Radiation Properties of a Large Faceted Reflector Antenna

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Outline

- ▷ Introduction to the Large Adaptive Reflector (LAR)
- ▷ Analysis method
- ▷ LAR geometry
- ▷ Efficiency of reflector panels
  - ▷ flat panels
  - ▷ sagging panels
  - ▷ other outlines
- ▷ Grating lobes generated by faceted reflector
  - ▷ generation of grating lobes
  - ▷ array configuration with grating responses
  - ▷ methods to suppress grating lobes

The Large Adaptive Reflector (LAR)

- Large diameter: $\sim 200\text{–}300\mathrm{m}$
  - Long focal length: $\sim 500\mathrm{m}$
  - $\Rightarrow f/D = 2.5$
- Reflector segmented and supported by vertical actuators
  - use flat panels
  - piece-wise approximation to parabola

What are the properties of such a reflector antenna?

Analysis Method

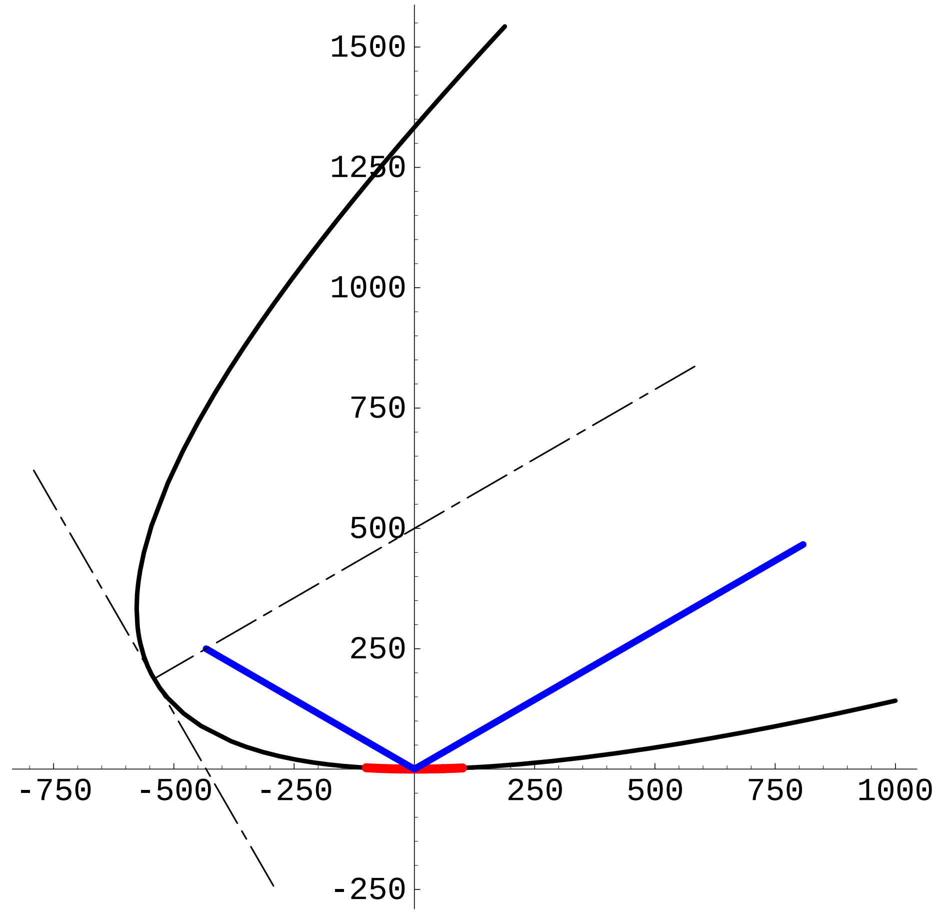
Use Convolution Theorem to separate radiation pattern of individual panels from that of the ensemble of panels

$$
\begin{array}{rclr}
g(u) & = & [p(u) \star \upuparrows(u)] \times a(u) & \text{Near field} \\
 & \mathcal{F} \updownarrow & & \\
G(\phi) & = & [P(\phi) \times \upuparrows(\phi)] \star A(\phi) & \text{Far field}
\end{array}
$$

$g(u)$	Aperture distribution	$G(\phi)$	Radiation pattern
$p(u)$	Panel illum.	$P(\phi)$	Panel pattern
$\upuparrows(u)$	Aperture sampling fnc.	$\upuparrows(\phi)$	Array pattern
$a(u)$	Aperture illum.	$A(\phi)$	Aperture rad. pat.

Treat reflector antenna as a phased array

LAR Geometry



Equation for Offset Parabola

- Symmetric parabola: $z = (x^2 + y^2)/(4f)$
- Apply coördinate translations
- Apply coördinate rotations
- Apply relations defining centre of new coördinate system
- Relate focal distance to parabola focal length
- Solve quadratic:

$$z_r = \frac{4R + 2\sin\theta_{za} x_r - \sqrt{4R^2 + 4R\sin\theta_{za} - y_r^2 \tan^2\theta_{za}}}{2\tan\theta_{za}\sin\theta_{za}}$$

- Avoid singularity for small angles:

$$z_{approx} = \frac{x_r^2\cos^2\theta_{za} + y_r^2}{2\cos\theta_{za}(2R + x_r\sin\theta_{za})}$$

Efficiency Calculation for Facets

- ▷ Assume symmetric case
- ▷ Path error (difference between parabola and flat panel):

$$\varepsilon(r) \simeq 2\frac{r^2}{4f} = \frac{r^2}{2f}$$

- ▷ Phase error:

$$\phi(r) = -\varepsilon(r)\frac{2\pi}{\lambda} \simeq -\frac{\pi r^2}{\lambda f}$$

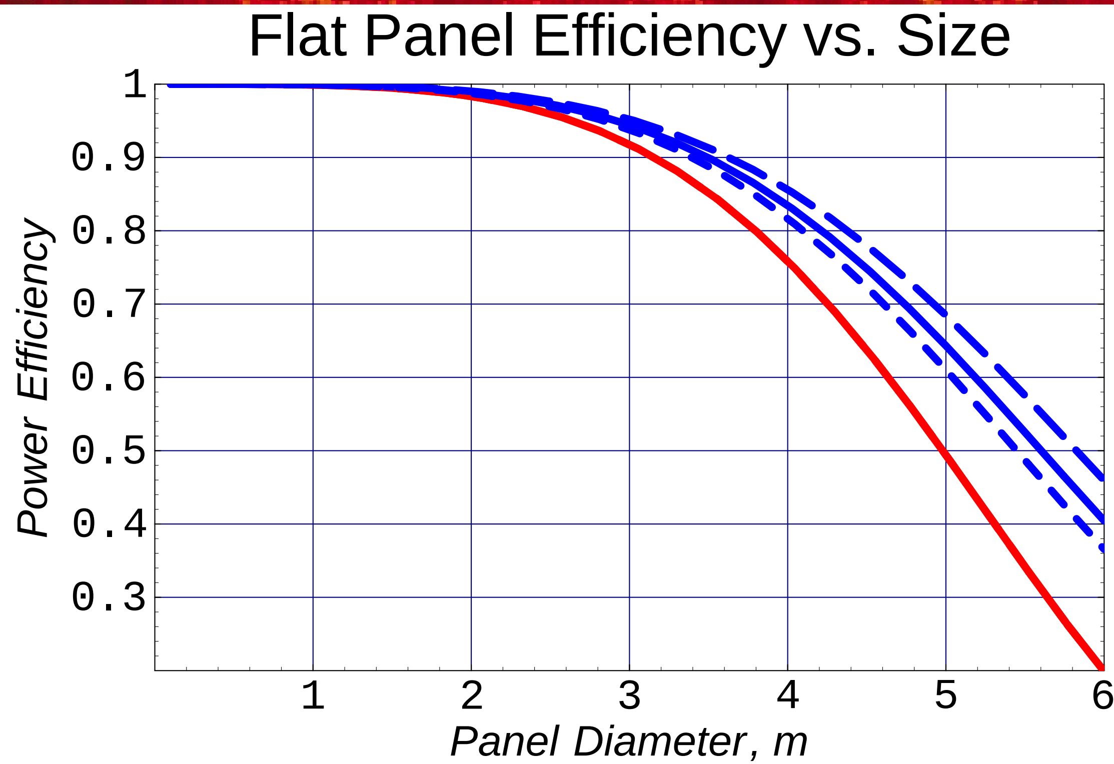
- ▷ Integrate over circular area
- ▷ Take magnitude and square to get power efficiency:

$$P(r) = (\mathrm{sin}(\frac{\pi L^2}{8\lambda f})/(\frac{\pi L^2}{8\lambda f}))^2$$

Efficiency Calculation — General Case

- ▷ Want efficiency for any panel, for any zenith angle
- ▷ Define path error as difference between tangent plane and ideal parabolic surface
- ▷ For zenith angles $\neq 0$ multiply path errors by $\cos\theta_{za}$ [ref: Levy]
- ▷ Integrate, take magnitude, and square
- ▷ Approximate hexagonal panels with circles
- ▷ Triangular panels require numerical integration

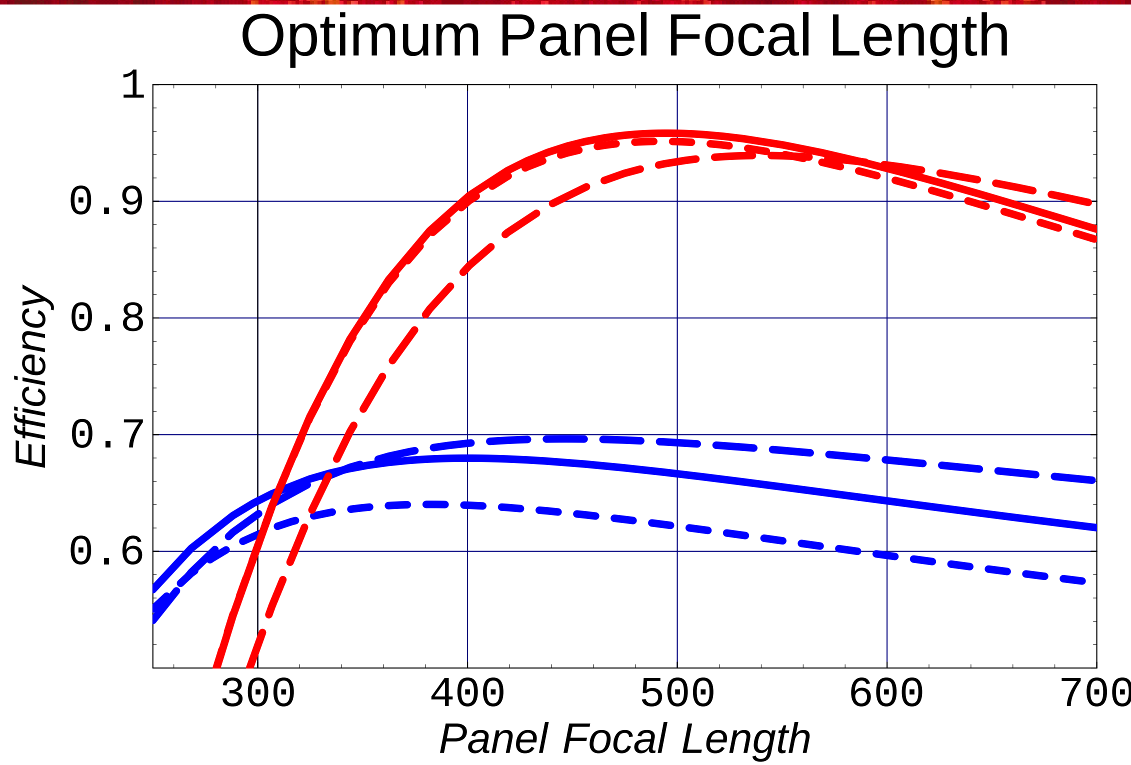
Efficiency Calculation — Flat Panel Results



$\lambda = 1.4$cm; Red $\Rightarrow \theta_{za} = 0$; Blue $\Rightarrow \theta_{za} = 60^\circ$

solid line $\Rightarrow$ central panel; dashed line $\Rightarrow$edge panels

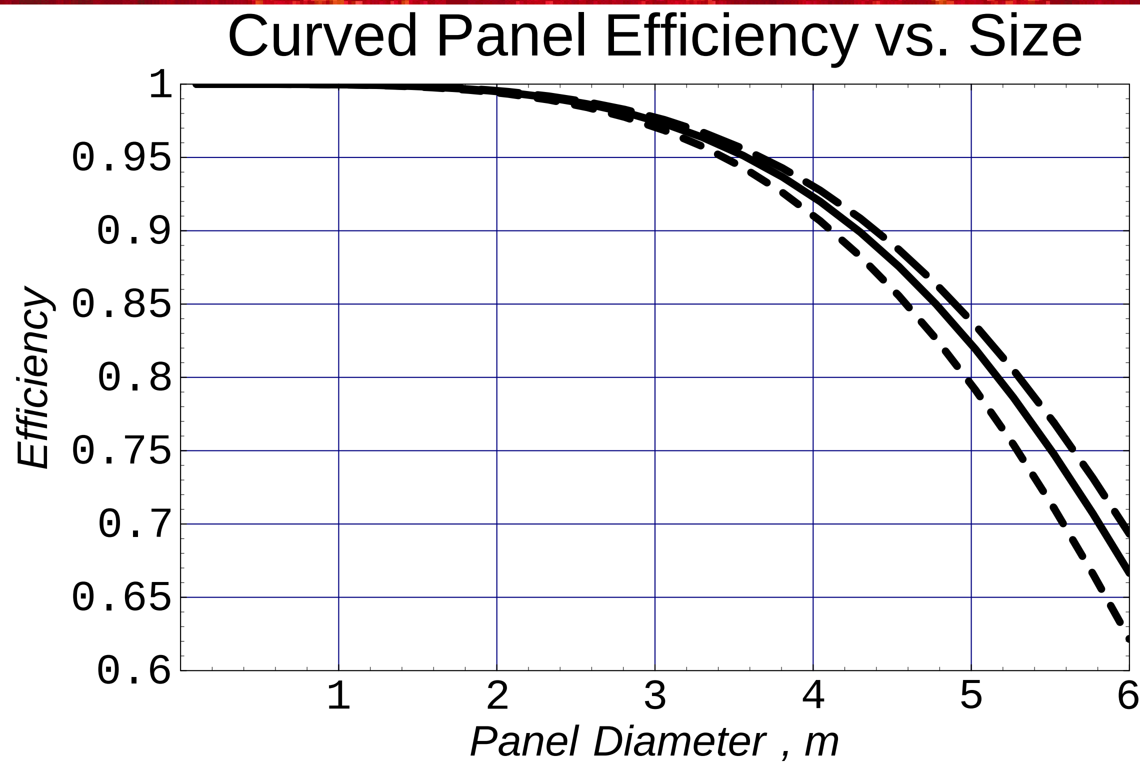
Efficiency Calculation — Sagging Panel Results



$\lambda = 1.4\text{cm}$; Red $\Rightarrow \theta_{za} = 30^\circ$; Blue $\Rightarrow \theta_{za} = 60^\circ$

solid line $\Rightarrow$ central panel; dashed line $\Rightarrow$ edge panels

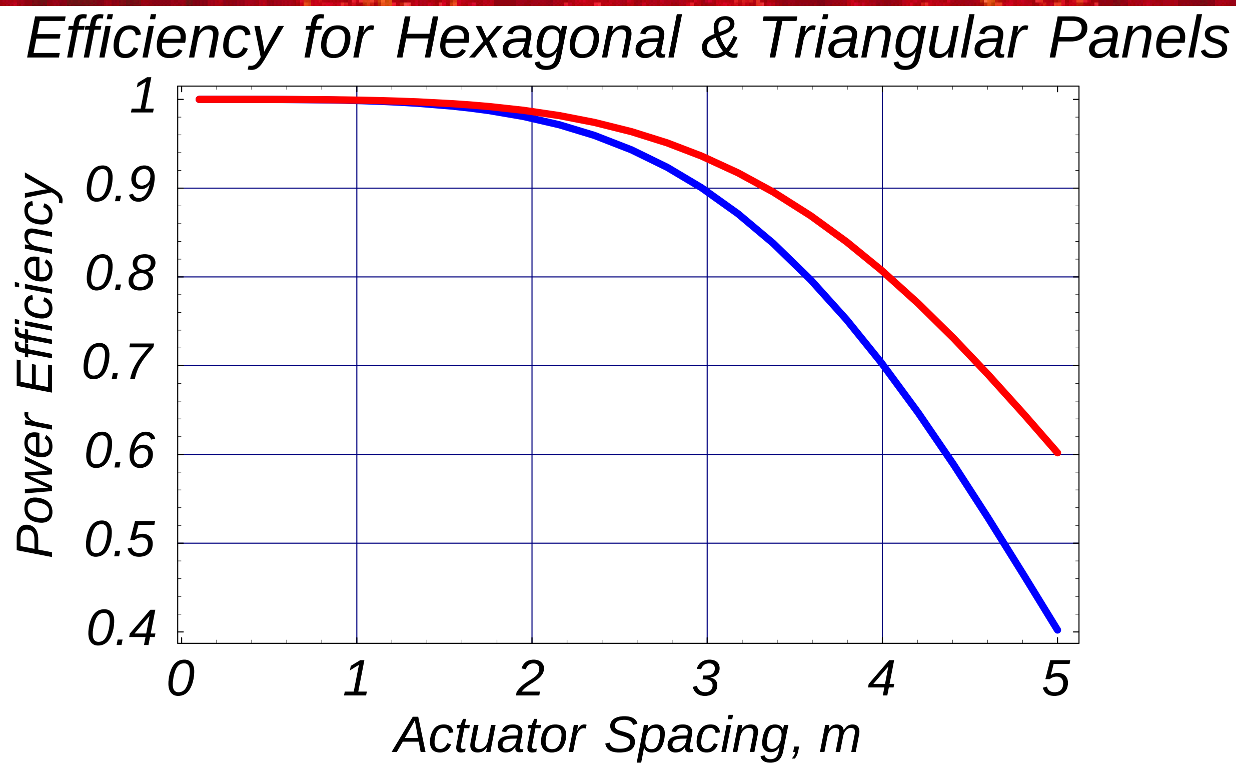
Efficiency Calculation — Sagging Panel Results



$\lambda = 1.4\text{cm}; \theta_{za} = 60^\circ$

solid line $\Rightarrow$ central panel; dashed line $\Rightarrow$edge panels

Efficiency Calculation — Triangular Panels



$\lambda = 1.4\text{cm}$

Red $\Rightarrow$ Triangular; Blue $\Rightarrow$ Hexagonal

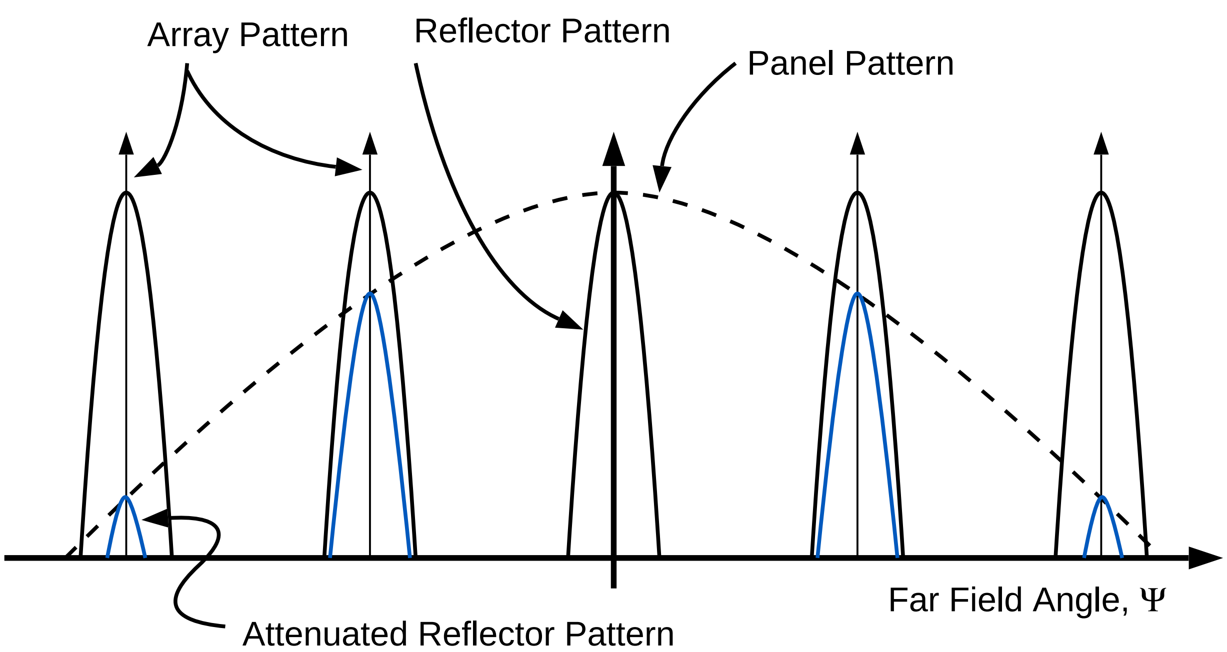
Efficiency Calculations — Summary

- Panels with slight sag can be larger than truly flat panels
  - reduce number of panels & actuators by $\sim \frac{1}{3}$ to 1600
  - optimal panel focal length $\sim$ total reflector focal length
  - sag $\sim$ 3mm for 5-metre panels
- Triangular panels
  - actuator spacing can be 13% larger that for hexagonal spacing
  - $\sim 2\times$ as many panels required, $\sim$ same number of actuators

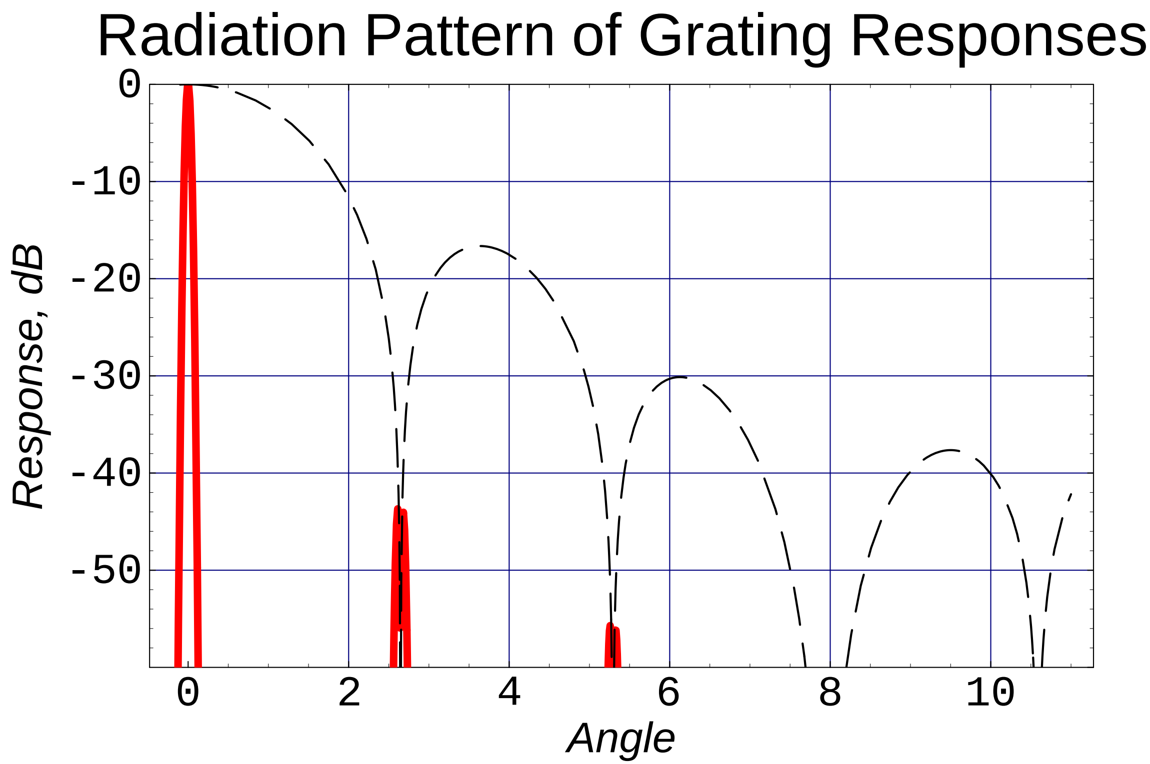
Grating Lobe Response

- Grating lobes *will* be generated because of regular repeating pattern of reflector panels
- Calculate using Convolution Theorem:
  - panel spacing determines array pattern ($\upuparrows(\phi)$) as a set of delta functions with spacing $\Delta\phi \sim \lambda/d$
  - reflector pattern ($A(\phi)$) has half-power beamwidth $\sim \lambda/D$
  - these are convolved...
  - and multiplied by the panel pattern ($P(\phi)$)

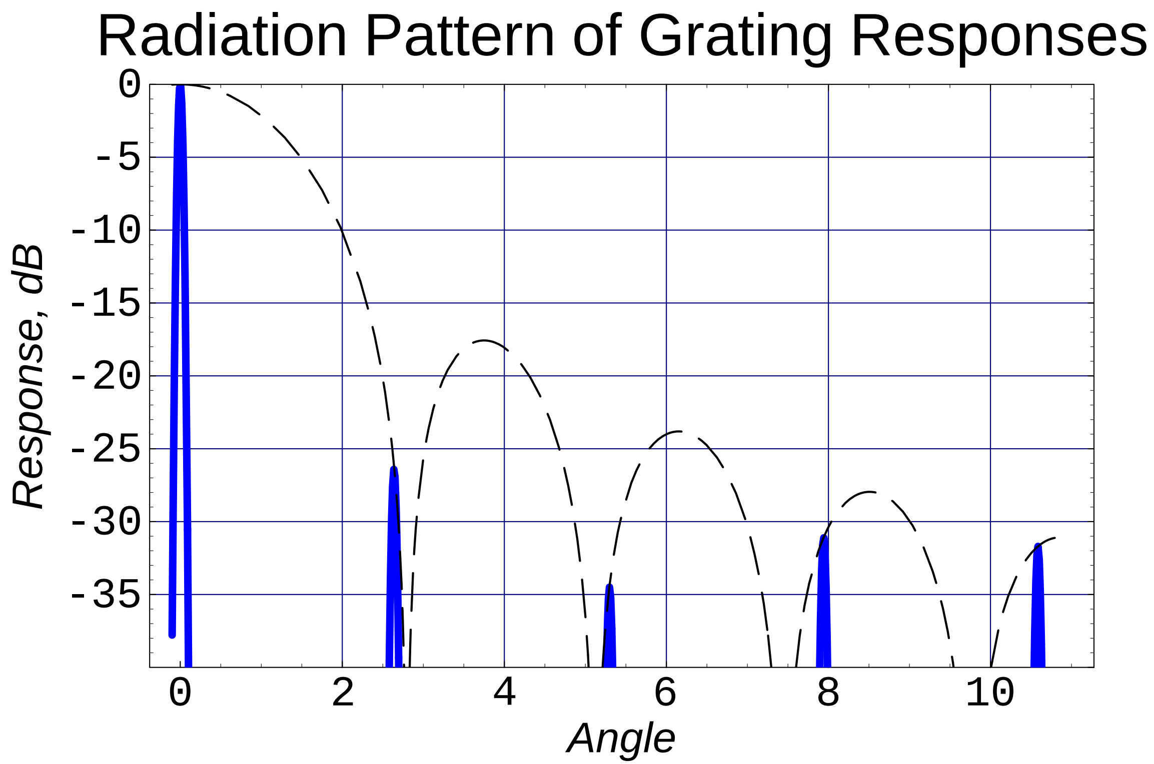
Grating Lobe Response — Diagram



Grating Lobe Response — Calculations



Grating Lobe Response — Calculations



Slight mismatch between panel size and panel spacing

⇒ grating lobes and panel response nulls offset

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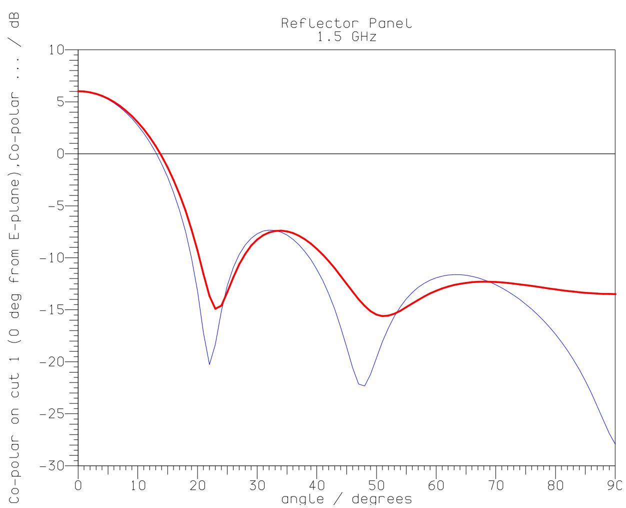
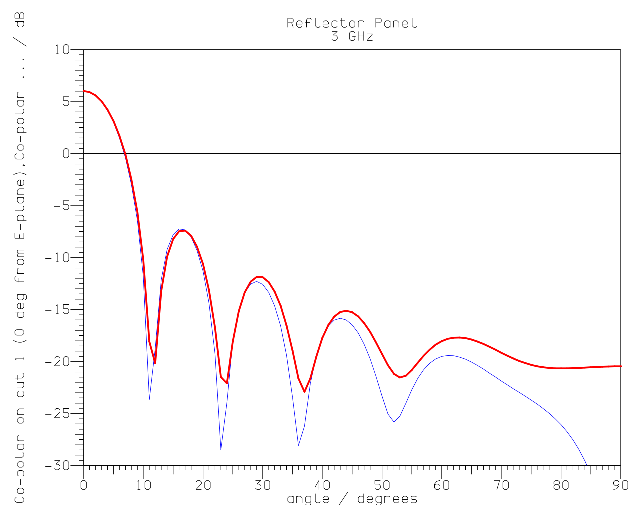
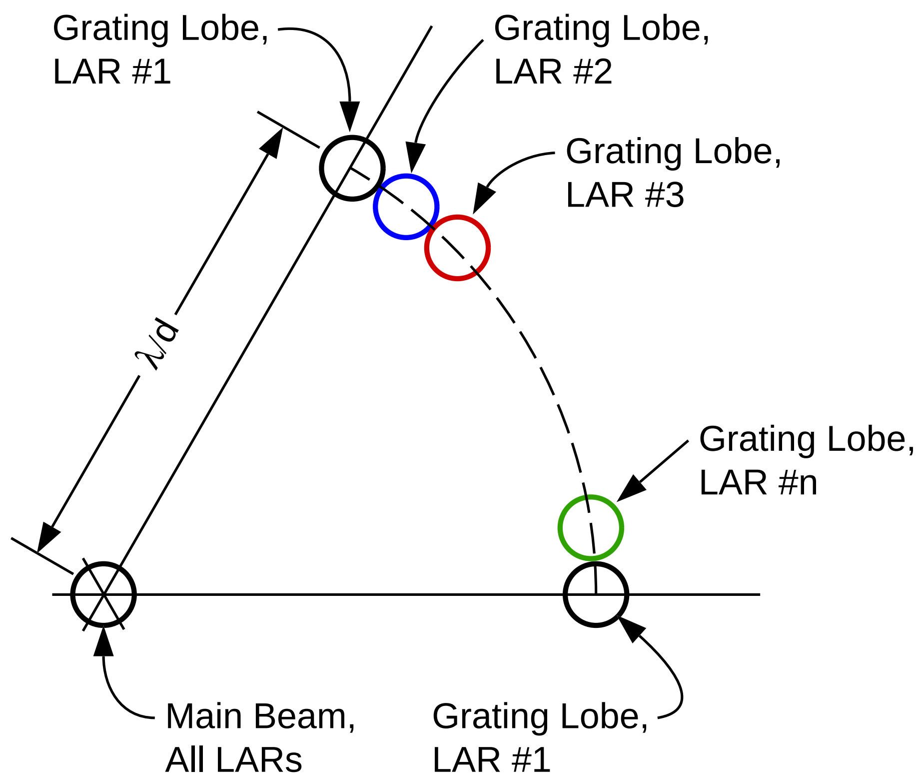
Grating Lobe Response — Panel Size/Spacing

- ▷ Important that panel size and spacing be the same
- ▷ Panel gaps (to allow for motion of panels) makes spacing larger than panel size
- ▷ Frequency-dependent effect since surface currents cannot run off edge of panel





Grating Lobe Response — Mitigation



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Grating Lobe Response — Mitigation

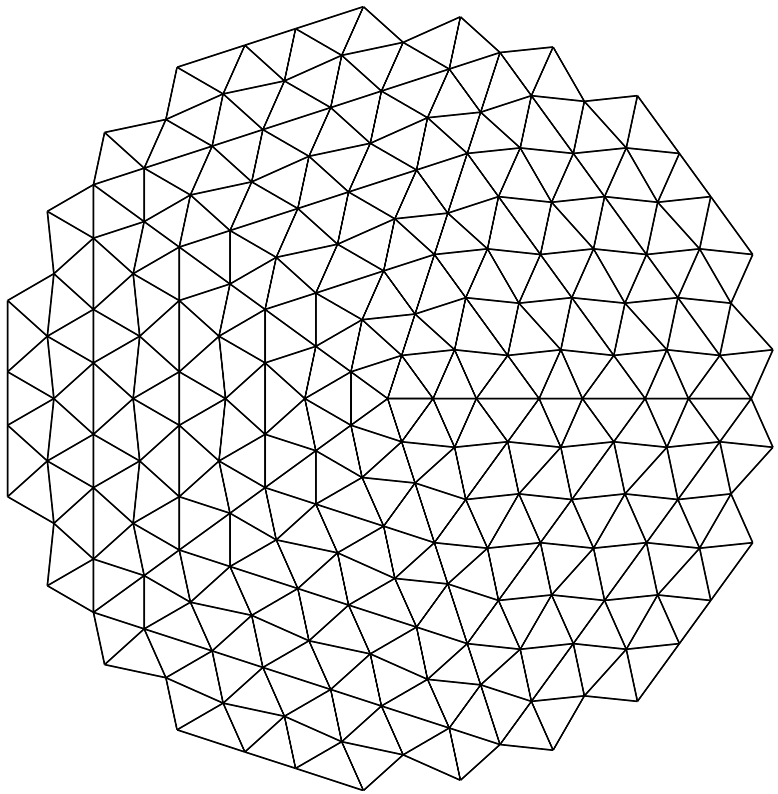
- ▷ Interferometer case
- ▷ Assemble array so that grating lobes from different LAR elements do not point in the same directions
  - ▷ Lobe diameter $\sim \lambda/D$
  - ▷ Angular arc length $\sim (\pi/3)(\lambda/d)$
  - ▷ Number of LARs $\sim (\pi D)/(3d)$

Overlap Taper	Number LARs
3 dB	41
10	23
20	16

Grating Lobe Response — Scattering

- Single-dish or interferometer
- Random panel placement (and panel shape!)
  - to suppress close-in sidelobes large perturbations ($\sim \pm 0.64$ panel diameter at $\lambda = 20$cm)
- Non-periodic tiling (eg. Penrose tiles)
  - shapes not convenient for making panels
  - there *are* sidelobes in far-field pattern
- pseudo-irregular tiling
  - some periodicity so grating lobes generated
  - however, many more grating lobes so power is diluted
  - $\sim$ 9 dB reduction calculated

Grating Lobe Response — Irregular Tiling



Equilateral + 3 types of isosceles triangles

Grating Lobe Response — Summary

- Grating lobe generation
  - nulls in panel pattern in the same direction as grating lobes
  - but real panels have gaps
  - and induced surface currents may decay at edge
  - therefore expect less than perfect suppression of grating response
- Rotate elements in an interferometer array
  - modest reduction for modest-sized arrays
- Scattering to reduce sidelobes
  - random or non-periodic tilings do not appear to be practical
  - pseudo-irregular tiling provides modest reduction in sidelobe level through dilution