ELT Laser Safety Functions - Installation Report

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1. Introduction

In preparation of the ELT experiment the Wettzell Laser Ranging System received an upgrade of the ranging pulse laser with laser pulses as short as 12 ps. This step was necessary, because the old active-active mode locked laser could not be modified to comply with the ELT experimental requirements. The new laser system consists of two independent hardware components. These are a HiQ mode locked pulse laser (20 Hz repetition rate, 1 mJ energy at 0.532 μm wavelength) and an Innolas amplifier stage with a maximum gain of a factor of 80. The laser and the amplifier are each entirely independent hardware units. There is a free air space linking the two systems together. The setup therefore allows two independent states of operation, a low power mode (Configuration A), where only the HiQ laser is in operation and a high power mode (Configuration B) setting, where the HiQ laser is operated together with the Innolas amplifier. According to the requirements of the Payload Hazard Report ACES-15-Wettzell a number of safety functions are in operation. In the low power mode, which we consider the nominal state of operation for the ELT experiment, the Innolas amplifier is physically switched off and bypassed on a different optical route specific to the ELT application. The laser beam divergence unit is set to a high divergence and two independent safety switches are physically closed by the moving lens structure to enable tracking. A laser power monitor is in operation that physically blocks the laser beam when a predefined power level of the laser pulses is exceeded. Furthermore the installation of the safety functions are integrated such that the system does not allow ISS ranging during regular SLR operations for satellites with no laser power restrictions. This document describes the integration of the required functions of the safety installation according to the Payload Hazard Report ACES-15-Wettzell.

2. Laser Repetition Rate

Since the Wettzell Laser Ranging System shares the same telescope between transmit and receive functions, it uses a mechanical rotating mirror to alternately connect either the laser or the detector to the telescope. Due to the significant mass of the rotating mirror assembly this function limits the effective repetition rate of the laser to 20 shots per second. In order to optimize the Science output, an upgrade to a repetition rate of 100 Hz is desirable. We believe that this can be possible by using a polarization switch rather than a rotating mirror, provided we operate in the low power mode, corresponding to configuration A. In the high power mode this concept will not be possible, because the focused back-reflections of the laser beam caused by the telescope would damage the detector. Table 1 lists the Maximum Permissible Energy (MPE) for a pulse train with several repetition rates.

Table 1: The dependence of the MPE as a function of the repetition rate of the laser.

Repetition Rate N [Hz]	N^(-1/4)	MPE (pulse train)
1	1	7.2e-8
10	0.562	4.05e-8
20	0.473	3.4e-8
100	0.316	2.28e-8
1000	0.178	1.28e-8
2000	0.150	1.08e-8

The energy density for configuration A of 3.9e-9 J/cm^2 as listed in Annex 2 of the ACES Payload Hazard Report stays well below any laser repetition rate that is used in SLR observations. It remains to be seen if the envisaged modification of the Wettzell Laser Ranging System can be achieved.
As the MPE (pulse train) limit is not exceeded for repetition rates between 20Hz up to 100Hz, the calcualtions in Hazard Report ACES-15-Wettzell remain valid, independent of the finally realized H/W capability.

3. Overview of the Laser safety installation of the Wettzell Laser Ranging System (WLRS)

In Satellite Laser Ranging (SLR) short laser pulses are transmitted towards a satellite target. The laser light is reflected from cube corner reflectors (CCR) and detected by a photomultiplier on the SLR observatory. A typical SLR station consists of 3 major components, the pulse laser (transmitter), the sensitive photo-detector (receiver) and a tracking telescope that is pointed at the satellite. A high resolution timing device establishes the time of flight between the laser pulse transmission and detection. Figure 1 shows the conceptual design of the SLR station in Wettzell. Please note, that the laser and the receiver are physically located in different rooms.

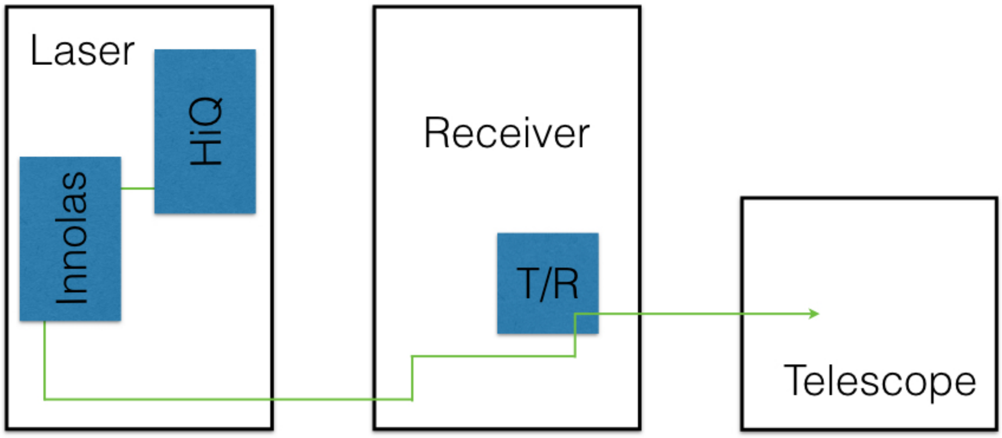


Fig. 1: *Block diagram of the WLRS with the transmit laser path indicated.*

The actual pulse laser is composed out of two individual components, namely the HiQ mode locked pulse laser (20 Hz repetition rate, 1 mJ energy at 0.532 µm wavelength) and the Innolas power amplifier. During the tracking of unrestricted targets, the laser pulses of the HiQ system are injected into the Innolas amplifier stage, where they get amplified by a factor of 80, before they are guided to the Transmit / Receive switch of the optical detector table. From the T/R switch they directly enter the telescope to be transmitted towards the satellite. For the low power mode of configuration A of the Payload Hazard Report ACES-15-Wettzell a different scenario is utilized as depicted in fig. 2.

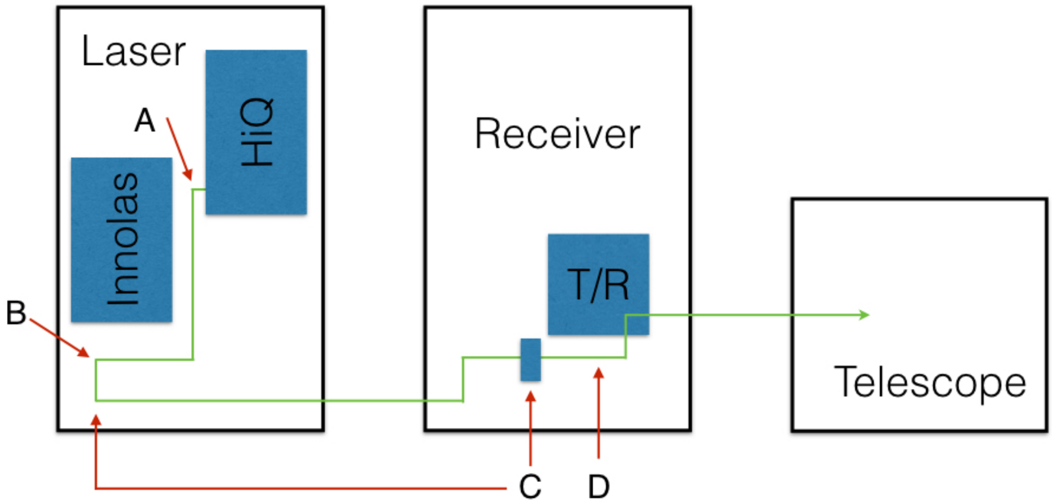


Fig. 2: *Modifications to the optical path and active safety features used in the low power mode.*

When the low power mode is enabled, motorized mirrors at the position (A) and (B) are moved into the beam path to bypass the Innolas amplifier stage. Micro switches at the mirror end position are closed when the mirrors have physically arrived in the bypass position. At the same time the amplifier is switched off physically (disconnected from the power line). The beam power monitoring device (C) composed out of a power meter (near position (B)) and a physical beam dump (near the T/R switch) are activated. This means that the beam dump can only be lifted out of the beam path, when the detected beam power is within the safe power range (Beam power = 0 is considered unsafe because this can indicate power failure). Finally, the beam expander at location (D) is commanded into the high divergence (end) position. Again, this function has two micro-switches in series, which can be enabled only, when the motor-driven lens physically closes them. These functions are detailed in the following.

4. Provisions for the discrimination between ISS tracking (low power mode) and unrestricted SLR

Before any ranging operations are carried out the SLR system can only have either of two distinct functional states, which are a) ELT (ISS tracking) operations or b) standard SLR operations. The required mode of operation is selected by a button on a controller box (see arrow A in fig. 3). Figure 3 shows the controller box next to the independent laser shut off button (B) and illustrates the controller box functions in a block diagram.

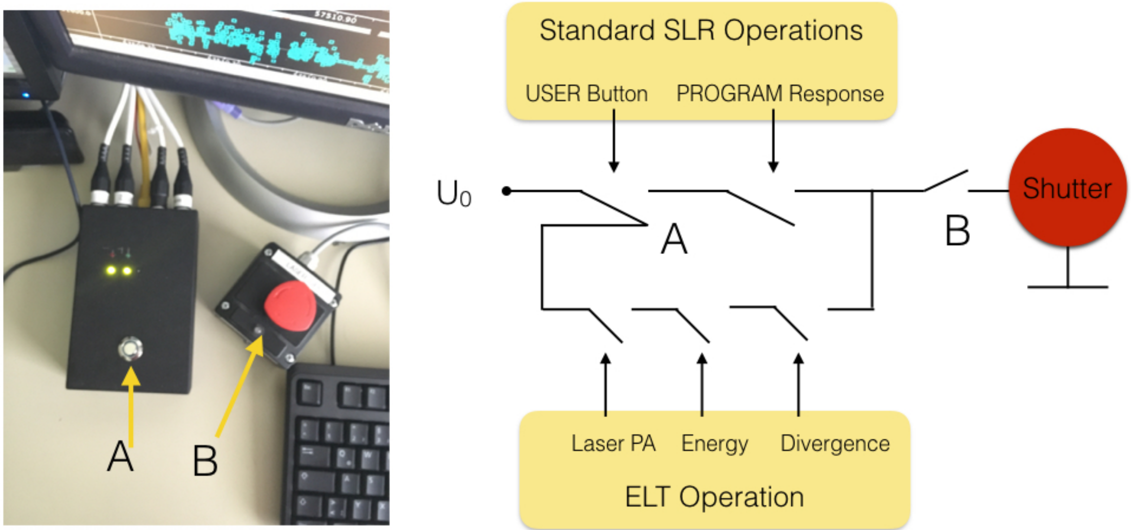


Fig. 3: The System state switch (A). When the button is actively pressed (activated) by the observer the system activates the "ELT Operation" Mode by routing the path for opening the shutter through the ELT safety functions. Furthermore it will now be possible to select ISS as a ranging target from the control program target list. For unrestricted SLR functions button A closes the upper path (default state). The second switch in the upper path is closed by the ranging program only if the user selected target is found in the SLR target list and the target name is NOT ISS. Under standard SLR operations it is not possible to access the ISS orbit predictions to point the telescope to the ISS. The laser disable button B is independently available to both modes.

The application of a control voltage U_0 to a shutter is required to lift the beam dump out of the optical path. This can be achieved either by the upper electrical path for standard SLR operations or by the lower ELT operations path, adhering to the safety features of the Payload Hazard Report ACES-15-Wettzell. As the main function the controller box contains an independent micro-controller, which is guarding the SLR functions additionally. Independently from the SLR ranging program, which does not allow to track a target that carries the name ISS unless the Button A on the controller box is pressed anyway, this micro-controller periodically polls the ranging program for the currently selected target name. If the actual target name is not contained in the internal micro-controller target list (that cannot be modified in any way by the SLR observer) or if the name contains ISS, the switch labeled "PROGRAM Response" in fig. 3 is not closed and the shutter cannot be moved out of the beam path. This function is entirely independent from the ranging program and apart from the target name exchange there is no linkage between the ranging program and the micro-controller. During normal SLR operations the "User Button" (A) is in a closed condition for the upper signal path and whenever a satellite target is selected from the list of available targets of the ranging program, the selection is checked against the list of implemented ranging targets in the computer program. In order to close the second contact via a computer driven relais under the micro-controller control, the selected target name must be contained in the preset list of known targets in the micro-controller and the name cannot be "ISS". Access to the orbit information for ELT operations is only possible if the target name ISS is used in the ranging program. The validity of this condition is checked continuously by the micro-controller in the controller box during ranging operations. Power failure, misspellings of target names or loss of contact between ranging program and the controller box lead to the immediate opening of the controller switch, which results in the separation of the laser from the telescope via the beam dump dropping back into the laser path.

When the observer presses the "User Button", the contact A opens the upper signal path and closes the lower path, so that the complete chain of the ELT safety functions becomes available. At the same time the target name "ISS" becomes selectable in the control program. In order to eventually transmit the laser beam all the ELT specific control conditions of the lower branch have to be met at the same time. These functions are:

1. The Innolas final amplifier stage is physically powered off. The contact inside the Innolas amplifier (corresponding to the first specific contact in the lower branch of fig. 3 (Laser PA) is only closed when the AC power is completely switched off.

2. The laser beam is bypassing the Innolas stage by physically moving 2 mirrors (position (A) and (B) in fig. 2) into the laser beam path. The contact is closed when the two micro-switches mounted to the mirror stages are closed, indicating the physical arrival of the mirrors in the bypass position.

3. Moving a lens from an arbitrary to the end position of the beam expander turns up the divergence of the laser beam. Two independent physical micro-switches are closed, when the lens has physically reached the required position.

4. The shot by shot beam power control is activated. This electronic unit is lifting a beam block out of the optical path only when the measured laser power is below the defined maximum value of 1 mJ and at the same time higher than zero. This excludes a possible error state where a power failure on this device would erroneously indicate a safe state.

The additional laser "off" button ((B) in fig. 3) at the operators console disconnects the laser from the telescope by dropping the safety shutter into the beam-path independent of the selected mode of operation.

5. ELT Tracking (Configuration A, Low Power Mode)

Detailed description: When the Wettzell Laser Ranging System is in the low power mode state, the Innolas Power Amplifier, which can be used during standard SLR operations to increase the energy of the laser pulses from 1 mJ up to 100 mJ, is physically powered off. The fact that no power supply voltage is available for the unit is closing a switch in a serial line of several switches for as long as this condition is valid (see fig. 3, right side, the "ELT operation path"). At the same time, two motorized mirrors are moved into the laser beam path to optically bypass the laser amplifier stage. As a consequence of this beam redirection process, the Innolas amplifier stage is taken entirely out of the ranging hardware chain. The state of the mirror setting command, that means the mirrors have reached or have not reached the commanded positions is detected by micro- switches, which are integrated into the movable mirror stages. When the mirrors have reached their commanded position, the switches are closed. Figure 4 shows the optical layout of the beam bypass of the final amplifier. Two sided arrows indicate the position of the moveable mirrors. The locations correspond to the locations (A) and (B) in fig. 2.

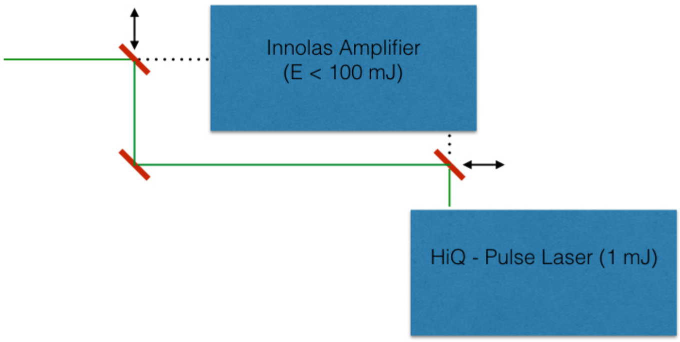
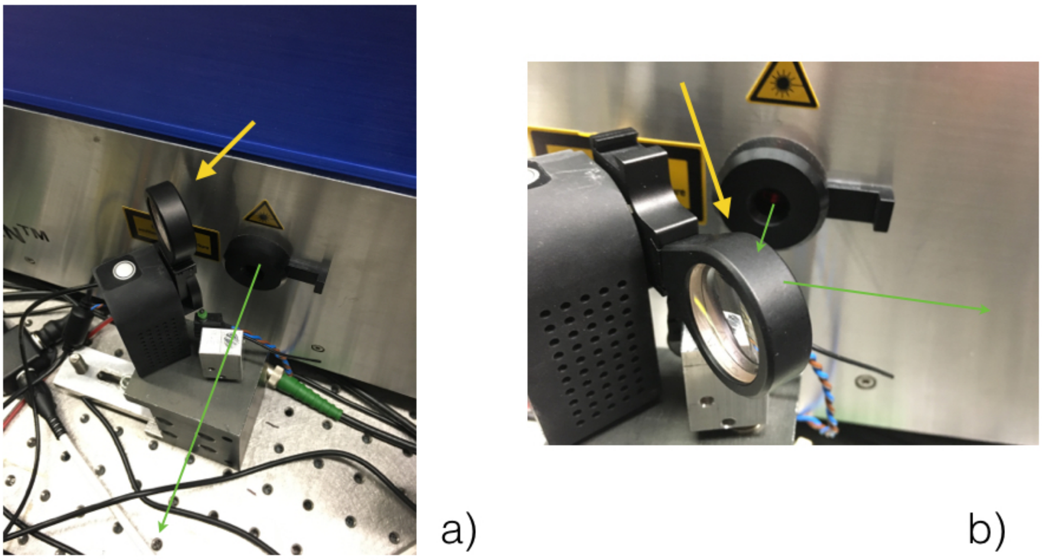


Fig. 4: Optical bypass of the final laser amplifier. The moveable mirror positions are detected by micro- switches, so that the actual position can be reliably established at all times.

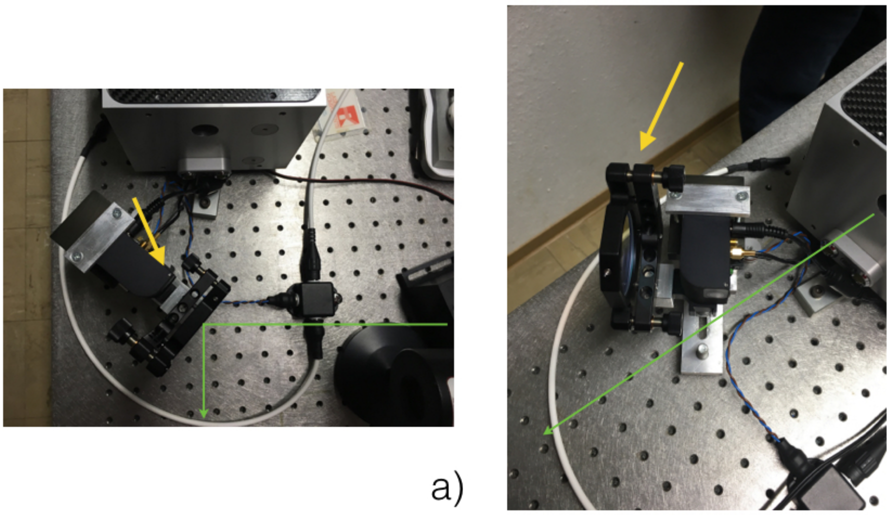
Figure 5 shows the making and the position of the adjustable mirrors with respect to the laser hardware in the WLRS. The state of the mirror position is evaluated by the controller box.



a) b)

Fig. 5: *The adjustable mirrors for the laser beam bypass shown in the two possible states (yellow arrows). The mirror is positioned at the output of the HiQ pulse laser and is shown in the routine SLR position (a), where it is not affecting the laser beam path. By rotating it around the horizontal axis during low power mode, the mirror can be moved into the beam path, steering the laser beam away from the power amplifier (b). The end position (b) is causing a switch to close.*

A similar setup is in operation for the second moveable mirror of the laser beam bypass, according to fig. 2, location (B). Figure 6 shows the second bypass mirror in the two possible states it can be in. While fig. 6 (a) shows the mirror in the low power mode (bypass position), (b) shows the mirror during standard SLR operations. The actual positioning of the mirror in the commanded position is detected by a micro-switch, which if closed together with the other bypass mirror shown in fig. 4 completes the validity (= closed state) of the first switch shown in fig. 3 in the ELT operation branch.



a) b)

Fig. 6: *The second adjustable mirrors for the laser beam bypass shown in the two possible states (yellow arrows). The mirror is positioned at the output of the Innolas amplifier and is shown in the routine SLR position (b), where it is not affecting the laser beam path. By rotating it around the vertical axis during low power mode, the mirror can be moved into the beam path, steering the bypassed laser beam into the telescope path behind the power amplifier (a). The end position (a) is causing a switch to close.*

In addition to the shut- down of the laser amplifier and the activation of the laser beam bypass the divergence of the laser beam is also increased. This is facilitated by physically moving a lens of a beam expander unit (realizing a Galilei type of telescope) in order to defocus the laser beam. The angle of divergence can be changed through the reduction of the distance of two lenses with respect to each other. Figure 7 illustrates the setup.

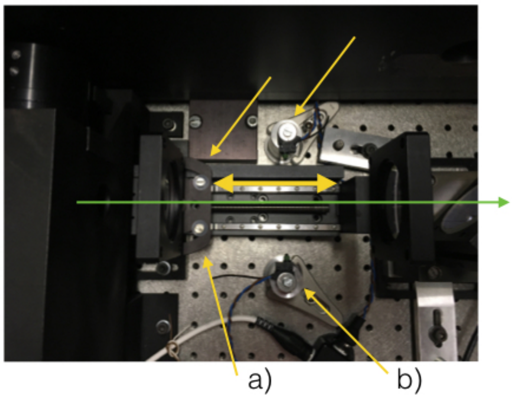


Fig. 7: Top view of the motor driven Beam Expander. The left lens can be moved along the indicated axis (two sided yellow arrow) under computer control. When the frame of the mirror a) reaches its final position, a micro- switch is closed and indicates the arrival at the requested high divergence mirror position. For extra safety, this function is redundantly realized on the other side of the mirror as well (see unmarked arrows). The two micro- switches are connected in series.

The view of fig. 7 is from the top. The laser beam would enter this beam expander unit from the left and exits through the right side (green arrow). The neutral position of the beam expander is the setting indicated in the figure, where both mirrors are located at maximum distance. This corresponds to a collimated laser beam. Under ELT operations (low power mode), the left lens is commanded to move along the rail to the other end position at about half the physical distance from the neutral position. As the lens physically arrives at the requested location, the wedged edges of the lens holder (a) are closing both micro- switches (b). Only when both micro- switches are closed, the respective enabling switch in the controller box is (fig. 3) is closed.

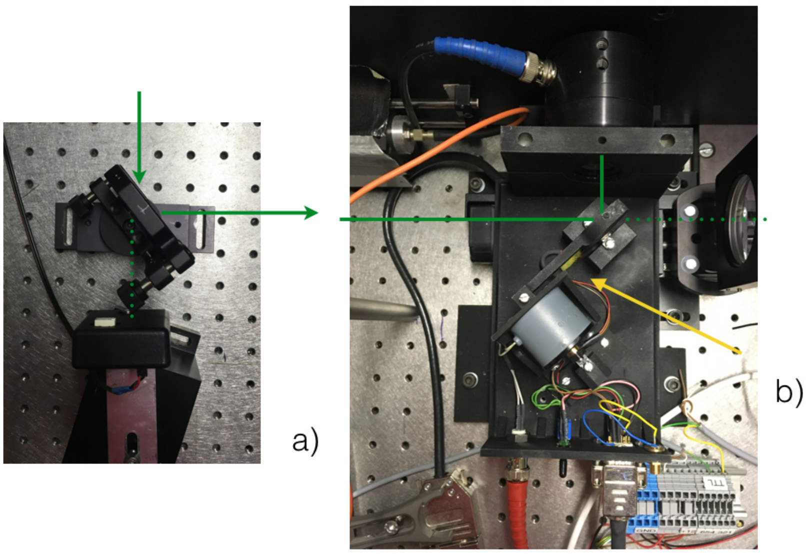


Fig. 8: *Laser Beam Power Control – The light leakage through a turning mirror is measured a). When the corresponding detected voltage is within a predefined range a motor lifts the physical beam block out of the beam path, physically connecting the telescope to the laser. Every time the conditions are not met, the beam block is dropping back into the beam path.*

The beam power control unit monitors the laser beam power on a shot by shot basis. For this purpose a photo detector is placed behind a turning mirror in the laser beam path on the laboratory table. The light leakage through the mirror is detected and converted into a voltage. If and only if the detected voltage is in a predefined range, an electronic unit is physically lifting a beam block out of the beam path, therefore physically connecting the laser to the optical telescope. For as long as the laser power is within the allowed range, this beam block remains out of the beam path. If the laser power exceeds the safe range or falls below a preset threshold value, the beam block drops back into the blocking position. This ensures that the laser beam cannot exit the telescope if the power is too high or in the case of a failure of the electronic circuit.

6. Compliance with Annex 1-2 of the Unique Hazard Report ACES-15-Wettzell

The required safety procedures for the configuration A (low power mode) are defined in the Unique Hazard Report ACES-15-Wettzell in Annex 1-2. The ELT specific safety functions require that the Innolas Amplifier is physically switched off during ISS ranging. This state is constantly monitored during the ISS ranging procedure. During standard SLR operations the menu option of tracking the ISS is not selectable. This means that the telescope cannot track the ISS in this state of setting.

When tracking the ISS the laser beam path is physically altered such that the low power signal from the HiQ pulse laser is bypassing the Innolas amplifier stage. This is done by shifting 2 mirrors under computer control. The arrival of the mirrors at the newly commanded end positions is detected by micro- switches (see solid green laser path indications in Annex 1-2).

The actual laser power is monitored by an electronic circuit, which shifts a mechanical beam block out of the optical path if the beam power is within a predefined power range with full power not exceeding 1 mJ of energy at 532 nm of wavelength. This function also requires laser fire to be enabled from the control program.

The divergence of the outgoing laser beam can be adjusted under computer control. When the beam expander is set to the high divergence end position this is detected by two micro-switches closing. Ranging can only commence when this condition is met along with the previous safety features. All functions are electrically connected in series. Technically this is done by a linking all functions up with a wire loop and a unit that senses a predefined current flowing through all switches.

All other safety functions detailed in Annex 1-2 are not specific to the ISS ranging. They have to be in process during SLR operations in general and to all targets.