CGGTTS guidelines
for manufacturers of GNSS receivers used for timing

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The Consultative Committee for Time and Frequency (CCTF) advocated in its Recommendation S 5 (2001) that the manufacturers of receivers used for timing with global navigation satellite systems (GNSS) implement the technical guidelines for receiver hardware compiled by the CCTF Group on GNSS Time Transfer Standards (CGGTTS). These guidelines have been compiled with the aim of achieving a system that can transfer time with an accuracy of 1 ns or better. They can be applied to all available global navigation satellite systems, such as GPS, GLONASS, WAAS, EGNOS, MSAS, and Galileo.

Receiver operation

We assume that a receiver system consists of a GNSS antenna and receiver, a microprocessor-controller, an input provided for an external frequency reference (typically 5 MHz or 10 MHz) to be used in all internal oscillator functions, an input provided to supply an external pulsed signal related to the external frequency standard (1 pulse per second, abbreviated 1 PPS), and possibly an internal time-interval counter [1]. The components may be integrated into a single package or may be separate and connected together by appropriate cables.

The receiver system must lock onto the GNSS satellite signals and track them continuously while in view in accordance with the established GNSS procedures. During operation the internal oscillator must remain locked to the external frequency reference. The epoch of the receiver clock can be either (1) set based on the GNSS signals themselves and continuously monitored against the external pulsed signal using a time-interval counter, or (2) locked directly to the 1 PPS signal. In the latter case the user must ensure that the 1 PPS epoch is coherent with the frequency reference and maintained sufficiently close to the GNSS time scale to assure proper operation.

It is stressed that for geodetic receivers to operate correctly for time transfer there should be a fixed bias relationship between the external 1 PPS reference timing signal and the external frequency reference, and both signals should of course be derived from the same clock. This means that the user has to determine the phase offset between the 1 PPS and the external reference when the receiver is first set up, and check it periodically during operation. This transfers the requirement for a time-interval counter from inside to outside the receiver.

Generally, the present generation of C/A-code and P-code timing receivers, developed for use with the common-view method, do not support this external frequency requirement. In most cases it is not essential for the external frequency reference and the 1 PPS signal to come from the same clock; if they *do* need to be from the same clock this should be clearly specified.

The raw observations should be made at a user-specified rate (at least once per UTC second) and the data should be made available with a minimum of manipulation. In general it is desirable to obtain data for as many observables as feasible (group and phase delays, delay rates, and signal-to-noise) for all possible frequency bands. Note that all measurements to all satellites on all frequencies must refer to a single epoch (corresponding to the nominal epoch of an internal clock which can be compared to an external clock). Channel-dependent delay biases should be applied as internal corrections [1] before the raw data are output. Other hardware delays – such as cable delays – depend on the configuration of the user's hardware and must be measured outside the receiver.

Depending on receiver type, there are two approaches to data output:

(1) Timing receivers developed for the common-view method [2]

Raw data sampled once per UTC second should be elaborated and formatted according to the technical directives established by the CGGTTS [3]. These directives were first developed for GPS C/A-code single-channel single-frequency time receivers, and have subsequently been extended to include multi-channel multi-system (GPS, GLONASS, WAAS, EGNOS) multi-frequency and multi-code observations [1, 4].

Some of the present common-view receivers provide in addition a list of the completely raw data. This can prove very useful and it is recommended that future generations of other common-view receivers do the same thing.

(2) Geodetic [5] and navigation receivers [6]

These receivers should provide raw data, with information about the timing of its internal time reference, to be elaborated on an external computer using software developed by the timing community [6 - 9].

It should be noted that at present some geodetic receivers accept only an external input of 20 MHz, whereas most timing laboratories work with 5 MHz or 10 MHz reference frequencies. The laboratories must therefore use an external device for converting one of the standard frequencies to 20 MHz. The phase instability of such a device (particularly with respect to temperature) can add a significant contribution to the overall uncertainty budget of the receiving equipment. Use by these receivers of a standard reference frequency (either 5 MHz or 10 MHz) is thus encouraged.

Remote access

The receiver should support remote access. Ideally, the access methods should include both a standard modem interfaced to a dial-up telephone line and a network connection that supports TCP/IP connections. Remote configuration of the receiver parameters is also desirable.

Accuracy of the time-interval counter

The time-interval counter, if used, should measure time intervals (of up to 1 s if required) with an accuracy approaching 100 ps or better. Ideally, the noise of these measurements will be characterized by white phase noise at a level consistent with the accuracy specification.

Trigger level for the 1 PPS reference input of the receiver

The trigger level of the 1 PPS reference input should lie between 0.25 V and 1 V and its value should be specified in the technical manual. Stability is improved if the trigger level is low relative to the maximum voltage of the 1 PPS pulses. The amplitudes of the pulses should be between 2 V and 5 V, and the triggering should take place at the leading (rising) edge of the pulse. To reach the goal of a 1 ns system, the stability of the trigger circuit should be 100 ps or better for rise times of the 1 PPS pulses of up to 10 ns.

Antenna and receiver electronics

Antenna and receiver electronics should be sufficiently stable with respect to environmental changes that the variation in delay through the system over the expected range of temperature and other environmental parameters is no more than 100 ps. In particular, the antenna should tolerate diurnal temperature changes of around 40 °C, as occur in certain parts of the world, and the receiver should tolerate changes of about 10 °C, as may be experienced in standards laboratories without robust temperature control [1, 10, 11].

Antenna cables

Antenna cables should be stable with respect to changes in temperature (the associated delay should vary less than 0.05 ps $°C^{-1}$ m^{-1} over the range –30 °C to +40 °C), and have low power loss. Cable lengths of up to 120 m are sometimes necessary [12, 13].

Impedance matching in the antenna cable and terminations

The impedance of the antenna cable and its terminations should be such that the power level of any extraneous signal reflected in the cable should be at least 40 dB below the direct signal at the receiver [14]. As far as possible, the impedance should be independent of temperature and other environmental conditions. A cable impedance of 50 Ω is desirable, as this facilitates connection of the system to standard test equipment.

Relation between the 1 PPS reference input and the external frequency reference

The relation between the 1 PPS reference input and the external frequency reference should be defined. If this relationship is not important, or if the two signals must be coherent, this should be stated.

Multipath

Antenna and receiver systems should have multipath mitigation systems, such as choke-ring antennas and narrow-band correlators. Contributions due to multipath noise should have time deviation (TDEV) values below 1 ns when averaged across satellites. Multi-element antenna designs may also be used to achieve this goal. Geodetic choke-ring antennas are suitable when using geometric calibration (keyword: antenna phase centre variation) for these antennas from the International GPS Service Central Bureau (IGSCB).

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