EUROPEAN SOUTHERN OBSERVATORY

VERY LARGE TELESCOPE

VLT Test Camera Calibration Plan

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Prepared	B. Leibundgut		
	Name	Date	Signature
Approved	P. Quinn		
	Name	Date	Signature
Released	M. Tarenghi		
	Name	Date	Signature

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1 Introduction

Calibration plans are an integral part of the scientific operations of the VLT observatory [1]. They form a key element in the definition of the observing modes and their application. They are tightly linked to the instrument pipelines as they provide the necessary input and provide the fundamental data collection for the quality control of the instrument performance.

1.1 Scope

Although the VLT Test Camera will not be used as a community instrument, it serves as the testbed for the combination of the VLT environment and the data flow operations. The calibration plan will be implemented at the latest during the UT1 Science Verification [2] and possibly be used during commissioning. It defines the required calibration observations for the large imaging CCD [3] only and does not deal with any of the special operation modes. Specifically it applies to mode 1 (Direct imaging with the imaging CCD [ICCD]) as referred to in Table 3.1.1.6 defined in [3].

Two aspects of the calibration plan have to be considered. On the one side is the calibration of all the scientific data acquired and on the other the need for a regular quality control of the state of telescope, instrument, and detector. The first category will need calibration data which in its configuration conforms to the science data. This means that the calibration data have to be obtained with the same detector setting (binning, readout mode, gain) and the instrument in the same configuration (filter). With a wide variety of scientific instrument setups the calibration needs can expand considerably. For quality control a standard subset, repeated at regular intervals, can be used to check the status of the instrument and detect any trends in its performance.

1.2 Purpose

This calibration plan defines the calibration observations for a regular science use of the VLT Test Camera. It is not concerned with regular maintenance activities and checks (like CCD temperature, mechanical structure). In section 2 we specify the assumed deliverables from maintenance of the VLTTC and its CCD.

1.3 Reference Documents

-[1]- Data Flow System Operations Model for VLT/VLTI Instrumentation (VLT-PLA-ESO-19000-1183)

-[2]- Science Verification Plan (VLT-PLA-ESO-10000-1366)

-[3]- VLT Test Camera - Technical Specification (VLT-SPE-ESO-11960-0839)

1.4 Acronyms

ADU	Analog Digital Unit
ICCD	Imaging CCD
IRAF	Image Reduction and Analysis Facility
OB	Observation Block
ODT	Optical Detector Team

PSF	Point Spread Function
SUSI	Superb Seeing Imager
SV	Science Verification (of VLT Unit Telescope 1)
TCT	VLT Test Camera Calibration Template
TOT	VLT Test Camera Observing Template
VLTTC	VLT Test Camera

2 Calibrations

This section gives a high-level overview over the need for calibration observations. It also includes some general remarks about accuracy of the calibration frames and the different ways of constructing certain calibration data.

2.1 CCD Calibrations

CCD calibrations have evolved to a fairly standard format over the last few years (e.g. 'User's Guide to CCD Reductions with IRAF' by P. Massey, 15. February 1997). What is needed are the corrections for the detector and the determination of detector controller noise introduced in the data. The following calibration data will have to be acquired for any gain settings, CCD binning, windowing, and amplifier used. They include determination of bias level, dark current, pixel-to-pixel variations, bad pixels, charge transfer efficiency, linearity and, possibly, fringe frames.

For SV the possible CCD settings will be restricted. The CCD will be read out either through a single readout port (always the same port), in dual mode (two ports, one for each half of the chip), or in quad readout (one readout port for each quadrant and simultaneous reading). There will be at most three gain setting available. (1) One to sample the full well capacity of the CCD, but undersampling the readout noise. This setting is used for observations of objects with large brightness contrasts. (2) A gain which fully samples the readout noise, but limits the saturation level by the 16-bit representation of the data. This mode is used for faint objects for which the CCD noise has to be resolved. This may be necessary for narrow-band imaging where the sky background is not dominating the noise. (3) An intermediate setting representing a compromise of the above. Binning will be an important issue for the test camera. Since it is oversampling the expected point-spread function even for the best seeing conditions, most science observations will bin the chip. We consider three cases with no binning, 2x2, and 3x3 binning with plate scales of 0.04 0.08, and $0.12''$/pixel, respectively.

For the calibrations of science data the calibration frames have to be obtained in the same configuration.

The following paragraphs describe the accuracy the calibrations should achieve and present preliminary values for the number of exposures needed. The exact numbers will be defined once the characteristics of the CCD are known.

2.1.1 Bias Frames

The calibrations of the VLTTC CCD will include regular bias frames. The noise contribution of the combined bias frame should be below 1% RMS of the counts which is normally achieved by combining about 20 individual bias frames (assuming an RMS noise of $7e^-$, a bias level of 250 counts, and conversion factor $\sim$1). Note that the bias level changes very little as long as the gain setting or CCD amplifiers are not changed. To remove any cosmic rays it is necessary to coadd several bias frames. This requirement is redundant since a series of bias frames is needed for the noise reduction anyway. Bias frames should be obtained for every night the specific configuration is used (typically in the preceding afternoon or the following morning).

The bias level is normally subtracted from the pre- and overscan regions on the individual exposures. The bias frames are only used to remove any amplifier structure which might be present in the data.

2.1.2 Dark Frames

The dark current of most CCDs has become a negligible quantity. Nevertheless, we plan to obtain a set of dark frames to measure the dark current. This is done to ensure that we do not have to worry about any significant contribution to the noise. The specification of the VLTTC asks for a dark current of $<$10 e^- $pixel^{-1}$ $hour^{-1}$. With a set of about 5 dark frames each of 1 hour duration per week the determination of the dark current and its stability can safely be established. Should the subtraction of the dark frames become necessary, we will combine all dark frames to a master dark and subtract this frame from the data. Multiple dark frames are required for an efficient removal of cosmic rays.

The dark frames further provide a means to find and characterize "hot" and "warm" pixels. This information will be used for specific analysis purposes, but not be implemented into a regular pipeline. In situations, where the counts in the "hot" pixel is of the order of the background counts special care in the reductions may have to be taken. These cases, however, are most likely be dealt with by the bad pixel mask (see below).

2.1.3 Flatfield Frames

The pixel-to-pixel variation of quantum efficiency depends on the wavelength and has to be established for each filter individually. It can be determined reliably by exposures to the light of an internal lamp for narrow- and intermediate-band filters where the wavelength range is fairly restricted and the influence of the wavelength dependence on the pixel response is limited. For broad-band filters it becomes important to match the color of the science object and the background sky as closely as possible. Often this is attempted with twilight flats. In some cases flatfields can be constructed from regular science exposures, if they have background flux dominating the readout noise (typically broad-band filter images only). By combining a large number of deep science frames with non-extended sources good flatfield images can be constructed. It may, however, be necessary to obtain "dark" sky images to match the color of the sky as accurately as possible. There will be no "blank" fields for the VLT and a careful offsetting between exposures has to be considered. This calibration should be done only in special cases where the observations depend on such an accurate color match.

The noise contribution of the flatfields should not exceed 1% per pixel which implies that they require an exposure level of at least 10000 e^-. This is very easily achieved for internal flats and most twilight flatfield observations even in a single integration. Note, however, that at least three (better five) exposures for each setup are required to efficiently remove cosmic rays.

Flatfield frames should be obtained preceding or following any night the filter has been used for science observations. This is to remove any irregularities which may arise from dust on the dewar window or the filters themselves. Such dust particles can move during a night and can create flatfielding errors of a few percent depending on the illumination.

The flatfield frames and the bias frames are used to derive the gain and the readout noise of the amplifier used. The suitable combination and also subsection of the chip to be used have to be carefully chosen so that the measurement is not affected by blemishes (bad columns) or cosmic rays.

2.1.4 Bad Pixel Mask

Non-linearities (i.e. charge traps, blocked columns, and hot pixels) in CCD pixels can occur and some chips also contain blocked columns which affect the data. For many applications these defects are purely cosmetic and can be safely ignored. A bad pixel map should be determined nevertheless for any applications which need cosmetically clean images. To construct the bad pixel map low level flatfields ($\sim$100 e^-/pixel), in combination with any high-level flatfield frames (2.1.3), are needed. The noise of the combined low level flatfields should be less than 2% which implies at least 20 individual exposures. The bad pixels are interpolated from neighboring pixels in the reductions and thus the exact value of the non-linearity is not required.

2.1.5 Fringe Frames

Fringe patterns from narrow-band filters are stable and can be removed by the regular flatfielding.

For broad-band imaging in the near-IR ($\lambda > 7000\AA$) the narrow night sky lines produce fringes in the CCD. The strength of the night sky lines varies on a time scale of minutes to hours. Thus the fringes in science exposures vary to some degree. Depending on the illumination the fringes also move on the frame and their removal is fairly difficult. Special fringe frames (deep sky frames) have to be obtained for this purpose. The signal in the sky has to be high enough in order not to introduce additional noise when defringing the science frames. It is not planned to obtain fringe frames on a regular basis as very few observations depend on the accurate removal of the small (amplitude typically about $<$5% on current chips) non-uniformity. Only observations which have objects of a similar spatial scale and signal may need defringing.

2.1.6 CCD System Linearity

The measurement of the CCD system linearity is done by exposing the CCD to a constant light source over a range of integration times. The CCD system response should be linear to better than 0.1% with the integration time (apart from shutter effects, see below). The linearity should be very stable and it is sufficient to measure it once per month. This measurement is combined with the shutter calibration (2.2.1). The linearity should also be tested at very low light levels to detect and charge leaking and similar effects.

2.2 Instrument Calibrations

The VLTTC is a very simple instrument with very few functions relevant for SV. We restrict the discussion of the instrument calibrations to the shutter. The measurement of the color term of the system will be described in the section 2.4.

2.2.1 Shutter calibrations

For accurate photometry it is important to measure the illumination variations introduced by the shutter. Also any shutter delays have to be known. For most VLT instruments these will be critical parameters as the observations of (bright) standard stars will often require short exposure times.

The shutter delay and illumination map will be created by a series of exposures with increasing (or decreasing) exposure times. Every second exposure in the series will have the same integration time as the first one to detect any possible drifts in the illuminating source. The shutter delay and timing will be determined with these data.

Once the integrations become long enough that the shutter timing becomes negligible the data measure the linearity of the CCD. With an appropriate choice of integration times this calibration can be combined with the CCD linearity calibration (see 2.1.6).

2.2.2 Astrometric calibrations

Since the VLT will be a telescope which can change the f-ratio by small amounts, it will be necessary to determine the plate scale of the VLTTC on a regular basis and whenever required for the data analysis. This is done by the observation of suitable astrometric fields. A single filter exposure should be sufficient for this.

2.3 Focus

The VLTTC does not have an adjustable focus. The focus in the focal plane has to be established with the telescope. With the active optics the focus will normally be maintained through the guide star. We included the through focus calibration here for completeness only.

2.4 Photometric Calibrations

Photometry depends on the condition in the atmosphere as well as the color sensitivity of the telescope-instrument combination. To establish these calibrations observations of standard stars during the night are required. The color term of the instrument (which also includes the telescope) is stable as long as there are no major changes in the system (CCD changes, re-aluminization of mirrors, filter swaps, mirror degradations, etc.). The second order extinction coefficient is also varying very little over time (except when major changes in the upper atmosphere occur, e.g. dust deposited by major volcano explosions). The first order extinction coefficient and photometric zero-point on the other hand change from night to night.

For broad-band photometry the method of Harris et al. (1981, PASP, 93, 507) combines standard star observations of several nights to determine the slowly-changing color term and second order extinction using the complete data set while simultaneously solving for the first-order extinction of each night individually. We will make use of this method to measure the extinction and the color terms. The minimum requirement for a good determination of the first-order extinction are about 30 standard star observations in each filter for which science observations are obtained during the same night. Note that they have to be distributed over a range of colors and airmass which spans all science observations. With suitably chosen standard star fields several standard stars can be observed at the same time thus reducing the number of standard star exposures. The latter have to be scattered throughout the night to detect temporal changes, if present. Doubtful nights typically require more standard star observations to track the evolution than impeccable nights.

Narrow-band photometry relies on the observation of spectrophotometric standards to determine the exact sensitivity at the given wavelength range. The extinction has to be determined in the same way as with broad-band photometry. Since spectrophotometric standard stars are normally isolated they have to be observed one by one.

3 Basic Templates

The following templates should be defined for the calibration observations defined in section 2:

1. Bias/Dark frames (`tc_img_cal_bias and TCT01`)
2. Internal flatfield frames (`tc_img_cal_flatfield and TCT02`)
3. Skyflat frames (`tc_img_cal_skyflat and TCT03`)
4. Shutter and CCD linearity calibration (`tc_img_cal_shutter and TCT04`)
5. Focus frames (`tc_img_cal_focus and TCT05`)
6. Regular science frames (`tc_img_obs_exp and TOT01`)
7. Series of science frames with offsets between exposures (`tc_img_obs_crsplit and TOT02`)

They are equivalent to the SUSI templates with the exception of the shutter and linearity template. Each template has a number of parameters which can be set in the appropriate template signature. The following paragraphs will describe for each template which parameters can be selected. Two template names are offered. The long version has a more descriptive form and should be sufficient for a reminder what the template is intended for. The short version is for internal use to abbreviate frequently used template names.

It is not foreseen to window the VLTTC chip at any time. Windowed frames can still make use of the calibration data by use of the detector coordinate system.

3.1 Bias and Dark frames (`tc_img_cal_bias and TCT01`)

The purpose of this template is to obtain a description of the detector characteristics when it is not illuminated. The shutter of the instrument stays closed during the exposure. The following parameters can be set:

exposure time Set to zero for Bias frames. Dark frames will be exposed for ~3600s, typically.

readout mode Two modes can be chosen: single port readout or quad readout.

gain setting Different gain settings have to be foreseen for specific programs.

binning Five binnings are considered (1x1, 2x2, 3x3, 4x4, and 5x5).

number of exposures Typically Bias and Dark frames are acquired in series to improve the signal-to-noise ratio and reject cosmic rays.

3.2 Domeflat frames or internal flatfield frames (`tc_img_cal_flatfield and TCT02`)

These are to find the sensitivity variations across the CCD (pixel-to-pixel). The image of a uniformly illuminated surface is recorded. Flatfields record the illumination pattern of the filter/instrument combination. The high-level flatfield frames should be independent of the gain setting as they are dominated by the photon noise rather than the readout noise and the noise sampling is adequate. This will have to be tested with the instrument For narrow-band filters these flatfields can further be used as fringe frames. Bad pixel maps can be produced by the combination of low-level with high-level flatfield frames. Parameters to be chosen:

filter The filter for which the flatfield is acquired.

readout mode Single port or quad readout mode.

gain setting Different gain settings have to be foreseen for specific programs.

binning Three binnings are considered (1x1, 2x2, and 3x3).

number of exposures Typically a series of flatfield frames are acquired to improve the noise statistics and reject cosmic ray events.

exposure level The exposure level can be set and is automatically determined within the template. Exposure times less than 5 seconds are rejected as they might introduce non-uniform illumination due to the shutter opening and closing time.

lamp The lamp (possibly internal source) to be used.

3.3 Skyflat frames (`tc_img_cal_skyflat` and `TCT03`)

A series of exposures is acquired changing the exposure times to compensate for the decreasing (evening) or increasing (morning) sky brightness. These calibration frames are also often used for an illumination correction of the science data. The template determines the exposure times according to the selected exposure level and the sky brightness. The selectable parameters are:

filter The filter for which the flatfield is acquired.

readout mode Single port or quad readout mode.

gain setting Different gain settings have to be foreseen for specific programs.

binning Three binnings are considered (1x1, 2x2, and 3x3).

number of exposures Typically a series of sky frames are acquired to improve the noise statistics and reject cosmic ray events.

offset The offset between individual exposures.

exposure level The exposure level can be set and is automatically determined within the template. Exposure time less than 5 seconds are rejected as they might introduce non-uniform illumination due to the shutter opening and closing time.

3.4 Shutter and CCD linearity frames (`tc_img_cal_shutter` and `TCT04`)

This template consists of a series of exposures of a uniformly illuminated screen or a uniform light source inserted into the beam (internal flat) with varying exposure time. The every second exposure has the same integration time as the first one to detect any drifts in teh illumination source. Both, shutter timing and linearity are independent of binning. The parameters of this template are:

readout mode Single port or quad readout mode.

gain setting For the linearity measurement for different gain settings

number of exposures The range of exposure times to be evaluated.

starting exposure time The integration time of the first and last exposure in the series.

increment of integration time The change from one exposure to the next in integration time.

3.5 Focus frames (`tc_img_cal_focus and TCT05`)

The focus template is does an automatic offsetting of the telescope and the focus values for a fixed integration time. The individual integrations must not be less than 10 seconds in order to average out any image movements produced by the seeing. The template parameters are:

readout mode quad readout mode

number of exposures The number of focus exposures in the sequence

exposure time The integration time of the individual exposures

starting focus value The start value of the focus

increment of focus The change from one exposure to the next in focus value

3.6 Regular science frames (`tc_img_obs_exp and TOT01`)

The most generic template for the observations will be a simple exposure. Basic flatfield observations could be obtained this way. This template will be employed for the generation of the data on photometric and spectrophotometric standard stars in photometric nights. Readout mode, gain setting, binning, windowing, filter, and exposure times are selectable.

3.7 Series of science frames (`tc_img_obs_crsplit and TOT02`)

This template could be used in an observation block for domeflat frames with fixed exposure times. The same parameters as in the single frame template apply here with the addition of number of exposures and positional offsets between integrations.

4 Observation Blocks for the calibration plan

The scheduling unit of the data flow system is the observation block. This section defines the OBs for the calibration plan. They are the basic components of the 'technical programs.' The latter are the OBs with the specific rules on how often the OBs have to be performed and what the results of the analysis should be before raising alarms.

4.1 CCD calibrations

4.1.1 Bias Frames

The template signature for the closed-shutter frame template (`TCT01`) is given in the following table for the basic bias case.

Template signature in Observation Block `bias_basic.ob`

Parameter	setting	description
readout mode	quad	4 port readout
gain setting	low gain	smallest gain available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
number exposures	5	five consecutive exposures
exptime	0	just readout

No acquisition template is required for this OB. This OB will also be used for quality control.

4.1.2 Dark Frames

The dark frames are obtained by scheduling the OB several times to provide the possibility to break the sequence gracefully. The template signature (for template `TCT01`) is then:

Template signature in Observation block `dark_basic.ob`

Parameter	setting	description
readout mode	quad	4 port readout
gain setting	low gain	smallest gain available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
number exposures	1	number of consecutive exposures
exptime	3600	1 hour integration

No acquisition template required. For the quality control this OB has to be scheduled 5 times per week. This OB should also cover all needs for any of the science data.

4.1.3 Flatfield Frames

The flatfield frames preferably are taken with the same instrument and detector configuration as the science data. The normal OB contains templates (`TCT02`) for each filter of a set (i.e. UBVRI or Gunn griz), thus there are typically several templates, one for each filter, in one OB. An example is given below.

Template signature for the U filter in Observation block `flat_UBVRI.ob`

Parameter	setting	description
filter	U	U filter
readout mode	quad	4 port readout
gain setting	high gain	largest gain available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
number exposures	3	three consecutive exposures
explevel	25000	exposure level in ADU

No acquisition template is required. Flatfield frames should be obtained daily to check the instrument and also to have good illumination measures (dust) which can change from day to day. Flatfield frames for the configurations used during the night time observing are required.

The total time to run the above OB on an internal lamp depends on the power of the lamp, but it is estimated that it takes less than 60 seconds for one exposure and the complete OB should then be finished in about 30 minutes (including overheads). The exposure time should not be shorter than $\sim$5 seconds to avoid introducing spurious effects from the shutter timing.

This OB will also be used for quality control and should be obtained for this purpose once a week.

4.1.4 Skyflat frames

The true illumination of the detector is obtained from images of the sky. To achieve a high S/N ratio observations during twilight are preferred. They do, however, not exactly match the color of the dark sky. The template signature for `TCT03` is the following:

Template signature in Observation block `sky_U.ob`

Parameter	setting	description
filter	U	U filter
readout mode	quad	4 port readout
gain setting	high gain	largest gain available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
number exposures	5	five consecutive exposures
offsetRA	10	offset in RA (in arcseconds)
offsetDEC	10	offset in Dec (in arcseconds)
explevel	25000	in ADU

The telescope is positioned at a 'blank field' by the acquisition template (simple pointing) and is tracking. It is offset by 10 arcseconds in RA between exposures.

There will be separate OBs for each filter so as to provide the flexibility to just obtain the necessary skyflats. To guard against cosmic rays five exposures are taken. The exposure time is scaled according to the brightness changes of the sky. Exposure times less than 5 seconds are not allowed. The skyflats have to be obtained in the configuration the instrument is used at night. The available time is about 30 minutes. The OB for one filter (broad-band) is estimated to last between 5 minutes and 15 minutes so that three filters can be observed during one twilight.

For quality control purposes UBVRI skyflats with the above signatures are obtained at least once per week.

4.1.5 Bad Pixel Mask

These are obtained in combination with the OB `flat_UBVRI.ob` defined above. Low-exposure level flats are required which can be obtained with the same template `TCT02` and an exposure level of 100 ADU. At least 20 low-level flats need to be acquired to get the noise near 2%. Together with the high-level flats this requires about 60 minutes. Exposure times shorter than 5 seconds are not allowed.

This OB is only run about once per month during day time and is part of the quality control procedure. The data will be obtained only in the standard configuration (no window, unbinned, quad-readout, low gain).

4.2 Instrument Calibrations

4.2.1 Shutter timing and CCD linearity

`TCT04` is used for this measurement. The signature is

Template signature in Observation block `shutter.ob`

Parameter	setting	description
filter	R	R filter
readout mode	quad	4 port readout
gain setting	low gain	smallest gain available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
number exposures	20	number of consecutive exposures
starting exptime	0.2	first exposure
exptime increment	0.2	increment of exposure time

No acquisition template required. Is done once per month during the day time. The time required for this OB is about 30 minutes. Only the standard configuration is used for this measurement. Part of the quality control.

4.2.2 Astrometric calibrations

Astrometric calibrations are obtained in the same way as the photometric calibrations, i.e. by a simple observation of an astrometric star field. An exposure in a single filter is sufficient. The OB has the same structure of the template signature as given below for the photometric calibration observations.

4.3 Focus

Focus frames should be necessary only in exceptional cases. For the use of focus frames a number of suitable star fields (adequate brightness, small crowding) should be selected.

Normally the field with the smallest airmass would be chosen. The OB makes use of the template `TCT05` with the following signature.

Template signature in Observation block `focus.ob`

Parameter	setting	description
filter	R	R filter
readout mode	quad	4 port readout
gain setting	low gain	lowest gain setting available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
number exposures	10	number of consecutive exposures
starting focus value	890	focus encoder value
focus increment	10	increment of focus encoder value

4.4 Photometric Calibrations

The acquisition templates are defined for the Landolt fields and some of the Graham E-fields for the UBVRI broad-band filters. Spectrophotometric standards (from the Hamuy et al. 1994, PASP, 106, 566) are used for narrow-band filters. Regular `TOT01` templates can be used. An example signature is given below.

The configuration has to match the science data. The signature of the template below is for the case of UBVRI on the Landolt stars.

The exposure time has to be adjusted for each field and filter. These are night time observations. A single standard star field can be observed in all five filters in <10 minutes.

Template signature for the U filter in Observation block `standard_UBVRI.ob`

Parameter	setting	description
filter	U	U filter
readout mode	quad	4 port readout
gain setting	high gain	highest gain available
window	False	no windowing of the CCD
binx	1	no binning in x
biny	1	no binning in y
exptime	25	exposure time

The exposure time has to be adjusted for the other filters in this OB.

5 Technical Programs for the VLT Test Camera

This section defines the rules and frequency of the application of the observation blocks defined for each of the calibration observations.

5.1 Regular calibrations

Regular science data have to be appropriately calibrated and all the calibration frames acquired. For an adequate discussion the different time scales of variations of detector, instrument, and atmospheric characteristics have to be distinguished. The following are considered stable configurations and a monthly check is sufficient: bad pixel mask, fringes introduced due to narrow-band filters, shutter speed, and CCD linearity. All these characteristics are independent or only weakly dependent of readout mode, gain setting and binning. They should be determined with the unbinned, non-windowed, small gain (to sample the noise correctly), quad port readout.

It should be measured about once per week. The single port readout with a small gain of the full, unbinned, non-windowed CCD is sufficient for this measurement. These data can be applied for calibration to all science data should this be required.

Bias level, flatfields, and photometry have to be determined whenever regular science data are acquired. They should be taken with the same setup as the science frames.

In special cases fringe frames are required to remove fringes introduced by night sky lines. These fringes can only be removed by observations of 'blank fields' or the combination of various science frames (not always possible). The same setup as for the science frames is required.

Table 1 lists all the quality control observations.

5.2 Quality control

For the regular check of the instrument performance a standard set of calibration data should be obtained. The same instrument characteristics as in the regular science calibrations are measured, but for a very restricted configuration. The configuration is the quad readout mode, low gain setting, unbinned, non-windowed chip in all broad-band filters (UBVRI). This set may overlap considerably with the regular calibration observations and in these cases should be drawn from those data. Contrary to the regular calibrations these technical programs will be carried out at fixed intervals.

Throughput measurements can be extracted from the standard star observations (independent of the exact setup).

Table 2 lists all the quality control observations.

A Summary Tables

Table 1: Summary of the VLT Test Camera technical programs for regular observing

Product	Accuracy	Frequency	Duration	Time	Comments
CCD Calibrations					
Bias frames	<1%	daily	5 min	daytime	with the CCD configuration used for that night
Dark frames	–	weekly	5 hours	daytime	covered by quality control program
Flatfield frames	<1%	daily	<2 hours	daytime	only in the filters used during nighttime observations
Skyflat frames	<1%	daily	30 min	twilight	only in the filters used during nighttime observations
Bad pixel mask	–	monthly	1 hour	daytime	covered by quality control program
Fringe frames	<1%	when required	1 hour	daytime	only in narrow-band filters used
	<1%	when required	1–2 hours	nighttime	only when required in Gunn i, and z filters or I filter
CCD Linearity					combined with shutter timing (see below)
Instrument Calibrations					
Shutter map	<5%	monthly	1 hour	daytime	both measurements
CCD linearity	<1%				covered by quality control program
Photometric Calibrations					
standard star frames	<1% per star	every photometric night	<2 hours	nighttime	all filters used during that night
					on several standard star fields

Table 2: Summary of the VLT Test Camera quality control observations

OB	Product	Accuracy	Frequency	Duration	Time	Comments
CCD Calibrations						
`bias_basic`	Bias frames	<1%	weekly	5 min	daytime	gain and readout determination
`dark_basic`	Dark frames	–	weekly	5 hours	daytime	5× 1 hour
`flat_UBVRI`	flatfield frames	<1%	weekly	<1 hour	daytime	used for bad pixel map; gain and readout determination
`sky_UBVRI]`	skyflat frames	<1%	weekly	30 min	twilight	OBs for individual filters
`flat_UBVRI`	bad pixel mask	–	monthly	1 hour	daytime	low-level internal flats to be combined with the high-level flats
CCD Linearity						combined with shutter timing (see below)
Instrument Calibrations						
`shutter`	shutter map	<5%	monthly	30 minutes	daytime	both measurements
	CCD linearity	<1%				are done together
Throughput Calibration						
individual OBs	standard star frames	<1% per star	once per month	<1 hour	nighttime	UBVRI