S-7-44

The INTELSAT Experience with Reconditioning of NiH_2 Batteries

Frank Scalici, Andrew Dunnet, and Daphne Xu
International Telecommunications Satellite Organization
Washington, D.C.

INTRODUCTION

INTELSAT has been reconditioning NiH_2 batteries since 1983 when the INTELSAT V F-6 geosynchronous communications satellite was launched. This was the first commercial use of NiH_2 batteries. INTELSAT has continued this practice on all 46 NiH_2 batteries it has operated in-orbit. The batteries are of several types including the classic INTELSAT cell, the HAC re-circulating design, and the Gates Mantech design.

Reconditioning is performed twice each year, prior to the Eclipse Season. At this time Water Migration problems, if present, are dealt with. Temperature limits are imposed for the discharge and charge cycles as a safety precaution.

In support of in-orbit operations, it is INTELSAT's practice to perform ground based life tests. In-orbit data and ground tests results are presented and the benefits of reconditioning noted.

PROCESS

Prior to each eclipse season the Power subsystem is configured such that half the batteries aboard can maintain the satellite in an emergency while the remainder are placed on the reconditioning load until a preset cell voltage limit is met or, in cases where cell voltage telemetry is unavailable, until a battery voltage limit is met. Where available, automated systems calculate amp hours removed by comparing battery voltage and the size of the load and then integrating over the period of the discharge. On the INTELSAT K and INTELSAT VI, the average voltage over time is used to integrate the amp hours removed. All other series use the average voltage method as a backup to the automated processes. The batteries are then recharged to a pre-determined Charge/Discharge (C/D) ratio. When these batteries have completed the cycle, the remaining batteries are then started.

The C/D is intentionally set 5% less than would be used for a typical eclipse recharge in keeping with INTELSAT policy of avoiding overcharge whenever possible. The schedule allows a sufficient amount of time spent at trickle charge to return to a full state of charge prior to the first eclipse. In addition to voltage limits, temperature limits are set to ensure safety. Table 1 lists the various types of cells used.

REASONS TO RECONDITION

There are several reasons INTELSAT continues to recondition NiH_2 batteries in-orbit and require a reconditioning capability on its future satellites. INTELSAT's position is that reconditioning NiH_2 batteries provides for:

- an assessment of state of health prior to each eclipse season .

- a method for dealing with water migration within NiH_2 cells should it occur.

- an evaluation of pressure increase to establish whether the increase is due to capacity gain or corrosion.

- an enhancement of performance in EODV and cell voltage matching during discharge.

- a correlation between life test data and in-orbit performance.

- a source of flexibility for battery operations.

RESULTS

1. Assessment of State of Health.

A assessment of state of health is derived during the reconditioning by collecting and tabulating various data (see Table 2). The total capacity to the voltage limit, battery EODV, cell EODV, and delta pressure or capacity are analyzed. These data are then compared to previous seasons to identify net changes. Particular attention is paid to the total capacity which should only vary seasonally and cell voltage spread on discharge. Recently, capacity below 1.0 volts to the voltage limit has been characterized to assess whether or not the amount of capacity below 1.0 volts is changing. This is of particular interest on new INTELSAT VII or VIIA batteries which tend to have larger capacities below 1.0 volts when launched then, with cycling, recover useful capacity.

2. Method for Dealing with Water Migration

The use of reconditioning as a method for dealing with water migration was documented in reference 1. Each eclipse season "Frank Plots" are made for the longest eclipse day for each battery in-orbit. Frank Plots show each cells minimum and maximum voltage over 24 hours referenced to the average voltage at either end of discharge or end of charge. These plots are analyzed for changes in cell impedance which is thought to be symptomatic of water migration from the stack. If problematic cells are identified the battery is subjected to the COMSAT/INTELSAT developed procedure to rejuvenate the cell.

As an example (see Figures 1 and 2), the plots for Spring 1996 longest eclipse indicated problematic cells on both INTELSAT V-F6 (506) Battery 1, (Cell 22) and INTELSAT V-F15 (515) Battery 2, (Cells 4 and 26). Both batteries were subjected to the procedure prior to the Fall 1996 eclipse season as part or the normal pre-eclipse reconditioning.

506 Battery 1 Cell 22 EODV increased 0.026 volts with a 0.6 amp greater load and the cell voltage spread (minimum to maximum) decreased from 0.051 volts in Spring to 0.025 volts in Fall. 515 Battery 2 Cell 26 EODV increase 0.063 volts with a 0.6 amp lighter load and the cell voltage spread decreased from 0.102 volts in Spring to 0.045 volts in Fall.

3. Evaluation of Pressure Increase

An accurate measure of pressure increase due to the effects of corrosion can be made by tracking the pressure at the end of reconditioning discharge. This is especially important on the INTELSAT VI which has a dry powder sintered positive and used the alcohol EC impregnation. These positive plates tend to corrode.

A study of INTELSAT VI-F2 in-orbit reconditioning data revealed that BOD pressure increased each season with cycling while EOD pressure remained essentially constant for the first five seasons in orbit. This rise in BOD pressure without a corresponding increase in EOD pressure shows up as increased useful capacity during the reconditioning. Beginning in sixth season the EOD pressure begins to ramp up and becomes the major component of the increase noted in the BOD pressure while a corresponding leveling and gradual decrease in capacity takes place. This increase in EOD pressure can only be excess hydrogen which has been liberated by the consumption of oxygen in the corrosion reaction. The data gained at end of reconditioning discharge is a measure of pressure growth due to corrosion.

4. Enhancement of Performance in EODV

The INTELSAT VI batteries were the first for INTELSAT with a Nickel pre-charge, the INTELSAT V's all having been Hydrogen pre-charged. In 1985 INTELSAT commissioned HAC, the prime contractor on INTELSAT VI program, to perform a series of life tests on flight representative packs of battery cells. Four packs were built up, two were the standard 16 cell design but with Hydrogen pre-charge. The other two packs contained 16 Hydrogen pre-charged cells and two Nickel pre-charged cells which were fitted into the growth area of the pack structure. It should be noted that at this time HAC had not yet made the decision to use Nickel pre-charge cells. The tests subjected one

16 cell pack to real time simulated life test which was terminated after six seasons. The second 16 cell pack was placed in cold storage with capacity checked every six months. The two 18 cell packs were put into a semi-accelerated life test, real time eclipse, with a solstice varied by the time necessary to recondition one of the packs. The eclipse season simulation was a daily 27.4A discharge for periods starting at 15 minutes, increasing to 70 minutes, with a corresponding DOD of 69.2%, and then tapering back to 15 minutes over a 46 day period. The recharge was at the standard C/10 for a return of 110%. Following each eclipse season Pack Q004 was put on trickle charge while Pack Q003 was reconditioned. The reconditioning involved a let-down of the pack using a 20 ohm, 35 watt resistor across the pack terminals until 5 volts was reached. The capacity to 1.0 volts was noted Following the reconditioning, the pack was recharged at 4.8A for 18 hours in an attempt to match the capacity of the two packs, a practice which stopped after Season 13 being replaced by a C/10 recharge to 115%.

Comparison of the data after season 30 shows that the EODV for reconditioned Ni pre-charge cells was 42mV higher than those not reconditioned (see Figure 4), an EODV increase of 1.34 volts on a standard INTELSAT VI 32 cell battery. For the H_2 pre-charge pack the EODV was 21mV higher or 0.67 volts for the standard INTELSAT VI battery. In addition, across the 18 cells in each of the two test packs the EODV spread for reconditioned cells was 26mV at BOL and 24mV at EOL. The spread for non-reconditioned cells was 26mV at BOL and 42mV at EOL. Review of the INTELSAT VI-F2, which has completed 14 seasons in-orbit, shows a cell voltage spread of 25mV on Battery 1 and 26mV on Battery 2. INTELSAT V satellites which have completed more than 22 seasons in-orbit show similar results with a 25mV spread on both batteries.

5. Correlation Between Life Test Data and In-Orbit Performance

All INTELSAT sponsored life testing is run in real time, including solstice. The tests are started several seasons ahead of the first in-orbit use. All operational requirements and environmental elements are simulated as closely as possible.

The INTELSAT VI life test at COMSAT Labs has completed over 20 real-time seasons, while the oldest INTELSAT VI in orbit, 602, has completed 14 seasons. Similar testing at HAC ran for 30 accelerated seasons. Both life tests simultaneously test(ed) identical cells with a Hydrogen and Nickel pre-charge.

The first concern to arise on these cells was a significant pressure increase. The initial assumption was that the batteries were being subjected to an excessive amount of overcharge thus contributing to corrosion of the positives. Examination of the first five reconditioning cycles showed that while the BOD pressure of the cells was increasing the EOD pressure was essentially constant (see Figure 5). Analysis of the reconditioning data showed this to be an increase in useful capacity due to cycling and not a deleterious effect. In season six the capacity peaked and has remained essentially constant on the Hydrogen pre-charge cells and slowly decreased on the Nickel pre-charge cells. A corresponding increase in EOD pressure has occurred over the same period on the Nickel pre-charge cells. The in-orbit data from 602 agrees well with the Nickel pre-charge line (see Figure 6).

When first launched INTELSAT VII/VIIA batteries experienced a capacity fade which showed up as reconditioning capacities that were lower than the battery nameplate. INTELSAT was unsure at this point as to the high rate useful capacity of the batteries. The correlation between reconditioning capacity and high rate capacity is of great importance to the satellite operators but a C/2 discharge capacity measurement to 1.0 volts is not feasible in orbit. In order to resolve this problem the real time life testing, that COMSAT Labs perform for INTELSAT, incorporates a C/2 discharge capacity measurement in each odd eclipse season. As cycling continued the in-orbit capacities increased until the reconditioning capacity exceeded nameplate, as expected, and closely matched the results from the life test. When the in-orbit reconditioning capacities were of the same order as those of the life test battery, the assumption was made that the high rate capacities were also similar.

6. Source of Flexibility

The reconditioning circuitry has proved valuable to satellite operators for purposes other than reconditioning. INTELSAT VII/VIIA has the reconditioning resistors configured as a backup battery heater, a feature which is now in use on one of the batteries.

Another use involved electro-thermal thrusters which run directly from the batteries. The process, which was developed by Lockheed Martin allows the thruster start-up transients to be minimized by offsetting the battery voltages for the first few seconds of the maneuver. This is achieved by charging one battery to elevate the voltage and using the reconditioning load to suppress the voltage of the other battery.

Conclusion

The INTELSAT position on reconditioning of NiH_2 batteries has been stated. It is beneficial to the health and operation of the batteries in-orbit. Further, the availability of the circuitry has proven to be helpful for dealing with anomalous situations.

Reference:

1. "Method for Rejuvenating NiH_2 Battery Cells" by Earl, Burke, and Dunnet, 27th IECEC 1992

Table 1

INTELSAT
NiH_2 Batteries

	INTELSAT V	INTELSAT VI	INTELSAT K	INTELSAT VII	INTELSAT VIIA
Manufacturer	EPI	HAC/EPI	EPI	Gates	Gates
Cell Diameter (cm.)	8.9	8.7	8.9	8.7	11.8
Total Length (cm.)	21.2	28.0	29.1	29.3	20.2
Cell Mass (gm.)	890	1460	1413	1840	2640
Cap (AH) to 1V @ 10 ^{o}C	36	56	55	96	130
Nameplate CAP (AH)	32	44	50	85	120
Stack Design					
Plate Shape	Truncated Disk	Pineapple Slice	Truncated Disk	Pineapple Slice	Pineapple Slice
Configuration	Single Stack	Single Stack	Single Stack	Single Stack	Single Stack
Arrangement	Back-to-Back Pos.	Recirculating	Back-to-Back Pos.	Back-to-Back Pos.	Back-to-Back Pos.
Terminal Design	Ziegler/Axial	Teflon/Axial	Ziegler/Axial	Ceramic/Axial	Ceramic/Rabbit Ear
Positive Electrode					
Plaque	Wet Slurry	Dry Powder	Wet Slurry	Dry Powder	Dry Powder
Impregnation	Aqueous EC	Alcohol EC	Aqueous EC	Aqueous EC	Aqueous EC
Thickness (mm.)	0.775	0.880	0.762	0.920	0.920
No. of Plates	24	40		48	38
Separator	Asbestos	2 Layer Zircar	Asbestos	2 Layer Zircar	2 Layer Zircar
% Electrolyte by wt. dischgd.	38	31	38	31	31
Negative Electrode					
No. of Plates	24	41	40	48	38
Thickness (mm.)	0.137	0.148	0.178	0.116	0.116
Reconditioning					
Began	Fall 1983	Spring 1990	Fall 1992	Spring 1994	Spring 1994
Cell Voltage Limit	1st Cell to 0.9 V	1st Cell to 1.0 V	1st Cell to 0.5 V	1st Cell to 0.5 V	1st Cell to 0.5 V
C/D Ratio	110%	100%	110%	110%	110%
Change	Fall 1987	N/A	Fall 1994	Spring 1996	Spring 1996
Cell/Battery Limit	1st Cell to 0.5 V	N/A	Batt to 25 V (2&4)	N/A	N/A
C/D Ratio	N/A	N/A	N/A	105%	105%

TABLE 2
BATTERY RECONDITIONING
CAPACITY AND MINIMUM VOLTAGE
INTELSAT V F-6 (506)

BATTERY 1										BATTERY 2								
RECONDITIONING			ETT	TOTAL	BATT	CELL	CELL	S/G		RECONDITIONING			ETT	TOTAL	BATT	CELL	CELL	S/G
SEASON	HRS	MINS	A*H	A*H	EODV	EODV	#	CAP		SEASON	HRS	MINS	A*H	A*H	EODV	EODV	#	CAP
F83	52	30		35.70	25.40	0.896	27			F83	56	8		38.1	25.0	0.901	5	
S84	32	54	16.00	36.30*	26.80	0.896	27			S84	52	5		35.4	27.2	0.895	5	
F84	48	17	8.10	40.00	26.40	0.889	6			F84	55	30		37.7	27.8	0.895	5	
S85	52	38		35.80	30.00	0.896	27	41.6		S85	55	20		37.6	34.0	0.895	5	48.6
F85	56	32		38.40	27.00	0.896	6	44.3		F85	55	12		37.5	30.8	0.895	5	48.5
S86	49	27		33.70	31.80	0.889	27	39.9		S86	55	46		37.9	29.2	0.895	1	47.6
F86	57	5		38.80	26.60	0.180	27	42.1		F86	55	17		37.6	28.6	0.220	5	48.6
S87	51	51		35.30	30.00	0.230	27	37.4		S87	46	55	7.3	38.3	27.8	0.260	5	39.2
F87	55	20		37.60	28.40	0.200	27	38.0		F87	54	43		37.2	28.8	0.310	5	38.8
S88	51	40		35.20	30.00	0.240	27	35.6		S88	56	59		38.8	26.2	0.270	5	39.9
F88	54	3		38.80	28.20	0.260	5	41.0		F88	55	37		37.8	26.8	0.230	5	39.0
S89	54	16		36.90	29.80	0.240	27	38.0		S89	54	16		36.9	28.8	0.340	5	38.0
F89	59	0		40.10	27.00	0.380	5	41.0		F89	59	3		40.2	25.6	0.220	13	42.0
S90	56	3		38.10	29.60	0.240	27	41.0		S90	56	42		38.6	29.0	0.410	5	40.0
F90	58	40		39.90	27.40	0.100	27	41.0		F90	52	59		36.0	29.8	0.290	5	37.0
S91	53	38		36.50	29.00	0.230	27	38.0		S91	58	6		39.5	28.2	0.310	5	41.0
F91	60	0		40.80	27.40	0.220	5	44.0		F91	57	20		39.0	28.6	0.290	5	41.0
S92	57	21		39.00	30.00	0.240	27	42.0		S92	58	9		39.6	28.6	0.310	5	41.0
F92	63	27		43.10	28.00	0.240	5	45.0		F92	57	0		38.8	29.4	0.320	5	41.0
S93	57	0		38.80	29.80	0.220	27	41.0		S93	59	26		40.4	27.6	0.360	1	43.0
F93	61	35		41.90	28.00	0.210	5	44.0		F93	60	52		41.4	26.8	0.950	5	43.4
S94	55	58		38.00	30.00	0.090	27	41.0		S94	59	43		40.6	28.4	0.350	5	42.5
F94	61	54		42.10	29.00	0.140	27	43.6		F94	58	9		39.5	29.2	0.490	5	41.5
S95	56	55		38.70	30.20	0.200	27	41.6		S95	59	21		40.4	28.2	0.490	5	42.5
F95	61	0		41.50	29.00	0.000	27	42.1		F95	61	55		42.1	26.2	0.460	5	43.5
S96	57	19		39.00	30.20	0.220	27	42.3		S96	59	24		40.4	29.6	0.320	5	40.4
F96	61	0		41.50	32.30	0.000	27	40.3		F96	62	57		42.8	25.9	0.170	5	43.6

Figure 1

506 Battery 1
Spring 1996 vs Fall 1996
Spring Load =12.4 Fall Load =13.02

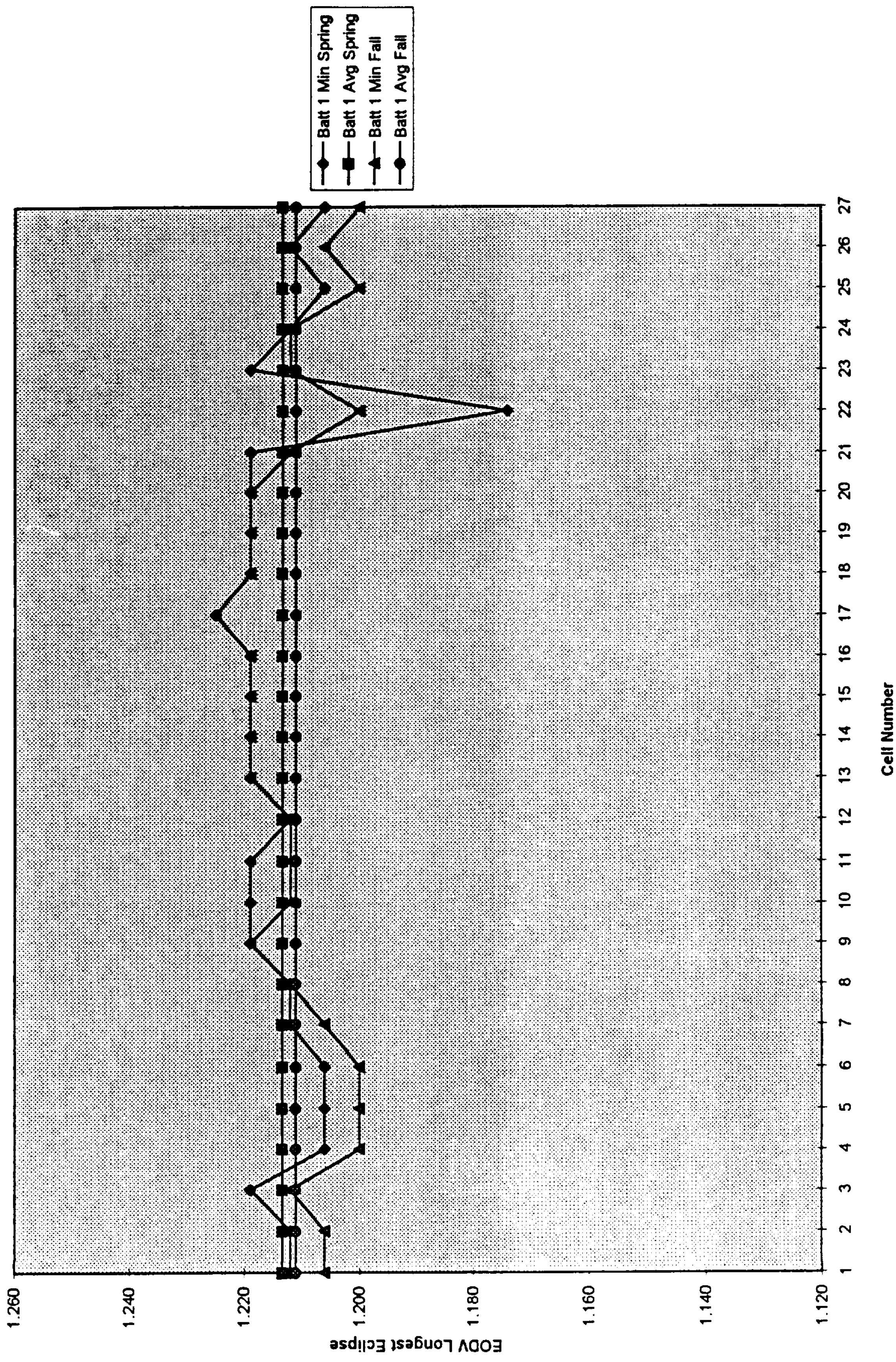

Figure 2

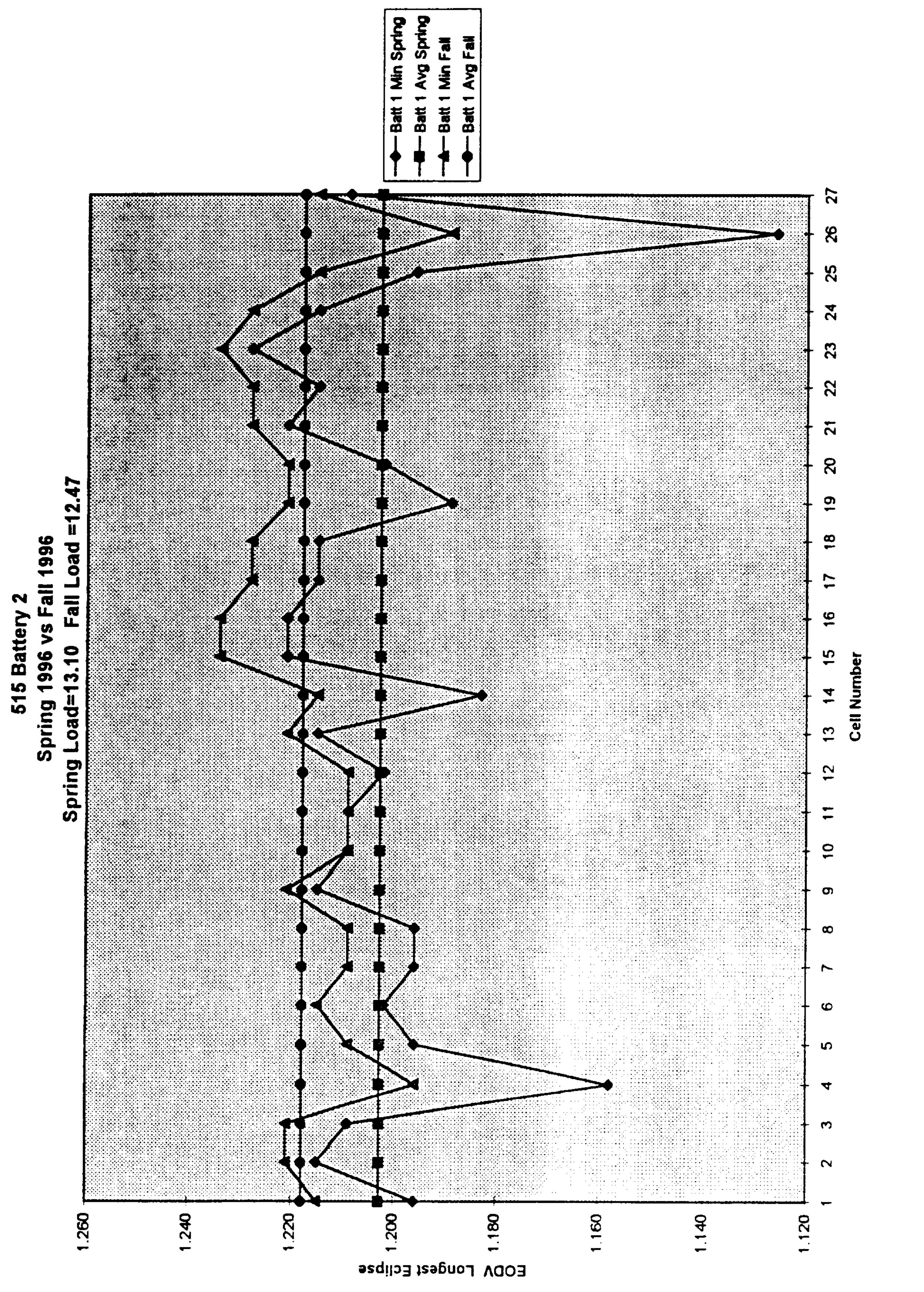
515 Battery 2
Spring 1996 vs Fall 1996
Spring Load=13.10 Fall Load =12.47
EODV Longest Eclipse
Cell Number
Batt 1 Min Spring
Batt 1 Avg Spring
Batt 1 Min Fall
Batt 1 Avg Fall

Figure 3

INTELSAT VI-F2
Battery Pressure Deltas

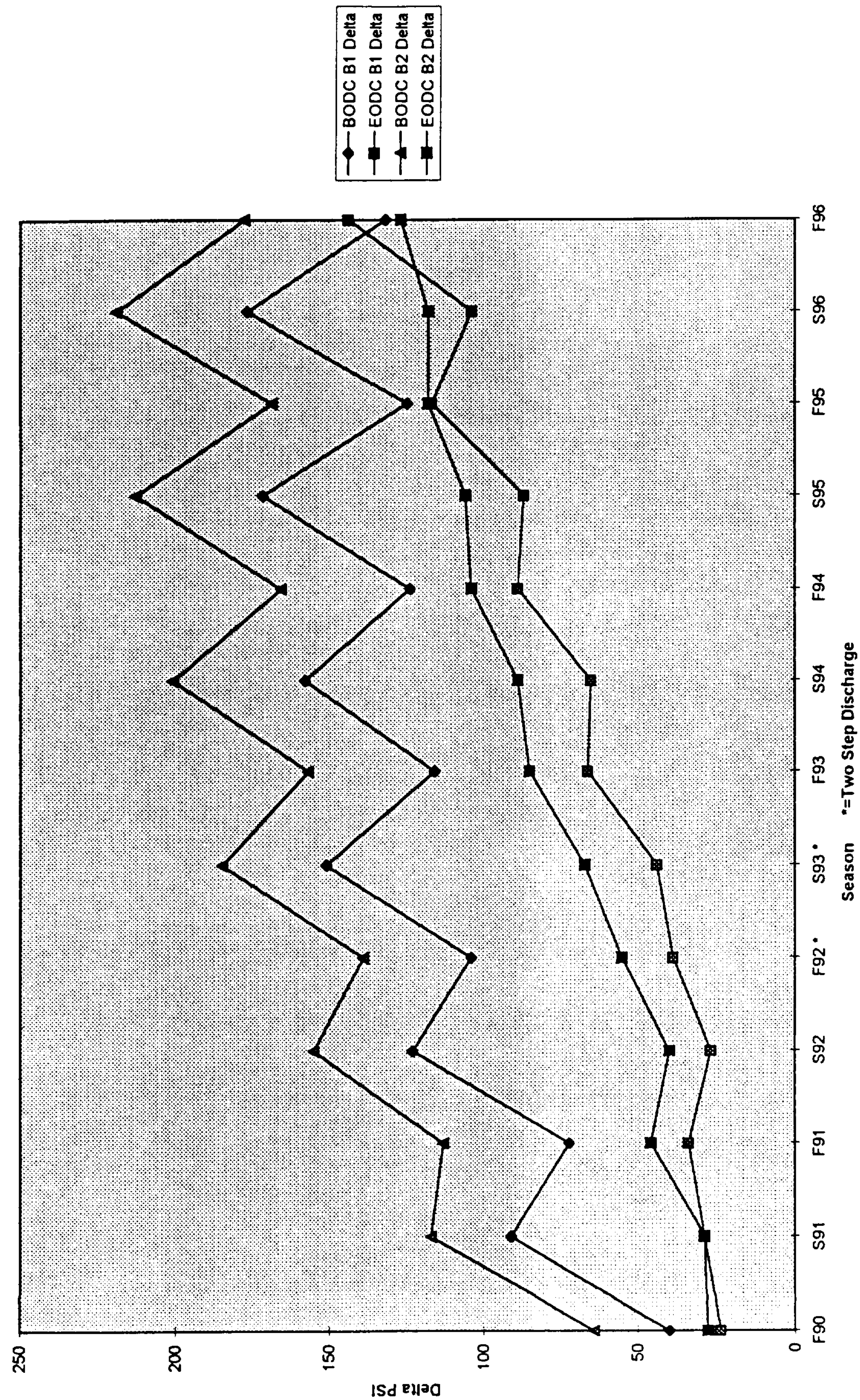

Figure 4

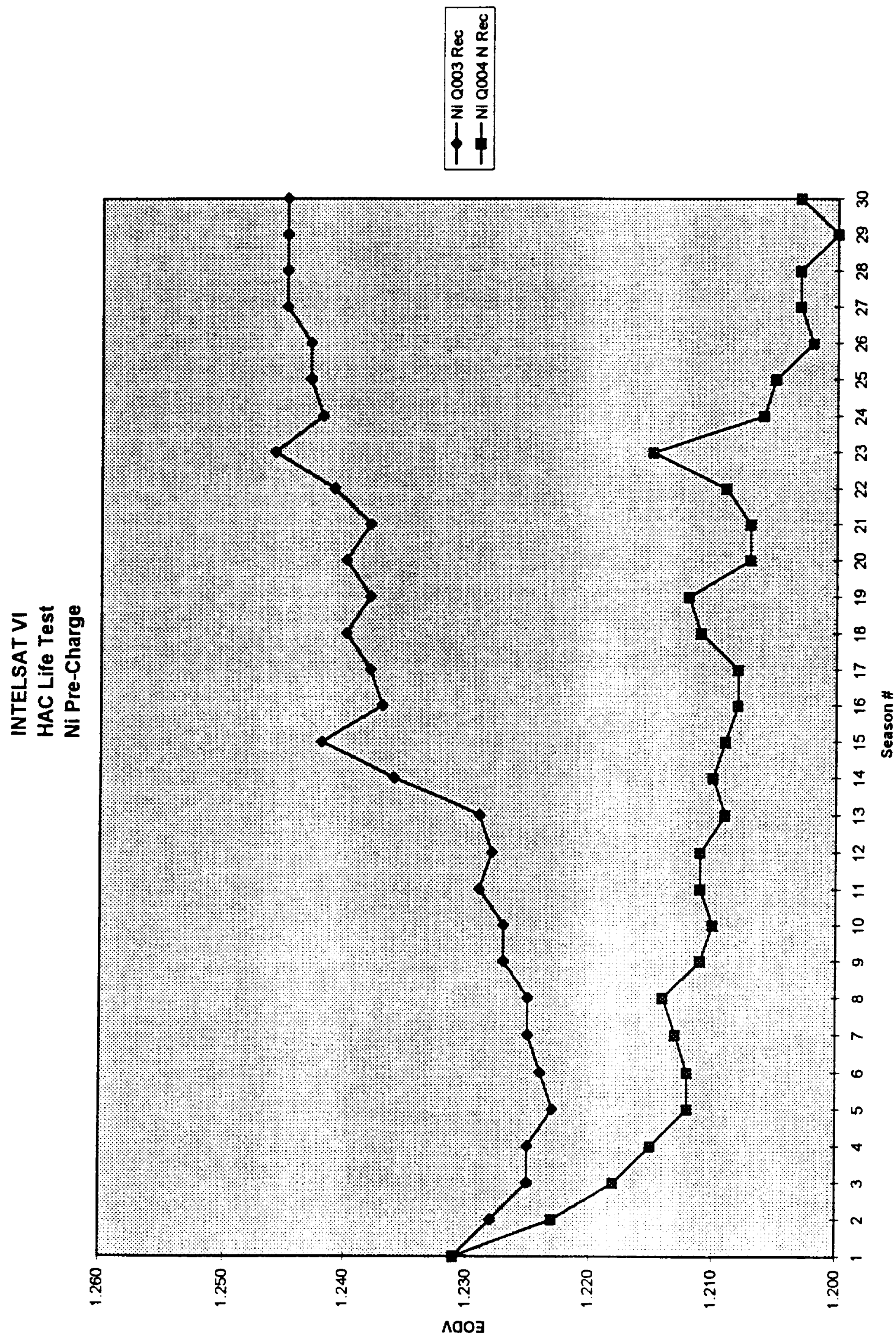
INTELSAT VI
HAC Life Test
Ni Pre-Charge
Ni Q003 Rec
Ni Q004 N Rec
EODV
Season #
1.260
1.250
1.240
1.230
1.220
1.210
1.200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Figure 5

INTELSAT VI Life Test

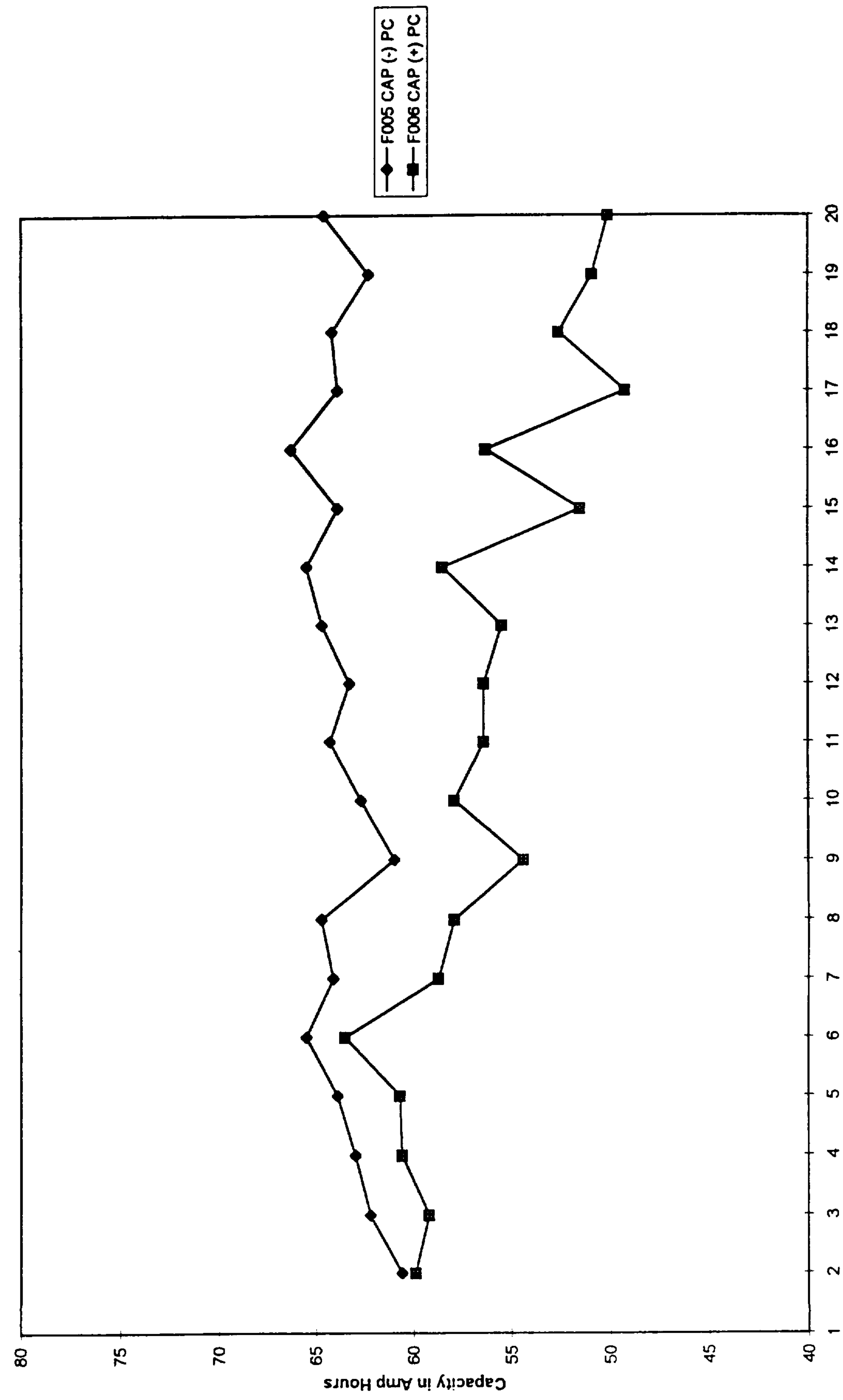

Figure 6

INTELSAT VI Life Test
vs
INTELSAT VI-F2 (602)