

Time And Frequency Transfer Using GPS Common-View.

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Abstract

An overview of precise frequency and time transfer methods available to UK users is provided, focusing on the GPS common-view method. The development of a GPS common-view receiver is described along with NPL's new GPS common-view service. Future developments for UK users of precise frequency and time are outlined.

1) Introduction

The common-view of GPS satellites [1] has for many years been used by primary timing laboratories as a high accuracy method of both frequency and time transfer. The method is particularly suitable for comparing the atomic clocks that contribute to International Atomic Time (TAI). The cost of the GPS hardware is however relatively high, which has restricted its uptake by other users within the UK. Inexpensive GPS receiver engines, suitable for high accuracy time and frequency applications, appeared in the market in the mid-1990s and have now been used to produce less expensive GPS common-view receivers. NPL has contributed both to the development of less expensive GPS common-view receivers, and in parallel has developed a UK based GPS common-view frequency and time transfer service. The new service will enable UK users of precise time and frequency to obtain time and frequency transfers traceable to national standards, at an uncertainty previously only available to primary timing laboratories.

2) Overview of frequency and time transfer methods.

The frequency and time transfer options available to UK users requiring the lowest uncertainties has been somewhat limited. Portable atomic clocks used as transfer standards will provide a high accuracy calibration with uncertainties better than 20 ns. Unfortunately this form of calibration provides only a "spot" measurement, and regular expensive recalibrations are required. Terrestrial standard frequency and time signals, for example MSF 60kHz and Droitwich 198kHz are often used as sources of precise frequency and time. These standard frequency and time transmissions offer continuous frequency signals traceable to UTC(NPL), the UK's national time scale. Normalised frequency uncertainties of 1×10^{-12} and 1×10^{-11} for an averaging time (τ) of one day are obtainable with the MSF and Droitwich transmissions respectively.

Satellite navigation systems provide a source of continuous high accuracy frequency and time signals. In practice, UK users will at present be restricted to the use of the US Global Positioning System (GPS). The GPS signals may be used directly as a standard frequency and time reference. High quality Quartz and Rubidium oscillators are often steered to the GPS signals. These GPS Disciplined Oscillators provide convenient high accuracy real time laboratory reference standards [2] with a frequency uncertainty of a few parts in 10^{13} over an averaging time (τ) of one day. Alternatively, a UK user may use the GPS common-view method to make traceable differential time and frequency measurements against UTC(NPL) the UK national time scale that is maintained at NPL. This differential common-view method provides improved uncertainties and integrity above that achievable through direct use of the GPS system.

3) GPS common-view method.

The GPS system consists of a constellation of 24 satellites in medium earth orbit [3]. The orbit period is half a sidereal day. Each satellite contains an on-board atomic clock that is steered to GPS System Time, which in turn is traceable to Coordinated Universal Time (UTC). Pseudo range (one-way) navigation signals are transmitted at two L-band frequencies. By simultaneously observing signals from four or more GPS satellites both the coordinates of a user's GPS receiver antenna and the time of the receiver's clock may be accurately determined. This method is not however the best method to use the GPS for frequency and time transfer. Operating the GPS receivers from predetermined fixed antenna coordinates, offers a very significant advantage in the precision obtainable from both GPS stand-alone and common-view time transfers.

The principle of the GPS common-view method is shown in Figure 1 below. GPS receivers located at a user's laboratory and at NPL simultaneously receive signals from the same GPS satellites. Both laboratories compare their GPS receiver's clock against the onboard clocks of the GPS satellites. NPL determines the difference between the two receiver's GPS measurements and relates the GPS receiver's internal clocks to the reference

time scale at each laboratory. The GPS system is then being used to make continuous high precision frequency and time transfers between the user's and reference laboratory's (NPL's) timescales.

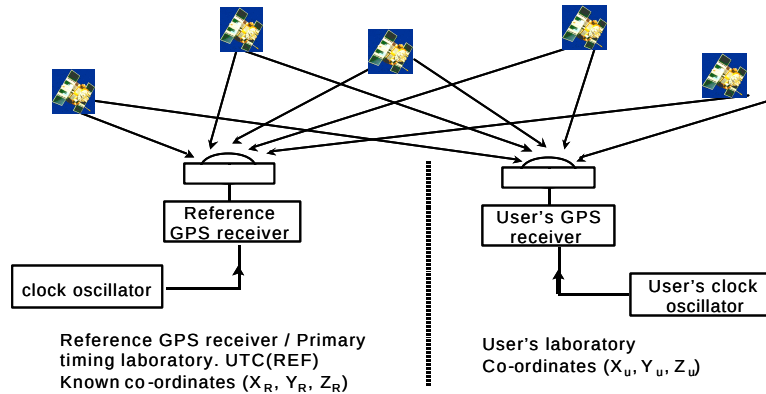
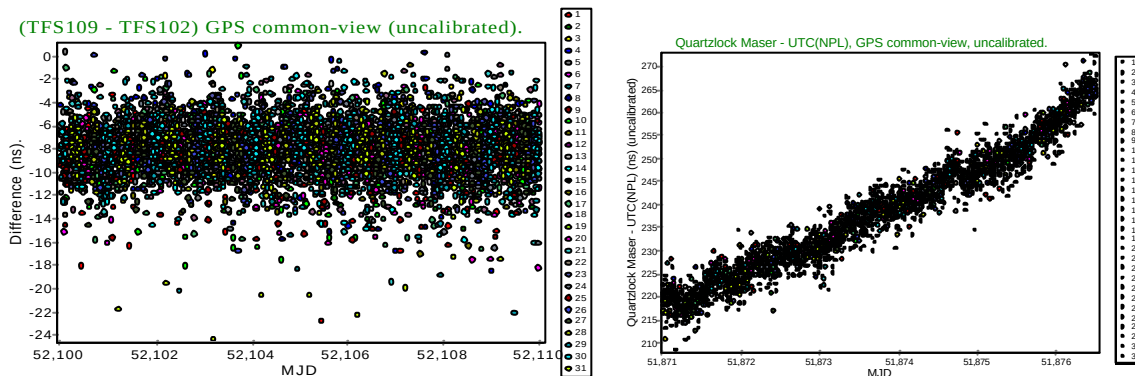


Figure 1 showing a schematic diagram of the GPS common view time and frequency transfer method.

The use of the GPS common-view method offers the advantages over stand-alone GPS methods of significantly improved precision frequency and time transfer, along with the potential to significantly improve the integrity of the measurements. A disadvantage of the method is that the measurements are not made in real time, although short latency measurements are possible through rapid data transfer.

4) Sources of error and uncertainty of GPS common-view measurements.

There are several well-documented sources of error occurring in both GPS common-view and GPS stand-alone measurements [4]. Receiver noise, receiver delay instability, antenna coordinate errors and antenna multi-path (multiple signal reflections) are sources of error that are strongly dependent on the GPS receiver's construction and its local environment. Other sources of error, for example satellite ephemeris, troposphere and ionosphere delay errors depend principally on the performance of the GPS system and so are generic to all GPS installations. Using GPS common-view measurements frequency transfers with a normalised (fractional) uncertainty of 3×10^{-14} and time uncertainty of 10 ns are achievable for an averaging time (τ) of one day.



Figures 2 and 3 showing GPS common-clock common view measurements made at NPL and a common-view frequency transfer between NPL and Quartzlock, Totnes, Devon. The individual GPS satellites are identified by their PRN values.

5) Development of the TFS/NPL GPS common-view receiver.

NPL and Time & Frequency Solutions (TFS) have jointly developed an 8channel GPS common-view receiver using Motorola's VP Oncore GPS engine. The VP Oncore was chosen because it provides sufficient information for the user to calculate the time difference between the receiver's 1pps (pulse per second) output and the time on-board individual GPS satellites. It is that property which makes the common-view feature possible, by allowing any visible GPS satellite to be used as a transfer standard. In contrast, GPS Disciplined Oscillators steer their outputs to GPS system time, calculated from an average of all the satellites in view which makes the traceability chain less transparent.

TFS developed the instrument hardware and NPL the data processing software. The receiver is operated via a laptop PC. In addition to the GPS engine the receiver hardware consists of a purpose designed counter timer card, the hardware to generate a 1PPS signal from a 5 or 10 MHz standard frequency input, and the required

interfaces. The receiver will operate from either a 1PPS timing pulse and / or a standard 5 or 10 MHz standard frequency input. This enables the user to perform both time and frequency transfer common-view measurements using the 1PPS input, or frequency transfer measurements using only the 5 or 10 MHz input.

The common-view software was developed at NPL. Daily output files are produced, these consist of data in the recognised CGGTTS format developed at the Bureau International des Poids et Mesures (BIPM) [5]. The logging software will run continuously. The PC used to control the receiver may be connected via a modem to a local telephone. A second software programme will automatically transfer the data files once per day from the receiver to an FTP site at NPL, for processing.

An example of a GPS common-view common clock measurement is shown in figure 2 above. This type of measurement eliminates clock, atmospheric and satellites ephemeris errors, enabling the receiver and location dependent errors to be more easily identified. In this example the receiver TFS 109 had not been calibrated. The delay difference of -8 ns represents the previously unknown delay asymmetry between the two receivers.

6) Traceability to national standards.

Traceability is the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. In the case of time and frequency the ultimate standard may be considered to be Coordinated Universal Time (UTC). If NPL's GPS common-view service is used then the traceability chain will include UTC(NPL) the UK's national time scale. The common view service will provide both estimates of the measurement uncertainty, and extensive validation of the common-view link to provide confidence in the traceability of the users time measurements or reference standards.

7) Operation of NPL's GPS common-view service.

NPL has launched the new GPS common-view service. The service is designed as a complete package offering lower frequency and time transfer uncertainties and a higher integrity than may be achieved through direct reception of the GPS signals. Data is transferred on a daily basis to NPL via the Internet, and is processed on a weekly basis. NPL will provide, data plots, statistics and detailed reports. Although the service is primarily designed with the TFS / NPL common-view receiver, NPL will process data from any receiver output in the BIPM format [5]. Frequency transfer uncertainties (relative to UTC(NPL) and UTC) of 5×10^{-14} (1σ) and time transfer uncertainties of 10 ns (1σ) relative to UTC(NPL) and 20 ns (1σ) relative to UTC at an averaging time (τ) of 1 day are achievable using this service.

The setting up and operation of a GPS common-view installation may be considered in four parts:

a) Initial characterisation and calibration of the common-view receiver

This is usually performed at NPL. A differential receiver delay calibration is performed against NPL's referenced GPS common-view receiver. In addition extensive measurements are made of the receiver's performance characteristics. These characteristics are then used as a "benchmark" against which to compare the receiver's performance when operating at a user's laboratory.

b) Installation and validation of the new common-view link.

The installation of a GPS common-view receiver is relatively straightforward and may easily be undertaken by the user. A key principle is to validate as much of the new GPS common-view link using normal GPS common-view data that has been routinely forwarded to NPL. The initial characterisation measurements are now repeated from which the performance of the receiver in its new operating environment may be evaluated.

c) Routine operation and performance validation of the GPS common-view link.

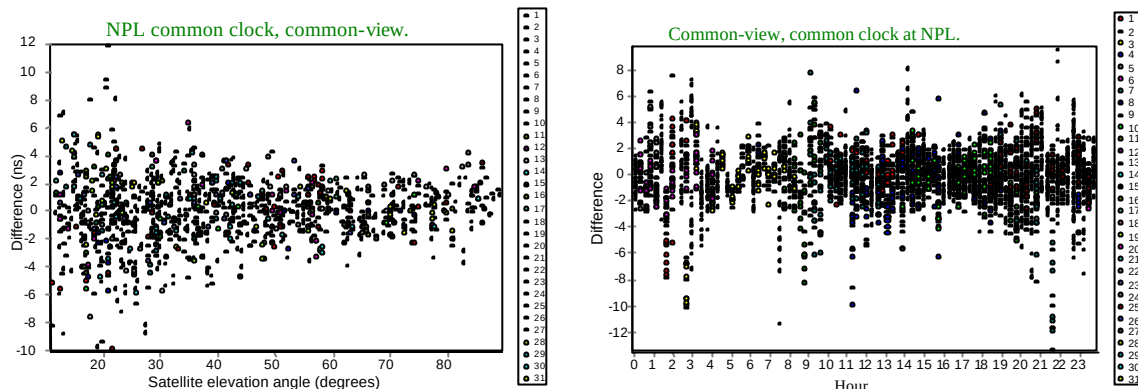
GPS common-view data is forwarded to NPL on a daily basis. NPL operates a series of validation tests in its data processing that will confirm the integrity of the GPS common-view measurements.

d) Regular re-calibration of the GPS receiver's time offset.

Frequency transfer measurements do not require the calibration of the user's GPS receiver. Regular recalibrations of the receiver are however required for time measurement. The duration between recalibrations will depend on the measurement uncertainty required. There are two recalibration methods. The user's common-view receiver may be sent to NPL. Alternatively, NPL may send a second common-view GPS receiver to the user's laboratory as a transfer standard. The latter method has the advantage that the user's receiver remains operational during the re-calibration process.

An example of UK GPS common-view frequency transfer is shown in figure 3 above. Active and passive hydrogen masers are being used as reference clocks at NPL and Quartzlock respectively, resulting in a highly stable frequency transfer.

8) Validation of the GPS common-view measurements.



Figures 4 and 5 showing the scatter of GPS common view data as a function of satellite elevation angle and a repeating sidereal day pattern due to code multi-path respectively.

Figures 4 and 5 provide good examples of the validation tests undertaken as part of NPL's common-view service. Within a single measurement epoch the scatter from the mean epoch value of each GPS satellite measurement is plotted. This metric is independent of either the user's or NPL's clocks. Figure 4 displays this scatter as a function of the satellite elevation angle. Any increase in this scatter indicates a degradation of the common-view link. Figure 5 shows these GPS scatter measurements plotted at the same time on successive sidereal days. There is clearly a repeating pattern present due to the presence of code multi-path.

9) Future developments

The GPS common-view method is a well-established technique, however the GPS system is undergoing a series of upgrades. Key amongst them will be the transmission of a second civilian GPS coded signal. Within Europe two new Global Navigation Satellite Systems (GNSS) are being developed. EGNOS is a GPS augmentation system that should provide improved accuracy over the use of the GPS System and is likely to become operational by the end of 2003. GALILEO is being designed as a completely independent satellite navigation system, and is planned to become operational by the end of 2008. Both systems offer considerable potential for precise frequency and time transfer.

10) Conclusions

NPL has many years of experience of international GPS common-view time and frequency measurements. This experience has been used to collaborate on the development of a new GPS common-view receiver and develop a high accuracy, high integrity GPS common-view service for UK users.

References.

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