TIME REFERENCE SYSTEM OF THE ESO VERY LARGE TELESCOPE.

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ABSTRACT

The necessity of supplying precise time information in large telemetry ground stations and astronomical observatories is very similar. Therefore the way of solving this problem as it is done in the Very Large Telescope of the European Southern Observatory can be easily adopted to telemetry stations and ranges, especially when fiber optics are used.

The European Southern Observatory (ESO) is building a new observatory in Chile for the Very Large Telescope (VLT). This VLT consists of 4 telescopes, each of them has a primary mirror diameter of 8 meters. the control architecture is based on workstations and VMEbus computers. The VMEbus computers are distributed over the whole building and are using real time operating system.

Since the availability of the Global Positioning System (GPS) the generation of highly accurate timing signals on remote locations without the use of expensive Cesium standards does not create problems any more. However, distribution of a timing signal to many computer with high accuracy is an issue. The accuracy of the commonly used IRIG B-code is not adequate if the requirements are in the 10 microseconds range.

This paper presents the design of a timing system that is adopted to the VLT. An overview of the requirements of the Time Reference System (TRS) is given. These requirements have been defined on the basis of experiences with the timing system of the ESO NTT telescope.

The hardware units are described. These are a Central Time Standard, a Time Distribution System and a VME Time Interface Module. The distribution is based on fiber optic transmission, using a simple digital modulation that outperforms the analog IRIG B modulation. The Time Interface Module in the computer does not only perform the timing signal decoding but contains also user-programmable timers that are synchronously clocked from the time source.

Presently all units of the TRS have been tested and the series production of the distribution and the Time Interface Modules are in progress.

KEY WORDS

Time Reference System, Time Signal Distribution, Accuracy 10 MIcroseconds, Digital Modulation, Fiber Optic Transmission

1. THE VLT OBSERVATORY

The 4 VLT telescopes can operate individually and in an interferometric mode. In the latter case, the light from the celestial object is combined via optical delay lines in the combined Coudé focus.

The control of all the functions is done with Local Control Units (LCU's). These are VME computers with the real-time operating system VxWorks. The LCU's are connected to Local Area Networks. Operator control is done from UNIX workstations, which are connected to these networks.

The VLT observatory will have about 150 LCU' s.
The size of the observatory is about 300 meter as its biggest diameter.

2. TIME REFERENCE SYSTEM

The individual telescopes with the distributed real time LCU's highlight that there is a requirement for a synchronous timing between LCU's. There are fast control loops which are physically separated between 2 or more LCU's. This is already the case for the individual telescopes, but the interferometric mode has even stronger requirements in this respect. This is accomplished with the Time Reference System (TRS).

The TRS will:

- contain the central clock for the observatory,
- provide synchronisation facilities for the workstations,
- distribute a timing signal to the LCU's
- provide accurate timing facilities in the LCU's.

2.1. TIME BASIS

Astronomical coordinates are based on Sidereal Time. This time is however local and can therefore not be accepted as the time basis for the VLT observatory. International time is UTC and ESO has decided to use UTC as the time basis for the TRS. All calculations of coordinates will be done in the UTC time frame. Sidereal Time is calculated with UTC as source.

2.2. DIFFERENCES BETWEEN UT1 AND UTC.

The difficulty that must be solved with this approach is the difference between UT1 and UTC. UT1 is based on the duration of a 'mean solar day' while UTC is based on a constant interval for the second. The UT1 is needed as an intermediate step in order to calculate the telescope coordinates. The difference between UT1 and UTC is a variable. It is estimated by the International Earth Rotation Society (IERS) one month in advance and is available as a table with the values listed per day. These values must be entered into the VLT computer system.

If the value approaches 1 second, a leap second is inserted into the UTC.

2.3. LEAP SECONDS

Leap seconds in the UTC are not (yet) handled by commercial available equipment. Some suggestions about this point are described in chapter 4.1.

It is necessary for the VLT to enter the UT1-UTC into the computer system. This list contains (obviously) also the information about leap seconds. A 'warning' about an upcoming leap second can then be made available in the VLT software system.

On the basis of these 2 arguments, ESO decided to put no requirements about leap seconds. It is however certainly an aspect that deserves proper handling by the UTC reception and distribution systems so that it is 'on-line' available for the users.

2.4. MODIFIED JULIAN DAY

The LCU's must count the time synchronously, also at the change of the day. They must therefore receive the full time information, that is also Modified Julian Day (MJD) or day of the year and year.

MJD has the preference as this allows simple calculation in the LCU's.

It should be noted that the MJD in this context is an integer. In the normal representation, it is a real (that is, it includes the fraction of the day).

Another aspect is that MJD is based also on 'mean solar days' and relates therefore to UT1, not to UTC The difference between these 2 is always less than 1 second.

Considering the existence of time codes, ESO chose to specify the addition of MJD (as integer) in the time code format. This MJD increments at midnight UTC. One could define this a Modified Julian 'Date'.

2.5. ACCURACY

The tracking of a celestial object requires an accuracy of the time at the LCU of better than 100 µs. If this value is reached, the effect of this is neglectable in the tracking.

Time tagging of events which are related to some types of astronomical observation require an accuracy of bettor than 10 µs.

The requirements from to interferometer on the accuracy are not known in detail yet, but this comes to the same class.

ESO decided therefore to put an accuracy requirement of 10 µs.

2.6. WORKSTATION TIMING

The timing must be unique and guaranteed in the whole observatory. LCU' s need accurate timing. Workstations need synchronisation as well, although not with the same accuracy requirements as they are not real time computers. ESO has put the accuracy requirement for the workstations to 10 ms.

2.7. SYNCHRONISATION

Time reception with the GPS system is vary reliable nowadays. Still, we consider a fault in the GPS transmission or reception a 'likely' failure. Also, the repair of a fault the GPS is not under direct control from ESO, but it depends on a third party.

We have put more emphasis on the synchronisation of the time in the VLT observatory than on highest accuracy.

Therefore, ESO specified one central clock from which all timing is derived.

Synchronous timing is then obtained, even if there is a fault in the GPS reception

2.8. STABILITY

It is an argument, particularly for an astronomical observatory, to minimise the repair effort during night time. ESO specified therefore a stability of the 'flywheel' that is sufficient to maintain the accuracy over a time interval of 10 hours. This is equivalent to 3.10^{-10}.

This allows to delay the repair activity to daytime.

2.9. RELIABILITY

The central part of the reception of the TRS is vital for the proper operation of the VLT observatory. The site provides an Uninterruptable Power Supply (UPS) of 230V AC All workstations and LCU's will be powered from that supply and it will power the TRS as well.

ESO has bad experiences with local UPS systems: they have proven to be the weakest part of a system.

We made the choice to specify a double central part of the system, without local battery back-up.

2.10. JITTER AND DISTRIBUTION CODING

Noise, which enters the time distribution system, causes time jitter in the detection mechanism at the receiver end.

The ESO observatory in La Silla uses the commonly used coding, the IRIG-B code. This is an analog signal: the carrier is a 1 kHz sine wave and the code is modulated as amplitude modulation. Each bit has a duration of 10 ms. This is not adequate for modern timing systems for the following reasons:

- The 1 kHz carrier does not allow easy re-generation of the UTC with high accuracy: In view of the 10 μs accuracy requirement, one needs a clock frequency of 1 MMHZat the receiver end. To phase lock this 1 MMHZwith a 1 kHz incoming signal will result in unacceptable jitter. This can only be avoided with special components like Voltage Controlled Crystal Oscillators and using very low bandwidth in the PLL.

This effect is reduced when a higher carrier frequency is chosen. Although codes with higher carrier frequencies are defined by IRIG, they are not common.

- The TRS must operate in an Electro Magnetic environment that can be compared with 'light industry', certainly not with a laboratory environment. Modern motor control is made with variable frequency inverters which generate electrical spikes. These spikes interfere with an electronic time bus distribution signal.

The second aspect has been clearly observed at the NTT telescope at La Silla and could only be solved by a redesign of the input circuitry at the receiver. Still, the accuracy of the timing at the receiver can not be guaranteed.

ESO specified therefore to use for the VLT observatory:

- Optical fibers for the distribution. Fibers are already common for LAN's.
- A digital coding scheme with a 1 MHZ carrier.

2.11. DECODING IN THE LCU'S

The functional requirements that were put on the LCU board were:

- decoding of the time distribution signal.
- a quartz oscillator for test and backup.
- UTC register, accessible from the LCU computer bus.
- Six user-programmable timers, synchronous with the time distribution signal.
- Programmable VME interrupts from the UTC register and the timers.

3. DESIGN AND TEST RESULTS

Based on these requirements, the Time Reference System (TRS) has been designed with:

- a Central Time Standard (CTS).
- a Time Bus distribution system.
- a Time Interface Module in every LCU that requires accurate timing.

This is schematically shown in fig. 1.

3.1. CENTRAL TIME STANDARD

The CTS has a GPS receiver, which disciplines a Rubidium Oscillator. A Rb oscillator is sufficient to obtain a low jitter in the time and to keep the accuracy within the specifications in case of a fault in the GPS

The CTS has a Time Server unit. This unit is connected to the Local Area Network. The workstations will synchronise their clocks with the CTS clock via the Network Time Protocol (NTP) [1].

The CTS has also a coder that codes the UTC into a serial distribution signal.

Physically, the CTS consists of 2 units:

- a DATUM GPS Time/Frequency System [2], incorporating the GPS receiver, Rb clock and serial coder.
- DATUM Network Time Server [4] , incorporating the Time Server with the NTP protocol.

Modifications were implemented by DATUM and LANGE in the Datum GPS unit in order to comply with the requirements:

- The Modified Julian Date was made visible on the CTS display.
- Modified Julian Date was inserted in the serial code.

The modulation method for though serial code was changed, see chapter 3.2.

The GPS unit provides an accuracy of 400 nanoseconds compared with the UTC, including SA effects.

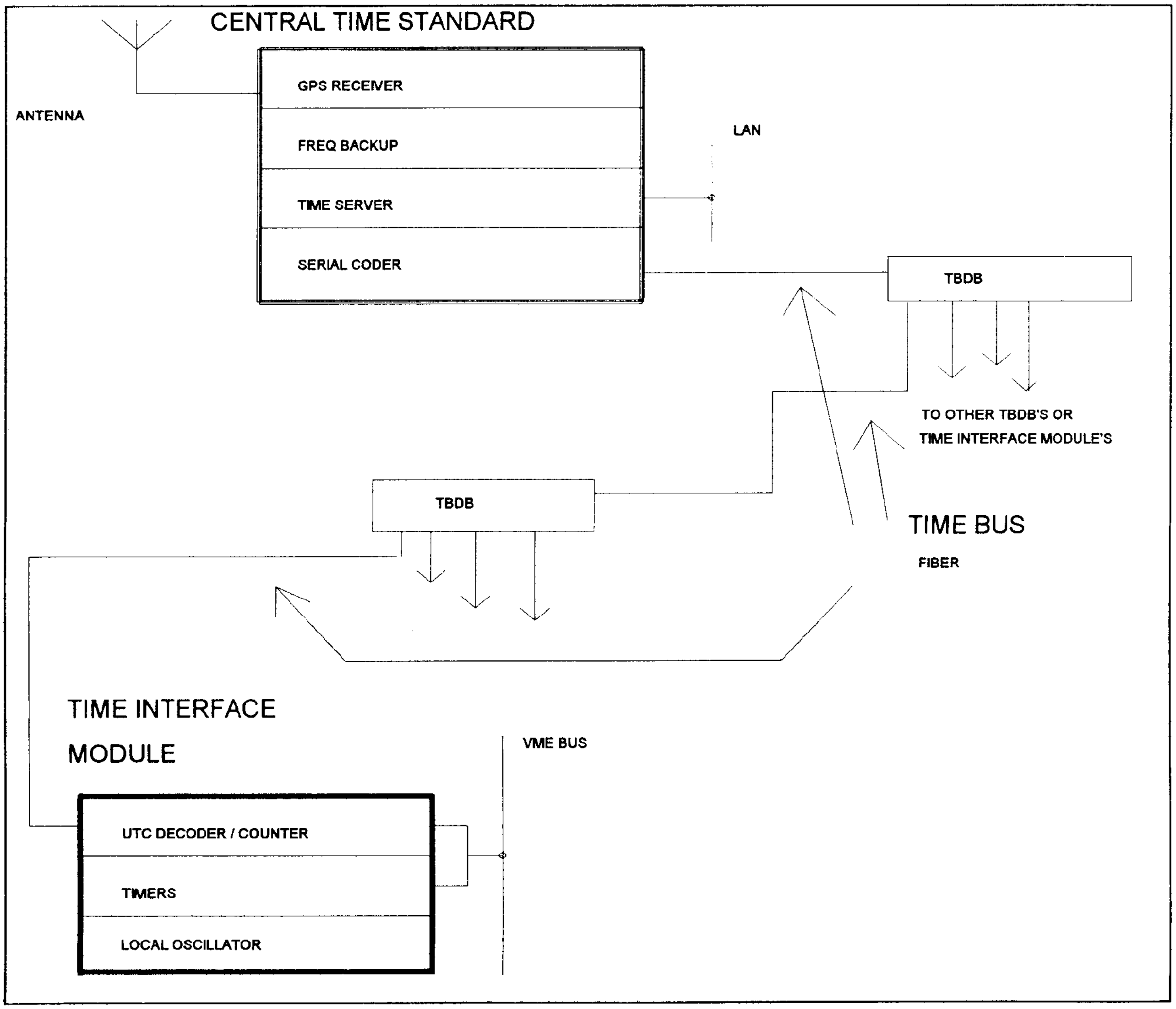

Fig. 1. TRS block diagram.

3.2. TIME BUS CODING

One can see on the basis of the requirements that the problems arise at the point where the distribution starts. The IRIG-B coding scheme as such can be used, but the modulation technique needs to be modified

We decided to change the modulation method into a digital pulse width modulated signal with a carrier frequency of 1 MHZ. If the code bit is , 1', the duty cycle is 75%. If the bit is '0', it is 25% This modified time code format can be translated by a standard IRIG-B time code reader if this reader has an appropriate low pass filter in its input.

3.3. DISTRIBUTION

This fiber optic Time Bus needs then to be distributed to the LCU's. This is done with a tree-like structure:
The serial code signal is transformed into an optical signal at the CTS and is distributed to all LCU's via Time Bus Distribution Boxes (TBDB). These TBDB's act like active optical splitters.

The size of the VLT observatory allows to accept the differences in time delay in the fibers due to propagation.

Special attention had to be given to the design of the TBDB's: Optical transmitters and receivers have a different propagation delay for the rising and the falling edge of the digital signal. This is known as pulse distortion. The effect is a function of the optical power, temperature, etc. It can easily be 50 ns per TBDB. This effect is cumulative when the signal passes through more than 1 TBDB. The VLT design needs a maximum of 5 TBDB's in the Time Bus: this would result in an unacceptable pulse distortion. Selecting fiber optic components with a bandwidth of 25 MHZ allowed to have a TBDB with the following specifications:

- Propagation delay: < 70 nanoseconds.
- Pulse width distortion: < 25 nanoseconds.

The TBDB is constructed as a receiver board and a transmitter board with 4 outputs. If more outputs are needed on a given TBDB, more output boards can be added.

The fiber which is used for the distribution is a 62.5/125 μm fiber. The same type of fiber is used for the LAN's.

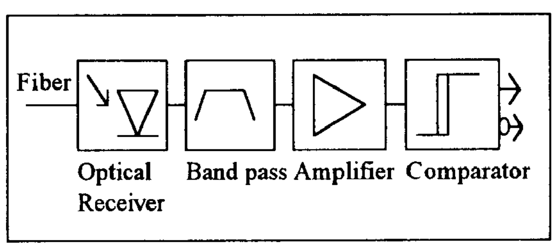

Fig. 2 TBDB receiver board, block diagram.

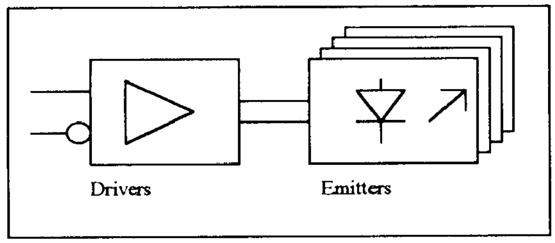

Fig. 3. TBDB driver board, block diagram.

3 4. TIME INTERFACE MODULE

3.4.1. TIME BUS DECODING

The decoding of the time bus signal in the TIM is relatively straight forward: the 1 MHZ PWM signal is fed to a Phase Lock Loop. The other PLL input is the VCO output: a 1 MHZ block wave with approximately 50 % duty cycle. That signal is used as a synchronous clock throughout the TIM.

As the PLL does not have a digital divider, the jitter between the Time Bus carrier and the 1 MHZ block wave is neglectable.

As both PLL input signals are digital, the phase shift between the 2 signals is neglectable as well.

These 2 arguments allow to use a simple PLL: there are not high requirements on the stability of the VCO. The PLL does not need to have a low bandwidth either.

The falling edges of the block wave are used to clock a flip-flop which D-input is fed by the time bus signal. The envelope of the Time Bus code signal is then available on the output of the flip-flop.

The 'lock indicator' of the PLL is used as a 'Time Bus OK' logic signal. If false, the TIM switches to a 1 MHZ quartz as clock source and loading of the UTC counters with the Time Bus data is inhibited.

The quartz oscillator has the common available tolerance of 100 ppm. It is intended to allow:

- the TIM to continue functionally in case of a Time Bus fault, and
- the TIM to operate in a stand alone mode for testing of the subsystem.

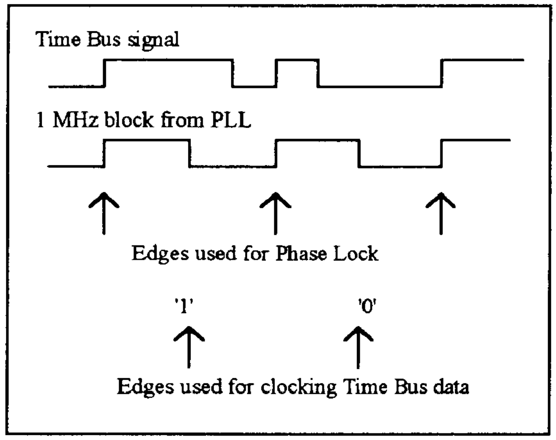

Fig. 4. Time bus decoding.

The UTC counter on the TIM is synchronously clocked by the 1 MHZ clock. Intermediate results of this process are synchronous clocks of 1 Hz to I MHZ in decimal steps. Any of these can be selected as clock for any of he user programmable timers.

The propagation delay from Time Bus input to VME interrupt is less than 350 nanoseconds.

3.4.2. SYNCHRONOUS TIMING

The major design driver for the Time Interface Module (TIM was to have all the LCU timing synchronous with the UTC..

- User-programmable timers should generate (repetitive) interrupts to the VME bus that are synchronous with the UTC.
- These interrupts should start on a programmable UTC.

These features, combined with the fact that there are 6 user programmable timers, allow synchronisation of different software processes in the same LCU and even in different LCU's.

The set-up of the timers is done via the LAN. At a defined UTC, both timers start to count by hardware. The synchronicity between 2 interrupts in the same LCU and also in two different LCU's is then guaranteed.

These interrupts can be single or repetitive.

It is possible to start and to stop this on a defined UTC, thus allowing to generate the same amount of timer interrupts in the 2 processes.

More details of the TIM hardware and driver software design are described in [3].

4. IMPROVEMENTS

The design of the TRS is finished and tests have been successfully passed. Nevertheless, we want to raise some aspects which could improve the overall system performance.

4.1. LEAP SECOND INFORMATION

The connection between the GPS unit and the Network Time Server is made with a short cable. It utilises the classical IRIG-B coding, which does not have a defined bit field for leap second information. The NTP protocol does have a field for it. It is however not used.

The TIM uses the IRIG-B code scheme and misses therefore also information about leap seconds.

The CTS has a serial port which provides access to this information. This needs then special software.

It would be good that the leap second information from the GPS is coded into the IRIG-B code scheme on an agreed field.

4.2. TIME FORMAT

The present TIM uses the hours, minutes and seconds bit fields to decide the time of the day. The CTS provides also the time of day in straight binary seconds.

Although HH:MM:SS is convenient of hardware displays, TIM hardware and driver software will be more straightforward if the binary seconds would be used.

4.3. AUTOMATIC UT1-UTC

The difference UT1-UTC needs to be entered 'by hand' into the VLT software system.

It would be good to have an automatic access to this information.

4.4. ACCURACY

The accuracy is mainly defined by propagation delay. This could be easily compensated in the TIM.

4.5. TIME BUS CODING

The presented PWM coding works well. Coding and decoding is simple. It contains however a DC component which caused some difficulty in the design of the TBDB.

From that point of view, a phase encoding would be better.

5. CONCLUSION

From the allocated accuracy budget of 10 µs, the presented system uses:

- 400 ns for the CTS,
- Approx. 100 ns per TBDB, this means 500 ns in total,
- 350 ns for the TIM
- 1500 ns propagation delay through the fibers.

This results in approx. 2.5 µs, most of it is propagation delay which could be compensated in the TIM.

6. ACRONYMS

CTS	Central Time Standard.
ESO	European Southern Observatory.
GPS	Global Positioning System.
IERS	International Earth Rotation Society.
IRIG	Inter Range Instrumentation Group
LAN	Local Area Network.
LCU	Local Control Unit.
MJD	Modified Julian 'Date'.
NTP	Network Time Protocol.
PLL	Phase Locked Loop.
PWM	Pulls Width Modulation.
TBDB	Time Bus Distribution Box.
TIM	Time Interface Module.
TRS	Time Reference System.
UTC	Universal Time Coordinated.
VLT	Very Large Telescope.

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