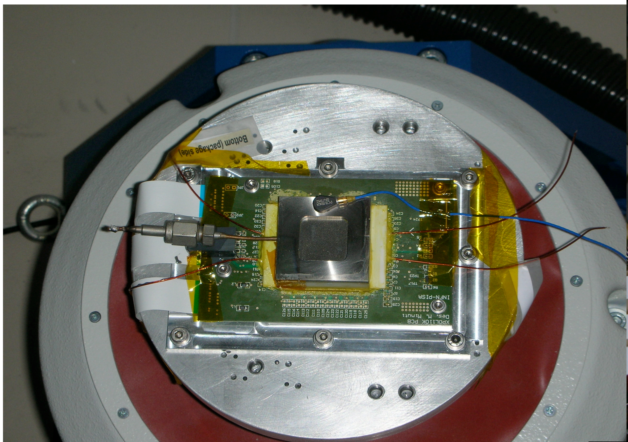
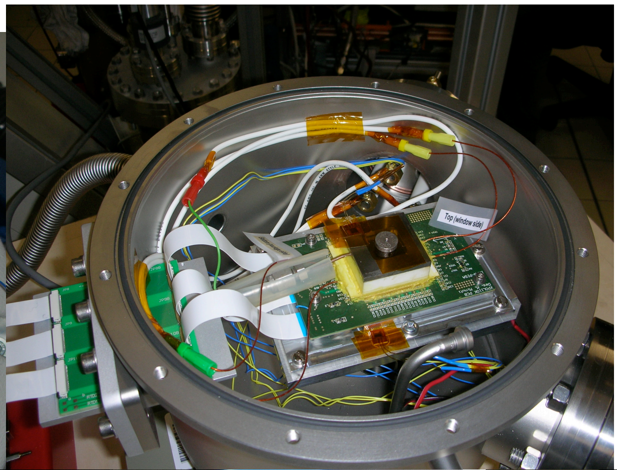
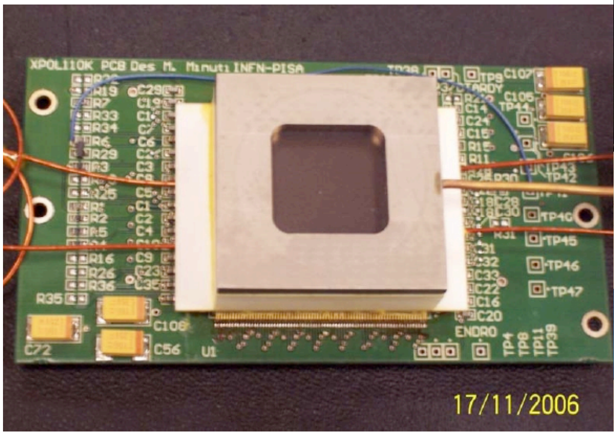
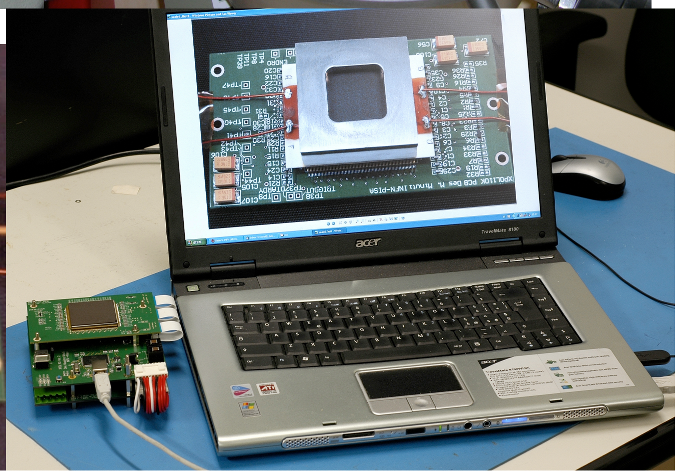
XPOL Technology Development Roadmap



prepared by

The XPOL Instrument Study Team

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1 Purpose

This document provides the technology development roadmap of the XPOL instrument for the IXO mission.

2 Acronyms and Definitions

ASI	Agenzia Spaziale Italiana
ASIC	Application Specific Integrated Circuit
BEE	Back End Electronics
CE	Control Electronics
CMOS	Complementary Metal Oxide Semiconductor
DHU	Data Handling Unit
DSP	Digital Signal Processor
ESA	European Space Agency
FPA	Focal Plane Assembly
FW	Filter Wheel
GEM	Gas Electron Multiplier
GPD	Gas Pixel Detector
HVPS	High Voltage Power Supply
IASF	Istituto di Astrofisica Spaziale e Fisica Cosmica
INAF	Istituto Nazionale di AstroFisica
INFN	Istittuto Nazionale di Fisica Nucleare
MM	Mass Memory
NASA	National Aeronautics and Space Administration
PCB	Printed Circuit Board
PDD	Payload Definition Document
ROI	Region Of Interest
S/C	Spacecraft
TBC	To Be Confirmed
TDA	Technology Development Activity
TRL	Technology Readiness Level
VLSI	Very Large Scale Integration
XPOL	X-Ray Polarimeter

3 Applicable & Reference Documents

Documents relevant to the development of this document include:

[1] NASA_SummarySchedule_2-25-09_PM.pdf

[2] ECSS-M-ST-10C Project planning and implementation, Jul/2008

[3] IXO-PDDv6 IXO Payload Definition Document v6, draft issue, Apr/2009

[4] IXO-XPOL-TDP XPOL Technology Development Plan, draft issue, Mar/2009

[5] IXO-XPOL-TDS XPOL Technology Development Status, draft issue, Mar/2009

4 Introduction

The purpose of the X-ray Polarimeter (XPOL) is to provide, in the energy range 2 – 10keV, polarization measurements simultaneously with spectral measurements (E/δE of ~5 @6 keV), 6" of angular resolution and timing information at a few μs level.

XPOL is based on a Gas Pixel Detector (GPD), a finely subdivided counter with proportional multiplication that is able to precisely reconstruct the photoelectron track and thence to derive its ejection direction. The track analysis also provides the x-ray impact point with a precision of ~150 μm FWHM. The baseline gas mixture is He 20 % DME 80% at 1 bar. The gas counter custom read-out chip (ASIC) has 105600 pixels with a 50μm pitch giving an instrument FOV of 2.6x2.6 square arc minutes. Each ASIC pixel contains a full standard front-end electronics chain with a common multiplexed output which is read out by a dedicated Back-End Electronics (BEE) system. The analog data are A/D converted by the BEE and then processed by the Control Electronics (CE).

4.1 Study Team and heritage

The Polarimeter will be developed by a collaboration of an INFN-Pisa team led by Ronaldo Bellazzini, and an IASF-Rome INAF team led by Enrico Costa.

INFN-Pisa will be responsible for the GPD design, development and overseeing the flight system fabrication. The INFN-Pisa team invented and developed the GPD specifically for space applications and the INFN labs are fully equipped for XPOL having electronics and mechanical engineering facilities and various test facilities including thermal-vacuum chambers, shakers, and class 10,000 and 100,000 clean rooms.

INFN-Pisa has a long and outstanding heritage in developing gas-detectors for particle physics (Micro-strip, Micro-gap, Micro-well). They also successfully built all the Fermi/GLAST towers for the Large Area Telescope (the tracker); and were responsible for the on-ground calibration. They developed the GPD to be used as a polarimeter in X-ray astronomy and proved the GPD in relevant environmental tests (vibration, thermal-vacuum, heavy ions exposure).

IASF_Rome will be responsible for the calibration of the GPD and for the Monte Carlo analysis of the GPD response both on the ground and that expected in space. For this calibration purpose they developed in their lab a facility that can provide polarized X-ray beams in the 2-8 keV range with the flexibility to select the beam position, polarization angle and incident angle.

IASF-Roma was responsible for providing the detectors (the imaging proportional counters), the readout electronics and the high voltage power supply for the Stellar X-ray Polarimeter (SXRP) which was supposed to fly on the Spectrum-X-Gamma (SXG) mission. SXG, unfortunately never flew due to polical developments in the former Soviet Union, but the Flight Model of SXRP was, built, fully tested and calibrated. IASF-Roma was also primarily involved in building the Gamma Ray Burst monitor for the Beppo-SAX mission and the high voltage supplies and the calibration source for the JEM-X experiment on board of INTEGRAL. It also, devised and built SuperAGILE, the X-ray monitor on board the AGILE mission which is currently performing simultaneous X and Gamma ray observations.

IASF-Roma collaborated with INFN-Pisa in developing the gas pixel detector (GPD) as a dedicated polarimeter for X-ray astronomy. The collaboration started its polarimetry development with a one-dimensional gas detector (micro-gap) devised and built by the same group at INFN.

The collaboration will entrust the production of the detectors and the associated electronics to qualified space industries. GPD prototypes and electronics readout breadboards have already been produced by Oxford Instruments Analytical Oy and Thales Alenia Space-MI Italy, both space qualified. These industries have expressed interest in supporting the collaboration.

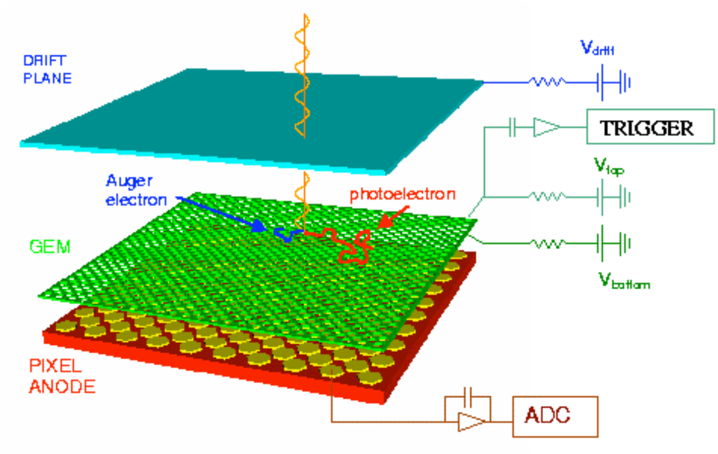
4.2 Instrument concept

XPOL exploits the photoelectric effect to derive the polarization of celestial sources. A photon is absorbed in the drift region of a gas cell where it is converted to a photoelectron and, possibly, an Auger electron of a smaller energy. The spatial distribution of the primary charge created by the photoelectrons contains information on the polarization of the original photon.

XPOL Focal Plane Assembly is composed of a GPD, a filter wheel, the back end electronics (BEE), and other associated electronics (CE):

Focal Plane Assembly - Gas Pixel Detector.

- **Beryllium window.** A 50 μm Beryllium window seals the gas volume while transmitting X-rays in the energy range of maximum sensitivity of the polarimeter. The Beryllium window is glued on a nickel frame.
- **Gas mixture**. The baseline gas mixture is 20%He-80%DME at 1bar which, presently, provides the best polarization sensitivity in the 2-10keV band.
- **GEM.** A Gas Electron Multiplier (GEM) collects the primary charge produced in the drift region and provides the necessary charge amplification for the readout electronics. The GEM is a kapton foil perforated by many microscopic holes (30 μm) with a 50 μm pitch on a triangular pattern. The gas gain required, 500, is rather small and therefore safe from the point of view of sparking and overall stability.
- **ASIC chip.** The charge multiplied by the GEM is then collected by the top layer of the dedicated ASIC CMOS chip. The top layer is patterned as a honeycomb hexagonal plane of 105600 pixels. Each pixel is connected to a charge-sensitive amplifier followed by a shaping circuit and a sample & hold-multiplexer circuit. Every 4 pixels (a mini-cluster) contribute to a local trigger. An internal wired OR combination of each mini-cluster self-triggering circuit holds the maximum of the shaped signal on each pixel. The event is localized in a rectangular area (region of interest) containing all triggered miniclusters plus a user-selectable margin of 10 or 20 pixels. The Xmin, Xmax and Ymin, Ymax rectangle coordinates are available as four 9-bit data outputs as soon as the data acquisition process following an internally triggered event has terminated, flagged by the DataReady output. Clock pulses transfer the analog data to a serial balanced output buffer. In this way, the ASIC defines a fiduciary region of interest around the photoelectron track which generated the trigger.
- **Cell spacers**. Cell spacers, made of machinable glass-ceramic (currently MACOR), constitute the walls of the gas pixel detector and define the spacing of the internal components.



4-1: GPD schematic and principle of operation

Focal Plane Assembly - Filter wheel.

- To maximize the scientific return of XPOL, the use of a filter whee is planned. Such a wheel will have a fully open and a fully closed position (the latter for internal background monitoring), a beryllium filter position for bright-source count rate reduction, a diaphragm position for obscuring a portion of the field-of-view, and finally a calibration source positions The calibration sources will be both polarized, through Bragg diffraction, and unpolarized.

Focal Plane Assembly – Back-End Electronics.

- **Back-End Interface Electronics**. The ASIC is controlled and powered by very compact interface electronics boards, which at the present stage of the project utilize commercial components. The Interface Electronics, part of the BEE, will be able to work in coincidence with the GEM signals and will provide the time tag to the event and perform the zero-suppression of the data. An A/D converter will handle up to 10 kframes/s.
- **Back-End HV Power supply**. A dedicated HV power supply board for the GPD bias will be housed inside the BEE will be located close to the GPD to minimize the high voltage cable length and the associated noise, and to minimize the impact on the P/L AIV.

Associated Electronics.

- **Control Electronics**. The data will be sent (via Space/Wire connection) to the Control Electronics. A dedicated Data Handling Unit will perform on-board data processing to measure the impact point and the emission angle for each photoelectron track. The DHU DSP should work event-by-event to minimize the requirement on the on-board memory. The Control Electronics will also set the different operative modes of XPOL and manage the telecommands and housekeeping. A dedicated 16 Gbyte memory will be used.

4.3 Instrument Performance Requirements

The basic performance requirement for this instrument is to enable polarimetric measurements to 1% minimum detectable polarization (3σ) for a 1mCrab source in 100ks, with the current IXO parameters (focal length of 20m and $2m^2$ of A_{eff} @2 kev). A further summary of the performance requirements is given in Table 4-1 and in Figure 4-2 for XPOL with a He-DME 20-80 fill gas mix (1 atm.), a 50 μm Be window, and a 1cm absorption and drift region.

Table 4-1: Summary of performance requirements (assuming a Focal length of 20m and $2m^2$ of A_{eff} @2 kev)

Performance Requirements		*Requirement satisfied by the current GPD prototype*
Detector size	15x15 mm^2	YES

Polarization sensitivity	1% MDP (3σ) for 1mCrab source in 100ks	YES
Energy range	2 – 10 keV	YES
Energy resolution	20 % at 6 keV	YES
Angular resolution	6”	YES
FOV	2.6x2.6 arcmin square	YES
Timing resolution	5 μs	YES
Efficiency	See Figure 4-2	YES
Modulation factor	See Figure 4-2	YES
Polarization angle resolution	~ 1 deg	YES
Dead time	≤ 5% at max count rate	NO

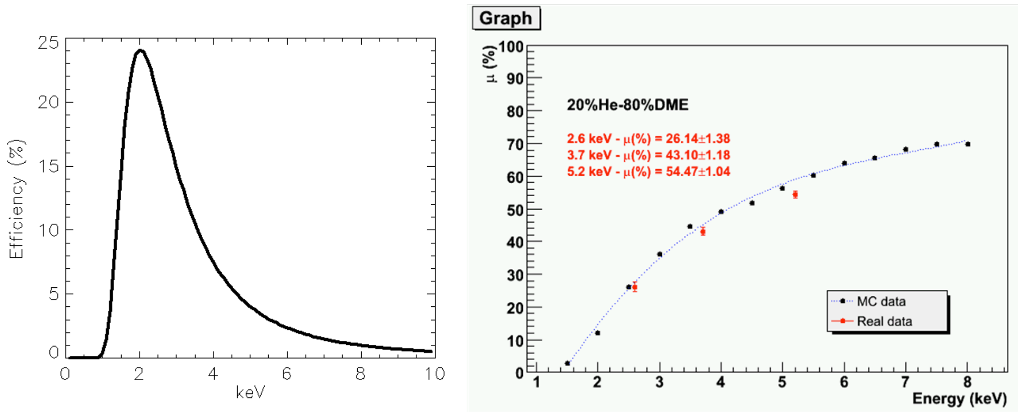


Figure 4-2: (Left) XPOL efficiency. (Right) XPOL modulation factor measured at 2.6 keV, 3.7 keV and 5.2 keV compared with the Monte Carlo predictions.

5 XPOL Technology Development Plan

5.1 Technology Development Status

The current XPOL GPD prototype has been tested in a relevant environment (vibration, thermo-vacuum and heavy ions) and is at TRL5. As shown in Table 4-1, above, the curent prototype instrument meets all requirements except that of dead time for the very brightest sources that IXO will observe. Other critical items and technologies for further investigation are:

- the GPD window survival
- the GEM readout signal and ASIC synchronization.

Other subsystems, such as electronics and mechanisms do not have critical requirements/technologies: the electronics will consist of off-the-shelf cards/components (TRL is 6/7) and the possible filter wheel will use the same design and components (TRL is 6/7) as the one flown on board XMM.

In the following MEL table the TRL status and heritage for all the XPOL items are summarized.

XPOL MEL and TRL STATUS		
Item	Technology	
	TRL	Heritage
Focal Plane Assembly (FPA)		
GPD+FW		

GAS Pixel Detector (GPD)	5	BeppoSAX
Filter Wheel (FW)	7	XMM
Mech I/F (+ prebaffle)	7	
Back End Electronics (BEE)		
Mech I/F (+ Backplane)	6	
#4 Cards cPCI (1 = HV Power Supply)	7	Off the shelf cards/components
Control Electronics (CE)		
Mech I/F (+ Backplane)	6	
#3 Cards Extended	7	Off the shelf cards/components
Mass Memory (MM) Card Extended	7	Off the shelf cards/components

Table 5-1 XPOL MEL and TRL status

5.2 List of the Technology Development Activities

A plan to develop, test and calibrate an enhanced GPD prototype with a reduced dead time ASIC has been defined. The technology development activities (TDAs) associated with this plan are described below and the schedules and deliverables are given in Chapter 6. The TDAs have been divided into two parts:

- GPD Performance Development (TDAs-PartI)
- GPD Environmental and Calibration Tests (TDAs-PartII)

ASI funds will cover the first part of the activities. ASI is well aware that new funding is also needed to cover the other activities.

5.2.1 GPD Performance Development (TDAs-PartI)

These activities conist of designing and manufacturing a higher counting rate ASIC and then prototyping the enhanced GPD. The new ASIC will be an improved version of the existing one with minor changes:

- an optimization of the ROI to include only pixels necessary for reconstructing the event, with a reduction of the number of channels to digitize
- an increase of the readout clock from 10MHz to 20MHz
- a reduction of the electronics threshold from 3000 electrons to a few hundred electrons.

These TDAs also include activities to develop, test and verify the other XPOL critical items: the GPD window safety margin and the GEM readout signal / ASIC synchronization. At the end of this TDAs-PartI, the GPD prototype will have demonstrate the required overall performances in a laboratory environment using EGSEs.

5.2.2 GPD Environmental and Calibration Tests (TDAs-PartII)

To achieve TRL6, the GPD must be operated in a relevant environment and fully characterized/calibrated. The environmental tests will consist of:

- a radiation hardness test of the ASIC
- a survival capability test of the GEM (heavy ions beam test)
- GPD vibration/shock/acoustic tests
- GPD thermal vacuum & cycling tests
-

To accomplish the GPD calibration test, the TDAs-PartII include the designing and manufacturing of calibration sources, a BEE brassboard and a CE brassboard.

There is no need to develop electronics component prototypes because off-the-shelf electronics cards/components easily match the 20MHz clock of the new ASIC and the maximum foreseen data rate of 5Mbps from BEE to CE (see [3] for data rate details).

5.2.3 Non-development activities

During and after the TDAs, the XPOL study team has planned various study activities similar to those meeting ESA requirements:

1) GPD study
    a. A study of gas filling and track analysis tools in order optimize the polarization sensitivity beyond the performance requirements
    b. A study of calibration strategies and tools
    c. A study of units' design in order to reduce the cross section of the device
    d. A study of the expected background level and of the detector performance to keep systematic effects below the level of statistics
    e. A definition of the requirements of background radiation filtering
2) Design of the Filter Wheel mechanics on the basis of the XMM design
3) Development of a mechanical and thermal concept of the XPOL assembly
4) Definition of the XPOL interface with the S/C and the instrument budgets
5) Cost estimates

6 Roadmap of Development Activities

Herein is shown the roadmap schedule, compatible with ESA/NASA requirements, to achieve the TRL6 for the XPOL subsystem to be developed, the GPD.

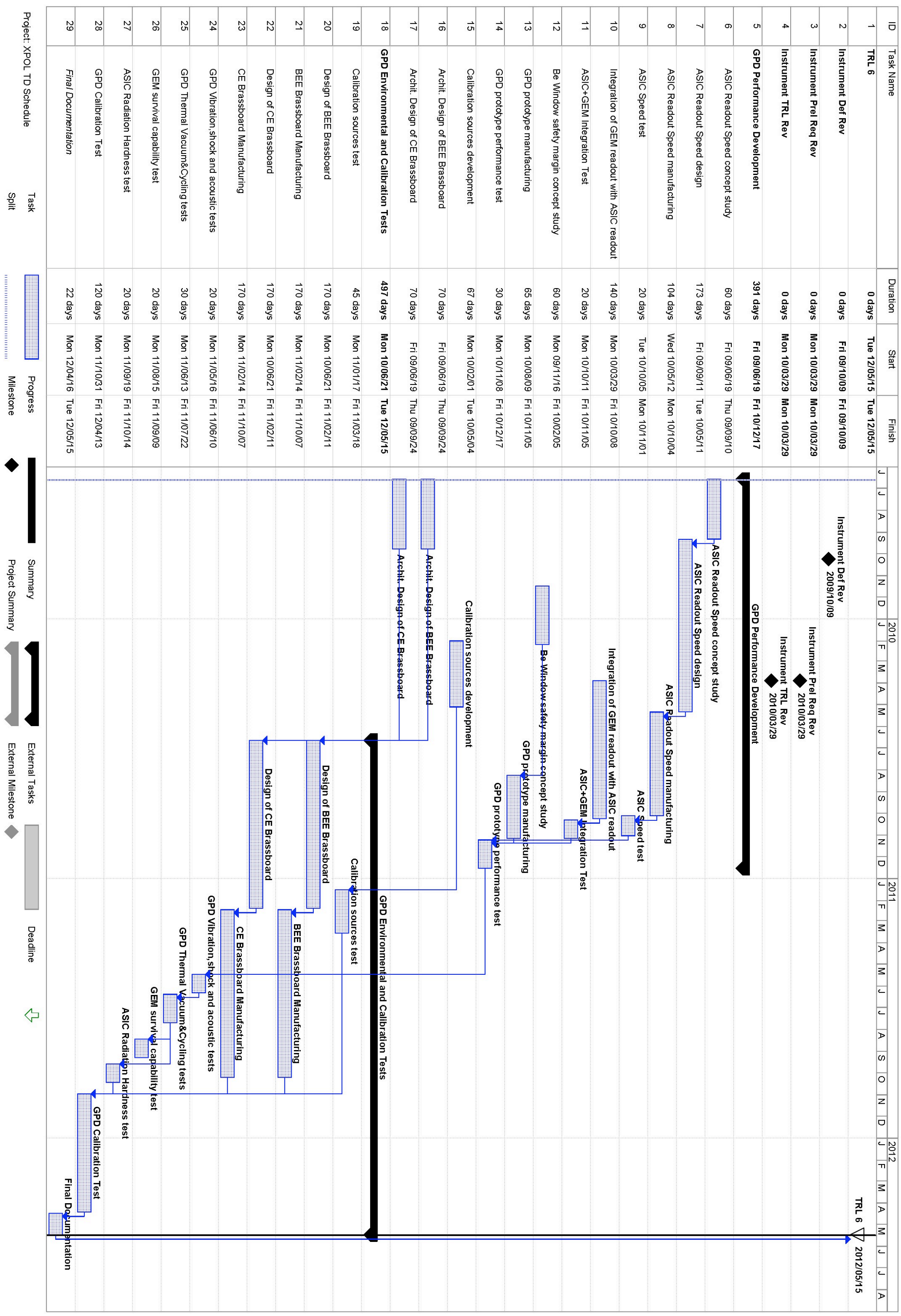
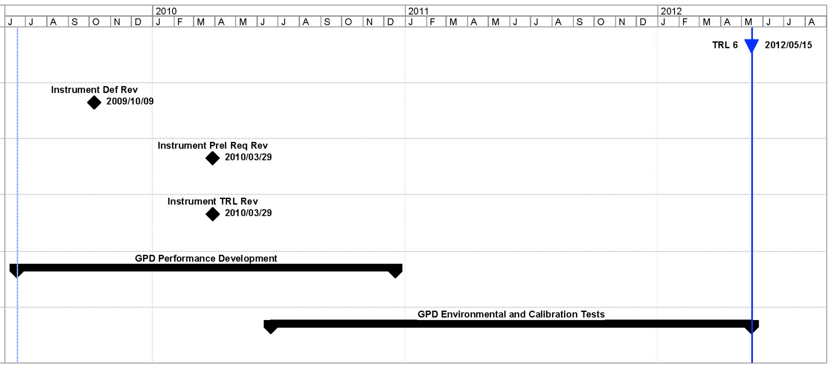


Figure 6-1 XPOL technology roadmap schedule

The figure below gives a summary of the schedule of the major milestones and TDAs:

ID	Task Name	Duration	Start	Finish
1	TRL 6	0 days	Tue 12/05/15	Tue 12/05/15
2	Instrument Def Rev	0 days	Fri 09/10/09	Fri 09/10/09
3	Instrument Prel Req Rev	0 days	Mon 10/03/29	Mon 10/03/29
4	Instrument TRL Rev	0 days	Mon 10/03/29	Mon 10/03/29
5	GPD Performance Development	391 days	Fri 09/06/19	Fri 10/12/17
18	GPD Environmental and Calibration Te	497 days	Mon 10/06/21	Tue 12/05/15



6.1 TDA Tests

The development tests and their schedules are summarized in the following figures.

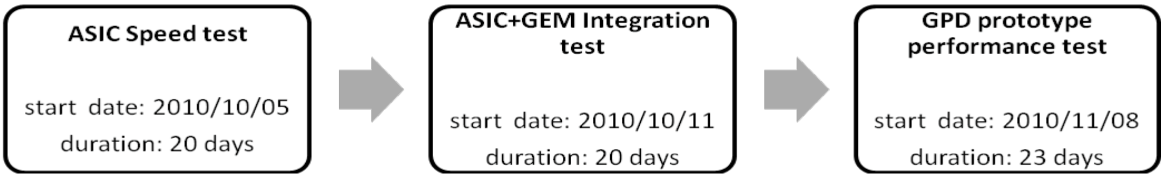


Figure 6-2 GPD performance development tests sequence

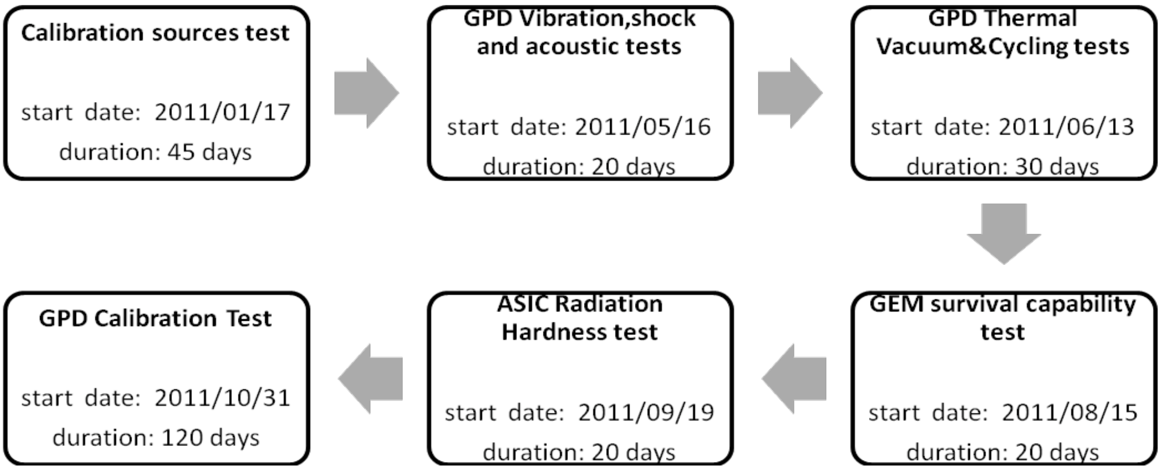


Figure 6-3 GPD environmental and calibration tests sequence

6.2 TDAs Deliverables

The relevant outputs that will be presented at the review meetings:

Milestone	Deliverables
Instrument Definition Review (Oct 2009)	Preliminary GPD architectural design Report on GPD parameter configuration definition Preliminary BEE architectural design Preliminary CE architectural design
Instrument Preliminary Requirements Review (March 2010)	GPD requirement document BEE requirement document CE requirement document
Instrument Technology Readiness Review (March 2010)	Test report on thermal tests of the best working temperature Test report on the window safety margin GPD preliminary technology readiness document
TRL6 Review (May 2012)	GPD prototype Calibration sources prototypes BEE and CE brassboards Test report on the ASIC performances Test report on ASIC/GEM interfacing Test report on the radiation hardness of the ASIC Test report on the survival capability of the GEM Test report on vibration/shock/acoustic tests Test report on thermal and thermal vacuum cycles Test report on calibration and performance test Final technology readiness document