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Project/WP: Systems Engineering

Standard Coordinate Systems and Basic Conventions

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3 Abbreviations

A	Azimuth angle
a	Altitude angle
α	Rotation angle around axis X
β	Rotation angle around axis Y
γ	Rotation angle around axis Z
X_T, Y_T, Z_T	Telescope Coordinate frame
X_{Az}, Y_{Az}, Z_{Az}	Azimuth Structure Coordinate frame
$X_{Alt}, Y_{Alt}, Z_{Alt}$	Altitude Structure Coordinate frame
X_d, Y_d, Z_d	Dome Coordinate frame
U, V, W	Site Coordinate frame
L	Optical axis coordinate
$X_{s.rr.aa}, Y_{s.rr.aa}, Z_{s.rr.aa}$	Local coordinate frame of M1 segment # S.RR.AA
M6N	<i>M6 mirror directing the optical beam to a lateral port at Nasmyth focus</i>
M6C	<i>M6 mirror directing the optical beam to a Coudé path</i>
S.RR.AA	M1 segment identification number (Sector, Ring, Azimuth)

⁴ See also acronyms defined in applicable document AD1 (see section 2.1 herein).

1. Scope

- ⁶ This specification defines unified systems of coordinates for the E-ELT project (telescope, dome, buildings, site layout), and basic rules to be adopted for the definition of further local coordinate systems that may be required during the project.
- ⁷ The sign and naming conventions contained in this document shall be used for all future contracts, specifications, and technical documents related to the E-ELT project.
- ⁸ This document also contains other definitions and naming conventions relating to the E-ELT project which are of a general nature and are not defined elsewhere. These definitions will be expanded in future issues of the document as required by the project.



2. Applicable documents

2.1 Applicable documents

- ¹¹ The following applicable documents form a part of the present document to the extent specified herein. In the event of conflict between applicable documents and the content of the present document, the content of the present document shall be taken as superseding.
- ¹² AD1 Common definitions and acronyms;
ESO-193178 Version 6
<https://kronosrv.hq.eso.org/kronodoc/HQ/ESO-193178/6>

2.2 Reference documents

- ¹⁵ RD1 M1 Geometrical Properties and Construction parameters for the 39-m EELT ;
ESO-192180 Version 3
<https://kronosrv.hq.eso.org/kronodoc/HQ/ESO-192180/3>
- ¹⁵⁶ RD2 Basic Wavefront Aberration Theory for Optical Metrology;
"Applied Optics and Optical Engineering," Vol. XI, Chapter 1; Wyant, J., Creath,
K. (1992).
- ¹⁵⁷ RD3 "Zernike polynomials and atmospheric turbulence",
J. Opt. Soc. Am., Vol. **66**, No. 3, p207 (1976).
- ¹⁶⁸ RD4 Born, M. and Wolf, E., (1959). Principles of Optics, pp. 464-466, 767-772.
Pergamon press, New York.
- ¹⁷⁵ RD5 Coarse Metrology Design Volume and Interfaces to the Main Structure and to the
Dome;
ESO-200883 Version 1

3. Coordinate systems

- 17 Several **absolute coordinate systems** are defined in this document for different aspects of the E-ELT. These are described in Sections 3.2
- 18 In addition to the absolute coordinate systems, **local coordinate systems** may be defined according to the requirements of individual subsystems. These systems are described in Section 3.3.
- 19 All absolute and local coordinate systems conform to the basic rules for the arrangement of axes, direction of rotations and labelling described in Section 3.1, and are referred to in this document as **standard coordinate systems**.
- 20 Coordinate systems, which are required for various aspects of E-ELT project, which cannot reasonably be made to conform to the basic rules, are referred to here as **non-standard coordinate systems**. Section 5 of this document specifies restrictions on the usage of non-standard coordinate schemes in E-ELT technical documents.

3.1 Basic rules

3.1.1 Arrangement of axes

- 23 All Cartesian frames shall use a **right-hand convention** for the arrangement of axes as shown in Figure 1.
- 24 All axis labels shall be assigned an alphabetic label with the cyclic alphabetic sequence corresponding to the right-hand axis sequence. Where required, the rotational directions shall be assigned a Greek letter with a cyclic alphabetic sequence corresponding to the axis sequence.

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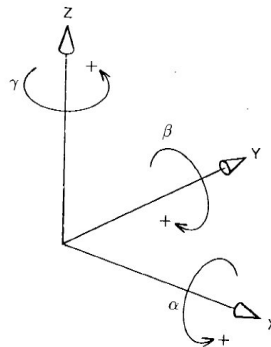


Figure 1: Arrangement of axes and rotations for E-ELT coordinate frames.



3.1.2 Direction of rotation

- 28 A right-hand convention shall be used for all axis rotations as shown in Figure 1. There is no general definition for the direction of the zero point for rotational axes. These will be defined individually for each coordinate system, but the zero point shall lie in the direction of one of the other two axes.

3.1.3 Notation for tri-dimensional rotation

- 30 The complete tri-dimensional (3D) rotation of a solid body (or another Cartesian frame) shall be defined by a triplet of rotation angles which order corresponds to the order in which the individual rotations are performed. For example $[\beta=30^\circ, \alpha=0^\circ, \gamma=55^\circ]$ means rotation of 30° around Y-axis followed by a rotation of 0° around the new X-axis followed by a rotation of 55° around the new Z-axis.
- 31 Alternatively, a complete tri-dimensional rotation can be expressed by a single rotation angle θ and a vector \mathbf{R} around which the rotation is applied. The notation, in that case, is: $[\theta, \mathbf{R}]$.

3.1.4 Notation for vectors

- 33 Vectors (independent of the coordinate system) shall be noted using bold letter (example: \mathbf{u} , or \mathbf{R}).
- 34 In cases where confusion might arise, vector coordinates (dependent on the coordinate frame) shall contain the information about the coordinate frame as subscript. For example: $[u_{xT}, u_{yT}, u_{zT}]$

$$\text{or } \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix}_{Telescope} \quad \text{or} \quad \begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix}_{AzimuthStructure}$$

3.2 Standard absolute coordinate systems

3.2.1 Telescope Coordinates

- 37 The E-ELT shall have a fixed coordinate frame, which is aligned with the geographical North-South axis and the local vertical (gravity vector) and has its origin at the nominal intersection of the Altitude and Azimuth axes of the telescope concerned. It shall be used for dimensioning all non-moving parts of the telescopes.

- 38 This frame also serves as the basis for the definition of three movable coordinate frames for the telescope Azimuth Structure, Altitude Structure and Dome as described in Sections 3.2.2, 3.2.3 and 3.2.4, respectively.
- 39 The telescope coordinates shall have axis labels X , Y and Z . The X -axis points towards the geographical West, the Y -axis towards the South, and the Z -axis points toward the Zenith.
- 40 The rotational angles about the X , Y and Z axes shall be designated α , β and γ respectively.
- 41 The zero points for the α and γ axes shall be in the direction of the Y -axis. The zero point for the β axis shall lie in the directions of the Z -axis.
- 42 In cases where confusion might arise between telescope coordinates and the movable coordinate frames for the Altitude Structure, Azimuth Structure and dome, the telescope coordinates axes shall be appended with a subscript to indicate the frame referred to (i.e. $X_T, Y_T, Z_T, \alpha_T, \beta_T, \gamma_T$, etc.).
- 43 The arrangement of the telescope axes is shown in Figure 2.
- 45

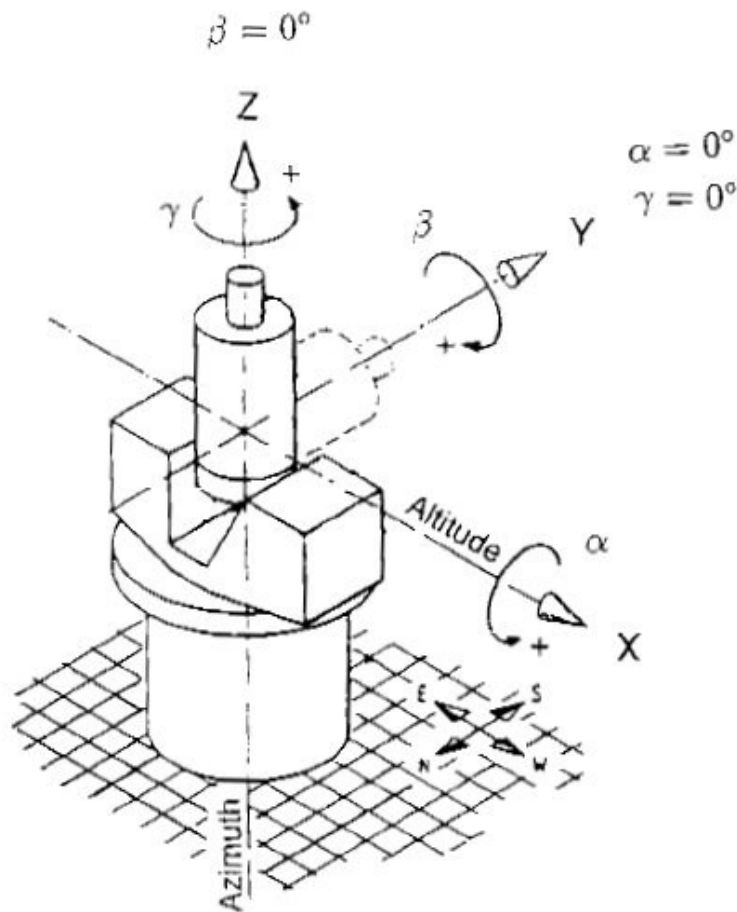


Figure 2: Orientation of the telescope coordinates.



3.2.2 Azimuth Structure Coordinates

- 47 The Azimuth Structure coordinate frame rotates about the Z_T -axis with respect to the telescope coordinates. The amount of rotation (measured eastwards of the south-point) corresponds to the **azimuth angle** A of the telescope. The Azimuth Structure coordinate frame is coincident with the telescope coordinate frame when azimuth $A = 0^\circ$.
- 48 The Azimuth Structure coordinate frame shall be used for dimensioning of the Azimuth Structure of the E-ELT and for the sub-systems fixed to the Azimuth Structure.
- 49 The Azimuth Structure coordinates shall have axis labels X , Y and Z and rotations α , β and γ . In cases where confusion between Azimuth Structure coordinates and other coordinate frames might arise, the Azimuth Structure coordinate axes and rotations shall be appended with a subscript to indicate the frame referred to (i.e. X_{Az} , Y_{Az} , Z_{Az} , α_{Az} , β_{Az} , γ_{Az}).

3.2.3 Altitude Structure Coordinates

- 51 The Altitude Structure coordinate frame rotates about the X_{Az} -axis with respect to the Azimuth Structure coordinate frame. The amount of rotation (measured from the horizon towards zenith) corresponds to the **altitude angle** a of the telescope. The Altitude Structure coordinate frame is coincident with the Azimuth Structure coordinate frame when altitude $a = 90^\circ$. Note the following relation between the rotation angle a and the altitude a : $a = a - 90^\circ$.
- 52 This frame shall be used for dimensioning of the Altitude Structure and for sub-systems fixed to the Altitude Structure.
- 53 The Altitude Structure coordinates shall have axis labels X , Y and Z and rotations α , β and γ . In cases where confusion between Altitude Structure coordinates and other coordinate frames might arise, the Altitude Structure coordinate axes and rotations shall be appended with a subscript to indicate the frame referred to (i.e. X_{Alt} , Y_{Alt} , Z_{Alt} , α_{Alt} , β_{Alt} , γ_{Alt}).

3.2.4 Dome Coordinates

- 55 The dome coordinate frame is used for defining the motion of the rotating part of the dome and the control interface between the dome and the telescope control system. The frame rotates about the Z_T -axis with respect to the telescope coordinates. The amount of rotation of the dome slit opening (measured Eastwards of the South-point) corresponds to the **azimuth angle** A_d of the rotating part of the dome. The dome coordinate frame is coincident with the telescope coordinate frame when $A_d = 0^\circ$.
- 56 The dome coordinates shall have axis labels X , Y and Z and rotations α , β and γ . In cases where confusion between dome coordinates and other coordinate frames might



arise, the dome coordinate axes and rotations shall be appended with a subscript to indicate the frame referred to (i.e. $X_d, Y_d, Z_d, \alpha_d, \beta_d, \gamma_d$).

3.2.5 Site Coordinates

- 58 The site coordinate frame shall be used for the layout and dimensioning of all buildings on the telescope area (including the telescope and dome foundations) as well as subsystems installed in the Coudé area.
- 59 The origin of the site coordinate frame is at the intersection of the Z_T axis with the nominal ground level of the telescope area (level 0).
- 60 The site coordinate frame shall be materialised by at least two permanent survey reference points of known geographical coordinates called Master#0 and Master#1. These permanent survey reference points are not necessarily at the origin of, or aligned with, the site coordinate system. They shall enable any point on the platform to be located in absolute terrestrial coordinates.
- 61 The site coordinates are aligned in such a way that the first axis is horizontal and pointing in the direction of the (center of the) main entrance door of the Dome and the third axis is vertical (aligned with Z_T).
- 62 The site coordinates shall be labelled U, V, W where U is pointing in the direction of the Dome main entrance door, W is aligned with Z_T and V complements the right-hand coordinate system. Labels for the rotational angles in this frame are designated $\theta_U, \theta_V, \theta_W$.
- 134 The angle between X_T and U is $+90.0^\circ$ (i.e. Dome entrance is 0° from the South towards East).

3.2.6 Optical axis coordinate

- 64 The optical axis coordinate is a linear coordinate with origin at the nominal intersection of the Altitude and Azimuth axes and which follows the nominal optical path through the telescope and beam transfer optics. The coordinate value increases in the direction of the light. It may be used for the definition of path differences and for the unambiguous specification of the sign of field and pupil rotations, etc.
- 65 The optical axis coordinate shall be labelled L , and the rotational angle about the axis shall be designated γ .
- 66 The zero point for γ at any focal plane on the L -axis shall correspond to the orientation of the Y_T -axis on the sky (i.e. South) as viewed through the telescope optical train from the focal plane concerned when azimuth $A = 0^\circ$ and altitude $a = 90^\circ$.
- 67 The zero point for γ at any pupil plane on the L -axis shall correspond to the orientation of the Y_{Az} -axis on M2 as transmitted by the telescope optical train to the pupil plane concerned when azimuth $A = 0^\circ$ and altitude $a = 90^\circ$.



3.2.7 Telescope azimuth and altitude axis definition

3.2.7.1 As-designed definition

- 160 During the design phase, the Azimuth and Altitude axes shall be understood as the **nominal** (as-designed) telescope axes.
- 161 Unless otherwise specified, deformation due to gravity shall not be considered in the definition of the axes.
- 162 Unless otherwise specified and in cases where a reference configuration needs to be defined, the reference configuration shall be the telescope pointing to Zenith.

3.2.7.2 As-built definition

- 164 During the telescope installation phase, the Azimuth and Altitude axes shall be understood as the **actual** (as-built) telescope axes measured after Main Structure installation (with all mirror units dummy masses in place).
- 165 The actual azimuth axis is defined by the axis connecting the two centers of the best-fit circles described by two points attached to Azimuth Structure when rotating in azimuth over 360 degrees, telescope pointing at Zenith ($\pm 2^\circ$). One point shall be located at the level of the telescope azimuth floor and another at the level of the M2 unit.
- 166 The actual altitude axis is defined by the axis connecting the two centers of the best-fit circles described two points attached to Altitude Structure when rotating in Altitude over 90deg. The points shall be located at the level of the Altitude cradle (side A and side B).
- 167 The actual (as-built) Azimuth and Altitude axes will be materialized by a set of topographic references points attached to the Main Structure at given locations (see RD5).

3.3 Standard local coordinate systems

- 69 Local coordinate systems are coordinate frames that are defined for the design and analysis of individual components, and shall conform to the general basic rules, notations and conventions given in Section 3.1.

3.3.1 Local Mirror coordinate systems

- 71 For each optical surface (mirror, focal plane, pupil plane, etc.) a local mirror coordinate system can be defined and shall be used for dimensioning of the corresponding subsystem. The local mirror coordinate frames are derived from one of the global



coordinate frames defined above in section 3.2 (called '**parent frame**') by applying one **translation** and one (or more) **rotation**.

- 72 Note for moving (or duplicated) mirrors: For mirrors mounted on a moving mechanism to change the optical configuration (such as M4, M5, M6N, M6C) and for mirrors that are duplicated for several optical configuration (such as elements inside the Prefocal stations A&B), the local mirror coordinates frame is built, following the rules given below, for a '**nominal configuration**'. For any other configurations, the local frame 'moves physically' together with the mirror. This ensures a unique local coordinate frame definition for a given mirror unit (useful for control system design, for interchangeability, etc.). Note that the orientation of the local coordinate frame in the non-nominal optical configuration depends on the actually selected kinematic for the moving mechanism. The 'nominal' optical configuration is defined below.
- 73 The **parent frame** is the one in which the mirror is fixed when the telescope is moving.
- 74 The **translation** consists in bringing the origin of the frame at the center of the mirror. The center is defined as follows:
- For on-axis aspherical mirrors: Vertex of the generating aspheric surface.
 - For off-axis mirrors: Geometrical center of the optical useful area, unless otherwise specified at subsystem level (for the M1 segments, see section 3.3.2.)
 - For flat or spherical mirrors: Geometrical center of the optical useful area, unless otherwise specified at subsystem level.
 - For focal/pupil surfaces: intersection of nominal optical axis with the focal/pupil surface
- 79 The **rotation** is chosen according to the following principles by order of precedence: i) Z_{local} is along the normal (inner or outer) of the mirror at its center, ii) number of rotation is minimized, iii) rotation angle is minimized (typ. $<\pm 90^\circ$).
- 80 The **nominal configuration** is the first relevant configuration encountered down the list: Nasmyth > Coudé, and the associated alphabetic or numerical order of sub-configurations.
- 81 Table 1 provides an overview of the most useful currently defined local mirror coordinate systems.

82

Mirror / element	Nomin. optical config.	Parent coord. Frame	Translation to	Rotation	remark
M1	Nasmyth A	Altitude	Mirror vertex (full mirror without central hole)	Rotation ($<\pm 90^\circ$) around Y_{Alt} to bring X_{Alt} -axis in the tangential plane of the mirror at its center.	For GI the frame moves to the new vertex position
M2			Geometrical center of optical useful area	In other words, the Y-axis remains parallel to itself and the Z-axis becomes the normal to the mirror surface (inner normal for even number mirrors and outer normal for odd number mirrors).	
M3					
M4					
M5			Azimuth	Intersection of nominal optical axis	Rotation around Y_{Az} of -90° (Nasmyth A1) or $+90^\circ$ (Nasmyth B1).
Image Plane at Nasmyth (unfolded)					



			with the focal surface	In other words, the Y-axis remains parallel to itself and the Z-axis points towards the direction of light propagation.	
Image Plane at Nasmyth (folded)		Azimuth	Intersection of nominal optical axis with the focal surface	Rotation around X_{Az} of -90° (Nasmyth A2/B2) or $+90^\circ$ (Nasmyth A3/B3). In other words, the X-axis remains parallel to itself and the Z-axis points towards the direction of light propagation.	
Exit Pupil Plane (virtual) as seen from Nasmyth	Pure translation of the corresponding (unfolded) Nasmyth focal plane local frame.				
M6N	Nasmyth A2	Azimuth	Geometrical center	Rotation around Z_{Az} to bring X_{Alt} in the plane of the mirror followed by a rotation around X_{M6N} of $+90^\circ$ to bring Z along the inner normal of the mirror. In other words, X_{M6N} is horizontal along the major axis of the elliptical useful area, Y_{M6N} is vertical up, Z_{M6N} is the mirror inner normal	For other folded Nasmyth, the local frame 'moves together' with the mirror
M6C	Coudé (A)	Azimuth	Geometrical center	As for M1-M5 above	
Coudé path (moving with Azimuth)					
Coudé lab. (i.e. not rotating with the Azimuth structure)	Coudé (A)	Site	Vertex/center	TBD according principles of §3.1.1 and §3.3.1	

Table 1: Summary of mirror local coordinate systems

3.3.2 M1 segments local coordinate systems

84 The geometry of the hexagonal segments constituting the M1 is defined in Annex 7.2 of RD1. For each segment, a local segment coordinate frame is defined as follows:

85 For segments in the reference sector #1 (see §4.3.1 for 'sector' definition):

The origin of the coordinate frame is at the centre of the hexagon defined in Annex 7.2 of RD1

The Z-axis is the outer normal to the optical surface at the location of the hexagon centre.

The Y-axis is obtained by rotating Y_{Alt} around X_{Alt} until it belongs to the plane tangential to the above Z-axis

The X-axis complements the frame following the basic rules of section 3.1.1.

90 For segments in other sectors, the local segment coordinate frame is derived from that of the equivalent segment located in sector #1 (i.e. belonging to the same 'family', see

§4.3.2) by an appropriate rotation (60° for sector#2, 120° for sector#3, 180° for sector#4, etc...) around the global M1 Z axis (Z_{M1}).

- ⁹¹ In cases where confusion might arise, the local segment coordinates shall be appended with a subscript indicating the segment name (using the S.R.A naming convention defined in §4.3.3). For example: $X_{1.10.01}$, $Y_{1.10.01}$, $Z_{1.10.01}$, $\alpha_{1.10.01}$, $\beta_{1.10.01}$, $\gamma_{1.10.01}$.

3.4 Non-standard coordinate systems

- ⁹³ Coordinate frames that are necessary for individual items and which cannot reasonably be made to conform to the general basic rules given in Section 3.1, for example that employed by commercial optical design software, are referred to as non-standard coordinate systems.
- ⁹⁴ All data resulting from the use of non-standard coordinate systems must be converted to standard coordinate systems for all E-ELT technical documents and memoranda.

4. Naming conventions

4.1 Nasmyth platform and focal station designations

- ⁹⁷ The E-ELT Nasmyth platforms are designated 'Platform A' and 'Platform B'. When $A = 0^\circ$, Platform A is on the East side of the Altitude Structure and Platform B on the West side as shown in Figure 3.

⁹⁹

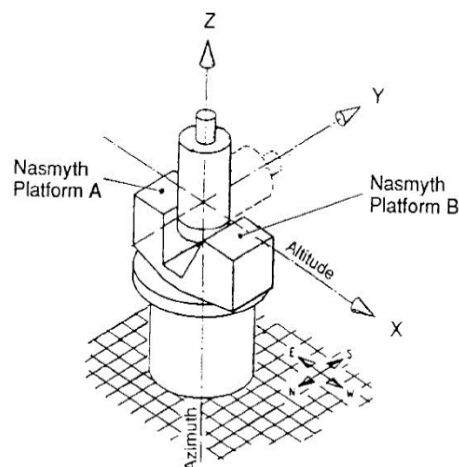


Figure 3: E-ELT Nasmyth Platform designations.

100 The naming convention for the various Nasmyth focal stations are defined in Figure 4

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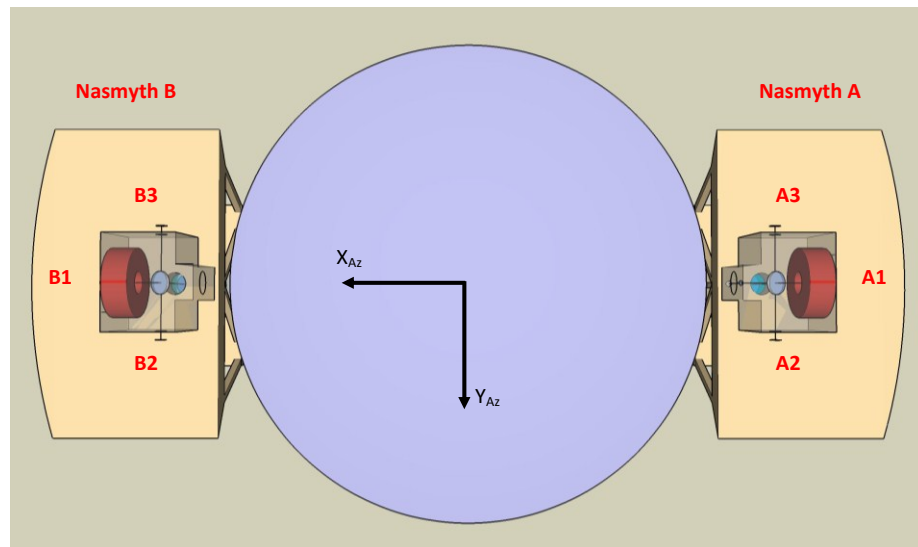


Figure 4: Nasmyth focal station designs

4.2 Coudé path designation

104 void

105 The Coudé optical path starts with its first folding mirror (mirror M6C) located on the 'Nasmyth Platform A'.

4.3 M1 segments naming convention

107 The M1 segments shall be identified using the naming convention described below (see Annex 7.2 of RD1 for precise definition of M1 segment geometry).

4.3.1 M1 sectors

109 The E-ELT M1 is made of hexagonal segments and has a six-fold symmetry. The complete M1 is therefore divided into 6 *sectors* as shown on Figure 5.

110 By convention, the first (reference) sector S=1 is pseudo-symmetric around the positive X_{M1} (M1 local X-axis as defined in §3.3.1). Sector S=2 is the next 60 deg sector when moving in positive trigonometric direction around the M1 Z-axis (anticlockwise). In other words, it corresponds to a rotation of sector S=1 by +60 deg around the M1 Z axis.

131

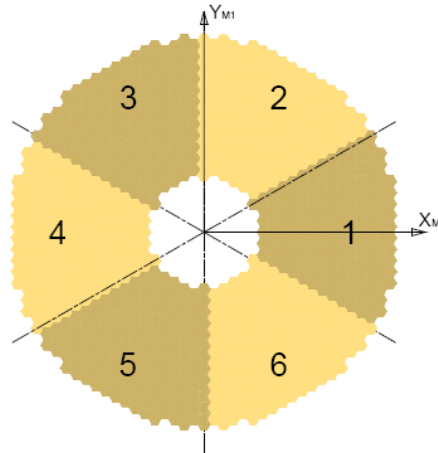


Figure 5: M1 sectors definition.

4.3.2 M1 segment families

- 112 A *family* of segments is defined as the ensemble of segments whose individual vertices (i.e. center of local coordinate system) are at the same distance from the optical axis of the M1, and whose azimuthal location differ by an integer multiple of 60° . Each family has 6 segments plus possibly spare(s).

4.3.3 M1 segment names

- 114 Each segment is identified by a name composed of three numbers in the form S.R.A (R and A are two digit numbers, therefore the exact format is S.RR.AA)
- 115 - S is the SECTOR in which the segment is located. For sector definition, see §4.3.1.
- 116 - R is the hexagonal RING to which the segment belongs. The central (virtual) segment of a completely filled M1 would be Ring #0. The first (virtual) ring would have a total of 6 segments, every next one has 6 segments more than in the previous ring.
- 117 - A is related to the AZIMUTHAL LOCATION of the segment within its ring and its sector. It is defined within the reference sector S=1 as follows: A=1 is the segment position whose centre has the minimum Y coordinate (within its ring and Sector#1). A=2 is the segment with the next increasing Y coordinate and so on. A nominal ring R within the reference sector S=1 includes R segments named R.1, R.2, ... R.R. Near the inner and outer edge of M1, some segment are missing.
- 118 One can think of the naming convention within a skewed coordinate system, as shown on Figure 6 with axis R -30 deg w.r.t X axis and A axis coinciding with Y (X,Y are coordinates of M1 local coordinate system).
- 119 It is easy to obtain a segment coordinate simply following the coordinate system grid. Sector definition is deliberately chosen such that there are no segments at A=0 coordinate.

- 120 With the population scheme shown on Figure 6 (see Annex 7.2 of RD1 for actual M1 segment geometry and population scheme), the first ring is ring #5, $R=5$ and the azimuth position of the first segment as read from A axis is 1, therefore the first segment will be noted: **1.05.01**. The last segment of that ring is **1.05.05**.
- 121 The first segment of ring #6 will be: **1.06.01**, the last one **1.06.06**.
- 122 Note that always $A \leq R$.
- 123 With the population scheme shown on Figure 6, the last two rings are not complete. Therefore ring #16 starts with **1.16.02** and ends with **1.16.14** and ring #17 starts with **1.17.04** and ends with **1.17.13**.
- 124 A given combination R.A. defines a 'FAMILY' of segments having the same optical and mechanical characteristics and that can, in principle, be placed on any of the 6 sectors.
- See also §4.3.2
- 125 In addition to its Serial Number, each segment should preferably be marked with its **R.A number** for easy identification.
- 126 The following convention shall be followed for a segment permanent marking:
 RR.AA
 SNXXXX
- 127 Where RR.AA is the above-defined segment number and XXXX is the segment serial number (defined during segment production).

133

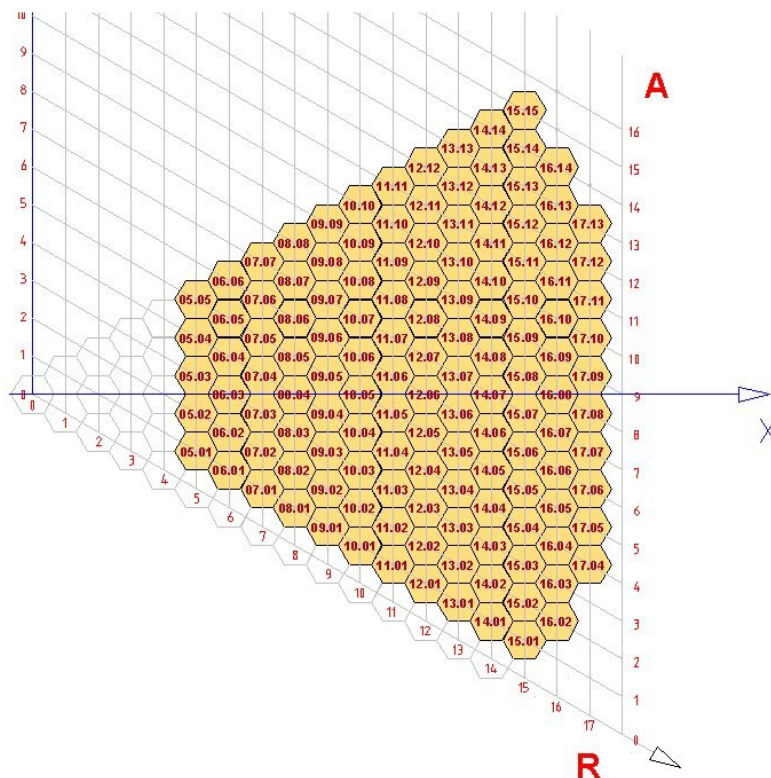


Figure 6: M1 segment naming principle.

4.3.4 M1 segment corners, edges, ES and PACT

138 The following principle is used to name the corners, edges, Edge Sensors (ES) and Position Actuators (PACT) of an M1 segment:

- a) Incremental integer numbers starting at 1 are used
- b) The number 1 is allocated to the item located in the direction of the X_{segment} axis or, if there is none, the first one encountered when moving away from the X_{segment} axis in a positive trigonometric rotation around Z_{segment} (anticlockwise). See §3.3.2 for definition of segment local coordinate frame.
- c) For the ES which are made of two components, a transmitter (T) and a receiver (R), the first component encountered following the above principle is, by convention, a receiver.
- d) Whenever confusion may arise, the following prefix letter shall be used: C for corners, E for edges, R for edge sensor receiver, T for edge sensor transmitter, P for PACT

The resulting naming convention is summarised in Figure 7 (upper sketch).

The naming principle is linked to the local segment coordinate frame (defined in §3.3.2), i.e. to the physical segment itself (and its support). As a consequence, the absolute orientation of the pattern shown in the upper sketch of Figure 7 changes in the various sector by the appropriate multiple of 60° , as indicated in the lower sketch of Figure 7.

139

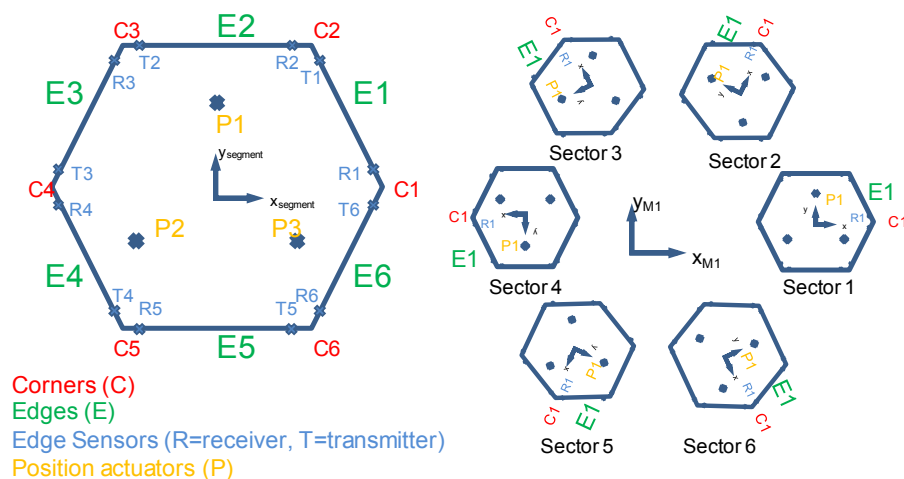


Figure 7: Naming convention for M1 segment corners, edges, ES and PACT

4.3.5 M1 colour code

170 The M1 segment hexagonal pattern can be filled using a three-colour code that ensures that all adjacent segments have a different colour. This segment classification has useful properties (e.g. for segment control).

171 The following standard 3-colour code shall be used, whenever it is necessary:

$$\text{Colour Code} = \text{mod}[(-1)^S(R+A), 3] + 1$$

where S, R, A are the segment numbers defined in section 4.3.3.

172 The associated colour are defined in Table 2 below and the resulting colour pattern on Figure 8.

173

Colour	blue	green	red
Code	1	2	3

Table 2: Definition of Segment Colour codes

174

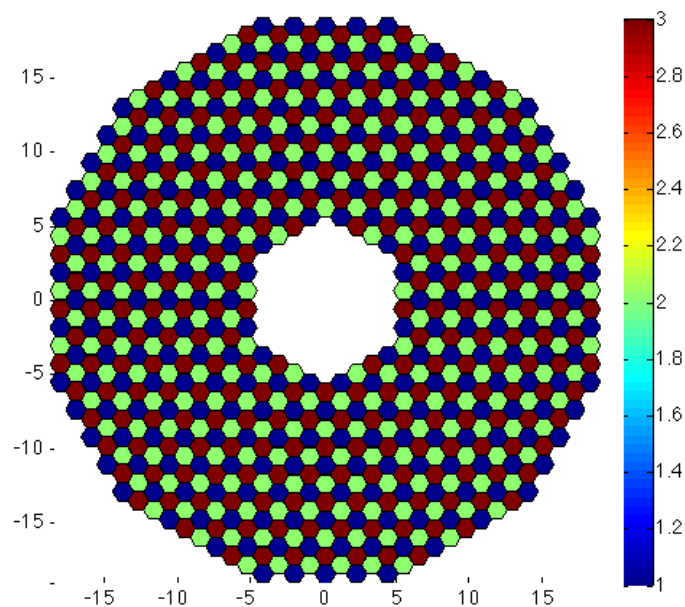


Figure 8: Standard colour codes for M1 segment hexagonal pattern

4.4 M6 naming convention

129 The various type of M6 folding mirrors are named as follows:

M6 name	Function
M6N	Folds the beam towards one of the lateral Nasmyth focal stations (A2/A3 B2/B3)
M6C	Folds the beam towards the Coudé focal station

Table 3: M6 naming convention

4.5 Laser Guide Stars naming convention

- 145 Up to 8 laser guide star units (including each a laser source and a projection subunit) can be accommodated on the Altitude Structure on the side of the M1.
- 146 Their naming principle is as follows:
- a) Incremental integer numbers starting at 1 are used
 - b) The number 1 is allocated to the first unit encountered when moving away from the X_{alt} axis in a positive trigonometric rotation around Z_{alt} (anticlockwise). See §3.2.3 for definition of the altitude coordinate frame.

The resulting naming convention is summarised in Figure 9.

147

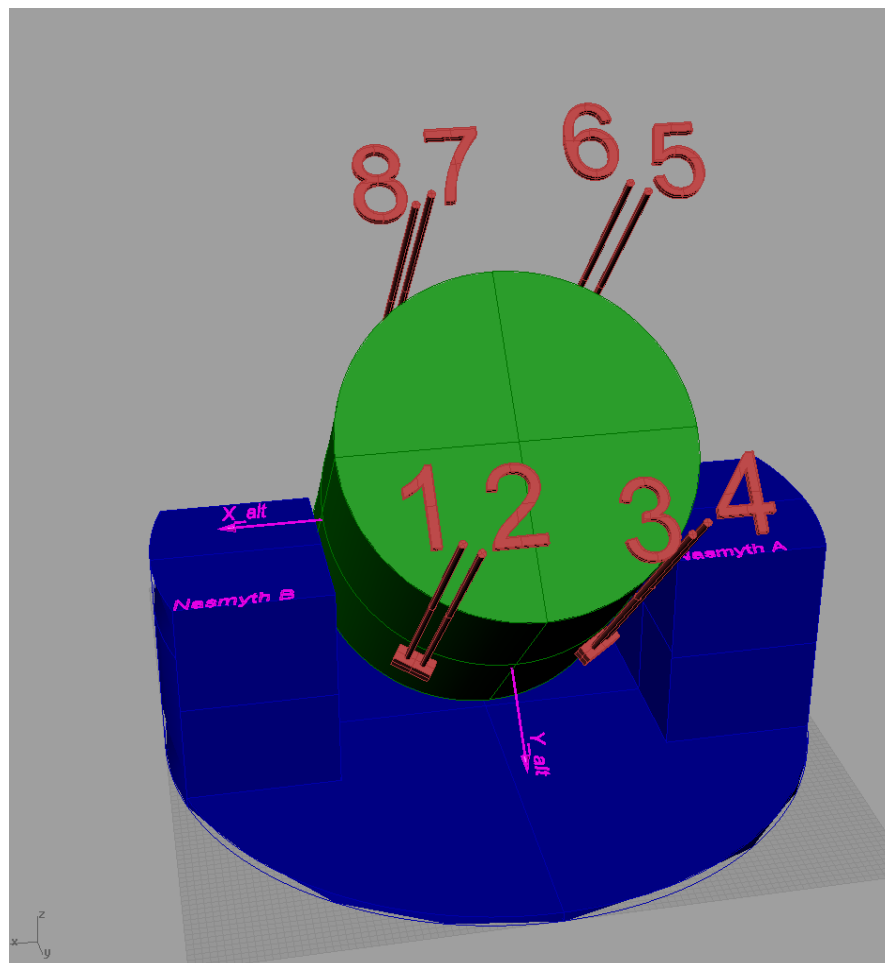


Figure 9: Naming convention for Laser Guide Stars



4.6 Zernike polynomials naming convention

- 150 The convention used for numbering Zernike polynomials shall **always be indicated** in any document referring to Zernike coefficient.
- 151 The **default** convention for numbering Zernike expansion of wavefront error shall be the so-called '*Fringe*' or '*University of Arizona*' convention (RD2) starting at Piston = Z_1 (not Z_0). This convention is recalled in Table 4 below that lists the expression of the 37 first polynomials (9th order + spherical 11th order). r is the radial normalized pupil coordinate and Φ the azimuthal coordinate (rotation about z-axis, with the x-axis corresponding to $\Phi=0$).

152

No	Name	Polynomial expression
Z1	Piston	1
Z2	Tilt x	$\rho \cos(\Phi)$
Z3	Tilt y	$\rho \sin(\Phi)$
Z4	Focus	$2\rho^2 - 1$
Z5	Astigmatism 0°	$\rho^2 \cos(2\Phi)$
Z6	Astigmatism 45°	$\rho^2 \sin(2\Phi)$
Z7	Coma x	$(3\rho^2 - 2)\rho \cos(\Phi)$
Z8	Coma y	$(3\rho^2 - 2)\rho \sin(\Phi)$
Z9	3 rd order Spherical	$6\rho^4 - 6\rho^2 + 1$
Z10	Trefoil x	$\rho^3 \cos(3\Phi)$
Z11	Trefoil y	$\rho^3 \sin(3\Phi)$
Z12	5 th order Astigmatism 0°	$(4\rho^2 - 3)\rho^2 \cos(2\Phi)$
Z13	5 th order Astigmatism 45°	$(4\rho^2 - 3)\rho^2 \sin(2\Phi)$
Z14	5 th order Coma x	$(10\rho^4 - 12\rho^2 + 3)\rho \cos(\Phi)$
Z15	5 th order Coma y	$(10\rho^4 - 12\rho^2 + 3)\rho \sin(\Phi)$
Z16	5 th order Spherical	$20\rho^6 - 30\rho^4 + 12\rho^2 - 1$
Z17	4-fold x	$\rho^4 \cos(4\Phi)$
Z18	4-fold y	$\rho^4 \sin(4\Phi)$
Z19	Trefoil r5 x	$(5\rho^2 - 4)\rho^3 \cos(3\Phi)$
Z20	Trefoil r5 y	$(5\rho^2 - 4)\rho^3 \sin(3\Phi)$
Z21	Astigmatism r6 0°	$(15\rho^4 - 20\rho^2 + 6)\rho^2 \cos(2\Phi)$
Z22	Astigmatism r6 45°	$(15\rho^4 - 20\rho^2 + 6)\rho^2 \sin(2\Phi)$
Z23	Coma r7 x	$(35\rho^6 - 60\rho^4 + 30\rho^2 - 4)\rho \cos(\Phi)$



Z24	Coma r7 y	$(35 \rho^6 - 60 \rho^4 + 30 \rho^2 - 4) \rho \sin(\Phi)$
Z25	7 th order Spherical	$70 \rho^8 - 140 \rho^6 + 90 \rho^4 - 20 \rho^2 + 1$
Z26	5-fold x	$\rho^5 \cos(5\Phi)$
Z27	5-fold y	$\rho^5 \sin(5\Phi)$
Z28	4-fold r6 x	$(6 \rho^2 - 5) \rho^4 \cos(4\Phi)$
Z29	4-fold r6 y	$(6 \rho^2 - 5) \rho^4 \sin(4\Phi)$
Z30	Trefoil r7 x	$(21 \rho^4 - 30 \rho^2 + 10) \rho^3 \cos(3\Phi)$
Z31	Trefoil r7 y	$(21 \rho^4 - 30 \rho^2 + 10) \rho^3 \sin(3\Phi)$
Z32	Astigmatism r8 0°	$(56 \rho^6 - 105 \rho^4 + 60 \rho^2 - 10) \rho^2 \cos(2\Phi)$
Z33	Astigmatism r8 45°	$(56 \rho^6 - 105 \rho^4 + 60 \rho^2 - 10) \rho^2 \sin(2\Phi)$
Z34	Coma r9 x	$(126 \rho^8 - 280 \rho^6 + 210 \rho^4 - 60 \rho^2 + 5) \rho \cos(\Phi)$
Z35	Coma r9 y	$(126 \rho^8 - 280 \rho^6 + 210 \rho^4 - 60 \rho^2 + 5) \rho \sin(\Phi)$
Z36	9 th order Spherical	$252 \rho^{10} - 630 \rho^8 + 560 \rho^6 - 210 \rho^4 + 30 \rho^2 - 1$
Z37	11 th order Spherical	$924 \rho^{12} - 2772 \rho^{10} + 3150 \rho^8 - 1680 \rho^6 + 420 \rho^4 - 42 \rho^2 + 1$

Table 4: Default naming convention for Zernike polynomials (Fringe convention)



153 As an **alternative**, the so-called Noll convention (RD3, RD4) recalled in Table 5 may be used. The use of this alternative shall be unambiguously highlighted in any document using it.

154

No	Polynomial expression
Z1	1
Z2	$2\rho \cos(\phi)$
Z3	$2\rho \sin(\phi)$
Z4	$\sqrt{3}(2\rho^2 - 1)$
Z5	$\sqrt{6}\rho^2 \sin(2\phi)$
Z6	$\sqrt{6}\rho^2 \cos(2\phi)$
Z7	$\sqrt{8}(3\rho^2 - 2) \sin(\phi)$
Z8	$\sqrt{8}(3\rho^2 - 2) \cos(\phi)$
Z9	$\sqrt{8}\rho^3 \sin(3\phi)$
Z10	$\sqrt{8}\rho^3 \cos(3\phi)$
Z11	$\sqrt{5}(6\rho^4 - 6\rho^2 + 1)$
Z12	$\sqrt{10}(4\rho^2 - 3)\rho^2 \cos(2\phi)$
Z13	$\sqrt{10}(4\rho^2 - 3)\rho^2 \sin(2\phi)$
Z14	$\sqrt{10}\rho^4 \cos(4\phi)$
Z15	$\sqrt{10}\rho^4 \sin(4\phi)$
Z16	$\sqrt{12}(10\rho^4 - 12\rho^2 + 3) \cos(\phi)$
Z17	$\sqrt{12}(10\rho^4 - 12\rho^2 + 3) \sin(\phi)$
Z18	$\sqrt{12}(5\rho^2 - 4)\rho^3 \cos(3\phi)$
Z19	$\sqrt{12}(5\rho^2 - 4)\rho^3 \sin(3\phi)$
Z20	$\sqrt{12}\rho^5 \cos(5\phi)$
Z21	$\sqrt{12}\rho^5 \sin(5\phi)$
Z22	$\sqrt{7}(20\rho^6 - 30\rho^4 + 12\rho^2 - 1)$
Z23	$\sqrt{14}(15\rho^4 - 20\rho^2 + 6)\rho^2 \sin(2\phi)$
Z24	$\sqrt{14}(15\rho^4 - 20\rho^2 + 6)\rho^2 \cos(2\phi)$
Z25	$\sqrt{14}(6\rho^2 - 5)\rho^4 \sin(4\phi)$
Z26	$\sqrt{14}(6\rho^2 - 5)\rho^4 \cos(4\phi)$
Z27	$\sqrt{14}\rho^6 \sin(6\phi)$
Z28	$\sqrt{14}\rho^6 \cos(6\phi)$

Table 5: Alternative naming convention for Zernike polynomials (Noll convention)