RCA SATCOM–IN-ORBIT EXPERIENCE

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RCA

About 2 years ago in this battery workshop, there was some data presented by a gentleman from COMSAT, which reflected for batteries that had been reconditioned to say just a little better than 1 volt per cell, we have been limited to shutting off loads after about 5½ years, or eleven eclipse seasons due to battery performance.

This past September at NASA/Lewis, I attended a reliability conference on TWTA's traveling-wave tube amplifiers, where there was strong evidence presented, indicating that TWTA life is being degraded and actually TWTA's are being lost by siphoning on and off.

It appears to me at this point that it is no longer just an inconvenience to our customers and to our users, and so forth, during these eclipse seasons, that we could drop them off, but it was actually now hitting us in the pocket where revenue is going to be lost because we no longer get these TWTA's back on.

This morning I would like to share with you a little bit of our experience that we have experienced in orbit with Satcom and give you a little bit of our test data results.

This morning's presentation will be split into two sections. I will give a little bit of our in-orbit experience, and then Steve Gaston from RCA Astro Electronics will try to answer the question that has been raised many times in the past about where we are going to be 6 years or 8 years into orbit.

I would like to, at this point, thank Dave Stewart, who is with Americom now for doing a lot of the research now and data analysis and development of some of the charts that I am going to present.

(Figure 3-14)

Just as a refresher, I want to highlight a couple of the system characteristics of the Satcom batteries and Satcom power system. The F-1 and F-2 have been in orbit for approximately 4 years. They are seeing either 7½ or 8 eclipse seasons, as of this juncture.

We have essentially three nickel-cadmium 22-cell batteries on board in parallel with independent redundant charges providing the charge rates as you see them. Only on the C/10 charge rate, which we use for reconditioning, do we have any kind of overcharge protection, a B/T-type charge protection system.

Typical temperature range in orbit for the operating periods, where we are actually discharging batteries and charging at the C/20 rates, is shown 2 to 15 degrees average. We do have some peak temperatures during solstice approaching the high 20s.

As I mentioned, we do have onboard reconditioning with individual cell bypasses with 1-ohm resistors. This data has been presented previously in these workshops.

(Figure 3-15)

Here, I have tried to plot out typical battery average minimum discharge voltage. This happened to be battery 3 on the F-1 spacecraft. What this is, is essentially an average data to get rid of some of the telemetry quirks, some of the transients, and so forth, that you see showing in the eight eclipses, minimum voltage about 25.95 volts. Our system requirement is that we must maintain a battery bus of about 25 volts, which is conservative. You might notice that the delta between the sixth and eighth eclipse season is fairly small.

(Figure 3-16)

This is a similar plot for the F-2 spacecraft. Again, it is the same battery looking at battery three on the F-2. The eclipse seasons here are essentially the first complete eclipse season. As indicated before, the F-2 is launched during an eclipse season, so this is really the 1½ eclipse season, if you want to call it that.

A couple of things I would like to point out here. I think the significant thing is that in the last eclipse season we have had a tremendous improvement. If you recall some of the previous workshops, we had indicated that we had a problem in the F-2 spacecraft. We had a blockage which was preventing us from rotating our solar arrays, which is Sun tracking 360 degrees, which required us to go through essentially a reverse slew on a daily basis, and which equates to about a 28-percent DOD on a daily basis.

As of last June this problem went away. It was a self-corrected problem. We were actually able to pass through the same zone and are now operating the spacecraft just like we are F-1. So I would attribute probably some of this improvement here in the seventh eclipse season to the lack of daily cycling at this point.

We also did a double reconditioning in the spring eclipse season for some operational concerns. There was a reconditioning performed after the eclipse season. This might also have contributed to some of the improvement.

I indicated we have a slight load change there, about 1 ampere, which I don't really think is the significant improvement factor here, because you divide that by the three batteries; it is really fairly insignificant.

The F-2 performance, in general, is a little bit worse than that of the F-2, as indicated by the fifth eclipse season data. However, the seventh eclipse season data is significantly improved. So this is something we are going to have to watch and try to figure out what is really happening.

(Figure 3-17)

What I have shown here is essentially the reconditioning-discharge curves for the first, fifth, and eighth eclipse seasons. Now, the question has always been raised, what happens to capacity? We know we have a voltage improvement. From this curve I don't know if I can really answer that question.

The rates here are through a 1-ohm resistor, so it is 1.2-ampere rate decreasing. Also, as we discharge, we have a tendency of warming the batteries because the resistors are mounted to the baseplate of the batteries themselves.

The only thing I can really draw from this particular curve is that things haven't changed. That is what I am really using it for, as a ruler or measurement between the fifth and eighth if reconditioning seasons are essentially identical.

(Figure 3-18)

As to the state of completeness, I have just included the F-2 seventh reconditioning cycle. If you overlay this over the F-2, they are pretty close. We do have a slight softening in the knees on both discharge curves, as would be expected with cycling.

I didn't plot here any of the previous reconditioning because this is the first reconditioning in which we did not have to rewind first. In all the other reconditioning cycles, we did our rewind, which is 28-percent C/2 discharge, and went directly into reconditioning. So, this will be the first real comparison point that we will monitor in the future.

(Figure 3-19)

GASTON: First of all, let me define a little bit better the minimum average cell voltage during eclipse versus number of eclipses. This is what we plotted here. By the minimum average, it is the minimum voltage during the eclipse, most likely at the maximum eclipse time. But it could also be slightly beyond. Average is based on the cell basis, the average cell voltage which we have in the battery.

What we have done is that we compared the top two curves, the Satcom curves, and the bottom three are the Intelsat IV-A data obtained on the cell basis.

Intelsat IV-A is about finished, a little bit more than 12 eclipse seasons, and was supported in last year's power sources when the information was taken from that.

(Figure 3-20)

The next thing we did, we compared and averaged from the previous curve, and we took all three spacecraft and averaged the values. That is the number of eclipse seasons, except in this case it is plotted on the same scale rather than a straight relationship. At the same time we took the Satcom F-1 and F-2 data and combined it, just to get some average number.

Then the third thing we did, we compared it with the Crane tests. We have selected a specific test which happened to be Pack 109, which had about a 60-percent DOD, conducted at 20° C. So, all the triangles here are Crane data.

In the next chart I explain why this one was selected, because it is closest to the DOD characteristics concerned, what the Satcom sees.

Another interesting thing on this Crane test is that the maximum eclipse season, the capacity is measured. By measuring capacity, it is in effect a reconditioning. So what this actually shows is that those data points practically coincide with the Satcom and the Crane tests.

The Crane tests lasted almost 10 years, or twenty eclipse seasons, until it gave out. It is about the minimum voltage which we can tolerate on Satcom, on the stellar base about 1.142, or about nine—eighteen eclipse seasons or 9 years. Since the Satcom tracks that closely with the Crane tests, it appears that that Satcom can perform to minimum voltage for about 9 years.

(Figure 3-21)

This slide compares the designs. It starts out with the Satcom F-1 and F-2 design and has an Intelsat IV design and the Crane test design.

The rated capacity is 12 ampere-hours for the Satcom and 12 ampere-hours in the GE cell, except in Satcom it is actually built in a 10-ampere hour case. Therefore its surface area and the total capacity are less than the regularly rated Crane test. Intelsat is 15 ampere-hours.

Then, we compare the actual DOD of Crane based on either rated capacity or measured capacity. Since the rated capacity is rather a flexible number, depending on what number you like to give, it is a little better indication. When you compare these three depth-of-discharges, they are not that much different. They come relatively close. Based on the rated capacity, it appears that again they are relatively close.

When you come to a current density based on the discharge current, the Satcom current densities are actually somewhat higher than either one of the other two.

The other differences which we have are in the negative electrode. In the Crane test there are no additives; in the Intelsat IV there was a silver additive; and the negative electrode treatment was teflon in the Satcom cell.

The electrolyte is still relatively a close comparison between the Crane test and the Satcom. It was a little bit skimpy as far as electrolyte in the Intelsat IV is concerned.

But each design is different. What I tried to bring out, I want to isolate what are the differences in the designs so we can compare them. But there are also differences in the treatment as far as handling is concerned.

DISCUSSION

DUNLOP: There are a couple of comments. As far as the negative electrodes are concerned, in the Intelsat IV, there were no additives. We had lithium in the electrolytes, but there was no silver treatment on the Intelsat IV. In the Intelsat IV-A we have a silver treatment.

GASTON: I apologize.

DUNLOP: As far as I know, I think the Intelsat IV battery design and the one that you are referring to on the Crane testing were almost identical.

The other point there I would like to make is that on the Intelsat IV, you showed the data up through twelve eclipses, which is the data that we show. But, if you compare it to the Crane data, you probably should compare it to something more like fourteen eclipse seasons, because on the Intelsat IV you have about 1 year–you have a fair amount of exercising of the battery before the launch. If you take into account all the exercising that is done–in those days we used a battery for all the electrical checkout of the spacecraft, thermal vacuum testing, etc.–if you take that into account, you can actually figure out that your prelaunch–that is your size of the battery–would be equivalent to ½ to 1 year in orbit.

So, if you want to compare it to Crane testing, when you take a battery pack and put it on test right away, you have to make a judgment factor as to how much exercise we put on the battery before it got launched.

I think another point is that when you talked about reconditioning, that was not reconditioning to 1 volt you mentioned, it was reconditioning to 1.15 volts. The difference between reconditioning to 1.15 volts and 1 volt really turns out to be quite significant in terms of the effect it has on the voltage performance.

For example, Intelsat IV-A battery, we do recondition it to 2.0 volt, or slightly less than average, and that battery pack was seeing voltage performance up to nine eclipse seasons. That would be very close to the data that you are talking about for equivalent DOD, about 1.19 volts per cell average after nine to ten eclipses.

GASTON: Yes, but I didn't want to put a judgment factor on it. This is the data as it exists and as it is shown.

DUNLOP: But, to make the comparison, you have to take into account that the battery is 1-year old prior to launch. It has been exercised at least 40 different cycles prior so it is equivalent to at least one or two more eclipses.

GASTON: I agree. But the same is true for the Satcom, and I just don't know what weighting factor to add to that. I didn't go into reconditioning schemes or techniques like it was, let's say, to 1.15 or 1.0 or 0.5 volts, 0.5 volt like it was a Crane trest. I didn't want to go into details because I didn't have enough time.

DUNLOP: I am trying to make a point: That is the results of the Intelsat IV program in which reconditioning to 1.15 volts was practically useless as far as any effect it had on voltage. But reconditioning to something like 1 volt or less has a significant effect, as your data and the data we have on Intelsat IV-A show.

But one point that is a little confusing, is that the failure of the Intelsat-IV cells was not a function of end-of-discharge voltage. What actually started happening on the Intelsat IV cells is that we started running into high-voltage problems or shorting problems.

When we did try to go to deep reconditioning, once we got into those kinds of problems, deep reconditioning really didn't have any further improvement on the batteries.

So the real question we still have as to what the effect of reconditioning is—we know it is pretty well agreed that deep-discharge reconditioning does have a big effect on voltage performance as shown by your data. But, whether it is going to have an impact on lifetime or not is still to be determined.

GASTON: I agree. I am very partial to the individual resistors for each cell draining. This way it cannot reverse itself, and yet you get a good reconditioning.

As far as what the effect on life is, I don't know. The data compared to Crane data gives me some indication that we might expect in 9 years. Until we reach a voltage below that, we might be power limited because of the low-battery voltage. That remains to be proven in time. It's just a prediction.

FORD: Steve, two points: one to be clarified and then I have a statement. What pack number are you looking at at Crane?

GASTON: 209. At 60-percent DOD and run at 20°C.

FORD: 12-ampere-hour cells? I am sure I made this statement before, but I am going to make it again for the record.

All the GE cells that were put on test at Crane prior to 1970—I repeat, prior to approximately 1970—are an entirely different plate design that that we are using today.

GASTON: Yes, I agree. But yet it is the longest test which we had at Crane, and I used it for comparison.

LEAR: Paul, you didn't mention what capacity the cells were that you have on the spacecraft, and how was the power configuration hooked up? Are there three batteries in parallel connected to the bus?

DeBAYLO: Yes. The spacecraft batteries, the 12 ampere-hour, there are three batteries in parallel. All three are required at support mission loads.

GASTON: By the way, the load sharing was very close between the three batteries.

SCOTT: Paul, did I hear you say that in most cases of the data shown, that the batteries were discharged on their normal load before they were put on the resistors for reconditioning discharge?

DeBAYLO: No. What I said was on the F-2 spacecrasft when we had to do a daily rewind cycle, which is at 28-percent DOD cycle, the rewind was the first thing done as part of that reconditioning. In other words, we took out the 28 percent and then put them on resistors. The way the F-2 and F-2 spacecraft are now operating, the reconditioning is done from a full battery that has been on trickle charge for about 2 to 3 weeks before we go into the eclipse season. Put on resistors from the initial state.

HALPERT: I would like to ask Jim Dunlop a question, if I may, regarding lithium. You said you had lithium hydroxide in the Intelsat IV and you took it out for IV-A. I wondered why you put it in for IV and took it out for IV-A. Could you briefly discuss that?

DUNLOP: I think it was GE that chose to put it in, not me. We have been trying to figure out ever since, whether we liked it or not. One thing I will say about the addition of lithium hydroxide to the electrolyte, it gives you good low-temperature performance. You get good voltage performance at low temperature.

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BATTERY DESIGN/HISTORY

IN ORBIT:	F-1-12/12/75 F-2-3/24/76
BATTERY:	Three, 22 Cell NiCd
CHARGING:	Normal C/20 –Eclipse Seasons High C/10 –Reconditioning Trickle C/60 –In-Orbit Storage
OVERCHARGE PROTECTION:	V/T-Single Curve (C/10 Rate Only)
TEMPERATURE:	2 To 15°C Average
RECONDITIONING:	Individual Cell Bypass, To 0.1 V/Cell

Figure 3-14

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F-1 SPACECRAFT BATTERY 3 AVERAGED MINIMUM DISCHARGE VOLTAGE

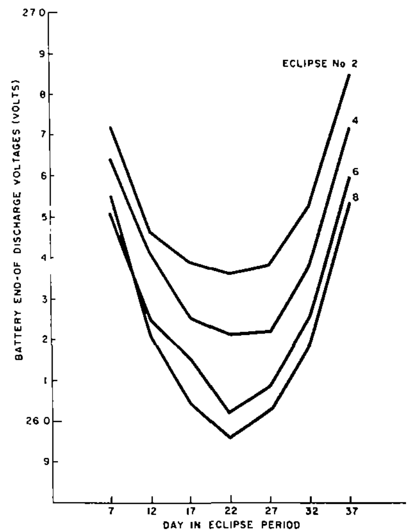

Figure 3-15

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F-2 SPACECRAFT BATTERY 3 AVERAGED MINIMUM DISCHARGE VOLTAGES

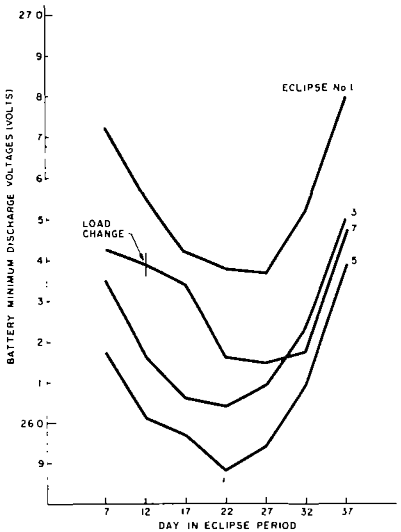

Figure 3-16

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F-1 SPACECRAFT BATTERY 1 RECONDITIONING

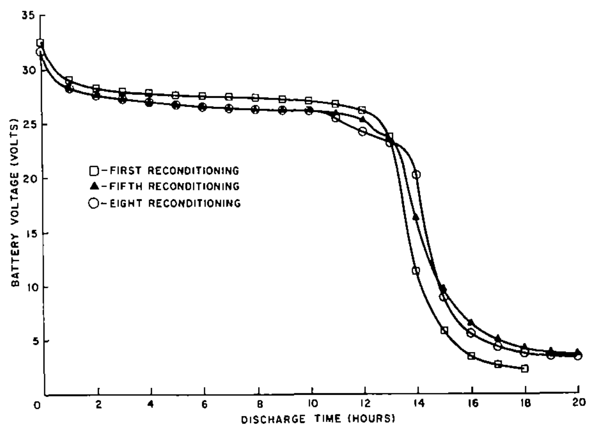

Figure 3-17

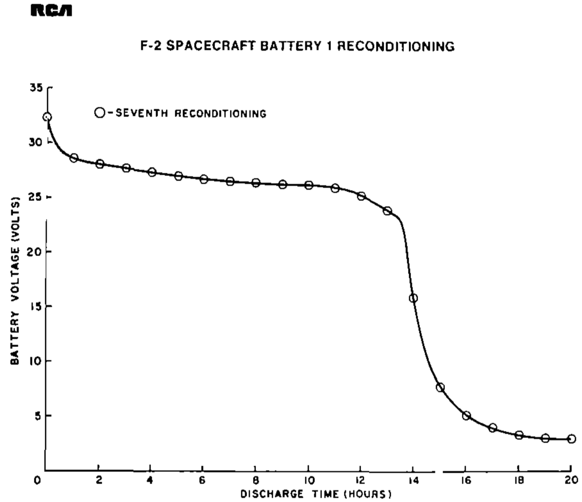

Figure 3-18

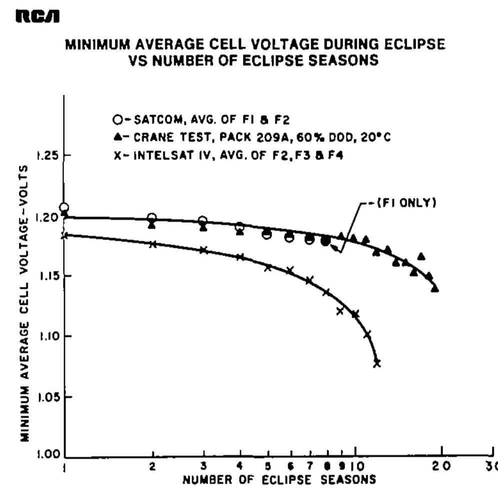

Figure 3-19

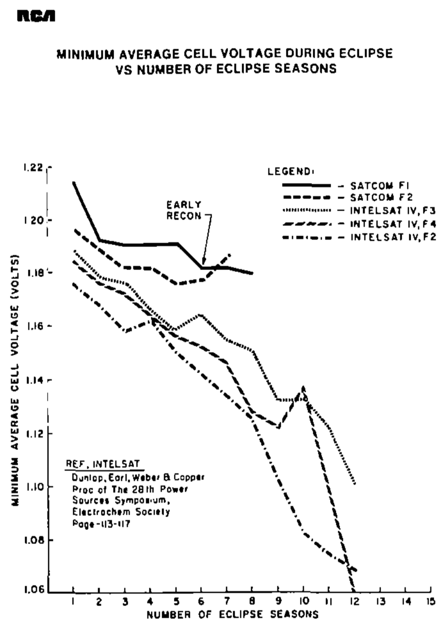

Figure 3-20

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DESIGN COMPARISONS

[illegible]	SATCOM F1&F2	INTELSAT IV F2-F4 *	CRANE TEST PACK 209A **
[illegible]	GE (GENERAL ELECTRIC)	G.E.	G.E.
[illegible]	12	15	12
[illegible]	14	20	16
[illegible] DISCHARGE CURRENT DURING ECLIPSE (AMPS)	5.4-5.9	6.6-7.2	6.0
CAPACITY REMOVED AT MAX ECLIPSE (A-H)	6.4-7.0	7.9-8.6	7.2
APPROXIMATE PERCENT D.O.D. AT MAX ECLIPSE			
• BASED ON RATED CAPACITY	53-58	53-57	60
• BASED ON MEASURED CAPACITY	46-50	40-45	45
TOTAL POSITIVE ELECTRODE SURFACE AREA (IN²)	149	250	182
DISCHARGE CURRENT DENSITY (MA/IN²)	37-40	26-29	33
NEGATIVE ELECTRODE TREATMENT	TEFLON	SILVER	NONE
QUANTITY OF ELECTROLYTE (CC)	35	45	45
CC ELECTROLYTE/AH MEASURED CAP	2.50	2.25	2.81
CC ELECTROLYTE/AH POSITIVE ELECTROCHEM CAP	2.34	2.14	2.37

NOTES: * REFERENCE J.D. DUNLOP, M.W. EARL, F.W. WEBER AND D.B. COOPER, INTELSAT IV, NI-CD BATTERY ORBITAL PERFORMANCE, PROCEEDINGS OF THE 28TH POWER SOURCES SYMPOSIUM, 12-15 JUNE 1978, ELECTROCHEMICAL SOCIETY, INC.

** REFERENCE J.D. HARKNESS, RESULTS OF CONTINUOUS SYNCHRONOUS ORBIT TESTING ON SEALED NI-CD CELLS, NAVAL WEAPONS SUPPORT CENTER, WQEC/C 77 134, JUNE 9, 1977 AND PRIVATE COMMUNICATION.

Figure 3-21