Miniature Beam Combiners for optical and NIR Interferometers.

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ABSTRACT

One of the critical components of a separated element interferometer is the beam combiner. The initial alignment of the separate optical elements that make up this device and the maintenance of that alignment is usually problematical. Fibre optic devices provide an answer to the alignment difficulties but in single mode form have a restricted bandwidth. This paper discusses the design of a number of devices to overcome these short comings. These beam combiners can be small in size, their dimensions largely governed by the beam diameter. Large diameter beams are only necessary to reduce diffraction effects on the journey from the telescope to the beam combiner. On arrival the beam diameter can then be reduced to suit the beam combiner. Small, stable and low weight beam combiners are an advantage on the ground but even more so in space applications. Designs for combining the beams for large numbers of telescope are described.

Keywords: beam combiners, astronomical interferometers.

1. INTRODUCTION

A precise and stable beam combination system is essential for any interferometic array of telescopes using pupil plane detection. They usually consist of an arrangement of beamsplitters and mirrors, each component individually mounted on an optic table. The beam combining system of the Cambridge Optical Synthesis Telescope (COAST)[1] has fourteen separate, adjustable, components. Such a number is not atypical and often leads to difficulties in the initial alignment of the system and the maintenance of that alignment . The COAST system is fairly stable but needs to be checked and adjusted on a routine basis. For the next generation of arrays with many more telescopes or for space based instruments this could prove problematical. One solution to this maybe to combine the beams in a fiber optic system, however, for interferometry these will almost certainly have be single mode, polarization maintaining fibers. Such fibers almost by definition have a narrow bandwidth. This means that an instrument such as COAST, which can observe from the visible to near infrared would require a number of switchable fiber combiners adding to the complexity and cost of the system. A number of alternative beam combining systems are outlined in this paper for which the design criteria are outlined below.

- Reliable operation
- Stability with time and temperature
- Wide optical bandwidth
- Minimum level of adjustment
- Possibility of combining 4 or more beams
- Ease of construction and cost
- Ease of alignment to the system
- Minimum of external components
- Low optical loss
- Small size

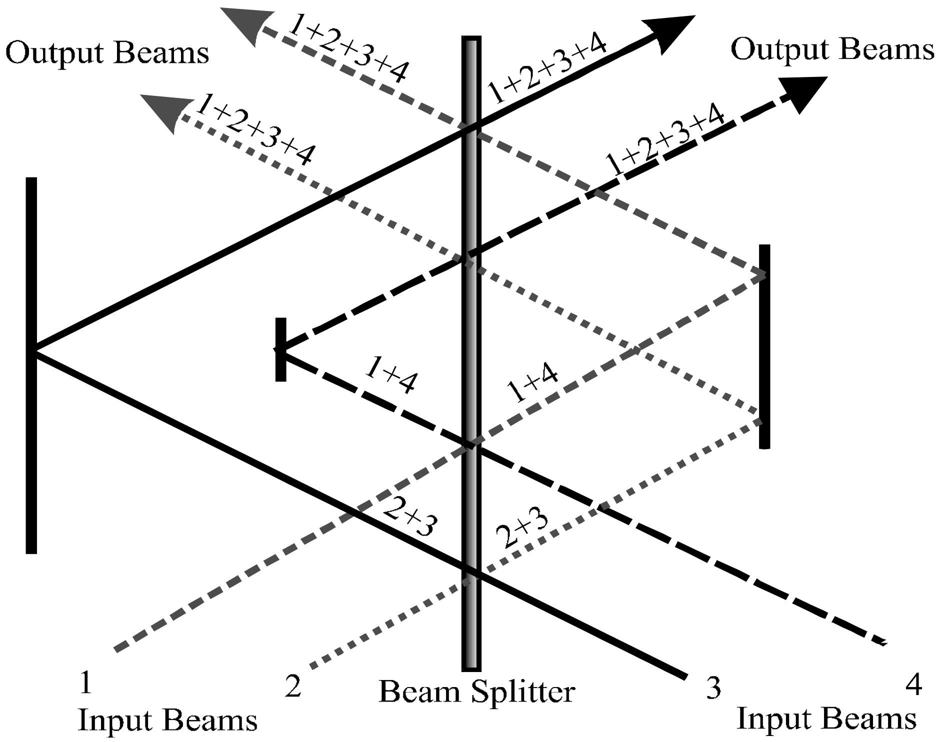
For obvious reasons the specification of these devices is based on the needs of COAST and its successor the Large Optical Array (LOA). In the present COAST system one inch (25.4mm) beams from four telescopes are combined such that four output beams are produced each containing quarter of the light from each of the telescopes. To ensure that any polarization effects are minimal the incidence angle of the beams upon any component is 10^0. Within the system there are four beam splitters, six mirrors and four dichroics, all individually adjustable. These devices occupy a space of approximately 1m by 2m on a optic table. Large diameter beams are only necessary to avoid diffraction effects on the long journey to the beam combiner and detector system. Once in the vicinity of the beam combiner the beam diameter can be substantially reduced.

The physical size of most beam combiners is directly related to the beam size, thus, reducing the beam diameter generally results in a corresponding reduction in the dimensions of the beam combiner. Unless taken to an extreme, small size would seem to offer the advantages of thermal uniformity, a compact overall system, low materials cost and lightweight, the latter only of real significance in space applications.

2. THE PARALLEL PLATE BEAM COMBINER

The parallel plate beam combiner is based on the principle that two beams entering a parallel system of mirrors at the same angle travel the same distance even if they one of them is reflected off an intermediate sub-mirror inside the system which is also parallel. This effectively means that if a system of accurately parallel mirrors and beam splitter surfaces can be manufactured and permanently locked together in some way a beam combiner requiring no internal alignment can be produced. External components will be required to launch the beams at the correct angle and position into the device. Such a system is shown in Figure 1. This device behaves exactly as the COAST beam combiner with four input beams being merged into four output beams each with a quarter of the light of the input beams. For clarity the beam angle of incidence shown is large, in practice this would be reduced to limit possible polarization effects. Diminishing this angle simply results in the device becoming proportionally wider and more squat.

Figure 1. The Parallel plate beam combiner



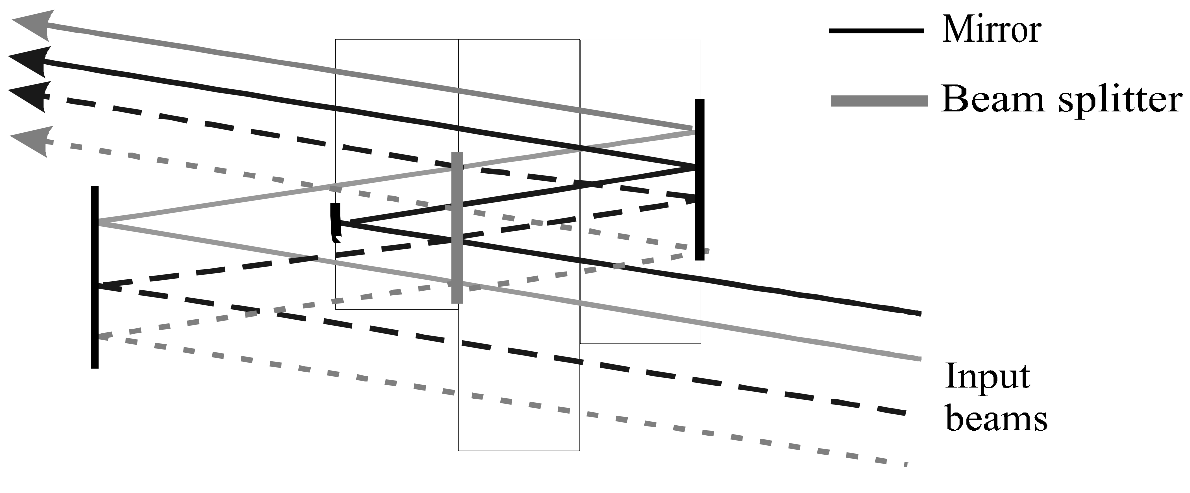
A four beam combiner can be constructed from three parallel sided pieces of glass with the appropriate thickness and coatings glued or clamped together. Once accurately made the internal alignment is then fixed and should remain correct as it is mechanically robust and expansion and contraction induced by temperature changes will simply rescale the whole device uniformly. To avoid any unforeseen problems it is prudent and no more difficult, to manufacture optics such as this from low expansion materials. Due to its simplicity, it is this type of beam combiner that we are presently constructing and hope to test in the near future. As previously stated the beam size largely dictates the dimensions of the device. If we reduce the beams to 2mm diameter and have 5mm separation between them with a beam incidence angle of 10^0 the resulting combiner can comfortably fit in a volume of 30mm by 60mm by 10mm. A much larger volume will of course occupied by the beam shrinking and launching optics.

The principle of parallel plate beam combination can be extended to many more than four beams. Using only three parallel plates it is possible to combine eight beams, although this means using different areas of the same surface as either a beam splitter or a mirror. If this does not prove practical or economic only one extra surface is required. Taken another step further , seven layers of glass are necessary to combine sixteen beams. Experience with COAST suggests that to combine more than six beams at once maybe counter productive as the number of photons per telescope per beam is being reduced to a level where their measurement is becoming difficult. However, the high resolution provided by interferometic telescopes often reveal rapidly changing phenomena, leading to a corresponding need for “snap shot” images. A solution to this problem is a large array of telescopes of which only a small sub-array are combined at any one time. This sub-array pattern is effectively rotated rapidly around the source by switching in or out other telescopes from the larger array. It may prove expedient to have all the telescopes permanently coupled to a single beam combiner and switch the unwanted telescopes out by simply blocking their beams. It should be noted that the number of internal reflections necessary increases with the number of beams combined resulting in a corresponding rise in system losses.

3. THE PARALLEL BEAM COMBINER

The parallel plate beam combiners described two slight drawbacks, the main one regards the ease of manufacture. It fairly difficult task to produce a piece of glass to the required parallelism for these devices but it is far more arduous to produce parallel sided glass, which at the same time has a specific thickness. The second drawback is rather minor in that the two groups of input and output beams diverge at large angles. In an attempt to circumvent these problems the parallel beam combiner was devised. This is shown in Figure 2. It will be seen that the device is constructed from three pieces of glass bonded together in such a way that the absolute thickness of each piece is not important as long as all three have an identical thickness. This is relatively easy to achieve by cutting all the segments form the same piece of glass which has already been made parallel. It will also be seen that the input beams are all parallel as are the output beams. A reduction in the complexity in the beam manipulation optics should result. The design shown does not contain all the reflections necessary within a single, multi segment, glass block. To achieve identical glass/air path lengths for each beam, an external mirror is required. Again mirror this still parallel to the main body of the combiner and two “units” of glass thickness away. Thus, with careful design other pieces cut from the parallel sheet can be used as precise spacers. The whole combiner system could be bonded to a glass base for stability and ease of mounting.

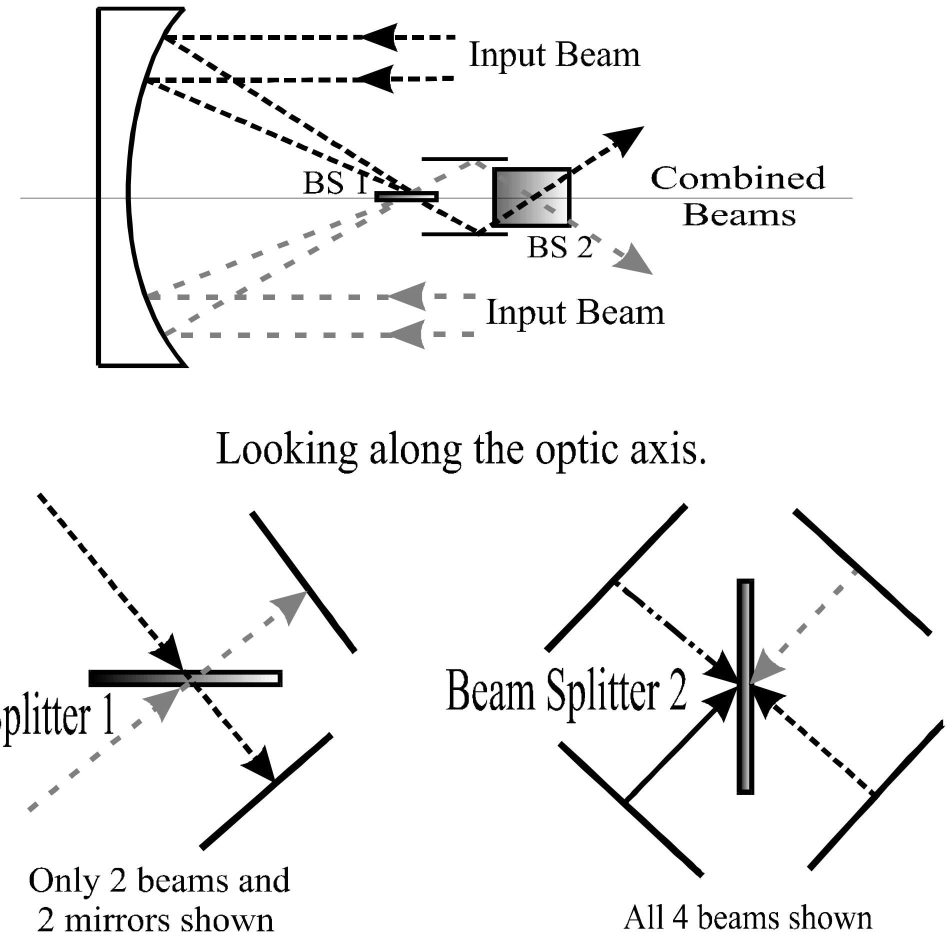
Figure 2. The Parallel Beam Combiner



4. “FOCAL PLANE” BEAM COMBINATION

Large diameter beams from the telescopes require size reduction optics if the combiner is to be compact. If the system is to be cover a wide range of wavelengths a reflective reducer is probably the best option and are usually based on Cassegrain telescope optics. Described here is a device which combines both the functions beam reduction and beam combination. Figure 3 shows the principle of operation. Although the device described is a four beam combiner, initially only two beams are shown to aid clarity.

Figure 3. The focal plane beam combiner



The large diameter, collimated beams from the telescopes are directed on to a parabolic mirror so that they are equally spaced on a circle drawn from the optic axis. This mirror then directs them to its focus where they meet a beam splitter placed at such an angle that pairs of beams are combined. With four beams, the angle of incidence each of the beams, looking along the axis of the mirror, is 45^0. The four pairs of combined beams leave the beam splitter and are each intercepted by a mirror which directs them back to the mirror axis where they meet a second beam splitter, at right angles to the first. At this point the incoming beam pairs are again merged so that the four output beams each contain a quarter of each input beam. Although this arrangement may sound complex it could, simply, be made from two beam splitter cubes bonded together with reflective areas on the faces of the cubes forming the mirrors. Once the beams pass through the focus of the parabolic mirror they begin to diverge again, this means that beam combiner should, ideally, be small enough to prevent this from becoming a problem. Beam splitter cubes with sides measuring only a few millimeters are commercially available indicating that such a combiner system could be made extremely compact. Although this not shown in Figure 3, the combined beams are intercepted by the secondary mirror of the beam reduction system and recollimated. The beams directed back past the combiner and through the central hole of the primary and on to the detection system. Both mirror must naturally be of interferometric quality, but such components are standard items. A device of this type can merge almost as many beams as can be equally spaced on the mirror. Unfortunately, the larger the number, greater the variation in angles of incidence on the beam splitter. Extreme angles will, almost certainly, lead to polarization difficulties. It maybe of interest to note that an odd number of input beams can be combined. In this case the number of output beams is twice the number of input beams. Within individual output beams some telescopes may not be represented, whilst in others embodied twice. As already stated, with a four beam combiner, the angle of incidence looking along the mirror axis is 45^0. However, looking from the side the beams have a angle of incidence largely determined by the focal length of the mirror. For this reason the mirror should have a high f number and the beam splitters be nonpolarizing. The initial combination of the beams is performed at the mirror focus dictating that the first beam splitter must be of a high optical quality. At present no work has been undertaken to establish the exact specification or the availability suitable beam splitters. The “focal plane” technique reduces the number of reflections and components as the beam reduction system is used to launch the beams directly into the combining optics. As a result such a system would be low loss, compact, lightweight and as a consequence, possess high thermal and mechanical stability.

5. SPATIAL BEAM COMINATION

By studying the geometry of the “focal plane” beam combiner it will be seen that in order for the beams to superpose correctly at the second beam splitter, the incoming beams must be placed on the parabolic mirror at an identical radius. If this is not the case the beams begin to diverge after the focal point. It is possible to design the system to enhance this effect so that beams on dissimilar radii can be combined and emerge separately. This would mean that the same optics could be used to combine the beams from a number of sub arrays of telescopes independently.

6. CONCLUSIONS

Although the wide band, miniature beam combiners discussed in this paper have yet to be tested and much development is probably required, there seems to be no apparent technical reason why they should not function as intended. The potential advantages seem to be significant as they offer both mechanically and thermally stability coupled with low optical loss. Their compactness, potential reliability and low weight are also advantageous but of particular interest in space applications. Once their initial development phase has been completed and a reliable manufacturing technique has been devised, combiners of this type may prove to be cheaper than conventional optics. Certainly a reduction alignment man hours should result. They may prove to be a step towards an interferometer array that can be called “ Common User”.

6. REFERENCES

1. J. E. Baldwin et al. “Design and performance of COAST”, SPIE Vol. 2200, Amplitude and Intensity Spatial Interferometry II, pp. 118-128, 1994.