Practical Evaluation of Relativistic Effects in Two-Way Satellite Time and Frequency Transfer

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A method is investigated for the practical application of existing theory to take account of relativistic effects in Two-Way Satellite Time and Frequency Transfer (TWSTFT). This is achieved using satellite position data available from internet sources. This work has been undertaken as part of the EMRP-funded ITOC project[1] and provides an input to a broadband TWSTFT experiment to be conducted later in the project. The aim of this is to compare optical atomic clocks to an experimental uncertainty of $1x10^{-16}$. In order to achieve this, relativistic corrections are required to be evaluated to a fractional frequency uncertainty of 5 parts in 10^{17}.

Existing theory[2] on relativistic effects in TWSTFT describes that the Sagnac effect and a variation in signal path delays due to satellite motion need to be considered. The effect of signal delay variations can be reduced to much lower than the required uncertainty by applying a deliberate time-offset in the pulses transmitted by the ground stations. The impact of the Sagnac effect is an apparent frequency change in the optical clock comparisons over time, resulting from diurnal satellite motion, which has to be evaluated and removed.

Here we have obtained position data for the satellite currently used in regular TWSTFT measurements, Telstar 11N, and assumed position coordinates of the TWSTFT ground stations at four European NMIs, namely Istituto Nazionale di Ricerca Metrologica (INRIM), National Physical Laboratory (NPL), Observatoire de Paris (OBSPARIS) and Physikalisch-Technische Bundesanstalt (PTB). These data have been used to evaluate the time-offsets that would be applied between ground stations and the frequency shift induced by variations in the Sagnac effect for pairs of NMIs. We describe the magnitudes of the frequency shift at 12 and 24 hour averaging times. We also specify the accuracy requirements of the satellite and ground station position coordinates in order to achieve the required measurement uncertainty. Finally, we comment on whether or not it might be possible to use the TWSTFT measurements to derive useful satellite position information for the evaluation of relativistic effects.

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[1] H. S. Margolis *et al*., "International timescales with optical clocks (ITOC)", pp. 908–911 in Proceedings of the Joint European Frequency and Time Forum and International Frequency Control Symposium (EFTF/IFCS), 2013.

[2] G. Petit & P. Wolf, "Relativistic theory for picosecond time transfer in the vicinity of the Earth", Astronomy and Astrophysics, vol. 286, pp. 971-997, 1994.