Simulating Reflector Antenna Performance with GRASP9

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September 2011

National Research Council Canada   Conseil national de recherches Canada

Opening Remarks (Bruce)

- Very sorry that I can't attend this workshop as originally planned.
- Connecting receptor properties to imaging performance is critically important to the SKA (and other telescopes).
- I think that this workshop can make significant progress in helping to resolve this issue.
- Thanks to Walter Brisken for presenting my slides.

Tutorial Outline

- What is GRASP9?
  - What can it do?
  - What can't it do?
- How does it work?
  - Physical Optics (PO)
  - Physical Theory of Diffraction (PTD)
- Implementation
- Some examples
  - symmetric reflector
  - offset shaped Gregorian antenna
- Where to learn more

What is GRASP9?

- Commercial software for calculating radiation properties of reflector antennas
  - really an optics program for microwaves
  - cannot calculate properties of feeding antenna
- Developed by TICRA (Denmark) with support from ESA
- Often considered "industry standard"
  - note various people have their own custom codes
- But several 10^4 $/€ to buy

Analysis Method

- *Not* true full-wave solution to Maxwell's Equations
- Reflector antennas typically 10s or 100s of wavelengths across
- With sub-λ gridding leads to a very large problem size
- Difficult to solve (especially on computers that were available when GRASP was first written)
- Therefore resort to approximate methods (PO/PTD)
- Note this may have changed recently with modern techniques and computers: see Isak's talk

Physical Optics (PO)

- Suppose we have an incident wave ($\bar{H}^i$) launched by a horn, plane wave, etc.

- Calculate currents induced in planar conductor with normal $\hat{n}$

$$\bar{J} = 2\hat{n} \times \bar{H}^i$$

- From $\bar{J}$ the re-radiated (i.e. scattered field) can be calculated exactly

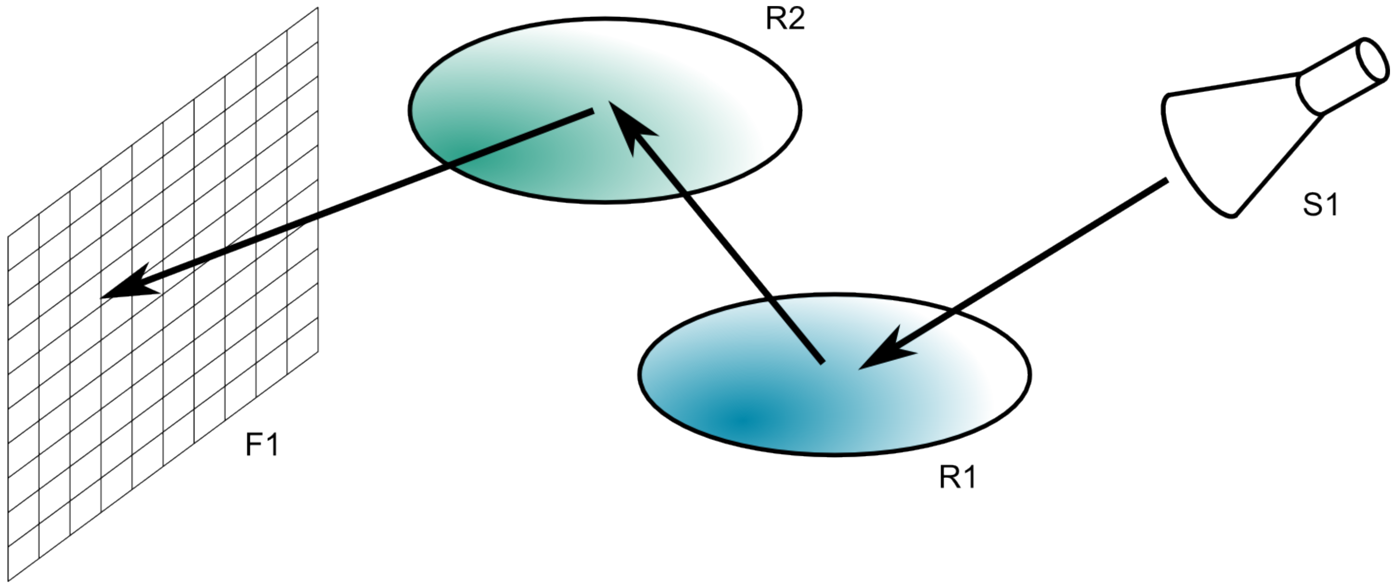
- Total field = incident field + scattered field

- Approximation: real reflectors are not infinite or flat

Physical Theory of Diffraction (PTD)

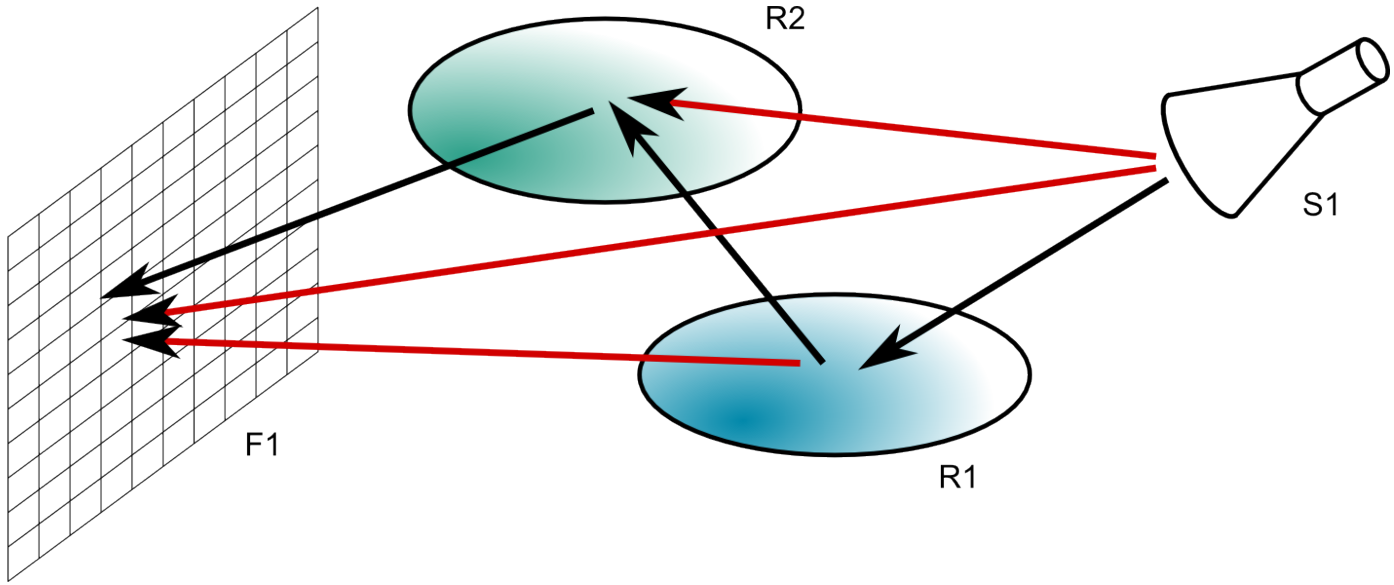
- Real reflecting surfaces have boundaries but PO cannot model currents near edge
  - PTD provides correction to PO fields
- PTD based upon diffraction from infinite conducting half-plane
- Calculate edge currents $\Longrightarrow$ diffracted field
- Limitation: $\sim$perfect conductors only

Analysis Flow: Transmit Point of View



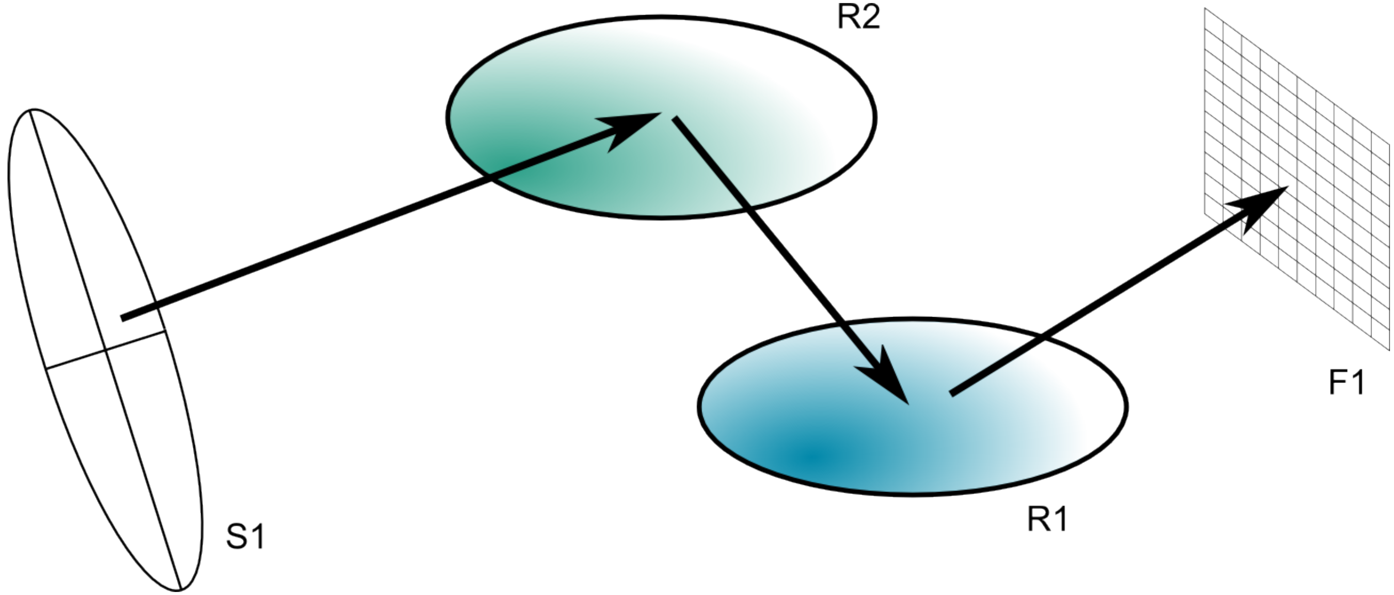
1. Horn S1 illuminates reflector R1, inducing surface currents
2. Currents on R1 induce currents on reflector R2
3. Calculate field on F1 from currents on R2

Analysis Flow: Other Signal Paths



- Other signal paths possible and these must be explicitly stated
- Depends upon significance of other paths
- Allows us to turn "on" or "off" different components (e.g. struts)

Analysis Flow: Receive



- Possible to launch plane wave S1 at reflector system
- Calculate fields in focal plane (F1) or anywhere in optical path
- Ray tracing also possible

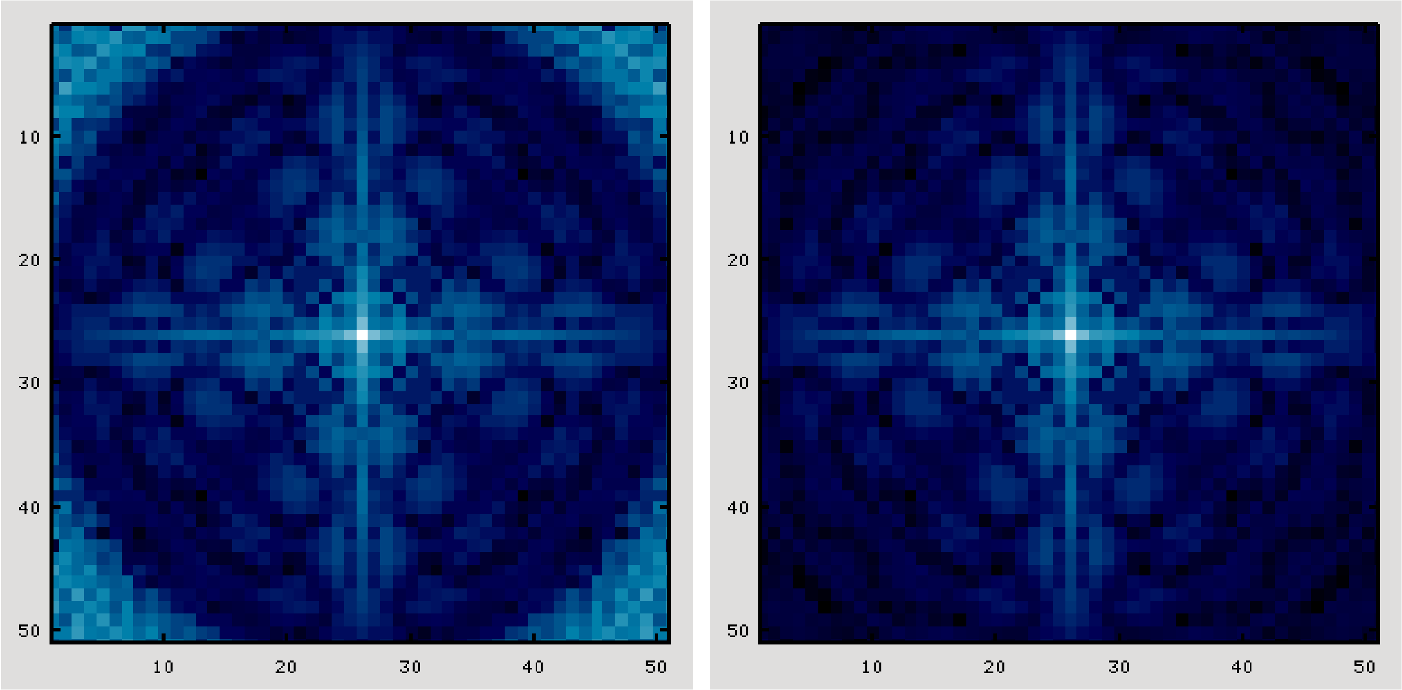
Struts

- Struts are *not* quasi-planar so could be a problem for PO
- Several options (GRASP can auto-select)
- Simple PO
  - If many wavelengths across then can use PO with polygonal approximation to strut
- Canonical PO
  - For circular cross-section struts with size $\sim \lambda$, GRASP has a special model
    - based on analytic solution to plane wave striking cylinder
    - includes effect of current wrapping around into shadow region
- Method of Moments
  - For very thin or oddly-shaped struts a Method of Moments plugin is available (more \$/€)

Gridding

- Anyone who has used EM simulation software knows that how the problem space is gridded is critical
  - tradeoff: accuracy vs. sim time and compute resources
- In GRASP no explicit gridding
  - in earlier versions had to adjust PO-points and PTD-points parameters
  - now can automatically determined
  - but be careful: if wrong then sidelobes don't look right
    - e.g. asymmetric pattern in a symmetric design
- In general the further one goes off boresight, more points required and longer sim time

Example of Incorrect Gridding

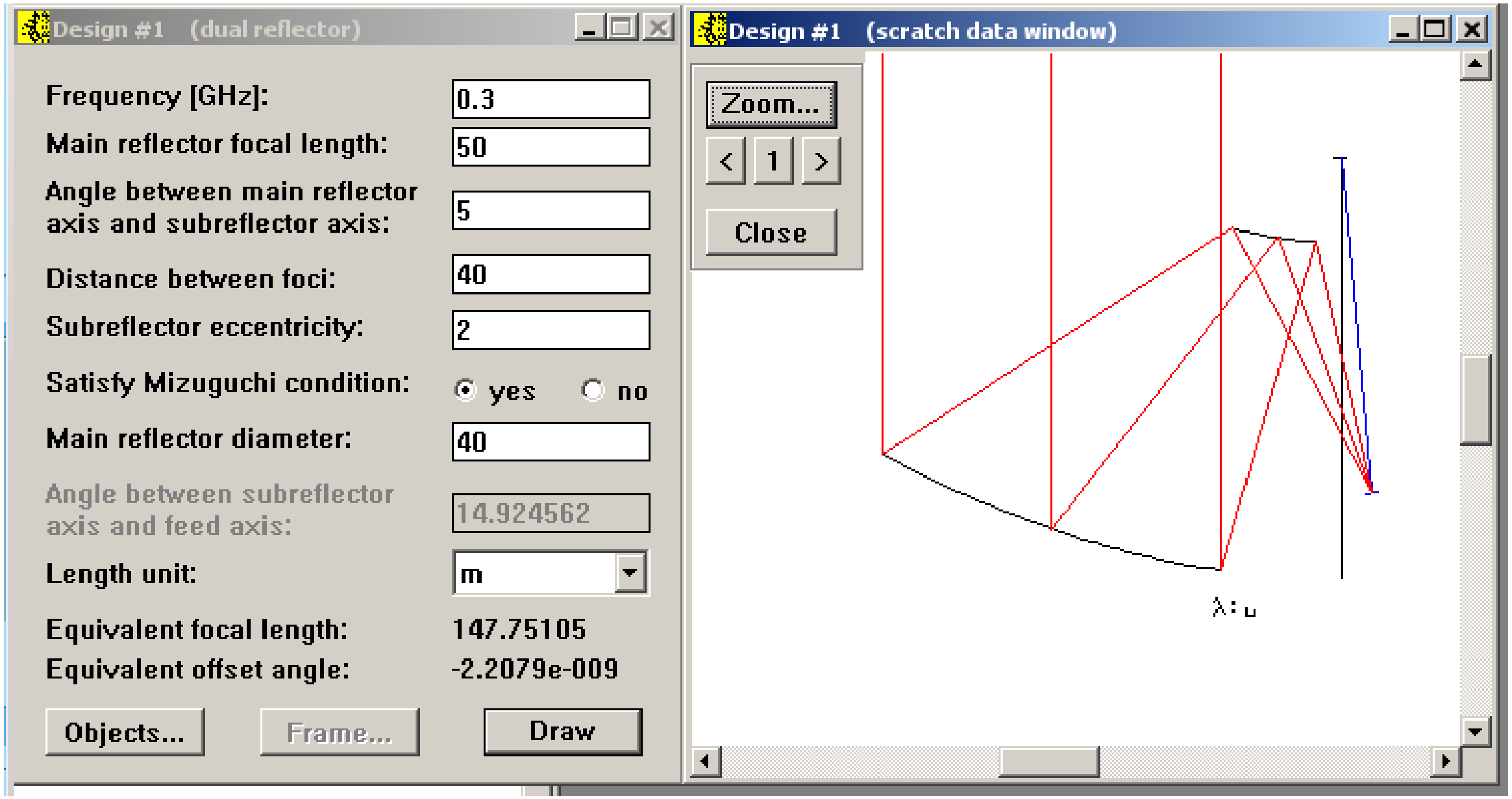


- Left-side beam plot looks OK in principle planes
  - Noisy in corners
- Right-side plot has slightly different gridding parameters
  - Corners now clean

Setting Up a Problem

- Usually start with built-in design tool
- Sets up basic structure of the problem
- Then modify using GUI
  - add struts
  - add field measurement planes
  - add other objects
  - change properties
- Could also work with text file generated
  - e.g. scripting batch processing

Model Setup


Design #1 (dual reflector)
Frequency [GHz]:
0.3
Main reflector focal length:
50
Angle between main reflector axis and subreflector axis:
5
Distance between foci:
40
Subreflector eccentricity:
2
Satisfy Mizuguchi condition:
yes
no
Main reflector diameter:
40
Angle between subreflector axis and feed axis:
14.924562
Length unit:
m
Equivalent focal length:
147.75105
Equivalent offset angle:
-2.2079e-009
Objects...
Frame...
Draw
Design #1 (scratch data window)
Zoom...
1
Close

Coordinate Systems

- All objects tied to a coordinate system
- Each object likely to have its own coord system
- All coord systems based on a global coord system
- Can move an object (reflector, feed, etc.) by simply changing its coord system offset
- Or change pointing by rotating coord sys for incoming plane wave

Reflectors/Scatterers

- Surfaces
  - conic sections (e.g. parabolas, ellipsoids, etc.)
  - point cloud (e.g. shaped surface)
  - planes
  - struts
  - surface with errors
- Rim defined separately
  - many outlines possible

Sources

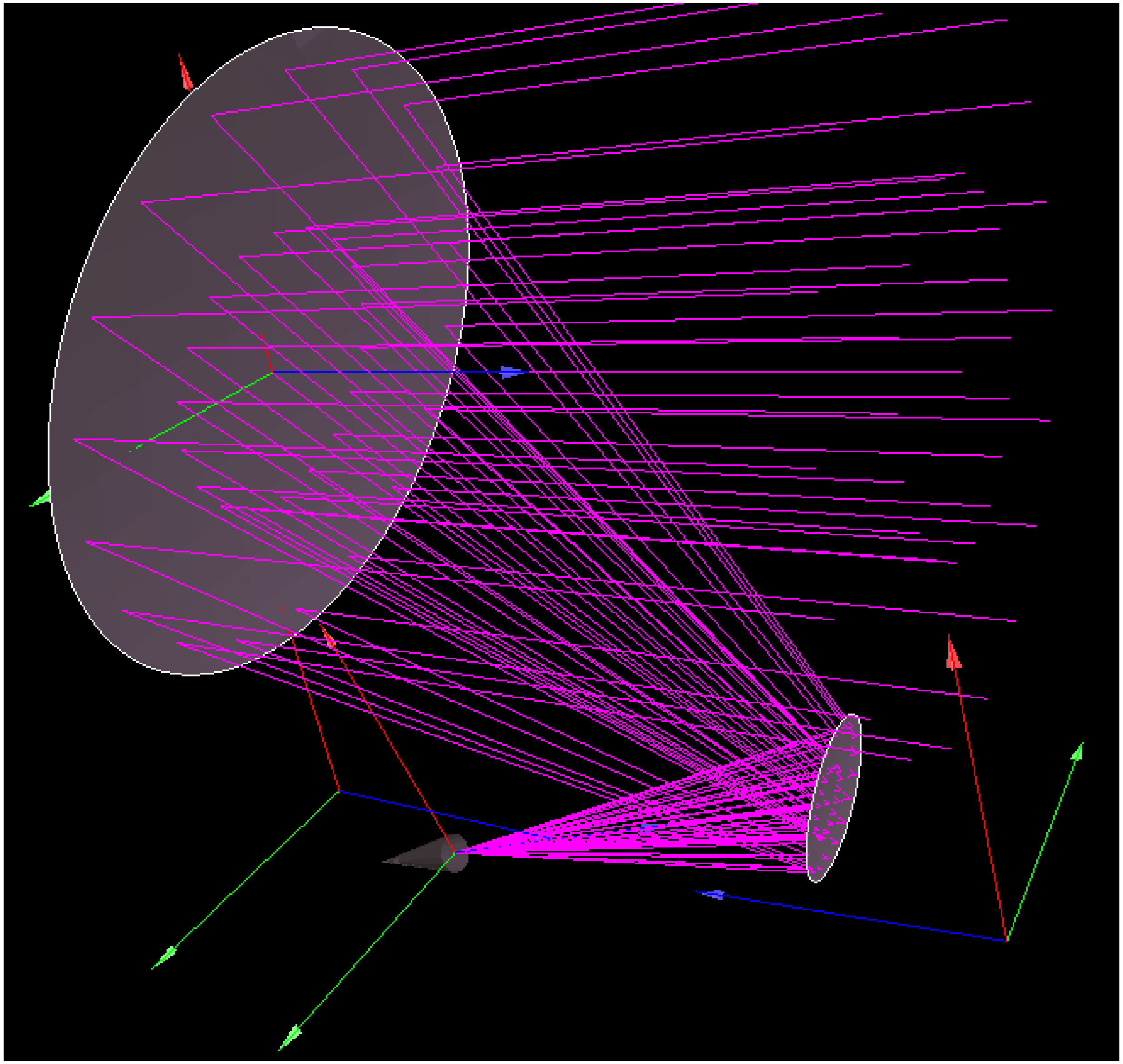
- Patterns
  - Gaussian (far or near)
  - analytic functions
  - points from file
- Horn models
  - conical
  - corrugated
  - rectangular
  - Potter
  - open-ended waveguide
- Dipole
  - Hertzian
  - Half-wave
- Array of sources
  - individually
  - beamformed
- Plane wave

For feed antennas near-field affects accounted for.

Results

- Polarized
  - linear
  - circular
- Cuts at principle (and other) planes
  - e.g. E, H, and D planes
- Projection onto l-m grid on sky
- Grid in near-field zone
  - e.g. at focal plane
- Output files in well-documented text format
  - easy to read with other software

Raytracing



Further Analysis Outside of GRASP

- Some examples
  - Publication quality plots (Matplotlib)
  - Produce Stokes beams
  - Beamforming analysis of fields in focal plane (Octave)
  - Imaging capabilities with far-field beams (Meqtrees)
- Results stored in ascii text
  - Documented in *GRASP9 Reference Manual*
  - Reverse engineering not needed!

Platforms

- Windows, Linux, or Mac
- Windows version works *very* well running on Wine in Linux
  - complete functionality
    - installation
    - multi-core processing
    - graphics (OpenGL)
    - license management
- Can be run in GUI-mode or from command line (or script)

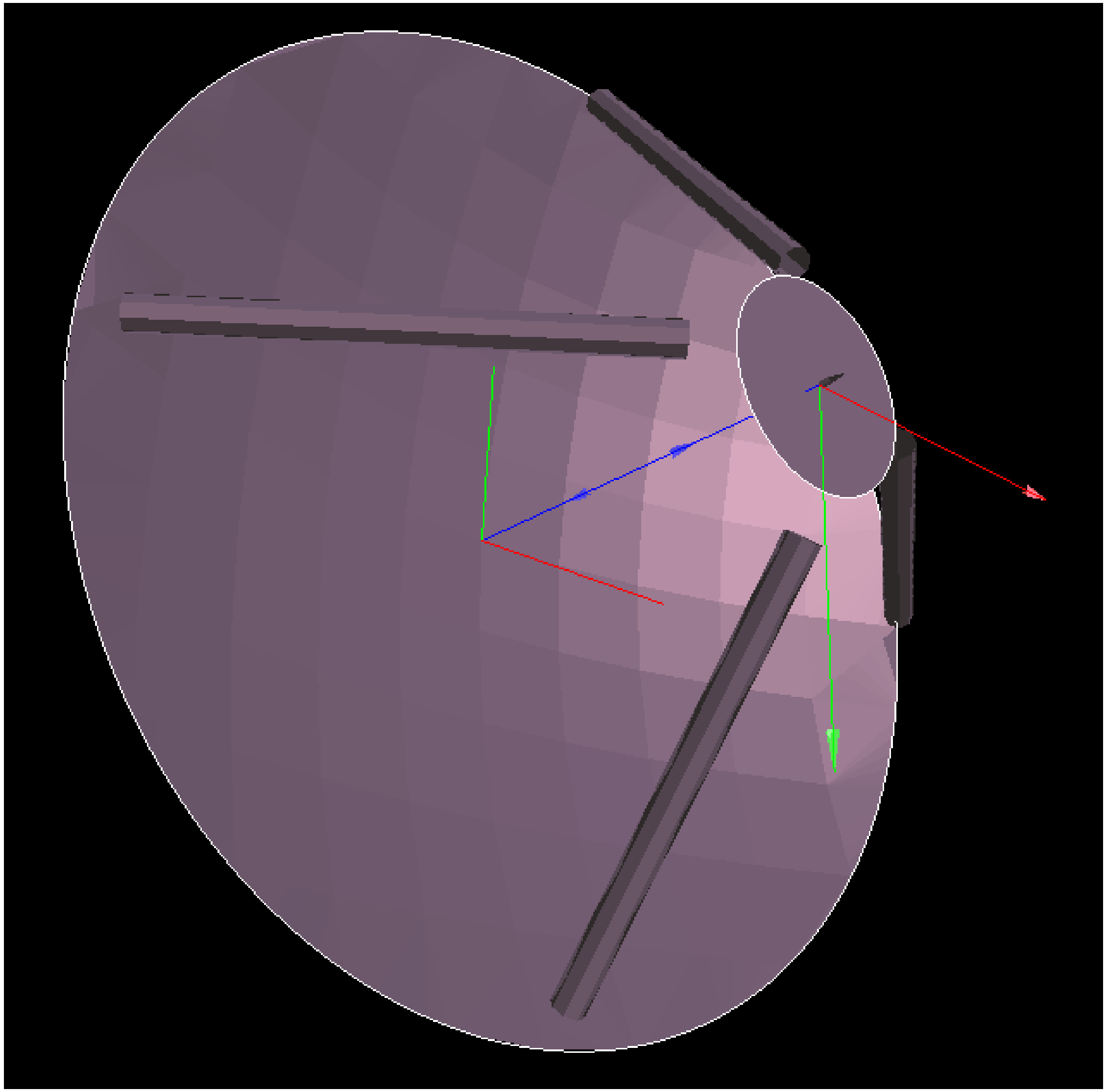
Some Examples

- Symmetric dish with struts and large blockage
  - outline simulation steps
  - show effect of various types of blockage
- DVA-1 shaped off-set Gregorian
  - importing tabulated points to define surface
  - ray tracing
  - radiation patterns
  - secondary diffraction effects

Symmetric Dish Parameters

Diameter	15.9 m
Equiv. Unblocked Diameter	15 m
f/D	0.45
Blockage Diameter	3 m
Strut Diameter	0.5 m
Strut Number	4
Feed Taper	12 dB
Frequency	3 GHz

Symmetric Dish Model

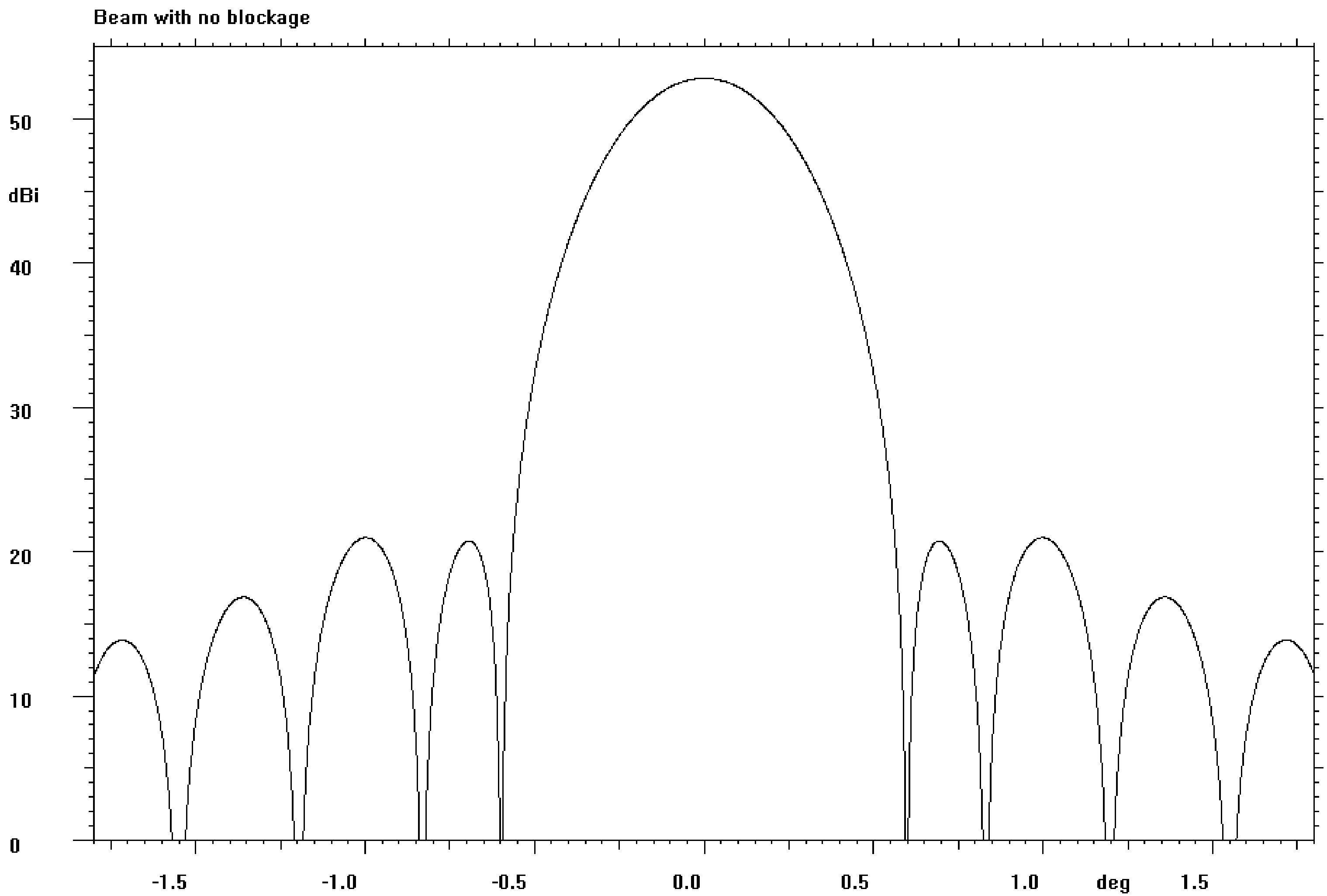


Simulation Outline

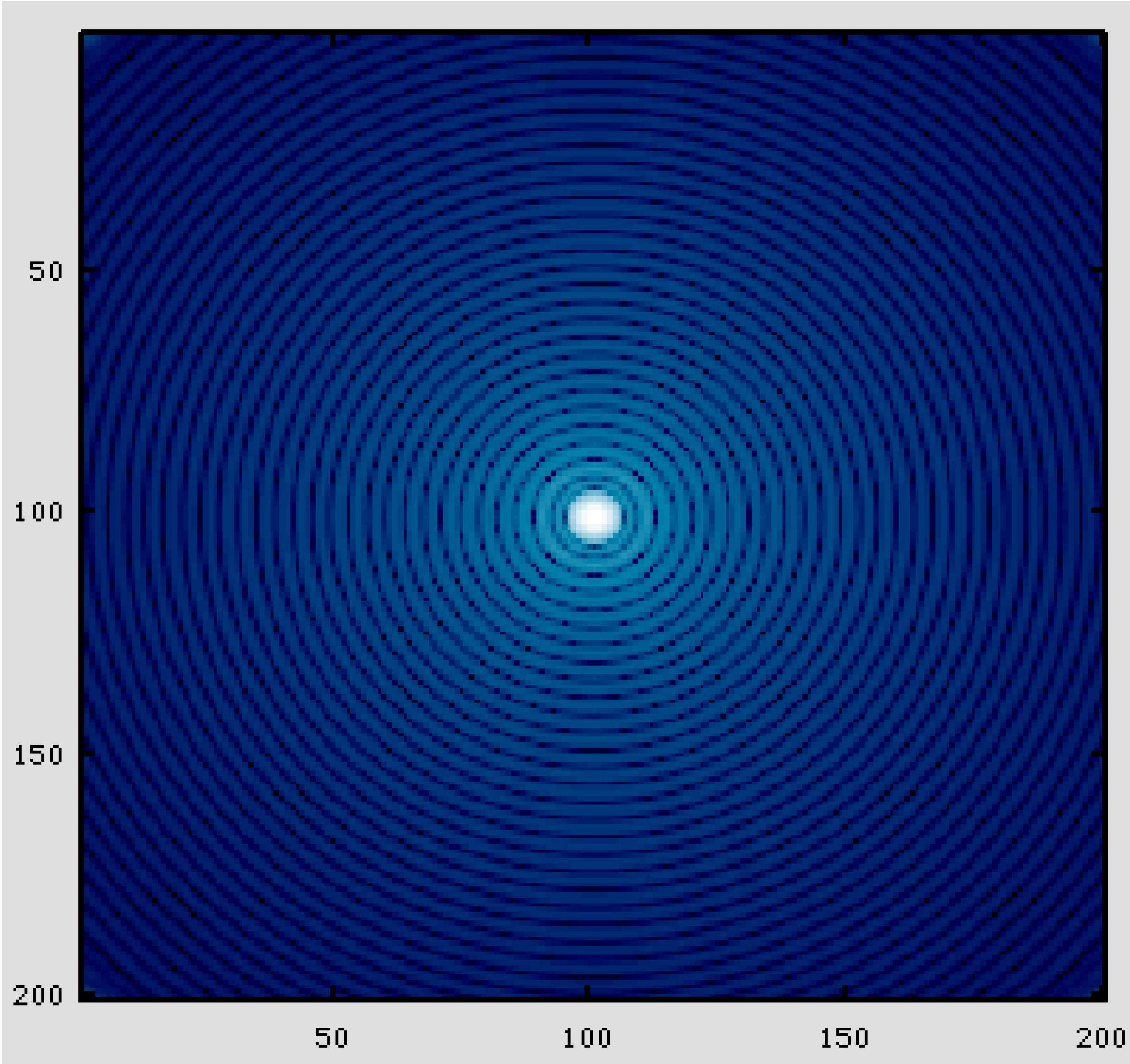
Source	→	Target	Convergence Test	Notes
Feed	→	Reflector	Pattern	Unblocked pattern
Reflector	→	Pattern		
Feed	→	Reflector	Plate	Add pattern for circular blockage
Reflector	→	Plate	Pattern	
Plate	→	+Pattern		
Feed	→	Reflector	Struts	Add pattern for strut scattering
Reflector	→	Struts	Pattern	
Struts	→	+Pattern		

- Only considering plane-wave strut scattering (struts run to dish rim)
- Struts do not touch reflector surface to reduce simulation time (as per TICRA's recommendation)

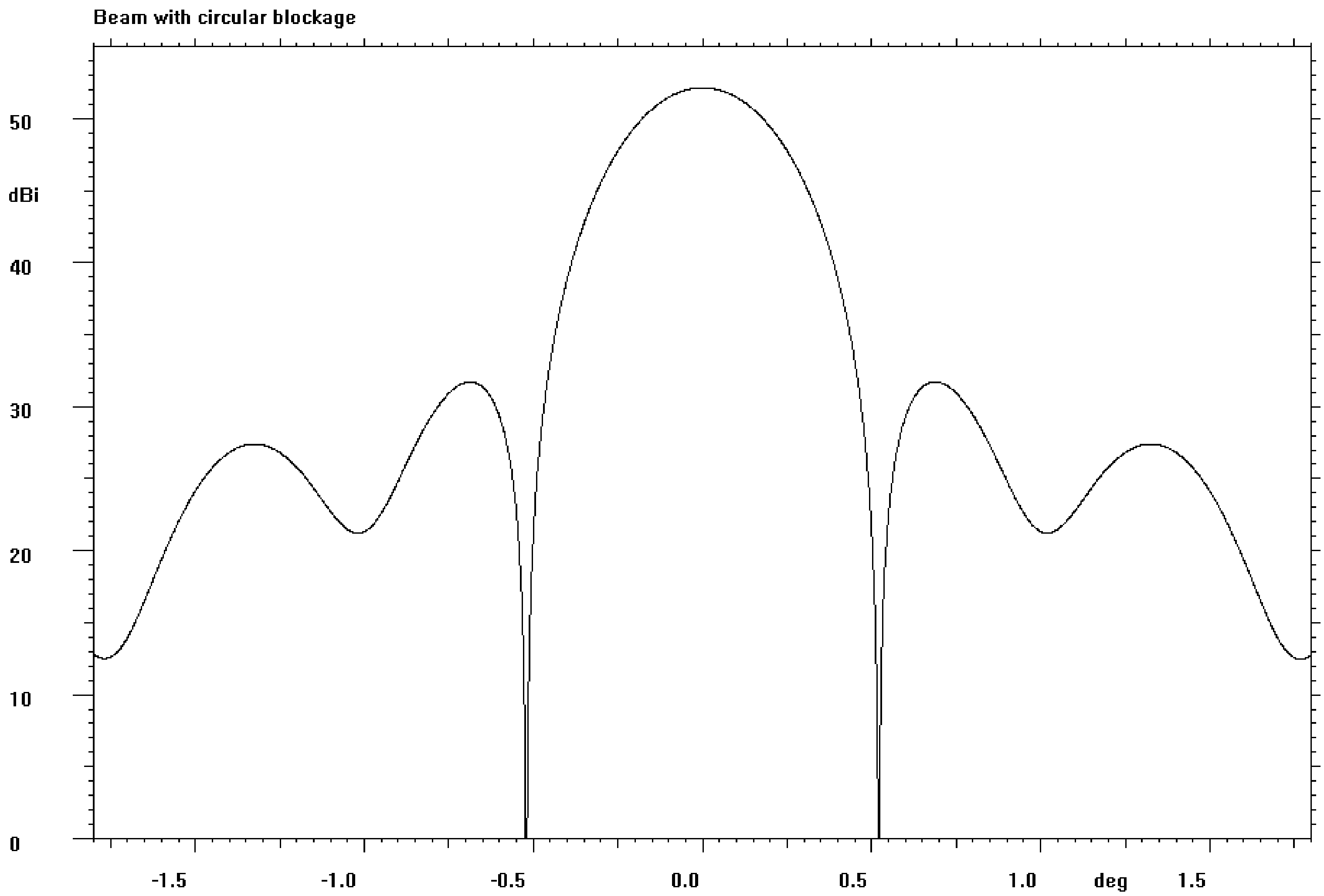
Pattern Without Blockage



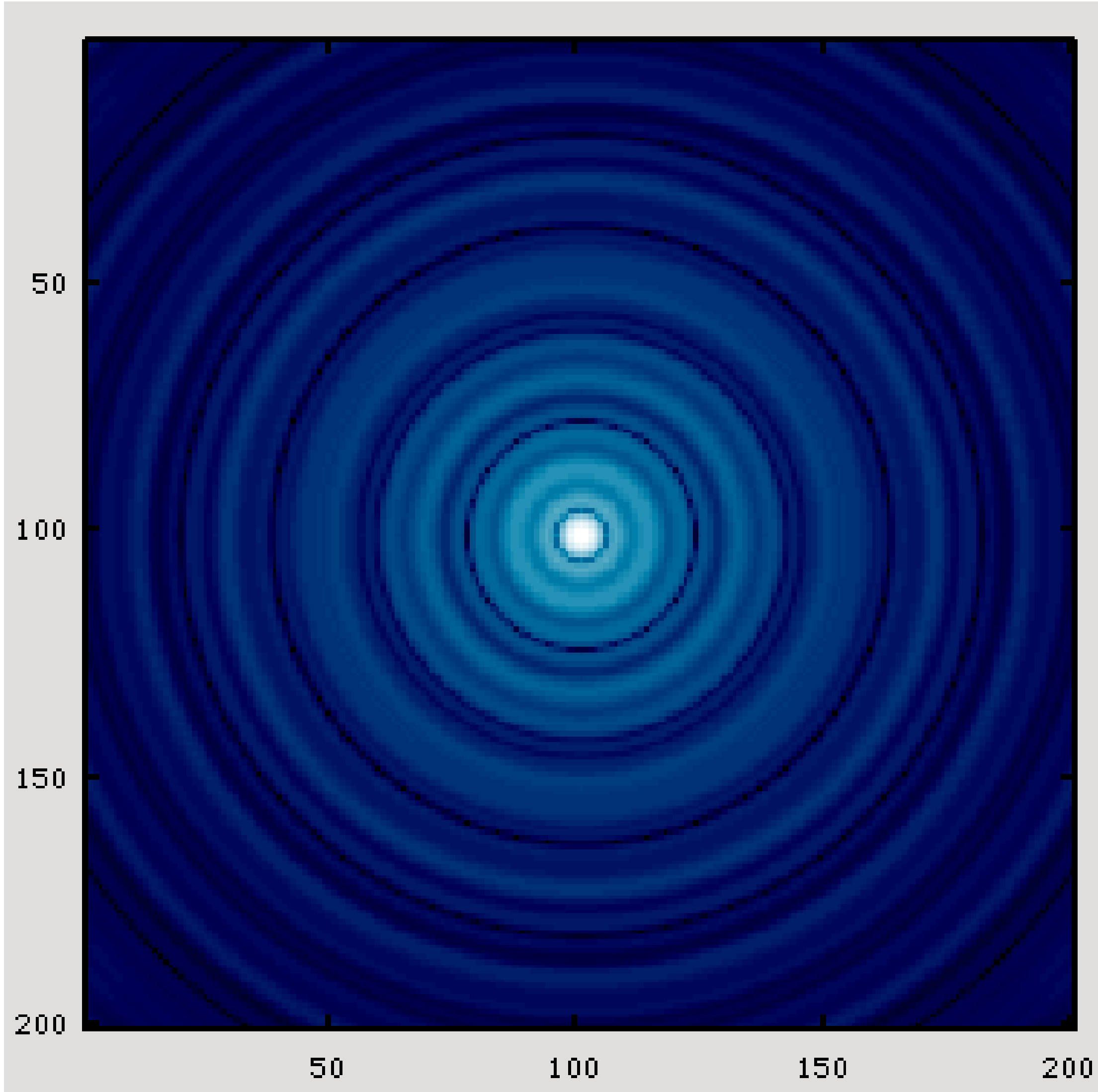
Pattern Without Blockage



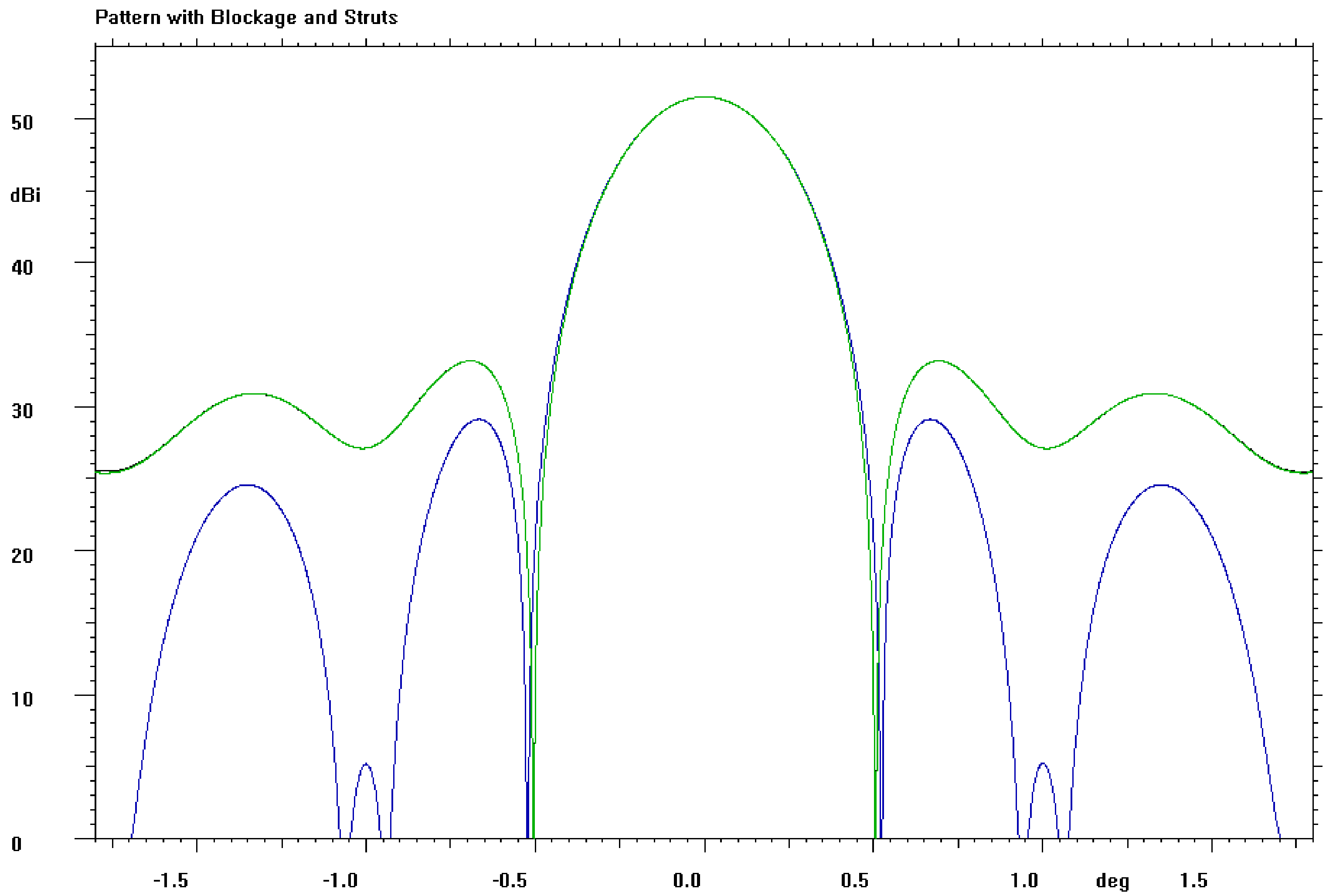
Pattern With Circular Blockage



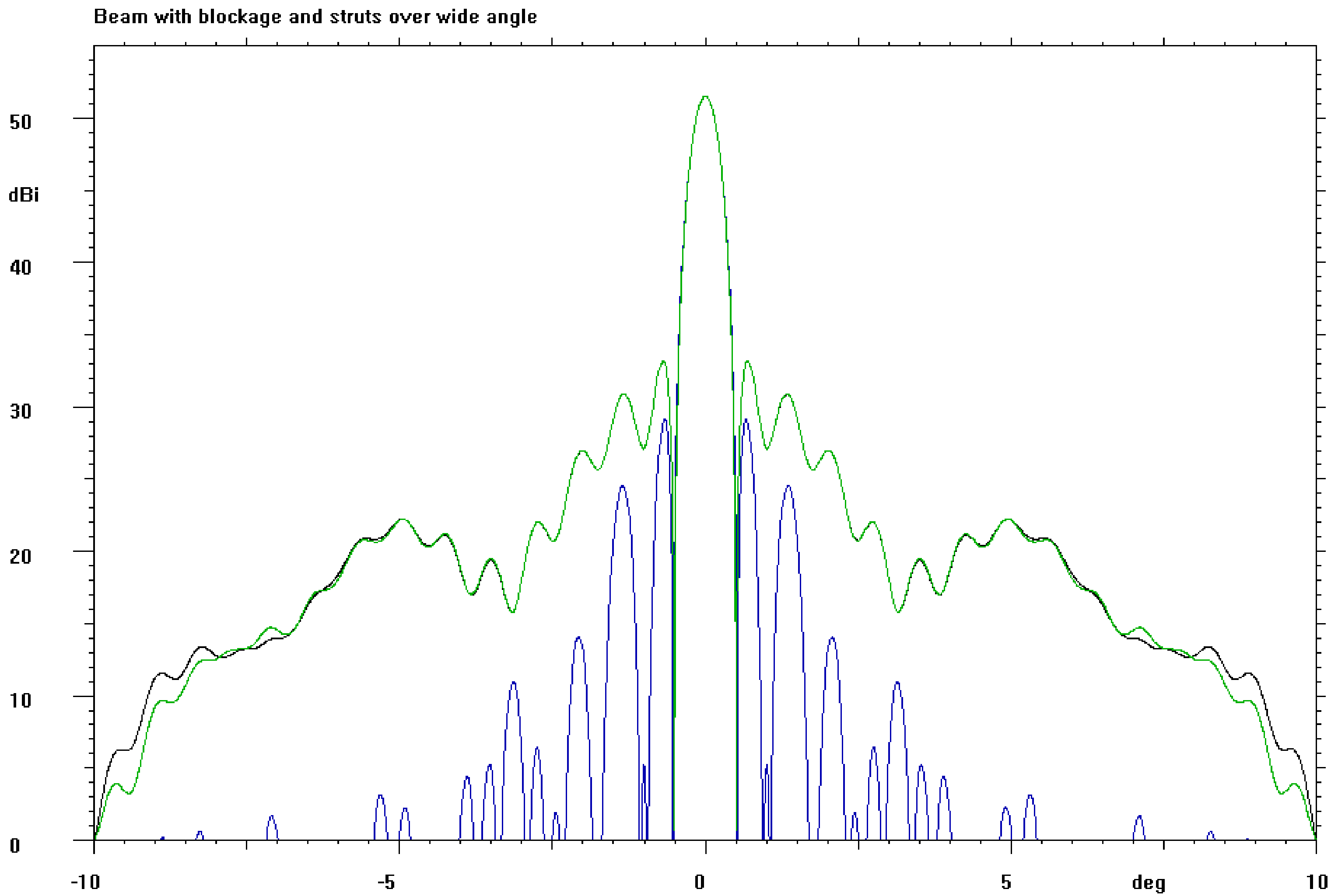
Pattern With Circular Blockage



Pattern With Blockage and Struts

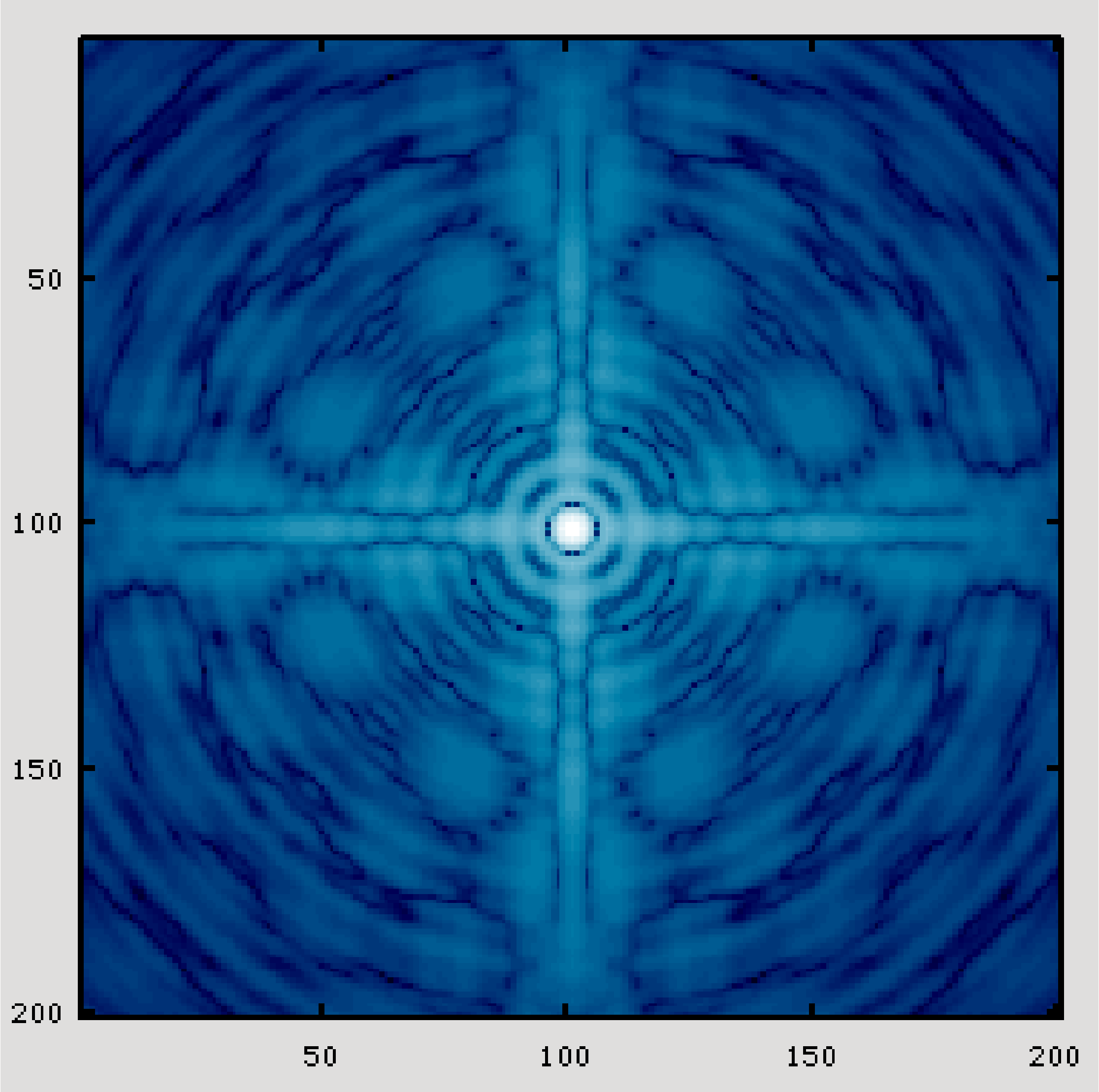


Wider Pattern (±10°)

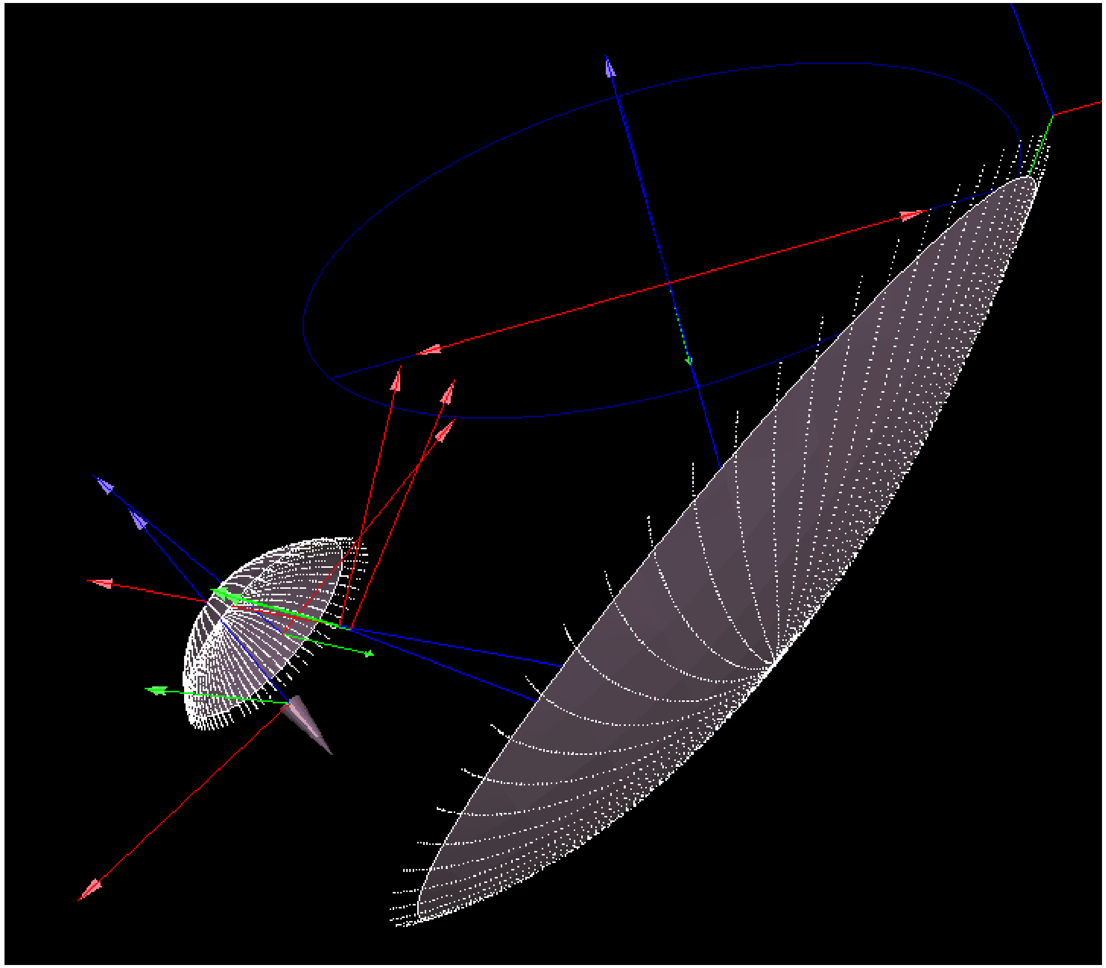


E-, H-, and D-plane cuts

Wider Pattern ($\pm 10°$)



DVA-1 Offset Shaped Gregorian

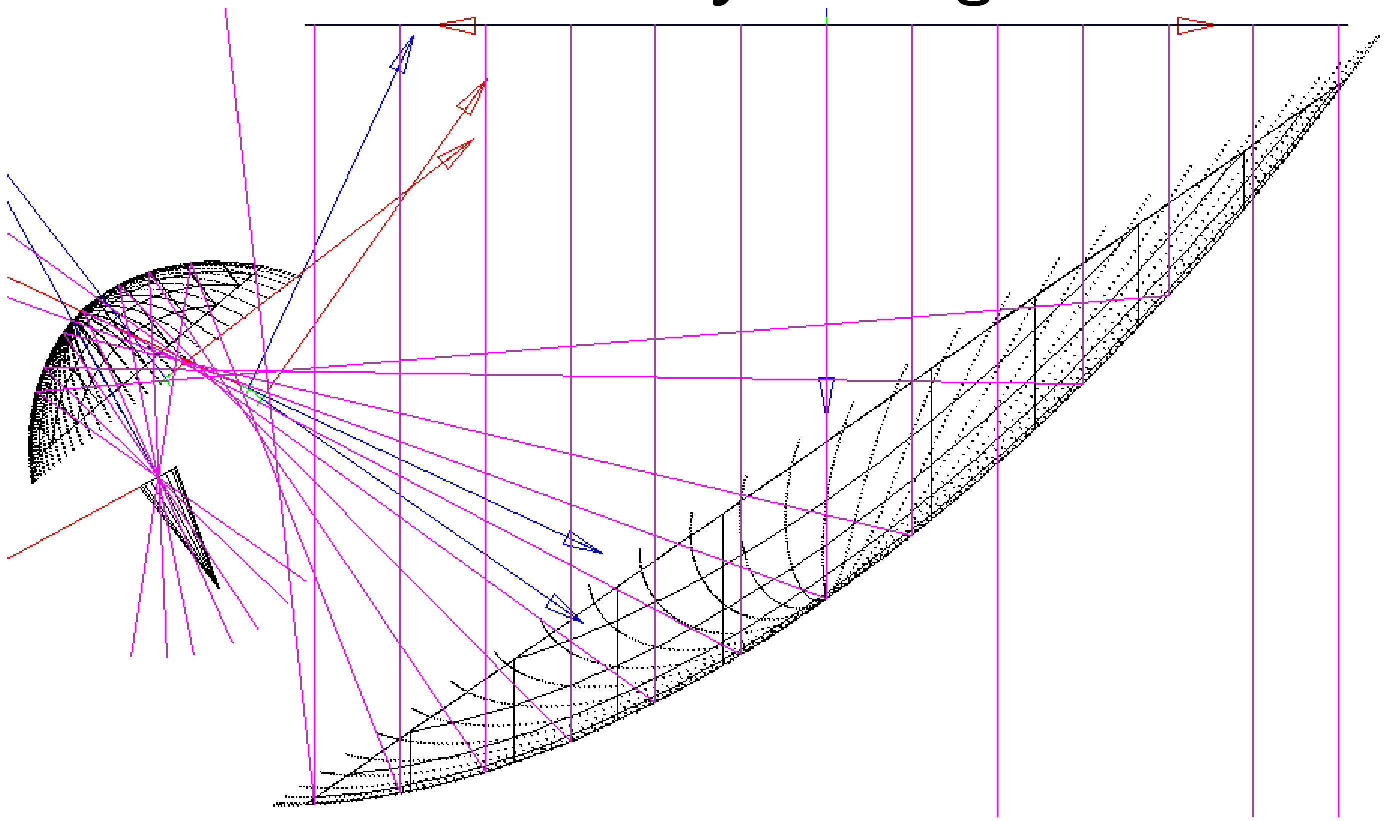


Aperture: 15-m diameter	
Prime: 18.5 m × 15 m	Secondary: 4-m diameter

DVA-1 Surface Specification

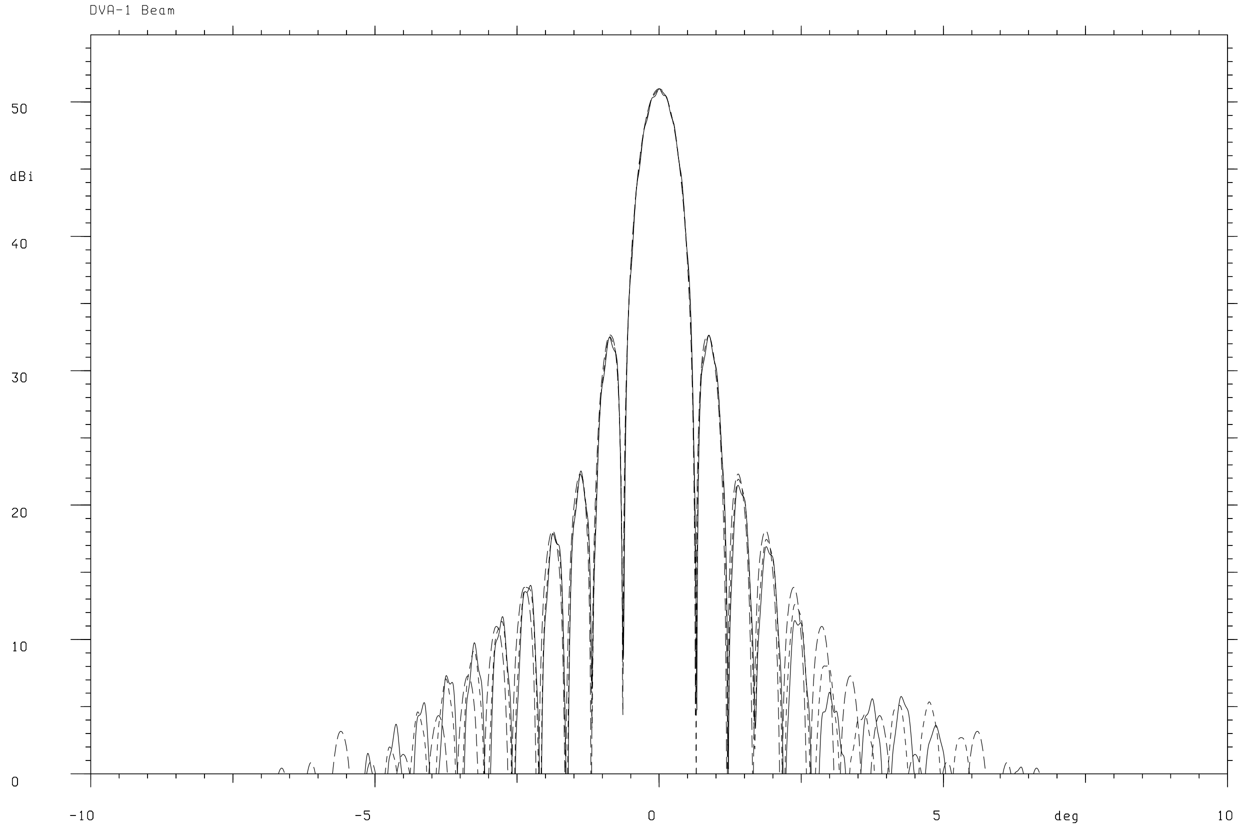
- Shaped surfaces from Lynn Baker (Cornell)
  - increase A_{eff} by $\sim$ 10% from shaping
  - Both primary and secondary surfaces shaped
- File with $\{x, y, z\}$ points imported as a tabulated surface into GRASP
  - use built-in pseudo-spline interpolation
  - points extend outside rim to ensure smooth interpolation over full surface
  - points must be defined in a 'local' coord sys, not global coord sys otherwise interpolation fails (solution thanks to Christian Holler)

DVA-1 Ray Tracing



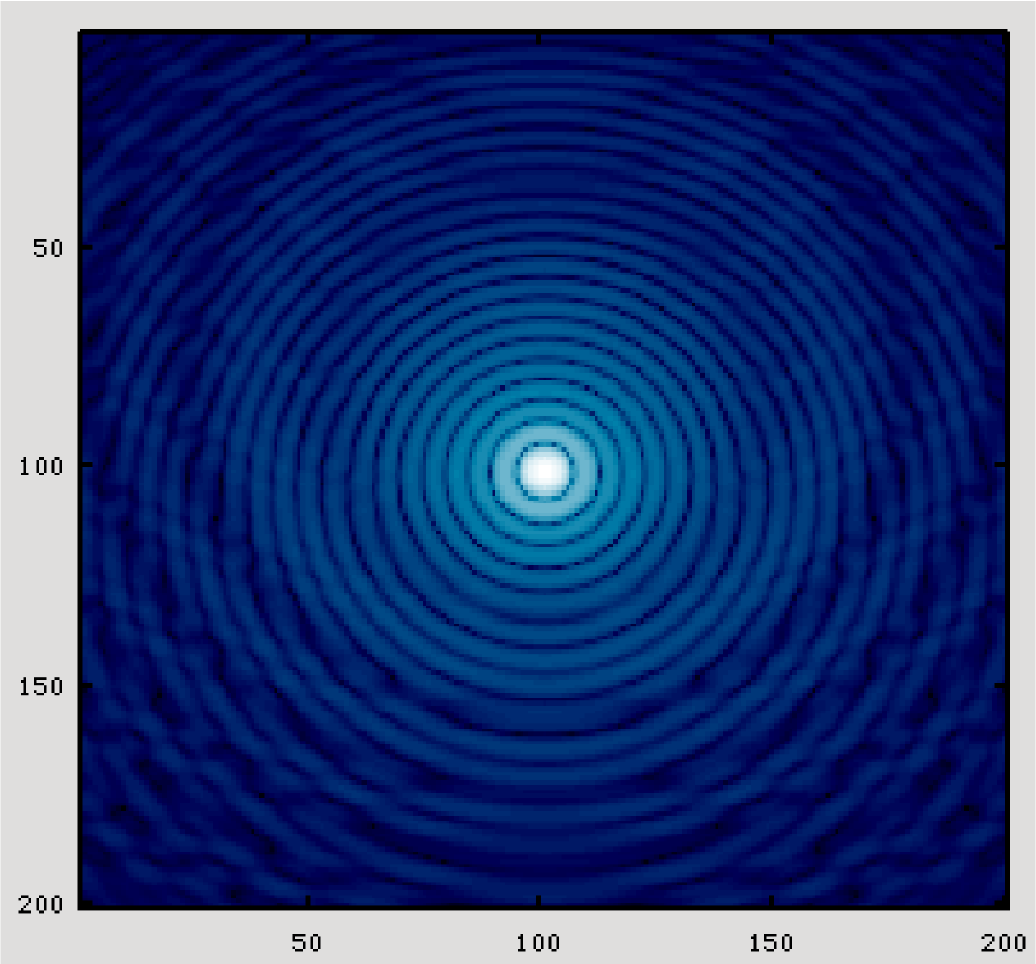
- Launch plane waves at reflector antenna (top of picture)
- Note caustic at prime focus due to shaping
- Reason for rays penetrating surface unknown

DVA-1 Beam Cuts



- 3 GHz
- 16 dB feed taper
- E, D, and H planes plotted

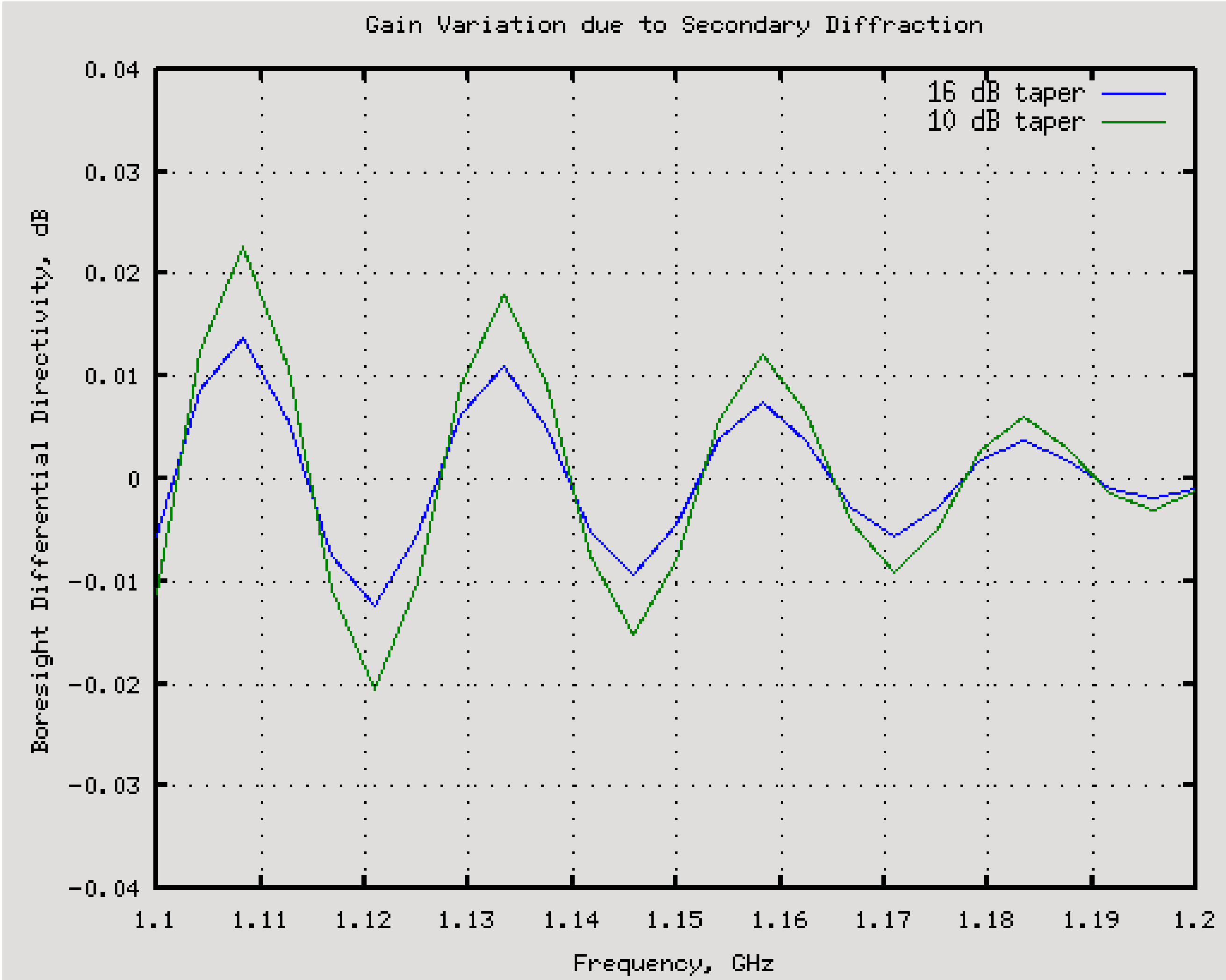
DVA-1 Beam ($\pm 10°$)



Diffraction Effects

- Isak Theron has noted periodic variation in beam as a function of frequency
- Dirk de Villiers (Stellenbosch) [IEEE APS Symp. 2011] has analyzed this
  - Diffraction from rim of secondary interferes with wavefront reflected by primary
- Analyze with GRASP
  - Compare diffraction case with no diffraction
    - plot difference
  - Compare 16 dB edge taper with 10 dB
  - Different optical configuration (larger) than de Villiers'

Diffraction Results



Timings

Problem		Time
Symmetric:	No Block	11 sec
	Central Blockage	18 sec
	Block + Struts	7:18 min
DVA-1 Shaped Gregorian Offset		1:13 min

- Hardware
  - 3 GHz dual-core
- Software
  - GRASP 9.7.02 (Win version)
  - Running on linux using wine

Summary

- GRASP9 can be considered "industry standard" simulation SW
- Intended for solving optical problems at $\sim$ microwave frequencies
- Uses PO/PTD $\Rightarrow$ optical components many λ in size
- User specifies which couplings to calculate or include
- requires some user skill/knowledge to set up problem correctly
- Shown several examples
  - symmetric reflector with scattering
  - offset reflector with shaped reflecting surfaces
  - but other capabilities not shown here

Where to Learn More

- Download free student version from www.ticra.com
  - Contains extensive documentation (2 books)
- Diaz & Milligan, *Antenna Engineering Using Physical Optics*, Artech House 1996
  - Has Matlab and Fortran code
  - *But* check book review in *IEEE Ant & Prop Magazine* which lists errors
- Or contact me: bruce.veidt@nrc.ca