THE VLT TIME REFERENCE SYSTEM: A MICROSECOND-ACCURATE TIME/SYNCHRONIZATION BUS FOR DISTRIBUTED CONTROL SYSTEMS

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Abstract

The demanding timing and synchronisation requirements of the VLT (Very Large Telescope) array of telescopes operating in interferometric mode, have led to the development of a dedicated fibre-optic bus, the Time Bus, distributing accurate timing to more than 100 Local Control Unit computers (LCU) scattered on a wide area. The UTC (Universal Time Coordinated) is received from the Globalstar GPS (Global Positioning System) satellites, processed and distributed through the Time Bus to the Local Control Computers with accuracy in the range of few microseconds. Means for processing, backing up and relay the time information as well as for interfacing the Local Control Computers with the Time Bus, have been developed and integrated. Software drivers have also been developed providing means to synchronise processes running on different local computers to the absolute time from better than 10 microsecond accuracy at interrupt level to scheduling processes, or sending messages with millisecond accuracy. Tests have been performed to evaluate the performances both at ESO (European Southern Observatory) headquarters and at the VLT observatory on Cerro Paranal, Chile, where the system is now in regular operation. The compliance with leap seconds, Y2K and GPS week rollover has been investigated.

1 THE VLT OBSERVATORY

The VLT observatory, located on Cerro Paranal in the Atacama Desert, northern Chile, is composed by four telescopes equipped with 8.2m diameter main mirror. The four telescopes can be operated independently or in a combined way to reach a total collected power of a 16-m equivalent telescope.

In addition, with the help of three re-locatable 1.5-m auxiliary telescopes, the telescopes can be operated in an interferometric mode to attain very high angular resolution imaging.

At this time the first telescope, named Antu (after the mapuche name of the sun) is under scientific operation, the second one (Kueyen, the moon) is being commissioned and the other two, Melipal (the Southern Cross) and Yepun (Sirius) are under test.

All the four units are planned to be fully operational shortly after the turn of the century.

More than 100 Local Control Unit computers (LCU) implement a distributed real time control system: accurate synchronisation among the LCU's operating in a single telescope as well as in different telescopes is a key issue.

In addition, the absolute time information is needed in order to perform astronomical observation.

The Time Reference System (TRS) has been developed in order to supply each LCU and workstation with the absolute time information and guarantee the synchronisation among all the LCU's.

2 THE TIME REFERENCE SYSTEM

The main purpose of the TRS is to supply a unique clock with suitable accuracy to all the LCU's and workstations throughout the VLT observatory.

Since the LCU's implement high-speed control loops with real time constraints, the timing accuracy required is better than 10 microseconds.

On the order hand, the workstations have high-level supervising/monitoring purposes and the accuracy required is in the range of 10 milliseconds.

Two different means have been used to distribute the time to workstations and LCU's.

The workstations can access a "time server" that supplies the time through the Local Area Network (LAN).

The LCU's, instead, are connected through a "Time Interface Module" (TIM) to a "Time Bus" (TB) dedicated fibre carrying high accuracy time information.

Although astronomical coordinates are based on the standard UT1, the standard Universal Time Coordinated (UTC) has been selected to represent the time information in the VLT system.

The difference between UT1 (based on the mean solar day) and UTC (based on a fixed duration of second) is always kept less than 1 second, and as soon as it approaches the second, a unit, called leap second, is added or subtracted from UTC.

The difference between the two, as well as notice of leap second occurrence, is supplied in advance by the International Earth Rotation Society (IERS).

The VLT control system needs this information in order to compute UT1 starting from UTC.

It is composed by the following sub-systems:

- Central Time Standard
- Time Server
- Time Bus Encoder
- Time Bus Distribution Boxes
- Time Interface Modules

The architecture of the TRS is shown in fig. 1

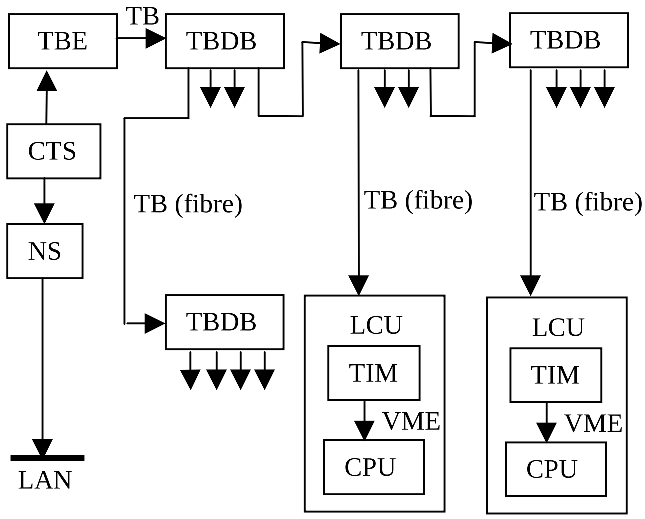

Figure 1: TRS architecture

2.1 Central Time Standard

The Central Time Standard (CTS) retrieves the UTC time from the GPS satellites.

This information is used to discipline a local high-stability rubidium clock.

The rubidium clock acts as a backup in case of failure of the GPS, which, although highly reliable, is not under ESO control. The rubidium clock guarantees at least one night at full time accuracy. The synchronisation between the computers, which is of main concern for the operation of the observatory, is kept indefinitely.

The CTS is a commercial unit manufactured by Datum Inc., type ExacTime GPS Time Code and Frequency Generator (part number 9390-6000) [1].

2.2 Time server

The Time Server (TS) distributes the time information through the LAN.

It gets the information from the CTS as an IRIGB (Inter Range Instrumentation Group) coded signal and makes it available to all the workstations according to the Network Time Protocol (NTP) [2].

Due to the network delays, the timing accuracy is in the order of 10 milliseconds.

The Time Server is also made by Datum Inc., type tymServe 2100 [3].

2.3 Time Bus Encoder

The time output from the CTS is also fed to the Time Bus Encoder (TBE). It converts the time into the time bus signal: a PWM modulated 1MHz signal.

This has several advantages against the traditional IRIGB code, from which it has been derived.

The IRIGB is a 1KHz amplitude modulated code.

Its low frequency does not allow reaching the required timing accuracy of 10 microseconds.

In addition, being analogue, it is sensitive to environmental noise and is not suitable for the transmission through fibre optic.

The Time Bus code is based on a high frequency carrier on which a simple PLL (Phase Locked Loop) can lock with accuracy better than 1 microsecond.

It is a digital signal, as consequence the transmission through fibre is easy.

The modulation scheme, represented in figure 2, consists in a low level PWM encoding in which the logical one is represented by a pulse having duty cycle larger than 50% (500ns) and the logical zero by a pulse having duty cycle smaller than 50%.

The low-level encoding is used to generate the high-level 10ms bit stream (which has the same structure as the standard IRIGB).

In this bit stream a high-level "zero" bit is encoded as a train of low level ones longer than 5ms (but shorter than 8ms) followed by a train of low level zeroes up to 10 ms.

A high-level "one" bit is encoded as a train of low level ones shorter than 5ms followed by a train of low level zeroes up to 10 ms. Figure 2 shows the encoding scheme.

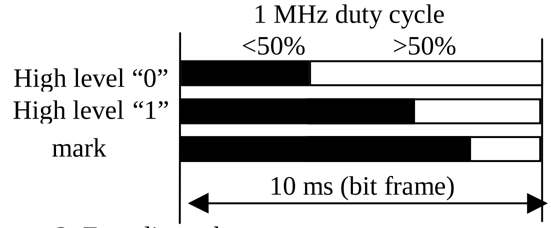

Figure 2: Encoding scheme

An additional symbol is encoded to mark the beginning of a message word, it is coded as an 8ms train of low level ones, followed by low level zeros up to 10ms.

The fibre used for the distribution is a popular 62.5/125 microns multi-mode fibre, the same type normally used for LAN's.

The time bus encoder is a custom device, made by Lange elektronik GmbH.

2.4 Time Bus Distribution Box

The signal generated by the TB encoder is converted to optical and then distributed by a tree made up of Time Bus Distribution Boxes (TBDB) connected through fibre.

The time distribution box can accept an electrical or optical input and delivers four or more optical outputs.

Only the first TBDB, the one connected to the TB encoder, uses the electrical input, all the others use the optical input.

Each TBDB contains a receiver that converts the incoming signal to electrical and feeds one or more transmitters, each having four optical outputs.

The conversion from optical to electrical and back to optical introduces both phase distortion and a width distortion in the signal. These two effects limit to four the maximum number of TBDB's that can be cascaded.

The timing error introduced by the TBDB is <100ns.

The time bus distribution boxes are custom devices produced by ESO.

2.5 Time Interface Module

A VME card has been developed at ESO to interface each LCU with the time bus, the Time Interface Module (TIM) [4].

This card contains the logic needed to decode the time bus signal and let the CPU's connected on the bus access the time information.

Whenever the TB is not available, the TIM automatically switches to a low-accuracy local oscillator that keeps the functionality of the TIM, although with degraded accuracy.

The card contains also six user-configurable timers, which can be programmed to generate frequency signals or cyclic interrupts.

Since the timers are clocked synchronously with the time bus, timers on different LCU's count synchronously.

An additional "next 100 ms" interrupt can be generated at the edge of the next 0.1 second of UTC time. This feature helps synchronising to absolute time the tasks running in the LCU.

A software driver has been developed under VxWorks real-time operating system to give the user software full access to the card.

The timing error introduced by the TIM is <1microsecond.

A new release of the card is under test, which has some additional features:

- Robust time code check to avoid noise in the time bus signal or sporadic CTS/GPS malfunctions affect the time.
- Alarm interrupt to generate an interrupt at a specified date/time
- Battery backed up real time clock to keep (low accuracy) time information after power off, when disconnected from TB

3 TESTS

Tests have been performed for several years both at ESO headquarters in Europe and at the VLT site in Chile, to qualify all the components of the TRS.

Particular conditions like the year 2000, leap years handling and the GPS week rollover have been checked either by simulation or at real occurrence.

4 POSSIBLE EXTENSIONS

Although the TRS is performing satisfactorily, some extensions are envisaged that could improve the performances of the system or make it suitable for other applications.

4.1 Fibre delay compensation

The largest contribute to the timing error is due to the propagation of the light through the fibre. Since it is a constant parameter related to the location, it would be possible modify the TIM or the TBDB to be configurable to compensate for the propagation delay.

4.2 Local generation of TB

If the time bus fails, the TIM automatically switches to local mode using the inaccurate on board clock.

This has two consequences: the LCU's cannot get any longer an accurate absolute time and they loose synchronisation. To limit the impact of a TB failure, the TBDB could be designed in such a way that it can generate the TB basing on a low accuracy local clock, when the incoming signal fails. This obviously doesn't improve the accuracy of the absolute time, but at least keeps the synchronicity among all the LCU's fed by the relevant sub-tree.

4.3 Extension of supported buses

The local computers used in the VLT are based on the VME bus architecture. As a consequence the TIM has been developed for such a bus.

The possibility to develop TIM's for different standard buses could be considered.

5 CONCLUSION

The presented central time reference system, based on the GPS system, provides an accurate timing source with backup capabilities.

It supplies more than 100 local control computers distributed on an area of about 300m across with a time information having a measured absolute accuracy better than 2.5 microseconds.

Means for accurate synchronisation between tasks running in separate computers have been developed.

It also feeds time information with accuracy of 10 milliseconds to several workstations.

6 REFERENCES

[1] "ExacTime GPS Time Code and Frequency Generator User's Guide", DATUM Inc., August, 1997

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[3] "TymServe 2100 Network Time Server User's Guide Rev. B", DATUM Inc.

[4] M. Ravensbergen, "VLT TRS Time Interface Module Technical Manual", ESO document VLT-MAN-ESO-17300-473 Issue 2, July 1995