GEOSYNCHRONOUS PERFORMANCE OF A LITHIUM-TITANIUM DISULFIDE BATTERY

Burton Otzinger
Rockwell International

ABSTRACT

An ambient temperature rechargeable Lithium-Titanium disulfide ($Li-TiS_2$) five cell battery has completed the first orbital year of accelerated synchronous orbit testing. A novel charge/discharge, state-of-charge (SOC) control scheme is utilized, together with taper current charge backup to overcome deleterious effects associated with high end-of-charge and low end-of-discharge voltages. The results indicate that ten orbital years of simulated synchronous operation may be achieved. Preliminary findings associated with cell matching and battery performance are identified.

INTRODUCTION

Ambient temperature rechargeable lithium cells hold promise as advanced energy sources for future space application. The $Li-TiS_2$ couple, with nonaqueous electrolyte, is the best known ambient temperature system. A battery of this type is of interest due to its expected high energy density (greater than 100 Wh/Kg) and long life (greater than 10 years). However, $Li-TiS_2$ cell research and technology are in an early development stage with only hand or custom made cells available.

An accelerated synchronous orbit life test of a five cell, $Li-TiS_2$ battery was initiated using advanced JPL designed and fabricated cells and a novel Rockwell charge/discharge, SOC-control method. This first test in the industry of these advanced rechargeable Lithium cells as a battery was initiated to obtain the following results:

1. Determine if the battery performance goal of ten orbital years of synchronous operation, established by NASA (RTOP), can be achieved, on an accelerated life test basis.

2. Gain an early look at battery related problems that arise in the selection and performance of cells to assist JPL in their cell development program.

3. Evaluate the capability of the Rockwell SOC-control method to extend the cycle life of a $Li-TiS_2$ battery.

This paper summarizes the results of the first orbital year of accelerated life testing.

METHOD OF INVESTIGATION

In a paper presented last year (Ref. 1), it was concluded that the rechargeable Lithium battery had good potential for synchronous satellite application. It was decided to explore this potential further by conducting an accelerated synchronous orbit life test on a 5 cell Li-TiS_2 battery. The Li-TiS_2 cells were fabricated at JPL and the cell design details are described in Table I.

The synchronous orbit life test was accelerated by reducing each solstice period between eclipse seasons to two weeks. The battery was charged after the last eclipse of each season and placed on open circuit stand during the two week period. Charged open circuit status was selected since this condition should result in minimum battery degradation during stand periods. The battery was also given a "top-off" charge at the end of the two week period to restore any stand losses. All charges were conducted within the selected SOC-control cut-off and rate limits.

A simulated 46 day eclipse season was used in this synchronous orbit life test and was conducted on a real time basis. The simulated eclipse period values are shown in Table II. The diagram in Figure I shows the test parameters and typical performance of the battery during a maximum eclipse day. All discharges were started at 9:00 A.M. and all charges started at 2:00 P.M. to make it possible to observe critical test events during normal work-day hours. The battery was allowed to stand open circuit after charge until the next morning to maintain the 24 hour real-time test basis.

The charge duration values shown in Table II and Figure I are approximate values since the charge was terminated based on the return of 100% of the capacity (Ah) removed during the prior discharge. This charge termination function was accomplished by the (Ah) integration and comparison capability of the test control computer. The discharge rate of 150 mA was selected to provide a maximum DOD (72 minutes) of 45% based on the 0.4 Ah rated battery capacity. Prior cell characterization testing indicated that extensive cycle capability could be expected at 45% DOD. The extended test time should expose any time dependant as well as cycling failure mechanisms.

The control of charge/discharge SOC was set to operate the battery between 90% and 45% SOC during the maximum (72 minutes) eclipse period. During other eclipse periods the recharge returned the SOC to approximately 90% in each case. This SOC positioning was accomplished prior to the first eclipse season by a discharge to 45% SOC from full charge and subsequent recharge to 90% SOC with a return of 45% of rated capacity. The charge voltage at 90% SOC is approximately 2.53 volts per cell and should remain constant with successive cycles until degradation of capacity exceeds 45% of rated. After capacity degradation in excess of 45%, the charge voltage during maximum eclipse must increase to allow the SOC to increase above 90% and eventually to full charge at 2.64 volts per cell. Degradation beyond 55% of rated capacity will cause battery failure/test termination at maximum DOD. The charge supply is set to provide a constant charge rate of 77.5 mA until a constant/clamp voltage of 2.64 volts per cell is reached with subsequent current taper. The constant voltage/taper charge feature is a back-up to prevent an excessive charge voltage across the cells. Charge to 2.64 volts/cell has been shown to result in full charge of the battery.

RESULTS

Two important variables used to evaluate battery performance during a synchronous cycle life test are the end-of-discharge voltage (EODV) and end-of-charge voltage (EOCV). The end-of-discharge voltage versus eclipse cycle is shown in Figure 2 for the first two eclipse seasons or first orbital year of operation. The ordinate in Figure 2 is provided with an equivalent average cell voltage scale to make it convenient to visualize the battery voltage value in terms of cell voltage. It can be seen in Figure 2 that, battery operation is well above an average of 2 volts per cell. The eclipse durations during the first eclipse season did not conform with the Table II values for all cycles due to computer program errors. Direct comparison of season 1 and 2 EODV is therefore not possible for cycles 19, 25 and 26. The Li-TiS_2 couple typically loses capacity and voltage performance during the early cycles of operation. This characteristic is evident in a comparison of season 1 and 2 EODV values from cycle 1 thru 18. After the non-uniform initial cycling losses, the relative performance in cycles 27 thru 46 indicate stable operation at a nearly fixed voltage performance loss. The character of this voltage degradation can be better seen in Figure 3. Note in Figure 3 that the voltage versus time characteristics during cycle 24 for the two seasons run parallel showing a nearly constant polarization factor from season 1 to season 2. It appears that, the polarization factor acts the same as the insertion of a pure resistance would to the discharge characteristic.

The range of EOCV values is shown in the following table:

Season	EOCV Range
1	12.55 to 12.69
2	12.65 to 12.79

The range is actually not as great as indicated due to a computer program deficiency that has been corrected prior to season 3. The EOCV trend has not shown any sign of degradation through the first two eclipse seasons.

The continuing good match of cell characteristics is reflected in the cell EODV and EOCV for cycle 24 of season 2 shown in the following table:

Cell No.	EOCV	EODV
1	2.548	1.994
2	2.557	1.963
3	2.546	1.998
4	2.547	2.010
5	2.550	1.965

The system under-voltage limit for the purposes of the life test is 8 volts. When the battery voltage drops to less than 8 volts (1.6 volts/cell) the test will be terminated. The voltage during season 2, maximum DOD, was about 9.93 volts. The difference (1.93 volts) between 9.93 and 8.00 volts equals the loss margin available prior to test termination. Assuming an average loss in battery voltage at maximum DOD of 0.1 volt per season, there are then approximately 19 seasons remaining. This estimate supports the possibility of demonstrating a ten orbital year (20 season) life.

CONCLUSIONS

The results of this life test support the estimate that ten orbital years of simulated synchronous operation can be achieved by a Li-TiS_2 battery. It was found that cells with capacities within a 6% range provided satisfactory battery operation while a 14% range did not. It was shown that the Li-TiS_2 couple performs well within a battery providing a real 2 volt/cell system under load to 45% DOD.

REFERENCES

1. Otzinger, B.M., Somoano, R.B.: Charge Control Investigation of Rechargeable Lithium Cells. Proceedings of The Goddard Space Flight Center Battery Workshop, November 1983, NASA Conference Publication 2331, pp. 45-63.

2. Yen, S.P.S., Shen, D.H., and Somoano, R.B.: Elastomeric Binders for Electrodes. Electrochem. Soc., Vol. 130, No. 5, May 1983, pp. 1107-1109.

Table I. DESCRIPTION OF JPL Li-TiS_2 CELL

Configuration	Cylindrical - plates spiral wound
Capacity	
Analytical	0.47 Ampere-hours
Rated	0.40 Ampere-hours to 1.7 volts
Voltage	
Open Circuit	2.7 Volts
Load (Ave.)	2.0 Volts at C/3 rate
Number of Plates	2
Plate Area	77.4 square cm
Positive Plate	TiS_2 on Ni Exmet-Elastomeric binder (0.020 in.) (Ref. 2); no conductive diluent
Negative Plate	Li Foil pressed on Ni Exmet (0.012 in.)
Electrolyte	(1.5M) $LiAsF_6$-2Methyl THF
Separator	2 Layers of Celgard 2400
Case Material	Stainless Steel
Size	2.3 cm diameter by 6.4 cm long
Weight	85 Grams

Table II. SIMULATED ECLIPSE SEASON PARAMETERS

ECLIPSE DAY		150 Ma DISCHARGE DURATION (MINUTES)	CHARGE 77.5 Ma CUT-OFF AT (HRS.)	(MIN.)
1	46	12	0	23.2
2	45			
3	44	30	0	58.1
4	43			
5	42			
6	41	45	1	27
7	40			
8	39			
9	38			
10	37	53	1	43
	36			
11	35			
12	34	60	1	56
13	33			
14	32			
15	31			
16	30		2	8
17	29	66		
18	28			
19	27			
20	26			
21	25	72	2	19
22	24			
23				

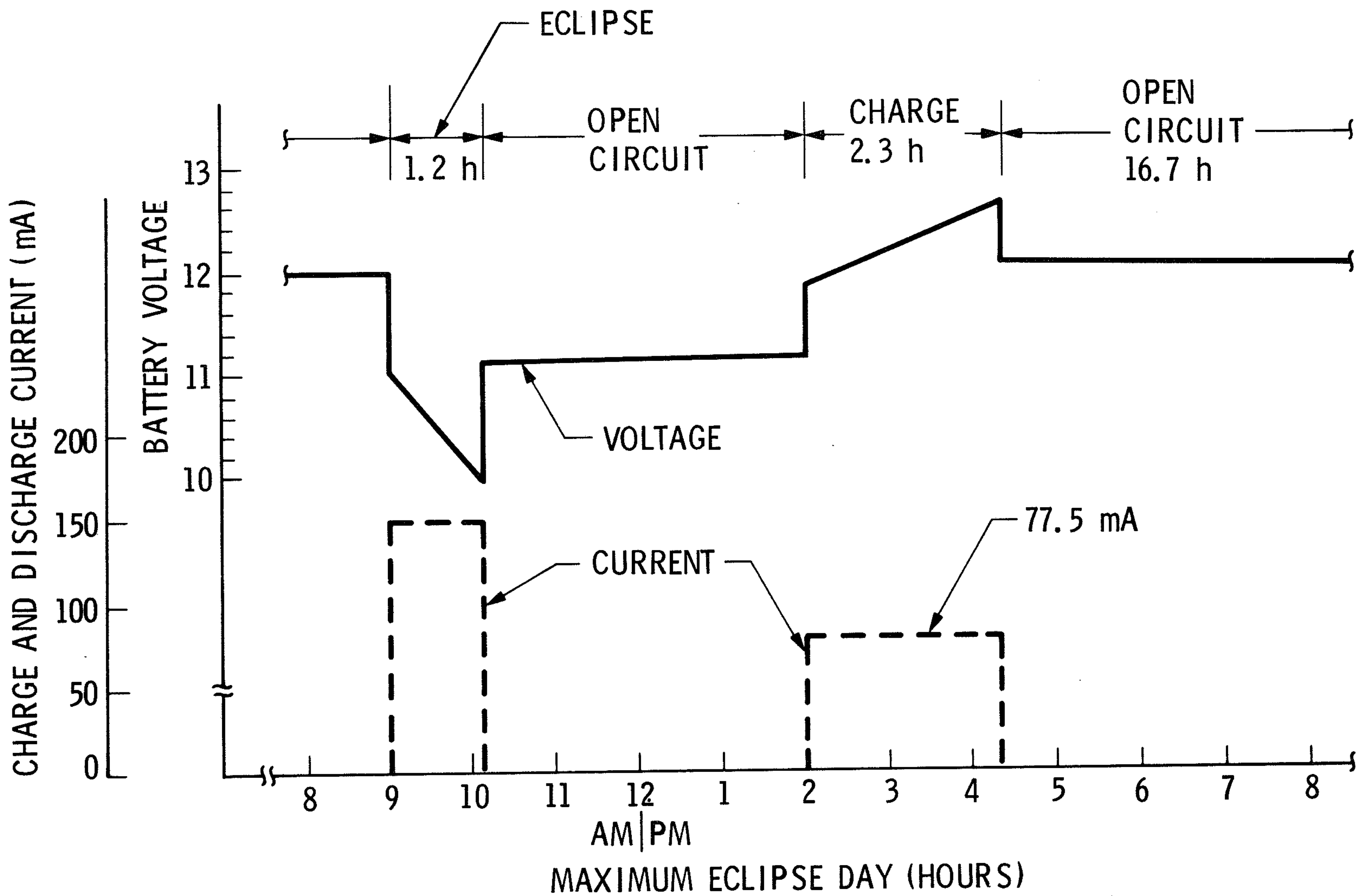

Figure 1 - Simulated Real-time Eclipse Season Test Parameters and Performance for Maximum Eclipse Day.

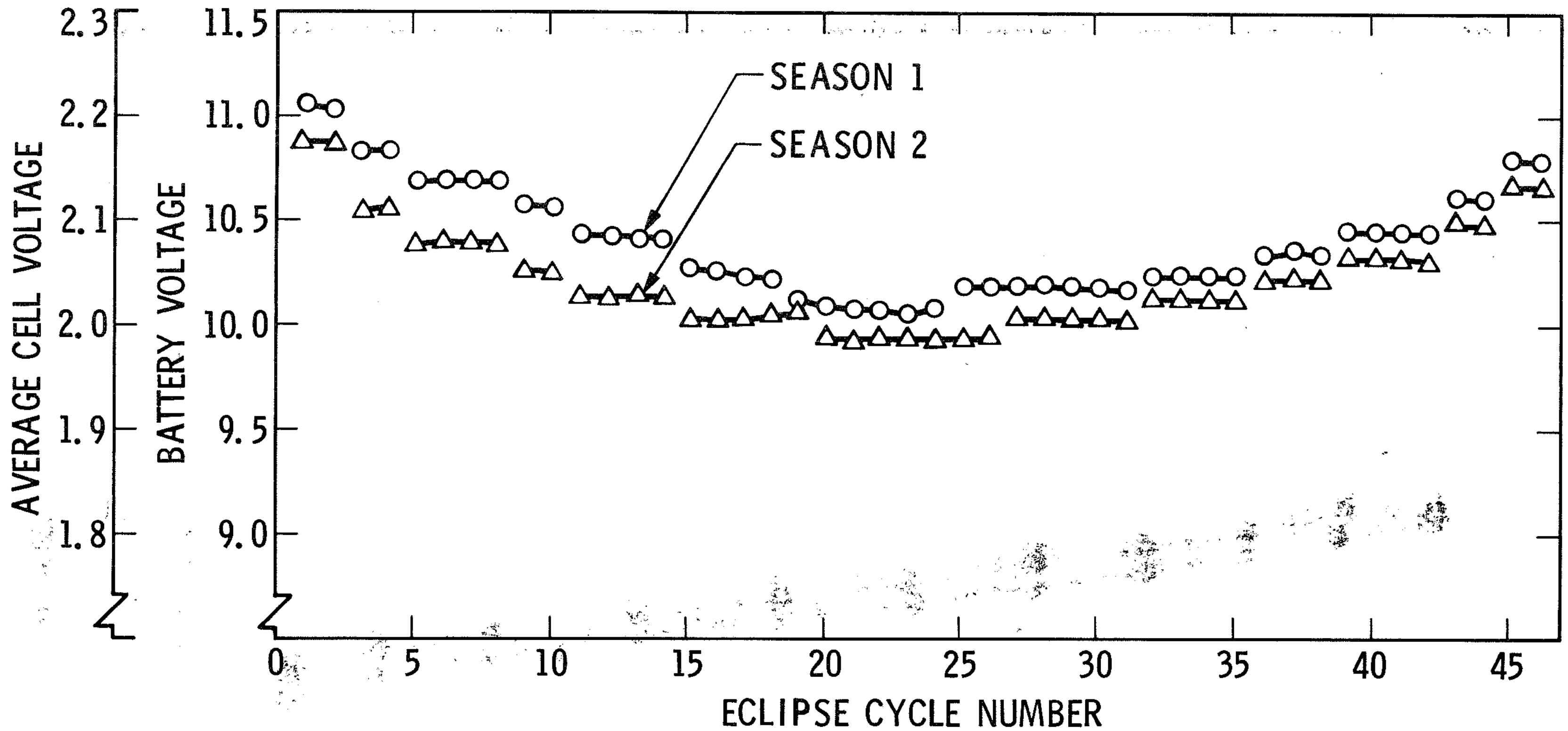

Figure 2 - End of Discharge Voltage Versus Cycle During Simulated Real-time Eclipse Seasons for 5 Cell Li-TiS_2 Battery.

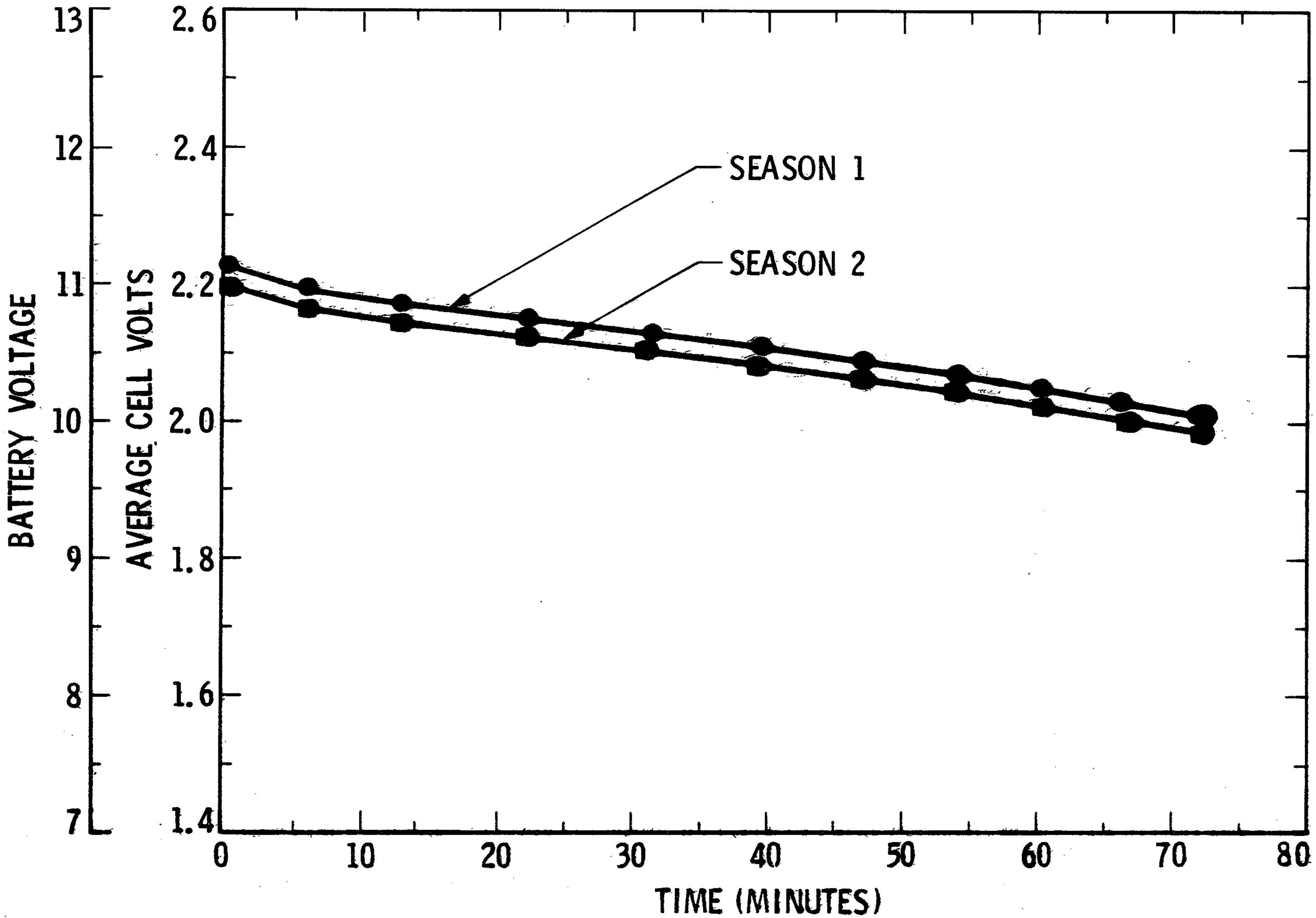

Figure 3 - Discharge Voltage Versus Time During Simulated Real-time Eclipse Seasons for Cycle 24.