Towards Integration of the Unit Telescope for the Magdalena Ridge Observatory Interferometer

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ABSTRACT

The Unit Telescope (UT) for the Magdalena Ridge Observatory (MROI) is composed of four major hardware components: The Unit Telescope Mount (UTM), Enclosure, Optics and the Fast Tip Tilt System (FTTS). Integration of the UT started in 2016 when the UTM arrived and its Assembly, Integration and Verification activities began. Critical activities included: installation at the Maintenance Facility, integration and alignment of the Optics and Wave Front Sensor (WFS) and finally the complete optical alignment. End-to-end UTM Site Acceptance Tests (SAT) were performed. Subsequent activities included receiving and integrating the FTTS. With the arrival and assembly of the Enclosure, the last component of the UT was ready for integration on a dedicated concrete pier. Specialized equipment will be used for the final integration of the UT, and for transportation to its final location on the array where SAT for the UT will take place.

1. INTRODUCTION

The Magdalena Ridge Observatory Interferometer (MROI) project is an international consortium between New Mexico Institute of Mining and Technology (NMT) and the Astrophysics Group of the Cavendish Laboratory (MRAO) at the University of Cambridge in the UK. In a past SPIE meeting we presented a global overview of the project (Figure 1), per mechanical subsystems, and report on progress [3]. Although we had a delay in funding for 3 years, we are again progressing, the project has progressed adequately towards construction, integration and testing. In this paper, we present the major components or sub-systems of the UT, we will specially emphasize on the integration of these components, such as UTM and Unit Telescope Enclosure (UTE), the transportation from the Integration Station (UTIS) to the interferometer array and the main infrastructure support. First light on the UT is scheduled to happen in August 2018 and the commissioning phase to start from then on. Other papers about MROI are presented in this conference. See references on the last page.

Figure 1 - 3D-CAD drawing of the MROI overlaid with the array infrastructure.

2. UNIT TELESCOPE

2.1. Unit Telescope Mount

The MROI Unit Telescope Mount (UTM) is a 1.4m Mersenne optics design assembled on an elevation over elevation gimbal configuration. It takes an input beam of light from the night sky and delivers a collimated beam of 95mm in diameter. The optical train is composed of an f/2.25 concave parabolic primary mirror (M1) with 1.4m a diameter, a convex parabolic secondary mirror (M2) with a 115 mm diameter and a flat elliptical tertiary mirror (M3) that is articulated to allow light to be directed to a fixed horizontal position out of the telescope. The UTM arrived on the NMT campus in November 2013, due to the lack of the Unit Telescope Enclosure (UTE) the UTM was stored in a warehouse at NMT. In May 2016 the UMT arrived at the MROI site and its Assembly, Integration and Verification (AIV) activities began. Critical activities were carried out with the UTM: installation at the Visitor Center & Maintenance Facility (see Figure 2), integration and alignment of the optical system and finally the UTM alignment on-sky. End-to-end UTM Site Acceptance Testing (SAT) was performed with the vendor, AMOS, and verification of the ambitious operational requirements of the UTM were conducted during fairly severe (winter) environmental conditions. Tests included: pupil stability, pointing and tracking accuracy and M2 open loop tracking. The UTM "First Light" was accomplished in November 2016 and site acceptance testing was a success [1]

Figure 2 – Unit Telescope Mount being placed at the VCMF telescope pier

2.2. Unit Telescope Optics

As mentioned above, the UTO consists of a f/2.25 1.4m diameter concave parabola (M1), a matching 115 mm diameter convex flat (M2), and a flat elliptical (M3). Combined wavefront aberrations from the three mirrors are specified to be no greater than 44nm RMS. The alignment and integration of the M1 UTO into the UTM mirror cell was carried out in the VCMF mechanical room by AMOS and MRO personnel. The M1 mirror, secured in transportation crates, arrived from coating and was transported to the VCMF soon after. UTM mirror cell arrived on site with the UTM, after which, the mirror cell was removed from its crate and moved to the VCMF. After completion of the integration of the mirror into the mirror cell, the task of alignment began. The M1 mirror has a fixed position in relation to the mirror cell which needs to be aligned to a nominal position within the "supporting ring". The required concentricity between the M1 mirror and its supporting cell is within a few microns. For initial alignment, calipers and a dial indicator were used. For the final centering, a laser tracker was used to achieved the accuracy of the alignment, within less than 20 microns. Then the M1 assembly was integrated with the UTM in preparation for the final “on-sky” alignment.

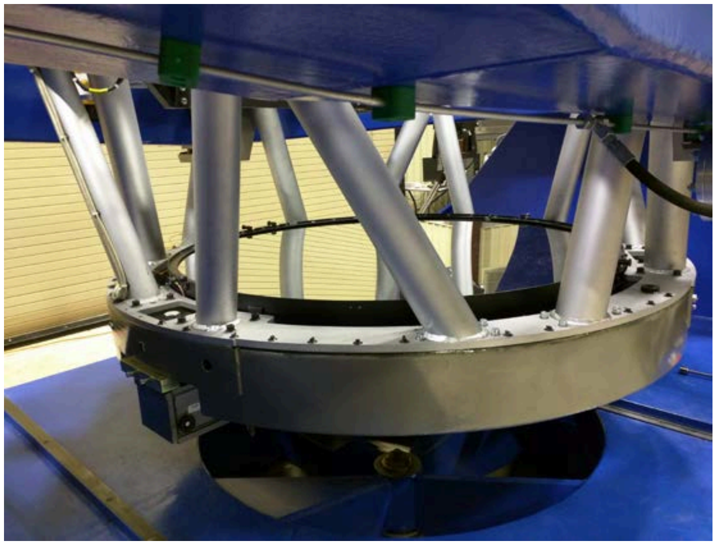

Figure 3 – M1 Unit Telescope Optics installed

2.3. Unit Telescope Enclosure

Each UTM/O is housed within an enclosure (hereafter called UTE) that has been designed to operate under three different modes: a) Observation Mode: UTM is mechanically disconnected from the UTE and operates for science or engineering on-sky observation under an optimum observing environment or reduced performance observing environment; b) Shut-down Mode: UTM is parked and protected by the UTE; and c) Relocation Mode: UTE and housed UTM are being transported from one station to another within the array. The fabrication of the UTE was finished in January 2018, then a set of test were performed at the factory, such as dimensional, thermal, control and functional tests. Thereafter the UTE was disassembled and packed in five 40’ containers and shipped to its final destination on-site. The UTE arrived in May 2018 and assembly was started at the VCMF building (see Figure 4). The integration with the UTM has been programmed for July 2018 [2].

Figure 4 – Left UTE during FAT and Right during assembly at VCMF

2.4. Fast Tip-Tilt / Narrow-field Acquisition System

The functions of the FTTS/NAS are twofold. One is to provide fast tip-tilt correction signals to the hexapod actuators that allow fast tip-tilt motion of M2. The other is to operate under narrow acquisition mode which allows a UTM operator to find an object in the full field of view of the UTM. The FTT opto-mechanical components were successfully integrated and aligned on the optical table of the UTM, as well as, all the utilities that are required to run the system were checked (compressed air, water chiller, communication, power). The pre-SAT activities also had the goals to do functional testing of the system on-sky as a stand-alone system, and then, integrate it with the Interferometer Supervisory System (ISS). At the time of this writing, the pre-SAT activities are nearing completion. End-to-end FTTS SAT will be carried out after the UT has been placed on the interferometer array.

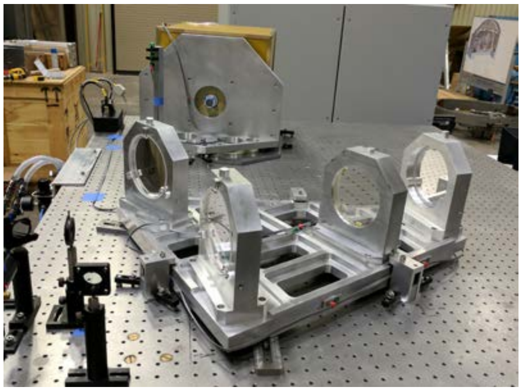

Figure 5 – FTTS installed on the UTM optical table

3. FACILITIES AND INFRASTRUCTURE

3.1. Visitor Center & Maintenance Facility

The VCMF supports operation, maintenance and assembly of the major sub-systems of the UT and is located about 390 m north of the interferometer array. It has a large bay area that has been used to carry out the AIV-SAT of UTM and is now keeping the UTM safe from outside environment. Right now a part of the bay is being used for the assembly of the UTE. It has a built-in concrete pier to support both the UTM and UTE. It provides all necessary utilities such as network, power, liquid cooling, compressed air, etc. to run the UT. The VCMF also has a separated control room from where personnel can work during on-sky testing of the UT.

Figure 6 – VCMF North door and UTIS (UTIS)

The VCMF will support the activities related with the AIV of the UTE and to carry out some of its functional tests. One of the major features of the VCMF is the North door with the overall dimensions of 7200(W) x 6800(H) mm. When the North door is fully opened, it is possible to access part of the sky, close to 15% of the field of view of the UTM. Recently, the building has been fitted with a 5-ton gantry crane to support the activities of the UTE assembly and associated safety signs.

3.2. Unit Telescope Integration Station

In order to integrate the UTM and UTE in the VCMF it is necessary to have a double girder top running crane with a capacity of 40 tons. Due to the high cost involved, MROI has decided to do the integration outside of the VCMF in order to use a rented mobile crane or reach stacker. The integration station is located 5-meter East of the VCMF with orientation S-N (see Figure 6) and it has the same mechanical interfaces as the station on the array, with the difference that it does not have the vibration isolation between the UTM and UTE concrete, as the piers on the interferometer array do. Some utilities are provided through an extension from the VCMF (water chiller and compressed air), power is available at close proximity to the integration station. All these are necessary to run preliminary functional tests of any UT installed on the UTIS. A grounding system has also been installed to mitigate issues with lightning.

3.3. Interferometer Array

A significant amount of technical design work has had to be undertaken to properly design the foundations for the most vibration-sensitive elements of the interferometer. The construction of the first seven stations from W000 to W031 and N008 for the UT and the Beam Relay System (BRS) on the central array was completed a few years ago, see [3]. The current work is focused on installing the utilities for the UT on station W007. To function, the UT requires compressed air, power distribution, data communication, daytime and nighttime cooling loops and a lightning protection system. All interfaces for the concrete pier and the UT have been installed and aligned as required. External monuments and monuments at the Inner BCA have been used to carried out this task. In house effort is involved on the design and implementation of the utilities and interfaces.

4. UNIT TELESCOPE INTEGRATION

In order to carry out the integration of the UTM/O and UTE, a few different procedures were investigated in order to mitigate the risk of this operation, due to the lack of a reach stacker. The reach stacker is a vehicle used in ports to handle shipping containers and uses four rigid lifting points to move the load with great accuracy and low/mid speed. Instead of using it, the integration will be carried out using a mobile crane, heavy duty rollers, a spreader bar and a proper guiding system.

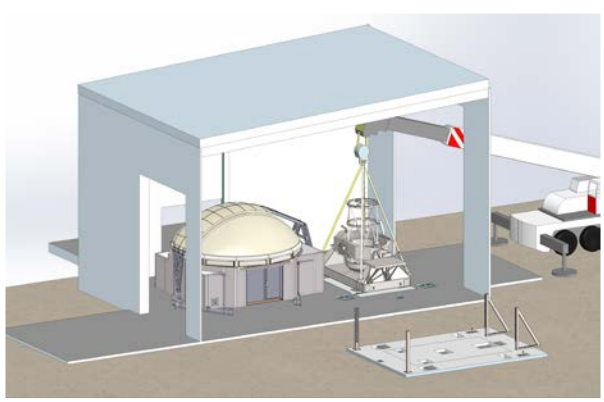

Figure 7 - 3D-CAD drawing of the UTM & UTE at VCMF

Followed by the final assembly and a comprehensive list of functional tests of the UTE, the UTE is ready for its integration and positioned on the heavy duty rollers. The UTM is located on its pier close to the VCMF north door ready to be lifted. As a preparation before lifting of the UTM/O, the following tasks have been identified: relocate the main electronic cabinet to its final location in the two cabinets of the UTE, park it in the zenith position and install the pins for the outer and inner axes, secure the M1 mirror using the auxiliary pads, install protective covers for M1, M2 and M3 mirrors, configure the Nasmyth table for transport mode, shut down the complete system properly and disconnect all the connections to the facility (water chiller, power, data). For safety reasons the local emergency stop should be activated. The FFT opto-mechanical components and camera are to be removed from the Nasmyth table, WAS and WFS should be put into safe mode. Disconnect mechanical and electrical utilities from the UTM and then prepare all the interfaces for lifting.

4.1. Environmental conditions during Integration

Before beginning the UT integration, there are environmental conditions that we must adhere to in order to carry out the activities. Wind speeds can be no more than 5 m/s. This will produce a pressure of 18Pa against the walls of the UTE, with a total force of 75 Kg*f. This magnitude of force can be safety controlled by the guiding system. Wind direction: is desired in the NE direction, since the VCMF will act as a shield.

4.2. UTM relocation procedure

The 40-ton mobile crane is placed at the North door, about 7.6 m from the center plug of the UTM to the “0 crane” reference point. Then we start lifting the UTM, including the UTO, with the crane using the four lifting points, keeping the UTM at horizontal is possible. When the fork has been lifted by 250 mm and the central pin of the UTM has been removed completely from the central plug of the station, a set of heavy duty roller are placed underneath the UTM to “pull out” from the VCMF. In advance, the anti-vibration gap between stations has been covered with a metal sheet to avoid getting the rollers stuck. When the UTM is seated on the rollers, the mobile crane can start moving the UTM toward to the north door and the concrete apron available beyond the VCMF. Once the lifting point of the UTM is out of the VCMF, the crane can start to lift the boom to secure the load and lift the telescope to a reasonable height, about 400 mm from the ground. When the UTM is up, by means of the slings/shackles, the level of it needs to be checked in order to have it as horizontal as possible, to better than 2-3 degrees. Then the UTM can be rotated counter clockwise by 90 degrees to start moving it to the integration station. It is planned for this operation relocating the mobile crane in order to avoid leaving the UTM on the ground and save time during the procedure. This can be achieved by parking the crane in a specific location that allows rotating the boom clockwise (about 270 degrees) as is shown in Figure 8.

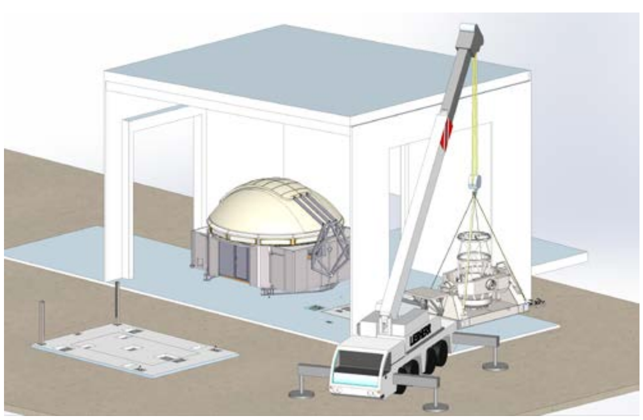

Figure 8 - 3D-CAD drawing of the UTM being lift it

After the UTM is secured at the integration station and the mechanical interfaces with the concrete pier are checked and secure, a tarp can be used to protect the UTM from dust and the weather conditions while the UTE is moved out the VCMF.

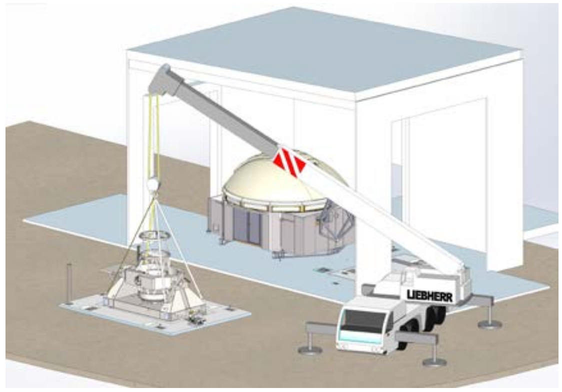

Figure 9 - 3D-CAD drawing of the UTM being lift it

4.3. UTE relocation procedure

Four heavy duty rollers were installed underneath a template used to assembly the UTE. As with the UTM, the UTE can be pulled out from the VCMF with a heavy duty vehicle, e.g. front loader, and using a benchmark on the floor as a reference, guide the UTE toward the north door and the concrete apron available beyond the VCMF (see Figure 10), avoiding the pockets of the UT concrete pier. If for any reason the heavy duty roller doesn’t follow the adequate trajectory, they can be adjusted.

Once the template is disconnected, the UTE is ready for lifting. The crane, slings, spreader bar (needed in order to avoid plastic deformation of the relocation frame) and relocation frame are installed, then the lifting of the UTE can start (see Figure 10). The current location of the UTE will allow it to rotate the boom on the crane clockwise by 270 degrees. After the UTE is lifted the template can be removed and the four safety pads can be installed under the UTE. The crane can now start moving the UTE outside of the VCMF toward to the integration station. Due to the size and weight of the UTE it will be necessary to do the relocation in at least two steps (see Figure 11).

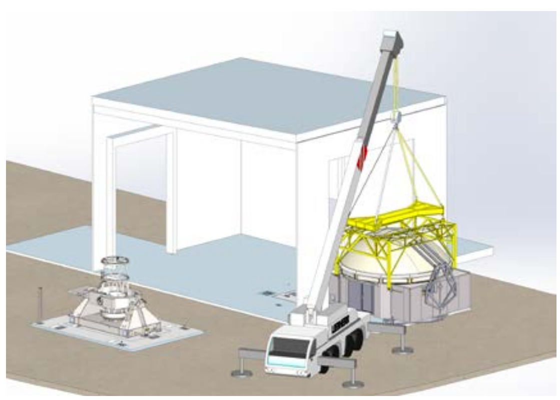

Figure 10 - 3D-CAD drawing of the UTE being lift it

The reach stacker vehicle not only provides a rigid and semi-rigid connection with the load, but also higher accuracy during transportation or motion of the load. Because this vehicle will be not available for the integration of the UT and a mobile crane will replace it, a guiding system will be necessary to carry out this operation. Once the crane is relocated to the optimal position to lift the UTE to the necessary height to pass over the telescope, at least 5 m above the integration station, then the UTE can start being lowered slowly over the UTM. The opening in the bottom of the UTE is 6.2 m x 2.8 m, so there is a fair margin to avoid collision with the tube of the telescope. The lowering down of the UTE will require a few lateral maneuvers to avoid collision with the gimbal, fork and the Nasmyth table of the telescope. In those more critical points where its clearance is about 200 mm the guiding system will play a key role. Three longitudinal maneuvers are required toward the North direction and they need to be done while the UTE is lowering down.

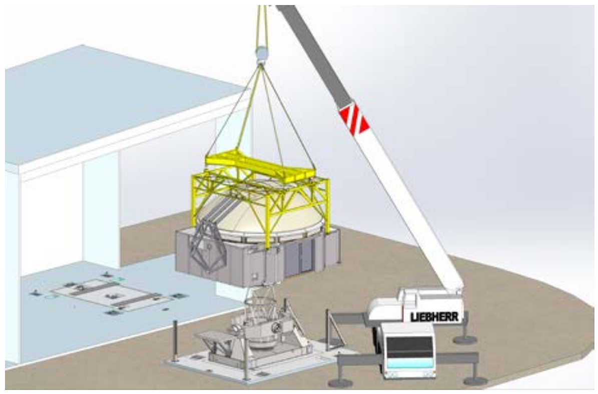

Figure 11 - 3D-CAD drawing of the UTE being integrated with UTM

The guiding system is composed by two vertical beams and two triangular frames equipped with a simple linear measure system. The verticals keep guiding the UTE down and avoiding unwanted lateral motions The two triangular frames will help control the longitudinal maneuvers and avoid unwanted longitudinal motions. Cameras will be installed on the UTM to closely follow this maneuver/procedure and at the same time, keep personnel safe. It is not show on Figure 11, but it is planned to use a pair of cables to maintain the contact between the UTE and the two triangular frame.

When the UTE is placed on the station and its alignment is checked, the sling and spreader bar will be disconnected from the UTE and the crane parked in safe place. All the mechanical interfaces with the station can be connected and a visual inspection outside and inside of the UTE can be performed. Now the temporary utilities from the VCMF can be connected to the UTE and some of the functional tests can start. Limited tests can be carried out at this location; that will reduce the risk on the interfaces between UTM-UTE before moving the UT to its final location.

4.4. UT Mass Budget

Unit description	Mass [Kg]	Main Materials
UTM/O	15500	Steel plates / Glass
UTE	16000	Steel beam / composite
Relocation Frame	1575	Steel beam
Spreader Bar	1425	Steel beam
Total Mass	**34500**	

Table 1 – Mass Budget

5. UNIT TELESCOPE TRANSPORTATION

In order to transport the UT, and because the reach stacker is not available as a transporter for this procedure, the same mobile crane and a special transporter will be used instead. Once the UT has successfully passed all the functional tests at the UTIS, such as, functionality of the UTM, functionality of the UTE, operability of the main utilities from the UTE through the UTM, possible interferences and relocation method, the UT is ready to be relocated to its final location on the Interferometer Array.

To start the relocation there is a procedure that is described in a document from the UTE manufacturer. Once the UT is on the hydraulic lifting jacks it is ready for lifting. As previously mentioned, the lifting of the UT required a spreader bar will to avoid plastic deformation of the transportation frame, due to the heavy load of the UT (see Table 1).

The template used to assemble the UTE will be used as interface between the UT and transporter during relocation. Starting with the template being loaded on the transporter and attached firmly, the UT can now be loaded up on the transporter as shown on Figure 12. The UT is attached firmly to the transporter and is ready to be moved. Sensors for measuring shock loads and vibrations will be installed on the UTM in order to track them during relocation.

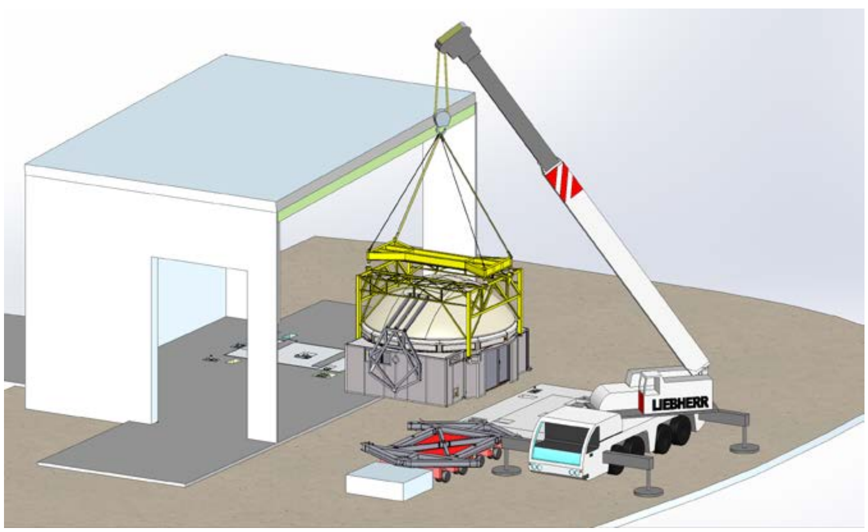

Figure 12 - 3D-CAD drawing of the UT being loaded on to the Transporter

5.1. Transporter

This modular vehicle (see Figure 13) is a perfect solution for when a convectional heavy load trailers no longer has sufficient pulling force to move an extremely heavy load and the load needs to be transported at certain angle. The UTE was designed to transport the UTM in horizontal orientation, as the reach stacker does when the UT is transported. The route from the VCMF building to the interferometer array has a considerable slope (see 5.2), thus a trailer with self-leveling characteristics is necessary.

Some of the specifications of the transporter are; maximum capacity of 144000 kg, max. gradient of 13%, temperature work range: -20°C to 40°C, steering angle maximum of +/- 60° and minimum speed of 1 km/h. The speed during transportation will play an important role due to the shock load requirement on the telescope. It should also be mentioned that the center of gravity of the UT is located close to the center of it and 1.8m from its base, making the transportation safe.This equipment will be rented by MRO, but operated by the rental company that has more than 50 years of experience on crane services.

Figure 13 – Self-propelled Semi Trailer

5.2. Route from VCMF to the Interferometer Array

To transport the UT from the VCMF to the interferometer Array there currently exist a gravel/dirt route that connect this two points as shown in Figure 14. The route is approximately 390 m and runs from North to South with a slope of ~10%. The route has one main turn with an important slope that is located after the VCMF route turning left toward the Water Canyon route. Also there are few significant bumps on the route toward the interferometer array. These parts of the route and the surface of the route need to be improved and compacted to allow a smooth transportation of the UT.

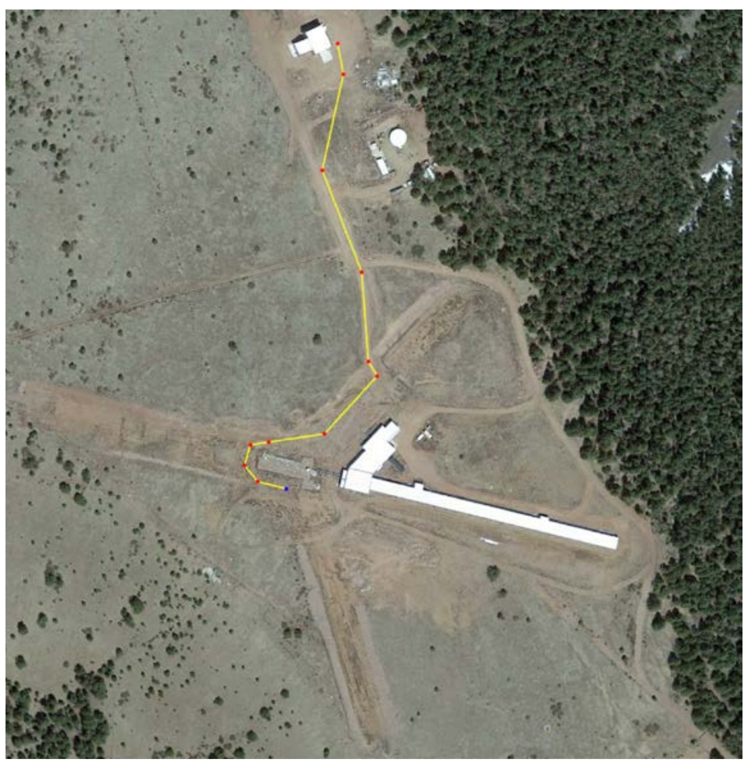

Figure 14 - Route VCMF to Interferometer Array Station W007 through Water Canyon route

Using a bulldozer, we will reroute the path from the VCMF to the Water Canyon route in order to make the trajectory of the transporter as straight as possible and avoid the curve that intersects them. Some minor work has to be done at the Water Canyon route to keep the slope within 10%. Crushed fine material will be placed and then compacted where it is needed, to make the route for transportation as smooth as possible.

5.3. Installation on the Interferometer Array

The final step is to place the UT on the interferometer array, the station W007 has been selected and prepared to receive it, as mention in section 3.3. Unlike the Figure 15, the BRS won't be installed yet on that station and it will facilitate the installation and the process of lowering down of the UT safely. The mobile crane will be parked close to the station ready to unload the UT from the transporter and position it into the station. Once the UT is on the hydraulic jacks and aligned with respect to the station, the final lowering down should start.

Figure 15 - UT being installed at the Interferometer Array

The procedure to place the UT on the station should continue until all external and internal mechanical connections for the transportation are removed. Then the UTE is ready to receive the utilities (power, chiller water, compressed air) and continue with final functional test, finishing with the Site Acceptance Test.

5.4. UT Site Acceptance Test (SAT)

Following successful SAT on the UTM/O and UTE as standalone systems, it is now time to continue with SAT of the UT as a one unit. As mentioned in section 2.1 the SAT activities of the UTM were performed at the VCMF which has a reduced field of regard (FOR) with respect to the final enclosure, with elevation from 30° to 60° and Azimuth ranges from 70° West from North to 20° East from North, which represent about 15% of the total FOR of the UTM. With the arrival and integration with the UTE the telescope has access to the full FOR, so it is planned to run similar test as UTM-SAT. Some of them are:

- Pointing and tracking accuracy test
- Acquisition camera re-alignment test
- Telescope exit beam accuracy
- M2 law update

6. CONCLUSION

The integration of the first Unit Telescope of MRO Interferometer is near completion, the UTM passed SAT in December 2016 and the first UTE is being assembly onsite at the VCMF. This document has presented the major components of the UT and its current state, associate infrastructure and the top level activities to carry out the integration and final transportation. UT first light on the telescope Nasmyth table is scheduled for August 2018.

The project is now working to get prepared for a major milestone, which includes most subcomponents installed already onsite, such as, beam relay, delay line and all components inside the Inner BCA [4] plus the installation of the UT on the interferometer array. An ambitious program has first light for the interferometer occurring at the Inner BCA building for December 2018.

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