THE DEVELOPMENT OF MULTI-CHANNEL GPS RECEIVERS AT THE CSIR — NATIONAL METROLOGY LABORATORY

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Abstract

The primary responsibility of the Time and Frequency laboratory of the CSIR-National Metrology Laboratory (CSIR-NML) is the maintenance of the South African time scale. To perform this duty, the highest level of accuracy in time transfer is required. To this end a multi-channel GPS receiver was developed in the Time and Frequency Laboratory, as a replacement for the NBS-type single-channel receivers. This paper discusses the development of this Motorola-based GPS receiver.

INTRODUCTION

In 1998 the Time and Frequency laboratory of the CSIR - National Metrology Laboratory (CSIR-NML) had to decide on its replacement strategy for the NBS type Allan Osborne and Associates (AOA) TTR5 and TTR5A single-channel Global Positioning System (GPS) timing receivers. These receivers would have stopped working at the GPS week rollover, which occurred on 22 August 1999 at 0h Coordinated Universal Time (UTC). It was extremely important to replace these receivers, as they formed the primary traceability link for time in South Africa at that time.

Several options were available to the CSIR-NML. These included replacing the firmware of the AOA receivers, purchasing new timing receivers and designing and building receivers in-house. The replacement of the firmware of the AOA receivers was ruled out due to cost and the age of the receivers. The purchase of new timing receivers was ruled out due to cost.

The most cost-effective solution to this problem was the development of new GPS timing receivers at the CSIR-NML. An additional benefit of this solution is the development of expertise in the operation of GPS receivers, generation of Consultative Committee on Time and Frequency (CCTF) Sub-group on GPS and GLONASS Time Transfer Standards (CGGTTS) GPS data format files, and interpretation of GPS timing results. Utilizing this solution also means that the GPS receiver could be upgraded with relative ease as new hardware becomes available, providing that the software interface remains compatible. An additional motivation for choosing this solution is that several other laboratories around the world have decided to follow this route [1,2].

HARDWARE

Motorola has developed a GPS module specifically for use in timing applications, the model Oncore UT+. This module forms the basis for the GPS timing receivers designed and operating at the CSIR-NML. Most of the other timing centers use the older (and now discontinued) Motorola Oncore VP module.

In addition to these modules, each receiver consists of a power supply, data interface, and a Pentium-class computer for downloading data and computing results. A counter in time-interval mode is used for measuring the offset between the GPS One Pulse Per Second (1PPS) and the reference clock 1PPS (see Fig. 1).

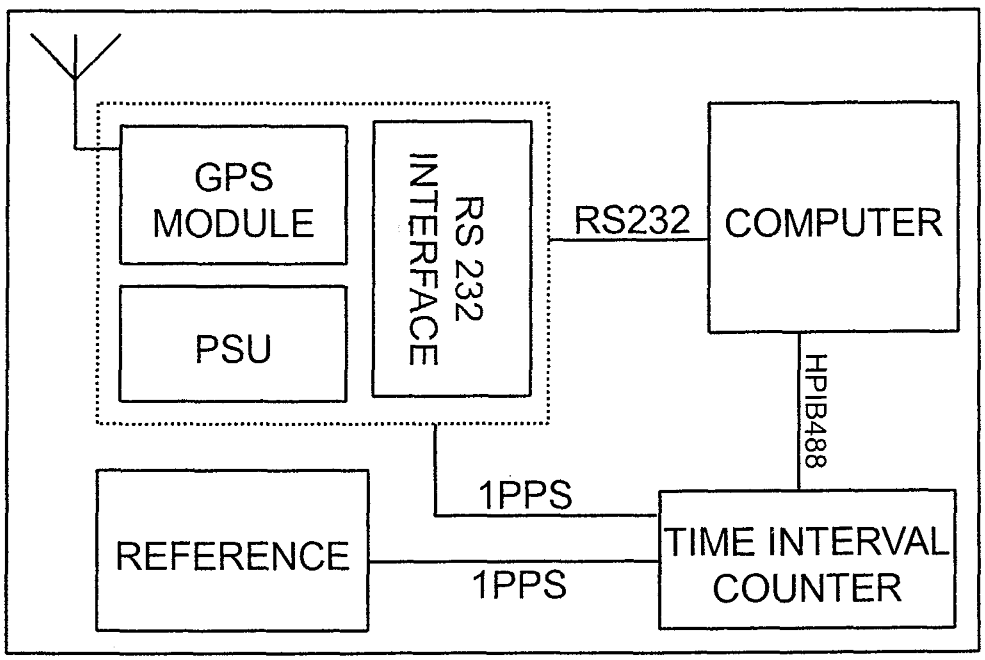

Fig. 1: Block diagram of GPS receiver.

The computers used are Pentium class machines, running either the Windows NT4 or the Windows 95 operating system. The software development language used was Borland (now Inprise) Delphi 4, with serial communication components by Turbo Power Software.

The counters used are Hewlett-Packard (now Agilent Technologies) model 53131A counters. These were the lowest cost counters with sub-nanosecond resolution and remote programmability available on the market at the time.

SOFTWARE

The software developed had to generate data files in the CGGTTS GPS data format [3]. For this to be possible, the contribution of each satellite to the timing solution generated by the receiver, had to be extracted. In addition, the offset between the reference and the receiver had to be corrected for the granularity of the receiver output.

Both this correction (known as the negative saw-tooth error) and the individual corrections for each satellite are extracted from the Motorola receiver using the *'En'* firmware command [4]. According to the CGGTTS directives, a Common View (CV) track is 780 seconds long, and has 52 data points, to which a least-squares linear fit is made. Each data point is the mid-way value of a fit to 15 consecutive readings (15 seconds) to which a quadratic least-squares fit is made.

At present the software developed for the receiver only calculates the average Elevation, Azimuth, and Time Transfer values (Mid-point value, slope, and delta-sigma values). The UT+ module does not provide a raw data output, which means that the internally generated values of the receiver must be used to report the calculated values. The atmospheric corrections used are not available, although the module does have a feature to turn the modeled ionospheric and tropospheric corrections on or off individually. Future versions of the receiver (most probably with new hardware providing raw data output) will include the modeled atmospheric corrections.

The computer software downloads several of the binary protocol messages from the GPS module. It also receives the time-interval measurement from the time-interval counter. During initialization the offset between the reference and the GPS receiver is adjusted through a Motorola firmware command to be within a 200 microsecond wide window, centered at 300 microseconds. This window is maintained continuously, although it should never be exceeded during normal operation. This feature ensures that proper timing is maintained for the signals. The offset introduced is subtracted from the result in software.

The first step is to correct the time-interval measurement for the negative saw-tooth error. This produces the corrected offset between the GPS receiver 1PPS and the reference 1PPS. The individual satellite contributions to the average 1PPS output by the receiver is then extracted and each observed satellite offset is calculated. These values are calculated every second.

If the receiver is within a common-view track, the calculated values for each satellite is stored and the relevant values, calculated according to the technical directives in [3], is computed and stored. In addition to the CGGTTS data, a 5-second average value is also stored in a separate data file.

The Motorola Oncore UT+ cannot be forced to track only one satellite, or set to track a specific satellite using a specified hardware channel. If a tracked satellite switches hardware channels during a track, that measurement is flagged as "bad." A comment is added after each recorded data track in the data file, stating which channel was used to perform the measurement.

PRELIMINARY RESULTS

More than a year of data is now available from each of the receivers, which were installed in the TF clock room in the week preceding the GPS week rollover. The calculated drift rates using the 5-second average values and the GGTTS data files agree very well with the results calculated using the 3S Navigation R100/30T multi-channel receiver (reference receiver) CGGTTS data.

An offset has been noted between the Motorola and the reference receiver results, but it is not possible to determine the source of this offset at this time, as none of the CSIR-NML GPS receivers have been absolutely calibrated. A calibration receiver from the Bureau International des Poids et Mesures (BIPM) visited the CSIR-NML during 1999, and the results of this calibration are expected soon. Once the results are available, it will be possible to calibrate all the other GPS receivers of the CSIR-NML.

In Fig. 2 and 3 below the results for one of the Motorola GPS receivers are shown for a week and a month. In Fig. 4 and 5 the results for the reference receiver is shown for the same period.

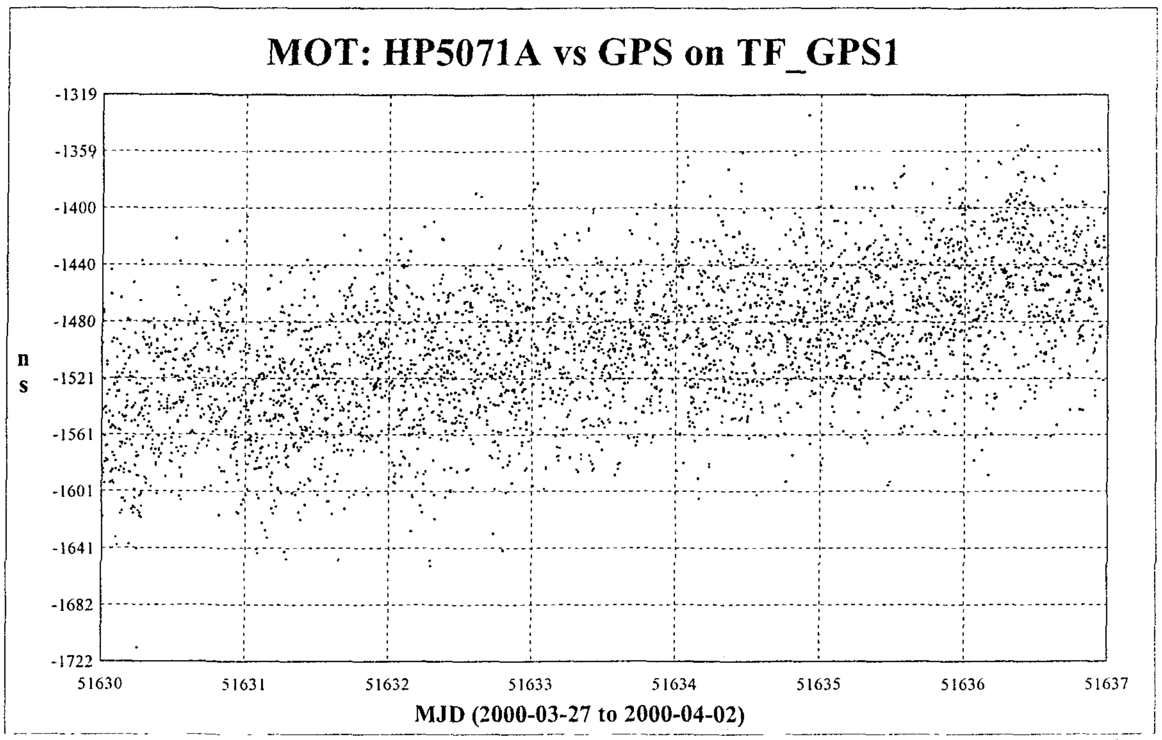

Fig. 2: Motorola data for MJD 51630 to 51636.

The weekly data plot is generated using all full (duration of 780 seconds) tracks for the observation period, with the full dataset being filtered using a 3-sigma filter. An additional constraint is placed on the 3-sigma filter, that being a maximum allowable standard deviation of 1 microsecond (at present).

The monthly data plot is computed using all full (duration of 780 seconds) tracks for the observation period, with the daily average and standard deviation being computed from a 3-sigma filtered subset of the data (each subset is 1 day's data). The 3-sigma filter has an additional constraint, this being a maximum allowable standard deviation set at 1 microsecond (at present).

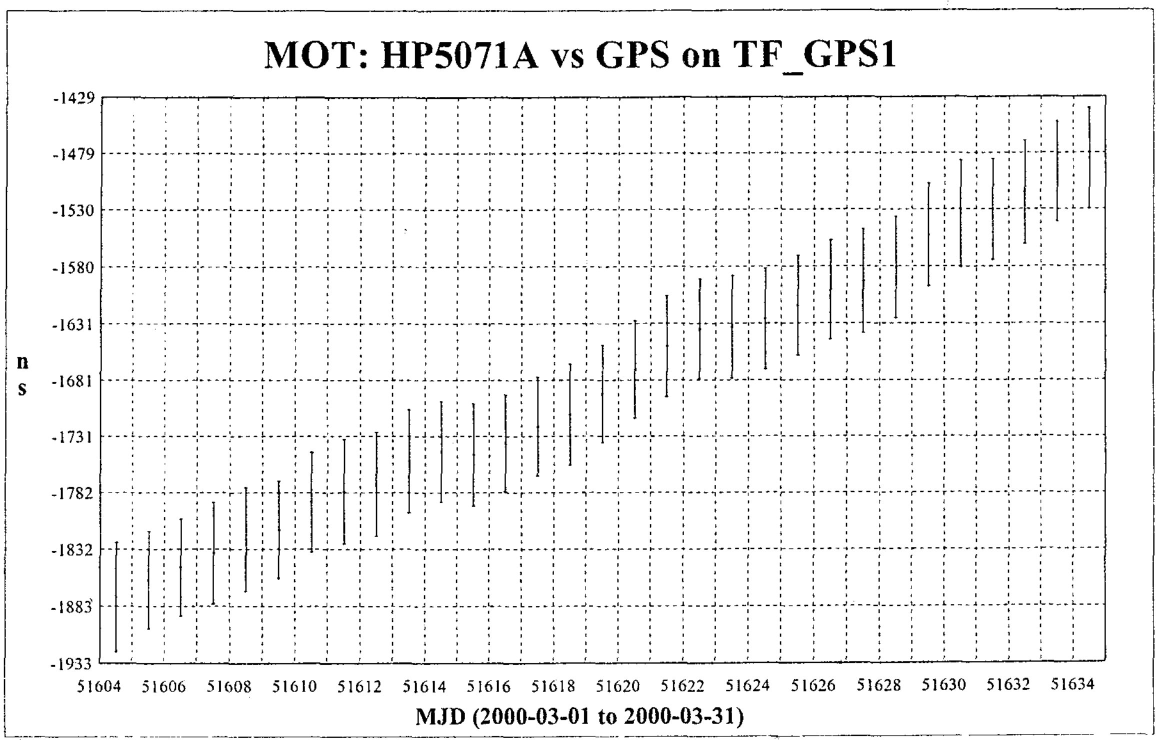

Fig. 3: Motorola data for March 2000.

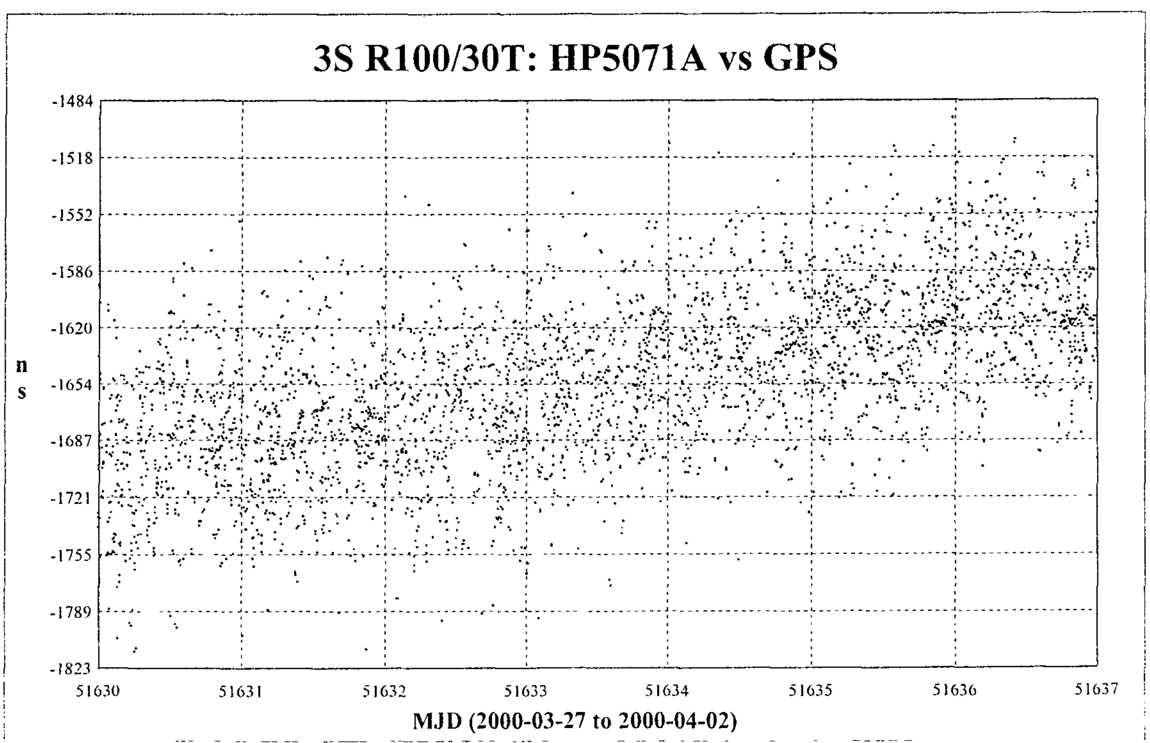

Fig. 4: 3S Navigation R100/30T data for MJD 51630 to 51636.

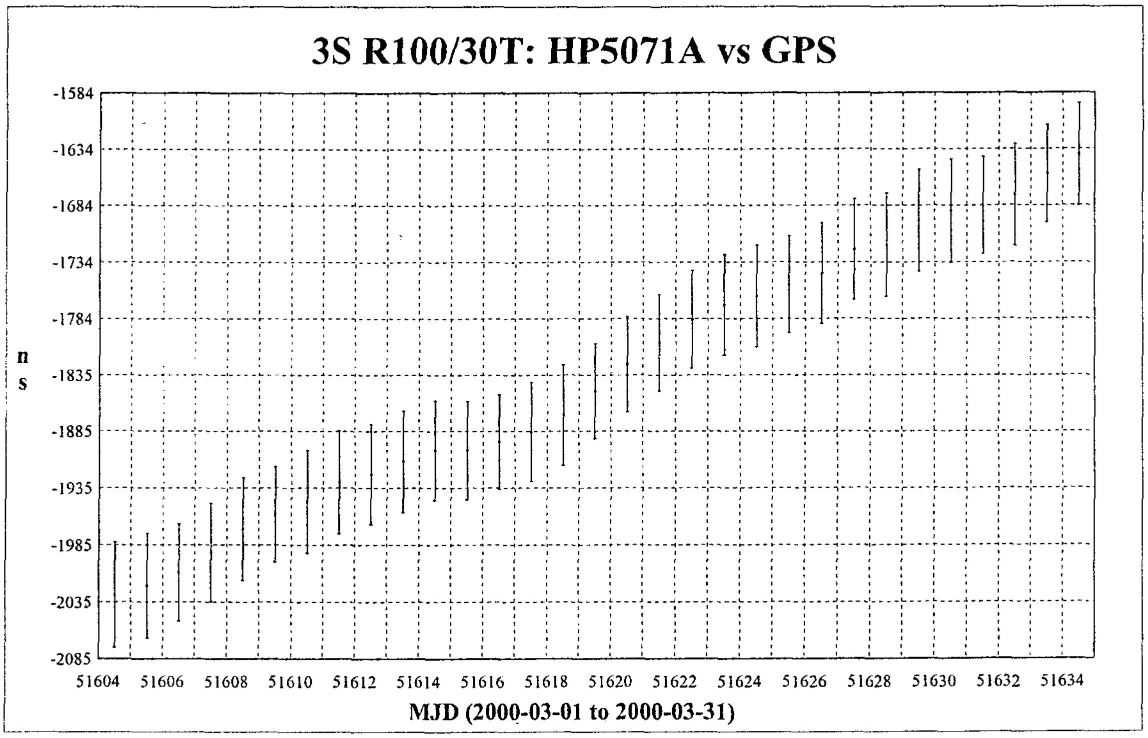

Fig. 5: 3S Navigation R100/30T data for March 2000.

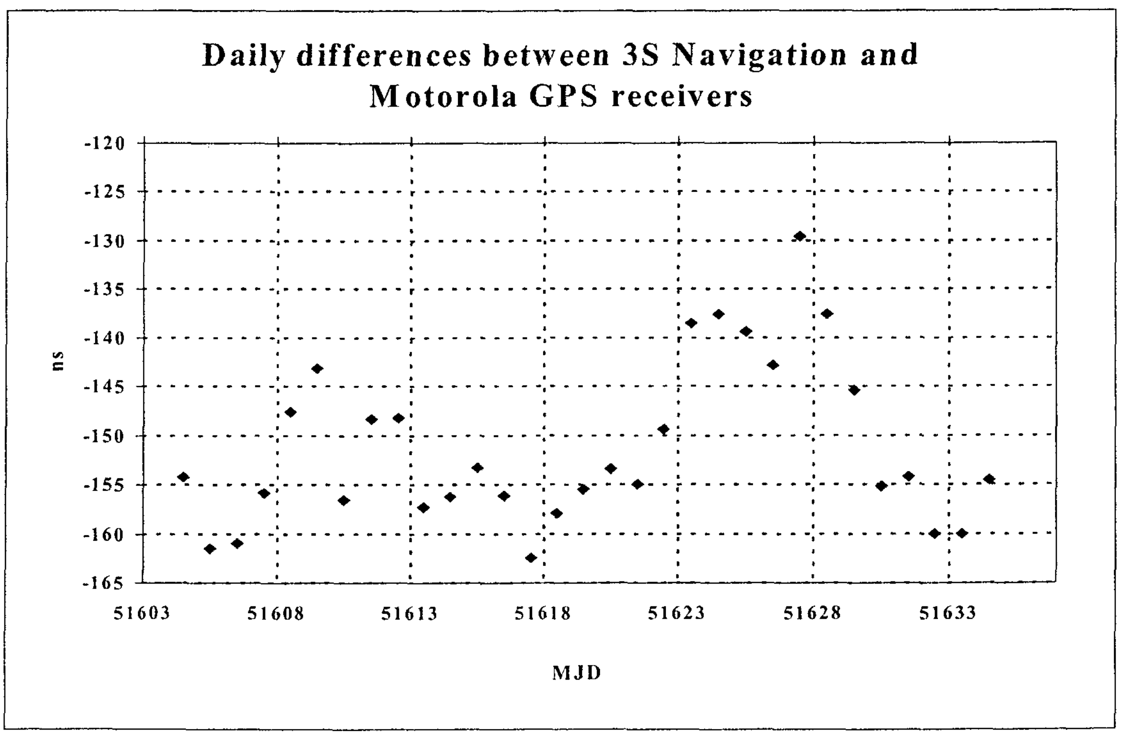

Fig. 6: Daily averages of offset between 3S Navigation R100/30T and Motorola receiver.

The offset between the two receivers for March 2000, as shown in Fig. 6, was found to be -151.2 ns, with an uncertainty of 63.6 ns. The uncertainty was calculated using the average uncertainty for each receiver, combined in a root-sum-square fashion with the uncertainty for the offset, which was 8.4 ns. This is not the best method for determining the offset, as the values are most probably not statistically independent.

The relative high noise on the results obtained can be attributed to a number of effects. Since no detail study of these differences have been made, it is not possible to pinpoint the sources of these differences. One or more of the following can contribute to these differences: Motorola antenna not temperature compensated, cables exposed to direct sunlight in daytime, position of Motorola antennas not known with very high accuracy, inaccuracy of ionosphere and troposphere correction models in one or both receivers, and perhaps some others.

FUTURE WORK

Further development of the Motorola-based GPS receivers are underway. The new M12 Oncore receiver from Motorola is being evaluated at present. This module may be a worthwhile replacement for the discontinued VP Oncore receiver, used in many parts of the world as the engine for GPS timing receivers It is hoped that the M12 will overcome some drawbacks of the UT+ Oncore.

In parallel to the Motorola Oncore M12 evaluation, an investigation of the capabilities of the u-Blox MS-1 receiver module is underway. This receiver uses the SiRF chipset, and can output raw GPS data. A project is also underway to build a low cost temperature-stabilized antenna (TSA), based on the patch antennas available from Motorola, as these TSAs reduce time transfer uncertainties considerably [5].

DISCLAIMER

Certain trade names and company products are mentioned in text of this paper. In no case does such mention imply recommendation or endorsement by the CSIR - National Metrology Laboratory, or the CSIR, nor does it imply that the products are necessarily the best available for the purpose.

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