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New General detector Controller (NGC)

Reliability Analysis

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CHANGE RECORD

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1 Scope

The expected reliability of NGC is estimated in terms of mean downtime and MTBF.

Apart from characterizing NGC itself and qualifying it for usage at the VLT, it also provides input necessary for reliability analyses of VLT instruments.

2 Introduction

NGC replaces both FIERA (for optical detectors [RD2]) and IRACE (for infrared detectors [RD3]). The strategy of this analysis is, therefore and in the absence of sufficient statistics from the usage of NGC itself, to draw heavily on the experience gathered with the two predecessors. The downtime experienced with FIERA and IRACE is fully satisfactory (see Sect. 8) and acceptable also for NGC (see [RD5]).

Because of the volume of the available database, the small fractional downtime of order 0.1%, and the functional, operational, and design similarities of NGC and its predecessors, the alternative approach of bootstrapping the analysis from the level of individual risks and failure modes (as described in, e.g., [RD4]) cannot be any more accurate and is, therefore, not pursued as a method.

3 Reference Documents

The following Reference Documents (RD) contains useful information relevant to the subject of the present document.

RD Nr	Doc Nr	Doc Title	Issue	Date
RD1	VLT-ICD-ESO-13660-4009	Interface control document for the New General detector Controller (NGC)	0.1 (draft)	20.02.2007
RD2	http://www.eso.org/projects/odt/Fiera/	FIERA: ESO's CCD Controller		March, 2004
RD3	VLT-TRE-ESO-14100-1654	Infrared Array Controller Electronics (IRACE) – Design Description	2.0	31.08.1998
RD4	ECSS-Q-30B	Space product assurance – Dependability (European Cooperation for Space Standardization, ESA-ESTEC Requirements & Standard Division)		08.03.2002
RD5	VLT-TRE-ESO-13660-3207	Next Generation detector Controller (NGC) - Requirements	1.01	11.03.2004
RD6	VLT-PLA-ESO-00000-0006	Very Large Telescope Programme – Software Management Plan	2.0	21.05.1992
RD7	Proc. SPIE, Vol. 6271, p. 627110	D. Guzman: Modeling the cost		2006

		of detector controller support in a multi-instrumetn observatory		

4 Acronyms and abbreviations

AO	Adaptive Optics
AT	VLTI Auxiliary Telescope
BOSS	Base Observation-Software Stub
CCD	Charge-Coupled Device
CMM	Configuration Management Module
DFE	Detector Frontend Electronics
ESO	European Organisation for Astronomical Research in the Southern Hemisphere
FIERA	Fast Imager Readout Electronics Assembly
IR	InfraRed
IRACE	InfraRed Array Controller Electronics
IWS	Instrument WorkStation
I/F	InterFace
LLCU	Linux-based Local Control Unit
LRU	Line Replaceable Unit
LSP	La Silla Paranal Observatory
MAIT	Manufacture, Assembly, Integration, and Testing
MTBF	Mean Time Between Failure
NGC	New General detector Controller
NRI	Night Reporting Infrastructure
PC	Personal Computer
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
PPRS	Paranal Problem Reporting System
PSU	Power Supply Unit
QC	Quality Control
RD	Reference Document
RTC	Real-Time Computer
SDD	Software Development Division (ESO)
TAT	Tools for Automatic Testing
TCCD	Technical CCD
UT	VLT Unit Telescope
VLT	Very Large Telescope
VLTI	VLT Interferometric mode
WFS	WaveFront Sensor

5 Building blocks of NGC systems

Any NGC system consists of the following sub-systems (cf. [RD1]):

- PSU's are composed to match the specific needs of each NGC system (optical or IR detectors; single chip or large mosaic; etc.). All PSU's are assembled from the same set of standard commercial devices.
- Each DFE consists of at least one Basic Board plus its associated Transition Board. Up to 6 such boards can be installed per customized housing. For multi-channel IR detectors, a 32-channel Acquisition Board is available. The possible number of DFE boxes that can be combined for one detector system is, for all practical purposes, not limited.
- Most optical detector systems use a commercially available power cable with manually added connectors. Most IR power cables and all cables between detector head and DFE are custom made.
- For scientific detector systems at least one LLCU (a PC running Linux) is required for data acquisition and formatting. From the LLCU, the data are sent to the IWS. AO and VLTI applications may instead ask data to be transmitted to their RTC. In close consultation with SDD and LSP it was determined that rack-mountable versions of the same PCs are used that are also deployed for VLT telescope and instrument control. Custom-made PCI boards provide the I/F to one DFE each.
- All software is developed by ESO and fully embedded within the VLT Control Software.

6 NGC quality control

Careful QC is integral part of the NGC development and production. All procedures are defined in writing to ensure consistent results.

6.1 Electronics

All components are selected from proven suppliers and are used well below their respective maximum ratings. PCB layouts take into account the well-known capabilities of the industrial partners chosen for the production and population. Emphasis is put on low power consumption (only 10-20 Watts per board), low heat dissipation, and the avoidance of hot spots. Electromechanical parts (such as relays) were excluded from the design. The number of electromechanical connections was kept as low as possible, and all connectors were carefully preselected and tested for solder (or crimp) friendliness and operational reliability. All PCBs underwent at least 3 or 4 cycles of design, layout, production, and testing with iterative improvements. Where possible/necessary, critical subcircuits were simulated and tested separately.

After production, every NGC board is subjected to the following QC measures:

- The producer of the PCB's performs an electrical test for shorts, etc.
- Every incoming board is visually inspected and comprehensively tested on a test stand.
- A history file is kept for each board, which includes the results of all tests as well as an account of any modifications or repairs. A photograph is added. This database will help to identify both troubled single boards as well as generic problems of one or more revision levels and/or production batches.
- NGC systems for new detector systems are tested at the system level.

- During the MAIT phase, new NGC systems are used and effectively burnt-in for typically 2 to 12 months before their delivery to the Observatory.

In addition, all cables are fully automatically tested with a commercial cable tester.

6.2 DFE housing

The DFE housings are custom made. Six-slot houses are water cooled; the coolant system is leak-tested at 10 bars.

6.3 Software

NGC follows the VLT paradigm for software development, life cycle management, and testing as described in [RD6]. The following tests are part of the standard quality control:

- Regression tests (using TAT procedures written in parallel to the main coding) at the level of individual modules are automatically performed centrally for all VLT software every night (using NRI). Test and coverage reports are issued to the respective software developers for immediate feedback.
- Performance tests with a broader scope are executed by NGC system developers.
- Comprehensive integration tests are performed by SDD in the VLT Control Model before any new release of the VLT control software. Because the application of all VLT instruments and detector systems is cast into sets of fixed Observing Templates, these tests can test a very high percentage of the actions and sequences actually to be supported at the telescope.

In addition, instrument-specific features are used for 2-12 months in the lab when the electronics engineers configure and test the hardware.

All software and all configuration parameters used by it are archived and kept under configuration control by means of standard VLT procedures and CMM.

7 The FIERA and IRACE experience

NGC was designed to provide, as a minimum, the same functionality and performance as the combination of FIERA [RD2] and IRACE [RD3]. Special care was taken to learn from the (not very numerous or severe) imperfections and problems of these predecessor systems.

Because FIERA and IRACE differ conceptually and technically in a number of areas, NGC could not inherit equally much from both of them. In fact, both hardware and software are significantly closer to IRACE than to FIERA. The IRACE designers were also available for NGC, and the manufacturer of the PCBs and their populator are the same as used with IRACE.

7.1 PPRS database

With an effective closing date of 31-05-2008, all PPRS entries mentioning the scientific detectors as the apparent source of a problem were extracted and compiled (by Nicolas Haddad, Paranal Instrumentation Group) without applying any additional filter or correction. Their total number is 255 (135 of which do not mention loss of observing time) for FIERA and 168 (79 w/o reported loss of time) for IRACE. There is no reported case of FIERA or IRACE having inflicted any problem on other VLT subsystems.

The break-down by FIERA- and IRACE-based instruments, respectively, is given in the following 2 tables, which provide the cumulative downtimes (in minutes) of the scientific detector systems since the commissioning of their parent instruments:

FIERA:

Instrument	Downtime (minutes)	Fraction related to shutter (%)
FLAMES (Giraffe)	193	26
FORS1	462	8
FORS2	143	--
UVES	774	--
VIMOS	3782	50
Σ	5354	

(For information: The total downtime in the report period of the optical AO WFS of NACO was 385 minutes.)

Via the house-keeping unit Pulpo, FIERA sends open and close commands to the shutter. Owing to the setup of PPRS, this leads to shutter failures being attributed to the detector system although the shutter is not at all part of the detector system. The case of VIMOS illustrates the importance of this point: This single instrument alone has reported more than 50% of all problems attributed to scientific detector systems of the VLT. But its 4 shutters account for at least half of the VIMOS downtime. The (near-)absence of shutter problems from other optical detector systems shows that the VIMOS problems are due to the shutter itself rather than its commanding, which is the same for all shutters.

The average downtime is 45 minutes per event with reported loss of observing time (without inclusion of shutter problems, this number drops to 35 minutes). Nine boards were sent back to Garching for repair. Six of them were video boards; they are sensitive to overheating, which sometimes also occurs as an operational mishap.

IRACE:

Instrument	Downtime (minutes)
AMBER	87
CRIRES	--
FINITO	--
IRIS	80
ISAAC	241
NACO	555
SINFONI	--
VINCI	--
VISIR	411
Σ	1374

(In 2007 April, the Sparc-based LCU of VISIR, which could cope with the workload only with difficulty, was replaced with a more powerful PC running Linux. For the time thereafter, PPRS shows 5 entries, of which only one mentions 10 minutes of downtime. NGC, too, will use a Linux-based LCU.)

The average downtime per event with loss of observing time amounts to 11 minutes. Eight boards were returned to Garching for repair.

The probable reasons for this value being much lower than the one for FIERA include the property of CCDs that readout problems can only occur at the end of an observation while for IR detectors they may happen also at intermediate times. IR detector systems do not use shutters. Moreover, while IRACE does not handle the telemetry for cryogenic temperature and vacuum, FIERA does and so is held responsible for any associated failure.

The above leads to an (uncorrected) grand total of 6,728 minutes lost due to problems attributed to the scientific detector systems of the VLT.

Since all VLT instruments use either FIERA or IRACE with their scientific detector systems, this figure is simply to be compared to the number of nights available with all 4 UT's from their commissioning through 31-05-2008:

VLT UT	Assumed start of operation	Number of nights
Antu	01-10-1998	3530
Kuyen	01-10-1999	3170
Melipal	01-04-2000	2980
Yepun	01-01-2001	2700
Σ		12380

Taking these numbers at face value and assuming

- an average nominal availability of each UT (the main losses are due to weather [typically 10%], technical maintenance of the UTs, and instrument commissioning), of 80%
- an average length of an observing night of 500 minutes

the fractional downtime caused by the FIERA- and IRACE-based detector systems amounts to 0.14%.

The average MTBF for the combination of FIERA and IRACE (only considering actual instrument night time and problems with reported loss of time) is almost 21,600 minutes or 54 nights (of effectively 400 minutes each).

7.2 Maintenance

FIERA, IRACE, and (by implication) NGC do not require preventive maintenance of the hardware. In fact, preventive maintenance is not expected to lead to a measurable reduction of corrective maintenance.

For all 3 systems, the control software is distributed and installed as part of the biannual VLTSW releases.

As is generally true for real-time computer systems not running in infinite loops, LLCU's and IWS's should be regularly rebooted. LSP does this at daytime.

In summary, maintenance and related activities will not reduce the operational availability of NGC systems and so are of no relevance for the reliability analysis of NGC systems.

7.3 Discussion

The above numbers and assumptions are all solid and conservative. However, there are a number of biases in the PPRS database. The ones possibly resulting in too low a downtime include:

- The typical design lifetime of VLT instruments is 10 years but the average age of the instruments used in the input statistics is lower. If aging leads to increased failure rates, this is only partly accounted for by the present statistics. Some of the oldest FIERA and IRACE systems are deployed on La Silla. Their performance, too, does not give rise to the assumption that aging is a significant factor.
- Because of its operational flexibility and the technical ease of changing from one instrument to another one, some downtime will have been avoided by changing equipment quickly.
- In some cases, users will have forgotten to enter the downtime after the problem was resolved.

Biases possibly leading to a spurious increase of the downtime include:

- The classification of PPRS entries is made by the operator before the true cause is identified. After elimination of telescope and instrument, category *Detector* may sometimes be chosen as the last one apparently remaining in the chain. This may not always be right.
- VIMOS and UVES feature two FIERA DFE's each. It is arguable whether or not they should be counted separately in the calculation of the number of nights. For the present study, this was not done.
- Problems that occurred with VLTI instruments when used with the ATs only were not removed.
- Sometimes, scientific detectors and TCCDs (e.g., used for slit viewing and autoguiding) are confused and problems with the latter are attributed to the former category.

The average downtime per incident is relatively low because most problems can be resolved by re-initializing the detector system or by replacing an electronics board or the entire DFE or PSU (both FIERA and IRACE are conceived as LRU's). In the report period, 17 FIERA and IRACE boards had to be sent back to ESO Headquarter for repair or replacement. This corresponds to a mean time between such major hardware failures of 2 years.

The very small fractional downtime of less than 0.15% makes a detailed discussion of the above biases a relatively academic discussion. An estimate of the most favorable and the worst combination of biases suggests that the most correct value of the downtime of FIERA and IRACE will be bracketed by 0.05% and 0.2%.

These fractional downtimes can be compared to the ones for several Gemini instruments as reported in [RD7], which are in the range of 0.8 to 2.1%. The order-of-magnitude difference is probably due primarily to all Gemini instrument having their own type of controller, which therefore do not get as thoroughly tested and debugged as a standard controller such as NGC does.

8 Conclusion

The similarity of many of their design roots lets it appear safe to assume that the reliability of NGC will not be inferior to the ones of both FIERA and IRACE. This is also supported by the fact that the effective overall reliability of FIERA (after correction for shutter problems) as well as IRACE has been quite similar and neither has suffered specific weaknesses with most of the problems being spread over a wide range.

The NGC standard means for recovery are the same as for FIERA and IRACE: replacement of the DFE or PSU or re-initialization of the detector system. The latter should be slightly faster with NGC while the time for replacement should be the same. The standardization at the board and unit power supply level makes stock keeping and the assembly of spare systems easy.

On this basis, the statistics from nearly 34 years of service of FIERA and IRACE provides a dependable basis for the reliability estimate of NGC:

a) <u>The average downtime per detector system is expected to fall in the range between 0.05% and 0.2%.</u>
b) <u>The MTBF with loss of observing time will be between 40 and 150 nights (of 400 minutes each).</u>

This is in full agreement with [RD5], which specifies (Sect. 3.2.10 therein) that *the actual NGC-induced telescope downtime (incl. mistakes by operations and maintenance staff) shall, averaged over all systems installed, not exceed 3% in the first year after coming into operation and be at most 0.5% after 3 years.*

The true values will also depend on the size/complexity of the NGC system in question: a system with just one single Basic Board will cause fewer problems than one with 4 DFE's with the maximum configuration of 6 Basic Boards each. While the failure rate should increase linearly with the number of boards, there is a considerable configuration-independent plateau so that a system with 4 DFE's will perhaps only be twice as often hit by problems as a one-board system.