Report M001

Pupil Plane Combiner
Slab and Spacers Requirements

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Preface

The COAST research group (Cambridge Optical Aperture Synthesis Telescope) from the Cavendish Laboratory, University of Cambridge, is working on the design of a new beam combiner for an astronomical interferometer.

The concept is a 4 way-in, 4way-out combiner. The basic layout of the combiner is described.

The aim of this document is to present the slabs and spacers requirements for this beam combiner layout.

Chapter 1

Introduction

1.1 Measuring visibilities

An astronomical interferometer combines the light from several telescopes on a single instrument.

One way of combining the collimated light beams (diameter : 18 mm in our case) coming from different telescopes is to use beam splitters. As in a table-top Michelson interferometer, the intensities of the output beams are a function of the optical path differences between the beams.

In an astronomical interferometer, an optical path delay (OPD) is added to each beam before reaching the beam combiner. When the OPDs are time-modulated, temporal fringes are measured at the outputs. By carefully choosing the path modulation frequencies, it is then possible to retrieve the fringe pattern for each pair of beams and compute the fringe contrasts (also called *visibilities*).

Since the spectral band considered is quite large (up to about 50 nm, between 1.1 μm and 2.4 μm), the fringe packet is extremely small in the OPD space.

The visibility measurements can then be used to reconstruct an image of the star the telescopes are pointing at.

1.2 Visibility requirement

The visibility requirements are simply that the maximum allowable visibility loss inside the combiner due to the slabs and spacers geometry is 5%, and that the geometrical compensation of the coatings (see section 3.5) should not introduce more than 0.5% visibility loss.

This directly translates into a set of specifications for the slabs and spacers : any non-nominal thickness, angle or position will introduce a beam tilt, a beam shear and/or an optical path difference that will degrade one or several visibility measurement(s).

Three types of errors on the slab shape have been identified : see Fig. 1.1.

The requirements for the spacers derive from the specifications of several Fabry Perot etalons as explained in the following chapters. Likewise, three types of errors on an etalon shape have been identified : see Fig. 1.2.

A home grown ray tracing code has been used to compute the slabs and etalons requirements.

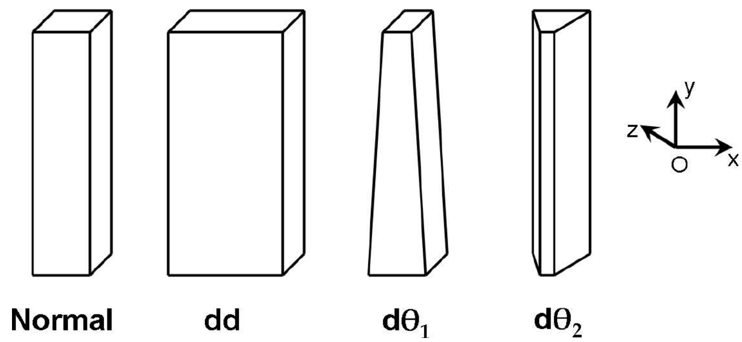

Figure 1.1: The 3 types of errors on the slab shape : thickness (dd), angle around Oz between the useful surfaces (dθ_1) and angle around Oy between the useful surfaces (dθ_2). The beams are travelling in the Oxy plane.

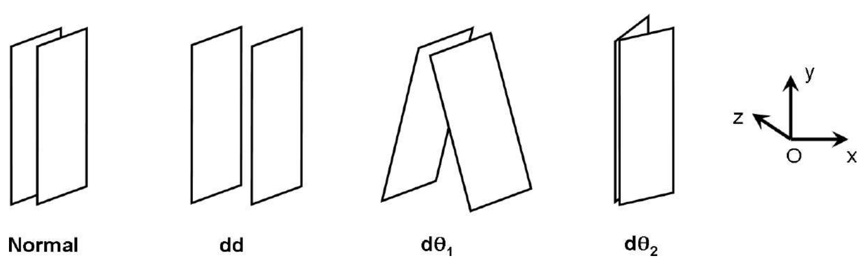

Figure 1.2: The 3 types of errors on an etalon shape : thickness (dd), angle around Oz between the useful surfaces (dθ_1) and angle around Oy between the useful surfaces (dθ_2). The beams are travelling in the Oxy plane.

Chapter 2

Slabs and spacers

2.1 Slabs

The length and thickness requirements for the slabs are presented in the next chapters.

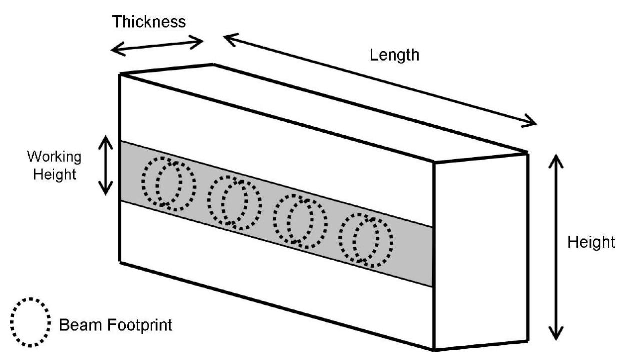

Figure 2.1: Slabs : geometry. The grey area represent the part of the surface that must be of optical quality.

The minimum height of the slabs is set by the size of the beams (see Fig. 2.1). The optical beams have a diameter of 18 mm. They all travel in the same plane. Therefore the working part of the slabs of optical quality must be at least 20 mm wide.

Spacers separate the slabs. Slabs and spacers are optically contacted. The height of the slabs should allow for the additional surface required to have the slabs and spacers optically contacted, while preserving the 20 mm strip of optical quality through which the beams will travel.

The two surfaces of the slabs the optical beams are travelling through must have a surface flatness of lambda/20 peak-valley (at 633nm) and have a cosmetic quality (scratch-dig) of 40-20.

The other surfaces do not need to be to be polished.

The bottom surface must be perpendicular to the left and right surfaces (the two surfaces through which the beams travel) to better than 1 degree.

The slabs must be highly transparent over a large spectral bandwidth (from 1.1 μm to 2.4 μm) hence the choice for the glass : Infrasil 301.

2.2 Spacers

The optical layout envisaged consists of two slabs and two mirrors separated with (and optically contacted to) glass spacers.

The pupil plane combiners layout can be considered as several stacked Fabry Perot etalons. The requirements for the spacers derive directly from the requirements on the Fabry Perot etalons.

The optical beams should not travel through the spacers. The role of the spacers is purely to set the distances between the surfaces of the etalons and to maintain them parallel.

The geometry of the spacers is left to the discretion of the glass manufacturer.

To comply with the thermal stability requirements of the combiners, the glass chosen for the spacers is : Zerodur Expansion Class 2.

Chapter 3

P4S combiner

3.1 Geometry

The layout of the P4S combiner is presented on Fig. 3.1 (top view). It is composed of 2 slabs and 2 mirrors. Four input beams (1, 2, 3 and 4 on Fig. 3.1) are combined and appear at each of the four output beams (I, II, III and IV on Fig. 3.1).

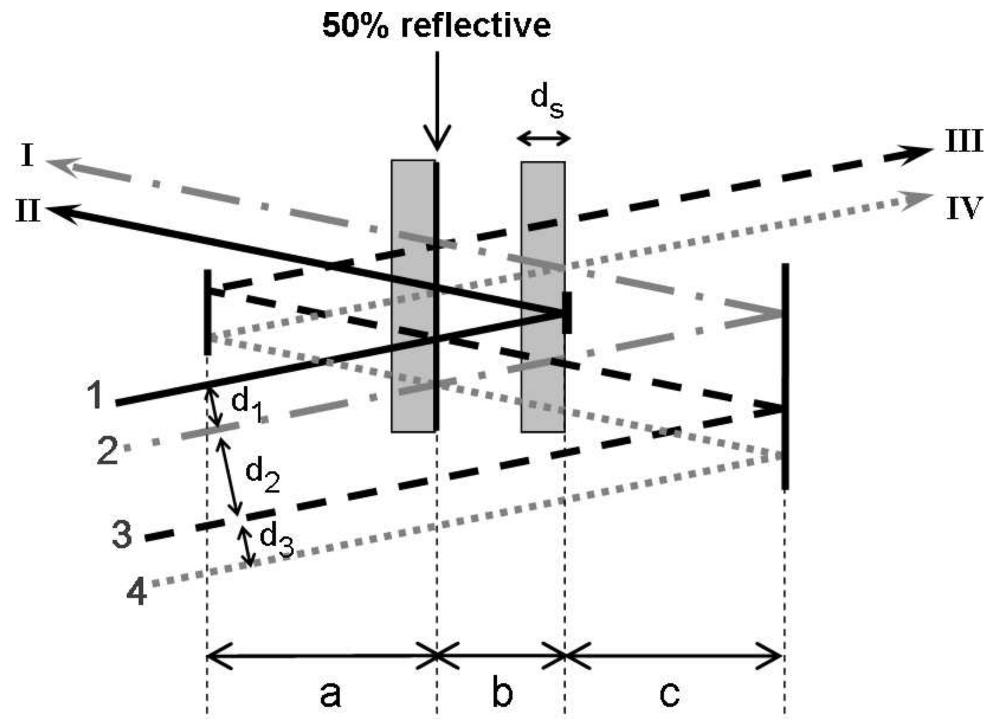

Figure 3.1: P4S beam combiner.

3.2 Parameters

The incidence angle of the beams is equal to $\theta = 15^o$. The layout has 3 free parameters :

- d_1 : the distance between beams 1 and 2,
- b : see Fig. 3.1,
- d_s : thickness of the slabs.

The other parameters can be computed from the formulae :

$$a = b + \frac{d_1}{2sin(\theta)} \tag{3.1}$$

$$c = \frac{d_1}{sin(\theta)} \tag{3.2}$$

$$d_2 = 2bsin(\theta) + d_1 \tag{3.3}$$

$$d_3 = d_1 \tag{3.4}$$

3.3 Blocks

It is possible to design a layout such that the thicknesses of the spacers are all multiples of the same smaller thickness (see Fig. 3.2) :

- $L_a = L_b + L_c/2 = kd_X$
- $L_b = ld_X$
- $L_c = md_X$

with k, l and m integers, and d_X a real number.

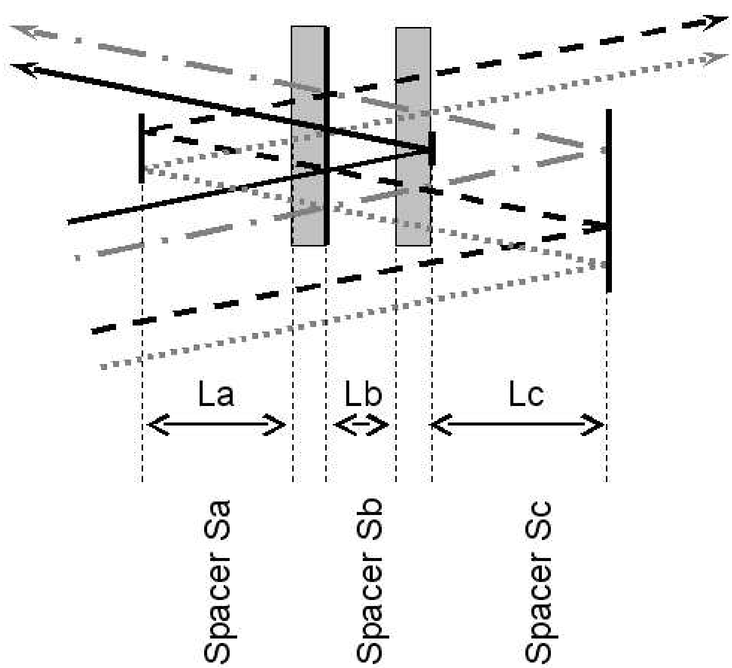

Figure 3.2: P4S Combiner - spacers.

From a practical point of view, this allows to use small identical *blocks* (thickness of the blocks : d_X) to build the spacers : spacer S_a is made of k optically contacted blocks, spacer S_b of l blocks and spacer S_c of m blocks.

With this type of layout, the thickness d_X of the blocks and the thickness d_s of the slabs are the free parameters. There are no requirements on the absolute thicknesses of the blocks or the slabs (only on the difference between the thicknesses of the blocks/slabs).

3.4 (2,1,2) layout

Such a layout with a reasonable slab thickness, based on the triplet $(k, l, m) = (2, 1, 2)$ and with the minimal block thickness d_X has the parameters (see Fig. 3.3) :

- $a = 194$ mm
- $b = 107$ mm
- $c = 174$ mm
- $d_s = 20$ mm
- $d_1 = 45$ mm
- $d_2 = 100$ mm
- $d_3 = 45$ mm
- $d_X = 87$ mm

Hence the length of the spacers :

- $L_a = 174$ mm
- $L_b = 87$ mm
- $L_c = 174$ mm

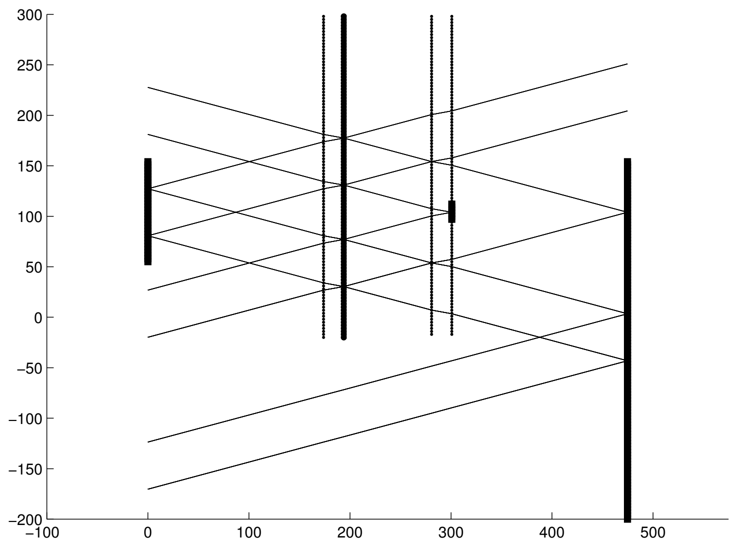

Figure 3.3: Ray tracing : (2,1,2) Layout. Minimal size. All units are in mm.

3.5 Coatings compensation

The equation presented in the previous sections do not take into account the coatings on the slabs and on the mirrors. To compensate for the additional path lengths introduced by the coatings, the spacers Sb and Sc (see Fig. 3.2) must be slightly smaller than the computed value from these equations. The exact thicknesses X_b and X_c that must be shaved of the spacers Sb and Sc will depend on the coatings design (order of magnitude : a few microns) : the lengths of the spacers Sb and Sc should actually be $(L_b - X_b)$ and $(L_c - X_c)$.

3.6 Tolerancing

3.6.1 Slabs

Both slabs have the same dimensions :

- Length : 230 mm ± 0.5 mm
- Height : see chapter 2
- Thickness : d_s - in range 10mm - 30mm

The vendor may choose any value of d_s in the range 10 mm - 30 mm to minimise the overall cost needed to meet the other requirements. All things being equal, smaller values of d_s are desirable.

See table 3.1 for the glass slabs requirements.

	dd	dθ_1	dθ_2
max	–	1.2 arcsec	1.3 arcsec
diff	0.6 μm	0.4 arcsec	0.4 arcsec

Table 3.1: Slabs requirements. max : maximum allowable error. diff : maximum allowable difference between slabs.

3.6.2 Spacers

Spacers separate the components.

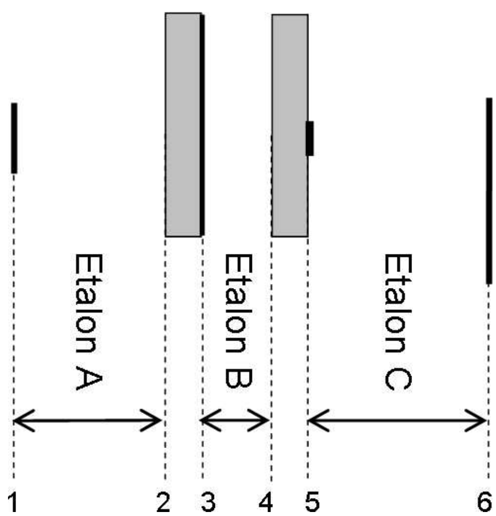

Figure 3.4: P4S beam combiner layout : 3 Fabry Perot etalons separated by glass slabs.

For the purpose of detailing the requirements, the layout can be considered as 3 stacked Fabry Perot etalons separated with glass slabs (see Fig. 3.4) :

- Etalon A : between surface 1 and 2
- Etalon B : between surface 3 and 4
- Etalon C : between surface 5 and 6

The optical layout presented in section 3.4 allows the use of small identical building blocks for each spacer : 2 blocks for spacer Sa (Etalon A), 1 block for spacer Sb (Etalon B) and 2 blocks for spacer Sc (Etalon C).

The requirements for the blocks are presented on table 3.2.

	dd	$d\theta_1$	$d\theta_2$
max	–	0.3 arcsec	0.3 arcsec
diff	0.9 μm	0.4 arcsec	0.4 arcsec

Table 3.2: Blocks requirements. max : maximum allowable error. diff : maximum allowable difference between blocks.

The vendor may choose any value of d_X in the range 85 mm - 150 mm to minimise the overall cost needed to meet the other requirements. All things being equal, smaller values of d_X are desirable.

As already stated in chapter 2, the geometry of the spacers is left to the discretion of the glass manufacturer.

3.6.3 Coatings compensation

A few microns will have to be shaved of spacers Sb and Sc (see section 3.5). The exact values X_b and X_c will depend on the coatings designs. The requirements on the accuracy for this reduction of the length of Sb and Sc is : 0.3 μm