Callisto Data Time-Stamping

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Introduction

The goal of the e-CALLISTO solar radio spectrometer network is to provide the best data possible. That goal is not achievable unless the data timestamps are accurate. In particular, when computational methods, such as Artificial Intelligence (AI), are used to identify and classify radio bursts, it is imperative that the timestamps be very accurate so that the data from different stations can be cross-correlated. For best accuracy, the PC that gathers the data at each station must be synchronized to Coordinated Universal Time (UTC) using the Network Time Protocol (NTP), and the Callisto instrument must use an external clock source. This article describes the application of external clock sources to Callisto instruments so that the quality of e-CALLISTO data is as high as possible.

Callisto Data Timing

The Callisto instrument in conjunction with its operating software (callisto.exe) produces Flexible Image Transport System (FITS) files that include metadata as well as the frequency, amplitude and time of the observations. The length of the FITS files can be any practical value but a typical setting is 900 seconds (15 minutes). In addition, Callistos typically are setup to produce four observations each second, giving a total of 3600 observations in each 15 minute FITS file. Each observation is time-stamped as it is transferred to the PC over the Callisto's serial data link at 115 200 b s^{-1}.

PC timing: As mentioned above, the PC that collects the Callisto data must be synchronized to UTC using NTP. The synchronization interval for most Windows PCs has been found to be 15 minutes to 2 hours with the shorter interval required for laptops and PCs in an unstable temperature environment. If the PC real-time clock is not synchronized often enough, the real-time clock drifts and the timestamp error accumulates. NTP setup on a Windows PC is beyond the scope of this article, but readers may refer to {Reeve15.1} and {Reeve15.2} for NTP installation and application details.

Even with the above considerations, the time uncertainty can be on the order of ±60 ms in older PCs but somewhat lower at ±20 to ±50 ms in newer PCs. Also, the time-stamps used by the callisto.exe software are determined several times per second, but the Windows operating system can introduce delays and other effects, resulting in an error that approaches ±1 s.

The rate at which the data is transferred from the Callisto to the PC is determined by the Callisto clock. The clock may operate *asynchronously* or *synchronously* according to the [`clocksource`] parameter setting in the Callisto configuration file (callisto.cfg).

Asynchronous operation: When operated asynchronously, the [`clocksource`] parameter is set to 1 and the Callisto processor's 11.0592 MHz quartz crystal determines the transfer rate. The frequency is scaled internally by the processor to perfectly meet standard baud-rates for purposes of serial data transfer. The crystals used in manufactured Callistos usually have a ±30 ppm frequency tolerance and ±50 ppm frequency stability over a

temperature range of –10 to +70 °C. Thus, the crystal frequency can vary by 80 ppm from its specified value of 11.0592 MHz. For example, if the crystal frequency is low by 80 ppm (80 Hz), a nominal 15 minute FITS file is actually filled with 3600 observations in 900.3 seconds.

Synchronous operation: For practical purposes, synchronous operation eliminates the potential timing errors inherent to the asynchronous operation described above. An external 1 MHz, 5 V TTL-compatible clock source is connected to the Callisto, and the [`clocksource`] parameter is set to 2. Synchronous operation typically uses a GNSS-disciplined oscillator (called GPSDO in this article). The accuracy is usually in the range 0.1 to 1 ppb, at least 80 000 times better than the quartz oscillator in the instrument. The external clock is connected to a processor input port where it is used to synchronously output the FITS data over the serial link to the PC.

External 1 MHz clock sources

Two GNSS-disciplined oscillators that may be used as an external clock source for the Callisto are: Mini Precision GPS Reference Clock (Mini-GPS) and LBE-1420 GPSDO Locked Clock Source (LBE-1420), both from Leo Bodnar Electronics {LBE}. The latter is the most current model (see also the Discussion section).

In the Callisto application, the oscillators are connected through the external clock connector (figure 1) to a high impedance load in the instrument. The load is equivalent to an infinite resistance in parallel with a 10 pF capacitor. The output amplitude of both units is 3.3 V-pk under these conditions (figure 2).

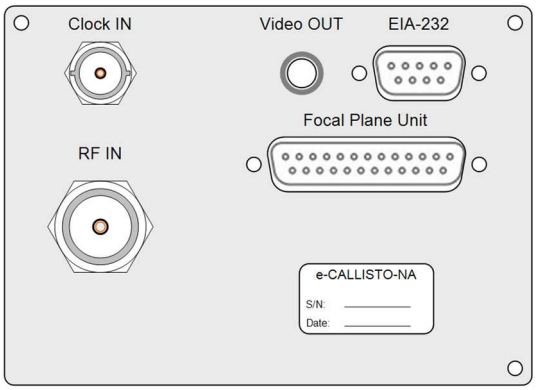


Figure 1 ~ Callisto front panel for instruments manufactured in USA. Units from Switzerland are very similar. The Clock IN connector at the upper-left is used to connect a 1 MHz external clock source.

The Callisto 1 MHz clock input uses a TTL CMOS buffer (IC8, 74HC244), which requires a nominal 0 to 5.0 V input signal. The basic specifications for CMOS technology require the high input state voltage to be ≥ 3.5 V and low input state voltage to be ≤ 1.5 V. However, the datasheet for the 74HC244 used in the Callisto indicates that the minimum voltage for a high input state is 3.15 V and the low input state is a maximum of 1.35 V. The two external clock sources easily meet the low state requirement, but the high state voltage is 3.3 V-pk, which falls between the two voltage levels. Although no reliability problems were encountered during testing, the setup has a low operating margin (see Discussion section).

Figure 2 ~ Input (yellow) and output (green) voltage waveforms for the clock buffer IC8. The input waveform is from the LBE-1420 and its amplitude is 3.28 V; the buffer input waveform and voltage from the Mini-GPS is identical. The output voltage from the buffer is TTL level at 5.12 V.

Application

The 1 MHz clock connection requires a single coaxial cable (figure 3). Because of the low operating margin of the GPSDO outputs (discussed above), the cable that connects the GPSDO output to the Callisto clock input must be high quality and short length.

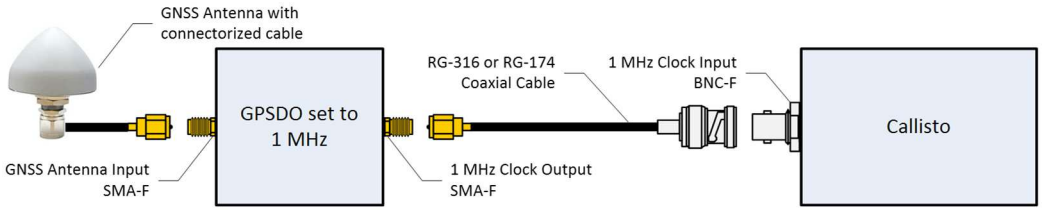


Figure 3 ~ RF connections for 1 MHz external clock source.

The Mini-GPS and LBE-1420 are supplied with an antenna that has an integral connectorized cable. The antennas are active types with relatively high gain, so the cable length can be extended if necessary. Online resources should be used to find information on the best GNSS antenna location and placement.

Both of the clock sources described above are powered by 5 Vdc and have a load current about 250 mA. A mini-USB-A connector is used on the Mini-GPS and a USB-C connector is used on the LBE-1420. A switchmode power supply should be avoided because of its inherently high noise and the possibility for electromagnetic interference (EMI). Instead, a 5 V linear power supply that is capable of delivering at least 250 mA should be used. The clock sources are configured through their USB interfaces with the software tools available from the manufacturer (figure 4). The GPSDOs may be disconnected from the PC after setup and then connected to a 5 V power supply for normal operation.

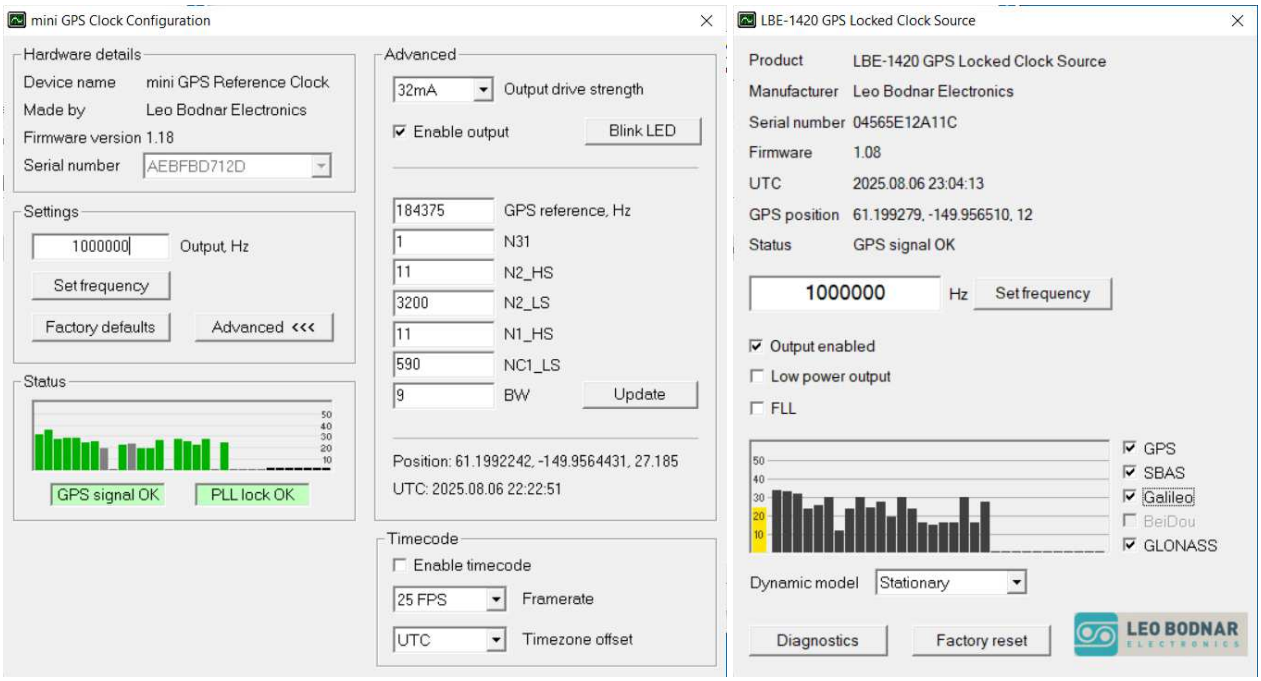


Figure 4 ~ Left: Mini-GPS setup software. The frequency must be set to 1 MHz (1 000 000 Hz), and the *Output drive strength* should be set to *32ma* and the *Enable output* box should be checked. Do not enable the *Timecode* setting. Right: LBE-1420 setup software. The *Output enabled* box for the LBE-1420 should be checked. After setup, the units may be disconnected from the Windows PC and then connected to a 5 V power supply for normal operation.

For stations that use two Callistos in a dual polarization system, two external clock sources are required, one for each instrument. It is not recommended that a single Mini-GPS or LBE-1420 be connected through a splitter to two Callistos because the voltage level probably will be reduced below the Callisto input buffer threshold and it will not properly detect the signal. One alternative is to use two Mini-GPS or two LBE-1420, but a better alternative is to use a single LBE-1421. The LBE-1421 has two outputs (both programmable to 1 MHz) and has the same dc power requirements as the LBE-1420. Also, a single LBE-1421 is less expensive than two Mini-GPS or two LBE-1420.

A typical e-CALLISTO station is setup to operate in the Automatic mode, in which case the Callisto is controlled by the scheduler.cfg file. If an external clock source is connected to the instrument, but the [`clocksource`] parameter in the callisto.cfg file is set to 1, the external clock signal is ignored and FITS data files are produced asynchronously as described above and according to the schedule.

On the other hand, if the [`clocksource`] parameter is set to 2 but no external clock source is connected or is lost, no FITS data files are produced, and callisto.exe displays various errors such as *Auto stop due to data loss* and *Check RS232 connection* (figure 5). The callisto.exe application will automatically recover when the external clock source is reconnected and will continue according to the schedule. The [`clocksource`] parameter usually may be changed on-the-fly but some Windows operating systems do not support this, so it is good practice to restart the callisto.exe application whenever the callisto.cfg file is changed.

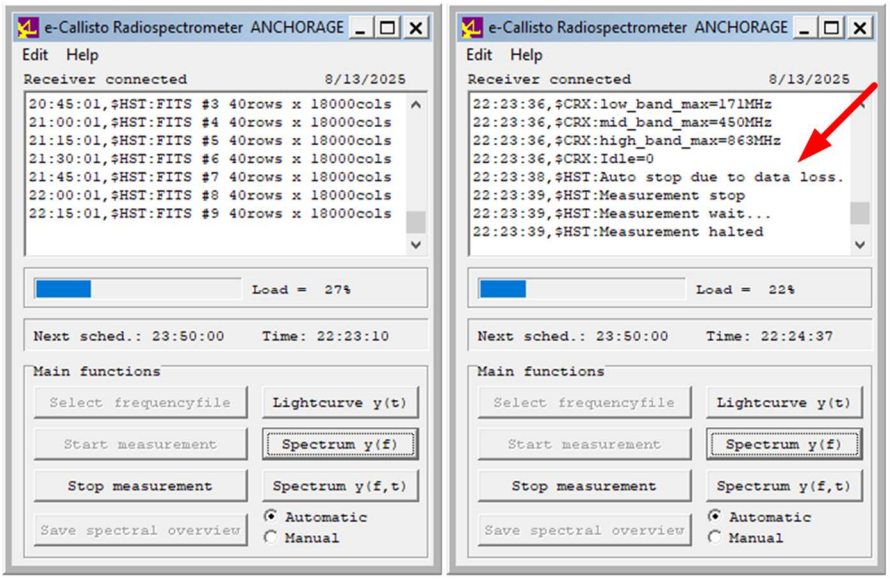
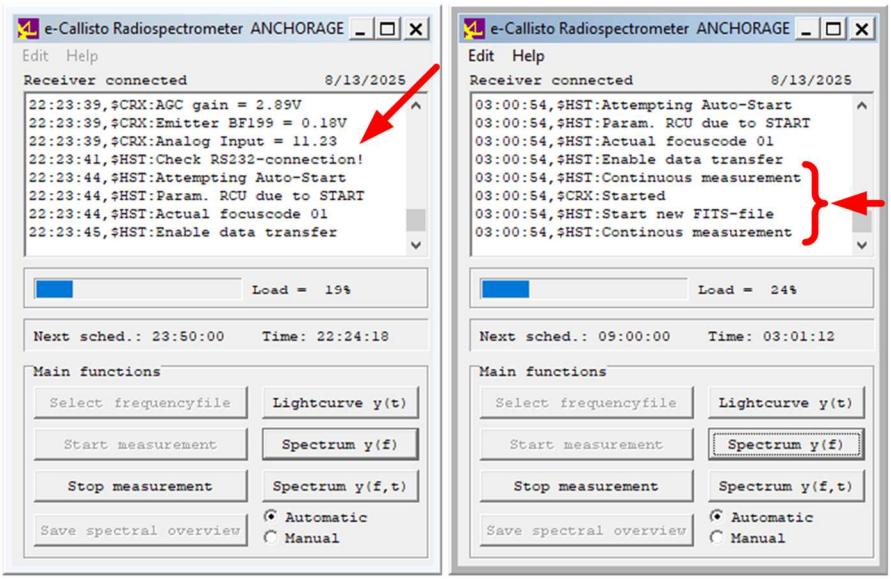


Figure 5.a ~ Left: Callisto.exe operating normally and collecting data with the external clock source connected. Right: Callisto.exe error (red arrow) when the external clock source was lost or disconnected.



igure 5.b ~ Left: Another Callisto.exe error (red arrow) that is shown when the external clock source was lost or disconnected. Right: Attempted Auto-Start was successful (red bracket) after the external clock source was reconnected and data collection back to normal.

Discussion

- The external clock input on the Callisto is through a 100 ohm resistor to the TTL buffer IC8 (figure 6). The resistor isolates noise that might be produced by the external clock connection, and its application is described in a Non-Conformance Report from 2011 (NCR20110617, https://e-callisto.org/Hardware/ncr/NCR20110617.pdf). All current production Callistos have the resistor installed.

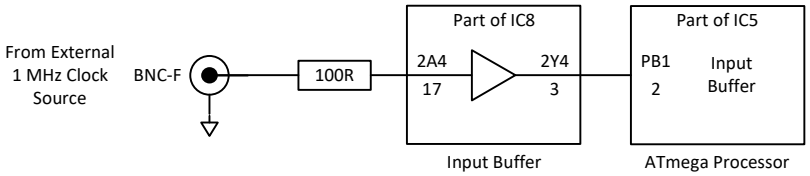


Figure 6 ~ Callisto clock source circuit schematic.

- If the external clock sources described above prove to be unreliable in a specific installation, it may be necessary to hand-select (trial-and-error) a different buffer integrated circuit (IC8) to find one with a low enough input voltage threshold. Of course, a GPSDO with a 5 V TTL output would not require any special considerations. Alternatively, a level-shifter could be used between the Mini-GPS or LBE-1420 and the Callisto to change the high state output from 3.3 V to 5.0 V. If noise induced into the coaxial cable from an external interference source is suspected of causing unreliable operation, clamp-type ferrite beads may be placed on the cable to reduce the common mode noise.
- The Leo Bodnar Electronics GPSDO units described above are the only commercial units known to the authors that are able to provide a programmable GNSS-disciplined 1 MHz output. There are many similar commercial GPSDOs that provide a fixed 10 MHz output, some with 3.3 V CMOS and some with 5.0 V TTL outputs. These units may be used with divider circuit that provides ÷10 ratio.

References

{LBE} Leo Bodnar Electronics: https://www.leobodnar.com/shop/

{Reeve15.1} Reeve, W., Network Time Protocol and Meinberg NTP Time Server Monitor ~ Installation Guide, 2015: https://www.reeve.com/Documents/Articles%20Papers/Reeve_NTP-MeinMon_Install.pdf

{Reeve15.2} Reeve, W., Meinberg NTP Time Server Monitor Guide, 2015: https://www.reeve.com/Documents/Articles%20Papers/Reeve_MeinbergMonGuide.pdf

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