# ALMA Phasing Project Hydrogen Maser Test Data Report

ALMA-05.11.21.03-0002-A-TDR

2014-10-07

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# Change Record

| Version | Date | Affected section(s) | Author | Reason/Initiation/Remarks |
|---|---|---|---|---|
| A.1 | 2014-08-14 | All | | Initial draft |
| **A** | 2014-10-07 | 5.3, 5.4 | | Power consumption detailed and updated housekeeping display included. |
| | | | | |

# Table of Contents

# 1. Description

## 1.1. Purpose

An integral component of the ALMA Phasing Project is the new Hydrogen Maser (HM) frequency standard, which will enable ALMA to function as a highly sensitive element in VLBI arrays. It will also allow long-term monitoring of pulsars and magnetars, for which stable timing is essential.
This document describes all tests performed to verify that the HM installed at the AOS meets specifications. These include tests carried out at the manufacturer (T4Science, based in Neuchatel, Switzerland), at MIT Haystack Observatory during PAI, and during installation at the AOS during PAS.

# 2. Related Documents and Drawings

## 2.1. Applicable Documents

| Ref | Document Title | Document ID |
|---|---|---|
| [AD01] | Backend IPT Product Assurance Requirements | BEND-50.00.00.00-079-B-PRO |
| [AD02] | ALMA Environmental Specification | ALMA-80.05.02.00-001-B-SPE |
| [AD03] | ALMA System General Safety Design Specification | ALMA-10.08.00.00-003-B-SPE |
| [AD04] | ALMA Safety Manual | ALMA-10.08.00.00-011-D-MAN |
| [AD05] | H Maser Procedures | ALMA-05.11.21.02-0001-A-PRO |
| [AD06] | H Maser Manual | ALMA-05.11.21.05-0001-A-MAN |

## 2.2. Interface Control Documents

| Ref | Document Title | Document ID |
|---|---|---|
| [ICD01] | ICD between APP and ALMA Back End | ALMA-05.11.10.00-50.00.00.00-A-ICD |

## 2.3. Abbreviations and Acronyms

| | |
|---|---|
| AD | Applicable Document |
| ADE | ALMA Department of Engineering |
| AIV | Assembly, Integration and Verification |
| ALMA | Atacama Large Millimeter Array |
| AOS | ALMA Operation Site |
| APP | ALMA Phasing Project |
| BE | Back End |
| CLOA | Central LO Article |
| COTS | Commercial Off the Shelf |
| CRD | Central Reference Distributor |
| CRG | Central Reference Generator |
| HM | Hydrogen Maser |
| ICD | Interface Control Document |
| LO | Local Oscillator |
| Maser | T4Science Hydrogen Maser |
| MFS | Master Frequency Standard |
| MIT | Massachusetts Institute of Technology Haystack Obs. |
| NRAO | National Radio Astronomy Observatory |
| OSF | Operations Support Facility |

| | |
|---|---|
| PAI | Preliminary Acceptance In-House |
| PAS | Product Acceptance On-Site |
| RD | Reference Document |
| TBD | To Be Determined |
| TDR | Test Data Report |
| UC | Universidad de Concepcion |

# 3. PAI: Manufacturer and MIT Haystack Tests

The HM delivered and installed at the AOS was procured in 2011 and delivered to MIT Haystack Observatory for testing and study for later integration at ALMA. The manufacturer (T4Science) supplied a full test report (Factory Acceptance Test) that demonstrated the HM met all signal specifications before delivery. This report is attached as an appendix to this document. The APP PI visited the T4Science facility to observe the testing conditions and procedures.

When delivered to MIT Haystack Observatory, additional tests, similar to those typically conducted in the field, were performed. These included stability measurements between the HM and high quality quartz oscillators to verify HM performance near 1sec integration time, and between the HM and another maser to confirm stability on longer integration times. The setup for measuring phase noise and Allan Deviation is shown in Figure 1. Figure 2 is a plot of measured Allan Deviation from comparisons of the HM to both another maser (NR4 at MIT Haystack Observatory) and a crystal (SC11).

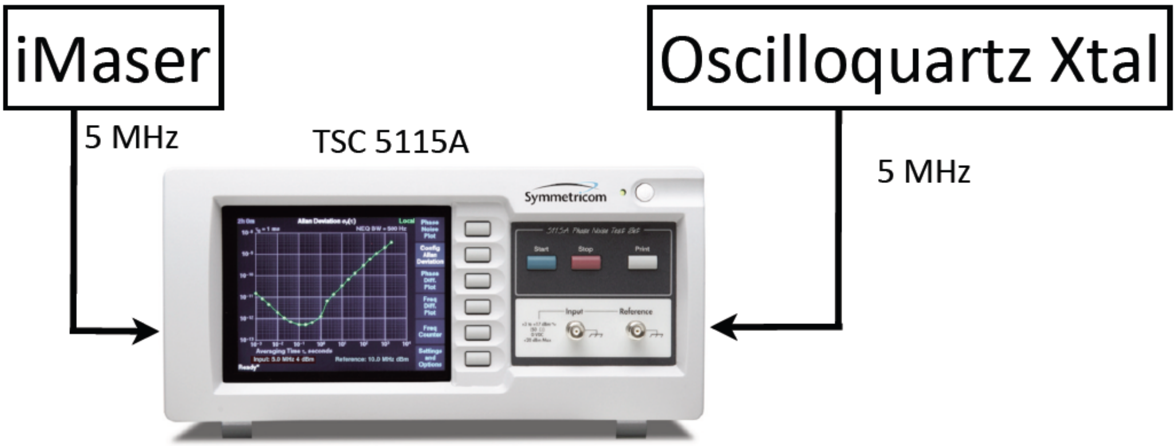


**Figure 1: Setup to measure phase noise and Allan Deviation of HM**

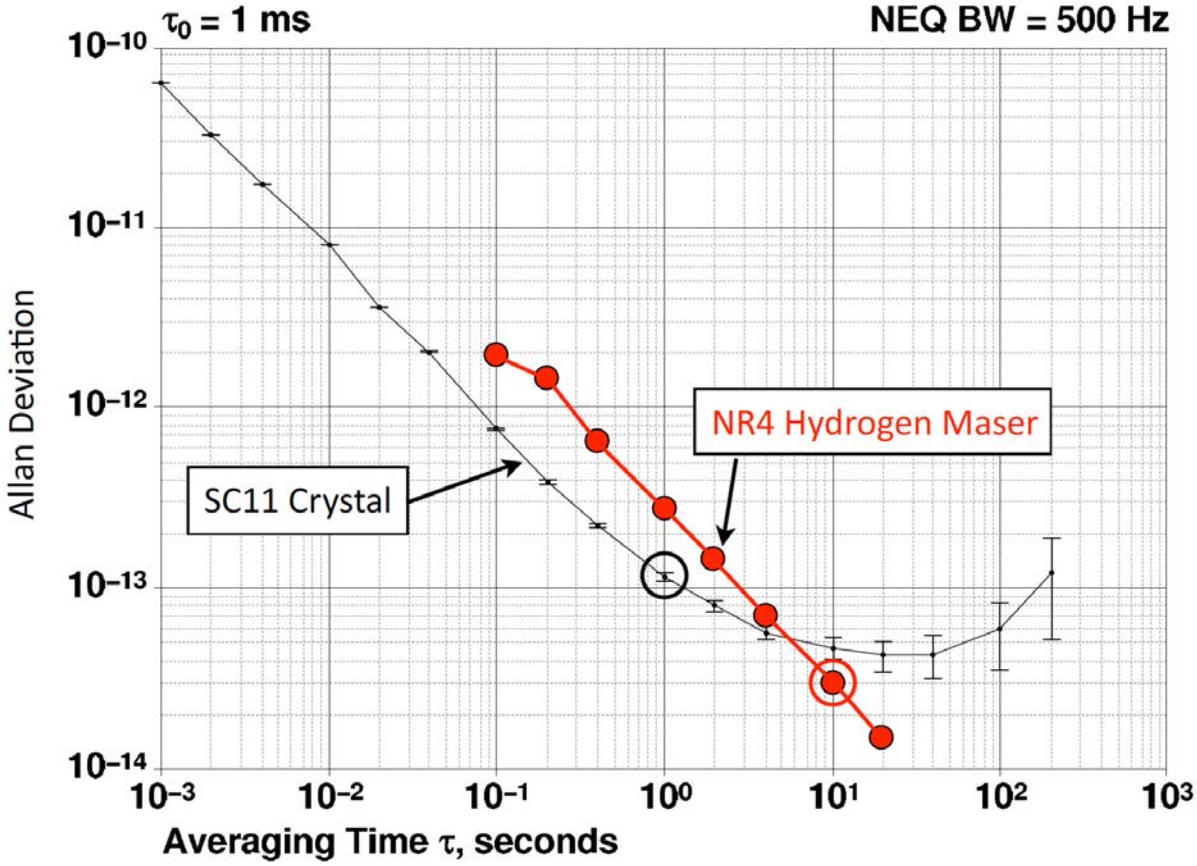


**Figure 2: Allan Deviation comparison between HM, a crystal (SC11) and another maser (NR4). At 1 second, the HM-SC11 ADev is 1.1e-13. Assuming equivalent standards, this yields an ADev for HM of 8e-14. At 10 seconds, the HM-NR4 ADev is 3e-14, which again assuming equivalent standards, results in an ADev for HM at 10 seconds of 2e-14.**

Figure 3 shows the PAI measurement of phase noise made by comparing the SC11 crystal against HM.

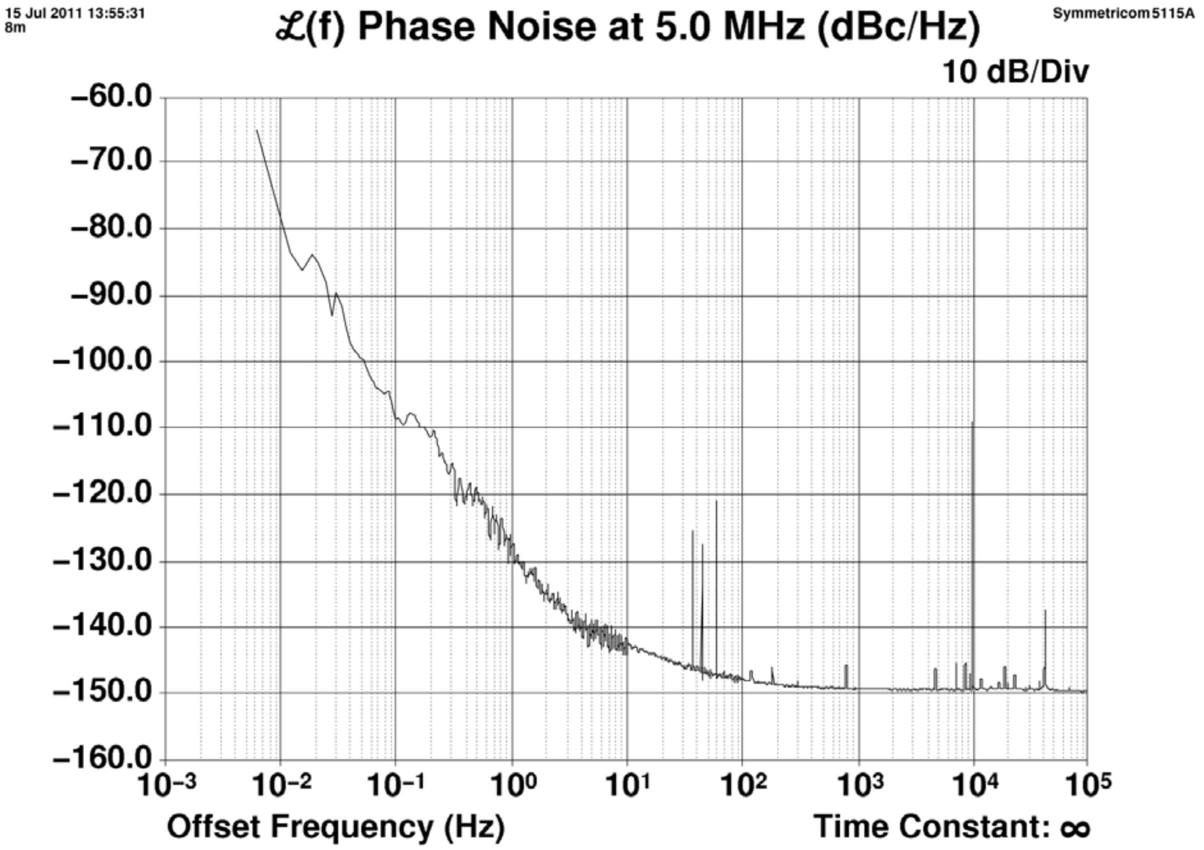


**Figure 3: Phase noise comparison between HM and the SC11 quartz crystal oscillator. At 1 Hz, the phase noise is -127 dBc/Hz. Assuming the HM and SC11 are equivalent at this frequency offset results in a phase noise level for HM at 1 Hz of -130dBc/Hz.**

These measurements confirm that at PAI, the HM met the two maser specifications:

- Allan Deviation < 2e-14 at 10 seconds: this was confirmed through measurements against the local MIT Haystack Maser (which was not as stable as the HM).
- Phase noise at 1Hz from the 5MHz output should be -130dBc/Hz: this was confirmed through measurements against a high quality quartz crystal.

# 4. PAS: Tests at AOS

## 4.1. Prior to HM Integration

After installation of the HM in the ALMA CLOA room, but before integration of the HM with the ALMA system, similar tests to those described for PAS were performed. Because there was not a second maser to verify long-term performance, comparison of the HM-produced 1PPS tick against a GPS 1PPS was monitored. Results of these tests are shown in Figures 4 and 5 below, and indicate the HM meets specifications on-site.

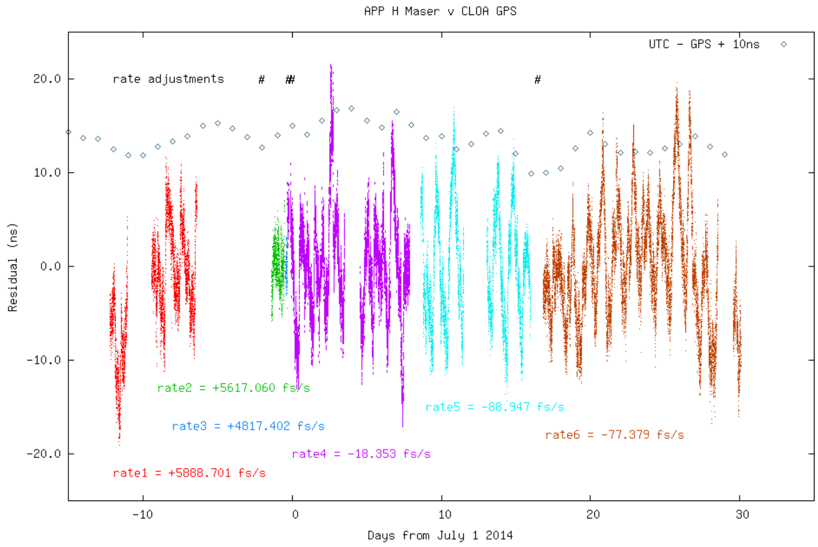


**Figure 4: Long term comparison of Maser-derived 1pps and GPS 1pps. Colored values show the offset in time between Maser and GPS 1pps ticks after the drift rates shown have been removed. Diurnal variations are due to ionospheric changes that affect GPS signal propagation. Times marked by '#' characters indicate when the maser synthesizer was adjusted to remove the measured drift rate. At the current drift rate, the maser will deviate from GPS by less than 7 ns per day.**

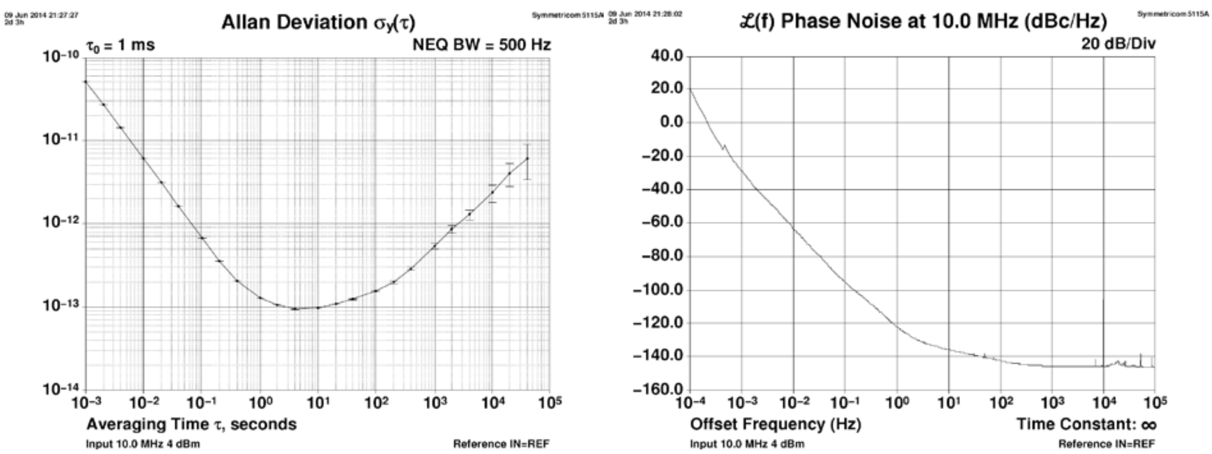


**Figure 5: Short term stability and phase noise of the Maser compared to an Oscilloquartz 8607 crystal. (left) Allan Deviation plot showing adev ~ 1.3e-13 at 1 second integration time. (right) Phase noise plot showing -122 dBc/Hz at 1 Hz from the 10MHz Maser signal. Both values are within VLBI specifications. Data taken 9 July 2014.**

## 4.2. During HM Integration

During the HM integration, the following power levels of the 5 and 10 MHz references from the maser and presented at the CVRR are listed below.

| Location | HM 10MHz Power | HM 5MHz Power |
|---|---|---|
| Top of HM | 11.6 dBm | 12.56 dBm |
| Input to CVRR | 11.45 dBm | 12.44 dBm |
| Within the CVRR | 11.40 dBm | 12.40 dBm |

The following verification of Lock Status was observed:

1. The CVRs (Agilent E8257D) relocked to the external reference.
2. The CRG locked to the 5 MHz.
3. The Analog rack LORR was locked.

## 4.3. After HM Integration

After integration, a series of EOC tests were carried out, including DelayCal's and observations of narrow line sources to check for broadening. All of these measurements are collected in EOC Memo #11 (8/3/2014). The conclusion of the EOC team, after analysis of the observations, is that the maser did not compromise normal ALMA operation in any way.

The total maser power consumption was calculated from the Housekeeping data shown in the next section.

Power = I*V = U.I[A] + U.I[B] = 2.576 * 27.905 + 0.837 * 27.661 = 95.0 W

This Power Level is well within specifications for the APP Maser (Requirement SIT-0100).

## 4.4. HM Housekeeping

The software Maser Device, available in releases starting with 2014.2 provides the internal maser housekeeping data to the usual ALMA web site (E.g. http://monitordata.osf.alma.cl/index.php?dir=2014%2F07%2F2014-07-12%2FCONTROL_VLBI_Maser%2F). Additionally, current values are provided by an embedded web server (http://10.197.48.50:80) available on the AOS network. A sample is shown in Figure 6.

**iMaser59**

14/08/2014 17:34:06 MONITORING RECORD ON 300 sec

| | | | | | |
|---|---|---|---|---|---|
| U batt.A[V] | 27.661 | EB heater[V] | 12.715 | Pirani heat.[V] | 12.115 |
| I batt.A[A] | 0.837 | I heater[V] | 6.66 | Unused | 0.054 |
| U batt.B[V] | 27.905 | T heater[V] | 8.247 | U 405kHz[V] | 11.803 |
| I batt.B[A] | 2.576 | Boxes temp[°C] | 46.777 | U OCXO[V] | 4.16 |
| Set H[V] | 5.38 | I boxes[A] | 0.585 | +24 VDC[V] | 24.9 |
| Meas. H[V] | 1.288 | Amb.temp.[°c] | 22.119 | +15 VDC[V] | 14.69 |
| I pur.[A] | 0.472 | C field[V] | 5.09 | -15 VDC[V] | -15.665 |
| I diss.[A] | 0.481 | U varactor[V] | 5.588 | +5 VDC[V] | 5.16 |
| H light[V] | 2.897 | U HT ext.[kV] | 3.502 | -5 VDC[V] | 0 |
| IT heater[V] | 10.908 | I HT ext[uA] | 5.737 | +8 VDC[V] | 8.09 |
| IB heater[V] | 8.384 | U HT int.[kV] | 3.508 | +18 VDC[V] | 17.34 |
| IS heater[V] | 0.054 | I HT int.[uA] | 6.226 | Unused | 0.08 |
| UTC heater[V] | 14.18 | H st.pres.[bar] | 1.143 | Lock | 1 |
| ES heater[V] | 11.836 | H st. heat[V] | 14.874 | DDS | 1420405750.294469 |

**Figure 6: Screenshot of Maser housekeeping from its embedded web server**

Since we were monitoring remotely, we used an ascii-based tool (derived from the aforementioned software Device), a sample output from which is shown here:

H Maser HK at <20/06/2014 11:28:27>

| | | | | | |
|---|---|---|---|---|---|
| U batt.A[V] | 27.734 | EB heater[V] | 12.681 | Pirani heat.[V] | 12.097 |
| I batt.A[A] | 0.706 | I heater[V] | 6.65 | Unused | 0.054 |
| U batt.B[V] | 28.003 | T heater[V] | 8.228 | U 405kHz[V] | 11.8635 |
| I batt.B[A] | 2.7 | Boxes tmp[C] | 46.85 | U OCXO[V] | 4.153 |
| Set H[V] | 5.38 | I boxes[A] | 0.583 | +24 VDC[V] | 24.9 |
| Meas. H[V] | 1.283 | Amb.temp.[C] | 22.18 | +15 VDC[V] | 14.77 |
| I pur.[A] | 0.471 | C field[V] | 5.088 | -15 VDC[V] | -15.74 |
| I diss.[A] | 0.481 | U varactor[V] | 5.588 | +5 VDC[V] | 5.175 |
| H light[V] | 2.897 | U HT ext.[kV] | 3.51 | -5 VDC[V] | 0 |
| IT heater[V] | 10.259 | I HT ext[uA] | 5.615 | +8 VDC[V] | 8.12 |
| IB heater[V] | 8.169 | U HT int.[kV] | 3.51 | +18 VDC[V] | 17.5 |
| IS heater[V] | 3.076 | I HT int.[uA] | 6.104 | Unused | 0.12 |
| UTC heater[V] | 14.104 | H st.pres.[bar] | 1.167 | Lock | 1 |
| ES heater[V] | 11.802 | H st. heat[V] | 14.862 | DDS | 1420405750.302645 |

The meaning and expected values of the various sensors is explained in [AD06].