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CALIBRATION HOME BASE FOR THE AIRBORNE IMAGING SPECTROMETER APEX

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ABSTRACT

ESA currently builds the airborne hyper-spectral push broom imaging spectrometer APEX operating in the spectral range from 380 to 2500 nm. In the scope of the APEX project a large variety of characterization measurements will be performed for verification of the instrument performance. Later, during the operational phases, regular instrument checks will be executed, i.e., on-board characterization, frequent laboratory characterization and vicarious calibration. The APEX instrument will achieve its challenging measurement accuracy by regular calibration of the instrument between flight cycles and secondly guarantee an excellent performance by using its "In-Flight Characterisation unit" (IFC) during flight operation. For on-ground characterisation, a dedicated characterisation and calibration facility is in preparation to enable a comprehensive and accurate calibration of the instrument. The so-called "Calibration Home Base" (CHB) is located at DLR Oberpfaffenhofen and will be operational from 2006. The CHB provides all hard- and software tools required for radiometric, spectral and geometric on-ground characterisation and calibration of the instrument and its internal references and to perform measurements on polarisation and stray light sensitivity and comprises a test bed and the provision of the infrastructure. In view of the high relevance to scientific objectives of its Living Planet Programme, ESA decided to contribute to the realisation of APEX by providing and funding among others the CHB. In this paper the calibration equipment and concept is outlined.

INTRODUCTION

The Remote Sensing Laboratories (RSL) of the Zurich University initiated in 1996 a project on the definition of an airborne imaging spectrometer which could represent a precursor mission to future planned spaceborne imaging spectrometers. This project includes the definition of an airborne dispersive pushbroom imaging spectrometer named 'Airborne Prism Experiment' APEX that will contribute to the preparation, calibration, validation, simulation, and application development for future imaging spectrometer missions in space[i], as well as to the understanding of land processes and interactions at a local and regional (or national) scale[ii], in support for global applications[iii].

The APEX project started in 1997 by performing a feasibility study on the design of an imaging spectrometer[iv], which resulted in a first performance definition[v]. Since autumn 2002 the project is in the Phase (design and manufacturing phase). Currently the bread boarding activities are finalized and the design review process of the overall APEX system is under investigations as well as the performance analysis of the processing chain [VII, VIII]. The rollout of the instrument is scheduled for 2006.

CALIBRATION HOME BASE

Based on the inherent flexibility of the APEX instrument varieties of characterization measurements are foreseen to ensure high calibration accuracy. The characterization contains frequent laboratory calibration cycles in the Calibration Home Base (CHB), the 'In-Flight' Characterization facility (IFC), by using natural targets (e.g. Fraunhofer lines etc.) and the final assimilation of the measurements in the software of the Processing and Archiving Facility (PAF) [VI].

The laboratory calibration methods are based on standardized laboratory procedures in which spectral response, geometric response, as well as radiometric gain and offset values are determined. The APEX instrument performance will be tested, verified and regular calibrated on the Calibration Home Base, developed and operated by DLR in Oberpfaffenhofen, close to Munich in Germany. The objective of the Calibration Home Base is to provide, in a well-controlled environment, spectrally, geometrically and radiometrically defined optical signals, which are used to measure among other parameters the functional relationship between the incident flux and the instrument output. The key elements of the CHB are a 1.6 m integrating sphere to enable the radiometric calibration and an optical bench for the spatial and spectral calibration of APEX instrument.

Regarding the demanding measuring accuracy, it was decided to operate the instrument close to the expected flight conditions. This means that the spectrometer will be measured also on-ground with its own cooling and air-conditioning systems. Considering that the overall system mass including counterweights will be about 240 kg the instrument will be kept in a fixed position during the angle-dependent measurements, and not tilted step by step in a gimble mount, as typically done with smaller and light-weighted instruments. Therefore a special design of the calibration configuration became necessary.

CALIBRATION BENCH

The entire mechanical set-up makes use of highly stable design, comprising a rigid granite optical bench, a vibrationally isolated fundament (seismic block) and a linear - and tiltable mirror positioned by means of special air bearings. This is necessary to achieve a high positioning accuracy in the order of some micrometer and angular orientation accuracy in the order of some arc seconds. The dimension of the optical bench amounts to 3 m x 1.6 m x 0.4 m and offers sufficient clearance on both sides of the folding mirror to accommodate the assemblies for the spectral and the spatial calibration. An additional benefit of the bench is that over a wide range it is independent of the actual APEX instrument dimensions and mass because any instrument can be positioning via an individual interface plate. The composition is shown in Figure 1.

To cover the full swath width of APEX (±14°) a special design will be realized for the spatial and spectral characterization measurements. Due to the overall system mass, APEX will be kept in fixed position during the characterization measurements. For calibration parallel light from two collimators is directed by a movable and tiltable folding mirror into the instrument, see Figure 2.

The CHB is currently in the bread-boarding phase; first characterization measurements are planned for begin of 2006.

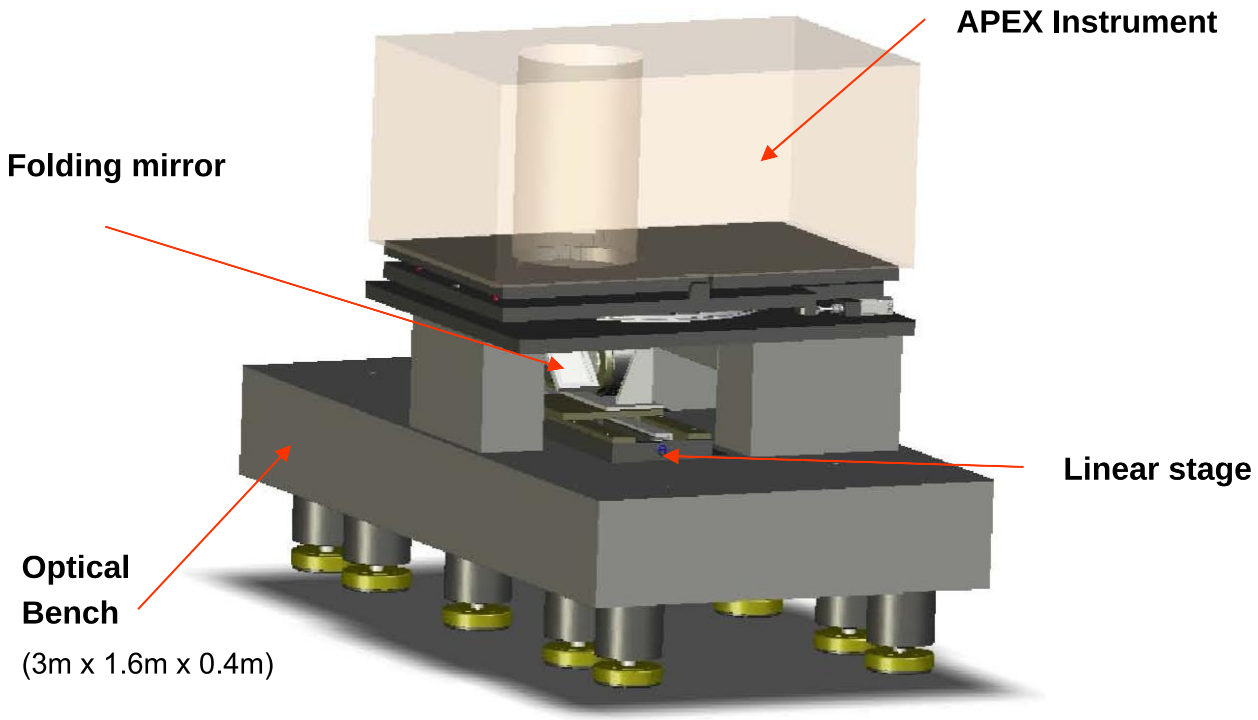


Figure 1: Side view of the calibration bench with the APEX sensor, the two working areas on both sides and the folding mirror

Folding mirror concept

The folding mirror concept offers the possibility of using two different collimators (see collimator 1 and 2 in Figure 2), to facilitate sequential directing of the optical stimuli, providing sources for the spectral and spatial calibration tasks. The key element of the concept is the device for moving and flipping the folding mirror between the collimators. As the actual position and direction of the reflected beam depends on the translatory and angular position of the mirror, the accurate synchronization of both actuators is computer controlled and the position provided by very accurate sensors.

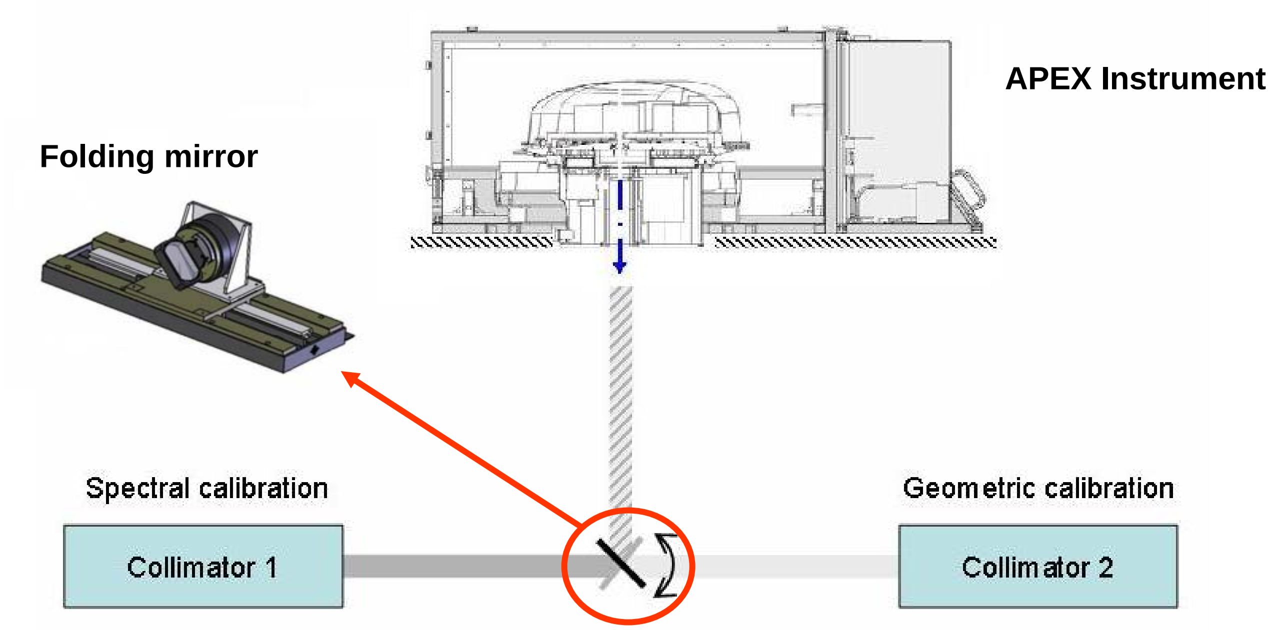


Figure 2: Schematic view of a set-up with fixed APEX instrument, fixed collimators and movable/flapping folding mirror.

Figure 3 shows how the components will be arranged on the optical bench; the instrument rack is not shown.

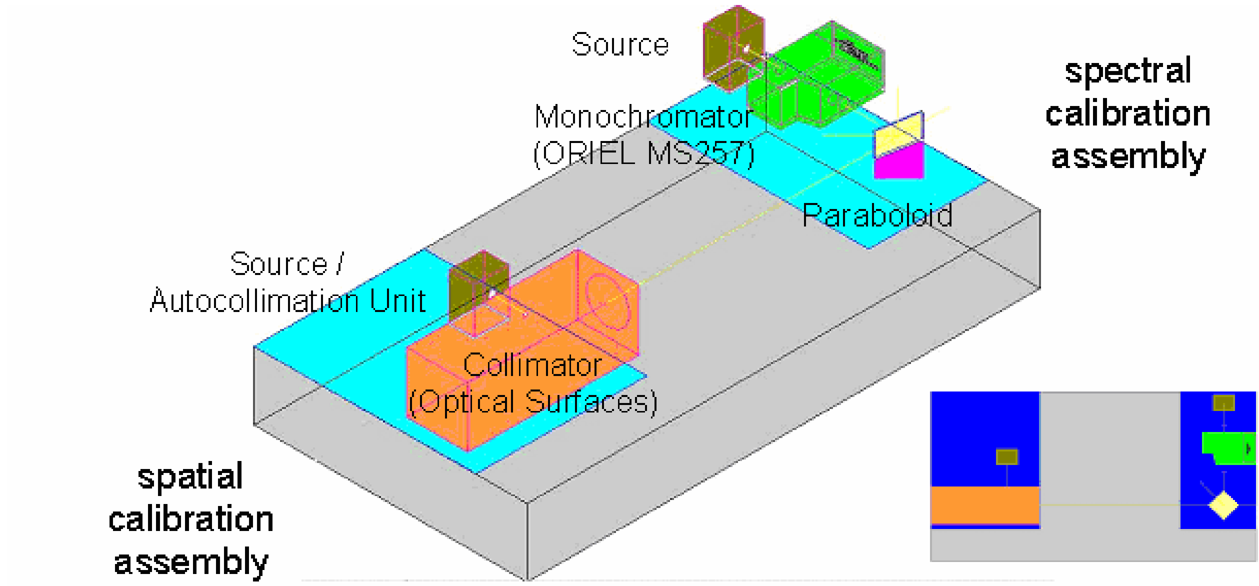


Figure 3: Oblique view and top view (right insert) of the working spaces on the calibration bench

Spectral Calibration

The stimulus for the spectral calibration will be a nearly monochromatic parallel beam, which on the APEX detector plane slightly overfills one detector element (pixel) in spatial dimension, while in wavelength dimension has sub-pixel extension. This is achieved by using a collimator/pinhole arrangement providing the appropriate divergence and a grating/slit combination at the monochromator giving the required spectral bandwidth. The determination of the spectral response function of the detector elements is realised in a two steps procedure. In the first step the stimulus is centred on a detector column by equalising the signal from neighbouring elements. In a second step the spectral response functions of the elements in this column are scanned by stepwise increasing and decreasing the wavelength of the stimulus.

There are two options for this measurement. The first is to cover all elements in a column by a continuous wavelength scan. The other is to only raster selected elements and leave out those in-between in order to reduce the number of individual measurements, and to perform an interpolation. The number and position of elements, which have to be characterised, depends on the properties of the instrument. For characterizing APEX "smile" and "frown" misregistrations, about 20 angular measurement positions across track with 150-1500 wavelength settings would be adequate.

Spatial Calibration

The procedure suggested for spatial calibration will make use of a panchromatic beam formed by a collimator/slit-combination to have a width of about one third of a single detector element in the focal plane.

Across track

As the beam will be panchromatic, the line spread functions of all spectral channels of single geometric pixel, i.e. of an entire detector column, will be measured simultaneously. For the characterization of the whole matrix the same considerations as with the spectral calibration apply. I.e. about 20 different angular positions distributed across the swath should be measured. To what extent the spectral radiance distribution in the panchromatic stimulus is suitable to calibrate all rows at once will be investigated during the bread boarding and the first calibration tests.

Along track

At least in the centre and at the outmost pixels of the FOV the along track line spread function will be measured. This is accomplished by shifting a vertical slit (perpendicular to the one used for the cross track LSF) in the focal plane of the collimator 2 slightly left and right (i.e. in along track - or cross FOV - direction). A rotating slit wheel will realize this movement, as the rotational component of such a small shift is negligible.

RADIOMETRIC CALIBRATION

For the radiometric calibration it is intended to use an integrating sphere with a diameter of about 1.6 m. The existing sphere has an exit port of 0.4 m x 0.6 m that covers the entire swath width of the APEX instrument. Under these conditions and with a sophisticated illumination concept an absolute radiometric accuracy of better 5% will be achieved. DLR provided the radiation levels for APEX relevant spectral range from 0.4 to 2.5 μm.

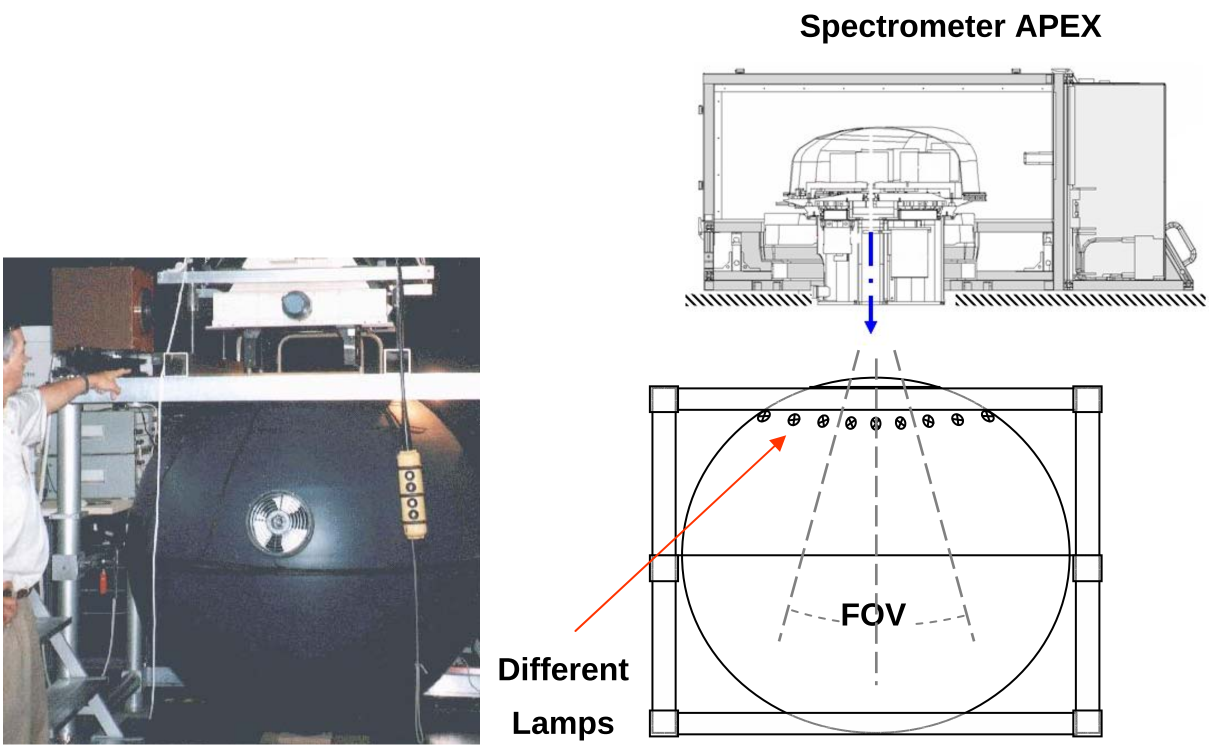
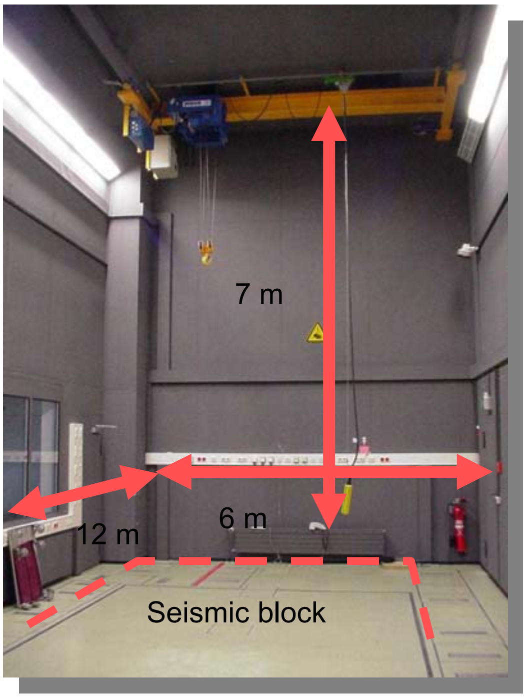


Figure 4: Picture and principle of the radiometric calibration of APEX imaging spectrometer using a large integrating sphere

CALIBRATION LABORATORY REQUIREMENTS

The size and mass of the calibration bench and integrating sphere, as well as the stringent requirements on stable environmental conditions call for a facility, which is far beyond a standard optics laboratory. At DLR Oberpfaffenhofen a huge laboratory with a built-in seismic block exists, which is fully vibration isolated and ideally located to fulfill all requirements. Figure 5 gives an impression of the room and summarizes all relevant features.



Large enough to host equipment
(Size: 12.8 m L x 5.9 m W x 6.7 m H)
Vibration damping by seismic block (8.25m x 3.5m)
Darkroom facility (no outdoor windows, shutter on interior windows)
Temperature controlled via air-condition
Humidity controlled via humidifier
Accessibility by large trolleys (ramp, door size 3m x 3m, no stairs, steps or elevators)
Short distance to airfield (approx. 100m driveway)
Crane to carry up to 2 tons
Semi-clean environment (air filters and air flow control)
Infrastructure (220V/380V power, independent power supply, water)

Figure 5: Huge optics laboratory at DLR Oberpfaffenhofen and its features

During the first months of the CHB project several tests and measurements have been performed to ascertain the suitability of the laboratory and prepare it for the set-up of the CHB. The properties of the seismic block were evaluated using a broadband seismometer, measuring all disturbances in a range from 0.5 to 40 Hz for a period of about one week. Resulting from this, the isolation of the seismic block is considered excellent to justify a mounting of the calibration bench without any further damping.

COMMAND AND CONTROL INTERFACE

An important issue is to define the software interface between the APEX instrument and the Calibration Home Base. For reasons of simplicity (to avoid a complex interface) and adequateness (to maintain same instrument set-up during operation and calibration) the scenario in Figure 6 was chosen. The description of the interface protocol and the contents of the commands and information exchanged are consulted with the manufacturer of the instrument.

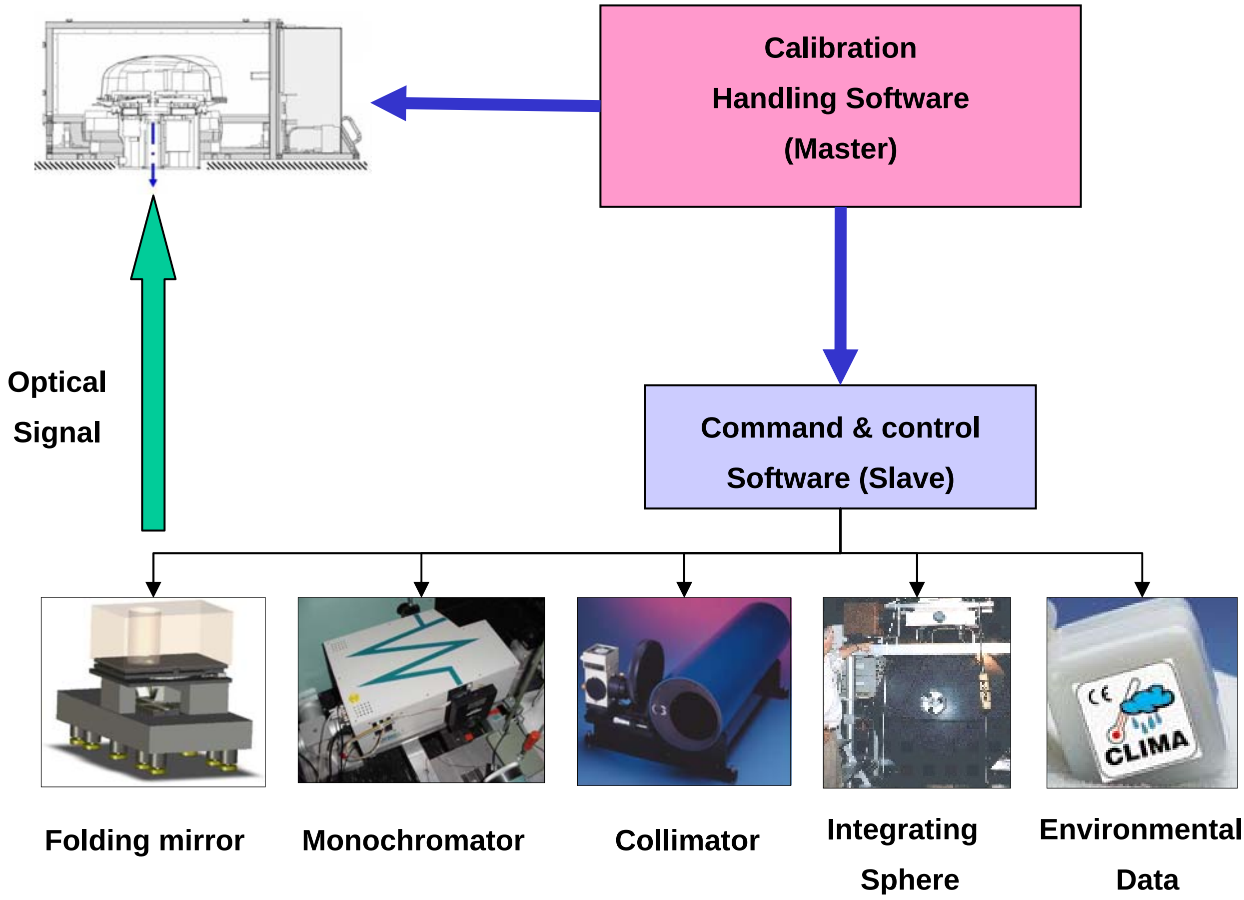


Figure 6: Interface between instrument and Calibration Home Base

The calibration handling software, which is needed to control the calibration cycle and analyze data from the APEX instrument, is part of the APEX system. The role of the Calibration Home Base is basically to provide proper stimuli according to the commands it receives from that master.

CONCLUSIONS

The calibration concept for the APEX instrument was first outlined in Schläpfer[ix] et al., 2000. The document delivered the framework of the entire calibration and validation process of APEX. It included the tasks and definitions related to calibration from the measurement strategy to the processing chain and the quality control procedures.

This paper shows the established baseline design of the Calibration Home Base and pointed out some details of the calibration equipment such as

- design of the calibration bench and facility
- description of the spectral, spatial and radiometric calibration equipment
- the planed calibration methods

The outlined calibration methodology will be pursued during the operational phase at the beginning of 2006 and with the first characterization of the APEX instrument.

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