ALMA Bandpass Calibration: Standing Waves

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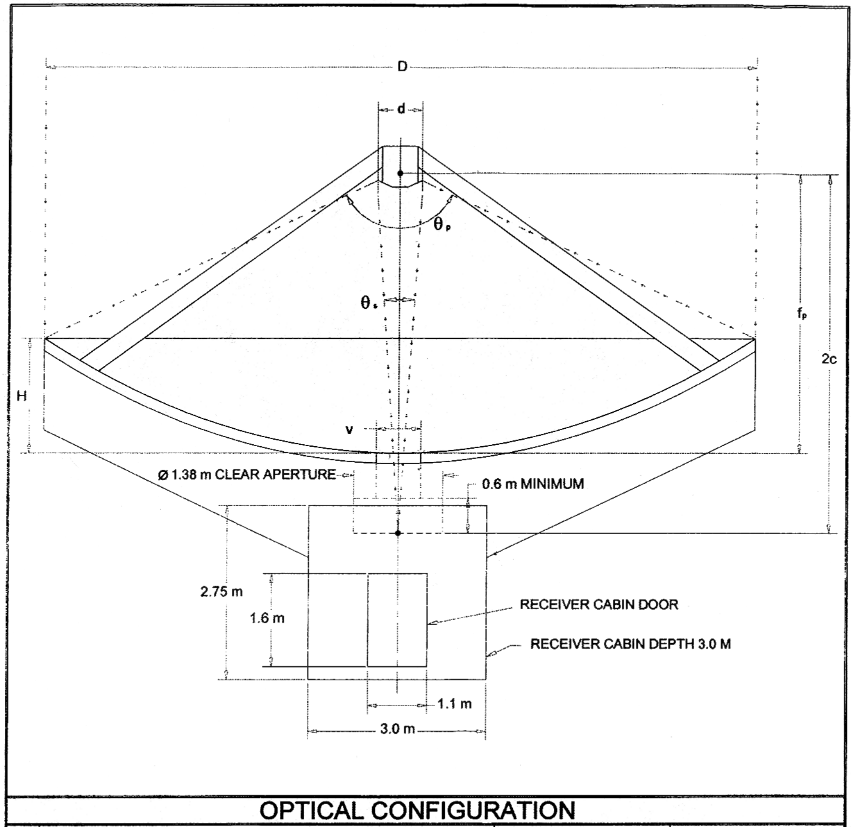
Standing Waves: background

- 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

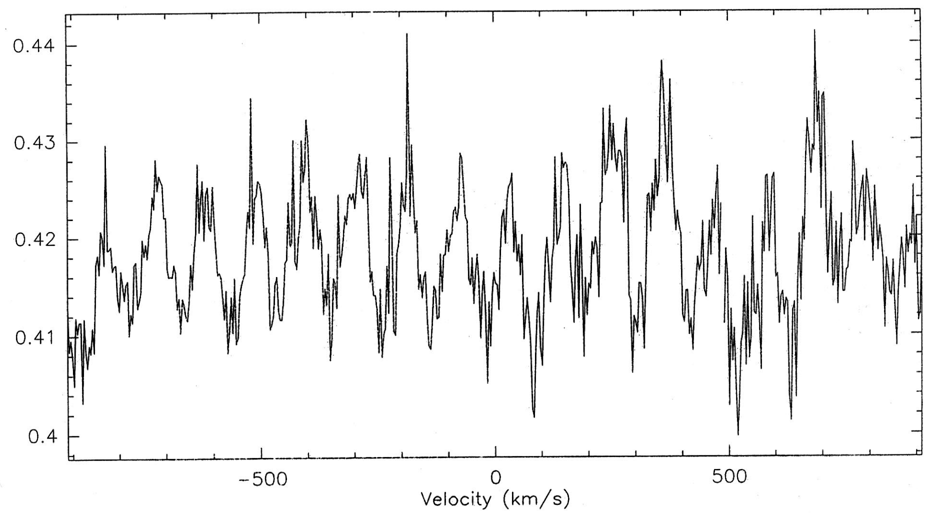
$$\upsilon_n = \frac{n \cdot c}{2 \cdot D}$$

Where *D* is the distance between the feed and the secondary

Consequence: ripple of frequency $\upsilon_{ripple} = \frac{c}{2D}$

Example: spectrum at the IRAM 30m

D = 5 m ⇨ υ = 30 MHz



Reducing standing waves

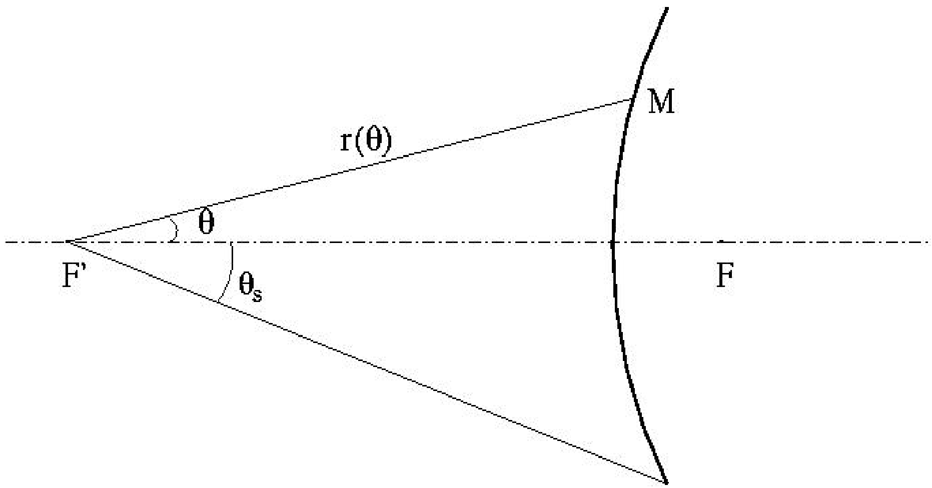
- Baseline ripple substantially degrades spectral observations
  - During observations: reflection receiver-secondary mirror "high frequency ripple"
  - During calibration scans: reflection receiver - calibration load

  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

$$\gamma = \int_{subref} \Psi(\Psi^*)^* \cdot dS$$



$$\Psi = F(\theta) \cdot \exp(-jkr(\theta))$$

F: gaussian illumination function

$$\gamma = \int_0^{\theta_s} 2\pi \cdot F^2(\theta) \sin(\theta) \exp(-2jkr(\theta)) d\theta$$

Asymptotical expression

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

e: eccentricity
L: distance to mirror vertex

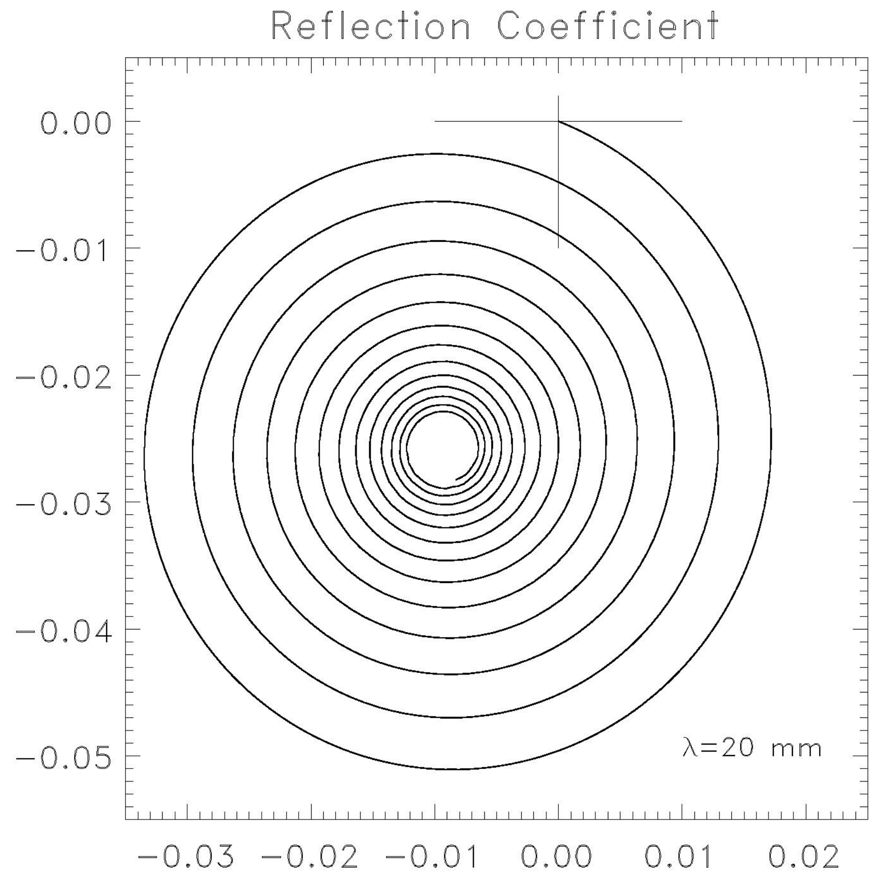
Due to gaussian tapering, the second term can be neglected

$$\Rightarrow \gamma \propto \lambda$$

Standing waves are most disturbing at long wavelengths

If both terms are considered: γ will oscillate with λ around an increasing mean value

Representation of reflection coefficient in the complex plane



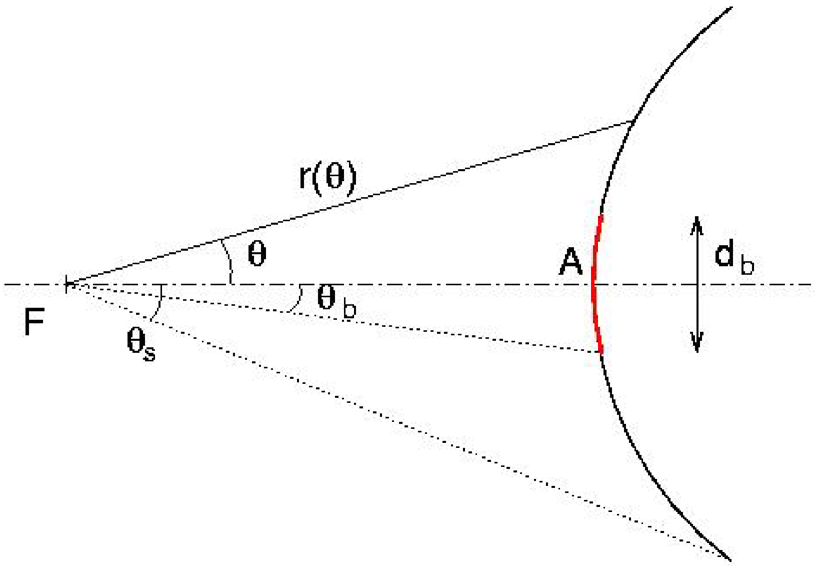
Considered Sub-reflector Geometries

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

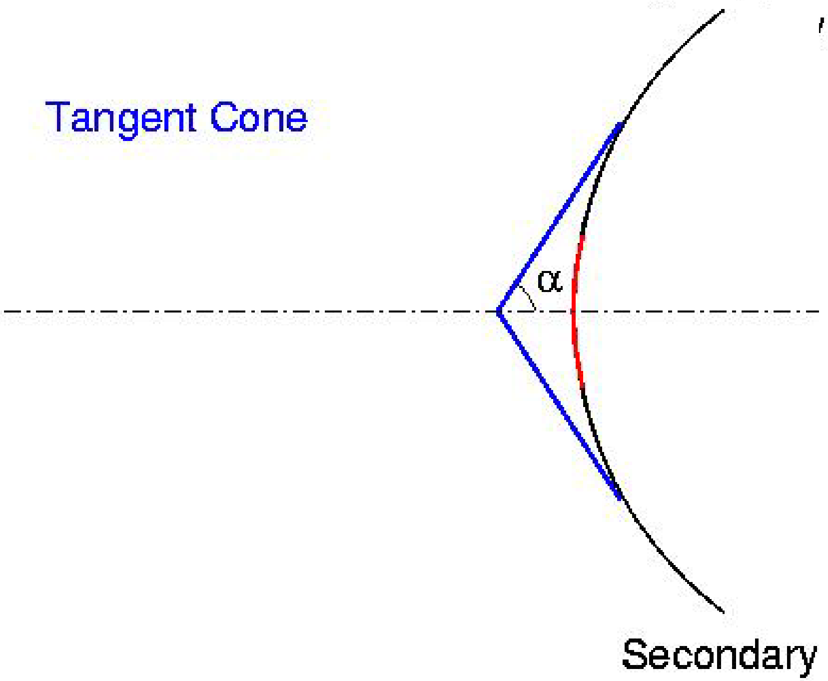
- Effect of an absorber on the blocage zone
- Effect of a discontinuity (aperture in sub-reflector)
- Effect of a scattering cone

Mirror alone

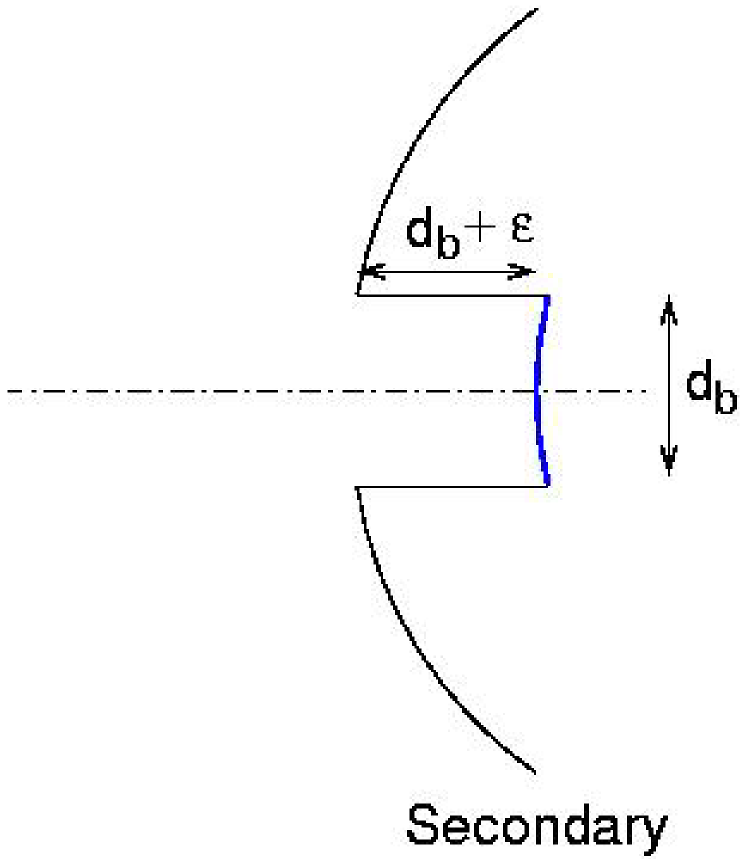
Mirror with absorbing disk between 0 and θ_b



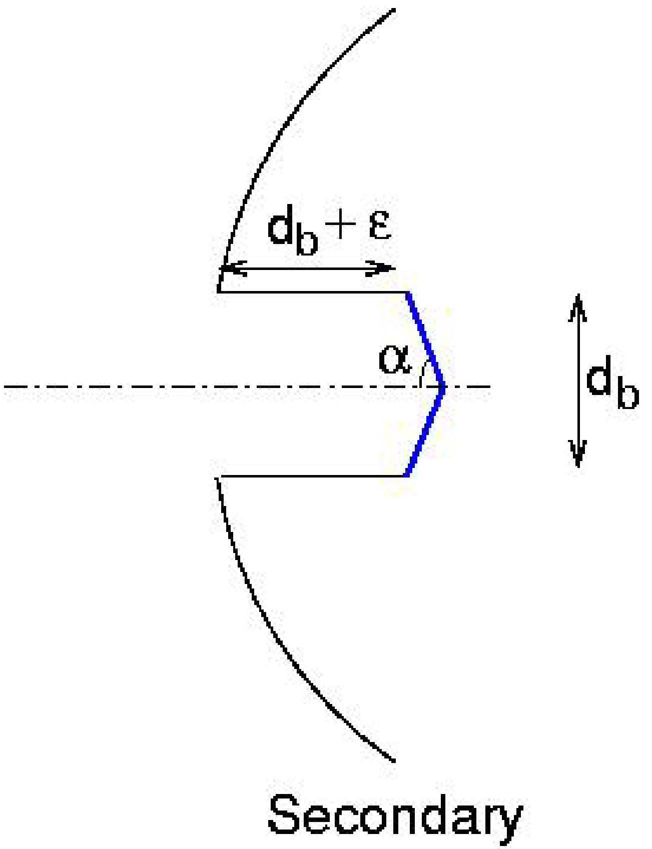
Mirror with tangent cone of semi-angle α



Sub-reflector with aperture



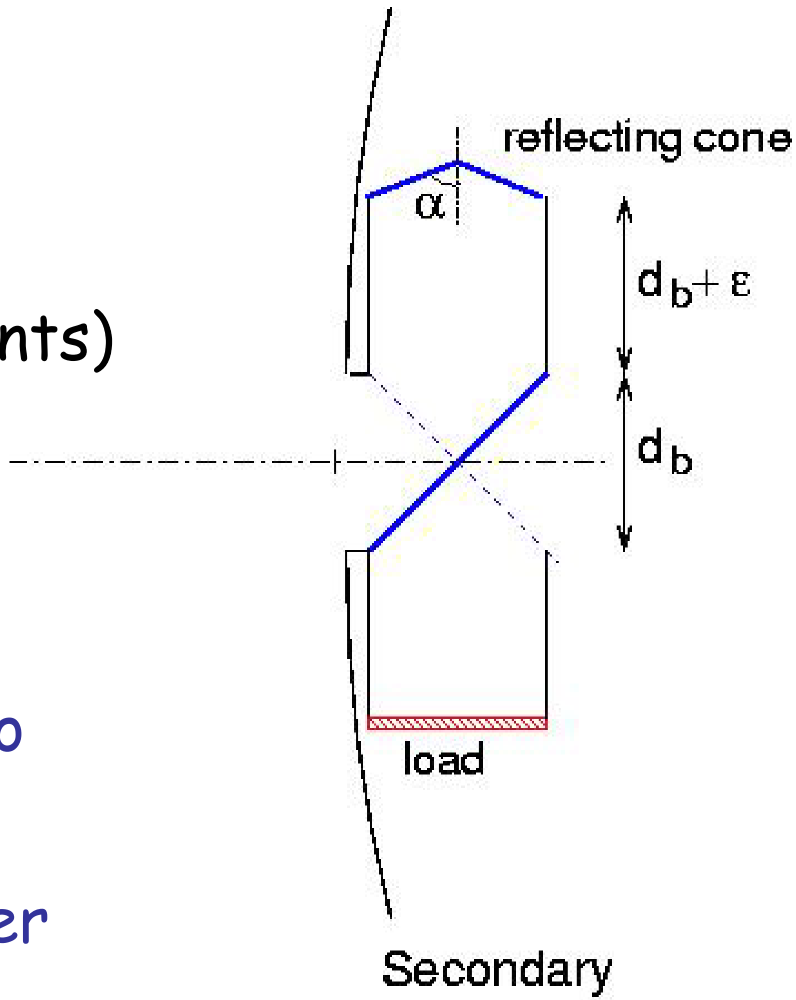
Sub-reflector with aperture, cone within aperture



Possible design for sub-reflector

Aperture in sub-reflector

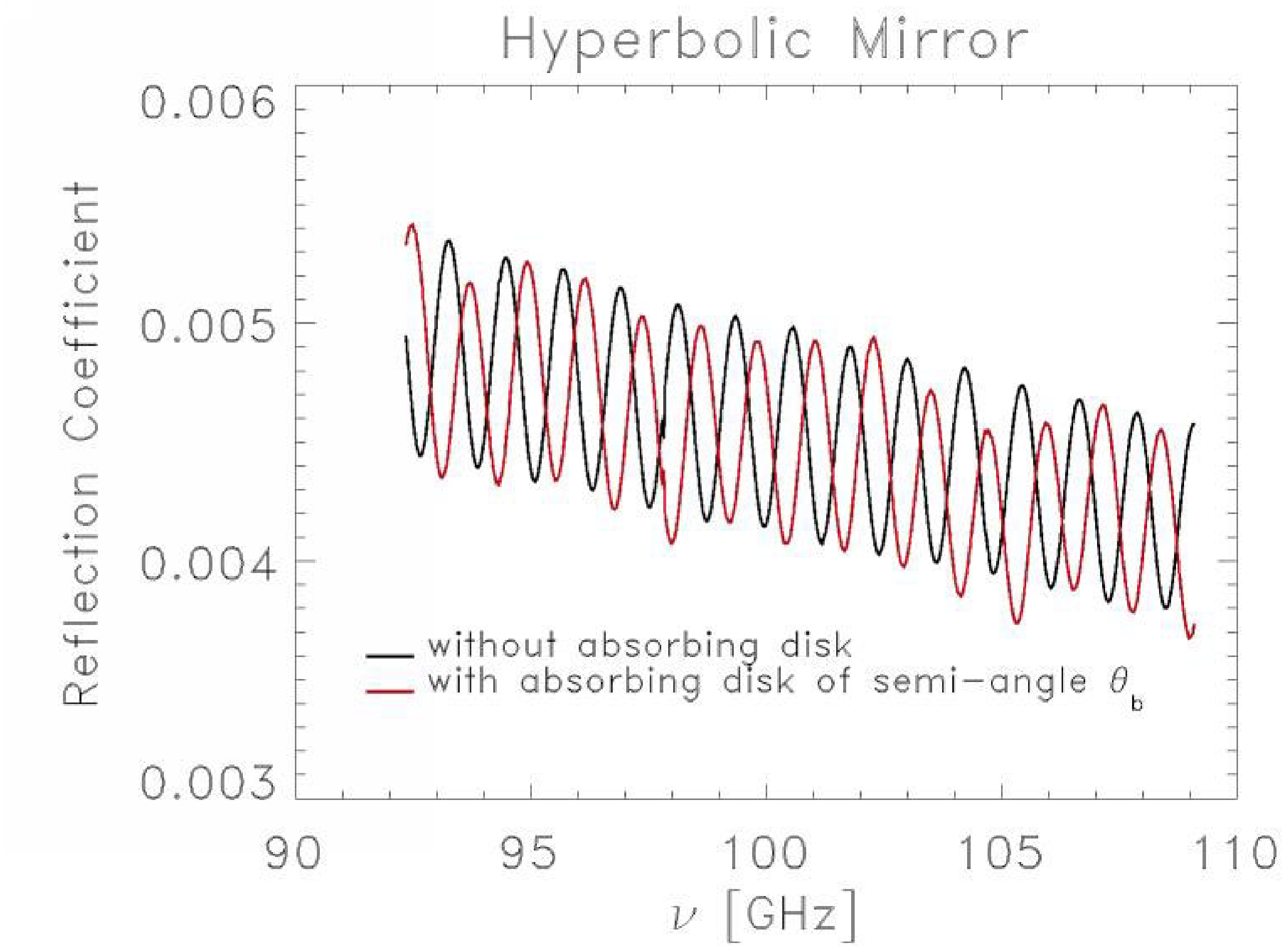
45° mirror
deflecting light towards
- load (calibration measurements)
- cone (observations)



Calibration: coupling of load to receiver ~ 1%

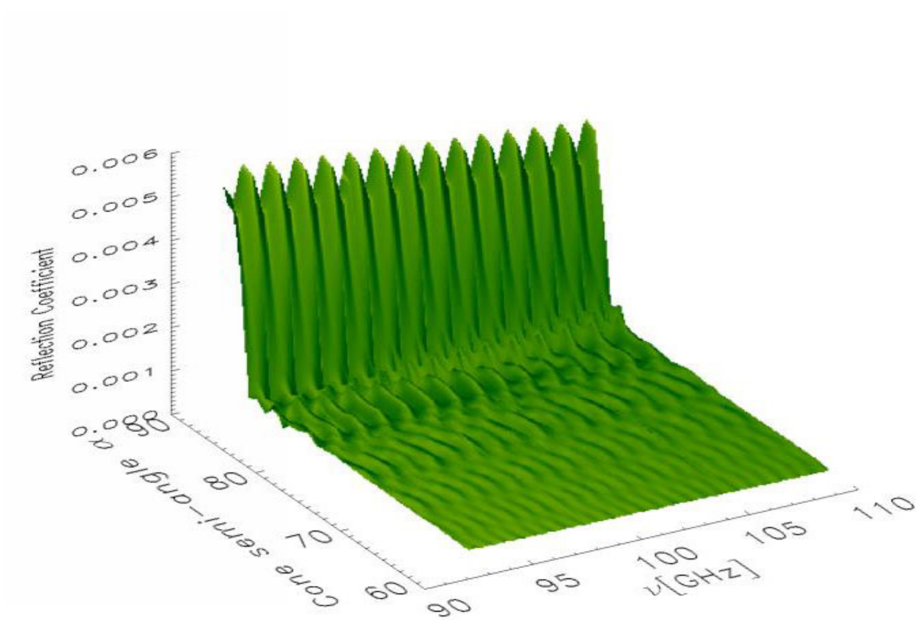
⇨ Avoids saturation of receiver

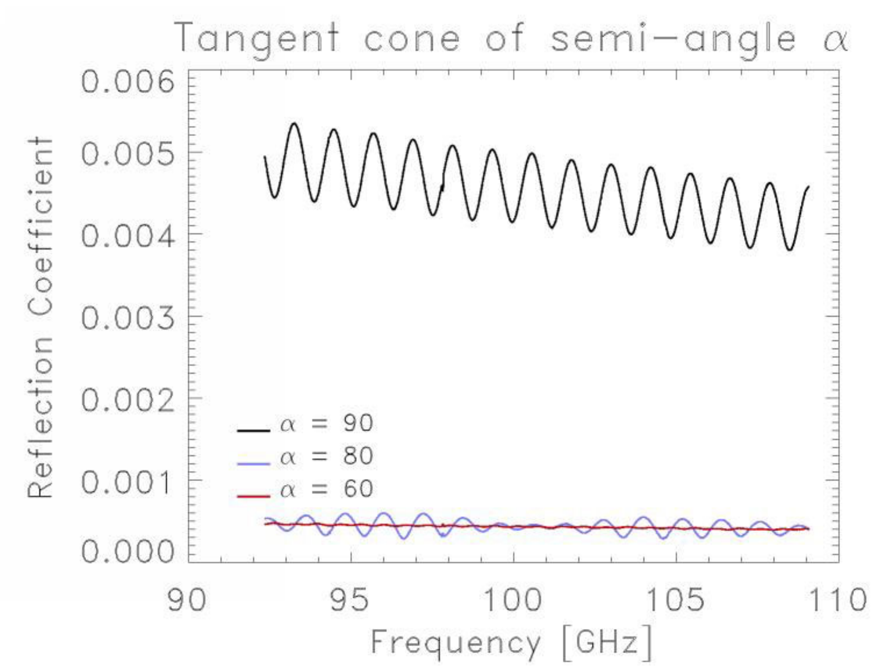
Simple sub-reflector



Tangent cone on Sub-reflector

3 mm



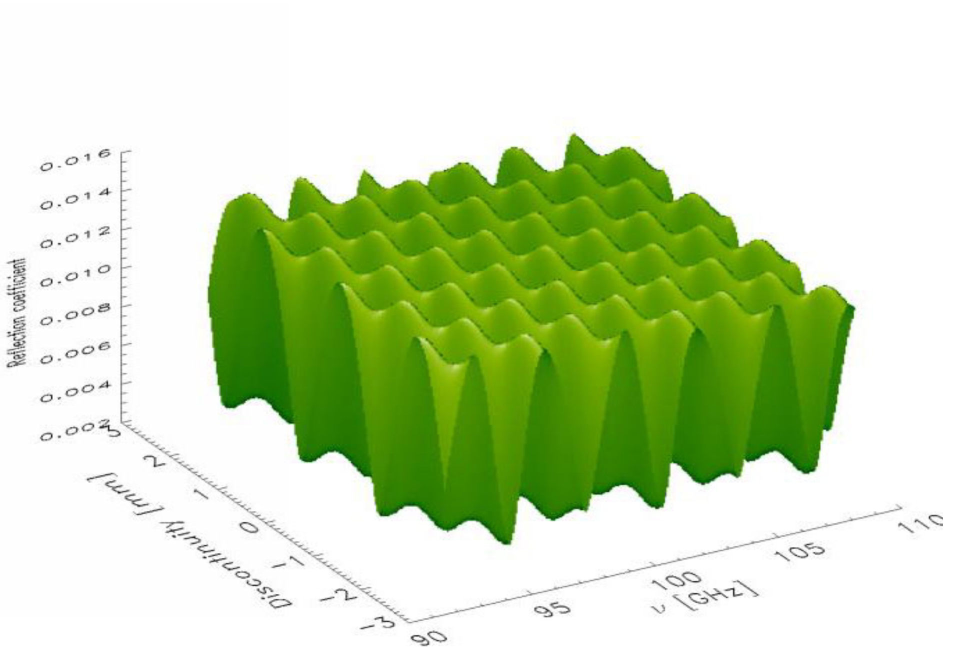


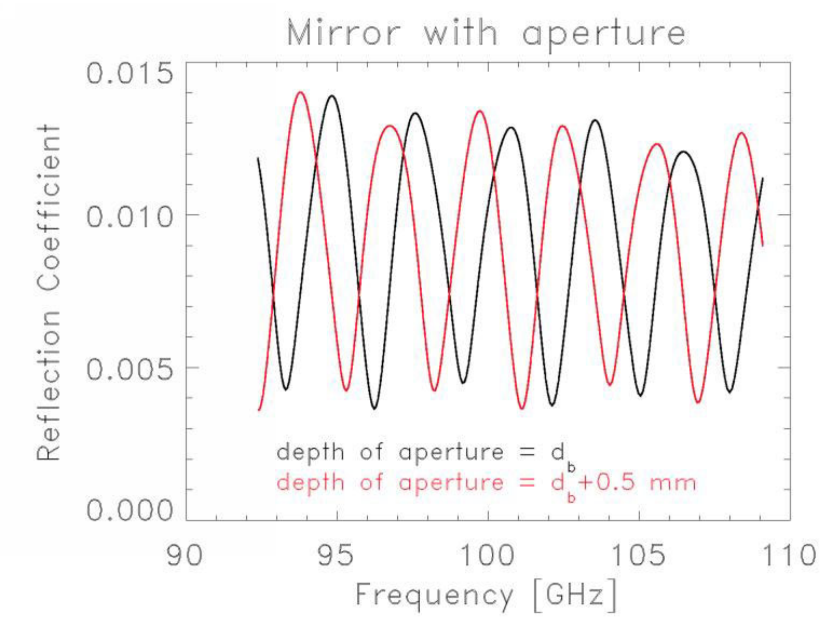
⇨ α < 87°

But if α is small, the cone covers much of the sub-reflector

Sub-reflector with discontinuity

at 3 mm

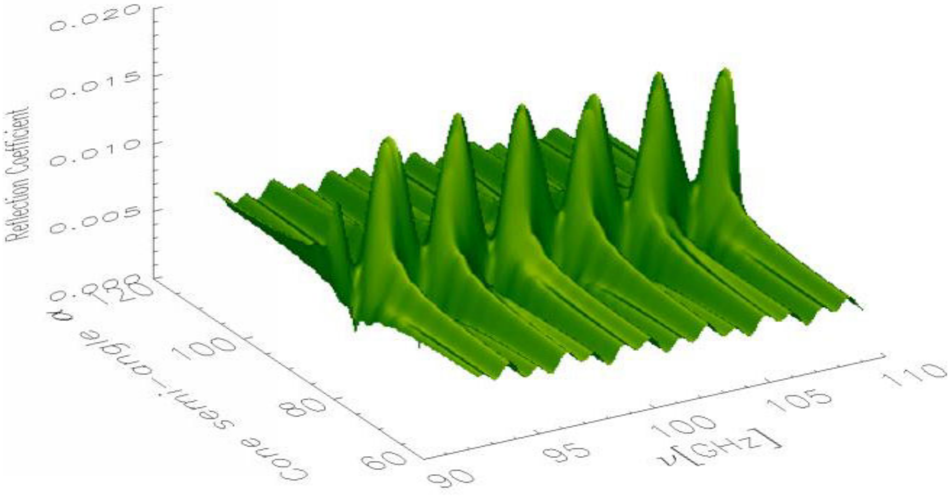


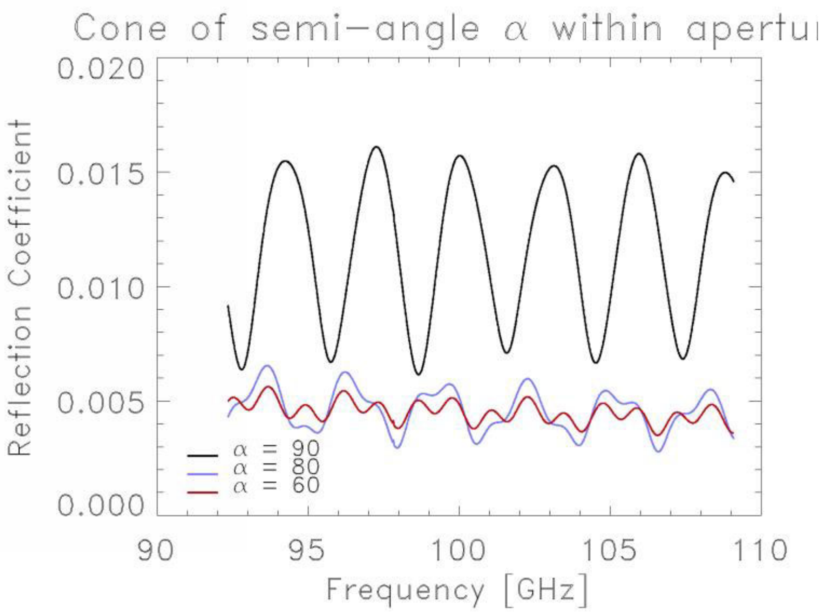


$\gamma \sim$ 0.009 with discontinuity
$\gamma \sim$ 0.0045 with absorbing disk

Aperture with cone

at 3 mm

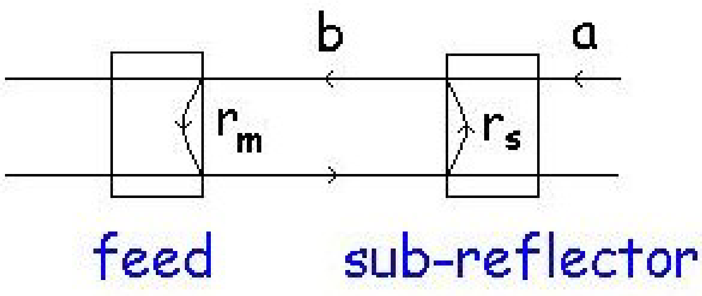




At angles < 85°, γ ~ same value as without aperture (0.005)

Standing Wave Ratio

- Incident amplitude on the feed:



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

In amplitude:

$$|b_{\max}| \big/ |b_{\min}| \approx 1 + 2 \cdot r_s r_m$$

In power:

$$P_{\max} \big/ P_{\min} \approx 1 + 4 \cdot r_s r_m$$

Values for ALMA

peak-to-peak ripple at 3mm

For $r_m \sim 0.4$

Absorbing disk	0.7%
Tangent cone	0.08%
Aperture without cone	1.3%
Aperture with cone	0.8%

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 α = compromise