FLIGHT EXPERIENCE OF SOLAR MESOSPHERE EXPLORER'S TWO NICKEL-CADMIUM BATTERIES

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ABSTRACT

This paper summarizes the performance of the power system on the Solar Mesosphere Explorer (SME) since launch and predictions for continued operation for the rest of the projected mission. The SME satellite's power system was characterized by both insufficient loading and excessive battery charging during the first year of the mission. These conditions affected battery performance and jeopardized the long-term mission. Increased loading on selected orbits has improved battery performance. Long term projections indicate steadily increasing temperatures for the remainder of the mission.

INTRODUCTION

SME was launched 6 Oct 1981 into a nearly circular, sun-synchronous earth orbit at an altitude of 534 km. Each 95 minute orbit at launch included 65 minutes of sunlight (battery charging) and 30 min of darkness (discharging). The attitude of the spacecraft is maintained with a constant sun angle of 37 degrees.

DESCRIPTION OF SME'S POWER SYSTEM.

The main emphasis of the design was to provide a simple, highly autonomous power system (fig 1). The secondary goal was to keep cost as low as possible. This was accomplished by using flight proven technology and hardware. SME was designed to have excess power capability throughout the first 18 months of the mission.

SME has an unregulated, direct energy transfer power system. Power is generated by fourteen parallel diode protected solar array panels, three of which can be commanded on and off line. The energy is stored in two nickel-cadmium batteries containing 21 cells each. While charging to each battery can be disabled, both batteries can discharge through a diode even when commanded off line. Overcharge protection is provided by a shunt regulator that can be commanded to shunt at one of four voltages-temperature (VT) levels (fig 2). These VT levels determine clamp voltages which are based on the desired full charge capacity and the temperature of the batteries. The spacecraft contains an automatic cell failure protection system. One of the batteries will be taken off line if the voltage of its upper ten cells deviates 190 mV from that of its lower eleven cells. Undervoltage protection is provided by logic that will turn off all non-essential loads if the voltage drops below 23.7 volts. Additional loading is provided by an internal resistive load, called the dummy load, which draws 1.4 amps.

DEFINITION OF PROBLEM AT LAUNCH

Upon launch the recharge ratios (coulombs of charge divided by coulombs of discharge) were high enough to cause cell voltage instability during the clamped portion of charge. Under ideal operating conditions the upper and lower halves of the battery would be balanced. However, the voltage in the upper cells of battery I soon became 190mV greater than the voltage in the lower cells and the automatic cell monitor took battery I off line. Because the batteries are in parallel it is undesirable to switch the batteries on and off line. To solve the problem of high cell imbalance several options were available: the automatic cell balance monitors could be disabled, battery I could be kept off line for the remainder of the mission, both batteries could be used one at a time by switching batteries on and off periodically, additional loading could be applied to both batteries in parallel, both batteries could be kept on line until one of the batteries became unbalanced and then that battery could be deep cycled by commanding additional loads on with only that battery on line. The decision was made to minimize the potential hazards to the spacecraft by maintaining cell imbalance as low as possible, disabling the automatic cell monitor function and reaching a minimum voltage of 24.5 volts at least twice a day.

BATTERY ONE DISABLED

During the first 215 orbits of the mission (6 Oct 1981 - 21 Oct 1981) the loading on the batteries resulted in an average depth of discharge (DOD) of 1 AMP-HR out of 12 AMP-HR or 8% of the name plate capacity. This resulted in a minimum voltage on the spacecraft of 26.8 volts. During this time the positive cell imbalance (upper cell voltage greater than lower cell voltage) on both batteries rose until the cell monitor logic disabled charging to battery I. To condition the batteries the dummy load was turned on for 2 full orbits with charging disabled to battery I. The clamp voltage was also reduced by switching to VT level 4 for the remainder of the mission. This resulted in a DOD of 11%. On orbit 3Ø6 the dummy load was turned on for 7 consecutive orbits with charging disabled to battery II. This resulted in a DOD of 14%. The cell monitors on both batteries improved in both the negative and positive excursions During this conditioning period it was noted that when the dummy load was turned on for a full orbit the average temperature of the batteries rose .75 degrees C per orbit. This deviated from the optimum operating temperature of nickel-cadmium cells.

BATTERY HISTORY

DISCHARGE

During the course of the mission the maximum voltage (FIG 3 MIN-MAX EP28V) on the SME bus has varied from 3Ø volts to 29 volts. The current drop in maximum voltage is caused by using the lowest VT level as the temperature of the batteries (FIG 4 AVE TPBAT1) increases. The depth of discharge of the batteries (FIG 3 MIN-MAX EP28V) has steadily decreased from 25.5 volts to the current 24.5 volts. This has been achieved by increasing the amount and duration of loading (FIG 5 MAX EPLOI) during eclipse. Currently twice each day all available loads are turned on for the duration of two uniformly separated eclipses.

CHARGE

The charging of the batteries has been controlled by the number of solar array panels turned on (FIG 6 AVE EPSAST). Due to changes in the solar intensity (FIG 7 MAX EPSAI) it has been necessary to switch some of the arrays on and off to adjust for incorrect charge rates (FIG 8-11 EPB1C,EPB2C). The number of solar array panels turned on has been adjusted from the maximum of 13 panels to the minimum of 11. Currently all switchable arrays are off.

CELL IMBALANCE

The cell imbalance monitor (FIG 12,13 AVE EPB1CF,AVE EPB2CF) have responded to changes in charging and discharging. While battery one was the only battery to go offline before the automatic cell monitoring was disabled both batteries have experienced high cell imbalances at various times. The major contributors to high cell imbalance seem to be too high charge rates, too low charge rates, too high a discharge rate at DOD and too shallow DOD.

FUTURE PREDICTIONS

FACTORS AFFECTING BATTERY LIFE

The most important consideration for the power system is the expected battery life. SME was launched with a one year mission which has now been extended. Due to changes in the ascending node time the power system will experience several changes in the next few years. The duration of eclipse of each orbit is shortening from a maximum of 32 minutes during the second year of mission to an expected value of zero during the ninth year of mission The daylight portion of each orbit is lengthening during this same period. The change is a continuous one and has caused the following problems:

1)Temperature of the batteries is increasing. (FIG 14)

2)Duration of battery discharge is decreasing.

3)Rate of discharge at deepest discharge is too high

4)Duration of trickle charge to the batteries is too long.

5)Cell imbalances increasing.

6)Life of the batteries is decreasing.

BATTERY MODELS FOR PREDICTING BATTERY LIFE

Three battery models for life prediction have been considered: McDermott model, Lander model, JPL failure model[ref 7]. The temperature predictions for the remainder of the mission are a least squares fit of empirically determined factors that affect battery temperature. These factors in order of there significance are:

1)Ratio of daylight/eclipse

2)Distance of satellite from the sun.

3)Effective solar array surface area.

4)Amount of loading on the satellite

The McDermott and Lander models give similar results for the life of the SME batteries at the predicted battery temperatures (FIG 15).

EFFORTS TO EXTEND BATTERY LIFE

The first two factors are outside of our control. The effective solar array surface can be partially controlled and currently all switchable solar arrays are off and the satellite is torqued to provide the minimum possible effective solar array surface area. The amount and duration of loading is the only variable over which we have direct control at this time.

Currently twice per day at approximately 12 hour intervals all available loads are turned on and the load current is increased to a maximum value for the duration of eclipse (FIG 16,17). This discharges the batteries to within .8 volts of the undervoltage cutoff. During this period we see two ominous signs from the batteries. The first is an increase in the cell imbalance in either of the batteries sometimes to levels in excess of .5 volts. This imbalance has occurred at various times on both of the batteries and either just before or just after the transition from eclipse to daylight (FIG 18,19). This high imbalance does not occur when the voltage is above 25.Ø volts. The second problem is an uneven sharing between battery I and II near the end of discharge period below 25 volts the current from battery I increase with a corresponding decrease from battery two (FIG 2Ø,21). This uneven sharing has been a feature of the batteries since the second year of mission.

SUMMARY

The temperature of the SME batteries will be increasing over the next 5 years. This will degrade the performance of the batteries and shorten their life. The life of the batteries may be extended beyond the predicts if they can be conditioned sufficiently and if the shortened eclipse puts increasingly less demand on the them.

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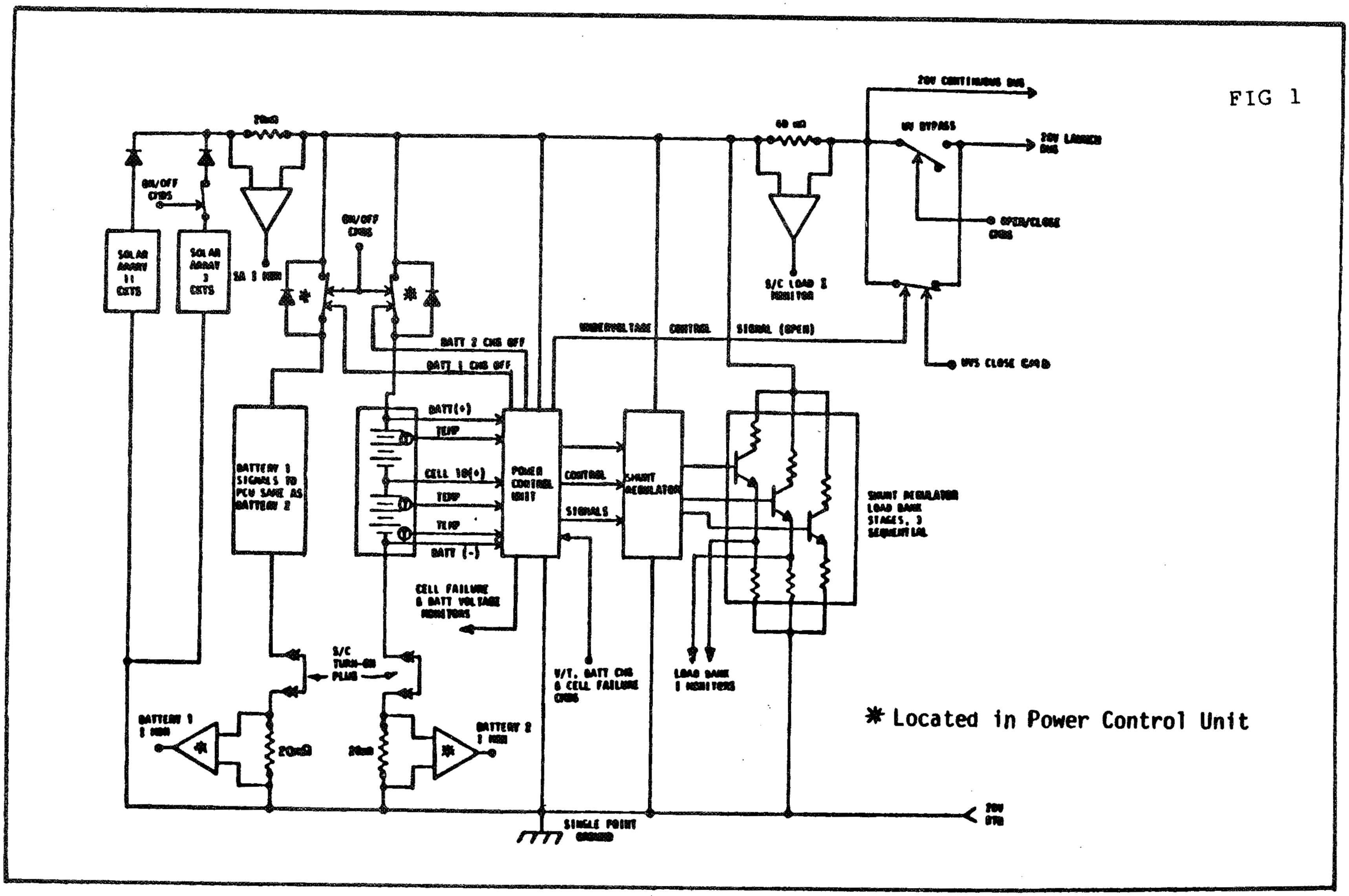


Figure 1. EPS Functional (Simplified)

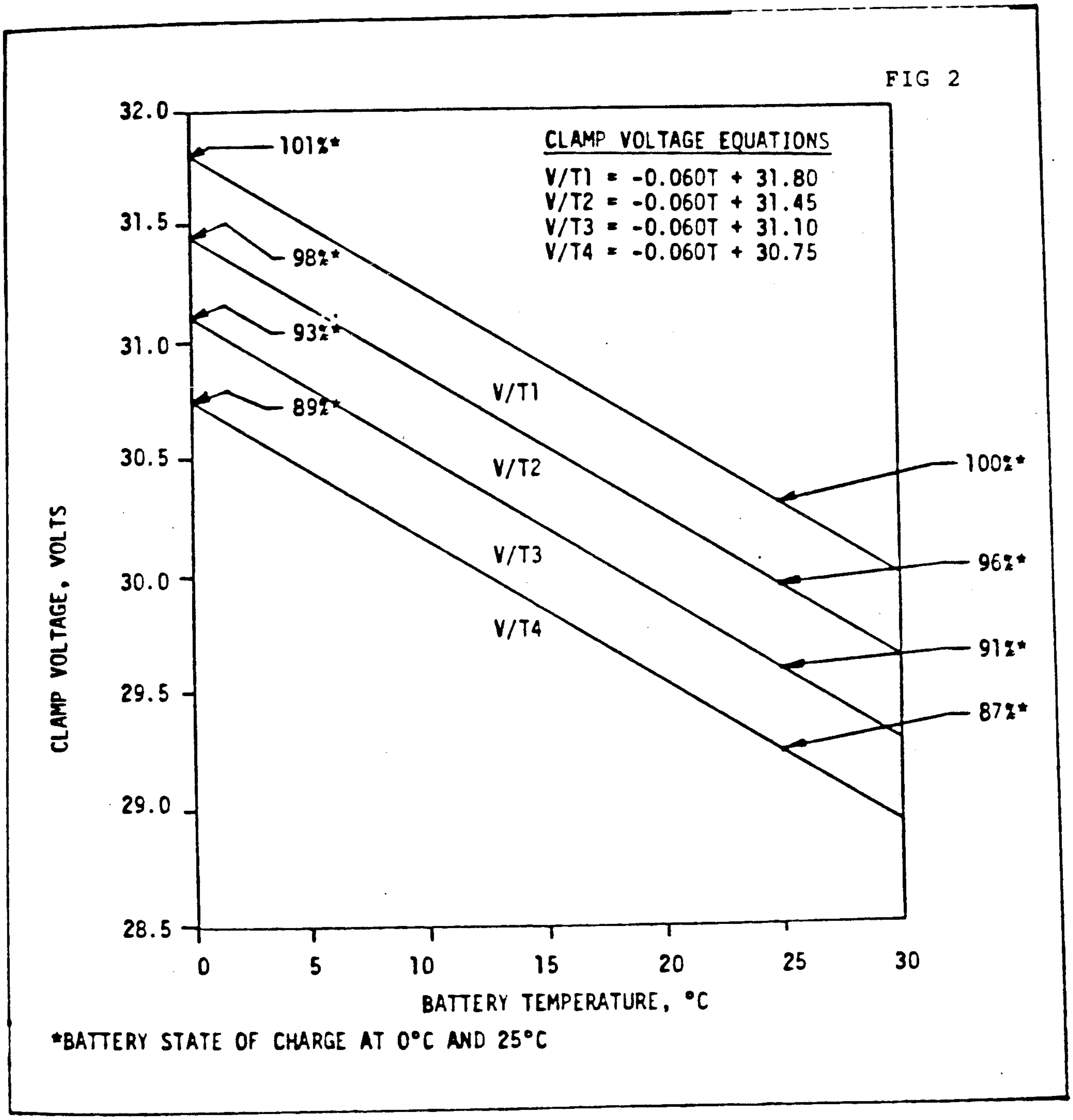
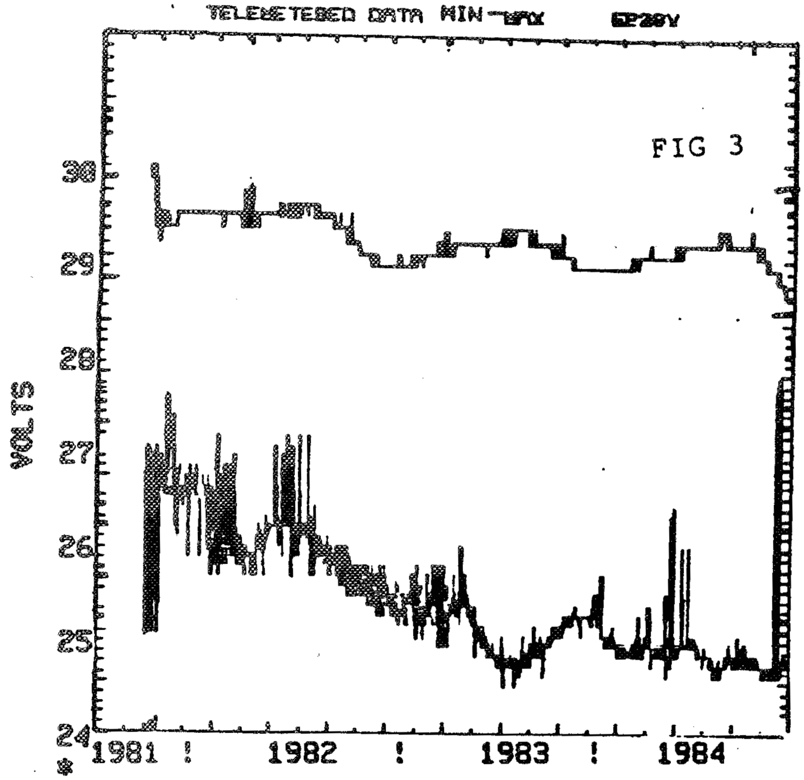


Figure 2. SME Voltage-Temperature Control Levels



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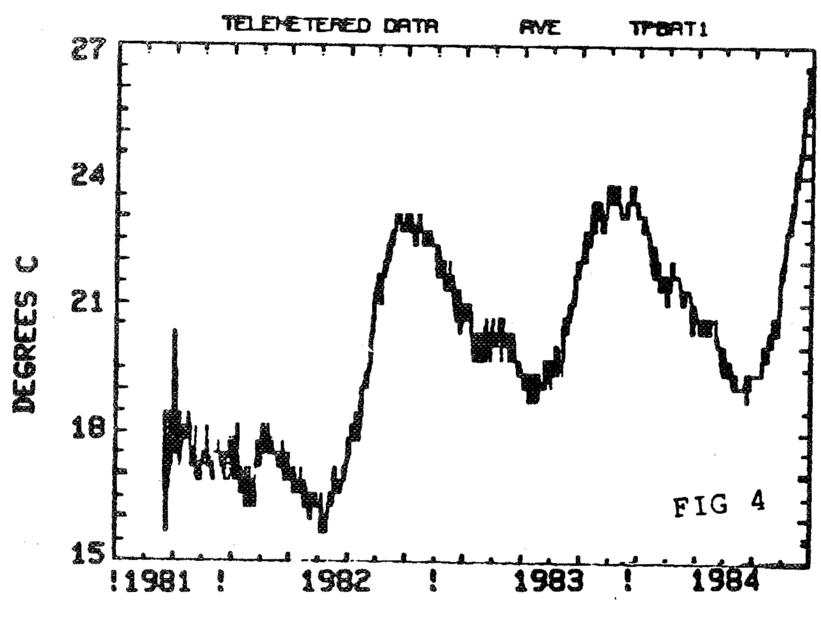

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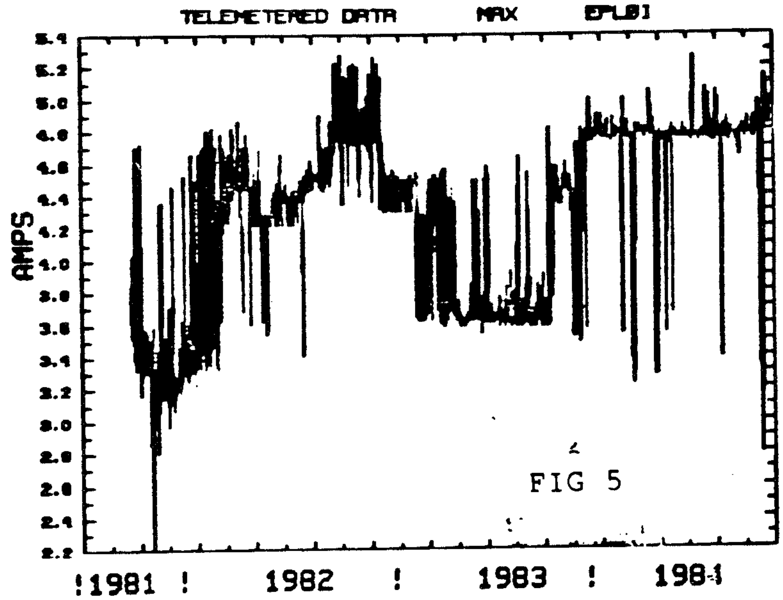

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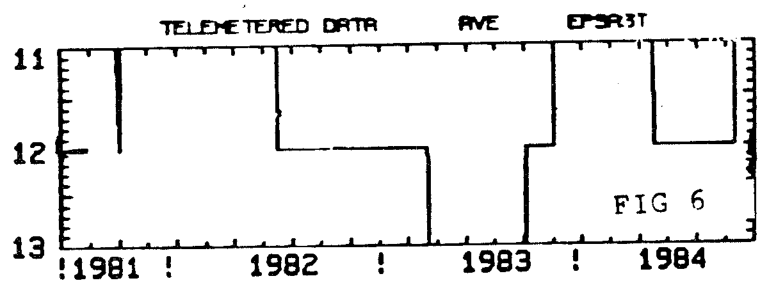

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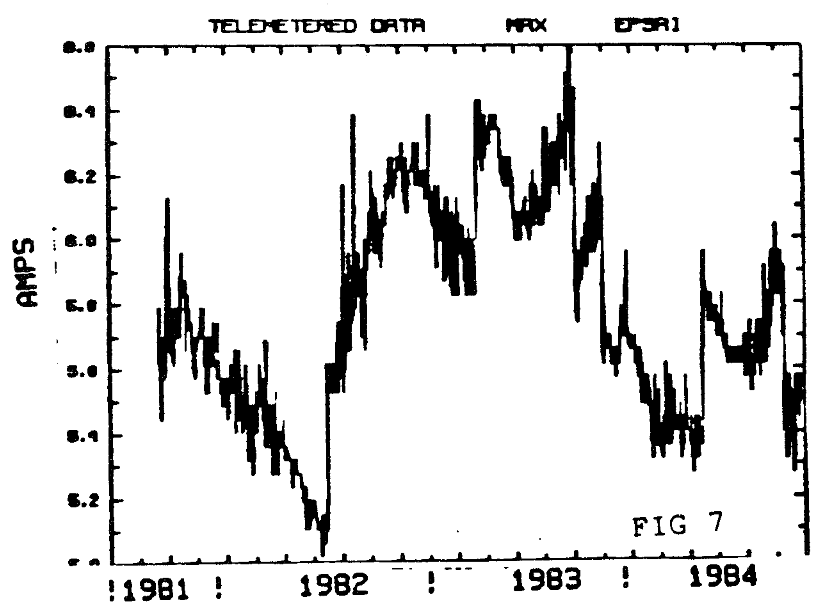

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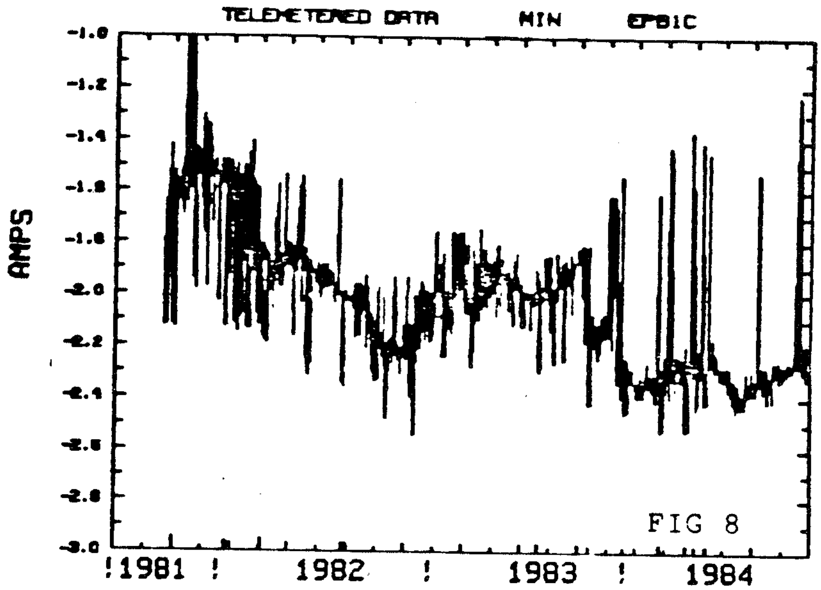

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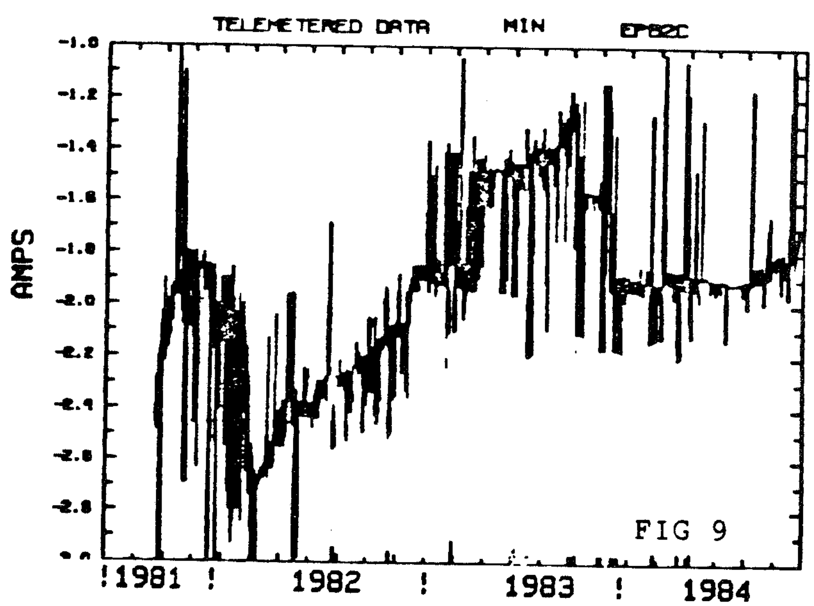

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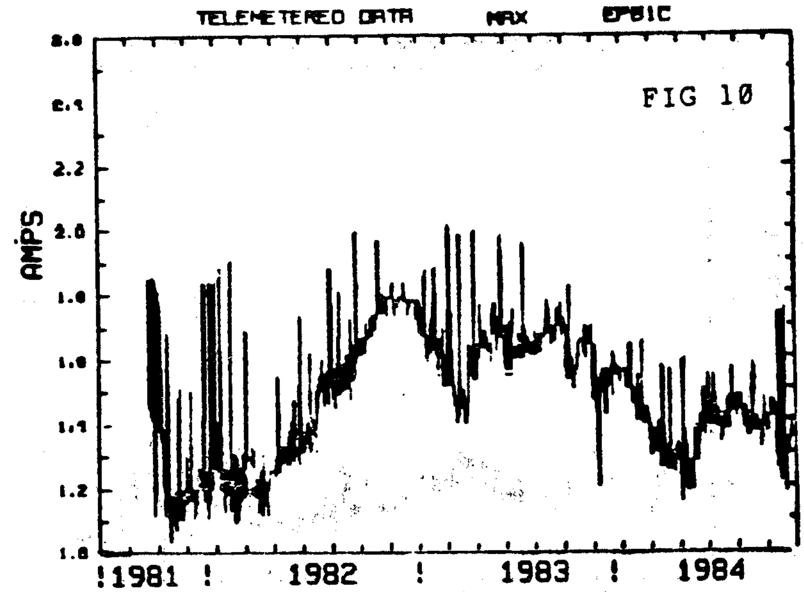

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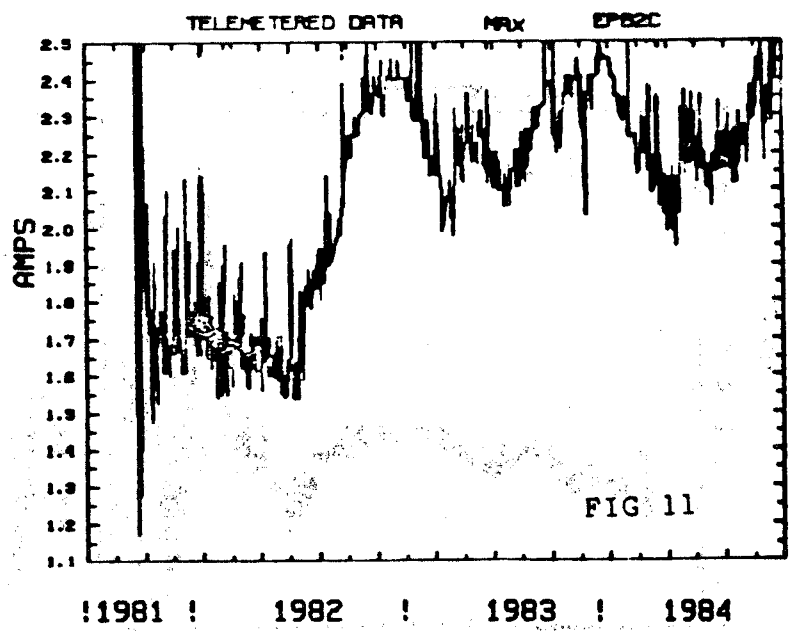

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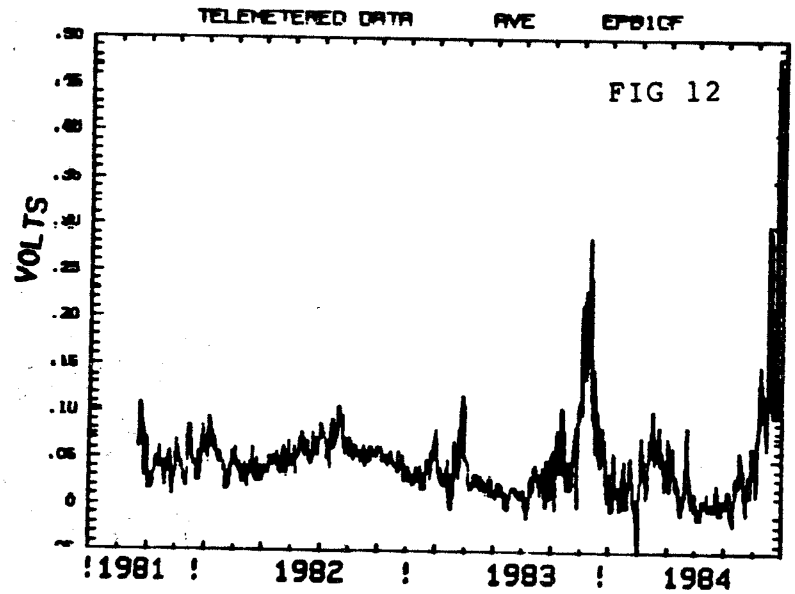

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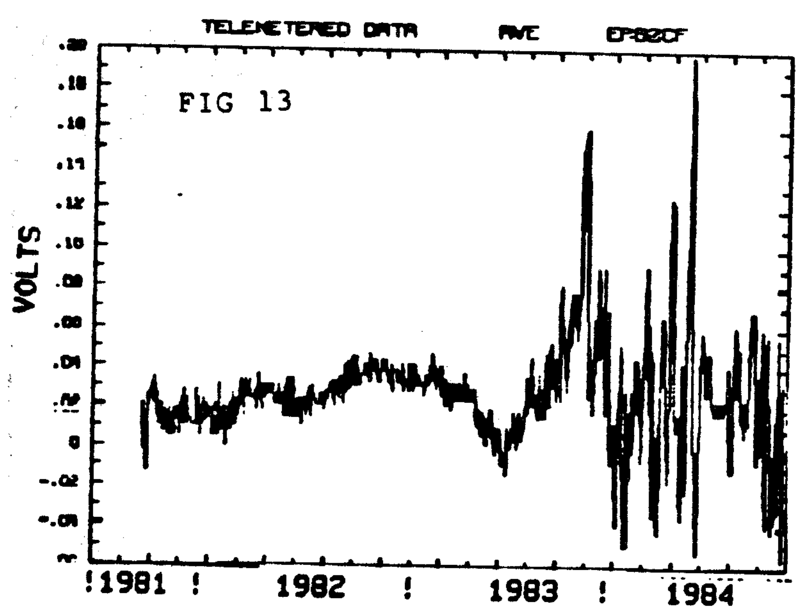

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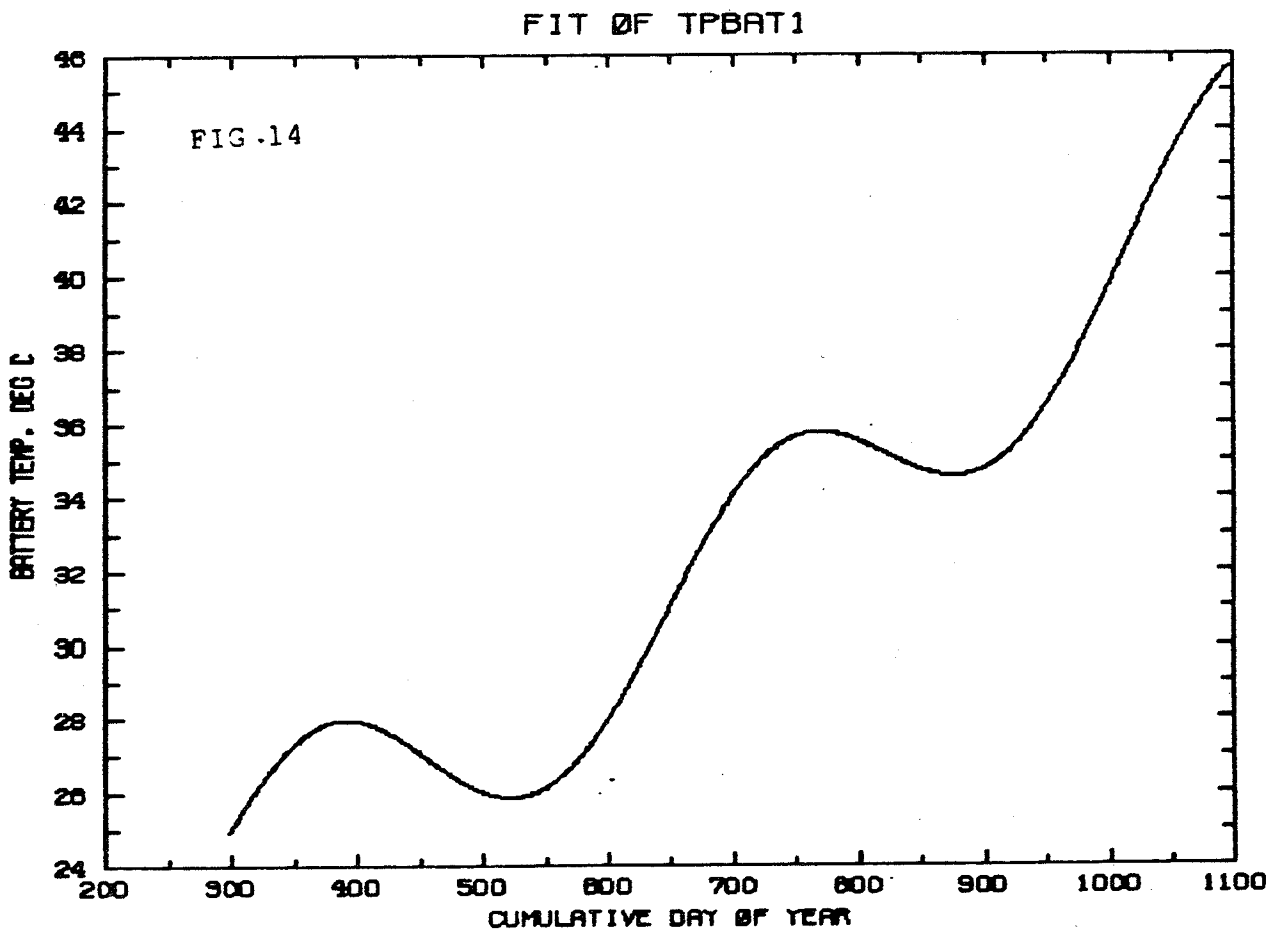

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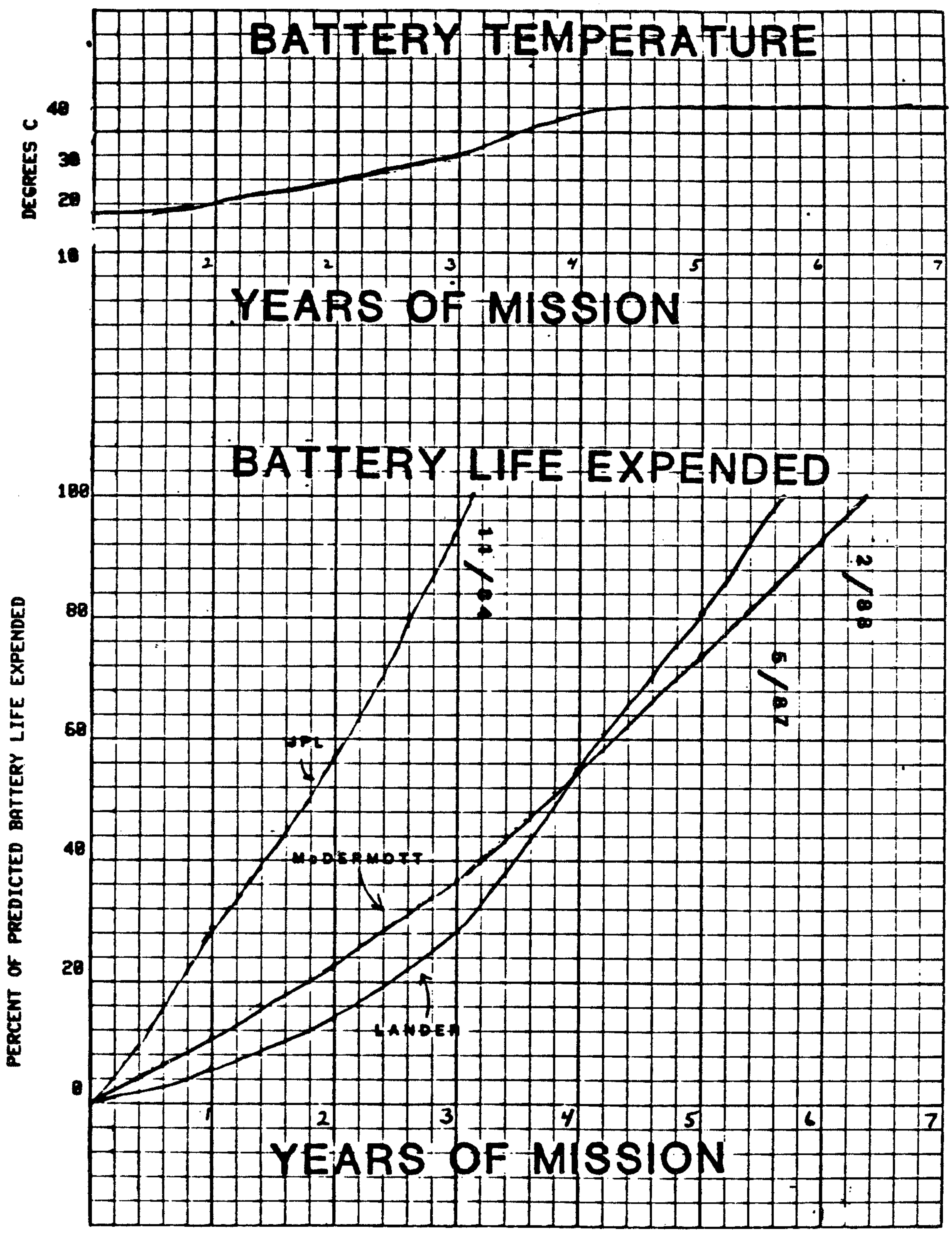
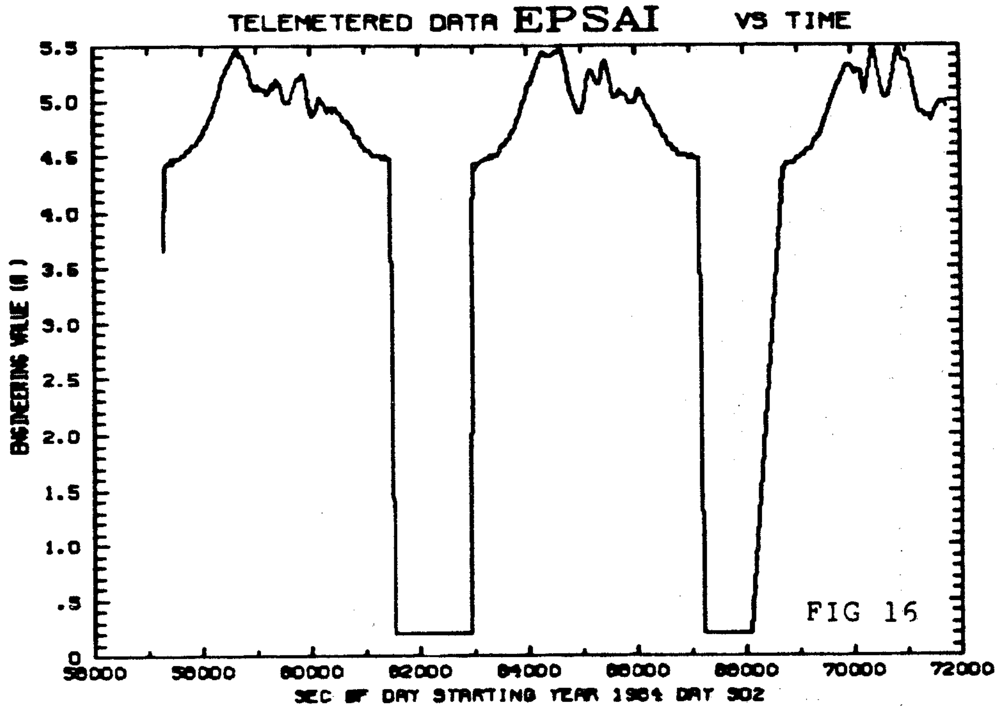
Figure 14.



BATTERY TEMPERATURE
DEGREES C
40
30
20
10
YEARS OF MISSION
BATTERY LIFE EXPENDED
PERCENT OF PREDICTED BATTERY LIFE EXPENDED
100
80
60
40
20
0
11/84
2/88
6/87
JPL
McDERMOTT
LANDER
1
2
3
4
5
6
7
YEARS OF MISSION

Figure 15.



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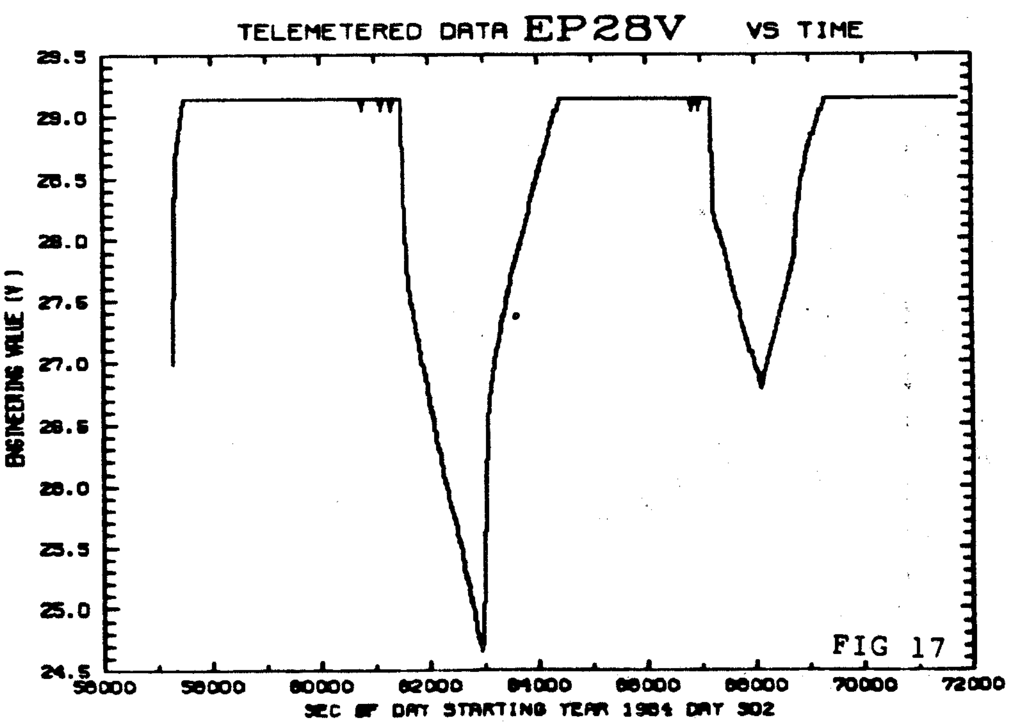

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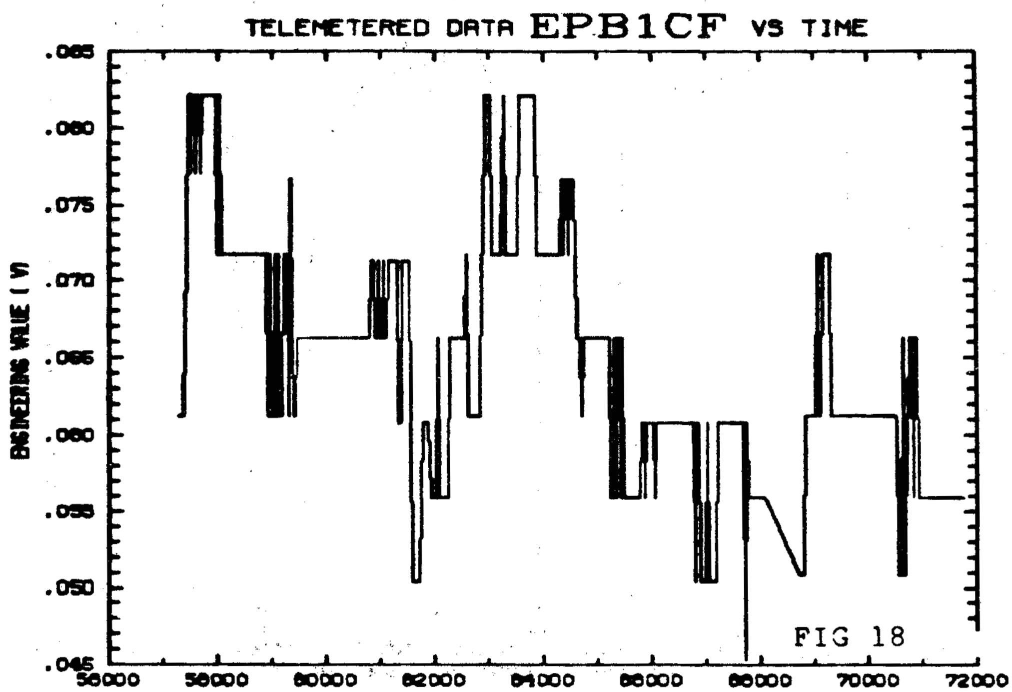

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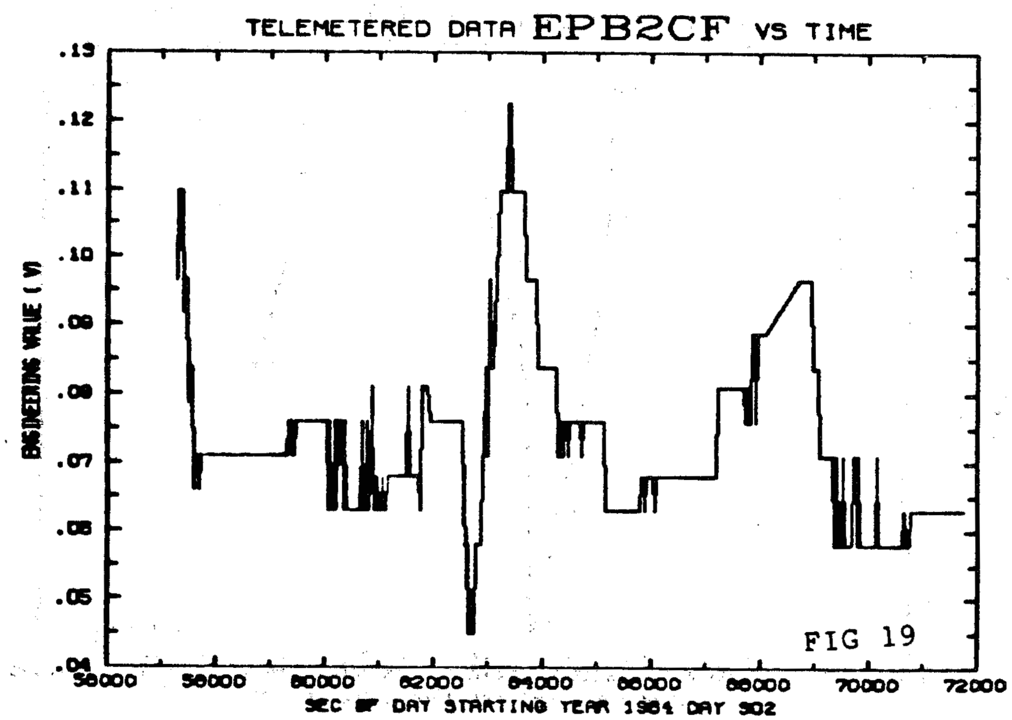

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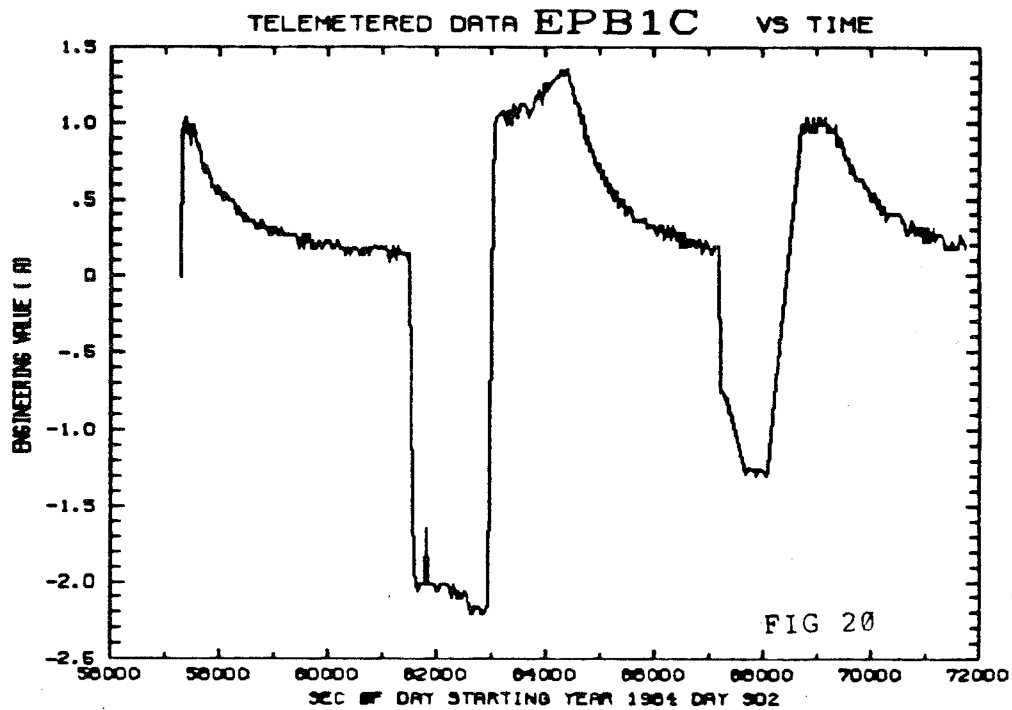

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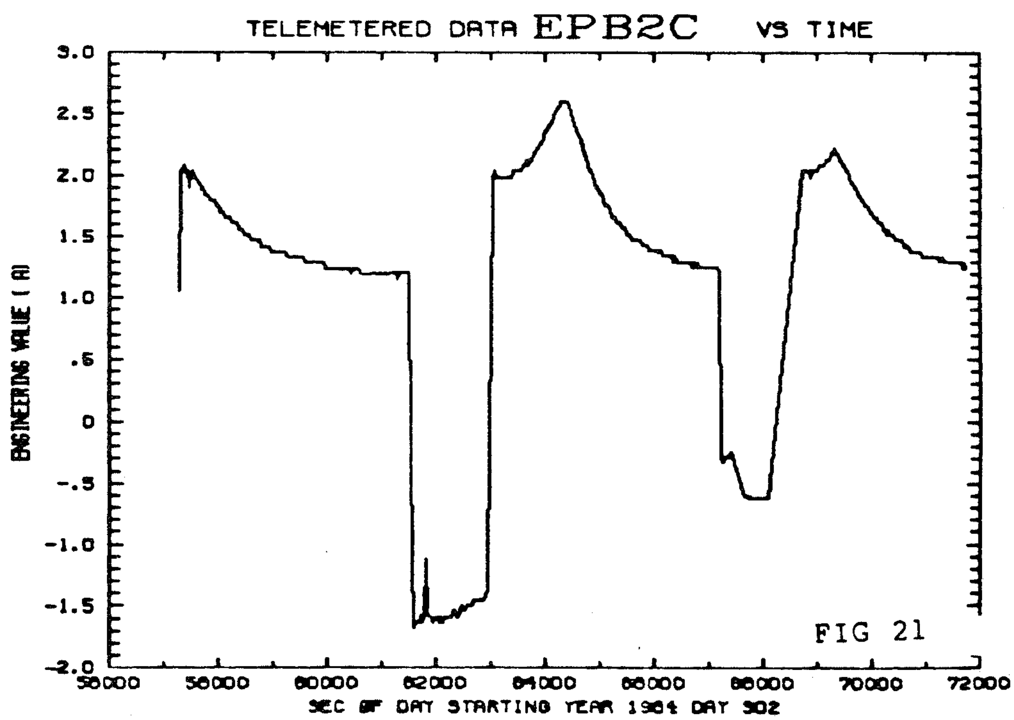

Figure 21.