The VLT Interferometer

I. Proposed Implementation

J.M. Beckers
D. Enard
M. Faucherre
F. Merkle

European Southern Observatory
D-8046 Garching bei München, FRG

G.P. Di Benedetto

Instituto di Fisica Cosmica, CNR
I-20133 Milano, Italy

R. Braun

Radiosterrenwacht
NL-7990 AA Dwingeloo, The Netherlands

R. Foy

Observatoire de Paris-Meudon
F-92195 Meudon Principal, France

R. Genzel

Max Planck Institut für Extraterr. Physik
D-8046 Garching bei München, FRG

L. Koechlin

Observatoire de Côte d'Azur
F-06460 St. Vallier-de-Thiey, France

G. Weigelt

Max Planck Institute für Radioastronomie
D-5300 Bonn, FRG

ABSTRACT

The Very Large Telescope Interferometer (VLTI) is one of the operating modes of the VLT. In addition to consisting of the four stationary 8 meter diameter telescopes, it includes a number of movable Auxiliary Telescopes which both complement the (u,v) plane coverage of the large telescopes and provide a powerful interferometric facility by itself (available 100 % of the time). We describe the current plans for the implementation of the VLTI. These plans will be finalized after the choice of the VLT site in 1990.

1. INTRODUCTION

The ESO Very Large Telescope (VLT) incorporates a number of different operational modes, including the operation as four individual 8 meter diameter telescopes, the operation in the combined incoherent focus as telescope of 16 meter equivalent diameter, and the operation as an optical interferometer using the combined coherent focus. In the latter mode the VLT will be assisted by a number of smaller Auxiliary Telescopes with 1.5 to 2 meter diameter (we will assume 1.8 meter in this paper unless mentioned otherwise), which will provide added (u,v) plane coverage. By additional contributions of some ESO member countries, it is expected that the number of Auxiliary Telescopes will be increased from the 2 included in the VLT proposal to at least 3, thus making the subarray of Auxiliary Telescopes a dedicated interferometer with a substantial capability in its own right. In an earlier paper in this conference Enard[1] gave a status report of the implementation of the VLT. This paper will focus on the interferometric mode of the VLT, referred to as the VLT Interferometer (VLTI).

Although older than astronomical interferometric imaging at radio wavelengths, optical interferometry is still in its infancy. The technical difficulties associated with the shorter wavelengths/higher frequencies and with the effects of atmospheric seeing, have prevented high-resolution optical interferometric imaging from achieving the rapid growth that occurred in the last 30 years in radio astronomy. These difficulties are now being rapidly overcome, resulting both in high resolution (speckle) interferometric imaging with large single aperture telescopes and in observations with interferometric arrays of telescopes with both small and large apertures.

Large aperture telescope, working in the so-called multi-speckle mode, are limited in their sensitivity for <u>broadband</u> interferometric observations[2] (signal-to-noise ratio SNR ,for sources unresolved by the individual telescopes, grows only as $D^{1/6}$ with the diameter D, or their sensitivity ≡ SNR^2 as $D^{1/3}$). Recent successful adaptive optics experiments at near-infrared wavelengths[3,4] gives confidence that the adaptive optics systems planned for the VLT 8 meter telescopes will allow them to be used in the single speckle mode. In that case the sensitivity for interferometric imaging increases as D^4 (or 400 between the large and Auxiliary Telescopes) since the noise (either readout noise or thermal background noise) in this wavelength regime (> 1.5 µm) is independent of D. Because of the wider applicability of adaptive optics to the infrared[5], and because of the relaxed tolerances in its implementation[6], the use of the VLTI at infrared wavelengths will be emphasized. However, because of the successful current use of both large and small telescopes for interferometry at visible wavelengths, because of the use for narrow band observations (where the sensitivity in the multi-speckle mode grows as D^2), and because of the anticipated gains in using "Partial Adaptive Optics" at the shorter wavelengths[7], the implementation of the VLTI will also include the visible wavelength region.

2. ASTRONOMICAL AND OPTICAL ASPECTS

Because of their impact on the design of the VLTI, it is important to review shortly some of the scientific aspects, astronomical as well as optical, of interferometry.

2.1 <u>Sensitivities</u>

We follow the formalism developed by Léna in summarizing the sensitivity estimates of the VLTI[8] for pointlike astronomical objects (= unresolved by the individual telescopes) at infrared wavelengths (see Paper IV[7] for visible wavelengths). Figure

1 summarizes the expected limiting magnitudes for the 8 meter telescopes, for the conditions listed, together with the fluxes for some astronomical objects of substantial current interest. The three sensitivity curves shown refer to the following situations:

CASE I Gives the limiting magnitude in case the radiation of the study object at the indicated wavelength is used to phase the individual telescopes by means of adaptive optics where needed (monochromatic adaptive optics using IR wavefront sensing). Adaptive optics is only required at the shorter wavelengths (≤ 10 µm). At the longer wavelengths it refers to the limiting magnitude for an exposure time equal to r_o/V_{wind}. For cophasing the apertures, also in the following two cases, the same exposure time has been assumed and the fringe visibility has been taken as unity. For this case the limiting magnitudes are aperture independent but seeing dependent. *This case applies to the entire sky*. Many interesting astronomical objects are included in this case, like NGC 1068, many stars and their (planetary?) companions, and protostellar and starforming regions

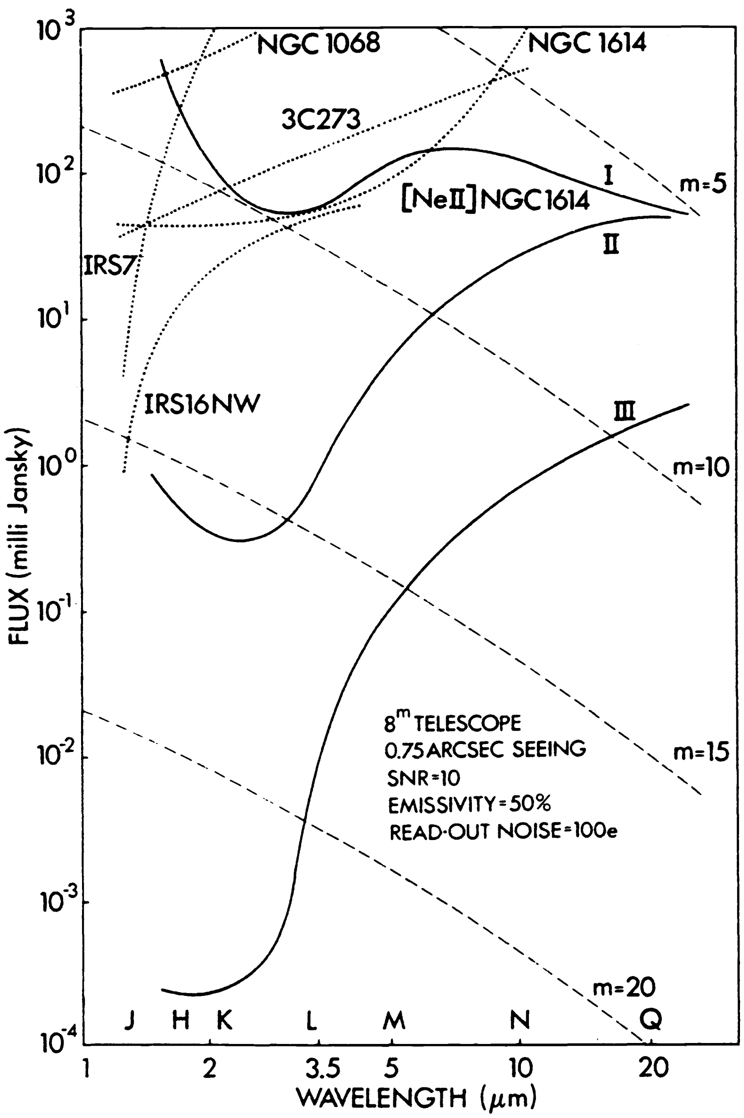


Figure 1 Sensitivity Estimates for the 8 meter VLTI Array (see text)

CASE II Assumes that phasing of the individual apertures is done by other means, eg by polychromatic optics[9], on another bright object within the isoplanatic patch, or on an artificial (laser) star[10]. Combining the former two at near IR wavelengths (2.2 µm) is predicted to lead to *almost full sky coverage within our galaxy*[5] for this case. For example, the bright IR object IRS 7 can be used for aperture phasing for studies of the central regions of the Milky Way (IRS 16). The limiting magnitudes are now determined by the photon flux (aperture dependent) and noise (aperture independent) of the object under study which is used at the same wavelength to cophase the apertures. It is therefore aperture dependent (sensitivity proportional to D^4). We have assumed the same exposure/integration times and fringe visibilities as in Case I.

CASE III Same as Case II except that aperture cophasing is done by other means, eg by cophasing at another wavelength ("polychromatic cophasing") and/or by using another bright object in the interferometer field-of-view. In this case exposure times much longer than r_o/V_{wind} can be used (10 minutes taken in Figure 1). This case is *limited to a small fraction of the sky* and is dependent on the interferometer field-of-view[11]. Nonetheless, it could include such objects as the center of the Milky Way (field-of-view > 6 arcsec), and the supergiants αSCO and αHER (field-of-view > 3 and 5 arcsec respectively) for which the low fringe visibility and the desire for narrow spectral bandwidth observations make this case attractive. Readout noise disappears as a factor contributing to the limiting magnitudes since integration times can be made long enough to overcome it. The sensitivity is determined entirely by background photon noise, and hence is still proportional to D^4.

2.2 The Need to Maintain High Fringe Contrast

The sensitivity estimates above assume unit fringe contrast. The actual fringe contrast is determined both by the image structure of the object and by instrumental effects. The former corresponds to the interferometer signal, the latter to the signal deterioration. It is important to maintain as high as possible a fringe transfer F as possible since the interferometer sensitivity is proportional to F^2. In another paper in this conference[6] the factors contributing to the fringe contrast transfer will be discussed. The present goal is to maintain F to 73 % or better, calibratable to 4 % or better.

2.3 The Need for a Wide Field-of-View

It is important to distinguish between the field-of-view of the individual telescopes needed for the adaptive optics wavefront measurements (needed for Cases II and III) and the field-of-view the of the interferometer (needed in Case III only). The wavefront sensing will be done at the so-called coudé focus of the 8 meter and Auxiliary Telescopes where the field-of-view has a diameter of 120 arcsec. The field-of-view in the combined coherent focus[11] is limited to a few arcsec depending on the size of the beamcombining optics, especially the delay line optics diameter. For the initial implementation of the VLTI we plan a field-of-view of 1 to 2 arcsec, possibly extending to 8 arcsec in the future. This field-of-view refers to arrays of identical aperture telescopes (either 8 meter or Auxiliary Telescopes). When combining telescopes with different size apertures for optimum sensitivity, the field-of-view automatically becomes restricted to little more than the size of the Airy disk[12].

2.4 The Need to Manage Seeing Inside the Interferometer

Ideally the light inside interferometers should be combined in a vacuum to eliminate seeing effects in the internal lightpath and so-called longitudinal chromatic aberrations due to wavelength variable pathlengths resulting from the refractive properties of air. However, practical considerations led us to propose to initially combine the beams in air. That implies strict control of the internal seeing and glass compensation of the longitudinal chromatic aberrations as described by Lacasse and Traub[13]. Seeing effects in interferometers can be divided in three parts:

(i) *Image Deterioration* by differential wavefront distortions across the lightbeam. Measurements of seeing[14] result in seeing estimates for a ≈ 200 meter long horizontal lightpaths in free air 2 meters above ground which are about a factor of 2 worse than the external seeing at the VLT sites (r_o(int) ≈ 7 cm at 500 nm wavelength vs r_o(ext) ≈ 14 cm). In evaluating the impact of this on interferometric measurements one has to take into account the demagnification M of the beam diameter. Without the use of adaptive optics one therefore should compare Mr_o(int) with r_o(ext), so that for the M = 100 taken for the VLTI the internal seeing effects are negligible. With the use of adaptive optics one should compare Mr_o(int) with D, so that in the near IR internal seeing appears just acceptable. It is however clear that care must be taken to manage internal seeing, and hopefully improve upon the free air seeing situation. In the case when wavefront sensing can be done in the combined coherent focus, the adaptive optics can of course be used to remove internal as well as external seeing effects. It may also be possible to relay the image of the wavefront sensing object in the coudé focus to the interferometric field-of-view, depending on its size, in which case internal seeing effects are always removed.

(ii) *Isoplanatic Patch Size Decrease* resulting from the angular magnification by M. The diameter of the isoplanatic patch equals approximately $.6r_o/d$, where d is the average distance to the seeing layer. For external seeing d(ext) equals the average height of the seeing, or typically maybe 5000 meters. For internal seeing d(int) ≈ 100 meters. One should compare r_o(int)/d(int) with Mr_o(ext)/d(ext) making the internal isoplanatic angle about one fourth that of the atmosphere above the telescope. This is therefore a serious potential limitation for Case II and III type applications. However, the limited interferometric field-of-view (1 to 8 arcsec) makes it impossible to use the entire isoplanatic angle, so that, at least in the IR, deviations of isoplanicity are therefore tolerable. Again careful internal seeing management is mandatory. The fact that for cophasing apertures the external isoplanatic angle for average wavefront variations is more likely to be .6D/d(ext) than $.6r_o$/d(ext) does not affect these conclusions.

(iii) *Coherence Time Decrease* can result when the internal seeing time scales are short compared to those of the external seeing. It would result in a decrease of exposure time and hence in a decrease of sensitivity. It is therefore necessary to shield the lightpath from wind motions.

The choice for airpaths inside the interferometer is therefore not as clearcut as one might wish. It is dominated by budgetary considerations, by the expectation that it will be possible to manage the seeing adequately, and by the real option to do the wavefront sensing (and cophasing) in the combined focus using image relay in the coudé focus.

2.5 The Need for High Time Resolution

With high angular resolution comes the need for high time resolution since many of the objects of interest are expected to change on the smaller scales, eg as the result of stellar rotation. Time resolution for the individual baselines can be made quite small; many baselines are however needed to do good interferometric imaging. These can be obtained by using many telescopes, by time synthesis, and/or by rapid reconfiguration of the Auxiliary Telescope array. Initially we propose to use 6 simultaneous baselines (4 telescopes) and the possibility of daily reconfiguration. As the VLTI progresses and as its calibration and metrology improves, it is anticipated that more rapid reconfiguration will become possible and that more baselines may be added, thus increasing the time resolution to a fraction of a day.

2.6 The Need for Polarization Control

As is the case with time variability, high angular resolution is likely to result in larger polarization effects. Many of the objects of interest to interferometric imaging are likely to show significant polarization. The control of instrumental polarization is also mandated by the need to maintain high fringe contrast transfer[15]. The VLTI design therefore includes polarization control both for instrumental and astrophysical reasons.

2.7 The Need for Wide Wavelength Coverage

Although the prime wavelength region of interest to the VLTI extends from 1.5 µm upwards, visible light observations are likely to command substantial interest in the VLTI especially when partial adaptive optics[7] become available. As will be seen later, it is unavoidable to include a substantial number of reflections (≈ 16) in each of the lightpaths because of the desire to use the 8 meter telescopes, to use adaptive optics, and to avoid polarization effects. That requires efficient mirror coatings, and eliminates for the time being the ultraviolet wavelength region. It is proposed to use enhanced silver coatings (Figure 2), which transmit the wavelengths above 420 nm.

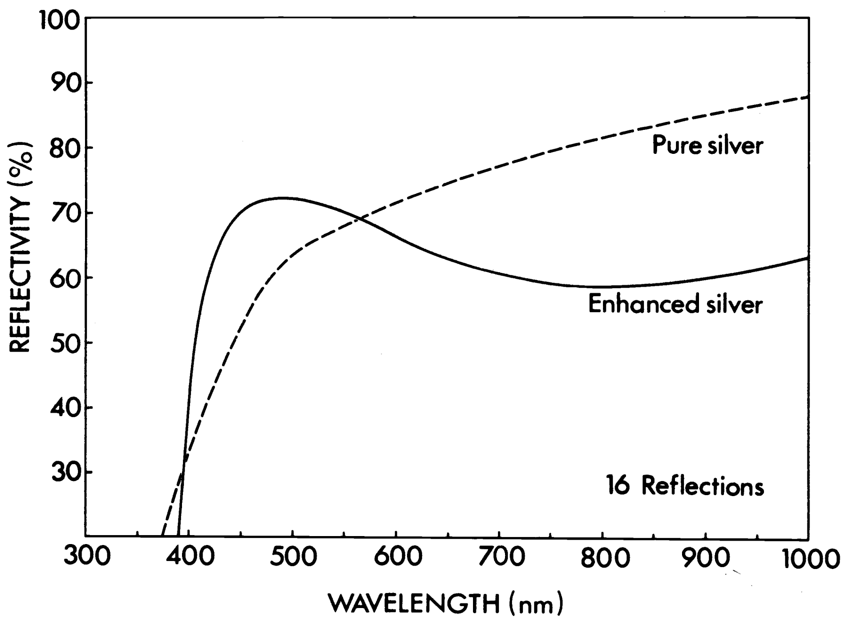


Figure 2 Reflectivity of 16 Surfaces Using Enhanced Silver Coatings

2.8 Other Science Considerations

The length of the interferometer baseline is of course a prime parameter in an interferometer. The VLTI will use baselines of up to approximately 120 meters. Longer baselines are desirable for higher angular resolution. More compact arrays are desirable, however, for fuller (u,v) plane coverage. Longer baselines also enhance problems in providing a wide field-of-view and in avoiding internal seeing problems. Except when used in the N-S directions, long baselines result in a need for longer and faster delay lines. At a later stage longer baselines (≈ 1000 meters) may therefore be added to the VLTI in approximately the N-S direction using small field-of-views only.

The sensitivities shown in Figure 1 refer to broadband observations (spectral resolution ≈ 10). Many interferometric observations will require high spectral resolution (3000 to 60000 at visible wavelengths, 200 to 8000 in the IR) with an equivalent decrease in limiting magnitude.

3. THE 8 METER TELESCOPE ARRAY

The VLT as an array of 4 identical eight meter telescopes on one site, will provide a unique large aperture interferometric capability, probably for a long time to come. In addition being located in the southern hemisphere it has optimal access to the galactic center, the Magellanic Clouds, and many other objects of interest. As already mentioned, their large aperture results in sensitivities orders of magnitude larger than those of other arrays. Even though it will be initially available only for a small fraction of the time for interferometric imaging, it is nonetheless important to emphasize the importance in optimizing the 8 meter telescope array for interferometry. As the techniques of optical interferometric imaging mature, one might anticipate the demand for the interferometric use of the 8 meter array to increase as the result of the need for the highest sensitivity and maximum number of baselines. We therefore describe the layout of the 8 meter telescope array first, it being the core of the VLTI.

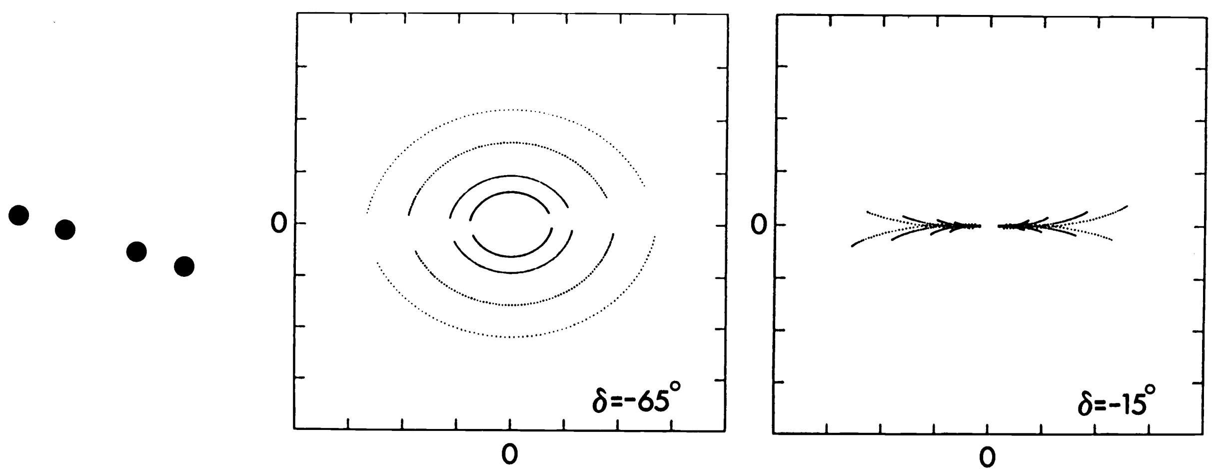


Figure 3 (u,v) Plane Coverage for the Linear Array Shown (tilted 15° to the E-W Direction) to the Left. Maximum Zenith Distance is 60°.

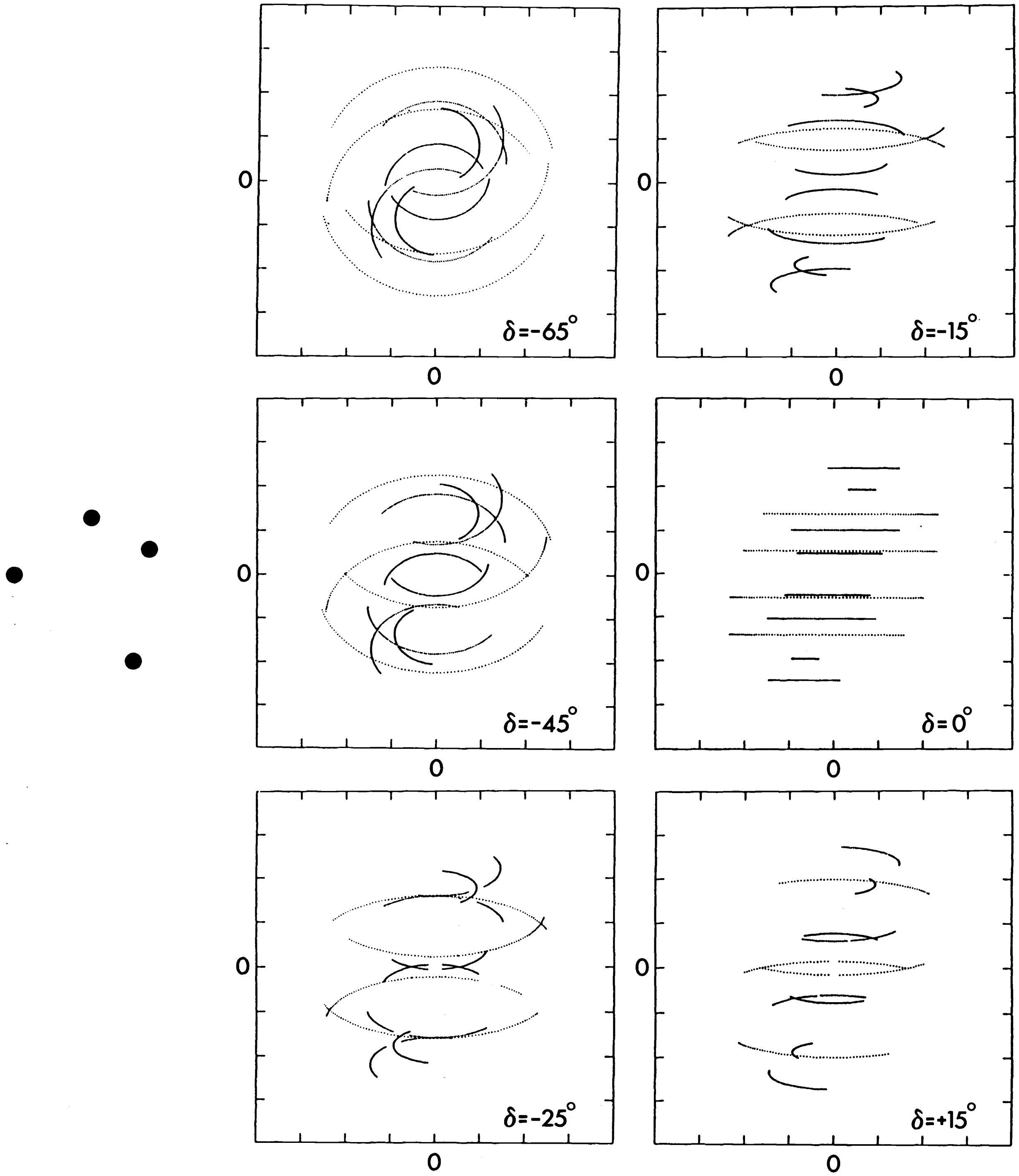
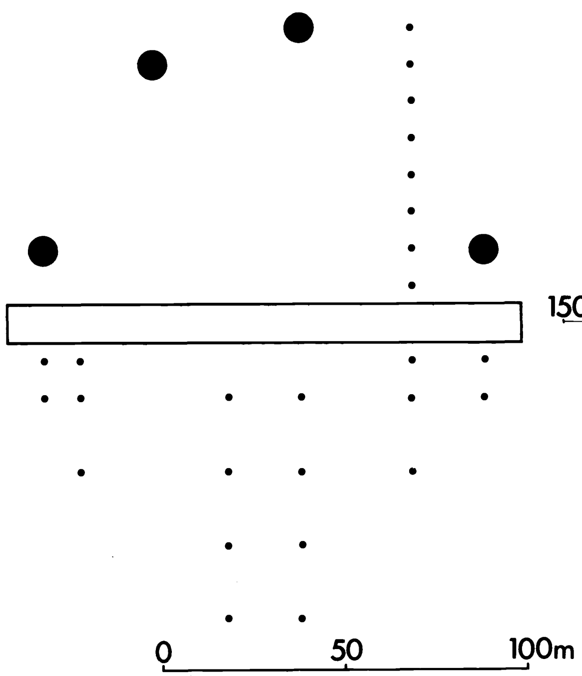


Figure 4 (u,v) Plane Coverage for the Trapezoidal Array Shown to the Left.

3.1 Array Configuration

As originally proposed, the 8 meter telescopes of the VLT are arranged in a highly redundant, linear, approximately E-W configuration, at right angles to the prevailing N-S wind direction. This results in a very limited (u,v) plane coverage with large "holes" especially in equatorial regions of the sky; 2-dimensional imaging becomes virtually impossible (see Figure 3). A major function of the movable Auxiliary Telescopes is, of course, the filling in of these holes. Because of their smaller aperture this can only be done at a lower sensitivity and also at the cost of the field-of-view.

From the point of view of interferometry a non-redundant, 2-dimensional configuration of the 8 meter telescopes is therefore much to be preferred. After examining different options, we propose to arrange the telescopes in a quadrilateral configuration in the shape of a trapezium, derived from configurations proposed by Cornwell[16]. Figure 4 shows the (u,v) plane coverage resulting from such a lay-out. In such a configuration the base and roof of the trapezium would be placed at right angles to the wind direction, and the two telescopes at the roof placed close together to give a short baseline and to minimize their wind effects on the base telescopes.



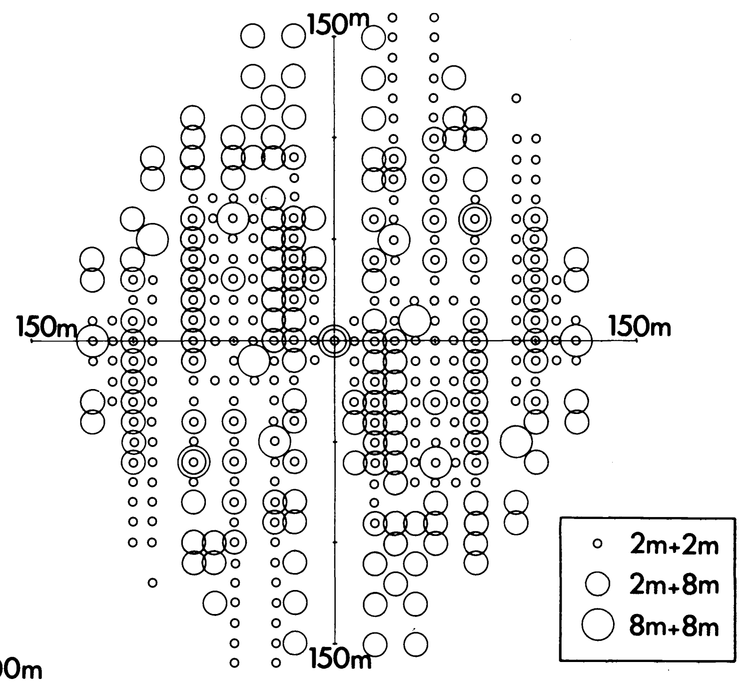


Figure 5 Left: Assumed Configuration of 8 Meter Telescopes (Large Circles) and Movable Auxiliary Telescope's (Small Circles) which are taken as having a 2 Meter Diameter. Prevalent Wind Direction is from above. Right: The Resulting (u,v) Plane Instantaneous Access for an Object at Zenith for Different Possible Telescope Configurations. The Actual (u,v) Plane Coverage is Determined by the Configuration of Auxiliary Telescopes Chosen, by the Number of Telescopes Included, and by the Time Synthesis.

The effect of wind on building-caused-seeing on neighboring telescopes is not well known, nonetheless it is of sufficient concern that it will influence the placing of the 8 meter telescopes. Figure 5 shows the configuration preferred from the (u,v) plane coverage point of view. It will be taken as the configuration for the present description. If wind related seeing effects turn out to be a problem, the two upper (roof) telescopes will be moved closer to the base at the cost of (u,v) plane coverage. The final configuration will be chosen after the VLT site has been determined taking into consideration these wind effects.

3.2 Summary of the 8 meter Telescope Optics

Figure 6 shows the coudé optics of the 8 meter telescopes (see also Enard[1]). A total of 5 reflections are needed to relay the image from the Nasmyth foci to the stationary f/50 (1 arcsec ≈ 2 mm) coudé focus. It includes the formation of a ≈ 100 mm diameter pupil image on the 16x16 element adaptive mirror (M8). Separate optical trains will be provided for the two Nasmyth foci, optimized for short and long wavelengths respectively. The field-of-view at the coudé focus is 120 arcsec diameter. As seen in the coudé focus the images and pupils rotate as a function of the telescope elevation, in opposite sense for the two Nasmyth foci. It is important for both field-of-view considerations and polarization control (the polarization frame-of-reference rotates with the image/pupil) that these rotations remain identical while the light is transferred to the combined coherent focus.

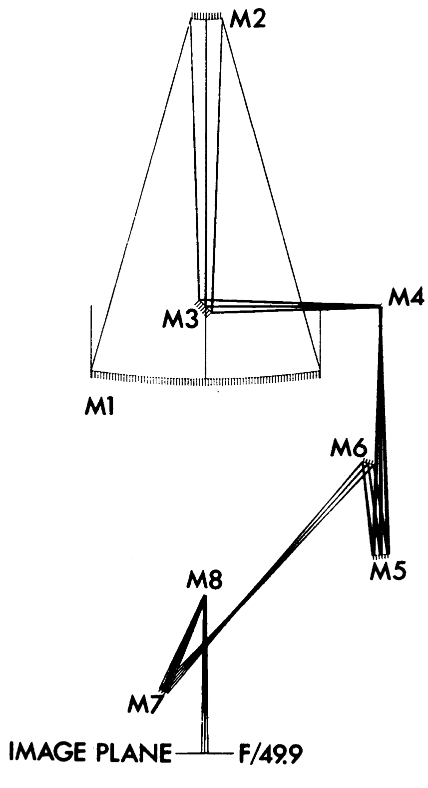


Figure 6 Coudé Feed Optics for the 8 Meter Telescopes (Shown to Scale)

3.3 Coudé Relay Optics

Figure 7 represents schematically the optics in the coudé focus needed for the VLTI. A dichroic mirror (DM) separates the coudé beam in the parts needed for wavefront sensing and interferometry. The interferometry beam is relayed by means of a field mirror placed in the focus (FM), and the collimator mirror CM.

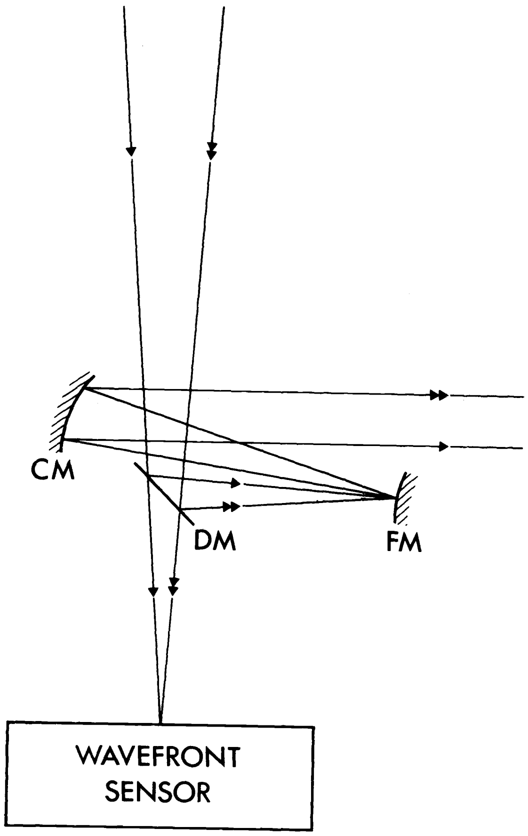


Figure 7 Coudé Relay Optics (not to Scale)

To achieve the desired beam diameter compression M of 100, the focal length of CM has to be 400 cm. FM is curved to image the telescope pupil near the beamcombining station of the VLTI (see Figures 8 and 10). FM will probably also be tilt-actuated to provide for pupil guiding (see section 3.7). The diameter of CM is determined by the pupil image diameter (8 cm) and the required field-of-view coupled to the distance to the pupil image formed by CM. For a 75 meter distance the used CM diameter equals 38 and 15.5 cm respectively for an 8 and 2 arcsec field-of-view.

3.4 Transfer Optics

Figure 8 shows the proposed transfer of the light to the beamcombiner station. It is arranged in such a way that image/pupil/polarization directions are preserved for the 8 meter telescopes. Also equal angles in the reflection angles and equal numbers of reflection assure that retardation effects are identical (again necessary for polarization control). All the transfer optics is mounted in the so-called interferometric tunnel feeding the beamcombiner in the adjoining interferometric laboratory. For seeing control the temperature in the interferometric laboratory/tunnel and coudé focus will be maintained close to air temperature. The light transfer will probably occur just below ground, probably with ≈ 20 cm vertical offsets between the four (more later) beams to facilitate beamcombination (see section 3.6).

3.5 Optical Delay Lines

The delay lines uses cat's eye optics in which the small secondary mirror will be a so-called zoom-mirror with variable curvature which will reimage the entrance pupil

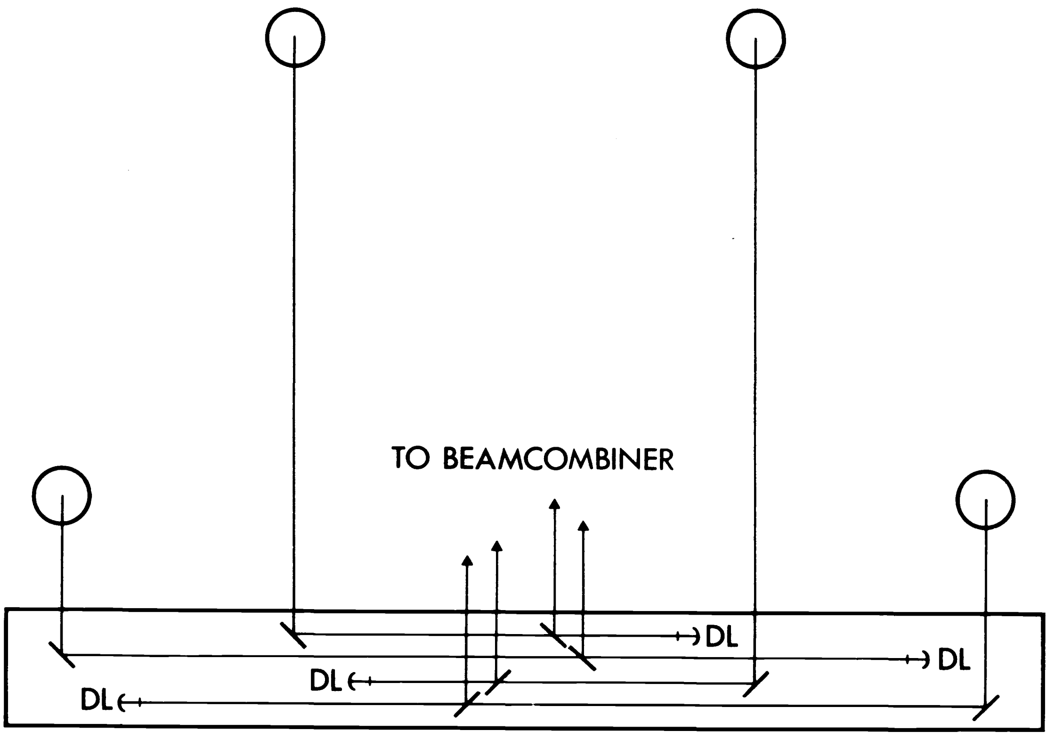


Figure 8 Transfer Optics Between the Coudé Optics of Each 8 meter Telescope and the Beamcombiner (BC) Consist of Three 90° Reflections (last one into BC not shown) and a Delay Line (DL)

image (formed by FM in Figure 7) from its location near the BC back onto the same location at the entrance of the BC. The size of the delay line depends on the field-of-view at the combined coherent focus. The optics dimensions shown in Figure 9 (75 cm used primary diameter) are for an 8 arcsec field-of-view. The minimum diameter (very small field-of-view) is about 20 cm. The interferometer field-of-view will to a large extend depend on the difficulties associated with making such a long delay line (≈ 60 meters), of large size and weight, moving with the speed (up to 10 mm/s) and precision (fraction of wavelength) required. The lateral precision of the track is also related to the required field-of-view since sideways displacements and tilts of the delay lines move the pupil images. Pupil position control, however, relaxes the required lateral positioning (section 3.7).

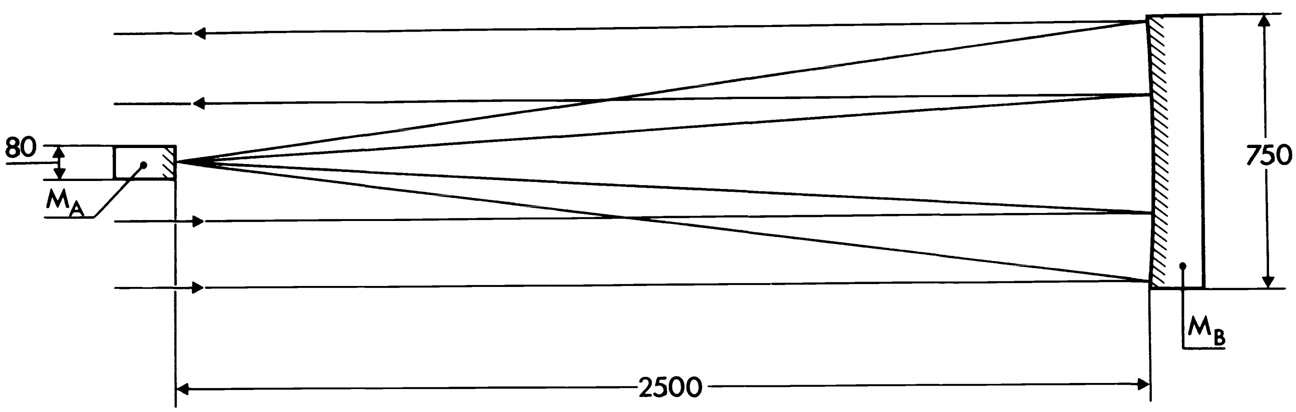


Figure 9 Delay Line Optics

3.6 Beamcombiner

There are many ways to combine the beams of an interferometer like the VLTI. One way is by means of a so-called beamcombining telescope in which the afocal light beams are brought together in the image recombining mode (see Figure 10). It results in a combined image with superposed fringe patterns which are detected by means of area photon counting detectors. By moving the entrance pupils on the beamcombining telescopes around it is possible to chose the spacing and orientation of these fringe patterns to fit the particular experiment. For spectroscopy one might, for example, choose to put all entrance pupils on a line with non-redundant spacings by moving the two flat mirrors (M_p and M_q in Figure 10) which feed the beamcombining telescope to their appropriate locations. In this way the spectra will show the fringes optimally, with spatial frequencies along the slit which encode the different baselines.

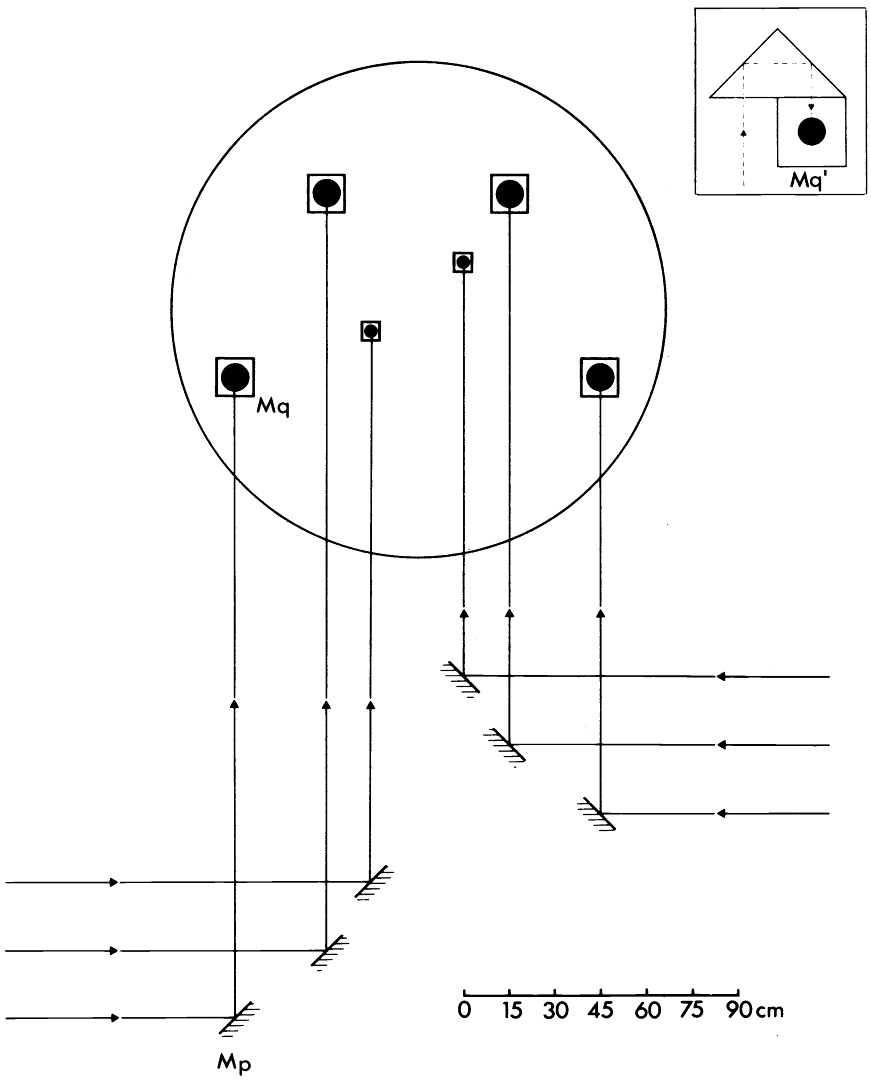


Figure 10 Pupil Configuration at the Entrance of the Beamcombining Telescope. The Four Large Dark Circles are the Pupil Images of the 8 meter Telescopes, the Two Small Circles those of Two Auxiliary Telescopes. M_p and M_q are Flat Translatable Mirrors used to Move the Pupil Images across the Beamcombining Telescope. M_q' replaces M_q in Case the Pupil needs Rotating by 180° (see section 4.4).

Such a mode of beamcombination results, however, in a very small field-of-view (the size of the Airy disk). Only by precisely mapping the entrance pupil configuration (as seen from the astronomical object) onto the beamcombiner does one obtain a significant field-of-view[11]. That implies: (i) maintaining the relative dimensions between pupil diameters and pupil distances, even as the latter change due to foreshortening as the object moves in the sky, and (ii) maintaining the orientations of the pupils with respect to the orientation of the foreshortened pupil configuration even as the pupil images rotate due to the telescope elevation changes. For a wide field-of-view operation it is therefore necessary to continuously adjust the positions of mirrors M_p and M_q in Figure 10 to maintain configuration and orientations. The wide field-of-view operation also determines the minimum diameter of the beamcombining telescope as the maximum dimension of the array (≈ 150 meters) divided by the beam compression factor M (100), or 150 cm.

3.7 Image, Pupil, and Fringe Trackers

For optimum operation, it is necessary to include both image, pupil, and fringe tracking in the VLTI. The precise form which these will take remain to be defined, but they will probably use the following concepts:

(i) Accurate *Image Tracking* is needed to obtain the maximum fringe visibility[6]. It implies an autoguiding system for each beam as part of the beamcombining telescope. The actuator for this would best be the small mirrors M_q in Figure 10 which are located near the pupil images. Because of the angular magnification M = 100 the ≈ .005 arcsec resolution required in the final image corresponds only to .25 arcsec resolution of the M_q tilts.

(ii) *Pupil Tracking*, needed to maintain the wide field-of-view and to relax the lateral precision requirements for the delay line, will probably use a light emitting diodes located at the center of the telescope secondary mirrors to sense the pupil position. As actuators the field mirrors FM in the coudé relay optics (FM in Figure 7) will be used. If light scattering by the LED is a problem, it will be used intermittently, with the system relying on the quality of the VLTI (especially the delay line track) to track the pupil with the required precision in the meantime.

(iii) For fringe acquisition (Case I, II, and III) and tracking (Case II and III) the VLTI will need *Fringe Tracking*. The devices for maximizing fringe contrast and determining fringe position may have different properties for the acquisition (relatively long observing times allowed) and tracking (rapid measurements needed). The actuators are the delay lines for coarse acquisition and piezoelectrically controlled elements (eg the small secondary mirrors in the delay lines) for small, fast adjustments.

4. THE AUXILIARY TELESCOPES

The design of the array of Auxiliary Telescopes, also referred to as the VLT Interferometric Subarray or VISA, follows closely the design of the array of 8 meter telescopes.

4.1 Optical Configuration of the Auxiliary Telescopes Themselves

The desire to use the Auxiliary Telescopes together with the 8 meter telescopes leads to the requirement to match their polarizing properties. That means equal retardation and equal polarization frame-of-reference orientation[15]. That is achieved by using a similar optical configuration (see Figure 6) to feed the coudé focus: equal number of reflections, same coatings, same sum of the off-normal angles squared, all reflections in one plane. The optical train incorporates a pupil image of approximately the same scale as the pupil image in the 8 meter telescopes, so that similar adaptive mirrors can be used, of course with fewer elements. Present design studies for the Auxiliary Telescope's use a 180 cm diameter f/1.5 primary mirror and give a f/40 coudé beam (1 arcsec = .36 mm).

4.2 Configuration of the Auxiliary Telescope's

We propose that the Auxiliary Telescopes be movable between a number of fixed stations. Figure 5 shows a possible configuration of these stations for the Auxiliary Telescopes, the final configuration being determined after the selection of the VLT site. The stations are located on straight lines which are at right angles to the direction of the interferometric tunnel. Only one Auxiliary Telescope can be used per line. The Auxiliary Telescopes share the delay lines and most of the transfer optics to the beamcombiner with the 8 meter telescopes, in fact the VLTI is so arranged that many telescope combinations are possible with a common interferometric setup. As implemented initially the VLTI can be used with up to 4 Auxiliary Telescope's, with one 8 meter telescope and 3 Auxiliary Telescopes, or with all 8 meter telescopes, with a minor change in the optical configuration.

4.3 Coudé Relay Optics

The coudé relay optics are similar to those shown for the 8 meter telescopes in Figure 7 except for one important difference, the field mirror FM being flat. The focal length of the collimating mirror is only 72 cm. FM being flat causes the pupil image to be formed just beyond FM and not near the beamcombiner as is the case for the 8 meter telescopes. The disadvantage of this arrangement is that the beam expansion at the delay line is larger causing the field-of-view for the Auxiliary Telescopes to be limited. The smaller pupil image size of the Auxiliary Telescopes (18 mm vs 80 mm for the 8 meter telescopes) partially offsets this disadvantage. The advantage is the absence of the need for a zoom mirror with very strong curvatures for FM and the use of a smaller collimating mirror CM (used diameter ≈ 20 mm). The coudé relay optics assembly will probably move with the Auxiliary Telescope's requiring it to be compact. The secondary zoom mirror in the delay line will again be used to reimage the pupil onto the beamcombiner.

4.4 Beamcombiner

The transfer optics, delay lines, and beamcombiner are all identical to those for the 8 meter telescopes except for one exception, a possible modification of M_q. All telescopes on the same side of the interferometric tunnel give identical image/pupil/polarization frame-of-reference orientations at the entrance to the beamcombiner. Telescopes on the opposite side of the tunnel give, however, orientations 180° different. This does not affect the fringe contrast, but it ruins the field-of-view. It can be restored by replacing M_q with the three reflection device M_q' shown in Figure 10, provided that its additional retardation effects are properly compensated by eg optical waveplates.

4.5 Transporters

The Auxiliary Telescopes transportation devices are presently being defined. They will probably consist of carriages moving on railroad tracks, the carriage being an integral part of the Auxiliary Telescope structure. The carriage will carry a windscreen for the Auxiliary Telescope and other telescope operation support items. When in station position the carriage will be therefore be mechanically uncoupled from the Auxiliary Telescope. The Auxiliary Telescopes themselves will be selfsheltering so that they can stay in place in inclement weather.

5. FUTURE ENHANCEMENTS OF CAPABILITIES

The VLTI as described above will have both very powerful capabilities but also major restrictions. Many of the restrictions can be overcome in an enhancement program following the implementation of the initial VLTI. The following table summarizes these initial and enhanced capabilities.

TABLE I

Capabilities of Present and Enhanced VLTI

Item:	Initial VLTI	Enhanced VLTI
Number of Delay Lines	4[a]	6?
Number of Auxiliary Telescopes[b]	3	6?
Number of Large Telescopes[b]	4	4
Number of Baselines	6	15
Coherent FOV (arcsec)	2	8
Reconfiguration Time ATs	hours	minutes
Wavelength Coverage	> 420 nm	> 350 nm
Blind Fringe Acquisition[c]	no	yes
Maximum Baseline	≈ 150 m	≈ 1000 m (N-S)
Design Wavelength Adptve Optics	2 μm	1 μm
Use of Artificial (Laser) Star?	no	yes

comments: [a] consists of three movable delay lines, and one stationary unit.
[b] number simultaneously usable with listed number od delay lines.
[c] no cophasing done on object in interferometer field-of-view.

6. CONCLUSION

The authors of this paper constituted the membership of the so-called VLT Interferometry Panel and participating ESO staff members. The full report of this panel on the VLT Interferometer implementation will be available as an ESO publication. This paper summarizes the result of a 9 months study by this panel. The study benefitted greatly from contributions by P. Léna and J.-M. Mariotti. Final definition of the VLTI will be done after the Phase A/B design studies of the components have been completed, after the site has been chosen, and after the required additional contributions by ESO member countries has been defined. This will happen shortly after the VLT site choice because of the need to prepare the site well before the VLT arrives. It appears possible to implement the VLTI itself in the 1996/1997 timeframe, after which an extensive experimentation period must lead to a general user operation.

7. REFERENCES

1. D. Enard, "ESO-VLT Project: I. A Status Report," SPIE Proceedings **1236-08**, 1990.
2. M. Dyck and E. Kibblewhite, "Giant Infrared Telescopes for Astronomy: a Scientific Rationale", Publ. Astr. Soc. Pacific **98**, 260, 1986.
3. F. Merkle, J.-P. Gaffard, F. Rigaut, C. Boyer, P. Kern, P.J. Léna, P. Cigan, J. Fontanella, and G. Rousset, "Adaptive Optics Prototype System for IR Astronomy: I. System Description," SPIE Proceedings **1237-30**, 1990.
4. P. Kern, P. Léna, G. Rousset, F. Merkle, and F. Rigaut, "Adaptive Optics Prototype System for IR Astronomy: II. First Observing Results," SPIE Proceedings **1236-29**, 1990.
5. J.M. Beckers and L. Goad, "Image Reconstruction Using Adaptive optics," *Instrumentation for Ground-Based Optical Astronomy* (ed. L. Robinson, Santa Cruz), Springer Verlag, 315.
6. J.M. Beckers, "The VLT Interferometer: II. Factors Affecting On-Axis Operation," SPIE Proceedings **1236-31**, 1990.
7. J.M. Beckers, "The VLT Interferometer: IV. The Utility of Partial Adaptive Optics," SPIE Proceedings **1236-16**, 1990.
8. P. Léna, "The Interferometric Mode of the European Very Large Telescope," Proceedings of the NOAO-ESO Conference on "*High Resolution Imaging by Interferometry*" (ed. F. Merkle), ESO Conference and Workshop Proceedings No. 29, 899, 1988 (see also VLT Report No. 49).
9. J.M. Beckers, F. Roddier, and P. Eisenhardt, "National Optical Astronomy Observatories (NOAO) Infrared Adaptive Optics Program; I General Description," SPIE Proceedings **628**, 290, 1986.
10. R. Foy and A. Labeyrie, "Feasibility of Adaptive Telescope with Laser Probes", Astron. & Astroph. 152, L29, 1985.
11. J.M. Beckers, "The VLT Interferometer: III. Factors Affecting Wide Field-of-View Operation," SPIE Proceedings **1236-33**, 1990.
12. J.M. Beckers, "Some Thoughts on the Combination of Beams in Interferometer using Telescopes of Unequal Size," Proceedings NATO Summerschool on *Diffraction Limited Imaging with Very Large Telescopes* (eds. D. Alloin, J.M. Mariotti) Kluwer Academic Publishers, 365, 1988.
13. M.G. Lacasse and W.A. Traub, "Glass Compensation for an Air Filled Delay Line," Proceedings of the NOAO-ESO Conference on "*High Resolution Imaging by Interferometry*" (ed. F. Merkle), ESO Conference and Workshop Proceedings No. 29, 959, 1988
14. F. Forbes, "Near-Ground Atmospheric Turbulence Effects," SPIE Proceedings **1114**, 28, 1989.
15. J.M. Beckers, "Polarization Effects on Astronomical Spatial Interferometry," Proceedings SPIE **1166-37**, 1989.
16. T. Cornwell, IEEE Trans.Ant. Prop. **36**, 1165, 1988.