Characteristics and Performance of the North American ALMA Prototype Antenna

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Abstract. The submillimeter antennas of the Atacama Large Millimeter Array (ALMA) have specifications that are beyond the current state of the art in accurate reflector antenna technology. Considering that as many as 64 of these antennas would eventually be needed, the ALMA partners AUI/NRAO and ESO each agreed to acquire a prototype antenna, and subject these to an extensive evaluation program. In this paper we summarize the performance of the ALMA North American prototype antenna.

1. Design Characteristics

The ALMA antennas are alt-azimuth mounted Cassegrain dual-reflector systems of 12m diameter with a reflector surface and pointing accuracy suitable for observations in the 0.3 mm submillimeter band. On 2003/10/01 VertexRSI delivered the North American prototype antenna to AUI/NRAO. The VertexRSI prototype antenna (Figure 1) includes a number of innovative design features to ensure its performance to the ALMA specifications:
Figure 1. The VertexRSI ALMA prototype antenna.

Figure 2. Left: Three BUS segments (foreground) installed on the Invar mounting ring (white disk, bottom). Note the open box structure of each of the BUS segments. Middle: Installation of insulating material on the VertexRSI prototype antenna fork arm (left) and receiver cabin. All insulated structures are additionally covered with a white metal skin to complete the insulation structure and provide weather resistance. Right: Reflector panel installation on the VertexRSI prototype antenna.
• To minimise the structural deformations due to temperature changes, carbon-fiber reinforced-plastic (CFRP) is used for the back-up structure (BUS) of the reflector.

• The BUS is a box-structure, thus avoiding the need to design and fabricate the intricate joints of a space-frame structure in CFRP (Figure 2).

• Insulated steel is used for the receiver cabin and fork arms (Figure 2). Invar is used for the connection cone to the BUS.

• The drive system uses a traditional pinion and gear rack system.

• The reflector panels are made of machined aluminum and chemically etched to achieve the required effective scattering of solar heat radiation (Figure 2).

2. Performance Specifications and Results

The major performance specifications, results, and the primary operating conditions during which these specifications apply, for the ALMA prototype antennas are listed in Table 1. In the following we briefly describe how the performance of the VertexRSI prototype antenna was derived within the context of each performance specification. A more detailed description of the evaluation results for both ALMA prototype antennas can be found in Mangum et al. (2004), Baars et al. (2006), Greve & Mangum (2006), Mangum et al. (2006), and Snel (2006).

### Table 1. VertexRSI Prototype Antenna Performance Overview

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification</th>
<th>Performance</th>
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<tbody>
<tr>
<td>Surface Accuracy</td>
<td>25 µm RMS with 20 µm RMS goal</td>
<td>16±5 µm</td>
</tr>
<tr>
<td>Absolute Pointing</td>
<td>2 arcsec over all sky</td>
<td>1.3–1.8 arcsec</td>
</tr>
<tr>
<td>Offset Pointing</td>
<td>0.6 arcsec over 2 degrees radius</td>
<td>0.3–1.1 arcsec</td>
</tr>
<tr>
<td>Fast Switching</td>
<td>1.5 degree move in 1.5 seconds, settle to 3 arcsec peak pointing error</td>
<td>1.5–1.8 seconds</td>
</tr>
<tr>
<td>Path Length Stability</td>
<td>15/20 µm (Nonrepeatable/Repeatable)</td>
<td>10–30 µm for Δt&lt; 30 min</td>
</tr>
<tr>
<td>Primary Operating Conditions</td>
<td>−20°C ≤ T_{amb} ≤ +20°C; ΔT_{amb} ≤ 0.6/1.8°C in 10/30 minutes; V_{wind} ≤ 6/9 m/s (day/night); Full solar loading</td>
<td></td>
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2.1. Reflector Surface Accuracy

A near-field holographic method was used to measure and set the surface to an accuracy of better than 20 µm RMS. A transmitter on a 50 m high tower at a distance of 310 m provided the signal at 79 or 104 GHz. See Mangum et al. (2004) and Baars et al. (2006) for further details describing this holographic technique. Figure 3 shows a typical surface error map derived from these holographic measurements.
Figure 3. Holographic surface map of the VertexRSI antenna. The measurements were made in February 2005. Note that the “+” feed leg structure and the difficulties encountered with holographic measurements near these structures leads to the poor measurement results in these areas.

Figure 4. Sample good (left) and typical (right) OPT pointing residual plots. Shown are the measurement residuals following application of a 13 term pointing model.

2.2. Absolute and Offset Pointing

Pointing tests relied on measurements made with three distinct systems:

- An optical pointing telescope (OPT) mounted within the BUS. The OPT is a NRAO-designed refracting telescope composed of a 4 inch lens mounted within a rolled-Invar tube. The detector used was a commercial CCD camera coupled to a video frame grabber. Figure 4 shows a sample absolute (all-sky) pointing residual plots obtained with the OPT system.

- Radiometric measurements at 1 and 3 mm wavelength. Figure 5 shows a sample single dish image obtained with this receiver system.

- Accelerometer measurements. Detailed information on this measurement system and the evaluation results obtained can be found in Snel (2006).
2.3. Fast Switching

The fast switching performance of the VertexRSI prototype antenna was measured using the same three systems used to derive the pointing performance (see §2.2.). Figure 6 shows a sample fast switching performance measurement made with the 3mm radiometric system.

2.4. Path Length Stability

The path length stability of the VertexRSI prototype antenna structure was measured using an Automated Precision Incorporated (API) 5-D laser interferometer. Since the total path length variation cannot be measured with a single measurement, the total path length was separated into four parts (pedestal, fork arm, Invar cone to subreflector, and subreflector to surface) and measured during a representative sample of observing conditions and operation modes. Figure 7 shows a summary of these path length stability measurement results.

3. Conclusions

The overall design and performance of the VertexRSI prototype antenna represents an attractive option for a production antenna which will satisfy the stringent ALMA requirements.

Acknowledgments. The contributions of the following individuals were necessary for the success of the ALMA prototype antenna evaluation process: Marc Rafal (Commonwealth Technical Associates LLC); Fritz Stauffer, Nicholas Emerson, Jinquan Cheng, Jack Meadows, Mark Holdaway (NRAO); Angel Otárola (ESO); José Lopez-Perez (OAN); David Smith (MERLAB); Michael Bremer (IRAM); and Henry Matthews (HIA).
Figure 6. Radiometrically-inferred AZ (left) and EL (right) pointing errors or an AZ- and El-slew, respectively, along with encoder errors. The mean radiometrically-inferred (solid black) and mean azimuth (cyan triangle) and elevation (purple dashed) encoder pointing errors as a function of time since the start of the 1.5 deg fast switching slew are shown. The source is reached with 3 arcsec pointing errors about 1.7 s after the start of the slew, and the mean AZ pointing error after 2.0 s is less than 0.5 arcsec.

Figure 7. Summary path length stability results for the VertexRSI prototype antenna. Shown are the daily RMS variation of path length L1 (pedestal, top), L2 (fork arm, middle), and L3 (Invar cone to subreflector, bottom) as a function of time of day (UT). The data have been binned into time intervals of 3, 10, and 30 minutes. Note the difference in scale for each path length measurement. The stability of the L2 and L3 paths are significantly better around 15 hr (UT), which is near sunrise in New Mexico, where the ambient temperature change is near zero.
References


