In-orbit Earth Radiation Budget Satellite (ERBS) Battery Switch

Anisa Ahmad
Marlon Enciso
Gopalakrishna Rao
Code 563, Power Systems Branch
Electrical Systems Center
Applied Engineering and Technology Directorate
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

ERBS Spacecraft

- Launched October 5, 1984
  - 610 km circular orbit, 57 degrees inclination
  - 3 instruments:
    - Earth Radiation Budget Experiment (ERBE) Scanner, ERBE Non-Scanner, Stratospheric Aerosol Gas Experiment (SAGE) II
  - ERBE Scanner failed in 1990
  - ERBE Non-Scanner & SAGE II collecting 99 % data
- SAGE II - provides long term global trending of ozone, aerosol, water vapor and nitrogen dioxide
- Spacecraft is needed to be in operation until launch of SAGE III + ~ 6 months

ERBS Power System & Battery History

- Peak Power Tracker Standard Power Regulator Unit (SPRU)
- Launched with Two 22-cell 50 Ah NiCd Batteries (GE/GAB)
- Battery Charging using VT Mode & Constant Current Mode
  - VT 6, avg. C/D = ~1.16, avg. T = 10 C, avg. DOD= 9% (max=14%)
- Half Battery differential voltage (Cell Balance) began to diverge in 9/89 (Bat 1 increased to 200 mV & Bat 2 to over 450 mV by 7/90)
- Battery load sharing divergence
  - VT Level for both batteries reduced from VT 6 to VT 5 in 1/92
  - VT Level for both batteries reduced from VT 5 to VT 4 in 7/92

ERBS Battery Cell Failures

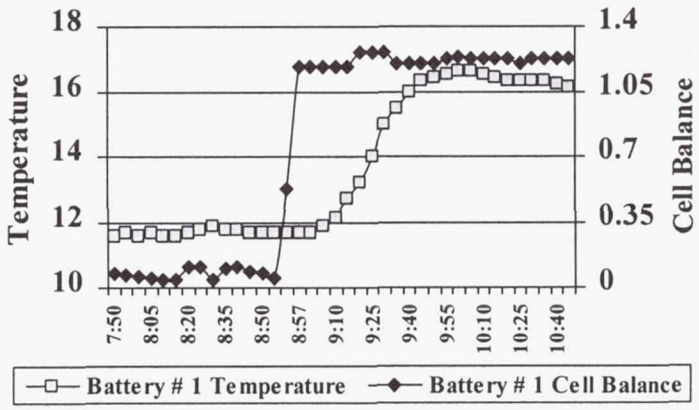
- Aug. 1992, cell short on Battery # 1
  - Cell Balance increased from 90 mV to 1.2 V
  - Temperature Rise greater than 5 degrees C
  - VT reduced from VT 4 to VT 3
- Sept. 1992, 2nd Cell shorted on Battery # 1
  - Cell Balance increased from 1.2 to 2.5 V (Max. possible Cell Balance in telemetry)
  - Temperature Rise greater than 5 degrees C
- October 1992 Battery # 1 taken off-line
- Battery # 2 supporting all loads

ERBS Battery Cell Failures (Continued)

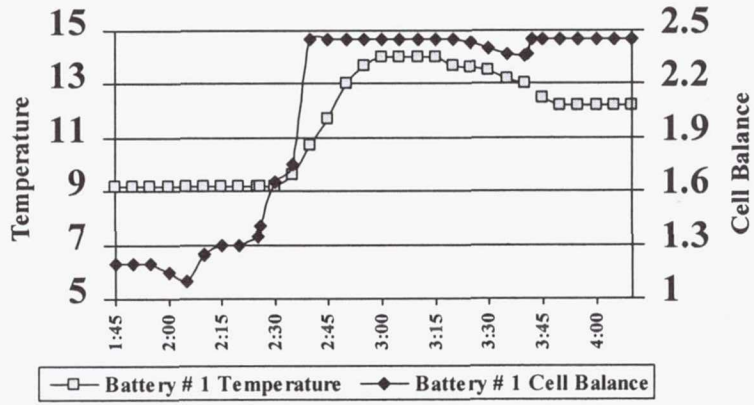
- June 1993, cell short on Battery # 2
  - Cell Balance increased from 50 mV to 1.28 V
  - Temperature Rise greater than 5 degrees C
- July 1993, 2nd Cell shorted on Battery # 2
  - Cell Balance increased from 1.25 to 2.5 V
  - Temperature Rise greater than 5 degrees C
- Battery # 1 & Battery # 2 both have 20 cells
  - Attempts made to bring Battery # 1 back on-line 8/93
  - Unsuccessful due to poor load sharing - Battery # 2 was healthier of two batteries
- Battery # 2 (20 cells) continued to support all loads

ERBS Battery # 1 & # 2 Cell Failures

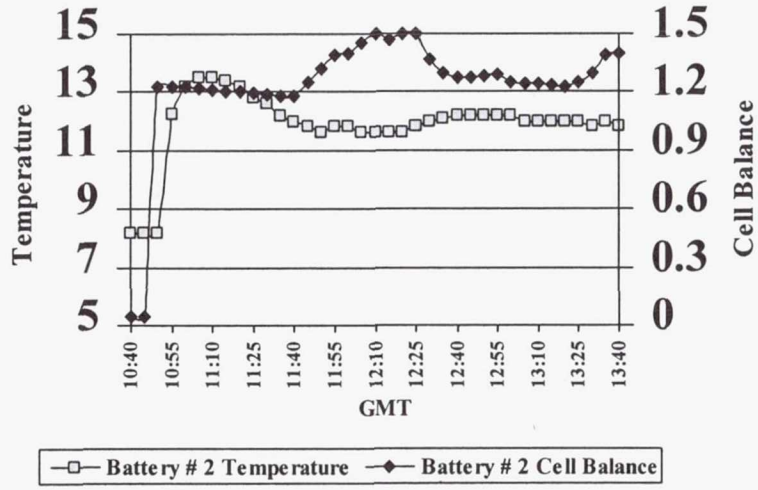
Battery # 1 Cell Failure # 1 (8/7/92)



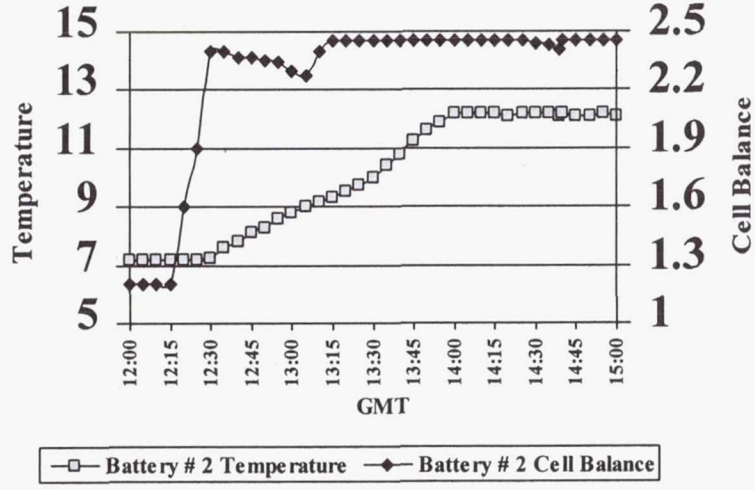
Battery # 1 Cell Failure # 2 (9/4/92)



Battery # 2 Cell Failure # 1 (6/21/93)



Battery # 2 Cell Failure # 2 (7/22/93)



20-Cell ERBS Battery # 2 Operation

- Manual battery charging by uplinked commands switching between three Constant Current Modes (CCM)
  - VT charge mode cannot be used
  - Charged at beginning & end of orbit day at 2.74 Amps
  - Middle of orbit day charged at 11.4 Amps
  - 5 Amp discharge rate used during full sun periods & during less than 7% DOD orbital nights to minimize battery overcharge
  - CCM changed every orbit to maintain C/D of ~1.1& End of Night (EON) cell V > 24 V
  - C/D Ratio lowered to 1.02 by 3/94 to further minimize overcharge
  - Battery Temp: 3 - 5 degrees C, DOD: 7 - 14 %
  - 11.4 A rate varied from 0 to ~ 40 min.
  - Battery discharge period varies from 0 - 55 min due to orbit inclination and fixed solar array

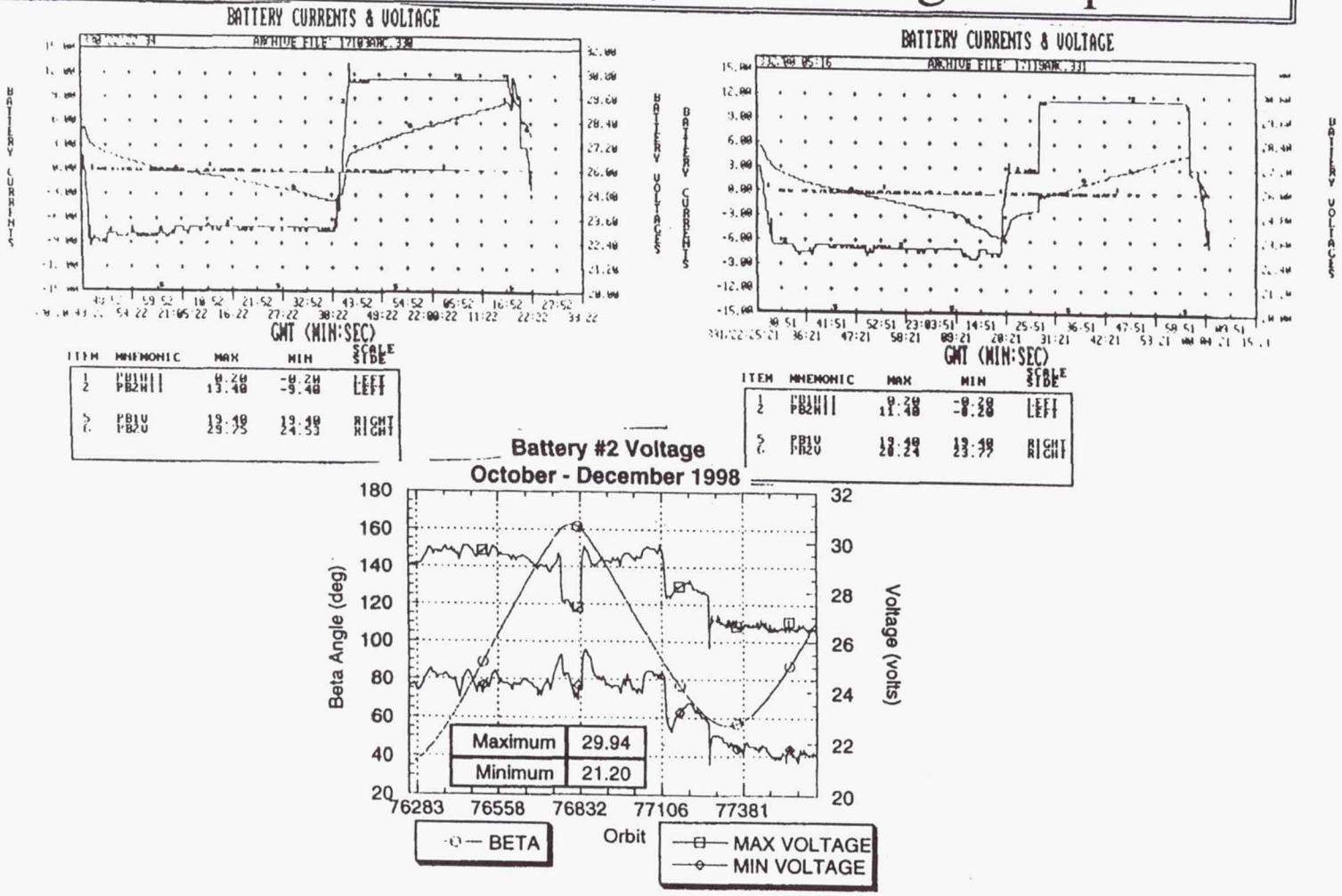
ERBS Spacecraft Failures

- 5 of 6 Gyros failed
- ERBE scanner instrument failed on 2/90
- Command Memory # 1 & # 2 subject to random Bit Flips since launch
- Command Memory # 2 failed on 10/93
- Digital telemetry Unit # 1 failed on 4/98

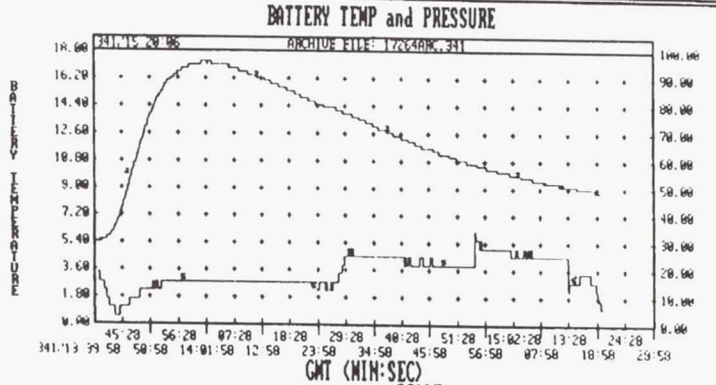
Battery # 2 Additional Cell Failures

- 6/98 Cell balance began to dip from the maximum telemetry value of 2.5 to 2.0 V at EON
- 7/27/98 ERBS completed 5 years of operation on a single 20-cell battery.
- 10/98 EON V decreased below 24 V.
- 11/98 EON V decreased further by 1 Volt (23.1 V).
  - Only a 0.9 degrees C temperature rise seen over the entire orbit.
  - No Cell Balance change observed
- 12/7/98 EON V reached 21.68 V and a 5 degree temperature rise. Additional Cell failure.

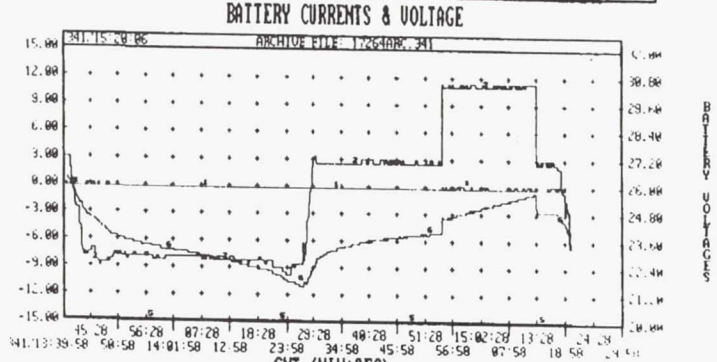
10/98 - 11/98 Battery # 2 Voltage Drop



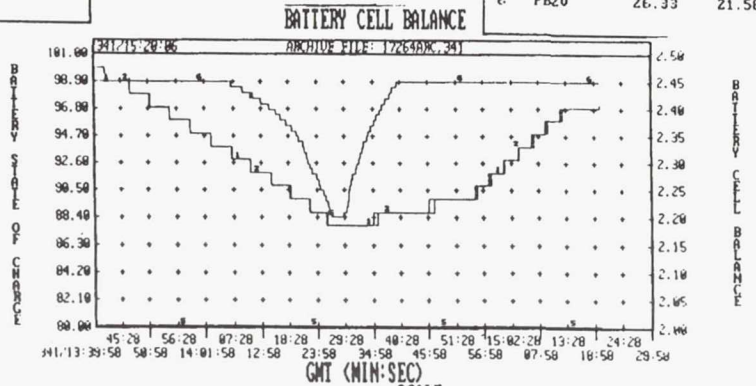
12/98 Battery # 2 Cell Failure



ITEM	MNEMONIC	MAX	MIN	SCALE SIDE
2	PB2TP	17.39	5.42	LEFT
5	PB2P	34.54	3.14	RIGHT



ITEM	MNEMONIC	MAX	MIN	SCALE SIDE
1	PB1H|||	0.20	-0.20	LEFT
2	PB2H|||	11.40	-9.80	LEFT
5	PB1V	19.40	19.40	RIGHT
6	PB2V	26.33	21.58	RIGHT

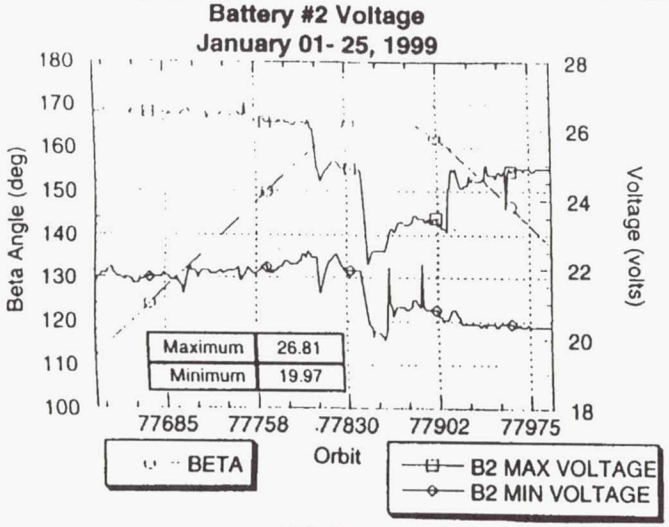


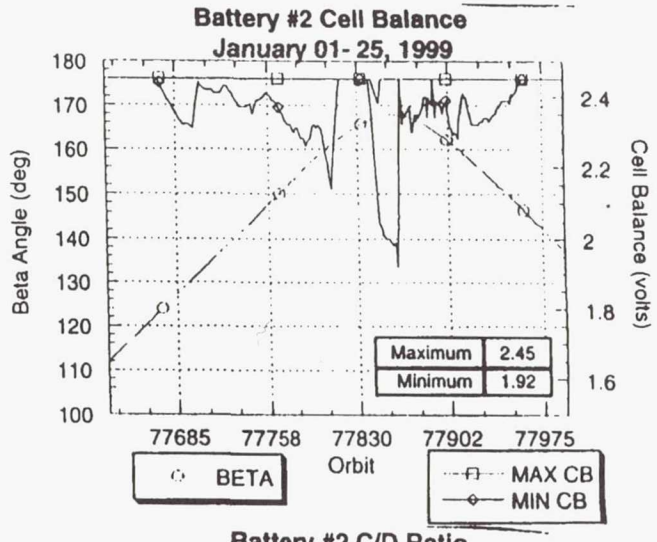
ITEM	MNEMONIC	MAX	MIN	SCALE SIDE
1	PA1SOC	100.00	87.81	LEFT
2	PA2SOC	100.00	87.81	LEFT
5	PB1CB	1.88	1.87	RIGHT
6	PB2CB	2.45	2.20	RIGHT

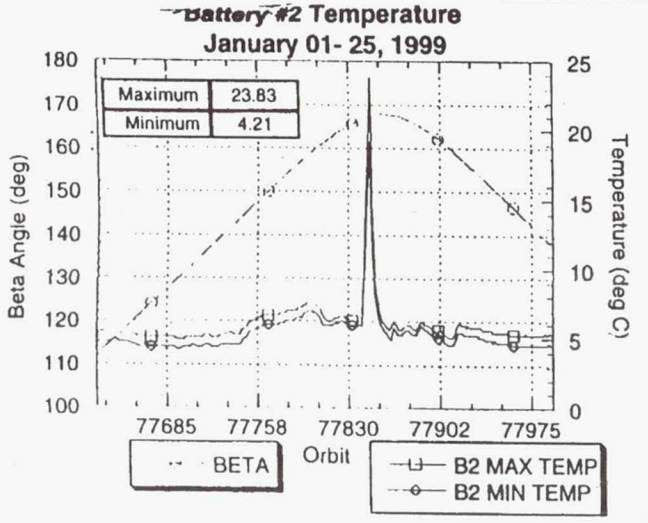
Battery # 2 Additional Cell Failures (Continued)

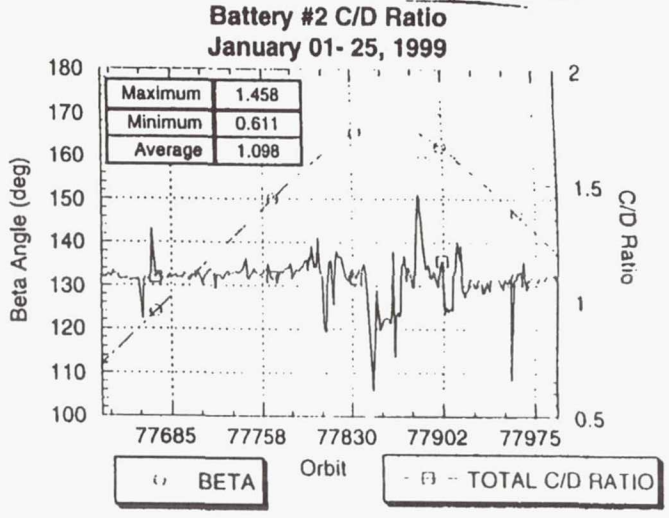
- Battery # 2 @ 18 - 19 cells (?)
  - YAW Maneuver accomplished on 12/25/98
- January 15, 1999 Battery # 2 lost another cell and EON V dropped to 20.4 V with a simultaneous temperature rise of ~ 20 degrees C
  - Battery # 2 @ 17 - 18 cells (?)
- Attitude Control System and Transponder are unreliable at V < 20 V
- Battery charging unstable. Battery going to VT charge control mode instead of 5 A discharge mode (default charge mode)
- Battery Voltage reached 19.67 V
- Spacecraft went into a B-dot mode where the spacecraft tumbled twice per orbit.
- Spacecraft attitude system stabilized, battery charging stabilized and battery EON V reached 20.4 V

1/99 Battery # 2 Cell Failure









Battery Operations Dilemma

- Predicted Battery # 2 Voltage < 20 V at upcoming (2/3/99) Yaw maneuver
- Battery # 1 has been open circuit for > 5 years. The Voltage via telemetry is at the low rail of 19.4 Volts. Battery # 1 has 20 out of 22 cells (last time it was on-line)
- Risk of bringing Battery # 1 on-line:
  - Battery # 2 being drained to charge Battery # 1 (Voltage going below min. safety V)
  - Relay concern: Being vaporized, or arcing
  - Poor sharing of batteries under parallel configuration (Battery # 1 stuck on-line)

Battery Management Decision

- Bring Battery # 1 on-line on January 26, 1999
- Attempt two-Battery Operation
- Take Battery # 2 off-line if Battery #1 alone could support the spacecraft load

Bringing Battery # 1 On-Line

- Brought Battery # 1 online during the orbital day so voltage doesn't drop below 20 V.
- Goal - Keep Battery # 2 adequately charged while charging up Battery # 1.
  - Orbit # 1 - Battery # 1 relay connected - Voltage immediately rose from 19.4 to 22.44 V and Bat # 1 began charging.
  - Orbit # 2 - Charge Bat # 1 @ 3 A for 5 Min (Bat # 2 off-line)
  - Orbit # 3 - Charge Bat # 1 @ 3 A for 16 min (Bat # 2 off-line) Discharge Bat # 1 for 4 min (Bat # 2 off-line)
  - Orbit # 4- Charge Bat # 1 @ 11 A for 15 min (Bat # 2 off-line) Discharge Bat # 1 for 15 min (Bat # 2 off-line) at beg. of night
  - Continue charging scenario by increasing Battery # 1 charge time and discharge time with Battery # 2 off-line

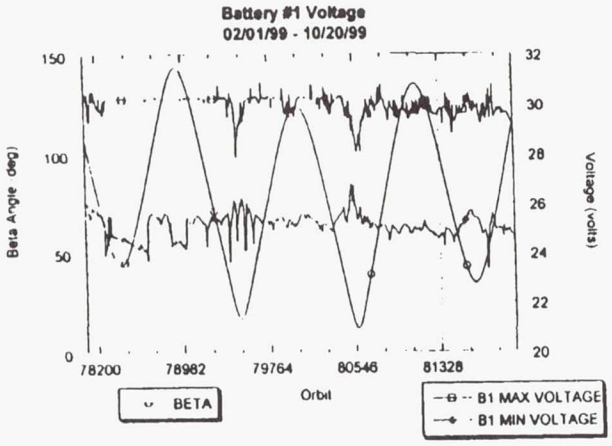
Stabilization of Battery # 1

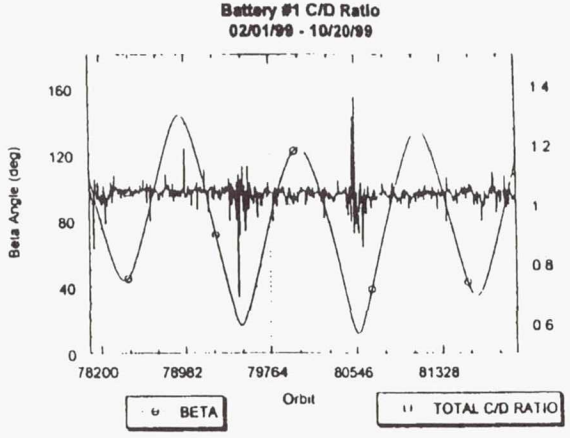
- As Battery # 1 got fully charged - Battery # 2 did not discharge during eclipse & Battery # 1 discharged during orbital day to charge Battery # 2
  - Battery # 2 was over charging
- Battery # 2 was disabled 32 hours after bringing Battery # 1 on-line
- Spacecraft Voltage reached: 25.95 - 29.57 V
  - Prior to 1/26/99: 20.35 - 24.72 V
- Battery # 1 Charged at NASA VT 1 (1.5 V/cell @ 5 C) for 3 orbits to ascertain fully charged battery
  - Battery Current & Temperature closely monitored to minimize overcharge

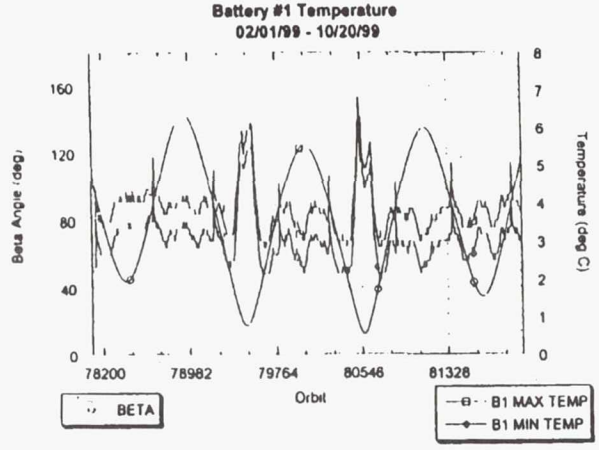
Present Battery Operations and Performance

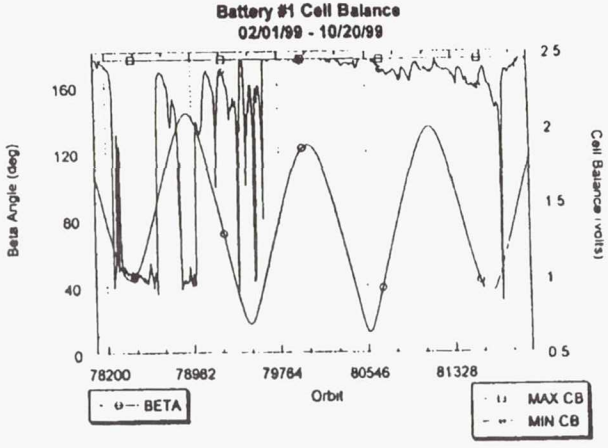
- Battery charged by a power command load uplinked at least twice per day (default VT mode overridden)
- 3 CCM rates being used to charge battery (Same as for Battery # 2, before being taken off-line)
- Battery # 1 C/D Ratio being maintained at ~ 1.05
- Battery # 1 Voltage: 23.58 - 30.8 V
- Cell Balance:
  - 2.45 for first month after Battery # 1 brought online
  - 0.89 - 2.45 V from 2/99 - 5/99
  - Since 5/99, 2.13 - 2.45 V
- Temperature: 1.97 - 6.84 degrees C
  - Higher temperature at Beta 0 (Full Sun)

Present Battery Operations









Summary

- Battery # 1 adequately supporting load
- Cell Balance divergence needs to be monitored
- Power System closely monitored
- New Power Command Loads must be uplinked every 22 hrs
  - Concern in case of ground power failure or loose commanding with spacecraft (Leonids Meteor storm, Y2K)
- SAGE III scheduled for launch in April 2000
- > 15 YEARS SUCCESSFUL LEO OPERATION SUPPORTING SPACECRAFT LOAD
- FIRST EVER KNOWN ON-BOARD "STORED" BATTERY (even with two failed cells) BROUGHT INTO OPERATION

Acknowledgments

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