BUILDING A GROUND-LEVEL AZ/EL MOUNT: Volume I

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Contents

Foreword

The set of documents in this series are comprised of progress reports that have been created in near-real-time during the design, construction, and testing of a ground-level azimuth/elevation (AZ/EL) mount for a 28' diameter Kennedy parabolic dish antenna that will be used primarily for amateur radio astronomy observations. The principal objective of these documents is to provide a history of the steps that have been taken by the author while building and installing the mount.

Details of the design and construction of this mount are, as far as the author is aware, unique among amateur and professional radio astronomy antenna installations. Any similarities to previous or existing AZ/EL mounts, if they happen to occur, are purely coincidental as the author is, as of this writing, unaware of any such similar mounts or designs.

Further, and importantly, no claim is made herein that the specific design and/or steps taken to fabricate and install this mount as described are optimized in any sense whatsoever, nor is any claim given that anyone else should attempt them. The design and fabrication steps adopted by the author are simply a result of the author's thinking at the time of execution and no claim is made as to the fundamental engineering viability nor is any claim made as to the intrinsic safety of the construction steps or structural materials selected for use as described herein.

The documents generally comprise a simple accounting of steps taken by the author during the project and largely consist of numerous photographs taken during the project to show how the various steps were completed. Any errors or miscommunications in them are solely the fault of the author.

It is hoped that this history of the project will provide some level of entertainment, or perhaps a limited general utility, for the reader; nothing more is implied nor intended. Any attempt to reproduce any steps described herein by anyone else is done so at the sole risk of the person attempting such activity. No responsibility of the author is implied nor given that the steps described herein are reasonable or safe to perform by anyone.

The complete set of documents represent a chronological, real-time reporting of the steps taken and results achieved during the project as they occurred. Multiple documents have been created sequentially to avoid creating a huge single document that would be cumbersome and inefficient for both reader and author to use.

Introduction

This project originated as a result of the author's desire to create a ground-level AZ/EL mounting scheme for the 28' Kennedy parabolic dish he previously used in a tower mounted scheme for several decades performing moonbounce communications and amateur radio astronomy observations. During these activities it was sometimes noted that the tower-mounted scheme was somewhat less than ideally stable during target pointing. Thus, in early 2022 when a problem occurred with the azimuth drive mechanism that required removal of the dish and mount from the tower the author decided to not use the previous tower mounting scheme at all hereafter for this dish and instead focus on developing a new design implementing a ground-level mounting scheme that would be both safer for the author to work with during maintenance and repair operations and that would result in improved pointing stability during use.

Initial Design Concepts

The fundamental concepts of the envisioned ground-level AZ/EL mount are depicted in the simple line drawings shown below.

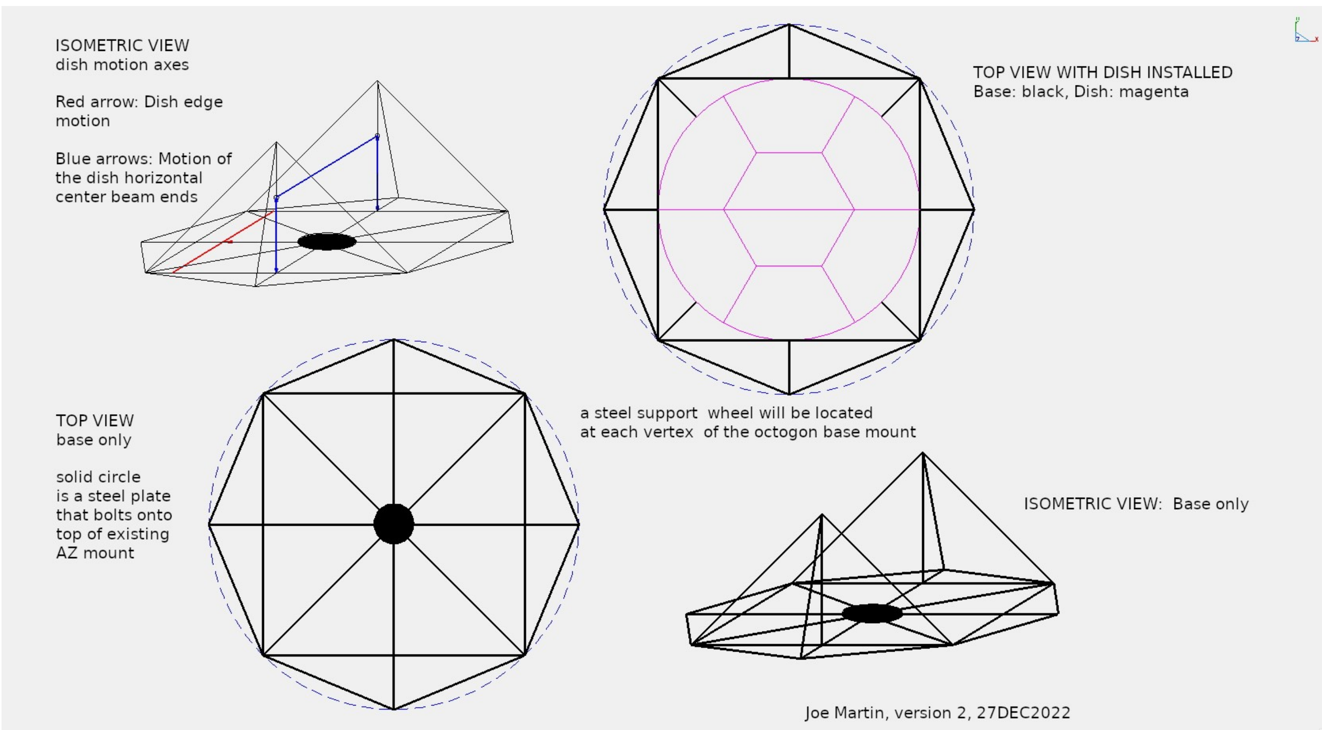

Figure 1. Line drawings depicting the fundamental concepts of the proposed ground level AZ/EL mount.

Basically the design consists of a large horizontal platform structure that is rotated from a center drive to achieve dish pointing motion in the horizontal plane and a vertical lifting scheme to tilt the dish to obtain pointing motion in the vertical plane (i.e., both AZ and EL motions). Not shown in the drawings are eight steel wheels of the assembly that will be located at the peripheral corners of the structure which will roll upon the top of a circular steel rail as the AZ angle changes, the rail position is indicated by the dashed-line circle in the top-view drawings. The magenta colored portion of the upper left drawing is a representation of how the the 28' Kennedy dish showing its 8 petal components will be oriented on the structure when the dish is pointed at 90-degrees elevation (i.e. the so-called “bird bath” position).

To study the mount concepts in detail it was decided that building scale models of the proposed designs would be beneficial to ensure that clearances, motions, and stability of the various components could be identified and evaluated. A scale of 1/20th full size was selected for the models and these models have been used to study various aspects of the design. Once a model was constructed it was animated using stepper motors and drivers via a Python program running on a Raspberry Pi computer. Short videos, typically about 2 minutes in length were made to demonstrate performance of the designs. Two such models and animations are shown in the two video links below:

This design uses a ball/screw lifting scheme:

https://www.dropbox.com/s/6k5evq2dibmprcu/IMG_2773.MOV?dl=0

whereas this modified version uses dual winches/cables to achieve the lifting/lowering elevation motions:

https://www.dropbox.com/s/ifr992aqv66kh9x/Winch-cable_elevation_config.MOV?dl=0

The latter design was selected as the design that will be implemented in full scale due to the expected excessive costs and delays that would likely be associated with obtaining suitable ball/screw assemblies of the first design. As much as possible, the new design will incorporate components of the old mount to save cost and effort.

Modifications Of The Original AZ Mount

The original AZ mount used by the author for the Kennedy dish was a modified military surplus radar mount similar in design to the AN/FPS-6 azimuth drive assembly used by the Canadian military among others. It consisted of a lower section containing large gearing mechanisms driven by a 90VDC motor and a large oil bath reservoir upon which was bolted a top section. The top section contained a hydraulic pump, ballast tank, and electrically operated hydraulic valves to achieve elevation motion. Also on the top section was a massive horizontal mating section that used three 2” diameter pins to attach to the steel dish back structure. A photograph of the original AZ/EL mount assembly is shown below.

Figure 2. Original configuration of the AZ/EL mount previously used by the author.

A photograph of the mount is shown below with the hydraulic components removed and the top section unbolted from the lower section.

Figure 3. Original AZ mount shown with the top section cleared of hydraulic components and unbolted from the lower section.

The photograph below shows the top section with unnecessary, interfering structures cut from it.

Figure 4. Original top section with unnecessary/interfering structures crudely cut from it.

The chalk lines show the approximate positions where eight square steel tube “spokes” for the rotation connections to the final base structures will be positioned and welded into place. More on that later.

Because the center hole passes completely through the top and lower sections of the mount to the lower non-rotating I-beam “Y” of the lower mount section it will be possible to mount the AZ encoder into the hole of the rotating top section plate with the AZ encoding rod passing through the mount and fixed solidly to the non-rotating "Y" structure. This is very convenient because it will allow for replacing/servicing the az encoder from an easily accessible position and permit the encoder cable to pass from underneath the mount through the center hole to the encoder without exposing the cable to any top side structures that may exist in the final configuration of the mount.

The photograph below shows how three mounting posts have been attached to the interior of the center post, ready to receive the encoder itself.

Figure 5. Three AZ encoder mounting posts have been installed on the top plate, ready to mount the encoder itself.

The photograph below shows the complete AZ mount with the AZ encoder installed, without the extra post lengths trimmed and without the weather protection cap installed.

Figure 6. Assembled AZ mount with the AZ encoder installed. The extra post lengths will be trimmed and a weather protection cap will be installed before the AZ mount is positioned outside.

The AZ mount will be installed such that the three feet of the mount will be bolted onto three subsurface concrete piers to obtain the lowest mounting practicable. The photograph below shows the site before the subsurface installation activities began.

Figure 7. Site where the new ground level AZ/EL mount will be located, shown before construction began on Jan 23, 2023.

The photograph below shows the initial excavation work done for the AZ mount, which includes three 12” diameter holes for the pier supports.

Figure 8. Initial excavations, pier holes, and a center support block stack are shown in preparation for the AZ mount installation.

A center located stack of solid concrete blocks will be used to support the AZ mount in position while the concrete piers are curing.

The photograph below shows two of the three ½" dia steel "rebar" structures that were fabricated to be placed into the pier holes before concrete is poured.

Figure 9. Two of three rebar structures that were fabricated to strengthen the three AZ mount concrete piers for the AZ mount.

The rebar pieces were tack welded together to form the strengthening structures for the piers. The photograph below shows the rebar structures in position in the pier holes.

Figure 10. Rebar structures are in position in the pier holes.

The tops of the rebar structures will overlap with twelve (4 on each leg) “J” type concrete anchor bolts that will be attached to the AZ mount feet. Concrete will initially be poured to a level just below the horizontal cross pieces before positioning the AZ mount over and into the pier holes.

AZ Mount Concrete Work

The photograph below shows how the concrete mixer will be positioned for the first pour of concrete into the pier holes, partially filling each hole, prior to positioning the AZ mount.

Figure 11. Concrete mixer in position to partially file each pier hole prior to positioning the AZ mount feet into the holes.

After partially filling each pier hole with concrete, leaving the top portions of the rebar structures uncovered, the AZ mount will be put into position for adding the final amounts of concrete (by shovel) into each hole.

The photograph below shows the twelve 5/8” diameter x 12” long “J” type anchor bolts attached to the feet of the AZ mount prior to lowering the mount feet into the pier holes.

Figure 12. Twelve “J” type anchor bolts are attached to the feet of the AZ mount prior to lowering the mount into its final position over the pier holes.

Cardboard concrete forms are placed over each pier hole and the mount is lowered into its final position prior to adding the final amounts of concrete to the piers, as shown in the photo below.

Figure 13. Cardboard forms are placed over each pier hole and the AZ mount is lowered into its final position prior to adding the final amount of concrete to the piers.

The photograph below shows how the AZ mount is being leveled and supported in position for the final concrete pour and curing by using a gantry, a chain hoist and an electric cable winch. Only two chain/cable supports are needed as the center of the mount is resting on the solid concrete blocks. The chain/cable leveling supports will remain in place for a week before removing them to allow time for the concrete to cure enough to support the balance and weight of the mount.

Figure 14. Final concrete has been added to each pier and the mount is leveled and supported by a chain hoist and a cable winch as well as being supported by the center stack of solid concrete blocks until the concrete cures for at least a week (poured 6FEB2023).

The excavation, including the curing concrete, will be covered with dirt while the concrete sets. Dirt cover protects the concrete from the overnight freezing temperatures that occur here presently. The photograph below shows the final configuration of the AZ mount.

Figure 15. Ground work for the AZ mount installation is now completed (8FEB2023) while curing of the subsurface supporting piers continues. The white cap is a temporary weather-protection measure for the AZ encoder.

After concrete curing, the AZ mount will be ready for the next step of the project.

Circular Rail And Support Post Design

The 30’ diameter circular rail for this system will be constructed from five pieces of 4” x ½” x 20’ steel bar (strap) that are mechanically shaped into curved sections and each will be cut to 18’ 10” length.

The five curved sections will be bolted together to form the circle. Each curved section will subtend a 72 degree arc of the circle. The circular rail will be mounted/welded to adjustable-height post assemblies; the basic arrangement for the circular rail and support posts is illustrated below.

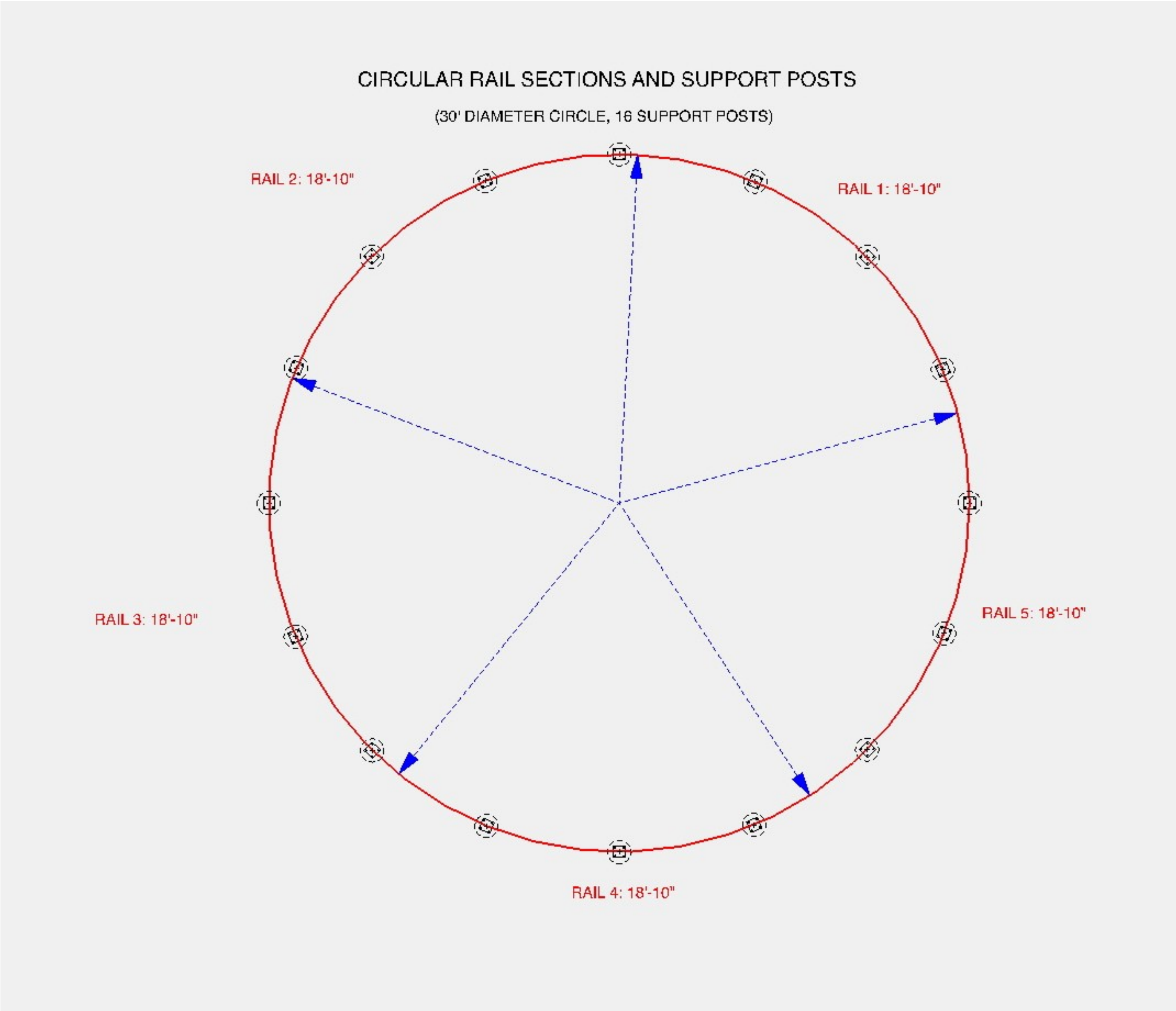

Figure 16. Arrangement of the circular rail and support post locations.

Details of the rail support system design are shown in the figure below:

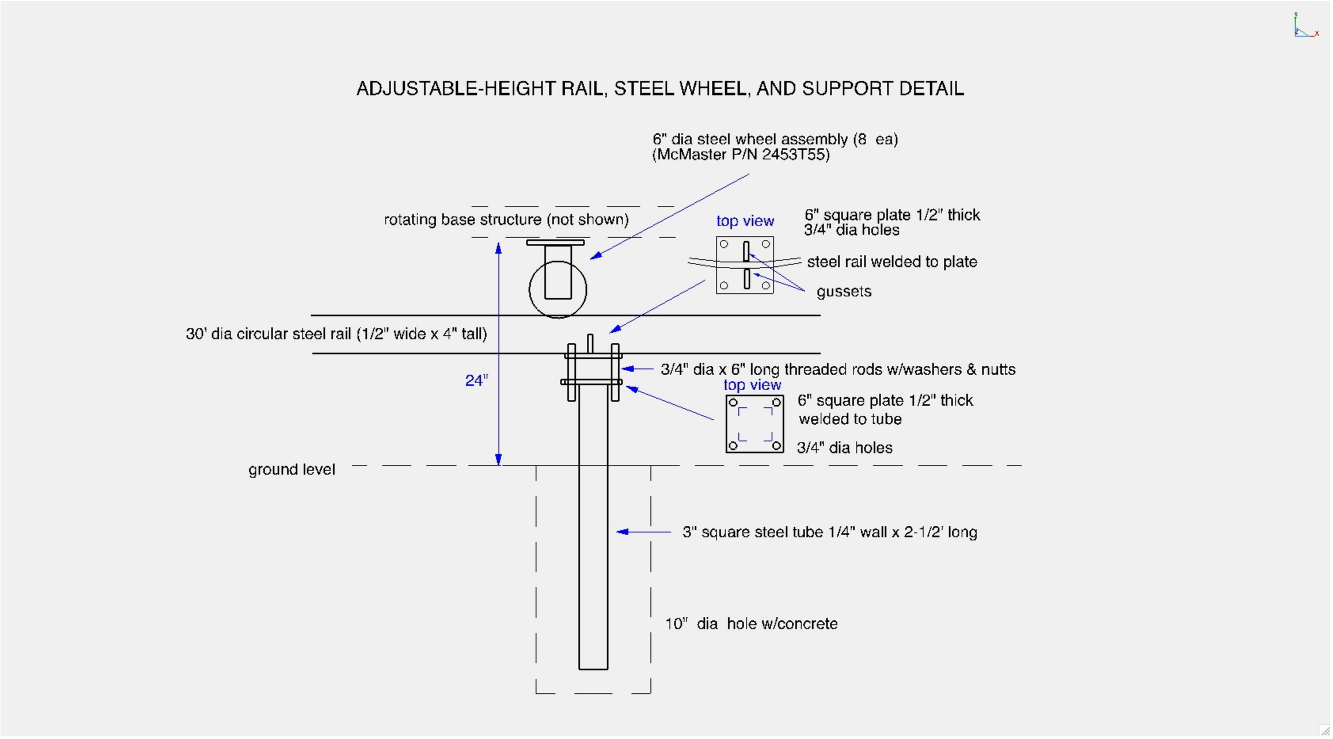

Figure 17. Details of the design of the adjustable-height rail support system (9FEB2023).

The circular rail will be welded onto a 6” square plate at each post. Each plate is attached to a second 6” square plate using four ¾” diameter threaded rods. Nuts and washers will secure the plates to the rods and will thereby permit height adjustment for the rail at each post. The rail system will be made level by adjusting the nuts on the threaded rods at initial installation and also later, as necessary, if the rail shifts vertically over time for any reason.

Proof Of Principle Demonstration: Controlled Bending Of A Rail Section

The curved rail sections will be formed from straight steel bar by using a 16-ton hydraulic tube bender oriented horizontally so that the straight sections may be fed on edge into the bender conveniently. At each foot along the lengths of the straight sections the press will bend the rail by about ½”. The photograph below shows how this is done with a proof of principle rail bend with the hydraulic tube bender.

Figure 18. Demonstration of ability of the hydraulic tube bender to bend the 4" tall x ½" thick rail material.

The bender bends the rail material straightforwardly. Likely, later when the five rails are bent into the appropriate curve a wider top piece for the hydraulic ram will be used to make the bend smoother to better match the ideal curvature.

The rail wheels that will be used with the rails are shown in the photograph below.

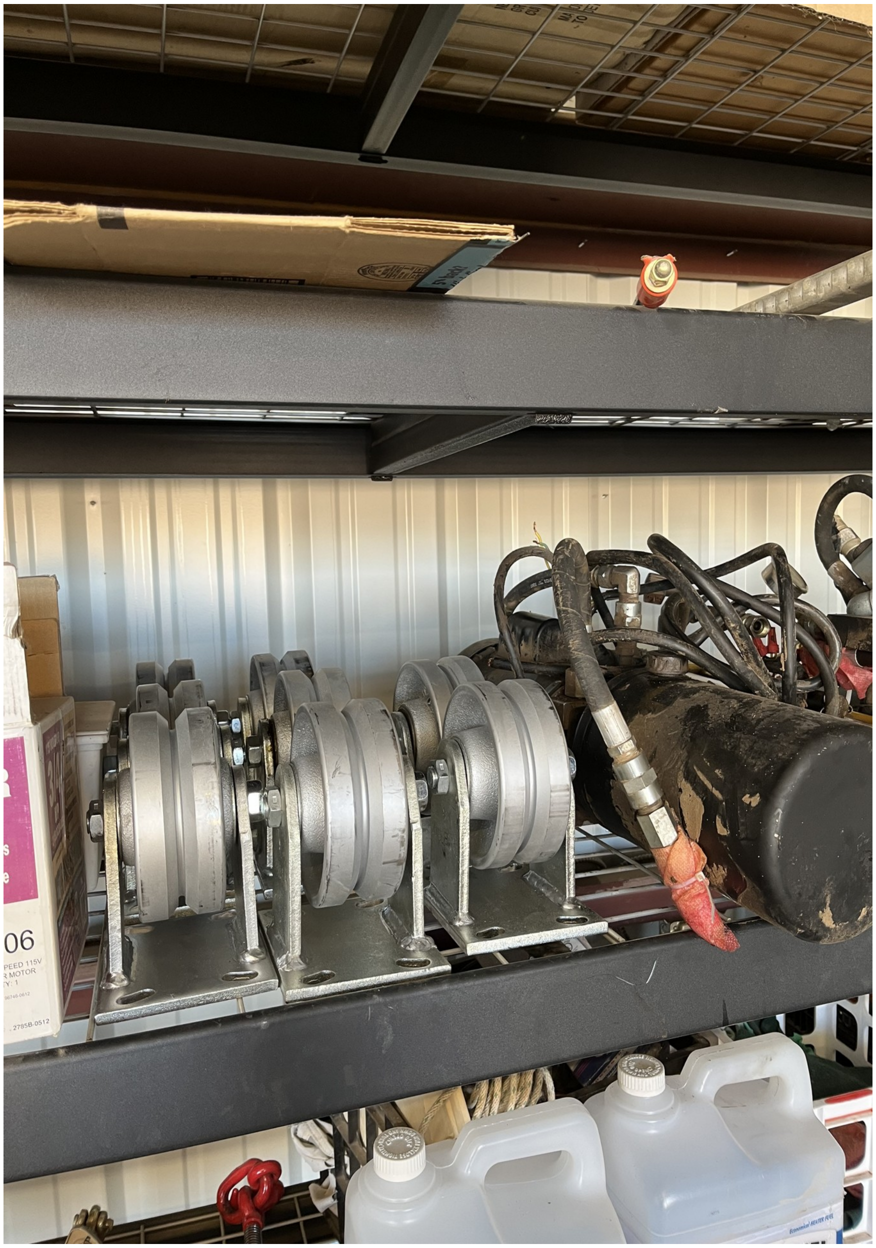

Figure 19. Eight 6" diameter steel wheels that will be used atop the rail are shown in the photo (13FEB2023).

The rail wheels are designed to be able to carry a load of up to 2500 lbs each.

Fabricating Rail Support Plates

The photo below shows how holes for ¾” diameter threaded rods are bored into a 6” x ½” x 20’ steel bar as part of the support plate fabrications process.

Figure 20. Holes for the threaded rods are bored into a 6” x ½” x 20’ steel bar as part of the fabrication process for the 32 6”x6” support plates for the circular rail (14FEB2023).

The holes are bored using a 13/16” diameter cutter fitted onto a magnetic drill. Center hole positions are established using a steel punch to make a small indention for each hole prior to boring. The photo shows work beginning on the holes for what will become plate 9 of 32 total plates that need to be fabricated. After the holes are bored the plates will be cut from the bar to form the finished support plates.

The photo below shows the 6”x1/2”x20’ steel bar with the needed 128 13/16” holes bored. Now the bar is ready to sbe liced into 32 6”x6” rail mounting plates.

Figure 21. The 6”x1/2”x20’ steel bar has been bored with 128 13/16” diameter holes (4 holes per 6”x6” plate) for the threaded rods that will be used to adjust the height of the circular rail (15FEB2023).

The photo below shows a plate being cut from the 20’ steel bar.

Figure 22. A flange plate is being cut from the 20' long steel bar. The saw blade is half through the plate as shown.

The photograph below shows the 32 flange plates that have been bored and cut.

Figure 23. All 32 flange plates have now been bored with four 13/16” diameter holes through each plate and cut to a 6”x6” size.

The plates are now ready to be welded to the tops of sixteen rail support posts and the other 16 are ready to be welded to the circular rail after the rail is installed on the support posts with threaded rods.

Fabricating Rail Support Posts

The 16 rail support posts will be fabricated from 20’ pieces of 3”x3” x ¼” wall square steel tubes. Each post needs to be about 40” long with a flange plate welded to the top end. The photograph below shows how 40” pieces are cut from the long tube.

Figure 24. Cutting 40” long pieces of steel tube for the rail support posts.

The photograph below shows the 16 rail support posts and the 32 flange plates ready to weld 16 of the flange plates to one end of each of the rail support posts.

Figure 25. Rail support posts and support post flange plates are shown above ready to assemble the complete rail support posts (16FEB2023).

The support posts are 40” long. Approximately 8” of the top end of each post will be above ground level while the remainder will be sub-surface in concrete. The circular rail will sit on the topmost support plate with two flange plates per post separated by four threaded rods, washers and nuts.

The photograph below shows how a flange plate is welded onto the support post.

Figure 26. Showing how a flange plate is welded onto a rail support post.

The photograph below shows all rail support posts have flange plates welded to them.

Figure 27. All 16 rail support posts have flange plates welded to them.

The photograph below shows all plates and support posts have been painted and are ready to assemble.

Figure 28. All 16 support posts and 16 top rail plates have been fabricated and painted and are now ready to assemble with galvanized threaded rods (18FEB2023).

Center AZ Mount Tilt Measurements

Before the rail support post positions can be determined it is necessary to check how level the center AZ mount is and if necessary correct any tilt of the mount. A simple and accurate method for measuring how level the mount is by mounting an absolute inclinometer encoder onto the mount and rotating the mount in azimuth recording the output value of the inclinometer at regular azimuth angle positions. The absolute inclinometer that will be used in this test and that will also be used in the final configuration of the project to determine dish elevation angle is a US Digital A2T-S-S-D encoder. The azimuth encoder is a US Digital A2-S-B-D-M-D encoder. The photograph below shows the two encoders mounted on the AZ mount.

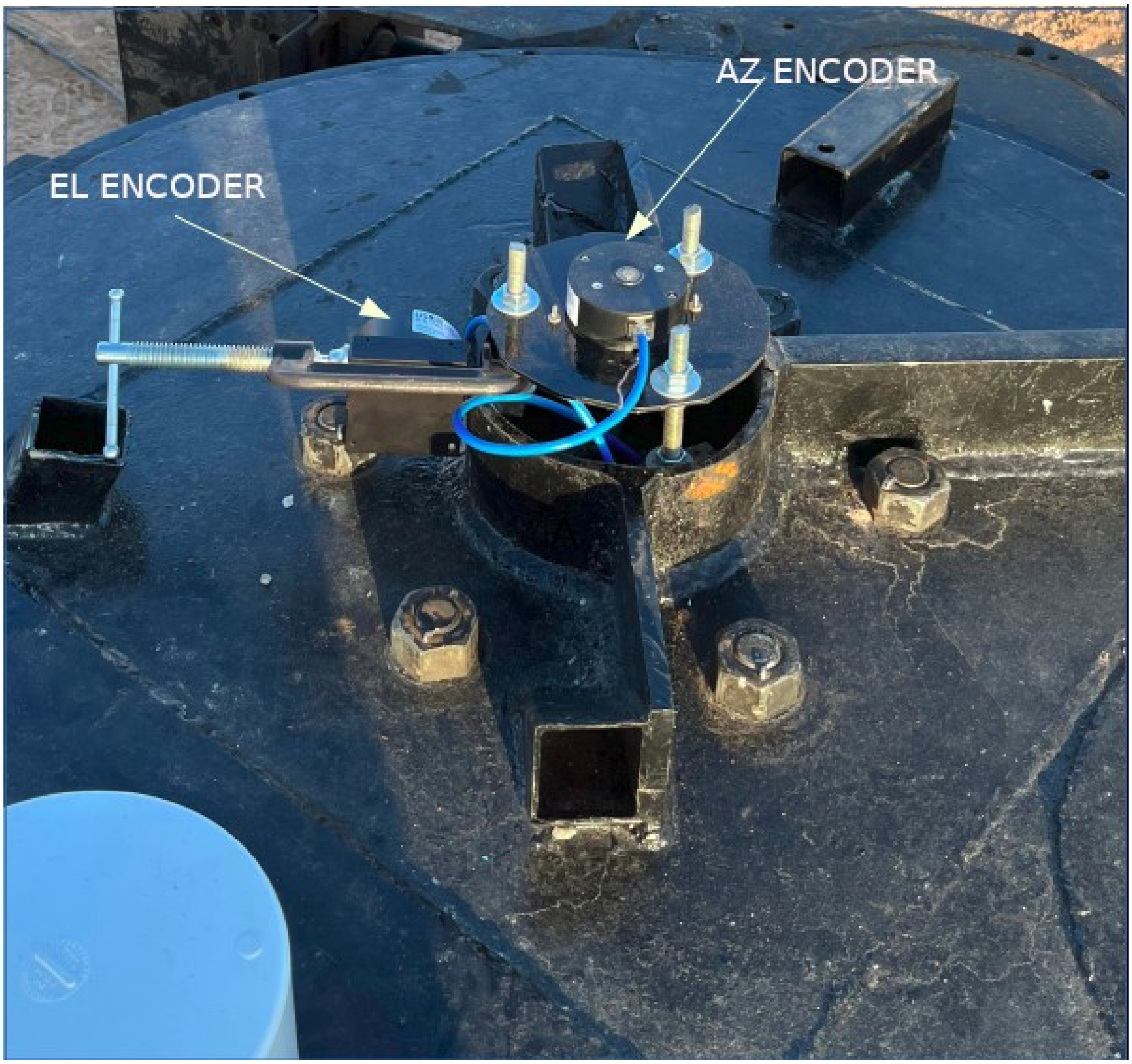

Figure 29. AZ and EL encoders mounted onto the AZ mount for level measurements.

For the level measurements the encoders can be configured and read remotely by using the US Digital Device Explorer program via the SEI/USB bus line running between the AZ mount and the telescope control room. Both encoders are 12-bit resolution encoders. This results in 4096 steps in a 360 degree rotation for each encoder. To measure how level the mount is the output readings from the elevation encoder (absolute inclinometer) are manually recorded versus azimuth angle being displayed in the Explorer window. A typical display result is shown in the image below:

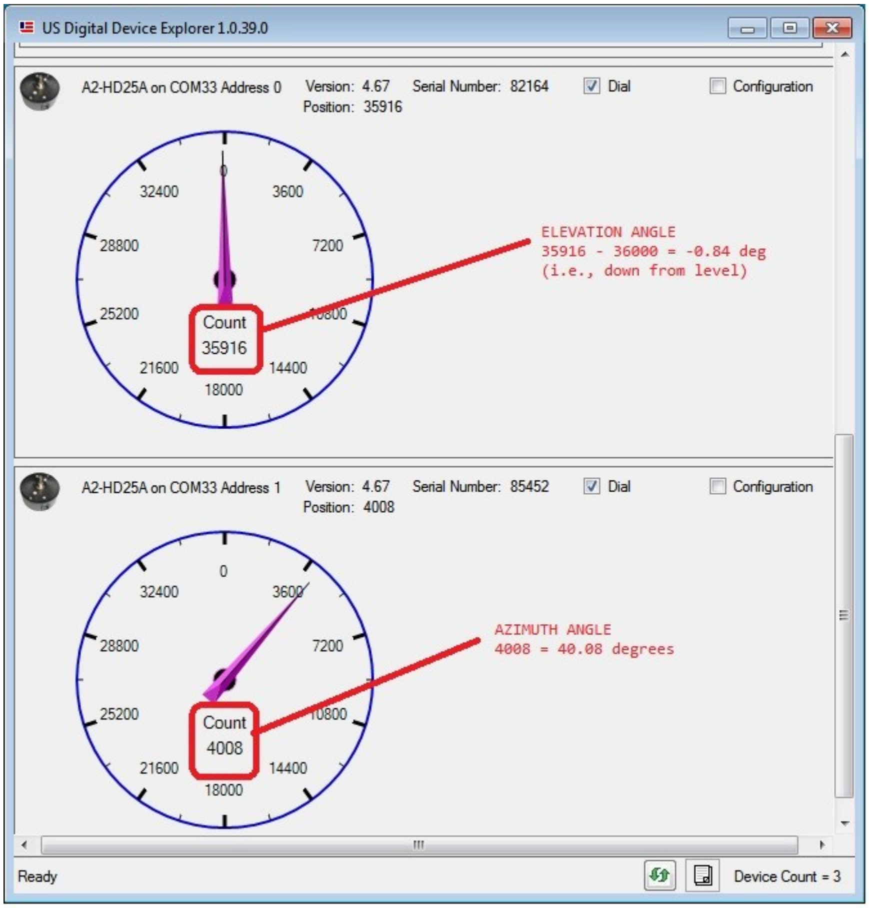

Figure 30. A typical encoder readout display obtained during the tilt measurements.

Note that the display seems to show a 0.01 degree precision in the angles; however, because the encoders are 12-bit encoders, the actual step values for each encoder is 360 degrees / 4096 steps = 0.088 deg/step not the 0.01 precision which seems to be indicated in the display.   Also, elevation angle readouts that are below zero (level) are actually negative, as indicated in the red comment. Values taken from the display at 5 degree azimuth increments were manually recorded and plotted in the image below.

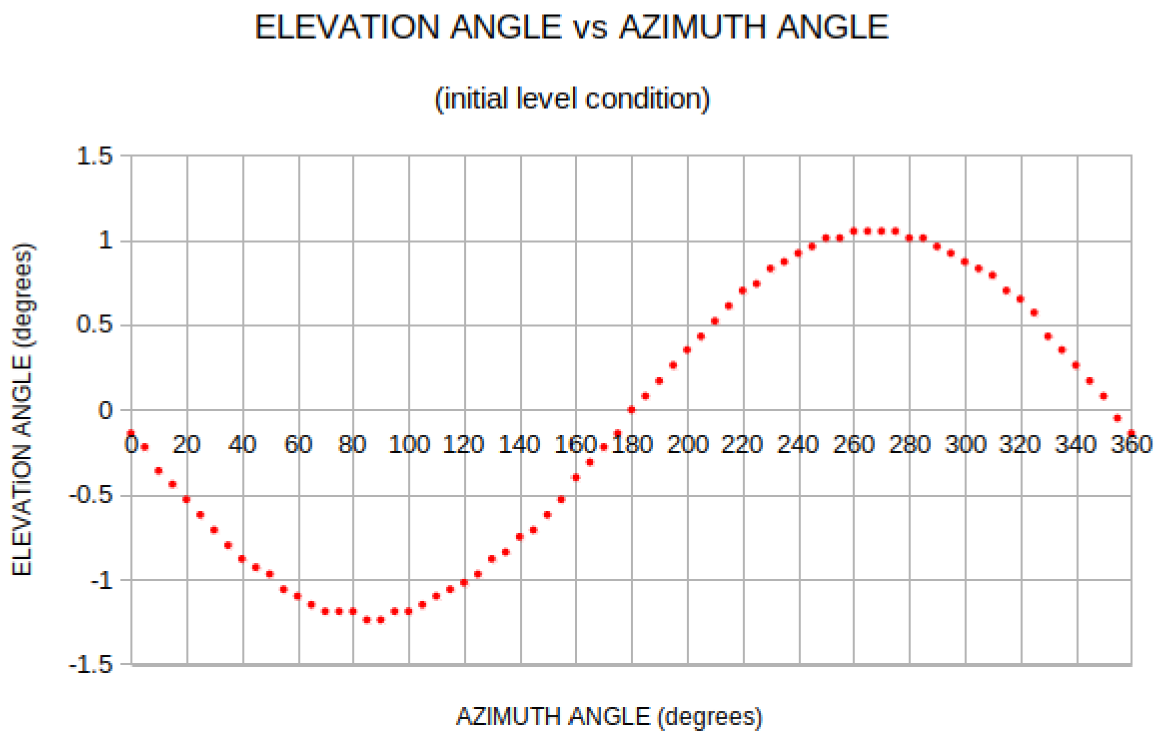

Figure 31. Plot of elevation angle vs azimuth angle for the initial tilt measurement for the AZ mount (18FEB2023).

The sinusoidal behavior of the elevation inclinometer output with azimuth angle indicates that the AZ mount is not quite level but is instead slightly tilted. From the plot it can be seen that the tilt is upward by about 1.1 degree at about 270 degrees azimuth and therefore downward by the same amount at an azimuth angle of 90 degrees. This tilt can be corrected by adjusting one or more of the three large bolts/screws on the legs of the mount. Performing the tilt correction is the next step to be done.

As it happened the large adjustment nuts on the AZ mount were too tight for me to loosen by hand using a 24” pipe wrench with a 5’ foot steel tube extension so I used a tractor to push the extension tube to initially loosen the nuts, as shown in the photo below.

Figure 32. Using a 24” pipe wrench with a steel tube extension and tractor to initially loosen the leveling nuts on the AZ mount.

Sometimes large mounting hardware that has been industrially tightened many years earlier cannot be broken loose by hand using simple tools so other means to get the required torque must be used to initially loosen it. In this case the tractor was instrumental in applying the necessary torque to initially loosen the leveling nuts of the mount.

After adjusting the leveling nut first on a single leg, then in a fine adjustment on two legs, measurable tilt was removed. The leveling nut adjustments reduced tilt to within the measuring accuracy of the inclinometer (+/-0.088 degree) and to within my ability to re-tighten the leveling nuts without re-introducing detectable tilt. The final measurements show a tiny amount of residual tilt remaining that is less than the measurement accuracy of the inclinometer. This amount of tilt is negligible for this project.

Initial and final tilt measurements for the mount are shown in the plot below.

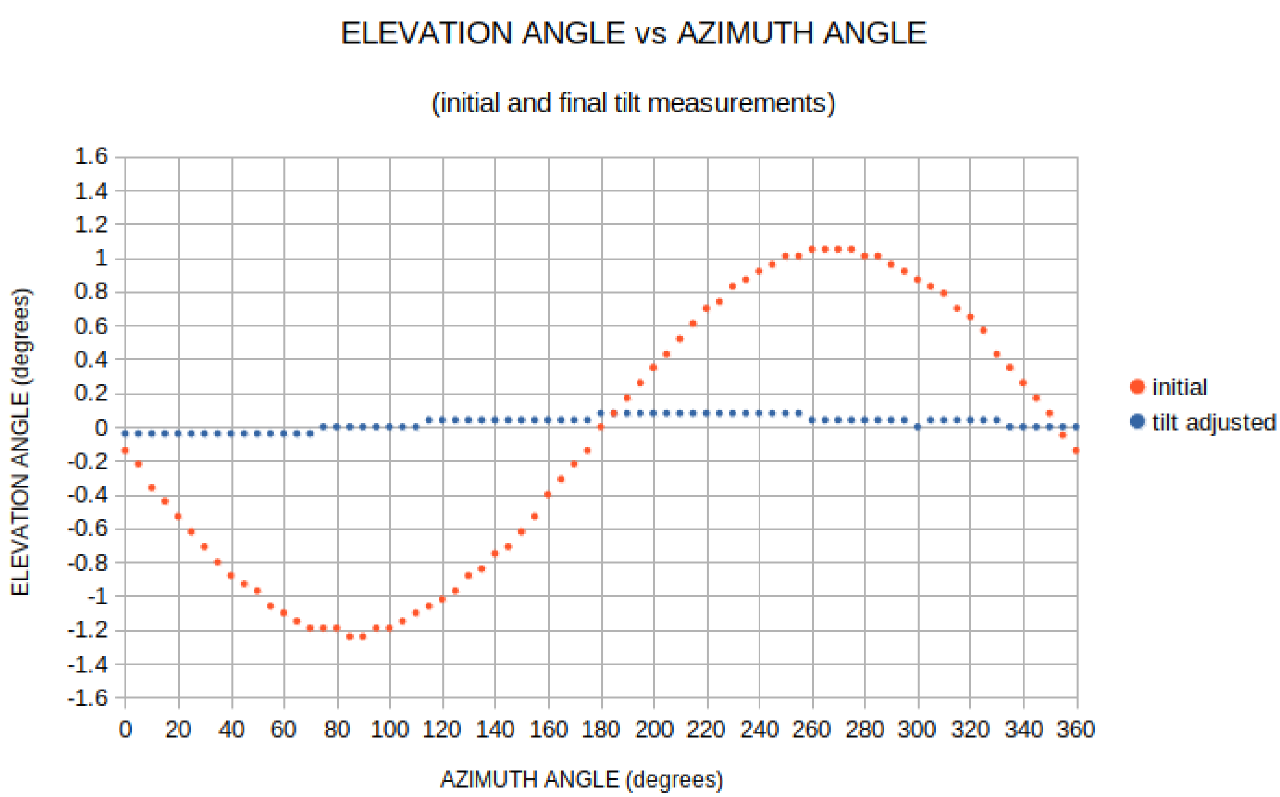

Figure 33. Tilt of the AZ mount has been removed as much as can be accurately measured by the inclinometer (20FEB2023).

At this point the mount is sufficiently level to serve as a level reference for guiding the installation of the rail support posts and circular rail system. A laser distance measuring meter and the AZ encoder will be used to set the radii and angle positions of the rail support posts and to set the height of the circular rail sections relative to the AZ mount reference surface.

Next task is to use the AZ encoder to identify and mark 22.5 degree positions for the rail support post holes around the mount and begin boring the rail support post holes.

Real-time progress reports continue in Volume II of the series, beginning with a description of the Rail Support System Concrete Work.