

TIME DISSEMINATION IN THE UNITED KINGDOM USING SIGNALS FROM GEOSTATIONARY TELEVISION SATELLITES

J A Davis and P R Pearce,
Division of Electrical Science, National Physical Laboratory,
Queens Road, Teddington, Middlesex, TW11 0LW.

ABSTRACT

The results of a time and frequency transfer experiment coordinated from NPL are reported, using signal from geostationary television satellites. This method has been developed as an inexpensive alternative to the use of either the Rugby MSF 60 kHz standard time and frequency signals, or the use of signals from Global Positioning System (GPS) satellites for comparing commercial atomic clocks. Sources of error are examined. The largest source of uncertainty is identified as being due to the residual motion of the near geostationary satellite. A self calibrating correction method has been developed. In this method television signals from two separate geostationary satellites are simultaneously received at three or more locations. Sufficient redundancy is contained within the measurements, to permit the elimination of the effects of satellite motion from the time transfer. The possible operation of a satellite television time dissemination service is examined.

1) INTRODUCTION

The principle source of time and frequency dissemination in the United Kingdom is NPL's Rugby MSF 60 kHz transmissions. There has been a steady improvement in the performance of commercial atomic frequency standards, notably caesium clocks, over a period of many years. This has resulted in the MSF 60 kHz signal no longer providing sufficiently accurate time and frequency dissemination for the comparison of these standards. Established satellite methods, for example using signals from Global Positioning System (GPS) satellites require the use of relatively expensive equipment. There is a requirement for an inexpensive, yet highly accurate time and frequency dissemination method, which may be used for the comparison of atomic frequency standards.

2) TELEVISION TIME TRANSFER METHOD

The principles of common-view television time transfer are well known. The same television signal is received at both timing laboratories (Figure 1). Relatively simple electronics may be used to extract the same synchronisation pulse out of the television signals. A counter timer is used to measure the difference between a one Pulse Per Second (1 PPS) signal provided by a local atomic clock and the television line synchronization pulse. Knowing the path delays from the satellite to each receiving station, and also the instrumentation delay asymmetries the time transfer between the clocks may be determined.

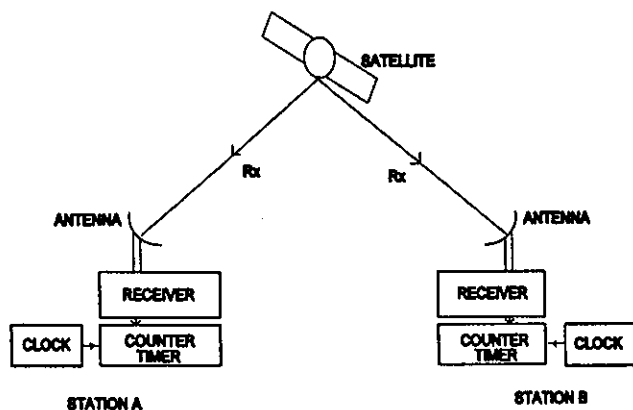


Figure 1 Satellite Television Common-View Time Transfer

Four laboratories participated in the NPL coordinated experiment [1], [2]. These were the National Physical Laboratory (Teddington), Rugby Radio Station, Hillmorton, (Rugby), Hewlett Packard Ltd, (Winnersh), and Radiocode Clocks Ltd, (Penryn), Cornwall. Data was collected from both the Astra and Marco-Polo satellites. Small domestic satellite antenna and receiving

equipment were used. Inexpensive pulse extractor electronics, an IEEE interfaced switch box, MSF linked system clock and a PC were used to complete the apparatus. Intensive post processing of data took place at NPL, from which the time transfers were determined. Neglecting the counter timers and PC which should be available in most time and frequency laboratories, the remaining equipment may be constructed for approximately £1,500.

3) SOURCES OF ERROR

Residual motion of the near geostationary satellite is by far the largest source of uncertainty in the satellite television method. Measurement noise, instrumentation delay asymmetries and instrumental delay changes limit both the time and frequency transfer capabilities. The position of the receiving antenna must be accurately determined for precise time but not precise frequency transfer. Ionospheric and tropospheric delay changes may occur, delay variations of a few nanoseconds may occur in both cases. For high accuracy time transfers over long distances sagnac corrections must be added to account for the relativistic effects of the earth's rotation.

4) RECEIVER INSTRUMENTATION DELAYS

Values of Allen variance σ_y ($\tau=1s$) of 4×10^{-8} and 4×10^{-9} are obtained for time transfers using the Astra and Marco Polo satellites respectively. The measurement noise is lower for signals from the Marco Polo satellite, where the transmissions are made at higher Equivalent Isotropic Radiated Power (EIRP). Comparisons may be made with the measurement noise obtained from Two-Way Satellite Time and Frequency Transfer (TWSTFT) equipment used at NPL. The measurement noise from the satellite television system is typically three times greater than the noise from the TWSTFT system. There is a difference in cost of between 30 and 100 times.

Co-located common view measurements have been made using two sets of both the Astra and Marco-Polo satellite receiving equipment. This work was undertaken both to calibrate the absolute delay asymmetries within the receivers and to measure the delay instabilities of the instrumentation. The most stable receivers displayed delay instabilities of only a few nanoseconds over a period of 24 hours. This stability is not as high as is obtained with TWSTFT, where delay stabilities between 200 picoseconds and 3 nanoseconds have been observed. The stability is however equal to the stabilities obtained from co-located GPS receiver measurements. These comparisons demonstrate that the transfer capabilities of the satellite television method are comparable with the best existing time and frequency systems.

5) CORRECTION OF THE TIME TRANSFERS FOR SATELLITE MOTION

To exploit the time and frequency transfer potential of the satellite television method an effective method must be developed to correct for the residual motion of the near geostationary satellite.

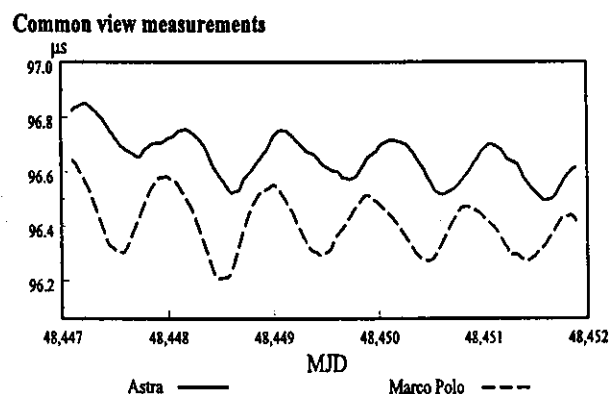


Figure 2 Common-View Measurements (Rugby-Teddington)

A self calibrating method has been developed at NPL by using the signal collected from both the Astra and Marco Polo satellites, which were recorded at three distant locations. A satellite in near geostationary orbit experience a set of forces which result in a small perturbed motion about its geostationary position. When viewed from a coordinate system referenced to the earth's surface, periodic variations of the satellite's position are observed along with a slow longitudinal drift. [3].

Linear combinations of common-view measurements have been formed using data collected from three locations which forming a triangle on the earth's surface. These combinations included measurements collected from two satellites which are well spaced in the geostationary arc. The time transfers may then be determined free from the effects of changes in the satellite orbit longitude [2]. In the absence of satellite orbit corrections, the mean value of the latitude and radius components of the satellite motion, averaged over a sidereal day, is assumed to remain constant.

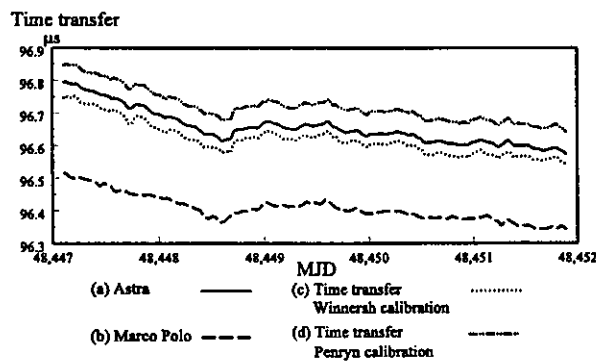


Figure 3 Time Transfer
(Rugby-Teddington)

A digital filtering technique was used to remove the periodic variations of satellite origin from the time transfer. Corrected common view measurements obtained from the Rugby-Teddington link are shown in Figure 2. The time transfers are shown in Figure 3. Winnersh and Penryn acted as the calibrating station contributing data to the linear combinations. Results are shown in curves (c) and (d). The effect of digitally filtering the common view measurements without forming linear combinations are shown in curves (a) and (b). Variations between the shape of the curves agreed to within 10 ns.

Plots of $\log_{10} \sigma_y$ against $\log_{10} \tau$ are shown for the Winnersh - Teddington time transfers in Figure 4. Curves are shown for the common view measurements before post processing, these curves show oscillatory changes (a) (b). These curves reach a minimum when τ is a multiple of a sidereal day, due to the periodic variations of the geostationary satellite. Curves have been calculated from the digital filtering of the common view measurements (c) (d). In contrast these curves do not possess minima when τ is a multiple of a sidereal day. This demonstrates the effectiveness of the digital filtering method. Curves (e) and (f) are calculated from the time transfers, after forming linear combinations and digitally filtering. The values of σ_y are lower in these cases, this demonstrates the effectiveness of the linear combination method. Frequency transfer capabilities of a few parts in 10^{14} have been

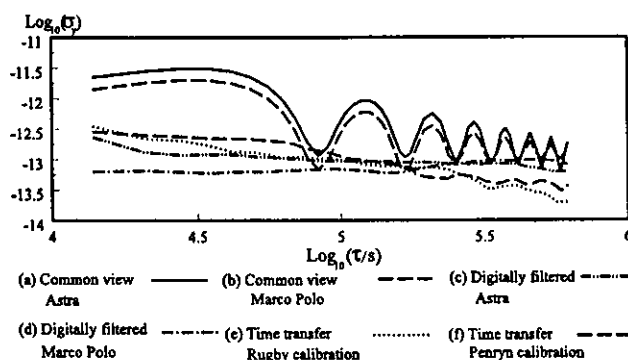


Figure 4 Plots of $\log_{10} \sigma_y$ against $\log_{10} \tau$
(Winnersh-Teddington)

demonstrated along with absolute and relative time transfer accuracies determined to better than 100 nanoseconds and 10 nanoseconds respectively. The accuracy obtainable from this self calibrating method will depend on the delay stabilities of the receiver instrumentation, the location of the calibrating stations, and the stability of the clocks at all three locations.

6) TIME AND FREQUENCY DISSEMINATION SERVICES

The footprints of almost all geostationary television satellites received in the UK cover a substantial proportion of Europe. This would enable Europe wide time and frequency dissemination services to be developed. The important decisions in setting up a service are in the choice of satellite, receiving equipment and method of calibrating the satellites position. To use the NPL self calibrating method to calibrate the satellite's position, two satellites must be observed by the calibrating stations. The automatic post processing of data to deal with the satellite orbit corrections are quite complicated. The use of GPS receivers located at primary timing laboratories may provide an alternative and simpler calibration system. This system is however not independent of GPS. The use of high powered DBS satellites is advantageous because of the possibility of using small domestic receivers. However there is a wide range of television satellites which may be received with a 90 cm diameter dish. Data transfer is important for the rapid calculation of results. Telephone modem links between the data logging PC's may be a suitable method. In operating the data exchange, the calibrating laboratories should first exchange data, the user may then obtain a set of data from a single telephone call to the nearest calibration laboratory. Software on the users PC may be used to calculate the time transfer. True real-time television time transfer will be more difficult to achieve.

7) CONCLUSION

Time and frequency transfer using television satellites has been shown to offer capabilities comparable to other high precision time transfer methods. A self calibrating method has been developed at NPL to correct the time transfers for the effects of satellite motion. Time transfers with absolute uncertainties better than 100 ns have been achieved along with frequency comparison of 2×10^{-14} with averaging times of a few days. The possibilities of operating a Europe wide television time dissemination service is considered.

ACKNOWLEDGEMENTS

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