NRAO NATIONAL RADIO ASTRONOMY OBSERVATORY

TOWARDS OPTICS DESIGN FOR THE ngVLA

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NSF Associated Universities, Inc.

ngVLA
The Next Generation Very Large Array

Session J2: Next Generation Very Large Array

January 4, 2017

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INTRODUCTION

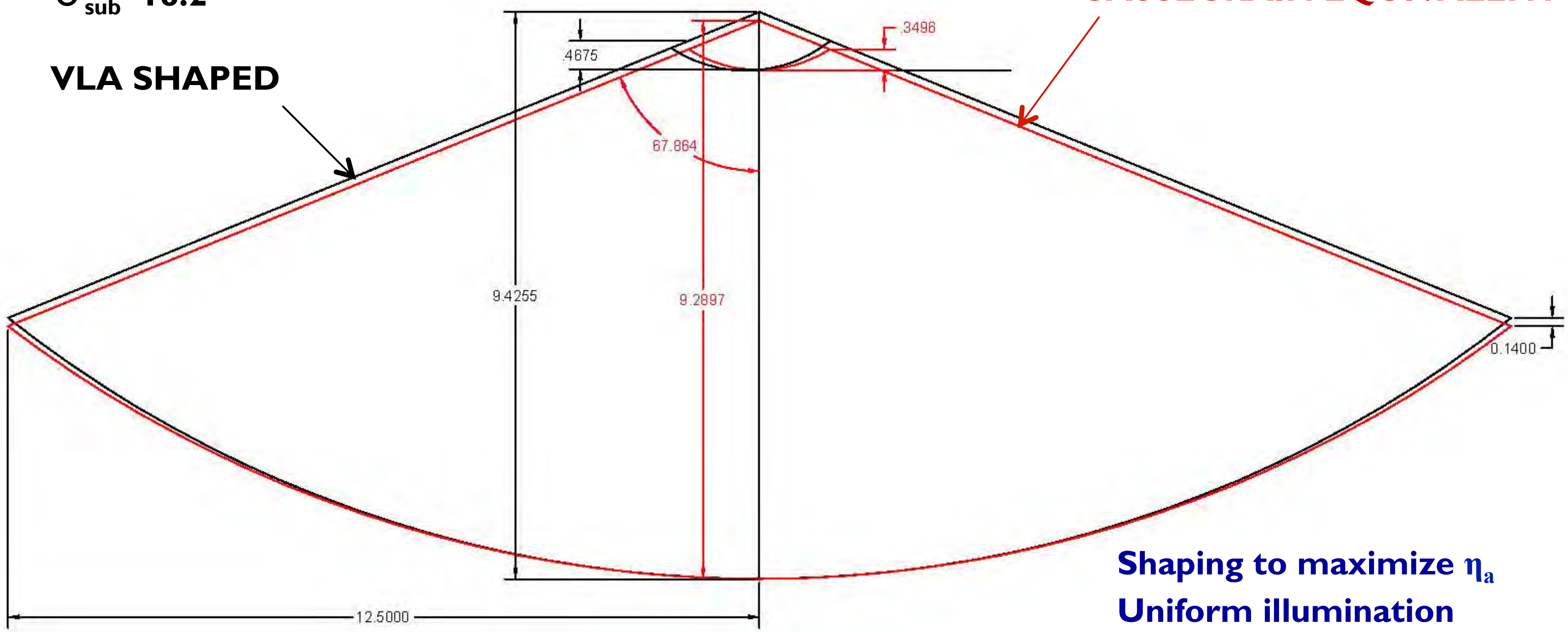
Sensitivity 10x VLA (35 GHz)
~300 antennas-18 m diameter; Diameters 12-25m considered
1.2-116 GHz
1.2-10.8 GHz (2 or 3 bands; h_a =0.65)
11-50 GHz (3 bands; h_a=0.75)
70-116 GHz (1 band; h_a=0.4,0.3)
Dual-offset reflector antenna
Shaping to optimize G/T_{sys}

VLA (SHAPED) & CASSEGRAIN EQUIVALENT

CASSEGRAIN DEPTH 34.9 cms; Dia 2.35m
SHAPED DEPTH 46.7 cms
Θ_{sub}=18.2°

VLA SHAPED

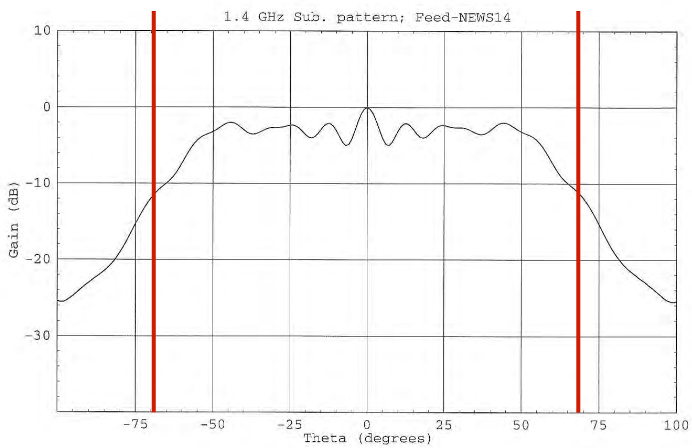
CASSEGRAIN EQUIVALENT

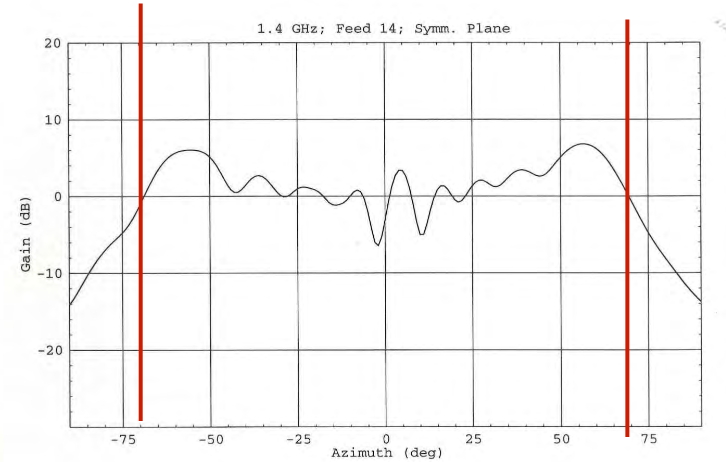


Shaping to maximize η_a
Uniform illumination

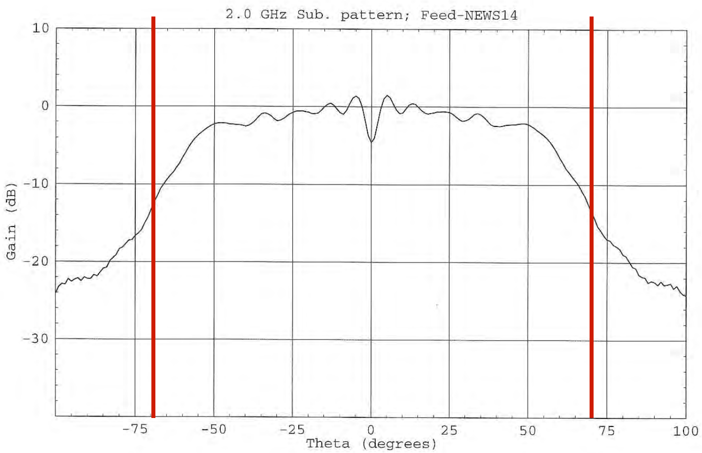
PARABOLA DEPTH 420 cms
SHAPED DEPTH 434 cms

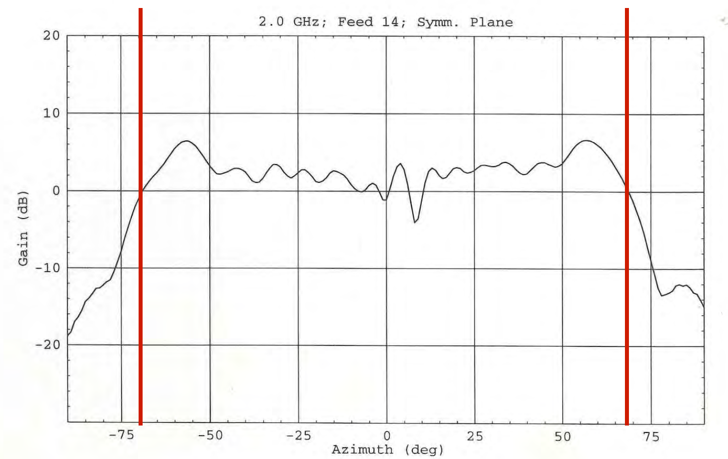
SUBREFLECTOR SCATTERED BEAM





1.4 GHz





2.0 GHz

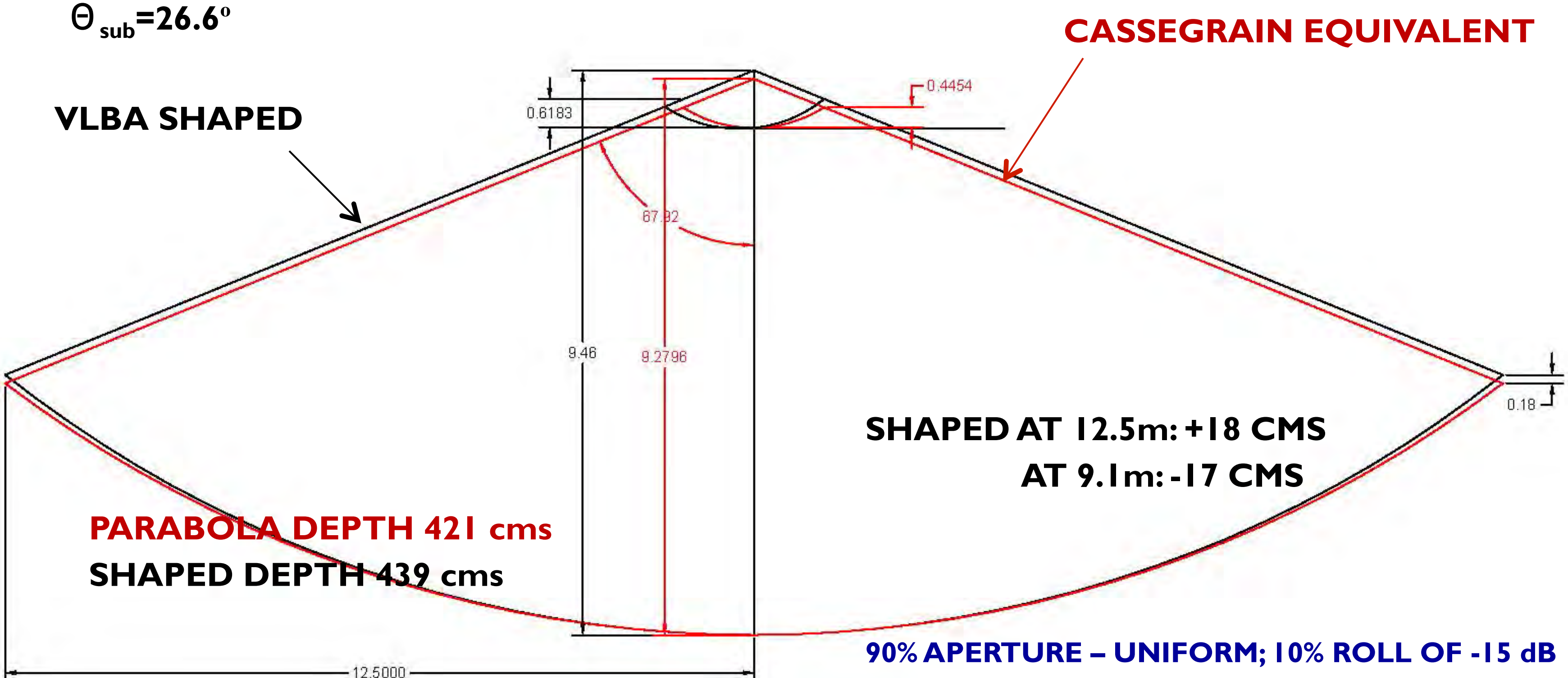
HYPERBOLIC SUBREFLECTOR

Θ edge = 67.86°

VLA SHAPED

VLBA (SHAPED) & CASSEGRAIN EQUIVALENT

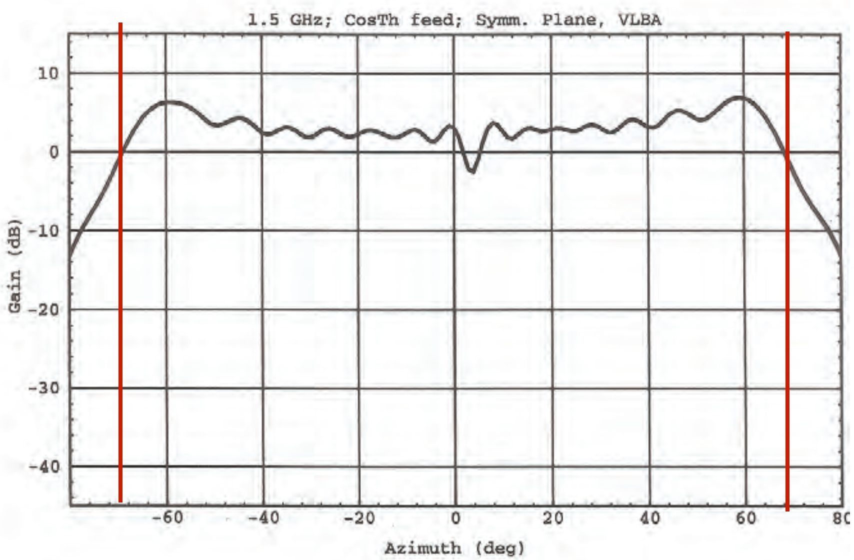
CASSEGRAIN DEPTH 44.5 cms; Dia=3.2m
SHAPED DEPTH 61.8 cms
Θ_{sub}=26.6^{o}



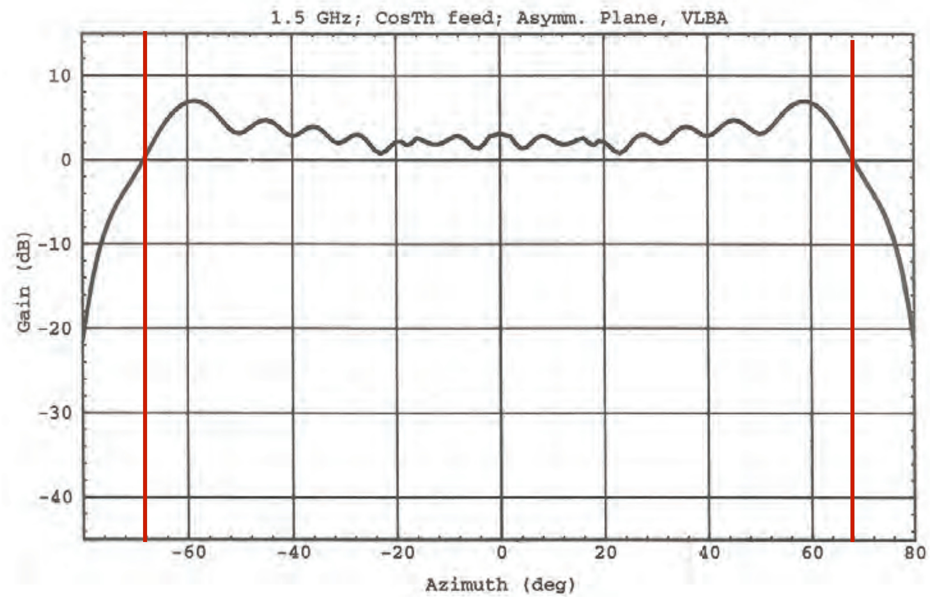
90% APERTURE – UNIFORM; 10% ROLL OF -15 dB
G/T maximized 1.5, 2.3 GHz
Gain loss 5% at 600 MHz FROM PRIME FOCUS

SUBREFLECTOR SCATTERED BEAM (1.5 GHz)

Θ edge = 67.92°



SYMMETRIC PLANE



ASYMMETRIC PLANE

More uniform illumination and faster roll-off

DISADVANTAGES OF SHAPING

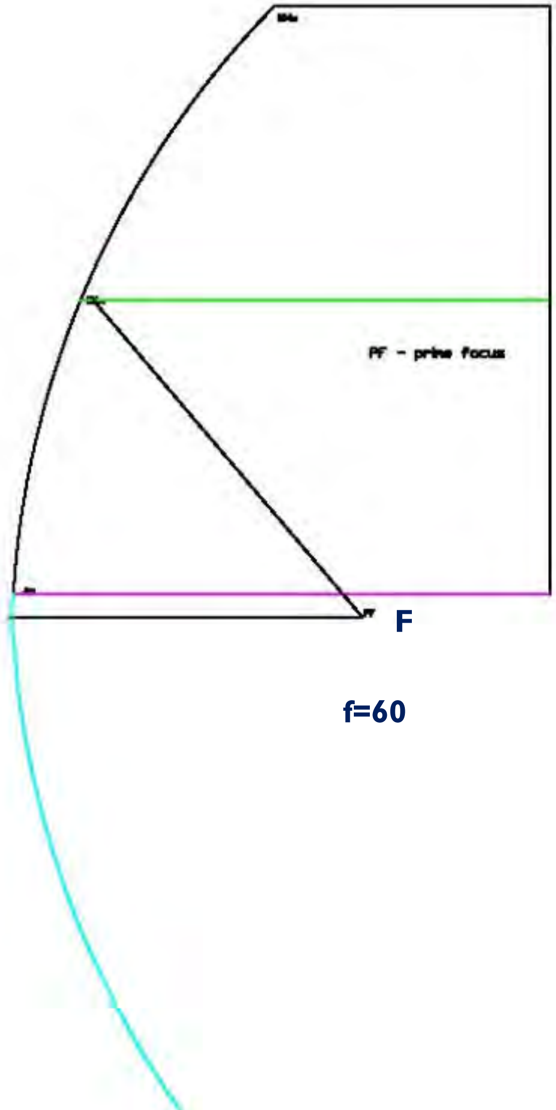
1. FREQUENCY DEPENDENT

2. LIMITED FIELD OF VIEW

3. LOSS IN GAIN FROM PRIME FOCUS

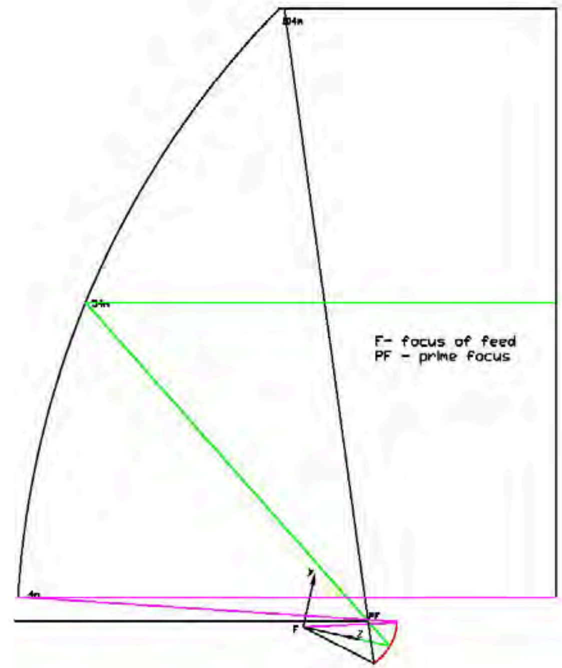
4. RELATIVELY LARGER FEED HORNS (MORE SEVERE ILLUMINATION TAPER)

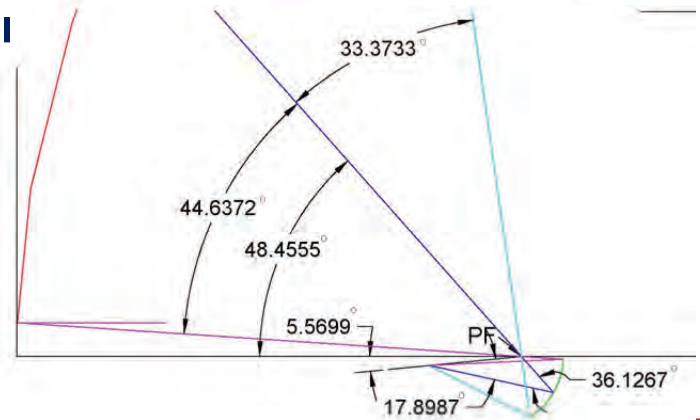
DUAL-OFFSET ANTENNA (GBT)



CYLINDER DIA 100
CENTER AT 54

ecc=0.528
Yc=54, f=60
fellip=11
M = 3.17
Sub=7.55x7.95
FA=15.1





UNBLOCKED APETUTRE Vs SYMMETRIC

ADVANTAGES:

Higher aperture efficiency 3 to 5%

Lower side lobes ~15 dB

Lower $T_{antenna}$ ~3K

Minimized standing waves ~25 dB

Larger real estate

DISADVANTAGES:

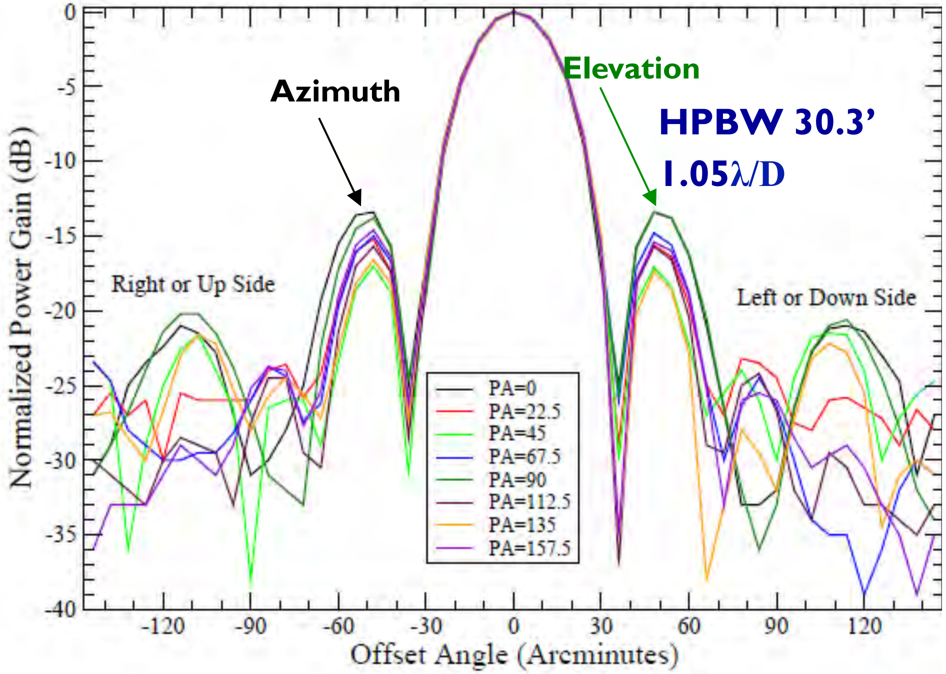
Complex structure

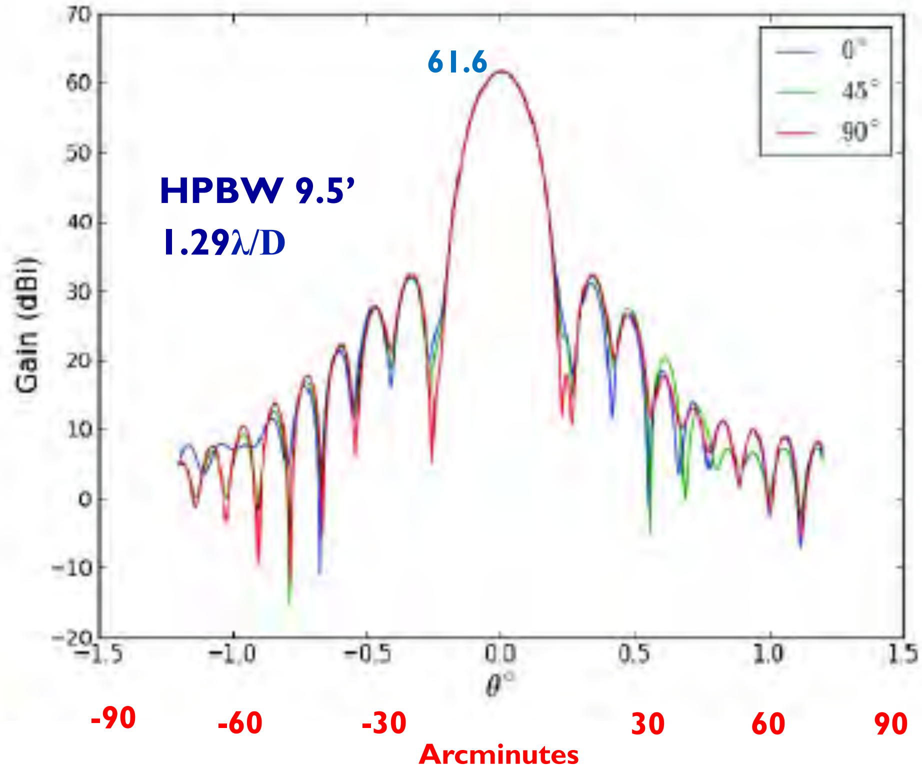
Poorer polarization performance – prime focus

Higher scan loss

Requires turret rotation/translation

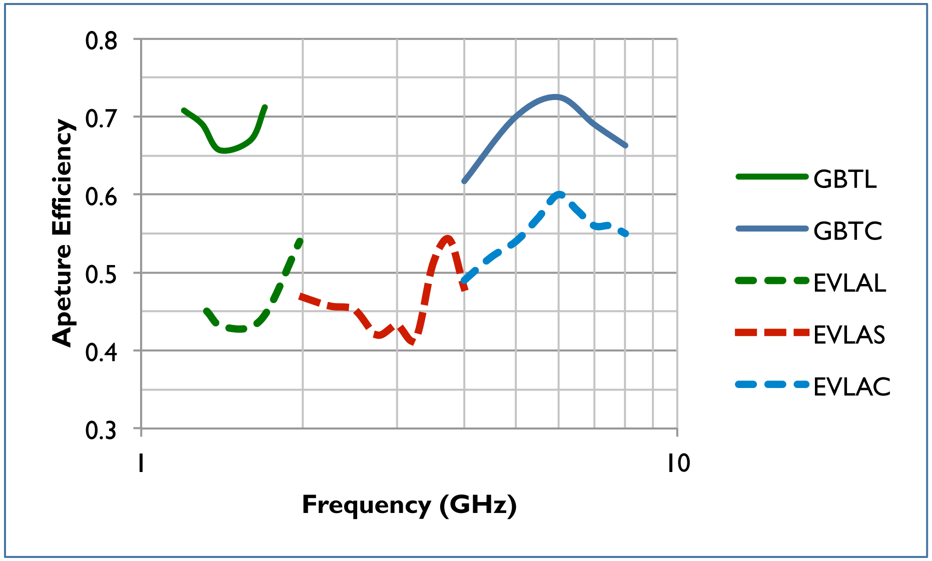
BEAM OF THE EVLA (1.425 GHz) & GBT (1.4 GHz)

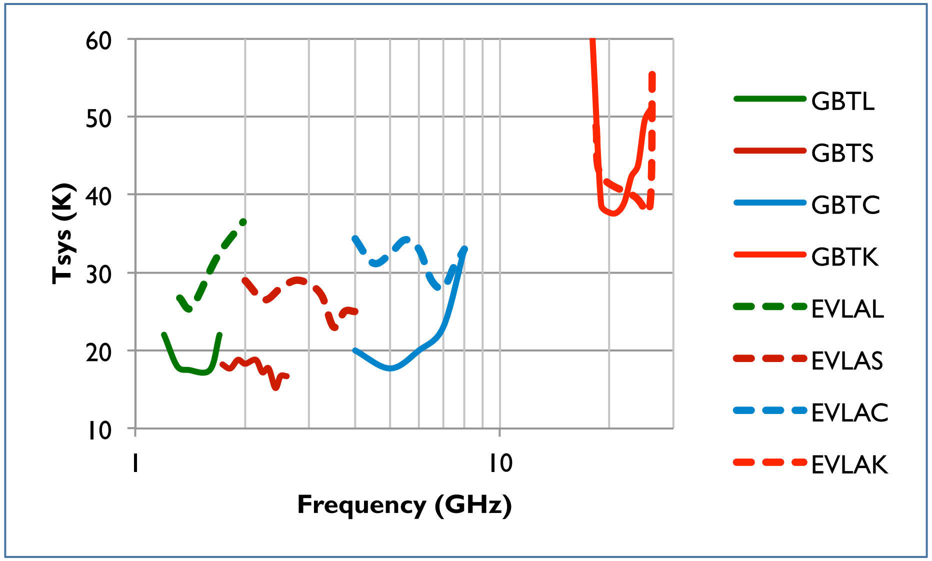




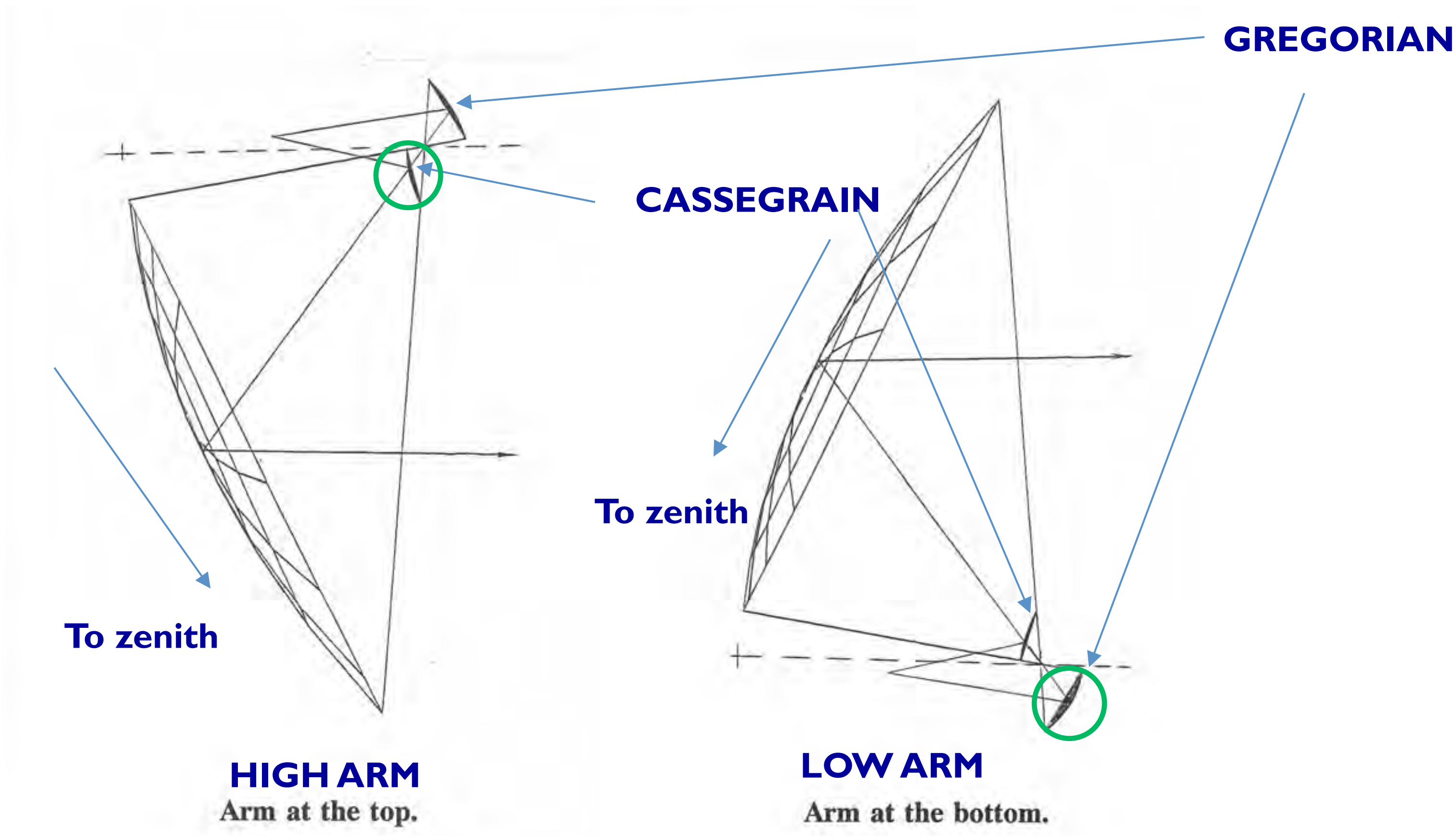
R. Perley et al., "Testing of theEVLA L-Band Feed", EVLA Memo 85

APERTURE η AND SYSTEM TEMPERATURE

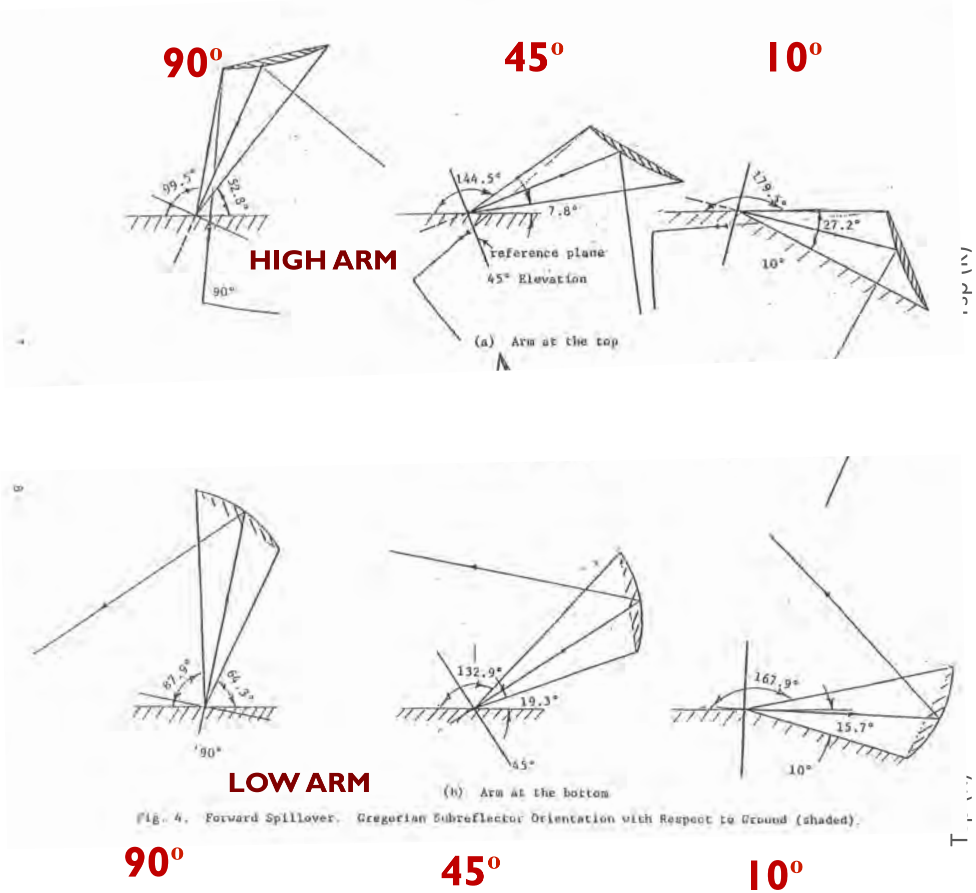


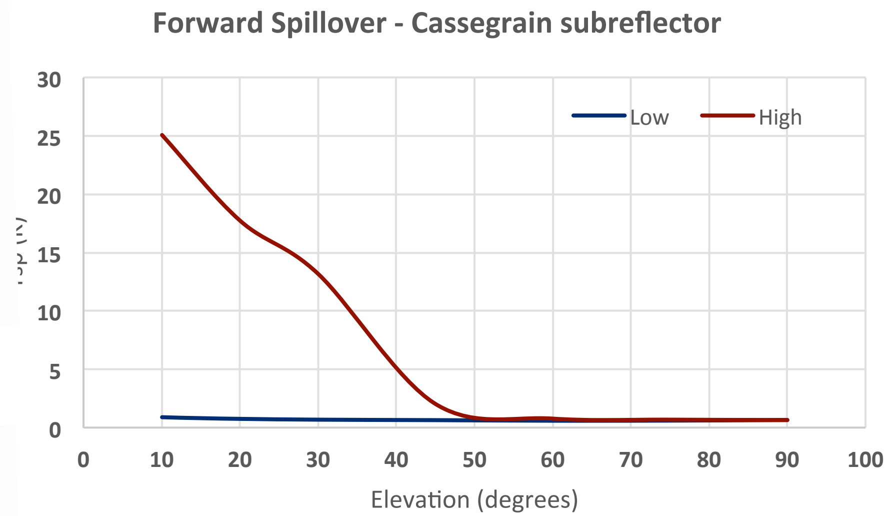


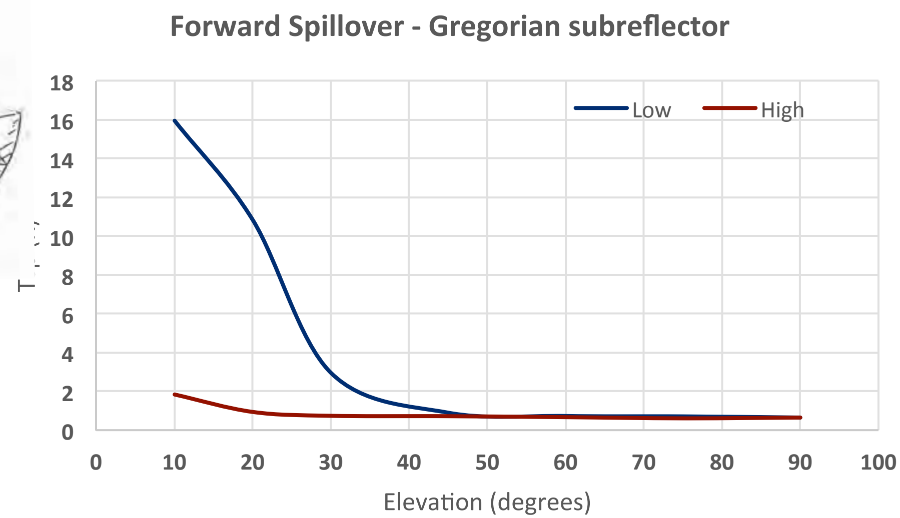
DUAL-OFFSET CASSEGRAIN, GREGORIAN ANTENNA



FORWARD SPILLOVER – PAST SUBRFLECTOR





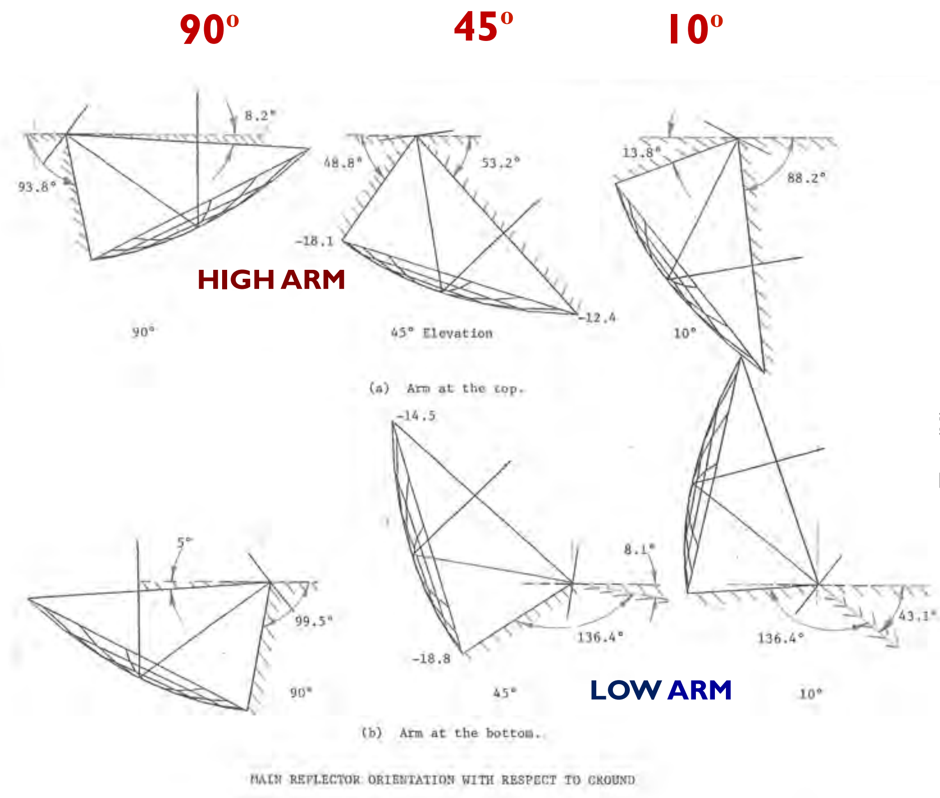


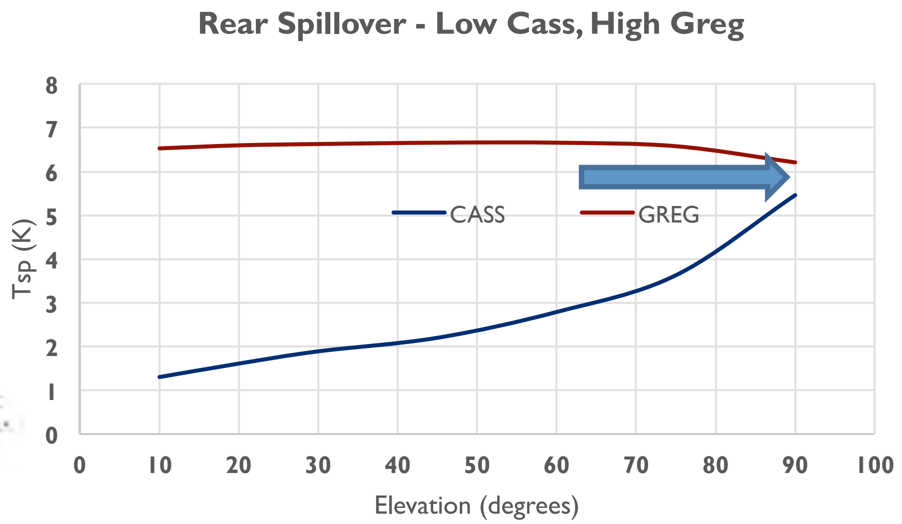
1.42 GHz; -12 dB taper

$D_{sub}=35\lambda$; $\Theta_{sub}=28°$

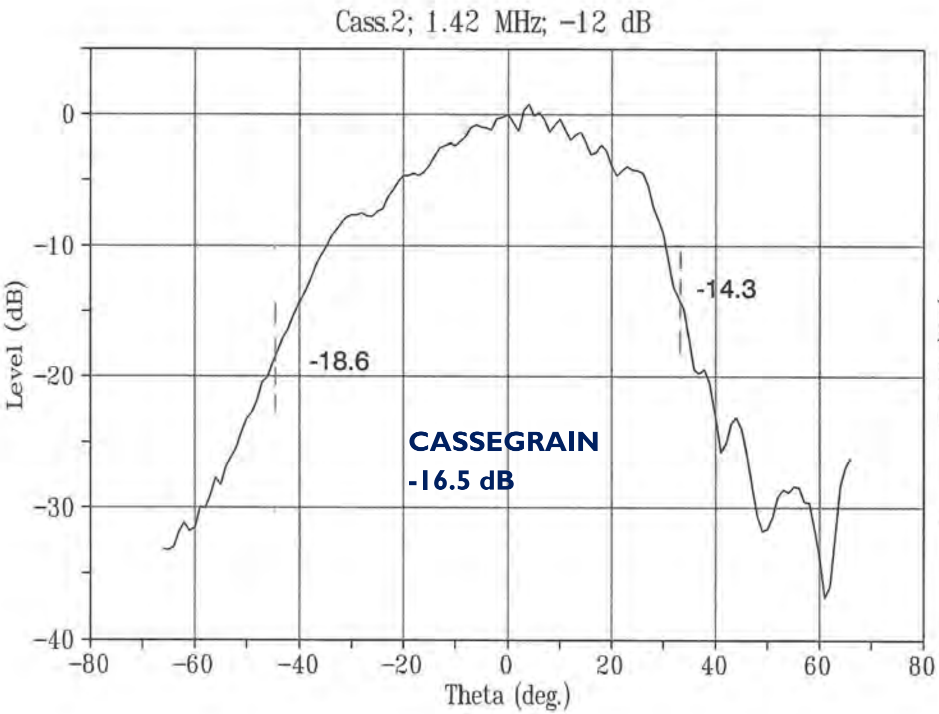
S. Srikanth, "Spillover noise temperature calculations for the Green Bank clear aperture antenna," GBT Memo #16, October 4, 1989.

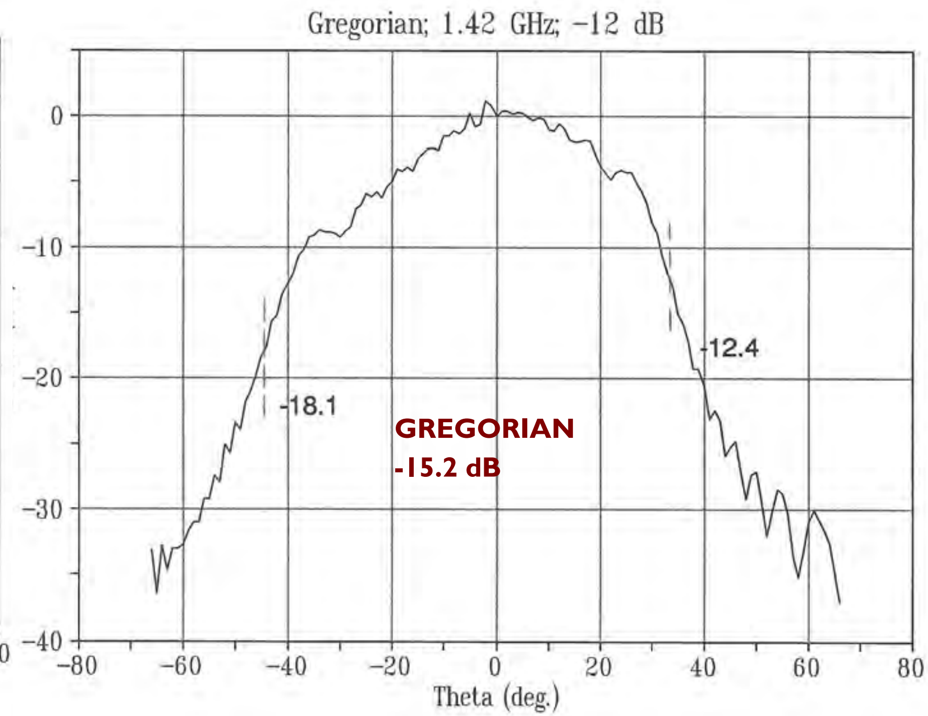
REAR SPILLOVER – LOW CASS., HIGH GREG.





SUBREFLECTOR SCATTERED PATTERN





DIFFRACTION LOSS

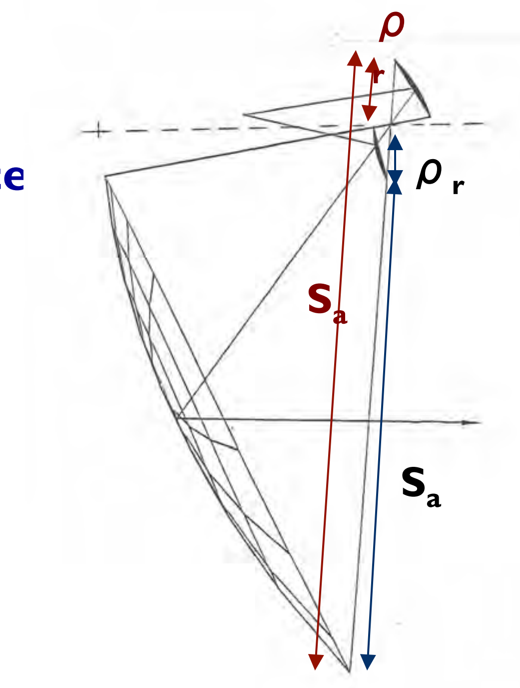
Lateral extent of the transition region of edge diffracted field

$\Delta\rho=\sqrt{\lambda}/\pi\, \mathbf{Sa}/|\mathbf{1}\pm\mathbf{Sa}/|\rho\mathbf{r}||$

S_a – distance between edges of subreflector and main reflector

ρ_r – subreflector edge to prime focus distance

$\Delta\rho_{gregorian} > \Delta\rho_{cassegrain}$



Spillover past main reflector for -10 dB taper

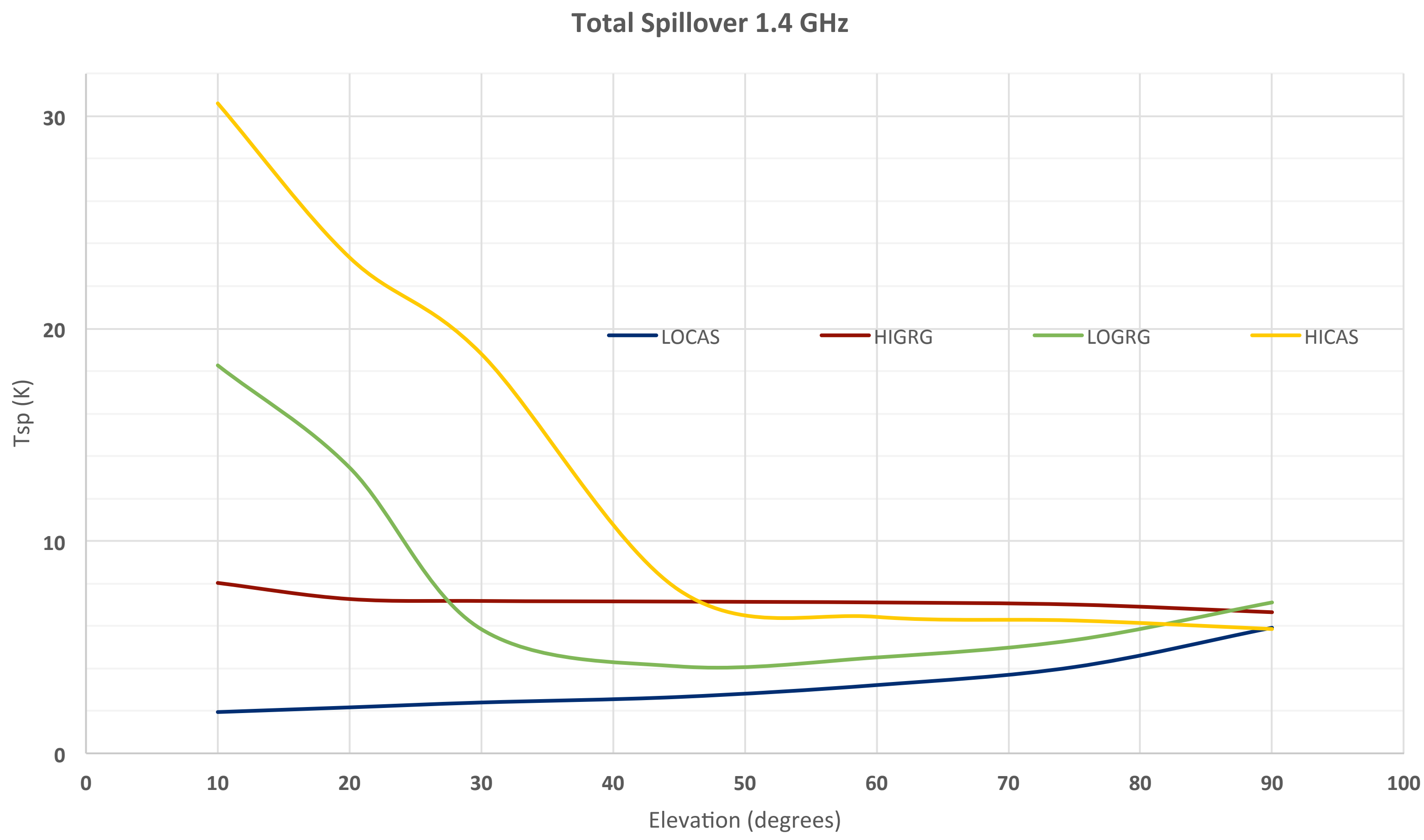
$\Delta p = \mathbf{0.09}\Delta\rho\, \boldsymbol{a/D}$

$\Delta\rho_a$ – average of $\Delta\rho$ of the two edges

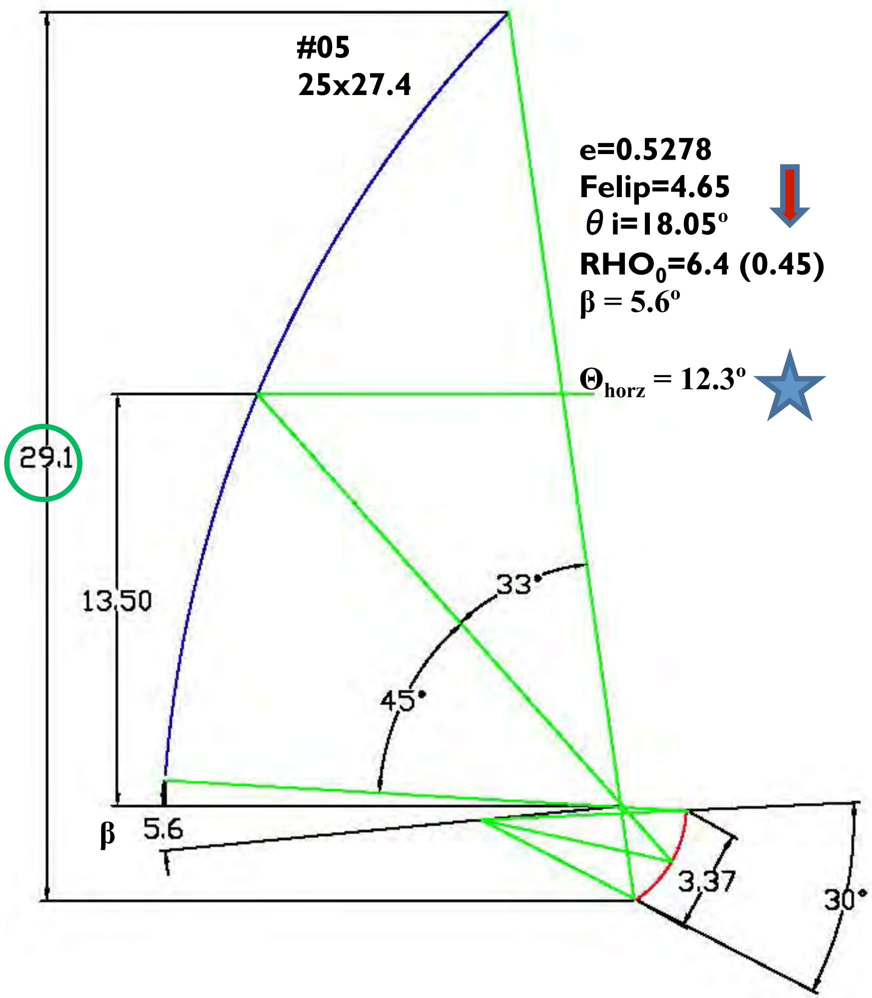
D – diameter of main reflector

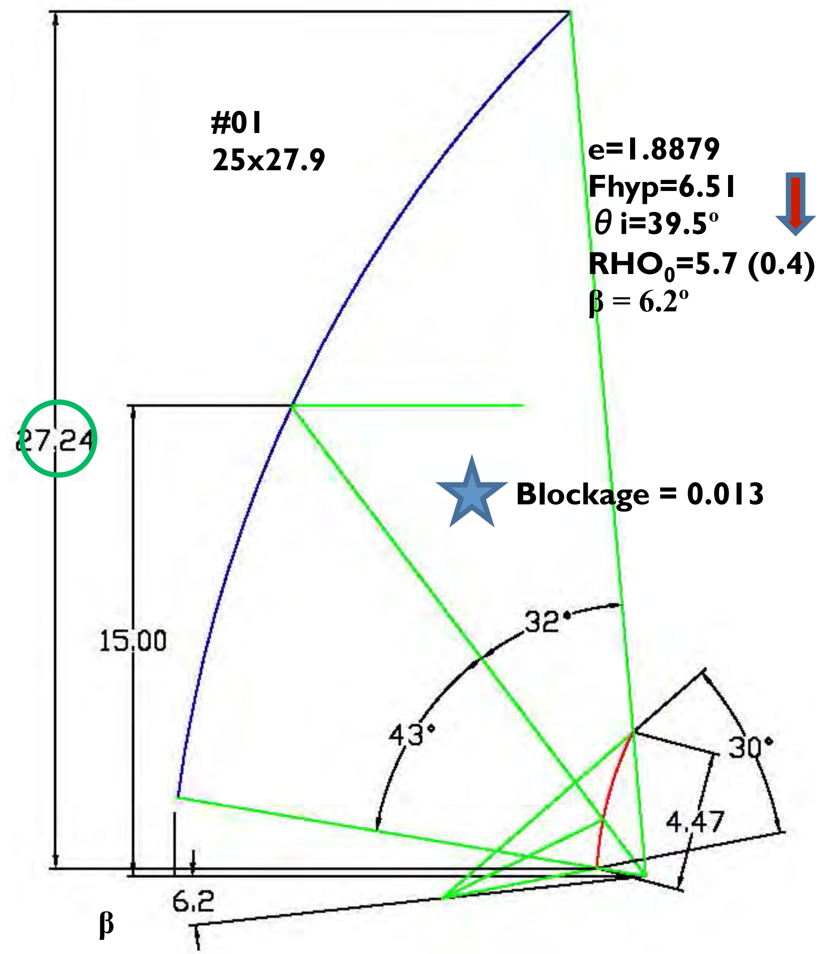
1. P. Kildal and J. Stamnes "Asymptotic transition region theory for edge diffraction, Part I and Part II," IEEE Trans. Antennas and Propagation, Sept. 1990. AP-S Digest pp. 1350-1373
2. Private commn. P. Kildal Sept. 19, 1990.

TOTAL SPILLOVER

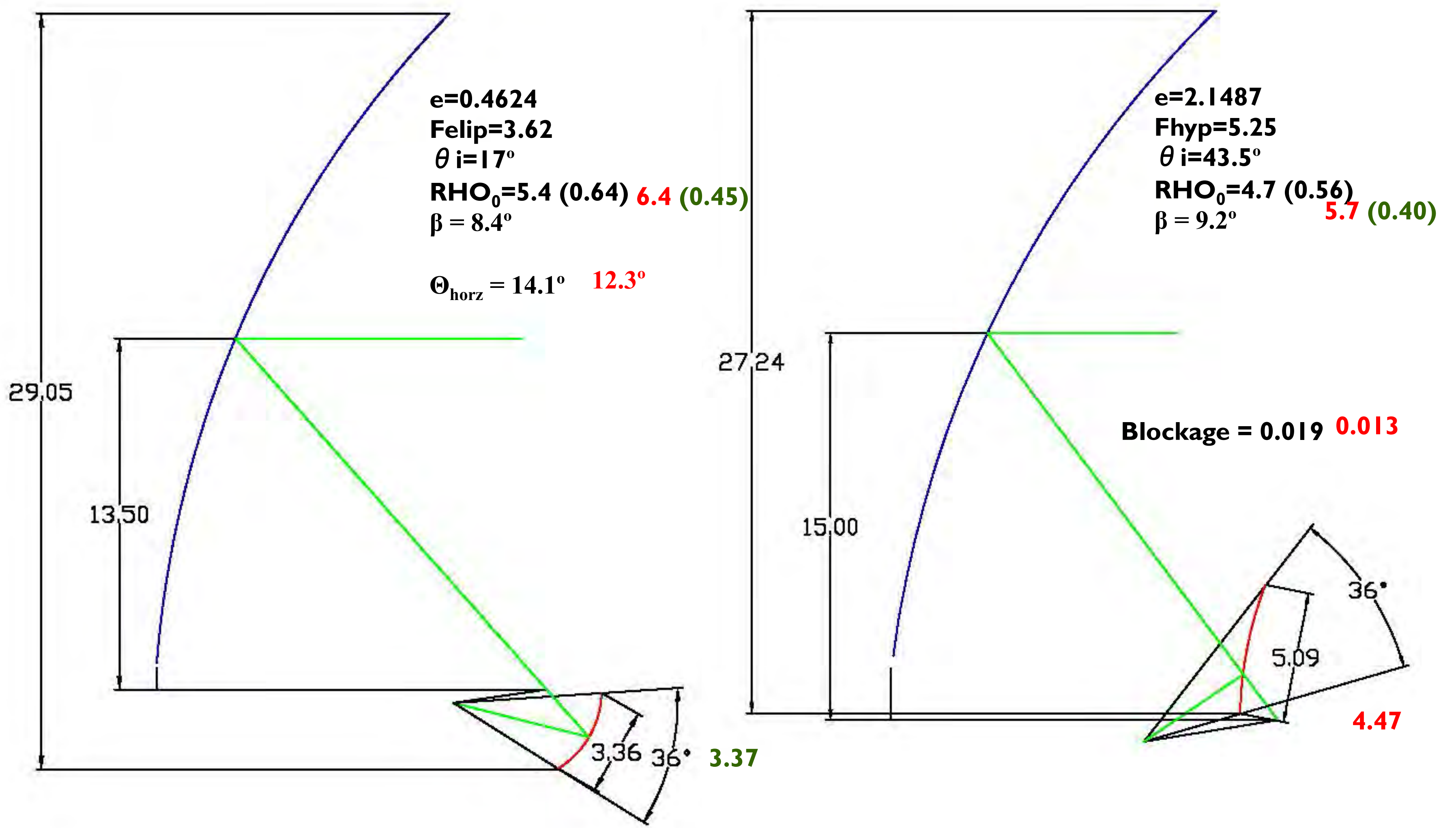


25m MAIN; F=15m; θ_{sub}=30°

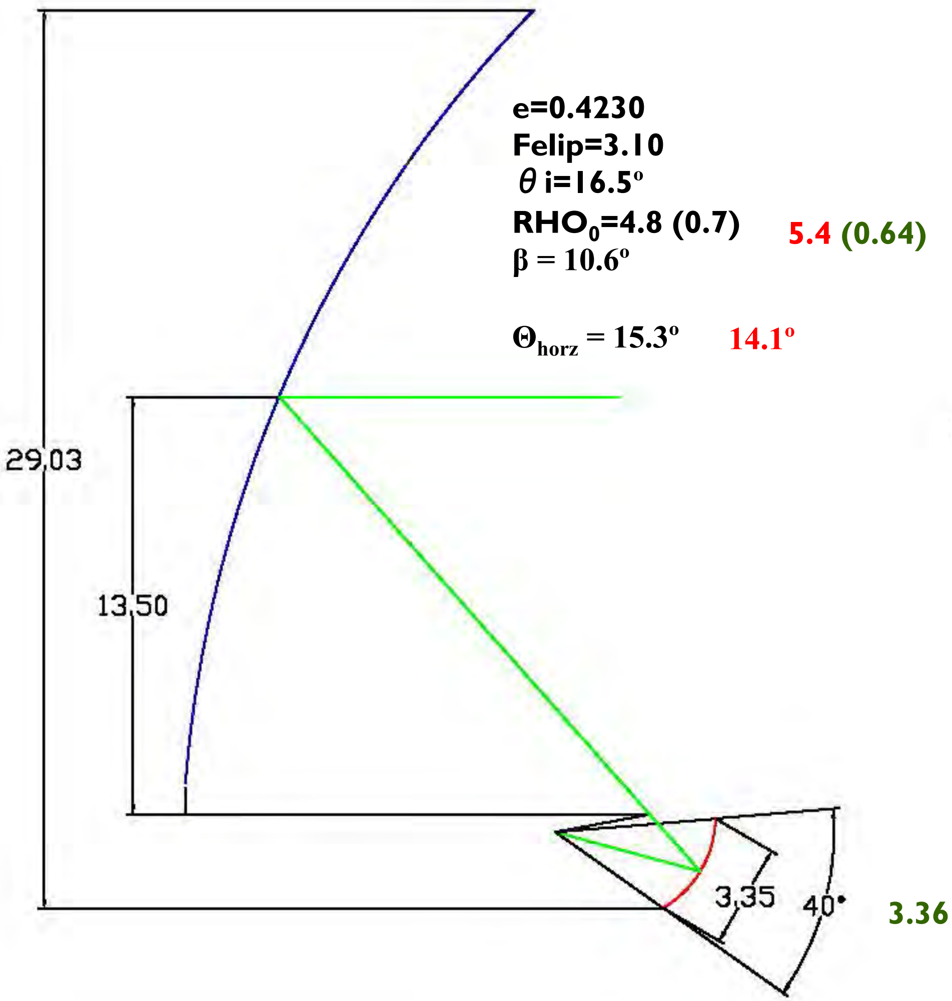


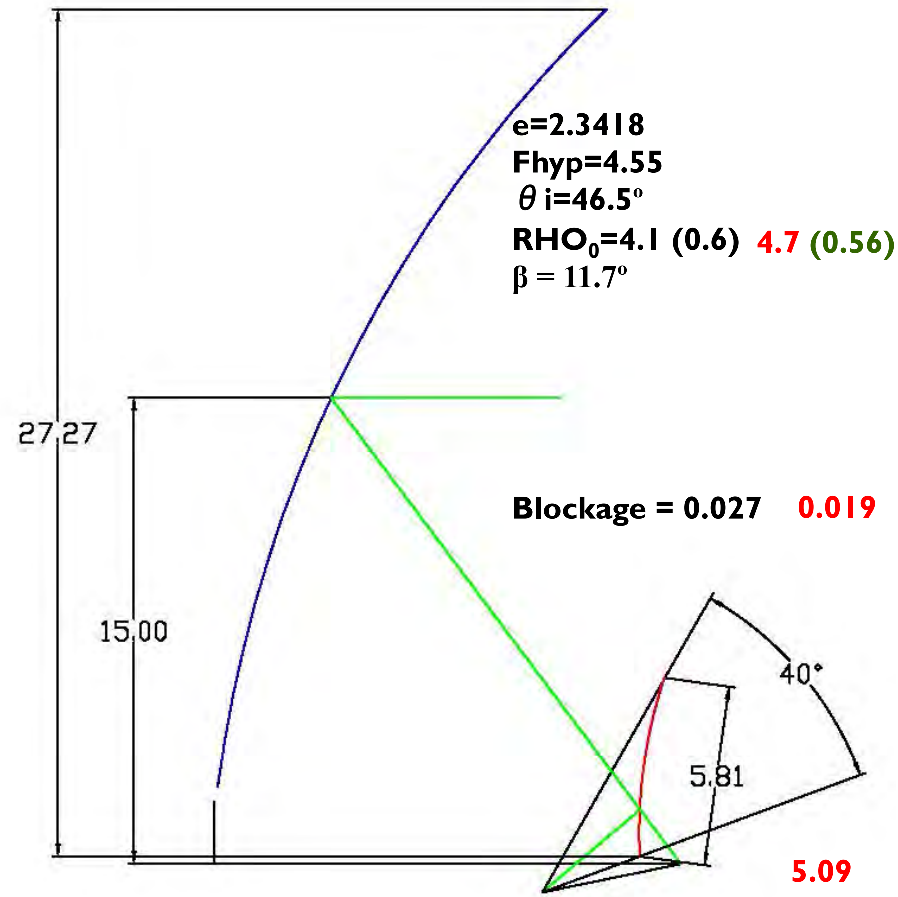


25m MAIN; F=15m; θ_{sub}=36°

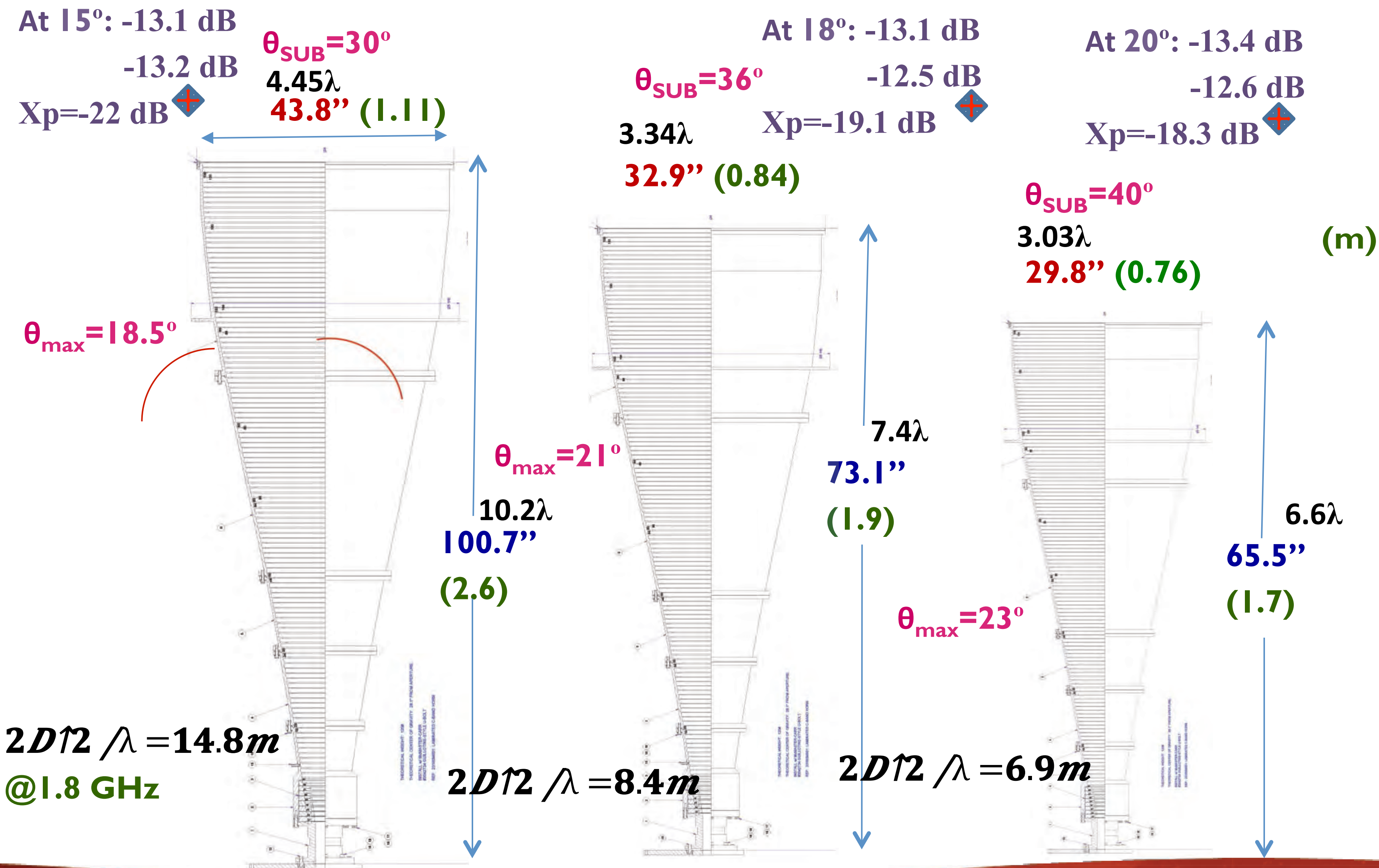


25m MAIN; F=15m; θ_{sub}=40°

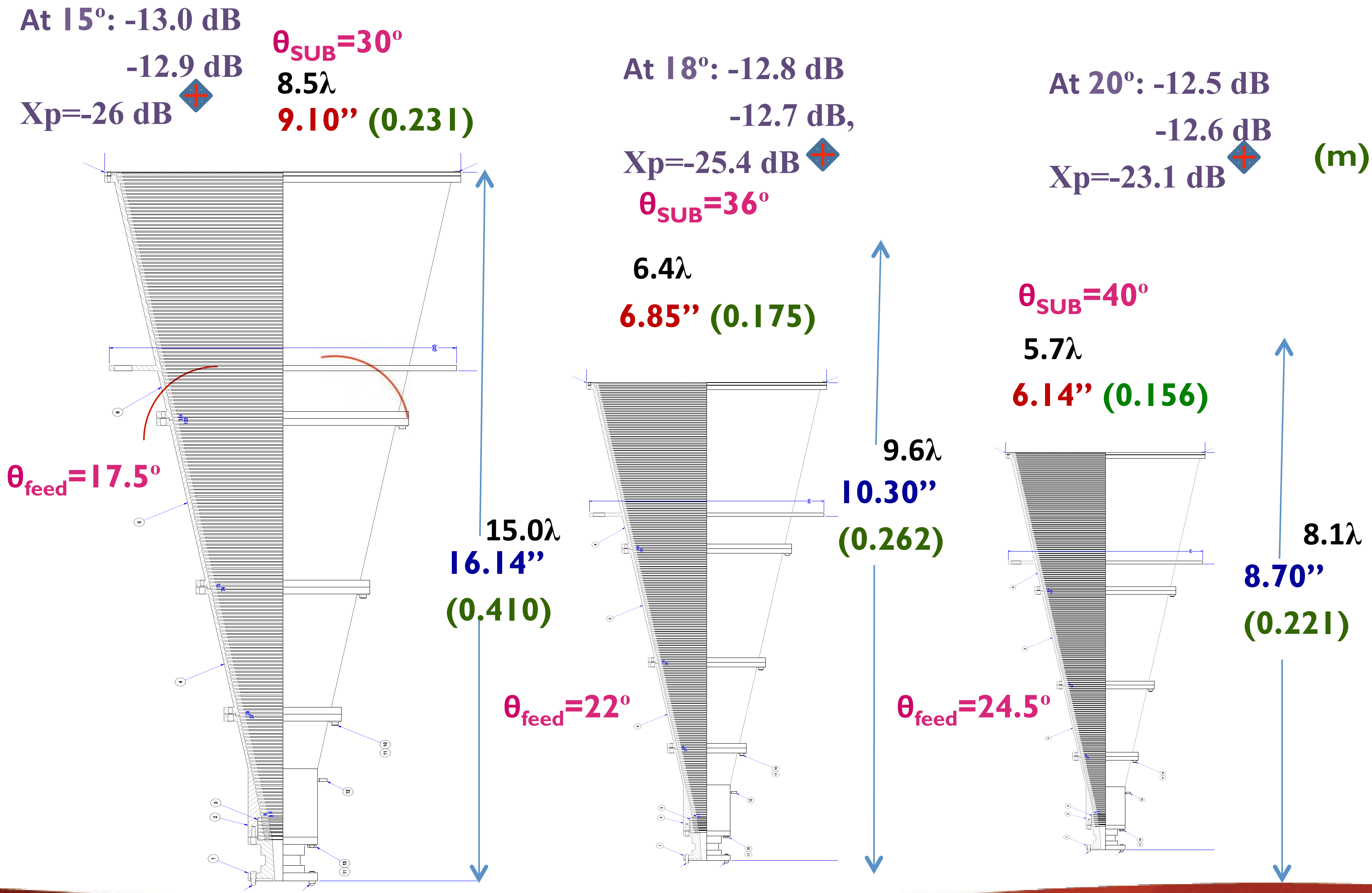




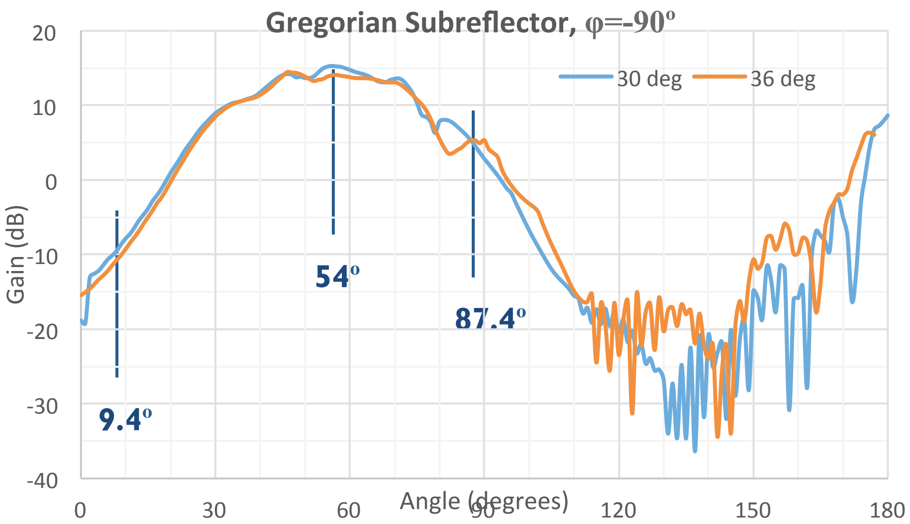
COMPACT FEED HORN – 1.2 to 2.4 GHz

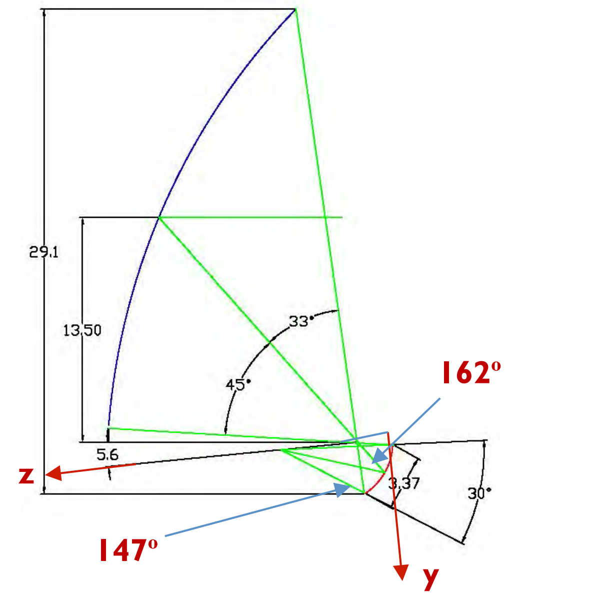


LINEAR TAPER FEED HORN – 11 to 18 GHz

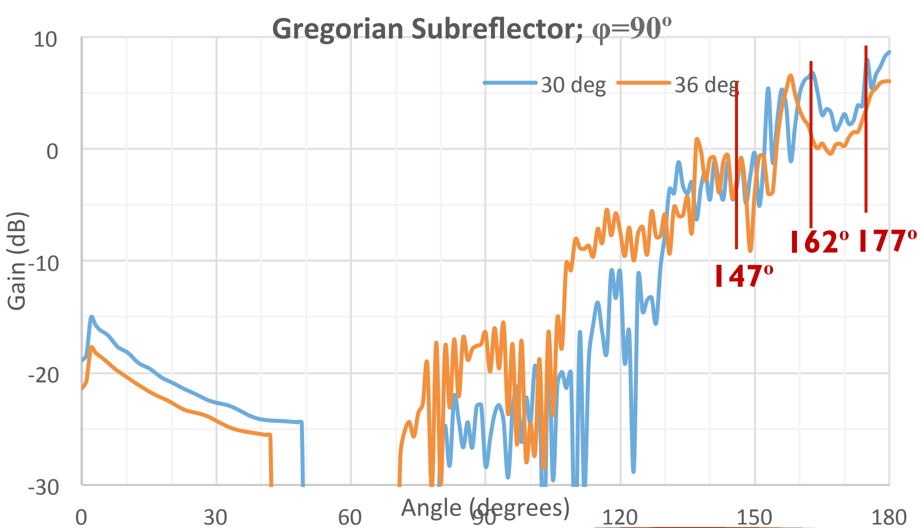


GREGORIAN SUBREFLECTOR SCATTERED PATTERN

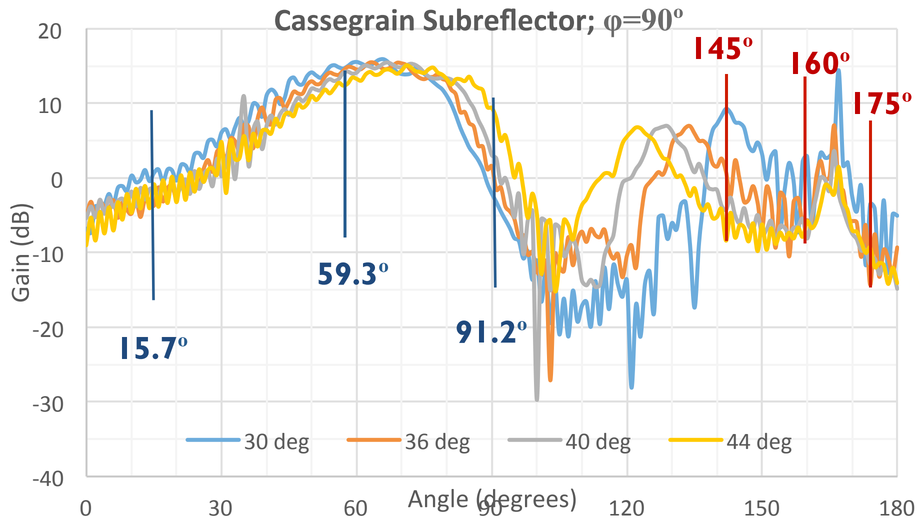


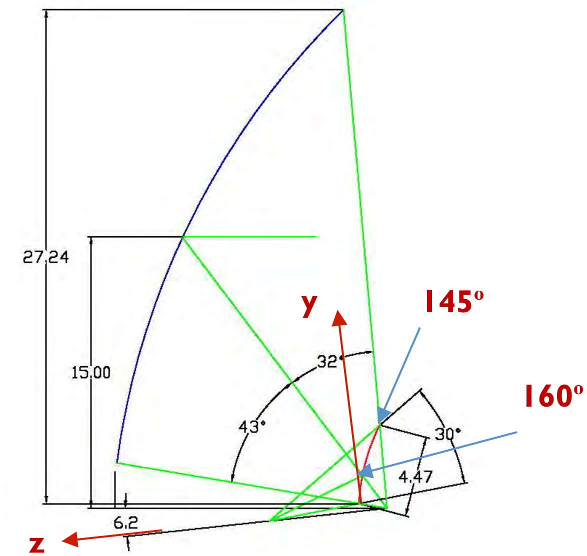


1.6 GHz
At 15° -13.7 dB (H)
-13.2 dB (E)

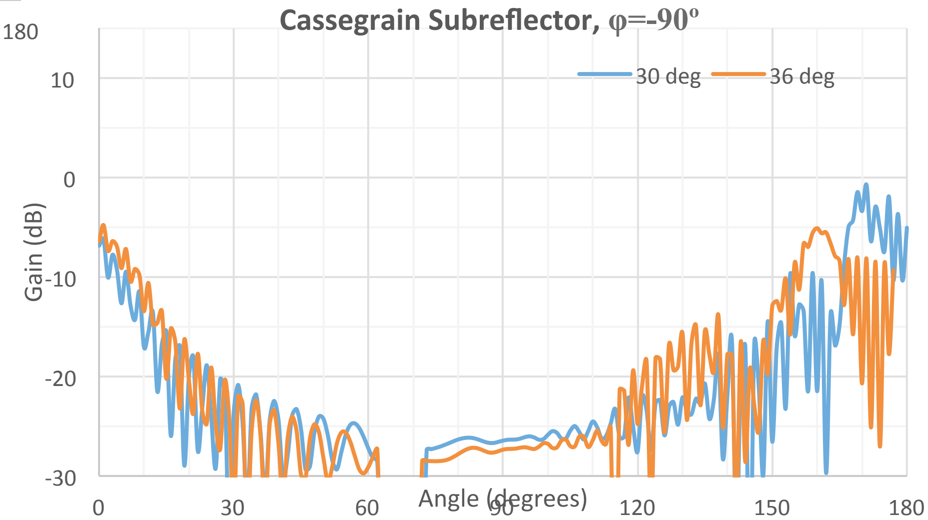


CASSEGRAIN SUBREFLECTOR SCATTERED PATTERN



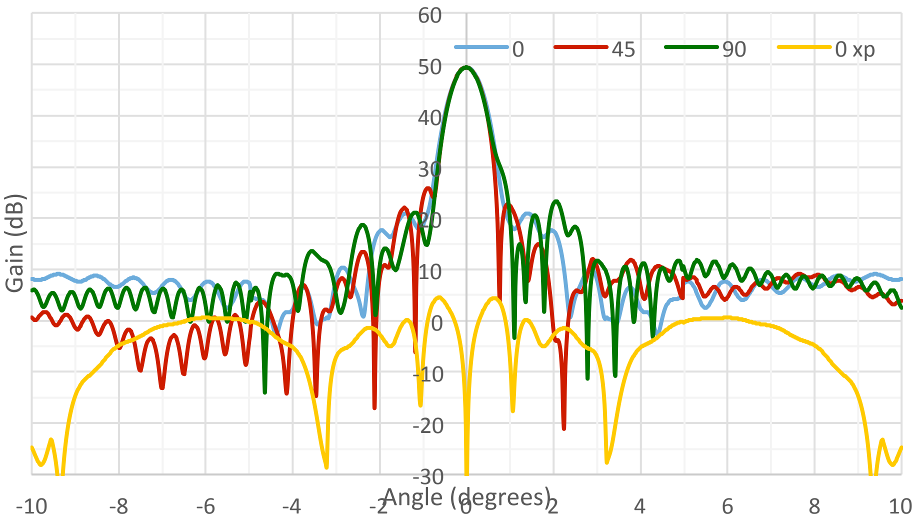


1.6 GHz
At 15º -13.7 dB (H)
-13.2 dB (E)



ANTENNA BEAMS AT 1.6 GHz , θsub=30º

30 degrees Gregorian



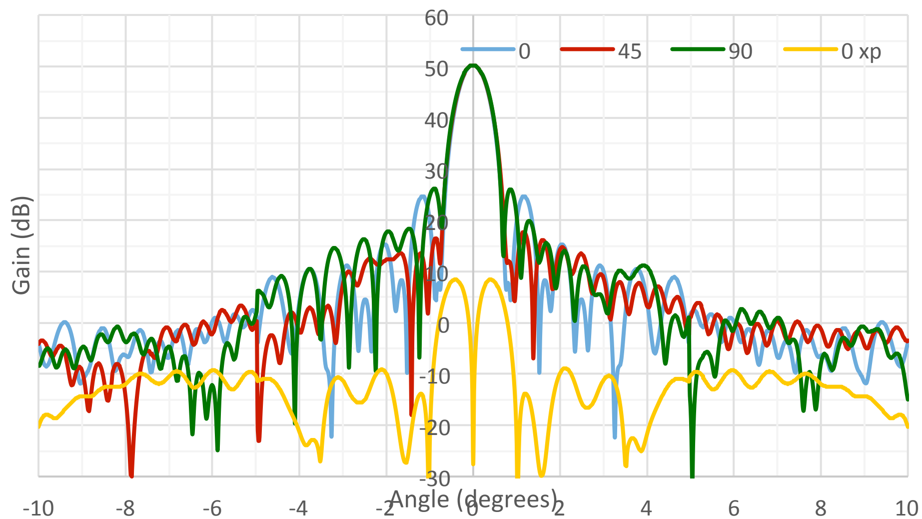
GREGORIAN

Blockage loss = 0%

η_a= 64%

Xpol= -45 dB

30 degrees Cassegrain



CASSEGRAIN

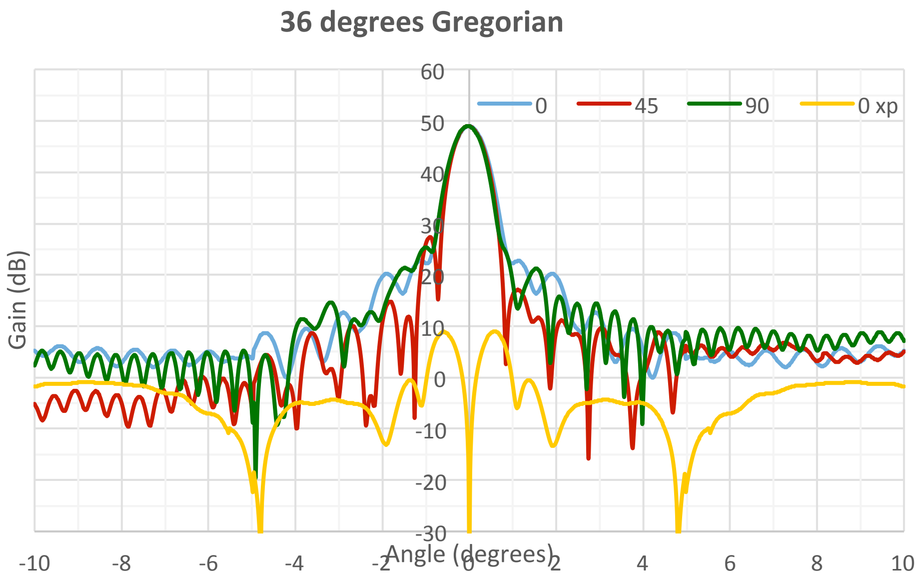
R_{sub}^2/R_{main}^2 = 1.3%

Blockage loss = 2.4%

η_a= 63%

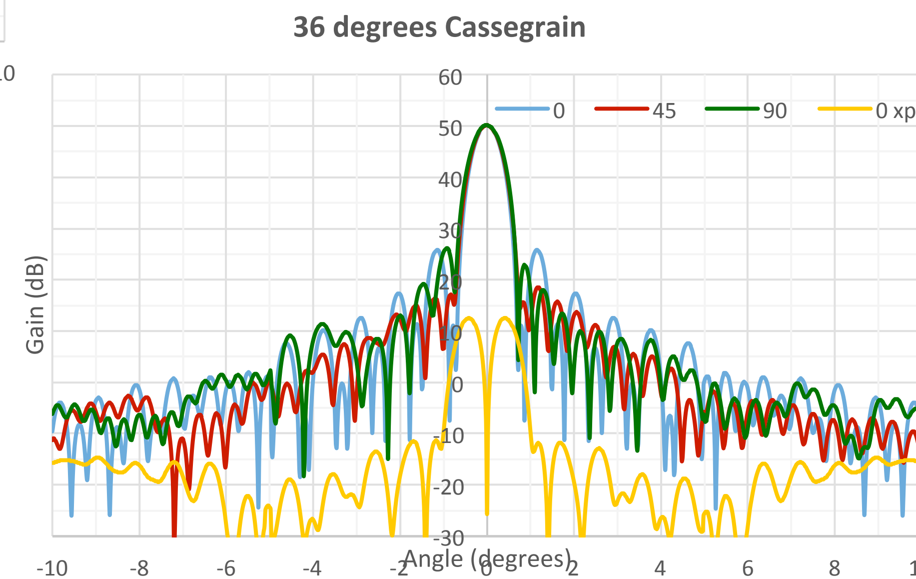
Xpol= -42 dB

ANTENNA BEAMS AT 1.6 GHz , θsub=36º

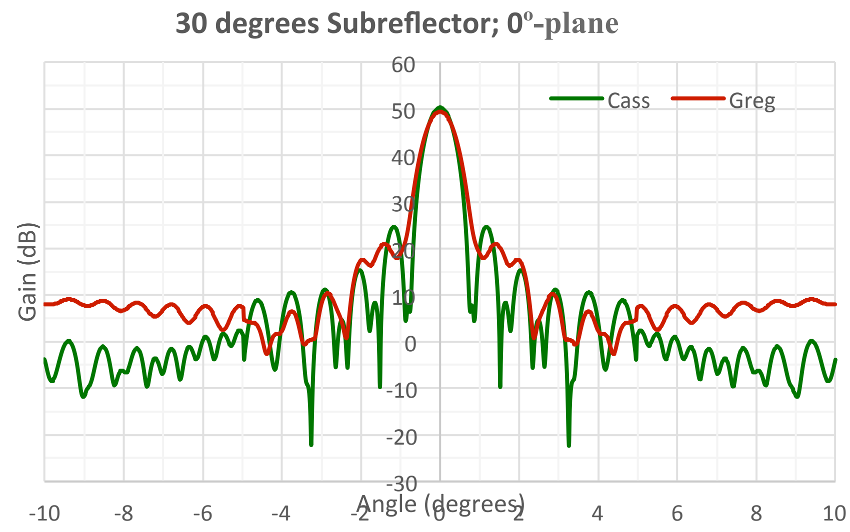


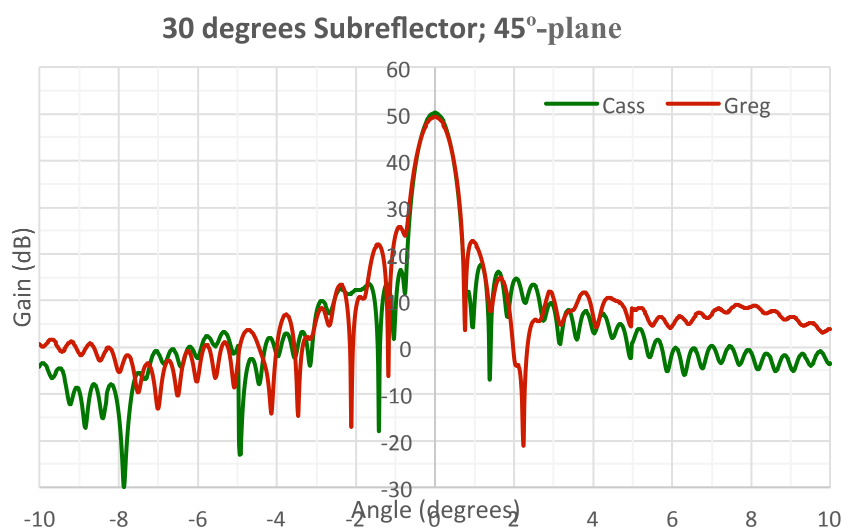
GREGORIAN
Blockage loss = 0%
η_a= 62%
Xpol=-41 dB

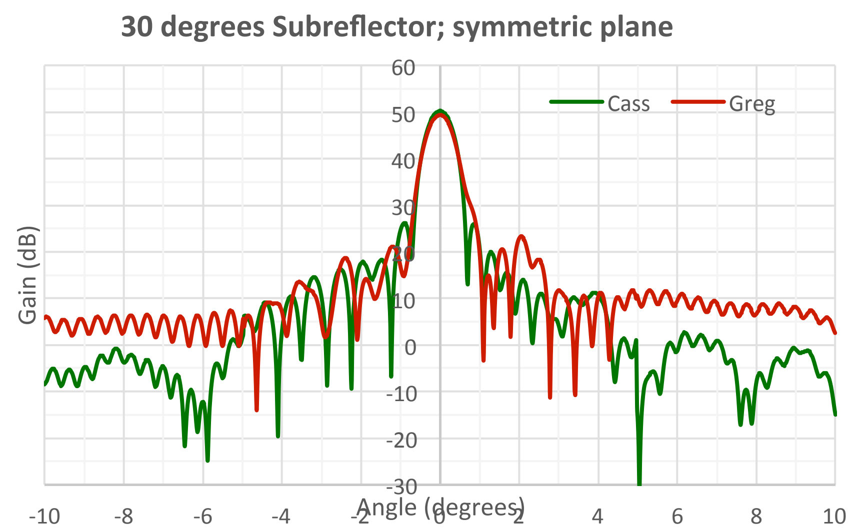
CASSEGRAIN
R_{sub}^2/R_{main}^2 = 1.9%
Blockage loss = 2.6%
η_a= 61.4%
Xpol= -39 dB



ANTENNA BEAMS AT 1.6 GHz , θsub=30º







CONCLUSIONS

Gregorian Antenna:
Smaller subreflector
Marginally higher gain
Lower crosspolarization
Larger extent of diffracted fields
Requires ground blocking shield – baseline problems

Cassegrain Antenna:
Blockage
Lower spillover
Smaller envelope
Large real estate

Larger subreflector Opening Angle: $2D^2/\lambda$
Smaller feed horns
Feed to reflector distance smaller – **Even samller**
Higher crosspolarization
Cassegrain - larger subreflector
Gregorian – feed horn points more towards ground

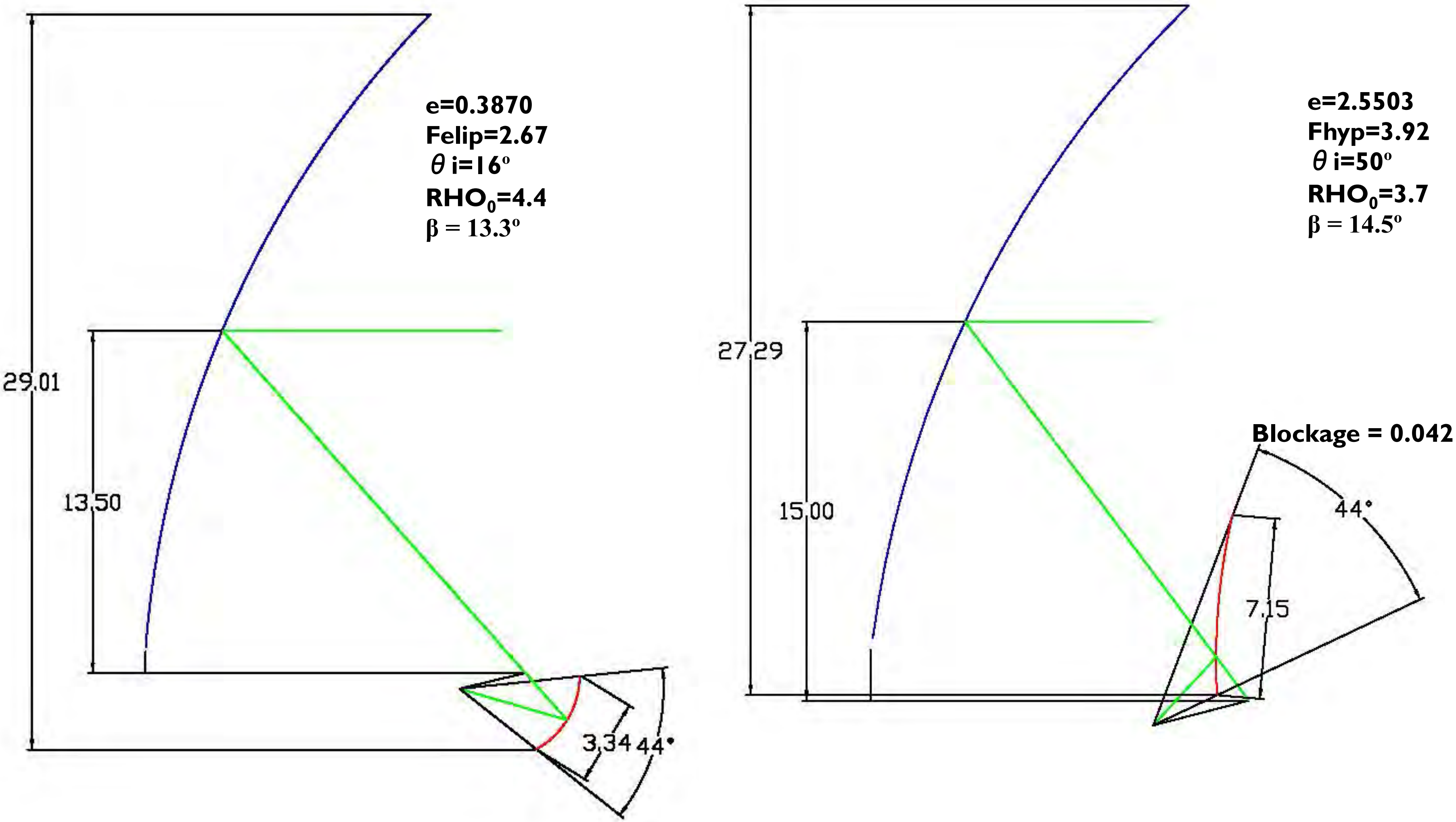
GROUND SHIELDS

ATA ANTENNA

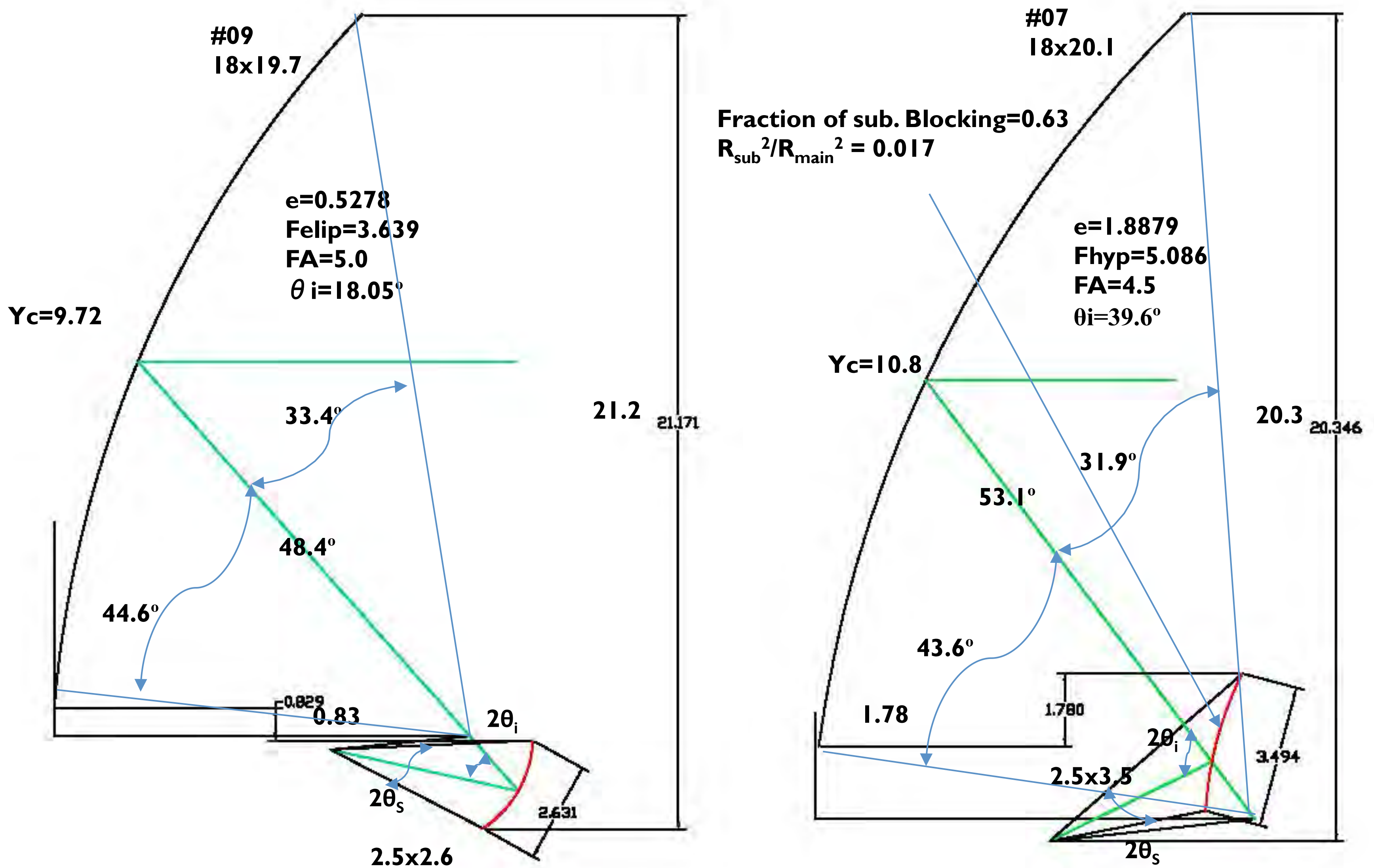
MEERKAT ANTENNA

?

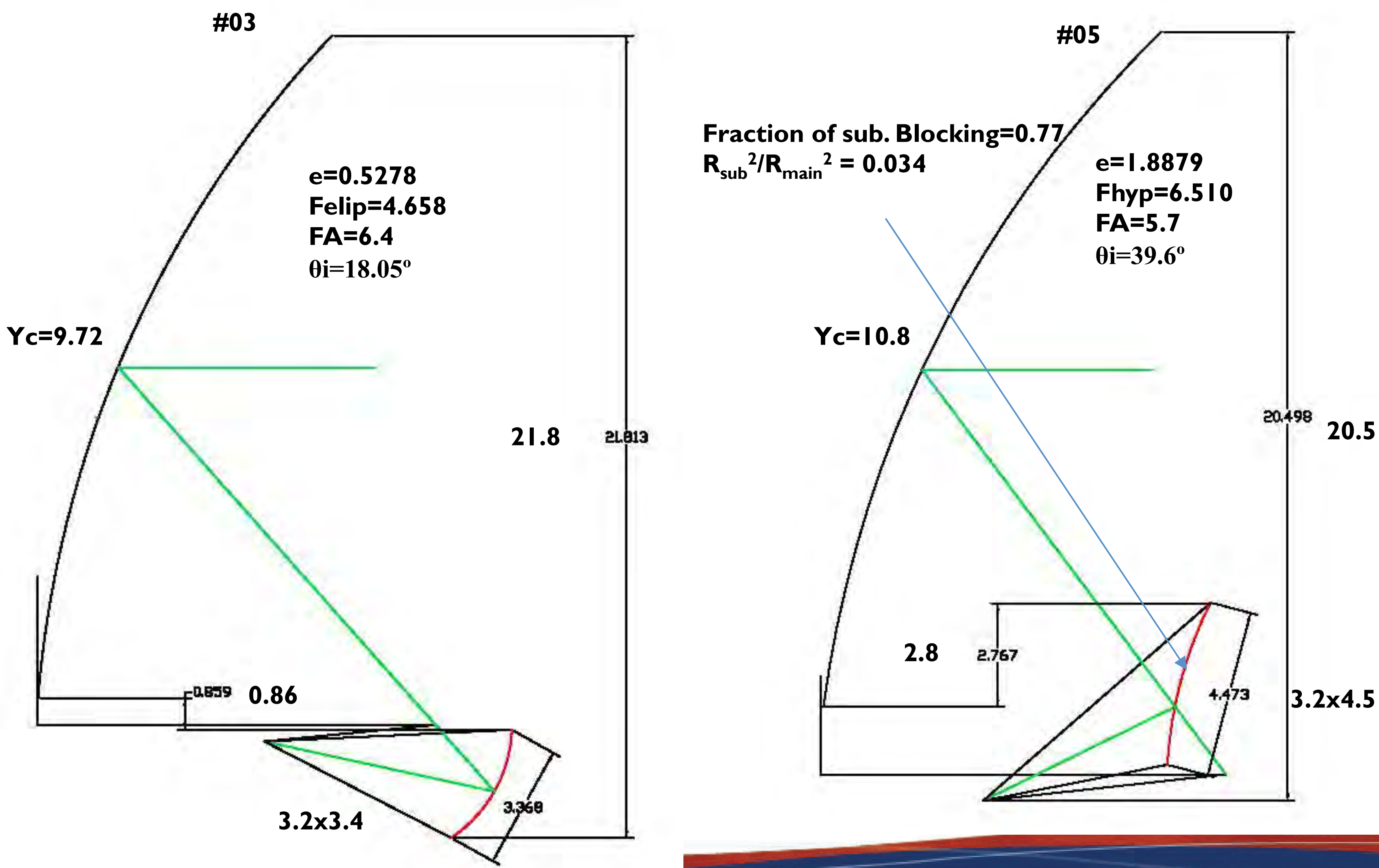
25m MAIN; F=15m; θ_{sub}=44°



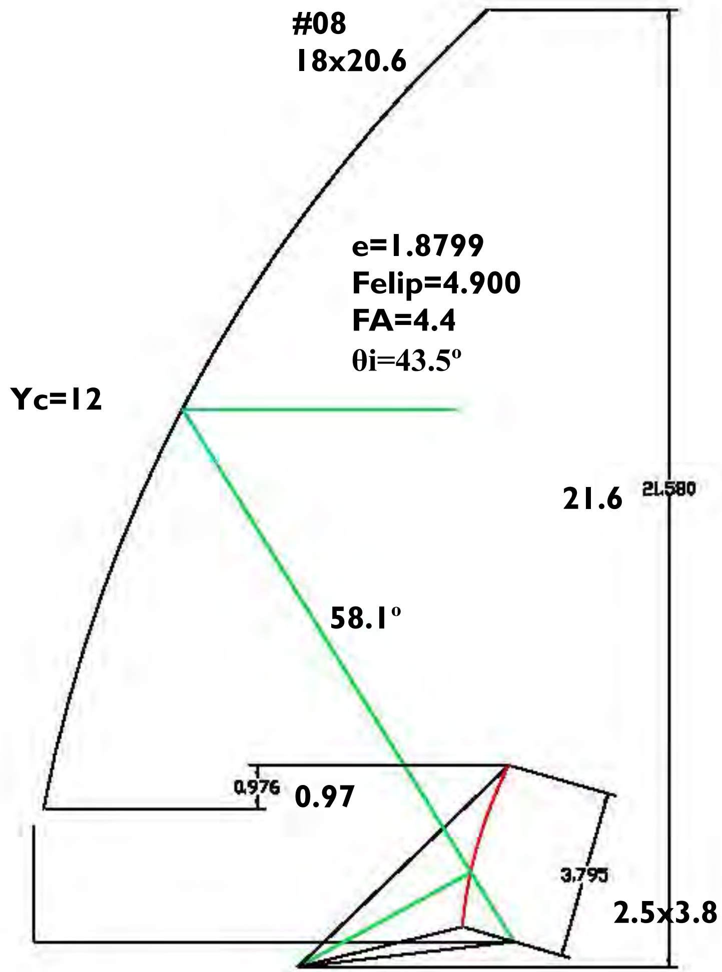
18 m MAIN, F=10.8; 2.5 m($10\lambda_{1.2}$) SUB; θ_{sub}=15^o



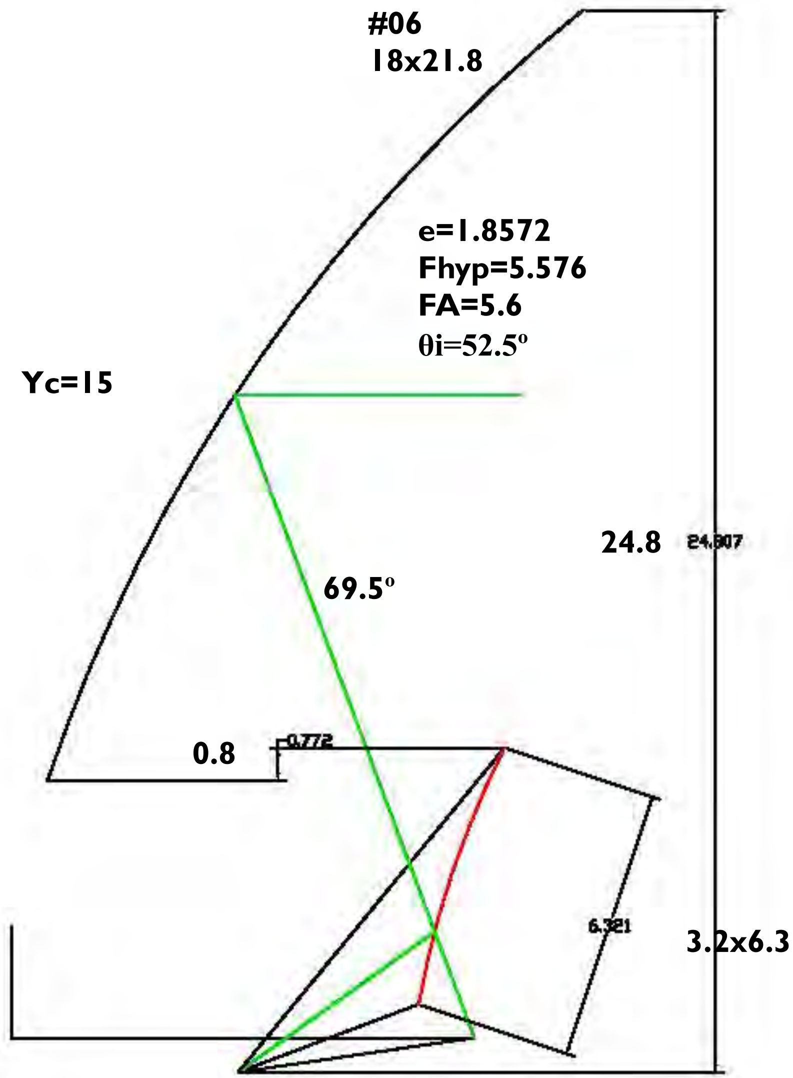
18 m MAIN REFLECTOR; 3.2 m ($12.8\lambda_{1.2}$) SUB; $\theta_{sub}=15^0$



18 m MAIN REFLECTOR; 2.5, 3.2 m CASS SUBREFLECTOR



Main 18x20.1; Yc=10.8: 2.5x3.5, 2θi=79º, ENVLP 20.3

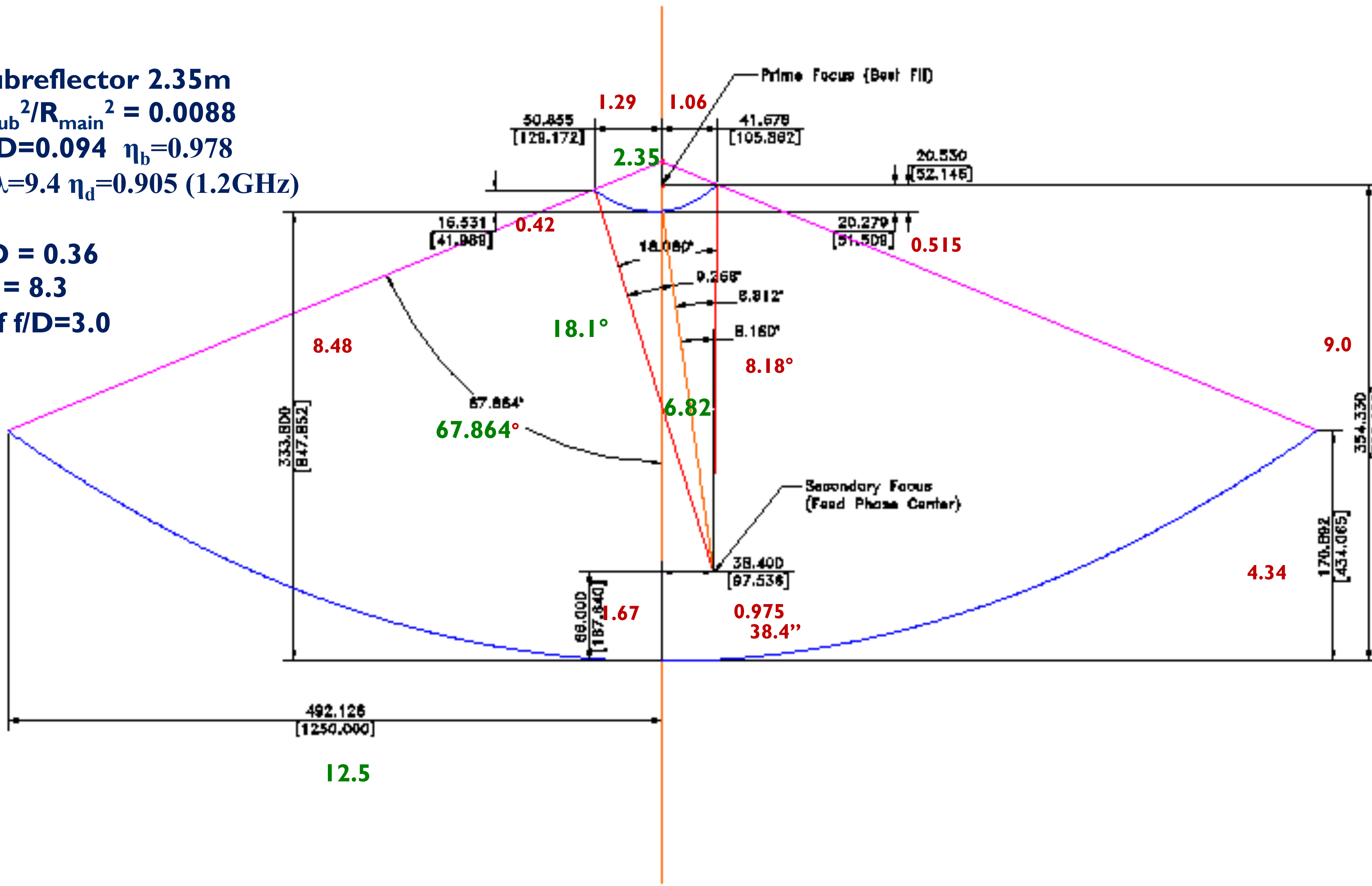


Main 18x20.1; Yc=10.8: 3.2x4.5, 2θi=79º, ENVLP 20.5

VLA ANTENNA GEOMETRY

Subreflector 2.35m
R_{sub}^2/R_{main}^2 = 0.0088
d/D=0.094 η_b=0.978
d/λ=9.4 η_d=0.905 (1.2GHz)

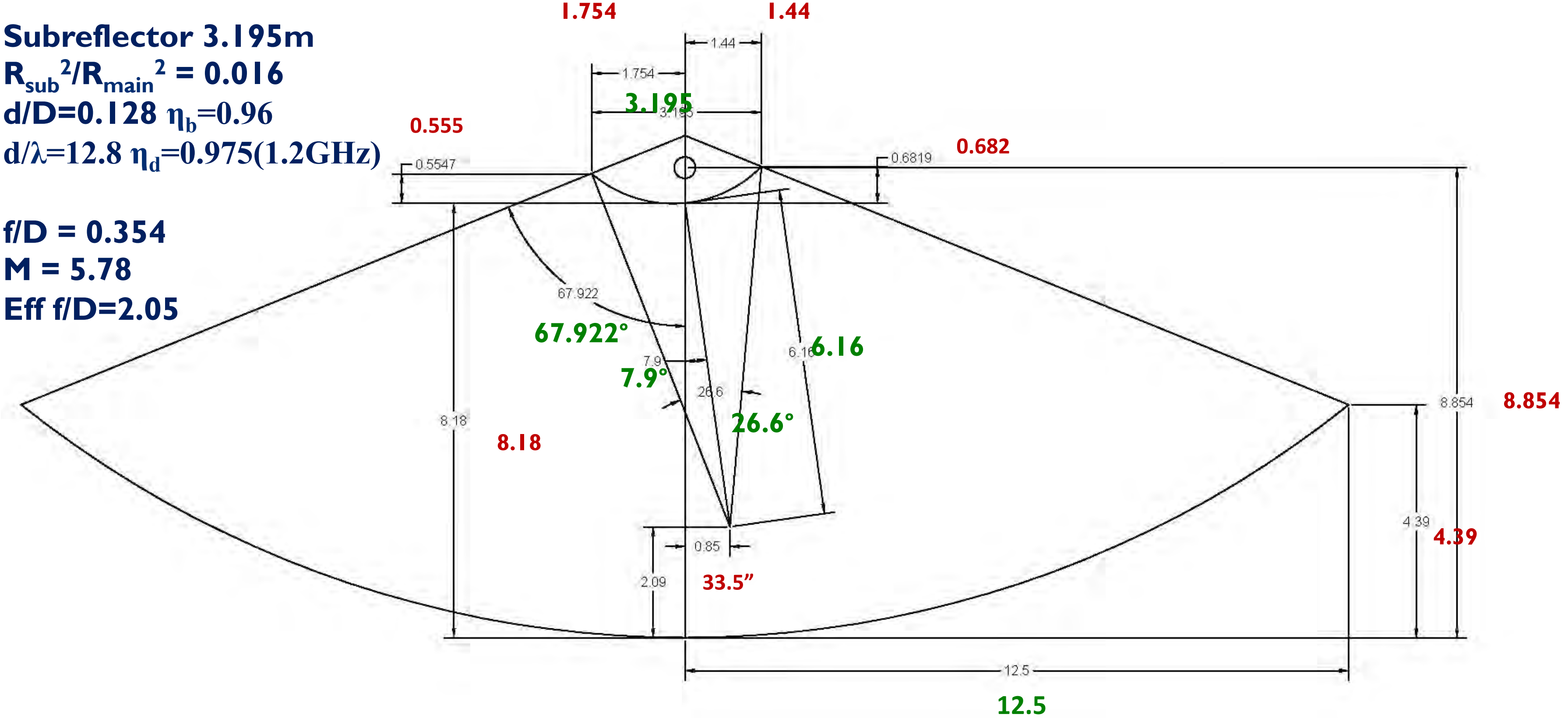
f/D = 0.36
M = 8.3
Eff f/D=3.0



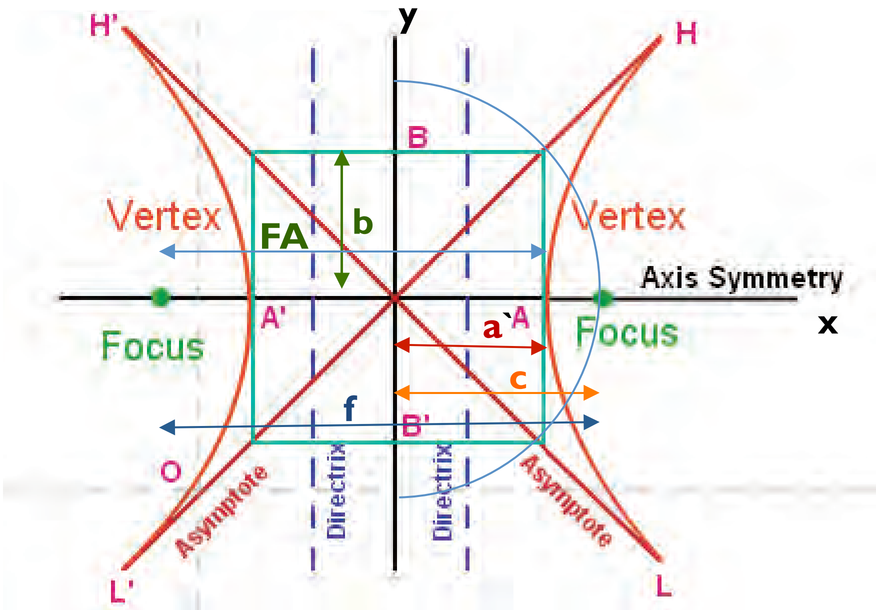
VLBA ANTENNA GEOMETRY

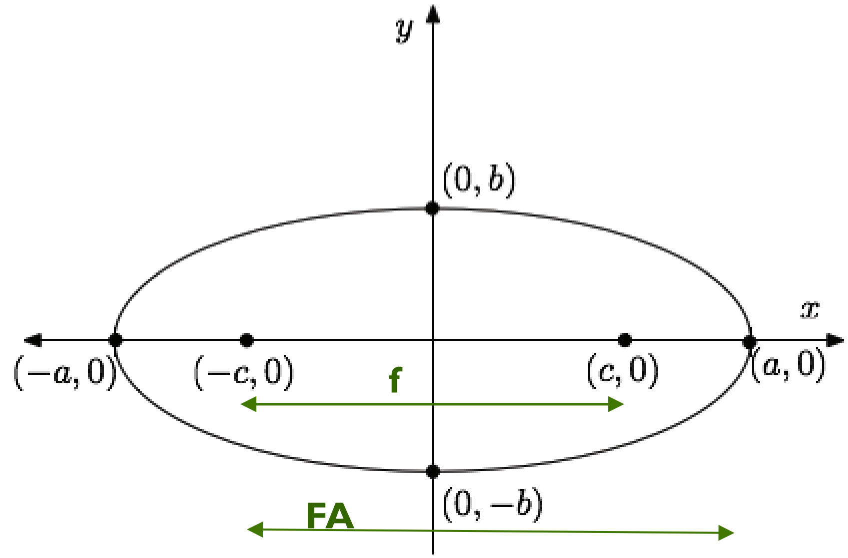
Subreflector 3.195m
R_{sub}^2/R_{main}^2 = 0.016
d/D=0.128 η_b=0.96
d/λ=12.8 η_d=0.975(1.2GHz)

f/D = 0.354
M = 5.78
Eff f/D=2.05



HYPERBOLA / ELLIPSE PARAMETERS





$x^2/a^2 - y^2/b^2 = 1$

$e = \sqrt{a^2+b^2}/a$ $\quad c = \sqrt{a^2+b^2}$ $\quad e > 1$

$f = 2c$

$x^2/a^2 + y^2/b^2 = 1$

$e = \sqrt{a^2-b^2}/a$ $\quad c = \sqrt{a^2-b^2}$ $\quad e < 1$

$f = 2c$

CASSEGRAIN TELESCOPE DESIGN PARAMETERS

	DIA Main	F Main	Θ_{main} °	e	f_{hyp}	MAG	Θ_{sub} °	DIA Sub	FA
VLAeq	25.0	9.2897	67.864	1.2734	7.691	8.3164	9.250	2.350	6.865
				1.2600	7.691	8.6923	8.8518	2.253	6.897
				1.2900↑	7.691	7.8966	9.7397↑	2.468↑	6.827↓
VLAeq	25.0	9.2897	67.864	1.2734	7.691	8.3164	9.250	2.350	6.865
				1.2734	7.500	8.3164	9.250	2.291	6.695
				1.2734	7.900↑	8.3164	9.250	2.413↑	7.052↑

GREGORIAN TELESCOPE DESIGN PARAMETERS

DIA Main	F_{Main}	Y_c	Θ_{sub} °	e	f_{ellip}	MAG	°	DIA Sub	FA
18x19.7	10.8	9.72	15	0.5278	3.639	3.1649	2.5x2.6		7.659
				0.7600	6.738	7.3333	10.484	2.697	7.802
				0.8000 ↑	6.738	9.0000	8.5503 ↓	2.158 ↓	7.580 ↓
25mGreg	25.0	9.2897	67.864	0.7853	6.738	8.3166	9.250	2.350	7.659
				0.7853	6.540	8.3166	9.250	2.281	7.434
				0.7853	6.940 ↑	8.3166	9.250	2.421 ↑	7.889 ↑

GREGORIAN TELESCOPE DESIGN PARAMETERS

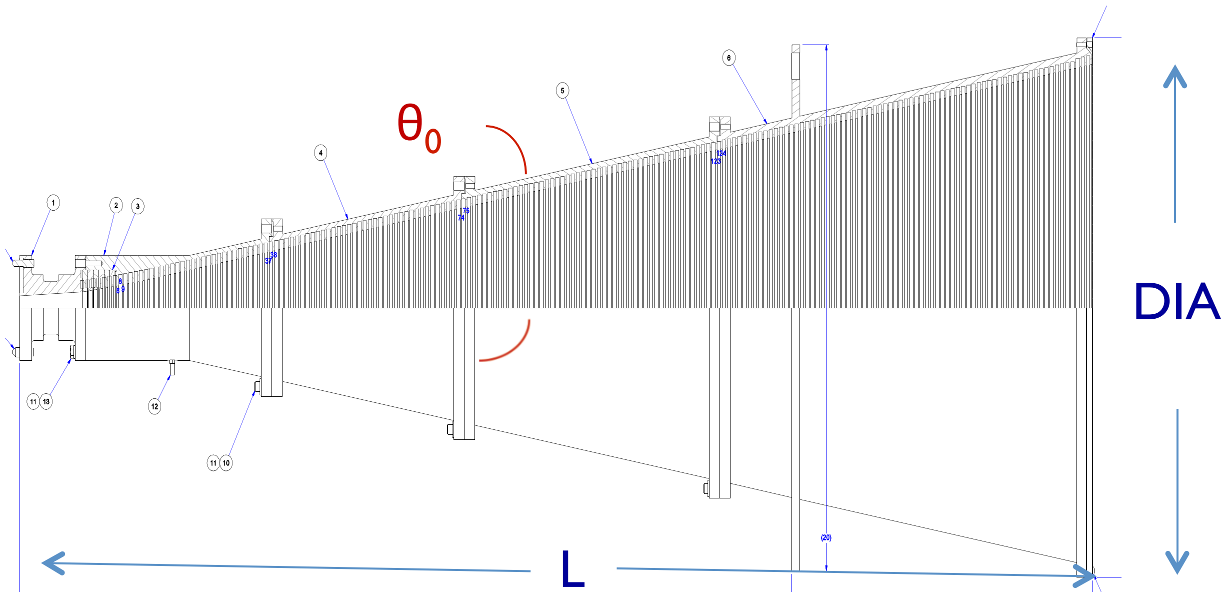
	DIA Main	F Main	Θ_{main} °	e	f_{ellip}	MAG	Θ_{sub} °	DIA Sub	FA
25mGreg	25.0	9.2897	67.864	0.7853	6.738	8.3166	9.250	2.350	7.659
				0.7600	6.738	7.3333	10.484	2.697	7.802
				0.8000 ↑	6.738	9.0000	8.5503 ↓	2.158 ↓	7.580 ↓
25mGreg	25.0	9.2897	67.864	0.7853	6.738	8.3166	9.250	2.350	7.659
				0.7853	6.540	8.3166	9.250	2.281	7.434
				0.7853	6.940 ↑	8.3166	9.250	2.421 ↑	7.889 ↑

CASSEGRAIN TELESCOPE DESIGN PARAMETERS

	DIA Main	F Main	Θ_{main} °	e	f_{hyp}	MAG	Θ_{sub} °	DIA Sub	FA
VLAeq	25.0	9.2897	67.864	1.2734	7.691	8.3164	9.250	2.350	6.865
	25.0	9.2796	67.922	1.4179	7.691	5.7857	13.300	3.313	6.558
VLBAeq				1.4179	7.416	5.7857	13.300	3.195	6.323
ALMA	12.0	4.8	64.01	1.0526	6.177	20.00	3.6	0.750	5.883
GBT	100	60	39.005	0.528	11.00	3.166	15.0	7.950	15.1

LINEAR TAPER CORRUGATED HORN

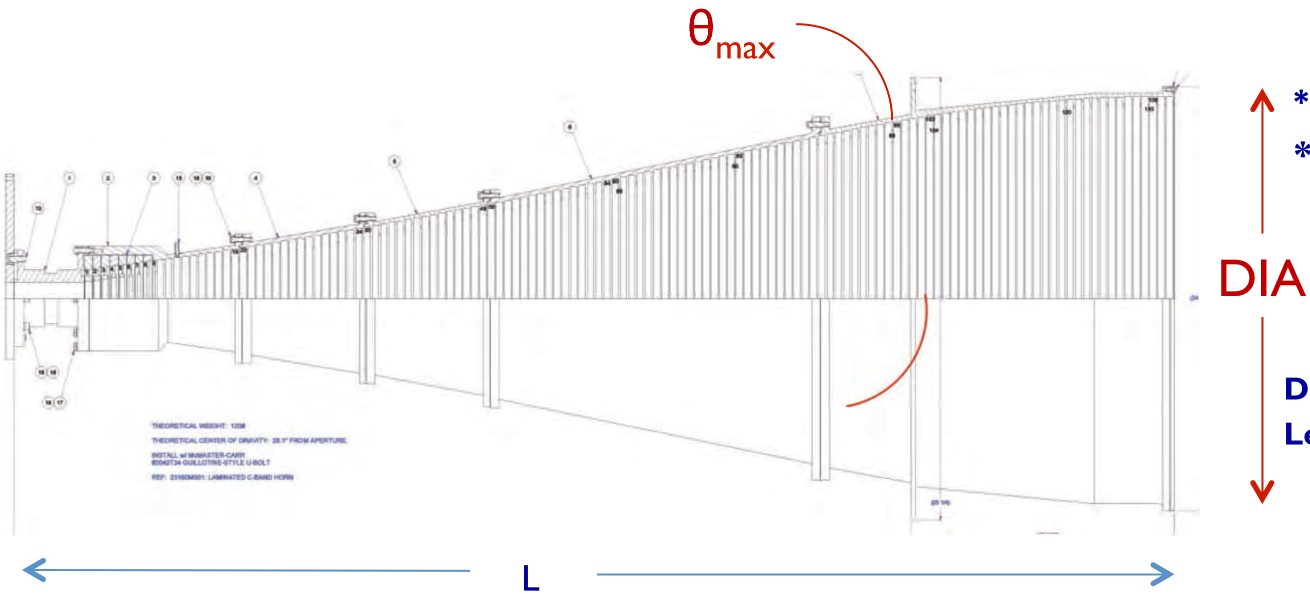
FEED	Freq (GHz)	Taper (dB) @θ_{sub}	θ_0	DIA	DIA/λ *	L/λ *	Taper **
EVLA-Ku	12-18	-14@9.25°	10.5°	12.3”	12.5	33.8	-14.0
VLBA	12-15.4	-14@13.25°	14°	8.0”	8.1	16.2	-14.5
SHAO-Ku	12-18	-15.5@13°	13°	8.5”	8.7	19.3	-15.6



* λ at low end
** Measured (dB)

PROFILE TAPER (COMPACT) CORRUGATED HORN

FEED	Freq (GHz)	Taper (dB) @ θ_{sub}	θ_{max}	DIA	DIA/λ *	L/λ *	Taper (dB)**	Lin. D/λ
EVLA-C	4-8	-13@9.25°	12.0°	22.0”	7.5	22.3	-12.5	12.2
VLBA-C	4-8	-14@13.25°	15.0°	14.0”	4.7	10.6	-13.7	8.1



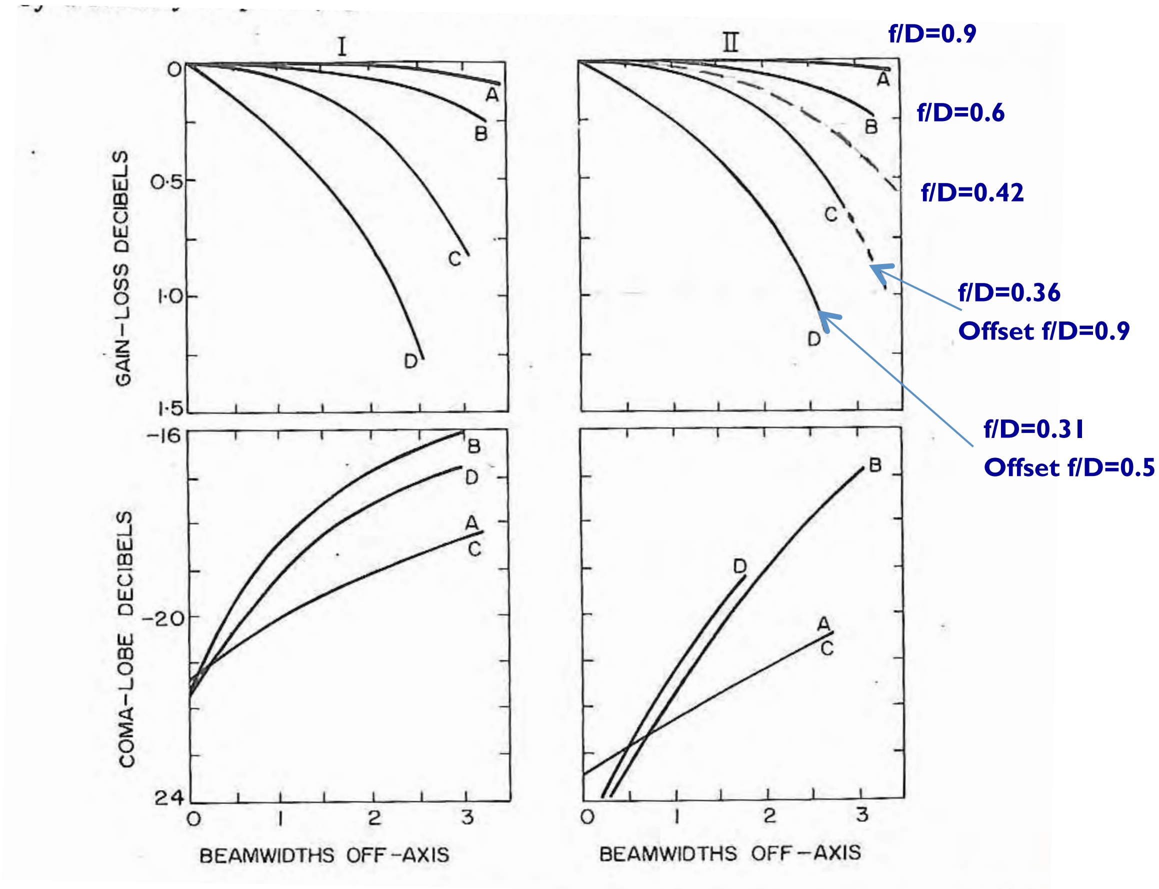
*λ at low end

** Measured (dB)

Diameter 35% smaller

Length 25% less

SCAN LOSS, COMA LOBE

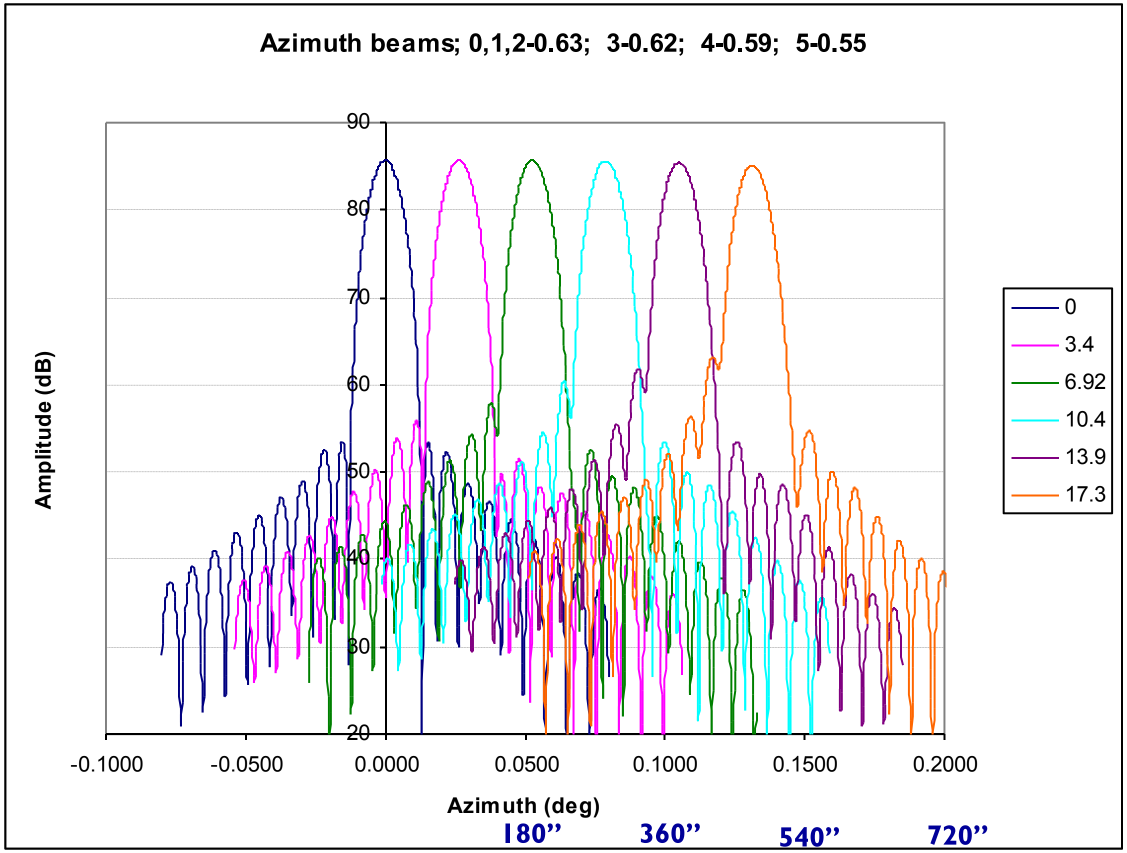


-6 dB TAPER

-10 dB TAPER

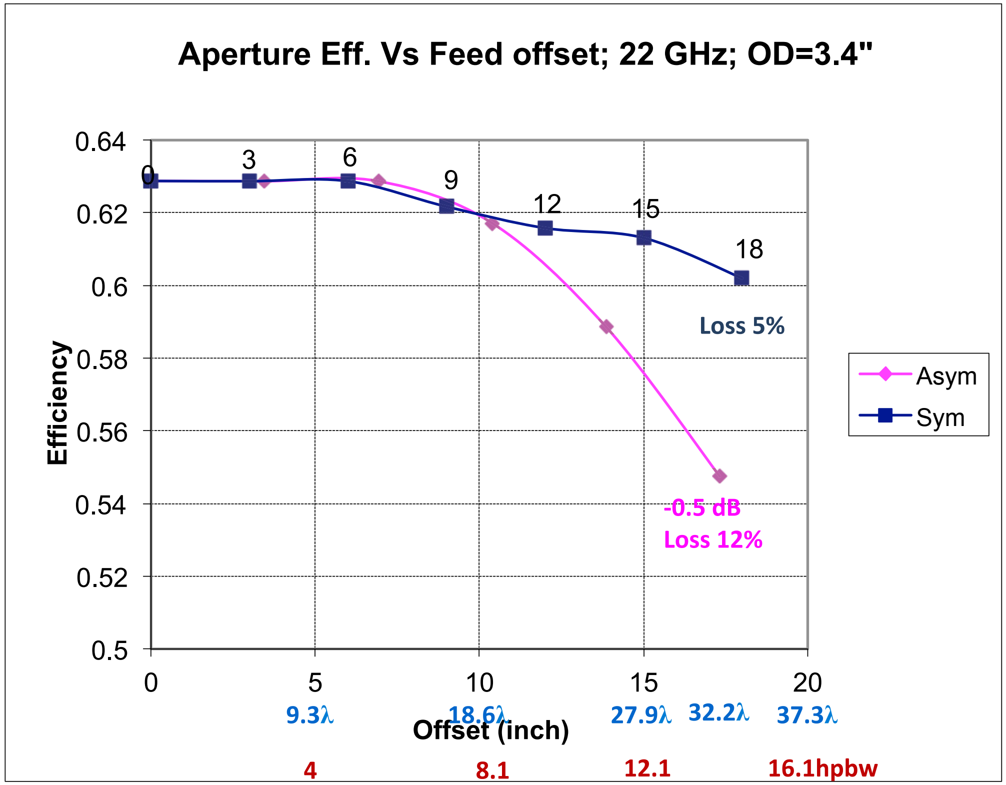
K-BAND ARRAY RECEIVER ON THE GBT

HPBW 34”; Beam throw 27.4”/inch; 0.43HPBW/λ



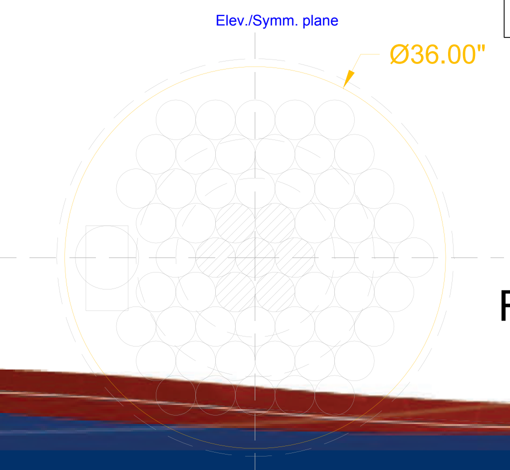
X”	Throw (arcsec)	Throw (HPBW)
0	0	0
3.45	94	2.7
6.9	189	5.5
10.4	284	8.2
13.8	378	11.0
17.3 32.2λ	473	13.7

K-BAND ARRAY RECEIVER - LOSS



M=3.166
f/D(effect)=1.9

HPBW=34”
SCAN=27.4”/inch
(0.43HPBW/λ)



Ring #1 (3.4”rad): 62.9%

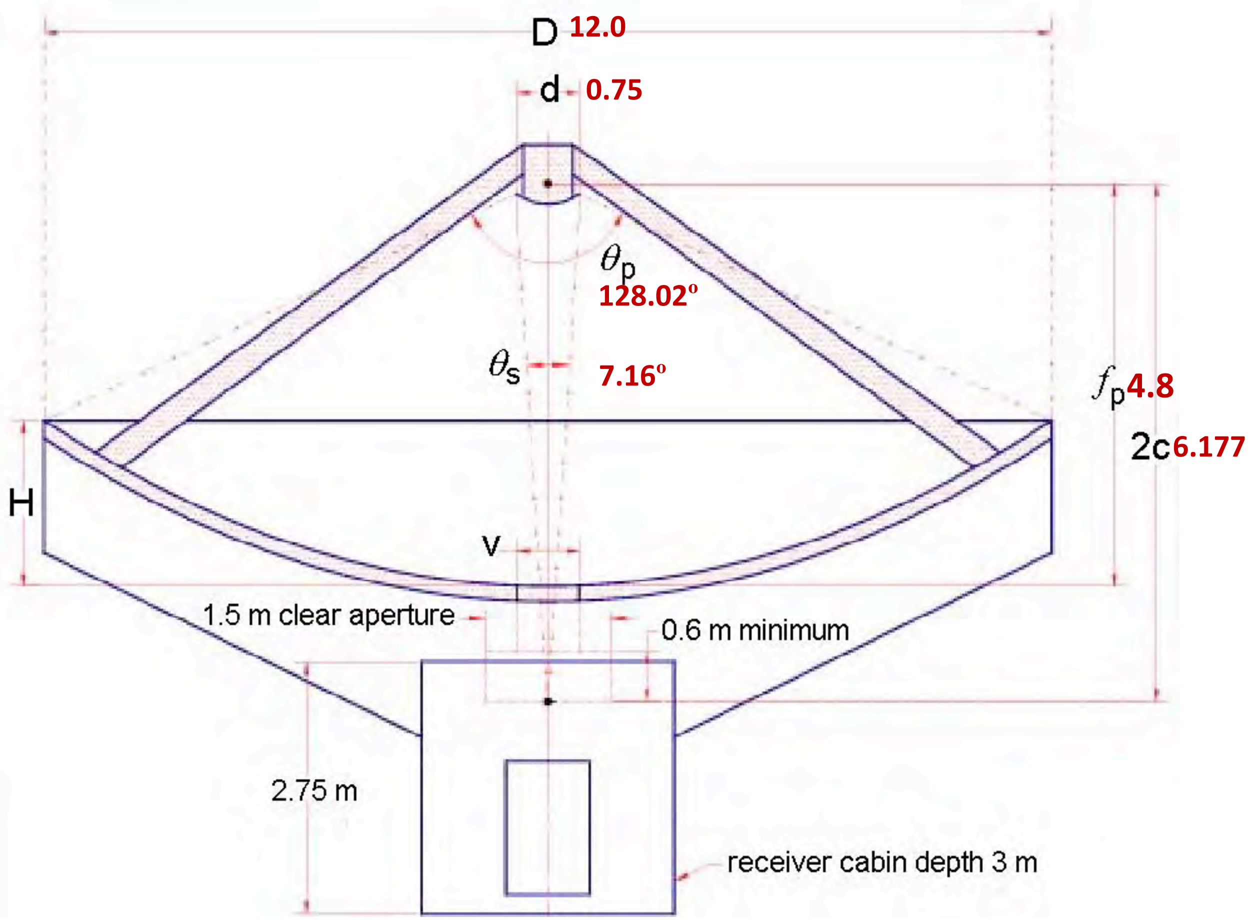
Ring #2 (6.9”rad): 62.9%

Ring #3 (10.4”rad): 61.7% min. -2%; measured -5% at 8.4”offset

Ring #4 (13.8”rad): 58.9% (az) -6.3%; 61.6% (el) -2%

Ring #5 (18.0” rad): 54.7% (az); 60.2% (el)

ALMA ANTENNA



$R_{sub}^2/R_{main}^2 = 0.0039$

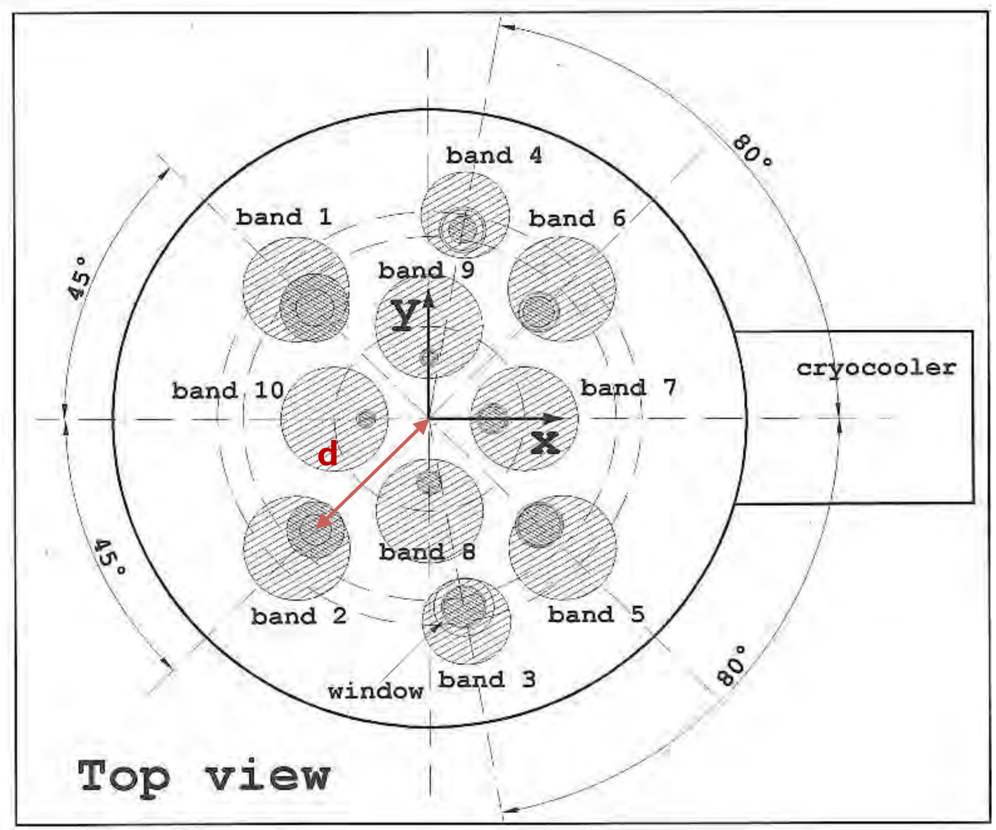
f/D = 0.4 (primary)
M = 20
f/D = 8.0 (effective)

	DIA Main	F $_{Main}$	Θ_{main} °	Ecc	F$_{hyp}$	MAG	Θ_{sub} °	DIA Sub	FI
ALMA	12.0	4.8	64.01	1.0526	6.177	20.00	3.6	0.750	5.883
				1.0526	5.250	20.00	3.6	0.637	5.000
				1.12445	5.250	17.0707	4.193	0.743	4.959
				1.12445	5.294	17.0707	4.193	0.750	5.001

ALMA ANTENNA CRYOSTAT

Feed dia 14mm (3.2λ)
Len 85mm (19.3λ)

Band	d mm	Θsec °	d/λ	θs/bw	η
1	255	2.48	36.1		
2	255	2.48	67.2		
3	181	1.76	60.4	6.4	0.853
4	181	1.76	86.9		
5	245	2.38	153		
6	245	2.38	198	19.1	0.758
7	100	0.97	108	10.7	0.856



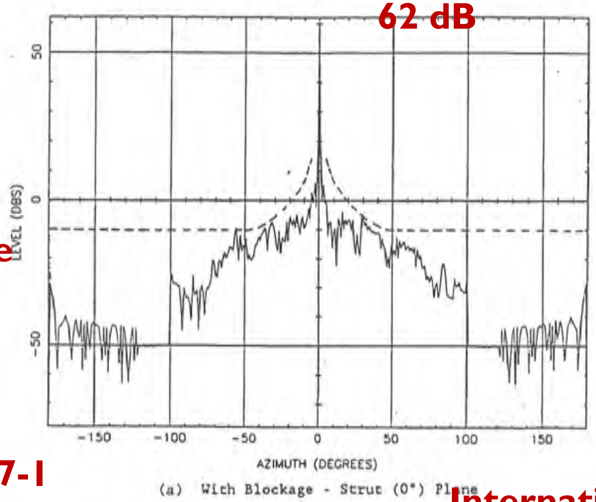
Θsec- Incident angle at the secondary
Θs- telescope beam scan angle
0.1HPBW/λ

SYMMETRIC AND UNBLOCKED ANTENNA BEAMS

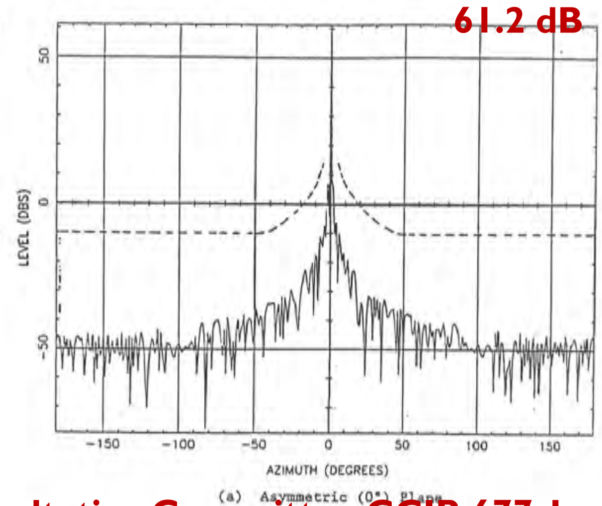
1.4 GHz

Strut plane

62 dB



61.2 dB

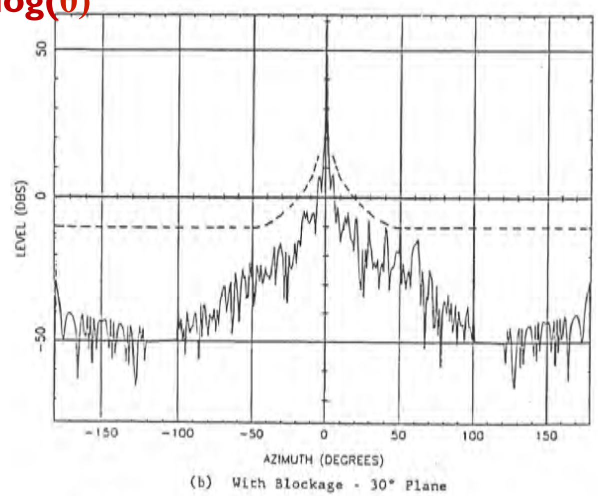


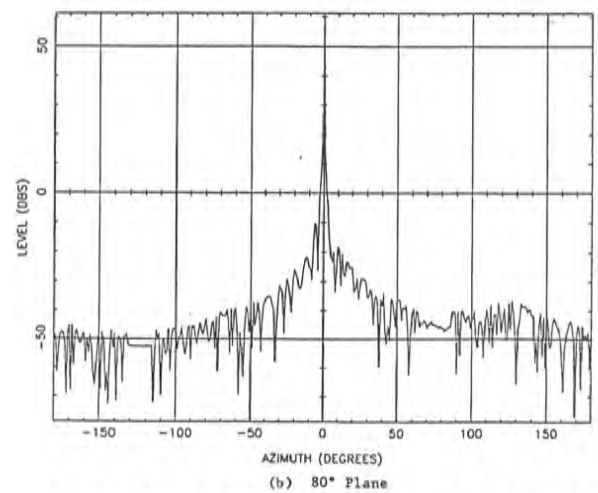
CCIR 677-1

32-25*log(θ)

International Radio Consultative Committee CCIR 677-1

30° off

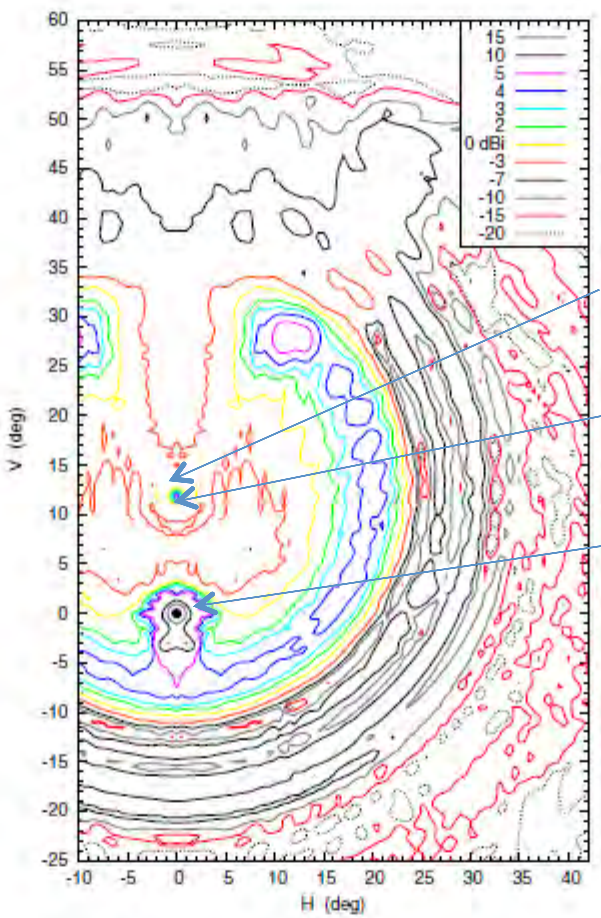




Symmetric 100m, f/d=0.4, sub 7m

Asymmetric 90m, f/d=0.62, sub 7m

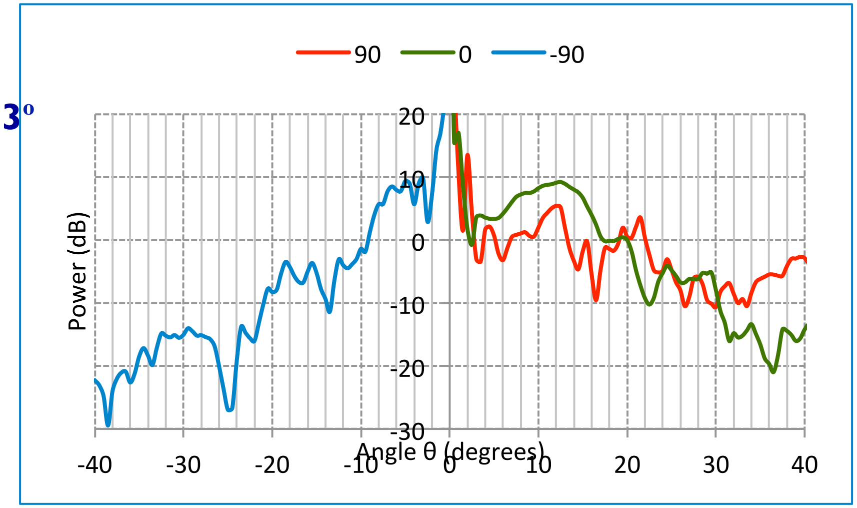
MEASURED SIDELOBE CONTOURS OF GBT AT 21 CMS



Subreflector at 12.3°

Poisson spot

Main beam
61.6 dB



CALCULATED FAR-FIELD PATTERN 1.4 GHz

Boothroyd, A. I. et. al., "Accurate galactic 21-cm H1 measurements with the NRAO Green Bank Telescope", Astronomy & Astrophysics 536, A81 (2011)

FORWARD SPILLOVER – CASSEGRAIN SUBRFLECTOR

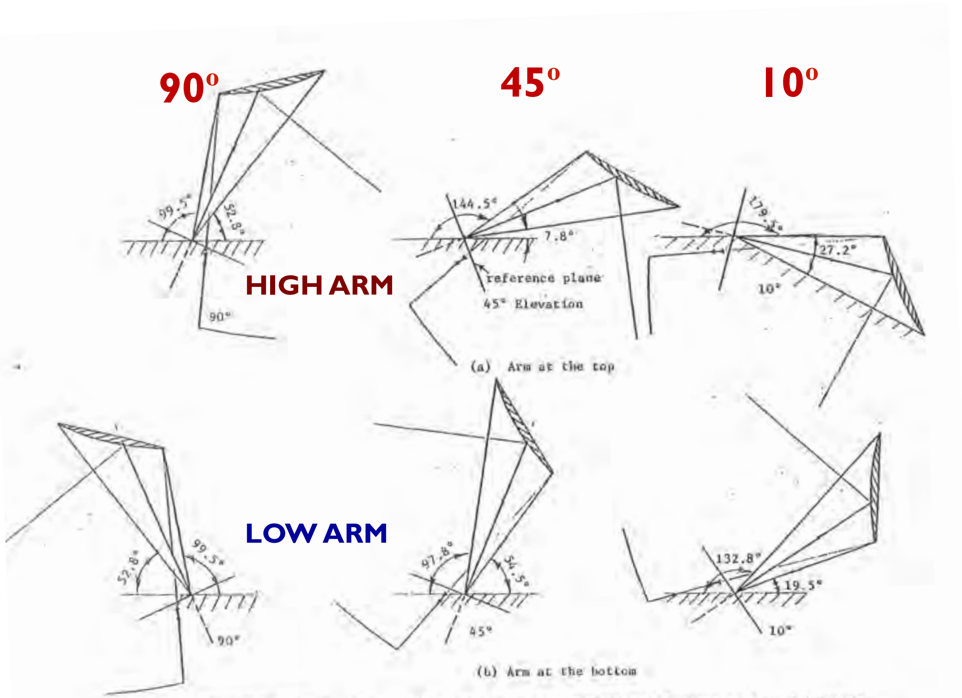
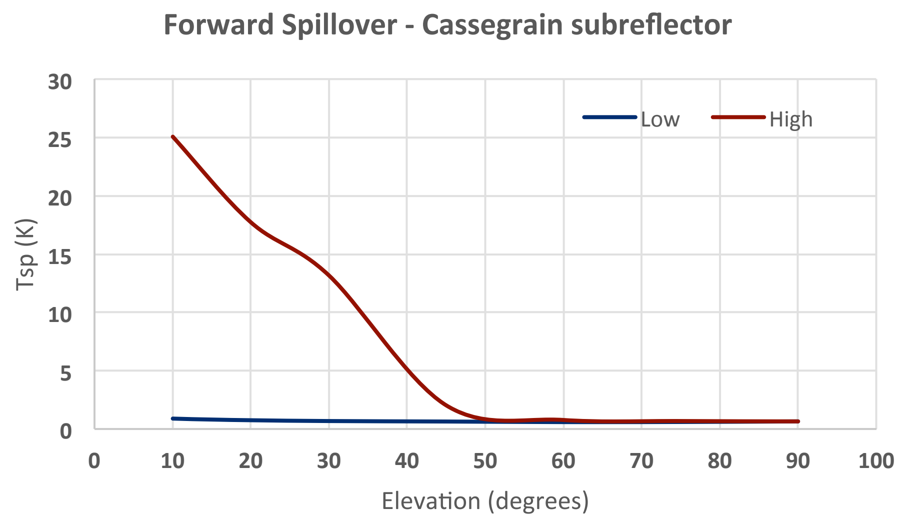


Fig. 3. Forward Spillover. Cassegrain Subreflector Orientation with Respect to Ground (shaded).



S. Srikanth, "Spillover noise temperature calculations for the Green Bank clear aperture antenna," GBT Memo #16, October 4, 1989.

1.42 GHz

-12 dB taper

$D_{sub}=35\lambda$

$\Theta_{sub}=14^\circ$

FORWARD SPILLOVER – GREGORIAN SUBRFLECTOR

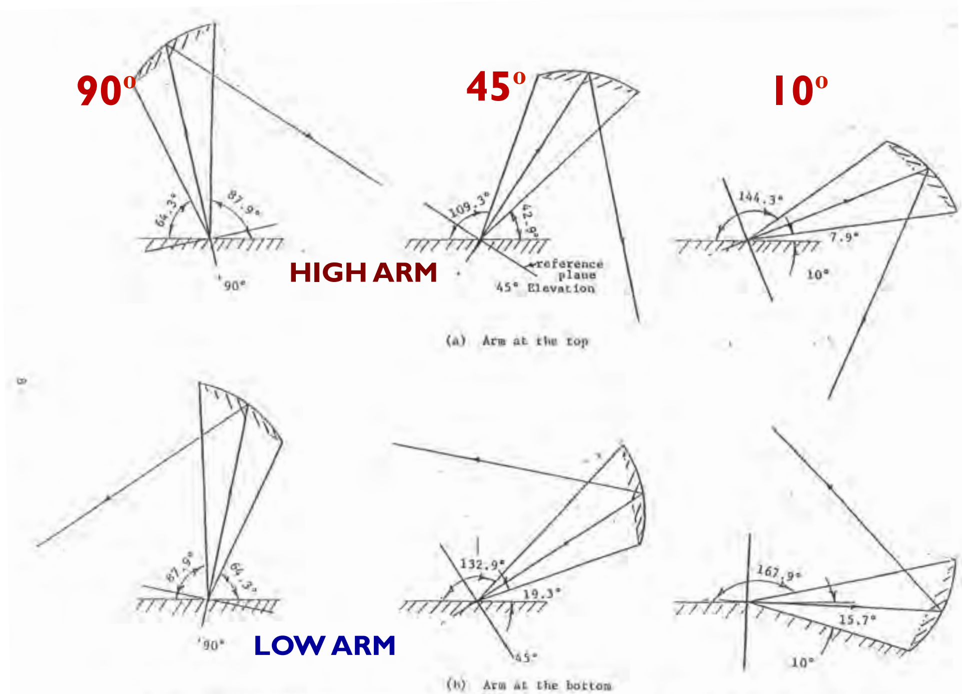
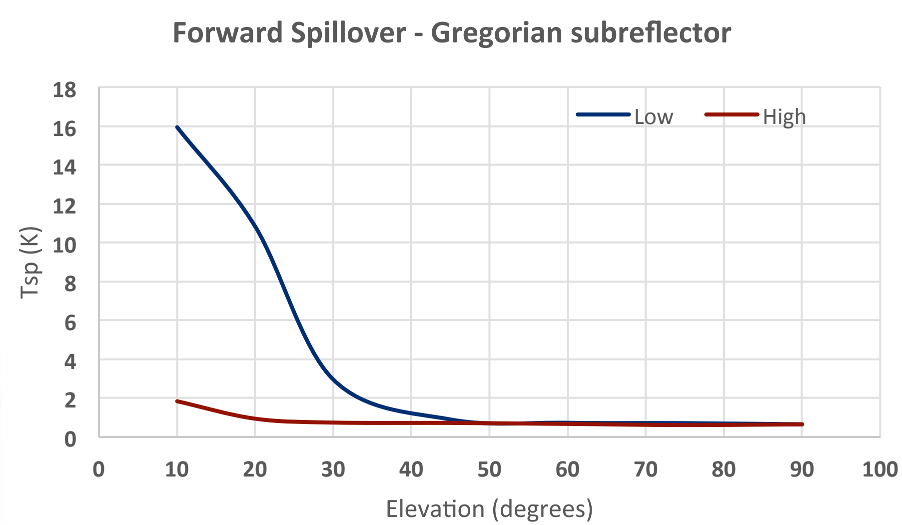


Fig. 4. Forward Spillover. Gregorian Subreflector Orientation with Respect to Ground (shaded).



1.42 GHz

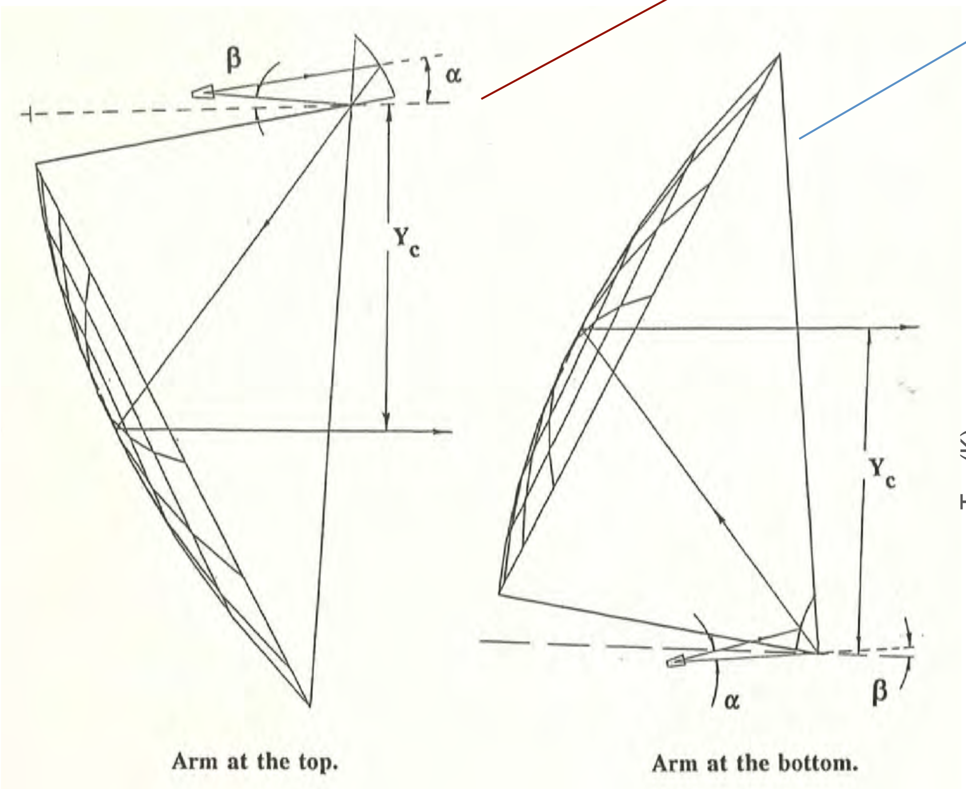
-12 dB taper

D_{sub}=35λ

Θ_{sub}=14°

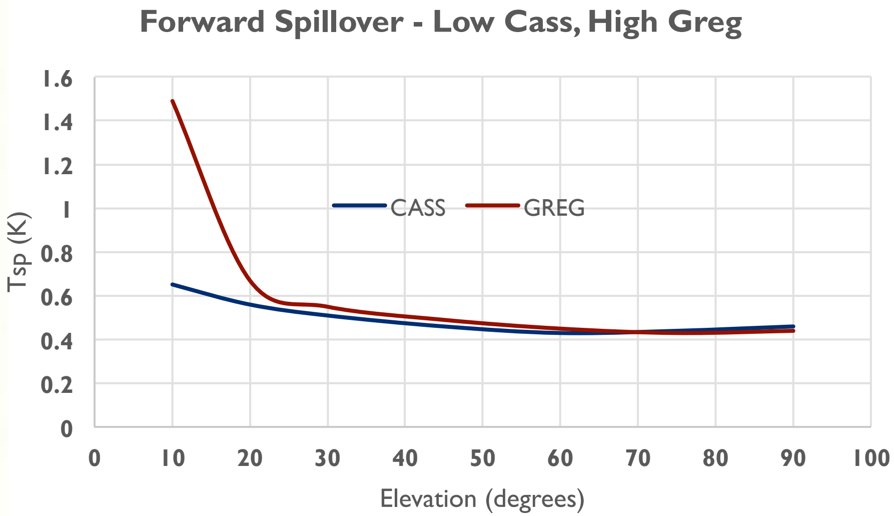
FORWARD SPILLOVER – HIGH GREG., LOW CASS

	f (m)	Ecc	Yc (m)	α (º)	β (º)	sub (mxm)
GREG	11	0.528	54	17.9	5.57	7.6x7.9
CASS	14	1.894	54	17.9	5.57	6.8X8.7

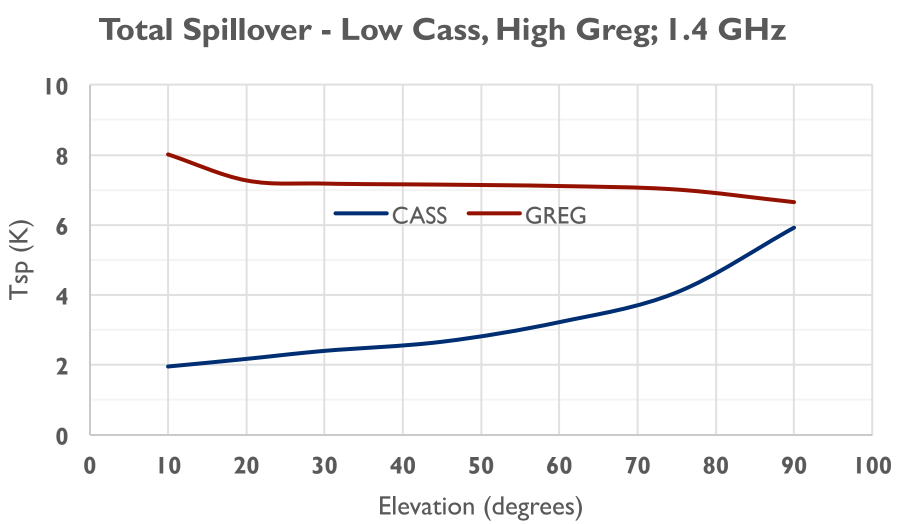


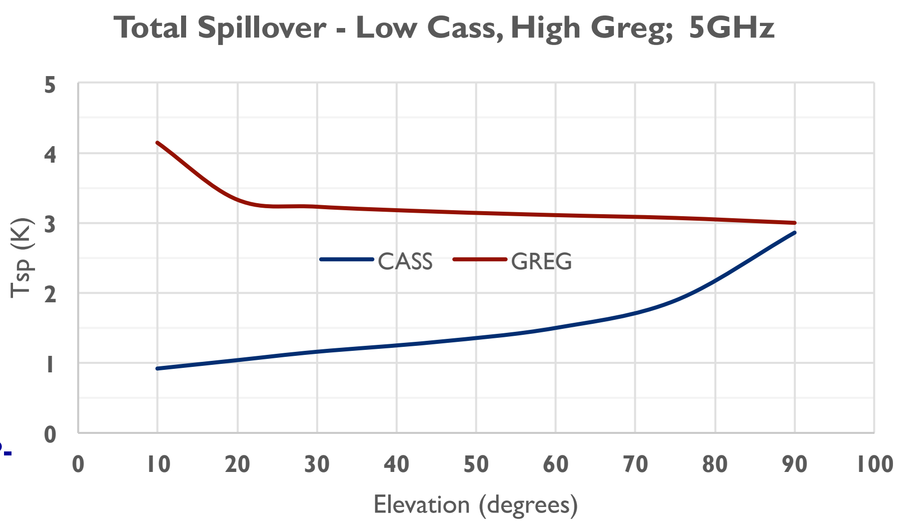
HIGH ARM

LOW ARM



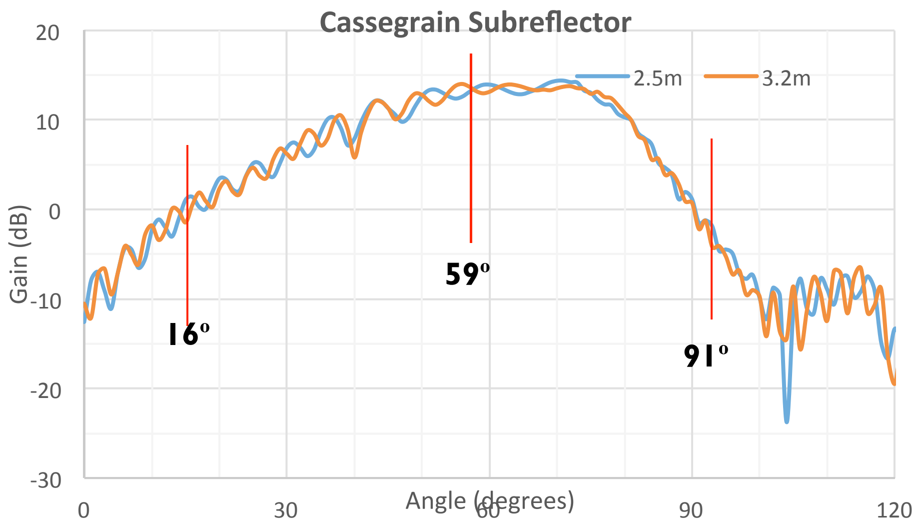
TOTAL SPILLOVER – LOW CASS., HIGH GREG.





S. Srikanth, "Comparison of Spillover loss of Offset Gregorian and Cassegrain Antennas," IEEE/AP-S Symposium , London, ON, 1991. AP-S Digest pp. 444-447

SUBREFLECTOR PATTERN AT 1.2 GHz

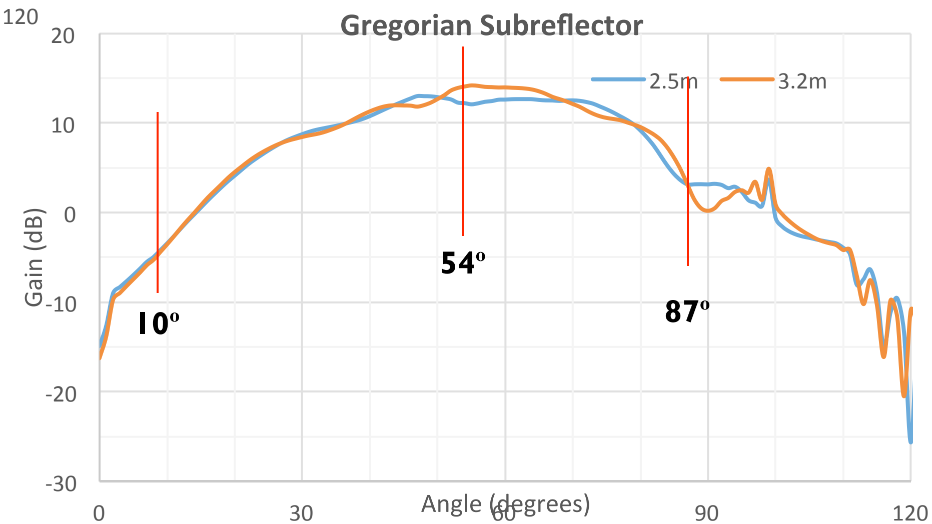


CASSEGRAIN SUBREFLECTOR

Average taper -13.9 dB (2.5)
Average taper -14.1 dB (3.2)

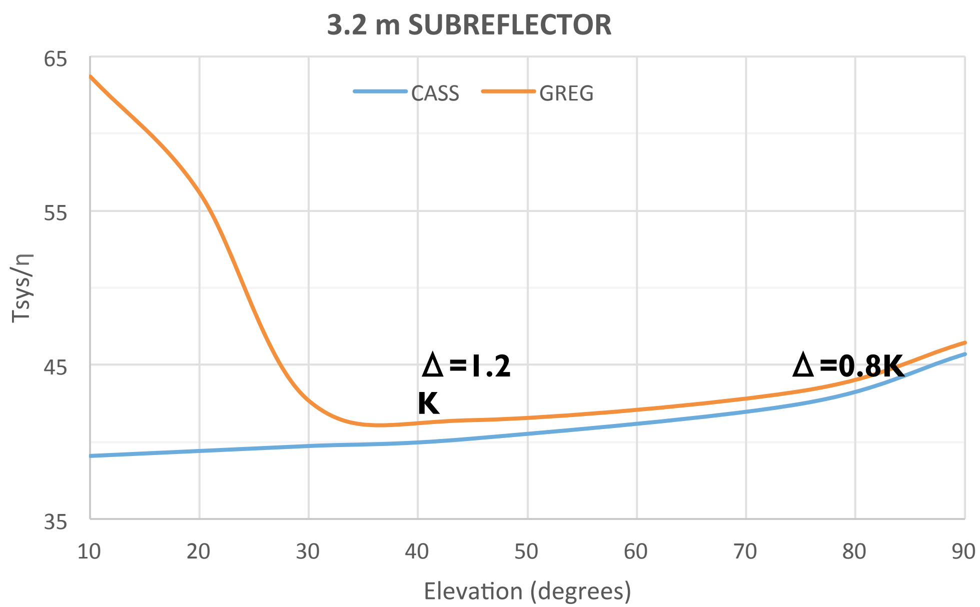
GREGORIAN SUBREFLECTOR

Average taper -12.3 dB (2.5)
Average taper -14.0 dB (3.2)



NRAO NSF Associated Universities Inc.

T_{SYS}/APERTURE EFFICIENCY



3.2 m SUBREFLECTOR
T_{rx}=14K
η_a= 62.3% CASS
η_a= 64% GREG

DISH VERIFICATION ANTENNA

MARCHING FORWARD

MARCHING FORWARD

1. CALCULATE SPILLOVER FOR 18 M ANTENNA
2. EFFECT OF SHIELD ON LOW GREGORAIN
3. GREGORIAN GEOMETRY – FEED TO HORIZON
4. CASSEGRAIN /GREGORIAN WITH WIDE ANGLE SUBREFLECOTR
5. SYMMETRIC ANTENNA WITH BANDS >10 GHz

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BLOCKAGE η, DIFFRACTION LOSS

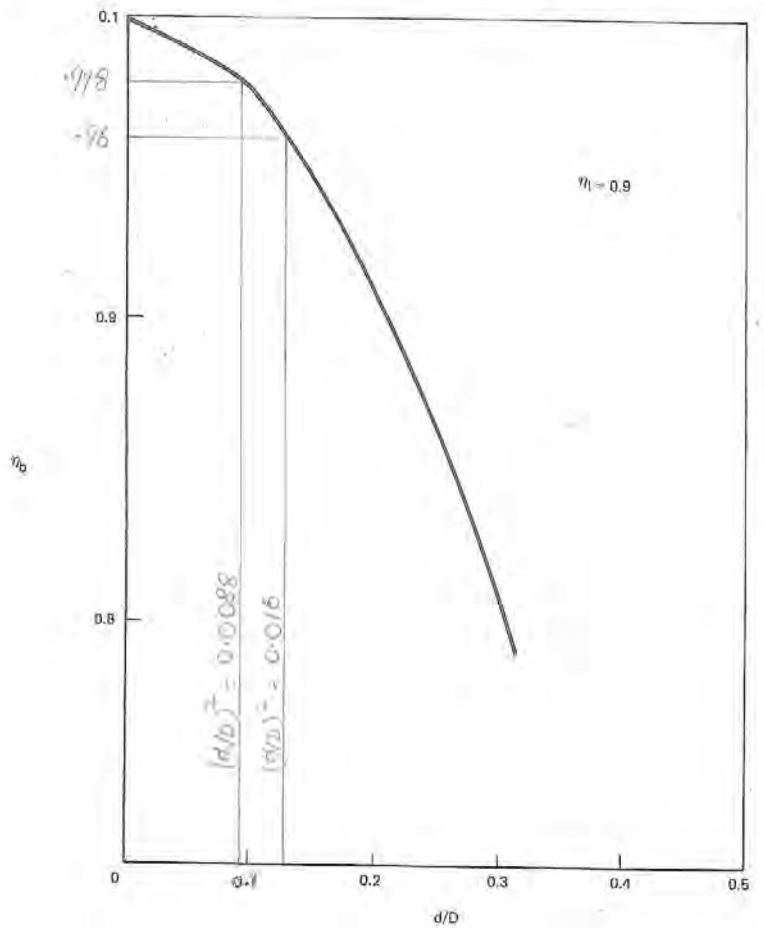


Fig. 3.34 *Blockage efficiency vs. blockage ratio*

aperture.

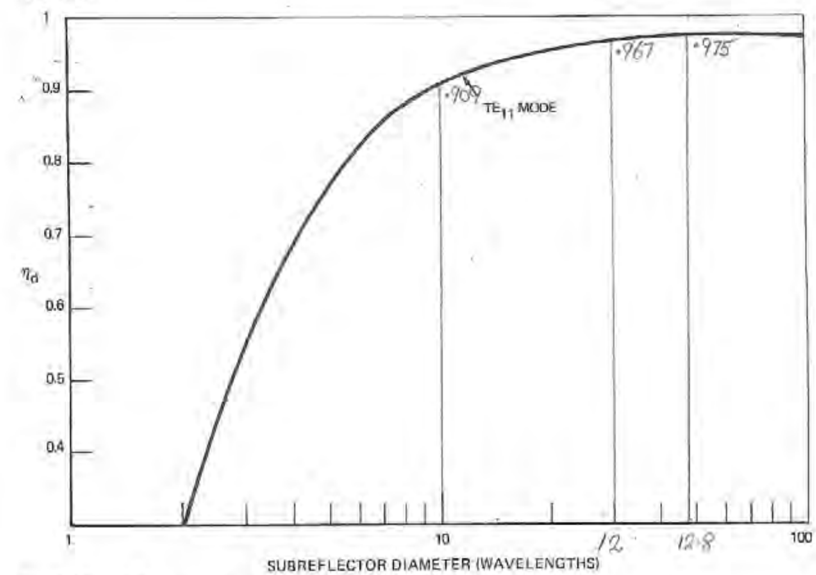
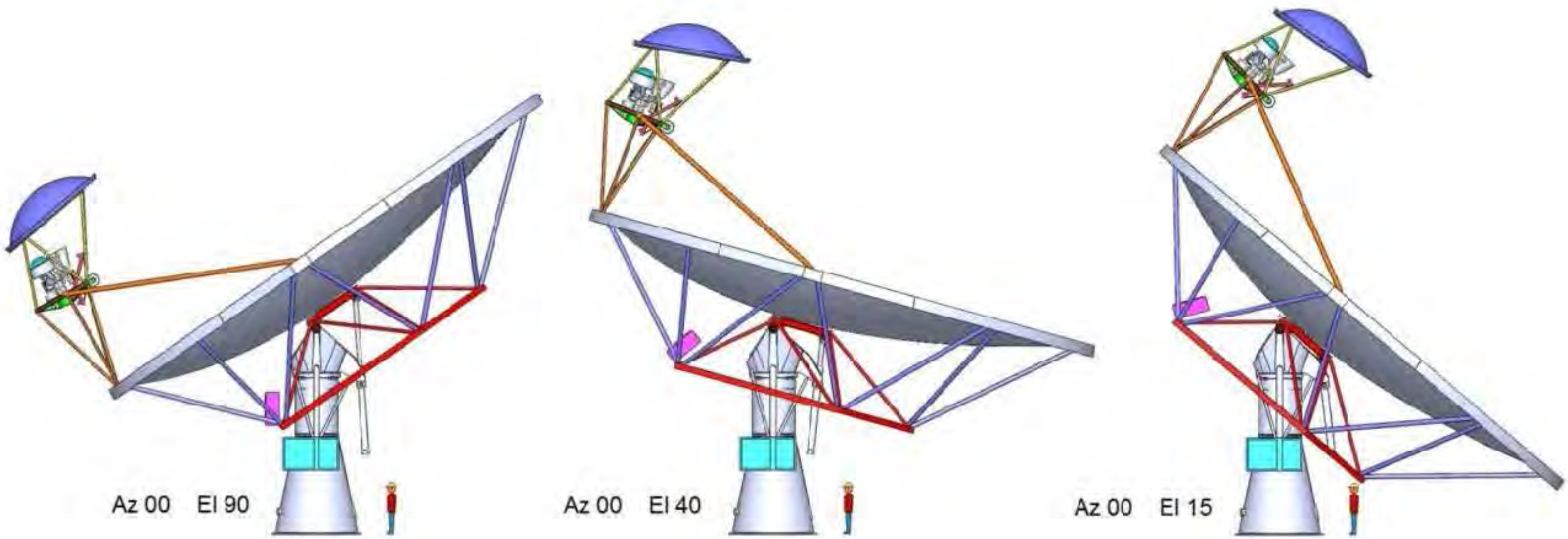


Fig. 3.35 *Diffraction loss vs. subreflector size*

The Object of Today's Talk

SKA Dish Verification Antenna 1, known as DVA-1

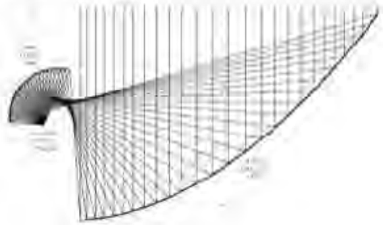
Antenna Several Positions



Zenith position   Stow Position   Low Position

Optics Design

Features of the design

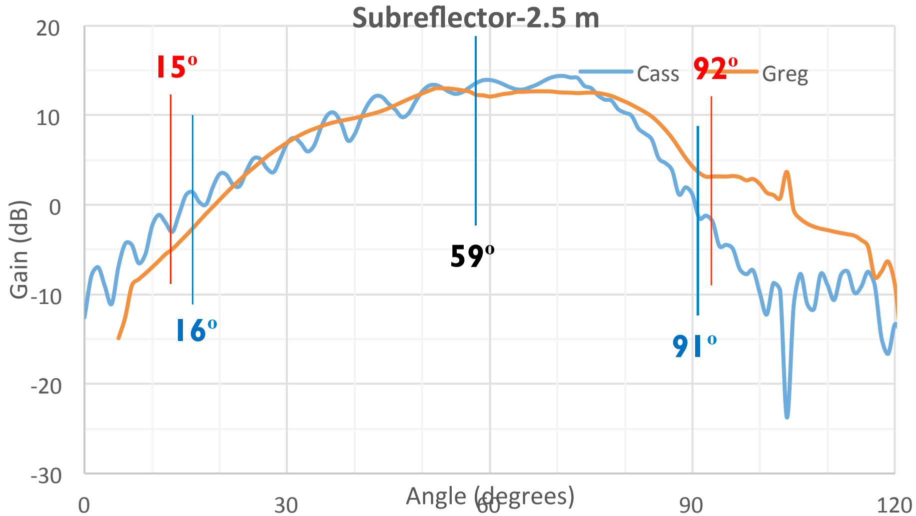


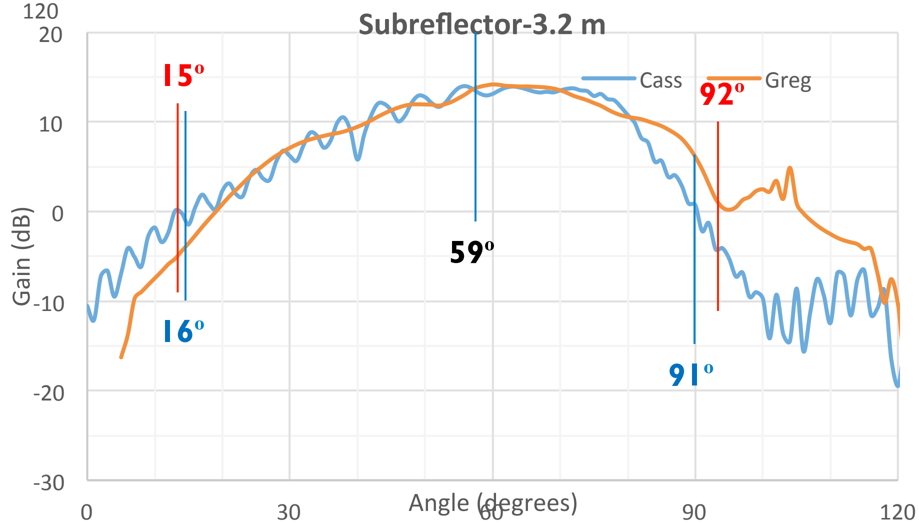
- Clear optical path, no blockage or scattering.
- Shaped optics, leads to very low spillover. (~ -50db wide angle)
- Very low spillover yields very low antenna noise temp. (<6 K ground)
- Very low spillover results in high rejection of RFI and strong sources.
- Shaped optics yield high efficiencies, total result is a high Aeff / Tsys.
- Ample space and access to mount multiple feeds on an indexer.
- PAF works effectively at either secondary or primary focal area
- Feed arm high chosen for structural cost reasons.
- Feed arm low may produce slightly lower spillover for some WBSPFs.
- Feed maintenance access via a standard bucket truck.
- Primary area is 22% over symmetric but antenna cost is 13% more.
- Primary surface accuracy will need to be <1mm rms, 1/30 λ.

More features will be listed in the structural design section.

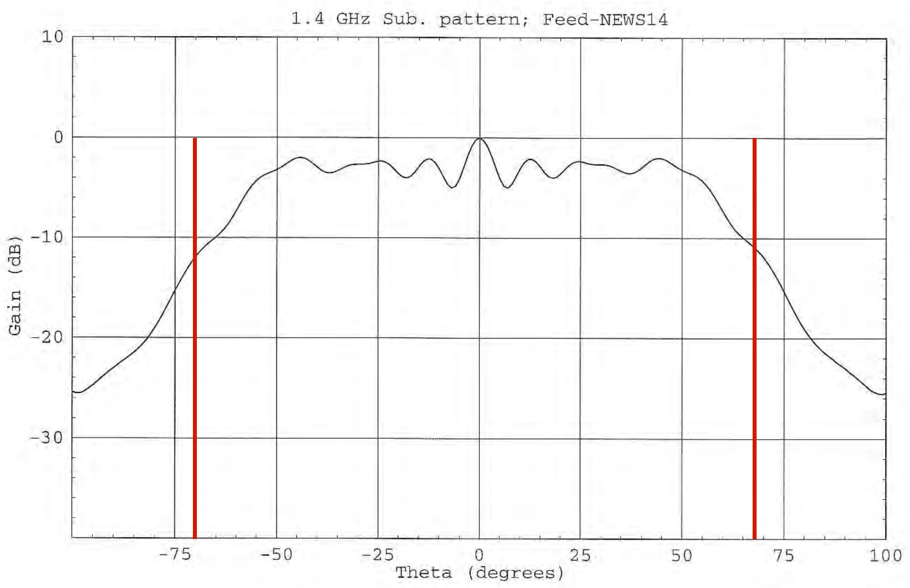
SCAN LOSS, COMA LOBE

SUBREFLECTOR PATTERN AT 1.2 GHz

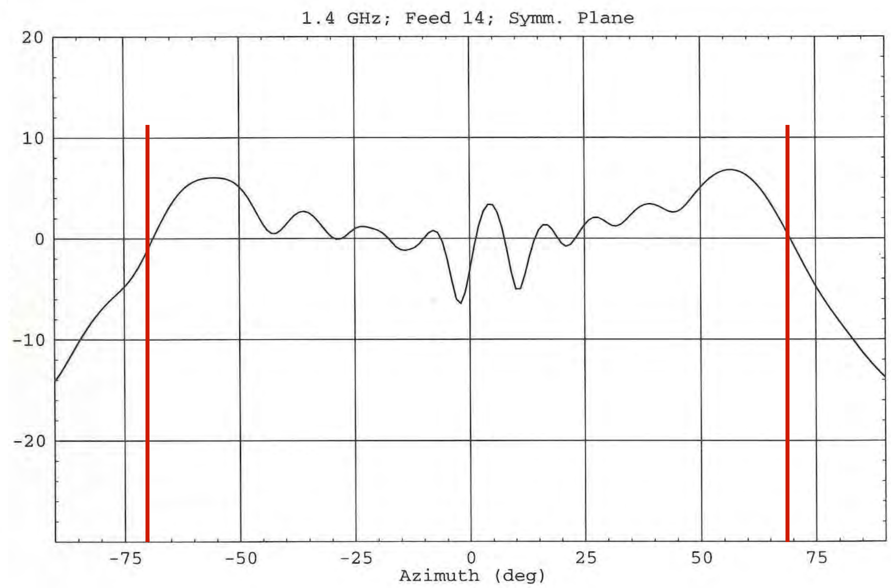




SUBREFLECTOR SCATTED BEAM (1.4 GHz)



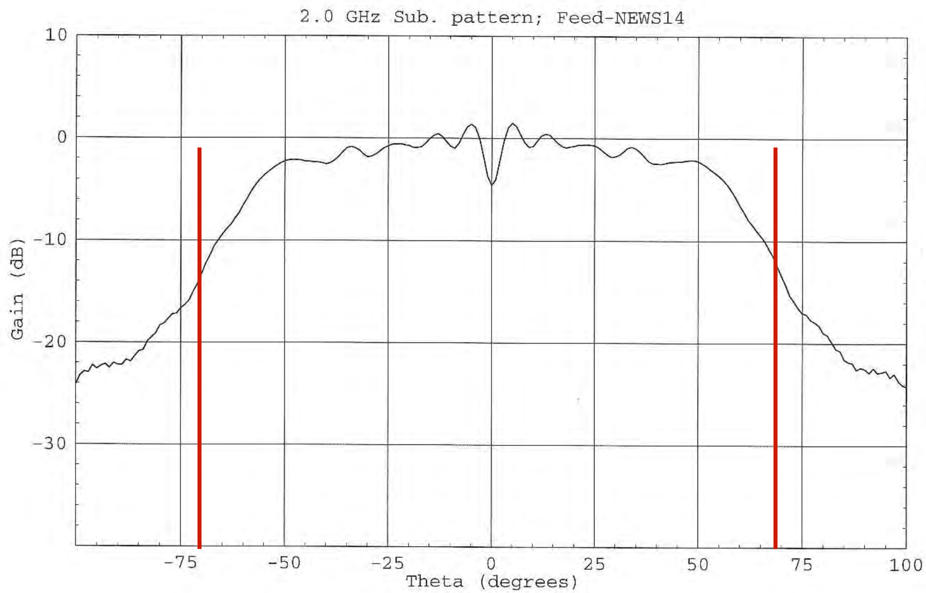
HYPERBOLIC SUBREFLECTOR



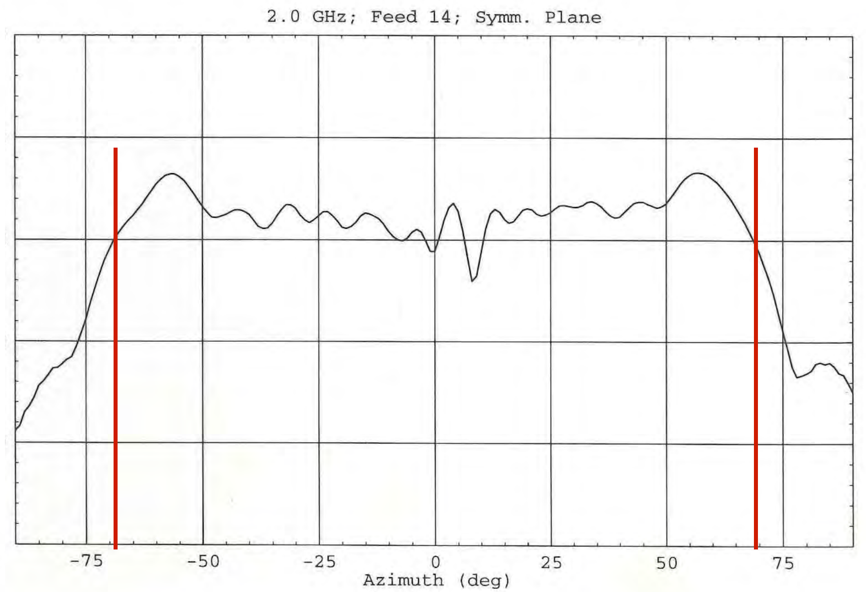
VLA SHAPED

Θ edge = 67.86°

SUBREFLECTOR SCATTERED BEAM (2.0 GHz)



HYPERBOLIC SUBREFLECTOR



VLA SHAPED

Θ edge = 67.86º