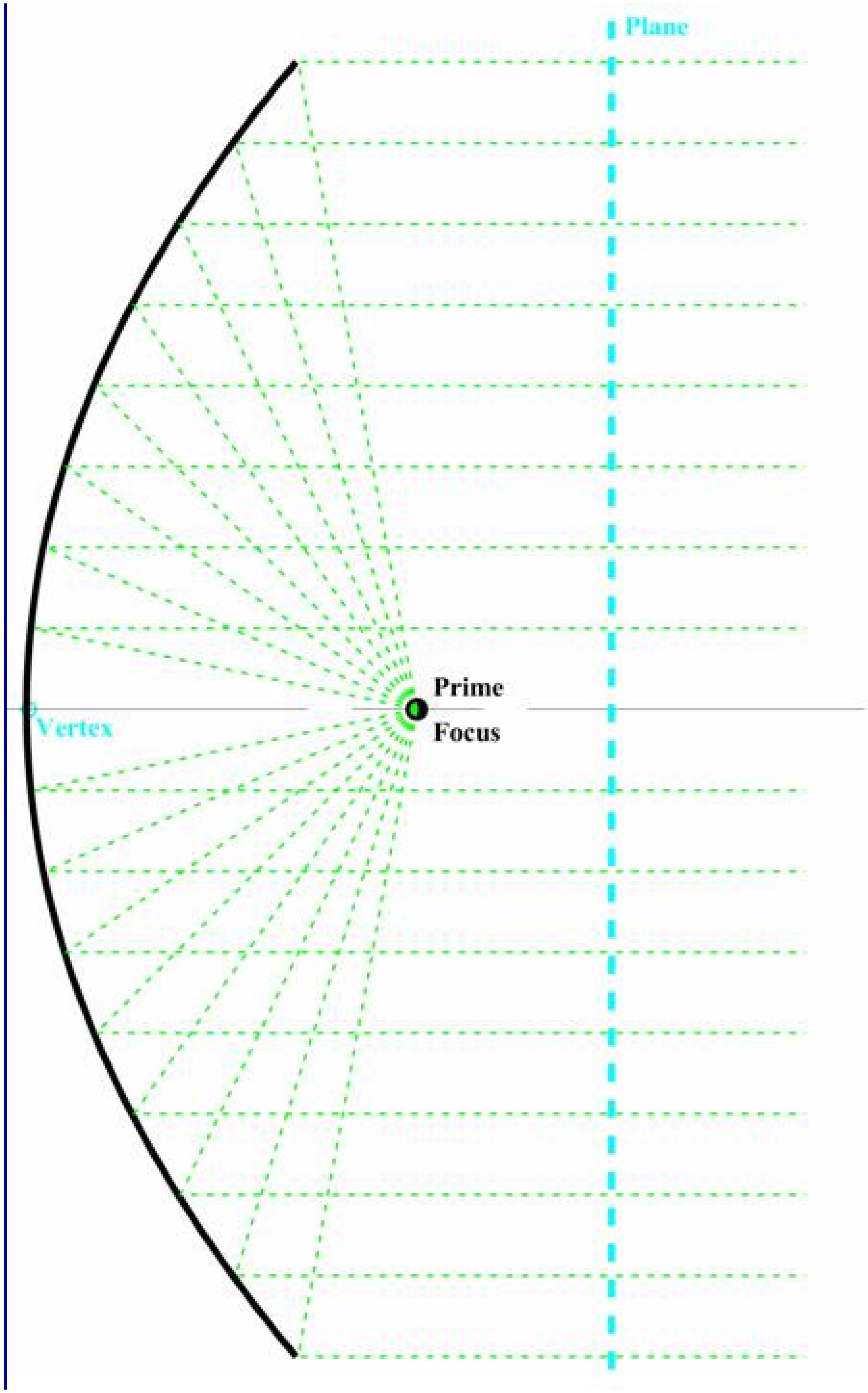
Multiple-Reflector Antennas and Feeds

Paul Wade
W1GHZ

Multiple-reflector Antennas

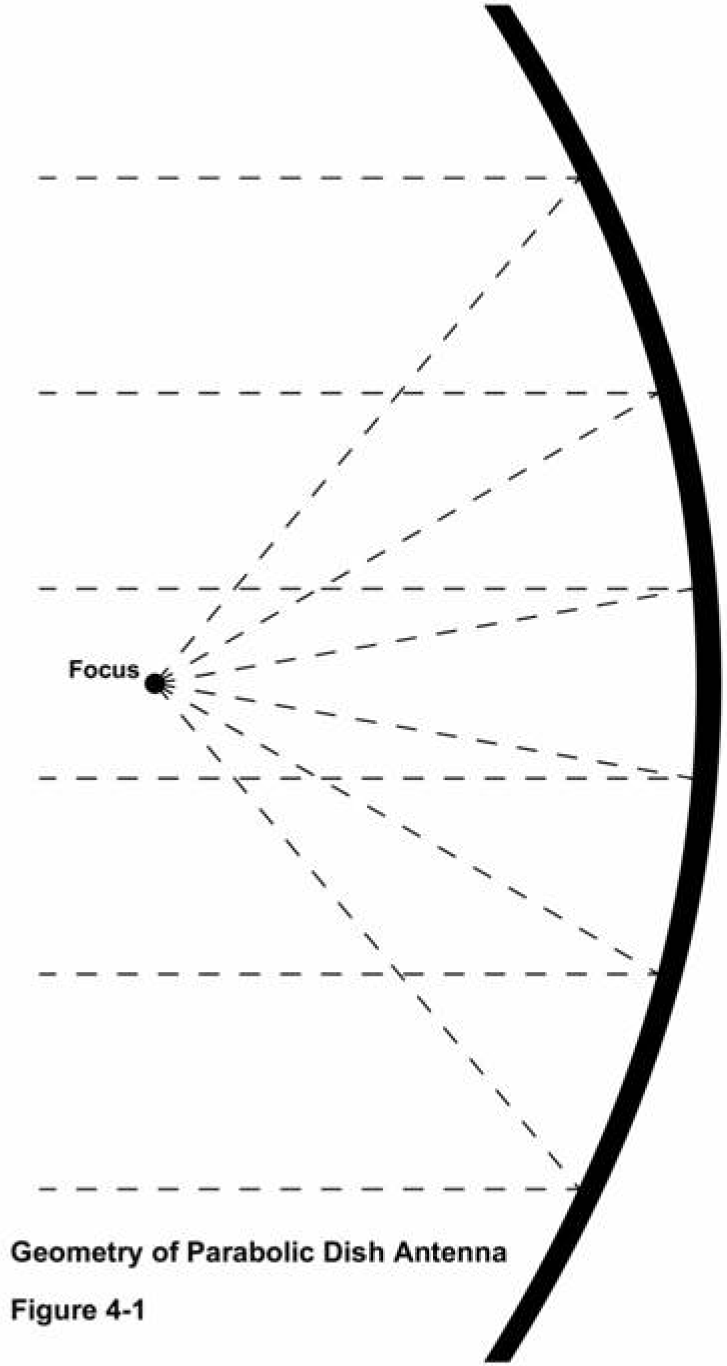
- Cassegrain
- Gregorian
- Others



Parabolic reflector

- All paths from focus to plane are equal length
- ***IN PHASE***

Parabolic Dish Feed Review

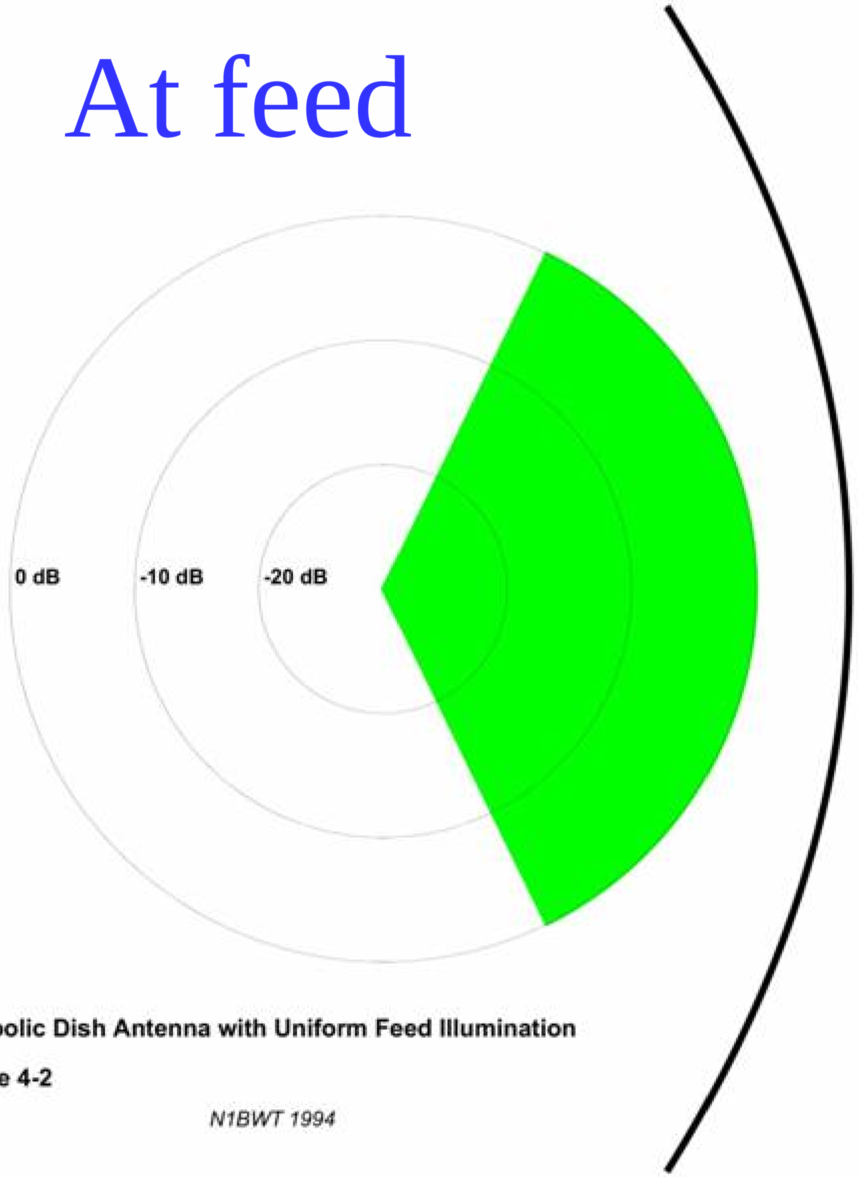


Geometry of Parabolic Dish Antenna

Figure 4-1

Uniform Illumination

At feed

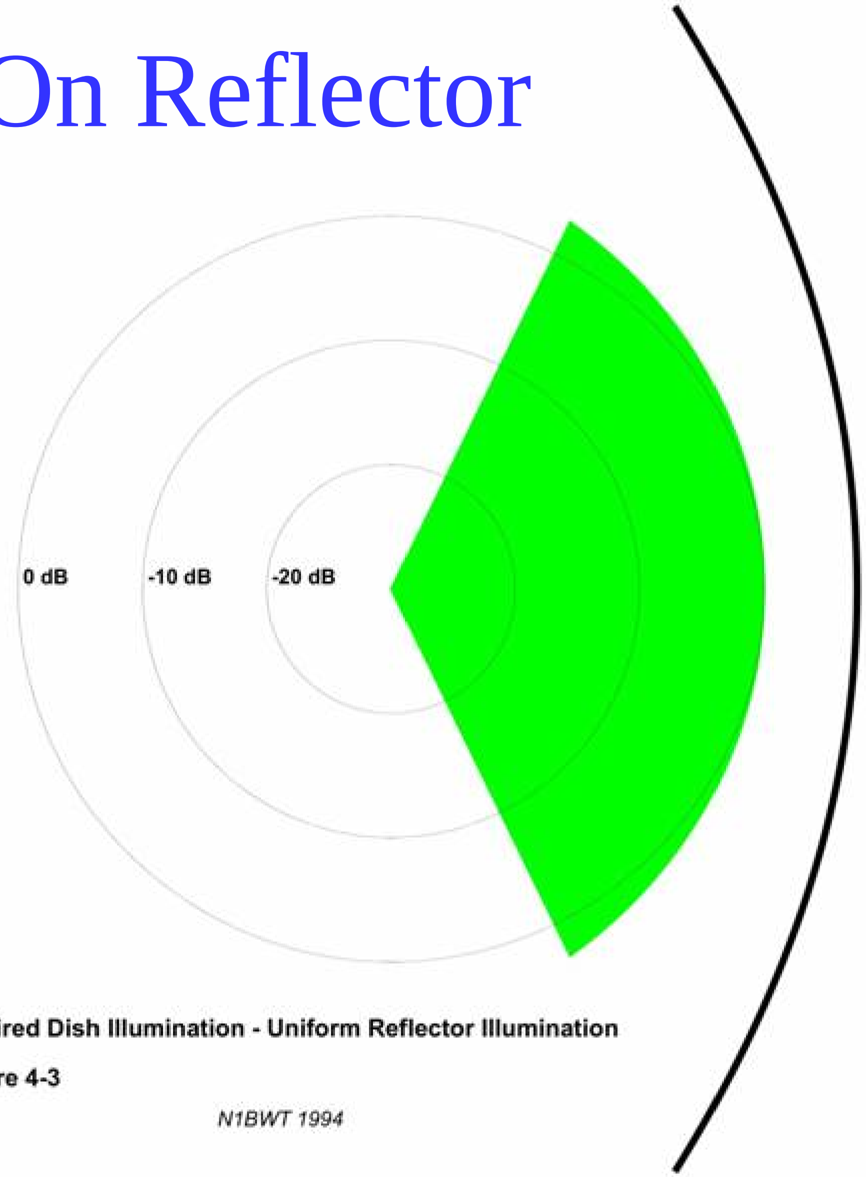


Parabolic Dish Antenna with Uniform Feed Illumination

Figure 4-2

N1BWT 1994

On Reflector

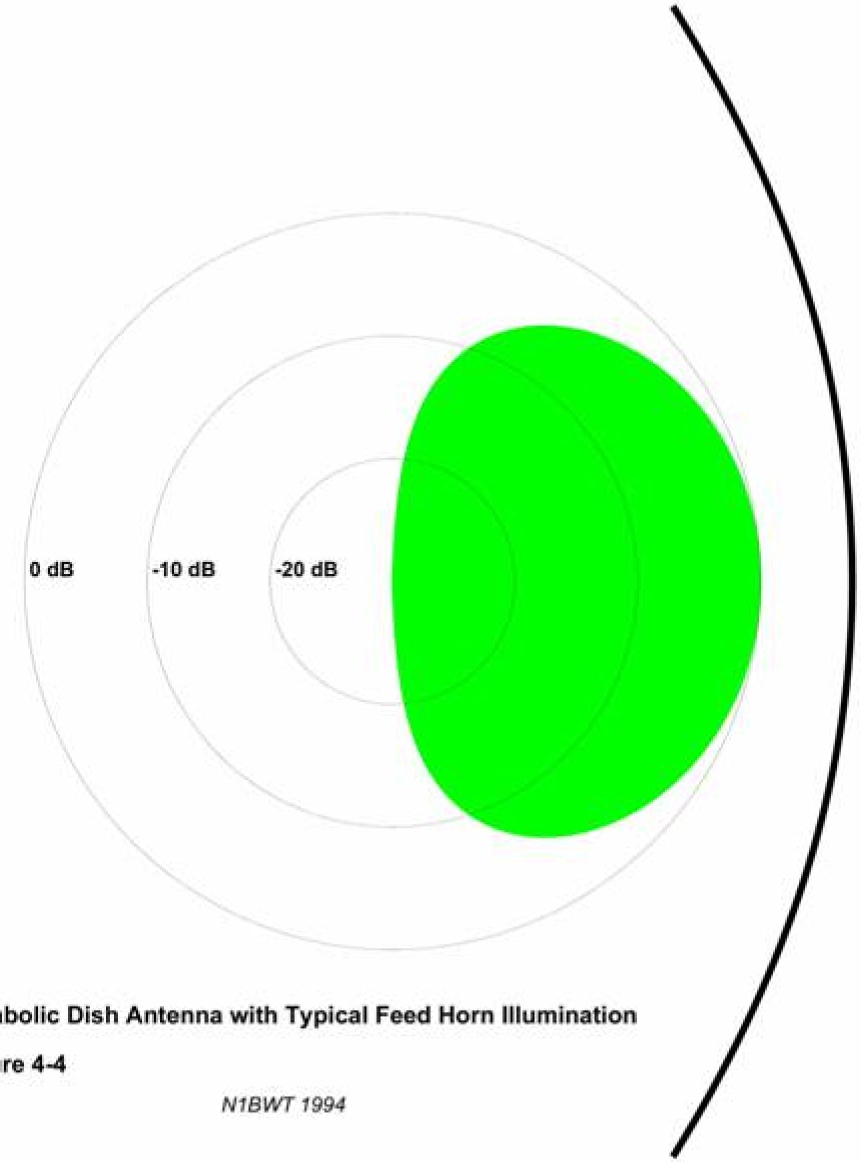


Desired Dish Illumination - Uniform Reflector Illumination

Figure 4-3

N1BWT 1994

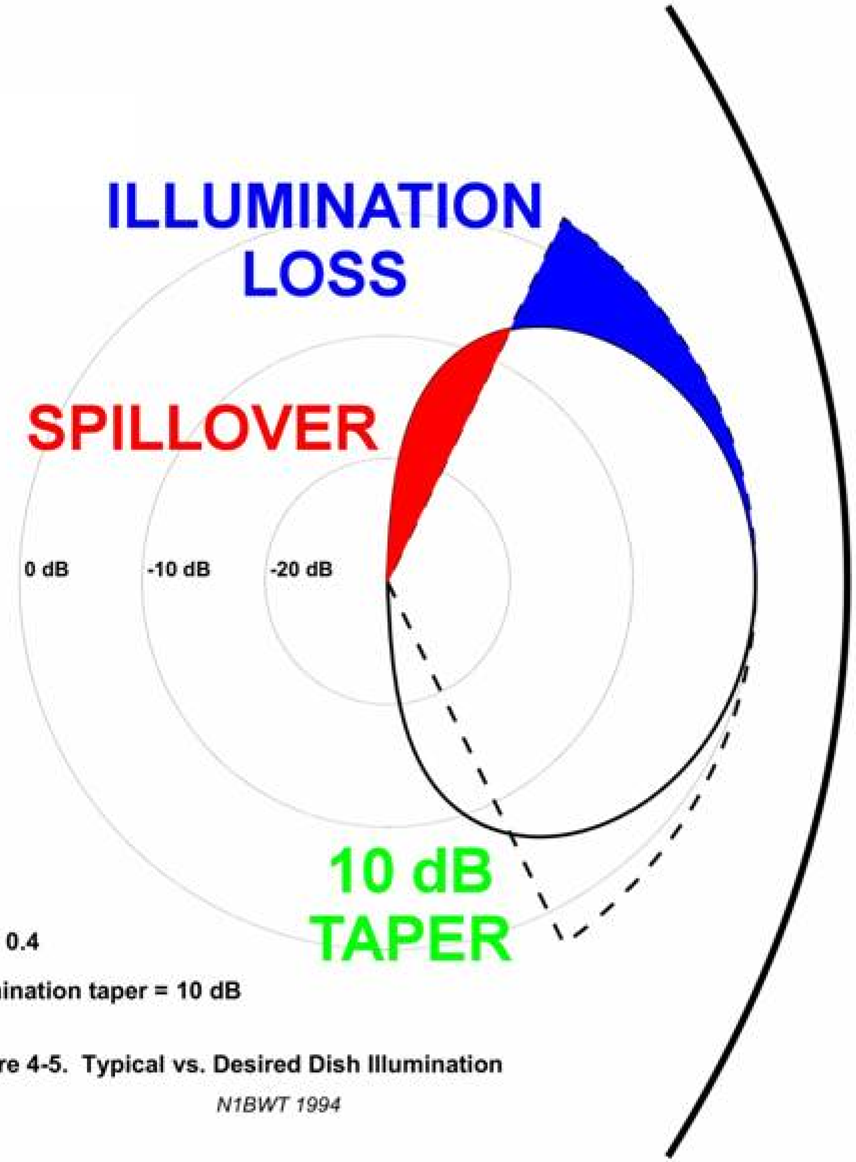
Typical illumination vs. desired



Parabolic Dish Antenna with Typical Feed Horn Illumination

Figure 4-4

N1BWT 1994



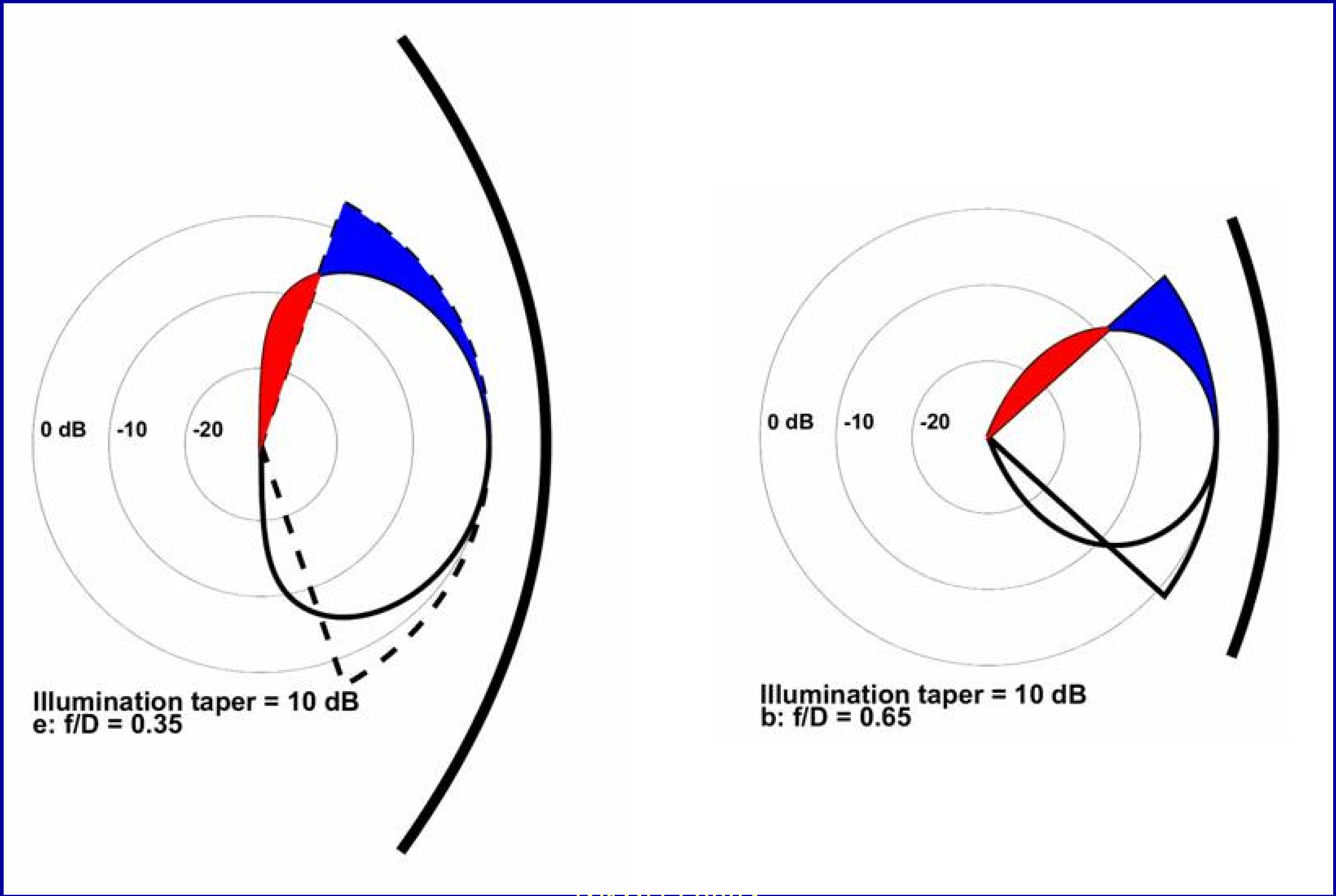
f/D = 0.4

Illumination taper = 10 dB

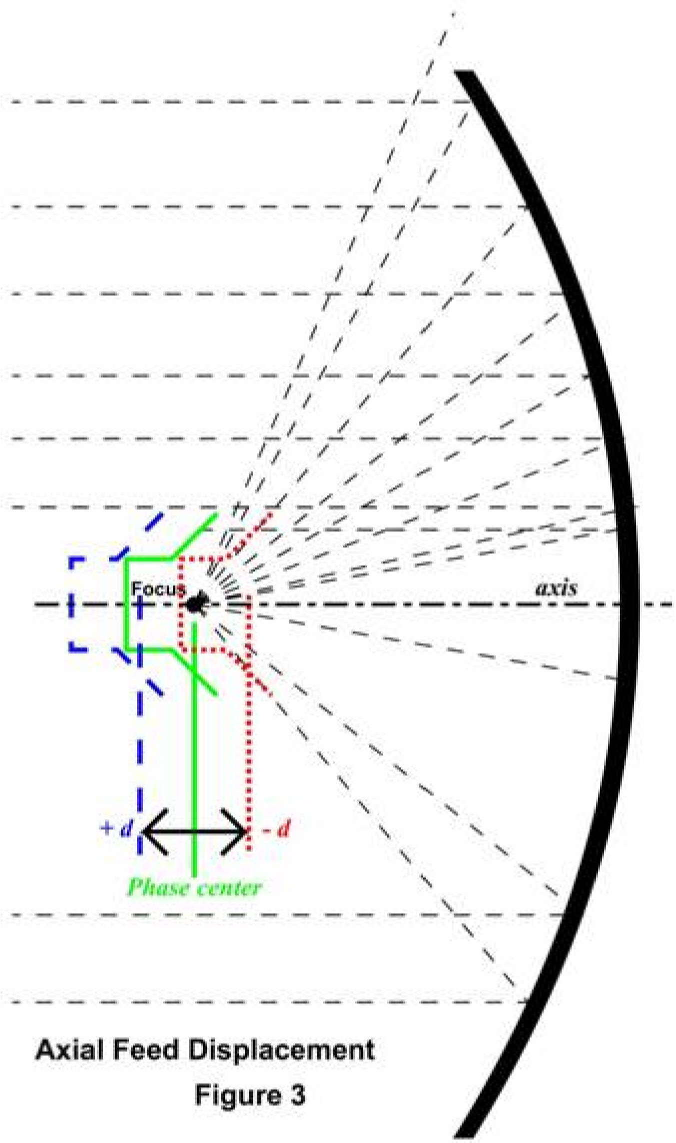
Figure 4-5. Typical vs. Desired Dish Illumination

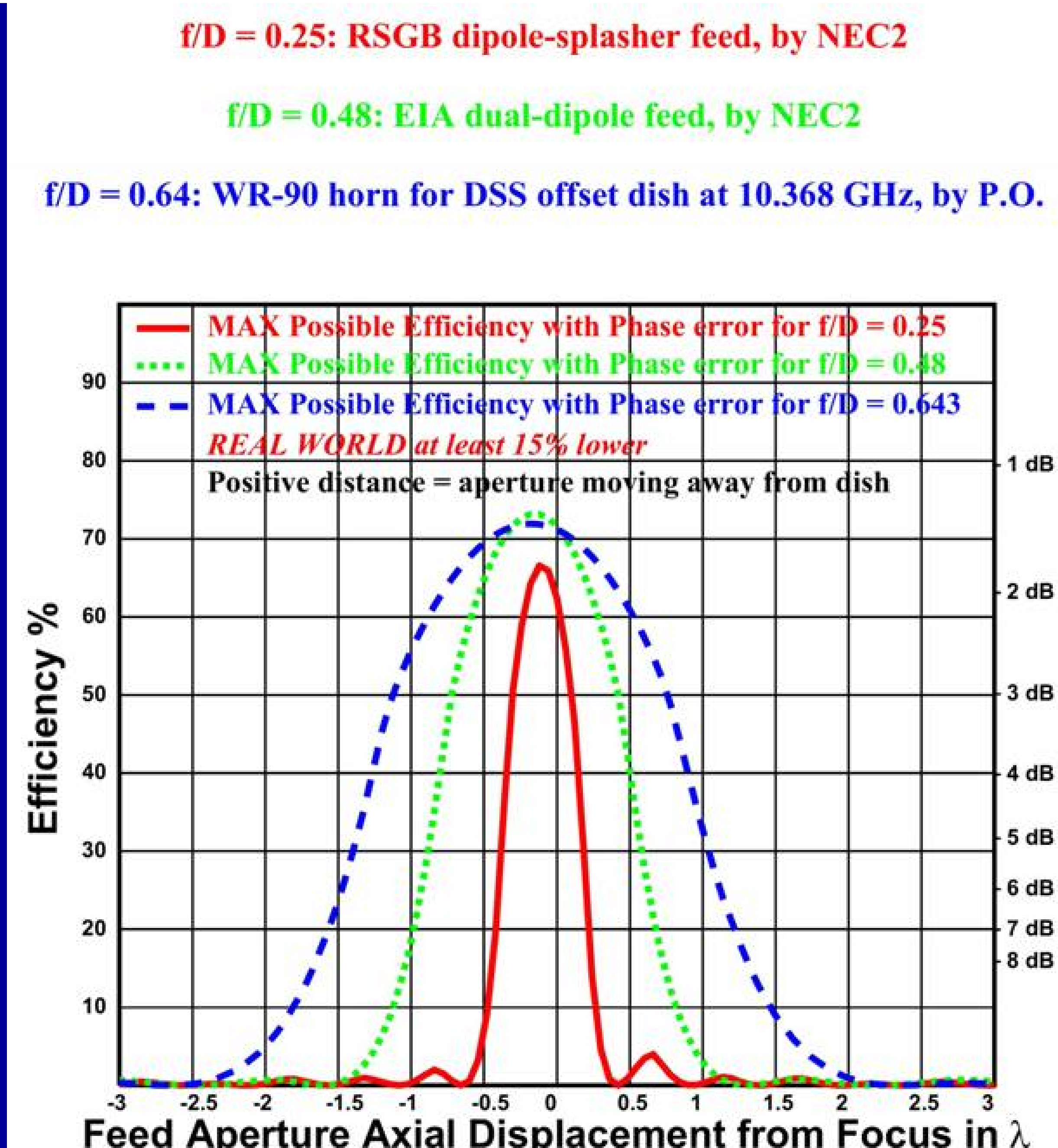
N1BWT 1994

Deep *f* / D vs Shallow



Focus critical





Parabolic Feed Summary

1. Feed Phase Center at Focus
   - *Error -> many dB*
2. Match feed to *f*/D
   - *Error -> dBs*
3. Minimize losses and blockage
   - *Error -> tenths of dB*

Why multiple reflectors?

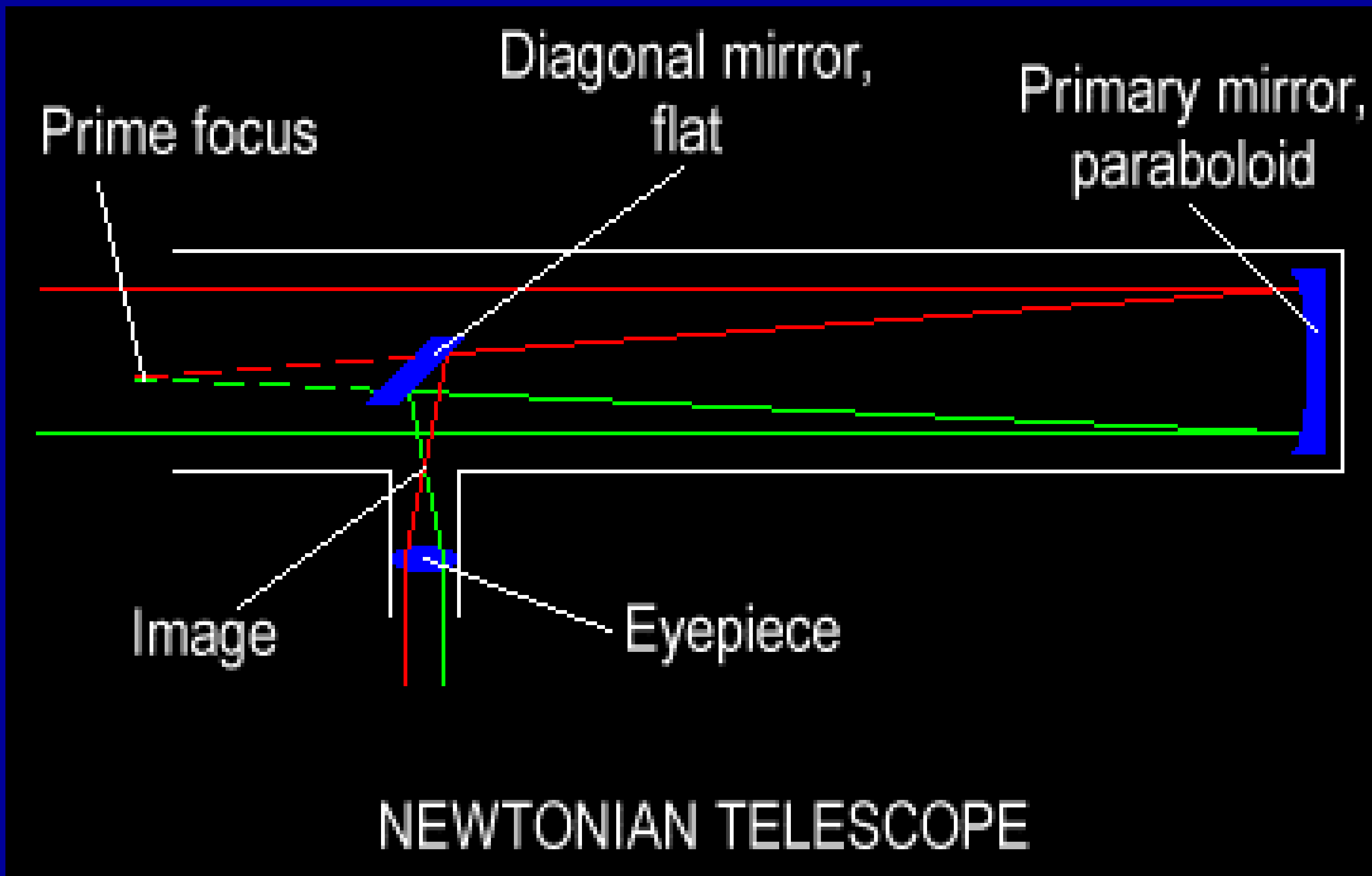
- Reverse feed
  - A convenience

- Reshape feed pattern
  + ***REAL ADVANTAGE***
  - No good prime feeds for deep dishes

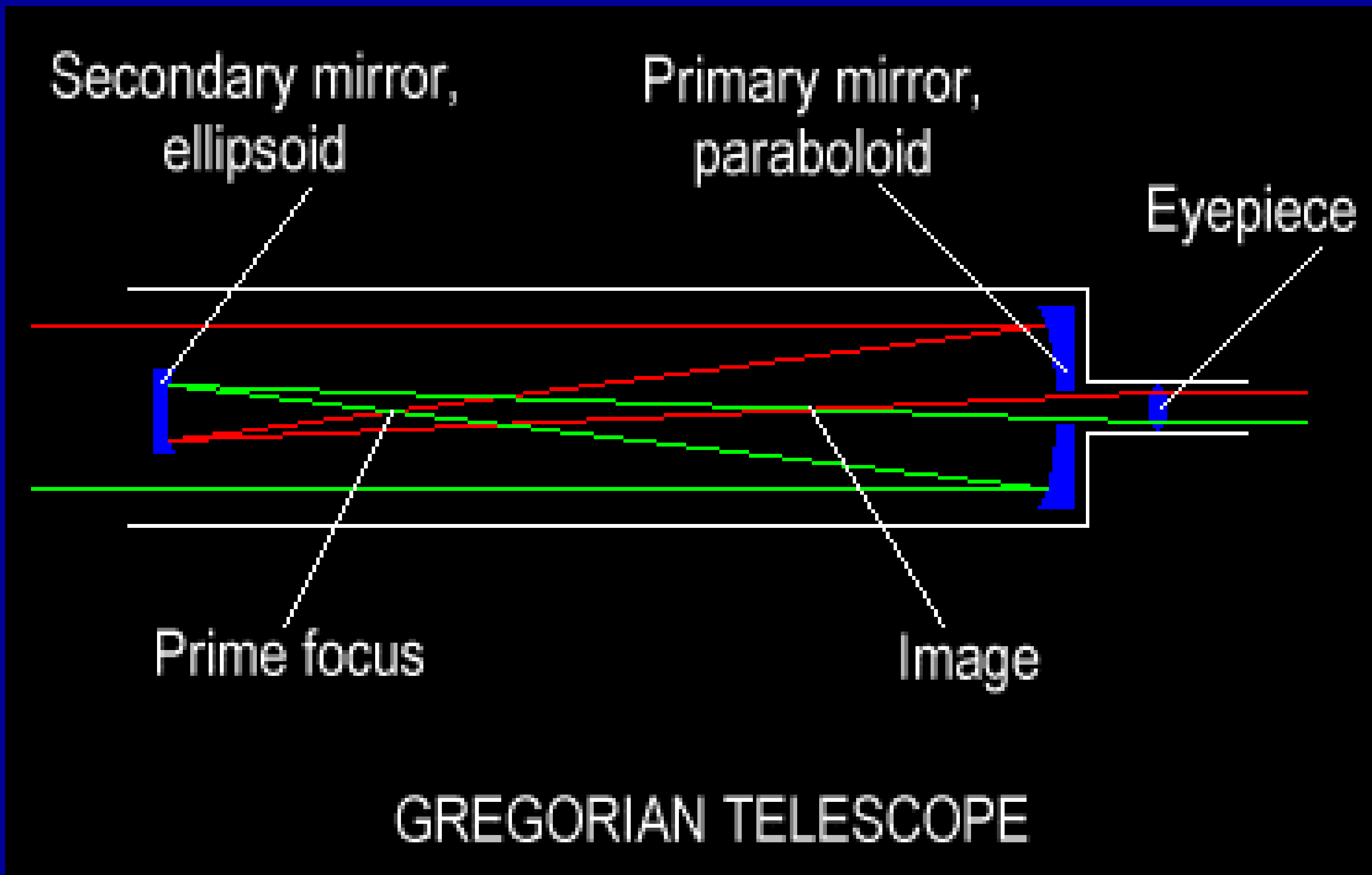
Derived from Telescopes

- Newtonian – flat subreflector
- Gregorian – elliptical subreflector
- Cassegrain – hyperbolic subreflector
- Schmitt-cassegrain – Spherical main reflector, correcting lens

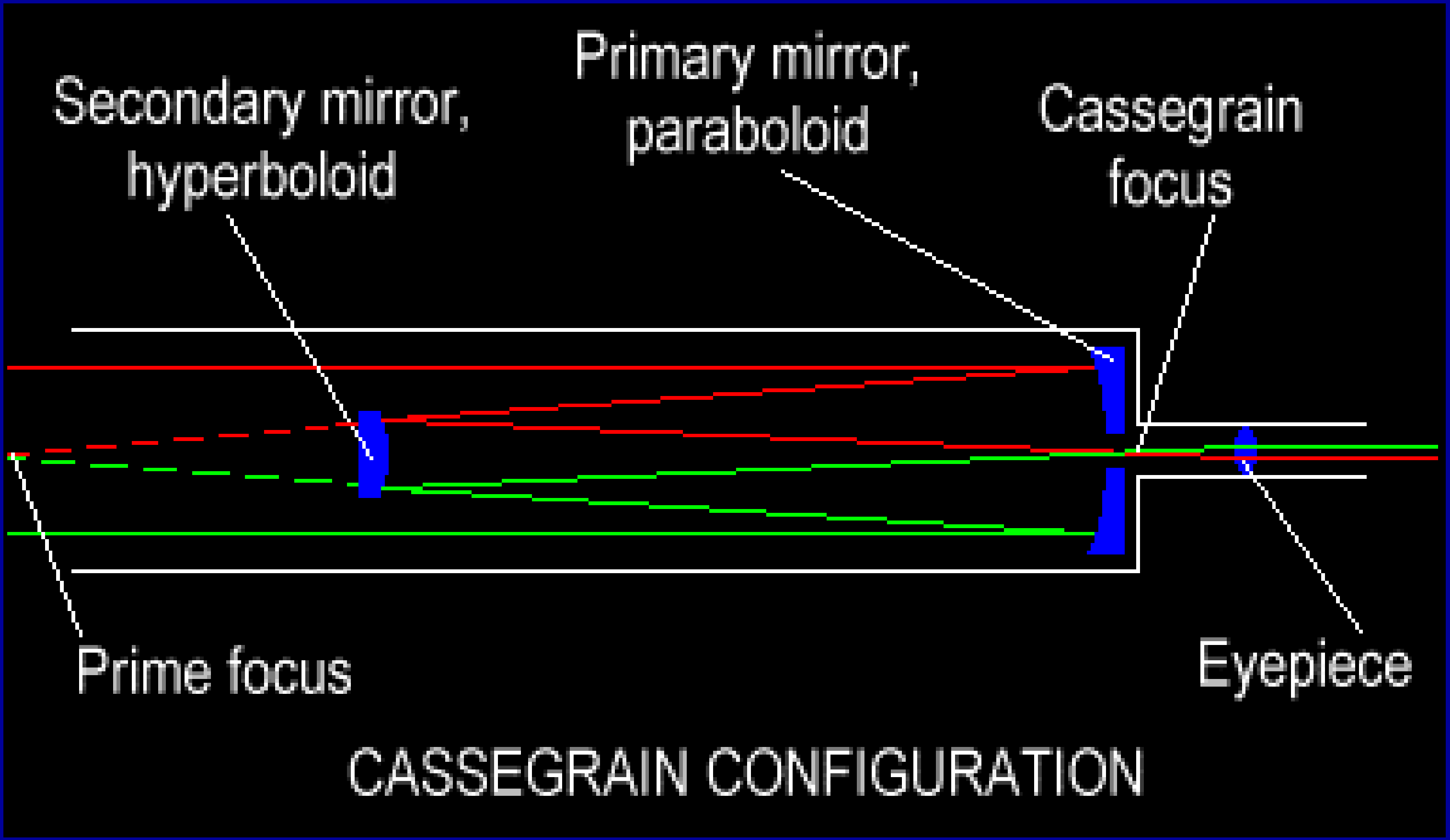
Newtonian telescope



Gregorian Telescope



Cassegrain telescope



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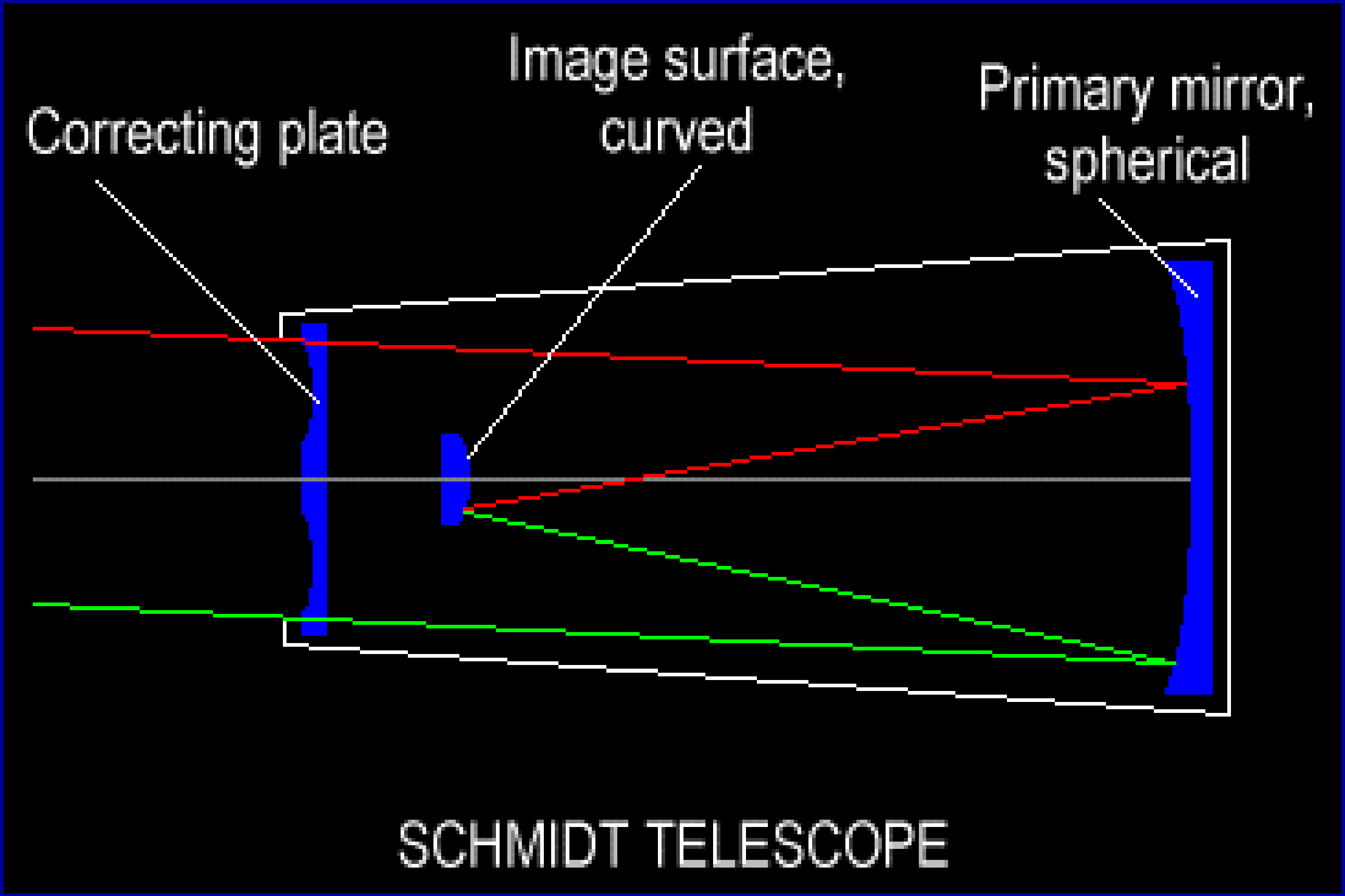
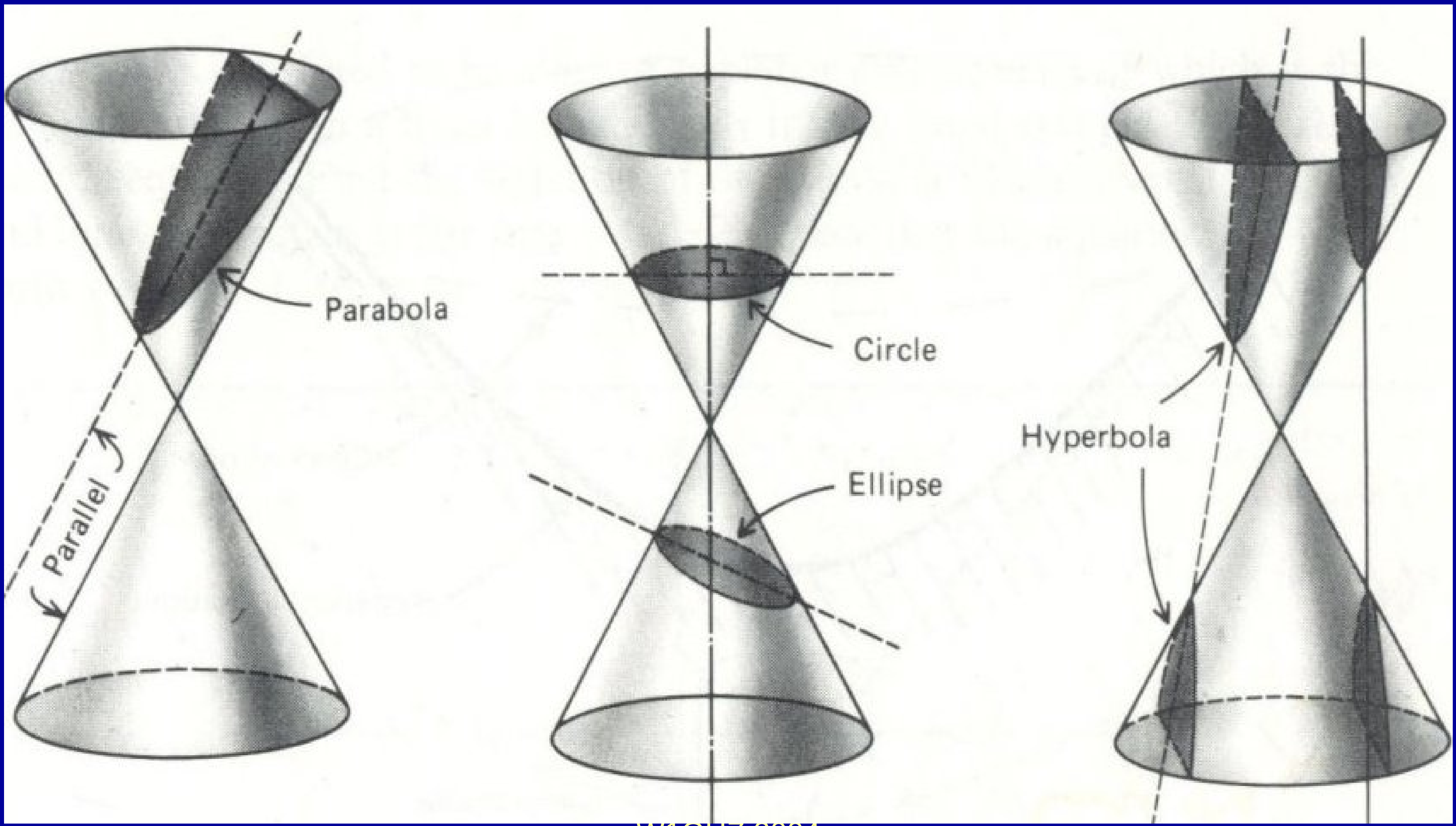
Schmitt-cassegrain telescope



Conic sections



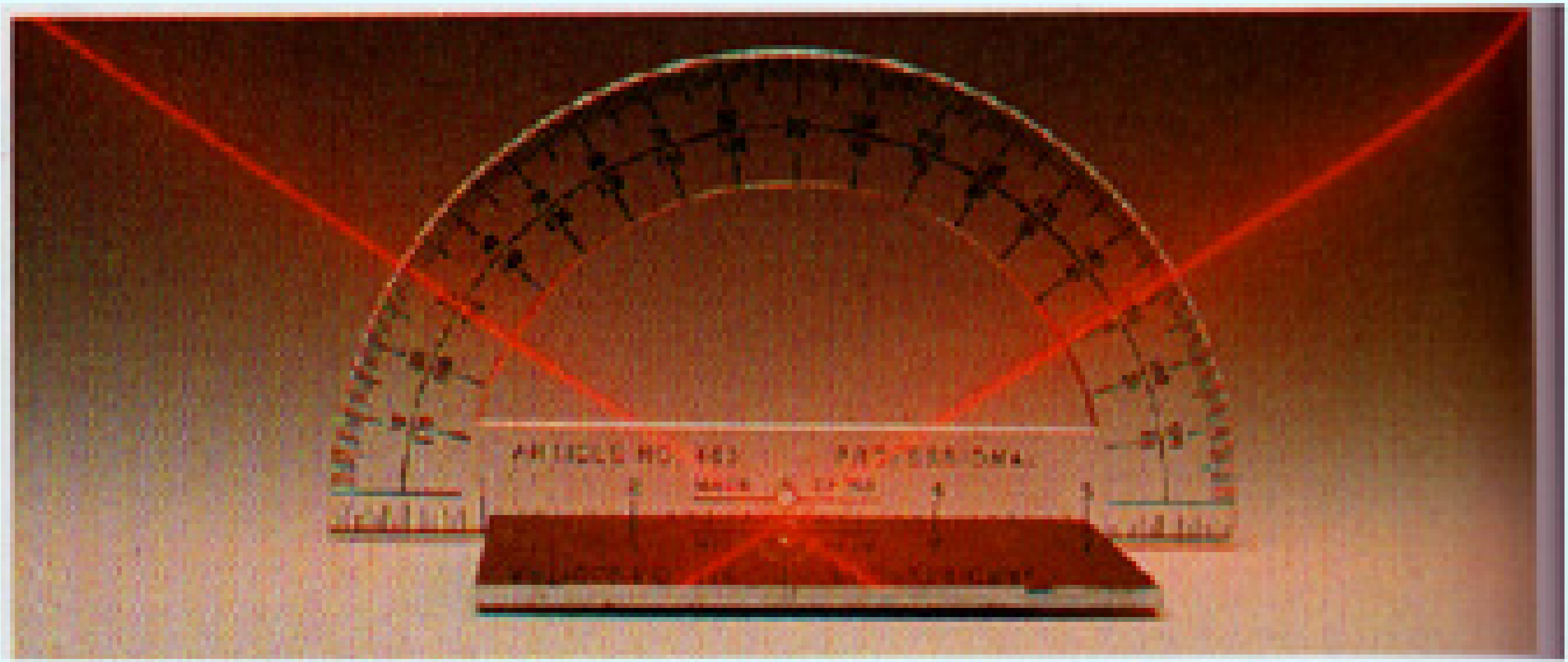
Geometric optics approximation

- Wavelength → zero
- Waves travel in straight lines – Rays
- Curvature >> wavelength
- Reflection from flat surfaces
  - Angle of incidence = Angle of reflection
- Refraction follows Snell's Law

Law of Reflection

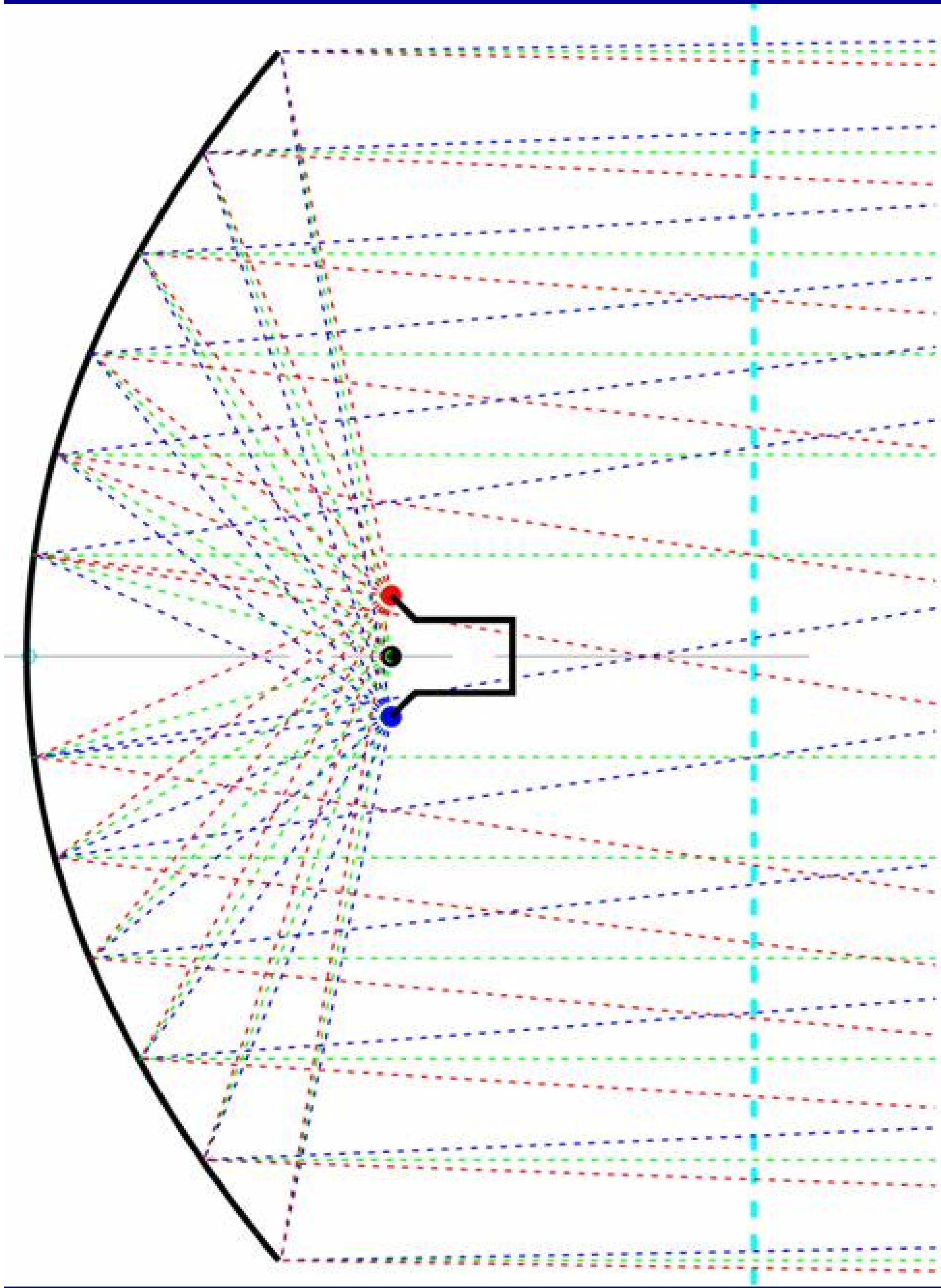
Reflection:

The angle of incidence = the angle of reflection.



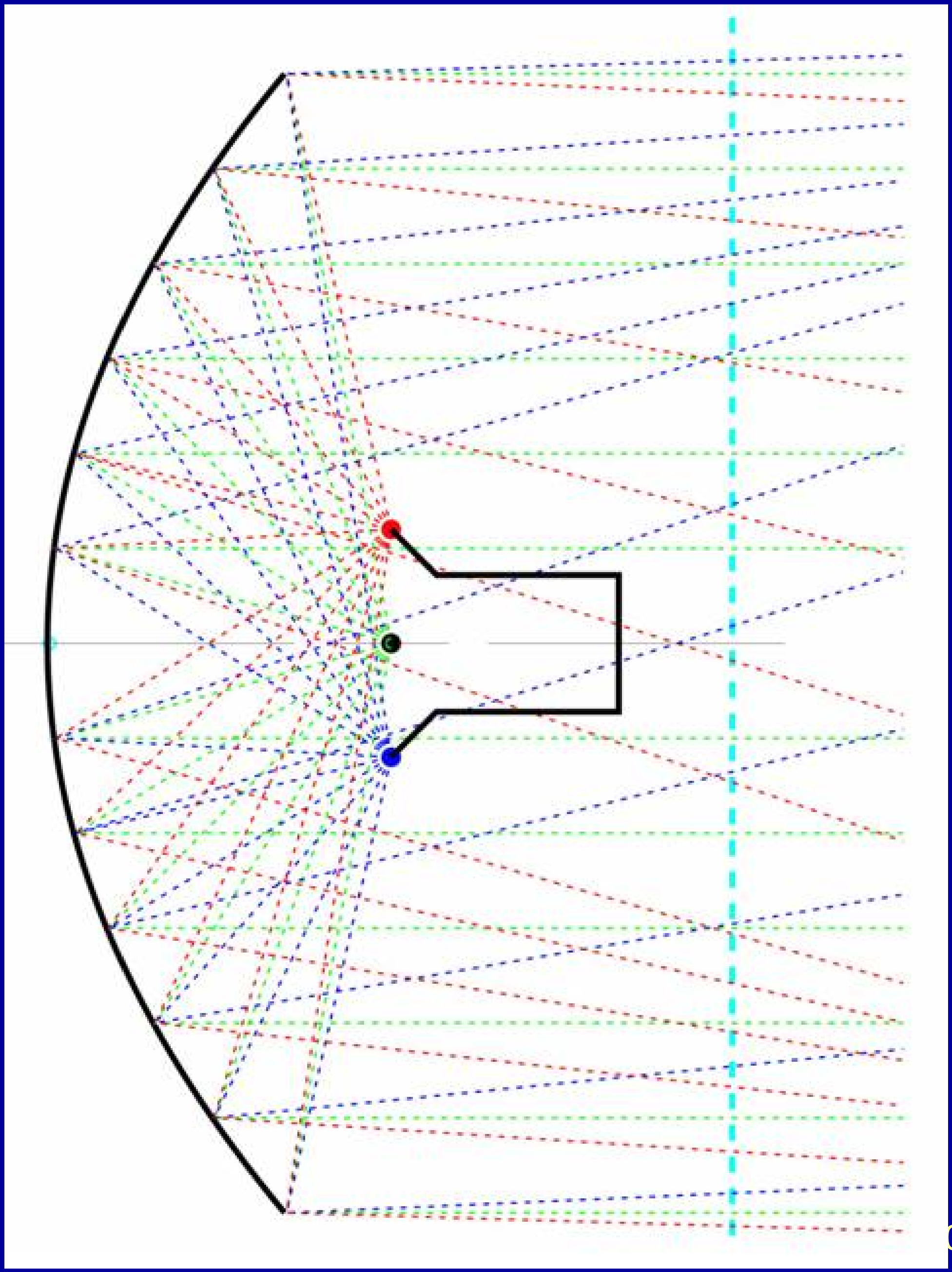
Diffraction
or
Why small dishes don't work well

- Wavelength is not zero
- Objects and curvatures ~ wavelength
- J. B. Keller
  - Geometric Theory of Diffraction

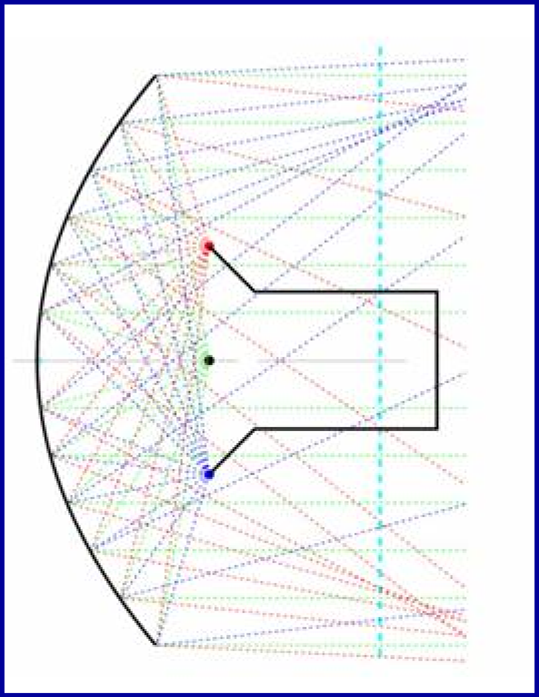


Small dishes

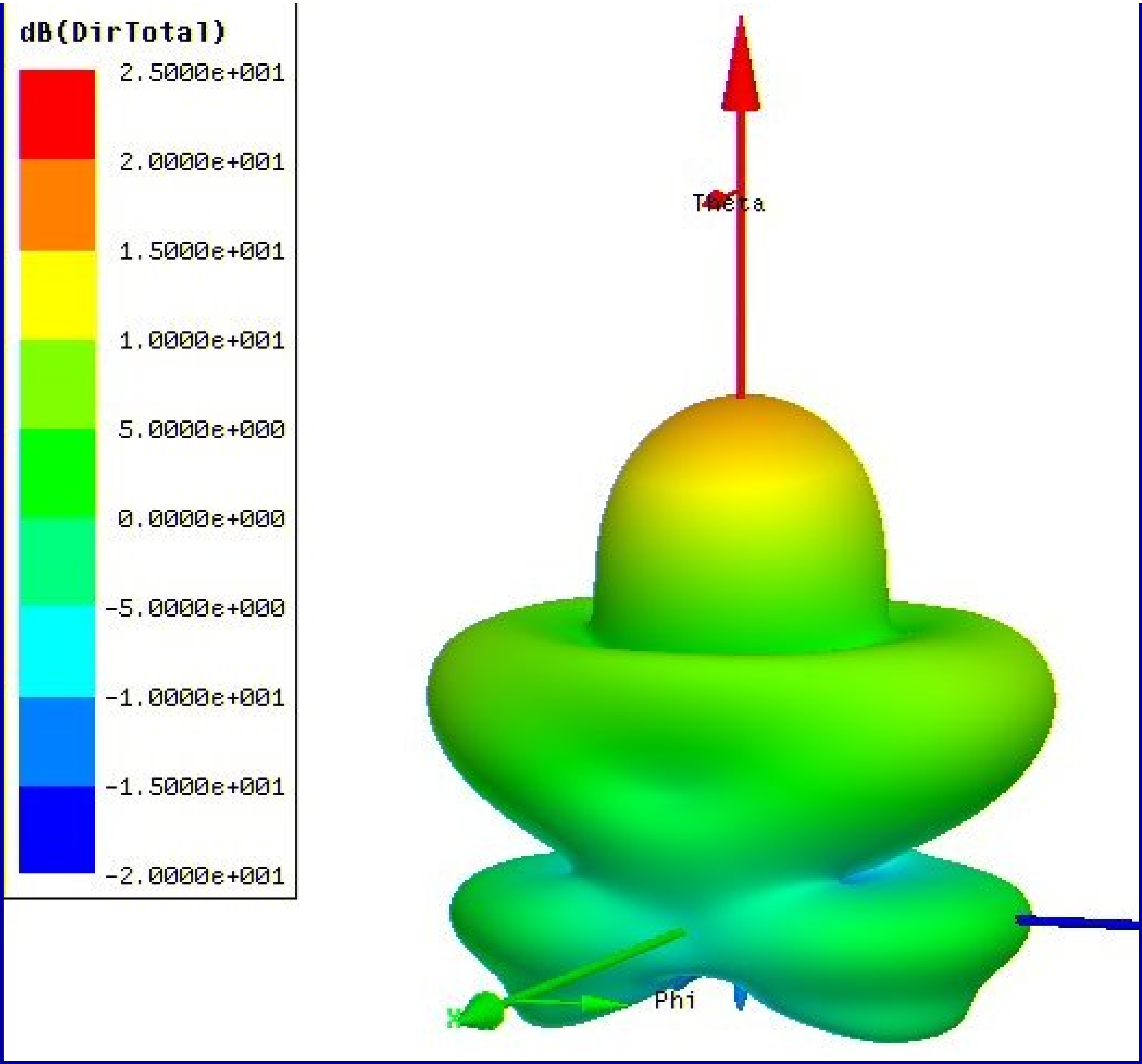
- Feed is not a point source
- *Huygen's Principle:*
  - Each point on feed aperture acts as a radiating source



Very small dishes: 5λ and 2.5 λ

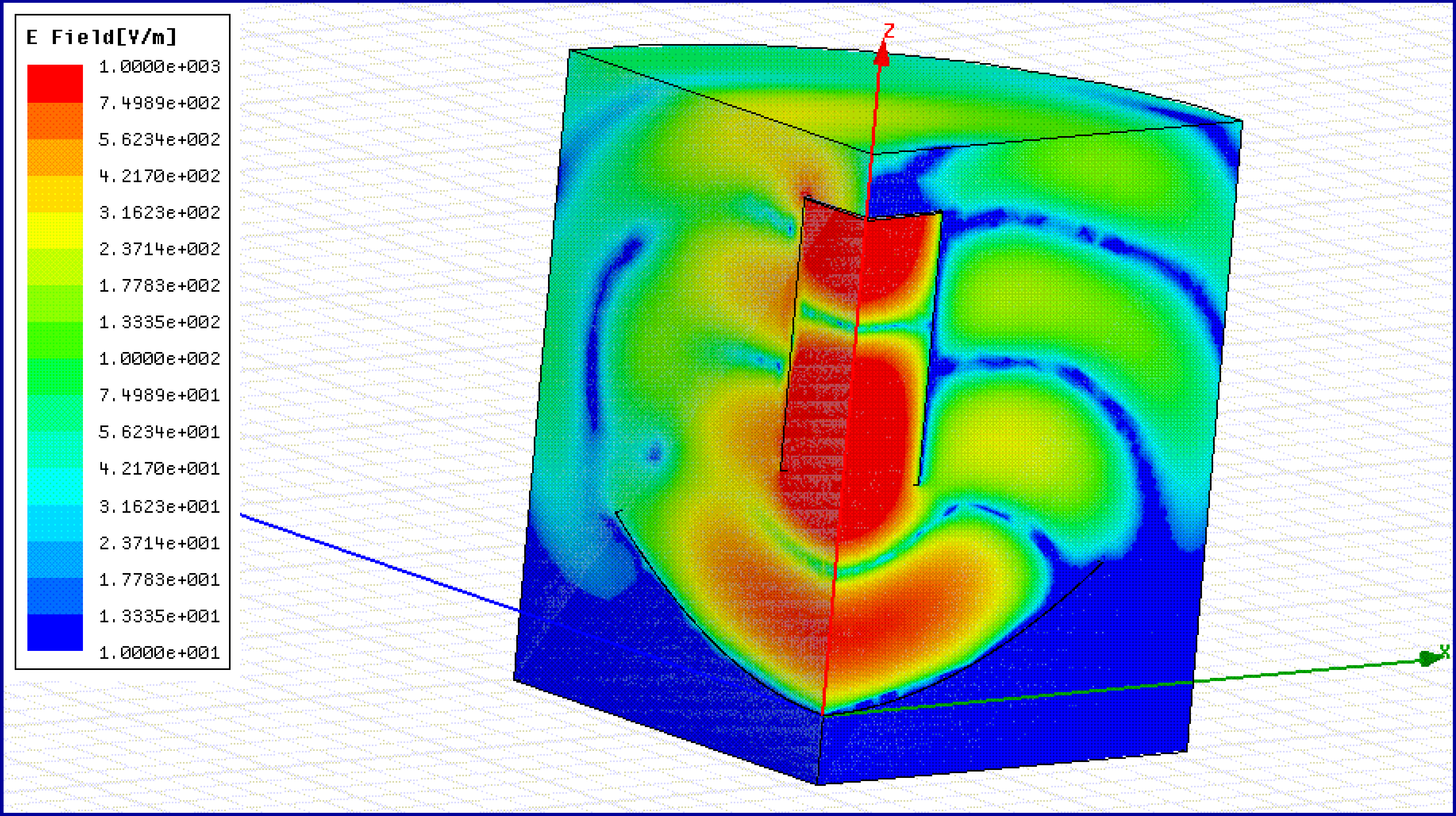


004


dB(DirTotal)
2.5000e+001
2.0000e+001
1.5000e+001
1.0000e+001
5.0000e+000
0.0000e+000
-5.0000e+000
-1.0000e+001
-1.5000e+001
-2.0000e+001
Theta
Phi

2.5 λ Dish

2.5 λ Dish – Near field



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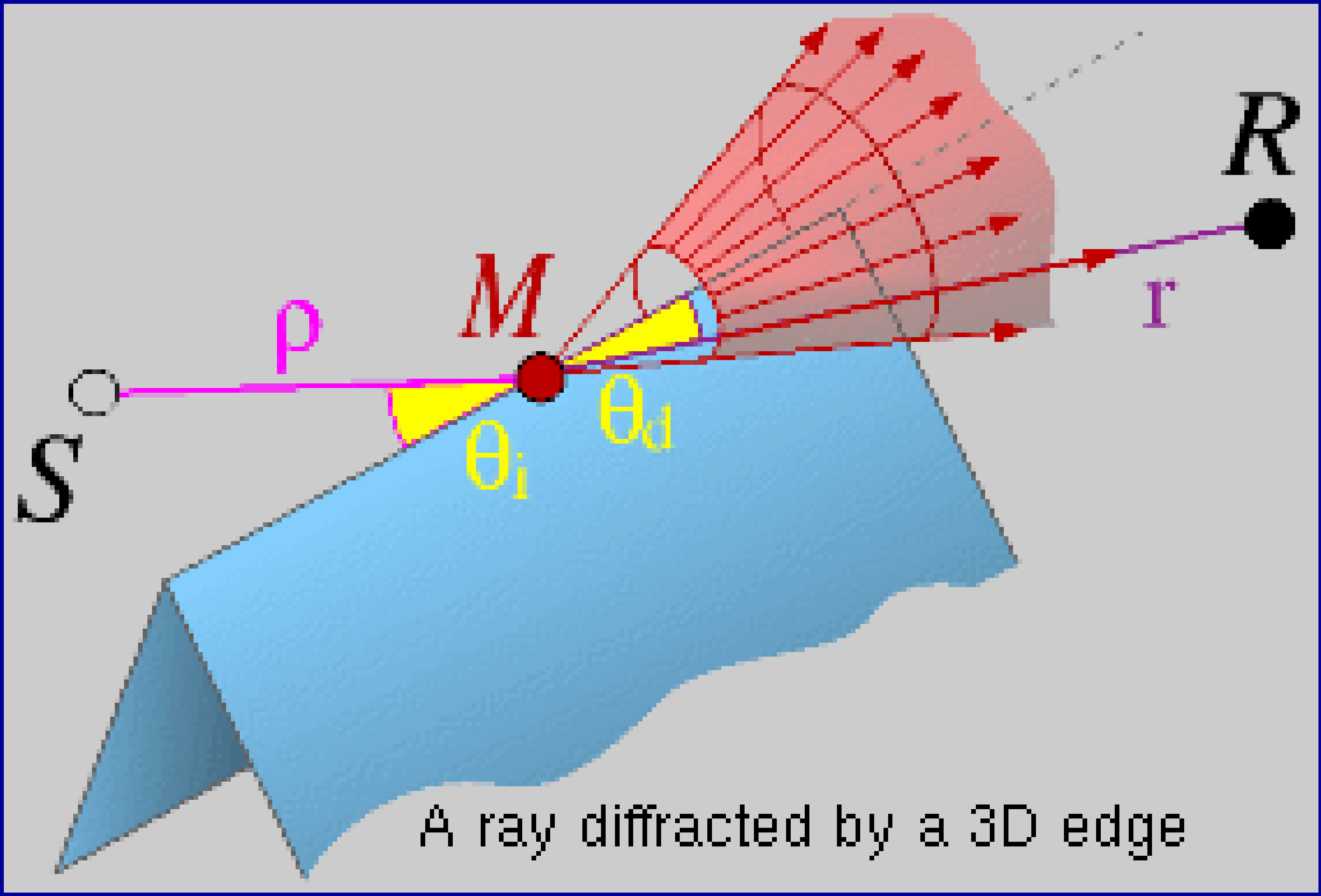
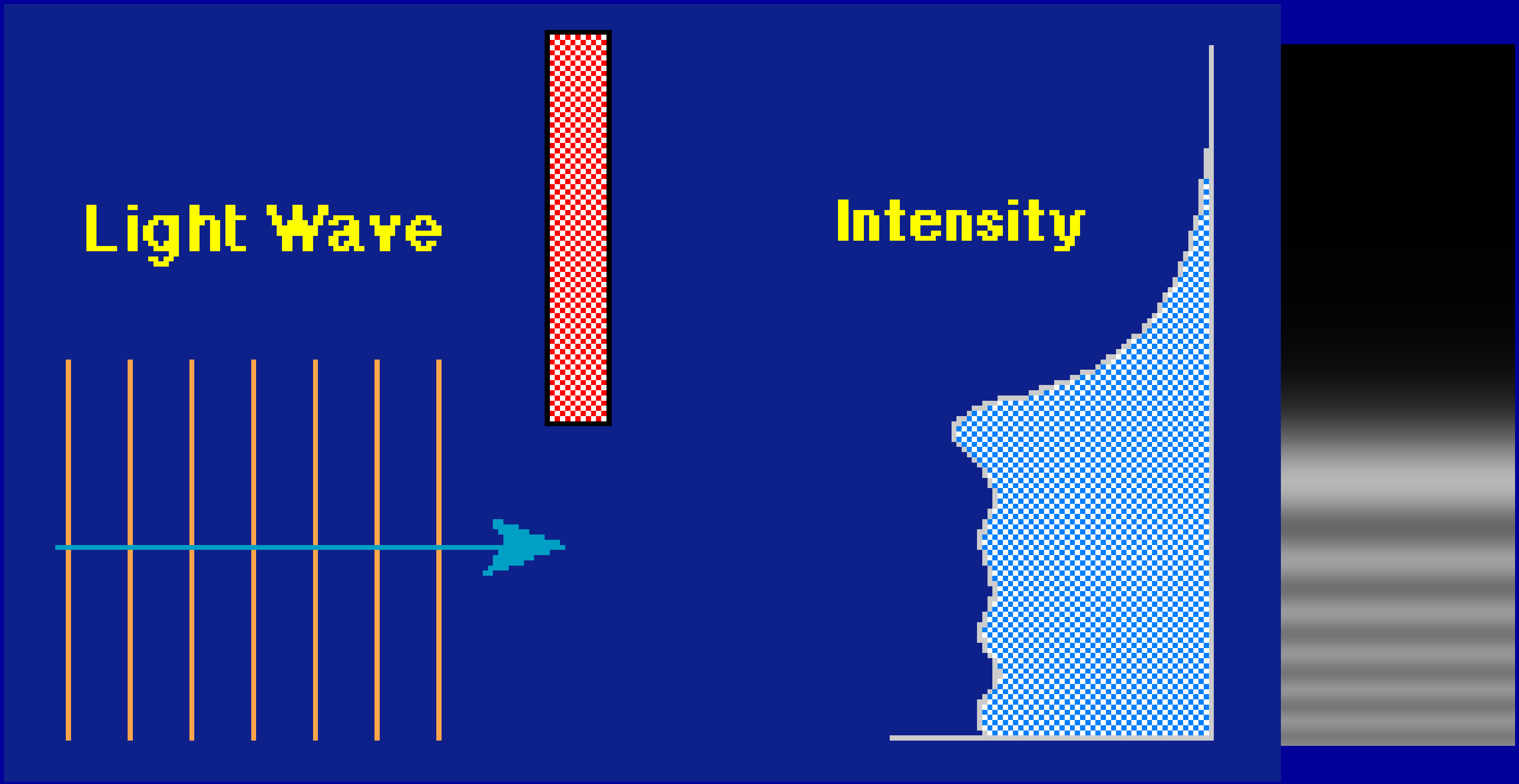
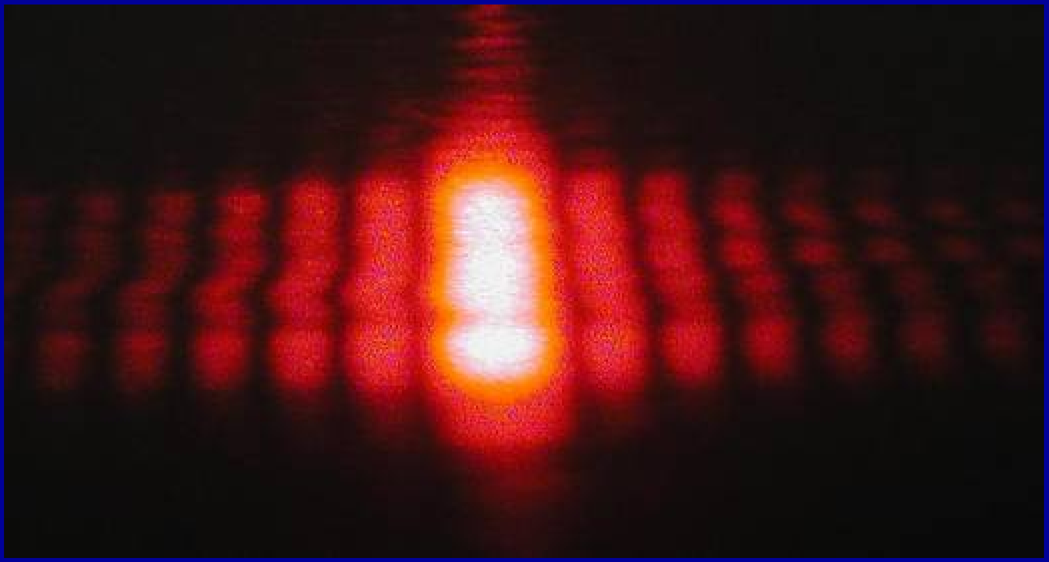
Diffraction – Keller cone



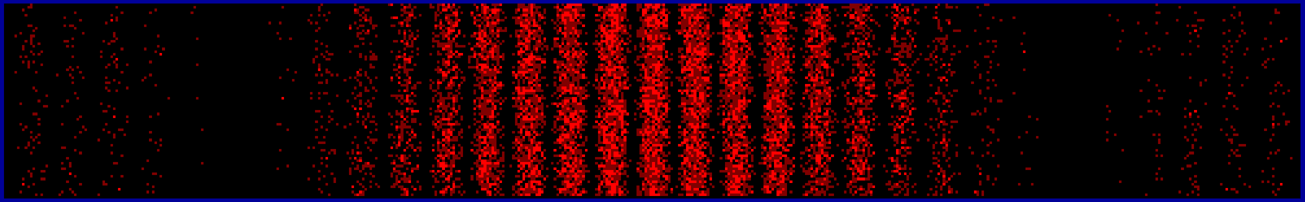
Edge Diffraction



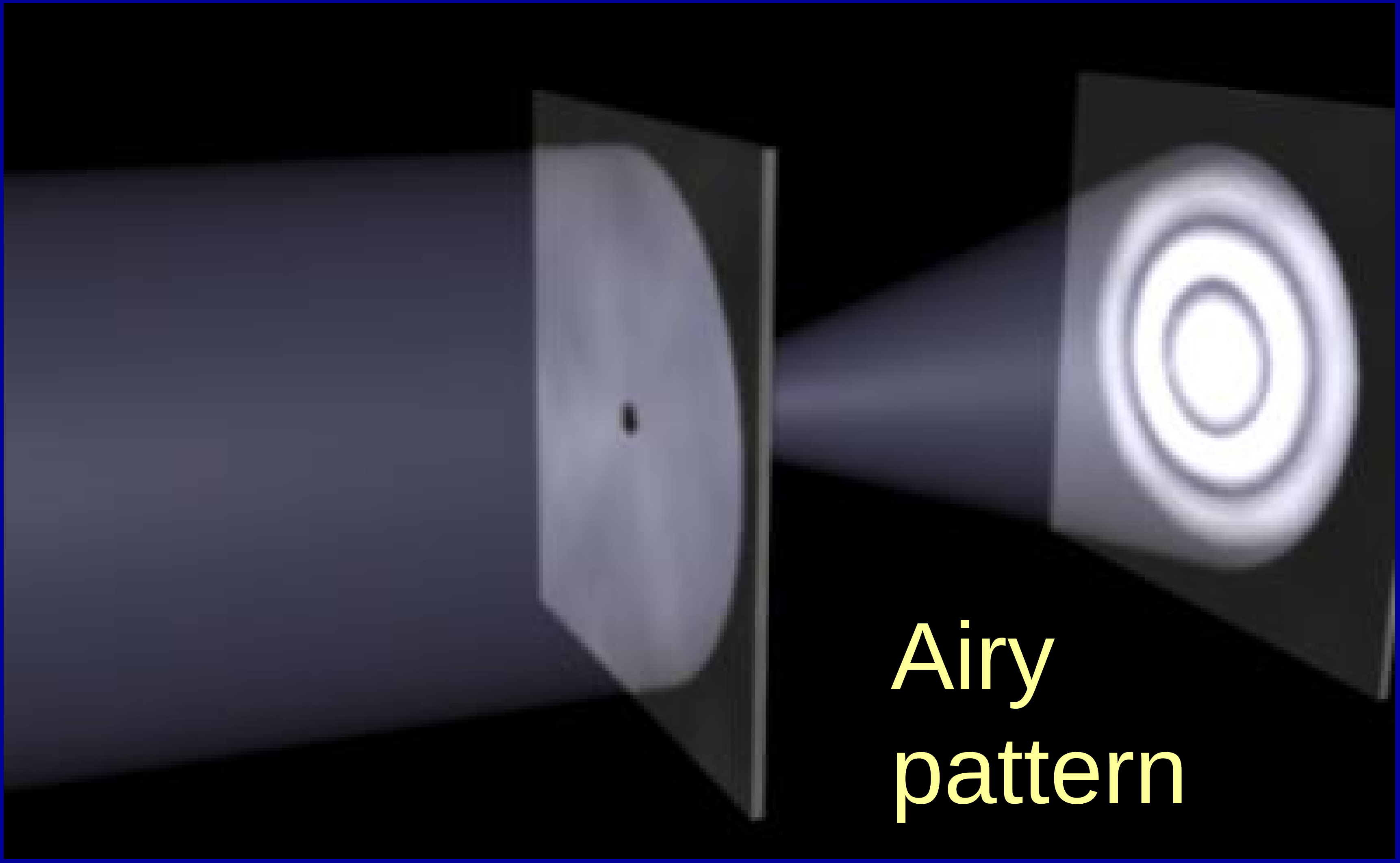
Diffraction thru a slit



2 slits →



Diffraction thru a hole



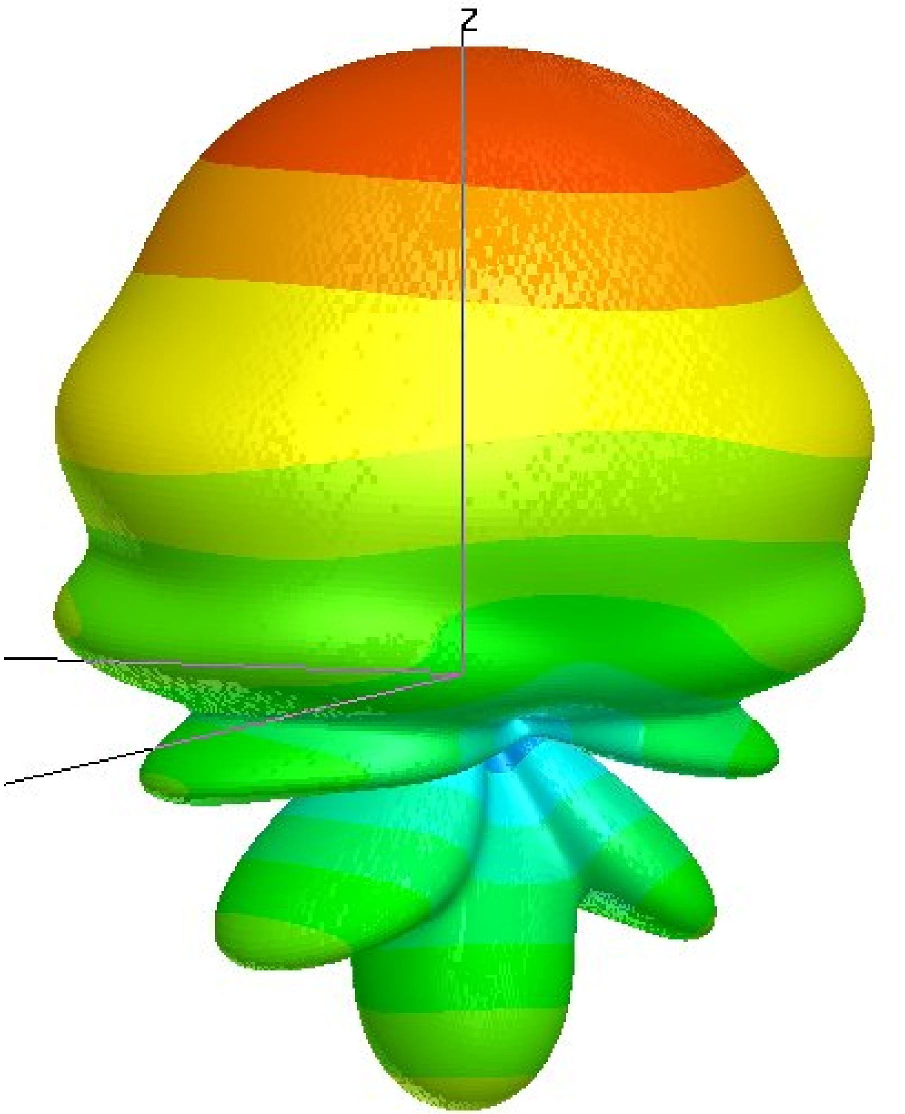
Diffraction from a strut

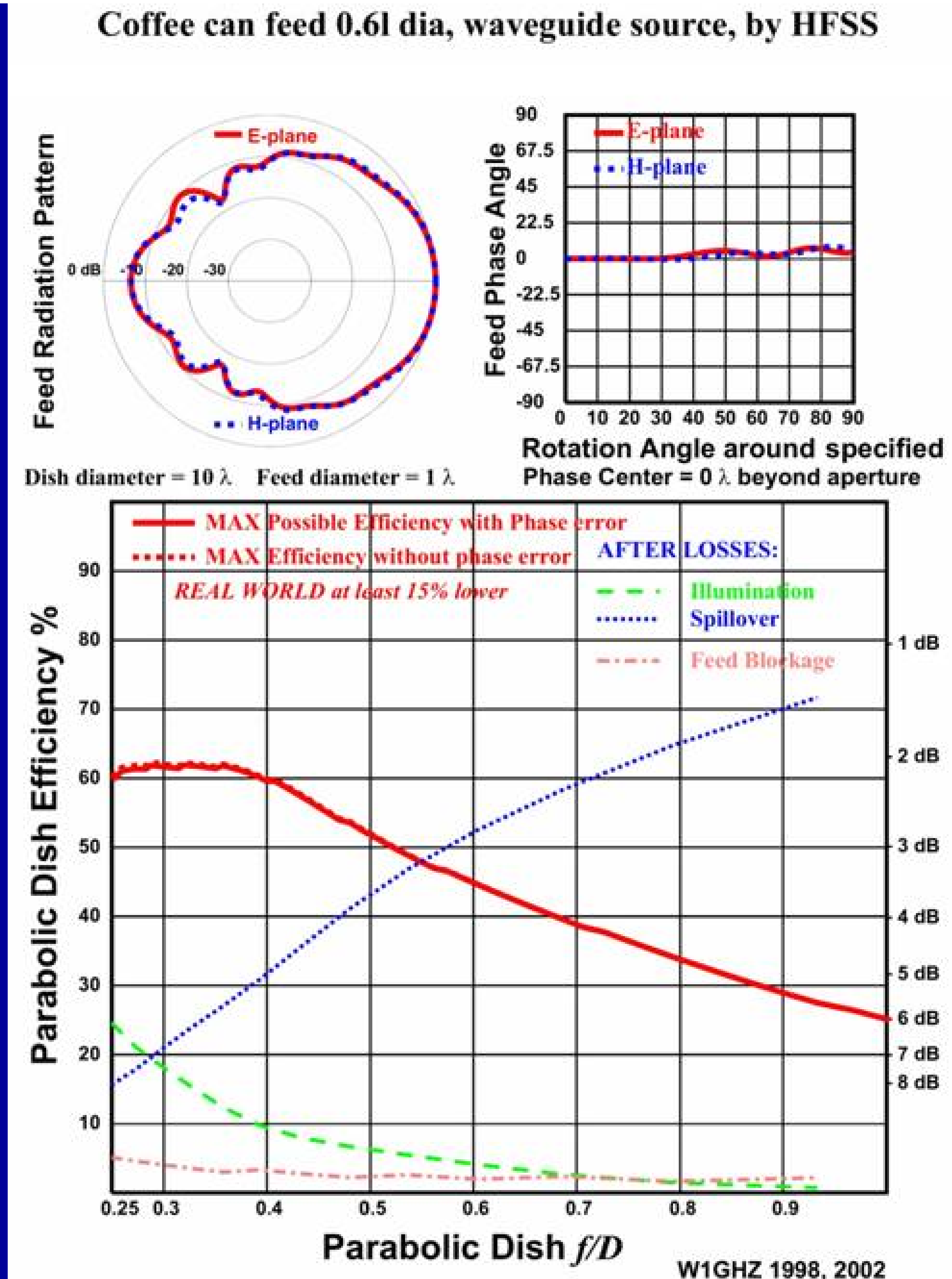
Telescope picture
Diffraction from struts

Prime focus feeds

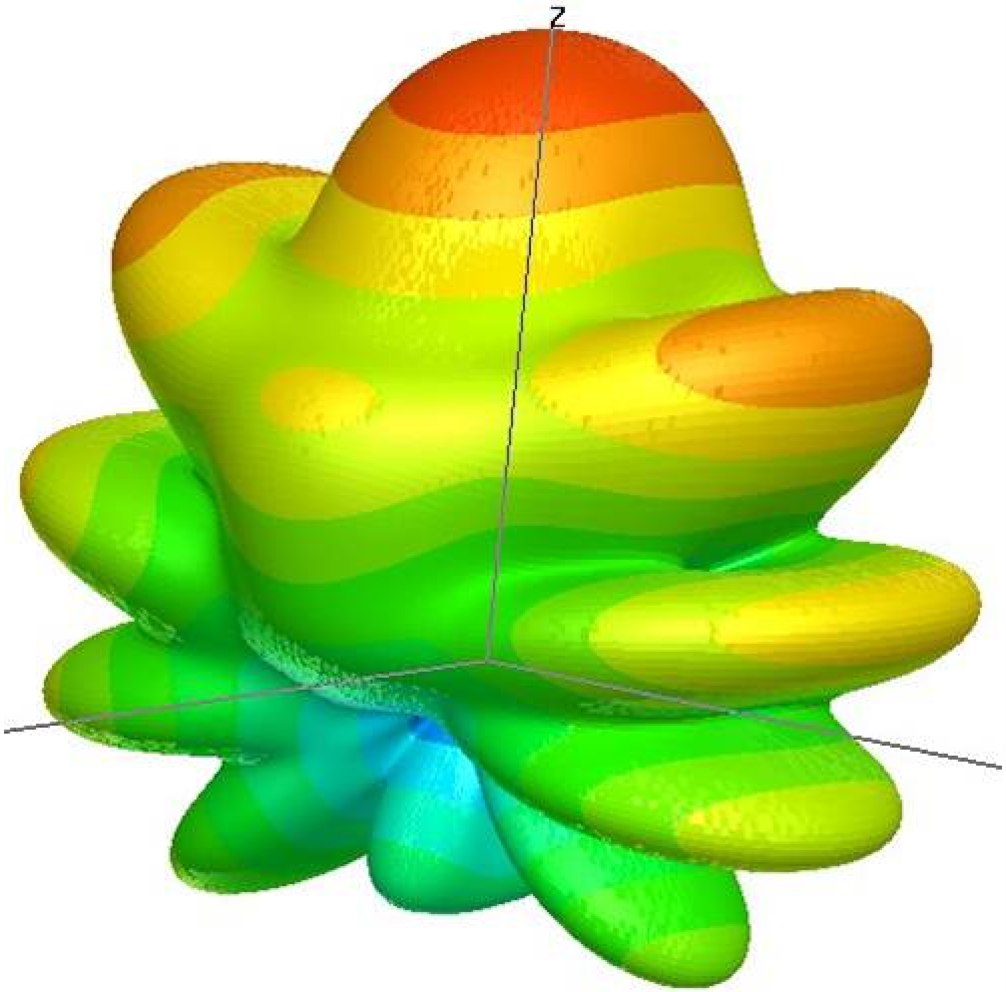
- Good efficiency for deep dishes
  - *f*/D ~ 0.35 to 0.45 (*circular waveguides*)
- Poor efficiency for very deep dishes
  - *f*/D ~ 0.25 (*Penny feed*)
- Very good for shallow dishes
  - *f*/D > 0.5 (*Dual-mode feeds*)
- **Subreflector reshapes shallow dish feed pattern to illuminate deep dish**

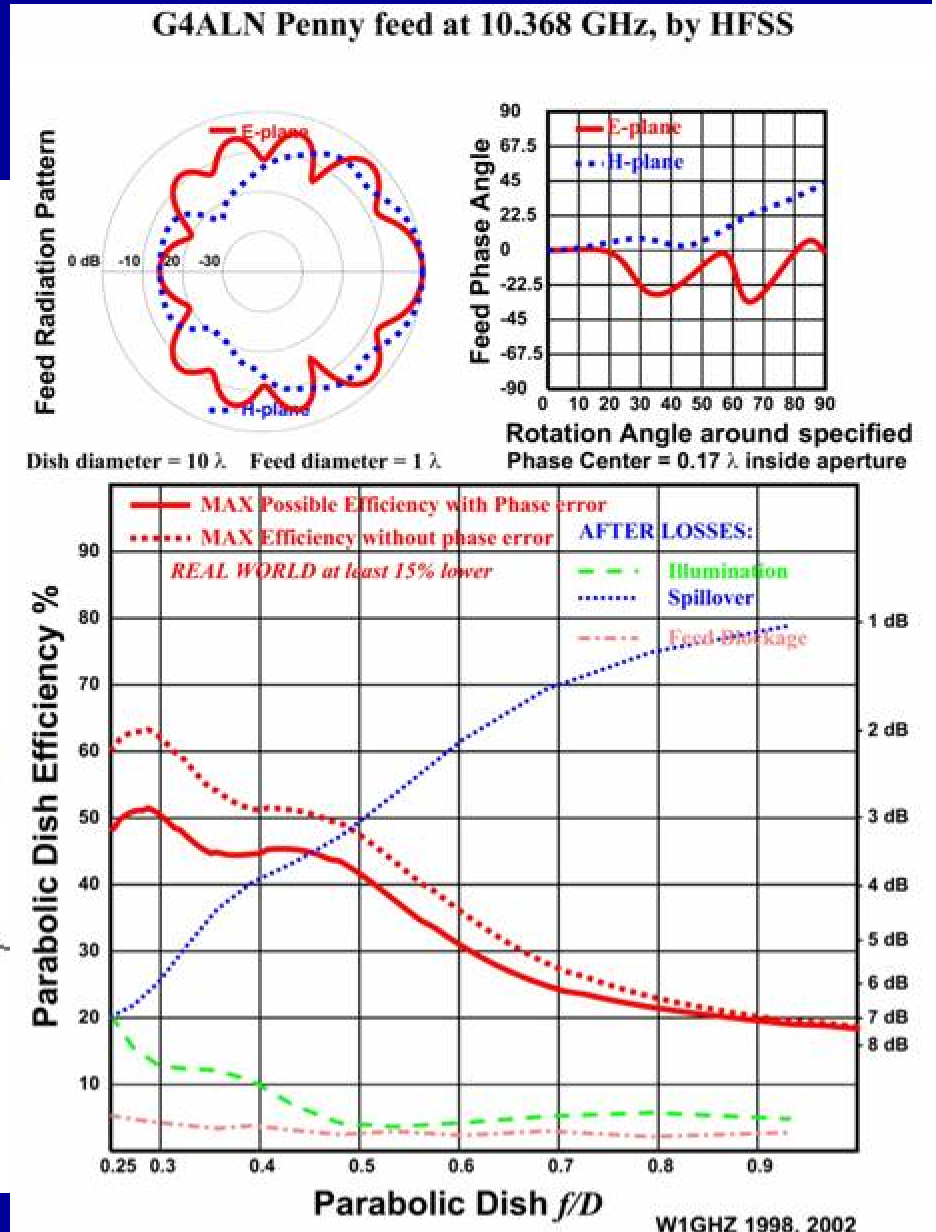
Coffee can feed



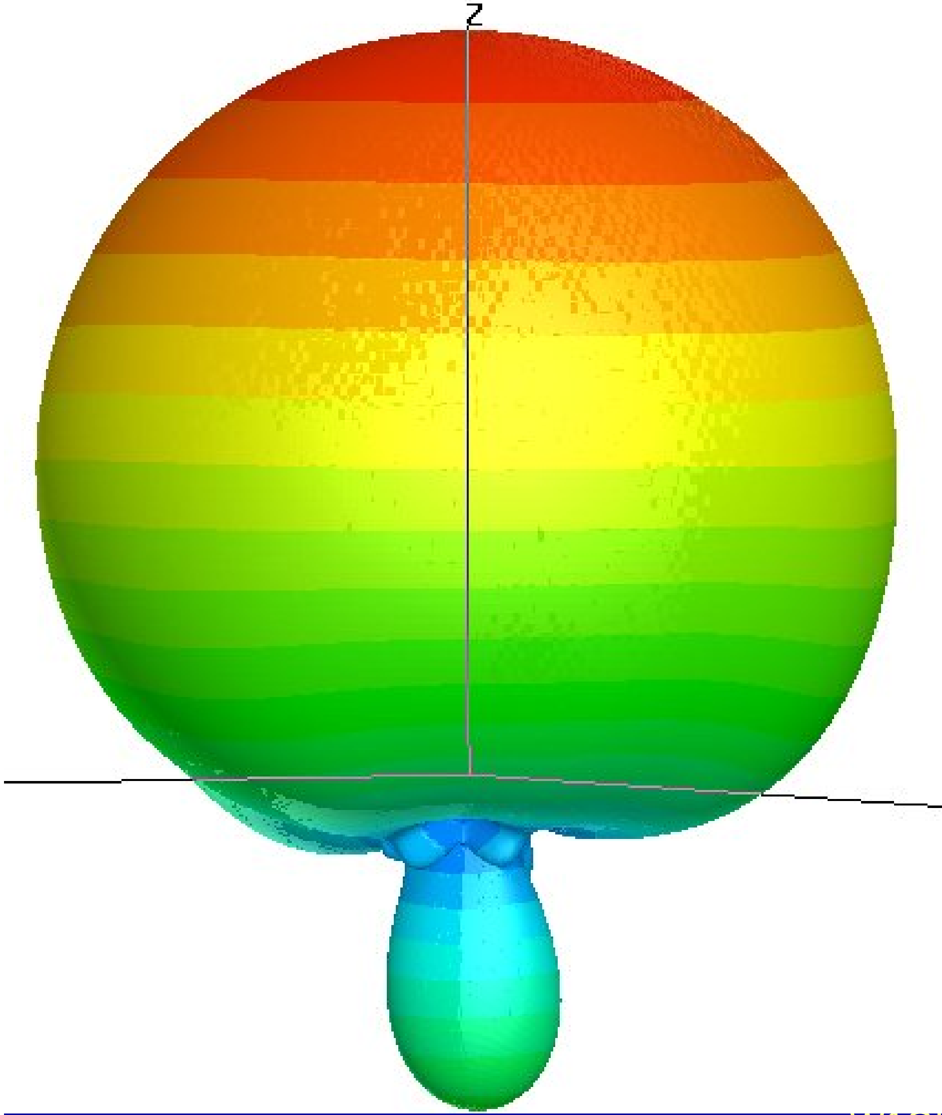


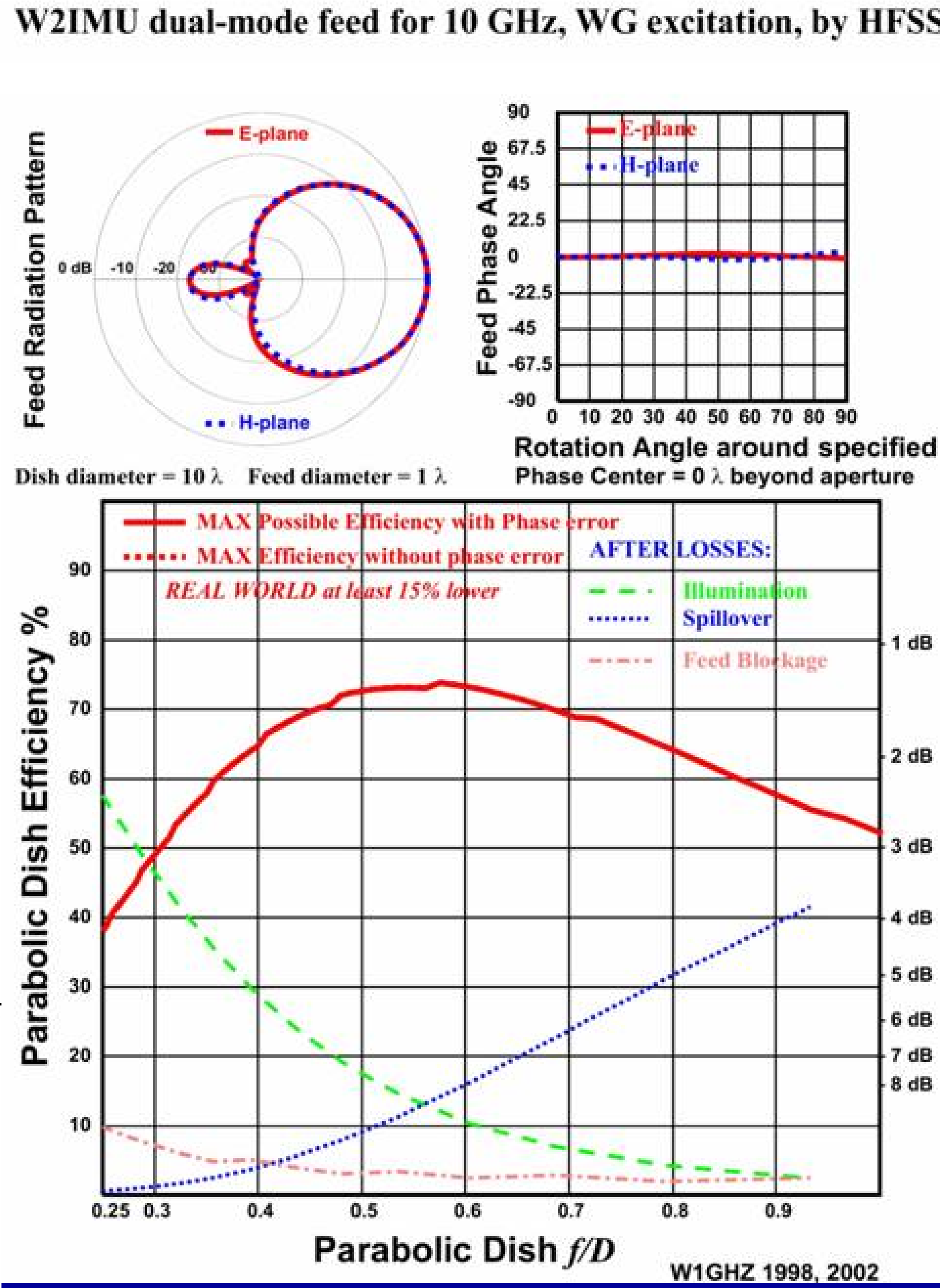
Penny Feed




G4ALN Penny feed at 10.368 GHz, by HFSS
Feed Radiation Pattern
0 dB -10 -20 -30
E-plane
H-plane
Feed Phase Angle
90 67.5 45 22.5 0 -22.5 -45 -67.5 -90
E-plane
H-plane
0 10 20 30 40 50 60 70 80 90
Rotation Angle around specified
Phase Center = 0.17 λ inside aperture
Dish diameter = 10 λ Feed diameter = 1 λ
MAX Possible Efficiency with Phase error
MAX Efficiency without phase error
REAL WORLD at least 15% lower
AFTER LOSSES:
Illumination
Spillover
Feed Blockage
Parabolic Dish Efficiency %
90 80 70 60 50 40 30 20 10
1 dB 2 dB 3 dB 4 dB 5 dB 6 dB 7 dB 8 dB
0.25 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Parabolic Dish f/D
W1GHZ 1998, 2002

W2IMU dual-mode

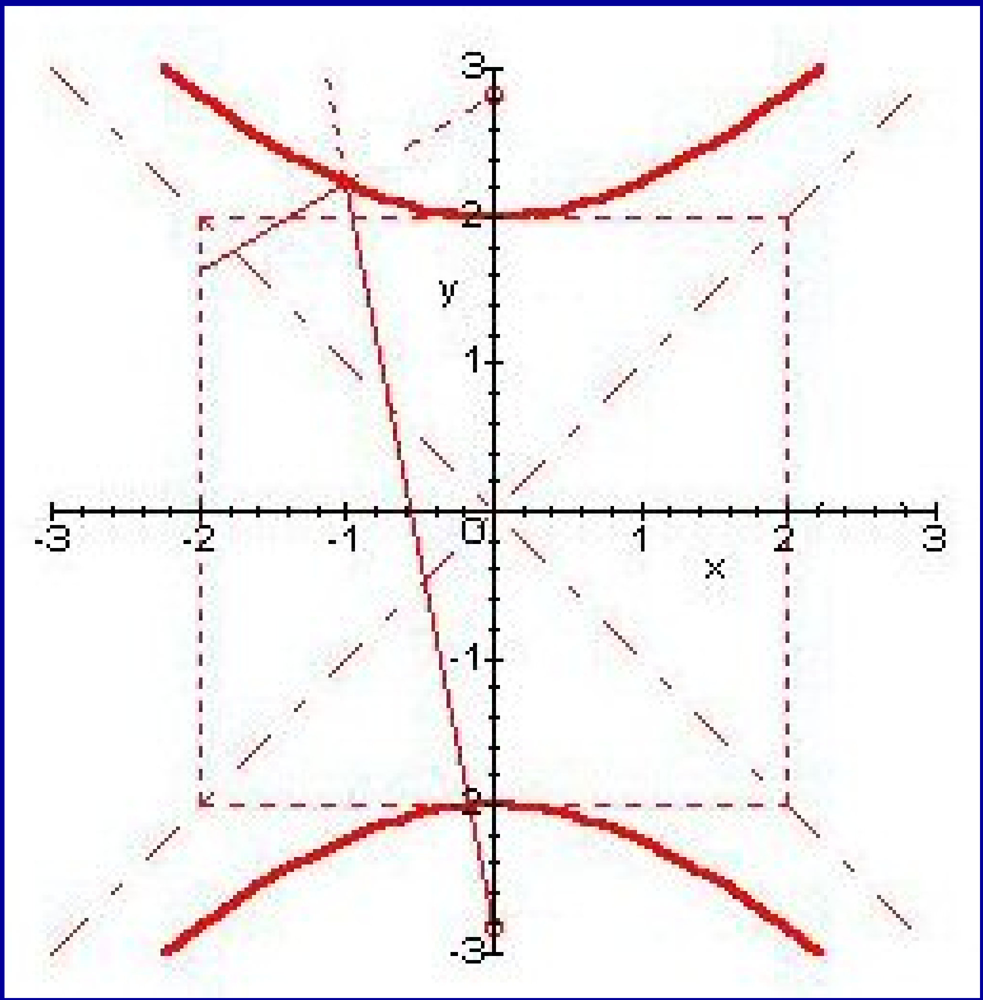




Low efficiency – *where does it go?*

- Energy must illuminate dish to contribute to gain – otherwise, reduced gain and efficiency
- LOSSES:
  - Sidelobes and backlobes
  - Poor illumination
  - Diffraction
  - Phase errors
- *Power in the wrong places*

Cassegrain Antenna Design



- **Hyperbolic subreflector**
- Rays from one focus are reflected so that they appear to radiate from second focus
- Feed P.C. at first focus
- Second focus is prime focus of dish

Small Cassegrain Antennas

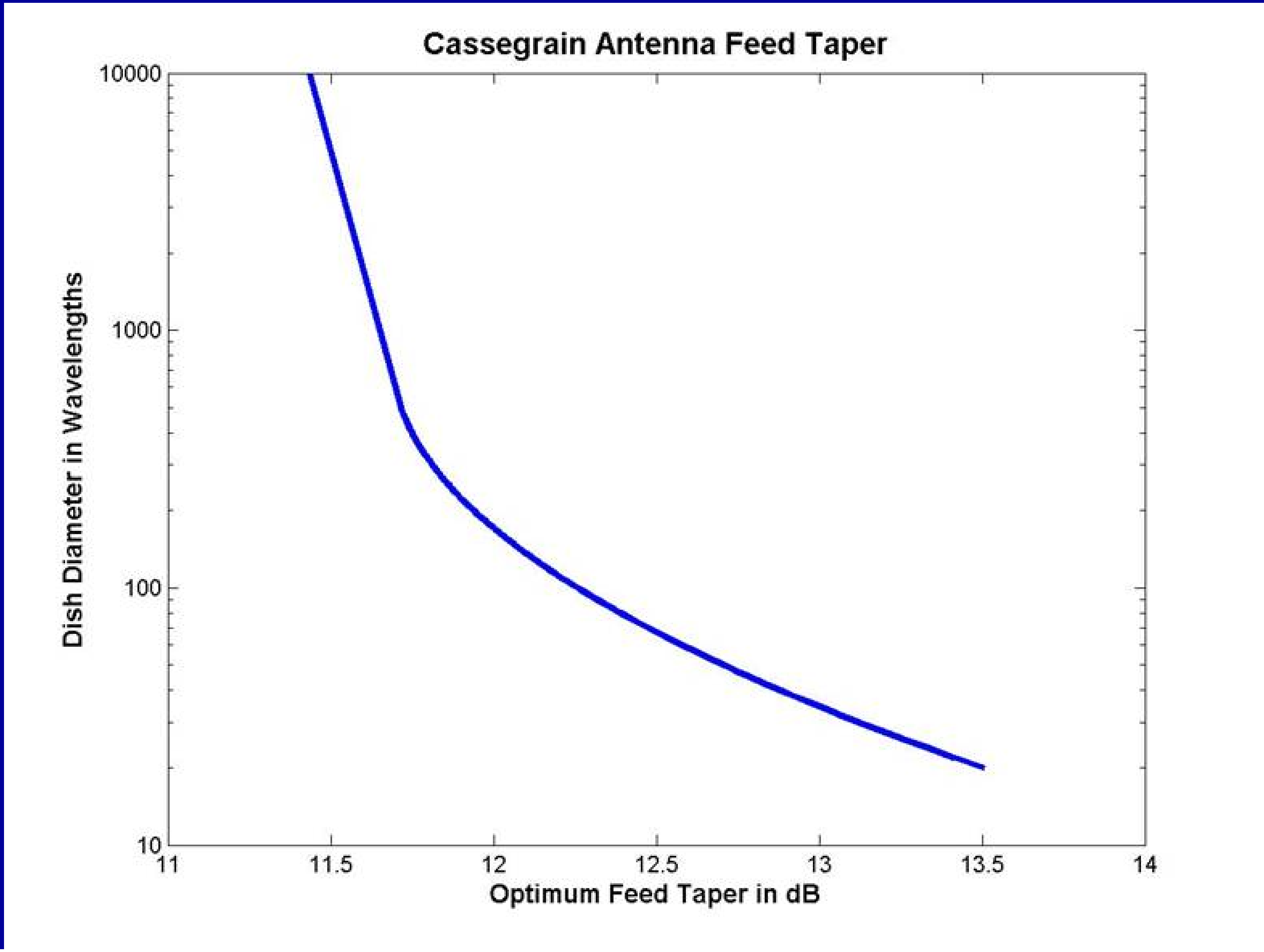
- Subreflector size tradeoff
  - Large subreflector → Blockage loss
  - Small subreflector → Diffraction loss

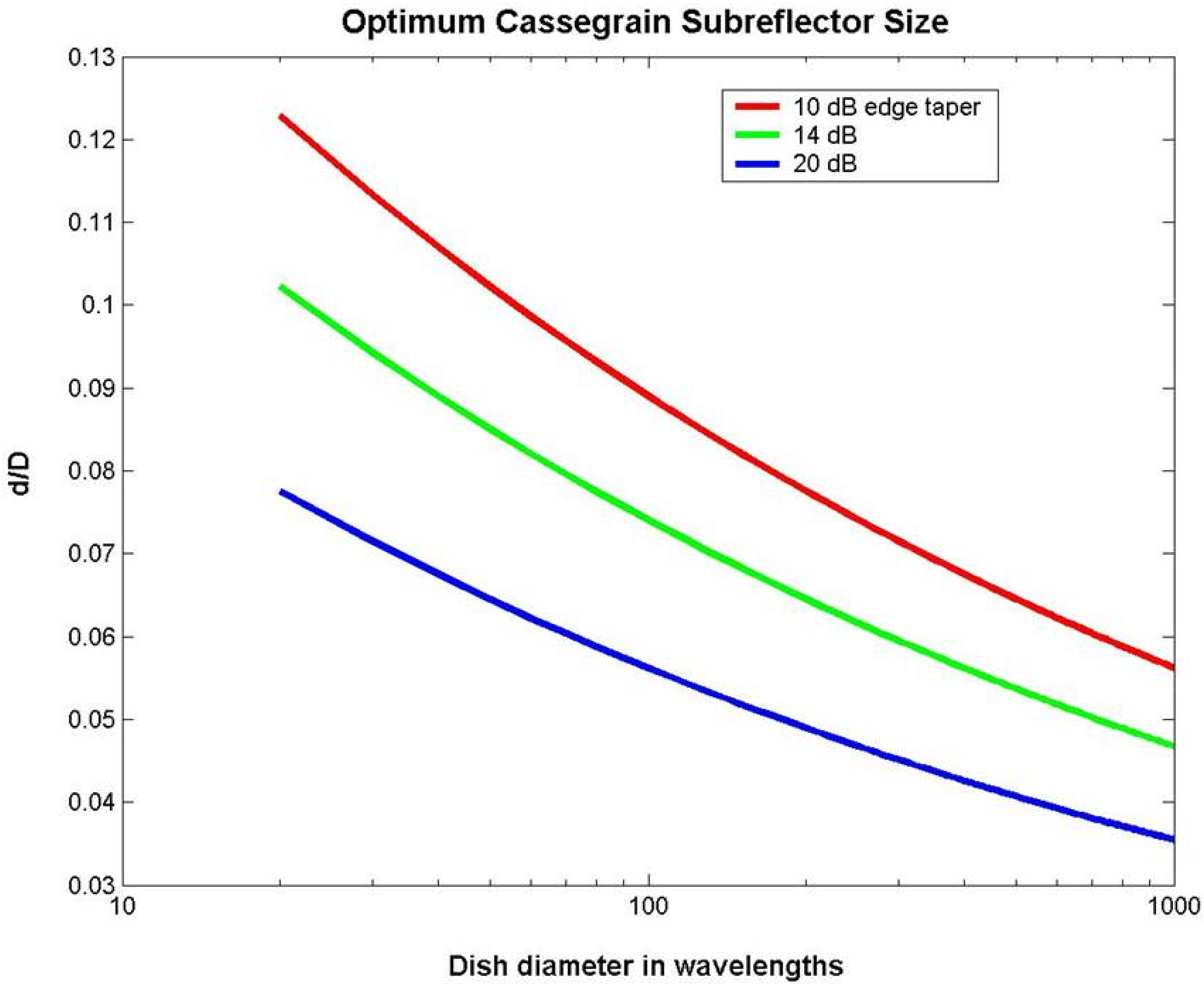
- Kildal – design procedure to balance losses
- Small is dish < 200λ

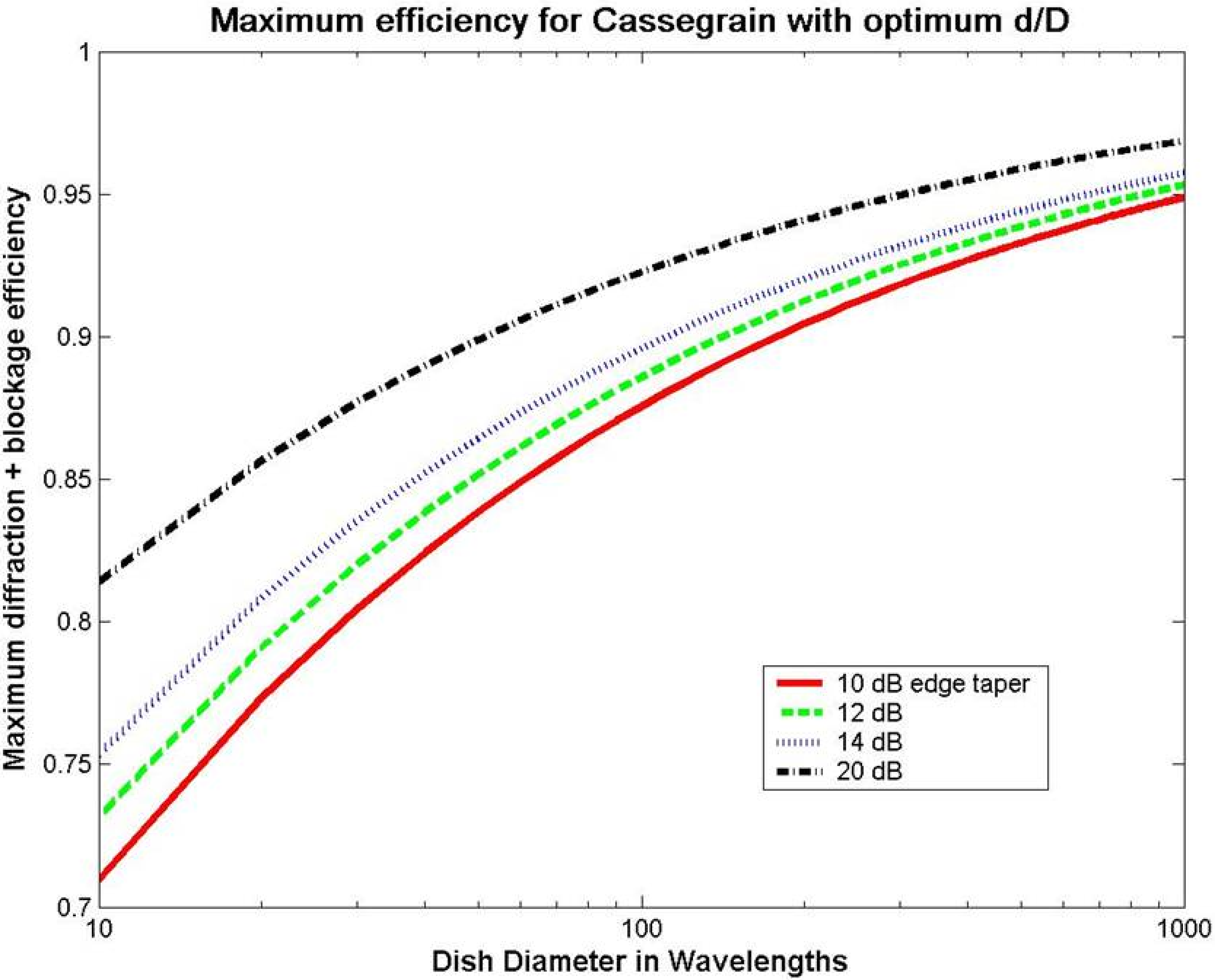
Cassegrain Design Procedure

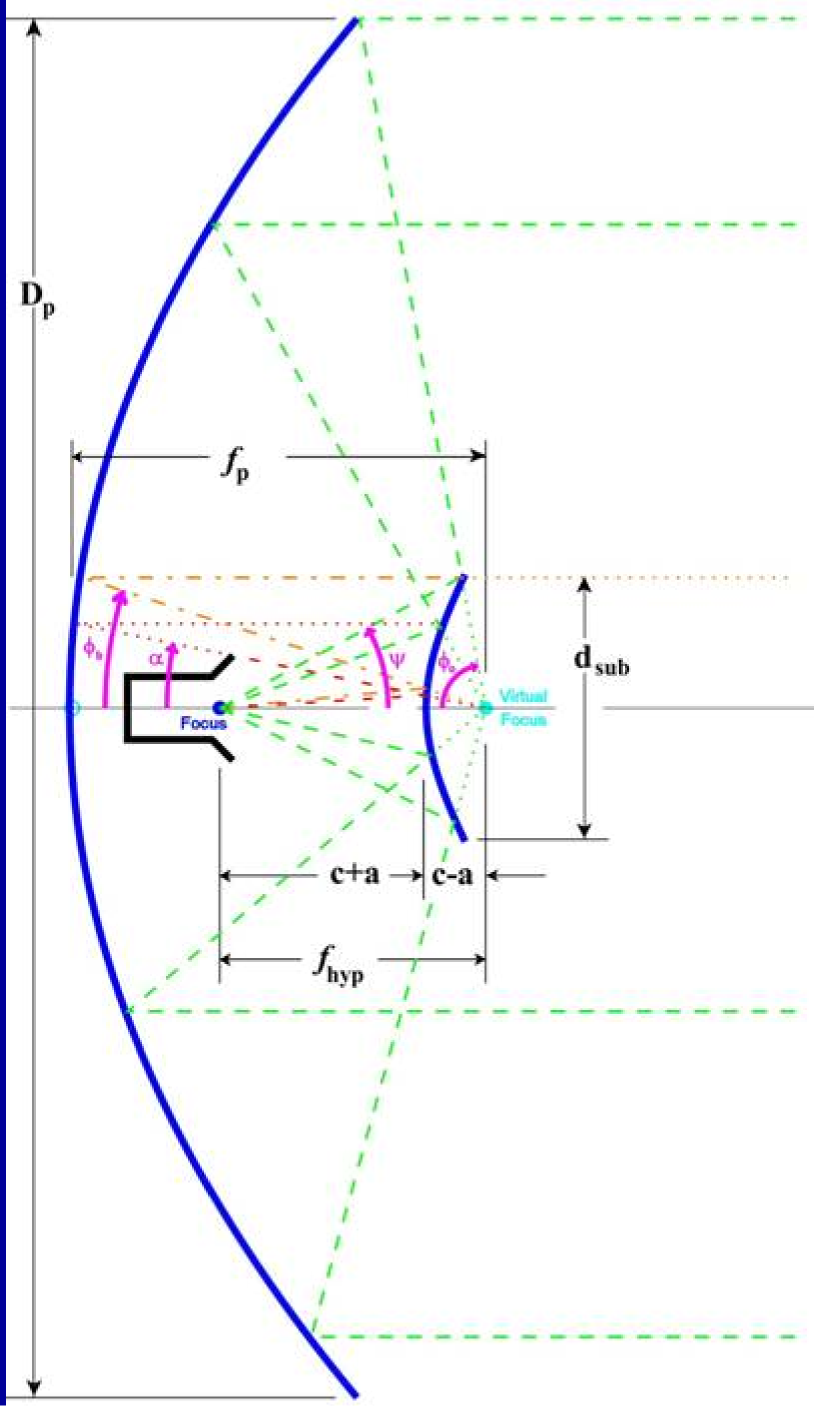
1. Optimum Edge Taper
2. Optimum Subreflector Size
3. Estimate Subreflector Efficiency
4. Choose a Feedhorn
5. Hyperbola focal length
6. Feed blockage
7. Subreflector geometry

Optimum Edge Taper




Optimum Cassegrain Subreflector Size
10 dB edge taper
14 dB
20 dB
d/D
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
10
100
1000
Dish diameter in wavelengths


Maximum efficiency for Cassegrain with optimum d/D
Maximum diffraction + blockage efficiency
1
0.95
0.9
0.85
0.8
0.75
0.7
10
100
1000
Dish Diameter in Wavelengths
10 dB edge taper
12 dB
14 dB
20 dB



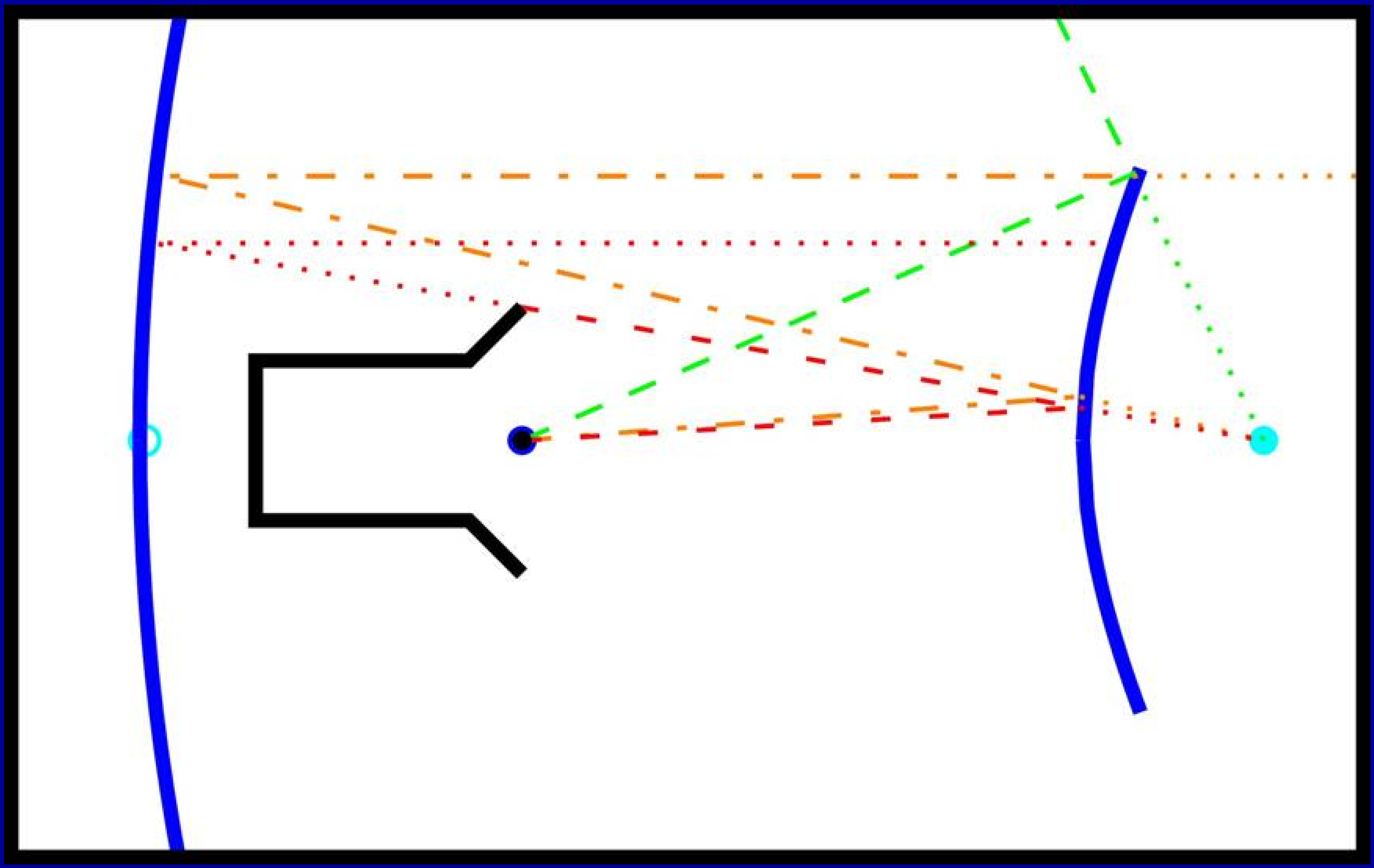
Cassegrain Geometry

- Ray paths must have equal lengths
- Feed blockage less than subreflector
- Subreflector in far field of feed

Rayleigh Distance =

$$2D^2 / \lambda$$

Subreflector and feed blockage



Feed reshaping

Magnification factor **M**

M = feed ***f*/D** **/** Dish ***f*/D**

Cassegrain Examples

1. 8 foot dish at 10 GHz, *f*/D = 0.36
    - 14.3 λ subreflector
    - Estimated subreflector efficiency ~ 80%
    - (0.95 dB loss)

2. 18 inch dish at 47 GHz, *f*/D = 0.25
    - 7.7 λ subreflector
    - Estimated subreflector efficiency ~ 86%
    - (0.64 dB loss)
    - Better feedhorn efficiency

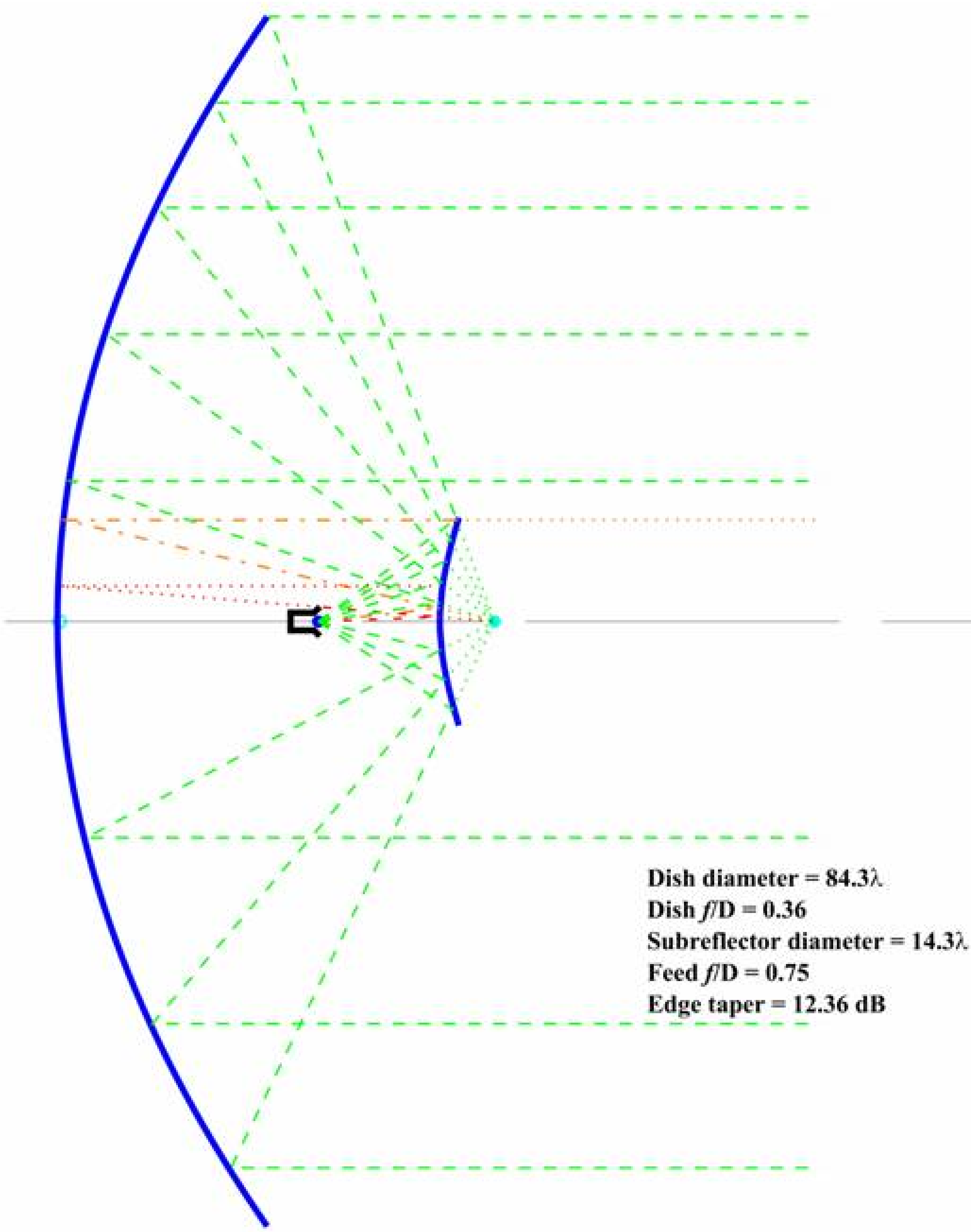


Figure 24. Cassegrain example: 8-foot dish at 10 GHz

Figure 23

CASSEGRAIN ANTENNA DESIGN CALCULATOR

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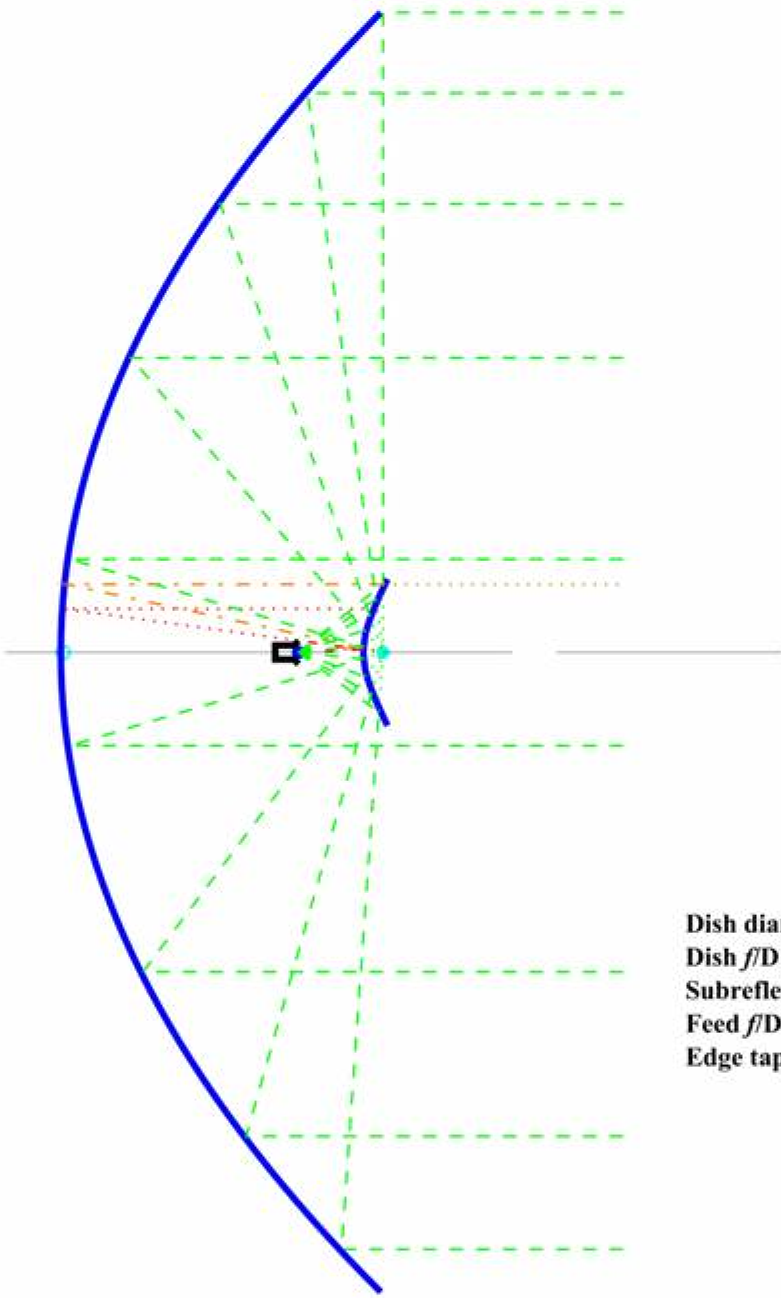
ENTER INPUT PARAMETERS HERE: *(Bold blue numbers)*

pi = 3.

Frequency	**10.368**	GHz			
Units:	mm	Inches	Wavelengths		
Dish diameter	**2438**	96.0	**84.3**		
Dish **f/D**				**0.36**	
Feedhorn equivalent **f/D**				**0.75**	
Feedhorn diameter	**59**	2.323	2.03904		
Feedhorn Phase Center (negative = inside horn)			**-0.11**		
Wavelength	**28.935**	1.139	**1**		
Dish Focal Length	875.2	34.5	**30.2**		
Dish Illumination halfangle				69.7	degrees
Feedhorn illumination halfangle				36.9	degrees
Redge (prime focus to rim)	1299.7	51.2	44.9		
Space attenuation for main dish				3.43	dB
Space attenuation for virtual dish				0.92	dB
Decision point:					
Suggested illumination taper =				12.36	dB
Enter desired illumination taper :				**12.36**	dB
With desired taper:					
Feedhorn illumination halfangle				36.5	degrees
Feedhorn equivalent f/D				0.76	
Minimum subreflector diameter	200.7	7.903	**6.94**		
Subreflector focal length	172.5	6.792	**5.96**		
Subreflector f/D			**0.86**		
d_sub/D_main				0.08	
Maximum subreflector efficiency (Diffraction loss = blockage loss)				**88.1%**	
Feedhorn blockage halfangle				9.9	degrees
Without feedhorn blockage -- increase subreflector diameter to eliminate feedhorn blockage:					
Minimum subreflector diameter	245.1	9.650	**8.47**		
Subreflector focal length	210.7	8.294	**7.28**		
d_sub/D_main				0.10	
Subreflector efficiency (Diffraction plus blockage losses)				**82.7%**	
Feedhorn blockage halfangle				8.1	degrees
Decision point:					
Enter desired subreflector diameter :			**14.3**		**in wavelengths**
or go back and change feedhorn					
With desired subreflector diameter:					
Subreflector focal length	355.6	14.001	**12.29**		
d_sub/D_main				0.17	
Subreflector efficiency (only blockage loss increases)				**80.4%**	
Cassegrain loss =				**-0.947**	**dB**
For overall efficiency, find efficiency on feedhorn PHASEPAT curve for f/D=				**0.76**	
and multiply by				**0.804**	



Dish diameter = 71.7λ
Dish *f*/D = 0.25
Subreflector diameter = 7.7λ
Feed *f*/D = 0.6
Edge taper = 12.46 dB

Figure 26. Cassegrain example: 18" Edmunds dish at 47 GHz

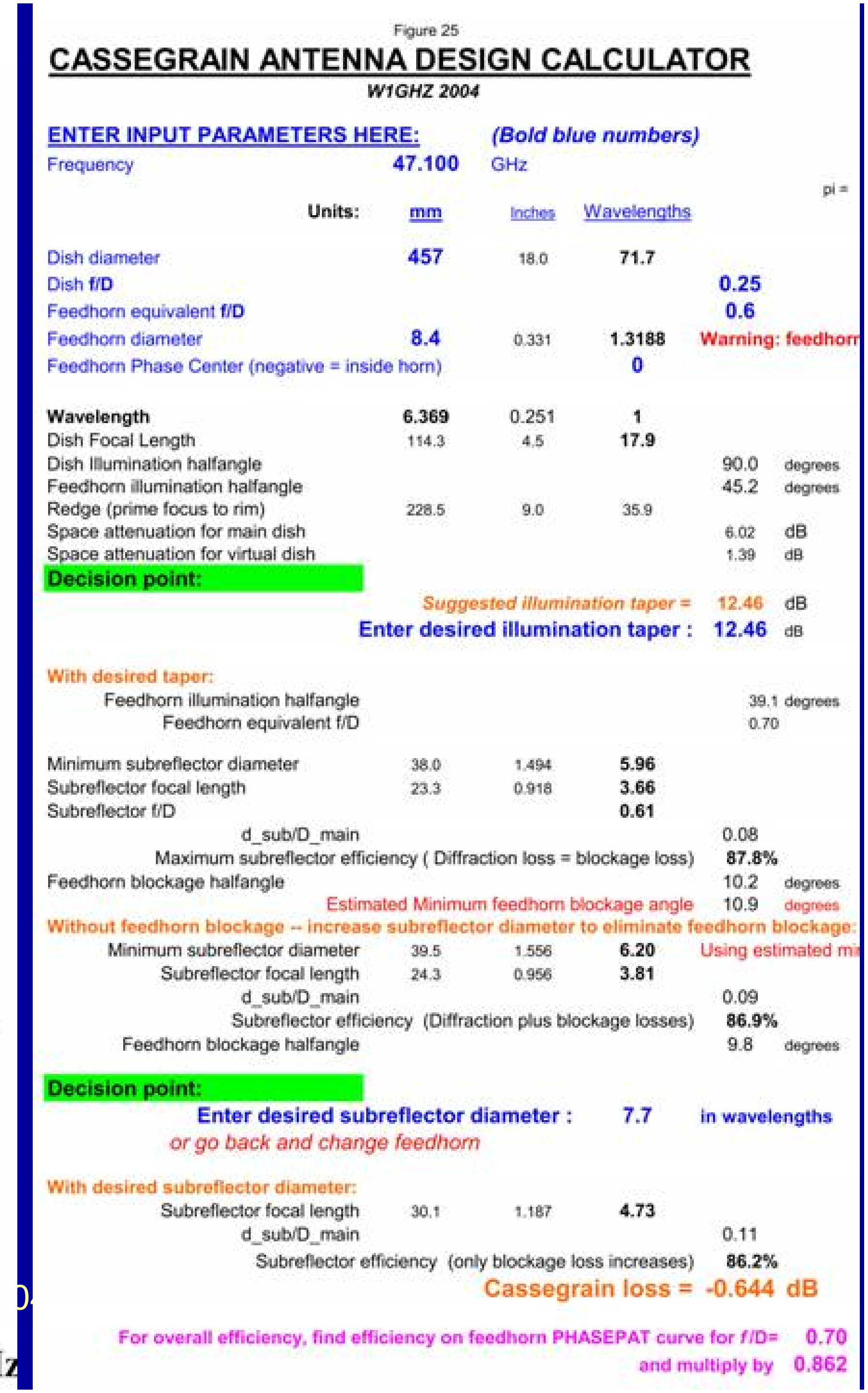


Figure 25

CASSEGRAIN ANTENNA DESIGN CALCULATOR

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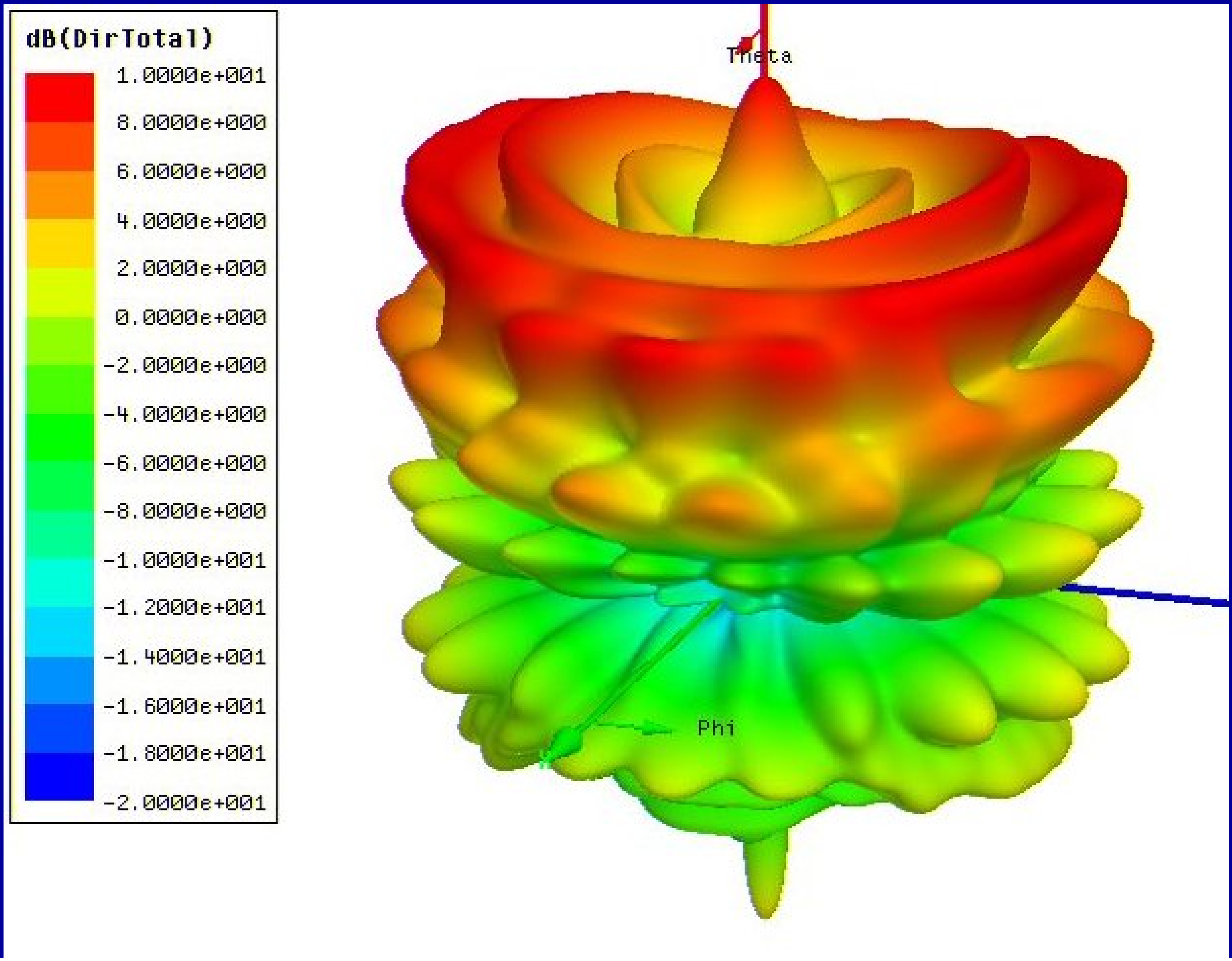
ENTER INPUT PARAMETERS HERE: *(Bold blue numbers)*

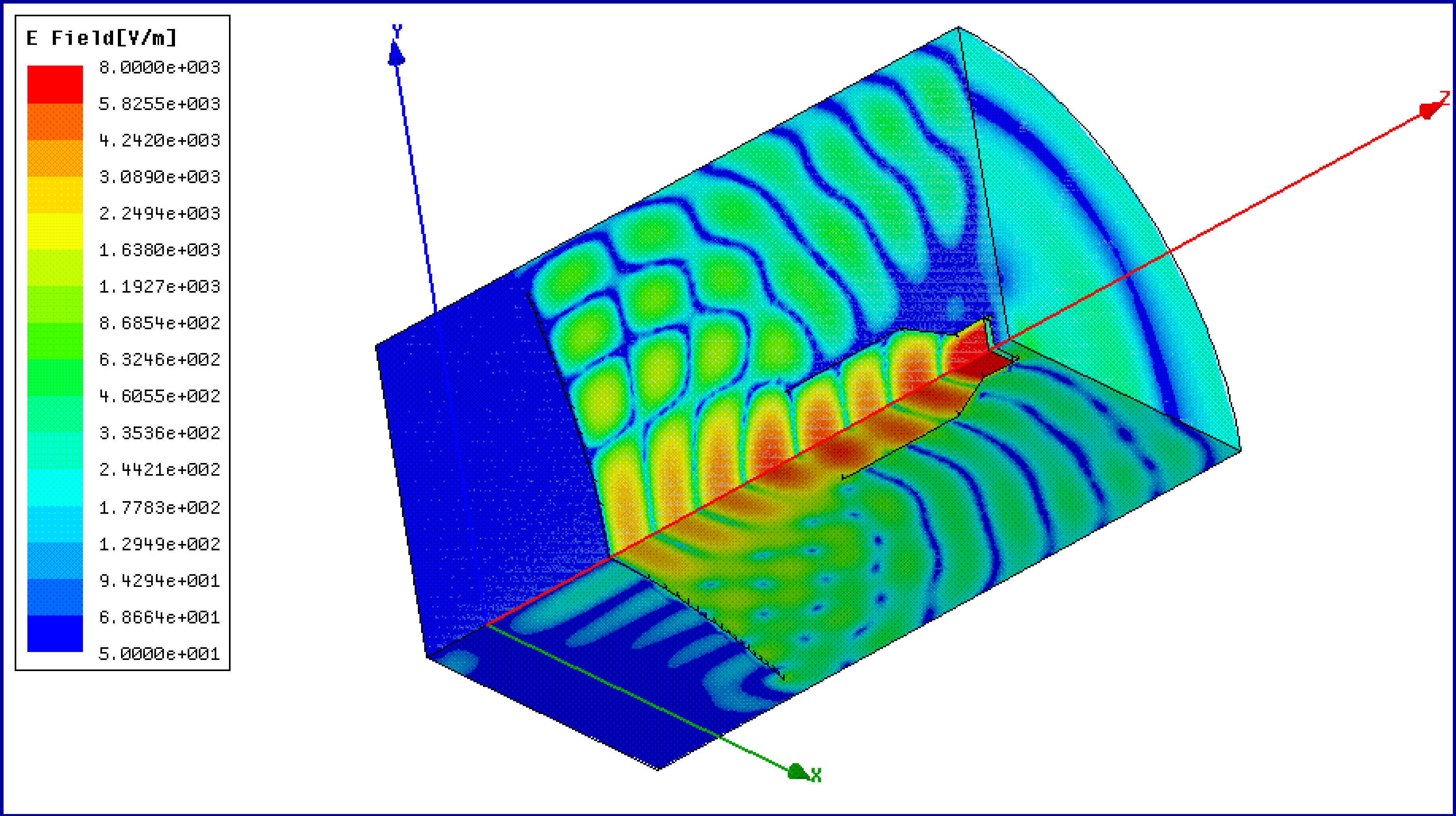
	mm	Inches	Wavelengths		
Frequency	47.100	GHz			pi =
Units:	mm	Inches	Wavelengths		
Dish diameter	457	18.0	71.7		
Dish f/D				0.25	
Feedhorn equivalent f/D				0.6	
Feedhorn diameter	8.4	0.331	1.3188	Warning: feedhorn	
Feedhorn Phase Center (negative = inside horn)			0		
Wavelength	6.369	0.251	1		
Dish Focal Length	114.3	4.5	17.9		
Dish Illumination halfangle				90.0	degrees
Feedhorn illumination halfangle				45.2	degrees
Redge (prime focus to rim)	228.5	9.0	35.9		
Space attenuation for main dish				6.02	dB
Space attenuation for virtual dish				1.39	dB
Decision point:					
Suggested illumination taper =				12.46	dB
Enter desired illumination taper :				12.46	dB
With desired taper:					
Feedhorn illumination halfangle				39.1	degrees
Feedhorn equivalent f/D				0.70	
Minimum subreflector diameter	38.0	1.494	5.96		
Subreflector focal length	23.3	0.918	3.66		
Subreflector f/D			0.61		
d_sub/D_main				0.08	
Maximum subreflector efficiency (Diffraction loss = blockage loss)				87.8%	
Feedhorn blockage halfangle				10.2	degrees
Estimated Minimum feedhorn blockage angle				10.9	degrees
Without feedhorn blockage -- increase subreflector diameter to eliminate feedhorn blockage:					
Minimum subreflector diameter	39.5	1.556	6.20	Using estimated mi	
Subreflector focal length	24.3	0.956	3.81		
d_sub/D_main				0.09	
Subreflector efficiency (Diffraction plus blockage losses)				86.9%	
Feedhorn blockage halfangle				9.8	degrees
Decision point:					
Enter desired subreflector diameter :			7.7	in wavelengths	
or go back and change feedhorn					
With desired subreflector diameter:					
Subreflector focal length	30.1	1.187	4.73		
d_sub/D_main				0.11	
Subreflector efficiency (only blockage loss increases)				86.2%	
Cassegrain loss =				-0.644	dB

For overall efficiency, find efficiency on feedhorn PHASEPAT curve for *f*/D= 0.70
and multiply by 0.862

5.7 λ Cassegrain Subreflector



5.7 λ Subreflector – Near Field



Cassegrain Design Summary

- Antenna efficiency =
  feed efficiency **X** subreflector efficiency
- Spreadsheet to estimate subreflector efficiency and iterate design
- <u>Bottom line</u>: is result less than prime feed with feedline loss?

Efficiency example

10 wavelength diameter dish

Efficiency	100%	80%	70%	60%	55%
Gain in dBi	29.94	28.97	28.39	27.72	27.35
dB from nominal					0.4
Efficiency	50%	40%	30%	20%	10%
Gain in dBi	26.93	25.96	24.71	22.95	19.94
dB from nominal	0.0	-1.0	-2.2	-4.0	-7.0

Efficiency – Reality

- **Difference** between good feed and poor feed is only **2 or 3 dB**
- To measure accurately, must swap feeds on same dish, same range
- **Is 2 dB significant?**

- *Different answer for EME!*

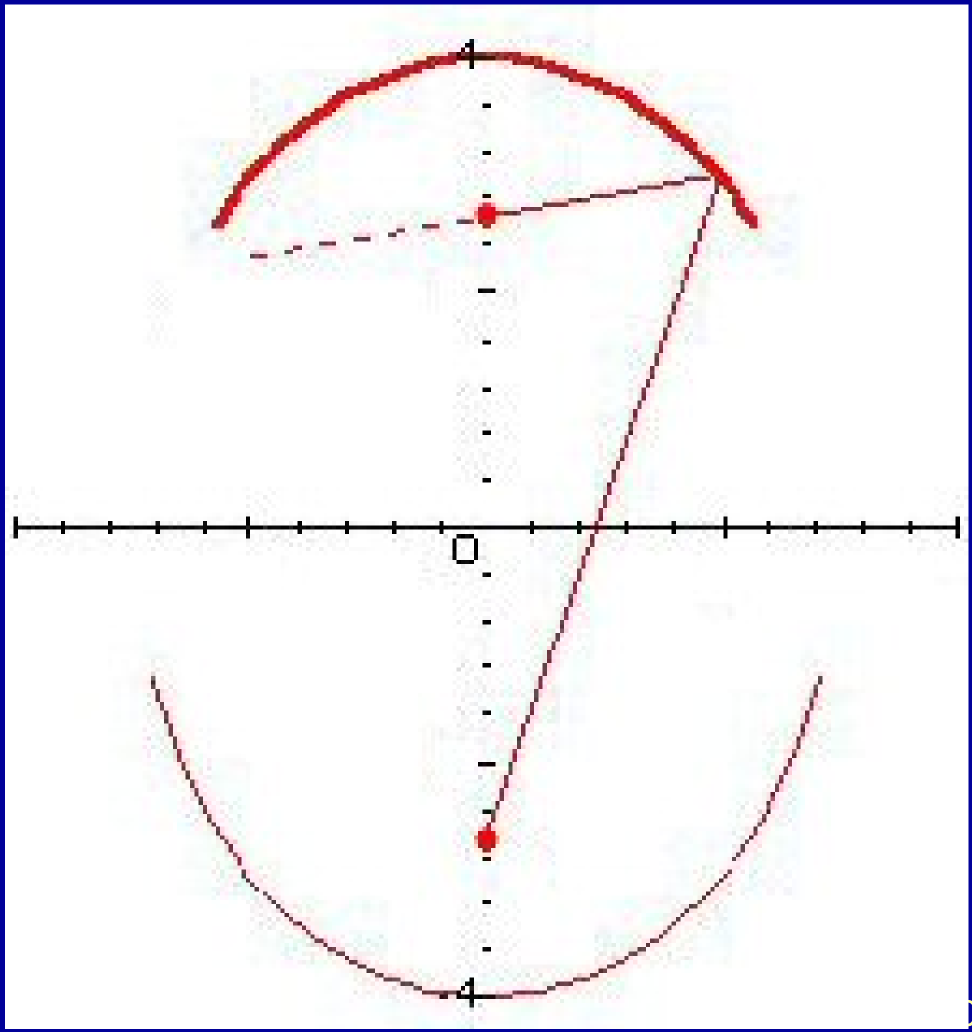
Subreflector

Subreflector reverse-engineering

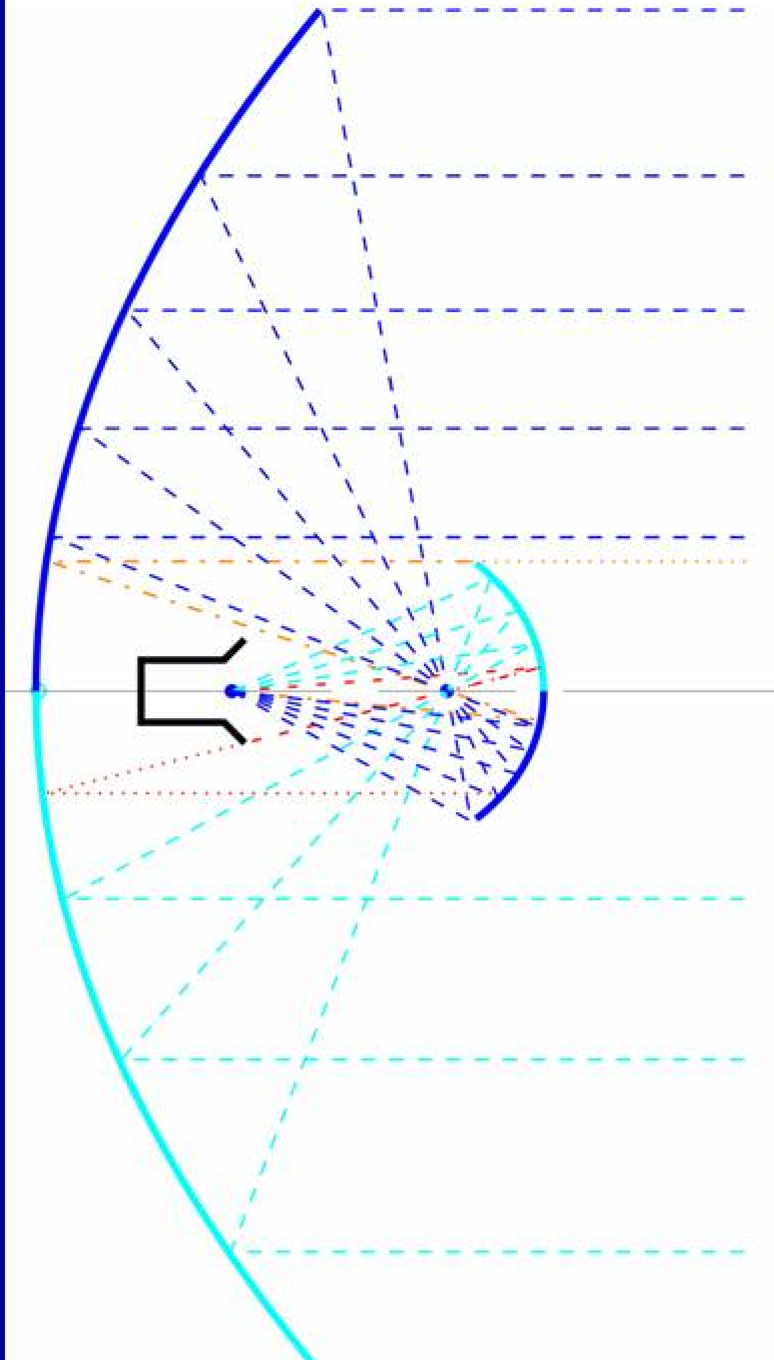
- Measure profile – 30 points
- Calculate hyperbola – curve fitting
- Hyperbola focal length = 155 mm
- **M** (magnification factor) = 6.67
- ***f*/D** for main reflector ~ 0.36
- ***f*/D** for feed ~ 2.4 (12º half-angle)
- Feed aperture ~ 6 λ
- Feed Rayleigh distance ~ 72 λ

72 λ = 155 mm at 140 GHz

Gregorian Antenna Design



- **Elliptical subreflector**
- Rays from one focus are reflected so that they appear to radiate from second focus
- Feed P.C. at first focus
- Second focus is prime focus of dish



Gregorian Design Procedure

- Similar to Cassegrain
- Use same graphs
- Different geometry calculations
- *Note crossover – opposite sides of reflectors*

Summary – Cassegrain & Gregorian

ADVANTAGES

- Feed pattern reshaping
- Better illumination for deep dishes
- Convenient feed location, shorter feedline
- Large depth of focus
- Sidelobes see cold sky
  – EME
  – Radio Astronomy

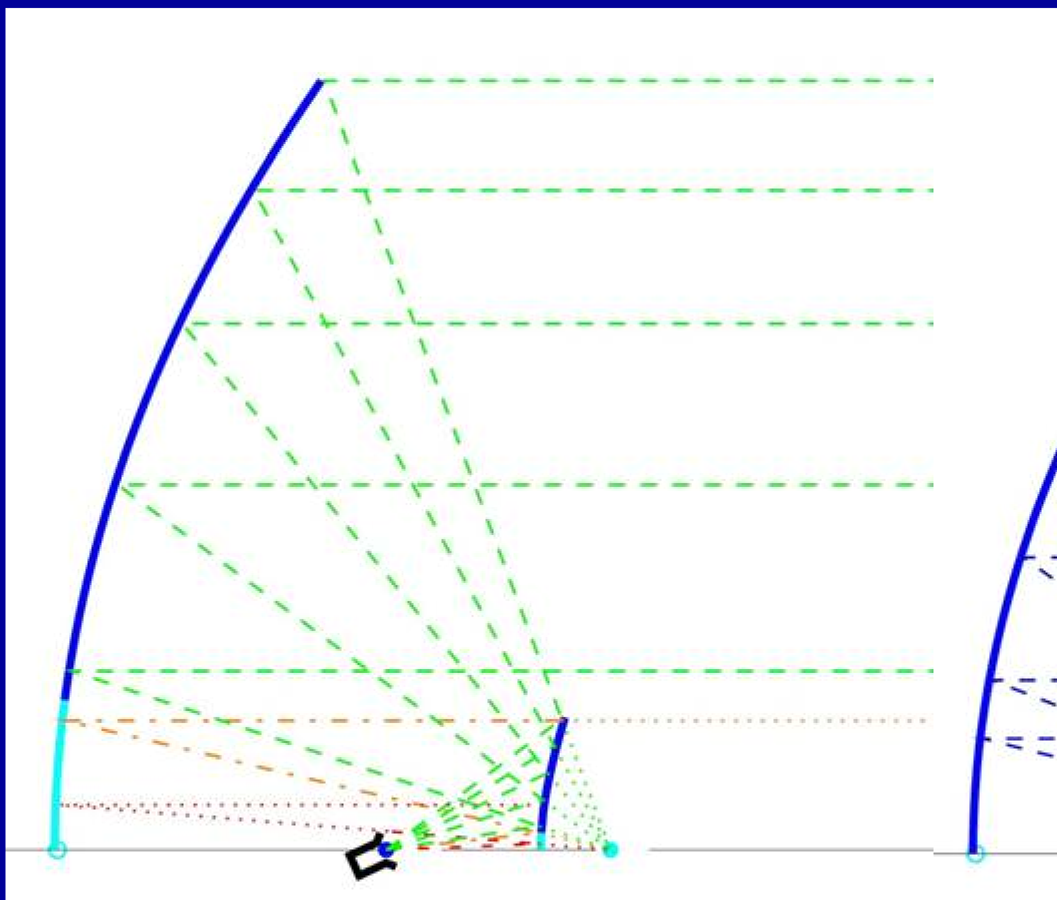
DISADVANTAGES

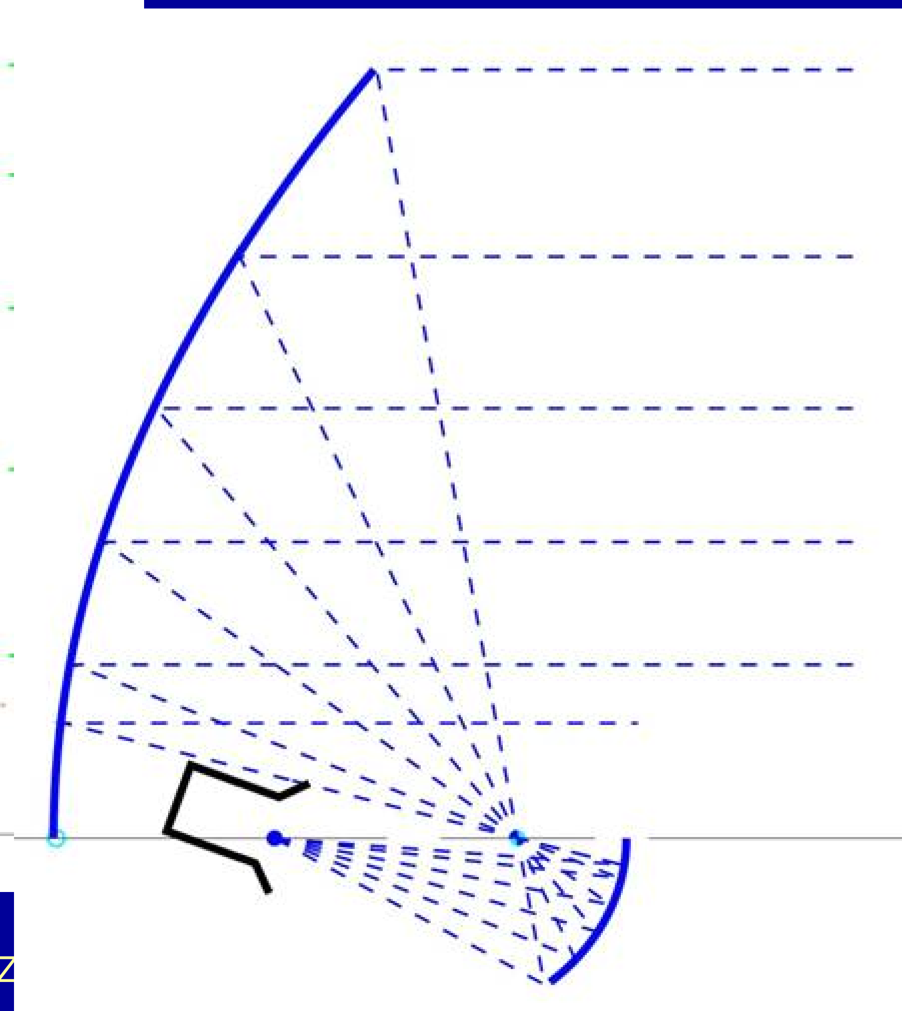
- Greater blockage
- Higher sidelobes
- Larger feedhorn
- Tighter tolerances

Other Multiple-Reflector Antennas

- Offset Cassegrain
- Offset Gregorian
- ADE (Axially-Displaced Ellipse)
- Dielguide
- Shaped reflector
- Beam Waveguide
- Periscope

Offset Cassegrain and Gregorian





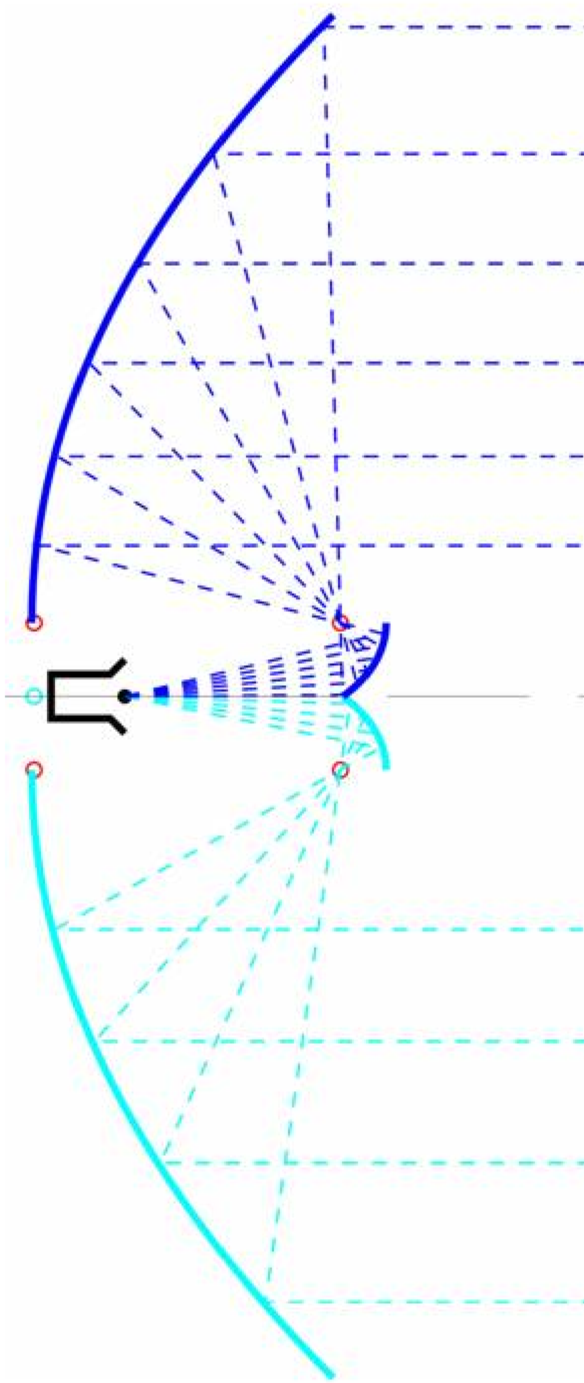
Flat subreflector

Cassegrain Magnification factor **M**

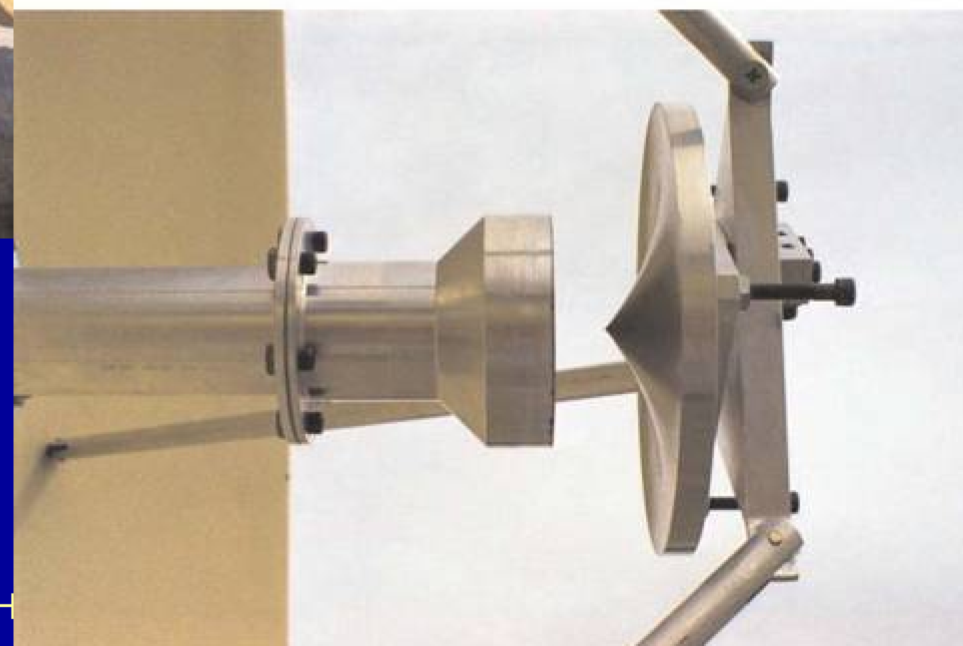
M = feed ***f*/D** **/** Dish ***f*/D**

- Convex hyperbolic subreflector M > 1
- Concave hyperbolic subrefl. M < 1
- Flat subreflector M = 1

Follow Cassegrain design procedure;
subreflector diameter **> 5**λ works well

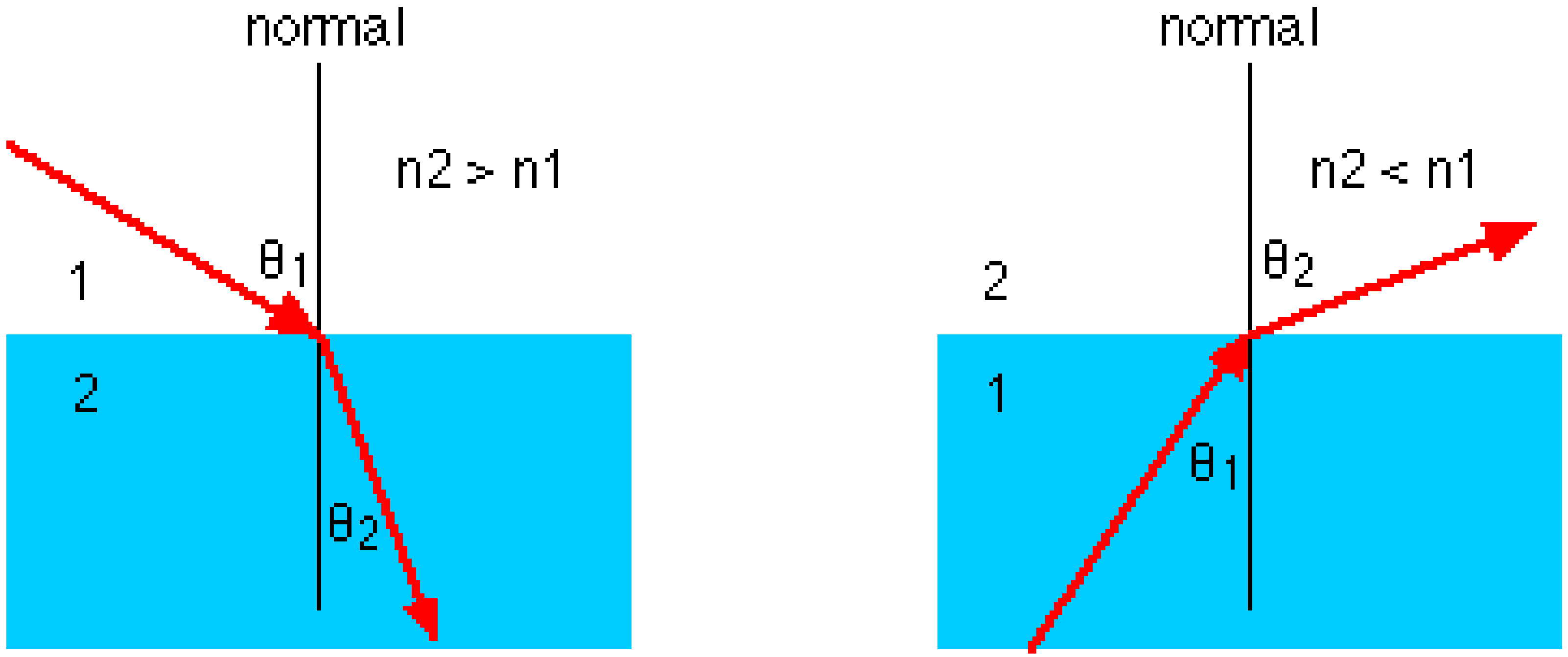


ADE
(Axially-Displaced Ellipse)

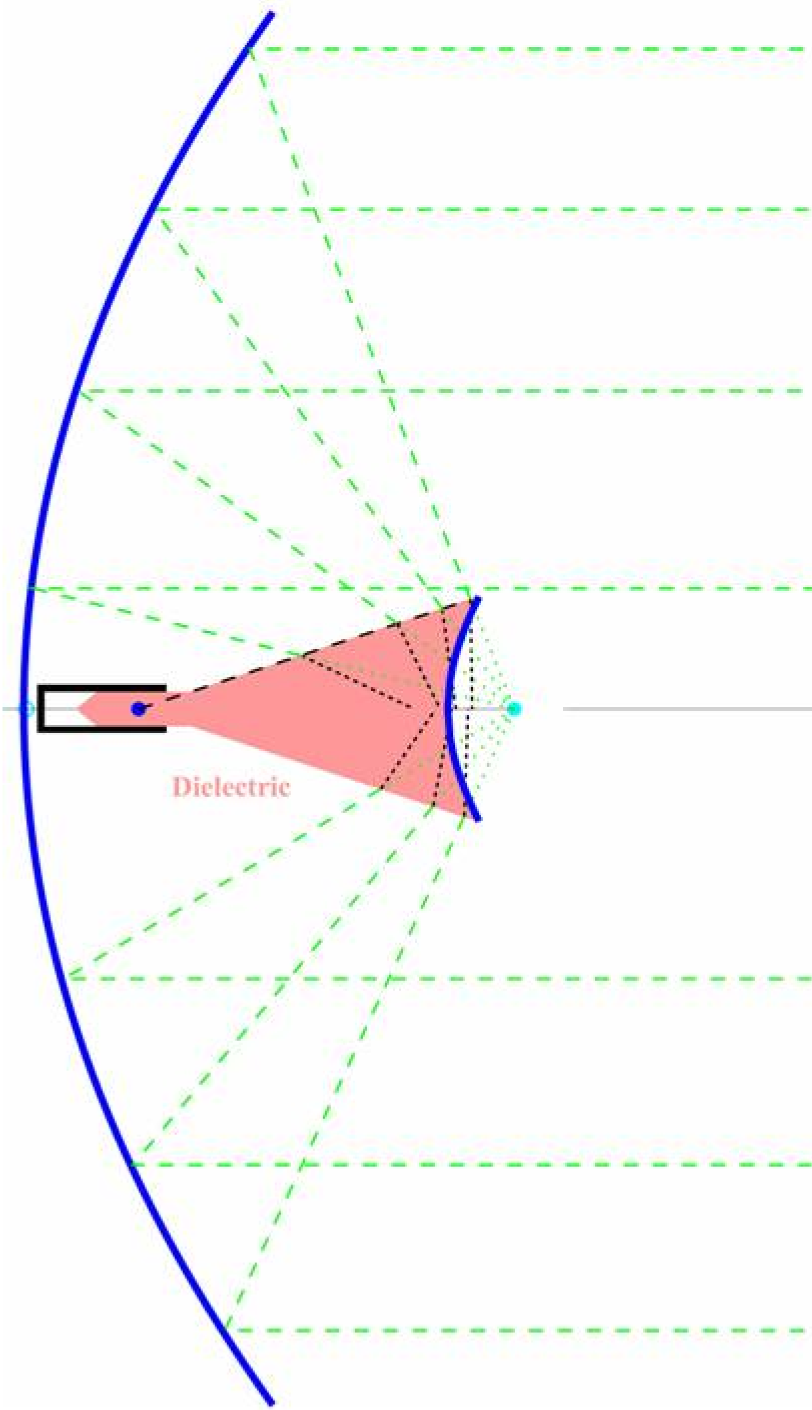


W1GH

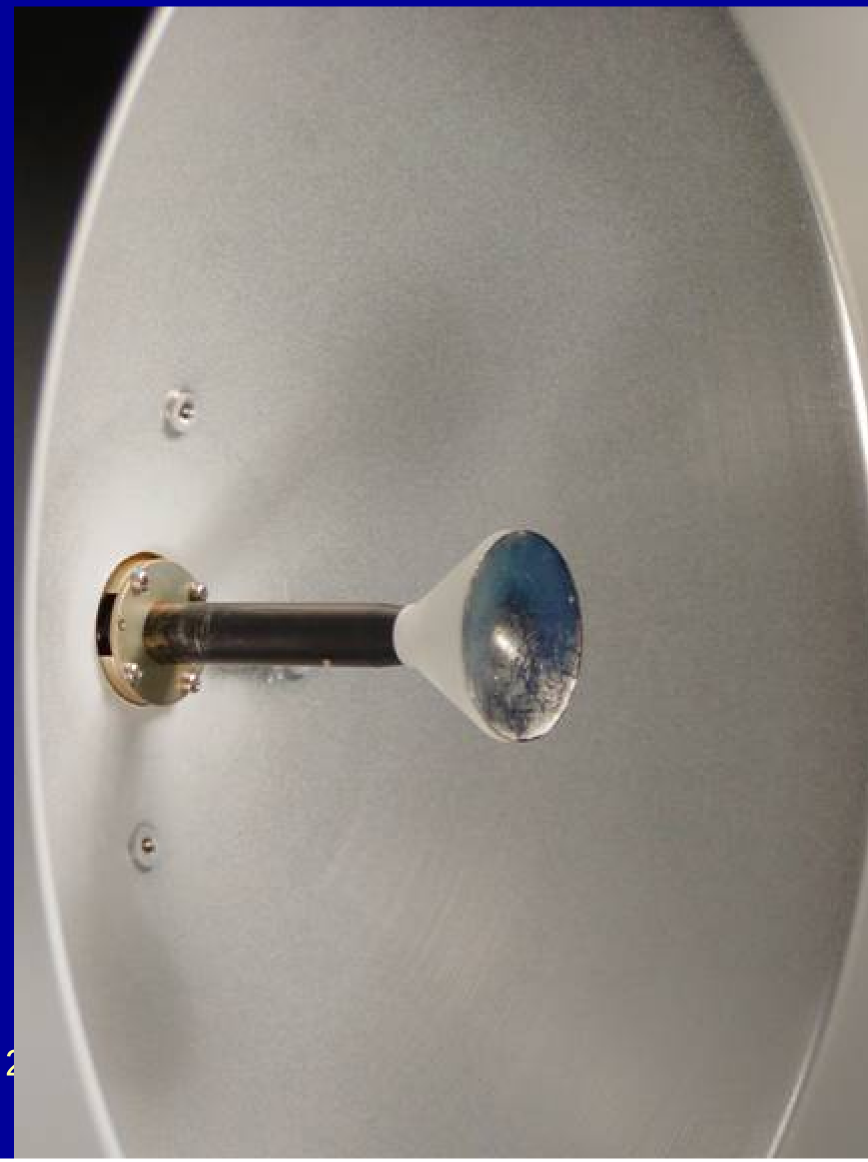
Refraction at dielectric



Snell's law : $n_1 \sin\theta_1 = n_2 \sin\theta_2$ or, equivalently, $\sin\theta_1 / \sin\theta_2 = v_1 / v_2$



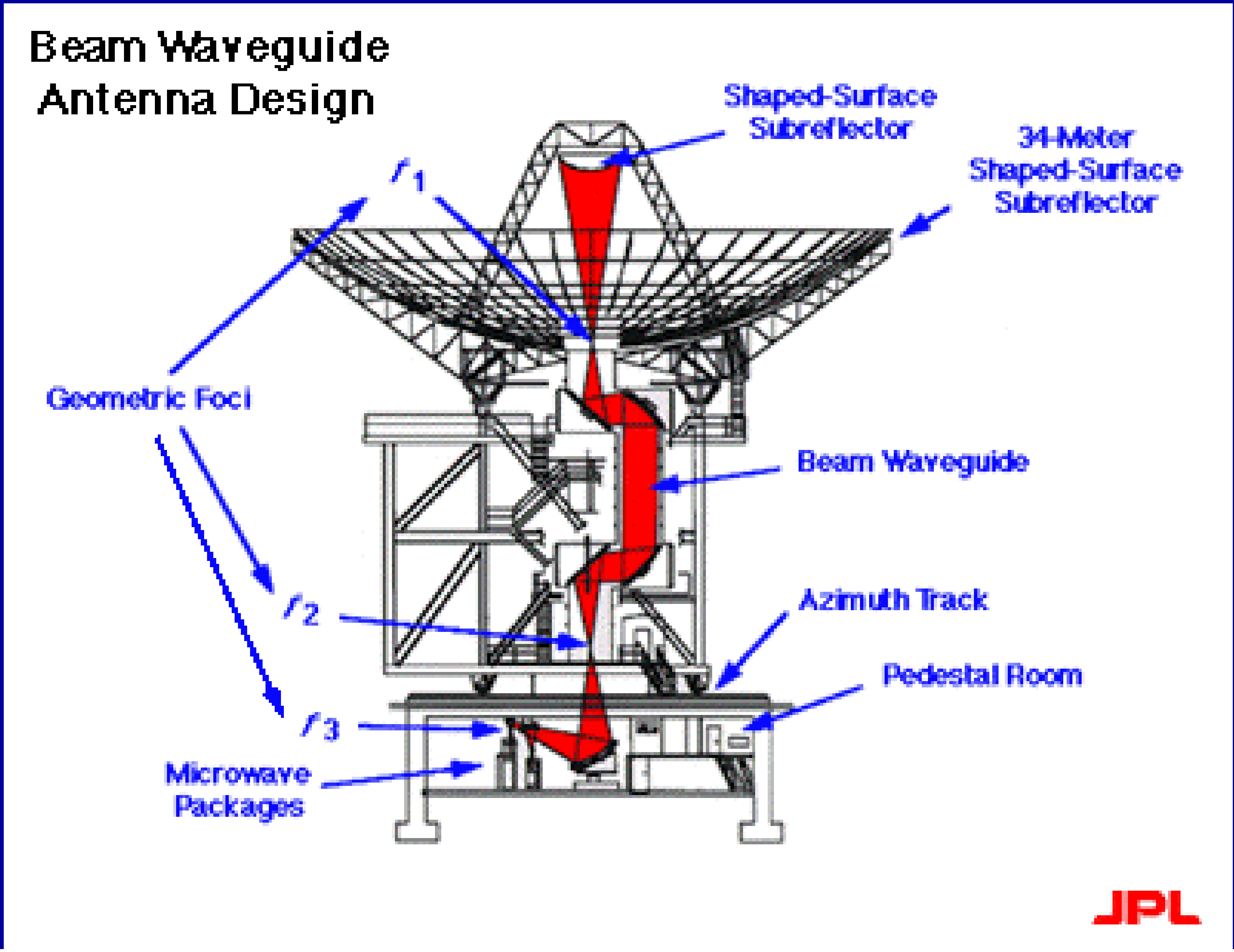
Dielguide



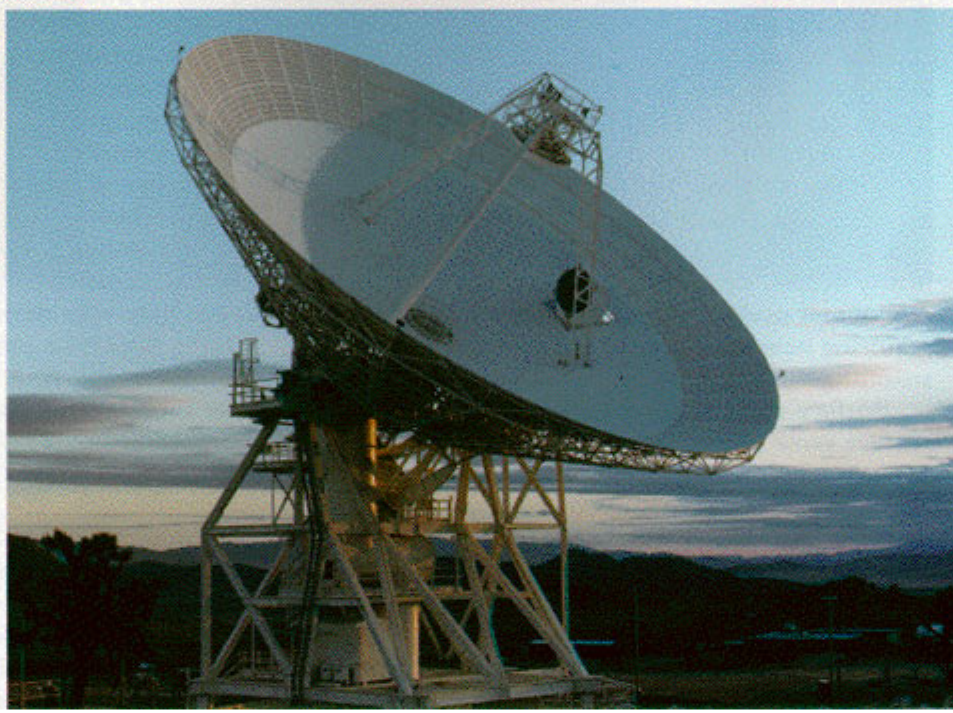
Shaped Reflector Antenna

- Shape subreflector to improve illumination
- Reshape main reflector to equalize path lengths
- Profiles are no longer conic sections
- Higher efficiency
- Poor imaging

Beam Waveguide Antenna



JPL Beam Waveguide Antenna



Periscope Antenna System @ W1GHZ

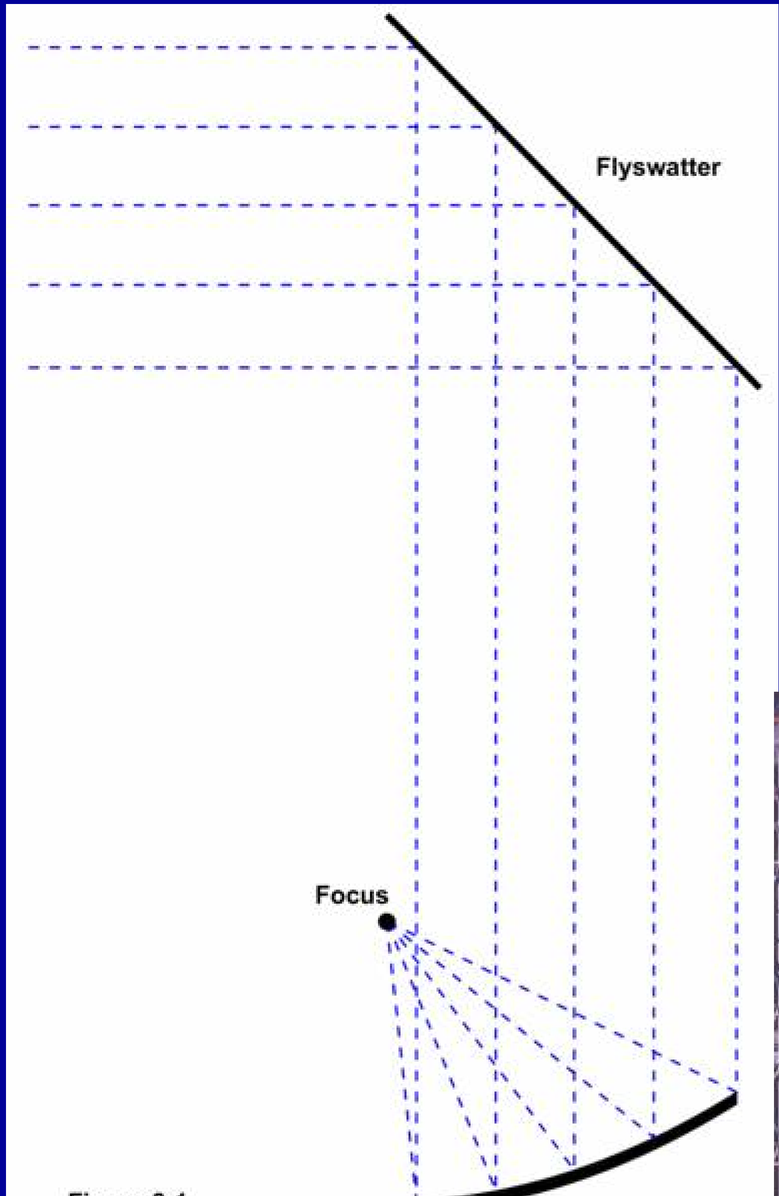


Figure 8-1
Periscope Antenna System with Offset Parabolic Dish

Summary
Multiple-reflector Antennas

- Potential for improved dish performance
- Better for large and deep dishes
- Reduce feedline loss at upper microwaves

- **Tradeoff – is complexity worthwhile?**

So, what's the best antenna?


RCA
Whatever gets you on the air

Online
(ex-N1BWT)

W1GHZ
Microwave
Antenna Book

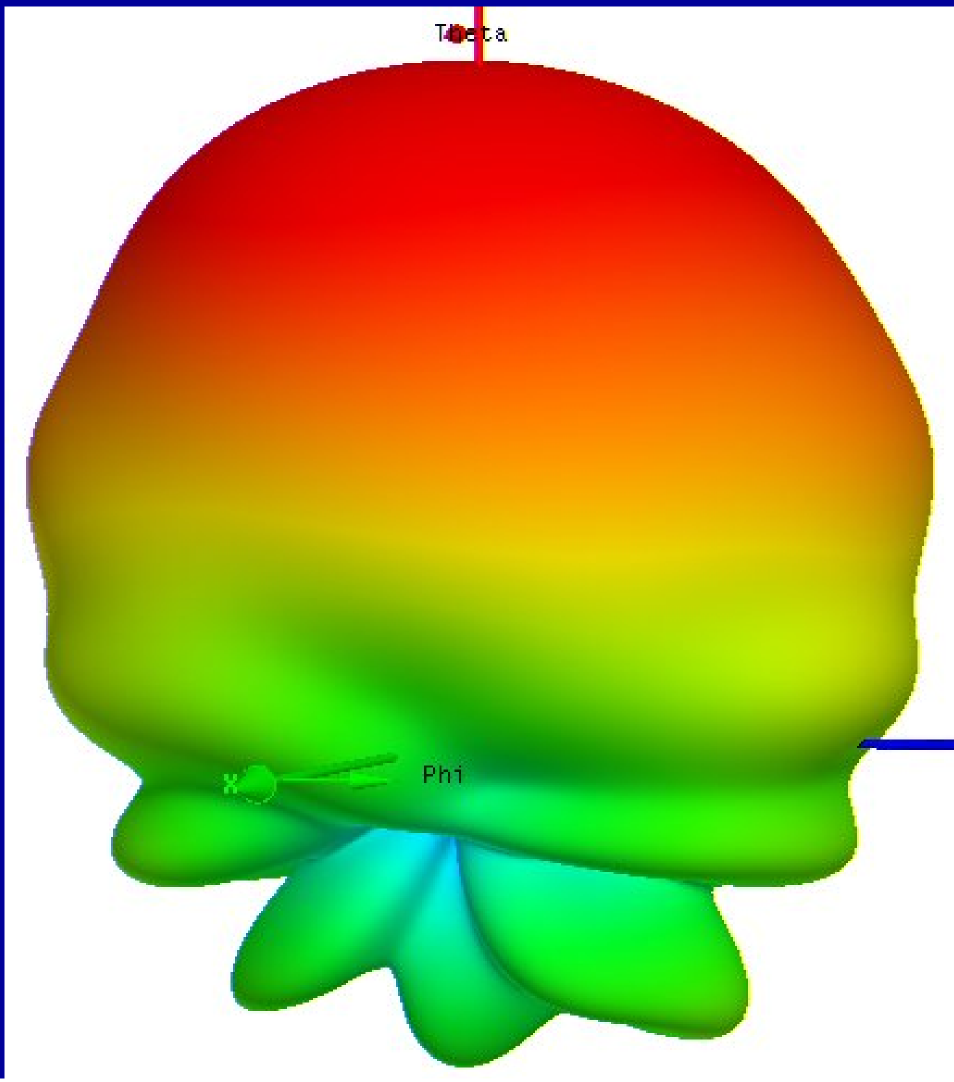
www.w1ghz.org

AD6FP & AA6IW 10&24 GHz feedhorn for offset dish (DSS)

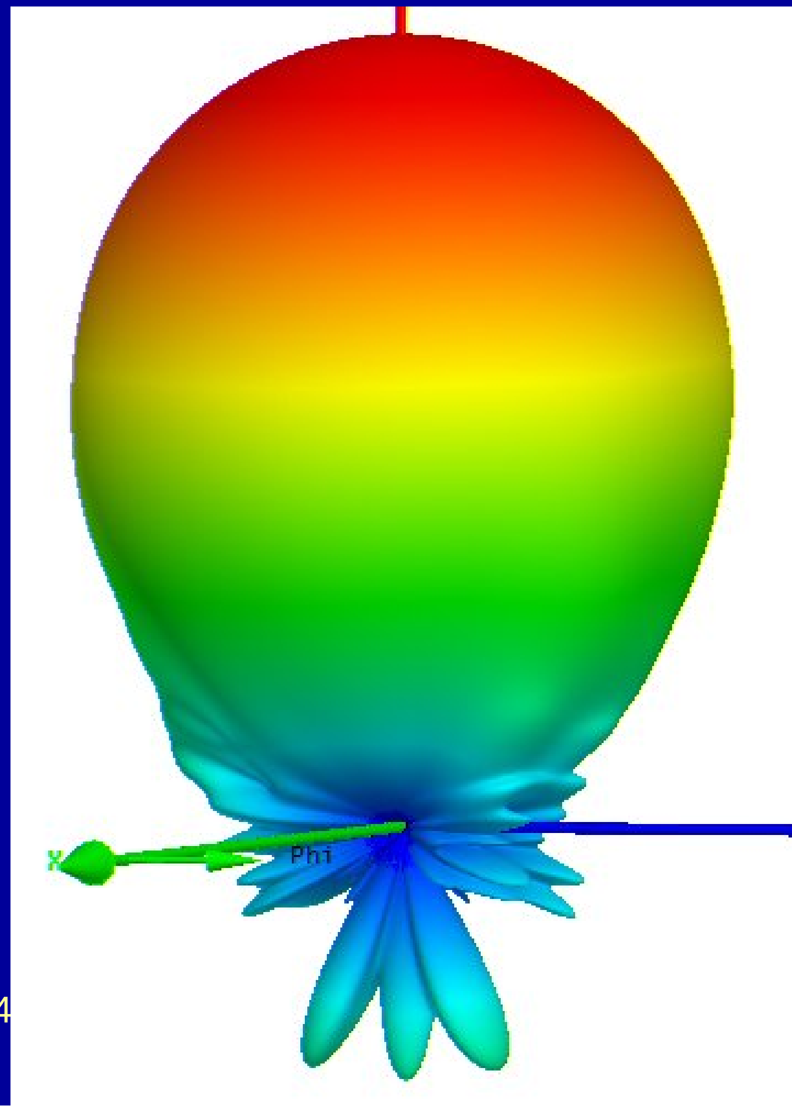
- 10 GHz
  - Cylindrical horn
- 24 GHz
  - Dual-mode horn (W2IMU type)

- *Add output horn for better performance*

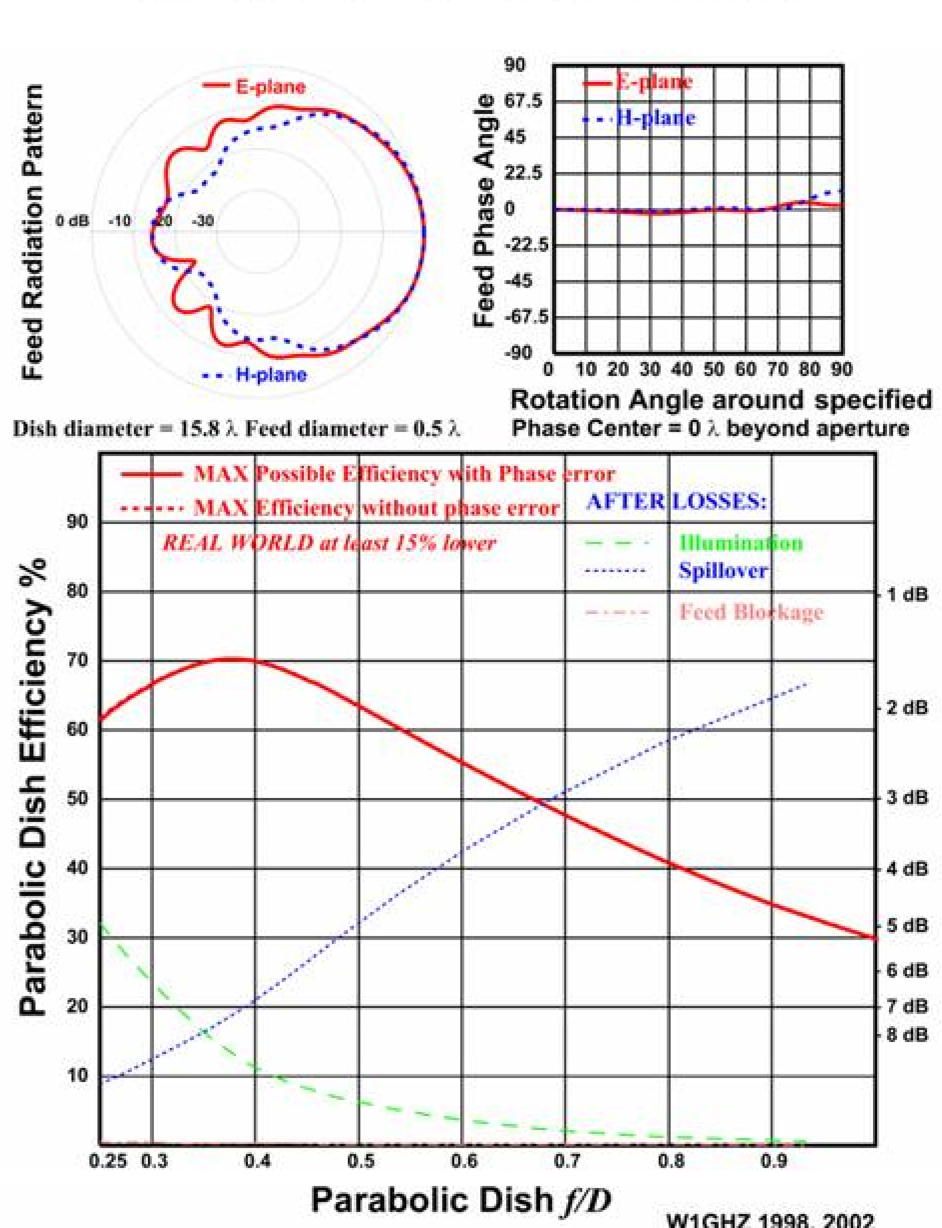
10 GHz *no horn* 24 GHz



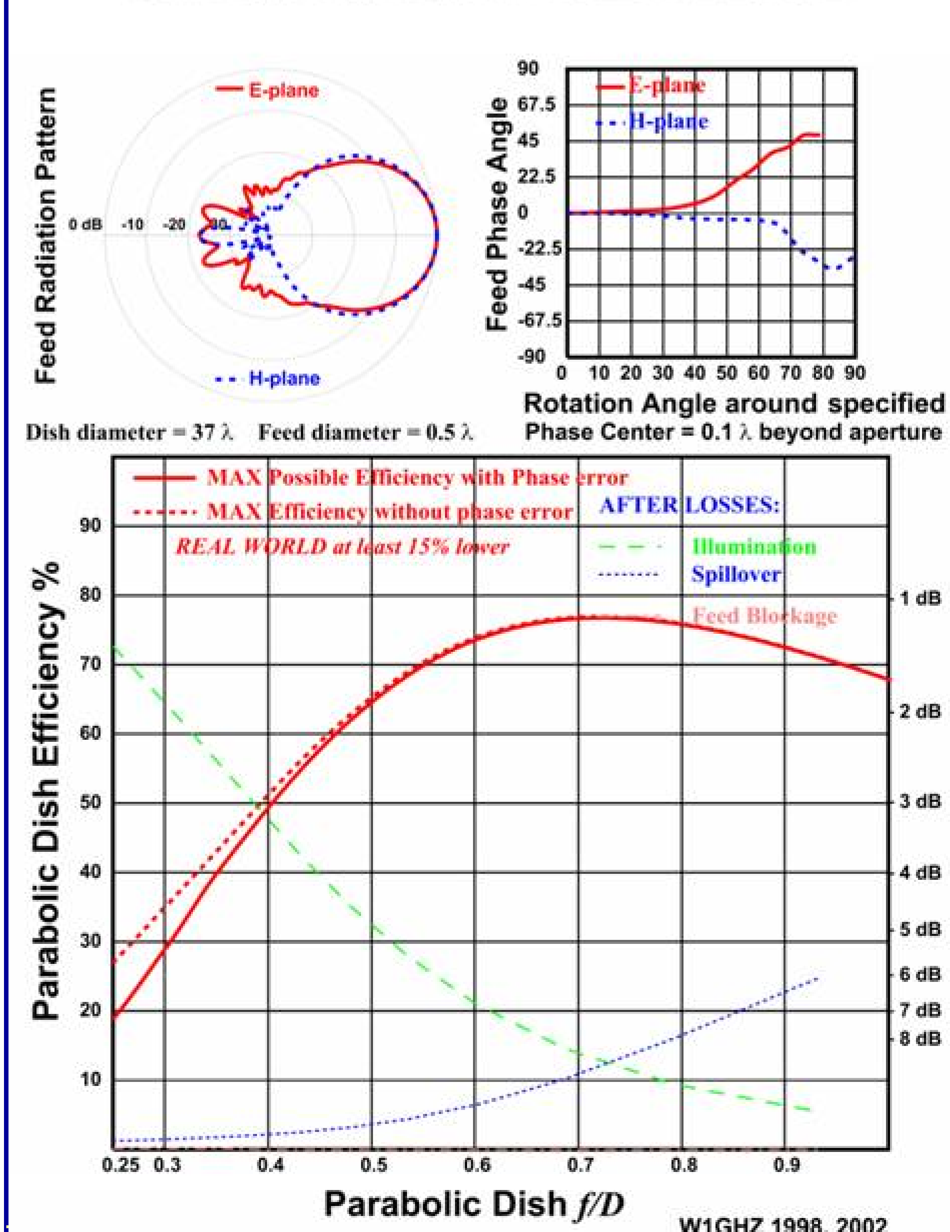
2004



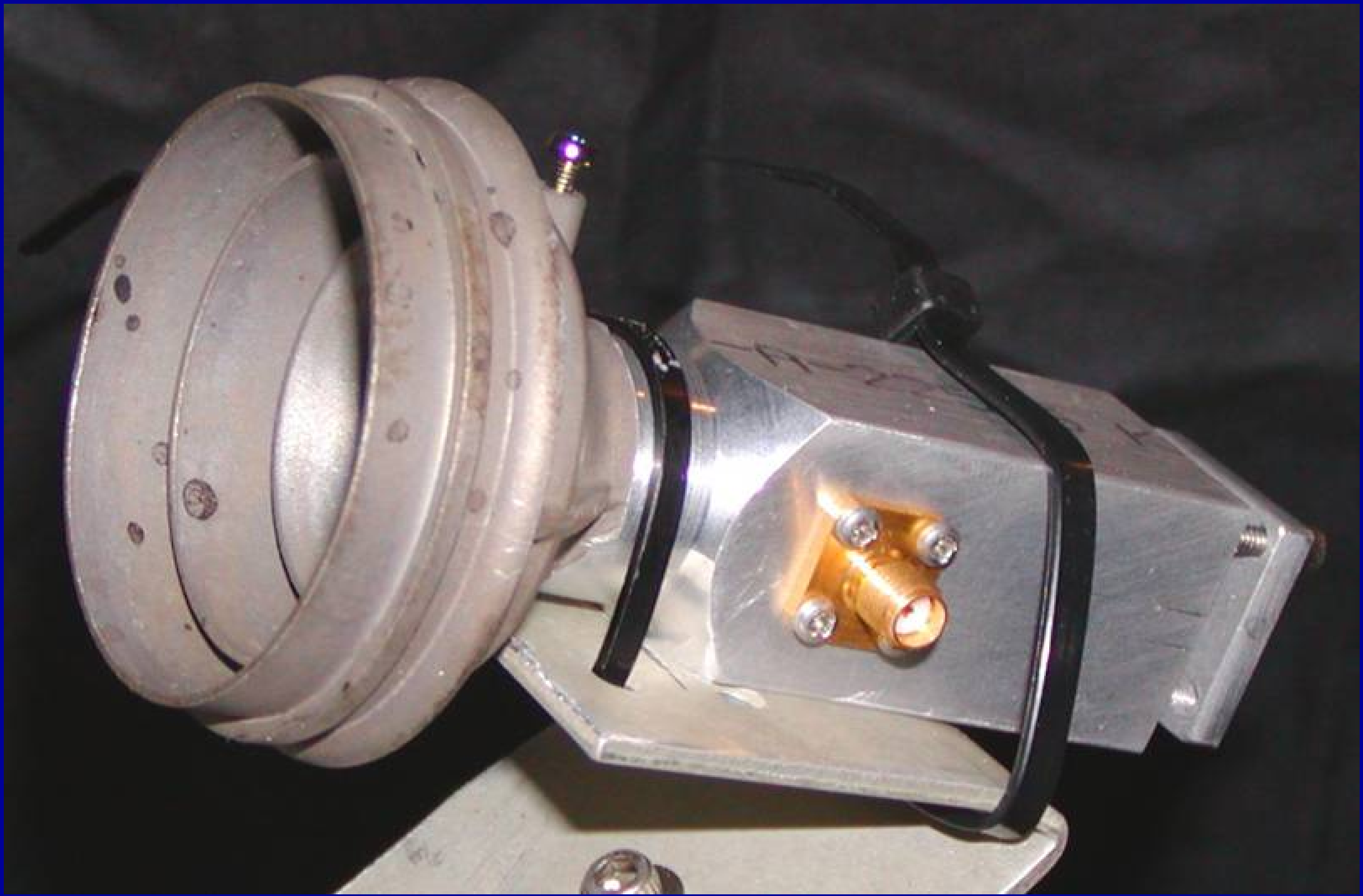
Dual-mode 10&24 feed at 10 GHz with no horn



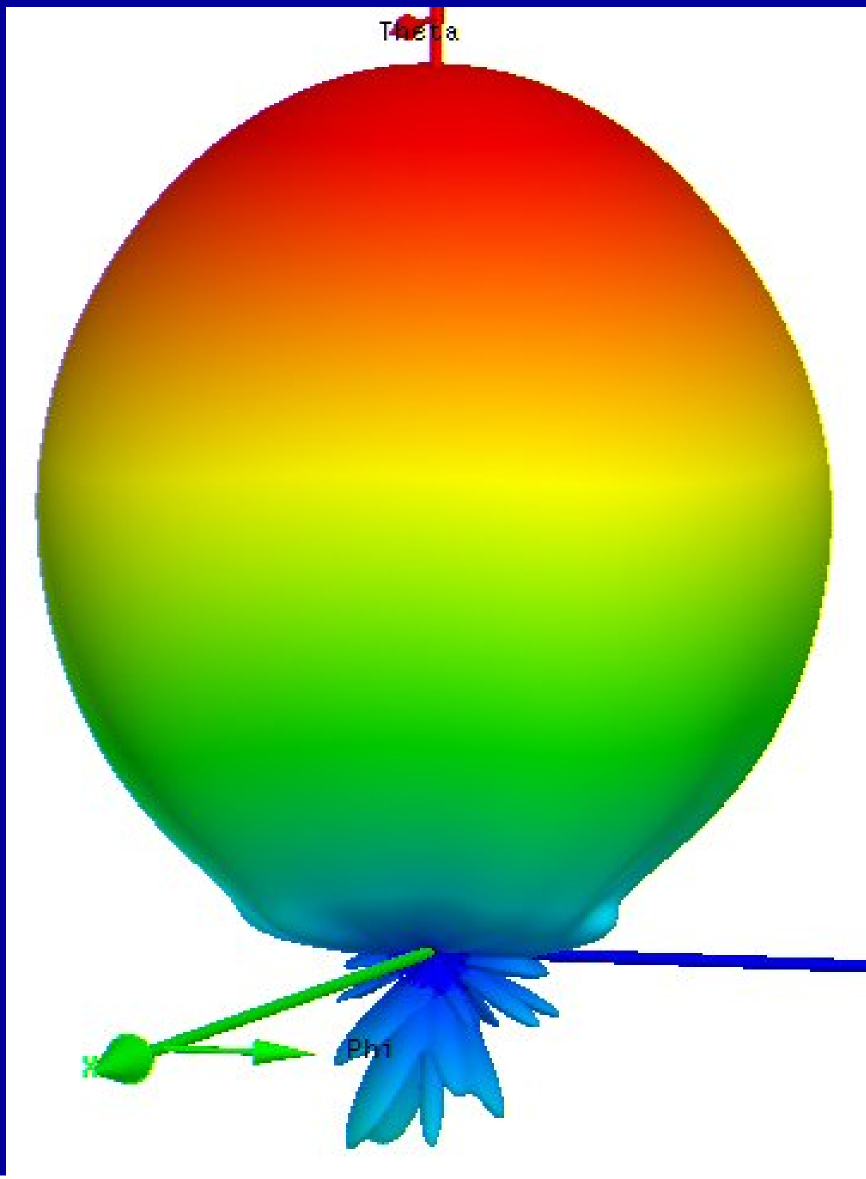
Dual-mode 10&24 feed at 24 GHz with no horn

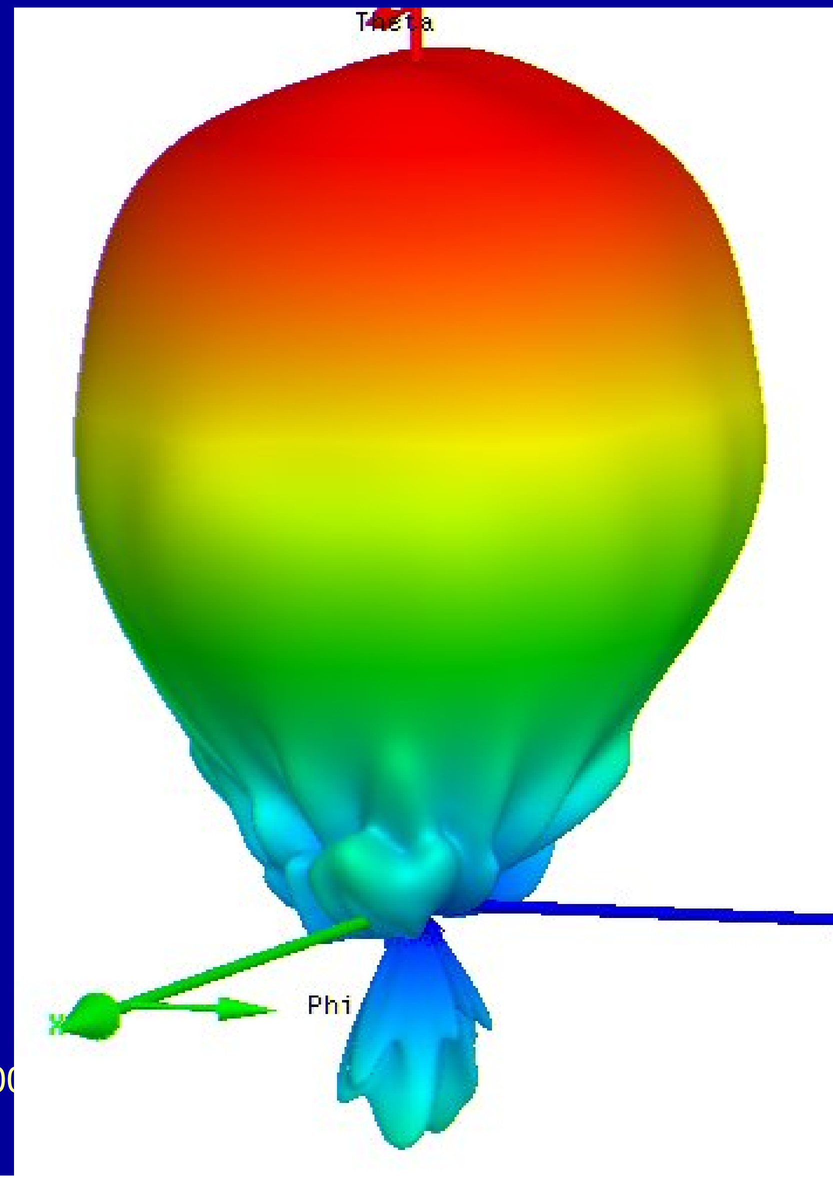


Corrugated horn on output



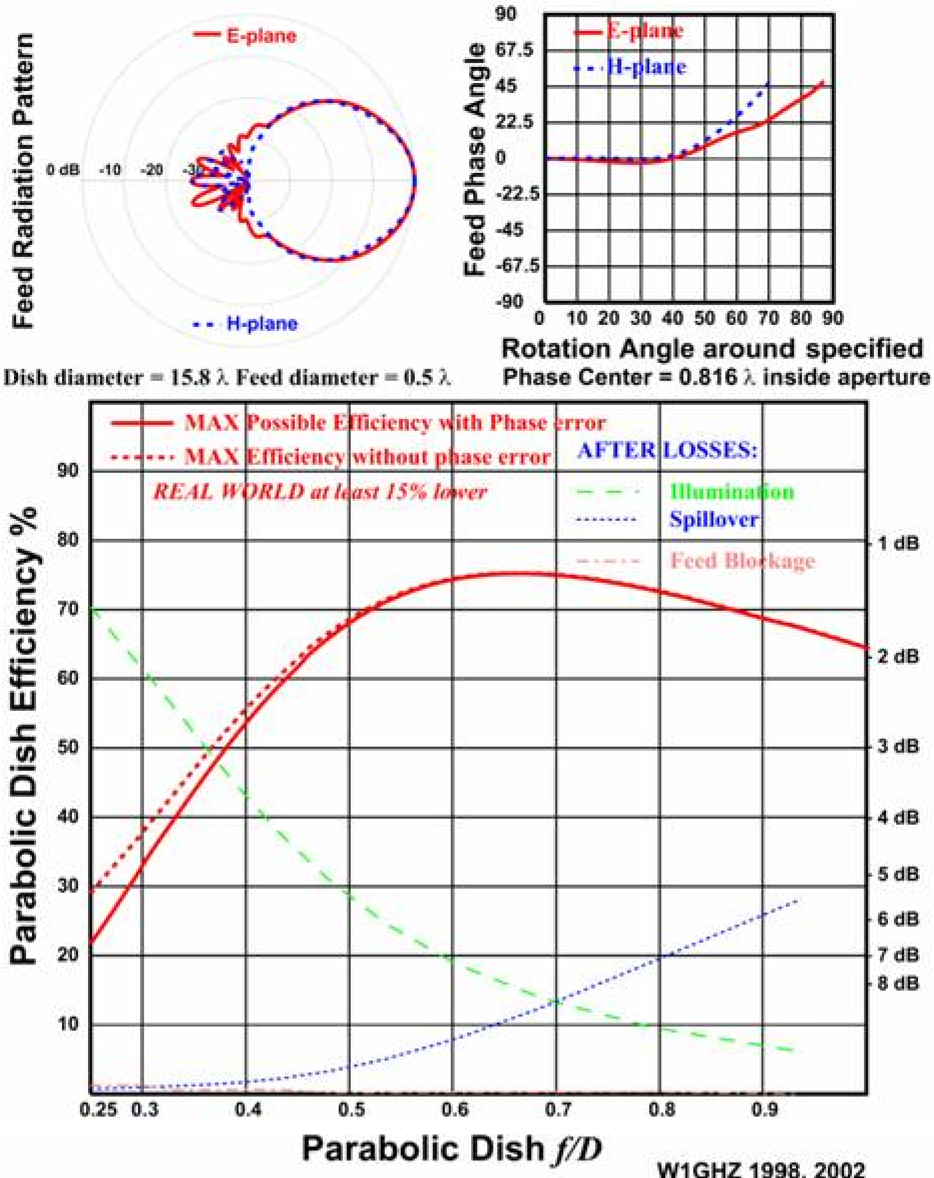
10G *with Chaparral horn* 24G





Dualmode 10&24 feed with Chaparall offset horn at 10 GHz

at 24 GHz Phase Center



Dualmode 10&24 feed with Chaparall offset horn at 24 GHz