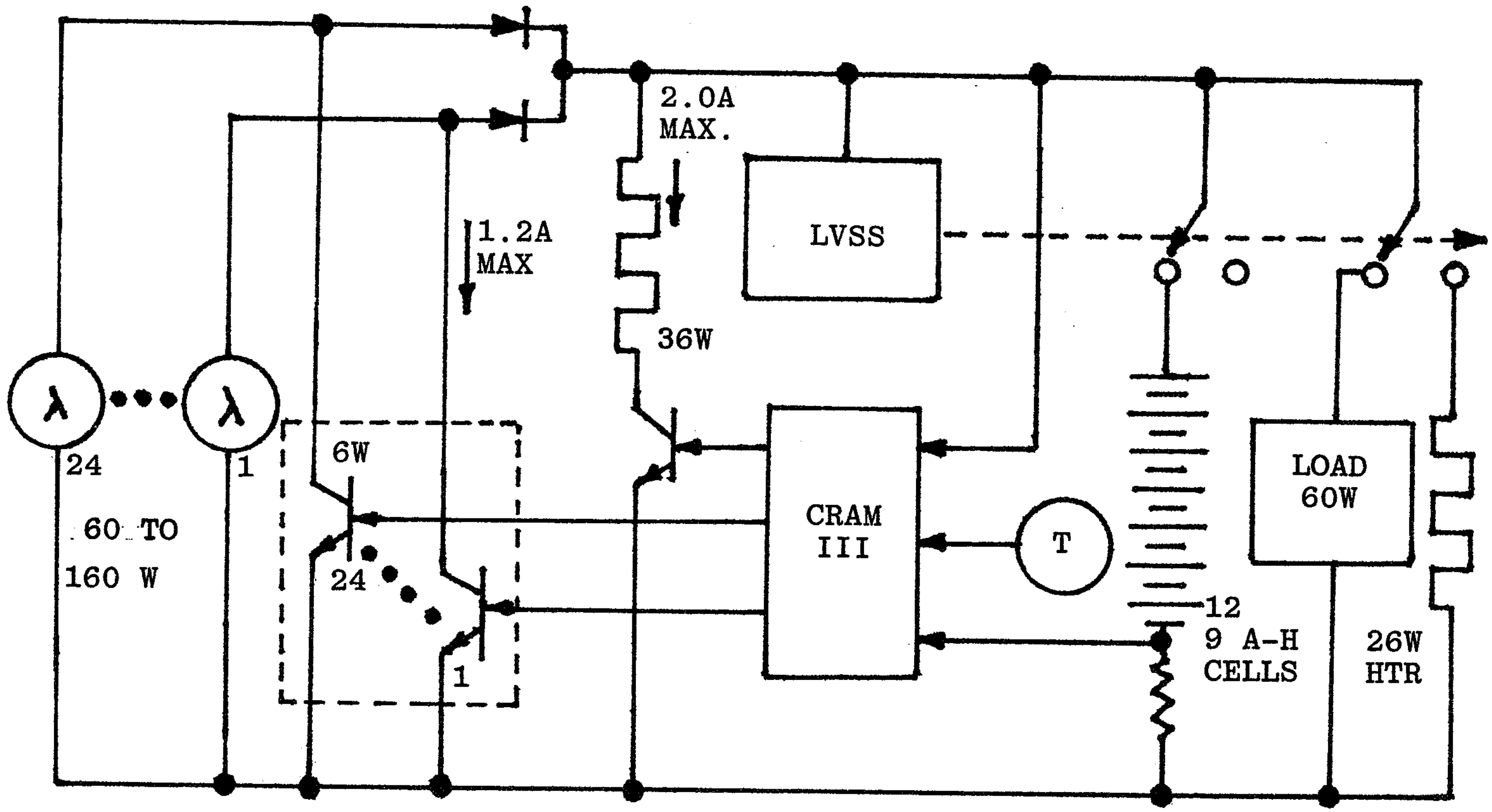

Fig. 4 SAS-C POWER SYSTEM (1975)

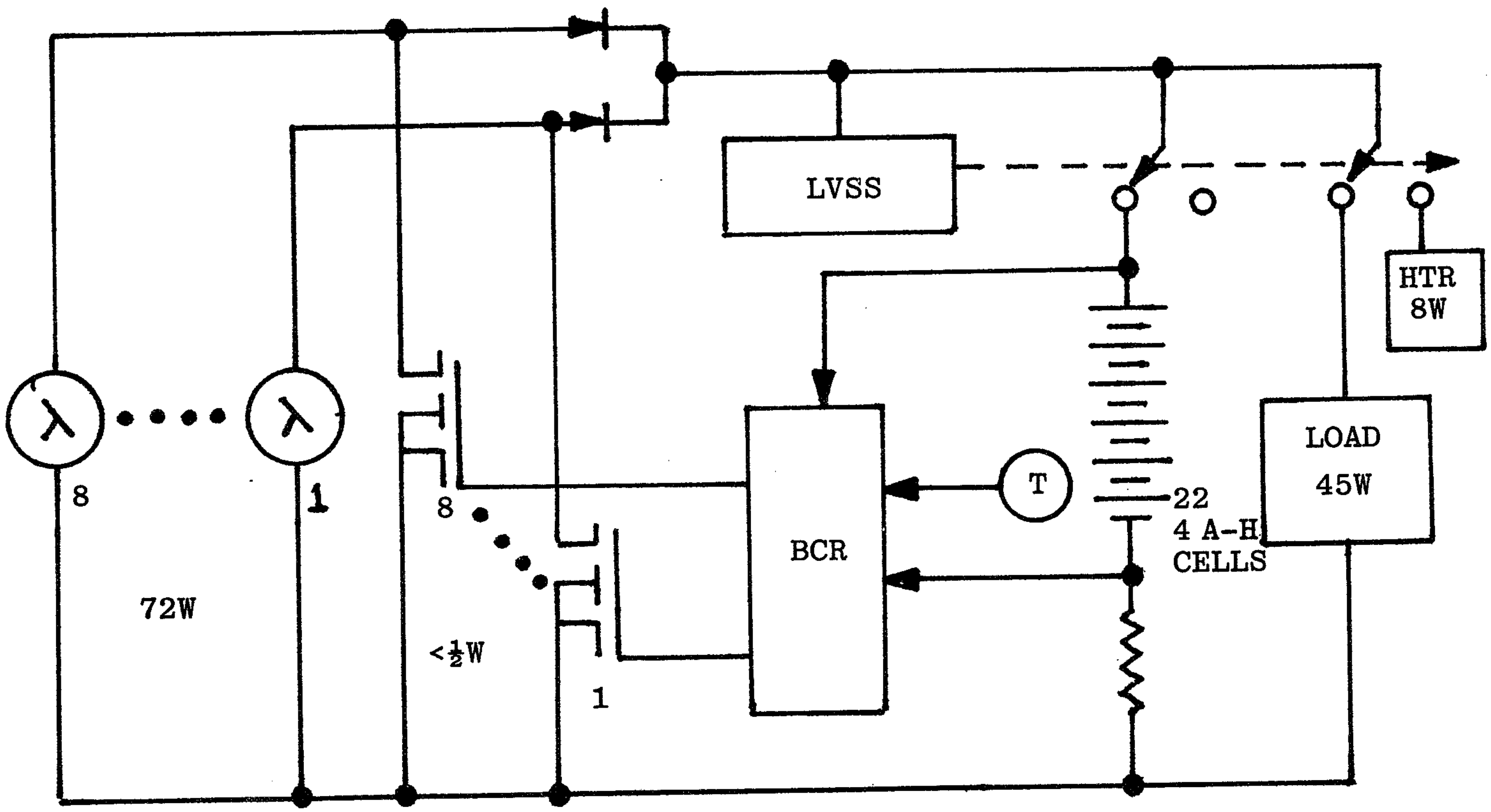

Fig. 5 CHARGE CONTROL CONCEPT AMPTE/CCE (1983)
(ONE SIDE OF TWO BATTERY SYSTEM)

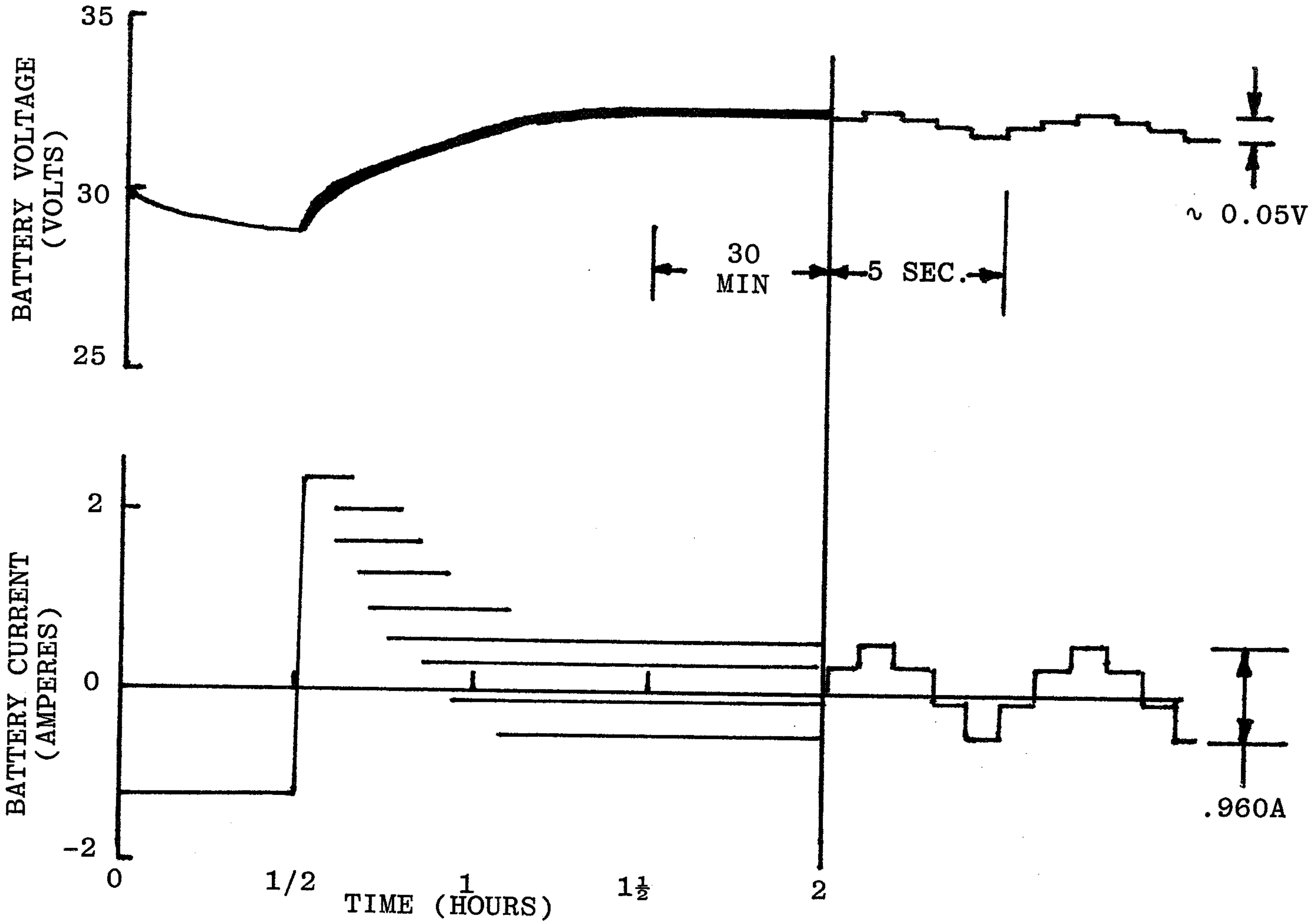

Fig. 6 AMPTE/CCE CHARGE/DISCHARGE PROFILE

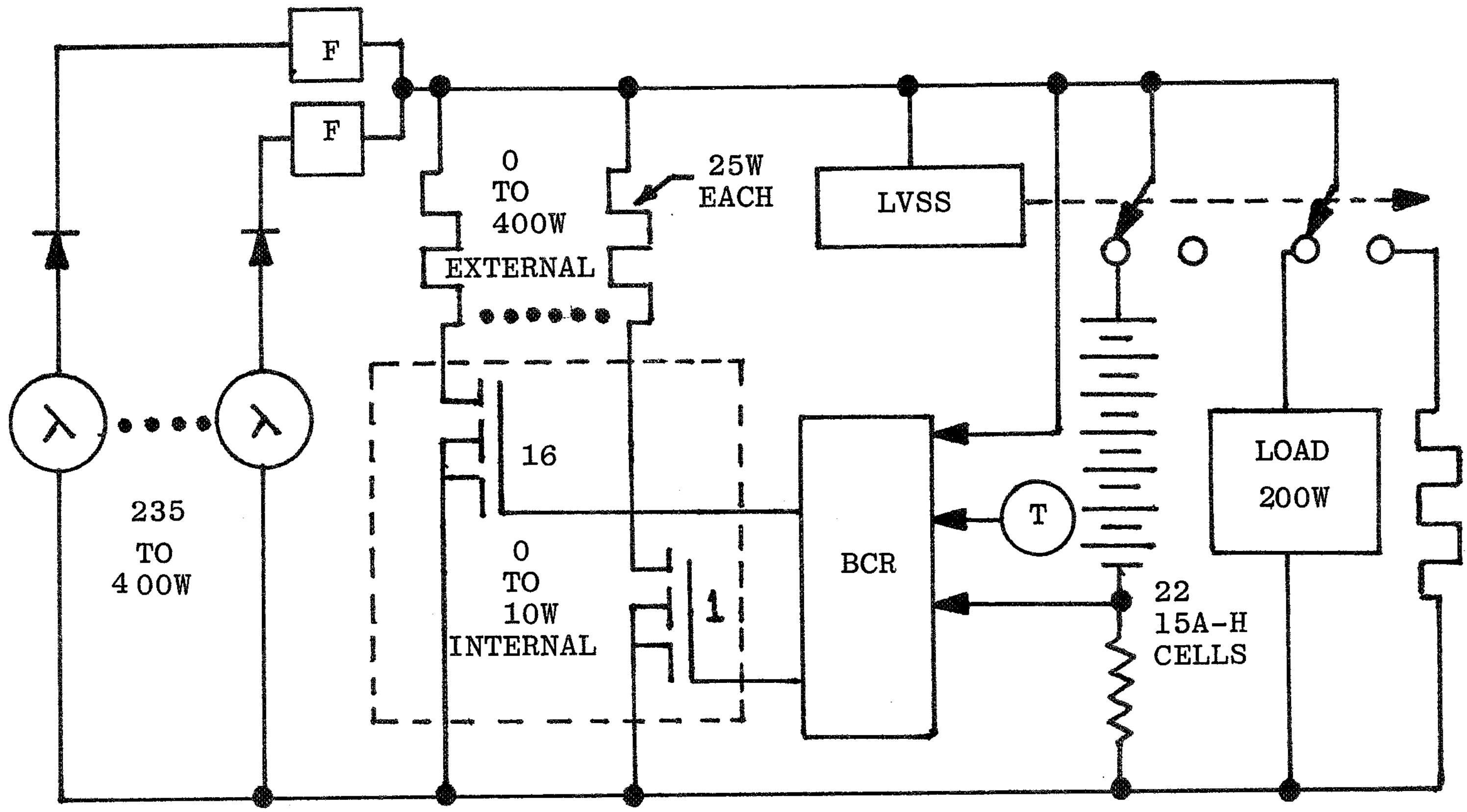

Fig. 7 PROPOSED CHARGE CONTROL CONCEPT, OPEN PROGRAM
(ONE SIDE OF TWO BATTERY SYSTEM)

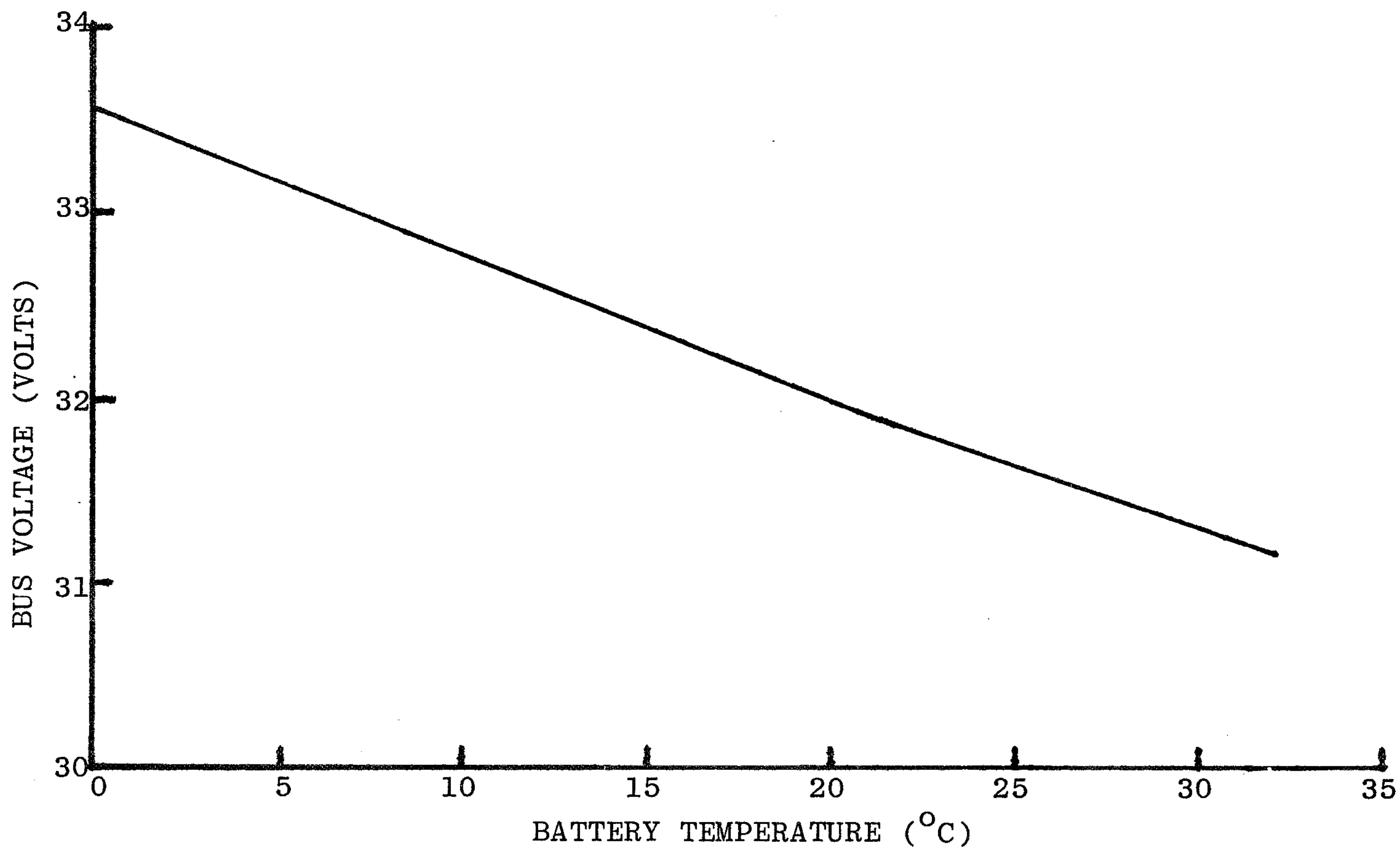

FIGURE 8 SAS-A/B BATTERY VOLTAGE LIMIT

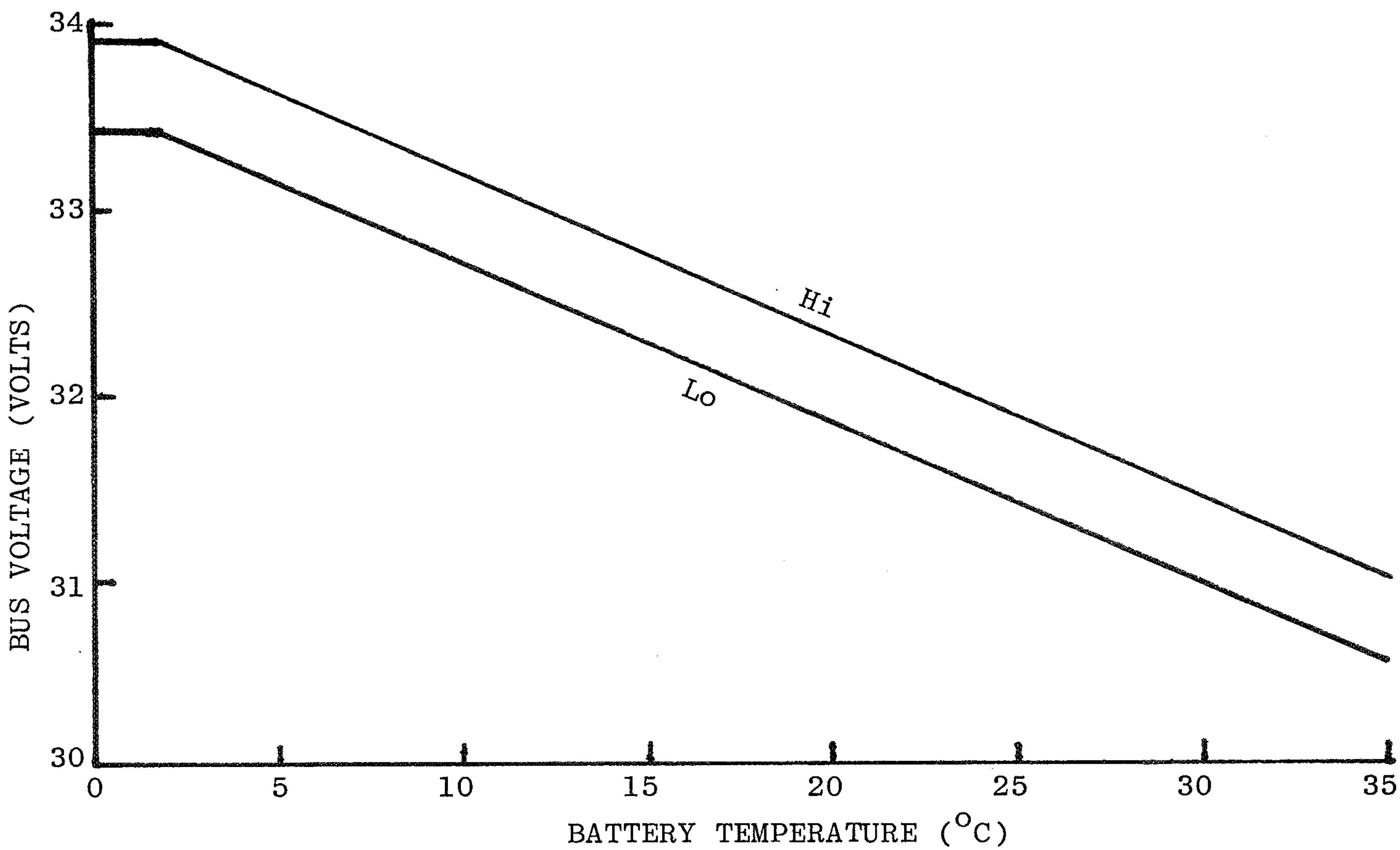

FIGURE 9 SAS-C BATTERY VOLTAGE LIMITS

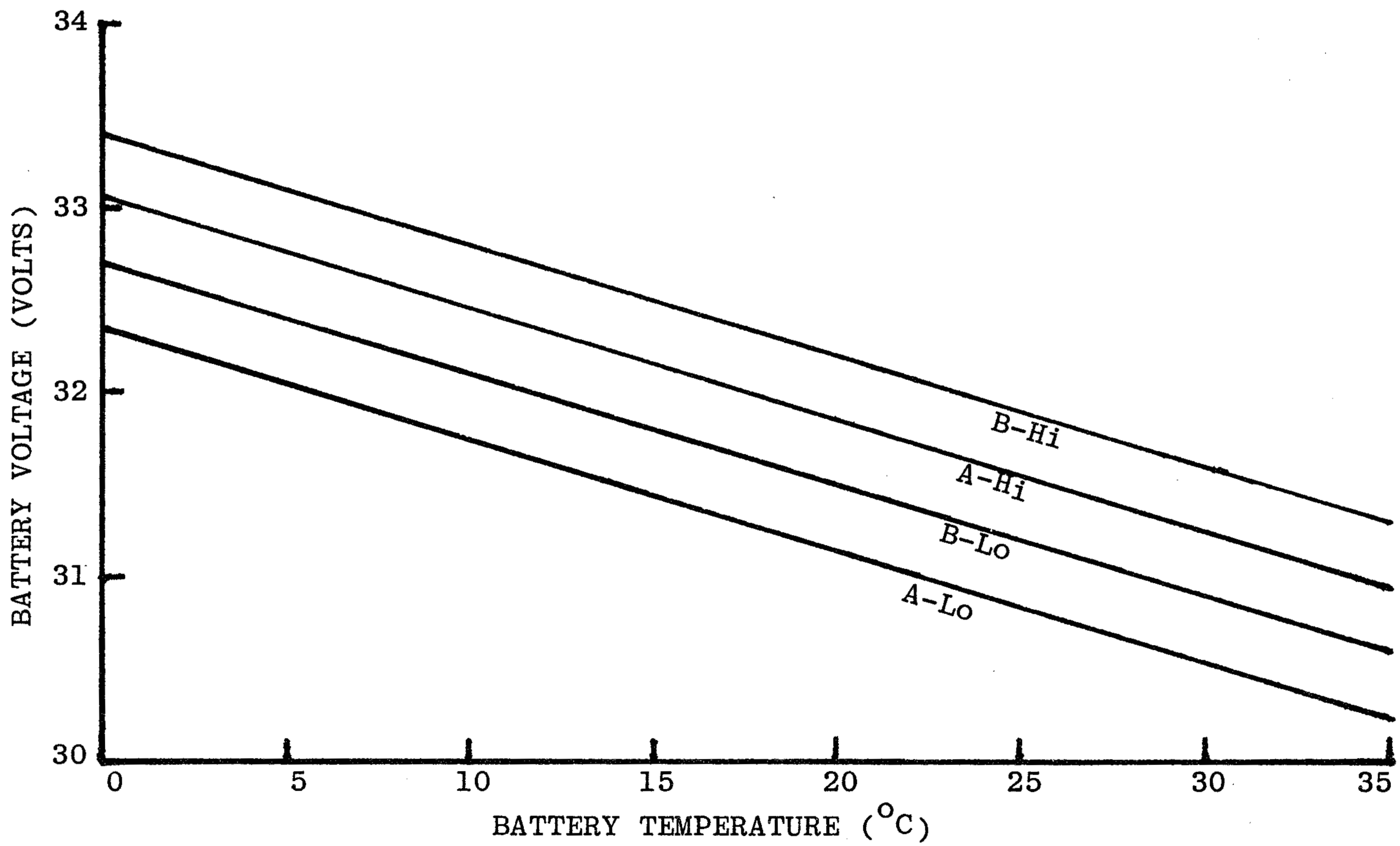

FIGURE 10 AMPTE/CCE BATTERY VOLTAGE LIMITS

A. Rogers, Hughes Aircraft: The newer silicon transistors would probably be a quarter of that in the same current device.

A. Sullivan, APL: Oh you are saying that there's another transistor I should be looking at. Okay thank you.