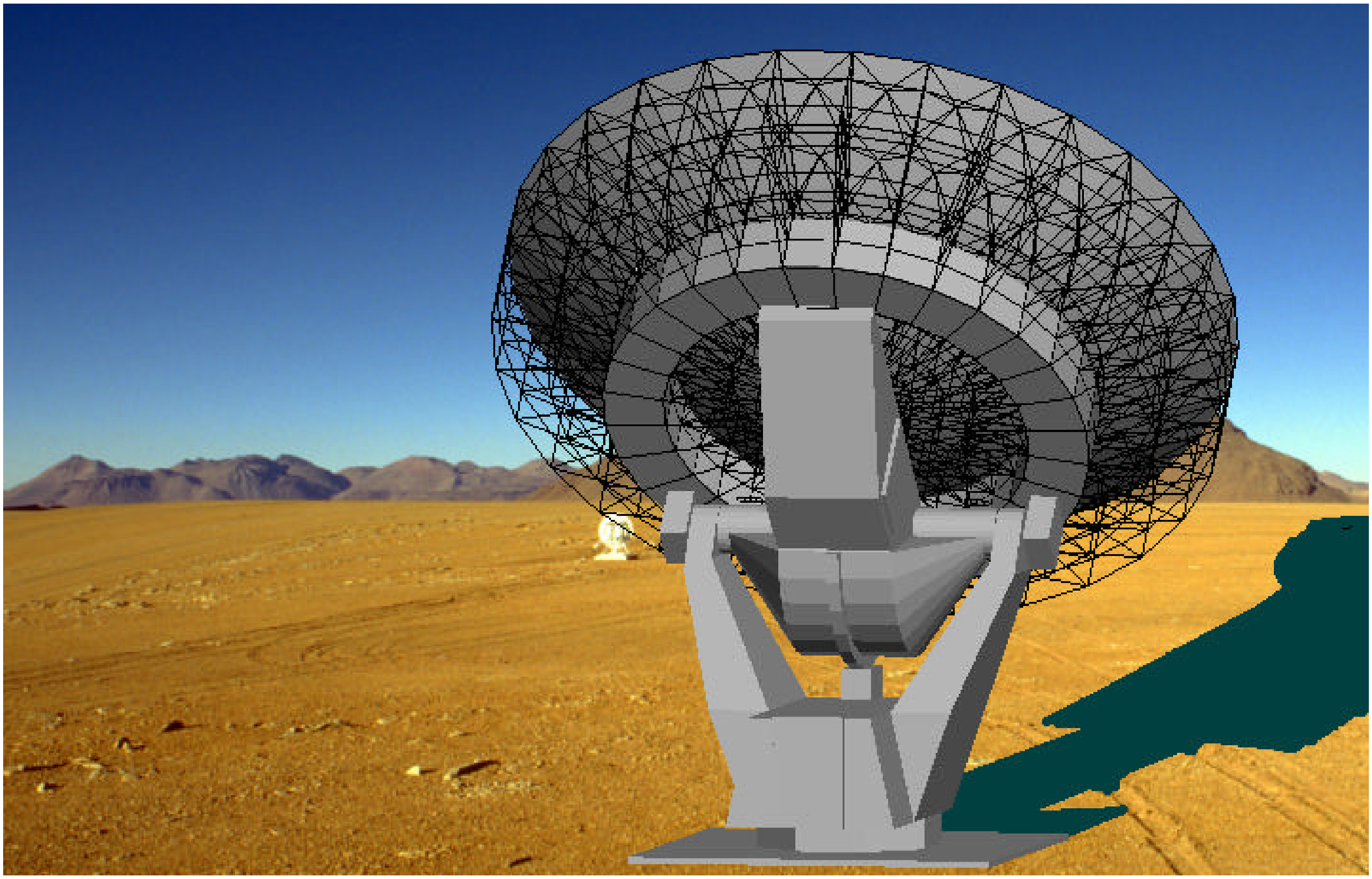

# A 12m Telescope
## for the
# MMA-LSA Project

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**Report prepared at IRAM in March 1999**

**MMA Memo 259**

# A 12m Telescope for the MMA-LSA Project

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Report prepared at IRAM
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March 1999

*Cover: Artist's view of the 12m telescope on the plain of Chajnantor, Chile*

*Photograph by Simon Redford*
*Rendering by Dietmar Plathner*

**ABSTRACT**

The present design of a 12m telescope is based on the IRAM report « The 15m (12.8m) Telescopes for the MMA/LSA Project » which was recently published as MMA Memo 254. The earlier 15m telescope already met the requirements for millimeter and sub-millimeter work. The proposed 12m telescope features the same high quality standard and is modified only in areas where recent studies promise technical and scientific advantages. So the main reflector back structure and the tripod are still from carbon fibre reinforced plastic tubes to obtain thermal stability, and the panels and the subreflector from machined aluminium.

The optical layout is based on a pure Cassegrain arrangement with a fully symmetrical main reflector and secondary. The elevation axis is displaced again; in this case by typically 2m from the optical axis and by 1m from the azimuth axis.

We have also kept the mechanically advantageous three-point connection between reflector assembly and the mount structure. The originally proposed linear elevation drive, however, has been replaced by a pinion/gear segment with backlash compensation by doubled gear trains as for the Plateau de Bure 15m antennas. This drive system is also applied for the rotation in azimuth and is combined with a single, big roller bearing.

These changes required a more compact design of the mount, which has now become a welded box structure instead of a truss configuration. The lower end of the mount is equipped with a ring flange, which can easily be bolted to counterparts on the foundation. The system permits one to align the telescope to a vertical position when it is still carried by the transporter. And it is in this position fixed to the ground which releases many constraints concerning the precision requirements for the foundations or actuated fixation systems.

Such an aligned telescope structure favours also the installation of a load-free substructure (similar to the ideas of J. Lugten, NRAO) which is placed close to the ground fixation area, but above the azimuth bearing. This telescope-independent temperature stabilized structure is equipped at its upper end with displacement sensors to monitor non-repeatable motions of the elevation axis, and it is linked to the elevation encoder, which is directly fixed to the reflector backup structure.

**CONTENTS**

## I. INTRODUCTION

1. The present work is based on the report « The 15m (12.8m) Telescopes for the MMA/LSA Project » prepared at IRAM in September 1997 and recently published as MMA Memo 254. The important basic features of the earlier report have been kept:

- the advanced technologies for the applied materials and machining
- the ideas on supporting the back structure of the main reflector and
- as a consequence, the compactness of the mount.

The advantage of a three-point connection between the supporting mount and the reflector has also been retained, but the linear elevation drive has been replaced by a pinion and bull gear configuration which includes the structure for the receiver cabin. The wheel on track drive and bearing system for the azimuth motion has been changed to a single roller bearing with integrated gear wheel as in use since many years on the Plateau de Bure antennas.

Another change with respect to the earlier report has been made regarding the metrology system for which under atmospheric perturbations the ideas on optical metrology obviously cannot be materialized with the required precision. A load-free, telescope-independent structure similar to the proposals of J. Lugten (see MMA memo 232) now monitors the non-repeatable dislocations of the azimuth axis and the encoder.

Finally, a new fixation system is proposed which attaches the telescope in a levelled position to the foundation. Levelling is done by the transporter, which brings the unit to the station.

As the fundamental ideas of the whole telescope setup have not been changed, the present report concentrates on the description of the design and supposes that the earlier very promising computer verifications on surface accuracy, pointing, phase errors and dynamic behaviour will apply to or can be outperformed by the modified telescope structure.

The goal of this report is not only to propose a 12m telescope which complies with the technical and scientific specifications, but also to present ideas for an instrument which should be reliable and of particularly low cost because of its compactness, simplicity and the application of materials and technologies for which very good experience exists from the Plateau de Bure antennas.

## 2. TECHNICAL AND SCIENTIFIC SPECIFICATIONS

Table 2.1 lists some major details of the technical and scientific specifications according to which the 12m telescopes for the future interferometer array have to be built. The suitability for submillimeter work and the operation of the telescopes at 5000 m altitude on a desert site require high precision performance combined with simplicity and robustness of the mechanics, controls and metrological systems. It is expected that the telescopes stay operational during a period of at least thirty years.

The operational conditions at the high altitude site are somewhat eased by the fact that during most of the time of the year

- humidity values are low,
- there is no precipitation,
- the wind speeds are moderate,
- the wind is not gusty and,
- particularly, the wind pressure coefficient decreases to nearly half of the value at sea level.

In spite of this, the telescopes still must cope with very high UV-radiation, high survival wind speeds, hail, rain and ice.

In addition to these performance requirements, the telescopes have to be transportable for reconfiguration to various interferometer arrangements, i.e. the structures must have equipment to rapidly disconnect them from a station, fix them to a transporter which takes them over a probably non-paved road to another, eventually distant station, and sets the units with high precision onto the foundation where they are reconnected to the ground and cabled.

| ITEM | SPECIFICATION | NOTES |
|---|---|---|
| Site | Chajnantor, Chile | 5060 meters elevation, volcanic soil |
| Number of Antennas | > 50 | Transportable on rubber tire vehicle |
| Aperture | 12 meters | blockage < 2.5% |
| Frequency Range | 30 GHz - 950 GHz | |
| Surface Accuracy | < 25 µm R.S.S. | Total system |
| Pointing accuracy (9 m/s wind, 30 min. between calibration) | 0.6 arc sec R.S.S. | |
| Phase Stability | 7 µm R.S.S. | Median wind conditions |
| Close Packing | < 15 meters | |
| Fast Switching | Move 1.5 deg on sky in 1.5 seconds at 3 arc sec pointing peak | |
| Maximum Velocity | 3 deg/sec , 6 deg/sec | Elevation and azimuth respectively |
| Maximum Acceleration | 12 deg/sec$^2$, 24 deg/s$^2$ | Elevation and azimuth respectively |
| Lowest Resonant Frequency | > 10 Hz | |
| Azimuth Range | +/- 270 deg from North | |
| Elevation Range | 0 deg to 125 deg | |
| Configuration | Symmetric paraboloidal reflector, Elevation-over-azimuth mount, Cassegrain focus | |
| Subreflector Aperture | 0.80 m | Nutating |
| Solar Observing | Allowed | |
| Maximum Wind speed | 65 meters/sec | Survival |
| Design Wind speed | 6 meters/sec (daytime)<br>9 meters/sec (nighttime) | |
| Ambient Temperature | - 20°C to + 20°C | |
| Number of Foundations | > 200 | |
| Expected Lifetime | 30 years | |

**Table 2.1 :** Important Technical and Scientific Specifications

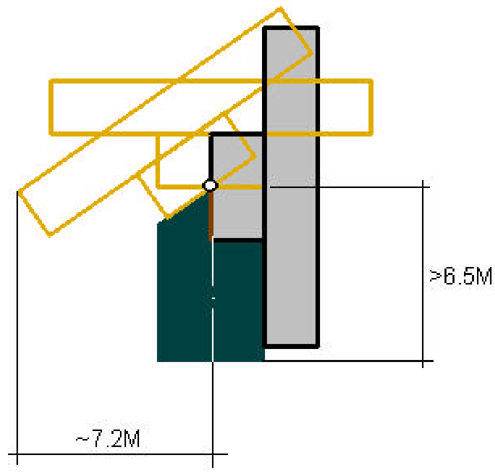
# 3. GENERAL CONSIDERATIONS ON THE TELESCOPE STRUCTURE

The prime elements of the present telescopes are the reflecting surfaces of the main dish and the secondary mirror. All other elements are support structures to keep the optics in good shape, point it within the specified limits to sources on the sky and direct the collected beam into the receiver unit. The expense in material, machining and general engineering for these « secondary » structures is often considerable and influences the overall performance and the costs of the related telescope, particularly when it sums up by a larger number. It is therefore important to minimize the structural design without compromising on the optical quality of the instrument.

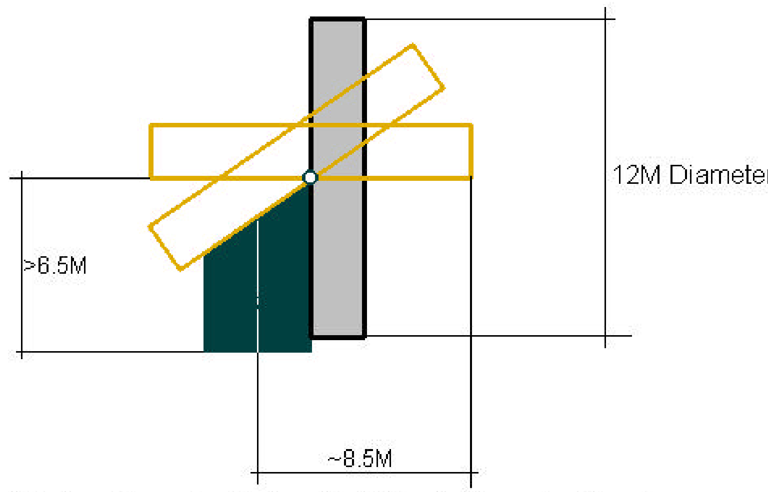
In Fig. 3.1.a, the configuration of a classic alt-az radiotelescope is very schematically shown with the main dish areas in light grey rotated through an elevation angle of 0 to 125 deg. As all three axes cross in one point, the backup structure of the main dish has to be placed relatively far from the center of rotation to give space for the mount represented by the darkest surface. The design results in a high mount and a heavy and complex backup structure.

One can already bring the main reflector backup structure closer to the elevation axis by displacing the axis horizontally, as shown in Fig. 3.1.b. The whole main reflector assembly becomes stiffer, and the lowest eigenfrequency values will go up. If it is felt necessary, the created unbalance can be compensated by a counterweight, typically the compressor cabin, at the very low end of the mount structure and close to the azimuth bearing and drive where it would only very little change the eigenfrequency to lower values. The disadvantage of such a solution compared to the classical structure is given by the large overhang of the rim of the main reflector with respect to the azimuth axis which extends the distance between two telescopes to about 17m compared to less than 15m for the indicated classical configuration of Fig. 3.1.a.

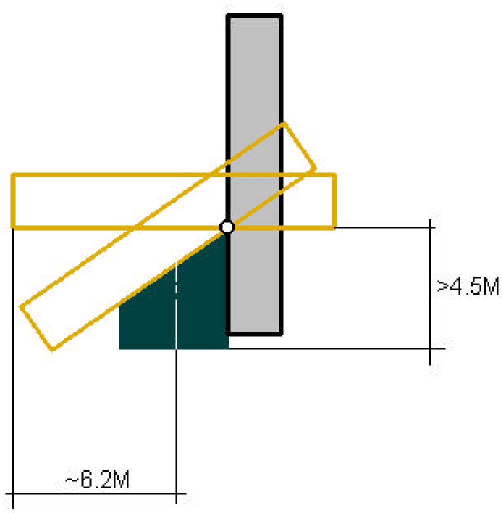
This drawback can be overcome by displacing the elevation axis relative to the azimuth and the optical axis, as shown in the sketch of Fig. 3.1.c. As the elevation axis is close to the backup structure of the main reflector and the center of the reflector coincides with




a) classical alt-az mount with all three axes crossing




b) elevation axis displaced relative to the azimuth axis




c) elevation axis displaced relative to azimuth and optical axis

Fig. 3.1: schematic view of a 12m telescope with various elevation axis locations

the azimuth axis in the zenith position, a very close telescope packing, typically the reflector diameter, can be obtained.

The second advantage of this configuration compared to the classical one is again the small distance between main reflector and elevation axis.

The third advantage, and probably the most important one, is clearly visible on the sketch where the height of the mount reduces from 6.5m, as for the above versions, to only 4.5m. The consequence is a considerable gain in weight (i.e. also costs) and stiffness. The modern light-weight main and subreflector assembly from carbon fibre tubing and aluminium panels can be balanced by an adequate choice of the elevation bull gear segment and the receiver cabin configuration, as shown by the side view on the computer model of the telescope in Fig. 3.2. Thus the center of gravity of the structures rotating about the elevation axis moves downwards by the same amount as the mount height is reduced, which changes the dynamic performance of the telescope to higher eigenfrequency values.

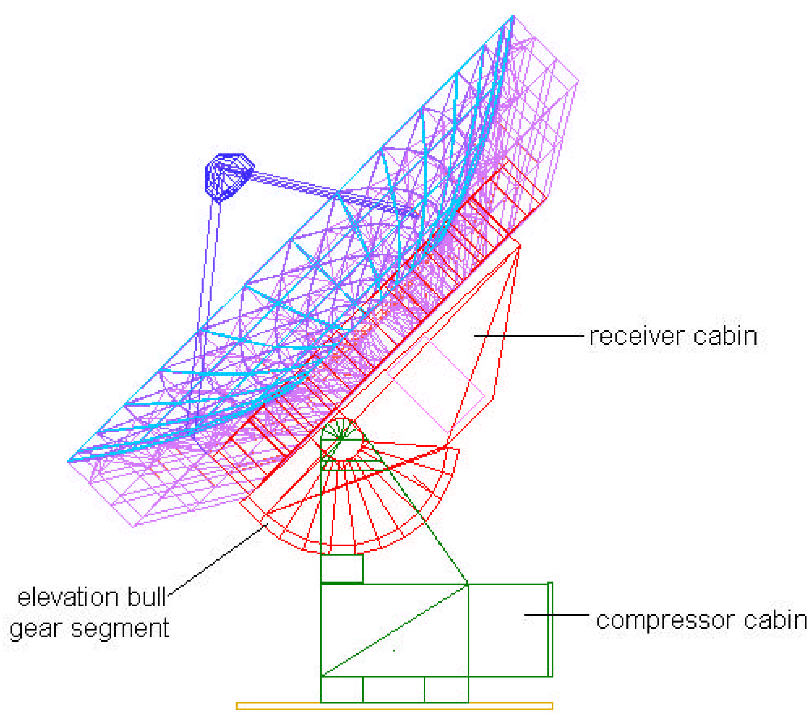



Fig. 3.2: side view on the computer model

Fig. 3.2 also shows the installation of the compressor cabin at the lower end of the about the azimuth axis rotating part of the mount. The cabin serves, as already mentioned for the solutions given in Fig. 3.1.b., also as counterweight for the elevation part, which is placed off the azimuth axis.

## 4. DESCRIPTION OF THE DESIGN FEATURES

By rendering the computer model of Fig. 3.2 to a shaded view, and adding a vertical pole of the size of a human being (1.75m), one can get a feeling for the compactness of the telescope, as shown in various observing positions in Fig. 4.1.a-d. Although the proposed telescope covers an elevation angle from 0 to 125 deg. and provides a spacious receiver cabin, it is remarkable how the structures belonging to the optics (main reflector and secondary mirror with tripod) dominate in size the mount assembly. This is achieved by displacing the elevation axis by typically 1m horizontally in the direction of the reflector and by about 2m vertically downwards with respect to the optical axis being in horizon position.

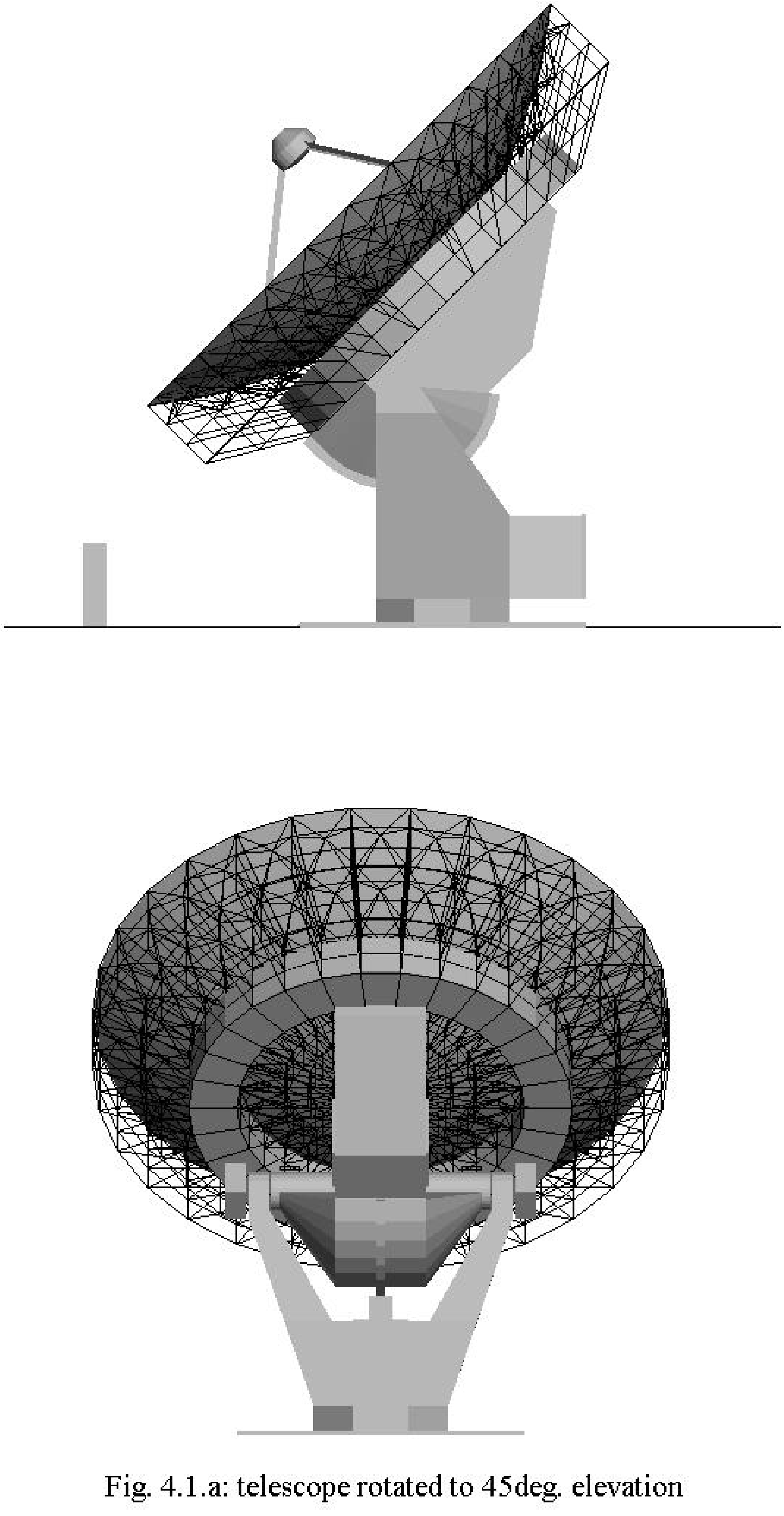


Fig. 4.1.a: telescope rotated to 45deg. elevation

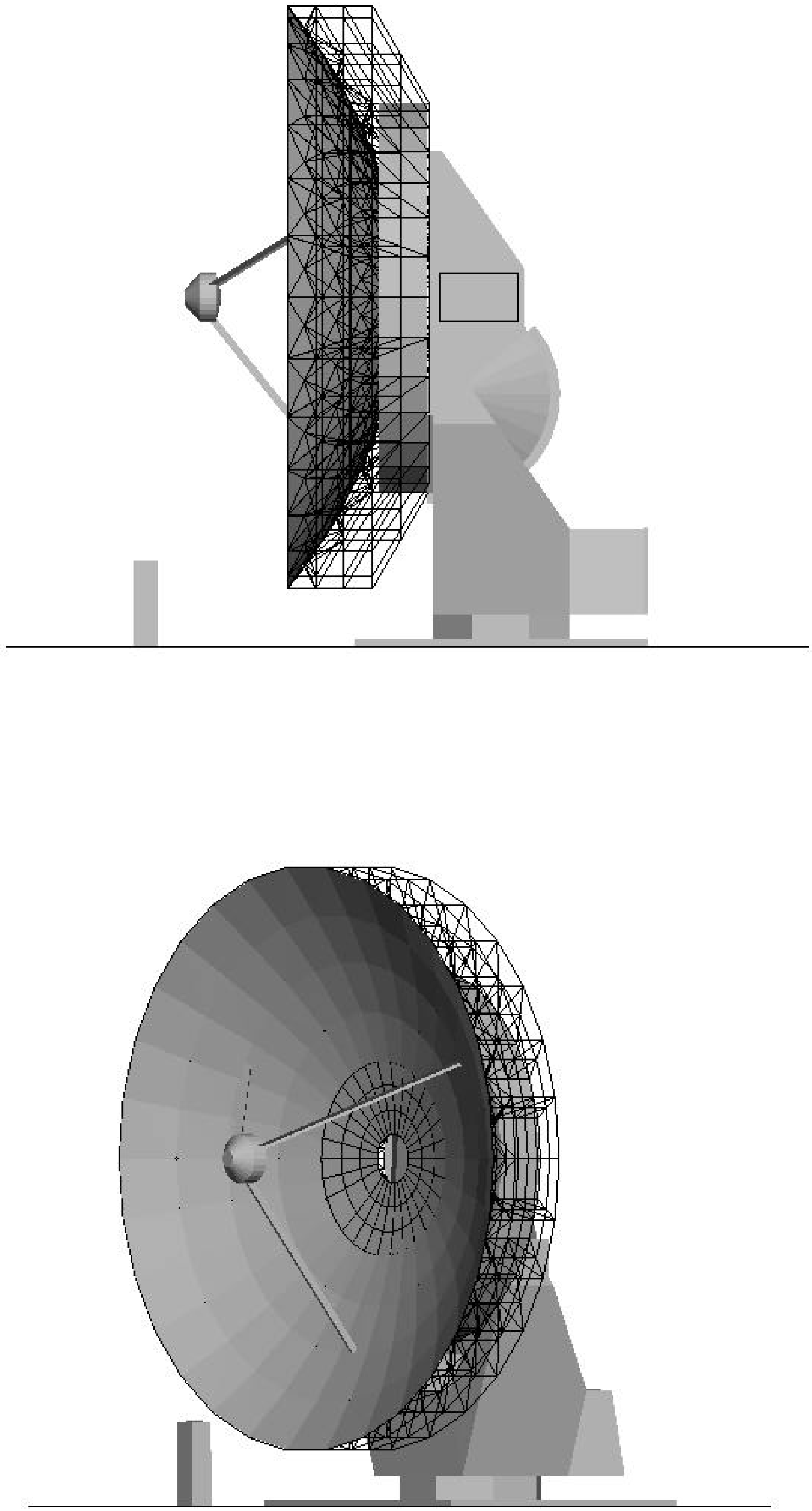


Fig. 4.1.b: telescope in horizon position

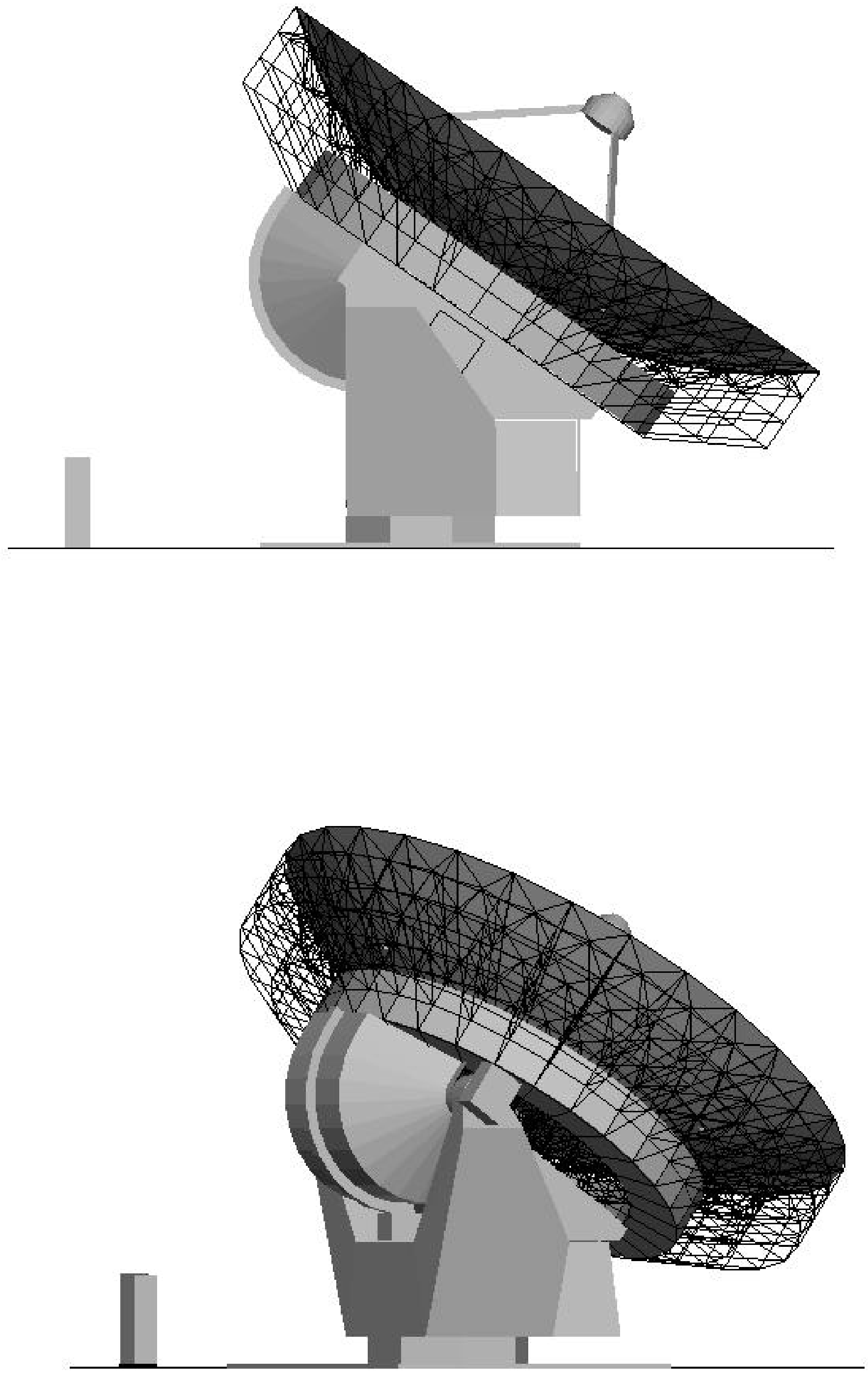


Fig. 4.1.c: telescope in 125deg. elevation position

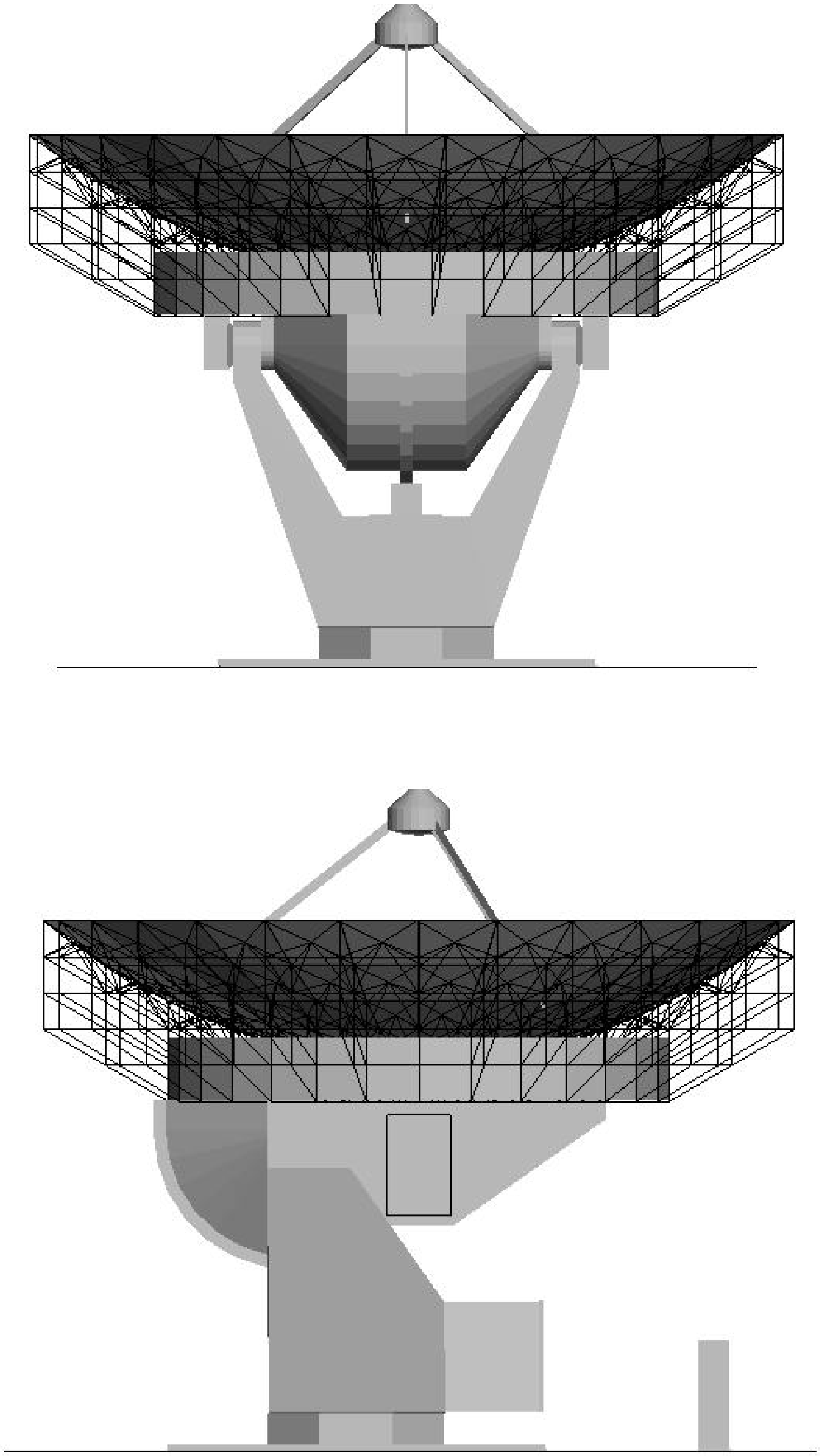


Fig. 4.1.d: telescope in zenith position

## 4.1 Telescope Optics

The proposed telescope is equipped with a symmetric main reflector. The specified Cassegrain configuration requires a secondary mirror. It is supported by a tripod which limits the overall geometrical blockage to about 2.4% (secondary + tripod).

Panels and the sub-reflector are machined from aluminium blocs probably in the same manner as on the Plateau de Bure telescopes (see Fig. 4.1.1 and 4.1.2). The announced hail conditions on the Chajnantor site might, however, require an increase of the surface plate thickness to avoid damages. The surfaces of the panels and subreflectors are machined and treated to permit observations of the Sun or of sources close to the Sun. The subreflector unit can be equipped with a nutating mechanism which rotates the secondary mirror about the prime focus which minimizes coma.

Two adjacent antennas can be placed in a closest packing configuration with a distance of 14.2 m and 2 cm clearance (see Fig. 4.1.3). The optical layout is shown in Fig. 4.1.4.

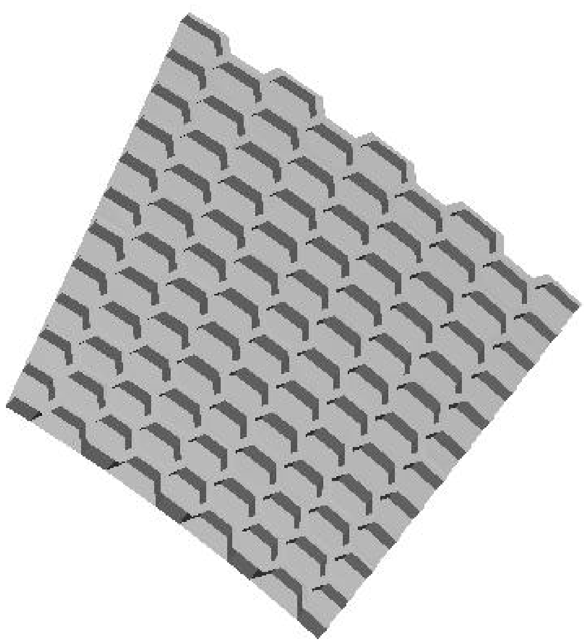


Fig. 4.1.1: machined aluminium panel (backside)

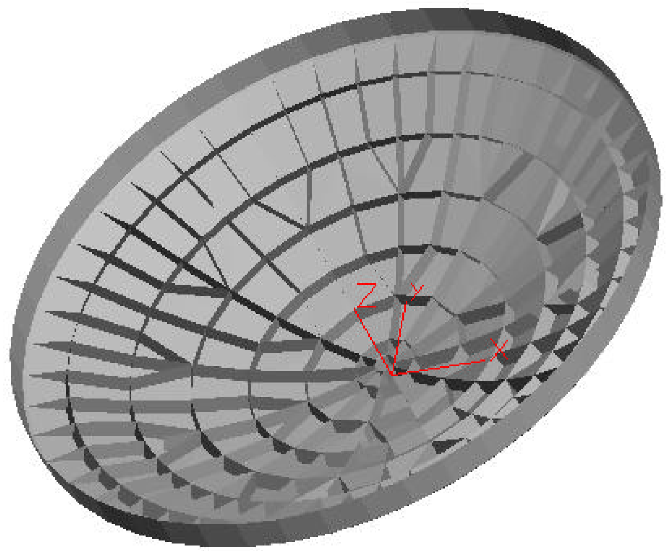



Fig. 4.1.2: subreflector structure in aluminium

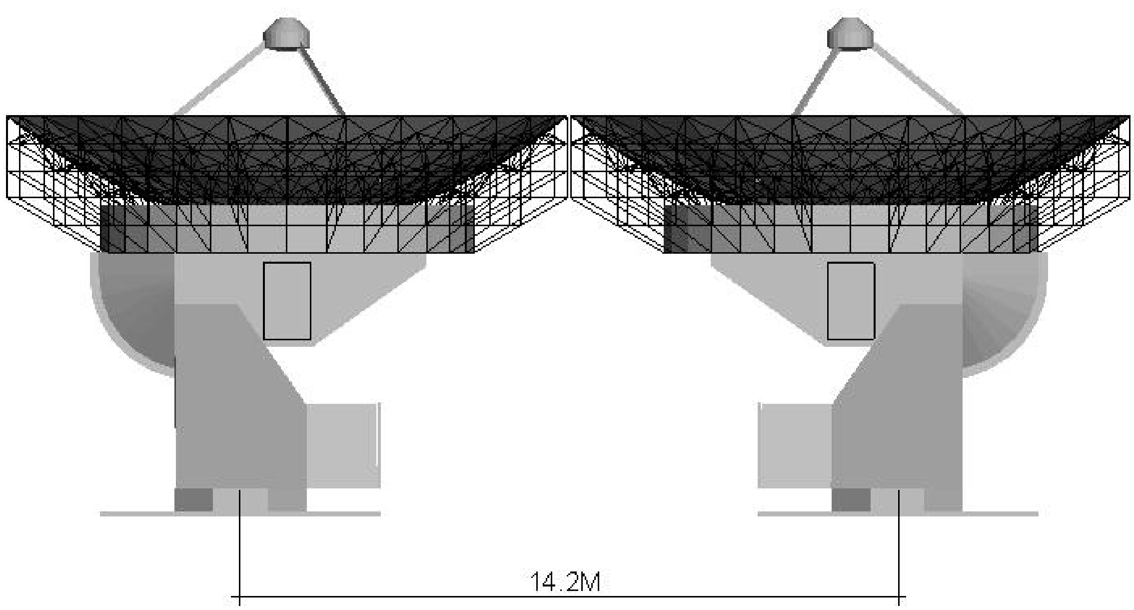
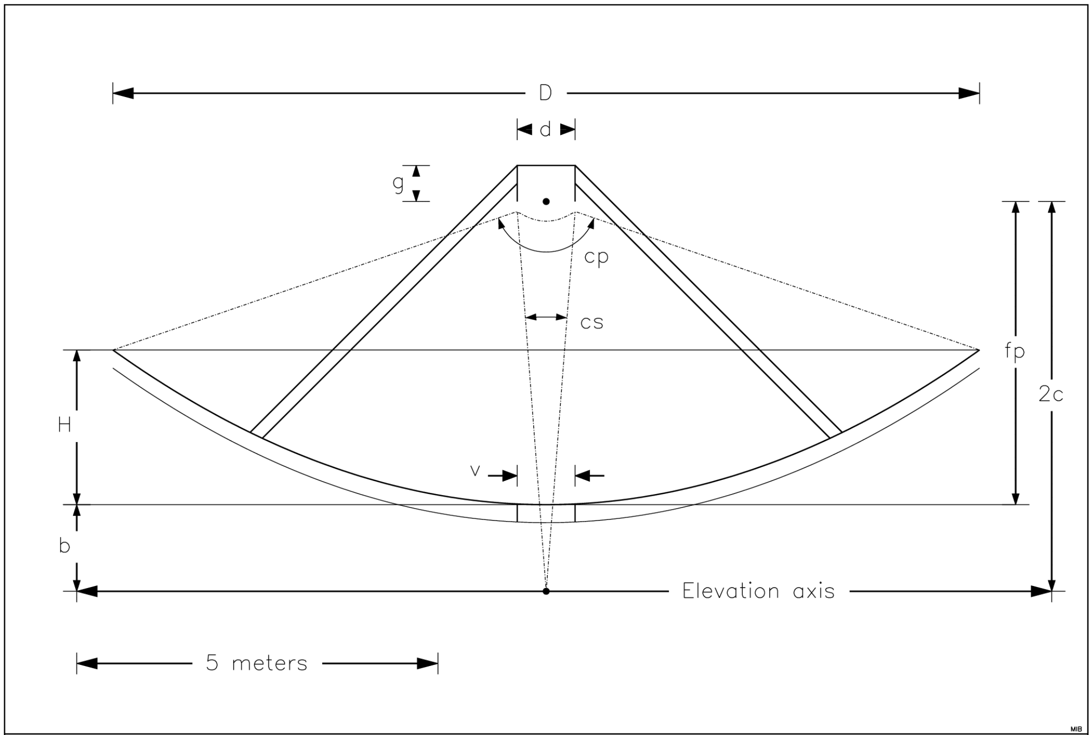



**Fig. 4.1.3:** two telescopes in a closest packing position




| OPTICAL CONFIGURATION | | |
|---|---|---|
| D | Primary Aperture | 12.000 meters |
| fp | Focal length of primary | 4.200 meters |
| | fp/D of primary | 0.350 |
| d | Secondary aperture | 0.800 meters |
| | Final f/D | 6.588 |
| | Magnification factor | 18.823 |
| cp | Primary angle of illumination | 142.151° |
| cs | Secondary angle of illumination | 8.693° |
| 2c | Distance between primary & sec. foci | 5.400 meters |
| H | Depth of primary | 2.143 meters |
| b | Distance from vertex to secondary focus | 1.200 meters |
| g | Distance from primary focus to top of quadripod | 0.500 meters |
| v | Cone & dish inside diameter | 0.800 meters |

**Fig. 4.1.4:** optical layout

## 4.2 Reflector Backup Structure and Tripod

The main reflector panels and the secondary mirror are supported by truss structures, as shown in Fig. 4.2.1. The struts of the trusses are made from low thermal expansion carbon fibre/epoxy tubes. It is proposed to use the same technology as for the Plateau de Bure antennas when assembling the single struts to the three-dimensional truss structures. The connecting elements are hollow spherical steel nodes onto which the various struts are bolted. The production of the items is cheap due to its standardization

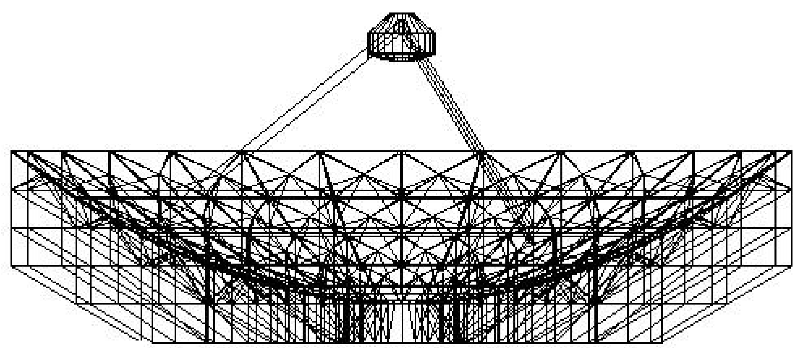


Fig. 4.2.1: main reflector and secondary mirror truss structures

of many identical parts, and the assembly can be done under torque-controlled conditions which is very important for site assembly, be it on Chajnantor altitude or on a location somewhat further down the mountain. Another advantage of the above truss structure is the possibility to use unidirectional pultruded carbon fibre tubes which are made by the most economic industrial production method. The node-tube configuration is shown in Fig. 4.2.2.

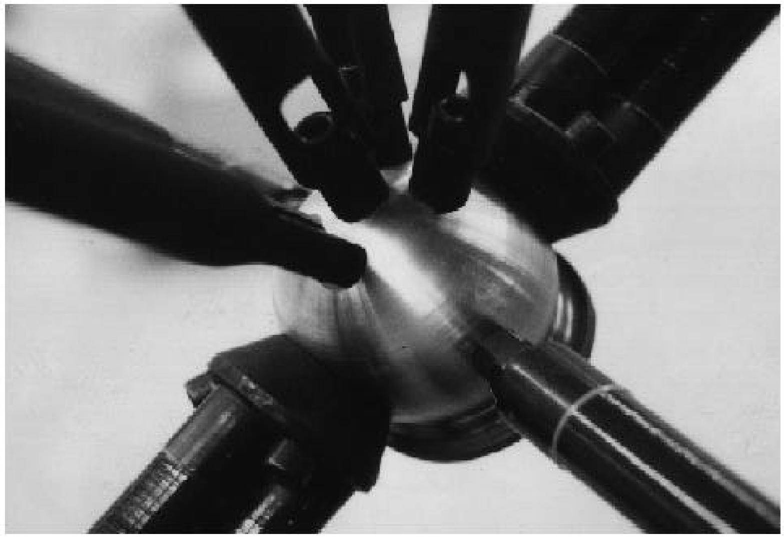


Fig. 4.2.2: node-tube configuration

As already proposed in the September 1997 report, the reflector backup structure will be connected in six points to a steel support box structure. The connections are designed to compensate differential expansions due to thermal variations in the carbon fibre backup and the steel support structure. Deviating from the September 1997 report is the integration of the steel structure as a toroidal box within the geometry of the backup structure (see Fig. 4.2.3).

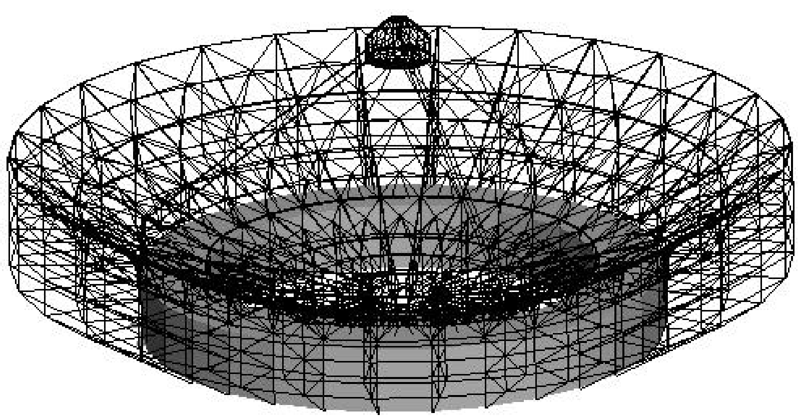


Fig. 4.2.3: toroidal box structure inside the reflector backup structure

There are many advantages to this scheme:

1. The steel structure can be made as a simple, but absolutely symmetric ring box accepting the six reflector supports in optimized positions which includes supports in a plane through the center of gravity of the reflector assembly.
2. The transfer from the six reflector supports to the further down described three-point connections to the mount is deformationwise ideal.
3. The reflector backup structure can be supported on a diameter which is rather far out to the rim; in this case, 8m were chosen which was found optimal in the September 1997 report for a 12m telescope to reduce deformations of the reflector surface under gravity loading.
4. There is no obstruction on the back of the reflector assembly which could collide with the mount when the reflector is rotated through its specified elevation angle of 125 deg.

As the reflector backup structure is bolted together anyway, the single struts can easily be passed through small holes in the steel ring for assembly. The steel ring is equipped with two brackets which each house a spherical roller bearing. The bearings define the position of the elevation axis and present two of the three points with which the reflector is connected to the mount. The position of the bearings with respect to the reflector geometry is shown in Fig. 4.2.4.

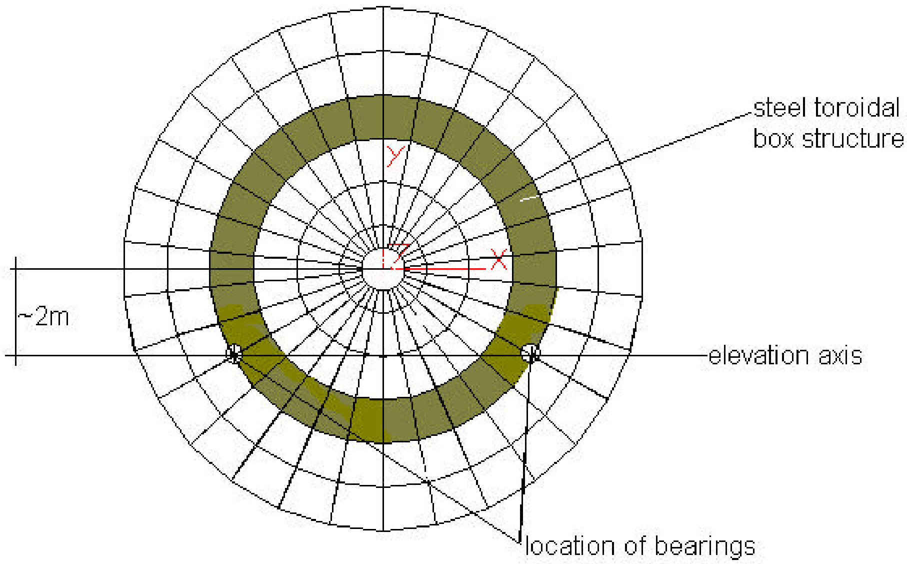



Fig. 4.2.4: position of elevation bearings with respect to the reflector geometry

### 4.3 The Hub and Receiver Cabin Structure

Due to the displaced elevation axis, relative to the optical axis, is the receiver cabin not located in the same area as the hub of the elevation assembly, as it is the case for a classic alt-az telescope. This has the great advantage that the elevation axis can be structurally materialized because it is not obstructing the beam nor the installation of the receiver. Fig. 4.3.1 shows a computer vision of the hub and cabin assembly. The hub structure carries at the ends of the conical parts spherical roller bearings with which it can rotate about the elevation axis. A gear wheel segment is installed in the center which matches with the elevation reduction gear and allows to rotate the hub through 125 deg.

The cabin extends over the whole length of the assembly, giving ample space for the receiver and the related equipment. The cabin is thermally insulated, air conditioned, and the opening for the beam can be closed by a shutter. The cabin has a door of 1m x 1.6m which can be entered from a service truck with the reflector in zenith position. In this position, cabin floor and door are typically only 3.7m above ground and could in emergency be accessed by steps on the mount structure.

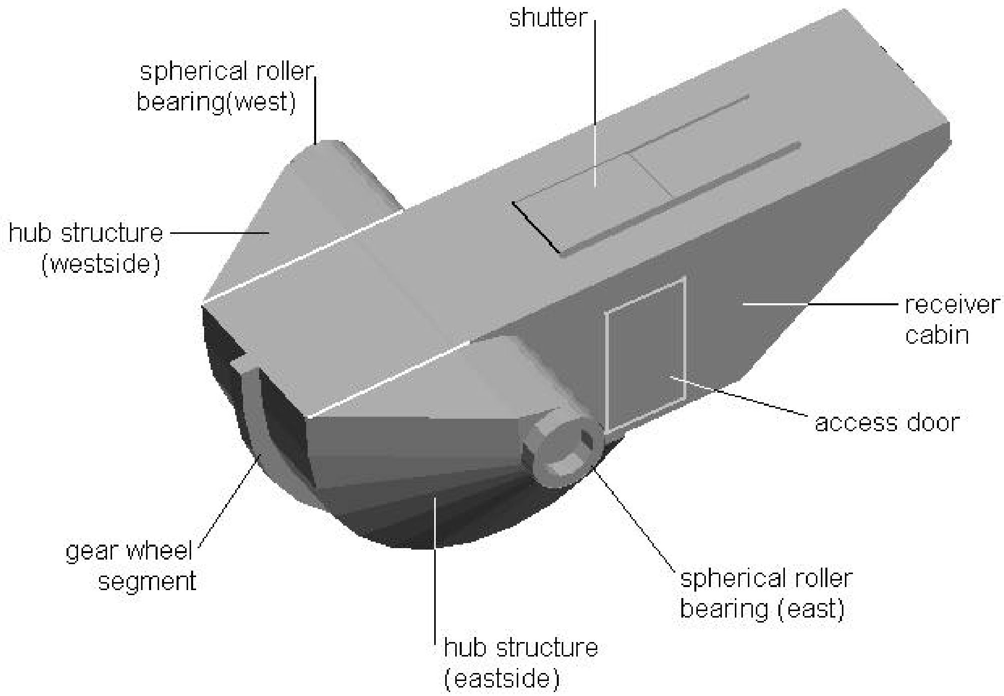



Fig. 4.3.1: computer vision of the hub and cabin assembly

The hub and cabin assembly can be considered as a cantilever beam which is rotated about the elevation axis, and which is used to move the reflector structure. For this purpose the tip of the beam is equipped with a link which is connected with the toroidal steel structure of the reflector assembly. The link is essentially a flat plate extending in a plane parallel to the elevation axis and perpendicular to the beam and thus allows differential expansion between the hub and cabin assembly and the reflector. Fig. 4.3.2 shows in a shaded view the whole arrangement. The sketch in Fig. 4.3.3 is the same assembly, but seen from top and indicating the location of the three-point support of the reflector ring box structure, the elevation axis and the bearings for the hub/cabin assembly.

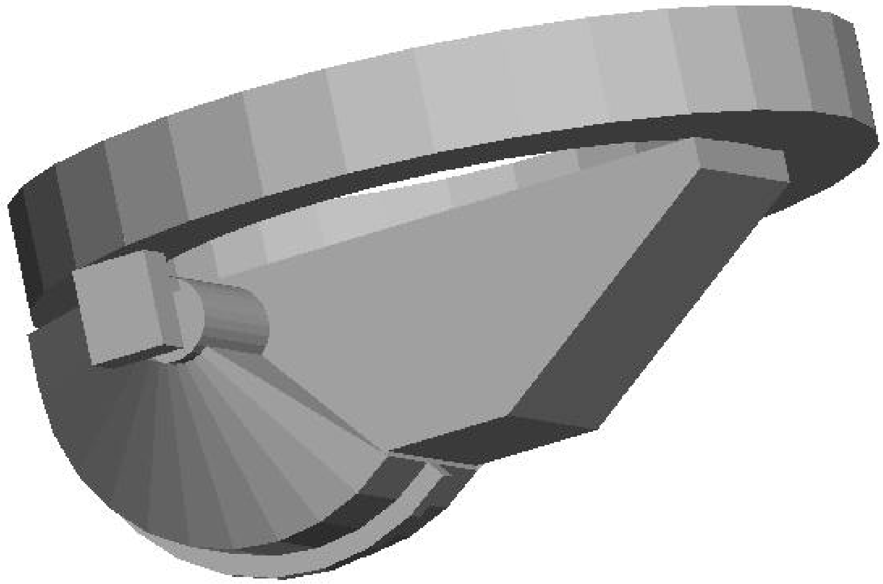


Fig. 4.3.2: shaded view on the assembly of receiver cabin, hub and ring box

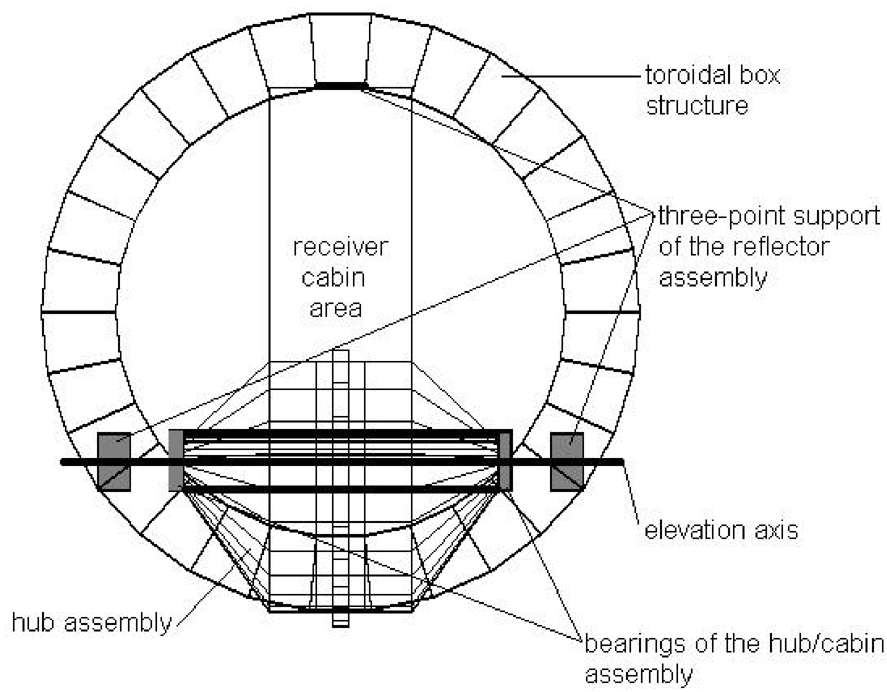



Fig. 4.3.3: three-point support of the reflector ring box structure

## 4.4 Yoke

The yoke of the telescope brings the loads from the elevation axis down to the azimuth bearing. Special care has to be taken to create sufficient stiffness without concentrating too much material. As the yoke is produced from welded steel plates, it will considerably contribute to the dynamic behaviour of the whole telescope.

It is therefore advantageous that the fork prongs, due to the displaced elevation axis, can be relatively short, and that the weight they carry is only in the order of something like 25 tons. Still with the intention to create high stiffness in this piece, the lower part of the yoke was designed particularly important in height and lateral extension. The stiffness is additionally increased by integrating the compressor cabin into the structure of the yoke, as shown in Fig. 4.4.1. An additional counterweight for the off-axis placed elevation

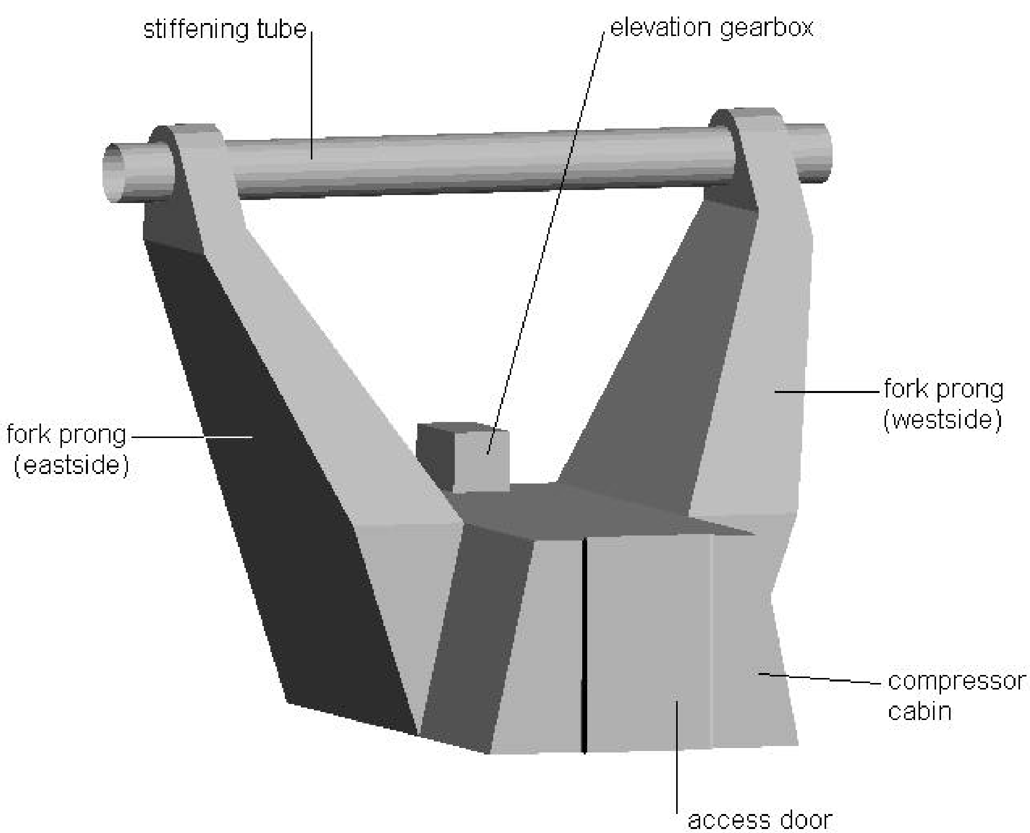



**Fig. 4.4.1:** yoke structure

part can be located under the compressor cabin. This brings the center of gravity for all parts rotating in azimuth rather far down, which is again favourable for the dynamic performance of the telescope.

The inside of the yoke is accessible through the compressor cabin and will house the telescope-independent reference structure, which is described further down. This system sits close to the area where the azimuth bearing is integrated into the yoke structure, an area which is designed to be intrinsically stiff to transmit loads from the telescope to the ground with only a minimum of deformations.

A particular advantage of the displaced elevation axis design can also be seen in Fig. 4.4.1 where the upper end of the fork prongs are connected by a solid tube, which increases the rigidity of the yoke remarkably. This is possible due to the absence of the beam in that area. The bearings of the hub/receiver cabin unit are installed at the ends of the tube just inside the fork prongs which reduces again one of the main deformation problems in that area.

As the yoke is a complex multi-purpose element, it should not be forgotten that it carries also the gear box for the elevation drive (its location is shown in Fig. 4.4.1), and the azimuth gear box which is probably installed inside the compressor cabin.

## 4.5 Base

As there will be a large number of telescopes, which are displaced to several MMA/LSA configurations, it is important to design them transportable and also easily disconnectable from their foundations. On the other hand, the research work, which is planned with the interferometer requires a rigid fixation on the ground to obtain an elevated eigenfrequency value and, for the same reasons, a precision positioning.

The fixation system for the proposed 12m telescopes uses the transporter which moves a telescope, to position it correctly above a station. A friction clamping, as shown in

Fig. 4.5.1, « freezes » this position and bolts the telescope to the foundation. The sequence of operations is as follows.

1. The transporter approaches the designated station with the telescope center line within a tolerance of 0.5m from the foundation center.
2. The transporter being on pneumatic rubber tires is lifted by safety pads, and its position is stabilized on the site ground.
3. A x-y displacement table which is fixed to the transporter, and which is carrying the telescope, is vertically adjusted so that the telescope is perfectly levelled.
4. The x-y table places the telescope exactly over the station center.
5. The telescope being supported by the x-y table above its center of gravity, i.e. somewhere on the upper part of the yoke, rotates the base to turn it into the angular position required by the station.
6. Now the telescope is lowered by the transporter and slides with the vertical ring flansh underneath the base into a set of vertical plates.
7. When the telescope has reached its final and still levelled position above the station, the ring is bolted against the set of vertical plates. The holes in the ring are slightly oblong to cope with the small tolerances in vertical direction between the ring and the plates. The plates are double articulated at the lower end (see enlargement in Fig. 4.5.1) so that they can be radially displaced when screwed to the ring.

The telescope is now fixed to the station. The advantages of the proposed solution are :

- No great precision is needed for setting the foundations, because small inclinations (± 1.5 arc min.) will not hinder the base from being correctly bolted in the levelled position ;
- The large number of telescopes must not all be equipped with a precision level and alignment system.
- The base is supported by a relatively large number of uniformly distributed support points which is essential for the perfect and smooth operation of the azimuth bearing.

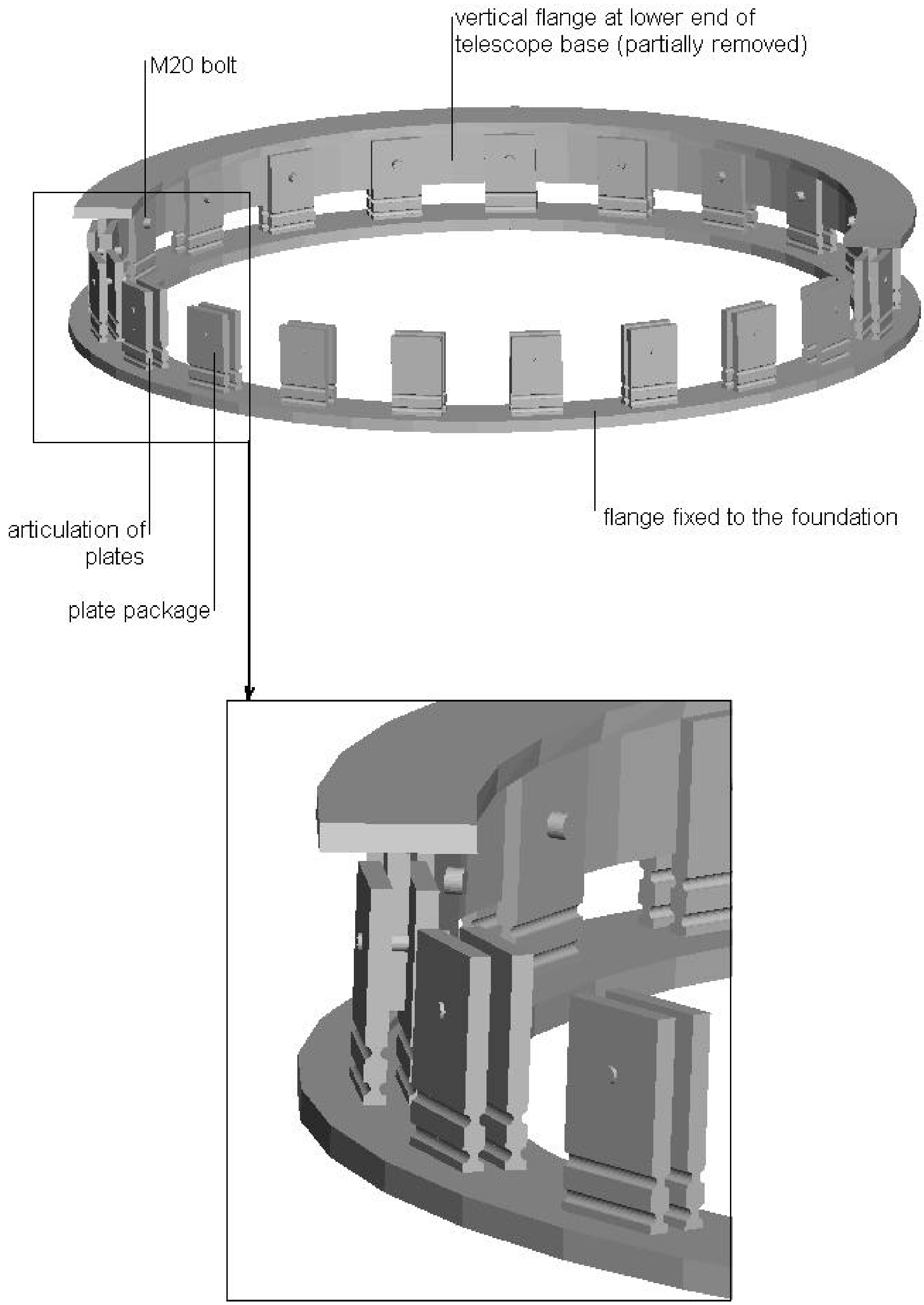



Fig. 4.5.1: clamping of the telescope base to the plate packages on the foundation

The plate packages can each take vertical loads of typically 5 tons which is the limit for safe operation of the double friction connection created by a M20 DIN 912 grade 8 bolt and tightened by a power wrench unit with a built-in electronic control system which operates a cut-out at the exact yield point of the screw. The moment created by the telescope under survival conditions (65 m/s wind speed) could be taken by 2 times 2 plate packages in opposite position. The total number of plate packages to support the base is typically 21. The horizontal loads in the base of the telescope are taken by 2 times 2 plate packages positioned 90 deg. from those loaded vertically (see also Fig. 4.5.1)..

## 4.6 Bearings

The bearings on the elevation axis are high precision spherical roller bearings which can carry radial and thrust loads. They are of medium size, and the rollers are probably treated with a very thin diamond-like layer which nowadays can be applied on request without considerably pushing the costs. The hardness of the roller surfaces is increased, and therefore the friction coefficient goes down by a factor of 2 to 4. Also the wear and rolling contact resistance, even under poor lubrication conditions, is changed to much better values.

This technique is particularly promising for the azimuth bearing which is proposed as a tapered crossed roller bearing equipped with a gear wheel driven by the azimuth reduction gear. The azimuth bearing links the base of the telescope with the rotating upper part. It can take radial, axial and tilt loads. It is preloaded to take out backlash. The roller path is at a diameter of about 2.5m. The matching surfaces on the base and the yoke have to be precision machined to high flatness, and the structures supporting the bearing must be extremely stiff to ensure a smooth operation of the bearing.

## 4.7 Drives, Brakes and Stow Pins

As on the Plateau de Bure antennas, the drive units should consist of planetary reduction gears of very high stiffness driven by torque motors. Each gear train in the drive units is doubled so that, when matching with the corresponding gear wheel, the backlash can be suppressed by opposing the couples in the gear trains. The motors are combined with a tachogenerator for speed control and are also equipped with a safety brake which stops the motion of the telescope in case of a power failure.

It would be interesting to look into the possibilities of applying the diamond coating, as described for the bearings, also to the pinions matching with the large gear wheels to reduce friction and maintenance efforts also in these areas.

Parallel to the drive units, motorized stow pins can be operated to lock the moving parts of the telescope in defined positions. These units should also operate rather backlash-free to protect the gears from dynamic loadings during survival conditions.

## 4.8 Cable Feed

Particularly the azimuth cable feed is often a problem because of the available space and the friction which is created between the cables. For the present project, it is proposed to create a cable feed at the outside of the base, which would ensure good accessibility, and to use energy chains.

Normal energy chains guide the cables in one plane and are available in rotary versions, but would occupy a rather large horizontal disc area around the base structure. Innovative cable chains are now available which operate in two levels while rotating about an axis. The system is shown in Fig. 4.8.1 and increases the diameter of the area where it is installed just by the width of the cable carrier elements. The single elements can be made from light-weight plastic, the interior cable duct is modular for better separation of the various cable types, and the assembled device is good to cover an overall rotation of ± 270 deg. The whole set-up may be enclosed by a sunshade.

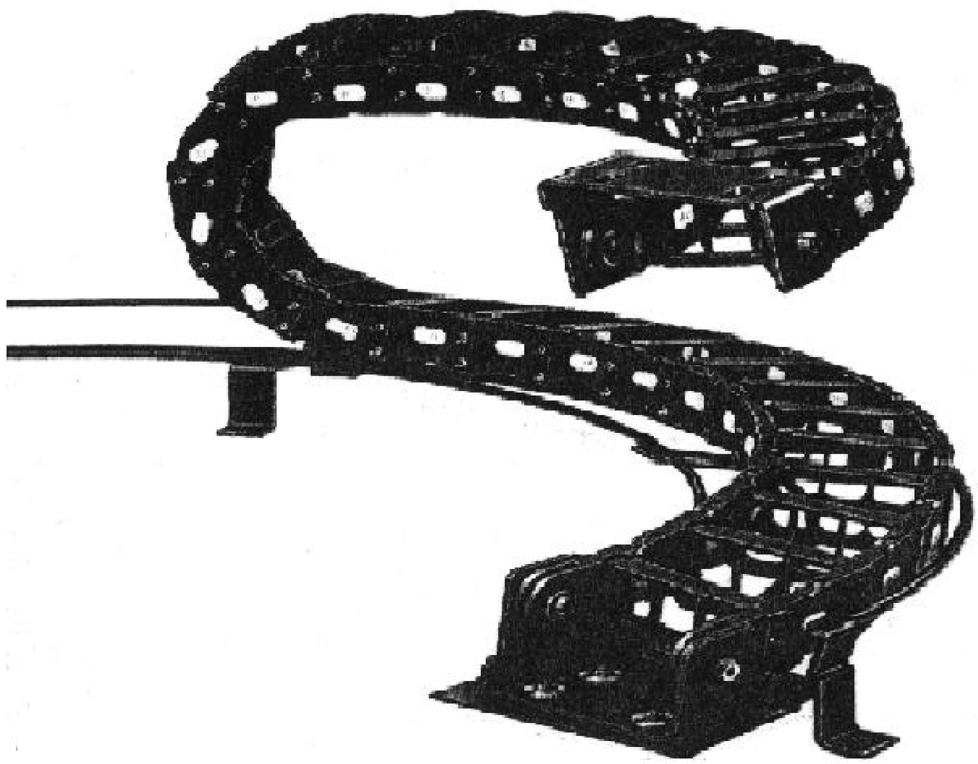


Fig. 4.8.1: double curved energy chain

**4.9 Foundation**

Although the foundations are in general not part of the mechanical structures fixed to them, some information about these items is included here, because the dynamic behaviour of the telescope can only be defined in combination with the foundation.

The soil on the selected site is probably mainly loose volcanic material with a modest modulus of elasticity of 100 - 200 MPa. Therefore the foundations will have a large underground extension to create low specific pressure values. The foundations will be designed as a thick concrete ring with a central hole for accessing the cable ducts. A ring configuration has been chosen to create the same stiffness in all directions. The upper part of the inner diameter of the ring is equipped with the plate packages to which the base of the telescope is bolted (see Fig. 4.9.1). In this area, also reference targets are installed which are needed to place an arriving telescope correctly on the station.

As there will be 4 to 5 times more stations than telescopes, it is proposed to protect the holes in the free stations from dust and thermal impacts by covering them. It is probably necessary to make the covers strong enough to carry a passing transporter with or without a telescope loaded.

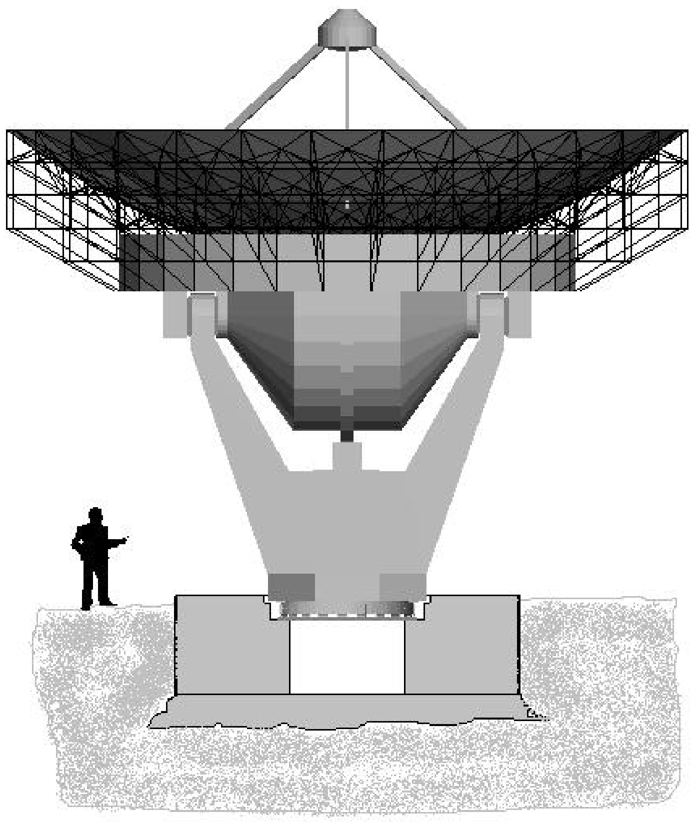


**Fig. 4.9.1 :** the telescope on its foundation

## 5. METROLOGY SYSTEM

Both axes of the telescope are equipped with high precision angular incremental and absolute encoders. The ends of the angular excursions are additionally indicated by two sets of limit switches. And the very ends of the rotational motions are materialized by mechanical stops.

### 5.1 Encoders

The motion of the elevation axis is monitored by encoders of the type housing plus central shaft with error compensating couplings for the connection to the telescope.

Due to the very open structure of the yoke and its base in the area of the azimuth bearing, it is proposed to use here Heidenhain strip encoders. The strip could be placed on a drum of typically 2m in diameter which would permit to obtain a very high resolution.

These two encoder systems should already make an operation of the telescope under certain weather conditions possible.

### 5.2 Telescope-Independent Metrology System

In view of the high requirements under which the telescope should produce excellent astronomical results, it will probably be necessary to add a telescope-independent metrology system. First ideas were presented in the earlier September 1997 report. They were mainly based on laser-optical methods to monitor the position of reference points on the main reflector backup structure relative to the ground. In the meantime, it could be verified that probably the perturbations by the surrounding atmosphere cannot be eliminated to the extent that the precision of the metrology system could cope with the requirements on the telescope.

The present configuration of the telescope would, however, easily accept the installation of a telescope-independent and stiff support structure similar to the proposals of J. Lugten in MMA Memo # 232.

A light weight, thermally stable carbon fibre structure can be installed inside the yoke, as shown in Fig. 5.2.1. The base of this structure is fixed to the yoke close to the azimuth bearing and encoder. The upper ends of the two structural prongs reach the elevation axis level where either the motions of the yoke in that area can be monitored -when exposed to wind and thermal loads- or the carbon structure can be extended further outwards so as to detect the displacements of the main reflector backup structure directly. Standard non-contact linear displacement sensors could be used. And by placing the encoders on the reflector backup structure and coupling them to the carbon fibre prongs, this would give angular readings in elevation with a stable, telescope-independent reference.

The reference coordinate system is in this case practically defined by the center of the azimuth bearing, the position of which is monitored by tiltmeters on the non-rotating part. All repeatable errors like run-out and tilt can be corrected by calibration.

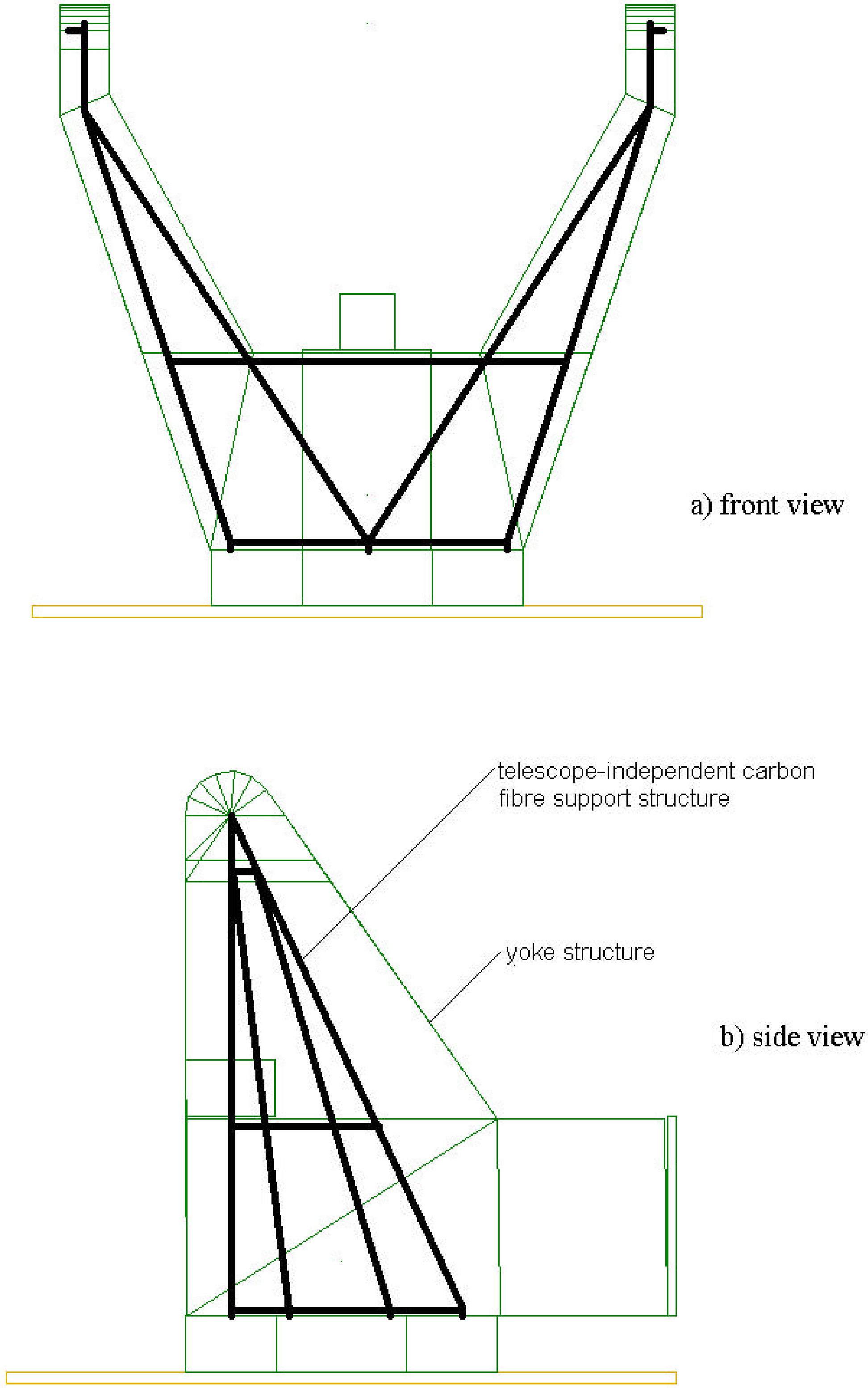



Fig. 5.2.1: sketch of telescope-independent reference
support structure in carbon fibre

## 6. SUMMARY OF THE PERFORMANCE DATA

As it was indicated further above, this report is mainly intended to describe modifications which were thought to be necessary to still increase the quality of the telescope structures presented in the IRAM September 1997 Report (MMA Memo 254). The performance data given below are derived from this report and adapted to the smaller reflector diameter, which changed from 15m to 12m.

The earlier data of the 15m telescope were already within the specifications (see chapter 2), so there is no doubt that the present 12m telescope with its improvements will meet them.

Information is summarized on

- the reflector surface error budget
- the pointing
- phase stability of the 12m telescope and
- the lowest eigenfrequency value.

### 6.1 Reflector Surface Error Budget

6.1.1 Backup Structure

- gravity — 10.2 µm r.m.s.
  (worst case for el. angles between 20 and 75 deg.,
  correction of secondary position included)

- windload (9 m/s at 5000m altitude static load averaged over attack angles) — 2.0 µm r.m.s.

  - 0 az., 60 el. — 3.0 µm r.m.s.
  - 90 az., 0 el. — 0.9 r.m.s.

- thermal (averaged over temp. gradients) — 10.4µm r.m.s.

  - temperature gradient of 10C front to back — 7.5 µm r.m.s.
  - temperature gradient of 10C left to right — 13.2 µm r.m.s.

- $\Delta T$ = 2.5C in entire structure — 3.3 µm r.m.s.

- **total back-up structure — 15.0 µm r.s.s.**

6.1.2 Panels

- ♦ machining (best fit for tilt and warp) 11.0 µm r.m.s.
- ♦ wind and gravity 3.0 µm r.m.s.

(static load for 9 m/s, form factor $c_f$ = 2, gravity, no best fit)

- ♦ thermal (deformation due to full face-on solar load) 0.5 µm r.m.s.
- ♦ **total panels** **11.4 µmr.s.s.**

6.1.3 Secondary

- ♦ machining (best fit for tilt and focal length) 8.0 µm r.m.s.
- ♦ thermal

ΔT = 10C entire element 0.0 µm r.m.s.
10C/m gradient 1.4 µm r.m.s.

- ♦ **total secondary** **8.1 µm r.s.s.**

6.1.4 Alignment **10 µm r.m.s.**

6.1.5 **GRAND TOTAL** **22.8 µm r.s.s.**

### 6.2 12m Telescope Pointing Error Budget

General remarks:

- ♦ For thermal loading, only the reflector structure has to be considered ;
- ♦ For the wind load, compensation by the proposed telescope-independent support structure for the elevation encoding is included.
- ♦ Pointing errors quoted shall be the total pointing error on the sky.

6.2.1 Wind loading (9 m/s at 5000 m altitude)

- ♦ attack angle 0 az., 60 el. 0.15 arc sec
- ♦ attack angle 90 az., 0 el. 0.19 arc sec

6.2.2 Thermal

- ♦ Δt = 3C left-right across the dish 0.19 arc sec
- ♦ Δt = 3C front-back across the dish 0.19 arc sec

6.2.3 Servo system 0.20 arc sec

6.2.4 Non-repeatable bearing errors and friction 0.20 arc sec

6.2.5 **TOTAL** **0.46 arc sec r.s.s.**

### 6.3 Phase Stability

Remarks :
1. the entire telescope has to be considered ;
2. due to the off-set between the el. and az. axes, certain pointing errors contribute to the aperture phase shift ;

| N° | Loading | Aperture phase shift | Optical path length | Total |
|---|---|---|---|---|
| 1 | dT = 1 K, el. = 0 deg. | - 11 µm | 16 µm | 5 µm |
| 2 | dT = 1 K, el. = 90 deg. | - 28 µm | 16 µm | - 12 µm |
| 3 | 9 m/s wind at 5000 m altitude, face on | 16 µm | - 10 µm | 6 µm |
| 4 | servo system mispointing | 1 µm | -- | 1 µm |
| 5 | mispointing due to bearings and fixations | 1 µm | -- | 1 µm |

### 6.4 Eigenfrequency

Lowest natural frequency value >10 Hz

## 7. CONCLUSIONS

The 12m telescope which is described in the present report, should meet the surface accuracy, the specified pointing and the required path length stability. The design is based on materials and technologies which are in use for nearly 15 years on the Plateau de Bure interferometer. Particularly the carbon fibre backup structure and the fully machined panels out of wrought aluminium as relatively new technologies in radiotelescopes have proven their long-term stability.

Also recent cost information is available from the IRAM 15m antennas, as the 6$^{th}$ unit is under construction in 1999. Without including either a reduction for the series production of 50 to 64 identical telescopes or the costs for the foundations, the unit price can be estimated to be not more than 3 M US $, due to the compact design and the selection of materials and technologies similar to those of the IRAM 15m antennas. Bearings, drives and encoder systems are from known « telescope » quality and again should correspond to the longevity requirements of 30 years. Particularly the « No wear » diamond-like layer applied to bearings will positively contribute to that requirement.

## 8. ACKNOWLEDGEMENTS

The present report was initiated by the many discussions within the MMA/LSA Working Group on the earlier IRAM proposal of a 15m telescope, but also by contributions from IRAM colleagues.

R. Neri and M. Bremer have provided information on the optics, and A. Greve looked into metrology problems. I also thank D. Downes for his comments.

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