

**A DUAL FREQUENCY GPS RECEIVER MEASURING IONOSPHERIC
EFFECTS WITHOUT CODE DEMODULATION AND ITS APPLICATION
TO TIME COMPARISONS**

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ABSTRACT

The GPS (Global Positioning System) satellites have become widely used for daily time comparisons between the major time and frequency laboratories. The precision of time comparison by GPS satellites is now between one and a few tens of nanoseconds depending upon the distance between the laboratories. In the case of long-distance time comparisons, the ionospheric effect is one of the largest sources of uncertainty. To compensate for the ionospheric effect, we have developed a novel GPS receiver which measures the total electron content (TEC) along the signal path to the GPS satellite. It uses the property of cross-correlation between the P-code (Precise-code) signals which are transmitted from GPS satellites by L_1 (1575.42 MHz) and L_2 (1227.6 MHz), without demodulating P-code signal. Preliminary results using the prototype receiver give, for about 3 minutes observation time, an uncertainty in the measurement of TEC of $2 \times 10^{16}/\text{m}^2$, equivalent to an uncertainty in the delay of L_1 signal of 1 ns. We have begun to apply the results of this receiver to the time comparisons between USA and Europe.

INTRODUCTION

The major errors of time comparisons by simultaneous trackings of GPS satellites (common view [1]) come from satellite position, receiving antenna position, estimation of ionospheric and tropospheric delays, calibration of receiver differential delays and radio-signal multi-paths.

GPS receiver transportation [2] and adapted means of reception largely reduce some of them. Short-distance comparisons (up to 1000 km) are weakly affected by satellite position error and by ionosphere effects [3], furthermore receiving antenna coordinates can be redetermined [4], allowing time transfer with uncertainties of a few nanoseconds.

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But long distance time links, like USA-Europe, are performed with a rather bad precision, of the order of a few tens of nanoseconds. This is mainly due to satellite position errors and rather bad estimations of ionospheric delays, deduced from a ionospheric compensation model accessible to users of one frequency GPS receivers and providing a relative precision of 50 % [5].

We have developed a new codeless dual frequency GPS receiver, named GTR2, for measuring the total electron content (TEC) of ionosphere along the line of sight and then the GPS signal ionospheric delay.

In the following a brief description of GTR2 is given. The obtained results are shown and analyzed by comparison with values coming from the ionospheric compensation model and also with values deduced from vertical sounding measurements. At last GTR2 results are applied to time transfer between Paris Observatory (OP, Paris, France) and the United States Naval Observatory (USNO, Washington D.C., USA).

1. GTR2 DESCRIPTION

A radio signal of carrier frequency L which crosses ionosphere is delayed by a quantity expressed, at the first order approximation, as follows:

$$T_{ion}(L) = \alpha \cdot \frac{TEC}{L^2} \quad (1)$$

T_{ion} is expressed in ns, L in Hz, α is a coefficient equal to 134,36 and TEC is the total electron content (in m^{-2}) of ionosphere along the signal path.

TEC, which is directly linked to the electron density and thickness of ionosphere, largely varies with solar activity, local time, longitude and latitude of the reception station. Examples are given in Table 1 with the corresponding ionospheric delays for both carriers L_1 (1575,42 MHz) and L_2 (1227,6 MHz) of GPS radio signals.

Table 1: Examples of vertical propagation delays of GPS L_1 and L_2 signals

TEC	$T_{ion}(L_1)$	$T_{ion}(L_2)$	$T_{ion}(L_2) - T_{ion}(L_1)$
2×10^{16} *1	1.08 ns	1.78 ns	0.7 ns
1×10^{17}	5.4 ns	8.9 ns	3.5 ns
1×10^{18} *2	54.0 ns	89.0 ns	35.0 ns

*1: typical value for night time of solar minimum

*2: typical value for day time of solar maximum

The propagation delay depends on the frequency and TEC can be estimated using a dual frequency method:

$$TEC = \frac{T_{ion}(L_2) - T_{ion}(L_1)}{\alpha} \left(\frac{1}{L_2^2} - \frac{1}{L_1^2} \right)^{-1} \quad (2)$$

Recently, for purpose of precise geodesy, several different types of interferometric equipments using GPS dual frequency have been realized [6-9]. These are codeless devices with separate reconstructions of L_1 and L_2 signals.

In the same way, GTR2 does not need to demodulate P-code but its original principle relies upon the cross-correlation between P-codes carried by L_1 and L_2 : because L_1 P-code and L_2 P-code are exactly identical and emitted in phase, the cross-correlation of the received P-codes gives access to the quantity $T_{ion}(L_2) - T_{ion}(L_1)$, as shown in figure 1.

TEC is then measured along the line of sight of the GPS satellites which allows ionospheric compensation on the real signal path.

2. GTR2 RESULTS

GTR2 is located at BIPM, Sèvres, France (longitude: 2,2 E and latitude: 48,8 N).

GTR2 program includes all observable satellites from BIPM but priority is given to the scheduled common views between Paris and Washington.

GTR2 works with 4 minute sequences: about 1 minute to point its directive antenna (gain 10 dBi for L_1 and L_2 frequencies) and about 3 minutes to perform the observation. The averaged value of TEC is provided with an uncertainty of $2 \times 10^{16} \text{ m}^{-2}$ which corresponds to an uncertainty of 1 ns for L_1 ionospheric delay.

Figure 2a shows L_1 ionospheric delays obtained on 1988 september 7. The diurnal effect is evident. The measured values are here converted to vertical estimations using a simple geometric expression based on the assumption that ionosphere is a spherical shell, lying from 200 to 450 km altitude and with uniform electron density. Figure 2b presents in details some values obtained for satellites 6 and 12 in early morning. The observed slight discrepancies correspond to an elevation effect. In fact, GTR2 measurement noise increases for high TEC values occurring for small satellite elevations ($< 25^\circ$) and the vertical conversion model is badly adapted in this case.

GTR2 measurements can be compared to values issued from ionosphere compensation model. These values are accessible from a one frequency GPS receiver located in Paris Observatory and correspond of course to the same scheduled trackings. Figure 3 comes from a five days analysis (1988 October 5 to 9) where about 130 trackings were available. Measured values are very often larger than model ones, the disagreement can even reach 20 ns. The discrepancy exceeds 10 ns for 28 % of the values and 5 ns for 62 % of the values.

At last GTR2 results are confirmed by measurement methods of vertical soundings: ionospheric delays, deduced from the values of the critical frequency of ionosphere F2 layer (foF2) measured by Centre National d'Etude des Télécommunications (CNET) in Lannion (France, longitude: 3,3 W and latitude: 48,4 N) are reported on figure 4 and agree fairly well with our measures.

3. APPLICATION TO TIME COMPARISONS

GTR2 measured ionospheric delays can be used to improve the daily time comparisons between OP (Paris, France) and USNO (Washington DC, USA).

Figure 5a shows a one week OP-USNO time comparisons obtained with raw GPS receiver output data. When measured ionospheric delays correct OP data, the biases are largely reduced as shown on figure 5b and OP-USNO time transfer is performed with a much higher precision.

Of course, it would be necessary to operate such a correction for both involved laboratories and satellite ephemeris errors remain. Nevertheless this first study appear to be full of promise.

CONCLUSION

A prototype of a codeless dual frequency GPS receiver operates on a regular basis at BIPM since September 1988. This equipment is able to provide measured ionospheric delays along GPS satellite lines of sight with an uncertainty of 1 ns. For our immediate purpose of improvement of long distance time transfer, this device brings a very interesting gain in precision. Furthermore its structure is very simple with no need of precise measurements of time interval or high accuracy frequency sources as atomic frequency standards, so it appears as an efficient complement of traditional one frequency GPS receivers. At last, though it exists other methods to measure ionospheric effects as utilisation of Faraday rotation or dual frequency transmitted by Navy Navigation Satellite System (NNSS), they will soon become unavailable and GPS appears to be one of the most important ionospheric monitoring system. Then our codeless receiver belongs to a very promising generation of equipments which would widely overstep geodesy and time transfer purposes.

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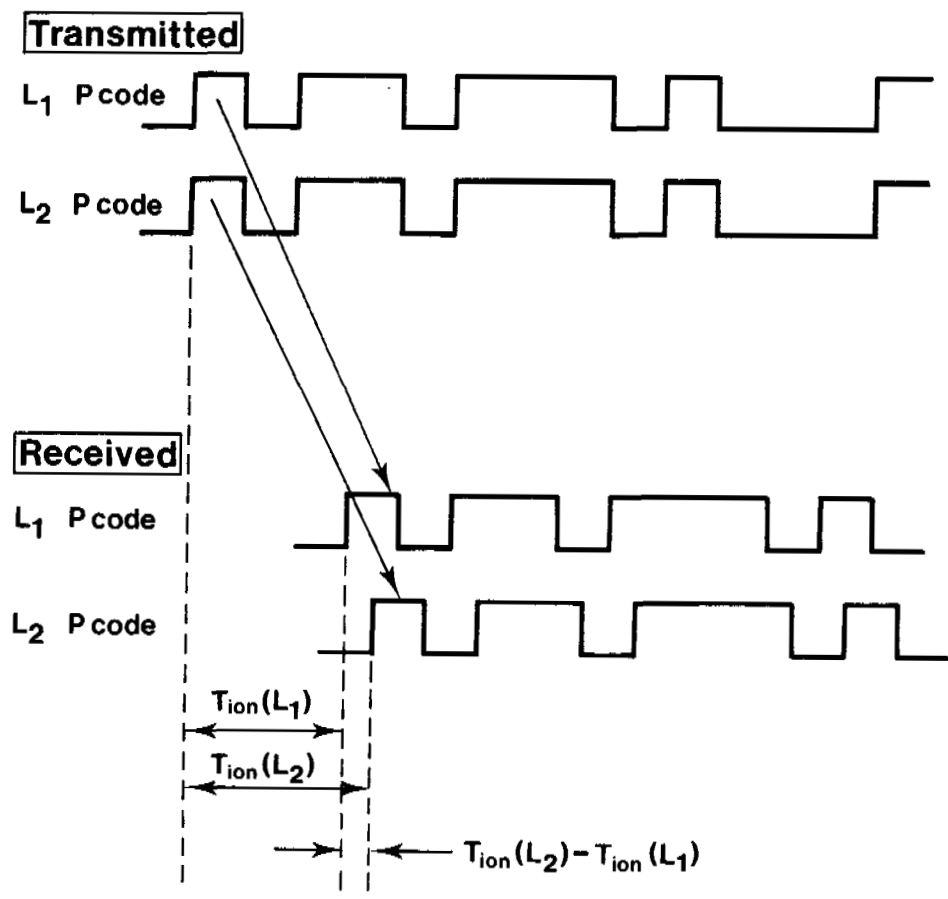


figure 1. Transmitted and received L₁ and L₂ P-codes.

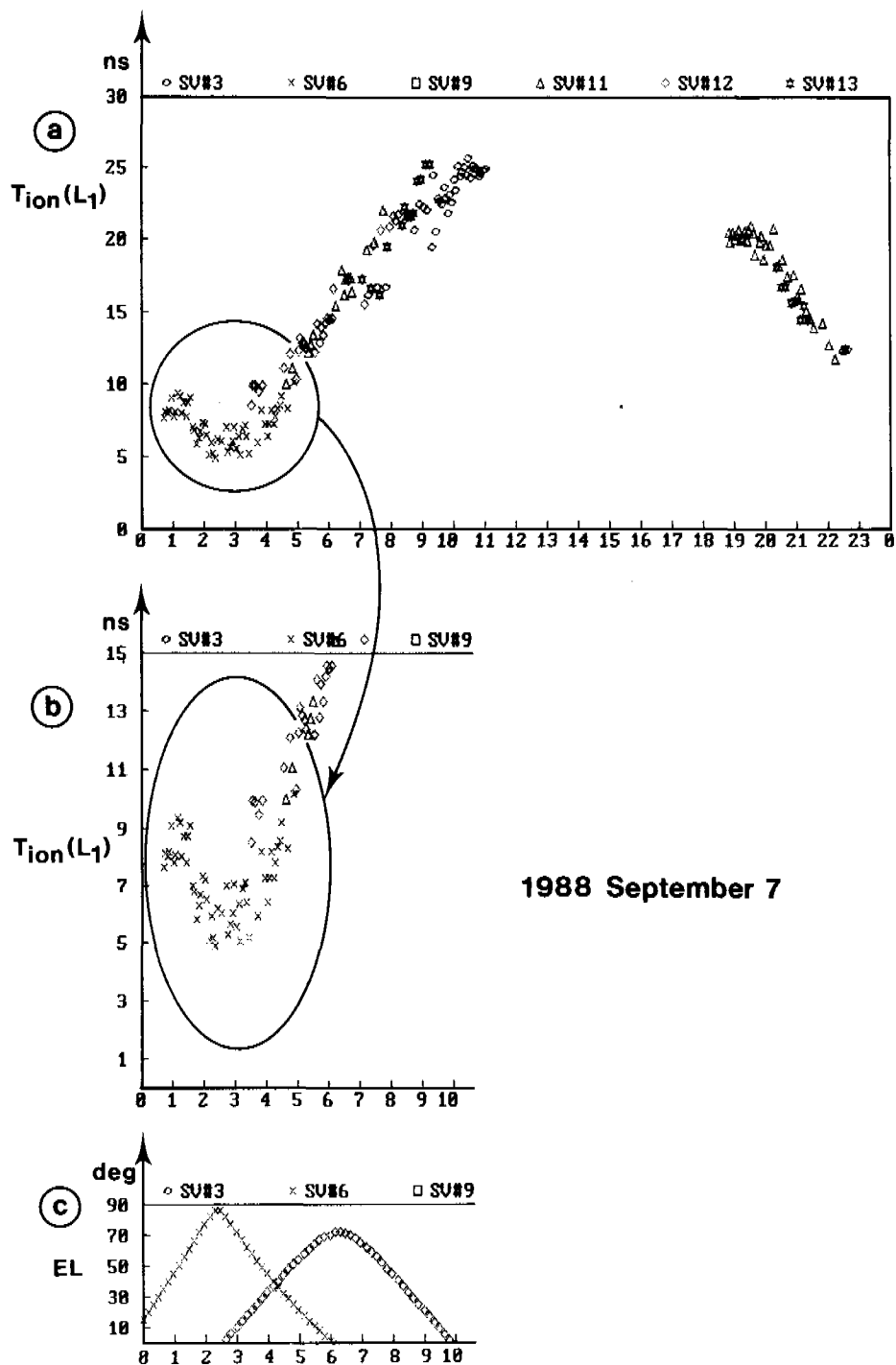


figure 2. Vertical L_1 ionospheric delays calculated from GTR2 results obtained on 1988 September 7
 a - diurnal results
 b - detailed SV 6 and 12 values for early morning
 c - corresponding SV 6 and 12 elevations

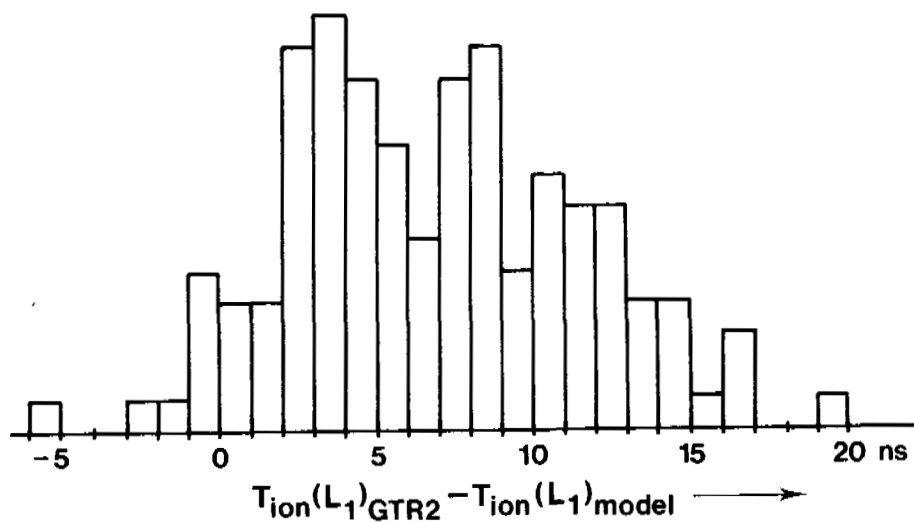


figure 3. Histogram of the values $T_{ion(L_1)GTR2} - T_{ion(L_1)model}$, obtained from 130 trackings for a five days period (no vertical conversion is applied)

- $T_{ion(L_1)GTR2}$ are GTR2 measurement
- $T_{ion(L_1)model}$ are the ionospheric compensation model estimations.

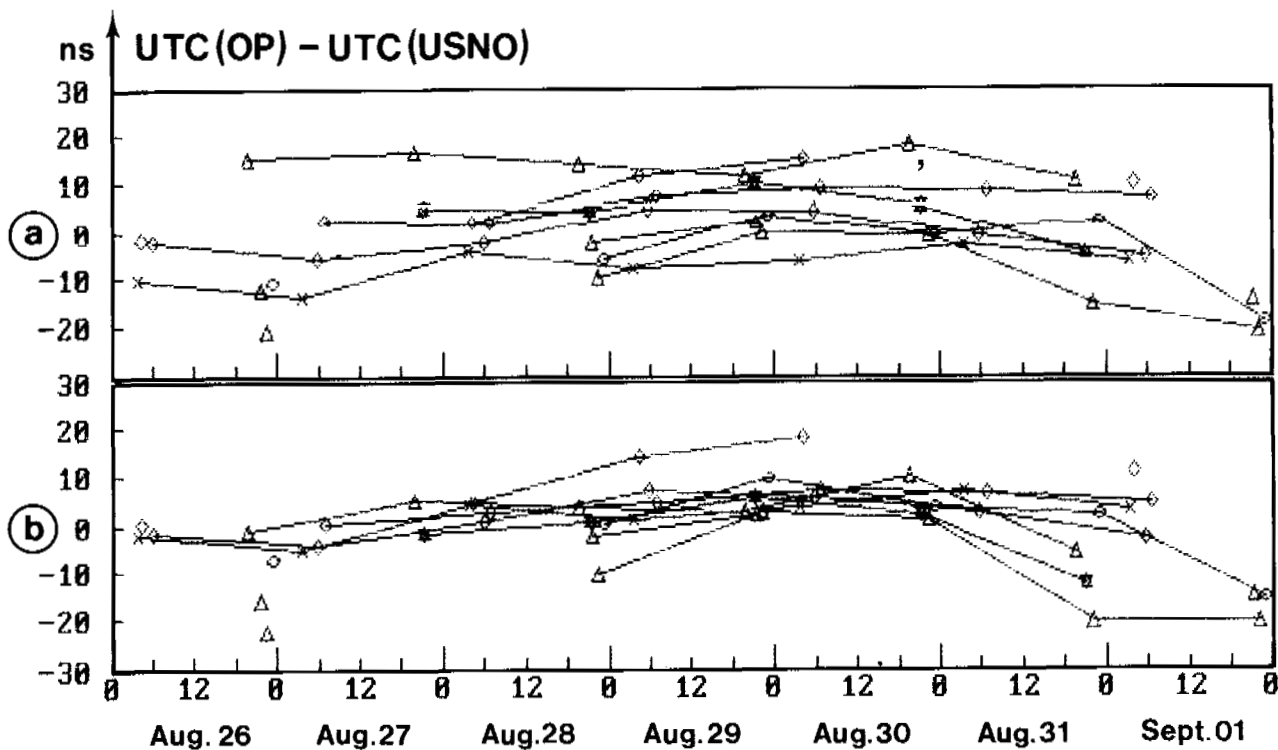


figure 5. Example of time comparison between OP and USNO

- a - before correction
- b - after correction of OP receiver output data.

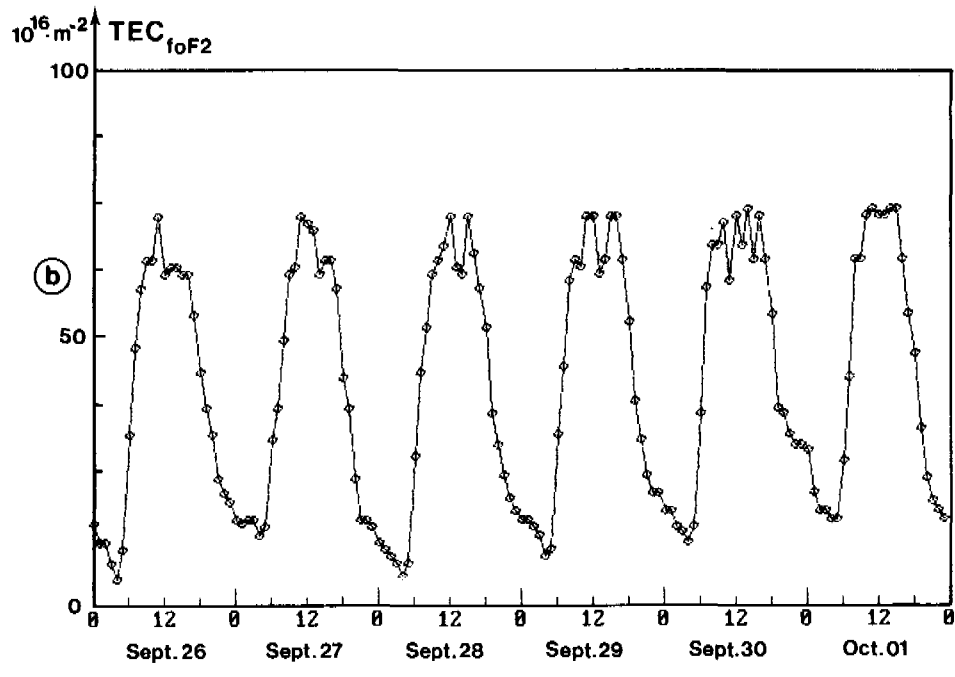
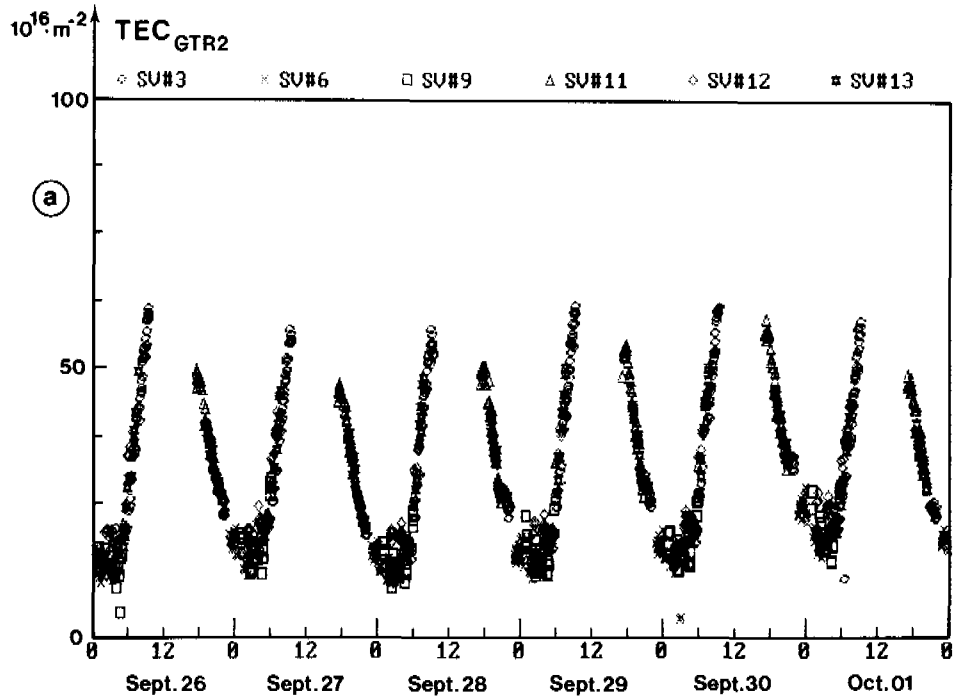


figure 4. Comparison between GTR2 measurement and results obtained by CNET Lannion.
 a - vertical TEC deduced from GTR2 measurement.
 b - vertical TEC deduced from CNET foF2 measurement.

QUESTIONS AND ANSWERS

JIM SEMLER, INTERSTATE ELECTRONICS: You mentioned the directional antenna. Do you think that you would have a problem operating with an omnidirectional one?

DR. THOMAS: It could not work with an omnidirectional antenna. It is a question of gain.

MR. SEMLER: The second question that I had was: You mentioned one nanosecond scatter on your ionospheric measurements. Was that averaged over the tracking interval?

DR. THOMAS: Yes. We have a three minute observation. Each measurement takes three seconds and we use a fast Fourier Transform to reduce the noise. The one nanosecond is the standard deviation of these observations over the (approximately) three minutes.

DR. GERARD LAPACHELLE, UNIVERSITY OF CALGARY: Because your antenna is a directive antenna, I assume that you have not tried to use your equipment in a dynamic mode. Could you comment on that and the possibility of adapting your equipment to a dynamic user with a multichannel capability? If you could do that, you could turn your equipment into a magnificent multipurpose geodetic type of equipment.

DR. THOMAS: At the present time we have not looked into that.

MR. YANAMADRA SOMAYAJULA, S. M. SYSTEMS AND RESEARCH CORPORATION: You mentioned one nanosecond for your measurements. What kind of integration time did you use?

DR. THOMAS: The integration time was three minutes.

DR. GERNOT WINKLER, USNO: The reason that you need more gain is that you do not decode the P-Code?

DR. THOMAS: Yes.

DR. WINKLER: The second question is: Do I see that you seem to have a systematic difference between the model and your measurements? Something like ten nanoseconds.

DR. THOMAS: Yes, but this was only the analysis for a given period—a five day period at the beginning of October. Another period could be different, this is only a sample. You see that at the beginning of September the discrepancy could be larger. I can not give a general conclusion from this data.