# Chapter 3 : Optical Modules

Up List of Subsystems

# Optical Modules Overview (OM: PBS4)

The Optical Module (OM) is a glass sphere containing a photomultiplier (PMT), the light-sensitive element of the ANTARES detector. The glass sphere consists of two hemispherical parts. One hemisphere holds the PMT. The other hemisphere is equipped with an electrical penetrator, a vacuum port and a manometer, and is covered, inside, with black paint.

The glass sphere has a diameter of 17 inches. The PMT has a diameter of 10 inches and a correspondingly large active area, and it is sensitive to single photons.

The base of the photomultiplier is a circular printed circuit which provides the high voltage for the PMT and amplifies and shapes the output signals from the anode and two of the dynodes. A bidirectional electrical cable, the OM-LCM link, brings the low voltage power to the base and transports the output signals back to the LCM for digitisation; the connection through the glass sphere is made via a penetrator. The PMT is protected from the Earth's magnetic field by a magnetic shield made of mu-metal. The magnetic shield is in the form of a cage composed of two parts: a hemispherical part which covers the photocathode of the PMT, and a flat part with a hole at its center for the passage of the neck of the PMT.

A LED system consisting of a blue LED and a pulser is used to measure the transit time of the PMT. The LED is glued to the bulb of the PMT and illuminates the photocathode through the aluminised surface of the bulb. The pulser card is also glued on the photomultiplier. The pulser is triggered by a clock signal.

The optical link between the glass sphere and the PMT is provided by a silicon-rubber gel, which also provides structural support for the components of the Optical Module. A special assembly tool is used during the gluing process.

After the gluing process, the two hemispheres are joined, pumped down to provide a small underpressure, and sealed with adhesive tape. After assembly, another special tool, the photomultiplier test-bench, is used to test and calibrate the completed Optical Module using a blue light source. The test results are stored in a database.

The requirements for the Optical Module are the following:

- Light detection must be optimised. Special care must be taken to maximise the optical coupling between the photocathode and the sea water.

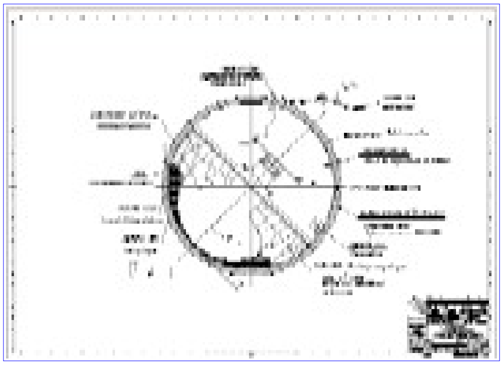
- Response to light excitation up to 1000 SPE.
- Due to the ambient pressure at a depth of 2400 m, the PMT and its associated electronics must be housed inside a pressure-resistant glass sphere. The Optical Module must withstand constraints commonly encountered during sea operations (shocks, corrosion, vibrations, exposure to sunlight ...) .
- The lifetime must be longer than 10 years.

The main steps for the assembly are the following:

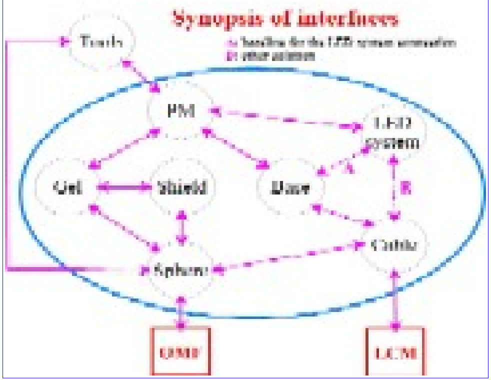
1. the gel, whose components were mixed beforehand, is poured into the lower hemisphere of the glass sphere and outgassed
2. the hemispherical part of the magnetic shield is positioned in the gel
3. the photomultiplier is positioned in the gel
4. the system is outgassed three times (closed, pumped, opened)
5. the system is left at least 4 hours for the gel to polymerise
6. the LED system is glued on the rear of the bulb of the PMT
7. the flat part of the magnetic shield is positioned around the neck of the PMT
8. in parallel, the base is soldered to the wires in the upper hemisphere of the glass sphere (already equipped with its cable penetrator)
9. the base is connected to the PMT
10. the two hemispheres are joined together, pumped down to create a small underpressure, and sealed
11. the OM is tested on the test bench.

When the assembly is completed, the Optical Module appears as a full sphere with a cable coming out of it. From this point on it must be considered as a whole, mechanically and electrically. Consequently, during the assembly of detector lines, **if an Optical Module is faulty, for any reason, it is not repaired, it is replaced.**

Optical module design



Organigram of interfaces



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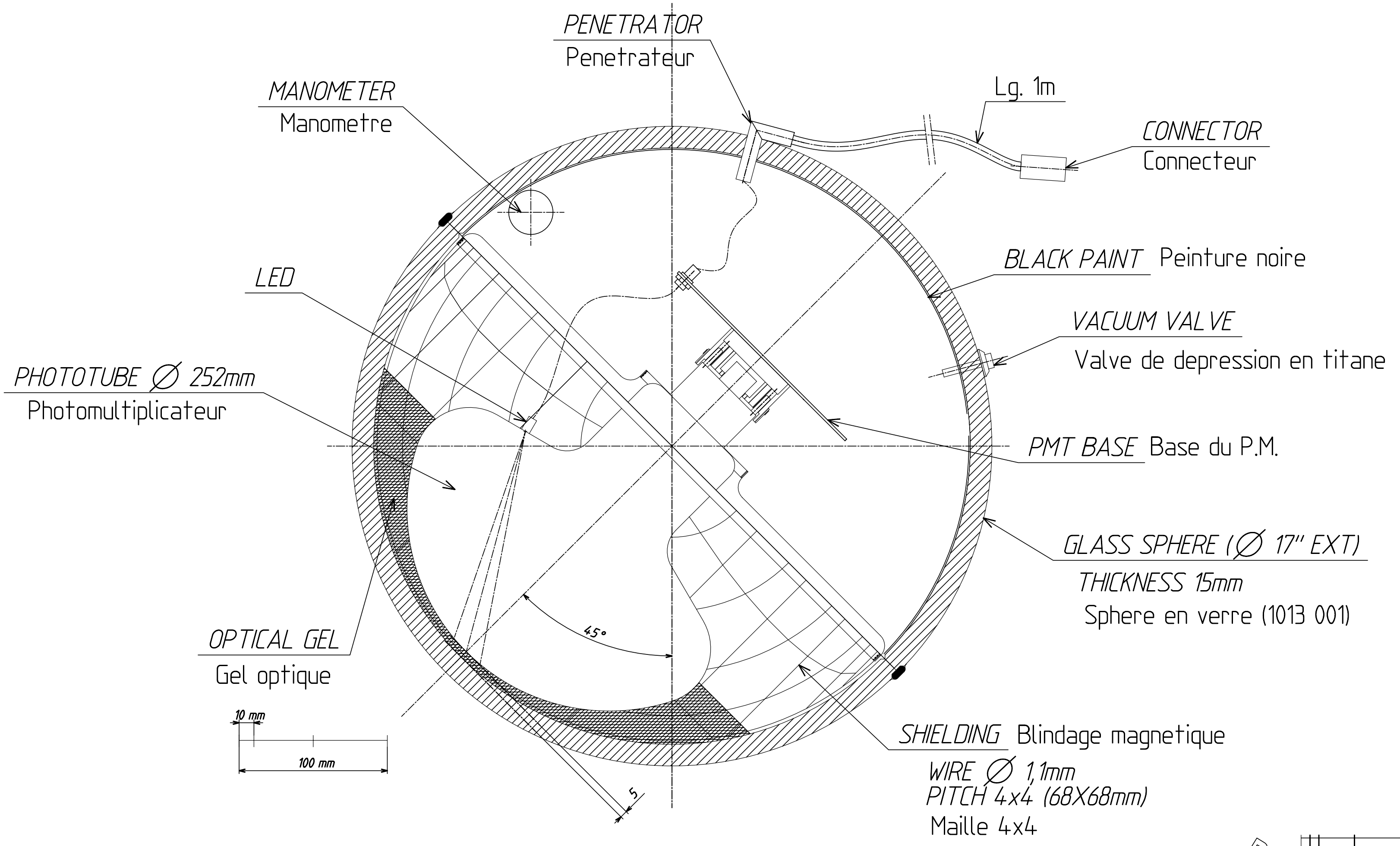
## Reference list

http://antares.in2p3.fr/internal/deci-km2/tableaux/OMS.htm

| | |
|---|---|
| 3OMS-06-01A | Cahier de clauses techniques |
| 3OMS_0802A | Vibrational test procedures for OM |
| 3OMS-08-01A | Plan de tests de qualification des MO |
| 3OMS-08-03A | Tests en environnement des MO; séquences de tests |
| 3OMS-08-04A | Environmental tests report |
| 3OMS-00-03A | AMDEC des MO (Analyse des Modes de Défaillances et de Criticité = French for FMECA) |



POUR INFORMATION

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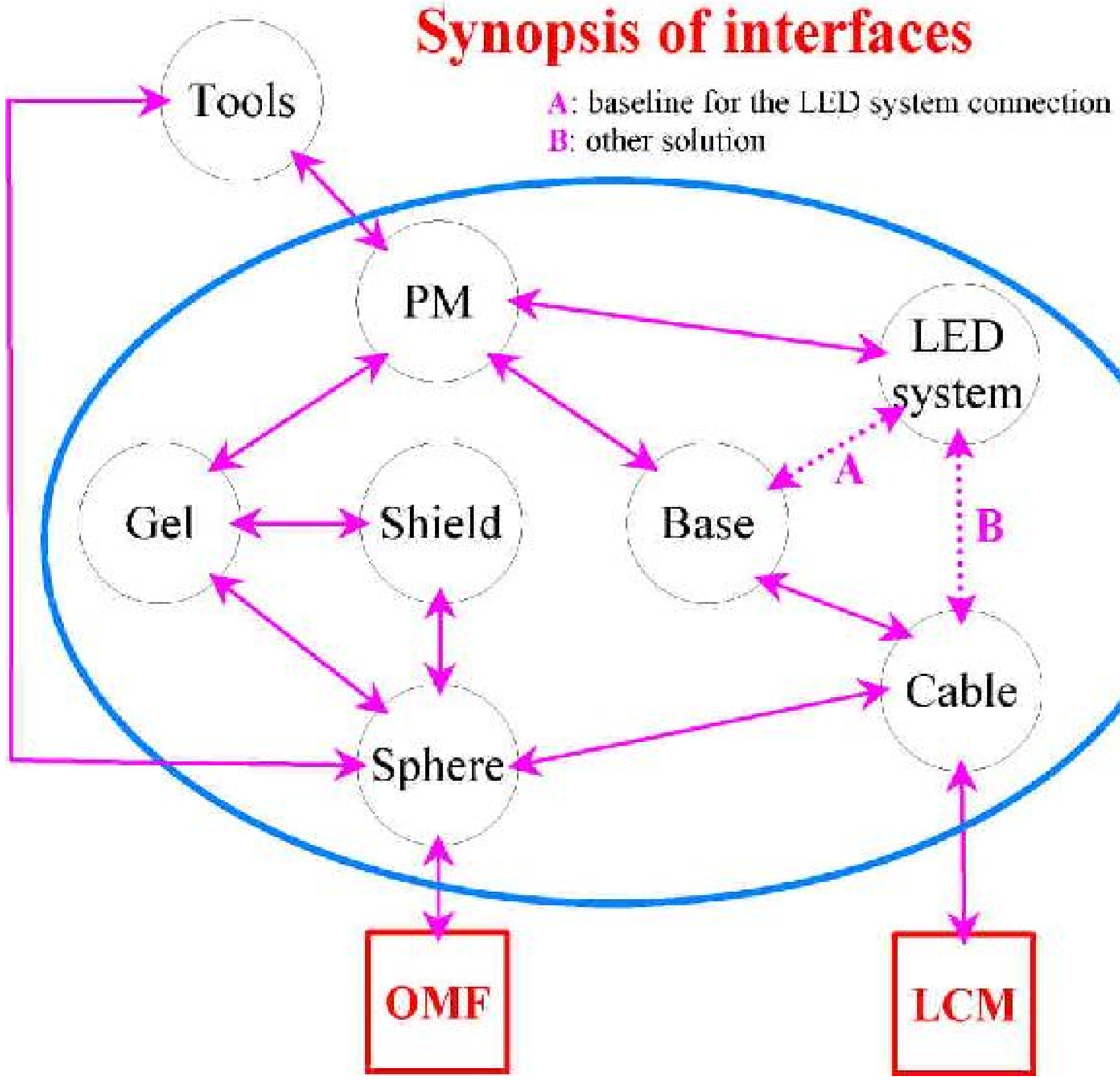
Synopsis of interfaces
A: baseline for the LED system connection
B: other solution
Tools
PM
LED system
Gel
Shield
Base
A
B
Cable
Sphere
OMF
LCM

| *Object in subsystem* | *Description* | *PBS number* | *test protocol* |
|---|---|---|---|
| Glass sphere | External envelope of the Optical Module | 4.3 | |
| Photomultiplier | Light sensitive detector | 4.1 | 3-OMS-01-05-A<br>3-OMS-01-09 |
| Base | Power supply and output signals access | 4.6 | |
| OM-LCM link | Interconnecting cable between OM and LCM | 4.2 | |
| Magnetic shield | µ-metal cage | 4.4 | |
| LED system | Internal calibration system | 4.7 | |
| Gel | Glue and optical contact | 4.5 | |
| Tools | Tools for integration and tests | 4.8 | |

# PBS 4.3 Glass sphere

## Functions

- Housing of the internal elements of the Optical Module.
- Protection of these elements from the surrounding water pressure and other environmental constraints.
- Mechanical interface with the Optical Module Frame.
- Support of the penetrator allowing communication with the outside world.
- Support of the manometer.

## Specifications

- The sphere must withstand high pressures: 260 bars when immersed and 700 bars as specified in qualification tests.
- It must be water tight.
- The size must be sufficient to house a 10-inch spherical photomultiplier and its electronics.

The sphere is made of transparent material; the requirements on its optical properties are:

- transmission > 87% for wavelengths greater than 400 nm.
- refractive index as close as possible to those of seawater and of the photomultiplier glass window, to minimise losses by reflection.

## Description

The glass sphere selected is a commercial product from Nautilus (VITROVEX® sphere). It is made of 2 hemispherical parts, with an outer diameter of 17 inches, and wall thickness of 15 mm. The precise grinding of the interface plane ensures water and air tightness. The material is a low-activity borosilicate glass, with a refractive index of 1.47.

The sphere is guaranteed to be fully resistant to corrosion, as well as to be chemically, electrically and magnetically inert.

One hemisphere supports the10-inch photomultiplier and the magnetic shield. They are glued together with an optical gel. This part is the eye of the detector.

The other hemisphere contains the following objects :

- the penetrator
- the titanium vacuum port, which is the only metallic part added to the glass sphere; it allows the sphere to be pumped out to establish an internal underpressure when the two hemispheres are assembled.
- a manometer to check the internal pressure at assembly time.

To reduce the sensitivity to photons hitting the back of the Optical Module, the inside of this hemisphere is covered with black paint (except for small areas for the manometer and the identification labels).

Once the hemispheres have been prepared, the base in one hemisphere is connected to the PMT in the other hemisphere, the two hemispheres are joined together, and their relative orientation is adjusted according to marks. A slight underpressure (-200 mbars) is established in the sphere in order to facilitate the remaining operations and to stabilise the OM during the transportation and subsequent integration phases.

After a final set of electrical tests, one layer of sealant mastic and 3 layers of adhesive tape are applied on the equatorial join. The final product, the Optical Module, will be treated as a single object throughout its subsequent integration into one of the detector lines.

A set of tests on implosion have been performed on spheres.

## Description of interfaces

- Glass sphere ↔ OMF

The sphere is fixed to the Optical Module Frame (OMF) via a wire mesh. The requirement is that in front of the photocathode, the segment of the sphere corresponding to a half-aperture of 60° must be free of shadows. The optical module is oriented such that the photomultiplier is looking 45° downwards from the horizontal plane. The penetrator and the vacuum port are used to position the Optical Module in its Frame with a tolerance of ±1°.

- Glass sphere ↔ Cable

The penetrator goes through the sphere through a hole (Ø 20.5 mm). In a small region (Ø 34 mm) around the hole, the surface of the sphere is flattened. Water tightness is ensured by a single O-ring.

- Glass sphere ↔ Gel

The key point is the quality of the contact (optical as well as mechanical) between the sphere and the gel. The glass must be free of dust and grease.

- Glass sphere ↔ Magnetic shield

Any contact between the glass and the wires of the magnetic shield is a potential starting point for bubbles. Hence, small stops are glued on the inside of the sphere, near the equatorial join. They are used to support the magnetic shield during the gluing phase.

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### List of References

3-OMS-03-03-A CCTP pour l'appel d'offre de fourniture de sphères haute pression

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# Implosion tests

We investigated the damages produced on the string by an accidental implosion of an OM by provoking a set of implosions of empty 17" Benthos spheres, between 1800m and 2600m depth. The conclusion is that such an event will cause the two other spheres of the same storey to implode about 4 ms later, but will leave undamaged a storey located 12m away and the string itself will not be broken by the implosion.

In addition, we observed in the 2600m depth case some limited distortions on the titanium OMF and heavy damages inside the LCM of the storey where the implosions occured. So a string could be recovered as a single piece after an implosion and possibly repaired.

More details about the implosion tests can be found in two reports (here and here).

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## List of references

| | |
|---|---|
| M. Orr and M. Schroemberg | Acoustic signature from deep water implosions of spherical cavities,<br>J. Acoust. Soc. Am., Vol. 59, No 5, May 1976. |
| P.W. Gorham et al | Mechanical and Acoustic Studies of Deep Ocean Glass Sphere Implosions<br>J. Acoust. Soc. Am., 1998 |

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# PBS 4.1 Photo-multiplier

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The photomultiplier is the sensitive element of the detector. For the overall efficiency of the apparatus, it must have a collection area as large as possible and a light sensitivity as high as possible.

## Function

- Conversion of light to electrical signal.

## Specifications

- Sensitive area > 500 cm$^2$.
- Combined efficiency (quantum $\oplus$ collection) > 16 %.
- Amplification factor 2 x $10^8$ for high voltage < 2500 V.
- Peak to Valley ratio > 2.

The nominal working point will correspond to a gain of 5 x $10^7$; the specification includes a safety margin to account for possible ageing effects. The following requirements must be satisfied at the nominal gain:

- Transit Time Spread (TTS) < 3 ns (FWHM).
- Dark count rate (at a threshold of 0.3 SPE) < 10 kHz.
- Pre-pulse, late-pulse and after-pulse rates < 1%, 1% and 10%, respectively.
- Shape of the signal:
  - Rise time < 5 ns
  - FWHM < 12 ns

### Definitions of the secondary pulses

- pre-pulses: 20 ns - 5 ns before the true pulse front edge
- late-pulses: 10 ns - 50 ns after the true pulse
- after-pulses: 50 ns - 16 µs after the true pulse

## Description

After consideration of several promising candidates, the R7081-20 photomultiplier from Hamamatsu has been chosen. It has been extensively tested and found to be well matched to specifications.

This is a hemispherical tube, 10 inches in diameter, with a sensitive area of around 550 cm$^2$ and a 14-stage amplification system. The nominal gain is reached for a high voltage of about 2000 V. Systematic measurements of the main characteristics have been performed on a sample of 80 tubes. The full results can be found in: ANTARES-Opmo/2000-7.

## Description of interfaces

The detailed procedure for the gluing of the photomultiplier can be found in the technical note 3-OMS-05-02-A. When the assembly is completed, the photomultiplier interfaces with the optical gel, the LED system and the base.

- Photo-multiplier ↔ Base

The pins of the photomultiplier are plugged into the base. For additional mechanical strength, a roll of glue is deposited at the junction between the socket (integrated to the base) and the neck of the photomultiplier.

- Photo-multiplier ↔ Gel

The key point is the quality of the contact (optical as well as mechanical) between the photomultiplier and the gel. The glass of the bulb must therefore be free of dust and grease.

- Photo-multiplier ↔ LED system

The LED is glued on the bulb, so the key point is again the quality of the contact (optical as well as mechanical) between the LED and the photomultiplier. Careful cleaning is required.

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## List of references

| | |
|---|---|
| 3 OMS-01-03-A | C.C.T.P. pour l'appel d'offre de fournitures des photomultiplicateurs |
| ANTARES-Opmo/1999-001 | Photomultiplier specifications for the ANTARES project |
| ANTARES-Opmo/2000-7 | Test results of 80 10-inch Hamamatsu PMTs |
| ANTARES-Opmo/2000-8 | New test results on 5 10-inch Hamamatsu PMTs |

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# PBS 4.6 Base

## Functions

- Conversion of the input low voltage (48 V) to high voltage for the photomultiplier.
- Collection of the signals coming from the anode and dynodes 12 &14.
- Passive interface for the LED system in Option A.

## Specifications

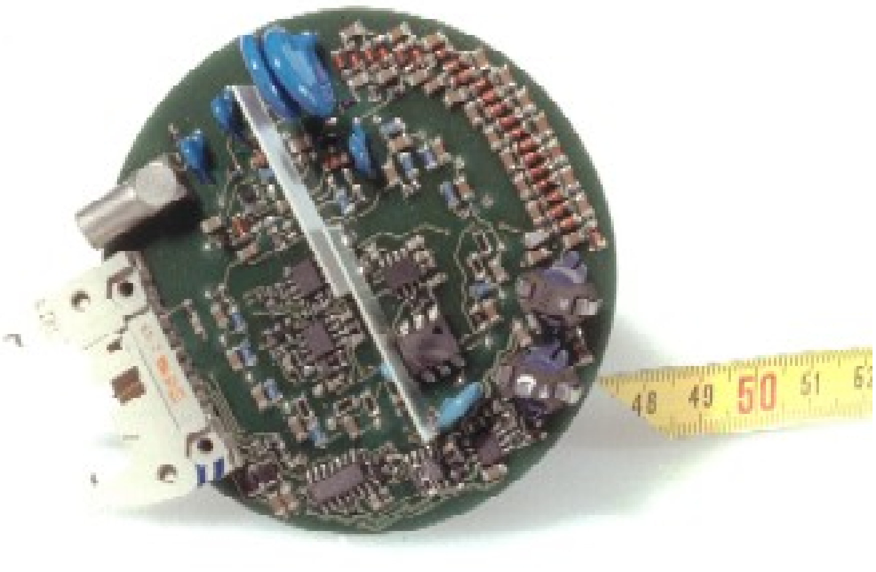
The main specifications are the following:

- High voltage between the cathode and the 1st dynode ($V_{KD}$) fixed at 800 V.
- High voltage between the 1st dynode and the anode ($V_{AD}$) adjustable in the range 500 - 1500 V.
- Pilot voltage for $V_{AD}$ scaled down by a factor 400 (1 - 4 V).
- Access to anode signals and signals from dynodes 12 and 14.
- Noise on outputs < 1 mV peak to peak.
- Recovery time after high count rate (1 MHz at the SPE level) < 0.5 s.
- Power consumption < 300 mW on load.

The detailed specifications can be found in technical note 3 OMS_06_01A.

## Description

The base is a circular printed circuit, 10 cm in diameter. It is connected to the photomultiplier via a 20-pin socket (JEDEC B20-102) directly soldered on the printed board.  Care will be taken to reduce the danger of high voltage discharges.



A prototype has been built by ISEG (http://www.iseg-hv.com) and tested by the collaboration.

## Description of interfaces

- Base ↔ Photo-multiplier

The pins of the photomultiplier are plugged into the base. For additional mechanical strength, a roll of glue is deposited at the junction between the socket (integrated to the base) and the neck of the photomultiplier.

- Base ↔ Cable

The wires of the twisted pairs are soldered on the printed board. Similarly, the cable shields are soldered to free pads for mechanical reasons (to strengthen the link between the base and the cable); these shields are kept floating at this end.

- Base ↔ LED system

In option A, the pulser and the base are linked by a cable, as short as possible, soldered on both ends.

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## List of References

| | |
|---|---|
| 3-OMS-06-01-A | CCTP pour l'appel d'offre de fourniture de bases alimentant des photomultiplicateurs. |

# PBS 4.2 OM-LCM link

## Function

- Bi-directional electrical link between the base and the Local Control Module (LCM).

## Specifications

- 1 shielded twisted pair, wire section 0.4 mm$^2$, for the power supply.
- 4 shielded twisted pairs, wire section 0.4 mm$^2$, 100 Ωimpedance, for signals and command.
- Length: 1.6 m, including pig-tails.
- Sheath corrosion-resistant.
- The cable terminated by a connector with water block on one end, and by a penetrator on the other end.
- Bulkhead matched to the connector, with a mechanical system to provide support and ensure proper electrical contacts.

## Description

The link is made by MacArtney (http://www.macartney.com), using connectors from Subconn (http://www.subconn.com). The full specifications with technical drawings can be found in 3-OMS-02-05-B.

## Description of interfaces

- Cable ↔ LCM

The cable is terminated by a 12-pin male connector. The pin-out is given in the following table:

| **Pin number** | **Connector cabling (plug and bulkhead)** | **Function** |
|---|---|---|
| 6 | TSP1.1 | 48 V supply |
| 7 | TSP1.2 | Ground |
| 4 | TSP2.1 | PMT HV control |
| 5 | TSP2.2 | PMT HV monitor |
| 2 | TSP3.1 | PMT anode |
| 3 | TSP3.2 | PMT dynode D14 |
| 11 | TSP4.1 | PMT dynode D12 |

| | | |
|---|---|---|
| 12 | TSP4.2 | Ground |
| 1 | Shield TSP3, TSP4 | Shield |
| 9 | TSP5.1 | LED pulser 12 V |
| 10 | TSP5.2 | Ground pulser |
| 8 | shield TSP1, TSP2, TSP5 | Shield |

This connector is plugged to a bulkhead fixed on the bottom tap of the LCM. The bulkhead is mounted through a hole (Ø 20 mm) with a single O-ring.

- Cable ↔ Glass sphere

The penetrator goes through the sphere via a hole (Ø 20.5 mm). In a small region (Ø 34 mm) around the hole, the surface of the sphere is flattened; water tightness is ensured by a single O-ring.

- Cable ↔ Base

The wires of the twisted pairs are soldered on the printed board. Similarly, all the drains of screens are soldered to free pads, but only for mechanical reasons (to strengthen the link between the base and the cable), these screens will be kept floating at this end.

- Cable ↔ LED system

In option B, the dedicated twisted pair coming from the penetrator is terminated by an appropriate connector to fit on the pulser. This is the preferred solution for the integration of the optical module.

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## List of References

3-OMS-02-04-B CCTP - Fourniture des liaisons d'interconnexions Module Optique - LCM

3-OMS-02-05-B Optical Module link

# PBS 4.4 Magnetic shield

The Earth's magnetic field influences electron trajectories between the photocathode and the first dynode. This phenomenon degrades the uniformity of the photomultiplier response. A magnetic shield has been developed and built in order to reduce this effect.

## Function

- Attenuation of the Earth magnetic field in the volume occupied by the bulb of the photomultiplier.

## Specifications

- Dimensions adapted to avoid contact with the glass sphere and to be as far as possible from the photocathode.
- Magnetic field attenuation factor as large as possible (at least 2).
- Shadowing effect on the photo-cathode area as small as possible.

## Description

The magnetic shield looks like a cage. Since the last two criteria act in opposite direction, an optimisation of the diameter of the wire and the size of the mesh was done, leading to the choice of a 1.1 mm diameter wire and a mesh of 68 mm x 68 mm.

The cage is made of 2 parts : a hemispherical part which covers the entire photocathode of the photomultiplier (outer diameter 395mm, height 199 mm) and a flat part outer diameter 395 mm, height 30 mm) with a hole in its centre to allow for the photomultiplier neck to fit through. An adhesive strip is added at the junction of the two parts.

The material used is μ-metal (77% Ni, 15% Fe, plus Cu and Mo) with a very high relative magnetic permeability (between 50000 and 150000).

## Description of interfaces

- Magnetic shield ↔ Glass sphere

Any contact between the cage and the glass is a potential starting point for bubbles. In order to avoid these contacts when it is immersed in the gel, the cage is supported by small stops glued on the glass sphere, near the equator. These stops also ensure the proper positioning of the cage between the sphere and the photomultiplier.

- Magnetic shield ↔ Gel

The risk is the appearance of bubbles. The best results are obtained by cleaning the cage in an ultrasonic alcohol bath, then outgassing it, before inserting it in the gel in the glass hemisphere.

## List of References

| | |
|---|---|
| ANTARES-Opmo/2000-10 | Effect of the mu-metal cages on the 10" Hamamatsu PMT |
| ANTARES-Opmo/2000-04 | Magnetic measurements of the ANTARES mu-metal cages |
| 3-OMS-04-01-B | Cahier des charges pour la fabrication des cages en mu-métal du 0.1 km$^2$ |

# PBS 4.7 LED system

The average transit time of the photomultiplier is one the ingredients for the global timing calibration of the detector. The LED system mesures the PMT transit time.

## Functions

- Measurements of the transit time of the photomultiplier as a function of the applied high voltage. This step is achieved during the calibration process.
- Monitoring of the transit time of the photomultiplier during data taking.

## Specifications

- Light intensity received by the photomultiplier limited to a few photon.
- Jitter of the light source trigger < 0.5 ns.
- Drift of the light emission delay < 0.25 ns per year.
- Preferably, it should be possible to record the transit time calibration data during standard data taking.

## Description

The light source is a blue LED powered and controlled by the pulser developed by the Sheffield group [3INS-03-01A]. This circuit has the required timing properties, but the light pulse generated has a high intensity: up to $10^8$ photons per pulse. Although the delivered intensity is adjustable by varying the power supply, the available range is too small; furthermore, working at reduced intensity degrades the timing properties. Reduction of the pulse intensity is therefore necessary for this application.

The required reduction is obtained in two steps:

- The LED is encapsulated in a black cap with a small hole (∅ 1 mm) drilled on the side of the cap to select a small fraction of the emitted light.
- The system is installed on the rear part of the photomultiplier, and the photocathode is illuminated through the thin aluminised layer deposited on the rear part of the bulb. This serves as an additional filter of high optical density.

This method has two advantages: the absence of a shadowing effect on the photocathode and a simple mechanical implementation. The uniformity and the reproducibility of the thickness of the aluminium layer have been checked with the manufacturer and by performing measurements. The conclusion is that differences exist, but they are small enough to be counterbalanced by adjustments, within reasonable limits, of the voltage applied to the pulser.

## Description of interfaces

- LED system ↔ Base

In option A , the pulser and the base are linked by a cable, as short as possible, soldered on both ends.

- LED system ↔ Cable

In option B, the dedicated twisted pair, coming from the penetrator, is terminated by an appropriate connector to fit on to the pulser. This is the preferred solution for the integration of the optical module.

- LED system ↔ Photo-multiplier

The cap is glued onto the glass. Special care is taken in order to have good optical coupling of the LED to the glass. The required positioning accuracy is about 1 mm. For additional mechanical strength, the pulser card is also glued onto the photomultiplier.

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## List of References

- ANTARES-Cali/2000-007 Conclusions of the Time Calibration Committee : the time calibration in ANTARES
- 3 INS-03-01 A Specifications and performance of the Optical Module LED pulser

Up Contents

# Remarks about Transit Time

## 1 Definition

The transit time is the time interval between the arrival of the photon at the photo-cathode and the detection of the corresponding current pulse at the anode. It can be split in 2 components: the first one is the time needed for the emitted photo-electron to reach the first dynode (collection process), the second is the time needed to go through the cascade of dynodes up to the anode (amplification process). For the 10" Hamamatsu at nominal high voltage, these two components are of the same order of magnitude with a value of about 20 ns.

## 2 Variability of transit time

Given the above definition, the transit time is determined by the velocity and trajectory of electrons. Hence, the parameters that can affect the transit time are:

- a) high-voltage
- b) wave-length (affects the modulus of the initial velocity of the photo-electron)
- c) magnetic field
- d) position of the impact point on the bulb
- e) direction of the initial velocity

Some are obviously uncorrelated with time: b,d and e. For the magnetic field, which is of course constant with time, a time-like effect can occurs because of the movements of the optical module induced by water current.

**Remarks:**

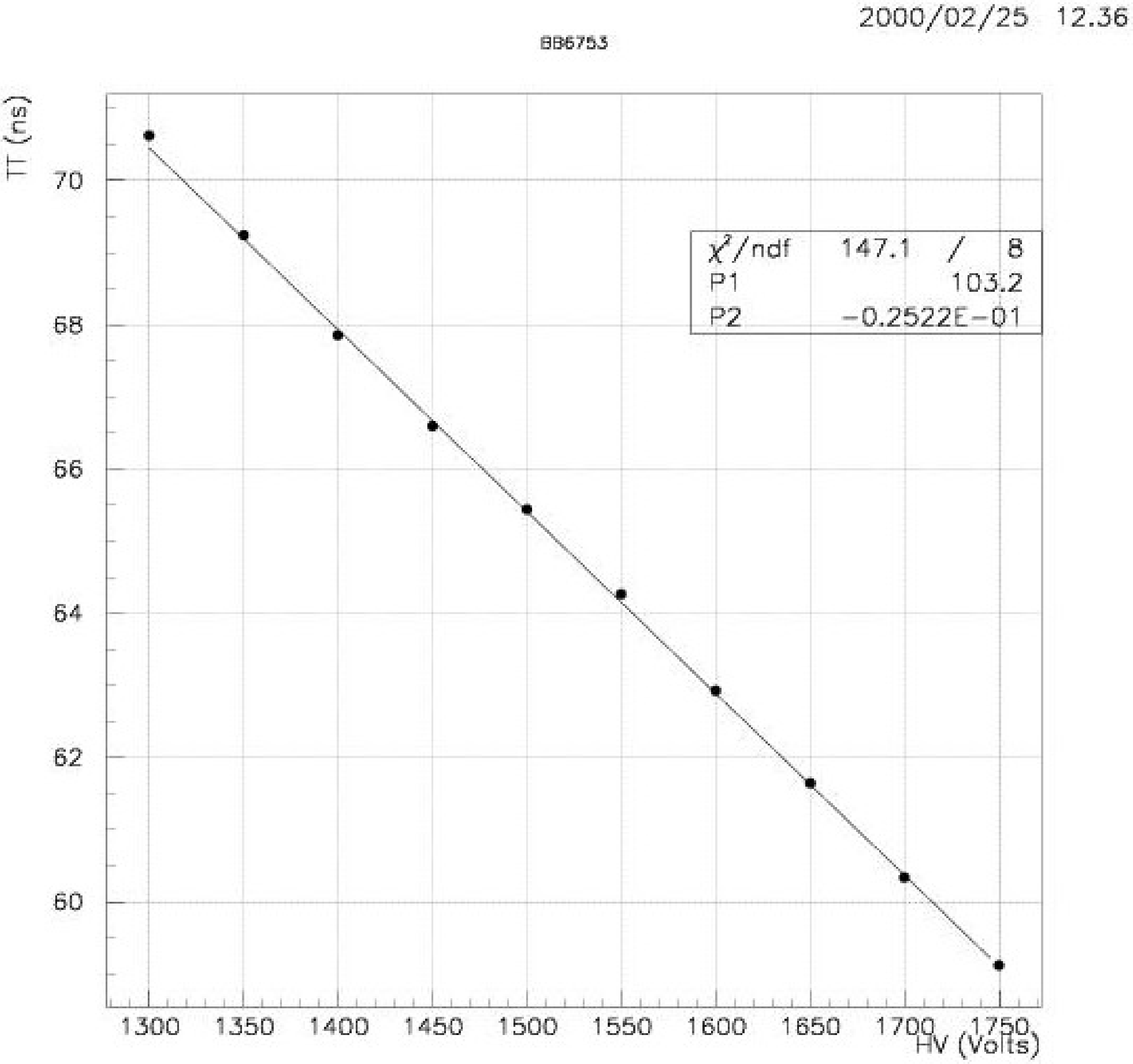
Effect b) is very small: differences of initial energy are fractions of eV, to be compared with the hundreds of eV acquired by the photoelectron at the level of the first dynode. Typically, the effect amounts to 0.1 ns per 100 nm.

The effect of c) is minimised by the μ-metal cage. No systematic study has been done, but measurements with and without cage give a difference of 0.5 ns on transit time. This is a very pessimistic upper limit of the effect.

Indeed, b), c) , d) and e) contribute to the dispersion of the transit time value.

We are left with a), the only parameter which can vary with time (incidentally or in a controlled way).

The variations of transit time as a function of high voltage have been measured on 3 O.M. of Line 5 (see figure below). For this example the slope is 2.5 ns per 100 V, with the standard value of high voltage between photo-cathode and first dynode (» 400 V).



**Transit time variation vs. high voltage**

This slope, already small, is reduced when 800 V is applied between photo-cathode and first dynode. Furthermore, the stability of the ISEG base is specified to be better than $2.10^{-4}$, hence the possible fluctuations of high voltage have no significant effects.

To be exhaustive, as we measure a global transit time (an averaged value on the whole photo-cathode), non-uniformity in the ageing of the first dynode, which modifies the global collection efficiency, can affect this averaged value. However, this is a very slow process and very small.

## 3 Dispersion of transit time: transit time spread (TTS)

As stated previously, even at a given working point, there are still variations of the transit time. The main contribution comes from d). We define the **<u>TTS</u>** as the FWHM of the distribution of the TT, the PMT being at a fixed high voltage and uniformly illuminated at the level of one photoelectron.

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# PBS 4.5 Gel

## Functions

- Optical link between the photomultiplier window and the glass sphere.
- Mechanical link between the sphere, the photomultiplier and the magnetic shield

## Specifications

- The refractive index of the optical gel has to be as close as possible to those of the glass envelope and the photomultiplier window (in order to reduce Fresnel losses)
- Its transmission in the wavelength range 400 - 500 nm must be above 85 %.
- It should be elastic enough to absorb shocks and vibrations induced by transportation and deployment, as well as shrinkage of the diameter of the glass sphere due to the high external pressure.
- Its optical and mechanical properties must be stable over a 10-year period.

## Description

The material chosen is Silgel® 612 A/B from Wacker. It is a two-component silicon rubber that cures at room temperature. After a period of studies to solve the problem of the appearance of bubbles, a safe procedure has been established. In this procedure, the gluing phase is performed in 3 steps :

1. The 2 components of the silicon rubber gel (900 ml each) are poured inside the glass hemisphere. The mixture is then out-gassed alone.
2. The m-metal cage and the photomultiplier, properly cleaned, are positioned very slowly in the gel and all the entities are out-gassed at about 1 mbar until all bubbles have disappeared. Optimum outgassing is obtained when this operation is repeated 3 times, for 3 minutes each time, with air entry between each operation.
3. The gel is left to polymerise at room temperature during a minimum of 4 hours.

After polymerisation, the essential optical and mechanical properties of the gel have been measured :

- refractive index : 1.404
- transmission > 88% for wavelengths in the range 400-700nm
- elasticity: the displacements (measured with a special tool) guarantee a damping factor sufficient to protect all components from the stresses occuring during transportation; these values do not evolve with time.

## Description of interfaces

- Gel ↔ Photo-multiplier

The key point is the quality of the contact (optical as well as mechanical) between the photomultiplier and the gel. The glass of the bulb must therefore be free of dust and grease.

- Gel ↔ Glass sphere

Again, the key point is the quality of the contact (optical as well as mechanical) between the gel and the glass sphere. Careful cleaning is required.

- Gel ↔ Magnetic shield

The risk is the appearance of bubbles. The best results are obtained by outgassing the cage, after a meticulous cleaning in an ultrasonic alcohol bath.

# PBS 4.8 Tools

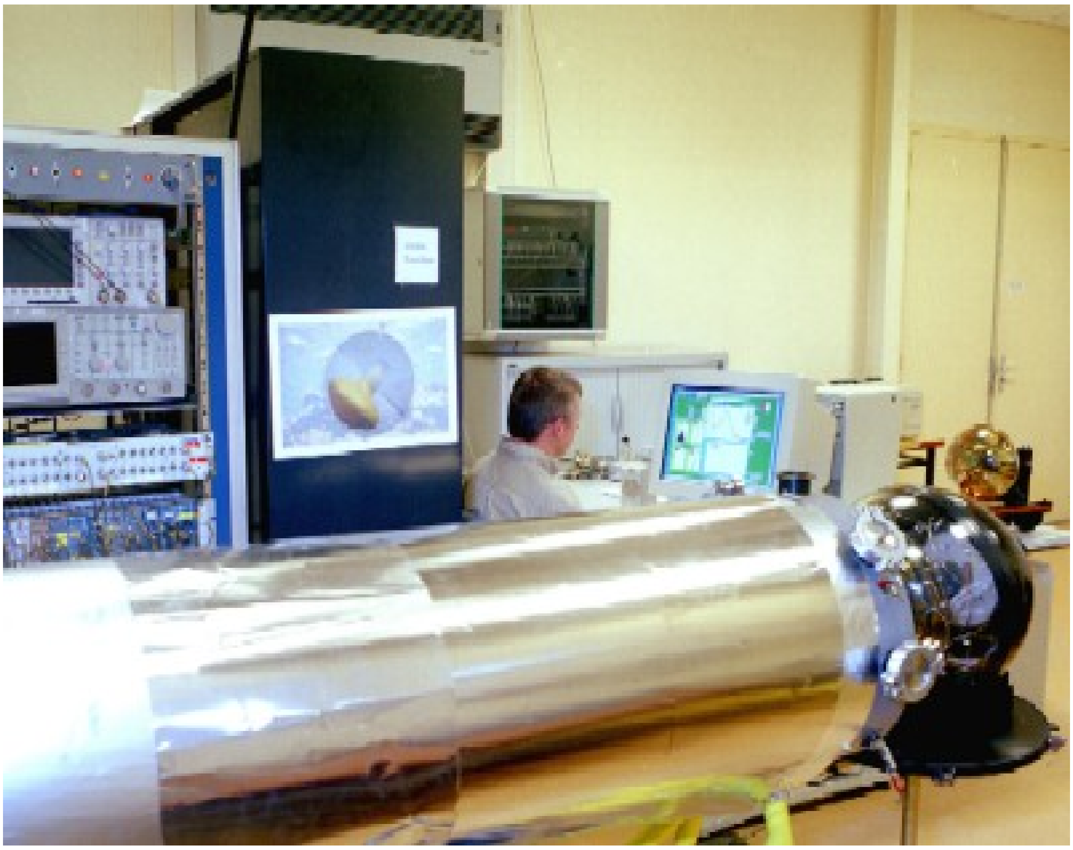
## The assembly tool

In this picture, the photomultiplier and the cage are glued in the hemisphere, waiting for polymerisation of the gel.

The lower hemisphere is positioned on the support, and the horizontality of its equator is controlled, and the label is used to define the rotation. The hemisphere is held by suction.

The orientation of the photo-multiplier around the vertical axis is defined by the supporting tool

## The photomultiplier test-bench



The cylinder in the foreground is the "black box" in which the photomultiplier is tested. It is surrounded by a µ-metal sheet. On the right, one can see an Optical Module ready to be introduced in the cylinder. A blue light source is situated at the other end of the cylinder.

The main characteristics of the photomultiplier are measured by the data acquisition program (LabView®) and stored in a data base.