ALMA Bandpass Calibration: Standing Waves

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Standing Waves: background

- Reflection of incident wave on feed system of standing waves between receiver and sub-reflector
- On single-dish telescopes: standing waves between receiver and calibration load

ALMA antenna
Frequency of standing waves

\[ v_n = \frac{n \cdot c}{2 \cdot D} \]

Where \( D \) is the distance between the feed and the secondary.

Consequence: ripple of frequency \( v_{\text{ripple}} = \frac{c}{2D} \)

Example: spectrum at the IRAM 30m
\( D = 5 \text{ m} \Rightarrow v = 30 \text{ MHz} \)
Reducing standing waves

- **Baseline ripple substantially degrades spectral observations**
  - During observations: reflection receiver-secondary mirror “high frequency ripple”
  - During calibration scans: reflection receiver - calibration load also end up in observed spectrum

- **reducing the amplitude of the ripple ⇒ reducing the reflection coefficient**
  - No control of the reflection on the feed
  - Need to reduce the reflection coefficient on the sub-reflector
Reflection coefficient

\[ \gamma = \int \Psi (\Psi^*)^* \cdot dS \]

\[ \Psi = F(\theta) \cdot \exp(-jkr(\theta)) \]

\( F \): gaussian illumination function

\[ \gamma = \int_{0}^{\theta_s} 2\pi \cdot F^2(\theta) \sin(\theta) \exp(-2jkr(\theta)) d\theta \]
Asymptotical expression

\[
\gamma = \frac{2\pi}{2 jkLe(e - 1)} \times \left[ F^2(\theta_0)(e \cos(\theta_0) - 1)^2 \exp(-2 jkr(\theta_0)) \right.
\]
\[
- F^2(\theta_s)(e \cos(\theta_s) - 1)^2 \exp(-2 jkr(\theta_s)) \right]
\]

\[
e: \text{eccentricity}
\]
\[
L: \text{distance to mirror vertex}
\]

Due to gaussian tapering, the second term can be neglected

\[
\Rightarrow \gamma \propto \lambda
\]

Standing waves are most disturbing at long wavelengths

If both terms are considered: \( \gamma \) will oscillate with \( \lambda \) around an increasing mean value

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Representation of reflection coefficient in the complex plane

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Considered Sub-reflector Geometries

Study of the effect of various sub-reflector geometries on the reflection coefficient

- Effect of an absorber on the blocage zone
- Effect of a discontinuity (aperture in sub-reflector)
- Effect of a scattering cone
Mirror alone
Mirror with absorbing disk between $0$ and $\theta_b$
Mirror with tangent cone of semi-angle $\alpha$
Sub-reflector with aperture

Sub-reflector with aperture, cone within aperture

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Possible design for sub-reflector

Aperture in sub-reflector

45° mirror
deflecting light towards
- load (calibration measurements)
- cone (observations)

Calibration: coupling of load to receiver \(\sim 1\%\)

\(\Rightarrow\) Avoids saturation of receiver
Simple sub-reflector
Tangent cone on Sub-reflector

But if $\alpha$ is small, the cone covers much of the sub-reflector

\[ \Rightarrow \alpha < 87^\circ \]
Sub-reflector with discontinuity at 3 mm

\[ \gamma \approx 0.009 \text{ with discontinuity} \]
\[ \gamma \approx 0.0045 \text{ with absorbing disk} \]

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Aperture with cone at 3 mm

At angles < 85°, $\gamma \sim$ same value as without aperture (0.005)
Standing Wave Ratio

- Incident amplitude on the feed:

\[ b = \frac{a \cdot t_s}{1 - r_s r_m \exp(-2j\psi)} \]

In amplitude:

\[ \frac{|b_{\text{max}}|}{|b_{\text{min}}|} \approx 1 + 2 \cdot r_s r_m \]

In power:

\[ \frac{P_{\text{max}}}{P_{\text{min}}} \approx 1 + 4 \cdot r_s r_m \]
Values for ALMA

peak-to-peak ripple at 3mm

For $r_m \sim 0.4$

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<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Absorbing disk</td>
<td>0.7%</td>
</tr>
<tr>
<td>Tangent cone</td>
<td>0.08%</td>
</tr>
<tr>
<td>Aperture without cone</td>
<td>1.3%</td>
</tr>
<tr>
<td>Aperture with cone</td>
<td>0.8%</td>
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</tbody>
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Summary

• At 3 mm, baseline ripple can reach ~1%

• Aperture in sub-reflector increases ripple by a factor of 2

• Can be reduced with cone within aperture

• Tangent cone is the best solution but choice of $\alpha =$ compromise