LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T080247-00-D

Advanced LIGO

09/24/2008

PSL Failure Modes, Effects and Analysis

Peter King (ed.)

Distribution of this document:

LIGO Science Collaboration

This is an internal working note

of the LIGO Project.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 159
Richland, WA 99352
Phone (509) 372-8106
Fax (509) 372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone (225) 686-3100
Fax (225) 686-7189

http://www.ligo.caltech.edu/

Summary

This failure mode, analysis and effects report finds that there no catastrophic failure modes for the PSL. A number of critical failure modes have been identified. Most of these relate to the possibility of failure of the interlock circuit. Additional critical failure modes relating to the metal armour jacket that surrounds each optical fibre bundle and the TwinCAT controls are listed.

Failure of the interlock circuit is critical because if it does not function when required, a laser beam will still be present when none are expected. It should be noted that the interlock circuit is tested at LZH during manufacture and at the observatories when the AdL Laser is installed. The circuit is designed such that it is fail safe, that is if in the unlikely event it does fail, it fails in a manner such that things are safe and no laser output is possible.

The failure of the metal armour jacket protecting the fibre bundles would only come about if something heavy were to be dropped on the metal armour jacket, for example if a load were to be dropped as it was being craned over the optical fibre raceway. The optical fibres will be run in a raceway that affords some degree of protection. However damage to the metal armour jacket cannot be ruled out entirely. It should be noted that spare optical fibre bundles are planned. However they will all be housed in the same raceway.

Failure of the TwinCAT controls is a remote possibility. TwinCAT is widely used in Europe for industrial controls and is robust. However we have all encountered some computer programs that can behave intermittedly for no apparent reason. A delay in response to a requested laser operation is a possibility. Depending on the requested operation, this may cause some system damage – not necessarily to the PSL – or result in an injury.

Failure of the cooling for the laser heads could result in major damage to the Nd:YAG rods in the high power stage. This would require either replacement of, or a rebuild, of the high power stage. Either scenario would result in more than a day’s down time for the AdL interferometer.

1 Introduction

This document is an analysis of the possible failure modes and their effects of the PSL. At the time of writing, the hardware for the PSL has not been finalised. As a result the analysis presented is mostly a functional analysis but has some hardware elements included. The analysis starts off at the unit level and progresses down to the assembly and sub-assembly levels.

1.1 Purpose

The purpose of this document is to study the results or effects of an item failure on the PSL and to classify each potential failure according to its severity.

1.2 Definitions

The severity categories used in this document are summarised in Table 1.

Category	Value	Description
Catastrophic	I	A failure which may cause death or system loss.
Critical	II	A failure which may cause severe injury, major property damage, or major system damage which will result in mission loss.
Marginal	III	A failure which may cause minor injury, minor property damage, or minor system damage which will result in delay or loss of availability or mission degradation.
Minor	IV	A failure not serious enough to cause injury, property damage, or system damage but which will result in unscheduled maintenance or repair.

Table 1. The severity categories and their values.

In performing a failure analysis, what constitutes a failure has to be defined. For the purposes of this document a failure condition is met when any of the following conditions apply:

- Premature operation.
- Failure to operate at a prescribed time.
- Intermittent operation.
- Failure to cease operating at a prescribed time.
- Loss of output or failure during operation.
- Degraded output or operational capability.

1.3 Assumptions

This document assumes that failures external to the PSL that subsequently cause a failure in the PSL need not be analysed here. For example, if the electrical power for the PSL at the observatories were to fail, causing a part of the PSL to stop functioning, this is seen as a failure of the facility and not of the PSL.

This document also assumes that administrative and procedural failures are external to the PSL and are not analysed here. An example of a procedural failure would be a person being injured whilst using the PSL that was not wearing laser safety eyewear. It is not within the scope of the PSL subsystem to enforce administrative and procedural measures.

2 The Pre-stabilised Laser

The Pre-stabilised Laser (PSL) is the light source for the Advanced LIGO Interferometer. It is built around a 200 W Nd:YAG laser designed and developed by Laser Zentrum Hannover (LZH) and is a significant power increase from the Initial LIGO PSL.

A simplified functional block diagram for the PSL is shown in Figure 1. The order of the function blocks is in decreasing importance from left to right, with the AdL Laser drawn as one block. The output of the AdL Laser is spatially filtered by the pre-modecleaner. A small sample of the output of the pre-modecleaner is used for the frequency and intensity stabilisation of the AdL Laser. The remaining output is handed over to the Input Optics subsystem for further conditioning prior to being injected into the AdL interferometer.

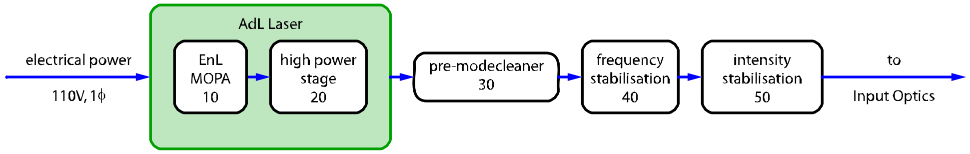

Figure 1. The functional block diagram for the PSL. The numbers in the function blocks are for identification purposes.

Components of the PSL are located in two areas: the Laser Area Enclosure and the Laser Diode Room. The Laser Diode Room houses the many pump laser diodes required to operate the AdL Laser and the chillers for providing cooling water to the pump laser diodes, the Nd:YLF crystals and Nd:YAG rods. The large current switching power supplies for the pump laser diodes are also located within the Laser Diode Room. This was done to reduce the amount of EMI/RFI within the LVEA.

The AdL Laser is physically located on the PSL table within the Laser Area Enclosure. Optical fibres couple the pump light from the pump laser diodes to the gain media. Furthermore an optical fibre Ethernet connection runs between the Laser Area Enclosure and the Laser Diode Room to allow the TwinCAT real time control software to talk to the various Beckhoff terminals used in the AdL Laser.

2.1 Unit Level Failures

The top level reliability block diagram for the PSL is shown in Figure 2. This diagram is expanded later in this document down to the sub-assembly level.

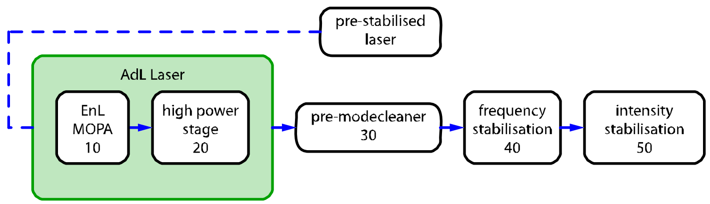

Figure 2. The top level reliability block diagram for the PSL.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10	EnL MOPA	The EnL MOPA is the seed laser for injection locking of the high power stage. It provides the frequency and intensity actuators for the AdL Laser.	No output. This could be caused by either an inadvertent, or safety related, trip of the interlock circuit. In addition, if the mains electrical voltage were to drop below certain levels – a “brown out” – then the power supplies will cease to function. Other consistency checks performed by the real time controls, such as pump laser diode temperature and output power watchdogs, may switch the laser off or place it in standby.	The EnL MOPA is operational at all phases of the AdL interferometer, from installation of the PSL, commissioning of the interferometer and during engineering and science data runs.	No frequency or intensity stabilisation is possible. A beam with higher non-TEM_{00} mode content is incident on the pre-modecleaner. The output power of the AdL Laser is reduced.	The increase in frequency and intensity noise may result in the inability to lock the suspended modecleaner.	The AdL interferometer either will not be able to operate or its performance is compromised.	Large drop in the output power of the AdL Laser, coinciding with a simultaneous loss of lock of the reference cavity. The software power watchdogs trigger an alarm. The high power stage no longer operates in a unidirectional manner. Visually out of bound or out of range parameters will be indicated on the MEDM screens in a manner similar to, if not identical to, the current practice with MEDM status screens.	None. Spare parts are on hand.	III. Marginal	At the time of writing, three units have been deployed within the LIGO Laboratory in addition to units at the AEI and LZH.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20	high power stage	The high power stage provides the high power of the AdL Laser. It contains the pump laser diodes that are used for the low frequency stabilisation of the intensity.	The output power of the high power stage is degraded. To date the most common fault experienced with the high power stage is that one of the optical components is damaged due to the presence of dust on the optical surfaces. Another reason for degraded performance is wear and tear.	The high power stage is operational at all phases of the AdL interferometer that require high power, from installation of the PSL, commissioning of the interferometer and during engineering and science data runs.	The AdL Laser operates at a greatly reduced output power.	The reduction in optical power reduces the thermal loading on the Input Optics phase modulators, which in turn deteriorates the mode matching into the suspended modecleaner.	The AdL interferometer performance is compromised.	Drastic reduction in output power of the AdL Laser. The software power watchdogs trigger an alarm. Visually out of bound or out of range parameters will be indicated on the MEDM screens in a manner similar to, if not identical to, the current practice with MEDM status screens.	None. Spare parts are on hand.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30	pre-modecleaner	The pre-modecleaner spatially filters the output of the AdL Laser. There are no interfaces to the pre-modecleaner outside of the PSL.	The pre-modecleaner loses lock to the laser. This is typically caused by a large glitch in laser frequency and the PZT not having sufficient dynamic range to cover the glitch. Another possible cause is that there is no light on the photodetector used for reflection locking of the pre-modecleaner.	The pre-modecleaner is operational at all phases of the AdL interferometer, from installation of the PSL, commissioning of the interferometer and during engineering and science data runs.	No frequency or intensity stabilisation is possible.	No light is passed to the Input Optics subsystem, so the suspended modecleaner will not be able to operate.	The AdL interferometer will not be able to operate.	The monitoring CCD camera would no longer display an image and the transmission photodetector signal would drop to zero. The suspended modecleaner would lose lock. Visually out of bound or out of range parameters will be indicated on the MEDM screens in a manner similar to, if not identical to, the current practice with MEDM status screens.	None.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	**Next Higher Level**	**End Effects**				
40	frequency stabilisation	The frequency stabilisation reduces the frequency noise of the AdL Laser by stabilising the laser frequency to the reference cavity. It accepts external inputs from the suspended modecleaner to allow the AdL Laser to simultaneously lock to the reference cavity and the suspended modecleaner.	The laser loses lock to the reference cavity. This could be caused by the pre-modecleaner losing lock to the laser. A large frequency glitch pulls the laser frequency off resonance with the reference cavity.	The frequency stabilisation is operational at all phases of the AdL interferometer, from installation of the PSL, commissioning of the interferometer and during engineering and science data runs.	There are no side effects to the PSL not being frequency stabilised.	Due to the increase in frequency noise, the suspended modecleaner most likely will lose lock.	The AdL interferometer will not be able to operate.	The monitoring CCD camera would no longer display an image and the transmission photodetector signal would drop to zero. The suspended modecleaner would lose lock. Visually out of bound or out of range parameters will be indicated on the MEDM screens in a manner similar to, if not identical to, the current practice with MEDM status screens.	None.	III. Marginal	With InL, this has proven to be a very robust servo. Given that the design for the AdL PSL frequency stabilisation servo is the same, there is no reason to expect different behaviour.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50	intensity stabilisation	The intensity stabilisation reduces the intensity noise of the AdL Laser.	The intensity noise from the PSL is higher than the performance requirement. This could be caused by not having light on the sensing photodetector, or at least off the photodetector's sweet spot.	The intensity stabilisation is operational at all phases of the AdL interferometer, from installation of the PSL, commissioning of the interferometer and during engineering and science data runs.	There are no side effects to the PSL not being intensity stabilised.	The increase in intensity noise will cause increased length noise in the suspended modecleaner.	The increase in intensity noise degrades the sensitivity of the AdL interferometer, resulting in a decrease in the range of the detector.	To the author's knowledge, there is no way to detect a failure without performing a measurement using the data acquisition system and either the suspended modecleaner or the AdL interferometer. Otherwise a failure of the intensity stabilisation could be classified as an undetectable failure. Visually out of bound or out of range parameters will be indicated on the MEDM screens in a manner similar to, if not identical to, the current practice with MEDM status screens.	None.	III. Marginal	The performance requirements for the intensity stabilisation are very challenging.

3 EnL MOPA

3.1 Assembly Level Failures

The EnL MOPA is the front end for the AdL Laser. It is a master oscillator power amplifier configuration with a 2 W InnoLight Mephisto 2000NE as the master oscillator followed by a 50 W power amplifier. The laser is currently in use in Enhanced LIGO for the PSL. The EnL MOPA includes the Control Box, the Diode Box, the Mephisto 2000NE power supply, the chiller and the laser itself. The chiller and Diode Box reside in the Laser Diode Room. Other elements of the PSL reside in the Laser Area Enclosure inside the LVEA.

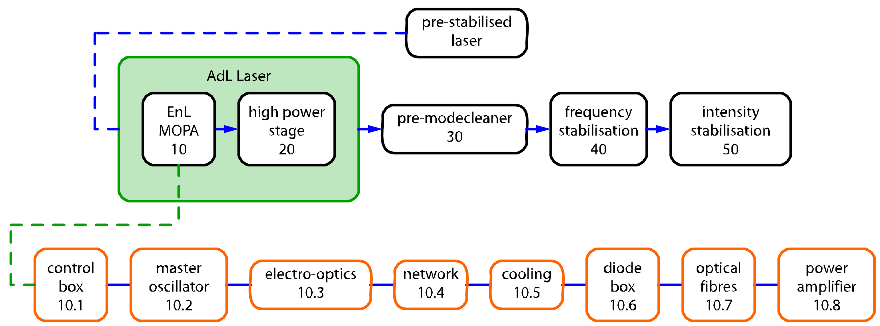

Figure 3. The reliability block diagram for the EnL MOPA.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.1	control box	The main function of the Control Box is to house the touch panel PC that forms the interface to the end user.	The touch panel PC no longer operates due to wear and tear. For example the compact flash memory used to store the operating system and TwinCAT software may become corrupted.	The Control Box is operational whenever the EnL MOPA is operational.	Operation and control of the EnL MOPA is not possible.	Operation and control of the EnL MOPA is not possible.	The AdL interferometer will not be able to operate. No light is passed to the Input Optics subsystem.	The EPICS signals related to the AdL Laser are no longer updated. The MEDM screens would freeze.	None.	III. Marginal	Spare parts are on hand.
10.2	master oscillator	The master oscillator is the low noise, single mode, single frequency laser used at the beginning of the optical train.	Failure due to wear and tear.	The master oscillator is operational whenever the EnL MOPA is operational.	The operation and or performance of the master oscillator is degraded.	Operation of the EnL MOPA is either not possible or seriously degraded.	The AdL interferometer will not be able to operate. No light is passed to the Input Optics subsystem.	The EnL MOPA power watchdog would trip, indicating a major loss in output power. This would be indicated by an alarm on the MEDM screens.	None.	III. Marginal	Spare master oscillators are on hand.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.3	electro-optics	The electro-optics includes the phase correcting electro-optic modulator, the acousto-optic modulator used for intensity stabilisation and the Faraday isolator used to optically isolate the master oscillator from the power amplifier.	Failure due to wear and tear. Reduced optical throughput, or performance, due to contamination of the optical surfaces.	The electro-optics are operational whenever the EnL MOPA is operational and either frequency or intensity stabilisation is required.	If the electro-optic modulator fails then the pre-modecleaner and frequency stabilisation If the Faraday isolator fails, then optical feedback from the power amplifier may cause the output of the master oscillator to be intermittent, or may cause the laser frequency to drift off its nominal set point.	The noise performance of the AdL Laser is compromised. Operation of the pre-modecleaner, frequency stabilisation or intensity stabilisation would be degraded and unreliable.	The AdL interferometer will not be able to operate.	In the case of the electro-optic modulator the pre-modecleaner servo cannot function. All attempts to lock the pre-modecleaner fail. In the case of the acousto-optic modulator, attempts to increase EnL MOPA output power by adjusting the excitation to the acousto-optic modulator fail.	None.	III. Marginal	Spare electro-optics are on hand. Typically the main failure mechanisms for the electro-optics is that their optical surfaces become dirty or damaged by having too high an intensity on the optical surfaces.
10.4	network	The network consists of the hardware necessary to maintain an EtherCAT link between the Control Box and the Diode Box.	Process communication between the Control Box and Diode Box is interrupted, caused by a break in the network link.	The network is required in order to operate the EnL MOPA.	Communication between the Control Box and Diode Box is not possible.	Operation of the EnL MOPA is not possible.	The AdL interferometer will not be able to operate.	Communications between the Control Box and Diode Box has either stopped or is interrupted. This results in an error condition within the EnL MOPA, ending with the laser being placed into standby.	Spare network equipment, the Ethernet hubs and network optical fibres are on hand or are installed in the case of the network optical fibres.	IV. Minor	Recovering from this error requires manual intervention to reset a laser control. The EnL MOPA does not automatically power up when the network connection is restored.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.5	cooling	The cooling is the hardware necessary to maintain cooling of the power amplifier and the pump laser diodes.	The chiller fails due to wear and tear. Cooling performance is degraded because of coolant loss through leaks or evaporation.	Cooling is required whenever the pump laser diodes are on.	The temperature of the pump laser diodes increases. This triggers the thermal protection circuitry and shuts the pump laser diodes off.	Long term operation of the EnL MOPA is not possible.	The AdL interferometer will not be able to operate.	Either the chiller fault condition or the pump laser diode temperature error condition is indicated on the MEDM screens.	None.	III. Marginal	Spare chillers are on hand.
10.6	diode box	The Diode Box houses the pump laser diodes and power supplies necessary to run them.	The DC power supplies fail due to wear and tear. The pump laser diodes fail due to wear and tear.	The Diode Box is operational at all times the EnL MOPA is required.	The pump laser diodes cannot be turned on.	Operation of the EnL MOPA is not possible.	The AdL interferometer will not be able to operate.	The EnL MOPA will shutdown. Power watchdogs trip and an alarm is indicated on the MEDM screens.	None.	III. Marginal	Spare parts are on hand.
10.7	optical fibres	The optical fibres deliver the pump light from the pump laser diodes in the Laser Diode Room to the power amplifier on the PSL optical table.	The optical fibres no longer deliver the pump light to the Nd:YLF crystals. This is caused by a mechanical break somewhere in the optical fibre.	The optical fibres are operational whenever the pump laser diodes are energised. They are required for operation of the EnL MOPA.	Depending on the number of fibres that are damaged, the local effect varies between reduced output power of the EnL MOPA to no operation.	Performance of the EnL MOPA is degraded.	The AdL interferometer will not be able to operate.	This is an undetectable failure. Each individual fibre would have to be checked.	A number of spare optical fibres have been pulled along with the optical fibres in use.	II. Critical — if all optical fibres, including spares, are damaged.	The symptoms of a failure of the optical fibres would be that the output power of the EnL MOPA decreases for no other reason. This failure should be suspected if any activity took place in the area of the fibre runs.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.8	power amplifier	The power amplifier provides the gain medium to amplify the 2 W output of the master oscillator up to a nominal 35 W.	Decreased output due to wear and tear.	The power amplifier is operational at all times for the EnL MOPA.	The output of the EnL MOPA is degraded.	Injection locking of the high power stage to the EnL MOPA is less robust.	The AdL interferometer will not be able to operate.	The output of the EnL MOPA decreases. This trips a watchdog and sets an alarm condition indicated on the MEDM screen.	None.	III. Marginal	Spare parts are on hand.

3.1.1 Sub-assembly Failures

3.1.1.1 Control Box

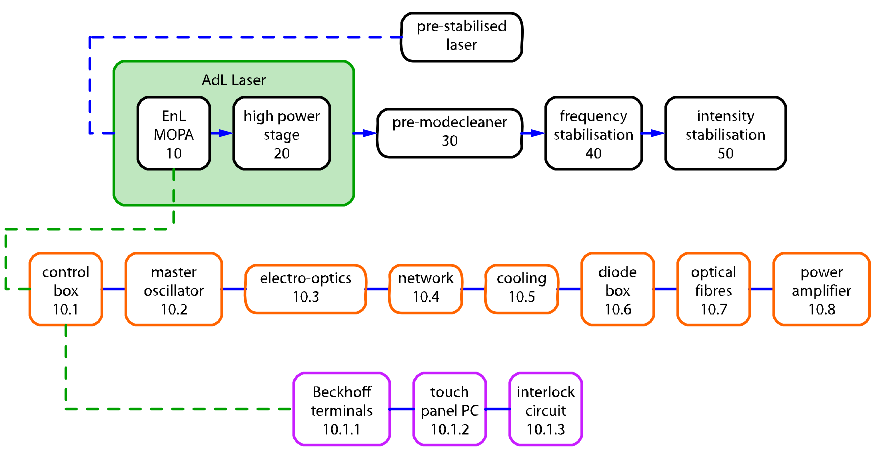

Figure 4. The Control Box reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.1.1	Beckhoff terminals	The Beckhoff terminals generate control signals and monitor signals from the EnL MOPA.	One of the terminals no longer operate due to wear and tear.	The Beckhoff terminals are operational whenever the Control Box is powered on.	The Control Box cannot perform all its input/output functions, resulting in the EnL MOPA being placed into standby.	Operation of the EnL MOPA is not possible.	The AdL interferometer will not be able to operate.	The EnL MOPA is placed into standby. This changes a status flag on the MEDM screens.	None.	IV. Minor	The Beckhoff terminals are used in industrial control systems and are robust. Failure of these terminals is expected to be rare.
10.1.2	touch panel PC	The touch panel PC provides the user interface to the EnL MOPA and runs the TwinCAT real time controls software.	The touch panel PC no longer operates due to wear and tear.	The touch panel PC is operational whenever the Control Box is powered on.	Operation of the EnL MOPA is not possible.	Performance of the AdL Laser is degraded.	The AdL interferometer will not be able to operate.	The MEDM laser screens no longer update. The touch panel itself appears as a dark monitor.	None.	IV. Minor	
10.1.3	interlock circuit	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	The relays used to close the interlock circuit fail due to wear and tear.	The interlock circuit is in operation at all times.	The EnL MOPA is placed in standby.	Performance of the AdL Laser is degraded.	The AdL interferometer will not be able to operate.	The EnL MOPA cannot be powered on for no apparent reason.	None.	II. Critical	The relays used fail in the open position, that is, they are fail safe.

3.1.1.2 Master Oscillator

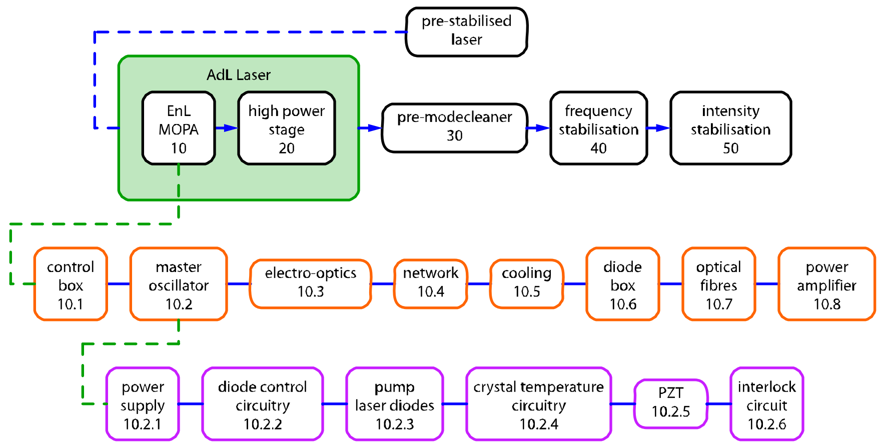

Figure 5. The master oscillator reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.2.1	power supply	The power supply provides the basic functions necessary for operation of the master oscillator.	The power supply does not turn, even though the correct electrical power voltage and current is applied. This could be caused by a blown fuse.	The power supply is in operation whenever the master oscillator is required.	Turning on the master oscillator is not possible.	No beam is available for the power amplifier to amplify.	No output from the EnL MOPA. The AdL interferometer will not be able to operate.	The signal from the EnL MOPA noise eater monitor drops to zero.	None. Spare power supplies are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.2.2	diode control circuitry	The diode control circuitry controls the operating current and temperature of the two pump laser diodes inside the master oscillator.	No output due to wear and tear.	The diode control circuitry is in operation whenever the master oscillator is energised.	The master oscillator pump diodes cannot turn on due to either an overtemperature condition or lack of current.	No beam is available for the power amplifier to amplify.	No output from the EnL MOPA. The AdL interferometer will not be able to operate.	The master oscillator power monitoring photodetector output is zero. This triggers an alarm, visible on the MEDM screens.	None. Spare master oscillators are on hand.	III. Marginal	
10.2.3	pump laser diodes	The pump laser diodes provide the pump light to excite the Nd:YAG gain medium.	No output due to wear and tear.	The pump laser diodes are operational whenever output from the master oscillator is required.	No output from the master oscillator.	No beam is available for the power amplifier to amplify.	No output from the EnL MOPA. The AdL interferometer will not be able to operate.	The master oscillator pump laser diode output monitor output would fall to zero, triggering an alarm on the MEDM screens.	None. Spare pump laser diodes are on hand.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.2.4	crystal temperature circuitry	The crystal temperature is used for large scale and slow adjustments of the master oscillator frequency. Within LIGO it is commonly referred to as the slow actuator.	No output due to wear and tear.	The crystal temperature circuitry is required whenever a change in the master oscillator frequency is called for.	No large scale adjustments to the master oscillator are possible. If the AdL Laser were to lose lock to the reference cavity, then re-locking the laser to the reference cavity may not be possible if there has been a large drift in the laser frequency.	The ability of the frequency stabilisation electronics to correct for long term drifts in the master oscillator frequency fails.	The AdL interferometer will still be able to operate and perhaps at full sensitivity. However the ability to make adjustments might be reduced.	The master oscillator cannot be tuned to the reference cavity by adjusting the slow actuator voltage. Long duration locks to the reference cavity would be diminished as the dynamic range left to the fast actuator would be effectively reduced.	The temperature of the reference cavity can be adjusted to compensate for the lack of tunability of the master oscillator.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.2.5	PZT	The PZT is used for fast adjustments of the master oscillator frequency. Within LIGO it is commonly referred to as the fast actuator.	No output due to wear and tear. If the frequency stabilisation electronics is left to oscillate for long periods of time, the energy dissipated by the PZT is in the form of heat which may damage the PZT.	The PZT is required for small, yet fast adjustments to the master oscillator frequency.	The frequency stabilisation servo cannot correct for fast changes in the AdL Laser frequency.	The ability of the frequency stabilisation electronics to correct for fast frequency transients fails or is seriously degraded.	Locking of the suspended modecleaner is not possible. The AdL interferometer will not be able to operate.	The AdL Laser cannot remain locked to the reference cavity for any period of time greater than a few seconds.	None. Spare master oscillators are on hand.	III. Marginal	
10.2.6	interlock circuit	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	The relays used to close the interlock circuit fail due to wear and tear.	The interlock circuit is in operation at all times.	Operation of the master oscillator is not possible.	No beam is available for the power amplifier to amplify.	The AdL interferometer will not be able to operate.	The master oscillator cannot be powered on for no apparent reason.	None.	II. Critical	This is rated critical because of the risk of an injury should the interlock circuit fail when required.

3.1.1.3 Electro-optics

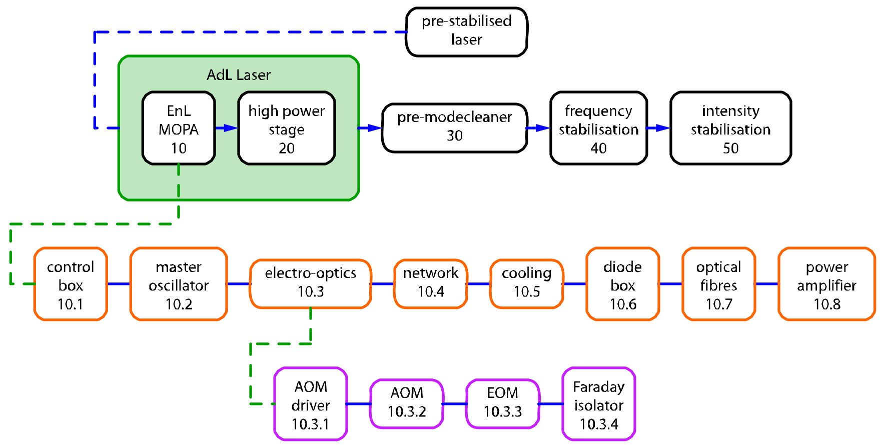

Figure 6. The reliability block diagram for the electro-optics inside the EnL MOPA.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.3.1	AOM driver	The AOM driver provides the RF signal to excite sound waves in the AOM.	No output due to wear and tear.	The AOM driver is required whenever intensity stabilisation is required.	High bandwidth suppression of the intensity noise is not possible.	The increase in intensity noise will result in increased radiation pressure on the suspended modecleaner mirrors.	Without intensity stabilisation, the sensitivity of the AdL interferometer will be diminished.	The input monitor to the VCO will alarm. This will be indicated on the MEDM user screen.	Spare parts are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.3.2	AOM	The AOM is the high bandwidth intensity actuator for the EnL MOPA.	The AOM no longer responds to the applied RF input. Damage to the sonic transducer of the AOM caused by too much RF power being applied.	The AOM is required whenever intensity stabilisation is required.	High bandwidth suppression of the intensity noise is not possible.	The increase in intensity noise will result in increased radiation pressure on the suspended modecleaner mirrors.	Without intensity stabilisation, the sensitivity of the AdL interferometer will be diminished.	Incident light is no longer diffracted by the AOM.	Spare parts are on hand.	IV. Minor	
10.3.3	EOM	The EOM provides the fast frequency corrections to the laser frequency and imparts the sidebands on the light to allow the pre-modecleaner to lock.	The EOM no longer phase modulates the incident laser beam.	The EOM is operational whenever either the frequency stabilisation or pre-modecleaner is required.	Locking of the pre-modecleaner is not possible. High bandwidth operation of the frequency stabilisation electronics is not possible.	No output to the Input Optics subsystem because of no subsequent output of the pre-modecleaner.	The AdL interferometer will not be able to operate.	The pre-modecleaner will not lock. If the pre-modecleaner does lock but the EOM has failed, then the frequency stabilisation servo bandwidth decreases which results in lower transmission of the reference cavity.	Spare parts are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.3.4	Faraday isolator	The Faraday isolator optically isolates the power amplifier from the master oscillator.	No output due to wear and tear.	The Faraday isolator is required whenever output from the power amplifier is required.	Optical feedback from the power amplifier to the master oscillator is possible. This could result in either frequency or intensity fluctuations of the master oscillator and EnL MOPA.	The suspended modecleaner will not be able to obtain a stable lock in the presence of frequency or intensity glitches.	Stable operation of the AdL interferometer is not possible.	Both the pre-modecleaner and frequency stabilisation servoes randomly lose lock for no apparent reason. The randomness is due to the unpredictable nature of optical feedback on the master oscillator output power and frequency.	Spare parts are on hand.	III. Marginal	

3.1.1.4 Network

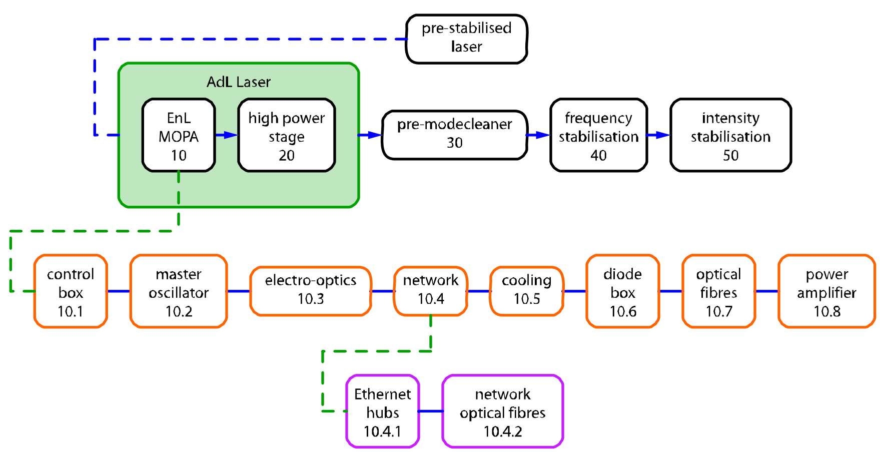

Figure 7. The reliability block diagram for the EtherCAT network between the Control Box and Diode Box.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.4.1	Ethernet hubs	The Ethernet hubs allow the TwinCAT control system to communicate between the touch panel PC, the Control Box and the Diode Box. They also serve to allow communications with the EPICS-OPC server.	The Ethernet hub does not work due to wear and tear.	The Ethernet hubs are in use any time that the EnL MOPA is operational.	Communications between the Control Box and Diode Box is lost. This results in the laser being turned off.	Failure of the EnL MOPA.	The high power stage no longer has its seed laser. Operation of the AdL interferometer is not possible.	A system message appears stating that communications between Beckhoff terminals is lost.	Spare Ethernet hubs are on hand.	IV. Minor	When the network link is re-established, manual intervention is required to reset the error condition in the EnL MOPA.
10.4.2	network optical fibres	The network communications fibres transport the network traffic between the laser diode room and the laser area enclosure.	The network optical fibre no longer transmits signals from the Ethernet hubs. This is typically caused by a break in the fibre or a faulty connector at either end of the fibre.	The network optical fibres are in use any time when the EnL MOPA is operational.	Communications between the Control Box and Diode Box is lost. This results in the laser being turned off.	Failure of the EnL MOPA.	The high power stage no longer has its seed laser. Operation of the AdL interferometer is not possible.	A system message appears stating that communications between Beckhoff terminals is lost.	A number of spare network optical fibres have been pulled along with the ones being used.	IV. Minor	

3.1.1.5 Cooling

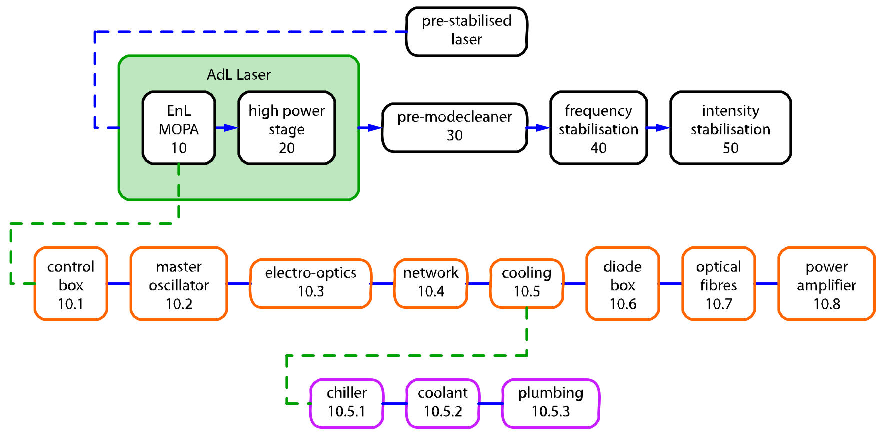

Figure 8. The reliability block diagram for the cooling of the EnL MOPA.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.5.1	chiller	The chiller provides the cooling water to cool the pump laser diodes and the Nd:YLF crystals.	The chiller ceases to function due to wear and tear. This would cause the temperature of the pump laser diodes to increase resulting in a shutdown of the EnL MOPA.	The chiller is in use any time when the EnL MOPA is operational.	The temperature of the pump laser diodes increases.	Failure of the EnL MOPA.	The high power stage no longer has its seed laser. Operation of the AdL interferometer is not possible.	The control software watchdog that monitors the pump laser diode temperature is triggered.	A spare chiller is on hand.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.5.2	coolant	The coolant removes the heat generated from the pump laser diodes and the heat generated from the unabsorbed pump power in the Nd:YLF crystals.	Lack of coolant due to accumulated slow leaks and evaporation.	Coolant is required any time when the pump laser diodes or power amplifier is operational.	For a fixed flow rate, the gradual loss of coolant results in a slow temperature increase in the Nd:YLF crystals. This is not necessarily observed with the pump laser diodes because each diode has their own TEC.	Failure of the EnL MOPA.	The high power stage no longer has its seed laser. Operation of the AdL interferometer is not possible.	A gradual lowering of the water level in the chiller sight glass is observed.	The coolant level shall be checked during maintenance periods.	IV. Minor	
10.5.3	plumbing	The plumbing carries the cooling water from the chiller to the Diode Box and to the EnL MOPA power amplifier.	Blockage due to contamination of the cooling lines or a leak due to breakage of the cooling lines.	The plumbing is required any time when the EnL MOPA is operational.	The coolant flow rate is decreased.	Failure of the EnL MOPA.	The high power stage no longer has its seed laser. Operation of the AdL interferometer is not possible.	Flow rate meters are part of the cooling system. The flow rate is displayed on one of the MEDM status screens. A visible and audible alarm is broadcast to the control room operator.	None.	III. Marginal	Checks of the plumbing should be performed after activity around them, such as the lifting of heavy items, has been completed.

3.1.1.6 Diode Box

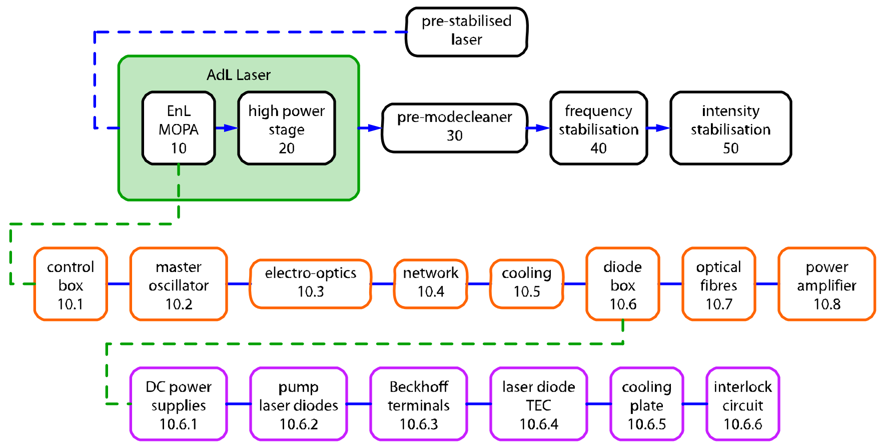

Figure 9. The Diode Box reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.6.1	DC power supplies	The DC power supplies supply the voltage and current necessary to run the pump laser diodes and Beckhoff terminals.	No output due to wear and tear.	The DC power supplies operate whenever output from the Diode Box is required.	The pump laser diodes cannot be turned on.	No output from the EnL MOPA.	Operation of the AdL interferometer is not possible.	The Diode Box does not power up.	None. Spare parts are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.6.1	DC power supplies	The DC power supplies supply the voltage and current necessary to run the pump laser diodes and Beckhoff terminals.	No output due to wear and tear.	The DC power supplies operate whenever output from the Diode Box is required.	The pump laser diodes cannot be turned on.	No output from the EnL MOPA.	Operation of the AdL interferometer is not possible.	The Diode Box does not power up.	None. Spare parts are on hand.	IV. Minor	
10.6.2	pump laser diodes	The pump laser diodes excite the Nd:YLF gain medium to the upper laser level.	No output due to wear and tear.	The pump laser diodes are required at all times output is required from the power amplifier.	The Nd:YLF crystals do not get pumped resulting in no amplification of the master oscillator output.	No output from the EnL MOPA.	Operation of the AdL interferometer is not possible.	No output from the EnL MOPA is observed. This triggers an alarm that is displayed on the MEDM screens.	None. Spare parts are on hand.	IV. Minor	
10.6.3	Beckhoff terminals	The Beckhoff terminals perform the real time control and monitoring of the pump laser diodes.	No output due to wear and tear.	The Beckhoff terminals are required at all times when operating the EnL MOPA.	No information about the pump laser diodes is possible. Operation of the EnL MOPA is not possible.	No output from the EnL MOPA.	Operation of the AdL interferometer is not possible.	No, or patchy, information about the Diode Box is received. Some signals on the MEDM screens fail to update or disappear altogether.	None. Spare parts are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.6.4	laser diode TEC	The laser diode TEC fine tunes the temperature of the pump laser diode.	No output due to wear and tear. No output due to a loose connection.	The laser diode TEC is required at all times the pump laser diodes are powered on.	The output wavelength of the pump laser diodes cannot be tuned for maximum absorption by the Nd:YLF crystals. As a result the output power of the EnL MOPA decreases.	No output from the EnL MOPA.	Operation of the AdL interferometer is not possible.	The difference between the actual pump laser diode temperature and the set temperature never approaches zero. Eventually a pump laser diode will go beyond a set temperature range and trigger a watchdog that will shut the laser down.	The chiller temperature setpoint can be adjusted to a value that all four pump laser diodes can operate at, although with decreased efficiency.	III. Marginal	
10.6.5	cooling plate	The cooling plate acts as a heatsink to wick the heat away from the laser diode TEC and conduct the heat to the cooling water.	Corrosion due to a chemical reaction between the coolant and the cooling plate.	The cooling plate is required at all times.	Gradual decrease in the cooling efficiency of the chiller.	No output from the EnL MOPA.	Operation of the AdL interferometer is not possible.	Apart from looking at data trends of the laser temperature and a physical inspection of the cooling plate, this failure mode is undetectable.	None. Spare parts are on hand.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.6.6	interlock circuit	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	The relays used to close the interlock circuit fail due to wear and tear.	The interlock circuit is in operation at all times.	The EnL MOPA is placed in standby.	No output from the EnL MOPA.	The AdL interferometer will not be able to operate.	The EnL MOPA cannot be turned on for any apparent reason.	None.	II. Critical	

3.1.1.7 Optical Fibres

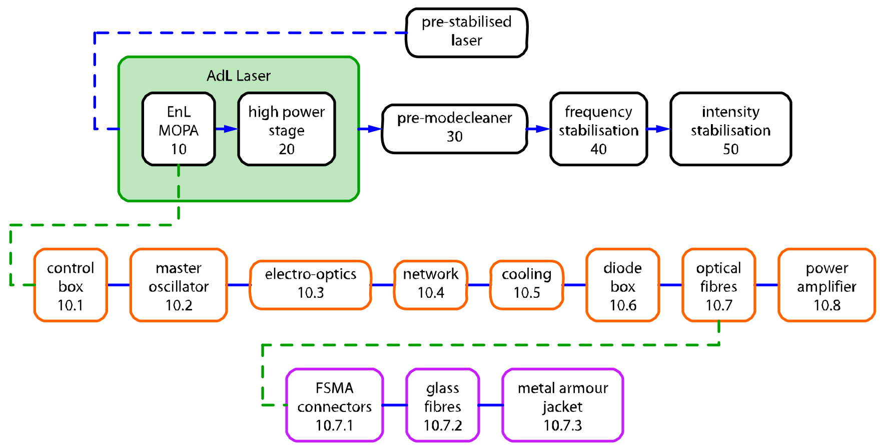

Figure 10. The reliability block diagram for the optical fibres.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	**Next Higher Level**	**End Effects**				
10.7.1	FSMA connectors	The FSMA connectors connect the optical fibre to the pump laser diode and the power amplifier.	The connector becomes loose because of incorrect alignment. The connector becomes hot from the pump light scattered from the end of the optical fibre.	The FSMA connectors are always operational.	Damage to the fibre ends is possible.	Reduced seed power to the AdL Laser.	Reduced laser power delivered to the Input Optics. No, or degraded operation of the AdL interferometer is possible.	Feeling the connector to see if things are tight. This also gives information about the temperature of the FSMA connector.	None. Spare fibres are on hand.	III. Marginal	
10.7.2	glass fibres	The glass fibres transport the output of the pump laser diodes to the Nd:YLF crystals.	The core or cladding of the fibre breaks. Caused by excessive mechanical pressure being exerted on the fibre ends.	The glass fibres are always operational when the power amplifier is required.	The output from one of the pump laser diodes is no longer available. This results in a decrease in the output of the EnL MOPA.	Reduced seed power to the AdL Laser.	Reduced laser power delivered to the Input Optics. No, or degraded operation of the AdL interferometer is possible.	One of the pump laser diodes appears to be dead.	None. Spare fibres are on hand.	IV. Minor	This could be the result of the fibre being bent with too tight a radius of bending.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.7.3	metal armour jacket	The metal armour jacket protects the fibre bundle.	The metal armour jacket breaks. Caused by excessive mechanical pressure being applied to the jacket.	The metal armour jacket is operational at all times.	Damage to the optical fibres, resulting in no or little pump light being delivered to the power amplifier.	No EnL MOPA output.	No seed laser for the AdL Laser.	This is an undetectable failure unless visually spotted.	None.	II. Critical	It is possible that if the metal armour jacket were to break, then pump light could be emitted from the exposed ends of the fibre. If mechanical activity near the optical fibre runs takes place and the EnL MOPA no longer functions, this should be checked.

3.1.1.8 Power Amplifier

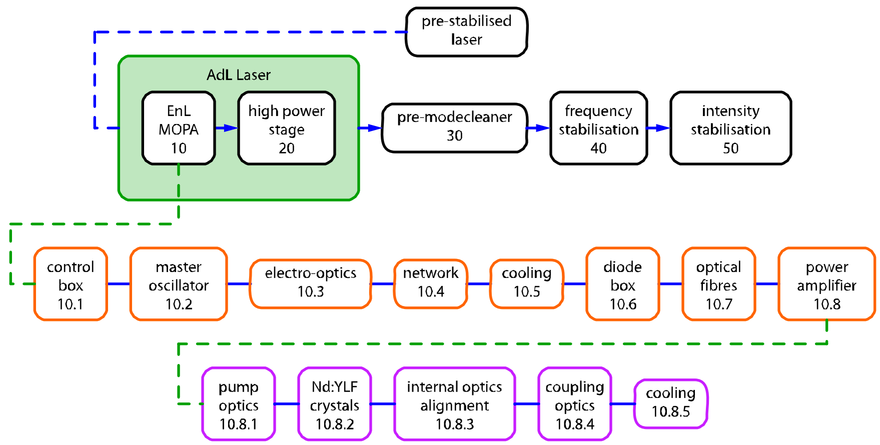

Figure 11. The reliability block diagram for the power amplifier.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.8.1	pump optics	The pump optics couple the output from optical fibres to the Nd:YLF crystals.	The alignment of the pump optics does not efficiently couple the pump light to the Nd:YLF crystals.	The pump optics are required whenever operation of the power amplifier is required.	No, or degraded output from the power amplifier.	No, or degraded output from the EnL MOPA.	No, or degraded operation of the AdL interferometer is possible.	The power monitors inside the power amplifier may indicate a problem with a part of the power amplifier. The signal decline from one of these power monitors would trigger an alarm on the MEDM screen.	None.	III. Marginal.	Spare parts are on hand.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.8.2	Nd:YLF crystals	The Nd:YLF crystals are the gain medium for the power amplifier. They amplify the master oscillator output.	The output of one of the power amplifier's gain stages is reduced due to damage to the Nd:YLF crystal. This is caused by damage to the optical surfaces of the Nd:YLF crystals.	The Nd:YLF crystals are in operation at all times that the power amplifier is operational.	No, or degraded, output from the power amplifier.	No, or degraded output from the EnL MOPA.	No, or degraded operation of the AdL interferometer is possible.	The power monitors inside the power amplifier may indicate a problem with a part of the power amplifier. The signal decline from one of these power monitors would trigger an alarm on the MEDM screen.	None.	III. Marginal	Spare parts are on hand.
10.8.3	internal optics alignment	The internal optics alignment of the amplifier direct the beam from the master oscillator through the beam path of the power amplifier.	Reduced output from the power amplifier. This results from damage to the optical surfaces.	The internal optics alignment is in use at all times.	No, or degraded, output from the power amplifier.	No, or degraded output from the EnL MOPA.	The laser power delivered to the Input Optics subsystem is reduced. This in turn degrades the performance of the AdL interferometer.	A gradual decrease in EnL MOPA output power when everything else has stayed the same. This failure mode would only be detected after looking at trend data of the EnL MOPA performance and during alignment checks of the EnL MOPA.	None. This failure requires servicing of the EnL MOPA.	III. Marginal	Spare parts are on hand.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
10.8.4	coupling optics	The coupling optics align and match the output of the master oscillator to the power amplifier.	Reduced master oscillator power coupled into the power amplifier.	The coupling optics is in use at all times.	The output of the power amplifier is degraded.	No, or degraded output from the EnL MOPA. The injection locking performance of the high power stage is degraded.	The laser power delivered to the Input Optics subsystem is reduced. This in turn degrades the performance of the AdL interferometer.	A gradual decrease in EnL MOPA output power when everything else has stayed the same. This failure mode would only be detected after looking at trend data of the EnL MOPA performance and during alignment checks of the EnL MOPA.	None. This failure requires servicing of the EnL MOPA.	IV. Minor	Spare parts are on hand.
10.8.5	cooling	The cooling removes heat from the Nd:YLF crystals.	A leak occurs due to wear and tear of the plumbing fittings.	The cooling is in use at all times.	The temperature of the Nd:YLF crystals increases.	No, or degraded output from the EnL MOPA.	Degraded performance of the AdL interferometer.	The temperature watchdog would be tripped, shutting the EnL MOPA down.	None.	III. Marginal	Spare parts are on hand.

4 High Power Stage

The high power stage is a 200 W Nd:YAG ring laser that is injection locked to the EnL MOPA.

4.1 Assembly Level Failures

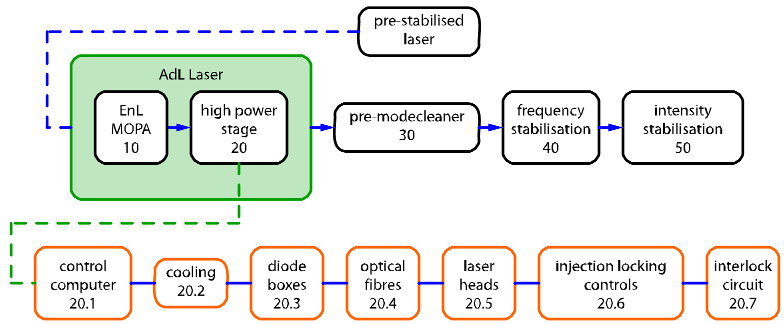

Figure 12. The high power stage reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.1	control computer	The control computer provides the monitoring and control of the high power stage.	The control computer no longer functions properly due to wear and tear, or corruption of its memory.	The control computer is required at all times in order to operate the high power stage.	Operation of the high power stage is not possible.	Reduced laser power is delivered to the Input Optics subsystem.	Degraded performance of the AdL interferometer.	All signals related to the high power stage no longer update on the MEDM screen.	None.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.2	cooling	Cooling is required in two places for the AdL Laser: the Nd:YAG rods and the pump laser diodes.	The chiller fails due to wear and tear.	The cooling is required at all times in order to operate the high power stage.	Operation of the high power stage is not possible.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The temperature of the pump laser diodes gradually increases. A temperature watchdog shuts down the pump laser diodes and the laser is shutdown. The temperature status is indicated on the MEDM screen and a visible alarm is displayed.	None. A spare chiller is on hand.	IV. Minor	
20.3	diode boxes	The diode boxes houses the pump laser diodes and power supplies necessary to run them.	The diode box power supplies fail due to wear and tear. The pump laser diodes fail due to wear and tear.	The diode boxes are required at all times whenever the high power stage is operational.	Operation of the high power stage is not possible, or its output power and beam quality are seriously degraded.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	A gradual decrease in the output power of the AdL Laser. The power watchdog is tripped, which shuts the laser down. The change in laser status is reflected on the MEDM screen.	None. Spare diode boxes are on hand.	IV. Minor	It is unlikely that an entire diode box would fail.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.4	optical fibres	The optical fibres transport the pump light from the pump laser diodes to the Nd:YAG rods.	The optical fibres no longer deliver the pump light to the Nd:YAG rods due to a mechanical break.	The optical fibres are operational whenever the pump laser diodes are energised. They are required for operation of the high power stage.	Operation of the high power stage is not possible, or its output power and beam quality are seriously degraded.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	A gradual decrease in the output power of the high power stage. The power watchdog is tripped, which shuts the laser down. The change in laser status is reflected on the MEDM screen.	None. Spare optical fibres will be installed.	IV. Minor	The high power stage requires four fibre bundles to operate. The current plan is to pull six fibre bundles.
20.5	laser heads	The AdL Laser consists of four laser heads. Each head contains a Nd:YAG rod and is pumped by seven pump laser diodes. It is a gain stage for the high power stage.	Damage to one of the optical components due to dust.	The laser heads are operational at all times. They are required for operational of the high power stage.	Operation of the high power stage is not possible, or its output power and beam quality are seriously degraded.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	A sudden decrease in the output power of the high power stage triggers the power watchdog that in turn shuts the laser down. The change in status is reflected on the MEDM screen.	None. Spare components are on hand.	III. Marginal.	Either a whole laser head assembly or spare parts of which will be at the observatories.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.6	injection locking controls	The injection locking controls control the high power stage to enable it to be injection locked to the EnL MOPA.	Failure due to wear and tear.	The injection locking controls are required at all times for operation of the AdL Laser.	Operation of the AdL Laser is degraded.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The injection locking status indicator changes state and is updated on the MEDM screen.	None. Spare injection locking controls are on hand.	IV. Minor	
20.7	interlock circuit	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	The relays used to close the interlock circuit fail due to wear and tear.	The interlock circuit is in operation at all times.	The high power stage is placed on standby until the situation is rectified.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The high power status indicator on the MEDM screen changes state.	None.	II. Critical	

4.1.1 Sub-assembly Failures

4.1.1.1 Control Computer

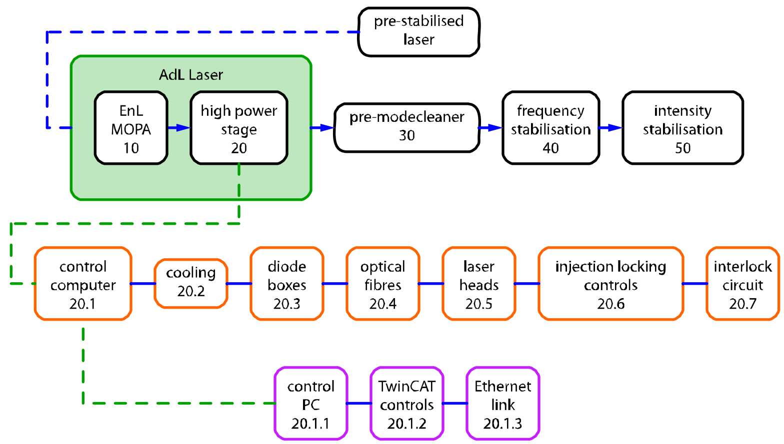

Figure 13. The reliability block diagram for the control computer.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.1.1	control PC	The control PC runs the TwinCAT real time control system.	Failure due to wear and tear.	The control PC is required at all times.	No operation of the high power stage is possible.	No light is passed to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The AdL Laser does not respond to user requests. The laser status channels indicated on MEDM screens no longer update.	None. A spare control PC may be provided.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.1.2	TwinCAT controls	The TwinCAT controls interface the control program to the Beckhoff terminals in the diode boxes.	Failure to operate, or intermittent operation due to a software bug.	The TwinCAT controls are required at all times for operation of the AdL Laser.	No operation of the high power stage is possible or operation of the high power stage is degraded.	No light is passed to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The AdL Laser shuts down.	None.	II. Critical	The software will be extensively tested during the final design phase. Note that TwinCAT is an industrial controls program and as such is quite reliable.
20.1.3	Ethernet link	The Ethernet link allows the control PC to communicate with the Beckhoff terminals in the diode boxes.	Failure due to wear and tear.	The Ethernet link is required at all times.	No operation of the high power stage is possible.	No light is passed to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	A communications error message is displayed on the control screen and MEDM screen. The laser is then shutdown.	None. Spare network components are on hand.	IV. Minor	

4.1.1.2 Cooling

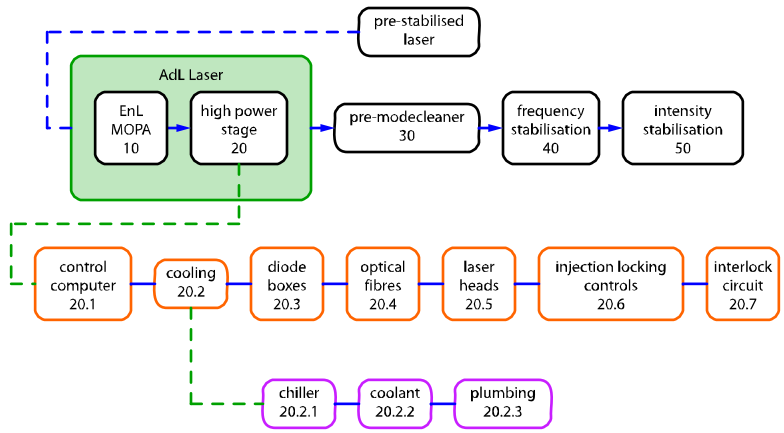

Figure 14. The high power stage cooling reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.2.1	chiller	The chiller provides the cooling water to cool the pump laser diodes and the Nd:YAG rods.	The chiller ceases to function due to wear and tear. This would cause the temperature of the pump laser diodes to increase resulting in a shutdown of the AdL Laser.	The chiller is operational at all times when the high power stage is operational.	The temperature of the pump laser diodes increases. It is also possible that the Nd:YAG rods might break.	No output from the high power stage. This reduces the output power of the PSL.	Degraded performance of the AdL interferometer.	The chiller is monitored by the control computer. A failure of the chiller would trigger a temperature watchdog and raise an alarm on the MEDM screens.	None.	III. Marginal	A spare chiller is on hand.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.2.2	coolant	The coolant removes the heat generated from the pump laser diodes and the heat generated from the unabsorbed pump power in the Nd:YAG rods.	A leak occurs due to mechanical wear and tear, or stresses caused by activity taking place near the cooling lines.	The coolant is required at all times the high power stage is operational.	A gradual loss of coolant takes place followed by a slow increase in the temperatures of the Nd:YAG rods and pump laser diodes.	Possibly none in the short term. However if left unattended, the loss of coolant will result in the shutdown of the laser and in turn no light being passed onto the Input Optics subsystem.	Possibly none in the short term. Unless rectified, the long term loss of coolant will cause the laser to shutdown, making operation of the AdL interferometer not possible.	Periodic inspections of the water level should be performed as part of a regular maintenance routine. The increase in temperature of the pump laser diodes and Nd:YAG rods will trigger a temperature watchdog that will shut down the laser. The out of bound temperature is indicated on an MEDM screen.	Periodic inspections of the water level should be performed as part of a regular maintenance routine.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.2.3	plumbing	The plumbing carries the cooling water from the chiller to the diode boxes and to the Nd:YAG rods.	Blockage due to contamination of the cooling lines or a leak due to breakage of the cooling lines.	The plumbing is required at all times the high power stage is operational.	Loss of coolant and a reduction in the cooling ability of the chiller. Any	Possibly none.	Possibly none.	The water level indicator in the chiller drops if there is a loss of coolant. If there is a blockage, the flow rate sensors trigger a visible alarm on the MEDM screen.	None.	III. Marginal	Note that the plan is to use deionised water, which should be free of impurities.

4.1.1.3 Diode Boxes

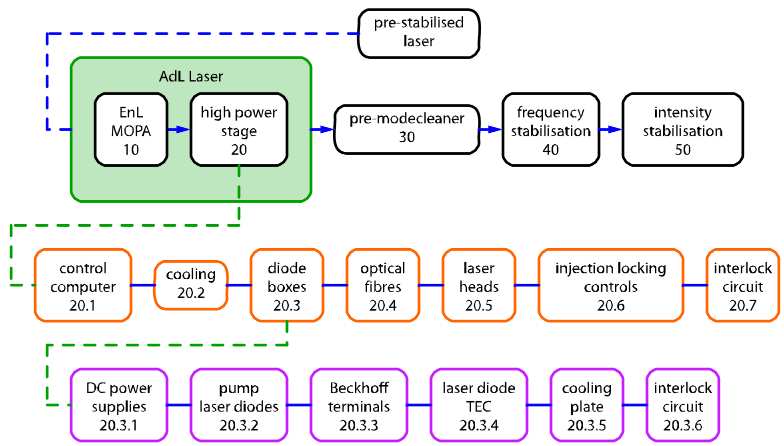

Figure 15. The high power stage diode box reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.3.1	DC power supplies	The DC power supplies convert the mains electrical power to the voltage and current required to operate the electronics and pump laser diodes.	Failure to operate due to wear and tear.	The DC power supplies are required at all times.	The diode box cannot be powered up, causing one laser head to not work.	No output to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The laser status indicator changes state and displays a visible error message and alarm on the MEDM screen.	None. Spare power supplies are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.3.2	pump laser diodes	The pump laser diodes provide the pump light to excite the Nd:YAG rods.	Failure to operate or degraded operationa due to wear and tear.	The pump laser diodes are required at all times.	The pump power available to one of the laser heads decreases.	Possibly none.	Possibly none.		None. Spare diode boxes are on hand.	III. Marginal	
20.3.3	Beckhoff terminals	The Beckhoff terminals perform various input/output functions required for operation of the high power stage.	Failure to operate due to wear and tear.	The Beckhoff terminals are required at all times.	Operation of the diode box is not possible.	No output to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.		None. Spare diode boxes are on hand.	III. Marginal	
20.3.4	laser diode TEC	The laser diode thermelectric cooler allows fine regulation of the laser diode temperature.	Failure to operate or degraded performance due to wear and tear.	The laser diode TEC is required at all times when the high power stage or diode boxes are operational.	The pump power available to one of the laser heads decreases.	No output to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.		None. Spare diode boxes are on hand.	III. Marginal	
20.3.5	cooling plate	The cooling plate acts as the heatsink for the laser diode TEC. It interfaces to the cooling water.	Degraded performance due to wear and tear.	The cooling plate is required at all times.	The pump power available to one of the laser heads decreases.	No output to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.		None. Spare diode boxes are on hand.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.3.6	interlock circuit	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	The relays used to close the interlock circuit fail due to wear and tear.	The interlock circuit is required at all times.	The high power stage is placed on standby until the situation is rectified.	No output to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.		None. Spare diode boxes are on hand.	II. Critical	The interlock circuit is designed to be fail safe. It should be noted that once the problem with the interlock circuit is fixed, the laser does not automatically power up. It requires manual intervention to proceed with the power up sequence.

4.1.1.4 Optical Fibres

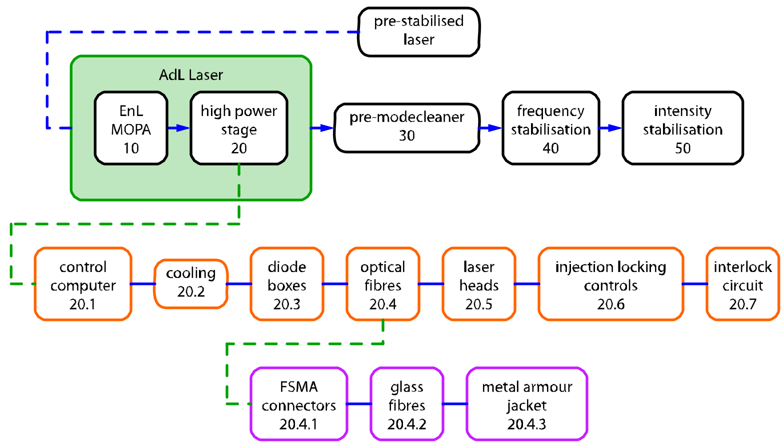

Figure 16. The reliability block diagram for the high power stage's optical fibres.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.4.1	FSMA connectors	The FSMA connectors connect the optical fibre to the pump laser diode.	The connector becomes loose because of incorrect alignment. The connector becomes hot from the pump light scattered from the end of the optical fibre.	The FSMA connectors are operational at all times when the high power stage is on.	Damage to the fibre ends is possible.	No output, or degraded output from the high power stage.	No, or degraded, operation of the AdL interferometer is possible.	Feeling the connector to see if things are tight. This also gives information about the temperature of the FSMA connector.	None. Spare fibres are on hand as part of the bundle.	III. Marginal	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.4.2	glass fibres	The glass fibres transport the output of the pump laser diodes to the Nd:YAG rods.	The core or cladding of the fibre breaks. Caused by excessive mechanical pressure being exerted on the fibre ends.	The glass fibres are operational at all times when the high power stage is on.	The output power of the high power stage is reduced. This is accompanied by an increase in higher order modes as the thermal loading on the resonator is different.	No output, or degraded output from the high power stage. A reduced laser power is delivered to the Input Optics subsystem.	Reduced laser power delivered to the Input Optics. No, or degraded operation of the AdL interferometer is possible.	One of the pump laser diodes appears to be dead.	None. Spare fibres are on hand as part of the bundle.	IV. Minor	
20.4.3	metal armour jacket	The metal armour jacket protects the fibre bundle.	The metal armour jacket breaks. Caused by excessive mechanical pressure being applied to the jacket.	The metal jacket is operational at all times.	Operation of the high power stage is not possible.	No output from the high power stage. The laser power delivered to the Input Optics subsystem is reduced.	The AdL interferometer can only operate in low power mode. Its performance is degraded.	This is an undetectable failure unless visually spotted.	None.	II. Critical	Note that the fibre bundle used for the high power stage is different from that in the EnL MOPA.

4.1.1.5 Laser Heads

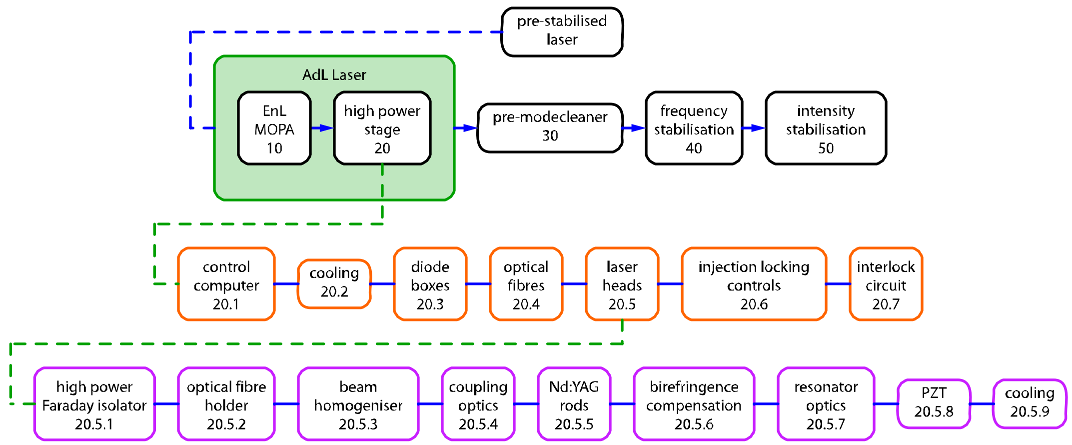

Figure 17. The reliability block diagram for the laser heads in the high power stage.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.5.1	high power Faraday isolator	The high power Faraday isolator optically isolates the high power stage from the EnL MOPA.	The transmission of the high power Faraday isolator is degraded due to damage to the thin film polarisers used in its construction.	The high power Faraday isolator is required at all times.	Optical feedback from the high power stage to the EnL MOPA increases. The high power stage cannot be injection locked to the EnL MOPA. Some damage to the EnL MOPA may occur.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The status indicator for the high power stage changes. This is reflected on the MEDM screen.	None. A spare laser head is on hand.	II. Critical	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.5.2	optical fibre holder	The optical fibre holder holds the seven fibres in the bundle and orients the output to the beam homogeniser.	The optical fibre holder may be damaged due to backscattered light from the beam homogeniser and other optics used in the laser head.	The optical fibre holders are required at all times when the high power stage is operational.	One of the laser heads no longer functions, severely changing the resonator characteristics of the high power stage. Operation of the high power stage is no longer possible.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The status indicator for the high power stage changes. This is reflected on the MEDM screen.	None. A spare laser head is on hand.	II. Critical	
20.5.3	beam homogeniser	The beam homogeniser mixes the output from the optical fibre bundle such that it looks like a single beam pumping the Nd:YAG rods.	The beam homogeniser may break due to thermal stress caused by an improperly aligned fibre bundle.	The beam homogeniser is required at all times when the high power stage is operational.	One of the laser heads no longer functions, severely changing the resonator characteristics of the high power stage. Operation of the high power stage is no longer possible.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The status indicator for the high power stage changes. This is reflected on the MEDM screen.	None. A spare laser head is on hand.	II. Critical	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.5.4	coupling optics	The coupling optics matches the output of the beam homogeniser to the Nd:YAG rods.	The optical surfaces of the coupling optics degrade due to contamination caused by dust particles.	The coupling optics is required at all times when the high power stage is operational.	One of the laser heads no longer functions, severely changing the resonator characteristics of the high power stage. Operation of the high power stage is no longer possible.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The status indicator for the high power stage changes. This is reflected on the MEDM screen.	None. A spare laser head is on hand.	II. Critical	
20.5.5	Nd:YAG rods	The Nd:YAG rods are the gain medium for each laser head.	The Nd:YAG rods are damaged due to contamination of the end surfaces caused by dust.	The Nd:YAG rods are required at all times when the high power stage is operational.	One of the laser heads no longer functions, severely changing the resonator characteristics of the high power stage. Operation of the high power stage is no longer possible.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The status indicator for the high power stage changes. This is reflected on the MEDM screen.	None. A spare laser head is on hand.	II. Critical	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.5.6	birefringence compensation	The birefringence compensation compensates for thermally induced birefringence in the Nd:YAG rods.	The optical surfaces of the birefringence compensation optics are damaged due to dust contamination or too high a circulating power in the high power stage cavity.	The birefringence compensation is required at all times when the high power stage is operational.	One of the laser heads no longer functions, severely changing the resonator characteristics of the high power stage. Operation of the high power stage is no longer possible.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The status indicator for the high power stage changes. This is reflected on the MEDM screen.	None. A spare laser head is on hand.	III. Minor	
20.5.7	resonator optics	The resonator optics form the laser cavity of the high power stage.	The resonator optics become damaged, or their performance is degraded, due to contamination of their surfaces caused by dust.	The resonator optics are required at all times when the high power stage is operational.	Performance of the high power stage is degraded.	Decreased laser power is delivered to the Input Optics subsystem.	Degraded performance of the AdL interferometer.	The reduction in laser power triggers the power watchdog. This is indicated on the MEDM screen.	None. A spare laser head is on hand.	III. Minor	
20.5.8	PZT	The PZT adjusts the resonator length of the high power stage.	Operation of the PZT is not possible or is intermittent due to a break in the PZT elements.	The PZT is required whenever the high power stage is injection locked to the EnL MOPA. For the PSL, it is required at all times when the AdL Laser is operational.	Injection locking of the high power stage to the EnL MOPA is not possible or is intermittent.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The injection locking status monitor changes state. This is updated on the MEDM screen.	None. Spare output couplers and PZTs are on hand.	III. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.5.9	cooling	The cooling removes the heat from the Nd:YAG rods.	A leak caused by wear and tear on the fittings connecting the pump chamber holding the Nd:YAG rod and the plumbing.	Cooling is required at all times when the high power stage is operational.	Likely damage to the Nd:YAG rods, resulting in degraded operational ability of the AdL Laser.	No pre-stabilised light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The increase in temperature triggers a watchdog that shuts down the laser. The change in status is indicated on the MEDM screen.	None. Spare pump chambers and Nd:YAG rods are on hand. Furthermore, spare laser head units are on hand.	II. Critical	

4.1.1.6 Injection Locking Controls

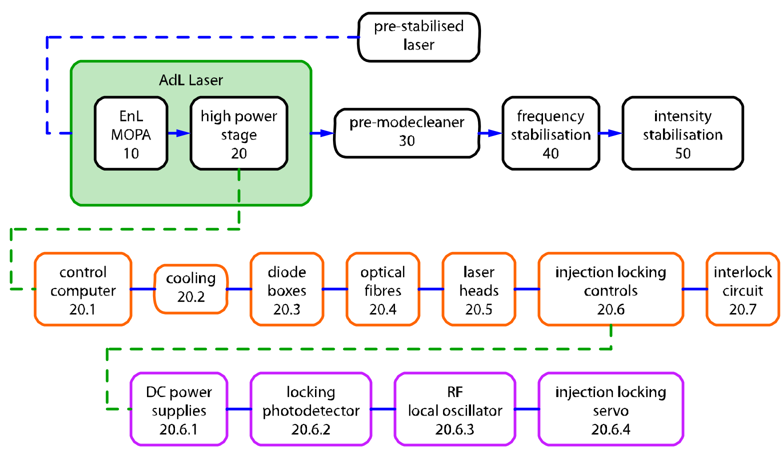

Figure 18. The reliability block diagram for the injection locking controls of the high power stage.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.6.1	DC power supplies	The DC power supplies provide the electrical power required to run the electronics.	Failure due to wear and tear.	The DC power supplies are required at all times.	Injection locking of the high power stage to the EnL MOPA is not possible.	Reduced output power is delivered to the Input Optics subsystem.	Degraded performance of the AdL interferometer due to the decrease in laser power.	All controls for the laser no longer respond to user input. The signals monitored would no longer be updated on an MEDM screen.	None. Spare power supplies are on hand.	IV. Minor	
20.6.2	locking photodetector	The locking photodetector is used as the sensor for injection locking of the high power stage to the EnL MOPA.	Failure due to wear and tear, or damage to the photodiode element.	The locking photodetector is required at all times.	Injection locking of the high power stage to the EnL MOPA is not possible.	Reduced output power is delivered to the Input Optics subsystem.	Degraded performance of the AdL interferometer due to the decrease in laser power.	The high power stage does not operate in a unidirectional manner. This would be indicated by a loss of lock signal from the injection locking electronics and would be displayed on an MEDM screen.	None. Spare photodetectors are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.6.3	RF local oscillator	The RF local oscillator provides signal to generate the sidebands required to injection lock the high power stage to the EnL MOPA.	Failure due to wear and tear.	The local oscillator is required at all times.	Injection locking of the high power stage to the EnL MOPA is not possible.	Reduced output power is delivered to the Input Optics subsystem.	Degraded performance of the AdL interferometer due to the decrease in laser power.	The signal monitoring the output of the local oscillator is no longer updated. This triggers a visible alarm on an MEDM screen.	None. Spare oscillators are on hand.	IV. Minor	
20.6.4	injection locking servo	The injection locking servo controls the high power stage so that it can be injection locked to the EnL MOPA.	Failure due to wear and tear.	The injection locking servo is required to operate the AdL Laser.	Injection locking of the high power stage to the EnL MOPA is not possible.	Reduced output power is delivered to the Input Optics subsystem.	Degraded performance of the AdL interferometer due to the decrease in laser power.	A status flag for the injection locking is triggered. This is a visible alarm on an MEDM screen.	None. Spare injection locking electronics are on hand.	IV. Minor	

4.1.1.7 Interlock Circuit

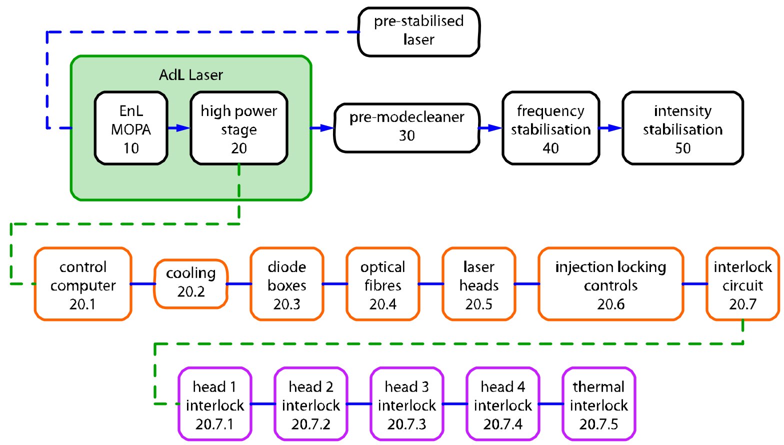

Figure 19. The reliability block diagram for the high power stage interlock circuit.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.7.1	head 1 interlock	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	Failure due to wear and tear.	The interlock is operational at all times.	The high power stage cannot be operated.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The tripped interlock message is displayed on the control screen and MEDM user screen.	None.	II. Critical	All interlocks are designed to be fail safe. The exact nature of the interlocks for the high power stage are not known at the time of writing.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
20.7.2	head 2 interlock	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	Failure due to wear and tear.	The interlock is operational at all times.	The high power stage cannot be operated.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The tripped interlock message is displayed on the control screen and MEDM user screen.	None.	II. Critical	
20.7.3	head 3 interlock	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	Failure due to wear and tear.	The interlock is operational at all times.	The high power stage cannot be operated.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The tripped interlock message is displayed on the control screen and MEDM user screen.	None.	II. Critical	
20.7.4	head 4 interlock	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	Failure due to wear and tear.	The interlock is operational at all times.	The high power stage cannot be operated.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The tripped interlock message is displayed on the control screen and MEDM user screen.	None.	II. Critical	
20.7.5	thermal interlock	The interlock circuit provides the safety interlock that ties into the facilities laser safety system.	Failure due to wear and tear.	The interlock is operational at all times.	The high power stage cannot be operated.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The tripped interlock message is displayed on the control screen and MEDM user screen.	None.	II. Critical	

5 Pre-modecleaner

The pre-modecleaner (PMC) is a three mirror ring cavity that spatially and temporally filters the output of the AdL Laser.

5.1 Assembly Level Failures

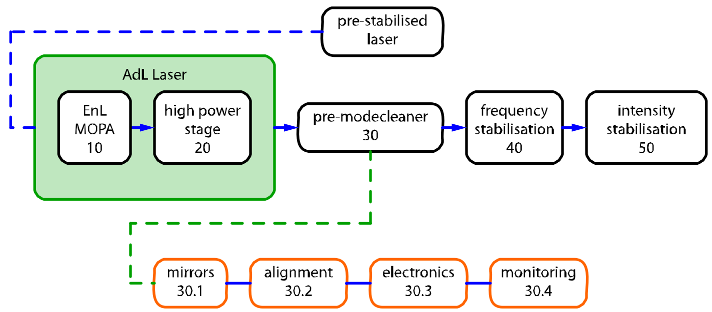

Figure 20. The reliability block diagram for the pre-modecleaner.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.1	mirrors	The mirrors form the optical cavity that make up the PMC.	Degraded output due to contamination or damage to the optical surfaces.	The mirrors are required at all times.	Reduced power transmitted through the pre-modecleaner.	Reduced power to the Input Optics subsystem.	Degraded performance of the AdL interferometer.	A gradual decrease in the transmission of the pre-modecleaner is observed without a corresponding decrease in laser output power. This would reveal itself in an examination of the trend data.	None. Spare pre-modecleaners are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.2	alignment	Alignment is necessary to couple the output of the AdL Laser to the PMC. It consists of the mirrors required to steer the beam and the mode matching lenses.	Change in alignment due to mechanical drift of the optical mounts used to house the optics.	Alignment of the mirrors and optics is required at all times.	Reduced power transmitted through the pre-modecleaner.	Reduced power to the Input Optics subsystem.	Degraded performance of the AdL interferometer.	A gradual decrease in the transmission of the pre-modecleaner is observed without a corresponding decrease in laser output power. This would reveal itself in an examination of the trend data.		IV. Minor	
30.3	electronics	The electronics is necessary to lock the PMC to the laser.	Degraded output due to wear and tear.	The electronics are required at all times for operation of the pre-modecleaner.	Locking the pre-modecleaner is not possible.	No light is passed to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The pre-modecleaner will not lock.	None. Spare electronics modules are on hand.	IV. Minor	
30.4	monitoring	The function of monitoring is to diagnose the performance and status of the PMC.	Degraded output due to wear and tear.	Monitoring of the pre-modecleaner takes place all the time.	Convenient monitoring of the output of the pre-modecleaner is degraded.	None.	None.	The monitor signals from the transmission photodetector and CCD camera are inconsistent with each other.	None. Spare parts are on hand.	IV. Minor	

5.1.1 Sub-assembly Level Failures

5.1.1.1 Mirrors

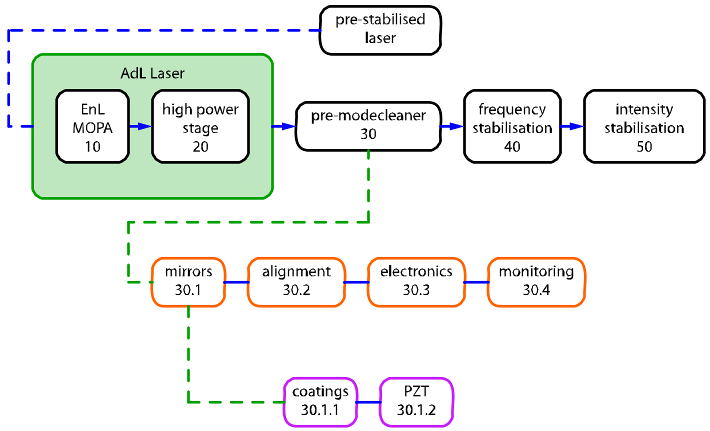

Figure 21. The reliability block diagram for the mirror coatings used in the pre-modecleaner.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects: Local Effects	Failure Effects: Next Higher Level	Failure Effects: End Effects	Failure Detection Method	Compensating Provisions	Severity	Remarks
30.1.1	coatings	The dielectric coatings give the mirrors the desired optical characteristics of transmission and reflection.	The coatings no longer impart the desired optical properties. This is caused by contamination of the mirror surfaces or damage caused by too high an incident laser power.	The mirror coatings are operational at all times.	Reduced power transmitted through the pre-modecleaner.	Reduced laser power is delivered to the Input Optics subsystem. In addition the beam parameters may be slightly different.	Degraded performance of the AdL interferometer due to a reduction in the laser power.	A gradual decrease in the transmission of the pre-modecleaner is observed without a corresponding reduction in the laser output power. Furthermore a scan of the pre-modecleaner cavity may reveal a larger number of non-TEM_{00} modes.	None. Should degradation of the mirror coatings occur, the whole pre-modecleaner would be replaced.	III. Marginal	The pre-modecleaner is housed inside a sealed chamber.
30.1.2	PZT	The PZT translates the curved mirror of the pre-modecleaner to adjust the resonant frequency of the pre-modecleaner cavity to match that of the incident laser light.	The PZT no longer contracts or expands. This is caused by mechanical damage to the PZT elements caused by an over voltage condition. Another reason is that the electrical connections to the PZT have been compromised.	The PZT is operational at all times when the pre-modecleaner is locked to the laser.	The pre-modecleaner resonant cavity length no longer adjusts to satisfy the resonance condition for the incident light.	No output to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The pre-modecleaner fails to lock reliably for long periods of time. Transfer function measurements of the servo loop show a discontinuity or peaks in the magnitude and phase response.	None. Should the PZT fail, the whole pre-modecleaner would be replaced.	IV. Minor	

5.1.1.2 Alignment

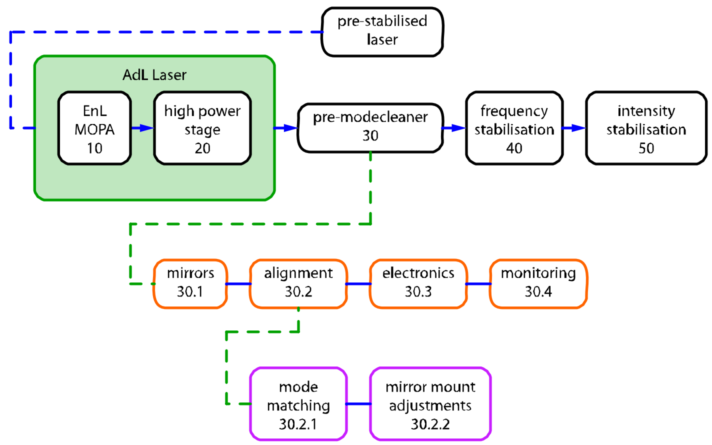

Figure 22. The reliability block diagram for the alignment and mode matching to the pre-modecleaner.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.2.1	mode matching	Mode matching couples the incident laser mode to the resonant cavity mode of the pre-modecleaner.	The mode matching lenses are not positioned properly. This is caused by incorrect adjustment or improper selection of lenses.	The mode matching is required at all times. Adjustments to the mode matching is typically done during the installation and commissioning phase of the PSL.	The mismatched light to the pre-modecleaner falls incident on the RF photodetector used to lock the pre-modecleaner. This could possible damage the RF photodetector or introduce an electronics offset in the system.	Reduced laser power to the frequency and intensity stabilisation beam paths.	Reduced laser power to the Input Optics subsystem.	This is an undetectable failure. Normally the mode matching is checked and optimised at installation.	None. Spare lenses and mirrors are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.2.2	mirror mount adjustments	The mirror mount adjustments align the output of the AdL Laser into the pre-modecleaner.	The beam is not properly aligned. This could be caused by mechanical drift of the mirror mount adjustment screws, or by inadvertent adjustment.	Adjustments to the mirror mounts are typically done during the installation phase of the PSL.	The coupling efficiency to, and hence throughput of, the pre-modecleaner, is reduced.	Reduced laser power to the frequency and intensity stabilisation beam paths.	Reduced laser power to the Input Optics subsystem.	A gradual decrease in the power transmitted through the pre-modecleaner without a corresponding drop in laser power.	None. Spare mirror mounts are on hand.	IV. Minor	

5.1.1.3 Electronics

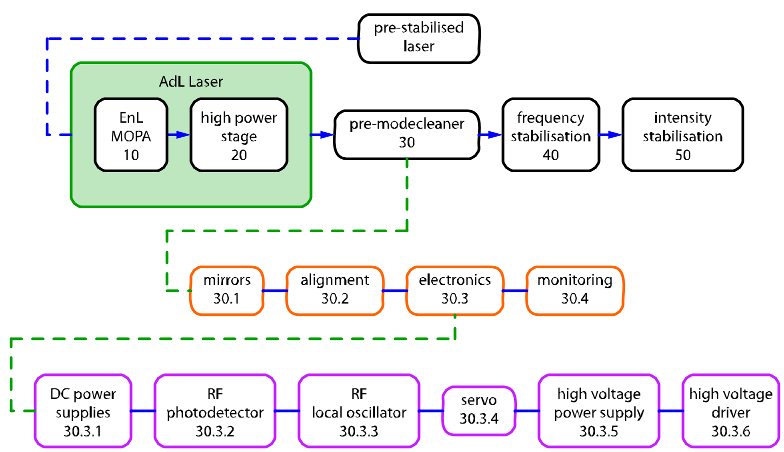

Figure 23. The reliability block diagram for the pre-modecleaner electronics.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.3.1	DC power supplies	The DC power supplies are used to supply power to the electronics components.	No output due to wear and tear.	The DC power supplies are required at all times.	Operation of the pre-modecleaner servo electronics is not possible. The pre-modecleaner cannot lock.	No light delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	All signals associated with the pre-modecleaner, not just the ones for the servo electronics, do not resolve on an MEDM screen.	None. Spare power supplies are on hand.	IV. Minor	
30.3.2	RF photodetector	The RF photodetector detects the light reflected from the pre-modecleaner.	No DC or AC output when light is incident on the photodetector.	The RF photodetector is required at all times in order to be able to lock the pre-modecleaner.	Locking of the pre-modecleaner is not possible.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The pre-modecleaner is not able to lock for no apparent reason.	None. Spare RF photodetectors are on hand.	IV. Minor	
30.3.3	RF local oscillator	The RF local oscillator is the frequency source used in reflection locking of the pre-modecleaner to the incident laser light.	No output at the reference frequency due to the RF amplifier no longer working.	The local oscillator is required at all times.	Locking of the pre-modecleaner is not possible.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The pre-modecleaner is not able to lock for no apparent reason.	None. Spare RF oscillators are on hand.	IV. Minor	
30.3.4	servo	The servo provides the control signal to the pre-modecleaner PZT to keep the pre-modecleaner locked to the incident light.	No, or degraded, output due to wear and tear.	The servo electronics is required at all times when operation of the pre-modecleaner is required.	Locking of the pre-modecleaner is not possible.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	The pre-modecleaner is not able to lock. Signals related to the pre-modecleaner displayed on the MEDM screen do not resolve.	None. Spare pre-modecleaner servos are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.3.5	high voltage driver	The high voltage driver generates the high voltage necessary to translate the PZT in response to a control signal generated by the servo.	No output due to wear and tear of the power op amp.	The high voltage driver is required at all times to control the length of the pre-modecleaner cavity.	Using the PZT to adjust the length of the pre-modecleaner is not possible.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	Adjusting the output of the high voltage driver to change the length of the pre-modecleaner cavity does not reveal any resonant modes on a monitoring CCD camera.	None. Spare high voltage drivers are on hand, if they separate from the pre-modecleaner servo.	IV. Minor	
30.3.6	high voltage power supply	The high voltage power supplies provide the voltage necessary to operate the high voltage driver.	No output due to wear and tear.	The high voltage power supply is required at all times to power the high voltage driver.	Locking of the pre-modecleaner is not possible.	No light is delivered to the Input Optics subsystem.	Operation of the AdL interferometer is not possible.	Adjusting the output of the high voltage driver to change the length of the pre-modecleaner cavity does not reveal any resonant modes on a monitoring CCD camera.	None. Spare high voltage power supplies are on hand.	IV. Minor	This fault can only be separated from a failure of the high voltage driver during a bench test of the electronics.

5.1.1.4 Monitoring

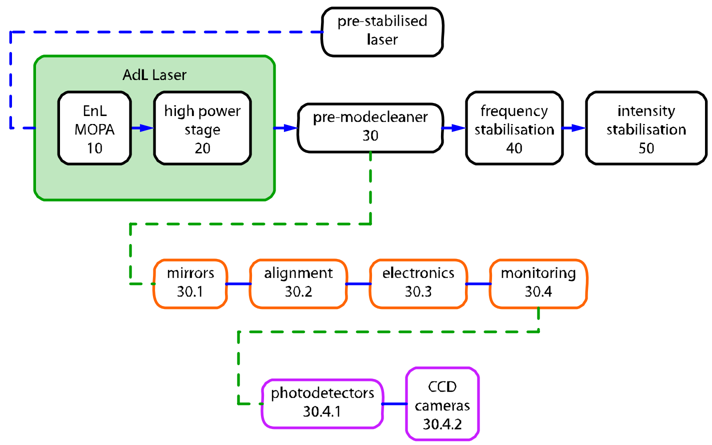

Figure 24. The reliability block diagram for the pre-modecleaner monitoring.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.4.1	photodetectors	The photodetectors monitor the transmission of the pre-modecleaner.	Failure due to wear and tear, or damage to the photodiode surface.	The photodetectors are in operation at all times.	Loss of the transmission signal.	No data is passed to the data acquisition system.	Loss of data.	No output is observed from then transmission photodetector when the pre-modecleaner is locked. This is indicated on an MEDM screen.	Spare photodetectors are on hand.	IV. Minor	Typically the reflected light is monitored by the DC output of the RF photodetector.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
30.4.2	CCD cameras	The CCD cameras monitor the mode transmitted, or reflected, by the pre-modecleaner and generate a signal capable of being displayed on a video monitor.	No output due to wear and tear.	The CCD cameras are in operation whenever the pre-modecleaner is locked.	Convenient monitoring of the pre-modecleaner status is lost.	None.	None.	An inconsistency appears between the pre-modecleaner transmission signal and the transmission mode displayed on a video monitor.	Spare cameras are on hand.	IV. Minor	

6 Frequency Stabilisation

The frequency stabilisation controls the output frequency of the AdL Laser.

6.1 Assembly Level Failures

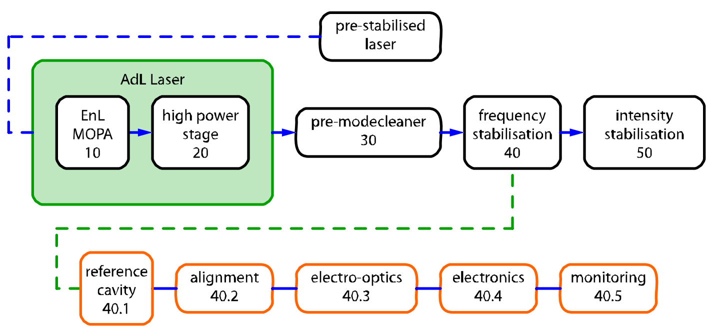

Figure 25. The reliability block diagram for the frequency stabilisation.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.1	reference cavity	The reference cavity is a fixed spacer Fabry-Perot cavity whose length is used as a frequency reference. The laser frequency is constantly adjusted so that it matches the resonant frequency of the reference cavity.	Degraded throughput due to contamination of the optical surfaces.	The reference cavity is in use at all times when the AdL Laser is frequency stabilised.	The optical gain of the frequency stabilisation loop is reduced.	Possibly none.	Possibly none.	A gradual decrease in the transmission of the reference cavity is observed without a corresponding decrease in the laser output power. This would reveal itself in an examination of the trend data.	The reduction in optical gain may be compensated for by increasing the electronics gain in the frequency stabilisation loop. This may come at the expense of servo bandwidth however, which in turn may degrade the performance of the suspended modecleaner.	III. Marginal	
40.2	alignment	The alignment directs the mode matched beam to the reference cavity.	Misalignment due to mechanical creep of the mirror mount adjustments.	Alignment of the optics is required at all times.	The optical gain of the frequency stabilisation loop is reduced.	None.	None.	A gradual decrease in the transmission of the reference cavity is observed without a corresponding decrease in the laser output power.	The reduction in optical gain may be compensated for by increasing the electronics gain in the frequency stabilisation loop.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.3	electro-optics	The electro-optics consists of frequency shifting acousto-optic modulator and the phase modulator used to impart sidebands on the beam coupled into the reference cavity.	Degraded or no output due to wear and tear or contamination of the optical surfaces.	The electro-optics are required at all times for frequency stabilisation.	The optical gain of the frequency stabilisation loop is reduced.	None.	None.	A gradual decrease in the transmission of the reference cavity is observed without a corresponding decrease in the laser output power.	The reduction in optical gain may be compensated for by increasing the electronics gain in the frequency stabilisation loop.	IV. Minor	
40.4	electronics	The electronics is necessary to stabilise the frequency of the AdL Laser.	Degraded performance due to wear and tear.	The electronics is required at all times for frequency stabilisation.	Frequency stabilisation of the AdL Laser is not possible.	The suspended modecleaner will not lock for long periods of time.	Operation of the AdL interferometer is not possible.	Signals related to the frequency stabilisation do not resolve on the MEDM screens.	None. Spare electronics modules are on hand.	IV. Minor	
40.5	monitoring	The function of monitoring is to diagnose the performance of the frequency stabilisation.	Degraded output due to wear and tear.	Monitoring is used once the AdL Laser is locked to the reference cavity. It monitors the mode resonant in the reference cavity and its transmission.	Convenient monitoring of the mode resonating in the reference cavity is not possible.	None.	None.	If the transmission photodetector fails, then the video image provided by the monitoring CCD camera can be used and vice versa.	None. Spare CCD cameras and photodetectors are on hand.	IV. Minor	

6.1.1 Sub-assembly Level Failures

6.1.1.1 Reference Cavity

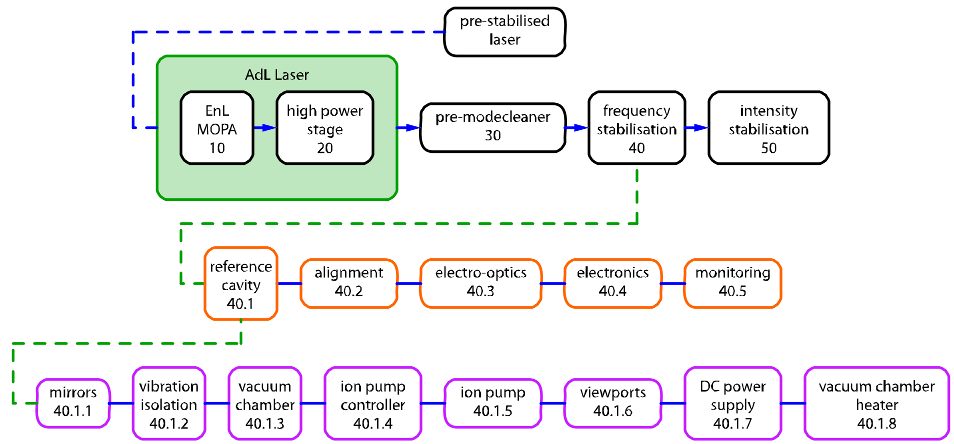

Figure 26. The reliability block diagram for the reference cavity.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects: Local Effects	Failure Effects: Next Higher Level	Failure Effects: End Effects	Failure Detection Method	Compensating Provisions	Severity	Remarks
40.1.1	mirrors	The mirrors form the Fabry-Perot cavity that is the reference cavity.	Degraded performance due to contamination of the optical surfaces.	The mirrors are required at all times.	The finesse and throughput of the reference cavity is reduced. This lowers the optical gain in the frequency stabilisation.	Possibly none.	Possibly none.	A gradual decrease in the transmission of the reference cavity when there is no corresponding decrease in laser power. This would only be detected by examination of trend data.	The reduction in optical gain may be compensated for by increasing the electronics gain. The servo gain for the frequency stabilisation is adjustable.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.1.2	vibration isolation	The vibration isolation reduces vibrations from ground motion coupling to the reference cavity.	After the correct installation of the vibration isolation stack, there are no known failures for this item.	The vibration isolation is required at all times.	Ground motions couple into increased motions of the reference cavity. These may result in an increase in the frequency noise.	Possibly degraded performance of the suspended modecleaner.	Possibly degraded performance of the AdL interferometer.	This failure is not detectable other than by visual inspection.	None. No major spare parts are provided for. The vibration isolation stack would have to be reassembled.	IV. Minor	There have been no known failures for the vibration isolation, even in the presence of large ground motions (ie an earthquake).
40.1.3	vacuum chamber	The vacuum chamber houses the reference cavity and vibration isolation stack.	Degraded vacuum integrity due to a damaged copper gasket.	The vacuum chamber is required at all times.	The reference cavity mirror surfaces may be contaminated if the vacuum integrity is compromised.	Possibly none depending on the contamination of the reference cavity. In a severe case frequency stabilisation would not be possible until the reference cavity and vacuum chamber are replaced.		The ion pump current would increase, indicating that the pressure inside the vacuum chamber is increasing. Currently there are no provisions for remote monitoring of the ion pump controller, which displays the ion pump current.	None. Leak checking of the vacuum chamber and appropriate fixes prior to installation. Apart from atmospheric pressure and applied heat, the vacuum chamber is not under any stress.	III. Marginal	
40.1.4	ion pump controller	The ion pump control provides the high voltage to power the ion pump.	Degraded performance due to wear and tear.	The ion pump controller is required at all times when the ion pump is evacuating the chamber.	The ion pump will not evacuate the vacuum chamber when required.	Possibly none.	Possibly none.	The front panel LED display is off, or displays an error condition.	None. Spare ion pump controllers are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.1.5	ion pump	The ion pump evacuates the vacuum chamber.	Degraded performance due to wear and tear.	The ion pump is required for reaching the ultimate base pressure of the vacuum chamber.	The vacuum chamber base pressure increases.	Possibly none.	Possibly none.	Provided the ion pump controller still works, the ion pump current indicates if the ion pump still functions properly.	None. Spare ion pumps are on hand.	IV. Minor	
40.1.6	viewports	The viewports allow the a beam to be coupled into the reference cavity.	Breakage due to impact of mechanical tools.	The viewports are required at all times.	Most likely damage to the reference cavity, or contamination of its mirrors. Frequency stabilisation of the laser will not be possible.	The suspended modecleaner will not be able to lock.	Operation of the AdL interferometer is not possible.	Visual inspection.	None. Spare viewports are on hand. See the remarks for further explanation.	III. Marginal	The viewports are covered by a thermal jacket except for a small area where the beam goes through. It is not desirable to have an additional protective window. The viewports used on the vacuum chamber were purchased from Nor-Cal and are of the "Larsen" design.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.1.7	DC power supply	The DC power supply provides the current and voltage to power the vacuum chamber heaters.	Degraded output due to wear and tear.	The DC power supply is required at all times when the vacuum chamber is temperature stabilised.	The temperature of the vacuum chamber decreases to room temperature.	None.	Possibly none. See the remarks for further explanation.	The control signal for regulating the temperature of the vacuum chamber is displayed on an MEDM screen. This would trigger a visible alarm on the screen if it fell below a preset value.	None. Spare power supplies are on hand.	IV. Minor	There is no formal requirement for the tidal actuator, since compensation for the Earth tides is done by the SEI subsystem with HEPI.
40.1.8	vacuum chamber heater	The vacuum chamber heaters heat the temperature stabilised vacuum chamber.	Degraded output due to wear and tear.	The heaters are required at all times for temperature stabilisation of the vacuum chamber. Normally the vacuum chamber temperature is held well above room temperature.	The temperature of the vacuum chamber is no longer stabilised. Inputs to the tidal servo are no longer valid.	None.	Possibly none. See the remarks for further information.		None. Spare heaters are on hand.	III. Marginal	There is no formal requirement for the tidal actuator, since compensation for the Earth tides is done by the SEI subsystem with HEPI.

6.1.1.2 Alignment

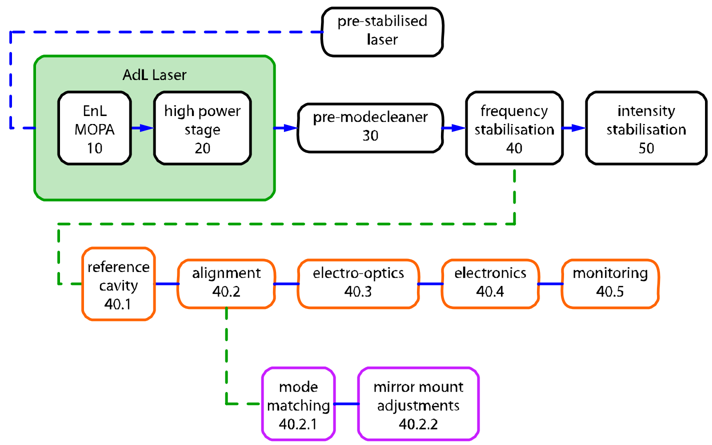

Figure 27. The reliability block diagram for the alignment to the reference cavity.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.2.1	mode matching	The mode matching couples the incident beam into the reference cavity.	The mode matching performance may not be optimal due to incorrect positioning of the lenses used or because of damage to the optical surfaces.	The mode matching optics are constantly in use.	Degraded performance of the frequency stabilisation.	Most likely none.	Most likely none.	This can be checked by measuring the visibility of the reference cavity. Or by inspection of the reflected modes with a CCD camera.	None.	IV. Minor	Tweaks of the mode matching and beam path alignment could be done during routine maintenance intervals.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.2.2	mirror mount adjustments	The mirror mount adjustments steer the beam into the reference cavity.	The position of the optics steering the beam towards the reference cavity changes over time due to mechanical creep.	The mirror mount adjustments are constantly in use.	Degraded performance of the frequency stabilisation.	Most likely none.	Most likely none.	A gradual decrease in the power transmitted through the reference cavity without a corresponding drop in laser power.	None.	IV. Minor	

6.1.1.3 Electro-optics

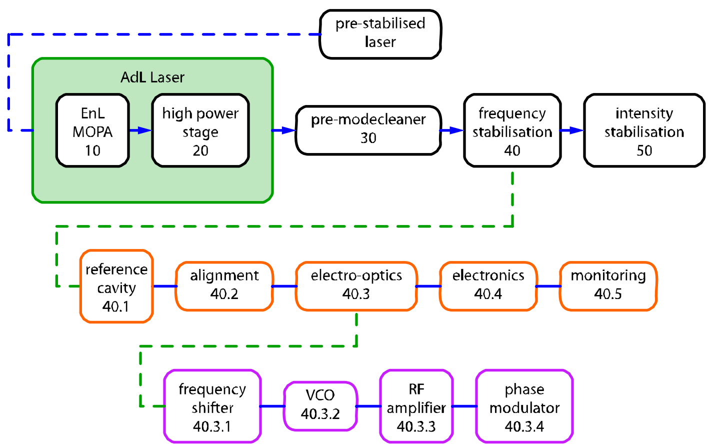

Figure 28. The reliability block diagram for the electro-optics in the optical path to the reference cavity.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.3.1	frequency shifter	The frequency shifter shifts the frequency of the light incident on the reference cavity.	The frequency shifter no longer diffracts light because the sonic transducer has been damaged.	The frequency shifter is operational at all times.	The performance of the frequency stabilisation is erratic.	The suspended modecleaner performance is degraded both in terms of duration and robustness.	Performance of the AdL interferometer is degraded.	The suspended modecleaner randomly loses lock for no apparent reason.	None. Spare frequency shifters are on hand.	IV. Minor	
40.3.2	VCO	The VCO generates a signal to drive the frequency shifter, that is related to the difference in resonance frequency between the reference cavity and the suspended modecleaner.	The VCO no longer accepts input from the modecleaner servo due to a failure in its tuning input.	The VCO is operational at all times.	None.	The suspended modecleaner will not lock.	No operation of the AdL interferometer is possible.	The suspended modecleaner does not lock. The VCO output monitor status changes and is indicated on the MEDM screen.	None. Spare VCO units are on hand.	III. Marginal	
40.3.3	RF amplifier	The RF amplifier amplifies the output of the VCO.	Degraded, or no, output due to wear and tear.	The RF amplifier is operational at all times.	The power transmitted through the reference cavity decreases even though the laser power has not decreased.	Performance of the suspended modecleaner may be degraded.	Performance of the AdL interferometer may be degraded.	The light transmitted by the reference cavity dims. The output of the VCO monitor decreases, which triggers a visible alarm on an MEDM screen.	This may be compensated for by increasing the electronics gains of the frequency stabilisation servo. Spare VCO units are on hand.	III. Marginal	Replacing the VCO also replaces the RF amplifier at the same time.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.3.4	phase modulator	The phase modulator imparts sidebands on the incident light in the presence of an RF excitation signal.	Degraded output due to contamination of the optical surfaces, or damage to the electrodes.	The phase modulator is operational at all times.	Performance of the frequency stabilisation is degraded.	Performance of the suspended modecleaner is degraded.	Performance of the AdL interferometer is degraded.		None. Spare phase modulators are on hand.	IV. Minor	

6.1.1.4 Electronics

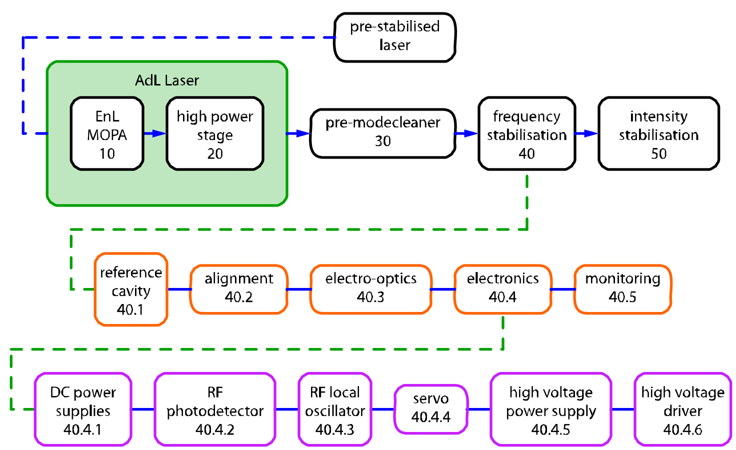

Figure 29. The reliability block diagram for the frequency stabilisation electronics.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.4.1	DC power supplies	The DC power supplies provide electrical power for the electronics.	No output, or degraded output due to wear and tear.	The DC power supplies are operational at all times.	Operation of the frequency stabilisation is not possible.	The suspended modecleaner cannot lock.	Operation of the AdL interferometer is not possible.	None of the signals from the frequency stabilisation electronics are updated. Requests for gain changes, activating or deactivatings buttons do not work. These are indicated on the MEDM screens.	None. Spare power supplies are on hand.	IV. Minor	
40.4.2	RF photodetector	The RF photodetector detects the light reflected from the reference cavity.	No output, or degraded output due to damage to the photodiode surface.	The RF photodetector is operational at all times the frequency stabilisation is required.	Operation of the frequency stabilisation is not possible.	The suspended modecleaner cannot lock.	Operation of the AdL interferometer is not possible.	The frequency stabilisation servo will not lock, even with low gain. The reflected light DC level will change as, presumably, the bias voltage across the photodiode is no longer present.	None. Spare RF photodetectors are on hand.	IV. Minor	
40.4.3	RF local oscillator	The RF local oscillator is the signal source for providing the phase modulation.	No output due to a failure of the internal RF amplifier.	The RF local oscillator is required at all times for frequency stabilisation.			Degraded performance of the AdL interferometer.			IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.4.4	servo	The servo provides the feedback to the AdL Laser's frequency actuators to control the output frequency of the laser.	No output due to wear and tear.	The servo is required at all times for frequency stabilisation.	Frequency stabilisation is not possible.	Locking of the suspended modecleaner is not possible.	Operation of the AdL interferometer is not possible as the suspended modecleaner cannot operate reliably.	Signals related to the frequency stabilisation are no longer updated by EPICS. This is reflected in the MEDM screens.	None. Spare servo modules are on hand.	IV. Minor	
40.4.5	high voltage power supply	The high voltage power supply provides the high voltage for the high voltage driver.	No, or degraded output due to wear and tear.	The high voltage power supply is required at all times to power the high voltage driver.	The high voltage driver cannot swing its full dynamic range.	The modecleaner may lose lock in the presence of large frequency transients fed back to the PSL.	Degraded performance of the AdL interferometer.	The dynamic range of the PZT has decreased.	None. Spare power supplies are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.4.6	high voltage driver	The high voltage driver drives the master oscillator PZT.	No output due to wear and tear. Degraded output due to incorrect loading.	The high voltage driver is required at all times for the frequency stabilisation. It drives the fast actuator of the AdL Laser.	There is a decrease in the closed loop bandwidth of the frequency stabilisation electronics.	Increased noise sensed by the suspended modecleaner. The modecleaner may not be able to lock in the presence of a large loop oscillation.	Degraded performance of the AdL interferometer.	The dynamic range of the PZT has decreased. This would be indistinguishable from a failure of the high voltage power supply, except that the power supply can be tested separately. The driver may be tested by inducing a loop oscillation. This would cause the high voltage driver output to go rail to rail and would be indicated on the MEDM screen.	None. Spare servo electronics are on hand.	IV. Minor	

6.1.1.5 Monitoring

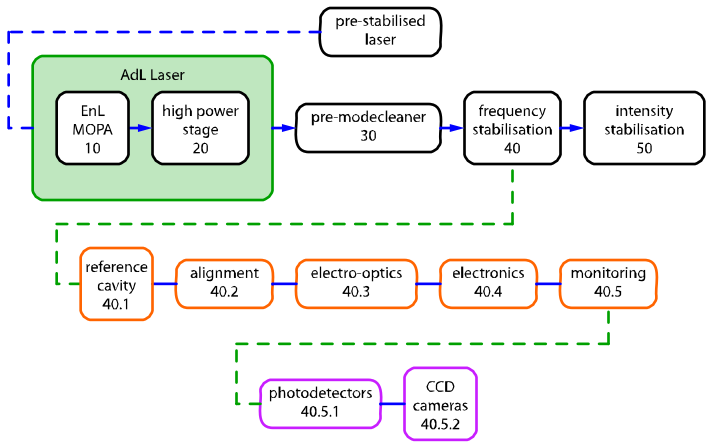

Figure 30. The reliability block diagram for the monitoring of the frequency stabilisation.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.5.1	photodetectors	The photodetectors monitor the transmission of the reference cavity.	No output due to wear and tear.	The transmission photodetector is operational whenever the AdL Laser is locked to the reference cavity.	None. Trend data monitoring the long term performance of the frequency stabilisation may be lost.	None.	None. Trend data monitoring the long term performance of the frequency stabilisation may be lost.	The transmission signal drops to zero, contrary to the visual signal from the CCD camera showing that light is transmitted by the reference cavity.	None. Spare photodetectors are on hand.	III. Marginal	This is rated marginal because of the possible loss of data.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
40.5.2	CCD cameras	The CCD cameras monitor the transmitted mode of the reference cavity.	No output due to wear and tear.	The CCD cameras monitor the reflected and transmitted beam from the reference cavity.	None. Just inconvenience.	None.	None.	The CCD camera image contradicts the transmission signal of the photodetector.	None. Spare photodetectors are on hand.	IV. Minor	With the exception of a power failure, there has been no known simultaneous failure of the photodetector and CCD camera.

7 Intensity Stabilisation

The intensity stabilisation reduces the free-running intensity noise of the AdL Laser to the the AdL requirement.

7.1 Assembly Level Failures

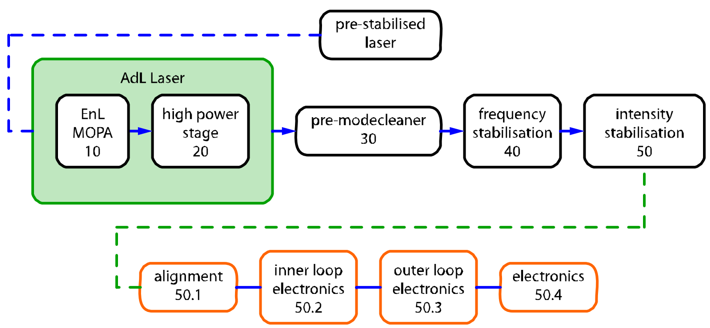

Figure 31. The intensity stabilisation reliability block diagram.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.1	alignment	The alignment serves to direct the laser light onto the photodetectors.	The alignment changes due to drift of the mechanical components.	Alignment to the photodetectors is required whenever the intensity stabilisation is operational.	In the worst case, there is no signal on the intensity stabilisation photodetectors. The performance of the intensity stabilisation may be degraded otherwise.	No intensity stabilisation.	In the absence of intensity stabilisation, the suspended modecleaner performance is compromised because of increased radiation pressure on the cavity mirrors. The performance of the AdL interferometer is degraded.	This failure is undetectable except in the worst case where the beam no longer hits the photodetector. Small misalignments do not sufficiently degrade the signal enough to be picked up by the usual monitoring methods. However a change can be indicated by the output of a quadrant photodetector, the output of which is displayed on an MEDM screen.	None.	IV. Minor	This should be checked during routine maintenance periods.
50.2	inner loop electronics	The inner loop electronics consists of the photodetectors and beam pointing control electronics to maintain the beam on the photodetector. These items are placed before the suspended modecleaner.	Failure due to wear and tear.	The inner loop electronics is required for intensity stabilisation before the suspended modecleaner. It is operational whenever intensity stabilisation is required.	The intensity noise cannot be reduced before being coupled into the suspended modecleaner.	The suspended modecleaner will see an increased level of intensity noise.	The performance of the AdL interferometer is degraded.	The intensity noise performance of the PSL does not change when the inner loop electronics is disengaged. The output of the intensity stabilisation photodetectors is monitored on an MEDM screen.	None. Spare electronics are on hand.	IV. Minor	The intensity noise may be improved by using the outer loop. This needs to be tested and confirmed.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.3	outer loop electronics	The outer loop electronics consists of the photodetectors and beam pointing control electronics to maintain the beam on the photodetector. These items are placed after the suspended modecleaner.	Failure due to wear and tear.	The outer loop electronics is required whenever intensity stabilisation after the suspended modecleaner is required.	The intensity noise cannot be reduced before being coupled into the AdL interferometer.	There is increased radiation pressure on the beamsplitter.	The performance of the AdL interferometer is degraded.	The intensity noise performance of the PSL does not change when the outer loop electronics is disengaged. The output of the intensity stabilisation photodetectors is monitored on an MEDM screen.	None. Spare electronics are on hand.	IV. Minor	
50.4	electronics	The electronics takes the signal from the photodetectors and applies a correction signal to the power actuators of the AdL Laser. The correction signal is split between the AOM and the pump laser diode current in the high power stage.	Failure due to wear and tear.	The electronics is operational whenever intensity stabilisation is required.	No intensity stabilisation is possible.	The suspended modecleaner will experience an increase in intensity noise. Its performance will be degraded	The performance of the AdL interferometer will be degraded.	The intensity noise does not change in response to requested gain changes in the electronics. Various monitoring signals no longer responds to EPICS updates. These are indicated on MEDM screens.	None. Spare electronics modules are on hand.	IV. Minor	

7.1.1 Sub-Assembly Level Failures

7.1.1.1 Alignment

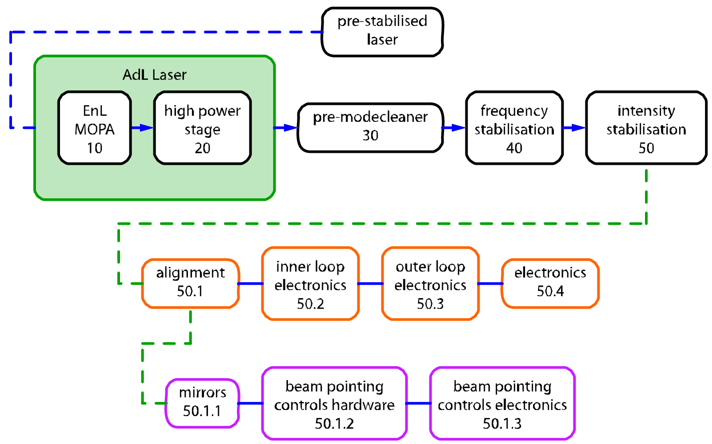

Figure 32. The reliability block diagram for the intensity stabilisation alignment.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.1.1	mirrors	The mirrors reflect the beam onto the photodetector used.	The mirror reflectivity degrades as the optical surface becomes contaminated with particulate matter.	The mirrors are required at all times to reflect the sample beam onto the photodetectors used for intensity stabilisation.	The intensity stabilisation may not reach the design requirement due to beam pointing fluctuations introduced by the damaged optical surface.	The suspended modecleaner may see an increase in the intensity noise level.	Possibly degraded performance of the AdL interferometer.	This is an undetectable failure. Checks of the mirror surfaces during maintenance periods would spot this failure.	The optical surface can be drag wiped clean. Alternatively a spare optic can be used.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.1.2	beam pointing controls hardware	The beam pointing controls hardware accepts input from the beam pointing controls electronics to position the beam onto the photodetector.	Degraded or intermittent output due to wear and tear. This can also be caused by mechanical shock to the mounting components.	The beam pointing controls hardware is required for fine adjustment of the beam position on the intensity stabilisation photodetector.	The intensity stabilisation may not reach the design requirement because the beam may not hit the intensity stabilisation photodetector at its sweet spot.	The suspended modecleaner may see an increase in the intensity noise level.	Possibly degraded performance of the AdL interferometer.	This is an undetectable failure except in the extreme case where the beam no longer hits the intensity stabilisation photodetector.	None. Spare hardware is on hand.	IV. Minor	
50.1.3	beam pointing controls electronics	The beam pointing controls electronics adjusts the position of the beam onto the photodetector given input from a position sensor, such as a quadrant photodetector.	No output due to wear and tear.	The beam pointing controls electronics is required for fine control of the beam position on the intensity stabilisation photodetector.	The intensity stabilisation may not reach the design requirement because the beam may not hit the intensity stabilisation photodetector at its sweet spot.	The suspended modecleaner may see an increase in the intensity noise level.	Possibly degraded performance of the AdL interferometer.		None. Spare electronics is on hand.	IV. Minor	

7.1.1.2 Inner Loop Electronics

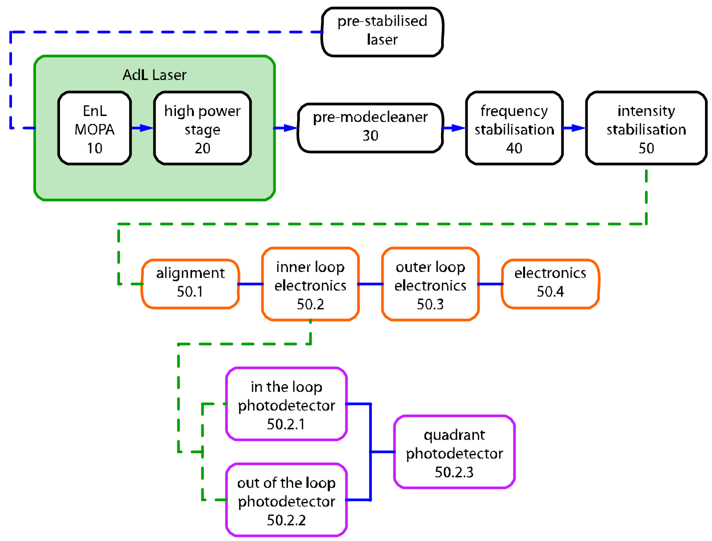

Figure 33. The reliability block diagram for the inner loop electronics.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.2.1	in the loop photodetector	The in the loop photodetector is used as the sensing photodetector.	Degraded output due to damage to the photodiode surface caused by too much light being incident on the photodetector.	The in the loop photodetector is required for the intensity stabilisation. It is the sensor used in the feedback control.	None if the out of the loop photodetector can be used as a substitute.	The suspended modecleaner will see increased intensity noise.	Performance of the AdL interferometer is degraded.	The output of the in the loop photodetector drops to zero. This raises an alarm on the MEDM screen.	The out of the loop photodetector can be used as a replacement. Otherwise spare photodetectors are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.2.2	out of the loop photodetector	The out of the loop photodetector is used as an independent sensor to verify the performance of the intensity stabilisation.	Degraded output due to damage to the photodiode surface caused by too much light being incident on the photodetector.	The out of loop photodetector is required for independent verification of the performance of the intensity stabilisation electronics.	No independent verification of the intensity noise level is possible as intended.	The suspended modecleaner will see increased intensity noise.	Performance of the AdL interferometer is degraded.	The output of the out of the loop photodetector drops to zero. This raises an alarm on the MEDM screen.	None. Spare photodetectors are on hand.	IV. Minor	
50.2.3	quadrant photodetector	The quadrant photodetector gives positional information of the beam, so that the beam may be directed towards the in and out of the loop photodetectors.	Degraded output due to damage to the photodiode surface caused by too much light being incident on the photodetector.	The quadrant photodetector is required for knowing the beam pointing on the photodetectors used in the intensity stabilisation. They are operational at all times when intensity stabilisation is required.	No beam pointing information can be gathered. The position of the beam on the in the loop and out of the loop photodetectors may not be optimal.	The suspended modecleaner may see increased intensity noise.	Performance of the AdL interferometer may be degraded if the quadrant photodetectors fail when the beam is not on the intensity stabilisation photodetector's sweet spot.	Beam pointing information is no longer available. This is not updated on the MEDM screen.	None. Spare quadrant photodetectors are on hand.	III. Marginal	

7.1.1.3 Outer Loop Electronics

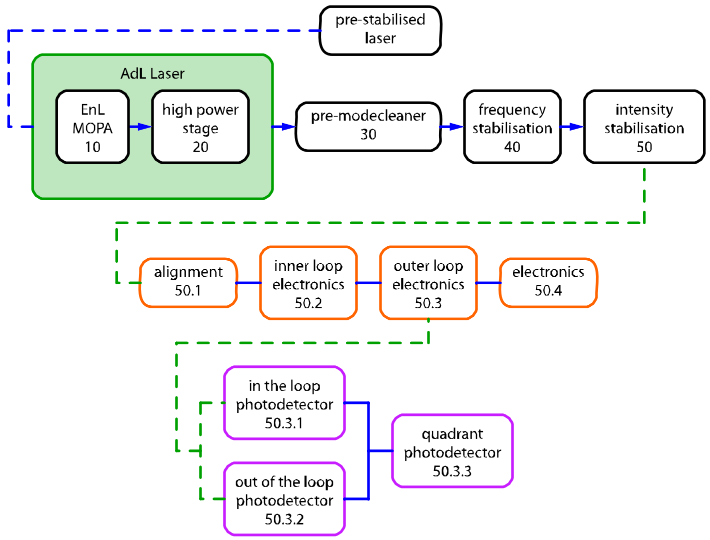

Figure 34. The reliability block diagram for the outer loop electronics.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.3.1	in the loop photodetector	The in the loop photodetector is used as the sensing photodetector.	Degraded output due to damage to the photodiode surface caused by too much light being incident on the photodetector.	The in the loop photodetector is required for the intensity stabilisation. It is the sensor used in the feedback control.	None if the out of the loop photodetector can be used as a substitute.	The suspended modecleaner will see increased intensity noise.	Performance of the AdL interferometer is degraded.	The output of the in the loop photodetector drops to zero. This raises an alarm on the MEDM screen.	The out of the loop photodetector can be used as a replacement. Otherwise spare photodetectors are on hand.	III. Marginal	The major difference between the outer loop electronics and the inner loop electronics is that the photodetectors are inside the vacuum vessel.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.3.2	out of the loop photodetector	The out of the loop photodetector is used as an independent sensor to verify the performance of the intensity stabilisation.	Degraded output due to damage to the photodiode surface caused by too much light being incident on the photodetector.	The out of loop photodetector is required for independent verification of the performance of the intensity stabilisation electronics.	No independent verification of the intensity noise level is possible as intended.	The suspended modecleaner will see increased intensity noise.	Performance of the AdL interferometer is degraded.	The output of the out of the loop photodetector drops to zero. This raises an alarm on the MEDM screen.	None. Spare photodetectors are on hand.	III. Marginal	
50.3.3	quadrant photodetector	The quadrant photodetector gives positional information of the beam, so that the beam may be directed towards the in and out of the loop photodetectors.	Degraded output due to damage to the photodiode surface caused by too much light being incident on the photodetector.	The quadrant photodetector is required for knowing the beam pointing on the photodetectors used in the intensity stabilisation. They are operational at all times when intensity stabilisation is required.	No beam pointing information can be gathered. The position of the beam on the in the loop and out of the loop photodetectors may not be optimal.	The suspended modecleaner may see increased intensity noise.	Performance of the AdL interferometer may be degraded if the quadrant photodetectors fail when the beam is not on the intensity stabilisation photodetector's sweet spot.	Beam pointing information is no longer available. This is not updated on the MEDM screen.	None. Spare quadrant photodetectors are on hand.	III. Marginal	

7.1.1.4 Electronics

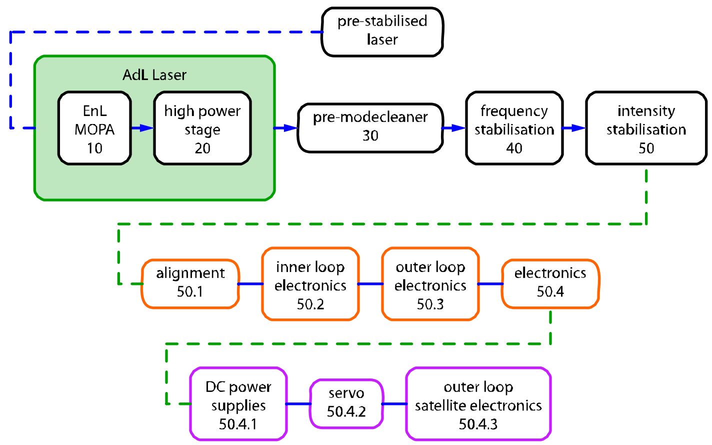

Figure 35. The reliability block diagram for the intensity stabilisation electronics.

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.4.1	DC power supplies	The DC power supplies provide power to the servo electronics and photodetectors.	No output due to wear and tear.	The DC power supplies are required whenever operation of the intensity stabilisation electronics is required.	No intensity stabilisation is possible.	The suspended modecleaner will experience increased intensity noise.	Degraded performance of the AdL interferometer.	None of the intensity stabilisation controls would respond to commands. The signals from the photodetectors would drop to zero, trigger an alarm on the MEDM screens.	None. Spare power supplies are on hand.	IV. Minor	

ID No.	Item/Functional Identification	Function	Failure Modes and Causes	Mission Phase/Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity	Remarks
					Local Effects	Next Higher Level	End Effects				
50.4.2	servo	The intensity stabilisation servo actuates on the AOM located in the EnL MOPA and the pump laser diode current of the high power stage, to reduce the intensity fluctuations from the AdL Laser.	No output due to wear and tear. Degraded output due to component failure.	The intensity stabilisation servo is operational whenever intensity stabilisation is required.	No intensity stabilisation is possible.	The suspended modecleaner will experience increased intensity noise.	Degraded performance of the AdL interferometer.	The signals monitored by the intensity stabilisation servo would no longer be updated by EPICS. All the intensity stabilisation related channels would not resolve on the MEDM screens.	None. Spare electronics are on hand.	IV. Minor	
50.4.3	outer loop satellite electronics	The outer loop satellite electronics performs any signal conditioning required from the outer loop photodetector. The output of the outer loop satellite electronics is then input to the intensity stabilisation servo.	Degraded output due to component failure.	The outer loop satellite electronics is required if intensity stabilistion after the suspended modecleaner is required.	No intensity stabilisation after the suspended modecleaner is possible.	The suspended modecleaner will experience increased intensity noise.	Degraded performance of the AdL interferometer.	The outer loop of the intensity stabilisation electronics does not respond. This triggers an alarm on the MEDM screens.	None. Spare electronics modules are on hand.	IV. Minor	