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A simple method for calibrating GPS disciplined clocks via direct comparison to a UTC(*k*) time scale

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GPS disciplined clocks (GPSDCs) produce a 1 pulse per second (pps) output that is referenced to UTC(USNO), the Coordinated Universal Time (UTC) scale operated by the United States Naval Observatory (USNO). In nearly all cases, unless the antenna cable is unusually long or if the antenna coordinates have a very large error, an uncalibrated GPSDC should agree with UTC(USNO) to within less than 1 µs, with ~100 ns accuracy being a typical specification. However, even when short antenna cables are used and even if the antenna coordinates have been determined to within less than 1 meter, getting the best available accuracy from a GPSDC still requires measuring and calibrating all hardware delays. The antenna cable typically introduces the largest delay, but the GPS receiver and its associated electronics and firmware, as well as the antenna, will also introduce delays. Once these delays are calibrated, a delay constant can be keyed into the GPSDC to correct the 1 pps output. This allows a GPSDC to be utilized as a true UTC synchronization source.

Several methods of GPS delay calibrations are routinely practiced. Some methods involve measuring cable, receiver, and antenna delays separately and then taking the sum of all delays, but some parts of this process can be difficult. For example, methods for measuring cable delays are well established, but measuring receiver delays might require the use of an GPS simulator with its own reference clock. Antenna delay measurements might be even more involved, requiring the use of a network analyzer and an anechoic chamber. For these reasons, it is common and usually preferable to calibrate a GPSDC as a system that includes the receiver, antenna, and antenna cable, and obtaining a single delay value that accounts for the entire system. This is usually done by simultaneously comparing both the GPSDC under test and a reference GPSDC, each connected to antennas separated by a short distance, to the same clock. The comparisons usually last for about three to 10 days, with one week being typical. The reference GPSDC is assumed to be correct, thus the average time difference between the two units is attributed to the GPSDC under test.

This paper introduces a simple method that retains the advantage of calibrating GPSDCs as a system, but that eliminates the need for a reference GPSDC. This is advantageous, because the reference GPSDC contributes uncertainty to the measurement, and because in many cases the reference GPSDC is a unit maintained elsewhere that must travel to the site of the calibration. The method described here consists of directly comparing the GPSDC under test to any UTC(*k*) time scale listed on the Rapid UTC (UTCr) reports that are published weekly by the Bureau International des Poids et Mesures (BIPM), and then applying a UTCr correction to measurement. The new method works because of the very close agreement between UTC, UTCr, UTC(USNO), and GPS time. It is viable to implement because the UTC(USNO) time scale provides the time reference for GPS, and because daily UTCr – UTC(USNO) results are freely available via the BIPM. For the purposes of this paper, the method is called the GUC method, an acronym for GPS/UTC calibration.

We begin by providing a short discussion of the close relationship between UTC, UTCr, UTC(USNO), and the time broadcast by the GPS satellites. This is followed by a description of the GUC method, including the application of UTCr data. Then, measurement results from several GPSDCs calibrated with this method at the National Institute of Standards and Technology (NIST) are presented, along with an analysis of the measurement uncertainty, which shows that uncertainties of 10 ns or less ($k = 2$) with respect to UTC can be achieved.