The ALMA Antenna Transporter

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The ALMA observatory will consist of an array of 54 12-m diameter and 12 7-m diameter antennas. In order to configure the different array modes, it is necessary to move the antennas to different configurations. In the compact array configuration, the antennas are packed as closely as possible within a circle of 200 m diameter; in the extended configuration the antennas are spread over an area of about 15 km in diameter. The frequent relocations of antennas will be accomplished by two special vehicles, the ALMA Antenna Transporters. The challenges encountered during their development and their main characteristics are described.

Definition of requirements and interfaces

Already in the early design phase of ALMA, the basic requirements for the ALMA Antenna Transporters were defined. They should, for example, have rubber tyres and be capable of negotiating slopes up to 15 %. Later more detailed requirements were added, such as the capability to move four antennas a day for array reconfiguration, or transport one antenna from the basecamp to the observation site within one work shift of six hours. These requirements defined the transport capacity and led to the need for two transporters.

During the site selection phase, the geographical conditions related to transport were studied, since the roads are also a primary component of antenna transport. The cost of the roads easily exceeds the cost of the transport vehicle. It was decided early in the planning phase to build a dedicated road from the selected basecamp location (the Operations Support Facility, OSF) at 3 000 m altitude up to the observation site (the Array Operations Site, AOS). The decision to build this road then allowed the definition of the road parameters to be fed into the specification for the transporter. Together with the site engineers the main road parameters were defined, with feedback from the basic parameters of the transporters (such as dimensions and weight). The second important and obvious component of the antenna transporters is their attachment to the antennas. After a first survey of possible industrial solutions for heavy transport vehicles and, in discussion with the teams developing the prototype antennas, the necessary details of attachment flanges on the antennas were defined.

A third important design consideration for an antenna transporter is the interface between the antenna and the foundation. After a transporter lifts off an antenna and sets it down on a foundation, the antenna is required to perform without realignment. The lifting and lowering mechanism of the transporter has to be designed such that reliable and precise loading/unloading to the antenna-foundation coupling can be achieved quickly and safely. The coupling interfaces were defined such that the various antenna types can use one standard interface.

Close cooperation was necessary with the scientists defining the antenna array configuration of the central cluster, where the antennas are placed as close together as possible. For efficient reconfiguration, and in case an antenna needs repair, it is necessary to carry antennas out of any location. After several iterations, transport passageways were designed into the antenna patterns to allow any antenna to be reached efficiently. The tolerance on the passageways limited the maximum dimensions of the transporter. The early definition of the interfaces and main parameters was a necessary process in order to allow the Call for Tender for industrial contracts for the transporters to be drafted.

Early concepts

In parallel with the discussion and definition of requirements, the available industrial solutions for heavy transport in the class of 50 to 100 tons were studied. Already proven industrial concepts were preferred in order to reduce development risk and cost and achieve a more reliable transport concept. First ideas were based on mining dump trucks or a mobile crane (see Figures 1 and 2).

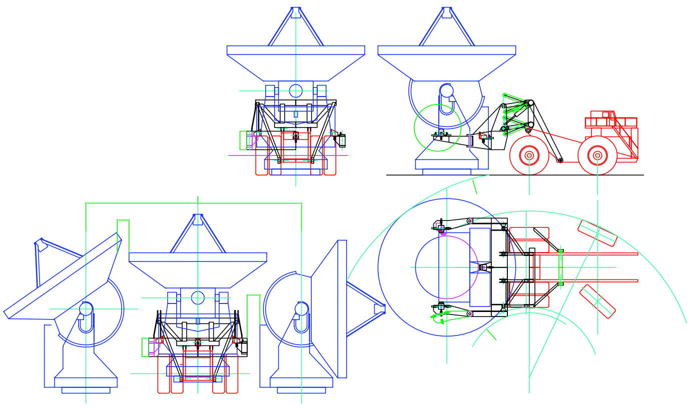

Figure 1. Antenna transport CAD layout based on a mining dump truck. Upper: Front and side views of an antenna transporter. Lower: Close passage in central cluster is shown in side (left) and top (right) views.

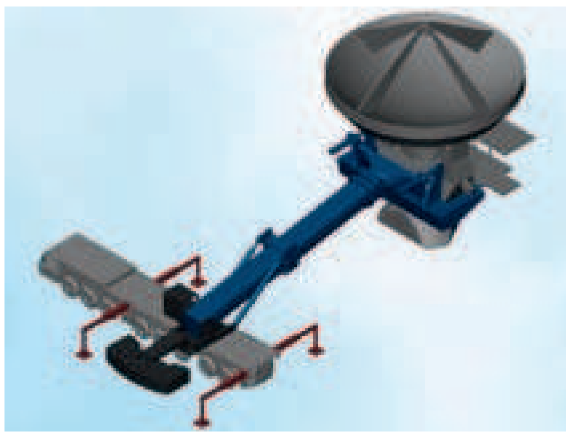

Figure 2. Transporter concept using a large mobile crane (to be used in combination with rented transport vehicles).

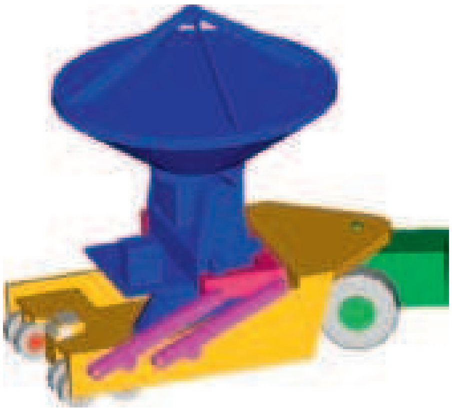

Figure 3. Advanced transporter concept based on an industrial dump truck, which is shown on the right.

Photo: Scheuerle Fahrzeug GmbH

Figure 4. Transporter design with hydrostatically driven wheels.

Further studies showed that a transport concept requiring a minimum road width and low wheel loads is the most economic, since the majority of the investment costs for antenna transport would go into road construction, not into vehicle production. This resulted in a concept derived from a so-called 'slag pot carrier' used in the metallurgy industry and consisting of a prime mover and a load trailer (see Figure 3). This concept was further developed and later investigated by two industrial feasibility studies. These studies confirmed the feasibility of this early ESO concept, but one of the studies showed that a hydrostatic drive for all wheels, instead of just the prime mover, has advantages: the total vehicle weight is reduced and the traction on critical road conditions is improved. A vehicle with a U-shaped frame and a large number of hydrostatically driven wheels was selected as a baseline concept (Figure 4) for the tendering process carried out by ESO.

Specification, tendering and contract

From the internal studies and the two industrial studies, sufficient material was collected to write a detailed technical specification for the ESO tendering process. Before the production antenna contracts were signed, a common antenna transport interface was designed at ESO and agreed with all teams involved in the antenna design. With the specifications all agreed, the tendering process could be started and resulted in a contract with the German company Scheuerle Fahrzeugfabrik GmbH *(www.scheuerle.com)*. Scheuerle is a world market leader in hydrostatically propelled module and shipyard transporters and regularly builds transporters with capacities of 1000 tons or more. Loads up to 16 000 tons have been successfully moved with their equipment. Scheuerle has all the required de-

Photo: A. Schilling, Scheuerle Fahrzeug GmbH

Figure 5. Transport with dummy load during loading sequence test.

Photo: A. Schilling, Scheuerle Fahrzeug GmbH

Figure 6. Both transporters parked at the OSF at the end of acceptance.

sign capacity in-house and collaborates closely with an established network of suppliers of major components, such as Deutz AG for the engines, Mannesmann Rexroth AG for the hydraulic drive system or Kessler & Co GmbH for the axles with brakes. At the Scheuerle premises in Pfedelbach near Heilbronn (Germany), the required manufacturing, assembly and testing facilities were all available.

Design challenges

In the early design phase a promising vehicle concept was quickly developed based on the results of the bidding process. But it soon became clear that the selected concept could not easily be realised, because the layout relied on large wheels with tyres from the earth-moving industry. These very large tyres were sold out at that time and no supplier could be found who could provide the tyres reliably within the required delivery time of about 15 months. As a consequence, a new vehicle layout had to be developed, calculated and investigated based on a larger number of smaller wheels which were available in the required production schedule.

Another challenge addressed during the design and production phase was the operation of the vehicle at the very high altitude of 5 000 m. Little experience exists in the relevant industries with machines operated under these conditions and most major components are rated for altitudes not exceeding 3 000 m. Special sub-contracting conditions were necessary to ensure operation under the required environmental conditions. The high altitude with the reduced oxygen content also affects humans with the consequence of reduced physical and mental capacities. Handling and transporting heavy loads is always dangerous and special care and experience is required. To allow safe operations under the high altitude conditions, various safety interlocks and supervision systems have been developed and built into the control system of the transporters to prevent dangerous operations when commanded by the operator.

Transporter design features

For the final design, an open U-frame layout was selected. On top of the vehicle is the loading system with two ramps which slide the antenna, after pick-up, to the centre of the vehicle. This design allows a relatively low weight of the vehicle and distributes the antenna weight evenly on the axles during driving. The loading system has two x-y-tables on each side which take the antenna on two dedicated brackets mounted permanently on the antenna transport flanges. These x-y-tables can position the antenna precisely on top of the station before setting down. Strong pins and automatic clamps block the x-y-tables during transport to secure the antenna.

On top of the frame are two identical engine units to power the transporter and a generator unit to supply the antenna with electric power during transport. This latter is necessary to maintain the cryogenic cooling of the antenna which remains operational during transportation and avoids warming up of the cooled

Photo: A. Schilling, Scheuerle Fahrzeug GmbH

Figure 7. Fast downhill test drive on the road between the OSF and AOS.

detector systems. Both engine units are redundant and allow operation at reduced speed with one engine only (see Figure 9). All critical components are concentrated in the engine unit, which can be replaced within a few hours in case of fault or for maintenance.

Below the frame is the driver cabin for two persons. This position was selected for safety reasons because all the wheels, and the edge of the road, are in the direct field of view of the driver. It is equipped with all controls and monitors for the cameras mounted on all corners and other critical areas of the vehicle. During the loading process and in other critical situations, the vehicle can also be operated from a remote control panel with fail-safe radiolink. Except for the safety functions of the service brake and the emergency stop system, all functions of the transporter are controlled via computers and specially developed software.

The wheels are mounted in pairs on boogies with swing axle and hydraulic support. All boogies are identical to facilitate maintenance. In case of a failure of one boogie the faulty boogie can be lifted and operation can be continued with reduced speed. The transporters are also equipped with a vehicle positioning system and an anti-collision system. The positioning system consists of a rotating laser installed on the antenna foundations and laser sensors on the vehicle. The sensors guide the driver to the final unloading position with a precision of a few centimetres. The anti-collision system consists of four laser scanners and a numbers of ultrasonic sensors. The laser scanners detect the structures of nearby antennas before the driver comes too close to them and would stop the transporter, after a warning, to avoid collisions. Both systems will ensure safe operation also under the difficult high altitude conditions.

Technical data

Weight (empty): 132.5 tons
Max. payload: 115 tons
Engine power main engines: 2 × 500 kW (2 × 320 kW @ 5 000 m)
Electric power generator: 100 kW (ca 50 kW @ 5 000 m)
Fuel capacity: 2 × 1500 l, diesel
Wheels: 28 × 6.00 R20 (1.35-m diameter) on 14 axles
Three brake systems:
- Emergency and park brake: spring operated (hydraulically opened) on all wheels
- Service brake: oil immersed multiple disc brakes on all wheels with oil circulation
- Continuous brake: engine brake with exhaust flap on all engines

Drive system:
- 2 pumps with variable flow rate on each engine
- 1 hydrostatic oil motor in each axle
- Differential lock and overdrive protection in each axle
- Max speed unloaded: 20 km/h (software limited)
- Max speed loaded: 12 km/h
- Speed limit with overspeed protection depending on road slope
- Max slope: 15 %

Steering system:
- Steering angle +/– 70 deg hydraulically actuated on each axle
- Electronically controlled by a safety certified system
- 4 selectable steering programmes

Support system:
- Hydraulic support with 600 mm vertical stroke on each axle
- Interconnected to 3 groups for isostatic support
- 2 additional outriggers for loading

Loading system:
- Loading time: < 20 min
- Unloading time: < 20 min
- Antenna adjustment on foundation: > 150 mm in all directions

Damping system

During the specification of the interface between antenna and transporter, the maximum possible oscillation of the antenna during transport was carefully studied. The antenna is a piece of precision mechanics requiring delicate alignment of the reflector surface. Investigations concluded that preparatory studies could not be performed because the outcome depended primarily on the performance of the tyres, and no reliable tyre data could be obtained from the manufacturers. Therefore the problem could only be solved at that stage by adopting conservative estimates and specifying large

Photo: A. Schilling, Scheuerle Fahrzeug GmbH

Figure 8. Uphill test drive with dummy load on road between OSF and AOS.

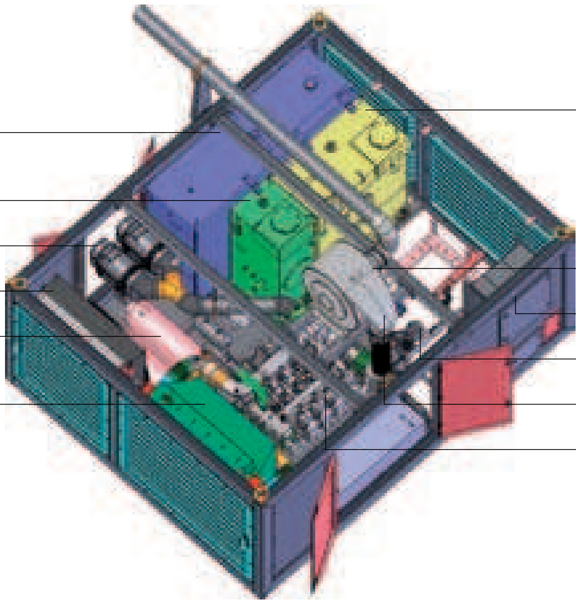

Figure 9. One of two installed engine units. Each unit is self-sufficient and can be quickly changed in case of problems. One unit is capable of moving the transporter in cases of emergency. (Figure: Scheuerle Fahrzeug GmbH)

margins in the interface control document. The experience at ESO in calculating and specifying earthquake loads from the VLT were very helpful in this study.

Provisions for adding a damping system in the transporter specification were defined, but the damping system was excluded from the contract since the specialist know-how for simulation was not available in the relevant industries. Later in the project, when the design was finished and the entire vehicle performance data were available, further studies could be conducted by ESO on this subject. It became evident that under certain road conditions with a washboard profile, dangerous excitations of the vehicle and the antenna could occur. Consequently a damping system was necessary. Using the ESO capabilities for dynamic simulations, usually employed for simulating the performance of telescope systems, the damping behaviour of the transporter was simulated and the components for a damping system were identified. With the help of the Scheuerle engineers, the final system was designed and implemented just before the vehicle left the factory.

Into operation

Although only an auxiliary logistic system for the ALMA observatory, with technologies coming from completely different areas compared to the other components of ALMA, the transporters are fundamental for the achievement of the scientific objectives of the observatory. High reliability and availability of the transporters are essential for minimal observatory down time. With the early collaboration between ESO, the international ALMA partners and industry, good technical solutions could already be developed and realised in the project definition phase. The anticipation of potential problems and the configuration control of interfaces and specifications has allowed parallel and undisturbed development of antennas, transporters and the site infrastructure.

The first ALMA Antenna Transporter was completed in July 2007 (see ESO PR 32/07) and given the name “Otto” at a naming ceremony at the Scheuerle factory (see ESO PR 45/07). The second transporter was completed shortly after and was named “Lore”. Both transporters were then shipped to Chile and arrived at the OSF on 14 Februrary 2008. They were successfully commissioned at the OSF in the following months and will enter service moving the first antennas, which are currently being commissioned at the OSF, to the Chajnantor plateau.

References

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