

GTC a CAN based controlled telescope

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The Gran Telescopio Canarias (GTC) is the most powerful ground telescope ever built. The segmented primary mirror has the largest collecting surface equivalent to one circular mirror of 10.4 meters. The control system (GCS) includes the hardware and software to control all the telescope subsystems, from the real time applications to the astronomer interfaces. Most of the real time GCS subsystems use CAN as the main control bus or to perform support functions.

The main CAN application is the control of the primary mirror which is composed of 36 hexagonal segments. The GCS is responsible for making the 36 segments behave like a monolithic mirror. Three positioners per segment (total 108) will move it in tip/tilt and piston. Two position sensors (total 168) between adjacent segments will measure their relative displacement. This loop controls the positioners and reads the sensors at 200Hz over CAN buses. The figure of each segment is also actively controlled thanks to 6 actuators (total 216) that act on three whiffletrees attached to the back of a segment. This actuation is made at very low frequency. Finally, the temperature of each segment is measured in six points (total 216). Specific CANopen protocols were developed to control the positioners and read the edge sensors.

CAN bus and CANopen protocols are also used to control and monitor several other subsystems of the GTC: tertiary mirror, dynamic counterweights, optics and filter wheels, temperature and humidity control loops, start up and stop systems, calibration lamps, etc. Primary Mirror Active Optic System

Primary Mirror Active Optic System

The GTC is a classical Ritchey-Chrétien reflecting telescope but instead of using a monolithic mirror, it uses 36 hexagonal segments arranged as shown in figure 1. The use of segmented mirrors has many advantages in terms of weight, cost, fabrication, assembly and maintenance but could degrade the final image quality if segments position and shape are not well controlled. The only way to guarantee the optical performance is implementing an active optic control system (AOS).

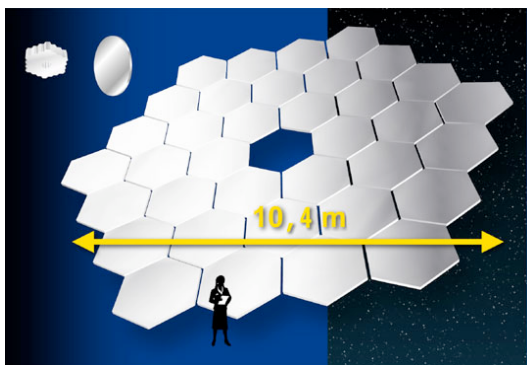


Illustration 1: Primary, secondary and tertiary mirror size relation

The AOS is divided in three sub-systems:

- Stabilization System, it controls the segments relative position and make the primary mirror behaving like a monolithic mirror,
- Deformation System, it controls the shape of each segment and correct it if necessary using mechanical actuators,
- Temperature System, it measures temperature gradient to determine the positioning compensation to apply to the position sensors.

Stabilization System

The stabilization system main purpose is to align the 36 segments and to make them behave like a monolithic mirror. This correction is necessary to compensate the variations induced by the constantly changing telescope structure inclination, the wind and the temperature variations. The sensing is performed by the edge sensors and the correction is applied thanks to positioners. No astrophysical observation is possible without the stabilization system.

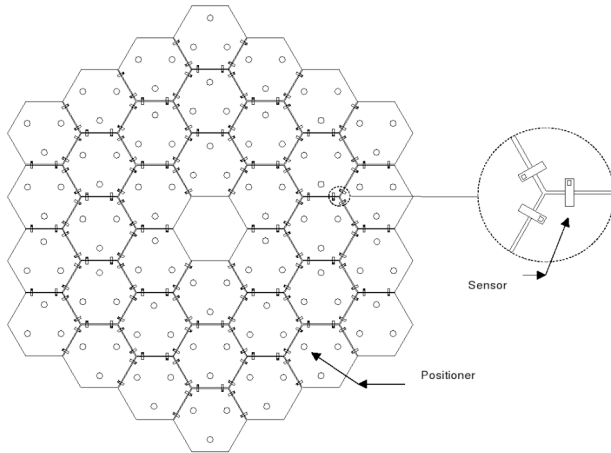


Illustration 2: Primary mirror sensors and positioners

The edge sensors

The edge sensors are capacitive sensors that measure the relative displacement between 2 segments edges. They can detect errors of few nanometers. The position is a 16bits data that is read at 200Hz. Each segment is fitted with 6 sensors that are controlled by an Acquisition and Communication Processor (ACP).

- configure and read the sensors,
- compute a infinite impulse response filter of the 8Th order,
- transmit the data to the telescope control system.
- monitor internal values (current, tension, temperature)

The figure 4 shows the ACP block diagram where it clearly appears 3 main parts: the CAN interface, the DSP and the reading of the edge sensors via a serial peripheral interface.

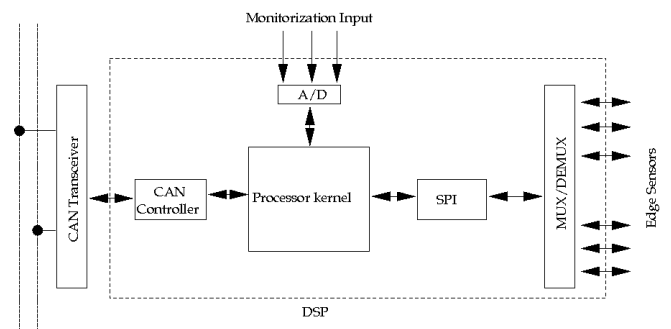


Illustration 4: ACP block diagram

The ACP CAN interface

The transceiver was selected on its capacity to protect against cross-wire, loss of ground, over-voltage, thermal shutdown, open circuit receiver fail-safe and overall for the high impedance output when the power supply is in under-voltage or failing. The DSP has a full-CAN integrated controller (2.0B) that interrupts the processor when a frame is received. From the DSP point of view, the CAN controller is seen like a 16 bits I/O. The CAN controller implements the Data link layer and the Physical Layer. The Application Specific Layer is stored in the DSP memory, the DSP firmware, included the CAN libraries can be updated via CAN. The position of the 6 edge sensors is read through PDOs: After SYNC reception, each ACP dispose on the bus 2 PDOs that contains the position off all the controlled sensors (6 * 16bits). All the others ACP parameters can be accessed through SDOs.

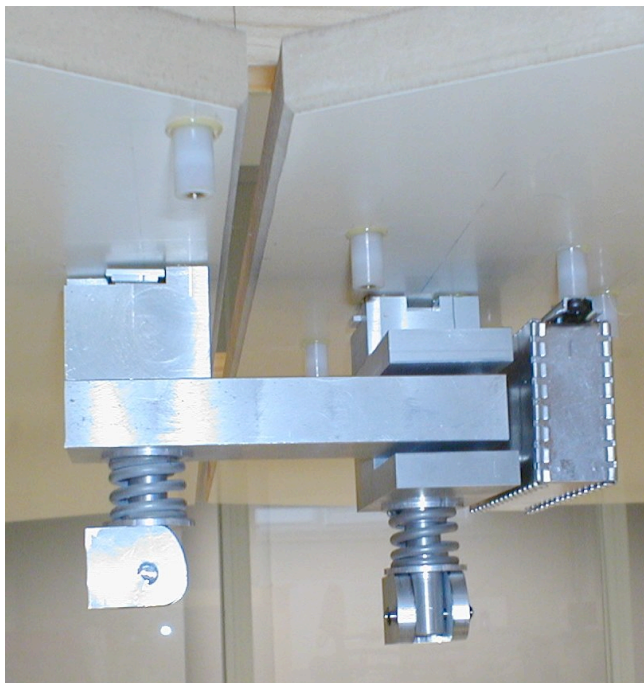


Illustration 3: Edge sensor between 2 dummy segments

The Acquisition and Communication Processor

The main functions of the ACP are:

Due to the telescope size and because of the bus length limitation, the 36 ACPs were dispatched into 6 buses. The finals tests shows that the reading of all the

buses and the conversion of the 168 sensors position (from ADC count into millimeters) can be performed at 500Hz using small bandwidth and high reliability.

The Positioners

Each segment has 3 positioners to move it into axial direction; there are a total of 108 positioners in the telescope primary mirror. A positioner is a motor with an optical encoder that moves a precision roller screw. The reduction is made using a hydraulic stage that reduces the displacement of the electromechanical stage, amplifies the output force and ensures a frictionless motion of the output shaft. A positioner step corresponds to a displacement of 1.19 nanometers. The positioner CAN hardware is very similar to the one of the ACP.

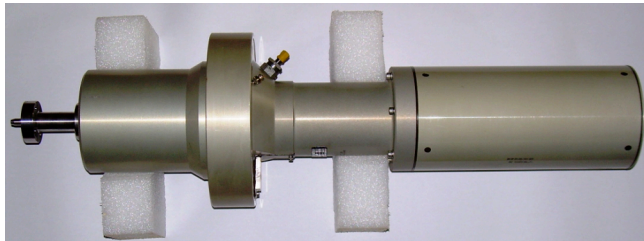


Illustration 5: A positioner

Design error

We have made an error during the design phase: protecting the CAN transceiver with a transient voltage suppressor. The chosen component was not the typical back-to-back zener diode but a zinc oxide (ZnO) based ceramic semiconductor devices with non-linear voltage-current characteristics (bi-directional). The problem came from the capacitance this component added onto the CAN bus. This capacitance had an effect on the rise/fall time of the CAN signal and after connecting few positioners it was impossible to communicate at 1Mbits/s anymore. Removing this protection the problem was solved.

Communication with the positioner

In order to optimize the active optic control loop, communications with the positioner were optimized. Once the positioner is initialized, there is no need to ask for its absolute position, we always assume that it is working correctly. In case of any failure

that impedes the positioner doing its job, an alarm message is sent. The most important one is the following-error message that indicates that the positioner did not reach its target in time. Using this philosophy, the communication during time-critical application is unidirectional and the overhead is minimized using a single PDO to indicate to the positioner the next target point. The primary mirror control system is able to correct the segments position at a rate of 200Hz.

We regret and recommend

The use of DB9 connectors: Due to their size they can create an important torque; a little cable tension can be enough to deteriorate the device case or even the electronic board. We recommend using low profile connectors.

No market solution for round connector with connectable termination resistance.

The positioners have no bus speed setting switch. Even if we do not need to work at lower speed, we regretted not to have an easy way to slow down the communication baud rate. Indeed, for debugging and test purposes it can be helpful to play with the baud rate that allows to use longer bus and to discard some physical layer communication problems.

Deformation System

The Deformation system's main purpose is to correct segment curvature errors generated by external factors like temperature variations and mirror support system gravitational effects. The figure correction rate is very low (0,001Hz) but fundamental to guarantee an optimal optical quality. The devices involved in the deformation system are stepper motors (linear actuators) and load-cells. The force generated by the actuators is transmitted as torque to the whiffle-tree through a lever arm. The system is controlled in closed-loop with the force read by the load-cell as feedback. Both devices are connected to the control system through a CAN bus.

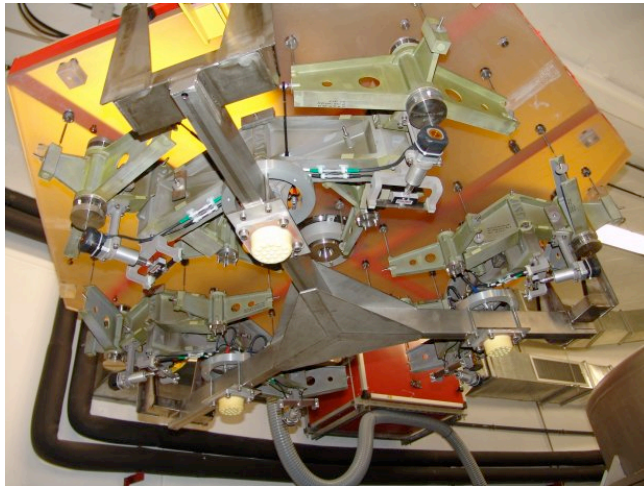


Illustration 6: A segment and its actuators seen from below

Modular CAN interface

We choose a market modular solution that allows connecting to a single CAN interface a great deal of drivers (for motors, PT100, digital and analog I/O, relays and so on). In our case, under each of the 36 mirrors we installed a refrigerated electronic cabinet containing all the modules to control the 6 linear actuators, the 6 load cells and the 6 temperature sensors. The very low frequency of the deformation control loop allows using lower baud rate hence longer bus: we use a single 200m bus that interconnects all the primary mirrors electronic cabinet.

We regret and recommend

The modules have a plastic case not suitable for the telescope environment. Indeed, the very dry air due to the altitude of the facility (2400m) is very favorable to generate electrostatic discharges.

The CAN module implements a CANopen-like protocol instead of a standard profile. It is very easy to use but a programming effort is needed to develop a brand-new driver.

Temperature System

The temperature system main purpose is to compensate the dilatation effect that skew the measurement of the edge sensors. Indeed, the nanometrical precision of the sensors could be spoiled by the dilatation of the sensor fixation pad (see figure 3) and by the dilatation of the

glue used to stuck the pad onto the mirror. The temperature sensors used are 4 wires high precision PT100, they are connected to a specific driver module. The module integrates an averaging filter that is very useful to get accurate results and to minimize main CPU needs. The CAN interface and the bus are the same than the one used for the linear actuators.

Object Oriented modular CAN drivers

The oriented object architecture used to represent the CAN devices into the GTC control system is based on the CiA profile.

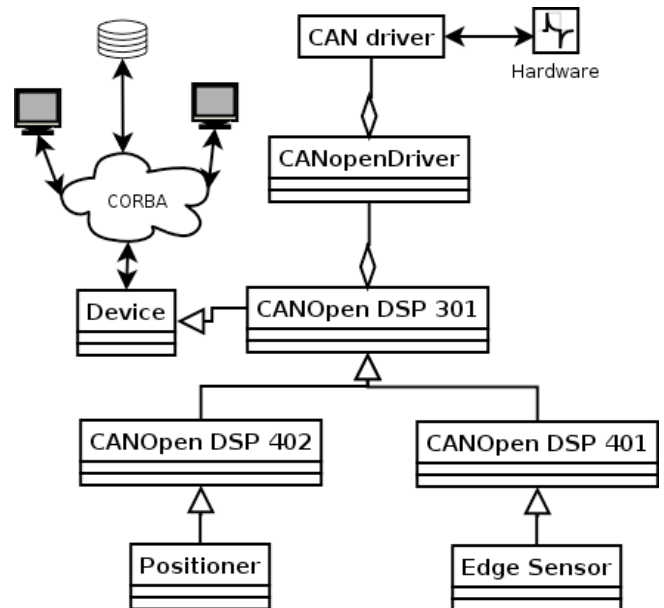


Illustration 7: Class diagram

CAN Driver class offers a generic interface with the hardware. It allows to setup and open CAN bus descriptor and to send and receive CAN frames.

CANopen Driver class allows writing and reading dictionary objects using PDO and SDO.

CANopen DSP 301 class offers method to access the object dictionary entries for communication (from 1000h to 1BFFh) such as reading the device type or the error register.

CANopen DSP402 class offers method to access all the entries defined in CiA DSP402.

CANopen DSP401 class offers method to access all the entries defined in CiA DSP401.

The *Device* class implement the

communication framework used in GTC that allow to start, to control, to monitorize and to stop all the elements of the entire telescope from any computer connected onto the network.

Using those classes, creating a new CAN device is fast and simple: we just need to implement the method to access the manufacturer specific entries of the dictionary. The process is so easy that it is possible to generate the C++ source code automatically using the device DCF/EDS file.

Others CAN subsystems

Plenty of others GTC subsystem depends on CAN:

The secondary mirror:

Essentially, a telescope is an optical system that can gather light photons and direct them on to a plane called the 'focal plane' or 'focus'.

The secondary mirror receives light from the primary mirror and deflects it to the Cassegrain focus or the tertiary mirror, from where it is deflected on to the Nasmyth and folded Cassegrain foci.

The GTC's secondary mirror is made of beryllium substrate, which is much lighter and tougher than ceramics, coated with a layer of nickel. Quasi-hexagonal in shape (adapted to the shape of the primary mirror) and with a convex hyperbolic surface, the secondary mirror weigh just 55 kg, have an area no greater than 1.2 m and feature state-of-the-art technology. Some parts of this subsystem are controlled through CAN.

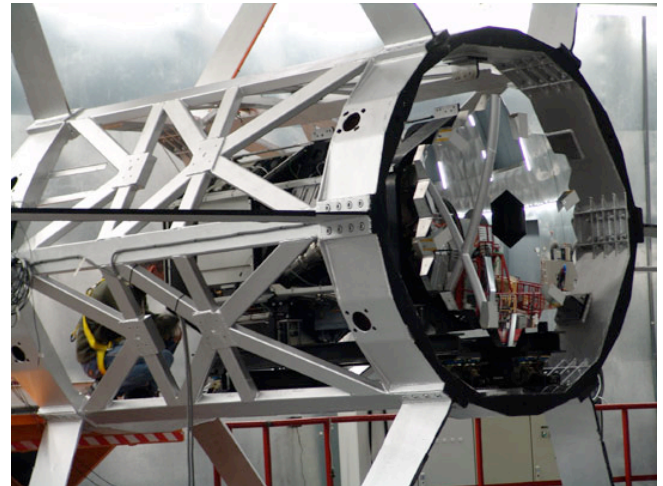


Illustration 8: Secondary mirror mounted on the telescope spider

Telescope Mechanisms

Moving a huge mass of equipment such as this will require a range of different systems.

Hydrostatic bearings will make the whole structure 'float' on a thin film of pressurized oil – the telescope will be so sensitive it will move with the touch of a hand. The hydrostatic bearings will ease the telescope's moving parts, forcing pressurized oil underneath them so they move smoothly, accurately and with little effort. The oil will pass through a circuit where it will be cooled and returned to the bearings.

There are two types of hydrostatic bearings: elevation bearings – which will be in the elevation ring - to support the tube, and azimuth bearings – between the azimuth ring and the base of the mounting - to carry the load of the mount.

Movement will be induced by the motors. Unlike other telescopes, which use friction or geared drives, the GTC will have direct drive motors. This type of motor needs little maintenance, eliminates potential inaccuracy due to intermediary components and reduces friction.

The encoders, the telescope's positioning devices, will be located in the azimuth and elevation rings and will be sensitive to movements as slight as hundredths of a micron. The information provided by the encoders will be used to calculate the telescope's position so that the motors can move it in the right direction.

The information that provides the

encoders is used in the 4kHz control loop as a feedback to control the motion of the motors. The drives monitorization is performed through CAN.

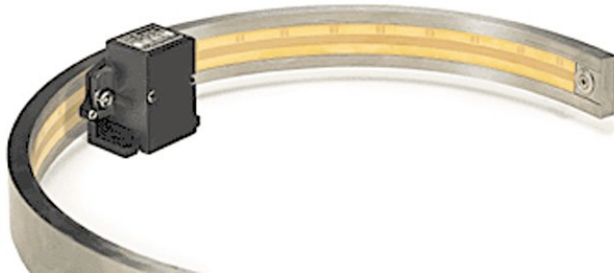


Illustration 9: Encoder tapes and optical reader

The dynamic counterweight

The dynamic counterweight system is used to compensate the small unbalance: it is impossible to incline the 350 tons of the telescope if the structure is not correctly balanced. The balancing is performed in two steps: first a rough balancing that consist in bolting down steel counterweight on the outside of the azimuthal ring then, using the azimuthal ring inner motorized counterweights (moving them horizontally and vertically) to compensate the remaining unbalance. All the motors are controlled by 402 profile CANopen devices.

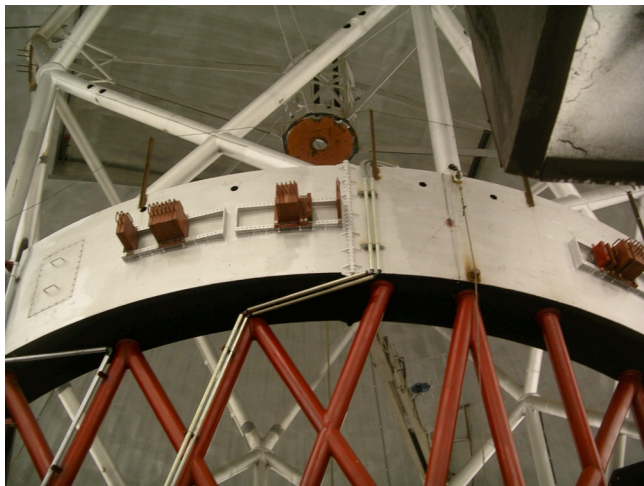


Illustration 10: Red counterweight on the azimuthal ring

The tertiary mirror

The light has to follow a precise path once it has been reflected by the primary and secondary mirrors. So that it does, the telescope has a tertiary mirror, which 'intercepts' the light, deflecting it to the foci

where instruments can be mounted.

In other words, it is the tertiary mirror's job to deflect the beam of light to the folded Cassegrain and Nasmyth foci.

Two problems came up when the GTC's tertiary mirror was being designed: first, how to deflect light directly from the secondary mirror to the Cassegrain focus if the tertiary mirror was in the way, and second, how to make sure the tertiary mirror deflected light to the 4 folded Cassegrain foci and the 2 Nasmyth platforms as and when needed.

The design adopted is a removable mirror, which rotates so it can deflect light to the different foci. It is a mirror that tilts automatically and that slides out of the way when not needed. All those motions are performed by CANopen motor drivers.

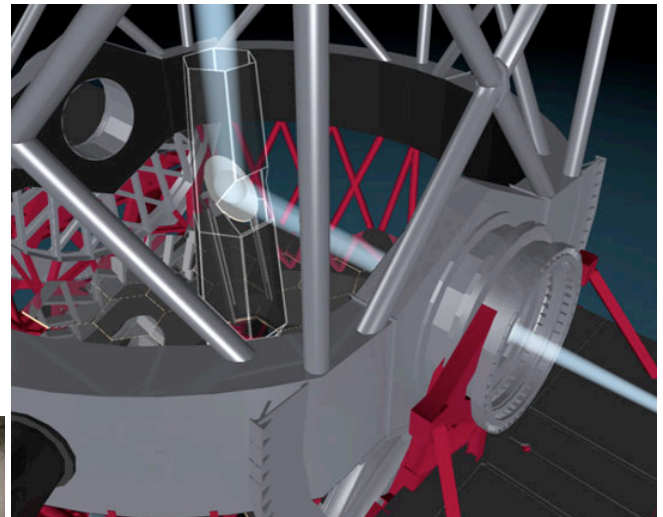


Illustration 11: Tertiary mirror reflecting light toward the Nasmyth plane

The guiding and acquisition module

The guiding and acquisition module is used to optimize telescope performance. These include wavefront sensing for active optics, fast telescope guiding and measurement of the sky quality (seeing). This system involves motors and optical sensors controlled through CANopen.

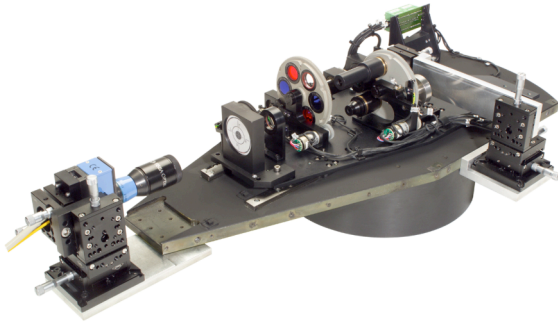


Illustration 12: Acquisition and guiding arm fitted with filter wheel, lenses and interferometer

The electronic cabinets cooling system

All the electronic devices are enclosed in cabinets in order not to produce any turbulence that could degrade the images quality. The thermal system controller is a PLC with a CAN interface that is in charge of opening/closing the electro valve that controlled the glycoled water flow and the activation of the fans in function of the temperature set point.

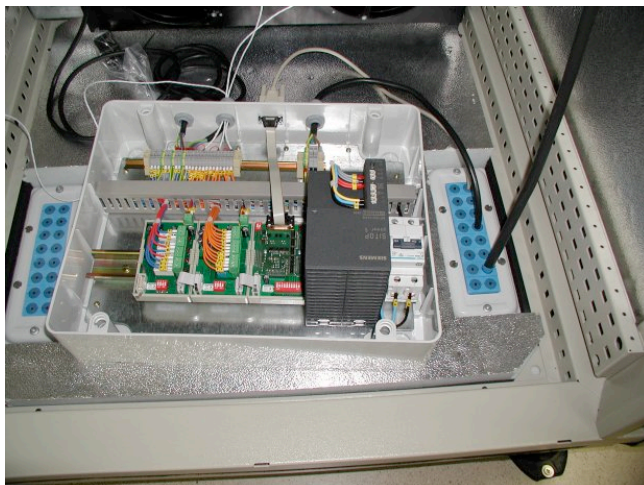


Illustration 13: Electronic Cabinet cooling system (PLC, relay and PT100 drivers)

The temperature and humidity monitorization system

Air turbulence can be created in the telescope chamber by temperature differences between the various levels and components. Air turbulence affects optical quality and so must be avoided, making it vital to control the temperature of the area around the telescope.

The temperature and humidity monitorization system is responsible for generating dew points alarms that force the telescope main door (shutter) to be closed immediately in order to protect optical components. It consists in tens of sensors of temperature and humidity that are connected to CAN I/O devices that convert the analogical signals into temperature or humidity values. Then, sensors data are downloaded to the control system in order to be interpreted.

Distributed Startup system

Many of the components of GTC are located into the telescope structure in inaccessible sites. The power-up of all those systems is performed remotely through an optical fiber CAN network that interconnect them.

Each control system is fitted with this distributed startup system (DSS) which is in charge of turning on all the components involved in this control system. For many of them it has to respect an order and a timing.

The DSS is composed of an optical fiber transceiver and a CAN PLC that controls relays.

Conclusion

CAN, just considering the primary mirror control system, has to deal with: 108 positioners that give 3 degrees of freedom to each segment, 168 position sensors installed between adjacent segments that measure nanometrical displacements, 216 actuators that control the figure of each segment creating torques, 216 load cells to quantify the applied deforming forces, 216 PT100 to visualize the primary mirror temperature gradient and to predict structural dilatations. CAN is well standardized, fast, reliable, space efficient

and its standardization via profiling allows fast and low effort programming. The fast growing CAN product market offers state of the art solutions that show that believing in CAN for our control system was a very good choice.

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