SYNCHRONOUS METEOROLOGICAL AND GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES BATTERY AND POWER SYSTEM DESIGN

D. A. Baer
Goddard Space Flight Center
and
W. J. Schedler
Ford Aerospace

INTRODUCTION

(Figure 50)

BAER: The prime contractor was Ford Aerospace, and they also built the battery. Eagle-Picher was the cell manufacturer. It was a three ampere hour nickel cadmium prismatic cell. The battery consisted of 20 cells connected in series. And I think the weight was typically about seven and a half pounds. There were two batteries per spacecraft.

(Figure 51)

The charge control was controlled basically from the ground. There were three ground commandable charge rates, C/13, C/20, and C/35. This is more typical of beginning of life. End of life they dropped off a little bit. The ground controller would select the charge rate based on battery voltage, temperature, and what use it was in, as to whether it was in Sun or whether it is in the eclipse. Also, there are the periods when there are loads on during the Sun periods. There is undervoltage of an average of 1 volt per cell, and these were in five cell groups. So if any one group dropped below 5 volts why then the battery would be taken off line. And one or both batteries could be placed on open circuit also by ground command.

(Figure 52)

I will just briefly run through this block diagram. The bus is a 29 volt bus, and during the sun periods it is maintained at 29.4 volts by clamping the lower part of the solar array with some shunt elements. I was going to briefly mention this area here is mostly control circuits for driving the shunt elements and also for the boost regulator. There is also charge control array. Actually there are two, one for each battery. And they are broken up into two different segments, and depending on which of these relays are thrown determines what your charge rate is. As you can see, like I said, there are two of them, one for each battery.

During discharge or dark, the batteries go through a boost regulator and boost the output up to 29.4 volts. About the only other pertinent item is that there is a battery undervoltage control that is located here. And there is also some overcurrent disconnects in the system.

OPERATIONS

SCHEDLER: I am from Ford Aerospace. However, I am assigned to NOAA - NESS locally here, real time engineering on the spacecraft.

I want to show some of the typical data on battery voltages and temperatures that the spacecraft see during a normal operational day.

(Figure 53)

We happened to pick a 302 here on SMS-2, and I have shown both batteries 1 and 2 to try and show you how closely or not so closely they track. In this particular case we see only voltage shown. There is one place you notice that is called satellite midnight. This is the time during the day when we have maximum load conditions relative to the sun, because this particular spacecraft has an opening in it which takes a proportion of the array during one part of the day. When your peak loads are occurring, when the visitor is taking a picture, you are also looking directly at the sun. So, as you look at some of these pictures you will see this effect, always off in that portion of the picture.

(Figure 54)

This is kind of the first available information on GOES-2 bird, which is the latest one that was launched. This is eclipse data, where we of course with the synchronous orbiting satellites don't have all these daily or orbital excursions and dipping into the battery. This happens two times out of the year for 30 or more days.

This is a day in the eclipse towards the middle of the eclipse period, where we got down to a 44 percent depth of discharge. The normal maximum depth of discharge is about 48 percent during the peak, the longest eclipse periods, which last somewhere around 72 minutes.

Some of the things that you will notice on here are the changes in temperature from batteries 1 to 2. There is almost 3 degrees difference in temperature. This also shows up on a normal operational day. If you just chop out the middle of discharge and recharge time and extend the lines across you will notice that they end up at about the same point. Some of these things we will talk about later on when we talk about eclipse problems.

(Figure 55)

One of the next things I want to talk about is, that one was more specifically in the area of delta T from batteries 1 to 2. Here we have a delta V problem. And you will see typically in this particular as it goes to one satellite that battery 1 tends to have overvoltage characteristics, whereas battery 2 doesn't. And those come from different cell lots. There is a difference there of maybe a volt and a half to maybe two volts. This is during the recharge of the battery. You will notice right in here we made a charge rate change. And the reason for this is we know historically with this bird that we couldn't leave it in the two-thirds charge rate during the recharge cycle after eclipse because it would exceed the voltage limits. So we make preplanned charge rate changes. Now this was this year, 1977. And the reason you see there are data missing in here is that we were time sharing, having to operate three birds instead of two, and we didn't have telemetry during that period of time.

(Figure 56)

This is the SMS-2 bird again, and we will see quite a dramatic overvoltage condition there, recharge up, or a smaller eclipse. And I don't know exactly what that depth of discharge was, but it looks like perhaps in the area of 12 to 15 percent.

In this particular case it wasn't expected seasonally that we were going to have to make this charge rate change, using the previous year's history. So we got surprised here, and the voltage went up over 30 volts, 30.143 volts. That is 1.5 volts per cell. The battery was at about 15 degrees at that time. The controllers did not catch this event. Presently we have a limit. I think it is about 30.05 volts, 15 degrees, not to exceed a half an hour. Then you are supposed to change the charge rate. But this one inadvertently was missed, and you can see right here when the charge rate was reduced it made a dramatic step down. And you can see what happened to the other battery, the one that seems to be much more stable.

One other point, they have had some play in this larger change. I also showed here the main bus current load profile during recharge. Normally this would have come up and stayed on here, but for some reason there was a load change made there so that you were recharging not with a full load on the system. That could have had some effect on that.

(Figure 57)

This is a picture of what we sort of expected to see during that eclipse. This is a 15 percent depth of discharge. We didn't expect it to exceed the 30 volts. So, the controllers weren't alerted to expect that.

(Figure 58)

Here is, just to point out the voltage differential thing, another eclipse day where the voltage peaked at a much later time. It stayed well within the limits. Here we are really trying to point out the kind of nominal voltage differential from battery 1 to battery 2.

(Figure 59)

This is a comparison here, and I will see if I can get most of it on. I will get it up as high as I can here. This is a comparison of two years, 1976 and this year 1977. It addresses about a half a year, starting at day 124 through day about 324, which is kind of where we are currently at the latest data.

We can see here that we had to make some operational changes, which we hadn't done in previous years. This is the -- let us see. Which spacecraft is this? I will have to skip over which one it is. This is one of the spacecraft that this year we operated at the three-thirds charge rate, which is something that we hadn't expected to have to do.

If you will look at the solid line here, the solid line in all cases are 1976 data. Our trickle charge is 80 milliamps, about a C/35. Our two-thirds charge rate, also known as intermediate, is 150 milliamps. You can see here the effects of temperature and voltage increasing. By the way, these are minimum and maximum voltages and temperatures. So we can see here that the spread in voltage, min and max, closed as we went to the higher charge rate. The dip that we see over here is the autumnal eclipse period. On this particular spacecraft we have no way of increasing loads or doing any sort of reconditioning, although we do what we call a pseudo-reconditioning at the start of each eclipse period. Instead of decreasing the loads, with an anticipation of going into an eclipse, we leave them on. And you can see here the voltage decreasing down towards the very first part of the eclipse. The first couple of days when we expect the eclipse to be very short we don't bother to change loads. We just let it ride through.

Historically we have gotten improvement in the batteries. You can see that the voltage is increased then.

The dotted line is of some interest this year because of the three-thirds charge rate. Here we can see the effect of going to the three-thirds charge rate on the maximum voltage. The spread seems to increase relative to the previous year's operation. The minimum voltage is going lower. Now some of this can be the effect of the way the spacecraft is being operated in that the batteries are demanded more. But the one interesting thing to note is that after being in this three-thirds charge rate for about two months right here we seem to be somewhat lower than the previous year data. At this point here we changed back to the two-thirds. We saw a subsequent drop in maximum voltage, which is approaching a volt difference from the year previous.

We attempted to do as an experiment a reconditioning by turning on every available load that we had in the spacecraft. Unfortunately, that was only about 9 percent. You can see the effect, that the lower voltage started to come up, whereas the upper voltage limit remained the same.

Thin line you see here is when this spacecraft was placed in a standby mode when the GOES-2 was brought on line as the operational bird. The load dropped maybe 3 or 4 amps. Shortly thereafter we went to the one-third charge rate. The minimum voltage came up. The maximum voltage continued on down to where there was very little difference between the two. Well, one of the reasons is they really aren't being exercised. But I think the trend, though, that we are looking at and we were worried about was the decrease in the battery voltage down to under 27 volts. So we watched as we went into this last eclipse.

Here you can see this eclipse reconditioning cycle. And right away the voltage started to go back up. And after going through this eclipse the voltages, minimums and maximums, are now again tracking the previous year's data. However, keep in mind they are not really being used. Their voltage is back where it is expected to be.

I want to talk a little bit about the problems involved in having to do this operationally. Each eclipse year we have to make a plan for each particular bird as to how we are going to operate it when the charges have to be turned off or modified. Where can this be a problem? The problem is, number one, that extra commands are required. The geostationary birds, those birds take pictures. There is only about a ten minute period of inactivity each half hour, so any extra commands that we are asked to send are rather involved in the operation. When we are asked to change charge rates, they oftentimes like to have a real time engineer there when this happens because they feel they can't ask the controller to make these kinds of decisions. So this demands more time to look at things until we can decide at what time of the day should we change the charge rate so we don't go over.

On occasion we have had problems where the commands that are sent aren't executed exactly correctly. We have sometimes ended up in the three-thirds charge rate when we have wanted to be in the one-thirds charge rate.

With the controller having so many things to do and so many things to look at on his screen sometimes he doesn't catch this voltage creeping up and creeping up. So it is a dangerous situation operationally.

The other things that we would like to talk about then is operationally how could a battery behave better where it wouldn't have these kinds of problems. One of the obvious things is to have better control over the cell to cell variations or in this case battery to battery variation. As you can see, this battery 1 takes precedence over battery 2. So anything that we have to plan on we have to look at the worst case. Presently we have gotten around operational problems, but as solar array degrades normally in time we are going to have to start looking at maybe placing one battery on a different charge rate than the other. Things have become a lot more complex. And it is not -- because it is in eclipse time that we are having to do this. The eclipses change every day, starting off at just a few minutes and go down to 72 minutes. It means that you have real variable situation on your hands, not like the non-synchronous where you can kind of predict that it will do this each day. You can't do that, so it is kind of custom planning involved.

The other obvious thing there is having cells that are less susceptible to the overvoltage problem in the first place.

We have a couple of questions that operationally would be helpful to us. One is a study on which is better, many small dippings into the battery or several larger ones spaced days apart. As the spacecraft gets older we are going to start getting into batteries on a daily basis.

And the last thing is something that is probably available that we just don't have and that is a better V/T plots or something that would be easier to use at the control level. Right now we have like three charge rates, three temperatures, and three upper voltage limits that with time you are allowed to be in that. And some of the problems you have is what happens in one case, where you saw the large excursion, the operator looked at that and said, "Oh, it went up to over the limit, 30.1." It is not allowed to be in there for over a half an hour. So 20 minutes later it dipped down for one sample period and went back up. Now you get another half an hour. So, operationally we need a better plan on how to tell them what has to be done.

DISCUSSION

NAPOLI: RCA. I didn't understand some of the things you had on that one chart. Would you go back to the one where you had all those --

NAPOLI: The one where you showed the 1976, 1977 comparisons. (See Figure 59)

What I don't understand is on the upper curve you have autumnal eclipse. For some reason I see the voltage is going up during eclipse rather than going down. I don't understand that curve, the top two lines, the dotted and the solid lines.

SCHEDLER: That is a good question. I don't really know the answer.

NAPOLI: I believe that that looks like a 44 day, you know, cycle, but I don't understand the curve above that.

BAER: I think what happens sometimes here is that they use them at varying depths of discharge. And it depends what loads are on during the eclipse as to how much depth of discharge you are going to go to. Now, if you go through an eclipse where they don't take any pictures or they have a very light load, then you aren't going to go to as low a depth of discharge as you did the previous.

OBENSCHAIN: I think also, Walt, that the upper curve is during the daytime, the night voltage --

SCHEDLER: Yes.

OBENSCHAIN: Okay, you just change your charge rate for the most part from a one-third to a two-thirds you have got a higher charge rate, and you are also using your battery, recharging it. The bottom curve is the minimum voltage during the night, and the upper curve is at a higher charge rate during the daytime.

SCHEDLER: Yes, and when he says night he means eclipse.

NAPOLI: You have got the end of charge and you have got the end of discharge.

OBENSCHAIN: Exactly.

SCHEDLER: Right. I think another thing that we see here too is this overcharge peaking situation on one of the batteries that is going to give us this situation.

OBENSCHAIN: Where is the overcharge peaking on that? It looks like they are all staying at 29 volts.

SCHEDLER: You are right. I guess on this one it is. One of the reasons that might be is that some of those data may not be included in that curve.

SPARKS: TRW. I take it from your comments that if you had your choice as far as manual control from the ground you would vote against it.

SCHEDLER: Well, I hate to speak on an operational problem coming from a company that built the bird. Sometimes you might say that that would be true, a more automatic system would be better. I guess there are problems with both.

SPARKS: Do you find, you know, in trying to handle this thing manually that it is taking up an awful lot of your operational time?

SCHEDLER: To date it hasn't been; however, again, the reason it isn't is that we select some time during the day where we feel it is a good time to change the charge rate. Now as we get later in life where we will have to use more and more of the capacity of the battery and there is less array power to recharge it this is going to be more difficult and perhaps require controlling the batteries individually.

OBENSCHAIN: I would like to make one comment here. Walt, not to minimize the concern and the problems you are going to have downstream it seems to me that so far you have less problems, say, than Phil Brandt or the other people who have had to work on the near earth orbits. I mean, this doesn't seem to be an extraordinary amount of work to me because it changes once a day, the charge mechanism. Whereas, on a lot of near earth orbiting satellites you have to work at many, many. So, you know, I just do not see a problem here.

SCHEDLER: I would say that I wouldn't want to be in a near earth orbit and have to do every day manual control.

OBENSCHAIN: You wouldn't want it, and it is probably not desirable. But it happens, and I think it was presented here for two hours. Okay, so, you know, I just don't see how this is a big problem when you compare it with the people who have to work near earth orbit satellites and have to do it every day.

SCHEDLER: I agree.

SMS/GOES BATTERY DESIGN

- CONTRACTORS: SPACECRAFT & BATTERY - FORD AEROSPACE
  CELL - EAGLE PICHER
- CELL SIZE & TYPE: 3 AH NICKEL-CADMIUM (PRISMATIC)
- CELLS/BATTERY: 20 CELLS CONNECTED IN SERIES
- BATTERY WEIGHT: 3400 GMS (7.5 LBS)
- BATTERIES/SPACECRAFT: 2

Figure 50

SMS/GOES CHARGE CONTROL & BATTERY PROTECTION

- CHARGE CONTROL: THREE GROUND COMMANDABLE CHARGE RATES - C/13, C/20, C/35
- UNDER VOLTAGE: AVERAGE OF 1.0 V/CELL, SENSED IN 5 CELL GROUPS
- ONE OR BOTH BATTERIES MAY BE PLACED ON OPEN CIRCUIT BY GROUND COMMAND

Figure 51

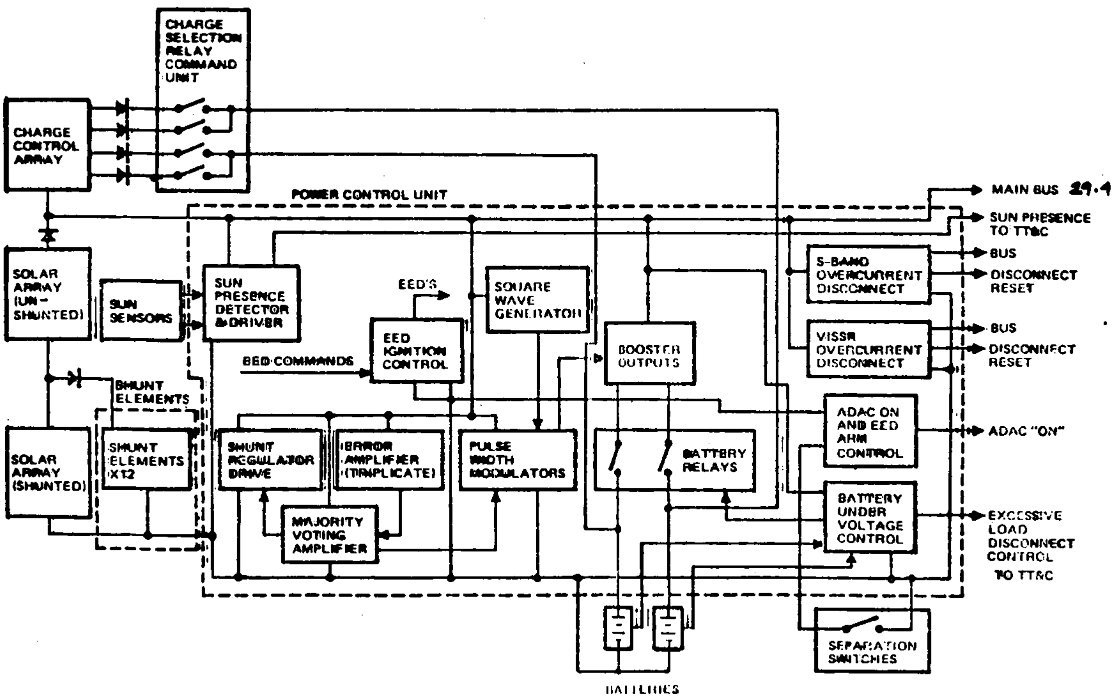
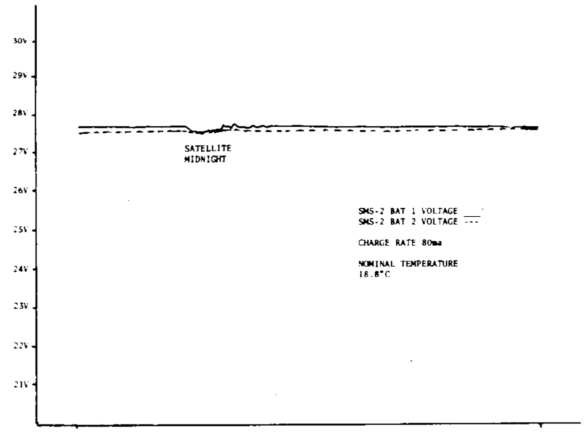


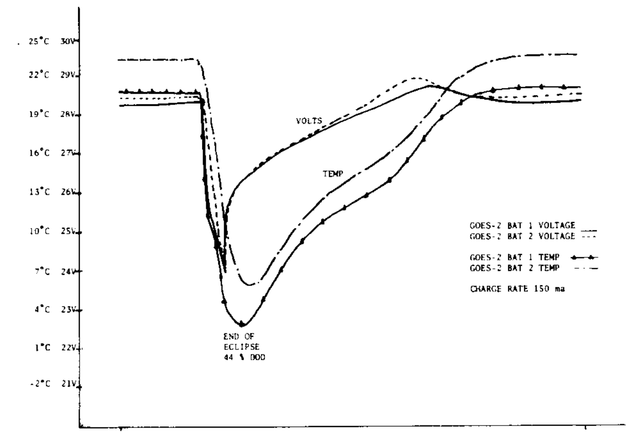
Figure 52. SMS/GOES Power Subsystem Block Diagram



J-DAY 302 1977

NORMAL NON-ECLIPSE OPERATIONAL DAY

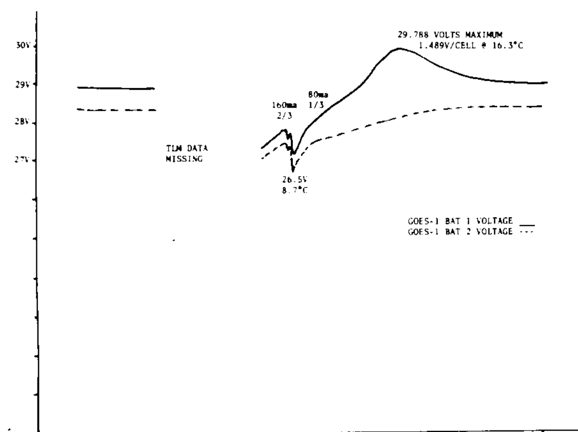
Figure 53



J-DAY 270 1977

ECLIPSE OPERATION - BATTERY 1-2 TEMPERATURE DIFFERENTIAL

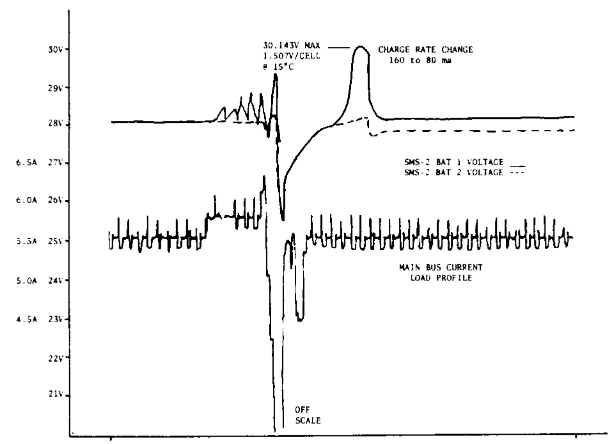
Figure 54



J-DAY 270 1977

GOES-1 ECLIPSE RELATED CHARGE CYCLING TO PREVENT OVERVOLTAGE

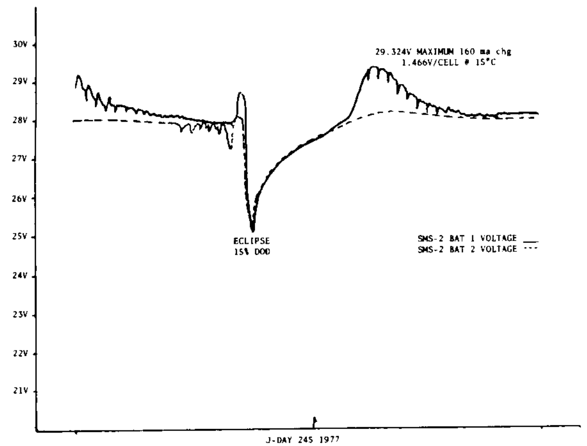
Figure 55



J DAY 287 1977

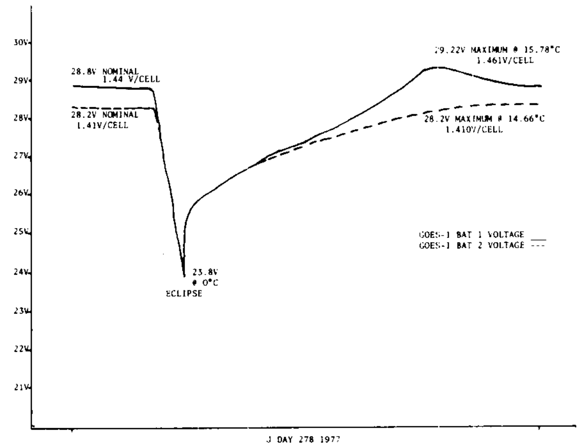
SMS-2 ECLIPSE RELATED CHARGE CYCLING TO PREVENT OVERVOLTAGE

Figure 56



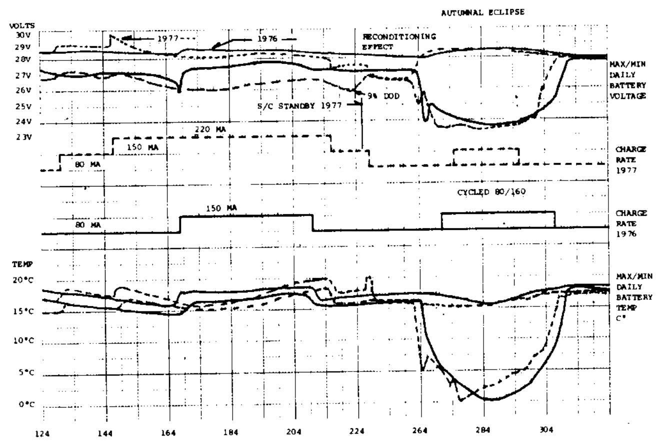
SMS-2 OPERATIONAL VOLTAGE DIFFERENTIALS

Figure 57



GOES-1 OPERATIONAL VOLTAGE DIFFERENTIALS

Figure 58



2 YEAR ECLIPSE COMPARISON

Figure 59