



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

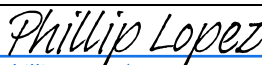


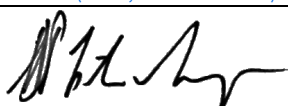



## Bins, Modules, and Racks Conceptual Design Description

020.30.55.00.00-0002-DSN-B

Status: **RELEASED**

PREPARED BY	ORGANIZATION	DATE
S. Sturgis, J. Allison, C. Bryant	Electronics Div., NRAO	05/27/2022

APPROVALS	ORGANIZATION	SIGNATURES
P. Lopez, Antenna Electronics IPT Lead	ngVLA, NRAO	 <a href="#">Phillip Lopez (Jun 6, 2022 16:25 MDT)</a>
T. Kusel, Systems Engineer	ngVLA, NRAO	 <a href="#">Thomas Kusel (Jun 6, 2022 20:42 EDT)</a>
R. Selina, Project Engineer	ngVLA, NRAO	 <a href="#">R. Selina (Jun 7, 2022 07:01 MDT)</a>
W. Esterhuyse, Telescope Project Manager	ngVLA, NRAO	

RELEASED BY	ORGANIZATION	SIGNATURES
W. Esterhuyse, Telescope Project Manager	ngVLA, NRAO	



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

### Change Record

Version	Date	Author	Affected Section(s)	Reason
A	2019-07-17	D. Gerrard, S. Sturgis, J. Allison	All	Initial Release
A.01	2022-03-30	S. Sturgis, J. Allison, C. Bryant	All	Updated per CoDR
B	2022-05-27	S. Sturgis	All	Updated doc per RIDS



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

## Table of Contents

<b>1</b>	<b>Introduction .....</b>	<b>4</b>
1.1	<i>Purpose and Scope.....</i>	4
1.2	<i>Applicable Documents.....</i>	4
1.3	<i>Reference Documents.....</i>	4
<b>2</b>	<b>Subsystem Overview .....</b>	<b>5</b>
2.1	<i>High level description .....</i>	5
2.2	<i>Design Driving Requirements .....</i>	8
2.3	<i>Key risks.....</i>	11
2.3.1	RFI shielding requirements .....	11
2.3.2	Environmental shielding requirements.....	11
2.3.3	Mass (primarily at the FE location).....	11
2.3.4	Insulation requirements (FE and AUX locations) .....	11
2.3.5	Cable Carrier Glide Table.....	11
2.4	<i>Design assumptions.....</i>	11
2.4.1	ARCS Modules and Bins.....	11
2.4.2	RFI Shielded enclosures.....	12
2.4.3	Cold Plates .....	12
2.4.4	FE Enclosure Radome.....	12
<b>3</b>	<b>Bins, Modules, and Rack Design.....</b>	<b>12</b>
3.1	<i>Product Context and Breakdown Structure Diagram .....</i>	12
3.2	<i>Product Mechanical Design.....</i>	14
3.2.1	ARCS Modules .....	15
3.2.2	ARCS Bin .....	21
3.2.3	Front End Enclosure.....	23
3.2.4	Auxiliary Enclosure.....	33
3.2.5	Front End Cable Carrier .....	36
3.2.6	Water Vapor Radiometer.....	40
3.2.7	Cryogenics RF Enclosure .....	42
3.2.8	Electronics Rack.....	45
3.3	<i>Manufacturability .....</i>	51
3.4	<i>Technology Readiness Assessment.....</i>	51
<b>4</b>	<b>Appendix A: Trade Studies .....</b>	<b>53</b>
4.1	<i>Air-cooled vs direct glycol cooled rack equipment .....</i>	53
<b>5</b>	<b>Appendix B: ARCS Module Shielding Report .....</b>	<b>54</b>
5.1	<i>Single Cover ARCS Module Shielding Report .....</i>	54
5.2	<i>Single Cover ARCS Module Shielding Report Addendum.....</i>	58
<b>6</b>	<b>Appendix B: Abbreviations and Acronyms.....</b>	<b>59</b>



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

## I Introduction

### I.1 Purpose and Scope

The purpose of this document is to describe the conceptual design of the Bins, Modules, and Racks subsystem (BMR). It covers the design approach, description of key components, interfaces, and risks associated with the conceptual design. This document will form part of the ngVLA Design documentation package.

The scope of this document covers the entire design of the Bins, Modules, and Racks subsystem. It includes the subsystem's design, how it functions, and its interfaces with other subsystems. It does not include specific technical requirements or budgetary information.

### I.2 Applicable Documents

*The following documents may not be directly referenced herein, but provide necessary context or supporting material.*

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA System Requirements	020.10.15.10.00-0003-REQ
AD02	LI System Environmental Specifications	020.10.15.10.00-0001-SPE
AD03	LI System EMI/RFI Requirements	020.10.15.10.00-0002-REQ
AD04	Main Antenna Electronics Block Diagrams	020.30.00.00.00-0005-BLK
AD05	Interface Control Document: Bins, Modules and Racks to Antenna Electronics	020.10.40.05.00-0040-ICD
AD06	Interface Control Document: Antenna to Antenna Electronics	020.10.40.05.00-0011-ICD
AD07	ngVLA System Electronics Specifications	020.10.15.10.00-0008-REQ

### I.3 Reference Documents

*The following documents are referenced within this text:*

Ref. No.	Document Title	Rev/Doc. No.
RD01	Single Cover ARCS Module Shielding Report	D. Mertely, 2020. (see Appendix B)
RD02	WVR Design Description	020.45.00.00.00-0002-DSN



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

## 2 Subsystem Overview

### 2.1 High level description

The BMR subsystem consists of mechanical packaging for Antenna Electronics within six key areas throughout the antenna (Figure 1): The FE Enclosure, the Auxiliary Enclosure, the FE Cable Carrier, the Electronics Rack, the Cryogenics Equipment, and the Water Vapor Radiometer. An overview of the products BMR will supply for each location is listed below.

The FE Enclosure, also known as the Front End Enclosure, resides on the feed arm at the prime focus and contains and protects the following equipment from the environment:

- SA500A Front End Cryostat A
- SA500B Front End Cryostat B
- SA501 Bands 5-6 IRD/LO Module
- SA502 Bands 1-4 IRD/LO Module
- L501 Main LO Module
- M507 Utility Module (combined Power Supply and M&C module)

The BMR subsystem shall provide:

- Front End Enclosure
- SA501 Bands 5-6 IRD/LO Module Metalwork
- SA502 Bands 1-4 IRD/LO Module Metalwork
- L501 Main LO Module Metalwork
- M507 Utility Module Metalwork
- Front End ARCS bin

The Auxiliary Enclosure resides on the feed arm between the FE Enclosure and the Primary Reflector and contains and protects the following equipment from the environment:

- F524 Cryogenics Vacuum Pump
- M506 Utility Module
- F523 VFD Control Module,
- F521 Cold Head VFD Driver Module,
- F522 Vacuum Pump and Feed Heater Driver Module

The BMR subsystem shall provide:

- Auxiliary Enclosure
- M506 Utility Module Metalwork
- F523 VFD Control Module Metalwork
- F521 Cold Head VFD Driver Module Metalwork
- F522 Vacuum Pump and Feed Heater Driver Module Metalwork
- Auxiliary ARCS bin

The Front End Cable Carrier is located adjacent to the FE Enclosure and carries all cables, fibers, hoses, etc. that connect to equipment in the FE Enclosure. The cable carrier is necessary because the FE Enclosure will move for band selection (lateral to the feedarm) +/- 25.6in (+/- 650mm), and focus (along boresight) +/- 3.9in (+/- 100mm). The BMR subsystem shall provide the cable carrier, including mounting hardware. The lines the cable carrier must accommodate are:

- Vacuum Hose
- Helium Hose (supply and return)



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

- Glycol Hose (supply and return)
- 48VDC Power Lines (x2)
- Feed Heater Lines (x2)
- Cryocooler Control
- 36 Core Fiber Optic (x2)
- Dry Air Hose

The Electronics Rack is located in the Antenna Pedestal RFI Shielded Room and contains:

- P500, -48VDC Power Subsystem
- M503 Antenna M&C Ethernet Switch
- M502, Utility Module
- D501 Digital Back End Module
- L503 Reference Receiver and Timing Module
- D502 WVR Back End Module
- M500 Supervisor Computer Module
- M501 Maintenance Computer Module
- Data Backhaul Equipment (multiple modules in one ARCS Bin), details TBD
- L502 Reference Dist. Repeater Equipment (multiple modules in one ARCS Bin), details TBD
- 36 Core Circular Fiber Connector and Splice Tray
- M504 EEC Electronics (location TBD)
- ARCS Bins as necessary

The BMR subsystem shall provide:

- Electronics Rack
- M502 Utility Module Metalwork
- D501 Digital Back End Module Metalwork
- L503 Reference Receiver and Timing Module Metalwork
- D502 WVR Back End Module Metalwork
- M500 Supervisor Computer Module Metalwork
- M501 Maintenance Computer Module Metalwork
- Data Backhaul Equipment Module Metalwork and ARCS Bin (details TBD)
- L502 Reference Dist. Repeater Equipment Module Metalwork and ARCS Bin (details TBD)
- M504 EEC Electronics Module Metalwork (location TBD)
- Electronics Rack ARCS bins.

The Cryogenics Equipment is located in the Antenna Turn Head and the portion supported by BMR consists of:

- Cryo RF Enclosure
- M505 Utility Module
- Helium Compressor VFD enclosure (if not COTS, TBD)
- Helium Pressure Regulator Electronics Module
- 12 Core Circular Fiber Connectors and Splice Tray

The BMR subsystem shall provide:

- Cryo RF Enclosure Metalwork
- M505 Utility Module Metalwork
- Helium Compressor VFD Module Metalwork (if packaged as a module)

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

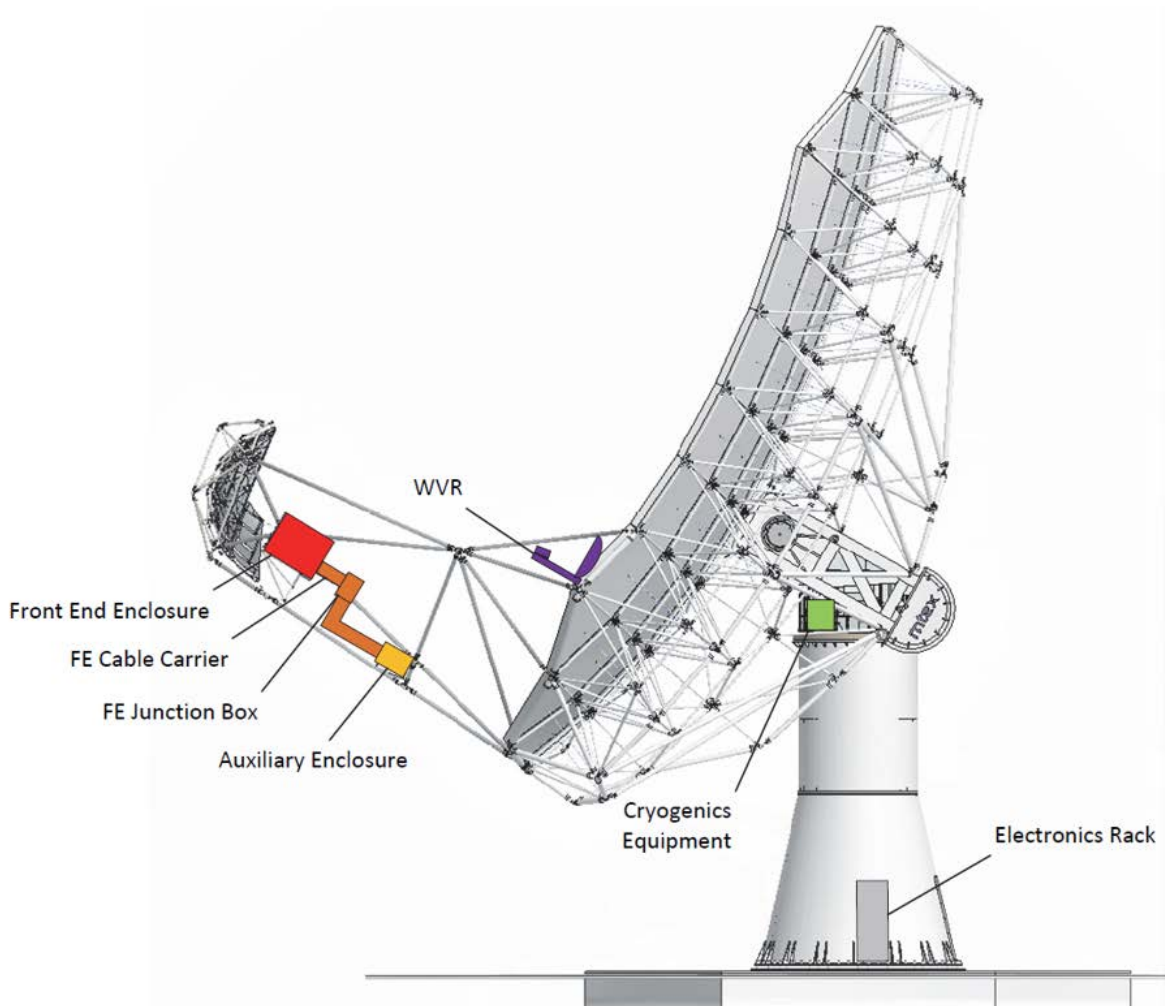
- Helium Pressure Regulator Electronics Module Metalwork

The Water Vapor Radiometer is located on the edge of the primary reflector and consists of a reflective dish with a dedicated Front End Receiver Module at the focus, and a Utility Module located behind the dish (or another suitable location close by). Each module will be within an environmental enclosure to protect it from the weather. The WVR subsystem consists of:

- F507 WVR Front End Environmental Enclosure
- F507 WVR Front End RFI Enclosure
- M508 WVR Utility Module Environmental Enclosure
- M508 WVR Utility Module RFI Enclosure

The BMR subsystem shall provide:

- F507 WVR Front End Environmental Enclosure Metalwork
- F507 WVR Front End RFI Enclosure Module Metalwork
- M508 WVR Utility Module Environmental Enclosure Metalwork
- M508 WVR Utility Module RFI Enclosure Module Metalwork





<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

Figure 1. Primary Antenna Electronics Locations

## 2.2 Design Driving Requirements

The driving requirements for the BMR sub-system originate from three primary sources, ngVLA System Electronics Specification (AD11), Antenna Electronics to BMR ICD (AD09), and System Environmental Specifications (AD02). The ICD's are expected to be major driver of requirements. Because the ICD's will only be developed during the preliminary design phase, this document will be updated once the ICD's have been completed. A subset of the key requirements that drive the design are shown in Tables 1-5 below.

Parameter	Summary of Requirement	Reference
Chromate Converted Surfaces	Aluminum surfaces where electrical conduction is required (RFI/EMI or safety grounding) shall be treated using a Chromate Conversion process as outlined in MIL-DTL-5541E. Either Class 1A or Class 3 can be used based on requirements determined by the designer.	ETRI 143
Stainless Steel Surfaces	Stainless steel can be used for RFI/EMC housing where deemed feasible by the designer. Surfaces can be painted but shall be left bare where electrical conduction is necessary.	ETRI 144
Anodized Surfaces	Aluminum Surfaces where no electrical conductivity is required can be anodized. Anodizing shall be of a color not mistakable for chromate (i.e. clear, yellow, brown, or gold). Anodizing shall not be used on surfaces requiring electrical conductivity for RFI/EMI shielding or good safety ground conduction and shall never be scraped or sanded off to achieve this.	ETRI 145
Fiber Optic Cable Twist	Fiber Optic Cables shall not be subject to twisting under any circumstances	Ant. to Ant. Elec. ICD

Table 1: Key System Electronics Requirements





<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

Parameter	Summary of Requirement	Reference
Ease of Access	Products within the subsystem must be easy to access.	BMR0001
Ease of Installation	LRU's within the subsystem must be simple and quick to install and uninstall.	BMR0002
RFI Shielding	Must provide sufficient RFI shielding to restrict spurious signal emission levels to within the constraints given in EMC0310.	BMR0003
Heat Dissipation	Must provide either a heatsink or an interface for a cold plate, as required for heat dissipation.	BMR0004
Mass	Products within the sub-system shall minimize mass where possible.	BMR0005
Contents requirements	Enclosures within the subsystem shall meet all requirements of the enclosure contents.	BMR0006

**Table 2. Key BMR Requirements**

Regarding the RFI shielding requirement (BMR0003), while the detrimental RFI emission limits are established in EMC0310 at the system level, the emission level of the housed components is not yet known. The specific level of shielding required from the BMR system components is therefore still TBD and will be established in the associated interface control documents. This design assumes representative emission levels based on comparable existing systems where the expected shielding levels required may drive the design.

Regarding the mass requirement (BMR 0005), there is a total mass constraint in the Antenna Electronics to Antenna ICD. While the allocation to BMR is flexible, the total is not, and BMR is expected to be a significant fraction of the total. A preliminary mass budget suggests that minimizing the mass of the design will be required.

Limits to Operating Conditions.

Parameter	Req. #	Value
Solar Thermal Load	ENV0330	Exposed to full sun, 1200W/m <sup>2</sup>
Wind	ENV0331	$W \leq 15$ m/s average over 10 mins; $W \leq 20$ m/s gusts
Temperature	ENV0332	$-20 \text{ C} \leq T \leq 45 \text{ C}$
Precipitation	ENV0333	Up to 5 cm/hr over 10 mins
Ice	ENV0334	Equivalent to radial ice of 2.5 mm
Relative Humidity	ENV0335	$0 \leq RH \leq 100\%$ ; condensation permitted

**Table 3. Limits to Operating Environmental Conditions**



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

Standby Conditions.

Parameter	Req. #	Value
Solar Thermal Load	ENV0360	Exposed to full sun, 1200W/m <sup>2</sup>
Wind	ENV0361	0 m/s ≤ W ≤ 30 m/s average
Temperature	ENV0362	-25 C ≤ T ≤ 45 C
Precipitation	ENV0363	Up to 5 cm/hr over 10 mins
Ice	ENV0364	Equivalent to radial ice of 2.5 mm
Relative Humidity	ENV0365	0 ≤ RH ≤ 100%; condensation permitted
Standby Recovery Time	ENV0366	The system shall resume operation to specification within 5 minutes of conditions returning to the constraints of the Normal or Precision Operating Conditions.

**Table 4. Standby Environmental Conditions**

The standby conditions are the set under which BMR needs to operate to full specifications, otherwise housed equipment may be out of spec, and the return-to-spec requirement ENV0366 cannot be met.

Some parts of the BMR subsystem are subject to the full open-air ambient conditions and some parts are protected from the environment by being located in the antenna turnhead or pedestal. The components subject to the full set of open-air ambient conditions are:

- FE Enclosure
- Aux Enclosure
- Cable Carrier
- WVR Front End Environmental Enclosure
- WVR Utility Module Environmental Enclosure

Survival Conditions.

Parameter	Req. #	Value
Wind	ENV0341	0 m/s ≤ W ≤ 50 m/s average
Temperature	ENV0342	-30 C ≤ T ≤ 50 C
Radial Ice	ENV0343	2.5 cm
Rain Rate	ENV0344	16 cm/hr over 10 mins
Snow Load, Antenna	ENV0345	25 cm
Snow Load, Equipment & Buildings	ENV0346	100 kg/m <sup>2</sup> on horizontal surfaces
Hail Stones	ENV0347	2.0 cm
Antenna Orientation	ENV0348	Stow-survival, as defined by antenna designer

**Table 5. Survival Environmental Conditions**



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

## 2.3 Key risks

### 2.3.1 RFI shielding requirements

The ARCS Modules have demonstrated impressive shielding levels (>80dB at 1-10 GHz, see Figure 12), however, once a full analysis is completed it is possible the shielding level will be found to be inadequate. Additionally, some RFI shielded enclosures may have glycol cooling lines penetrating them which could cause additional shielding degradation. Additional shielding can be attained in a variety of ways, the most extreme being enclosing the offending emitter in an additional layer of RF shielding enclosure. Ultimately the method depends on how much additional shielding is required.

### 2.3.2 Environmental shielding requirements

Environmental shielding for all components on the feed arm will have to withstand all environmental conditions that the full telescope encounters, including rain, snow, hail, high winds, high and low temperatures, etc. If an environmental enclosure should fail, expensive and sensitive equipment could be damaged.

### 2.3.3 Mass (primarily at the FE location)

Minimizing the mass of the subsystem is always important, but especially so for the Front End and Auxiliary locations. If the mass budget for these locations were to be exceeded it could have detrimental effects on the telescope performance (primarily pointing and surface error). As the provider of the environmental enclosures for both locations, the BMR subsystem could have a large impact on the total mass and as such all components should be designed to minimize mass wherever possible.

### 2.3.4 Insulation requirements (FE and AUX locations)

Some enclosures will require a greater degree of protection from changing temperatures, which can become a challenge on hot or cold days with strong direct sunlight as is often the case in the Southwest region of the US. The environmental enclosures, especially the Front End Enclosure, will have to be well insulated against air temperatures as well as direct sunlight.

### 2.3.5 Cable Carrier Glide Table

The Cable Carrier must be side mounted in order to accommodate the two axis motion of the Front End Enclosure. Side mounting will most likely require a glide table to support the moving section of the cable carrier as the carrier is not designed to hold significant loads in a side mounted configuration. The design and implementation of this glide table could be difficult because the cable carrier has to allow the FE enclosure side to side motion for band selection as well as forward and back motion for focus control. This motion will likely require a glide table with an expansion joint in it that does not cause excessive wear on the cable carrier glide feet, as well as minimizing any risk associated with ice buildup.

## 2.4 Design assumptions

### 2.4.1 ARCS Modules and Bins

The ARCS Modules have demonstrated impressive RFI shielding levels (>80dB at 1-10 GHz, see Figure 12), and are a flexible modular electronics packaging system. Whenever practical the ARCS module and bin system should be used for packaging of electronics, especially if RFI shielding is required.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

#### 2.4.2 RFI Shielded enclosures

One design assumption made early on was to not subject any RFI shielded enclosures to direct outside environmental conditions. The implication of this is that in a few areas additional environmental enclosures are required.

#### 2.4.3 Cold Plates

All cold plates utilized for Antenna Electronics are the responsibility of the EEC subsystem.

#### 2.4.4 FE Enclosure Radome

The FE enclosure will have a radome to protect the contents from the environment and allow the feeds to receive radio signals. The FE enclosure radome is the responsibility of the FE subsystem.

### 3 Bins, Modules, and Rack Design

#### 3.1 Product Context and Breakdown Structure Diagram

The BMR subsystem provides enclosures for hosting the antenna electronics on the different locations on the antenna. The various enclosures are shown in the decomposition in Figure 2. Some of the modules are designed for specific purposes while others are generic module enclosures that are used on multiple locations.

The BMR provides the following functions:

- a) Environmental protection against the elements (sun, moisture, etc).
- b) RF radiation shielding.
- c) Earthing of enclosures.
- d) Entry points for fiber optic penetrations.
- e) Mechanical mounting mechanisms.
- f) Mechanisms to regulate the temperature in the enclosures (through glycol or air ventilation).

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

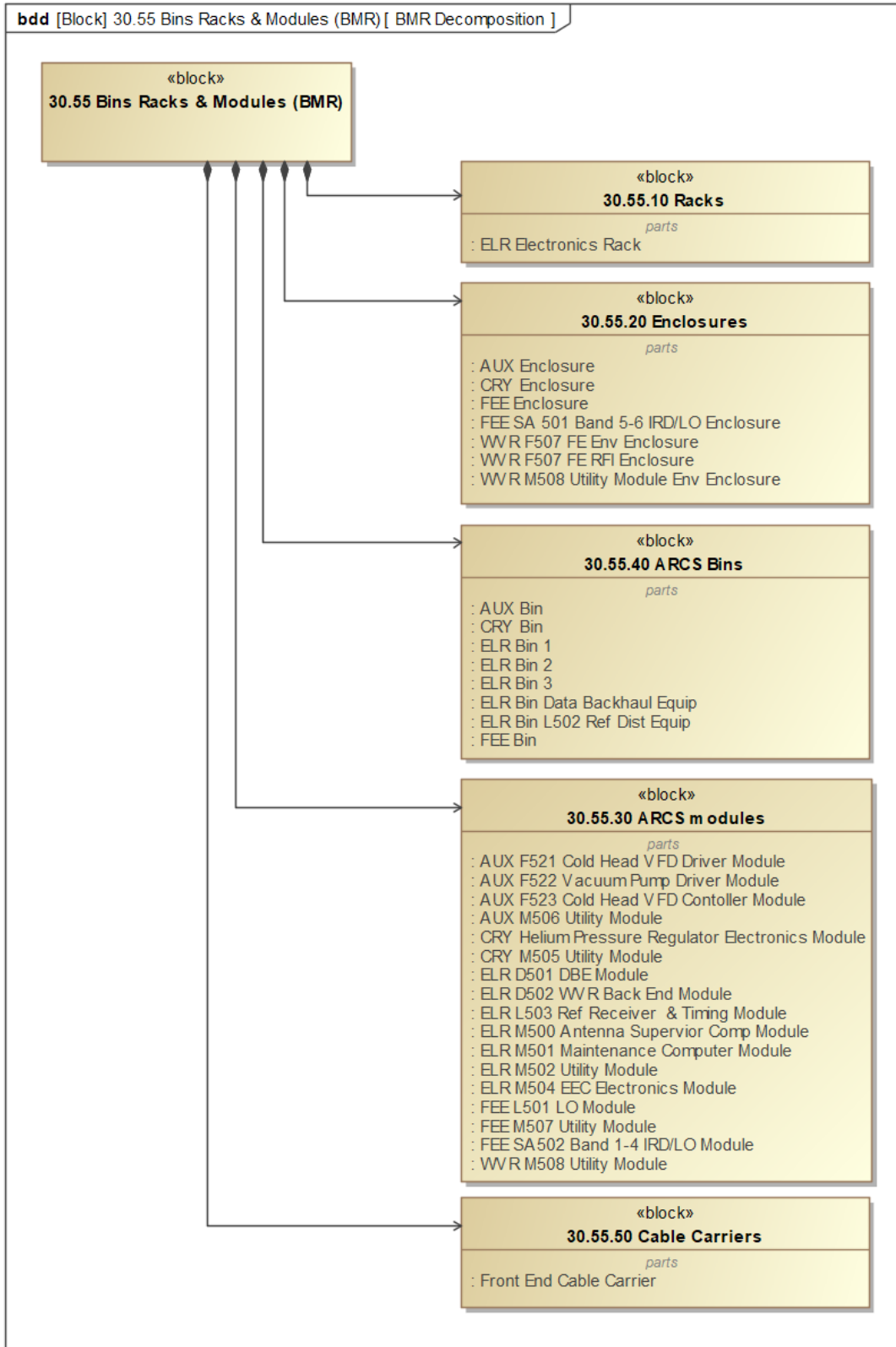


Figure 2. BMR Decomposition

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The external interfaces of BMR are shown in Figure 3 below. The BMR interfaces with:

- a) Antenna Electronics that are housed inside the modules/enclosures.
- b) Antenna: including mechanical interfaces for the mounting of enclosures, AC power connections and earthing connections.
- c) Penetrations of the modules/enclosures by the antenna fiber optic cable network (AFD).

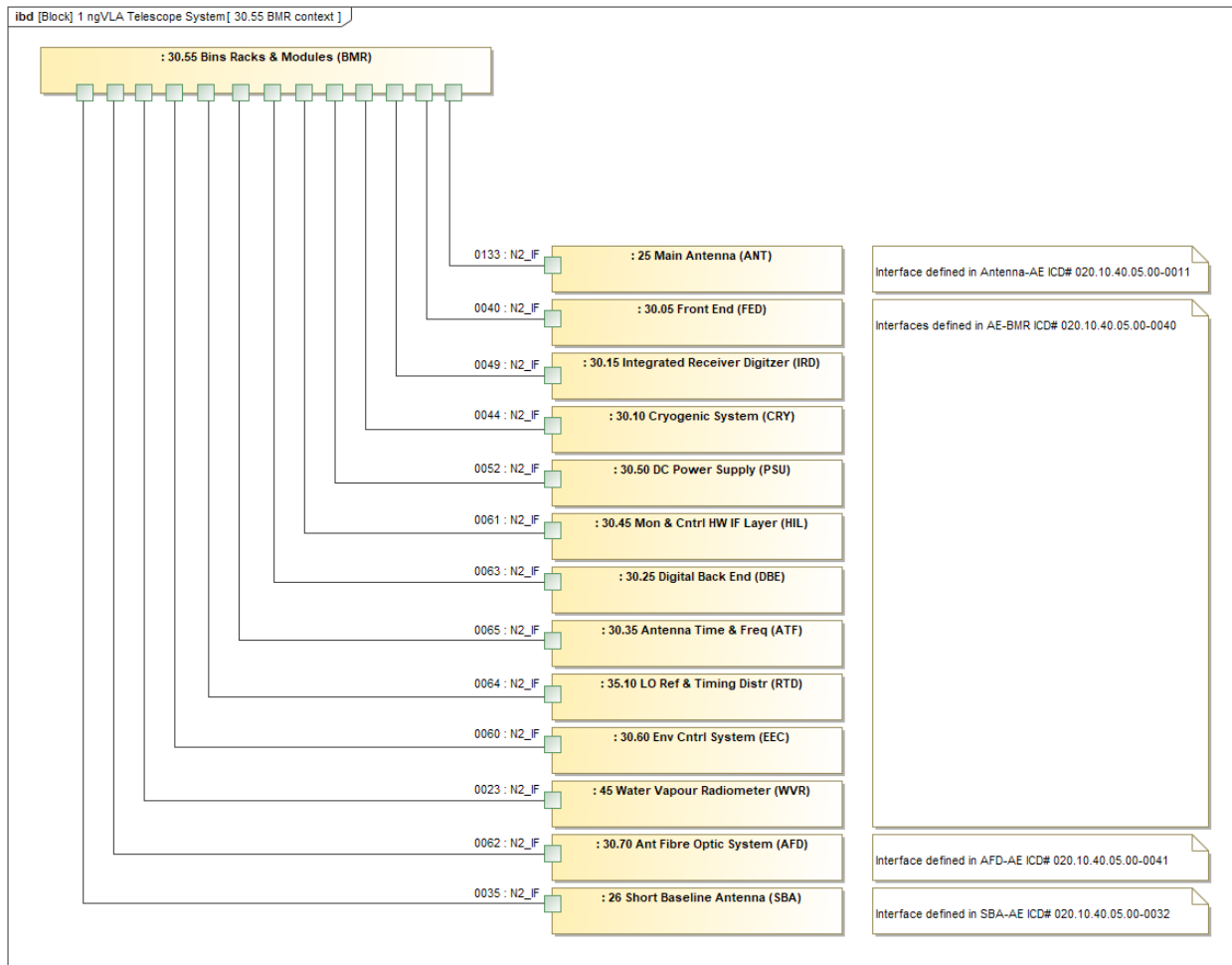


Figure 3. BMR external interfaces

### 3.2 Product Mechanical Design

The BMR subsystem consists of mechanical packaging for Antenna Electronics within six key areas throughout the antenna (Figure 1): The FE Enclosure, the Auxiliary Enclosure, the FE Cable Carrier, the



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

Electronics Rack, the Cryogenics Equipment, and the Water Vapor Radiometer. Detailed descriptions of each of the products BMR will supply is listed below.

### 3.2.1 ARCS Modules

Throughout all of the locations the Antenna Electronics equipment resides there is a need for packaging of custom electronics in multiple enclosures with RFI shielding as well as thermal control. In recent years, NRAO has developed a modular electronics packaging system called the Advanced RFI Containment System, or ARCS modules (US Patent No. 10,433,468). A general description applying to all ARCS modules is given here. Specific modules will be adapted to each individual module's requirements.

The ARCS modules were developed to improve upon previous module designs utilized in the EVLA and ALMA projects. These previous module designs, while adequate, suffered from poor shielding levels and were time consuming to maintain due to the large number of fasteners used to close them up (~50 – 80 per module). The poor shielding levels could be attributed to the multi-part design with long seam lengths, and the large number of fasteners was the result of using relatively thin, flexible panels to seal the modules, requiring close fastener spacing. The ARCS module design minimizes the total seam length and utilizes stiff, machined access panels to reduce the number of fasteners (6 per module). As a result, maintenance time is greatly reduced and the shielding level achieved is significantly greater than either the EVLA or the ALMA modules.

There are two types of ARCS modules, designated as series 500 and 700. The 500 series modules consist of two high-tolerance machined pieces of ATP-5 aluminum tool plate, a housing and a cover, that fit together like a clamshell leaving a cavity in the middle for mounting electronics (Figure 4). The ATP-5 aluminum is dimensionally very stable allowing for high precision machined parts to be easily achieved. All module pieces will be chromated per MIL-C-5541-CL.III after machining in order to maintain a conductive surface. The 700 series modules are three-piece modules, made from the same ATP-5 aluminum with a central housing and individually removable side covers that allow access to the internal electronics from either side of the module, as well as allowing for dual internal cavities that may be independently RFI shielded (Figure 5). Module parts from both series are generally interchangeable. The module style to be selected is dependent on the degree of access required for the components within, and the desired mounting layout of said components.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

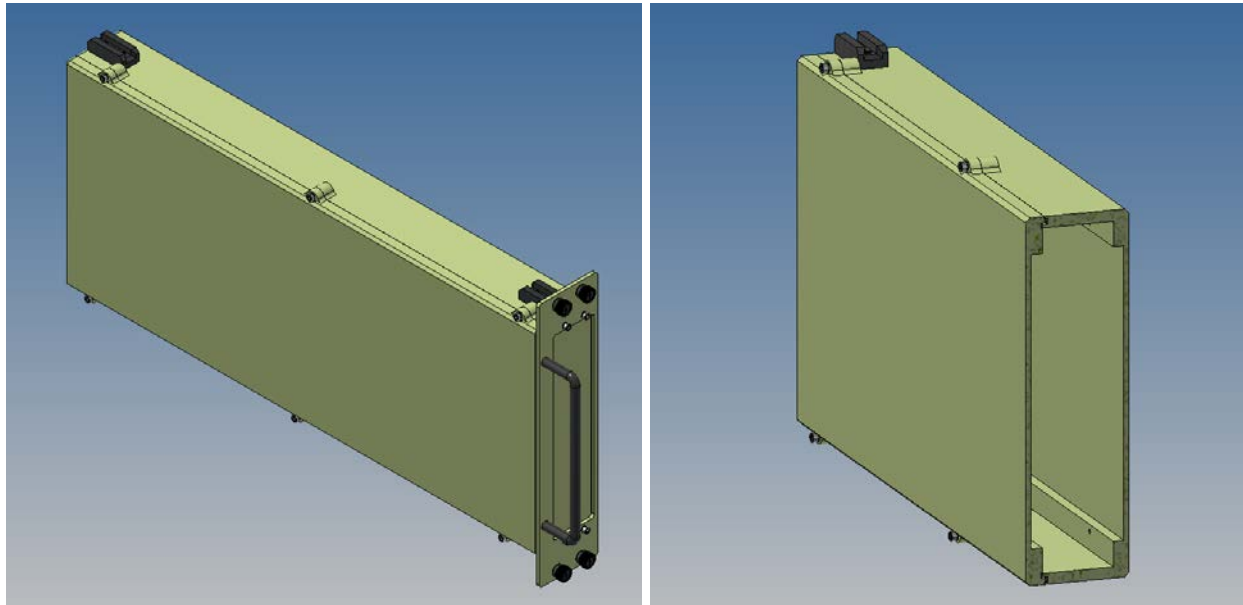


Figure 4. 500 Series ARCS Module, closed and cross section views

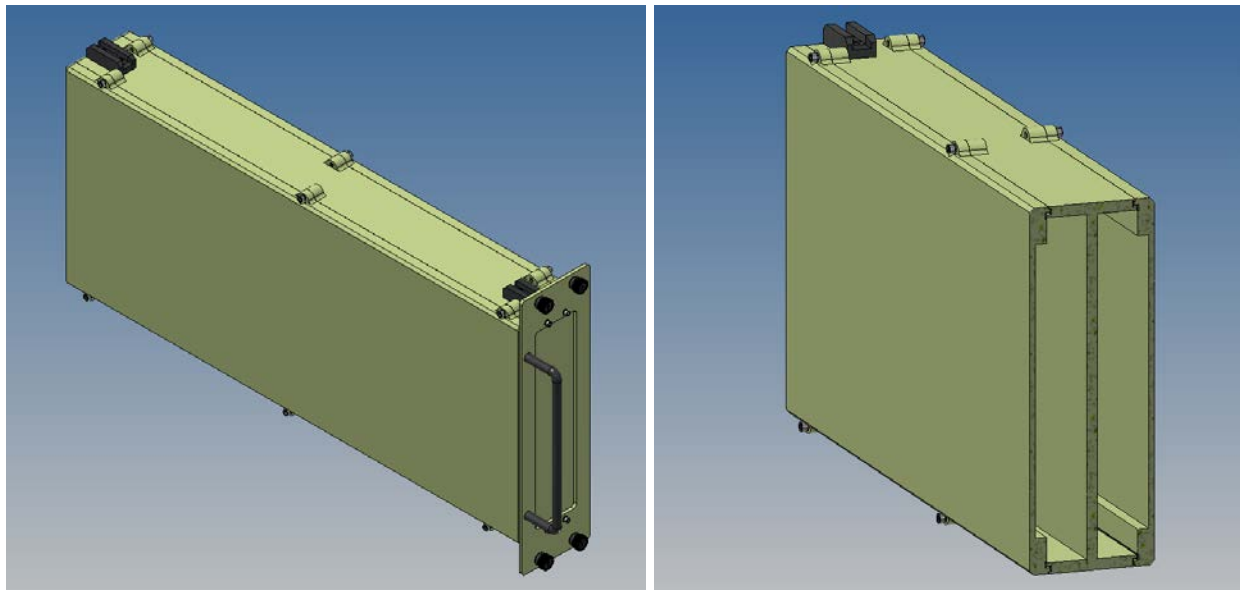
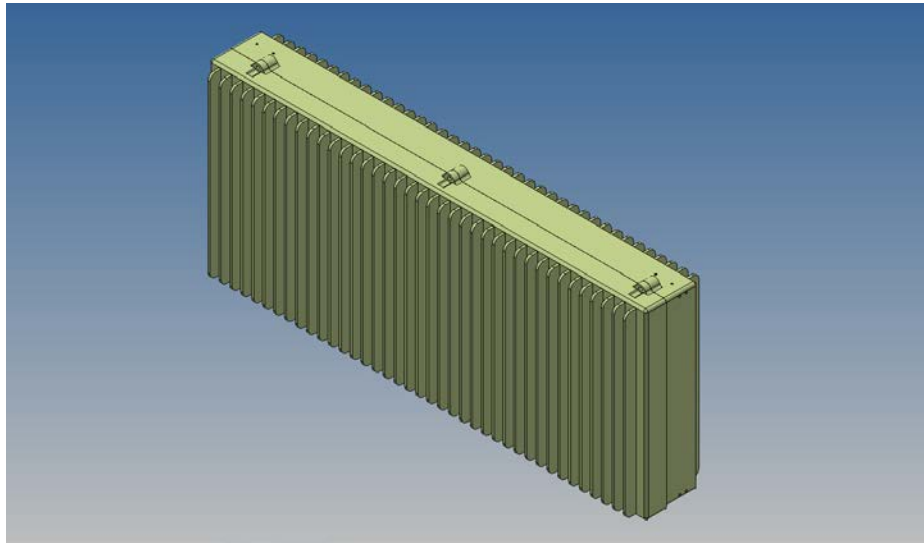


Figure 5. 700 Series ARCS Module, closed and cross section views

Both the housing and cover module pieces can vary in width by 1/2in (12.7mm) increments, so a large variety of sizes and styles can be achieved in order to optimize space for electrical components. Furthermore, both the housing and cover may be produced with heatsink fins for dissipating internal heat (Figure 6), and the interiors can be customized with pockets or ridges to better accommodate mounting of electrical components. Modules are sized by the combined housing and cover widths. For example, a 2 inch (50.8mm) housing with a 1/2 inch (12.7mm) cover would be a 2.5 wide module.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 6. ARCS Module with heatsinks on both housing and cover**

The design of the ARCS modules is such that there is no designated front, rear, top or bottom of the module. Modules may be inserted into the bin from either the front or the rear, and either right side up or upside down, and still fit consistently with any neighboring modules. However, once the orientation is selected, there will be a label on the front panel that clearly shows the orientation the module is intended to be installed in. The ARCS module concept can also be readily adapted for applications where rack or bin mounting is not a requirement or desired, as well as being adaptable in length and height for larger or smaller applications (see 3.2.3.2 SA501).

Input/output connections can be made on either the front or rear of the module. Blind mate connections are also possible with the addition of a panel on the rear of the bin to hold one side of the blind mate connector.

Modules are typically secured in bins, with multiple modules per bin (Figure 7). Modules have guide blocks that guide the module into the bin (Figure 8), as well as a front panel that is used to secure the module into the bin via four captive fasteners (Figure 9).

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

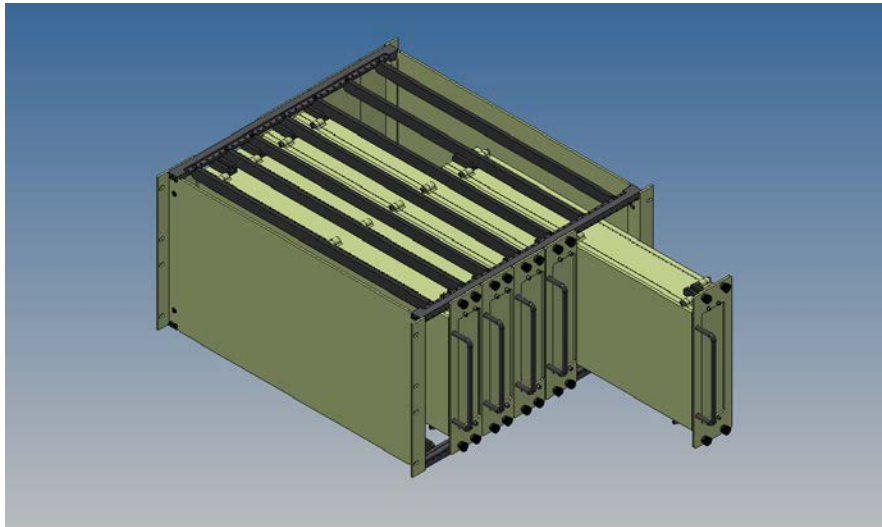


Figure 7. Multiple ARCS Modules in an ARCS Bin

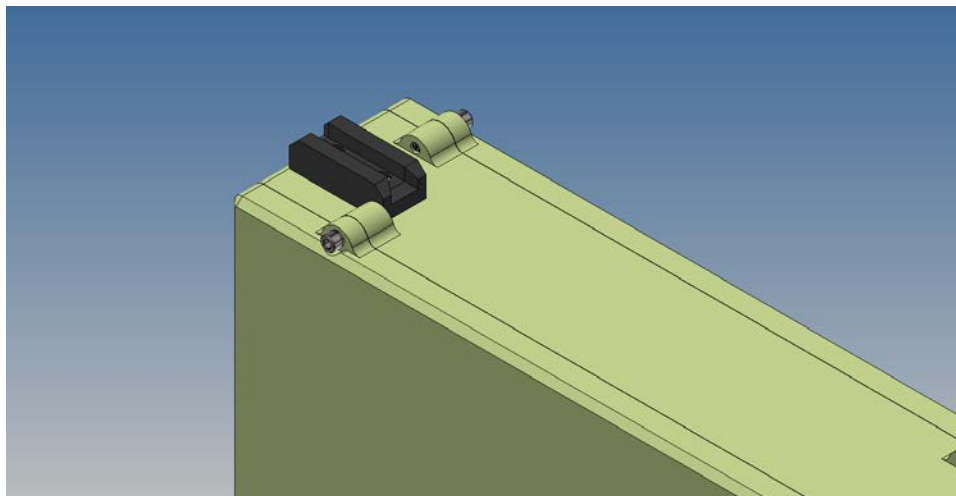
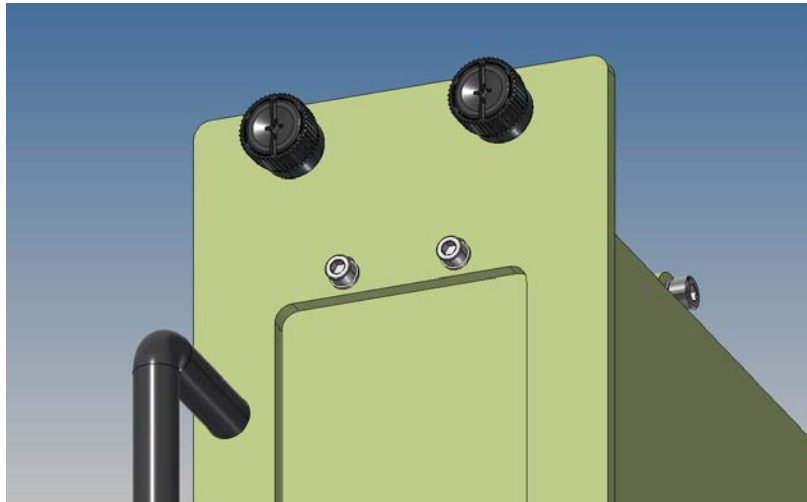


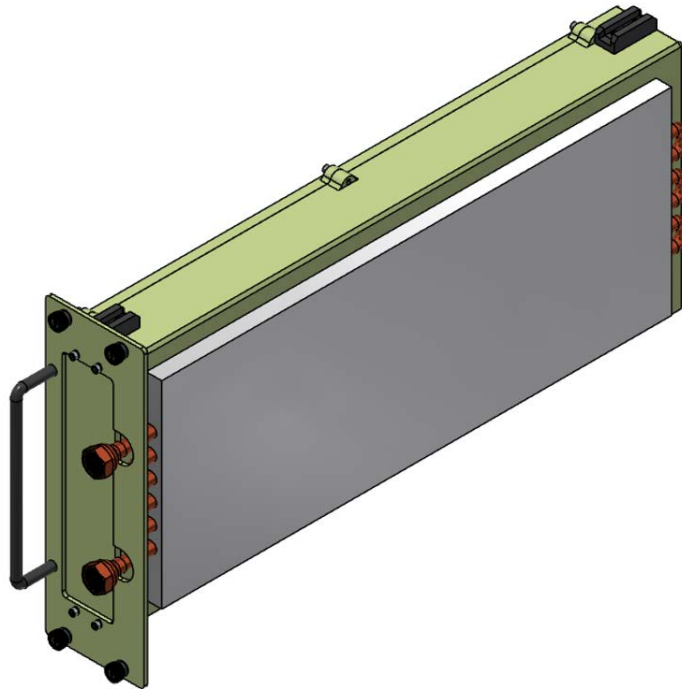
Figure 8. Module guide blocks

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 9. Captive fastener**

Many of the modules for ngVLA will be liquid cooled instead of air cooled. For these modules, liquid cold plates will be used instead of heatsinks (Figure 10). In order to preserve the high level of shielding of the modules, the cold plates will be mounted to the exterior of the module. This configuration will increase the thermal resistance between the hot components and the cold plate, but preserving the RF shielding level is of paramount importance.



**Figure 10. ARCS Module with cold plate attached.**

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

RFI shielding is achieved with double-gasket seams around the edge, utilizing low closure force fabric over foam RFI gaskets and electrically conductive pressure sensitive adhesive (Figure 11). The module covers are very stiff and as a result only require six machine screws to close up and compress the gaskets. This makes for rapid opening and closing of modules if necessary. Shielding levels of approximately 80dB from 1GHz – 10GHz and 70dB through 16GHz have been attained (Figure 12), although with multiple I/O connectors these numbers are expected to degrade some.



Figure 11. Fabric over foam RF gaskets

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

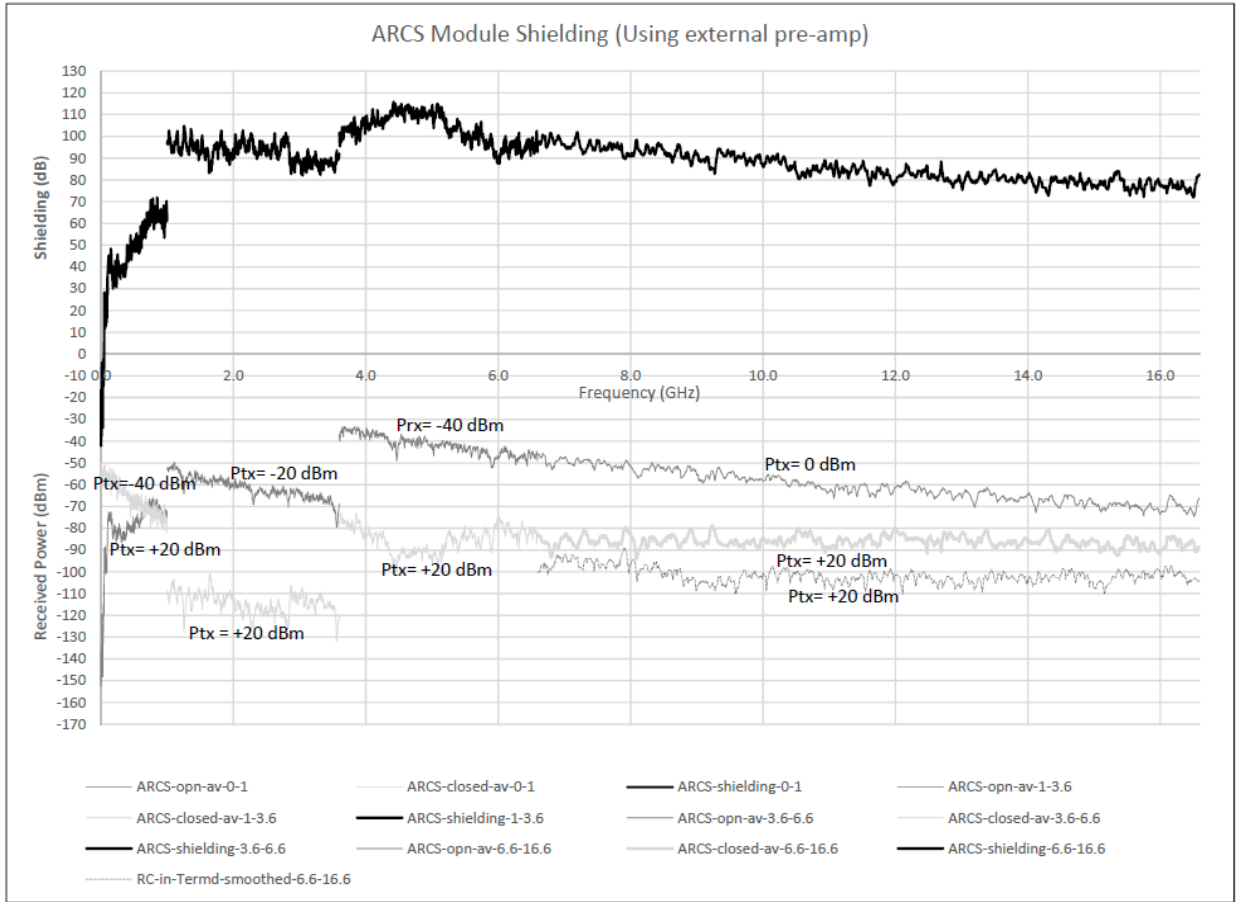
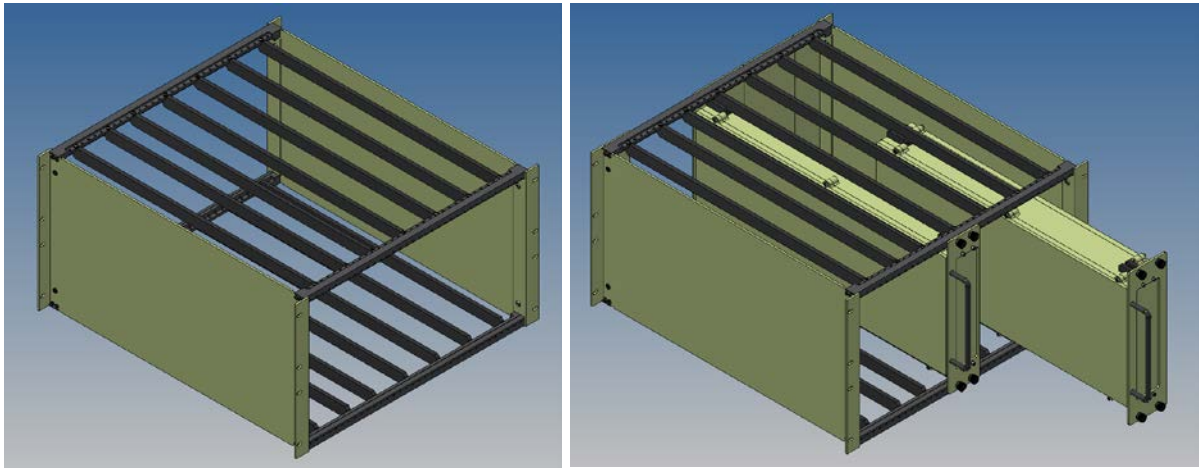


Figure 12. ARCS Module shielding effectiveness test, 500 series (RD01).

### 3.2.2 ARCS Bin

Bins provide a convenient and reliable method of organizing groups of modules near one another. The standard ARCS bin is six rack units (6 RU) tall by 20 inches (508mm) deep, and is designed to fit into a standard EIA 19 inch (482.6mm) wide rack. However, bins can be adapted to reside in places other than a standard EIA rack, like in the Front End and Auxiliary Enclosures. Figure 13 shows an example of an ARCS Bin with and without a couple of ARCS Modules.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



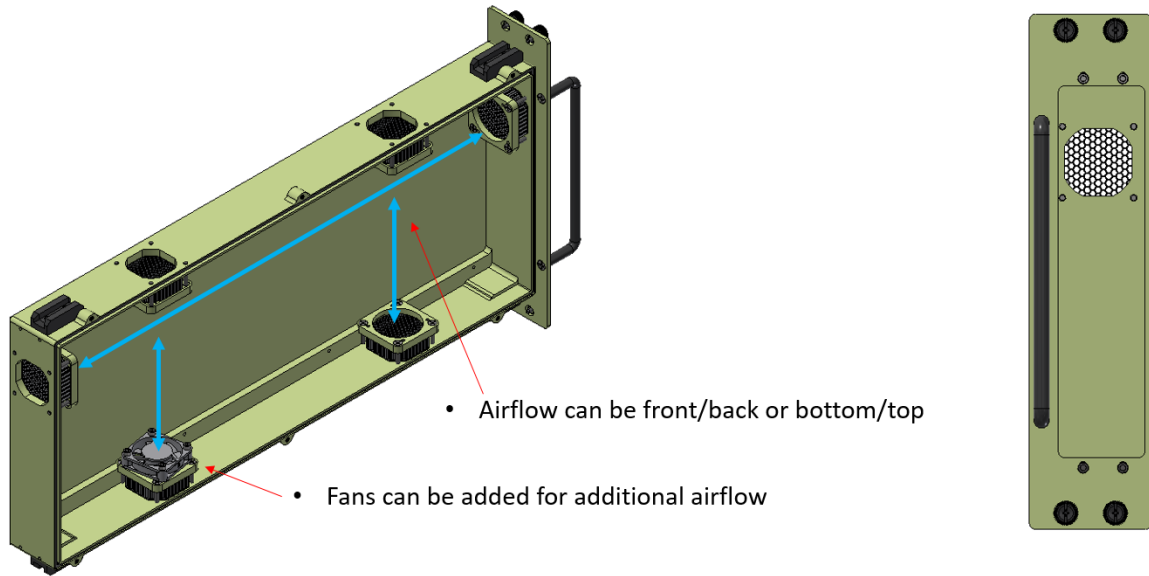
**Figure 13. ARCS Bin with and without modules**

The standard ARCS Bin is 17 inches (431.8mm) internal width. ARCS modules vary in 1/2 inch (12.7mm) widths, and can be mixed and matched to fit into the bin. Any unused slots can simply be covered with blank panels and filled with foam if necessary (typically RFI absorbing Zote foam). The foam inserts can also be used to help direct the air flow where it is required.

Bins with modules are typically used mounted in a rack with vertical airflow for cooling. When bins are mounted vertically adjacent, and appropriate fill panels are used to cover any gaps, a chimney is formed that directs all airflow past module heatsinks.

An alternate horizontal air flow configuration of front to back (or back to front) is also possible with the inclusion of fans internal to the modules (Figure 14), but the addition of the honeycomb filters can degrade the shielding levels.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



Note: Adding honeycomb filters will reduce the shielding effectiveness of the module

**Figure 14. Alternate air flow module cooling options**

### 3.2.3 Front End Enclosure

The Front End Enclosure resides on the feed arm at the prime focus and contains and protects the following equipment from the environment (Figure 15, Figure 16):

- SA500A Front End Cryostat A
- SA500B Front End Cryostat B
- SA501 Bands 5-6 IRD/LO Module
- SA502 Bands 1-4 IRD/LO Module
- L501 Main LO Module
- M507 Utility Module (combined Power Supply and M&C module)

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

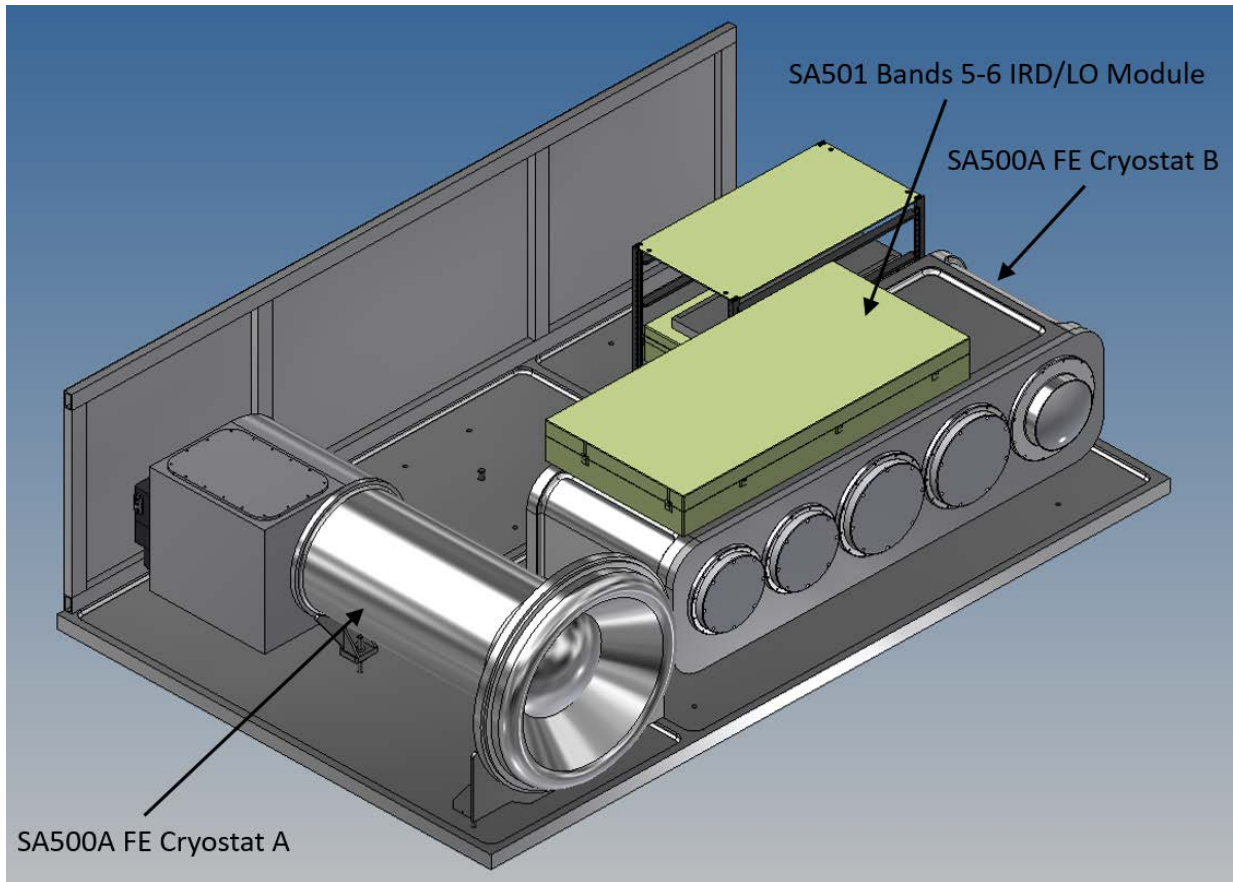
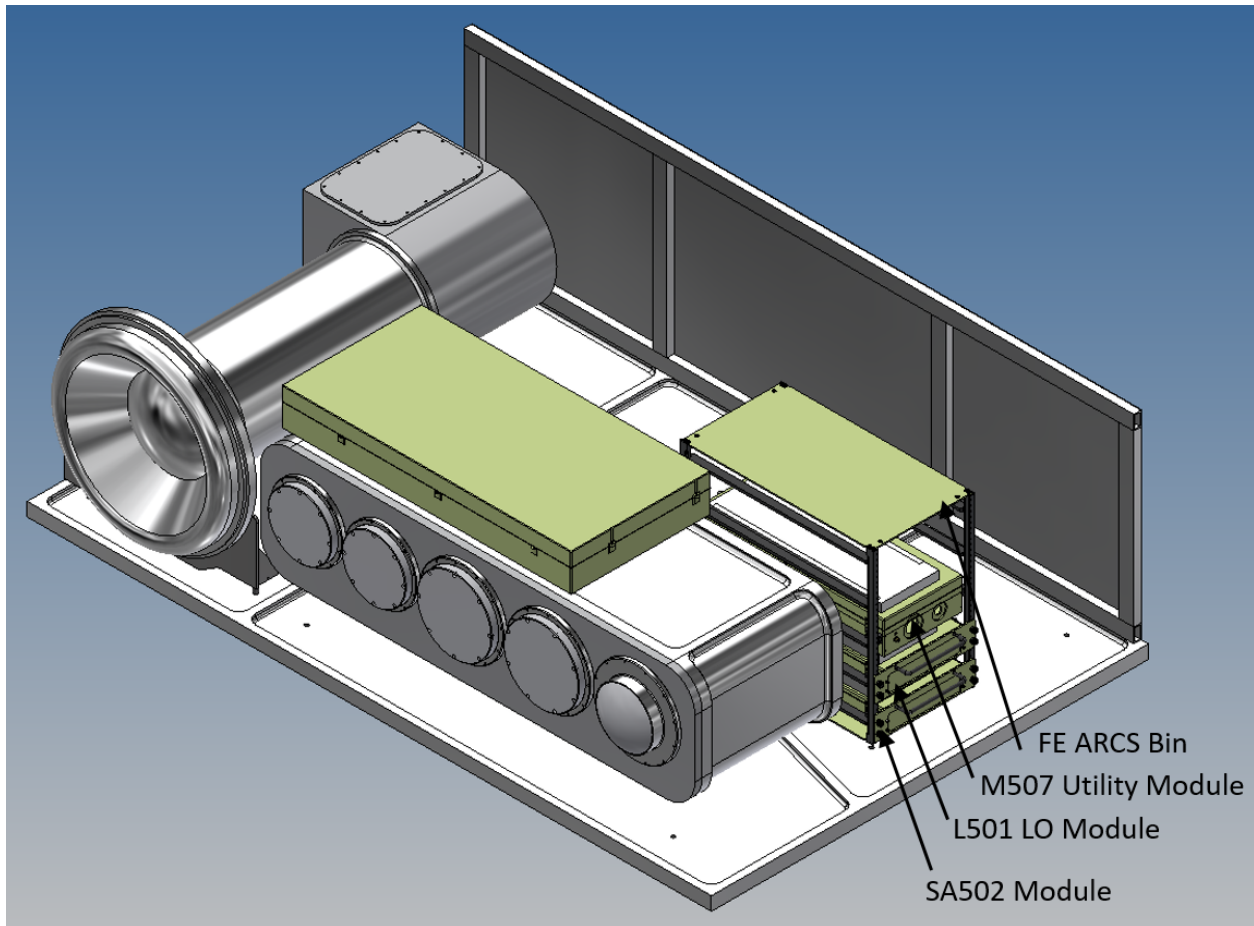


Figure 15. Front End Enclosure with Primary Equipment (access cover removed for clarity)



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 16. Front End Enclosure with Primary Equipment (access cover removed for clarity)**

The BMR subsystem shall provide:

- FE Enclosure
- SA501 Bands 5-6 IRD/LO Module Metalwork
- SA502 Bands 1-4 IRD/LO Module Metalwork
- L501 Main LO Module Metalwork
- M507 Utility Module Metalwork
- Front End ARCS bin

### 3.2.3.1 Front End Enclosure

The Front End Enclosure is not located in a regulated space and is therefore subject to the full set of environmental conditions specified in AD02. The Front End Enclosure will be insulated against environmental temperature changes and may also include a solar radiation shield, as necessary. The interior temperature and temperature stability will be regulated based on requirements as defined in the relevant ICD's, and humidity may also need to be controlled. The Front End Enclosure will not be explicitly RFI shielded, but may provide a low level of shielding to supplement the RFI shielded enclosures contained within it.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The conceptual design of the FE Enclosure consists of a box with dimensions 70.9in wide x 45.3in deep x 23.6in tall (1800mm x 1150mm x 600mm). The enclosure is constructed of a very stiff baseplate that all of the internal components are mounted to (Figure 17), a structurally stiff rear panel with removeable access panels for accessing cryostat cold heads, and a lightweight openable cover for general access to the interior (Figure 19). A front panel with a radome will be part of the lightweight cover. The cover will be made from foam cored carbon fiber panels (Figure 18) with aluminum C channel sections screwed and bonded to the carbon panels to cover and protect the bare edges. The entire enclosure will be painted white for UV stability and heat reduction. The cover will be hinged at the front, bottom edge to enable easy access to the interior (Figure 20). Either pneumatic dampers or a mechanical rod to support the open cover will likely be necessary for keeping the enclosure open during maintenance activity. The cover will have edge seals similar to a car door to keep out moisture and dust.

The rear panel is fixed relative to the baseplate and also must be structurally strong as a connection point for the cable carrier. The baseplate is initially considered to be made from aluminum, but higher stiffness may be necessary in which case a carbon fiber composite material may be investigated.

Cryostat cold heads will be accessible such that they may be swapped during regular maintenance activities. The cold head for cryostat A will have an access panel on the rear of the FE enclosure that once removed, will allow the cold head to be removed and replaced. The cold head for cryostat B can be removed by opening the hinged top cover of the FE enclosure. Sufficient space behind cryostat B will be reserved to allow the cold head to be pulled out horizontally and then lifted out of the enclosure.

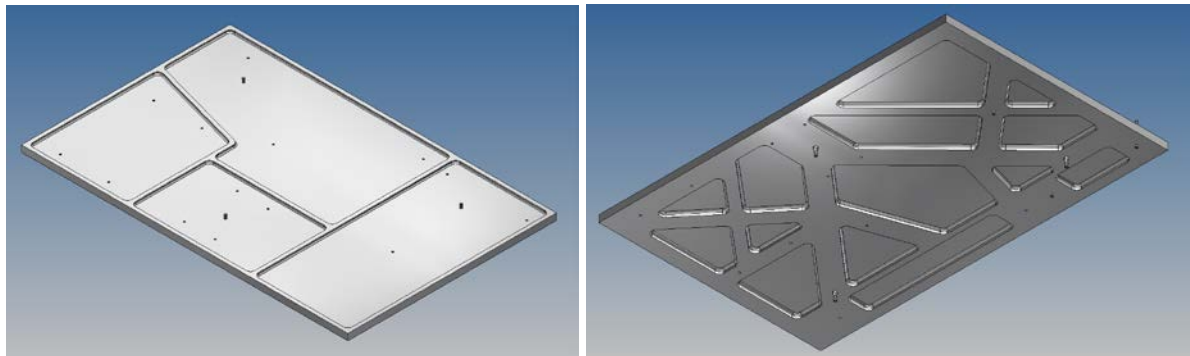


Figure 17. FE Enclosure Baseplate, top side and underside

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

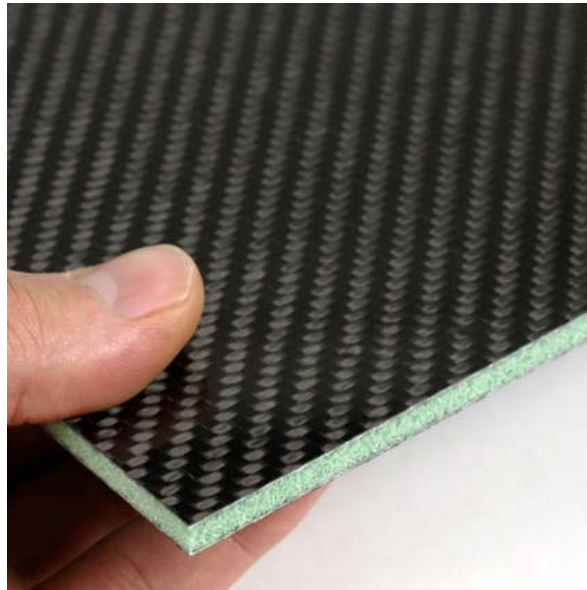


Figure 18. Foam core carbon fiber panel

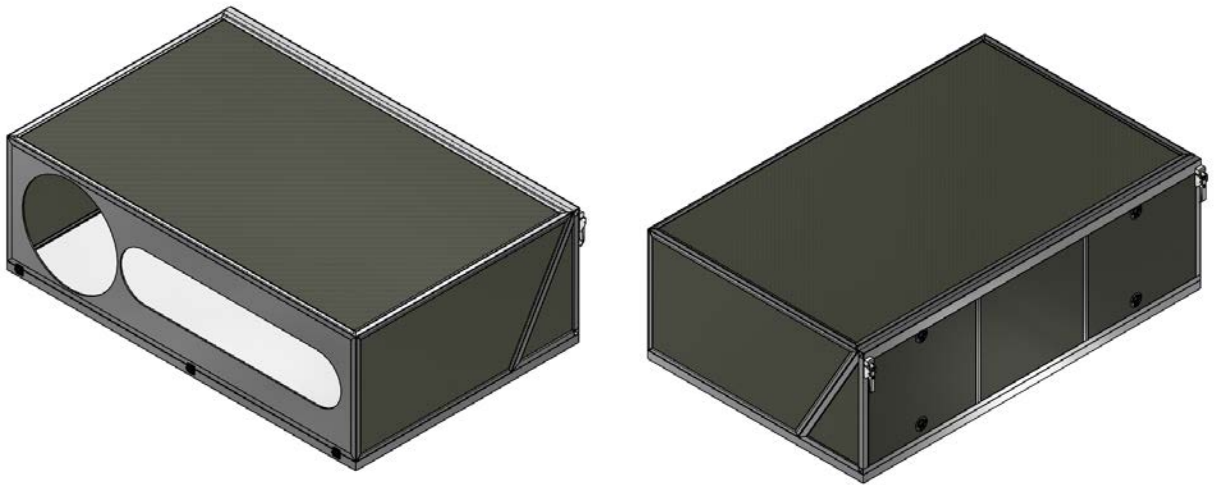
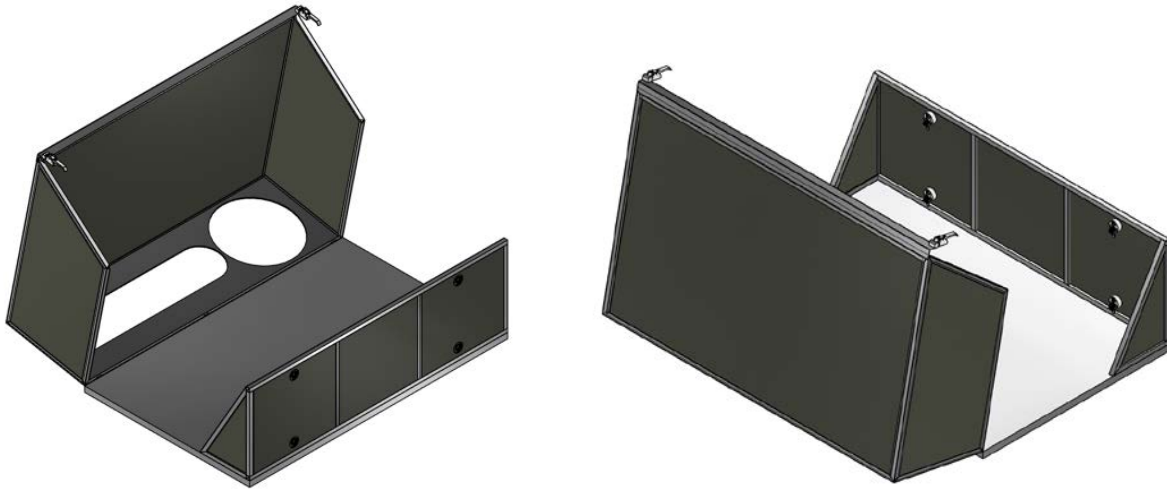


Figure 19. Front End Enclosure, closed

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 20. Front End Enclosure, open**

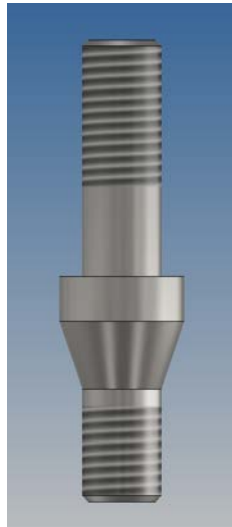
The enclosure will be insulated with polyisocyanurate rigid foam board (Figure 21) wherever possible. Polyisocyanurate is a closed cell rigid foam with R-values around 6-8 per inch of thickness, a temperature range of -100F to +250F, and very low moisture absorption.



**Figure 21. Polyisocyanurate foam board insulation**

The Front End Enclosure will mount to the antenna via a three point alignment pin method. The alignment pins will be made from stainless steel and will be tapered to aid in the installation process (Figure 22). The upper threads are used to bolt the pin to the enclosure base plate, and the lower threads are for bolting the entire enclosure to the indexer.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 22. Front End Alignment Pin**

The Front End Enclosure is considered to be an LRU and as such the majority of maintenance work will be done by removing the enclosure and performing any work in a lab environment. Exceptions may be made for the Cryo cold heads as well as electronics modules that can be swapped out with minimal effort. Due to the weight of the fully populated FE Enclosure (>500kg), a lift or crane will be required to install and remove it from the antenna. Lifting points are not shown here, but the concept is to have a specialized frame that would go over the top of the enclosure, connect to the base plate, and provide lift points.

### 3.2.3.2 SA501 Bands 5-6 IRD/LO Module Metalwork

The SA501 contains the IRD and LO sub modules (x12 each) for bands 5 and 6 (Figure 23). This module requires RFI shielding, and, due to the number of sub modules, will be packaged in a very large adaptation of an ARCS Module, 30.1in long x 14.6in wide x 3.9in tall (765mm x 370mm x 100mm). The level of RF shielding required is estimated at 100db (TBC). The assumption is that the IRD sub-modules might give approximately 40db of shielding and the ARCS module, fully outfitted with connectors, will contribute 60db of shielding. The SA501 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced. Due to the size of the enclosure, it may require two separate cold plates.

The SA501 may require a higher degree of temperature stabilization than the glycol system alone can deliver, in which case a thermoelectric, or Peltier, cooler will be used. If used, all components in the module will be mounted to a common heat spreader plate which is in turn mounted to the Peltier cooler. The Peltier cooler is mounted to the inside wall of the module with the liquid cold plate directly on the other side of the module wall. Insulation may be required internal to the module to ensure all heat flows through the Peltier.

The SA501 will be mounted directly to the Front End Cryostat B because there are waveguide connections between the cryostat and the module for bands 5 and 6. The conceptual layout places the

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

SA501 on top of the cryostat B as there is more space than below the cryostat, and this location also provides easier access to the module contents (Figure 24).

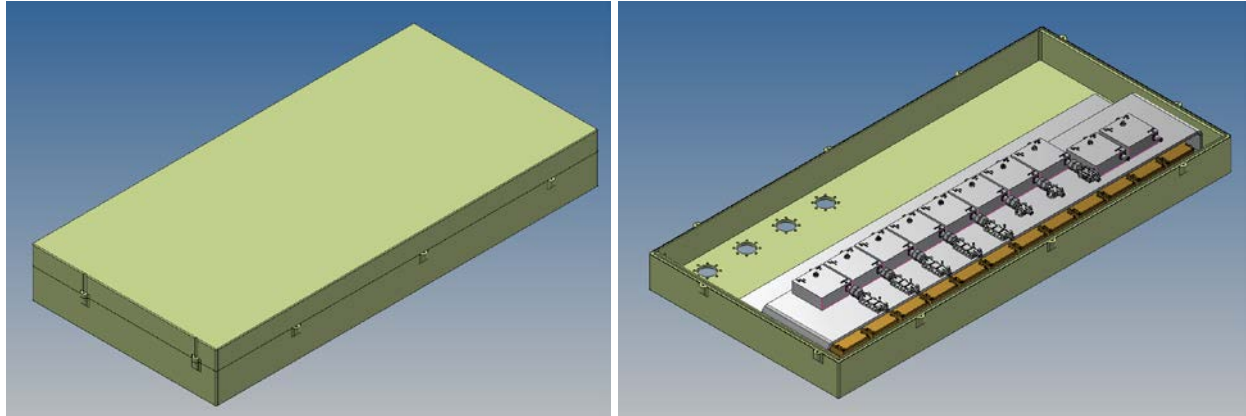


Figure 23. SA501 Module, closed and with cover removed

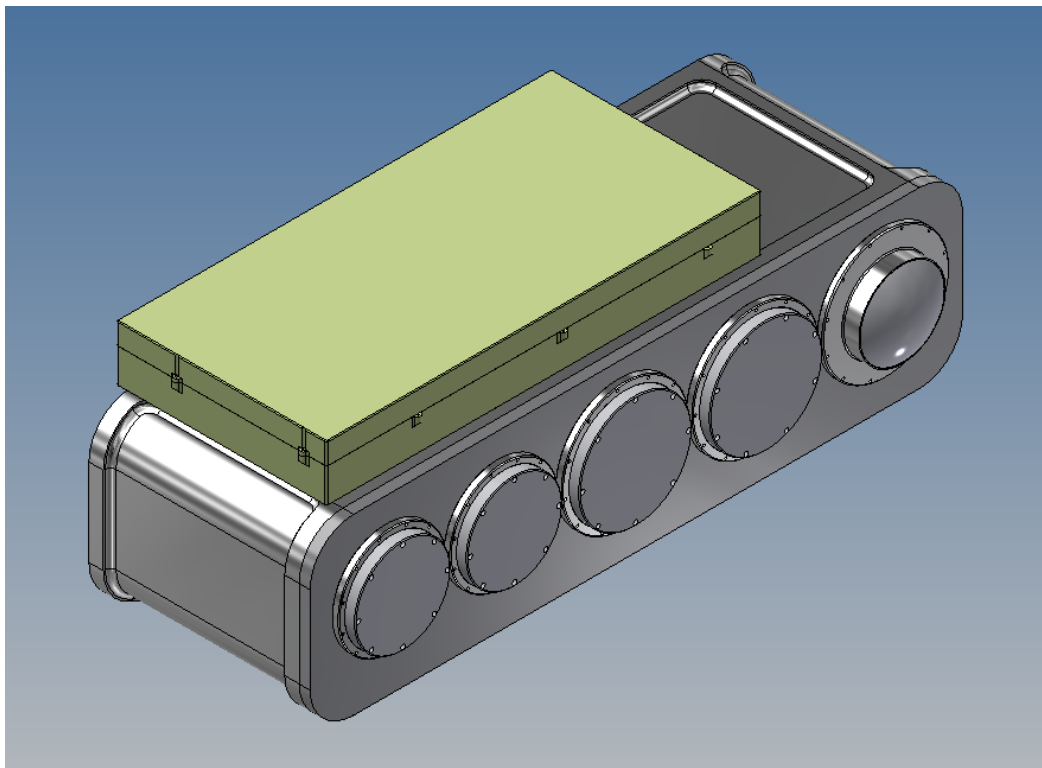


Figure 24. Cryostat B with SA501 attached

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

### 3.2.3.3 SA502 Bands 1-4 IRD/LO Module Metalwork

The SA502 contains the IRD and LO sub modules for bands 1-4 (x8 each). This module requires RFI shielding, so will be packaged in a 4 wide ARCS Module (Figure 25). The level of RF shielding required is estimated at 100db (TBC). The assumption is that the IRD sub-modules might give approximately 40db of shielding and the ARCS module, fully outfitted with connectors, will contribute 60db of shielding. The SA502 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The SA502 may require a higher degree of temperature stabilization than the glycol system alone can deliver, in which case a thermoelectric, or Peltier, cooler will be used. If used, all components in the module will be mounted to a common heat spreader plate which is in turn mounted to the Peltier cooler. The Peltier cooler is mounted to the inside wall of the module with the liquid cold plate directly on the other side of the module wall. Insulation may be required internal to the module to ensure all heat flows through the Peltier.

The SA502 will be mounted in the FE ARCS bin. In order to enable simple and easy swapping of modules, I/O connections will be on the front of the module. This is because any connections on the rear of the module would require opening the full Front End Enclosure to disconnect.

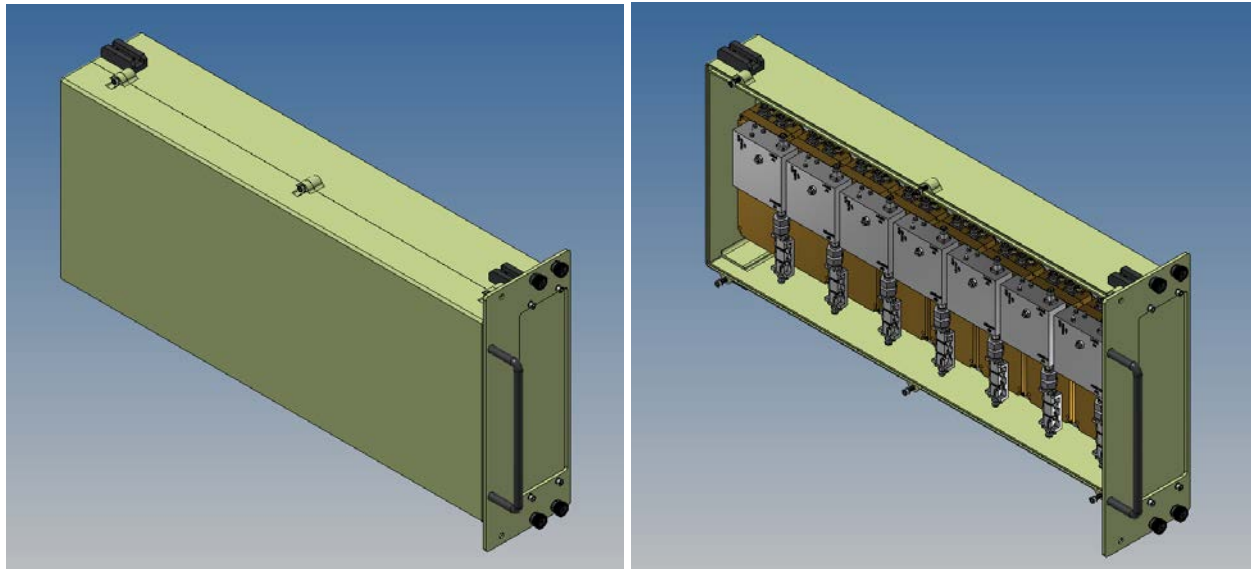


Figure 25. SA502 Module

### 3.2.3.4 L501 Main LO Module Metalwork

The L501 Main LO Module contains support electronics for the LO subsystem. This module requires RFI shielding, so will be packaged in a 2 or 2.5 wide ARCS Module. The level of RF shielding required is TBD. The L501 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The L501 will be mounted in the front end ARCS bin. In order to enable simple and easy swapping of modules, I/O connections will be on the front of the module. This is because any connections on the rear of the module would require opening the full Front End Enclosure to disconnect.

### 3.2.3.5 M507 Utility Module Metalwork

The M507 Front End Utility Module contains the front end power supply and monitor and control subsystem components. This module requires RFI shielding, so will be packaged in a 4 or 4.5 wide ARCS Module (Figure 26). The level of RF shielding required is estimated at 60db (TBC). The M507 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The M507 will be mounted in the front end ARCS bin. In order to enable simple and easy swapping of modules, I/O connections will be on the front of the module. This is because any connections on the rear of the module would require opening the full Front End Enclosure to disconnect (Figure 16, Figure 20).

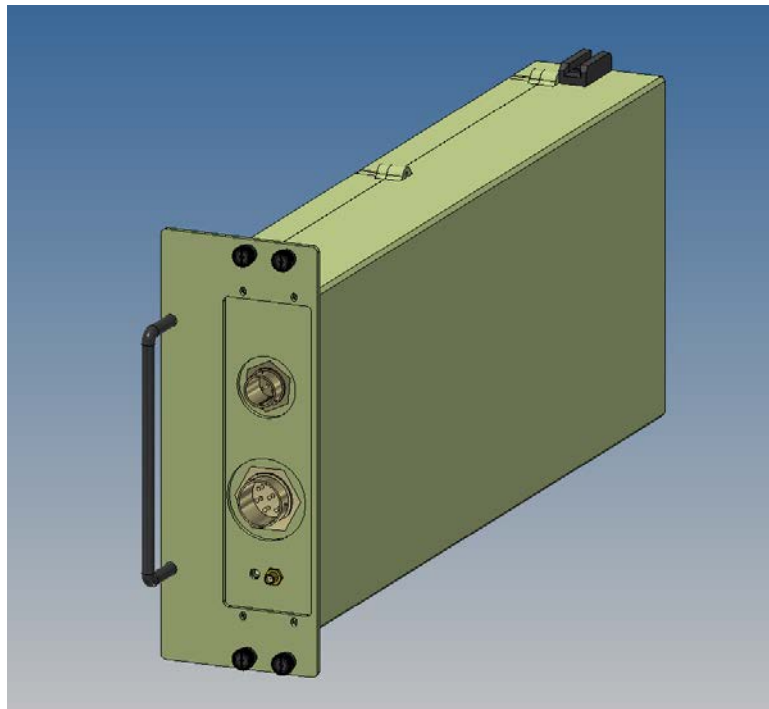


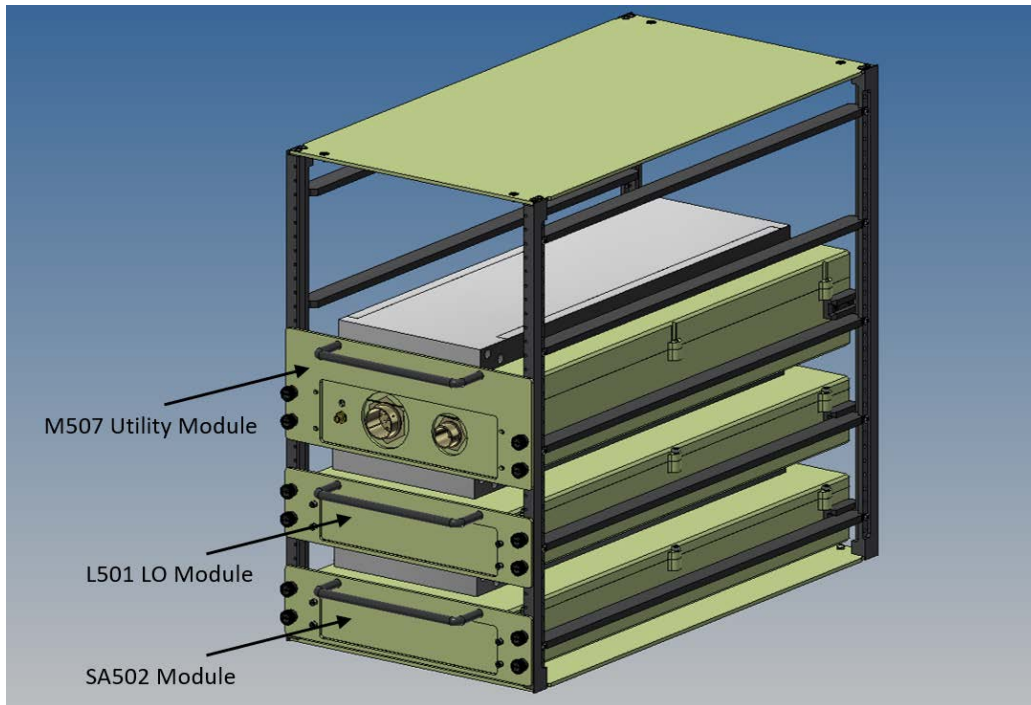
Figure 26. M507 Utility Module



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

### 3.2.3.6 Front End ARCS bin

The Front End enclosure requires one ARCS bin to contain the three ARCS Modules, the SA502, L501, and M507. This bin has been set on its side to better fit inside the FE Enclosure (Figure 27).



**Figure 27. FE ARCS Bin and SA502, L501, and M507 Modules**

### 3.2.4 Auxiliary Enclosure

The Auxiliary Enclosure resides on the feed arm between the FE Enclosure and the Primary Reflector and contains and protects the following equipment from the environment:

- F524 Cryogenics Vacuum Pump
- M506 Utility Module
- F523 VFD Control Module,
- F521 Cold Head VFD Driver Module,
- F522 Vacuum Pump and Feed Heater Driver Module

The BMR subsystem shall provide:

- Auxiliary Enclosure
- M506 Utility Module Metalwork
- F523 VFD Control Module Metalwork
- F521 Cold Head VFD Driver Module Metalwork
- F522 Vacuum Pump and Feed Heater Driver Module Metalwork
- an ARCS bin (holds ARCS Modules)

#### 3.2.4.1 Auxiliary Enclosure

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The Auxiliary Enclosure is not located in a regulated space and is therefore subject to the full set of environmental conditions specified in AD02. The Auxiliary Enclosure will be insulated against environmental temperature changes and may also include a solar radiation shield, as necessary. The interior will not be temperature regulated, but the components located within it will be regulated via the glycol system. The Auxiliary Enclosure will not be explicitly RFI shielded, but may provide a low level of shielding to supplement the RFI shielded enclosures contained within it.

The conceptual design of the Auxiliary Enclosure consists of a box with dimensions 47.2in wide x 29.5in deep x 22.2in tall (1200mm x 750mm x 565mm). The enclosure is constructed in a similar manner to that of the Front End Enclosure, namely consisting of a stiff baseplate that all of the internal components are mounted to and lightweight openable panels for general access to the interior (Figure 28). The top and side panels will be made from foam cored carbon fiber panels with aluminum C channel sections screwed and bonded to the carbon panels to cover and protect the bare edges. The removeable panels will have edge seals similar to a car door to keep out moisture and dust. The baseplate will be made from welded aluminum tubes and plate, providing a stiff surface with plenty of mounting options. The entire enclosure will be painted white for UV stability and heat reduction.

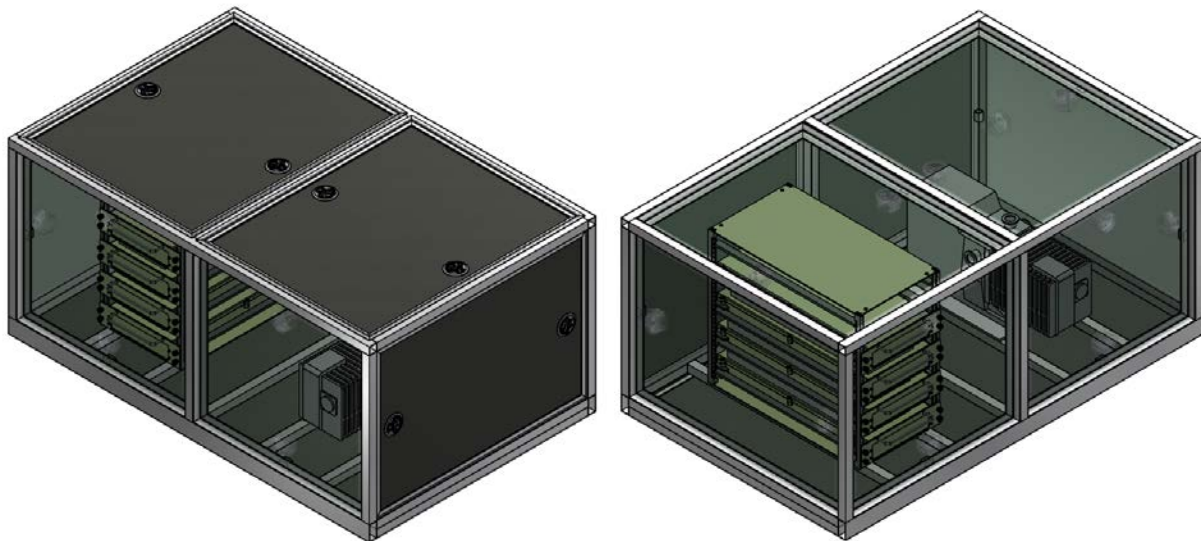


Figure 28

The Auxiliary Enclosure will mount to the antenna via a four bolt pattern on the base of the enclosure.

The Auxiliary Enclosure is not considered to be an LRU and as such maintenance work will be performed on the antenna. Individual components located within the Auxiliary enclosure will be LRU's.

### 3.2.4.2 M506 Utility Module Metalwork

The M506 Auxiliary Utility Module contains the auxiliary power supply and monitor and control subsystem components. This module requires RFI shielding, so will be packaged in a 4 or 4.5 wide



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

ARCS Module. The level of RF shielding required is estimated at 60db (TBC). The M506 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

In every major location antenna electronics equipment resides a utility module is present. Most utility modules are similar enough that every effort will be made to standardize the metalwork for all utility modules.

The M506 will be mounted in the auxiliary ARCS bin. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module. This is because in many locations connections on the rear of the module are difficult to access.

#### 3.2.4.3 F523 VFD Control Module Metalwork

The F523 VFD Control Module contains variable frequency drive control electronics for the Cryogenics subsystem. This module requires RFI shielding, so will be packaged in a 2 or 2.5 wide ARCS Module. The level of RF shielding required is TBD. The F523 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The F523 will be mounted in the auxiliary ARCS bin. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

#### 3.2.4.4 F521 Cold Head VFD Driver Module Metalwork

The F521 Cold Head VFD Driver Module contains variable frequency driver electronics for the Cryogenics subsystem. This module requires RFI shielding, so will be packaged in a 4 or 4.5 wide ARCS Module. The level of RF shielding required is TBD. The F521 also generates a significant amount of heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced. Due to the large heat load for this module (~100W), the use of two liquid cold plates will be investigated.

The F521 will be mounted in the auxiliary ARCS bin. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

#### 3.2.4.5 F522 Vacuum Pump and Feed Heater Driver Module Metalwork

The F522 Vacuum Pump and Feed Heater Driver Module contains vacuum pump and feed heater electronics for the Cryogenics subsystem. Although this module is not expected to require RFI shielding, it will still be packaged in a 2 or 2.5 wide ARCS Module for consistency. The F522 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

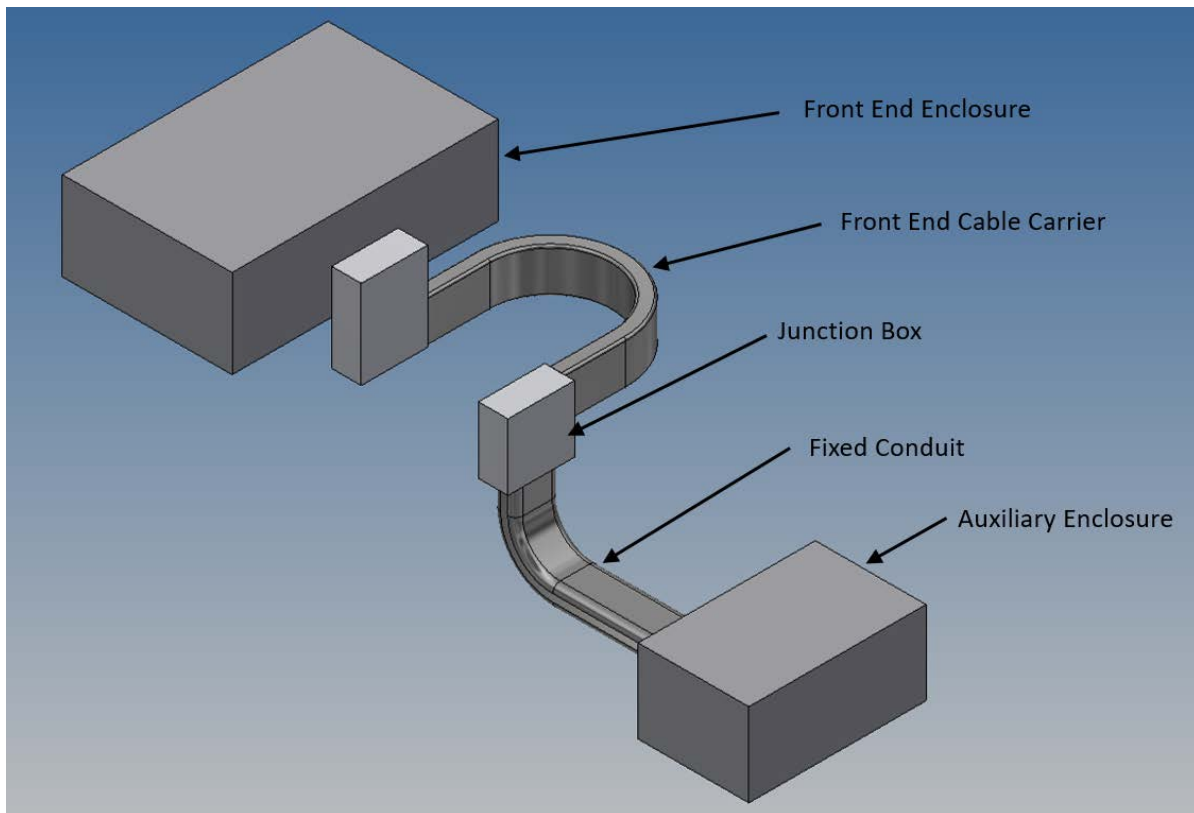
The F522 will be mounted in the auxiliary ARCS bin. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

### 3.2.4.6 Auxiliary ARCS bin

The auxiliary enclosure requires one ARCS bin to contain the four ARCS Modules, the M506, F523, F521, and F522. This bin has been set on its side to better fit inside the auxiliary enclosure.

### 3.2.5 Front End Cable Carrier

The Front End Cable Carrier is located adjacent to the FE Enclosure and carries all cables, fibers, hoses, etc. that connect to equipment in the FE Enclosure. One end of the cable carrier will attach to a transition box mounted to the front end enclosure and the other end of the cable carrier will attach to an appropriately located junction box bolted to the antenna structure (Figure 29).



**Figure 29. Conceptual layout of Front End Cable Carrier**

The BMR subsystem shall provide the cable carrier, including mounting hardware. The lines the cable carrier must accommodate are (Figure 30 and Figure 31):

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

- Vacuum Hose
- Helium Hose (supply and return)
- Glycol Hose (supply and return)
- 48VDC Power Lines (x2)
- Feed Heater Lines (x2)
- Cryocooler Control
- 36 Core Fiber Optic (x2)
- Dry Air Hose

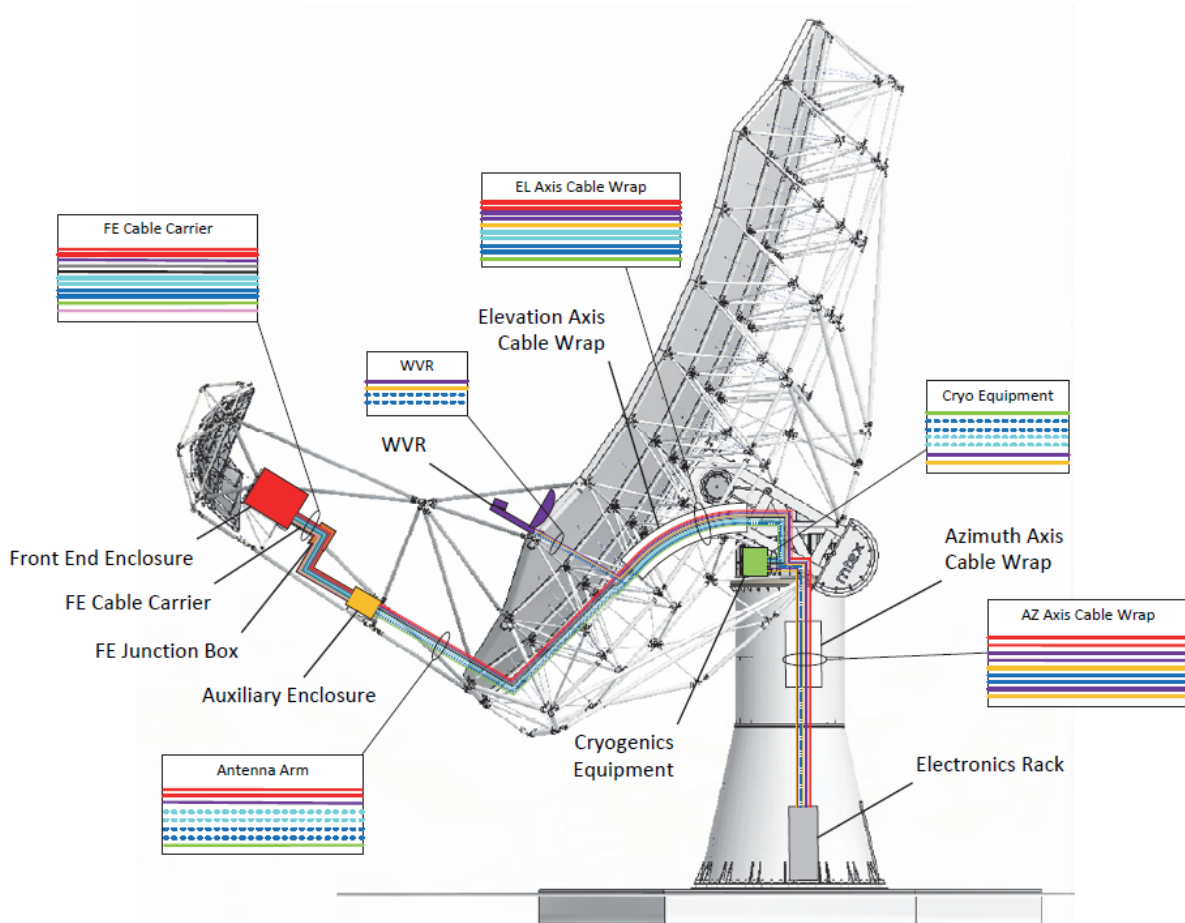


Figure 30. CFE Cabling Plan

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B












Cable Legend				
Line Type	Description	OD[mm]	Wt/l[kg/m]	Min. Bend Radius [mm]
	Helium Hose (Flexible)	40	2.0	250
	Helium Pipe (Rigid)	20	0.6	-
	Glycol Hose (Flexible)	33	0.6	250
	Glycol Pipe w/ Insulation (Rigid)	78	7.8	-
	48V DC Power Lines (x2)	14	0.2	108
	Feed Heater Lines (x2)	10	0.2	120
	Cryocooler Control Line	15	0.2	150
	8 Core Fiber Optic Cable	7	0.1	64
	36 Core Fiber Optic Cable	16	0.3	160
	Vacuum Hose	55	1.7	221
	Dry Air Hose	10	TBD	76

Figure 31. CFE Cabling Plan Legend

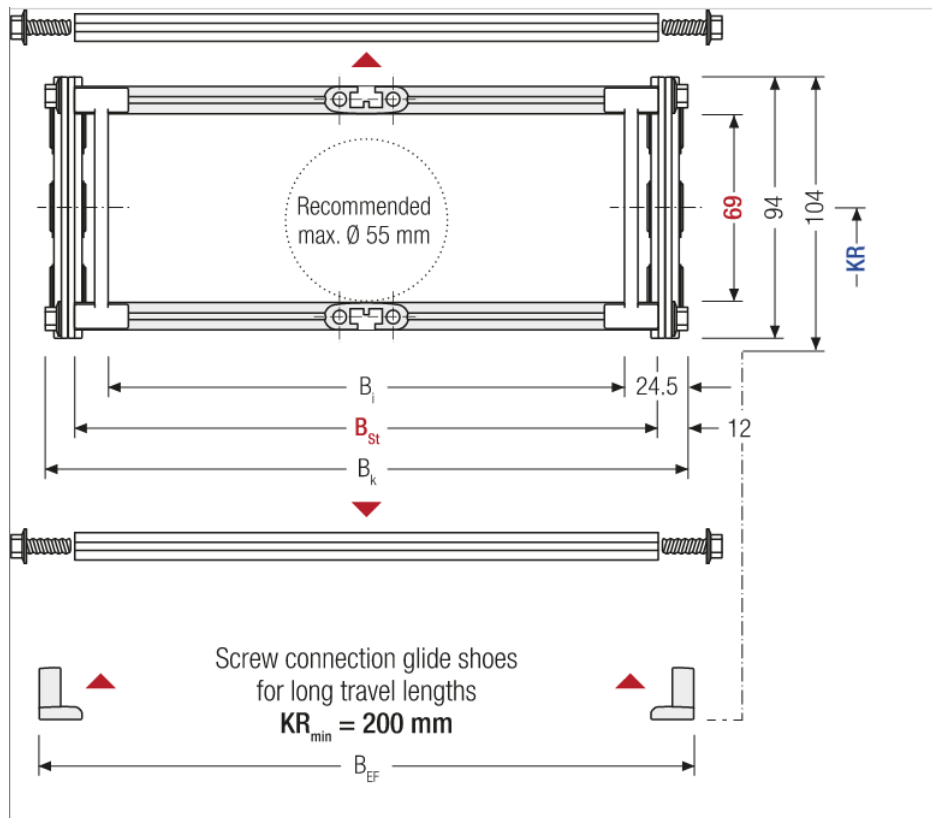
One cable carrier considered is the Tsubaki S/SX 1250 (Figure 32), made from either zinc plated steel or stainless steel, and with access from either the inside or outside via removeable covers. The cable carrier is necessary because the FE Enclosure will move for band selection (lateral to the feedarm) +/- 25.6in (+/- 650mm), and focus (along boresight) +/- 3.9in (+/- 100mm). Because the Front End moves in two axes, the cable carrier can only accommodate two axis motion if it is side mounted, i.e. with bending around a vertical axis. This arrangement will require glide shoes on the cable carrier as well as a smooth, horizontal surface that will support the weight of the cable carrier.



Figure 32. Tsubaki S/SX Series Cable Carrier

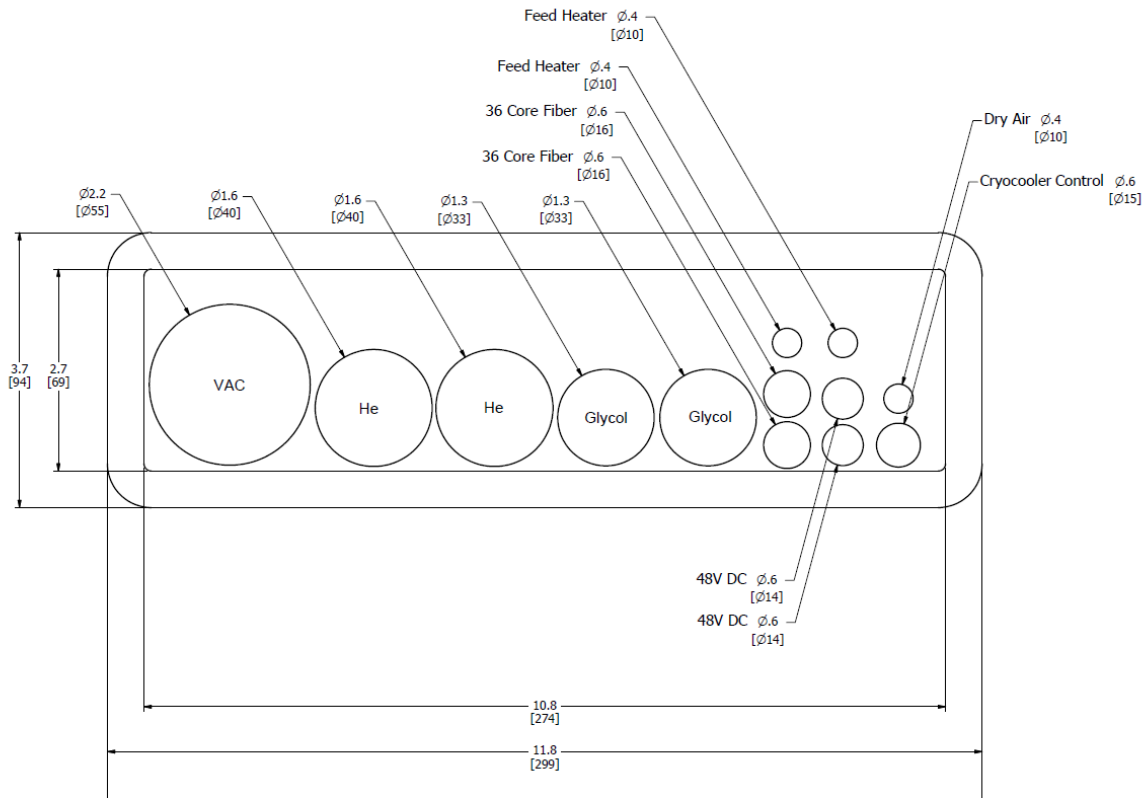
<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The internal size of the cable carrier is 2.7in tall (69mm), and the width can vary between 4.0in (101mm) and 29.6in (751mm), (Figure 33). Sketching the cable and lines expected to be in the cable carrier (Figure 34) shows that we have ample room if we use a width of about 10.8in (274mm), which is 11.8in (300mm) outside dimension. The cable carrier can be configured with different minimum bend radii, from 7.9in (200mm) up to 39.4in (1000mm) in 1.6in (40mm) increments. Figure 31 shows that 9.8in (250mm) is the largest minimum bend radius of all lines, which the Tsubaki S/SX series can easily accommodate.



**Figure 33. Tsubaki S/SX 1250 Cable Carrier cross section dimensions**

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 34. Sketch of Cables in Cable Carrier**

### 3.2.6 Water Vapor Radiometer

The Water Vapor Radiometer is located on the edge of the primary reflector and consists of a parabolic reflector with a dedicated Front End Receiver Module at the focus (Figure 35), and a Utility Module located behind the dish (or another suitable location close by). Each module will be within an environmental enclosure to protect it from the weather (RD02). The WVR subsystem consists of:

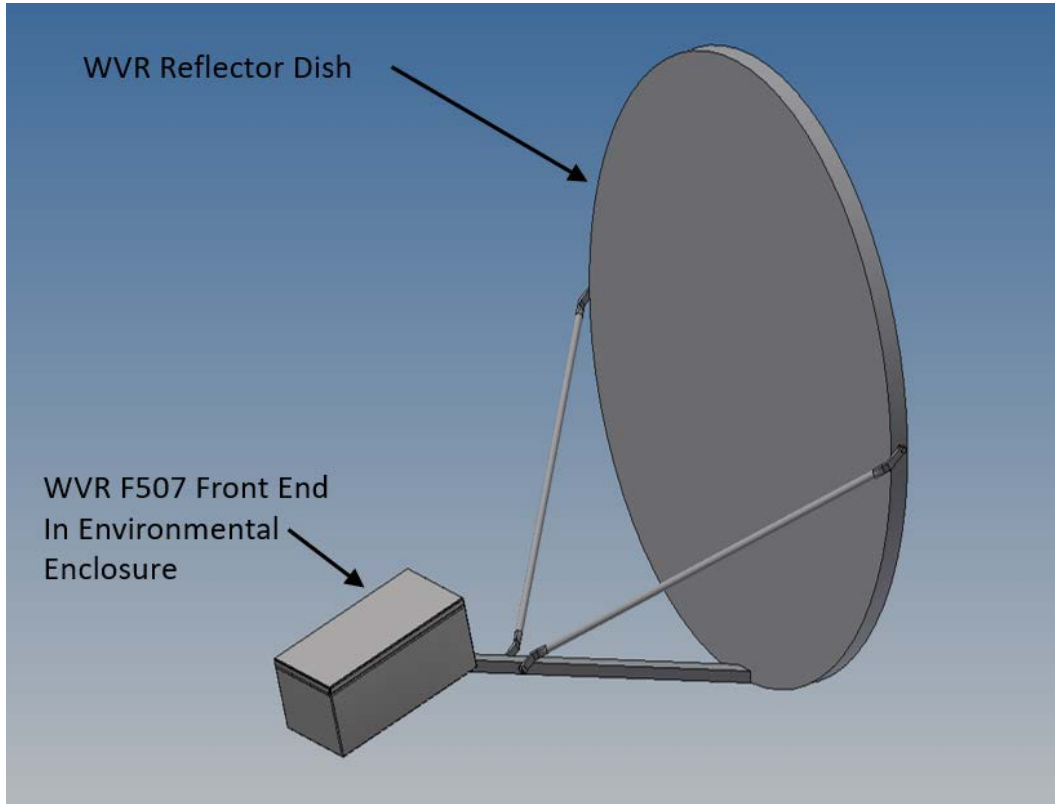
- WVR Dish Assembly
- F507 WVR Front End Environmental Enclosure
- F507 WVR Front End RFI Enclosure
- M508 WVR Utility Module Environmental Enclosure
- M508 WVR Utility Module RFI Enclosure

The BMR subsystem shall provide:

- F507 WVR Front End Environmental Enclosure Metalwork
- F507 WVR Front End RFI Enclosure Module Metalwork
- M508 WVR Utility Module Environmental Enclosure Metalwork
- M508 WVR Utility Module RFI Enclosure Module Metalwork



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 35. WVR Assembly (M508 not shown)**

### 3.2.6.1 F507 WVR Front End Environmental Enclosure

The WVR Front End Environmental Enclosure will be designed especially for this use and will be subject to the full set of environmental conditions specified in AD02. Design Details TBD.

### 3.2.6.2 F507 WVR Front End RFI Enclosure Module

The F507 WVR Front End Module contains the WVR front end receiver components. This module requires RFI shielding, so will be packaged in a modified ARCS Module, most likely a much smaller footprint than a standard ARCS module. The level of RF shielding required is TBD. The F507 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The F507 will require additional temperature stabilization which is the responsibility of the WVR subsystem and will likely be achieved with a thermoelectric device.

The F507 will be mounted in the WVR F507 Environmental enclosure at the focus of the WVR antenna.

### 3.2.6.3 M508 Utility Module Environmental Enclosure

The M508 Utility Module Environmental Enclosure will be a welded aluminum box with a front panel that is removable in order to access the M508 Utility module, similar in design and construction to the



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

Cryo RF enclosure but a bit smaller (Figure 36). The location is still TBD, but possible locations include behind the WVR dish or off to the side behind the primary antenna reflector.

#### 3.2.6.4 M508 Utility Module RFI Enclosure Module

The M508 WVR Utility Module contains the WVR power supply and monitor and control subsystem components. This module requires RFI shielding, so will be packaged in a 4 or 4.5 wide ARCS Module. The level of RF shielding required is TBD. The M508 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The M508 will be mounted in the WVR M508 Environmental enclosure. In order to enable simple and easy swapping of modules, I/O connections will be on the front of the module.

The M508 is not located in a regulated space and is therefore subject to the full set of environmental conditions specified in AD02.

#### 3.2.7 Cryogenics RF Enclosure

The Cryogenics Equipment is located in the Antenna Turn Head and the portion supported by BMR consists of (Figure 36):

- Cryo RF Enclosure
- M505 Utility Module
- Helium Compressor VFD enclosure (module or COTS TBD)
- Helium Pressure Regulator Electronics Module
- 12 Core Circular Fiber Connectors and Splice Tray

The BMR subsystem shall provide:

- Cryo RF Enclosure Metalwork
- M505 Utility Module Metalwork
- Helium Pressure Regulator Electronics Module Metalwork
- Helium Compressor VFD Module Metalwork (if packaged as a module)
- Cryo RF ARCS Bin

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

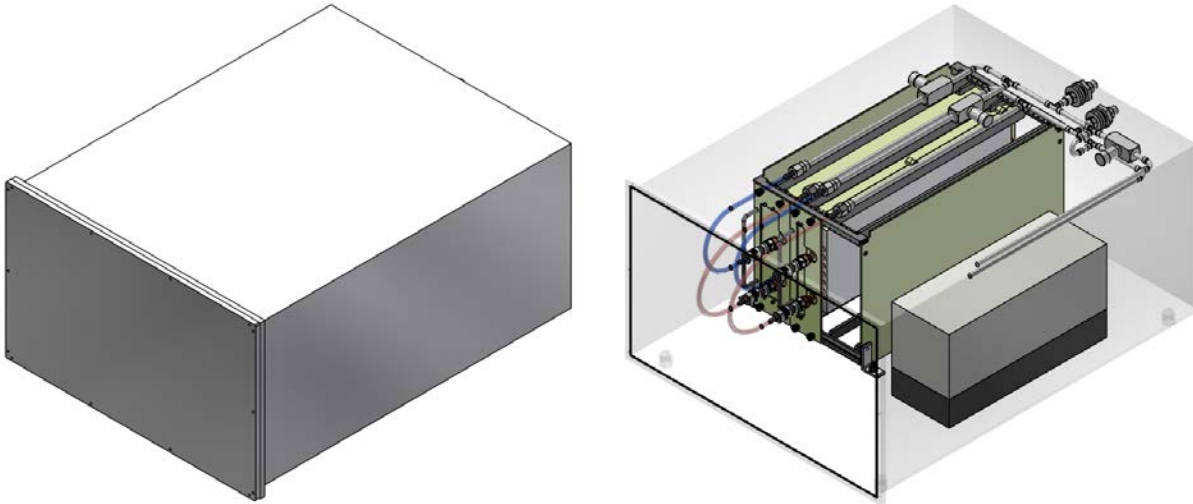


Figure 36. Cryo RF Enclosure overview

### 3.2.7.1 Cryo RF Enclosure

The design for this RFI shielded enclosure is a welded metal box with one removable machined front panel for access to the inside. The face that the removable panel would mount onto will have a fabric-over-foam RF gasket arrangement similar to that used on the ARCS modules.

One design feature that has yet to be verified is the glycol line penetration into the RFI shielded enclosure. RFI shielding requires a faraday cage, or conductive enclosure, which could be compromised by the glycol line penetration. For the ARCS modules this is accomplished by keeping the glycol lines outside of the RFI shielded volume. But if the glycol lines must penetrate the shielded volume as in this case, the theory is to keep a metallic barrier between the conductive glycol and the RFI shielded volume. This is generally solved by using metallic tubing, with the exception being the glycol line connection to the module, which must be quick connect style for easy change out of modules. One option is to use flexible metallic lines for the short sections near the quick connects. Another option is to use blindmate quick connects on the rear of the module which could be plumbed into rigid piping. Further investigation and testing is necessary to determine which option will work best.

### 3.2.7.2 M505 Utility Module

The M505 Cryo Utility Module contains the Cryogenics power supply and monitor and control subsystem components. This module requires RFI shielding, so will be packaged in a 4 or 4.5 wide ARCS Module. The level of RF shielding required is TBD. The M505 also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The M505 Utility module will be mounted in the Cryo ARCS bin inside of the Cryo RF Enclosure. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module. The design of the Cryo RF enclosure makes accessing the connections on the rear of the module impossible.

### 3.2.7.3 Helium Pressure Regulator Electronics Module

The Helium Pressure Regulator Electronics Module contains support electronics for the Cryogenics subsystem. This module requires RFI shielding, so will be packaged in a 2 or 2.5 wide ARCS Module. The level of RF shielding required is TBD. The Helium Pressure Regulator Electronics Module also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The Helium Pressure Regulator Electronics Module will be mounted in the Cryo ARCS bin inside of the Cryo RF Enclosure. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module. The design of the Cryo RF enclosure makes accessing the connections on the rear of the module impossible.

### 3.2.7.4 Helium Compressor VFD Module

The packaging for the Helium Compressor VFD Module has not been determined yet, but, as this module requires RFI shielding if possible it will be packaged in an ARCS Module. The level of RF shielding required is TBD. The Helium Compressor VFD Module also generates heat, so will require a liquid cold plate to transfer the heat to the glycol system. The liquid cold plate will be bolted to the exterior of the module and will be connected to the glycol system via quick connects on both the inlet and the outlet. This will enable the module to be disconnected from the glycol system and removed and replaced.

The Helium Compressor VFD Module will be mounted in the Cryo ARCS bin inside of the Cryo RF Enclosure. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module. The design of the Cryo RF enclosure makes accessing the connections on the rear of the module impossible.

### 3.2.7.5 Cryo RF ARCS Bin

The Cryo RF enclosure requires one ARCS bin to contain the three ARCS Modules, the M505 module, the Helium Pressure Regulator Electronics Module, and the Helium Compressor VFD Module. This bin has been modified for fewer modules and to fit inside the Cryo RF enclosure.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

### 3.2.8 Electronics Rack

The Electronics Rack is located in the Antenna Pedestal RFI Shielded Room and contains the following electronics (Figure 37, Figure 38):

- P500 -48VDC Power Subsystem
- M503 Antenna M&C Ethernet Switch
- M502 Utility Module
- D501 Digital Back End Module
- L503 Reference Receiver and Timing Module
- D502 WVR Back End Module
- M500 Supervisor Computer Module
- M501 Maintenance Computer Module
- Data Backhaul Equipment (multiple modules in one ARCS Bin), details TBD
- L502 Reference Dist. Repeater Equipment (multiple modules in one ARCS Bin), details TBD
- 36 Core Circular Fiber Connector and Splice Tray
- M504 EEC Electronics (location TBD)
- ARCS Bins as necessary

The BMR subsystem shall provide:

- Electronics Rack
- M502, Utility Module Metalwork
- D501 Digital Back End Module Metalwork
- L503 Reference Receiver and Timing Module Metalwork
- D502 WVR Back End Module Metalwork
- M500 Supervisor Computer Module Metalwork
- M501 Maintenance Computer Module Metalwork
- Data Backhaul Equipment Module Metalwork and ARCS Bin (details TBD)
- L502 Reference Dist. Repeater Equipment Module Metalwork and ARCS Bin (details TBD)
- M504 EEC Electronics Module Metalwork (location TBD)
- Electronics Rack ARCS bins.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

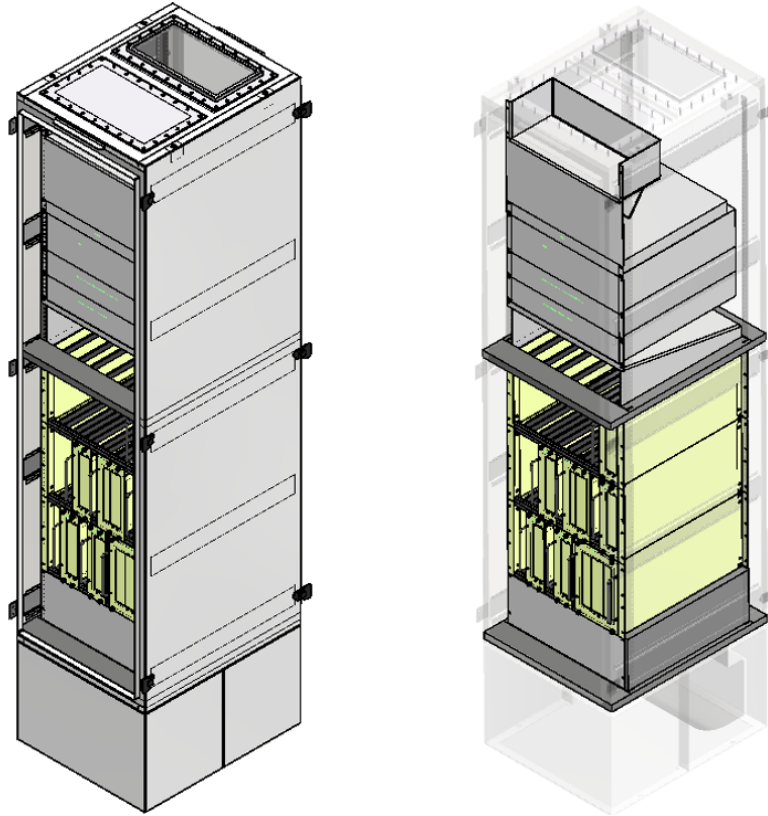


Figure 37. Electronics Rack overview

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

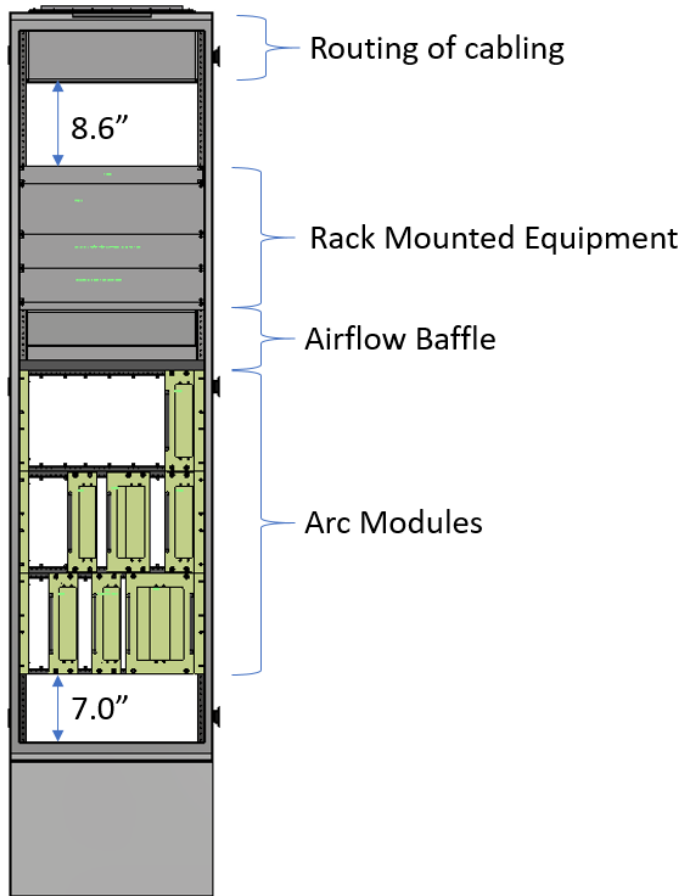
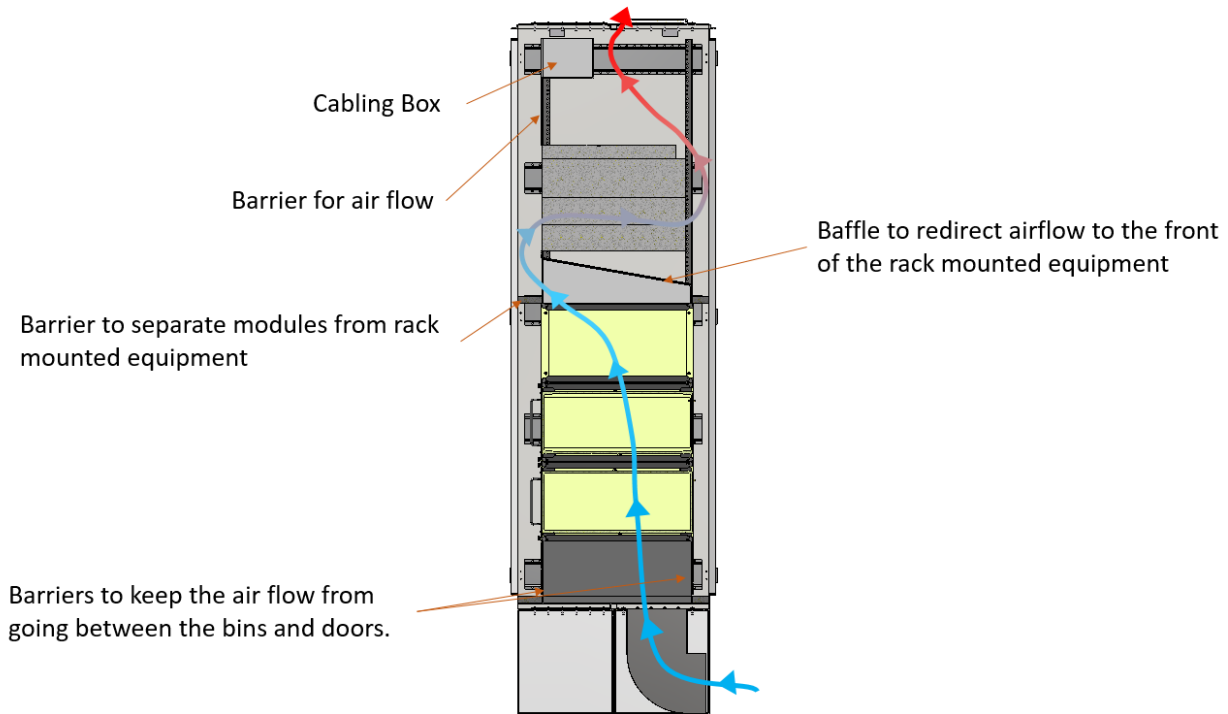


Figure 38. Electronics Rack arrangement

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 39. Airflow path through Electronics Rack**

### 3.2.8.1 Electronics Rack

The Electronics Rack resides in the RFI Room in the antenna pedestal. The preference is to use an unshielded rack, but this will have to be determined after selection of the COTS devices (network switch, rack mount computer, etc.) that will be housed in the rack. It is possible that these COTS devices will require their own custom shielded housings.

The Electronics Rack will be an EIA standard 19 inch (482.6mm) rack, 42U tall, initially with a depth of 36 inches (914.4mm) to reserve space in the event that direct glycol cooling of a high heat density rack mounted component is necessary, which requires more depth for the glycol fittings.

An electronics rack concept utilizing direct glycol cooling of all equipment was investigated, see Appendix A for more information.

The Electronics rack sits on top of a plenum box to allow forced air input to the bottom of the rack. The lower section of the rack houses all of the electronics packaged in ARCS modules and requires vertical air flow, while the upper section of the rack houses commercially packaged electronics that require front to rear air flow. The concept has forced air entering the bottom of the rack, and after passing through all of the ARCS modules it is directed into the space between the rack mounted components and the front door and then horizontally into the COTS equipment in the upper section of the rack, after which it then exits at the top of the rack (Figure 39). Careful arrangement of the ARCS modules may be necessary to optimize the cooling requirements of each one.





<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The Electronics Rack will have all inputs and outputs on the top I/O panel. All ARCS modules will have inputs and outputs on the front panels. As RF shielding is not necessary the I/O becomes much simpler with a wide array of options.

### 3.2.8.2 M502, Utility Module

The M502 Electronics Rack Utility Module contains the electronics rack power supply and monitor and control subsystem components. This module requires RFI shielding, so will be packaged in a 4 or 4.5 wide ARCS Module. The level of RF shielding required is TBD. The M502 also generates heat, so will require a heat sink to transfer the heat to the forced air cooling system.

In every major location antenna electronics equipment resides a utility module is present. Most utility modules are similar enough that every effort will be made to standardize the metalwork for all utility modules.

The M502 will be mounted in one of the electronics rack ARCS bins, the specific one is not known until a cooling analysis of the entire rack is performed and the placement of modules optimized. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

### 3.2.8.3 D501 Digital Back End Module

The D501 Digital Back End Module contains high power electronics and will likely require heatsinks on both sides of the module in order to dissipate enough heat. This module requires RFI shielding, but due to the large size of the electronics will likely be packaged in a 6 or 6.5 wide ARCS Module. The level of RF shielding required is TBD.

The D501 will be mounted in one of the electronics rack ARCS bins, specific placement being very important due to the large amount of power dissipated. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

### 3.2.8.4 L503 Reference Receiver and Timing Module

The L503 Reference Receiver and Timing Module requires RFI shielding, so will be packaged in a 2.5 or 3.0 wide ARCS Module. The level of RF shielding required is TBD. The L503 also generates heat, so will require a heatsink to transfer the heat to the forced air system.

The L503 will be mounted in one of the electronics rack ARCS bins, the specific one is not known until a cooling analysis of the entire rack is performed and the placement of modules optimized. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

### 3.2.8.5 D502 WVR Back End Module

The D502 WVR Back End Module requires RFI shielding, so will be packaged in a 2.5 or 3.0 wide ARCS Module. The level of RF shielding required is TBD. The D502 also generates heat, so will require a heatsink to transfer the heat to the forced air system.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The D502 will be mounted in one of the electronics rack ARCS bins, the specific one is not known until a cooling analysis of the entire rack is performed and the placement of modules optimized. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

#### 3.2.8.6 M500 Supervisor Computer Module

The M500 Supervisor Computer Module requires RFI shielding, so will be packaged in a 2.5 or 3.0 wide ARCS Module. The level of RF shielding required is TBD. The M500 also generates heat, so will require a heatsink to transfer the heat to the forced air system.

The M500 will be mounted in one of the electronics rack ARCS bins, the specific one is not known until a cooling analysis of the entire rack is performed and the placement of modules optimized. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

#### 3.2.8.7 M501 Maintenance Computer Module

The M501 Maintenance Computer Module requires RFI shielding, so will be packaged in a 2.5 or 3.0 wide ARCS Module. The level of RF shielding required is TBD. The M501 also generates heat, so will require a heatsink to transfer the heat to the forced air system.

The M501 will be mounted in one of the electronics rack ARCS bins, the specific one is not known until a cooling analysis of the entire rack is performed and the placement of modules optimized. In order to keep the module design consistent throughout the antenna electronics system, I/O connections will be on the front of the module.

#### 3.2.8.8 Data Backhaul Equipment

The details of the Data Backhaul Equipment are not known at this time except that they are expected to be multiple ARCS modules in a single ARCS bin. The Electronics rack has space for this bin full of modules.

#### 3.2.8.9 L502 Reference Dist. Repeater Equipment

The details of the L502 Reference Dist. Repeater Equipment are not known at this time except that they are expected to be multiple ARCS modules in a single ARCS bin. The Electronics rack has space for this bin full of modules.

#### 3.2.8.10 M504 EEC Electronics Module

The requirements or location of the M504 EEC Electronics module are not known at this time except that it is expected to be a single ARCS Module. The location is also TBD.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

### 3.2.8.11 Electronics Rack ARCS bins

The Electronics Rack requires at least three and up to five ARCS bins to contain the numerous ARCS Modules. These bins will most likely be identical, but may be modified for specific needs as necessary.

## 3.3 Manufacturability

### 3.3.1.1 ARCS Modules and Bins

The ARCS modules and bins are a proven solution that has been manufactured in limited numbers and implemented in the field. Prototype manufacturing will be done by machining blocks of ATP-5 aluminum tool plate which has proven to be a suitable manufacturing material. For large quantity production runs of modules (anticipated to be >1000 pieces), a casting with finish machining will be investigated.

ARCS Module guide blocks for prototyping will be either machined from Delrin or 3D printed from Markforged Onyx material (carbon particle infused nylon). Both solutions have been tested and proven to work. For production quantities (anticipated to be > 15,000 pieces) a molded solution will be investigated.

ARCS Bin parts will be conventionally machined.

ARCS Module RFI gaskets are a commercial part, but will need to be cut to a few different common lengths (typically four, two each for the module cover and the housing). Typically, gaskets require minor trimming during install to fit correctly, so the thinking is to have the manufacturer pre-cut gaskets a tad long and then the assembler would perform final trimming during installation.

### 3.3.1.2 Front End and Auxiliary Enclosures

Manufacturing of the Front End and Auxiliary Enclosures will be considered in the next phase of the project as there will be >250 of each enclosure required for production.

### 3.3.1.3 Cryo RF Enclosure

Manufacturing of the Cryo RF Enclosure will be considered in the next phase of the project as there will be >250 required for production.

## 3.4 Technology Readiness Assessment

The BMR Subsystem has some products with a high TRL level and others that have not been fully developed yet. The TRL level of the entire subsystem, primarily driven by overall design maturity, is estimated at TRL level 3.

The ARCS Modules and bins are fully developed and tested, and except for modifications required for individual modules are fully ready for production. TRL level 7.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

The Front End and Auxiliary Enclosures have not gone through detailed design yet and as such are not ready for prototype construction much less production. TRL level 3.

The Cryo RF Enclosure has not gone through detailed design yet, but it is based on similar designs that have been used before. TRL level 4.

The WVR Environmental enclosures have not undergone detailed design yet. TRL level 3.



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

## 4 Appendix A: Trade Studies

### 4.1 Air-cooled vs direct glycol cooled rack equipment

A brief study comparing air cooling or direct glycol cooling of the Electronics Rack equipment was conducted. In the past, NRAO has typically used air cooled racks, but for the ngVLA project all of the equipment on the feed arm will be glycol cooled which led to the consideration of direct glycol cooling in the rack.

A conceptual design and layout of the rack was developed with glycol lines and quick connects run to each device that required cooling. The first issue encountered was that some of the commercial rack mounted equipment was not available in any configuration except air cooled. This led to segmenting the rack into upper and lower sections, the upper section with the commercial equipment requiring air flow and the lower section with ARCS modules requiring glycol lines. The glycol lines were run from the underside of the rack, along the rear vertical rails, and then above each bin with modules. A manifold was used to split the main line out to lines going to each module. Quick connects are used in order to be able to remove and replace individual modules from the rack.

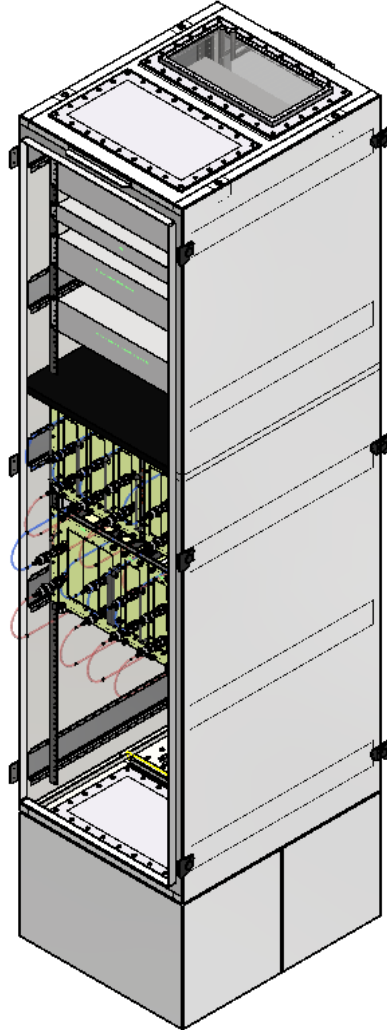
A couple of different issues were encountered with the glycol cooled rack design. For one, having the rack split between air cooled and glycol cooled requires an air inlet on only the upper section, implying it would have to be on the front door of the rack. This would make access to the contents of the rack more difficult. The second problem was cost. The added cost of welded stainless steel tubing and quick connects is far greater than the cost of a few air flow baffles, even including an air handler. Both of these previous issues push toward the air cooled solution. Additionally, around the time the glycol solution was being investigated, the mtex antenna team decided that they would use air cooling for all equipment located in the pedestal RFI room, making air cooling of the rack a more convenient choice.

A couple of different issues with the air cooling design were also investigated. For one, having air cooled ARCS Modules in the rack but nowhere else on the antenna means that these modules will necessarily be different than the ARCS Modules in other locations around the antenna. This means non interchangeable designs and parts as well as possibly different manufacturing techniques. However, the number of modules considered is great enough that this may not be a major concern. Another possible issue is that there are a couple of high heat dissipation modules that could be more difficult to properly cool with air and a heatsink, but not enough details of these modules are known yet. If this turns out to be the case, one solution might be to run a glycol line to that individual module as the high heat capacity of glycol may be able to transfer more heat than the forced air system.

Another quirk with the air cooled configuration is that the lower section of the rack containing ARCS Modules requires vertical air flow while the upper section of the rack containing commercial equipment requires horizontal, front to rear, air flow. The concept is to have bottom to top air flow for the lower section of the rack, and then direct the air into the space between the front door and the rack mounted equipment, horizontally through the commercial equipment, and then out the top of the rack (Figure 39).

In conclusion, it was decided to go with the air flow configuration as the baseline as it is simpler, less expensive, and with fewer drawbacks than the glycol cooled configuration.

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 40. Electronics Rack with direct glycol cooling**

## **5 Appendix B: ARCS Module Shielding Report**

### **5.1 Single Cover ARCS Module Shielding Report**

When: November, 2020

Who: Dan Mertely

What: RF shielding tests of a single cover ARCS module with I absorber.

Where: VLA Site EVLA/ALMA Reverberation Chamber

Summary:

The shielding test results for this single cover ARCS module (with absorbing foam) showed shielding



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

mostly in the 80+ dB range from UHF to X-band. Above that the noise floor of the test system caused a continuous decline to the mid 60 dB range by 16 GHz.

**Equipment:**

RX: Agilent/Keysight EXA N9010A 44 GHz spectrum analyzer

RX Cables: Teledyne-Storm 40 GHz uW coax assemblies.

TX: Agilent/Keysight 8257D 40 GHz synthesizer.

TX Cables: Teledyne-Storm 40 GHz uW coax assemblies + 8 ft RG141 semi-rigid (in chamber) + 6 inch Tensolite cable assembly in module.

TX antenna: RR planar PCB spiral.

No external pre-amp used.

Software: NRAO TRGEN proprietary tracking generator simulator.

Unit Under Test: ARCS single cover module. The module as supplied had a thin (1/4 inch?) layer of conductive foam on the non-cover side.

**Test Procedure:**

Shielding tests use a simple open/closed data collection. The “open” module power measurements were run with the module cover removed and the TX antenna fully exposed. (Previous tests of the GPM experimented with laying the cover on top of the otherwise open module, but with 3/8 inch cracks on 2 of the 4 sides. It was believed at that time that allowing for similar resonances to build up during the open and closed data acquisitions would produce a flatter delta response. Unfortunately, tests with this highly-shielded module indicated that the +20 dBm maximum power output of the TX synthesizer was not high enough to allow detection of the RF leakage out of the module during the module closed data acquisition.) The closed module power measurements were made with the module lids screwed down tightly after careful cleaning.

These 0-16.6 GHz tests used a high quality semi-rigid (100% shielding coverage) transmit cable into the module, a Ridgeway planar log spiral antenna as the transmitting antenna inside the module and no external pre-amp inside the chamber. The SMA connectors on either end of the transmit cable were sealed with conductive adhesive aluminum tape after the bulkhead wall in order to prevent leakage.

Extra care was taken to insure adequate power levels over the transmit cable leakage during the closed module leakage data collections.

In order to attempt to insure that the extremely weak module closed power levels do not approach the instrumentation noise floor or the TX cable leakage noise floor, pre-tests were made to discover those levels (See Figure [41]). The TX power levels were then set differently during the open and closed data collections in order to keep the full range of power variation within the dynamic range of the receiving spectrum analyzer (See bottom plots of Figures [41 & 42]). Various TX powers were used for different ranges of the open measurements. +20 dBm was used for all closed module and terminated TX coax tests. The receiver internal pre-amps (“Low” or “Full-Range”) were on for all tests, but no external pre-amp was used in order to minimize calibration difficulties and avoid saturation concerns. The RX spectrum analyzer has a pre-amp switch-over point at 3.6 GHz, which is why the frequency ranges were selected as shown.

The module under test was placed on a wooden table, >1m from any chamber wall. The table was located at the far end of the chamber (relative to the Pomeroy UWB receiving antenna and the mode stirrer).



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

3 open and 3 closed data sets were collected in each frequency range, with the mode stirrer rotated 120 degrees between each collection in order to provide reverberation diversity.

The 4 collection ranges (0-1, 1-3.6, 3.6-6.6, and 6.6-16.6 GHz) were chosen as a compromise between collection time, excessive dynamic range differences due to chamber insertion loss variations with frequency, and the RX internal pre-amp change-over point at 3.6 GHz.

A single test data collection was also made in the 6.6-16.6 GHz range with the TX cable terminated outside of the reverberation chamber, and the RC bulkhead terminated with a 50 Ohm RF load. The "RC-in-Termd-smoothed-6.6-16.6" plot shown in the "Received Power" section of Figure [42] shows that the quiet-chamber system noise floor power was within 10 dB of the system noise floor when the ARCS module was closed. If better results are needed above C-band, additional testing could be attempted using an external pre-amp in order to lower the system noise floor. The trade-off might be difficulty in adjusting for the high TX power levels during the module open tests.

**Analysis Procedure:**

The 3 power vs. frequency data vectors for open collections and the 3 power vs. frequency data vectors for closed collections were averaged on a frequency point-by-point basis, after conversion from dBm to mW units. The linear, averaged power data vectors were then smoothed on a 5 (frequency) point basis, reducing frequency resolution, but removing minor reverberation differences. The smoothed open and closed power levels were then subtracted, and the difference in open and closed TX power levels added back in for normalization.

**Results:**

See following charts showing the most reliable test data (FIGURES [41 & 42]). System sensitivity limits were mostly below -100 dB from the VHF/UHF range to X-band. The inability to source enough power into the sealed module to overcome the module shielding + reverberation chamber insertion losses above 8 GHz reduced the system sensitivity limit gradually to around 90 dB by 16.6 GHz, causing a corresponding apparent reduction in module shielding in that range.

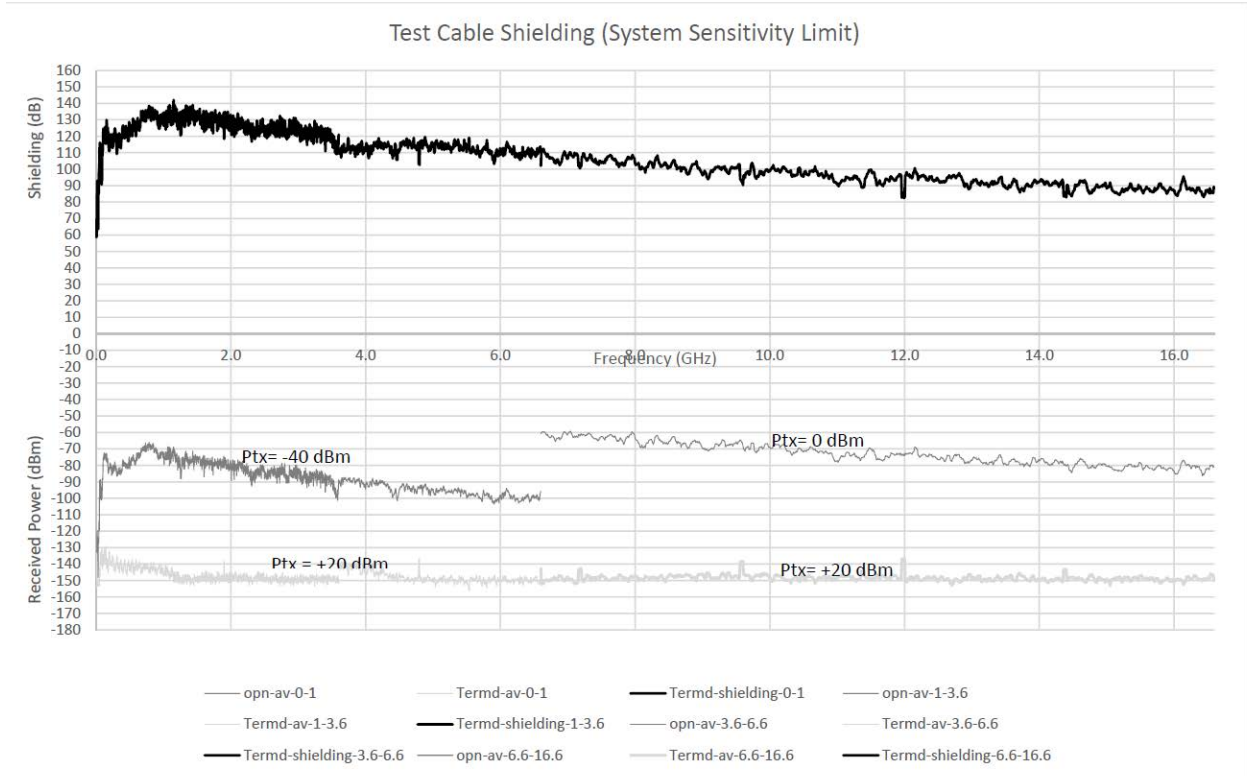
The 0-1 GHz shielding plot included at the low frequency end of FIGURE [42] includes a large number of resonances which make precise measurement of the module difficult. The plot shown is representative, given hardware difficulties. The tests results there can be considered reasonably accurate, with EVLA P-band shielding of 70 to 80 dB probably representative of the entire VHF/UHF range.

The microwave range shielding of the module ranged from a high of 110 dB in low C-band to a more typical 80-90 dB over most of the sub-X-band range. Above C-band the shielding slowly decreased to the 60-70 dB range due to RC sensitivity limits (see FIGURE [42]).



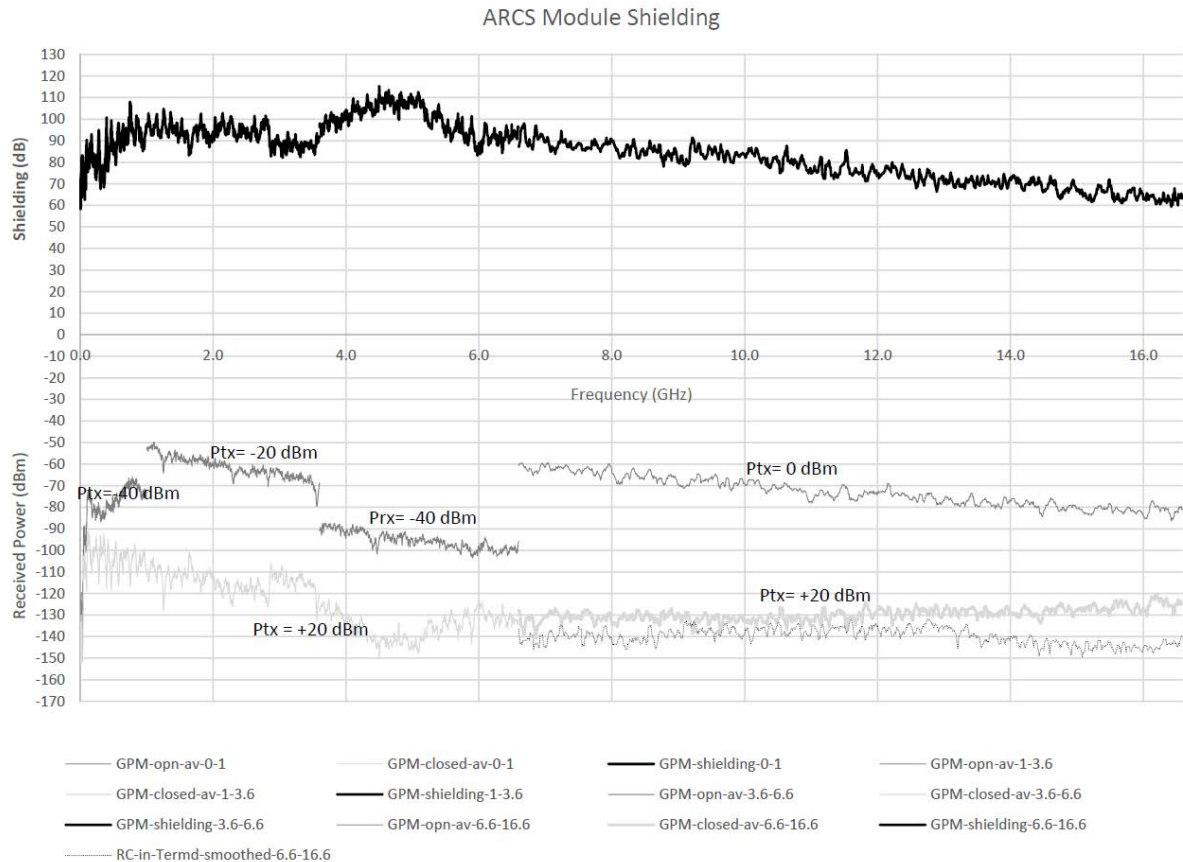


<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



**Figure 41. Test Cable Shielding (System Sensitivity Limit)**

<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B



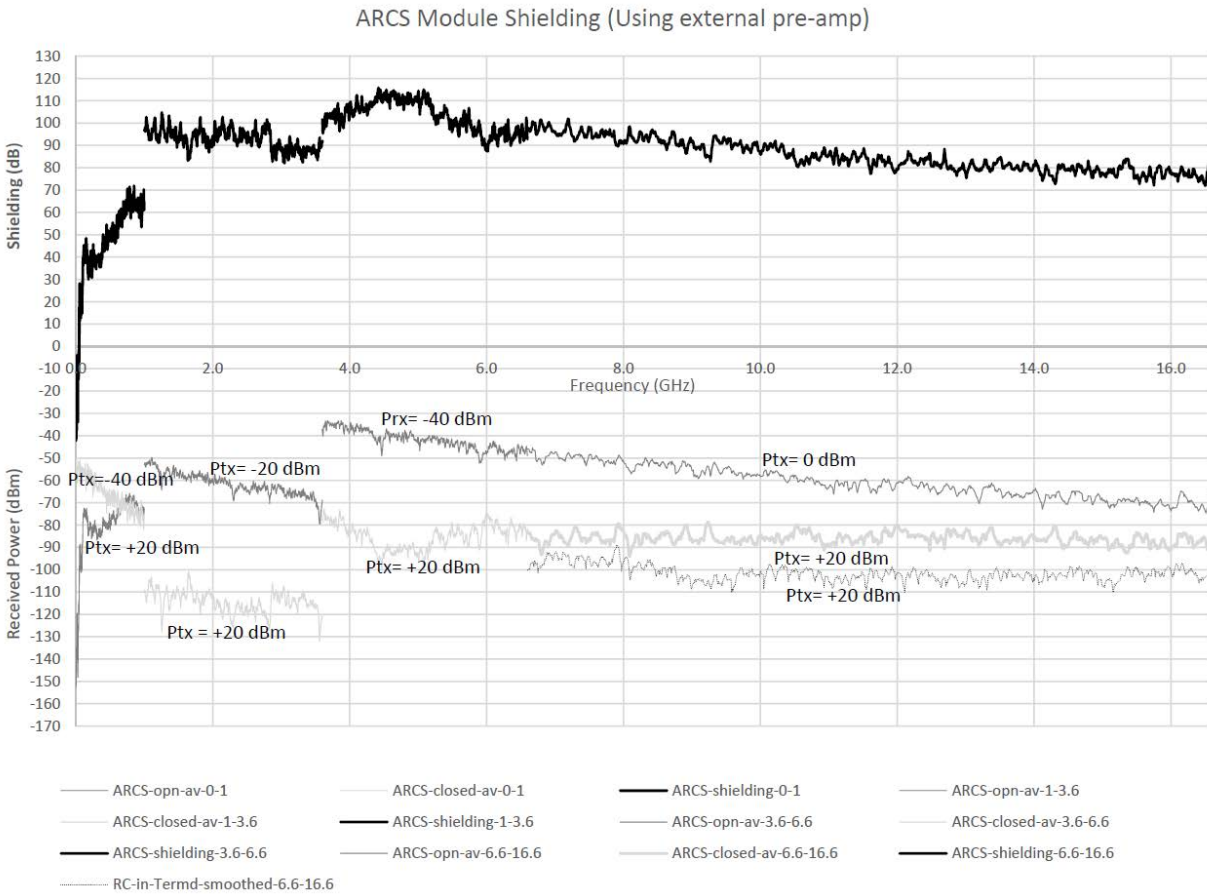
**Figure 42. ARCS Module Shielding**

## 5.2 Single Cover ARCS Module Shielding Report Addendum

Excerpt from email: dated 11-6-2020  
 From: Dan Mertely  
 To: Silver Sturgis, James Allison

“Yesterday tried re-doing the upper 2 bands (3.6-6.6 & 6.6-16.6 GHz) using the external pre-amp in order to try to see below the apparent noise floor. (It wasn't clear to me whether the system noise floor was due to TX coax connector leakage or the internal noise of the spectrum analyzer--it appears that it was at least partially due to the latter.)

I've attached an updated shielding curve showing the shielding above C-band 10-15 dB better than my previous test ([Figure 43] upper 70's rather than low 60's). That is good news added to already impressive results.”



**Figure 43. ARCS Module Shielding, v2 (same as Figure 12)**

## 6 Appendix C: Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
AFD	Antenna Fiber Distribution
ALMA	Atacama Large Millimeter Array
ARCS	Advanced RFI Containment System
BMR	Bins, Modules, and Racks
COTS	Commercial Off the Shelf
DBE	Digital Back End
EEC	Electronics Environmental Control
EMI	Electromagnetic Interference
EVLA	Jansky Very Large Array
FE	Front End
ICD	Interface Control Document



<b>Title:</b> Bins, Modules, and Racks Conceptual Design Description	<b>Author:</b> S. Sturgis	<b>Date:</b> 05/27/2022
<b>NRAO Doc. #:</b> 020.30.55.00.00-0002-DSN		<b>Version:</b> B

IRD	Integrated Receivers and Digitizers
LO	Local Oscillator
LRU	Line Replaceable Unit
ngVLA	Next Generation Very Large Array
RFI	Radio Frequency Interference
TBC	To Be Confirmed
TBD	To Be Determined
TRL	Technology Readiness Level
VFD	Variable Frequency Drive
WVR	Water Vapor Radiometer











# 020.30.55.00.00-0002-DSN-BINS\_MODULES\_RACKS\_DESIGN

Final Audit Report


2022-06-07

Created:	2022-06-06
By:	Alicia Kuhn (akuhn@nrao.edu)
Status:	Signed
Transaction ID:	CBJCHBCAABAAVOYhlvB8hn9giNmDNW2T4RDEEW60Rplv


## "020.30.55.00.00-0002-DSN-BINS\_MODULES\_RACKS\_DESIGN" History

-  Document created by Alicia Kuhn (akuhn@nrao.edu)  
2022-06-06 - 9:58:18 PM GMT- IP address: 107.242.117.31
-  Document emailed to Phillip Lopez (plopez@nrao.edu) for signature  
2022-06-06 - 9:59:36 PM GMT
-  Email viewed by Phillip Lopez (plopez@nrao.edu)  
2022-06-06 - 10:23:01 PM GMT- IP address: 67.42.69.170
-  Document e-signed by Phillip Lopez (plopez@nrao.edu)  
Signature Date: 2022-06-06 - 10:25:01 PM GMT - Time Source: server- IP address: 67.42.69.170
-  Document emailed to Thomas Kusel (tkusel@nrao.edu) for signature  
2022-06-06 - 10:25:03 PM GMT
-  Email viewed by Thomas Kusel (tkusel@nrao.edu)  
2022-06-06 - 10:30:08 PM GMT- IP address: 71.62.226.171
-  Document e-signed by Thomas Kusel (tkusel@nrao.edu)  
Signature Date: 2022-06-07 - 0:42:08 AM GMT - Time Source: server- IP address: 71.62.226.171
-  Document emailed to R. Selina (rselina@nrao.edu) for signature  
2022-06-07 - 0:42:11 AM GMT
-  Email viewed by R. Selina (rselina@nrao.edu)  
2022-06-07 - 12:59:11 PM GMT
-  Document e-signed by R. Selina (rselina@nrao.edu)  
Signature Date: 2022-06-07 - 1:01:05 PM GMT - Time Source: server




 Document emailed to Willem Esterhuyse (westerhu@nrao.edu) for signature

2022-06-07 - 1:01:08 PM GMT

 Email viewed by Willem Esterhuyse (westerhu@nrao.edu)

2022-06-07 - 1:47:28 PM GMT

 Document e-signed by Willem Esterhuyse (westerhu@nrao.edu)

Signature Date: 2022-06-07 - 1:48:16 PM GMT - Time Source: server

 Agreement completed.

2022-06-07 - 1:48:16 PM GMT

