IMPLEMENTATION OF A STANDARD FORMAT FOR GPS COMMON VIEW DATA*

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Abstract

A new format for standardizing common view time transfer data, recommended by the Consultative Committee for the Definition of the Second, is being implemented in receivers commonly used for contributing data for the generation of International Atomic Time. We discuss three aspects of this new format that potentially improve GPS common–view time transfer: (1) the standard specifies the method for treating short term data, (2) it presents data in consistent formats including needed terms not previously available, and (3) the standard includes a header of parameters important for the GPS common–view process. In coordination with the release of firmware conforming to this new format the Bureau International des Poids et Mesures will release future international track schedules consistent with the new standard.

INTRODUCTION

A new format for standardizing common view time transfer data, recommended by the Consultative Committee for the Definition of the Second (CCDS), is being implemented in receivers commonly used for contributing data for the generation of International Atomic Time (TAI). The primary means of remote clock comparison for generating TAI is common–view GPS time transfer[1] . The global accuracy for this type of time transfer is currently less than 10 ns[2] . Understanding the sources of inaccuracy, the BIPM initiated an effort to standardize data-taking methods used in receivers and data transfer methods used for reporting to the BIPM. By combining this effort with the use of good coordinates, precise GPS satellite ephemerides, and measured local ionospheric delays, we hope to increase the accuracy for common–view time transfer[3] .

One of the major motivations for standardization is the implementation of Selective Availability (SA) in GPS satellites. With SA, GPS timing is degraded as a way of limiting the navigation

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accuracy available to the standard positioning service (SPS) user. This follows since navigation in GPS is accomplished using measurements of time as received from satellites. If common–view time transfer is performed strictly, that is, with measurements taken on identical seconds, and with receivers which process the signals and the data identically, then the GPS satellite clocks cancel completely. SA makes this need for strict common–view even more important. We include in this paper some direct satellite data with SA and predict the effects on common–view time transfer due to differences in receivers. Thus, a standard can improve time transfer by allowing common–view time transfer to be done with different receivers and still cancel the effects of the satellite clock.

The new format has potential to improve GPS common–view time transfer due to a number of elements: (1) the standard specifies the method for treating short term data, (2) it presents data in consistent formats including needed terms not previously available, and (3) includes a header of parameters important for the GPS common–view process. Essential to common–view time transfer is that stations track satellites according to a common schedule. In coordination with the release of firmware conforming to this new format the Bureau International des Poids et Mesures (BIPM) will release future international track schedules consistent with the new standard. In this paper we summarize information about the short–term data processing, the header and the data format. When developing the standard for a receiver, one should obtain all the detailed information as reported in the Technical Directives[4] .

SHORT TERM DATA PROCESSING

Data processing is performed as follows:

1. Pseudo–range data are recorded for times corresponding to successive dates at intervals of 1s. The date of the first pseudo–range data is the nominal starting time of the track. It is referenced to UTC and appears in the data file under the acronyms MJD and STTIME.

2. Least–squares quadratic fits are applied on successive and nonoverlapping sets of 15 pseudo–range measurements taken every second. The quadratic fit results are estimated at the date corresponding to the midpoint of each set.

3. Corrections are applied to the results of (2) to obtain estimates of the local reference minus the Satellite Vehicle (SV) clock (REFSV) and of the local reference minus GPS time (REFGPS) for each 15 second interval.

4. The nominal track length corresponds to the recording of 780 short–term measurements. The number of successive and nonoverlapping data sets treated according to (2) and (3) is then equal to 52. For full tracks, the track length TRKL will thus equal 780 s.

5. At the end of the track, least–squares linear fits are performed to obtain and store the midpoint value and slope for both REFSV and REFGPS. Since these two are related deterministically by nearly a straight line they will have the same rms deviation around the fit, which is also stored as DSG. In addition, least–squares linear regression gives the midpoint and slope of the ionospheric and tropospheric model values, and the ionospheric measurements if they exist.

THE EFFECTS OF SA

We investigate the effects of SA by taking measurements every 15 s of GPS – UTC(NIST) tracking different satellites from horizon to horizon. We took data sequentially from three different satellites on two consecutive days, November 21–22, 1994. The satellites had pseudo-random code numbers (PRN's) 20, 22, and 25. Figures 1–3 show the data from the three satellites, and Figures 4–6 show the time deviation TDEV of the three, respectively.

The new standard will cancel all the clock dither when used for common–view GPS time transfer, provided that each of the two receivers involved track the same satellites over the same time periods. If there is a difference of 15 s in the tracking, for example if one receiver tracks 15 s less than the other, then the clock dither of SA will corrupt the common–view time transfer. We can estimate this by looking at the expected dispersion in time at due to SA at 15 s. The rms of the three TDEV values for $\tau = 15$ s is 11 ns. From the TDEV plots we see that the slope on the log–log plots starts consistent with a model of τ^0 from 15–30 s. If we assume a model of flicker phase modulation (PM) for $\tau = 15$ s this implies an expected time dispersion of 13 ns[5] . Over a 13 min track there are 52 estimates of REFGPS and REFSV each from a quadratic fit over 15 s of data. Let us consider the case where one track is a full–length track and the matching track in another receiver is 15 s short. If we can assume that the effects of one 15 s point average down in the linear fit as the square root of the total number of points, then we can expect the effect on the common–view time transfer to be

$$\frac{13\text{ns}}{\sqrt{52}} = 1.8 \text{ ns.} \tag{1}$$

Thus SA could add approximately 2 ns to a common–view uncertainty budget with only a mis–match of 15 s from exact common–view. With a goal of 1 ns we see the reason why a standard for data taking can help common–view time transfer.

Many users receive GPS time directly from the satellites without using the common–view method to compare with another lab. From considering the TDEV of SA, we can design a filter that averages SA optimally, to allow users to obtain the best possible restitution of GPS time[6] . From the three TDEV analyses we see a bump rising from 1 min and dropping at 16 min. This effect could be due in part to a periodic behavior with a period of approximately 16 min[7],8 . Averaging can improve the GPS restitution if the TDEV values drop with increasing <insert 4>. Yet there is no indication in these data that the TDEV values drop significantly beyond 16 min. This may be due to effects at the beginning and end of the tracks when the elevation is low. This suggests limitations on the potential for filtering SA. Yet our data were taken using a single channel receiver. A multi–channel receiver could improve on filtering. It may be that the combination of SA signals still drop in TDEV, allowing improvement from averaging.

THE DATA FORMAT

The data format consists of:

1. a file header with detailed information on the GPS equipment,

2. a line header with the acronyms of the reported quantities,

3. (3) a unit header with the units used for the reported quantities,

4. (4) a series of data lines, one line corresponding to one GPS track. The GPS tracks are ordered in chronological order, the track reported in line n occurring after the track reported in line (n-1). Each line of the data file is limited to 128 columns and is terminated by a carriage-return and a line feed. The format for one line of data can be represented as follows:

No measured ionospheric delays available

```
0000000000000000000000000000000000000000000000000
0000000000111111111122222222223333333333334444444
123456789012345678901234567890123456789012345 6
PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV*****
*************hhmmss**s**.1dg*.1dg****.1ns*****
*12*12*12345*121212*1234*123*1234*+1234567890*

0000000000000000000000000000000000000000000000000011
44455555555555566666666666777777777788888888889999999999 00
78901234567890123456789012345678901234567890123456789 01
*SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*
.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s
+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*

11111111111111111111111111111
0000000001111111111222222222
2345678901234567890123456 78
CK
**
12optionalcommentsoptionalc
```

Measured ionospheric delays available

```
0000000000000000000000000000000000000000000000000
0000000000111111111122222222223333333333334444444
123456789012345678901234567890123456789012345 6
PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV*****
*************hhmmss**s**.1dg*.1dg****.1ns*****
*12*12*12345*121212*1234*123*1234*+1234567890*
```

```
00000000000000000000000000000000000000000000000000000011
44455555555555666666666677777777778888888888999999999900
78901234567890123456789012345678901234567890123456789012345678901
*SRSV****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*
.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s
+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*


111111111111111111111111111111
000000001111111111222222222
23456789012345678901234678
MSIO*SMSI*ISG*CK
.1ns.1ps/s.1ns**
1234*+123*123*12optcomments
```

The following is an example of what the data looks like, using fictitious data.

Example (fictitious data)

```
GGTTS GPS DATA FORMAT VERSION = 01          '
REV DATE = 1993-05-28
RCVR = AOA TTR7A 12405 1987 14
CH = 15
IMS = 99999 or IMS = AIR NIMS 003 1992
LAB = XXXX
X = +4327301.23 m
Y = +568003.02 m
Z = +4636534.56 m
FRAME = ITRF88
COMMENTS = NO COMMENTS
INT DLY = 85.5 ns
CAB DLY = 232.0 ns
REF DLY = 10.3 ns
REF = 10077
CKSUM = C3 or CKSUM = 49
```

C-2.

No measured ionospheric delays available

```
PRN CL  MJD   STTIME TRKL ELV AZTH    REFSV       SRSV      REFGPS    SRGPS  DSG
IOE MDTR SMDT MDIO SMDI CK
             hhmmss  s  .1dg .1dg    .1ns      .1ps/s      .1ns     .1ps/s .1ns      .1ns.1ps/s
   3 8D 48877  20400  780 251 3560  -3658990     +100       +4520     +100   21 221   64 +90
-27 BBhello
  18 02 48877  35000  780 650  910  +56987262   -5602       +5921    -5602  350 123  102 +61
281  +26 52
  15 11 48878 110215  765 425 2700    +45893    +4892       +4269    +4890  306  55   54 -32
+15 A9
  15 88 48878 120000  780 531 2850    +45992    +4745       +4290    +4745  400  55   57 -29
+16 18receiv. out of operation
```

Measured ionospheric delays available

```
PRN CL  MJD   STTIME TRKL ELV AZTH    REFSV       SRSV      REFGPS    SRGPS  DSG
IOE MDTR SMDT MDIO SMDI MSIO SMSI ISG CK
             hhmmss  s  .1dg .1dg    .1ns      .1ps/s      .1ns     .1ps/s .1ns
.1ns.1ps/s.1ns.1ps/s.1ns.1ps/s.1ns
   3 8D 48877  20400  780 251 3560  -3658990     +100       +4520     +100   21 221   64 +90
-27  480  -37  18 F4hello
  18 02 48877  35000  780 650  910  +56987262   -5602       +5921    -5602  350 123  102 +61
281  +26 9999 9999 999 89no meas ion
  15 11 48878 110215  765 425 2700    +45893    +4892       +4269    +4890  306  55   54 -32
+15  599  +16  33 29
  15 88 48878 120000  780 531 2850    +45992    +4745       +4290    +4745  400  55   57 -29
+16  601  +17  29 00rec out
```

The definitions of the acronyms used in the data format follow. Note that a * stands for a space, ASCII value 20 (hexadecimal). Text to be written in the data file is indicated by ' '.

File header

Line 1: 'GGTTS*GPS*DATA*FORMAT*VERSION*=*01, title to be written.

Line 2: REV*DATE*=*' YYYY'-'MM'-'DD, revision date of the header data, changed when 1 parameter given in the header is changed. YYYY-MM-DD for year, month and day.

Line 3: 'RCVR*=*' MAKER'*'TYPE'*'SERIAL NUMBER'*'YEAR'*', maker acronym, type, serial number, first year of operation, and eventually software number of the GPS time receiver.

Line 4: 'CH*=*' CHANNEL NUMBER, number of the channel used to produce the data included in the file, CH = 01 for a one-channel receiver.

Line 5: 'IMS*=*' MAKER'*'TYPE'*'SERIAL NUMBER'*'YEAR'*', maker acronym, type, serial number, first year of operation, and eventually software number of the Ionospheric Measurement System. IMS = 99999 if none.

Line 6: 'LAB*=*' LABORATORY, acronym of the laboratory where observations are performed.

Line 7: 'X*=*' X COORDINATE '*m', X coordinate of the GPS antenna, in m and given with at least 2 decimals.

Line 8: 'Y*=*' Y COORDINATE '*m', Y coordinate of the GPS antenna, in m and given with at least 2 decimals.

Line 9: 'Z*=*' Z COORDINATE '*m', Z coordinate of the GPS antenna, in m and given with at least 2 decimals.

Line 10: 'FRAME*=*' FRAME, designation of the reference frame of the GPS antenna coordinates.

Line 11: 'COMMENTS*=*' COMMENTS, Any comments about the coordinates, for example the method of determination or the estimated uncertainty.

Line 12: 'INT*DLY*=*' INTERNAL DELAY '*ns', internal delay entered in the GPS time receiver, in ns and given with 1 decimal.

Line 13: 'CAB*DLY*=*' CABLE DELAY '*ns', delay coming from the cable length from the GPS antenna to the main unit, entered in the GPS time receiver, in ns and given with 1 decimal.

Line 14: 'REF*DLY*=*' REFERENCE DELAY '*ns', delay coming from the cable length from the reference output to the main unit, entered in the GPS time receiver, in ns and given with 1 decimal.

Line 15: 'REF*=*' REFERENCE, identifier of the time reference entered in the GPS time receiver. For laboratories contributing to TAI it can be the 7-digit code of a clock or the 5-digit code of a local UTC, as attributed by the BIPM.

Line 16: 'CKSUM*=*' XX, header check–sum: hexadecimal representation of the sum, modulo 256, of the ASCII values of the characters which constitute the complete header, beginning with the first letter 'G' of 'GGTTS' in Line 1, including all spaces indicated as * and corresponding to the ASCII value 20 (hexadecimal), ending with the space after '=' of Line 16 just preceding the actual check sum value, and excluding all carriage returns or line feeds.

Line 17: blank line.

Acronyms

The following are the defintions of the acronyms

PRN:	Satellite vehicle PRN number.
CL:	Common–view hexadecimal class byte.
MJD:	Modified Julian Day.
STTIME:	Date of the start time of the track in hour, min and second referenced to UTC.
TRKL:	Track length, 780 for full tracks, in s.
ELV:	Satellite elevation at the date corresponding to the midpoint of the track in 0.1 degree.
AZTH:	Satellite azimuth at the date corresponding to the midpoint of the track in 0.1 degree.
REFSV:	Estimate of the time difference of local reference minus SV clock at the middle of track from the linear fit, in 0.1 ns.
SRSV:	Slope of the linear fit for REFSV 0.1 ps/s.
REFGPS:	Estimate of the time difference of local reference minus GPS time at the middle of the track from the linear fit, in 0.1 ns.
SRGPS:	Slope of the linear fit for REFGPS 0.1 ps/s.
DSG:	[Data Sigma] Root mean square of the residuals to the linear fit for REFGPS in 0.1 ns.
IOE:	[Index of Ephemeris] Three digit decimal code (0-255) indicating the ephemeris used for the computation.
MDTR:	Modelled tropospheric delay at the middle of the track from the linear fit, in 0.1 ns.
SMDT:	Slope of the modelled tropospheric delay resulting from the linear fit in 0.1 ps/s.
MDIO:	Modelled ionospheric delay resulting from the linear in 0.1 ns.
SMDI:	Slope of the modelled ionospheric delay resulting from the linear fit in 0.1 ps/s.
MSIO:	Measured ionospheric delay resulting from the linear fit in 0.1 ns.
SMSI:	Slope of the measured ionospheric delay resulting from the linear in 0.1 ps/s.
ISG:	[Ionospheric Sigma] Root mean square of the residuals to the linear fit in 0.1 ns.
CK:	Data line check–sum: hexadecimal representation of the sum, modulo 256, of the ASCII values of the characters which constitute the data line, from column 1 to space preceeding the check–sum. (both included). There can be optional comments on the data line after the check sum out to the 128 character line length. These characters are not included in the line check–sum.

CONCLUSIONS

The new GPS data format, along with the prescription for processing short term data, can help improve common–view time transfer. Especially with the implementation of SA, common–view tracks can be significantly degraded if the two receivers tracking in common view do not work identically. The new standard can help us move toward a goal of 1 ns time transfer accuracy across intercontinental distances using GPS time transfer in common–view.

REFERENCES

[1.] Allan D.W. and Weiss M.A., *"Accurate Time and Frequency Transfer During Common-View of a GPS Satellite,"* In Proc. 34th Ann. Symp. on Frequency Control, 1980, 334–346.

[2.] Lewandowski W. and Thomas C., *"GPS Time Transfer,"* Proc. IEEE (Special Issue on Time and Frequency), vol.79, 1991, pp.991–1000.

[3.] Lewandowski W., Petit G. and Thomas C., *"Precision and Accuracy of GPS Time Transfer,"* IEEE Trans. Instrum. Meas., vol. IM42, 1993, pp.474–479.

[4.] Allan D.W. and Thomas C., *"Technical Directives for Standardization of GPS Time Receiver Software,"* Metrologia, 1994, vol. 31, pp. 69–79.

[5.] Allan D.W., *"Time and Frequency (Time-Domain) Characterization, Estimation, and Prediction of Precision Clocks and Oscillators,"* IEEE Trans. UFFC, vol. UFFC–34, 1987, pp.647–654.

[6.] Thomas C., *"Real-Time Restitution of GPS Time,"* Proc. 7th European Forum on Time and Frequency, 1993, pp.141–146.

[7.] Rutman J. and Walls F. L., *"Characterization of Frequency in Precision Frequency Sources,"* Proc. IEEE (Special Issue on Time and Frequency), vol.79, 1991, pp. 952–960.

[8.] Allan D. W. and Dewey W., *"Time-Domain Spectrum of GPS SA,"* Proc. Institute of Navigation GPS Meeting, Sept. 1994.

QUESTIONS AND ANSWERS

DAVID ALLAN (ALLAN'S TIME): I would like to just highlight the importance of the paper you presented on this new standard. Just to tell everybody, we believe, as we go through the theory of all the errors in common view, that with this new standard that an accuracy of one ns is achievable. To date, only about four ns has been documented just by way of where we are versus where we think the standard can take us. So I think it's very important work for the operational aspects, for clock input to TAI and UTC. So thank you for sharing it with us.

The other point that I would like to make is on the TDEV plot, that it is not a necessary and sufficient condition that if you have a hump in the data that it's due to a periodic event. There are at least two, and probably more, basic processes in the essay spectrum, and if one looks at longer-term data, in fact, this is confirmed; and there is not necessarily just the 60–minute type periodic phenomena. It's really two pretty much separate parallel processes; and, in fact, period modeling is not the best model that one would want to use.

I simply want to point out that it's not a necessary and sufficient condition, given a hump, that there is a periodic event.

M.J. VANMELLE (ROCKWELL): A couple of things. The rubidium is on 20 and not on 25. So it's hard to tell between rubidiums and cesiums there.

Also, did you ever do the experiment on the satellites that don't have SA on them, like number ten? Do you get that same two ns error with 15 seconds separation?

MARC A. WEISS (NIST): No, it's lower. I'm sorry, at 15 seconds, I'm not sure. There should be very short-term — - I'm not sure what we were trying.

HAROLD CHADSEY (USNO): A quick question for you. You were talking about the fact that when you do the common view that everything drops out. What about geometrical effects? Also, the fact that speed of the wave is not constant through the atmosphere, and you'll be effected more through a thick atmosphere than through a small atmosphere?

MARC A. WEISS (NIST): What I said that the effects of Selective Availability cancel completely if you do exact common– view time transfer and use a post–process ephemeris. Of course, the effects of ionosphere and troposphere are still there. Those need to be dealt with. The ionosphere, by measuring, and the troposphere can be helped also with measurements. They need to be if we're going to get the best we can.

GERNOT M. WINKLER (USNO): I think the time has come to start a little controversy, because we are all too peaceful down here. You have somehow attacked obliquely one of the tenants of my gospel which I have been preaching for 10 years. That is the melting pot method can average out by having a sufficient amount of data — - it can average out the effects of Selective Availability. Your comment was that you cannot be sure that biases are averaging out.

I want to remind you that the common view — - that's true; I mean, the common view cancels the effect of Selective Availability; but in the Selective Availability, the satellites themselves are not correlated; and the noise, which is superimposed, is strictly bounded. So if you have these

conditions and a sufficient amount of data collection, you completely suppress the individual noise. It just depends on how much data you need. And it turns out that if you have an eight–channel receiver and you average about six hours, that you cannot distinguish the resulting time transfer data from what we obtain with the keyed receiver.

The great advantage of a melting–pot method, compared to the common view, is that it is a robust method. You obtain perfection just commensurate with the effort that you have. You have internal checks on the result which you have, because we have a statistic of the variations. In a case of the common view, you have nothing. We know that in practice your one ns or two ns accuracy cannot be achieved. The question is, how do you check operation in an automatic system? How do you check that you really can rely on a single data point in comparison to the melting pot where you always have lots of data? Whatever happens, it will produce an outlier which is rejected.

So, I wanted to bring that out because there is a great difference in the basic philosophy. In the common view, theoretically you have a superior method; but in practice, I maintain there are weaknesses; and do you lack a measure of performance as compared to the melting–pot method where you have everything you need? Do you have really a robust method which protects you against outliers of whatever magnitude in fact?

MARC A. WEISS (NIST): I would like to respond to that. Thank you, Dr. Winkler. I know for years now we've had differences on this. It's going to wake people up a little bit. One point is that we don't have only a point in common view. We can do pretty much everything with common view that you do with a melting pot, and more. That with the melting pot, if you have a eight–channel receiver at two locations, then why not take the eight channels of data simultaneously at the two locations and cancel all the effects of SA, and then use robust statistics on the resulting data where all the biases have been cancelled, and all that's left is the noise? So I think all the statistics that you do with melting pot are still there with common view.

The other thing is that because data are bounded does not in itself imply that averaging brings you down to a single correct number. It may, in fact — - I don't doubt that it has worked on many occasions; but simply saying that they're bounded does not — - there's no reason that it should average down correctly.

GERNOT M. WINKLER (USNO): But we have a check, because you look at the distribution of your measurement points. On that you simply add all that area, which we have to do to obtain the competence of that area.

MARC A. WEISS (NIST): I don't agree with that. You can have all the data averaging down to the wrong number. I understand that that is not what you've found by doing it. But there's no guarantee that that always will happen.

CLAUDINE THOMAS (BIPM): Of course, I will have some words. For TAI, we have 46 contributing laboratories, I mean, laboratories keeping local UTC; and most of them are using GPS now. First of all, all of these laboratories, except maybe USNO, have only one channel CA code receiver. That is to say, except for USNO, no one has one channel receivers which are given reliable measurements. So obviously, we have no data to do the measurements at

the present time. Maybe it will come, but that's not the case for the moment. That's the first point.

The second point is that view of the BIPM for the computation of TAI has always been to try to reduce errors in the physical phenomena which are invoked; for instance, for the ionospheric delay, we like to use measured ionospheric delays as they are labelled. For the position of the satellite, we like to use precise satellite ephemerides. For the antenna coordinates, huge work was done some years ago by my colleague, Dr. Lewandowski (he can speak about that) in which he found accurate positions for the antennas. So we have always tried to phase all our sources and trying to reuse them. That was our viewpoint and that is what we did until now. That was the way we worked.

The last point, of course, common–view time transfer is done, it's computed. To find time difference between two local UTCs, we have a range, of course, for a long–distance time link, like between NIST and OP; we have a range common view for, let's say, two or three days. So we have some kind of average of course. For a smaller distance, like between Paris and PTB, Germany, we have a range, let's say, of less than one day. So that is to say we have some kind of average too.

I would say that what we are doing at the present time is the best we can do with the data we have.

RICHARD KEATING (USNO): You've stated that with common view, you're eliminating all these errors. I assume that's because of symmetry. But that's a theoretical position. When you get down to actual practice, reality doesn't always follow theory. I just have to ask you, how confident are you that you have no biases in common view? Can you really say that you can average and you are not getting any biases?

MARC A. WEISS (NIST): Well what would a bias be due to?

RICHARD KEATING (USNO): Well, for example, I'll give you an example. I have seen estimates of precise ephemeris accuracies. They've ranged from anything from one meter to 20 meters. There is a real possibility there that your precise ephemerides may not be as accurate and may contain real biases.

MARC A. WEISS (NIST): I think that's a good point in fact. Biases have to be due — – if you look at the common–view process, you have the satellite and then you have the ground stations on the earth; and then you have the atmosphere. So if you measure it exactly at the same time — – the only thing I'm claiming that cancels exactly is Selective Availability. In fact, the only thing I know for sure that cancels is clock dither. The ephemeris cancels to the extent that an error is perpendicular to the line between the satellites. If there is an error in the satellite position, it will add an error to common–view time transfer. And in fact, with precise ephemerides, prior to having the laser reflector, we had no way of knowing if they were accurate. They were simply consistent.

Errors can also come in the atmosphere due to ionosphere and due to troposphere, due to multi–path at the stations, and due to coordinate errors. So all of those things can add errors. It's going to be true whether you're using melting pot or common view or anything. Those are

all in GPS. Whenever you do GPS, you're concerned about ephemeris, ionosphere, troposphere, and multi-path, and coordinates.

I think a point that I would really like to stress about that — and I think your point is well made — is that it's the difference between accuracy and stability; that you can have numbers that agree perfectly, that are extremely well consistent and are consistently wrong. For example, if you took a commercial cesium clock — and this is the difference between a commercial cesium and a laboratory primary standard. If you have a commercial cesium and it's produced by a manufacturing technique, and there's a millimeter error in the end–to–end phase shift in the cavity, all the clocks will have that; and they'll all be off in frequency because of that, in exactly the same way; and all the other effects will average down and you'll end up with a bias that does not average.

That's an example of the difference between stability and accuracy. I think we need to be very careful when we use the word "accuracy." We're not talking about something that you can average; we're talking about something that you have to prove.

GERNOT M. WINKLER (USNO): You're example is making my point. How do you find out that all of these cesiums have a bias?

MARC A. WEISS (NIST): You evaluate them.

GERNOT M. WINKLER (USNO): You evaluate them and you look at the statistical distribution of what there frequencies are; and you compare them with a standard. You found out how it is.

MARC A. WEISS (NIST): But you don't compare with another standard. You evaluate them independently; you measure the effects through something that's completely independent.

CLAUDINE THOMAS (BIPM): There's a very big question of the difference between stability, precision and accuracy of course. There were some fundamental and formal papers about that at the BIPM. We consider that an accuracy is characterized by an uncertainty given as a one sigma value which was from the quadratic sum of the different uncertainties which are estimated from the different sources of errors which appear within common–view time transfer. I have already at the BIPM tried to do that, and I think that we can estimate an uncertainty of about 10 ns, it's eight to ten ns, one sigma for long–distant GPS common view, using precise satellite ephemerides from the IGS, and ionospheric measurements and with the hypotheses that the receivers themselves are correctly calibrated, which may not be the case; and which could add, of course, a bias. So let's say eight to ten ns, one sigma as the accuracy of GPS common views.

SOME PRELIMINARY RESULTS OF THE FAST CALIBRATION TRIP DURING THE INTELSAT FIELD TRIALS

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Abstract

At the beginning of 1994, field trials for an international two–way time transfer experiment using the INTELSAT V–A(F13) satellite at 307oE were started. The experiment was set up to last one year and involved six European time laboratories and two North–American time laboratories. Three times a week, 5–minute time transfer sessions were scheduled. At each of these laboratories, GPS common–view time observations were also performed.

From September 22 to October 22, 1994 a calibration trip which visited participating laboratories in Europe was organized. It involved a portable Vertex 1.8 meter two–way station (Fly Away STation [FAST]), belonging to USNO, and a portable GPS time transfer receiver, belonging to BIPM. The

calibration trip was conducted by members of the staff of USNO and Observatoire de la Cote d'Azur (OCA). It provided differential delays of the satellite Earth stations and GPS receivers. The initial analysis of this calibration campaign are reported here.

I. Introduction

The TWSTT technique has developed the reputation of being one of the most accurate and precise methods for time transfer[1,2]. One of the goals of the FAST Calibration Trip was to evaluate the quality of this measurement technique. While quality implies a somewhat nebulous expression, attempts can be made to quantitatively express the quality of the technique as a function of its capability. Its capability being defined in terms of its accuracy and precision. Obviously, a technique, where the accuracy is identical to the precision of measurement, is a technique which has reached its full capability. This relation can be shown as:

FULL CAPABILITY   **Accuracy = Precision**

If the accuracy of a measurement process is significantly less than its measurement precision than systematic errors are still affecting the process. The technique is, then, not yet of high quality.

In regard to TWSTT, estimates for the inherent precision of measurement for this technique range from 100–500 ns.[3]. It is possible to adopt 250 ps. as the current level of precision. Various estimates for the achievable accuracy range from 25 to 1 ns. This means that significant systematic errors are still affecting the results of TWSTT. It is the reason for undertaking this FAST Calibration Trip. It is hoped that, by careful measurements, more insight into the errors affecting TWSTT will be gained. It is assumed that one of the factors contributing to this error is our inability to measure the delays that signals undergo as they pass through the spacecraft. This thought to be one of the greatest contributors to the systematic errors affecting the measurement process.

II. FAST Calibration Trip

With regard to calibrating or determining delays through a system, there are three approaches. One is to design and develop equipment which will inject a signal into the system and consequentially trace its path throughout the station. This is the approach of Gerrit de Jong at VSL[1]. One can then take this calibration station around to different laboratories and measure the delays through other similar stations. This procedure could be called absolute calibration (AC).

Another approach would be to measure the delays throughout a small portable station and then transport this station to other laboratories in order to make side–by–side measurements with the station to be calibrated. This approach could be called absolute system calibration (ASC).

Still another approach would be to carry a transportable station around to different laboratories and make side–by–side measurements and refer all measurements to one primary reference

station. This is the approach adopted for this experiment since operational absolute calibration equipment has not yet been fully developed. This approach could be called relative system calibration (RSC)

Planning for the FAST calibration started at the Second Meeting of the CCDS Working Group on TWSTT held at NPL on 22 October 1994[5].

III. Observational Plan

The plan for RSC is rather simple. One makes initial measurements of the calibration station with respect to one fixed base station. A record of the difference is made. Similar measurements will be made at subsequent base stations and the differences also noted. At the same time, measurements are also made with respect to all other base stations participating in the experiment. Then, relative calibration with regard to any base station can be deduced.

The observation sequence followed at each laboratory visited by the FAST Team consisted of making side–by–side measurements between the FAST and visited laboratory for at least half an hour. Next, the FAST and laboratory base station each did time transfers with all other participating labs. This observation period usually spanned several hours. Finally, The FAST made side–by–side observations with the visited laboratory base station before going on to the next laboratory.

Also, at each base station, sufficient documentation of known, measured delays were made in order to correct for as many systematic offsets as possible.

IV. Data Analysis

The observed data obtained at VSL are presented in Tables 1, 2 and 3. Several consistency checks can be performed with this data. Because the FAST had not yet returned to its initial starting point at the time of the writing of this paper, a closure error or verification that nothing happened to the FAST during the trip has not yet been performed.

An initial analysis that can be done is to set up a three cornered hat method to see if there is consistency among the readings [6]. By differencing the data in Tables II and III, one can compute a value for the time difference between the FAST at VSL and the base station at VSL [FAST(VSL)–VSL(Base Station)]. These differences are given in Table IV. Next, one can compute the differences between the observed values for FAST(VSL)–VSL(Base Station) and the computed one. This is given in Table V. The data in Table V indicates that the two procedures agree to within about a nanosecond.

V. Discussion

The consistency check performed in Section IV points to another fact that has been the subject of some speculation. The data in Table I was obtained by going through the spot transponder on INTELSAT V–A (F13) which covers Europe. The data exhibited in Tables II and III was

obtained through the transponder which connects Europe to North America. Since the data measured for the difference between the FAST located at VSL and the VSL Base Station and the data computed from the set of measurements obtained using USNO as an intermediary is so close together, it seems that the delays through the different transponders are not that much different. This is not conclusively proven by this procedure. In any event, this is a notable observation. Once a permanent routine evolves in TWSTT, it is easy to visualize that data exchange may not always occur through the same transponders of the satellite being used. This observation merits further corroboration because it is a possible source contributing to the systematic errors of the measurement process.

VI. Conclusions

Preliminary analysis of some of the data obtained during the FAST Calibration Trip to Europe indicate that the equipment performed reasonably well. After additional data is obtained when the FAST is returned to USNO, it will be possible to verify this conclusion. It will also then be possible to establish a calibrated path between the stations which participated in the experiment. This will be an essential step to precede the next round of international time transfers.

References

[1] Veenstra, L., Kaiser, J., Costain, C., Klepczynski, W. and Allan, D. *"Frequency and time coordination via satellite"*, COMSAT Technical Review, Vol. 11, No. 2, 369–401, Fall 1981.

[2] Howe, D.A., Hanson, D.W., Jespersen, J.L., Lombardi, M.A., Klepczynski, W.J., Wheeler, P.J., Miranian, M., Powell, W., Jeffries, J. and Myers, A. *"NIST-USNO Time Comparisons using Two- Way Satellite Time Transfers"*, 43rd Annual Symposium on Frequency Control, 193–198, 1989.

[3] Hanson, D.W. *"Fundamentals of Two-Way Time Transfer by Satellite"*, 43rd Annual Symposium on Frequency Control, 174–178, 1989.

[4] de Jong, G. and Polderman, C. *"Automated Delay Measurement System for an Earth Station for Two-Way Satellite Time and Frequency Transfer,"* European Forum for Time and Frequency, 1994.

[5] Minutes of the Meeting of the BIPM Working Group of the CCDS on Two-Way Satellite Time Transfer, 20–21 October 1993.

[6] Winkler, G.M.R. *"Intermediate Term Frequency Measurements with the HP Computing Counter in the USNO Time System"*, Proceedings of the 4th Annual PTTI Planning Meeting, 152–167, 1972.

Table I Observed Time Differences [FAST(VSL)–VSL(Base Station)]		
MJD	49625.52419	49626.35815
Observed (FAST–VSL)	-667.28 ns	-669.31 ns.

Table II Observed Time Differences [USNO(Base Station) – VSL(Base Station)]		
MJD	49624.62534	49626.48090
Observed (USNO-VSL)	122.13 ns.	130.32 ns.

Table III Observed Time Differences [USNO(Base Station) - FAST(VSL)]		
MJD	49624.62327	49626.46942
Observed (USNO-FAST)	790.14 ns.	797.97 ns.

Table IV Computed Time Differences [FAST(VSL)–VSL(Base Station)]		
MJD	49625	49626
Computed (FAST-VSL)	668.01 ns.	667.65 ns.

Table V Observed–Computed Time Differences of FAST(VSL)- VSL(Base Station)		
MJD	49625	49626
(O-C) FAST-VSL	0.73 ns.	-1.67 ns.

PANEL DISCUSSION ON WORKSHOPS

Moderator: Raymond L. Filler
US Army Research Laboratory

RAY FILLER: Welcome to Part II of the audience moderator discussion which occurred yesterday. Today we're going to have our three session chairpersons (one is missing in action) give us a brief summary of what transpired at their session yesterday. Then for the rest of the time, we'll have audience questions. We're going to start with Joe White from the NRL whose session was entitled "Real Time Automated Systems."

JOE WHITE (NRL): We had a good crowd yesterday, we had about 30 or so people, pretty much a roomful. And we started off trying to define what a real-time automated system was, and basically came up with this kind of thing — that it was system that provided time or frequency, or both, to the user specification actually in real time; that it might include some sort of a historical calibration feature; but that basically what he wanted, he got out of the spigot right when he asked for it.

The other thing about the automated part, in particular, was there was not a frequent operator action required. In fact, in many cases, there wouldn't be an operator around it at all; we talked about fully-unattended and remotely-controlled type applications. The applications of these systems would typically include things like national time scales, remote time stations, and, as embedded pieces of equipment in military systems, telecommunication systems.

The class of performance that we were looking at for these systems, as far as time went, was on the order of 100 ns or better time accuracy; frequency accuracy to at least a part in 10^{11}; and again, this depended with some of them being as good as part in 10^{14}; and frequency stability, ranging from hydrogen maser systems, like a radio observatory system, to parts in 10^{13} at a second to other systems that might only be in parts in 10^{13} at a day. The other factor in this performance was that we required a synchronization to some national standard, or at least some network standard, and usually by a GPS or two-way time transfer measurements.

When we talked about the measurements, one of the things that came out that people thought was important there was that the measurements be accurately time-tagged when they're collected. Those of you that played with these systems, particularly things run by PCs, know that those time tags can often be in large error. And we talked about means of doing that, including having a hardware clock in the measurement system that provided very accurate time; or, alternatively, using one of the telephone or network time synch mechanisms for the control computer to keep it on time to the millisecond range.

Naturally, we all wanted nice quiet, unambiguous measurements, and we decided, in general, that meant making time measurements — or frequency measurements, I should say — at

5 MHz to get the smoother performance there. While one pps measurement was certainly necessary for things like GPS measurements, two–way time transfer measurements, in general, there were a lot of problems with those, as far as having a clean pulse to measure, establishing the right to triggering levels, the effects of long cables, those kinds of things.

We next talked about distribution systems, and we started off talking about the effects of the local environment on the distribution; that is, that the temperature, humidity, those kinds of things, often had an effect. The other thing that went with that is having a good way of connecting to it, that the connectors that were used and the types of cable were very important to achieving a good distribution, that just the distribution amplifier alone didn't really cover everything. We were typically looking for isolation of at least 100 dB between ports, and also 100 dB from output to input, which we have seen some systems not doing.

The other thing that was kind of interesting in distributions, we talked about widely–distributed systems, for instance, a communications network where the real–time automated system wasn't two racks sitting on one site, but a rack here, and a rack 100 miles away, and another that really is — in the terms of the way that system worked, really that was the system that they wanted to have as a real–time automated system. So sometimes the whole interconnection and distribution gets to be a pretty large problem.

From there, we went to software, or actually, robustness, which got us to software pretty quickly. Sam Stein gave what I thought was a nice definition of robustness; and that is that the small error in the system caused only small problems to the system operation. For instance, losing one device in the system shouldn't cause it all to die. That got us immediately to computers, and we decided there that you really need both stable user software, the specific software you wrote to make that system work, and stable underlying operating systems for the computer itself. A lot of times that's UNIX or OS–2, or something like that; that there often was great peril in changing versions of operating systems that ran the whole thing.

Also, in the robustness area, we talked about the trade–off between single point failures and the things that you do to try to avoid single point failures; there is a point of diminishing marginal returns as you add more and more redundancy and put in the switches to put the redundant sides together, that often you actually got to a system that was worse than what you started with; and that one of the solutions to that was to encourage your user of the system, the people that take the time and frequency outputs, to design their systems to be tolerant of small glitches; so that you really had a robust system in total, not just in the time and frequency part, but also in the piece that used the time and frequency.

We ended the robustness part with trying to define how you put robustness in the specification. And I think we came to the conclusion it was difficult to define that. There are really two problems. One was that you had to define what the users environment was, because what was robust for one environment may not be robust at all for another. And the other problem was that it's awfully hard to think of everything that can go wrong. You try to come up with very blanket–type statements that will cover everything; and when you field the system, you almost always find out there is something you left out. So I think we wound up agreeing that we had a difficult problem that we didn't quite know how to define.

We ended up talking about maintenance and testing. The general consensus, as far as maintenance went, was that we thought that systems should be maintained generally at the box level in the field; that the modern hardware is simply too complex to deal with in the field; that no matter how well you train your technicians, it's very difficult, it's very expensive; that, in general, you ought to have a lot of spares and rotate them around and let the manufacturer or at least some highly–trained depot deal with most of those issues. To support determining when we had problems, we talked about built–in tests; and also, about a remote diagnostics capability.

That's pretty much it.

RAY FILLER: Thank you. Next, we'll have Dick Sydnor from JPL. His session was entitled "Real World User Requirements."

RICHARD SYDNOR: None of us seemed to know exactly what that title meant, so it took a little bit to get the thing going and we sort of wandered over a large area.

The first part of the discussion was sort of a déjà vu; we have talked about this many times in the past, and it's the problem of communication between the supplier and the user. We had a number of examples of a user having incomplete specifications. He forgets that he's going to take the spacecraft oscillator and launch it. So it has to have a shock and vibration specification, and he's left that out. Then he comes and says "Gee, it broke." That kind of thing happens more often than you might think.

Also, on the other hand, sometimes the oscillator or frequency standard supplier doesn't have a really complete set of specifications in his catalog. He doesn't say what effect vibration has on phase noise, for example; so sometimes it's difficult to figure out exactly what this particular item is going to do in your environment.

It was suggested that the supplier whongets a set of specifications from a user should question those requirements. He knows more about his oscillators than the user does probably. And if something looks a little bit awry, then he should question that and find out if the user means what he says, or if he has left something out. Many times the user is not very familiar with the oscillator and how it works, and its problems. And so there is a misunderstanding of what some of the specifications need. So there is a need for user education.

But who is responsible for that? That was kicked around for quite awhile. And John Vig had some comments about availability of literature that would outline tests and give information to the user. Some users say there is no information out there. And it just means that they haven't really looked very much.

I think the best suggestion, but probably the hardest to implement in that area, was that the supplier should be involved in the procurement from the very beginning. And that's a little hard to do with the present legal situation where you have competitive bids, how you get all these suppliers involved in it. But still, it looks like the most logical way to handle some of those problems. Those problems have been discussed many times in the past, and no solution has been forthcoming as yet.

Then we sort of wandered away from that area, and we started talking about problems,

various specific problems in terms of, say, distribution systems, time delay variations in cables, fiberoptics, how you stabilize fiberoptic systems, good connectors, that sort of thing; how you make sure that if you have a large network and you distribute it in time to, say, a bunch of people that are all various distances away from your main control clock, how they all have the same time, rather than varying all over the place due to the length of the cables. We had quite a bit of discussion on that.

Somebody asked what do the margins mean in a specification; and there is 90 percent probability that it will do such-and-such. Do people really understand that? I think the answer on that one was that nobody really knows exactly what is meant by that margin statement, and most people would rather have a specification that says it's guaranteed to do no worse than such-and-such.

There were some comments about various problems with crystal oscillators. It was brought to our attention that crystal oscillators stored at a very low temperature sometimes comes back out of that as a completely different crystal oscillator than the one you put in. There are aging rate changes and everything else.

That pretty much handles it. We had a large group in here. I would say the room was half full. But we had only five or six people that really contributed. Thank you.

RAY FILLER: I'm sorry that our third session chairman is not here. But if anybody who was there wants to make some comments, that's fine.

We're going to open the floor now to anybody for questions, comments, discussion of any sort, on this topic or maybe any other.

GERNOT M. WINKLER (USNO): It may be useful to elaborate a little bit more on your comments about margins and specifications. It's a problem which comes up over and over again; and that is that a system, whatever kind, has certain system performances; and then you have accidents. The two come from different distributions. And I think they should be separated.

It makes no sense to include accidents in a system specification; if you separate them, you can put a limit on how many you will tolerate per year, or per month, or whatever. But the system should be characterized after these accidents have been separated; because otherwise, you characterize two different processes with one number.

RICHARD SYDNOR: The margin discussion would have more to do with things like radiation exposure; after a certain number of rads of radiation, the probability is ninety peercent that it will be within a certain range. That sort of thing is typically what you get with radiation exposure, for example. The specs you see in manufacturers' catalogs on something says, for example, at a second, a part in 10^{13}. To me, that means that it's no worse than that, under any condition. A benign environment, obviously.

But if you are talking about systems, then you have to know not only, say, an upper limit, you have to know what the spread, what the distribution of the things are. And that's not in the manufacturers' catalogs. And many of them probably don't even know what it is. Some manufacturers will supply that information, if it's available, and they give it in terms of a

histogram or something like that, a performance of the different ones that were produced. And that's essential if you're doing a system design. But that wasn't discussed during our meeting.

DICK KLEIN (LOCKHEED AT KENNEDY SPACE CENTER): One of the things we've noted with more than one vendor, they'll take the specification, particularly a short–term specification of an oscillator, and publish it as the short–term specification of the GPS receiver, ignoring the pertubation of the circuitry within the receiver itself. And we found that to be a problem in more than one vendor. Particularly one problem, you could almost see a IRIG A on the 1 MHz output. And it turned out that they were able to correct it. But apparently, it wasn't tested at the factory, only the specification that the oscillator manufacturer gave.

JOE WHITE: I think that happens.

FRED WALLS (NIST): One of the limitations and specifications for almost all oscillators and synthesizers, and things of that sort, is a lack of specification for AM noise. And in many system applications, it is the AM noise that limits noise floor for residual measurements on amplifiers and other things; you have AM to PM conversion in your amplifiers and on mixers and on non–linear things. You can have two oscillators with the same phase noise, and yet different AM; and one will work and one won't work. And so, we need to raise the consciousness of both manufacturers and users to insist on AM noise specifications.

RICHARD SYDNOR: That's a good point. Many manufacturers don't even know what the AM noise performance of the oscillators are, because they measure just the phase component and not the AM component.

JOHN VIG: In our experience in the Army, many of the problems that come to us originate from the fact that people who are assigned the job of writing a specification, and this often involves major systems — people just sit down and write specifications in isolation, without regard to what's been written before; and they invent their own definitions, invent their own way of measuring certain parameters for which others have already worked out the details. For example, Ray came back from a meeting recently on a major radar system. He was asked to review the specification for the oscillator, and he found several things that were just basically wrong with the specification; one, of which, was that a frequency of zero —

RAY FILLER: Yeah, a frequency of zero. The frequency aging specification was plus or minus F zero, I think, or something.

JOHN VIG: Yes, totally nonsensical specifications are being written by people who don't know what they're doing. And this is for multi–billion dollar systems. So I think the manufacturers probably could perform a service by including in their literature a list of existing specifications that people could at least start with. There are IEEE specifications, there are military specifications, there are IEC specifications; we have a set of definitions in a CCIR[1] glossary. That means they are all internationally recognized and accepted documents.

If somebody has a job of writing a specification, it's so much easier to go to the existing document and just call out a paragraph of an existing document rather than to sit down and scratch your head, 'How should I define 'aging,' how should I define 'phase noise?' " and

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[1]International Radio Consultative Committee, now named the ITU–R.

invent things when there is no need for that.

JIM DeYOUNG (USNO): I think you said that Dr. Hellwig wasn't here. I took some notes, and so maybe I could give a short synopsis of what happened in our group, "User Environmental Effects."

Dr. Hellwig introduced a document that is going to be published, I believe, in the spring of '95, discussing user environmental effects, including radiation, acceleration, temperature, humidity, et cetera. It's going to be IEEE Standard 1193–1994.

Our group – after Dr. Hellwig gave this little bit of introduction to get us going, he also introduced three areas he thought were important, which is fitness of use. Does your device or system really meet your requirements that you originally had formed? He had another consideration: "How do I characterize this?" or, optimize the design is the bottom line on that. And then he discussed liability and survival of systems that are important in your timing or frequency.

We talked about complex systems, as that's getting to be a problem. We have specifications on individual devices, but then how do you merge those specifications on those devices and get a global picture of how the system is going to perform? We decided communication; in my few years in PTTI, that's always been one of the things we discussed in most of these forums, is communication as one of the most important things that can happen.

There were a few specifics that we discussed, and that happens to be related GPS clocks on board the satellites. At least one gentleman – I'm not sure of his name – mentioned something about the Block II–R clocks where, in the early incarnations of the GPS clocks, they were doing frequency stability measurements; I believe it was temperature variation in a vacuum. Those tests were done and they found some problems with specific clocks. But those tests aren't even being done now in the Block II–R clocks. So that was pointed out as possibly a problem.

Then one final thing we discussed was that the design materials and the components are very important; therefore, you want the highest quality of those things. That's pretty much everything I have in my notes from that group.

RAY FILLER: Anybody have anything else to add to that or to any other topic of discussion? Thank you.