ALMA Phasing Project H-maser rack: Seismic Analysis Report

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1 Introduction

1.1 Purpose

This document performs an analysis of the seismic characteristics and evaluates compliance on ALMA seismic requirements for the H-Maser rack design proposed by the ALMA Phasing Project

1.2 Scope

The characteristics of the H-Maser rack are estimated, inferred or calculated from available documentation. The compliance evaluation is exclusively done through analysis. The validation of the aforementioned design is only for the rack that will house the H-Maser assembly which design is still undergoing.

1.3 Applicable documents

The following documents are part of this document to the extent specified herein. If not explicitly stated otherwise, the latest issue of the document is valid.

Appl.	Document Title	ALMA Doc. Number
[AD01]	BackEnd IPT Seismic Support Specification	BEND-57.00.00.00-001-A-SPE
[AD02]	Seismic Design Specification for ALMA-AOS and ALMA-OSF project	SYSE-80.10.00.00-002-B-REP
[AD03]	International Building Code 2000	
[AD04]	TR-NWT-000063, issue 5, September, 1993. Network Equipment –Building System, (NEBS) Generic Equipment Requirements, (TR-63)"	

1.4 Reference documents

The following documents contain additional information and are referenced in this document.

Ref	Document Title	ALMA Doc. Number
[RD01]	SSLOR Seismic Support Design Report	SouthWest Research Institute
[RD02]	EarthQuake Analysis of the Equipto Electronics Corp. Model 170-070-030 Cabinet with seismic Hardening kit	Bell Communications Research

1.5 Acronyms

The more complete list of acronyms and abbreviations used within this document are given below. For a complete set of acronyms and abbreviations, please go to the ALMA AIV web page.

Acronym	Definition
ALMA	Atacama Large Millimeter/submillimeter Array
AOS	Array Operations site
APP	ALMA Phasing Project
IBC	Internation Building Code
OSF	Operations Site Facilities
SSLOR	Seismic Support Structure for the Central LO Racks

2 H-Maser Rack Design

The H-Maser rack is intended to house the H-Maser assembly, made by the H-Maser enclosure and a 4-batteries bank. There is not a formal document release for the rack drawings, but they were available for this evaluation from APP. See annex A for the proposed drawings.

The H-Maser Rack will be made of two units of Equipto rack model 170-070-030 or equivalent that will be bolted together. The interior side panel will be removed to accommodate the design. The H-Maser rack will be installed on spare cabinet positions of the SSLOR and will be connected to rest of the CLOA racks in the row.

The mass of the H-Maser enclosure plus the four batteries it is estimated at 190 Kg and it will be shared symmetrically by the 2 rack units, thus each cabinet will house an 95 Kg payload. The center of gravity of the H-Maser rack can be made 740 mm above the base of the rack, which is below the geometric center of the rack.

3 SSLOR Seismic Performance

[RD01] concludes that the Support Structure design accomplishes the IBC requirements for seismic performance.

The Central LO racks are defined with the following characteristics:

- Cabinet weight: 107 Kg
- Maximum payload per cabinet: 193 Kg
- Maximum height of Center of gravity of loaded cabinet: 15% above geometric center

The finite elements model was focused on the dynamics of the support structure, and did not include detailed analysis of the Equipto cabinet. Modes of the representative cabinets were present in the analysis, but were not extracted.

The dynamic analysis shows that the SSLOR Support Structure deflections are insignificant compared to the cabinet deflections determined in the Bellcore test [RD02] and will not amplify the cabinet deflection.

4 Equipto Rack model 170 Seismic Performance

The model 170 is a sheet metal cabinet designed to house electronic equipment and instrumentation. The model 170 employ modular construction to permit junctioning side by side, front to back, or back to back. The seismic hardening kit is an option consisting of higher strength welded seams, gussets, and a mounting brace which provide additional cabinet strength and stiffness necessary to withstand earthquake forces.

4.1 Bellcore Earthquake Resistance Analysis

The Equipto Rack model 170 with seismic hardening kit was evaluated for conformance to Bellcore's environmental compatibility criteria in the area of earthquake resistance, which is defined by *"TR-NWT-000063, issue 5, September, 1993. Network Equipment –Building System, (NEBS) Generic Equipment Requirements, (TR-63)".[*AD04*]*

Results are reported in [RD02] with the conclusion that Equipto model 170 has sufficient strength and stiffness to withstand Bellcore earthquake risk zone 4 testing. See annex B for the detailed compliance matrix.

It might be noted that the rack testing was done under the following load conditions:

- 250-lbm top-heavy configuration, without stiffening plates.
- 300-lbm even weight configuration, additional side-to-side stiffness with faceplates.
- 400-lbm bottom heavy configuration, additional side-to-side stiffness with faceplates.
- 200-lbm top-heavy configuration, additional side-to-side stiffness with faceplates.

Configuration	Natural Frequency front-back/side-side (Hz)	Peak Deflection front-back/side-side (Inches-single amp.)	Results Deflection/Damage Requirements
Top heavy (250#) w/out stiffening plates	- / 4.5	- / 3.75	Failed / Failed
Bottom Heavy (400#)	9.5 / 6.2	.45 / 1.7	Passed / Passed
Even (300#)	9.5 / 5.3	.40 / 1.55	Passed / Passed
Top heavy (200#)	8.5 / 5.2	.50 / 1.95	Passed / Passed

Table 1 Dynamic Test Summary from [RD02].

For evaluating the seismic performance of the racks as configured for the Central LO, the most similar tested configuration was selected. Natural frequency and peak deflection can be inferred within an acceptable uncertainty margin. However, as stated in [RD01], the rack performance itself, was not in the scope of the design report.

4.2 Earthquake Resistance Criteria

The applied criteria are defined in [AD04], TR-63, Section 4.5.2.1, the set of requirements is:

4.2.1 Physical Performance Requirements:

- (R-100) Equipment shall be constructed to sustain the synthesized waveform testing of Section 5.5 without permanent structural or mechanical damage.
- (R-101) Equipment shall be constructed so that during the synthesized waveform testing of Section 5.5.7, the maximum single-amplitude deflection at the top of the framework, relative to the base, does not exceed three inches.
- (R-103) Equipment frames shall have a natural mechanical frequency greater than 2.0 Hz as determined by the swept sine survey of Section 5.5.7 of TR-63.

4.2.2 Use on Earthquake Risk Zones

- (O-102) Static pull testing procedures of Section 5.5.6 of TR-63 should be followed, meeting these objectives:
  - Maximum single amplitude deflection at the top of the framework should not exceed three inches.
  - Top of the framework should return to its original position, within 0.25 inches when the load is removed.
  - The framework should sustain no permanent damage during static framework testing.
- (O-104) Equipment frames should have a natural mechanical frequency greater than 6.0 Hz as determined by the swept sine survey of Section 5.5.7 of TR-63.

4.2.3 Framework and Anchor requirements and objectives

- (R-108) Framework shall be constructed for base mounting to the floor without auxiliary support or bracing from the building walls or ceilings.
- (R-109) Framework shall be constructed for base mounting to the floor without auxiliary support or bracing from the building walls or ceilings
  - Maximum nominal embedment depth of 3.5 inches
  - Maximum bolt diameter of 0.5 inches
- (O-110) Concrete expansion anchors used to base mount the framework to the floor should be suitable for earthquake (dynamic) applications, as specified by the manufacturer.
- (O-107) Framework should be of welded construction.

4.3 Test results: conformances and observations from the report

- The Model 170 does not conform with the earthquake physical performance requirements for the 250 pounds, top heavy configuration without stiffening plates. This weight distribution is not recommended by Equipto.
- The Model 170 conforms with the earthquake physical performance requirements for the bottom-heavy(400#), even(300#) and top-heavy(200#) load configurations and stiffening plates.
- The Model 170 does not conform with the static pull objective when stiffening plates are not used.
- The Model 170's conformance with the static pull objective when stiffening plates are used is not determined.
- The Model 170 conforms with the natural mechanical frequency objective when loaded in the bottom heavy configuration with stiffening plates.
- The Model 170 does not conform with the natural mechanical frequency objective when loaded in the top heavy or even weight configurations. Earthquake accelerations may be strongly amplified.
- The racks were tested without doors or front and rear panels. The manufacturer indicates that front and rear panels or doors increase the stiffness in the side-to-side direction.
- The Model 170 conforms with the base mounting and anchor requirements and objective for all configurations,
- The Model 170 does not conform with the welded construction objective, the manufacturer indicates that the seismic mounting braces are normally bolted on to allow for modular requirements. However they can be ordered from Equipto welded on.

5 Seismic Performance evaluation for proposed H-maser rack design

From section 2, the H-Maser rack is defined as an assembly of 2 cabinets bolted by the side and anchored into spare positions of the SSLOR. The racks to be used correspond to Equipto units with characteristics that are similar to the Model 170 and that correspond to the model used in the Central LO, which are deployed on the SSLOR.

As stated in section 3, the earthquake effects on the SSLOR are insignificant compared to the effects on the Equipto cabinets.

The Bellcore report referred on section 4 and compliance matrix in Annex B, show the test results obtained for different cabinet load configurations. The analysis for the H-maser rack design will be done choosing the most-similar tested configuration and inferring or delimiting the possible performance values to evaluate the compliance matrix.

5.1 H-Maser Rack characteristics

The H-maser rack assembly characteristics are summarized as:

- 2 Equipto Model 170 units
- Cabinet weight: 107 Kg
- H-Maser payload: 190 Kg
- Payload per unit: 95 Kg (209.5 pounds)
- Total weight per unit: 202 Kg
- Model 170 height: 1692.3 mm
- Model 170 geometric center position: 846.15 mm above the bottom of the cabinet
- Possibly Center of gravity position: 740 mm above the bottom of the cabinet. (-12.5% from the geometric)

From the Bellcore report it can be found that the most similar tested load configuration in weight and Center of gravity position is the 300 pounds (136 Kg), even weight configuration. The center of gravity position of the load configuration is 812.8 mm above the bottom of the cabinet (-3.94% from the geometric center)

5.2 Natural Frequency Estimation

The rack attached to the SSLOR can be modeled as a cantilever with mass m. The natural frequency of a cantilever is inversely related to the square root of the mass; thus, the lower the mass the higher the frequency. Supposing that mechanical characteristics as rigidity do not change with the change of mass, then for a cantilever with mass m1 and measured natural frequency f1, the natural frequency f for the same cantilever with mass m, can be estimated as:

$$f = \sqrt{\frac{m_1}{m}} f_1$$

From the data presented the natural frequency is estimated to be 10.42 Hz for from-to-back and 5.8 Hz for side-to-side.

5.3 Peak Deflection Estimation

The peak deflection is proportional to the applied force and the distance from the base where the force is applied. Knowing that the mass in the H-maser rack is less than 300 pounds and that the center of gravity has a shorter distance to the base, then it can be inferred that the peak deflection for both, from-to-back and side-to-side directions, will be lower than the value obtained for the 300 pounds even weight configuration case.

5.4 Structural integrity

From comparison with the 300 pounds, even weight distribution case; it is reasonable to assume that the structure under earthquake stress will have the same behavior. It is expected to have no permanent structural or mechanical damage if stiffening plates are used.

5.5 Compliance evaluation

The compliance of the proposed design is summarized on the following compliance matrix.

Physical Performance Requirements:

Code	Description	Measurement	Compliance	Comments
R-100	Equipment shall be constructed to sustain the synthesized waveform testing of Section 5.5 without permanent structural or mechanical damage.		YES	From comparison with 300 pound, even weight results
R-101	Equipment shall be constructed so that during the synthesized waveform testing of Section 5.5.7, the maximum single-amplitude deflection at the top of the framework, relative to the base, does not exceed three inches.	front-back:<0.40 side-side: <1.55	YES	
R-103	Equipment frames shall have a natural mechanical frequency greater than 2.0 Hz as determined by the swept sine survey of Section 5.5.7 of TR-63.	front-back:10.4 side-side: 5.8	YES	Values are estimations

Table 2 H-maser rack compliance matrix

Use on Earthquake Risk Zones

Code	Description	Measurement	Compliance	Comments
O-102	Static pull testing			
O-102.a	Maximum single amplitude deflection at the top of the framework should not exceed three inches.	front-back:<0.40 side-side:<1.55	YES	From comparison with 300 pound, even weight results
O-102.b	Top of the framework should return to its original position, within 0.25 inches when the load is removed.		Not Determined	
O-102.c	The framework should sustain no permanent damage during static framework testing.		Not Determined	
O-104	Equipment frames should have a natural mechanical frequency greater than 6.0 Hz as determined by the swept sine survey of Section 5.5.7 of TR-63.	front-back:10.4 side-side: 5.8	NO	Values are estimations.

Framework and Anchor requirements and objectives

Code	Measurement	Measurement	Compliance	Comments
R-108	Framework shall be constructed for base mounting to the floor without auxiliary support or bracing from the building walls or ceilings.		YES	Mechanical design is not changed
R-109	Framework shall be constructed for base mounting to the floor without auxiliary support or bracing from the building walls or ceilings		YES	Mechanical design is not changed
R-109.a	Maximum nominal embedment depth of 3.5 inches		YES	Mechanical design is not changed
R-109.b	Maximum bolt diameter of 0.5 inches		YES	Mechanical design is not changed
O-110	Concrete expansion anchors used to base mount the framework to the floor should be suitable for earthquake (dynamic) applications, as specified by the manufacturer.		YES	Mechanical design is not changed
O-107	Framework should be of welded construction.		NO	Bolted connections may require retorquing following an earthquake

Table 3 H-maser rack compliance matrix

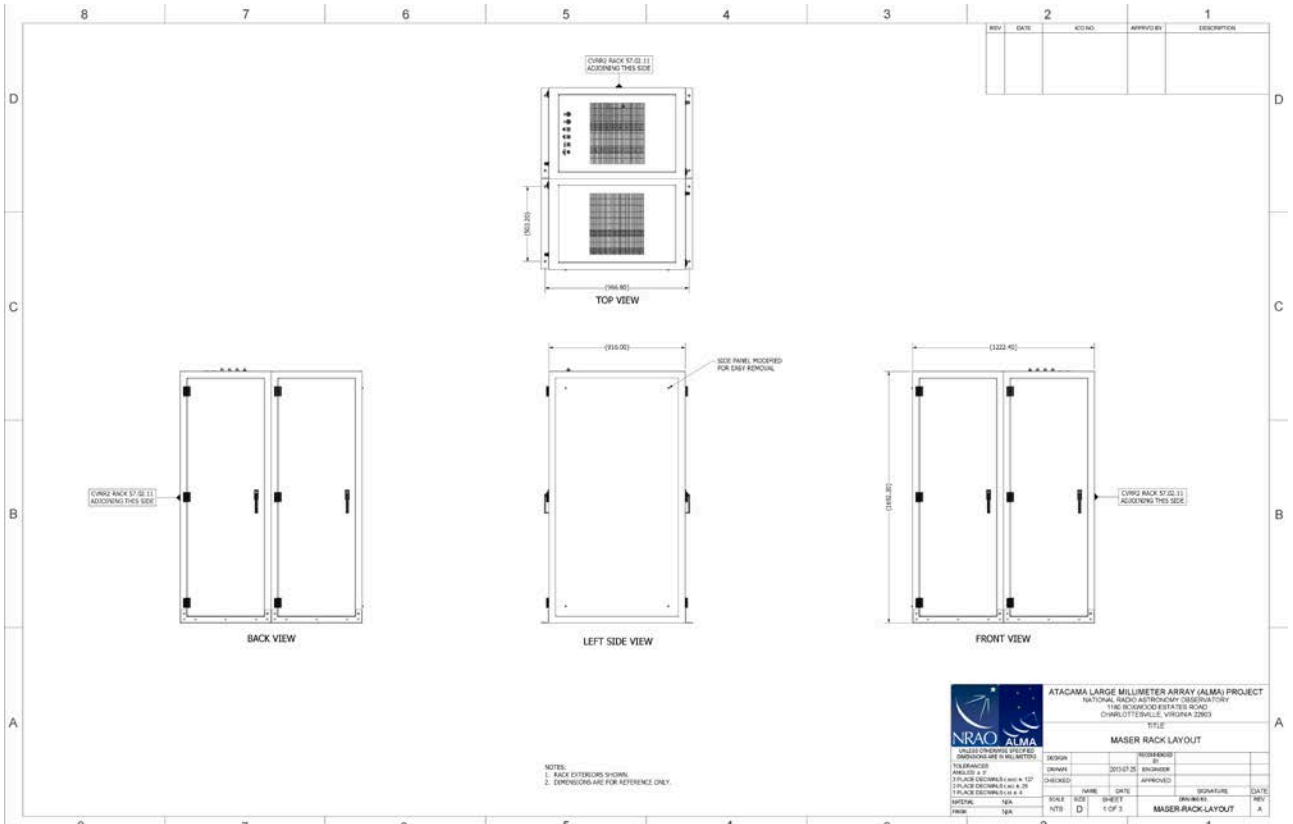
6 Conclusion

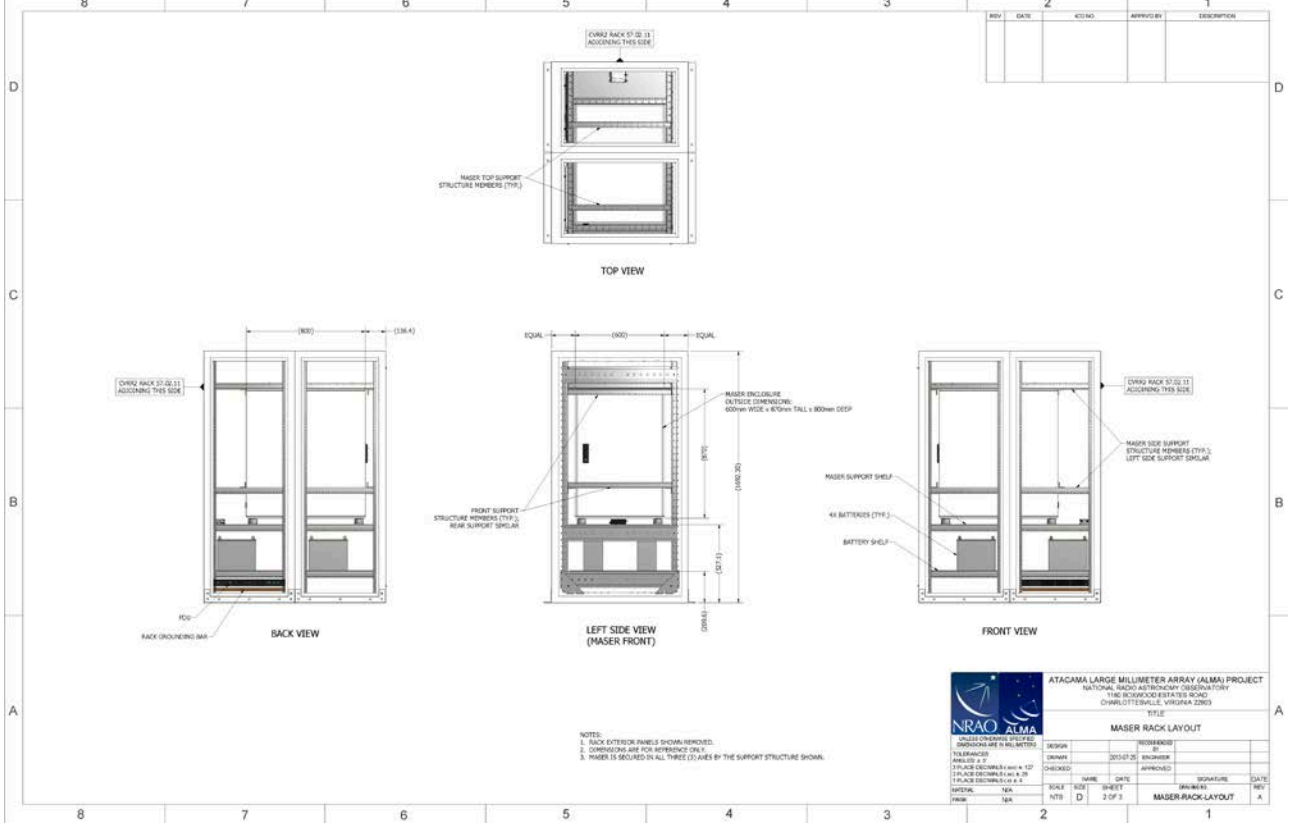
The performed analysis concludes that the proposed H-maser rack design is in compliance with ALMA seismic specifications. The weakest point of the rack design is the side-to-side stiffness, which **must** be compensated using stiffening plates and including doors and rear panels in the installation.

The design needs the removal of the interior panel, which connects the two cabinet units by the side. This panel will not affect the side-to-side stiffness.

The natural frequency of the side-to-side direction is not compliance with the IBC requirement of a minimum of 6 Hz. Although this requirement is not achieved by a small margin (less than 4%), it may be possible that earthquake accelerations are strongly amplified. It is recommended to add to the design a mechanism that can compensate the low natural frequency.

7 Annex A: H-Maser Rack Drawings





8 Annex B: Compliance Matrix for Equipo Model 170 and Bellcore environmental compatibility criteria in the area of earthquake resistance

Physical Performance Requirements:		Test Weight configuration							
		250lbm top-heavy *		300lbm even		400lbm bottom-heavy		200lbm top-heavy	
Code	Description	Measurement	Compliance	Measurement	Compliance	Measurement	Compliance	Measurement	Compliance
R-100	Equipment shall be constructed to sustain the synthesized waveform testing of Section 5.5 without permanent structural or mechanical damage.	small cracks in top of the uprights	NO		YES		YES		YES
R-101	Equipment shall be constructed so that during the synthesized waveform testing of Section 5.5.7, the maximum single-amplitude deflection at the top of the framework, relative to the base, does not exceed three inches.	front-back:- side-side: 3.75	NO	front-back:0.40 side-side: 1.55	YES	front-back:0.45 side-side: 1.7	YES	front-back:0.50 side-side: 1.95	YES
R-103	Equipment frames shall have a natural mechanical frequency greater than 2.0 Hz as determined by the swept sine survey of Section 5.5.7 of TR-63.	front-back:- side-side: 4.5	NO	front-back:9.5 side-side: 5.3	YES	front-back:9.5 side-side: 6.2	YES	front-back:8.5 side-side: 5.2	YES

Table 4 Equipto Model 170 compliance matrix

Use on Earthquake Risk Zones		250lbm top-heavy *		300lbm even		400lbm bottom-heavy		200lbm top-heavy	
Code	**Description**	**Measurement**	**Compliance**	**Measurement**	**Compliance**	**Measurement**	**Compliance**	**Measurement**	**Compliance**
O-102	Static pull testing								
O-102.a	Maximum single amplitude deflection at the top of the framework should not exceed three inches.	front-back:- side-side: 3.75	NO	front-back:0.40 side-side: 1.55	YES	front-back:0.45 side-side: 1.7	YES	front-back:0.50 side-side: 1.95	YES
O-102.b	Top of the framework should return to its original position, within 0.25 inches when the load is removed.	>0.25	NO		Not Determined		Not Determined		Not Determined
O-102.c	The framework should sustain no permanent damage during static framework testing.		NO		Not Determined		Not Determined		Not Determined
O-104	Equipment frames should have a natural mechanical frequency greater than 6.0 Hz as determined by the swept sine survey of Section 5.5.7 of TR-63.	front-back:- side-side: 4.5	NO	front-back:9.5 side-side: 5.3	NO	front-back:9.5 side-side: 6.2	YES	front-back:8.5 side-side: 5.2	NO

Table 5 Equipto Model 170 compliance matrix

Framework and Anchor requirements and objectives		250lbm top-heavy *		300lbm even		400lbm bottom-heavy		200lbm top-heavy	
Code	**Measurement**	**Measurement**	**Compliance**	**Measurement**	**Compliance**	**Measurement**	**Compliance**	**Measurement**	**Compliance**
R-108	Framework shall be constructed for base mounting to the floor without auxiliary support or bracing from the building walls or ceilings.		YES		YES		YES		YES
R-109	Framework shall be constructed for base mounting to the floor without auxiliary support or bracing from the building walls or ceilings		YES		YES		YES		YES
R-109.a	Maximum nominal embedment depth of 3.5 inches		YES		YES		YES		YES
R-109.b	Maximum bolt diameter of 0.5 inches		YES		YES		YES		YES
O-110	Concrete expansion anchors used to base mount the framework to the floor should be suitable for earthquake (dynamic) applications, as specified by the manufacturer.		YES		YES		YES		YES
O-107	Framework should be of welded construction.		NO		NO		NO		NO

Table 6 Equipto Model 170 compliance matrix