Requirements and Specifications for an Automatic Shutter Mechanism for the Arecibo ALFA Receiver

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1.0 Introduction

The ALFA receiver at the Arecibo Observatory is a seven pixel, L-band instrument. It is the principal receiver used for the large survey projects on the telescope, so its availability must be maximized. However, for its own protection, it must be covered during radar observations. Currently, the cover consists of a 1.2 m diameter aluminum disk that matches the dimensions of the receiver ground plane. This disk must be installed manually at the platform before radar operations begin. Later, when the radar observations are complete, the cover must be removed. This installation and removal process requires multiple workers to go up to the platform, and the time lost is significant.

To address this problem, the observatory has requested the design of an automatic shutter system. Such a system should still protect the receiver during radar operations, but must be operable from the control room. This would allow more rapid switching between ALFA observations and radar and would also eliminate the need to send a work team to the platform.

This document includes the design of the electromagnetic features of the shutter, which has been established by the observatory. The purpose of this document is to describe the requirements and specifications of the automatic system for supporting, opening, and closing the shutter so that the contractor may formulate a bid for the design and optional fabrication, assembly, and testing of the system.

2.0 System Description

The system to be designed is intended for use on the Arecibo radio telescope.

2.1 Information about the Telescope and Receiver

The optical layout of the Arecibo telescope is such that the *receiver cabin* (also called the *feed module*) is supported inside the Gregorian dome on a large moving structure suspended far above the primary reflector (Figure 1).

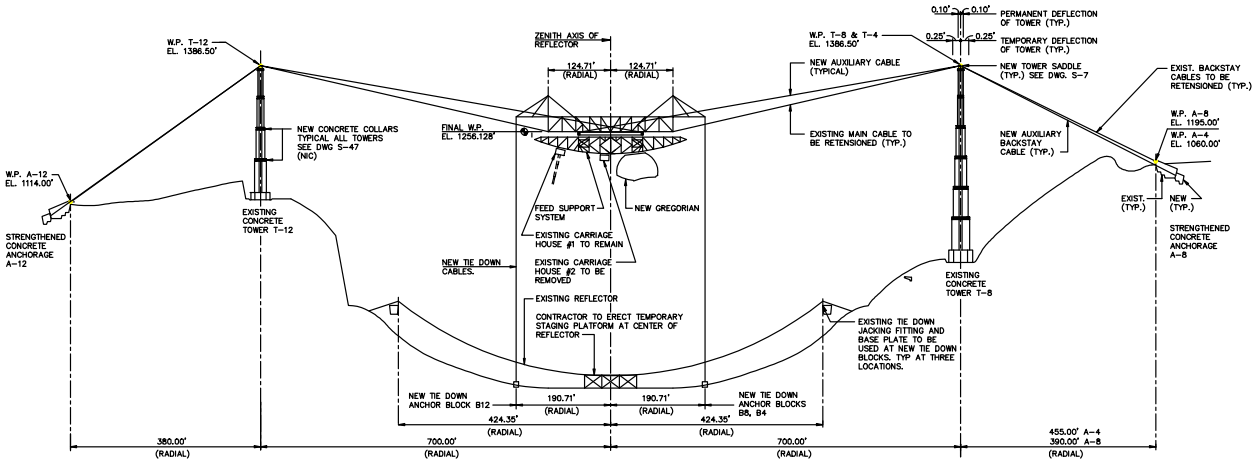

Figure 1: Elevation View of the Arecibo Telescope

The Gregorian dome, and thus the receiver cabin, is moved in azimuth and zenith angle to point to the desired astronomical source. Access to the receivers is available from a room of the receiver cabin for work on the upper portion of the receivers and from a service platform for work near the 'front' of the receivers below the floor (Figure 2). Because there are many receivers in use at the telescope, they are mounted on a rotating floor that can rotate the desired receiver into the optical path (Figure 3).

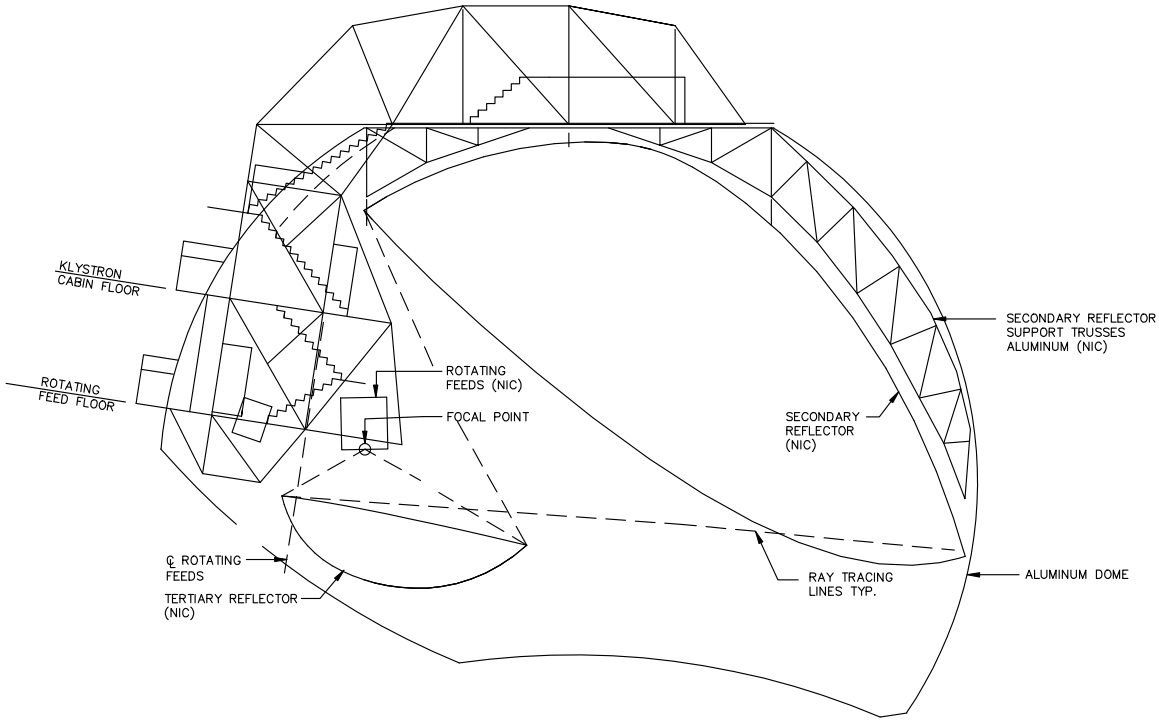

Figure 2: Receiver Cabin, Gregorian Dome, and Optics

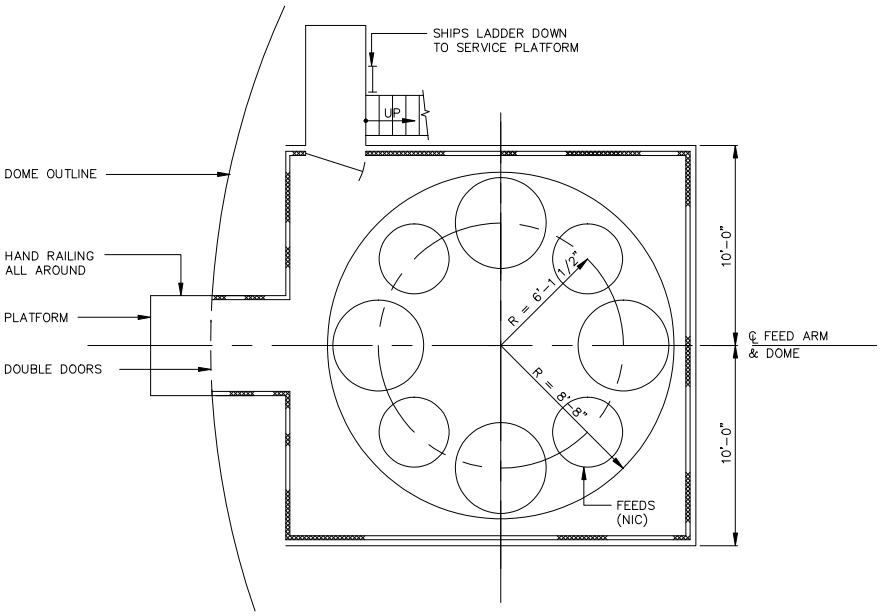

Figure 3: Plan View of Rotary Floor

One of the most important instruments in the Arecibo instrument suite is the ALFA receiver, which is an array receiver with seven horns (pixels). The front of the instrument is quite large (1.2 m diameter), and the instrument itself rotates axially about the center pixel during observations to preserve the orientation of the seven pixels as the telescope tracks a source across the sky. The ALFA receiver as mounted in the rotating floor is shown in Figure 4.

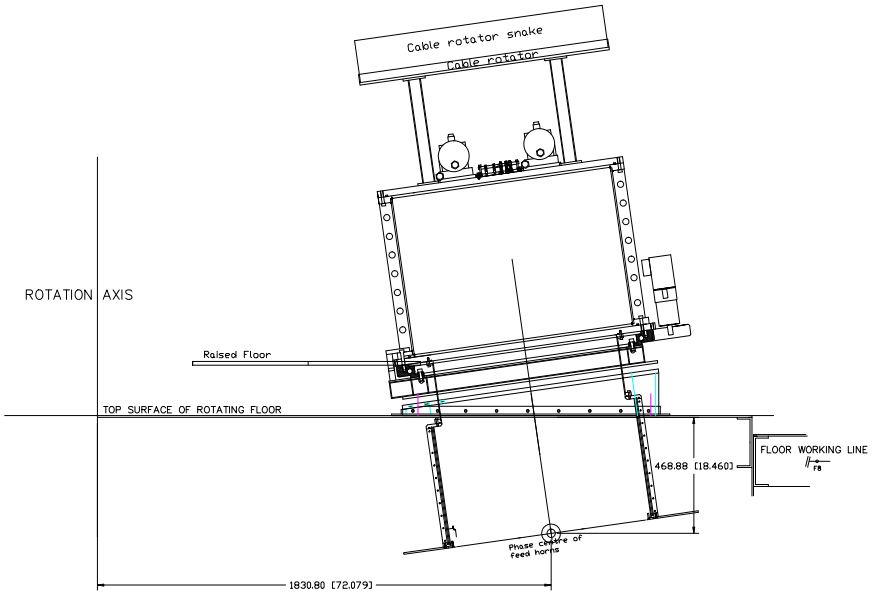

Figure 4: Side View of ALFA

2.2 System to be Designed

For this document, the system to be designed is referred to as the *ALFA Automatic Shutter Mechanism* or just the *Shutter Mechanism*. The purpose of this shutter mechanism is to move and support the *shutter* over the front of the ALFA receiver to protect this sensitive instrument during radar operations. The mechanism must also be able to retract the shutter when the ALFA receiver is in use so that it does not interfere with observations. While the designer is free to accomplish this in any way that meets the system specifications, the major components are the shutter itself, a means for supporting and guiding the shutter, and an actuator to drive the system.

2.2.1 Shutter

The electromagnetic design of the shutter (Figure 5) consists of a set of five concentric microwave chokes, cut from a monolithic piece of aluminum. An example of a physical shutter design that incorporates these electromagnetically important features while also providing mounting locations for a supporting mechanism is shown in Figure 6.

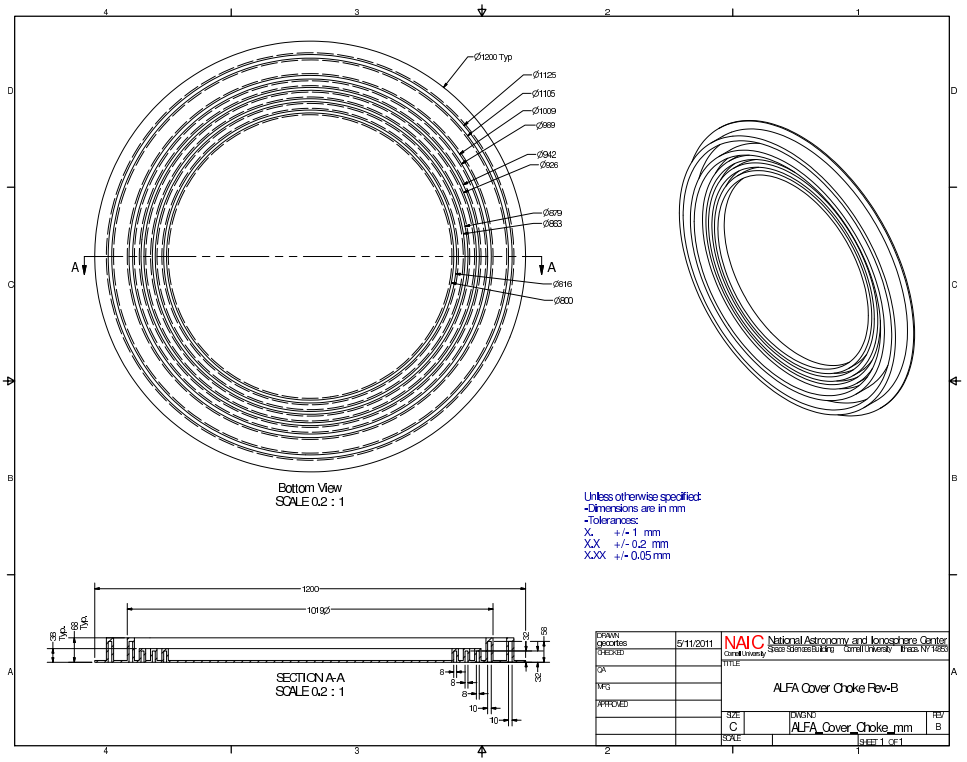

Figure 5: Shutter Electromagnetic Design

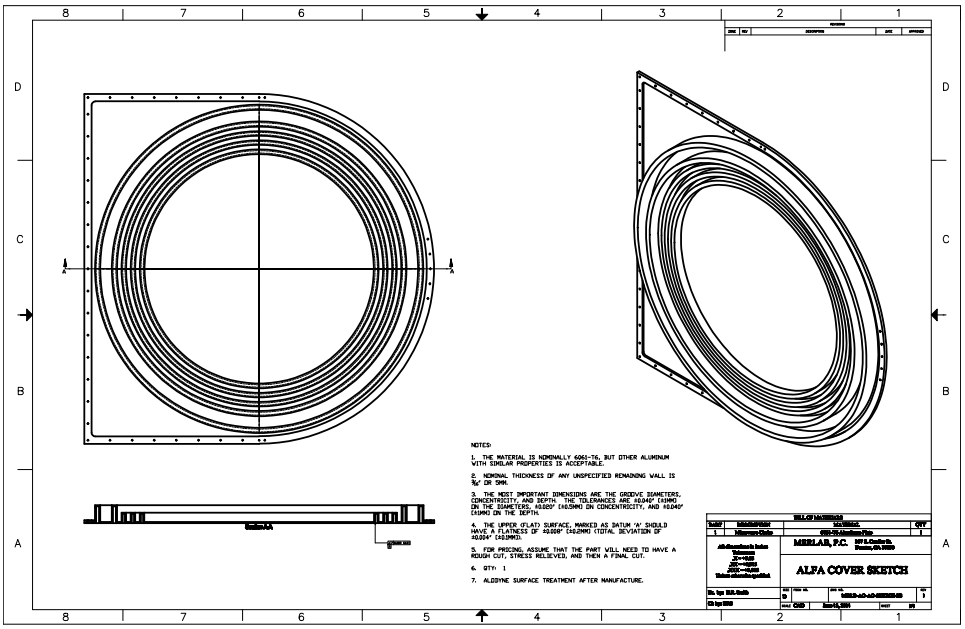

Figure 6: Example of a Physical Shutter Design

2.2.2 Support and Guiding

To minimize the volume swept by the system when it is opened and closed, the observatory has requested a sliding shutter. Further, because the ALFA receiver must rotate during normal use, no part of the shutter system can be permanently mounted to to the receiver itself. This means that a structure must be designed that can support and guide the shutter along its linear path. As the shutter moves into the closed position, it is acceptable if it engages the ALFA receiver for additional guidance or structural support. However, any such approach must still permit the ALFA receiver to rotate so that any accidental rotation with the shutter closed does not damage the shutter mechanism or the receiver. When the shutter is open, it must be completely clear of all receivers on the rotating floor.

2.2.3 Drive System

In order to control the shutter from the control room, an electromechanical actuator must be included as part of the design to drive the shutter between the open and closed positions.

3.0 Scope of Work

The scope of work for the design, fabrication, testing, and installation is as follows:

3.1 Design

As part of this document, the observatory provides an electromagnetic design of the shutter (Figure 5) and an example sketches of a physical shutter design (Figure 6) and a sample of how the mechanism might be carried out (Figure 7). These example sketches are not requirements, and the contractor may change the approach as necessary to meet the specifications.

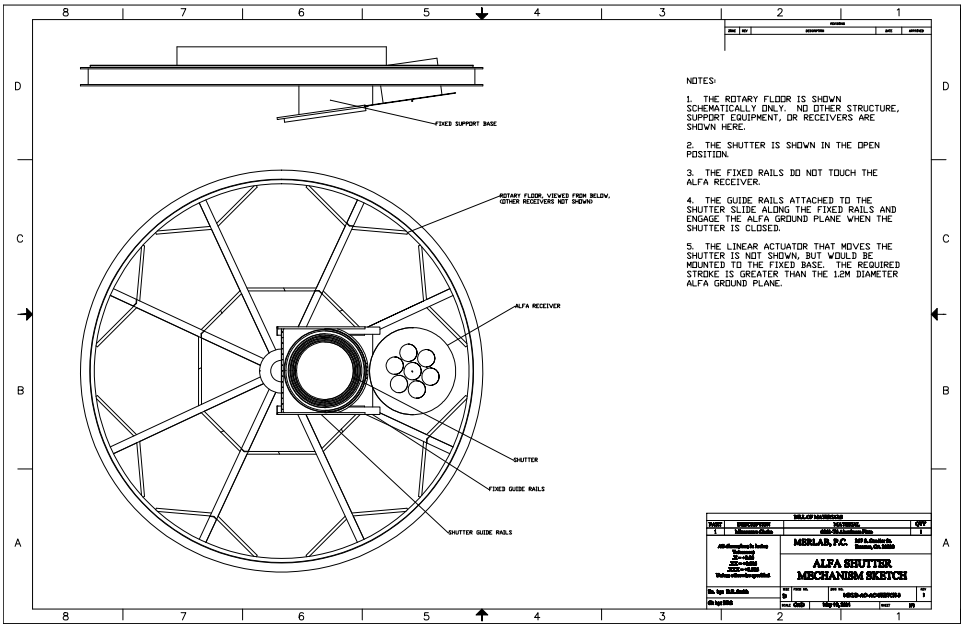

Figure 7: Example Sketch of a Shutter System

The bid is expected to include the following activities, in a manner compliant with the specifications given in this document:

1. Final structural design of the shutter, preserving the electromagnetic features, but adding any necessary stiffening ribs or mounting holes necessary for incorporating the shutter into the final assembly.
2. Design of the mechanical system to support the shutter and permit motion between its open and closed positions.
3. Design of the actuator system to move the shutter under computer control.
4. Design of the electrical cabinet to run the actuator system and communicate with the Arecibo telescope control system.
5. Development of the final acceptance test procedures.
6. Development of procedures for installation, alignment, and operation of the system.

7. Presentation of a Design Review at the observatory before final design acceptance and fabrication.

3.2 Fabrication

The bid is expected to include the following activities, in a manner compliant with the specifications given in this document:

1. Fabrication of the shutter itself, according to the final drawings. This portion of the bid should be listed as a separate item, because the observatory may prefer to handle the fabrication of this item in a separate contract.
2. Fabrication of the shutter mechanism, including procurement of all commercial parts, fabrication of custom-made components, and shop assembly.
3. Fabrication of the drive cabinet, including all cabling and wiring.
4. Fabrication of a test fixture for demonstrating the operation of the system.

3.3 Testing and Installation

The bid is expected to include the following tests:

1. Shop demonstration of the system moving both directions between open and closed positions in the test fixture. The acceptance test procedure shall, at a minimum, include demonstration of all high-level commands, safety interlock operation, and correct behavior of any TTL interfaces to the cabinet.
2. Optional additional cost for repeating the shop tests in a laboratory at the Arecibo observatory.
3. Optional additional cost for being present for supporting the final installation, alignment, and testing of the system on the rotating floor.

4.0 System Requirements

In order to provide the necessary function, the shutter system must meet requirements and specifications for safety, installation and alignment, size, weight, and loading, as well as in physical and electromagnetic performance.

4.1 Safety

The system should be designed so that it is safe, both during normal operation and certain specific events outside the normal operating loads.

4.1.1 Safe against falling

One of the most important features is that the shutter system and the shutter itself must be safe against separation from the rotating floor, since this would result in heavy objects falling onto the tertiary reflector or even >100 m to the primary reflector.

4.1.1.1 Factor of safety

The minimum factor of safety under the worst operational gravity loading conditions and floor accelerations shall be >2 at any point at or between the open and closed positions.

4.1.1.2 Independent Supports

The fixed portion of the system shall be restrained sufficiently that it can meet all specifications even if any single supporting bolt fails. Additionally, the shutter itself shall have a redundant safety support, such as a tether or chain, so that even if the shutter becomes separated from the mechanism, it will not fall. That is, the shutter must have two survival support systems: the nominal support and the tether.

4.1.1.3 Bolted Connections

Any bolted connections below the rotating floor must be 100% captive so that even in the event of unexpected loosening of the preload, the fastener will be held in place.

4.1.2 Safe against blocked motion

The motion system must include a stall timeout so that it cuts the power and sets the brakes if the system motion is blocked for more than 2 s.

4.1.3 Safe against floor rotation

The main goal of the sliding design for the shutter is that there will be no interference with any other equipment, receiver, platform, railing, etc., regardless of the position of the shutter or the rotating floor.

4.1.4 Safe against unexpected human loading

Neither the automatic shutter mechanism nor the shutter itself is specifically designed for human loading. However, the system must be able to survive a maximum load of a person grabbing onto the shutter for support in the event of a emergency (e.g., to prevent a fall). Specifically, the system must be able to accept a point load caused by a 100 kg person grabbing the shutter at a single location as their sole means of support. Thus, the support system and emergency tether must both be able to accept this additional load.

4.1.5 Safe against undetected shutter opening

To prevent the ALFA receiver from electrical damage due to an undetected opening of the shutter before or during radar operation, at least two independent sensors must be used to indicate that the system is in the closed position.

4.1.6 Safe against unexpected motion

There are two types of unexpected motion that the system should protect against. The first is to protect workers from unexpected motion of the shutter while they are carrying out maintenance. The second is unexpected rotation of the ALFA receiver while the shutter is closed.

4.1.6.1 Safe against unexpected shutter motion

In order to allow workers to protect themselves when working on the system, at least one emergency stop button must be located on the device. It must also be possible to tie the E-stop chain to the platform switch if desired by the observatory.

4.1.6.2 Safe against unexpected rotation of ALFA

While the mechanism is only intended to be in the open position when the ALFA receiver rotates, the system design should be such that it will not be damaged in the event that the ALFA receiver is inadvertently rotated to any position, regardless of whether the shutter is in the open or closed position.

4.2 Installation and Removal

Because the shutter itself is expected to have a mass of up to 40 kg, specific attention is necessary to the installation of the system.

4.2.1 Easy to install and remove

The ease of installation can be measured by the maximum number of people required, the number of those who must be harnessed and in rigging gear to safely perform their task, and how much other equipment must be removed.

4.2.1.1 Number of people

The maximum number of technicians required to install the system should be no more than three (3).

4.2.1.2 Number of people with rigging gear

Of the technicians installing the system, no more than two (2) should be required to be off of the service platform, harnessed and with rigging gear.

4.2.1.3 Number of other instruments to be removed

The installation procedure for the shutter mechanism should not require the removal of any other receivers on the rotating floor.

4.2.2 Easy to align

The ease of alignment can be measured by the maximum number of people required, the number of those who must be harnessed and in rigging gear to safely perform their task, and the number of reference marks provided on the system to help with the task. The alignment includes the adjustment of the shutter system support so that it places the shutter in the correct plane, as well as the limit switch adjustment so that it stops in the desired location.

4.2.2.1 Number of people

The alignment of the shutter should require no more than two (2) technicians.

4.2.2.2 Number of people with rigging gear

Of the technicians installing the system, no more than one (1) should be required to be off of the service platform, harnessed and with rigging gear.

4.2.2.3 Reference features

At least three (3) reference features shall be provided so that the location of the shutter can be located accurately.

4.3 Geometric and General

The most basic requirements are that the system must fit on the rotating floor without interfering with the structure or motion of other instruments, the service platform railing, or any other structure. Further, it must not place too much weight on the rotating floor and it must be corrosion resistant. Each of these is described in more detail below.

4.3.1 Fits in current space

The system must fit within the available space on the underside of the rotating floor. The relevant drawings from the observatory are included with this document, and are listed below:

1. S-42.dwg and related drawings to show the framing of the floor and relationship with the service platform.
2. AlfaPlanning.dwg to show the side view and dimensions of the ALFA receiver.
3. rotryflr5.dwg to show the layout of other nearby receivers.

Finally, there have been some changes to the underside of the rotary floor since the creation of these drawings, including a strengthening cross beam hub at the center of the floor. As a result, a visit to the platform is highly recommended before finalizing the design.

4.3.2 Lightweight

Because the rotating floor must support the mass of all instruments and mechanisms, it is critical that the mass of the system be kept low. To this end, the maximum total mass for the system, including the drive electronics should be less than 80 kg. Of this amount, the shutter itself is expected to be at most 40 kg, so the support system, actuator, additional structures, and drive electronics cabinet must have a combined mass of less than 40 kg. Lighter weight is strongly preferred.

4.3.3 Corrosion resistant

Since the telescope is in the tropics and the ALFA shutter mechanism will be open to humid outside air, all Aluminum parts, including the shutter itself, must be alodyne treated and steel parts must be galvanized. Plastic or stainless steel parts are acceptable as well.

4.4 Loading

The system will be subjected principally to gravity and dynamic loads. The dynamic loads arise from the rapid motion of the rotating floor.

4.4.1 Orientation of the system

The orientation of the shutter with respect to gravity depends on the angle of the system with respect to the floor, the rotation angle of the floor, and the zenith angle of the telescope.

4.4.1.1 Zenith angle range

The design range for the zenith angle of the telescope is 0°–20°.

4.4.1.2 Floor rotation angle range

The rotating floor can be at any rotation angle from 0°–360°.

4.4.1.3 Inclination of the shutter with respect to the floor

Due to the optics of the telescope, the ALFA receiver is inclined outward from the center of the rotating floor by an angle of 8.11° from vertical.

4.4.1.4 Combined Angles

Based on the specifications in sections 4.4.1.1–4.4.1.3, the peak angles of the shutter are from −8.11° to 28.11° along the direction of motion and ±20° perpendicular to the direction of motion.

4.4.2 Floor motions

The telescope is operated in a mode where a radar is rotated into position, a pulse is transmitted, a receiver is rotated into position, and the pulse is received. As a result, the floor is able to accelerate and move very rapidly. The dynamic loads from these motions must be taken into account in the design of the shutter mechanism. For conversion of the angular accelerations given below into linear accelerations, the distance from the center of the rotating floor to the center of the ALFA receiver is 1.83 m.

4.4.2.1 Floor angular acceleration

The maximum angular acceleration of the rotating floor is $26°/s^2$.

4.4.2.2 Floor angular velocity

The maximum angular acceleration of the rotating floor is 18°/s.

4.5 Performance

The purpose of the shutter system is to open and close the ALFA shutter in such a manner that it appropriately protects the receiver.

4.5.1 Open/Close Time

The time to open or close the shutter should be no more than 30 s. However, there is no particular driving factor to reduce this time. In fact, for the safety of any workers who are surprised by an unexpected motion of the system, the minimum allowable time for opening or closing the shutter should be 10 s.

4.5.2 Open and Closed conditions

In addition to any high-level communications from the drive system, a limit switch must be supplied at each end of travel to indicate whether the shutter is open or closed. If neither switch is activated, it will indicate that the shutter is in transit. In the 'closed' position, this switch may be one of the indicators used in requirement 4.1.5 above.

4.5.3 Shutter Deflection

In order for the shutter to work properly, its predicted peak deformation from the as-fabricated condition to the worst-case gravitational loading in the field should be <0.5 mm.

4.5.4 Shutter Fabrication

If fabrication is included in the bid, the tolerances on the shutter itself are as shown in Figures 5 and 6. The surface that faces the ground plane must be flat to within ± 0.1 mm. All other dimensions relevant to the electromagnetic performance of the shutter must be within ± 1 mm.

4.5.5 Shutter Alignment in the Closed Position

When closed, the shutter shall be held at a mean distance of no more than 2 mm, as measured by feeler gauges around the perimeter. As a goal, a mean distance of 1 mm would be preferred. Further, the shutter must be parallel to the ground plane (*i.e.*, the gap must be constant) to within ± 0.5 mm, again as determined from the same feeler gauge measurements. The shutter must not make electrical contact with the ground plane. The lateral alignment of the system should be within ± 1 mm.

4.6 Electrical

4.6.1 Power

The system shall be powered by a single 120 VAC grounded power outlet. The maximum power draw of the system should be less than 2 kW.

4.6.2 Electromagnetic Attenuation

The electromagnetic attenuation of the shutter in the closed position should be −50 dB at all relevant wavelengths. However, this portion of the shutter design will be provided by the Arecibo Observatory and is beyond the scope of this effort. The contractor is only responsible for providing a shutter design that includes the five electromagnetic choke rings as shown in Figure 5.

4.6.3 Electromagnetic Interference

To prevent the system from interfering with other instruments, the drive electronics cabinet must be appropriately designed.

1. The electronics cabinet shall be an RFI/EMI shielded enclosure (*e.g.*, from Hoffman).
2. All communication to/from the cabinet shall be via fiber optics (100BaseFX). The connection shall be use multimode ST connectors.
3. When the system is not in operation, all power to any actuators shall be able to be switched off so that they generate no RFI/EMI once the system is in the open or closed position.
4. Any cable feedthroughs to the electrical cabinet must have RFI/EMI shielding.

4.6.4 Command Interface

At a minimum, the high-level commands to the system over the fiber optic link will include the following:

1. *ON*

   Power up the system so that it can move. This may be a command issued to a network-controlled power strip.
2. *OFF*

   Power down the system so that it no longer generates any RFI/EMI. This may be a command issued to a network-controlled power strip.
3. *STATUS*

   Report the status of all limit switches and interlocks.
4. *OPEN*

   Move the shutter to the open position and indicate its arrival.
5. *CLOSE*

   Move the shutter to the closed position and indicate its arrival.

4.6.5 Cable Interfaces

Aside from the high-level communication via the fiber optic cables outlined in section 4.6.4, the electrical cabinet shall provide a two-wire shielded connector interface to provide a TTL indication for each of the position-indicator switches and interlocks. This will permit extension of the interlock chain or external determination of the state of the limits.

5.0 Deliverables

5.1 Design Phase

During the design, a brief weekly update summarizing the status and progress should be provided via e-mail. For the design review, the following documentation is required:

1. Shop drawings of all parts to be fabricated, including the final structural design of the shutter,
2. A parts list (vendors and part numbers) of any items to be purchased,
3. Data sheets of any items to be purchased,
4. An installation procedure,
5. An alignment procedure,
6. An operation description, including any proposed commands and protocols for communication, and
7. Pinout diagrams for all connectors on the electrical cabinet.

5.2 Fabrication Phase

During the fabrication, a brief weekly update summarizing the status and progress of procurements and fabricated parts should be provided via e-mail. The principal deliverable is the final system, including the test fixture, ready for shipping. However, a document containing the results of the demonstration test must also be provided.

6.0 Schedule

Bidders should indicate the amount of time they anticipate that the design and fabrication effort will require, including a milestone for the design review. However, the goal of the effort is to complete all work in three (3) months after receipt of contract.