AN OPERATIONAL CONTROL SEGMENT (OCS) UPDATE ON GPS CONSTELLATION STATUS AND FUTURE PROGRAM DIRECTIONS

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Editors Introduction

This paper is the edited transcript of Lt. Colonel Freer's presentation. The figures were the over head projection transparencies.

Lt. Colonel Freer's Paper

We run the GPS Master Control Station from the Second Space Operation Squadron out of Falcon Air Force Base, Colorado. This is our squadron symbol (Figure 1); the real story here is a big success story in terms of where GPS has gone and especially how PTTI applications have been so much a big part of GPS and how much a part of PTTI that GPS has become.

They asked me to speak this year and give you an update on what is going on with GPS. The message as far as GPS and PTTI are concerned is all a good one. I want to talk a few minutes this afternoon about the performance of GPS and then discuss the Federal Radionavigation Plan (Figure 2), which is a document outside the purview of the Department of Defense (DoD) and the Department of Transportation (DoT). One of the concerns with GPS, to not only the time users, but to a lot of other folks, is that the DoD has pretty much guarded GPS operations; and I want to talk a little bit about what the DoD and the DoT have signed up to in terms of assurances to this community and to aviation interests, as well as other modes of transportation in terms of GPS continuity and availability. Finally, I will bring up a couple of issues that hopefully will be of interest to many in this group.

The Federal Radionavigation Plan was the topic chosen because a person from the utility industry got up at last years PTTI and asked a question on how we can be assured that somebody is not going to turn GPS off tomorrow or the next day. I want to spend a little time on that logic because the military is very reliant on GPS and we're planning on operating it into the foreseeable future. So I will give you some of the real words in that regard straight from that plan. And, then I will discuss with you some of the issues that are current, including a blue ribbon panel between the DoT and the DoD that is looking at GPS management, operations, funding, etc.

Here is a slide in terms of GPS performance (Figure 3). Again, the performance charts are really a good news story. We talked about requirements, performance; you see that we don't even get on the requirements scale. We are looking at 100 ns as the specification that we are trying to meet; and it doesn't even make it onto the chart. So it is a good news story all around in terms of the UTC USNO time transfer that goes on with the GPS constellation.

We have 26 satellites on orbit. I will get into the status of the individual satellites, but it is a very successful program, time transfer being a by–product of the primary emphasis of navigation. For those who don't understand all of how GPS works, a nanosecond of time error equates to about a foot of navigation error in terms of the way we do business in looking at the navigation specifications. So, time is extremely important to getting all our error rates for the primary mission down into the requirements.

I will talk a little bit more about it later, but time transfer keeps finding better and better ways to do business, especially when it comes to secure telecommunications, cryptosynching, and into the next generation commercial telecommunication requirements. As we try to work at the margins in terms of better ways to do telecommunications; packet, burst, etc. GPS promises to be valuable.

I put this slide (Figure 4) up just to show you that again GPS is performing its primary mission extremely effectively. The reason I want to talk to you about this slide is this: the requirements for GPS, as I mentioned are in time 100 ns, the availability and the reliability requirements on GPS are far less than the actual performance of the system to date (Figure 5). So we get to the "chicken or the egg," what is the requirement? I think we need to start thinking about what is the expectation. In other words, I think the expectation is that we never get worse than what we have today, and that we look for ways to improve it. How we get that expectation into hard requirements that people can defend in the budget process is not a trivial task. But requirements, if you look at the hard definition of military requirements or specifications, the answer is that we are doing much better than we should be, so I cannot have any money to make any improvements. I think that logic does not follow. People expect GPS service at its current rate or better; then we need to figure out how we make those expectations and customer satisfaction indexes into requirements. Because unless we tackle that, we cannot do a very good job of defending the budget to make improvements to support PTTI capabilities.

I put this slide (Figure 5) up to show you that while some of you are focused strictly on PTTI, GPS is not. GPS has an important secondary payload of nuclear detonation detection. As we were saying at our workshop, the sensors and the sophistication of those secondary payloads actually takes up more time than the primary navigation clock payload activity on to meet our primary mission. A very important treaty monitoring capability, a very important national security capability, and clearly a political activity in terms of "civilianizing" what we currently know as "GPS." It is easy for people to say let's set up a civil organization to do GPS; but my input is that this secondary payload has a lot of heavy hitters that are going to be very hesitant to let that happen.

This slide (Figure 6) shows a look at time transfer. It goes from plus 60 to minus 60 ns. Over the course of up to three years, that is our daily performance. I am going to get into some more time transfer performance in a moment. But again, that is looking back. This peak is J–Day 355. Last Christmas season, we were doing some calibrations between USNO and we had a little miscommunication between a master control station. And we think we have those procedures ironed out. As a matter of fact, we did learn some lessons from that. Some more updated, a little bit less crunched data. Again, here is a look at a different way to format a quarter's worth of GPS data (Figure 7), the third quarter of '93. And we are now looking at RMS here as what we think is a better measurement of how we are doing in terms of steering to USNO. And you would expect that is okay only if your axis kind of goes around zero; I think this information points that, at least from a cursory look, that is the case.

Expanding a little bit more into the more current data, again it is a good news story (Figure 8). The margins there on the axis, plus or minus 20 ns, are five times better than specified. So GPS continues to perform with no regard with what the requirement is, in that we are looking for ways to do it better every day; and not provide any less service than people have come to expect to satisfy our customers. Again that is kind of not the schooled solution, but I think it is something that we on the government side of things need to be able to articulate on and then defend: that GPS is becoming a utility; in many ways it will soon be a utility that people are not going to expect less service than is available today – to the PTTI community, to the navigation community, or to people that rely on it for a variety of other applications, geodesy, etc., etc. So we don't really spend too much time patting ourselves on the back saying that we're exceeding specifications or meeting everybody's requirements. We are looking for ways to do better and looking to working with the community, both industry and other government agencies, to improve on an already–good product so that it will continue to be a national asset; and we will be good stewards of that national resource.

Here is the performance chart (Figure 9) that I would like to spend the most time on. And I will start at the top. These are the four satellites per plane; these are the planes we have on orbit. Please note the legend. As you can see, there is a little bit of activity in terms of clocks. The three Block 1 clocks are all on rubidium; that is SVN 10, 9 and 11. Nine is grounded right now because it is in eclipse season. However, there is another satellite, Block 2–A, SVN 37, that is in that same slot, so no big deal; except that Selective Availability ("SA") is turned on for all the Block–2 satellites. Some of you may have seen that. Eleven is a satellite that was qual–tested twice. Some of the parts weren't flight tested, but we flew them anyway. And it is performing very well. However, we are starting to see some problems with static–electric discharge so we give that satellite lots of care and attention. Unfortunately, the automatic features that check for proper signal on Block–2s weren't built into this satellite. It can run away and give you a bad time before we are able to set it "unhealthy" and basically turn it off. It looks like we will swap out the clocks on SVN 21 and SVN 16 in the next six months. They are displaying normal degradation and each satellite still has 3 spare clocks.

For those who are relying on GPS and have the capability to take out SA, which most of the sets do, I would stay away from 11 if you can get it out of your clock solution. If by chance you don't have that capability, then I would strongly recommend that you follow any suspected anomalies with checking on the notices and advisories that we put have out; because we have seen some problems with that clock.

SVN 10 is actually the satellite that is producing the navigation signal in Slot A–1. SVN 39 which is also in slot A–1 has been operated since November 2 without any updates to the clock or the navigation package, and we're going through and watching what we call an "extended navigation" portion of the payload test. The requirements were for it to operate and gracefully decline for 180 days. We don't expect to do that, but we are collecting data for at least two–weeks of extended navigation with no uploads. There is probably some scientific interest in that and we will be glad to share that information with anybody who has a legitimate need.

SVN–19, we're having trouble with the course acquisition code. It is not a problem for timing – well, maybe it would be. But it has been driven by interest in the navigation package to do carrier phase differential GPS on the standard positioning service; and we have a problem there that we are working on with our systems engineers.

Plane 2, all the satellites in this plane are in good shape. In August, we launched SVN–35 which has a laser retro–reflector on board as we try to sort out some clock movement versus error in ephemeris. The NRL folks are supporting this through the NASA laser network that we spoke about earlier this morning. We are excited to see some data. We don't expect it to have any immediate impact on the way we do business. In the long–term, we think we can fine–tune our Kalman filter and separate the clock error form the ephemeris error that we see in the constellation.

This satellite, SVN–31, is a second–source cesium clock; this is not a cigar, it's a thermometer. We found that it is a little temperature sensitive, and we are trying to get our arms around that. We are flying really four different companies' clocks on orbit right now. The rubidium clocks, Number 25, and all of the three Block–1 rubidium clocks are built by Rockwell. Most of the cesiums on the Block–2s were built by Frequency and Time Systems (FTS). And, we have two others: Frequency Electronics, Incorporated (FEI) built 31 and 32 and Kernco, Incorporated built 34 and one more. So we are actually flying three different kinds of cesiums. Right now, SVN 34 with a Kernco clock is the best performing clock we have on orbit.

The Federal Radionavigation Plan is updated every two years (Figure 10). The agreement was signed by the Secretary of Transportation and the Secretary of Defense. And GPS has now become kind of embedded in almost every page of this document. In terms of timing accuracy, they talk about two requirements, first, 100 percent availability at full operational capability. And second is the key that I wanted to emphasize: the guarantee by the U.S. Government (not the DoD but the personnel above the DoD), continuous GPS use for the foreseeable future; and a commitment by the President for six–years notice to any termination to GPS service as you know it today, which means free of direct charge. There is lots of talk to "get GPS out of DoD's control;" in fact, it is already being governed by the civilians who are in charge of DoD and work with other interagencies, especially the DoT, in terms of the way we do business. Let me make it perfectly clear that I **DO NOT** have a dial that changes the selective availability level at the master control station, nor does anybody in a military uniform have authority to direct that. That has got to come from the civilian sector and probably the President, in terms of changing selective availability on GPS.

Finally, a couple of issues (Figure 11). Initial operational capability and full operational capability. September 30, our commander of Space Command sent the message to the air staff saying that we think we're at an initial operation capability; the Secretary of Defense sometime this month is expected to notify the Secretary of Transportation that we have achieved initial operational capability and make it available to civil use in the transportation world. A "full operational capability" is a military term that will occur probably in February of '95; it has more to do with the maintainability and sustainability of the equipment that we use to run the operational control segment.

DoT–DoD Task Force is meeting; the report is due out this month as well. Initial indications are that, it doesn't make any radical changes to the way GPS has operated. It does make some recommendations in terms of cost reimbursement for enhanced GPS, which is differential GPS at this point. There is also some discussion about wide–area differential and local differential, using GPS. This is not really a timing issue. As I mentioned, we are testing SVN 39 and getting a lot of good information about the way the system works with a clock on orbit that is not updated and steered. That test we expect to be completed in the next couple of weeks.

QUESTIONS AND ANSWERS

Albert Kirk (JPL): On your plot of time errors, the one just before the smiley–faced plot, I detected what looked like periodicity. Can you comment on that please?

Col. Freer: We haven't been able to get any more systematic error out than we have right now. Again, it is a scale issue. If we scaled it to 100 ns, it would look like a straight line. And we do update it daily and we cannot steer one for one to the USNO time. Tom?

Tom Meyer (Falcon AF Base): I will be expanding on this tomorrow when I give my evening section, but very quickly, the steering algorithm we use within GPS Master Control Station, our common filter uses a least–squares fit of only two points. And it is a very old algorithm, not very robust, and certainly doesn't change on a day–to–day basis, as we would like to see it. So what you do see is if you introduce any sort of variation into it, you will see this oscillatory nature continue for a couple days; and then again you will see it if we introduce a couple more points that aren't on the norm or follow a predicted pattern.

Marc Weiss (NIST): I assume those RMS numbers, 15 to 20 ns, are using PPS, that is SA–capable receivers?

Col. Freer: That's right. And frankly, that is an issue that we, the Air Force, the military, is trying to deal with in terms that we have not designed a system to directly measure the effects of SA. And the FAA is concerned about that, and we are trying to sort out how to directly measure the effects of SA. We can add the math, but if something goes wrong then we don't have a direct measurement of the effects of SA and a concern (in terms of integrity) that we are guaranteeing a service that we are monitoring at the PPS level; and then making some mathematical assumptions; but we haven't closed the loop in terms of direct monitoring of the SPS signals.

Christian Veillet (Observatoire de la Côte d'Azure): You mentioned putting up GPS–35. Do you plan to have others in the near future?

Col Freer: Yes. The March launch, SVN–36, will also have a laser retro–reflector. Again, this is not an operational upgrade; it's an experiment that we're working on in conjunction with NRL and the NASA community and the clock research community. And we don't expect immediate operational impacts to the way we do business. It is a cooperative effort in terms of some research at that orbital level. The satellites mentioned in the presentation this morning, TOPEX, for instance is a low–flyer in relationship to GPS flying at a 12–hour orbit for 11,000 miles or so. There are not many satellites flying at that exact orbit with the exact time ephemeris mix that we are trying to isolate.

Christian Veillet: A second question. Do you plan in the near future to have a laser link, a LASSO–like type transfer equipment, on board of a GPS satellite?

Col. Freer: Not that I am aware of. Let me mention that we're bending metal on Block 2–R, which is the replenishment of the current constellation; and we are in the requirements phase of the follow–on to 2–R. Some of you may have heard the term "Block 2–F." That is no longer in vogue; they haven't figured out a letter; but they are still in the requirements phase in terms of deciding how to go and they haven't fully nailed that down. But I haven't heard anything about laser cross–link type stuff.

MASTER CONTROL STATION OPERATIONS

LT COL HARRISON C. FREER

FIGURE 1

OVERVIEW

PERFORMANCE

FEDERAL RADIONAVIGATION PLAN LANGUAGE

ISSUES

FIGURE 2

GPS-UTC
TIME TRANSFER PERFORMANCE

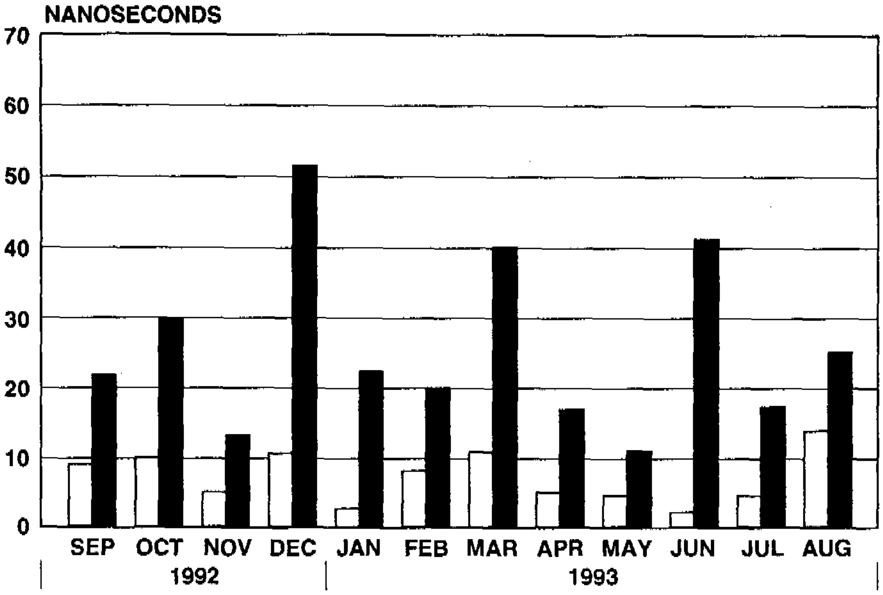
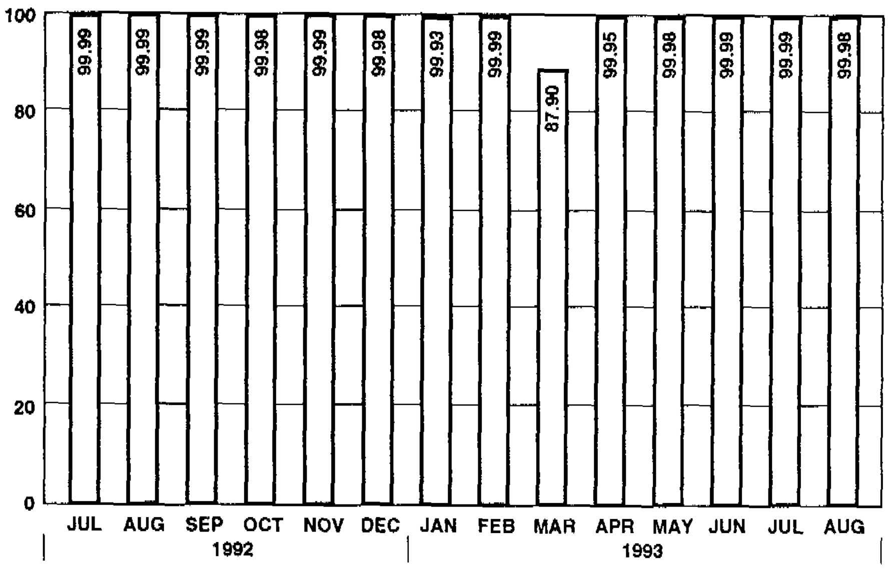


FIGURE 3

NAVIGATION SATELLITE AND SIGNAL RELIABILITY



CY '93: 98.50
CY '92: 99.98
CY '91: 99.98
CY '90: 99.92

– OPS RELIABILITY OF SATELLITES AT 12M OR LESS
– BLOCK II SATELLITES ADDED WHEN OPERATIONAL

FIGURE 4

NDS PERFORMANCE AND RELIABILITY

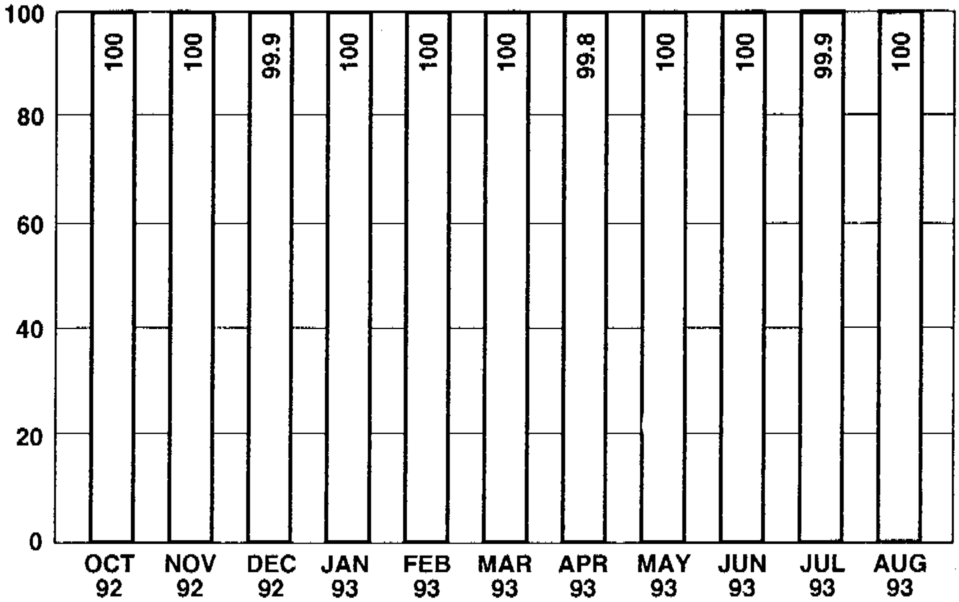


FIGURE 5

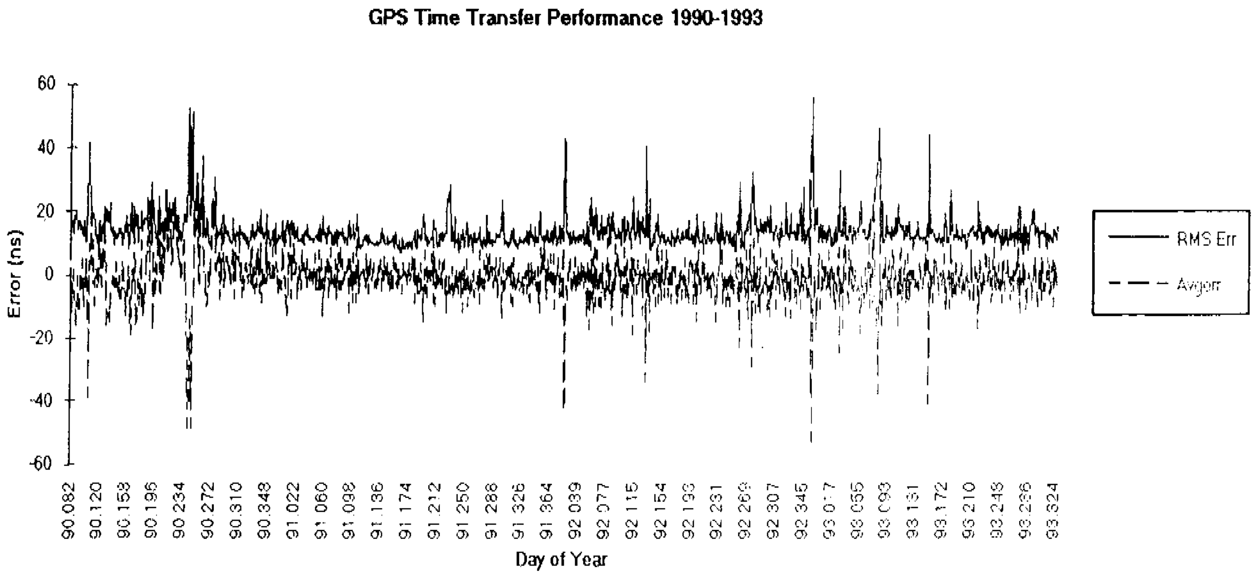


FIGURE 6

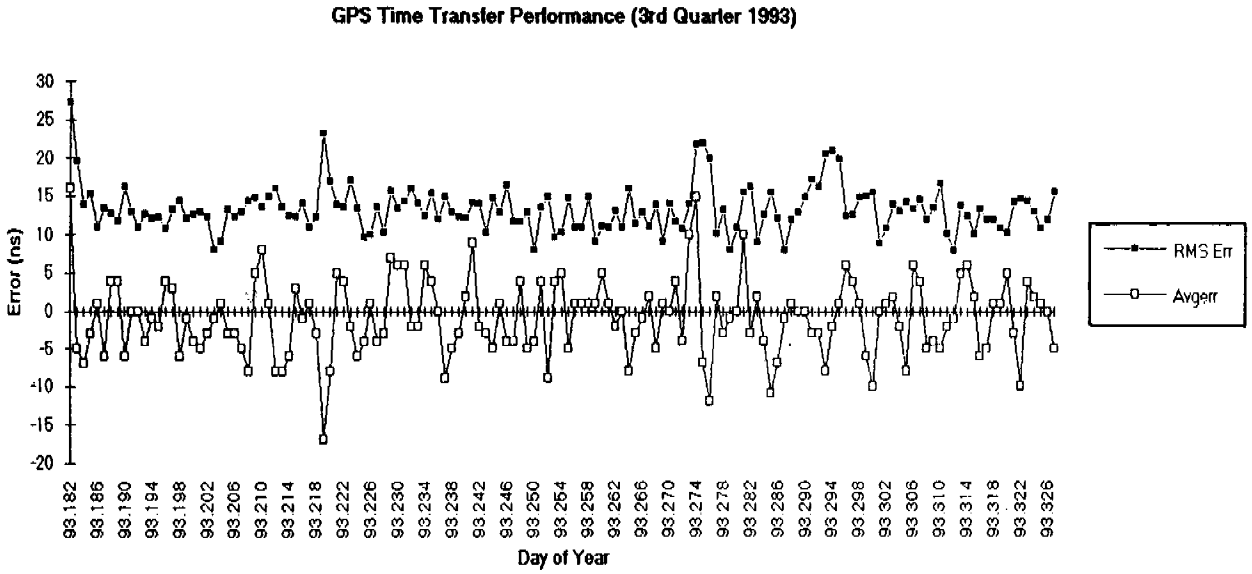


FIGURE 7

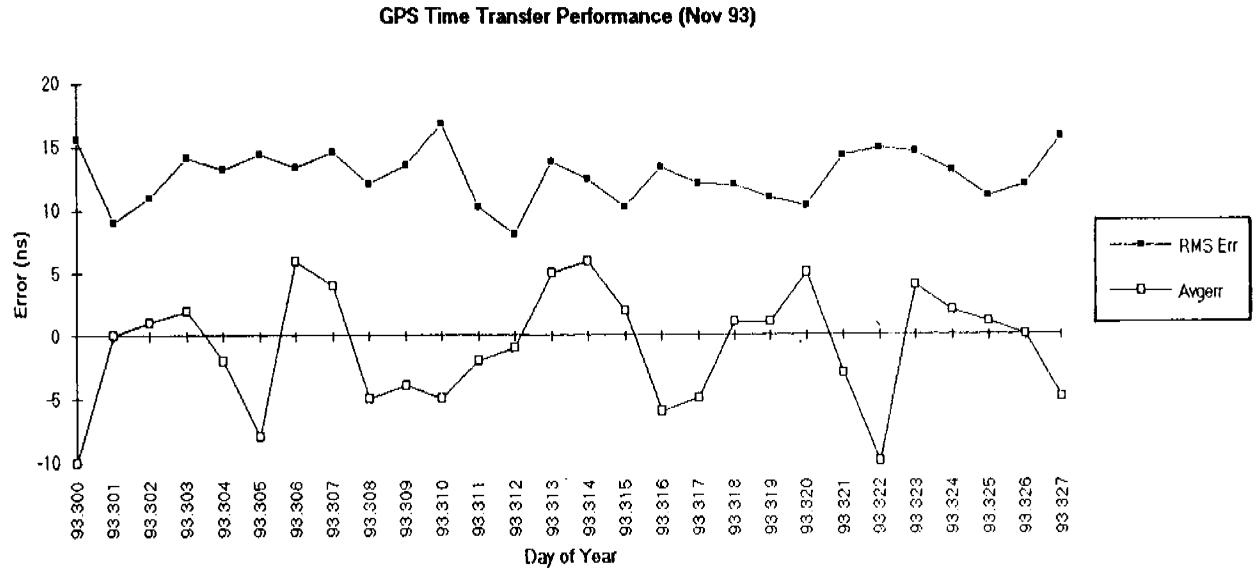


FIGURE 8

TABLE 6: NAVSTAR MISSION OPERATIONS STATUS

DECEMBER 1, 1993

ON-ORBIT VEHICLES

CLOCK OPERATIONAL PERFORMANCE OCT. - NOV., 1993

PLANE \ SLOT	1	2	3	4
A	SVN 39-Cs; SVN 10-Rb	SVN 25-Rb	SVN 27-Cs	SVN 19-Cs (C/A, P)
B	SVN 22-Cs	SVN 20-Cs	SVN 13-Cs	SVN 35-Cs
C	SVN 11-Rb; SVN-36 Planned March 1994	SVN 28-Cs	SVN 31-Cs$_2$	SVN 37-Cs; SVN 09 Rb
D	SVN 24-Cs	SVN 15-Cs	SVN 17-Cs	SVN 34-Cs$_2$
E	SVN 14-Cs	SVN 21-Cs	SVN 16-Cs	SVN 23-Cs
F	SVN 32-Cs$_2$	SVN 26-Cs	SVN 18-Cs	SVN 29-Cs$_2$

LEGEND

EXCELLENT | EXCELLENT TO GOOD | GOOD | FAIR | WARMING UP

FIGURE 9

1992 FEDERAL RADIONAVIGATION PLAN REQUIREMENTS

TIMING ACCURACY (P. A-38)

PPS 200 NS **SPS 340 NS**

AVAILABILITY

100 PERCENT AT FULL OPERATRIONAL CAPABILITY (P. A-40)
CONTINUOUS OPERATION OF GPS FOR THE "FORESEEABLE FUTURE" (P. 3-43)
MINIMUM SIX YEARS ADVANCE NOTICE OF DETERMINATION OF OPERATIONS (P. 3-43)

FIGURE 10

ISSUES

INITIAL / FULL OPERATIONAL CAPABILITY

DOT / DOD TASK FORCE

EXTENDED SVN39 TEST

FIGURE 11

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