CHALMERS
UNIVERSITY OF TECHNOLOGY

Feed Analysis ngVLA - SKA and DVA Optics

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ngVLA Optics Workshop, 19-20 June, 2018
Caltech, Pasadena, CA, US

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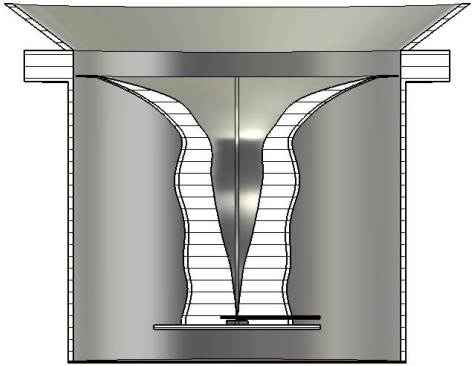
Outline

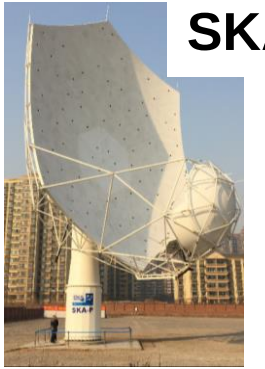
- Background
- Models
- Modelling
- Some Results
- Summary

Credit: Sander Weinreb



DVA1

SKA Prot.



Credit: SKA Organization

(Geodesy)

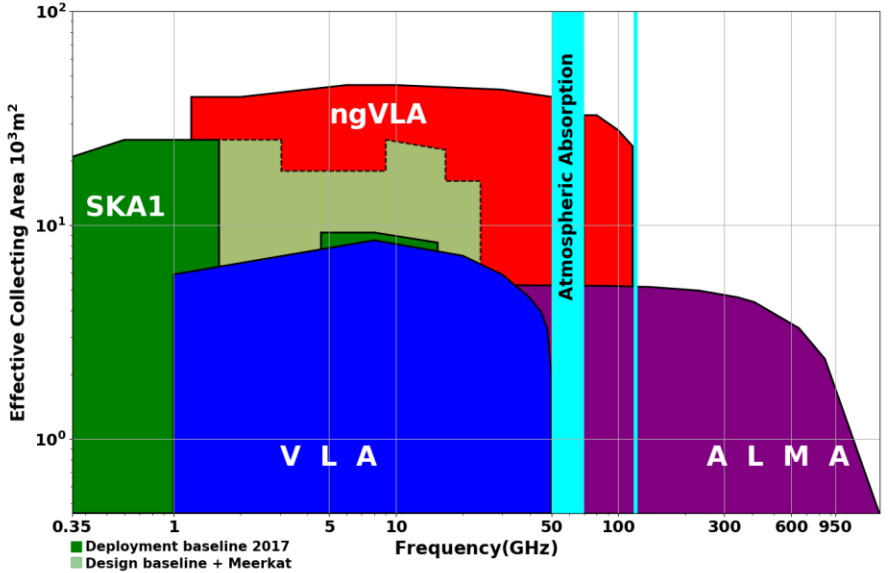
BL: 2-14 GHz
(- 18 GHz OTT)

Waveband	Default central frequency
18 cm	1664 MHz
13 cm	2268 MHz
6 cm	4992 MHz
5 cm	6668 MHz (Methanol), 6030 MHz (OH)
4 cm	8418 MHz
1 cm	22230 MHz

Waveband	Default Central Frequency
90 cm	327 MHz
50 cm	610 MHz
21 cm	1416 MHz
2 cm	15362 MHz
7 mm	43214 MHz

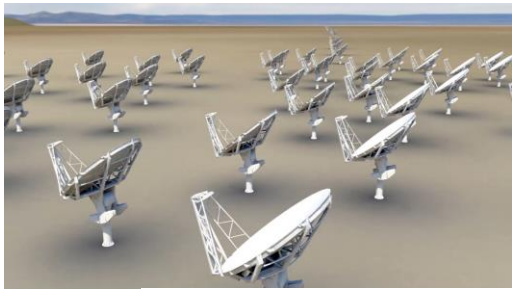
BRAND EVN
(UWB 10:1, 1.5-15.5 GHz)

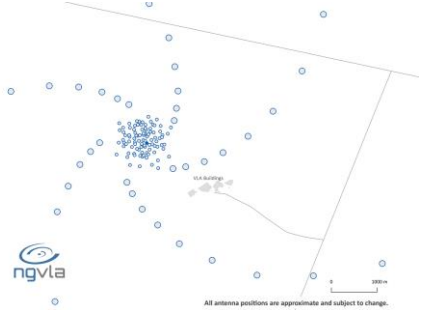
ngVLA, 214 telescopes
BL:1.2 - 116 GHz (excl. atmos. absorption)



SKA1 MID, ~130 telescopes
BL: 0.35 – 15.4 GHz

Credit: Roger Hammargren, ngVLA/NRAO, EVN





ngVLA

SKA

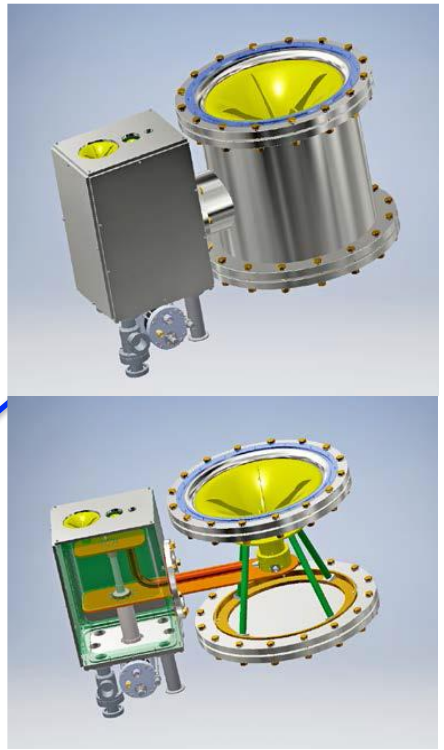
MeerKAT

Credit: SKA Organization, ngVLA/NRAO, Leif Helldner/EMSS/MeerKat

ngVLA 1.2 – 116 GHz

- 2 Dewars, sharing 1 cryo-vaccum system
  - 4-feed system
  - 1.2 – 4.2 GHz (~3.5:1) Prot.
  - 4.2 – 15 GHz (~3.5:1)
  - 15 – 50 GHz (~3.5:1)
  - 70 – 116 GHz (1.65:1)

Credit: Leif Helldner

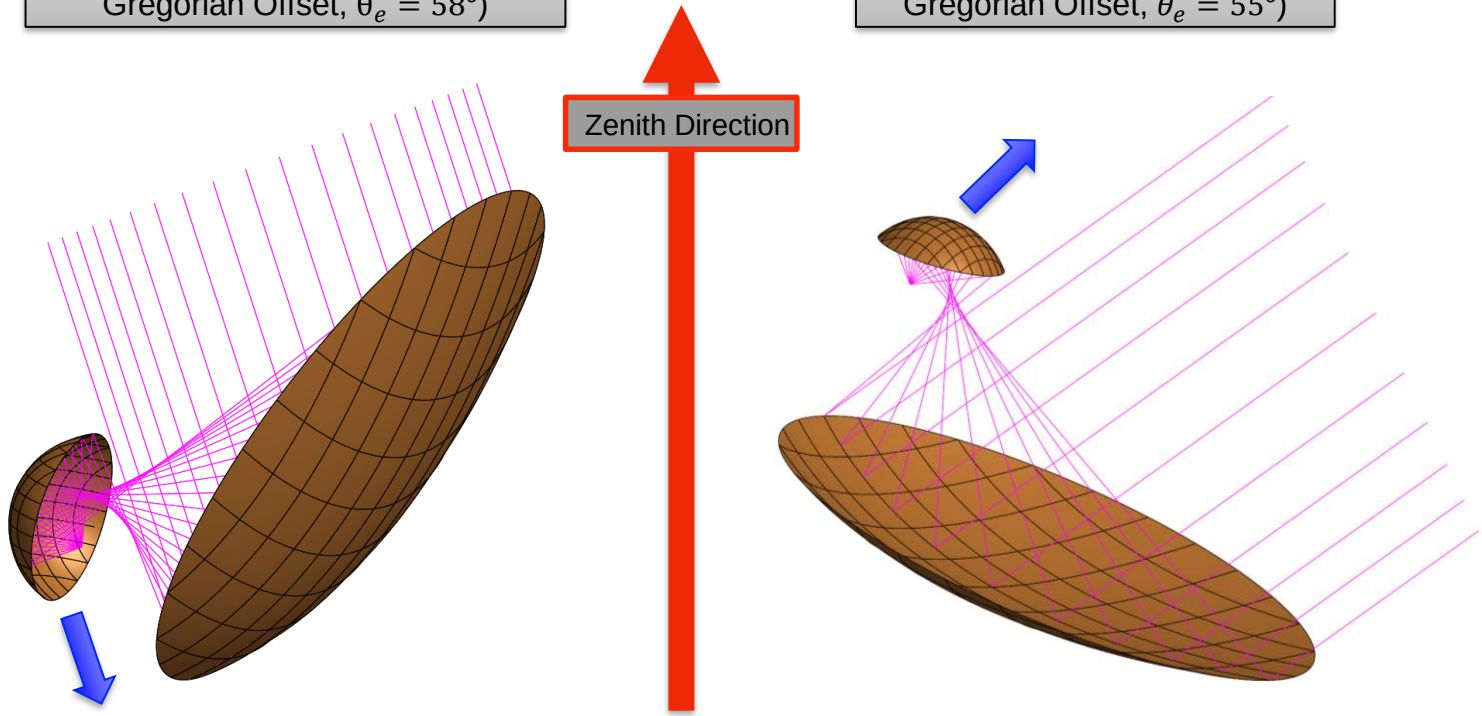


"Cryogenic 1.2 to 116 GHz Receiver for Large Arrays"
S. Weinreb, H. Mani, W. Zhong, J. Flygare, B. Billade, A. Akgiray, L. Dong.,
12th European Conference on Antennas and Propagation (EuCAP), London 2018 April.

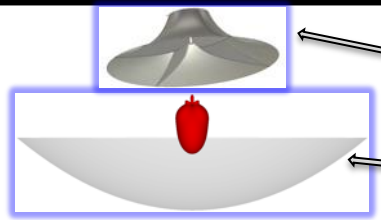
SKA Dish
(Feed down, shaped, spill-over shield Gregorian Offset, $\theta_e = 58°$)

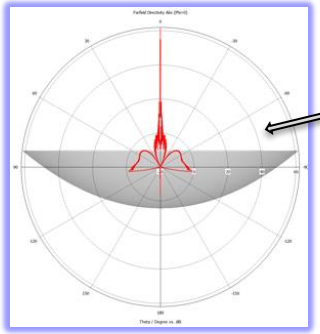
DVA Dish
(Feed up, shaped Gregorian Offset, $\theta_e = 55°$)

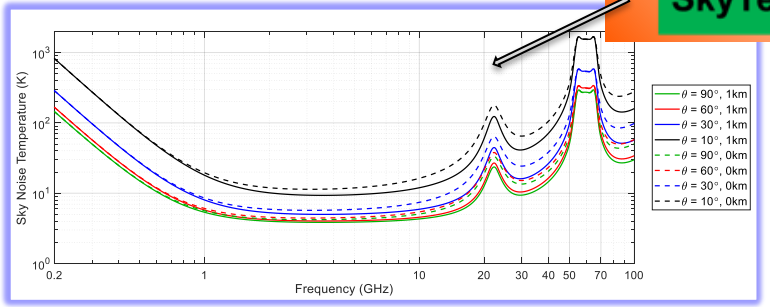
	SKA	DVA
Shaped	Yes	Yes
Tipping Conf.	Down	Up
SpillOver Ext.	40°	No
θ_e	58°	55°
MR Long Ax.	18m	18m
MR Short Ax.	15m	15m
Proj. (MR) D.	15m	15m
SR D.	~5.2m	~4m

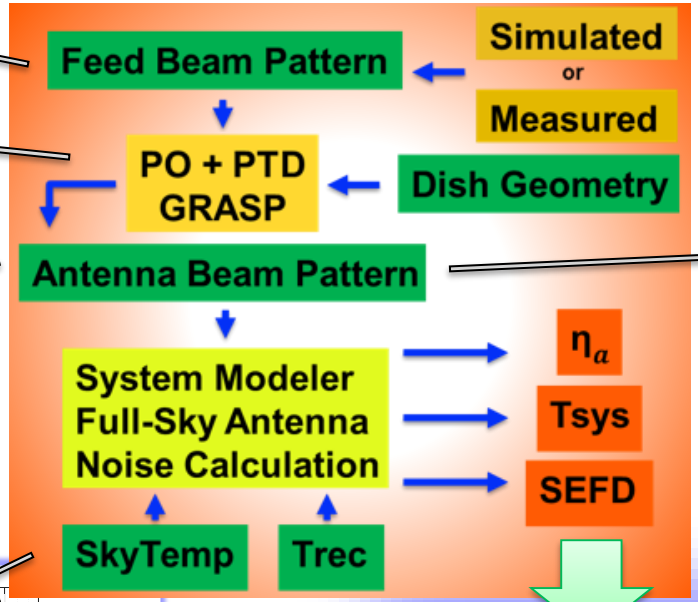


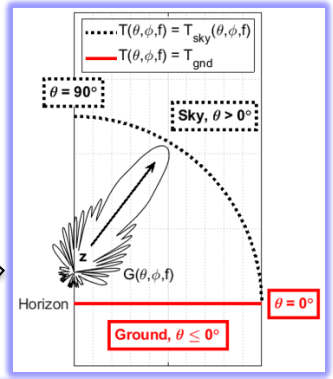
Simplicity: assuming perfect dish in simulations











$$T(\theta,\phi,f)=\begin{cases}T_{\mathrm{sky}}(\theta,\phi,f) & 90^\circ \geq \theta > 0^\circ \\ T_{\mathrm{gnd}} & 0^\circ \geq \theta \geq -90^\circ\end{cases}$$

$$T_{\mathrm{a}}=\frac{\iint_{4\pi} G(\theta,\phi,f)T(\theta,\phi,f)\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\phi}{\iint_{4\pi} G(\theta,\phi,f)\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\phi}$$

$$T_{\mathrm{sys}}=\eta_{\mathrm{rad}}T_{\mathrm{a}}+(1-\eta_{\mathrm{rad}})T_{\mathrm{phy}}+T_{\mathrm{rec}}$$

$$\eta_{\mathrm{a}}=(D\lambda^2)/(4\pi A_{\mathrm{phy}})$$
$$\eta_{\mathrm{ant}}=\eta_{\mathrm{rad}}\eta_{\mathrm{a}}$$
$$A_{\mathrm{eff}}=\eta_{\mathrm{ant}}\eta_{\mathrm{dish}}A_{\mathrm{phy}}$$
$$SEFD=2k_{\mathrm{B}}(T_{\mathrm{sys}}/A_{\mathrm{eff}})$$

- **Spill-over shield, feed down**
  - **MeerKAT 20°**
  - **SKA Dish 40°**

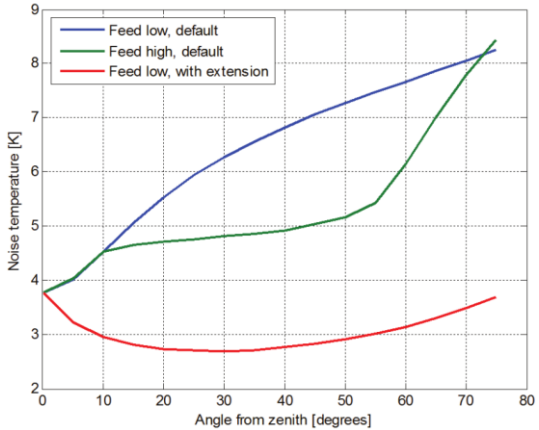
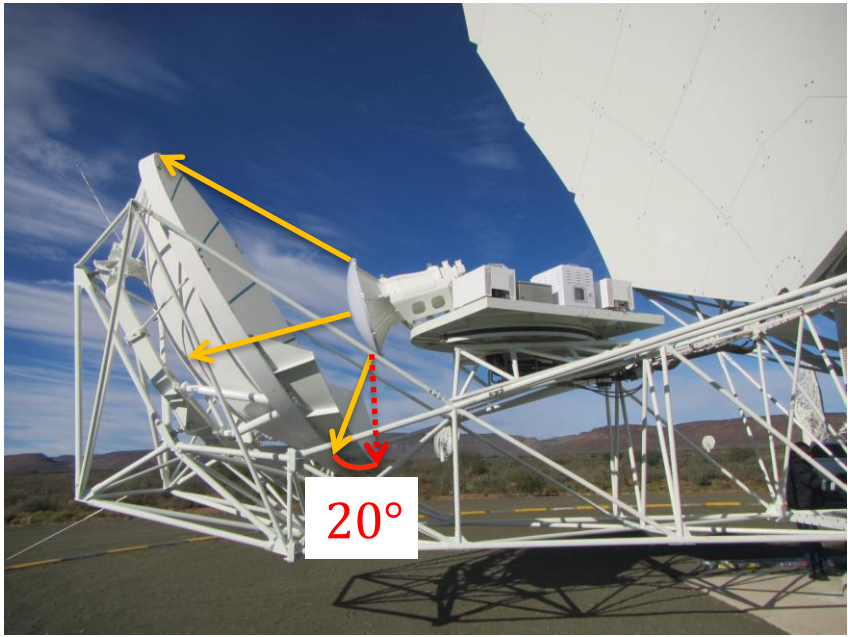


Figure 6: Spill-over tipping curve for the different configurations.

Credit: "The design of the MeerKAT dish optics"
I. P. Theron, R. Lehmensiek, D.I.L. de Villiers
ICEAA'12

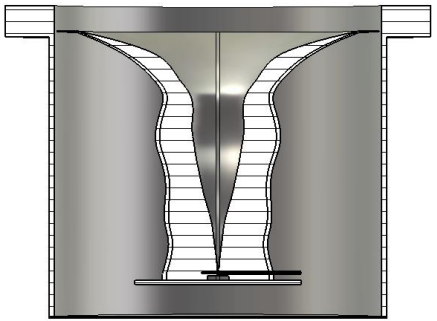
SKA Band 1 on MeerKAT



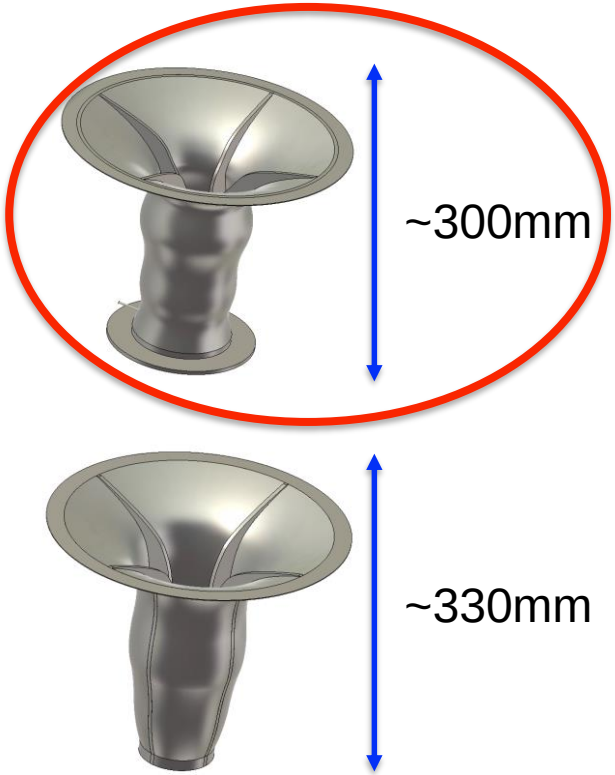
Credit: Leif Helldner, OSO

ngVLA 1.2- 4.2 Prototype

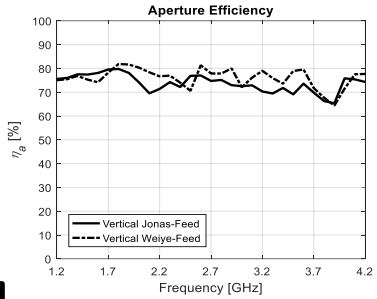
- Optimized for SKA Dish, 12 dB @ 58°
  - NOT optimized for DVA = 55°, 16 dB!
  - Keep in mind when looking at data
- Goal η_a > 75 % ave. (achieve > 77% on SKA, > 72 % on DVA)
- S11 < -10 dB (achieve < – 12 dB, average -15 dB).
- Dewar dimensions constraints

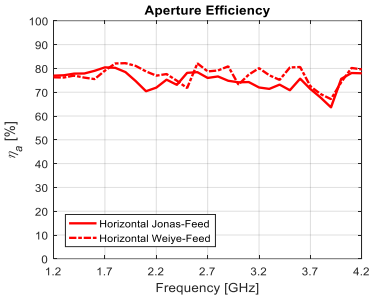


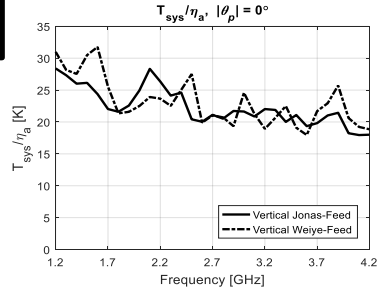
Pre-dewar Int., parallell design work

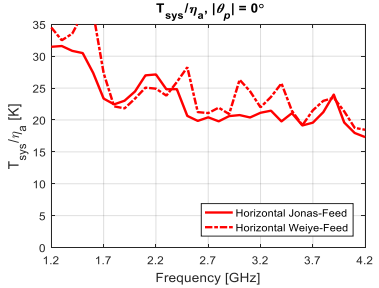


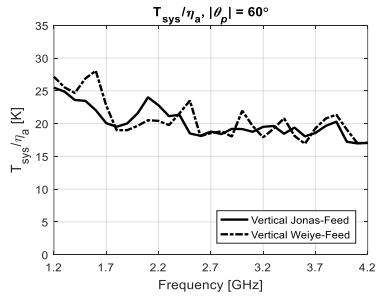
Smaller footprint

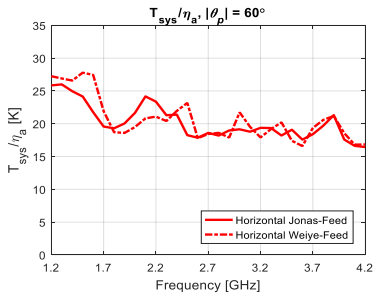




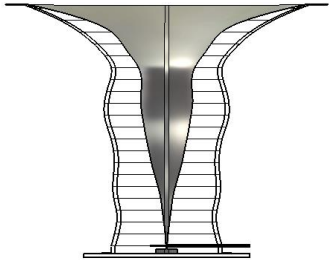


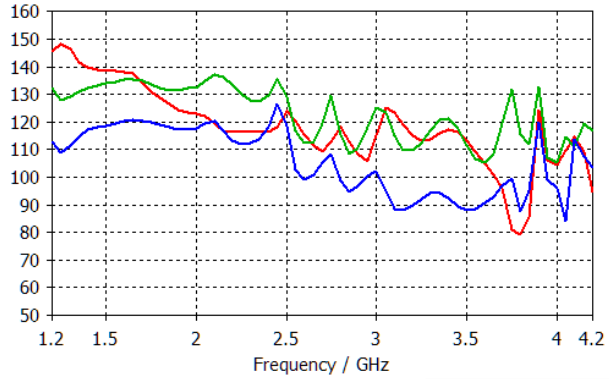




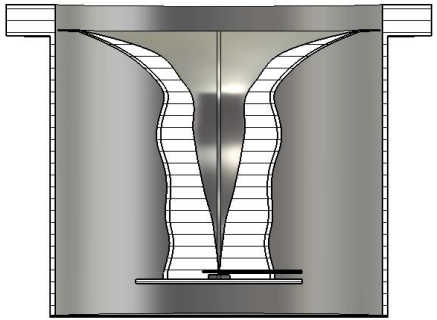


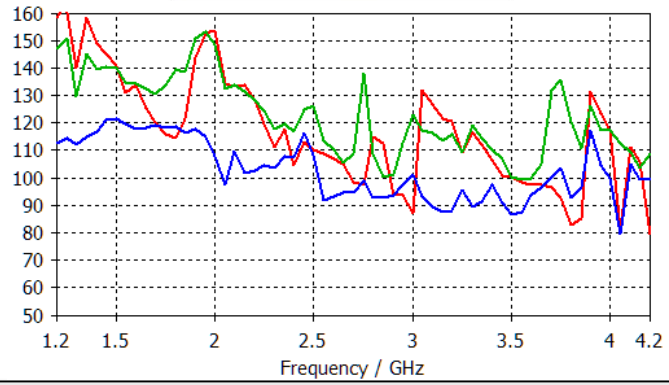
Feed



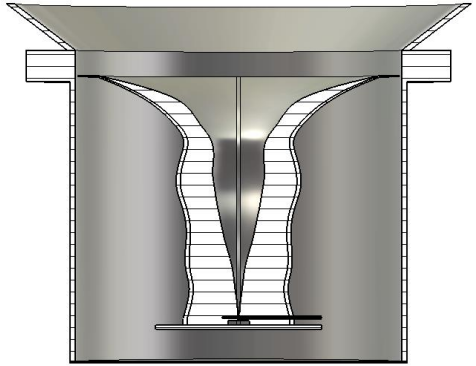


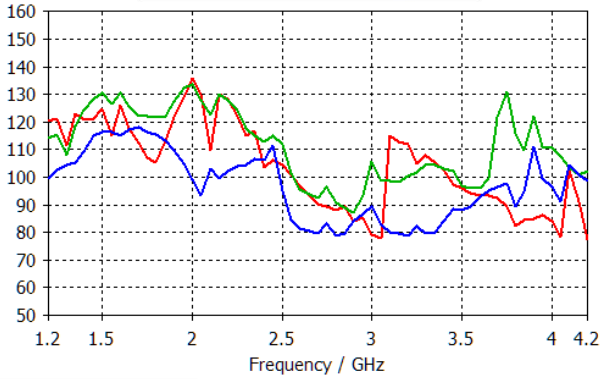
Feed in dewar





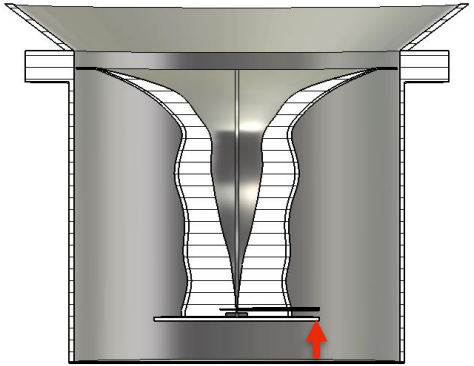
Feed in dewar + cone

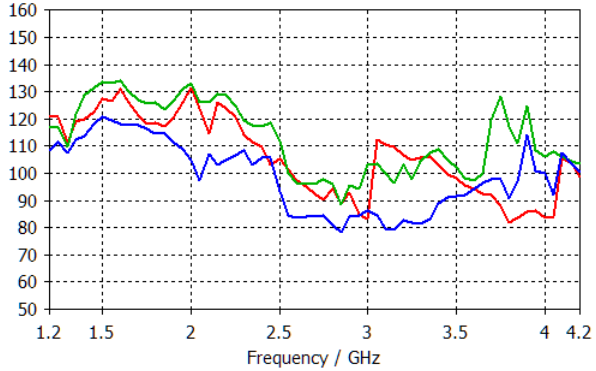




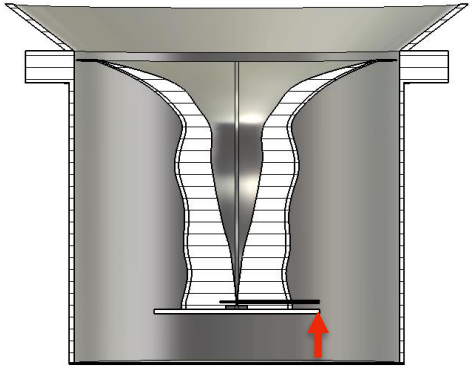
Beamwidth @ 12 dB - φ=0°, φ=45°, φ=90° - Goal: 2 x 58° = 116° (SKA)

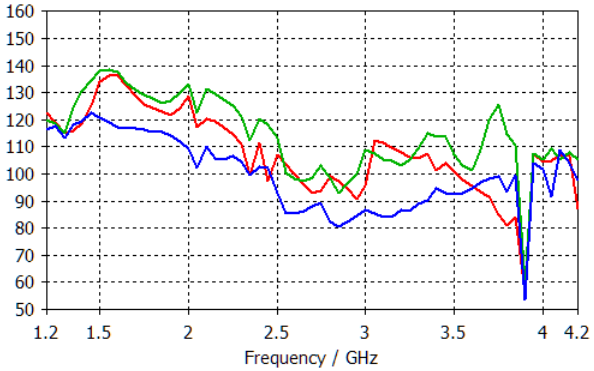
Feed (+10mm) in dewar + cone



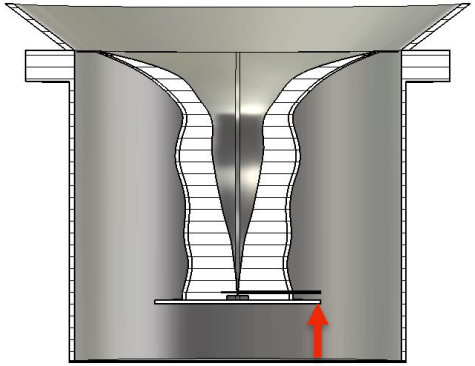


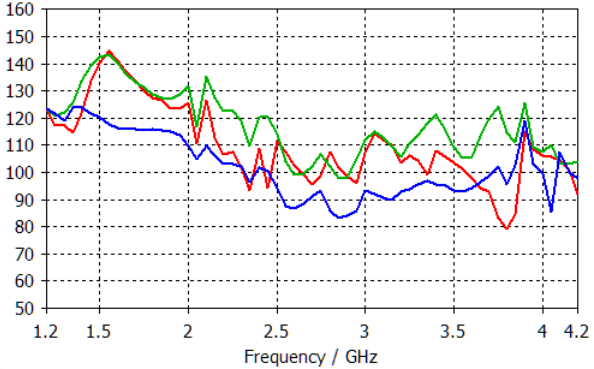
Feed (+20mm) in dewar + cone





Feed (+30mm) in dewar + cone

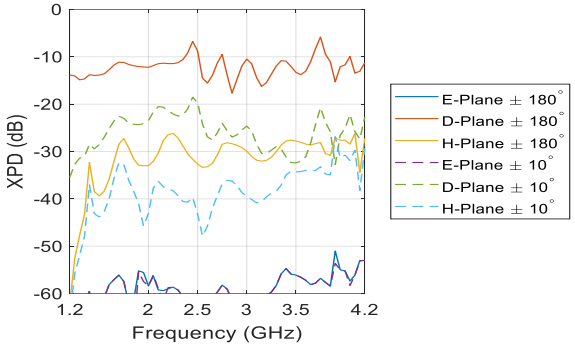




Beamwidth @ 12 dB - φ=0°, φ=45°, φ=90° - Goal: 2 x 58° = 116° (SKA)

XPD

Feed



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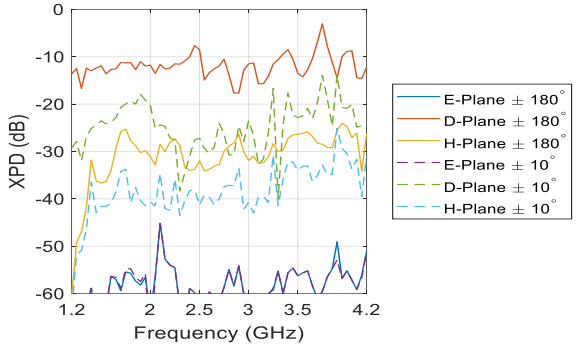
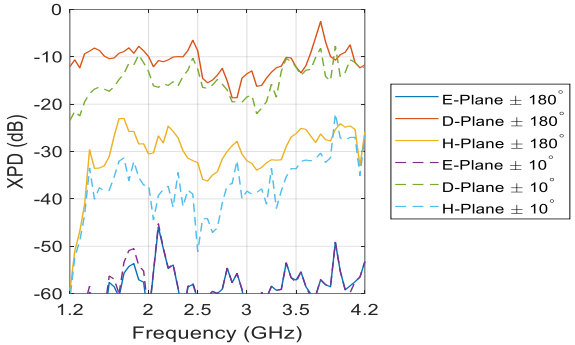
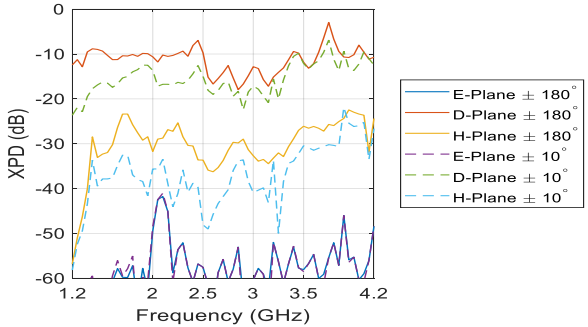


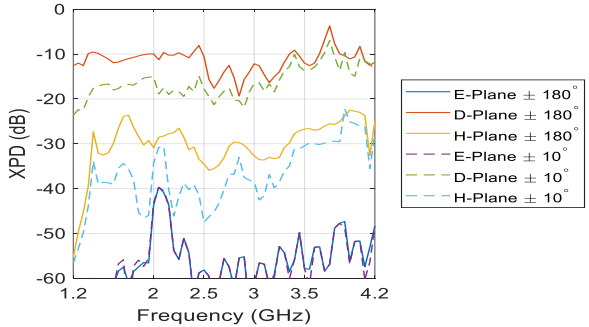
Feed in dewar + cone



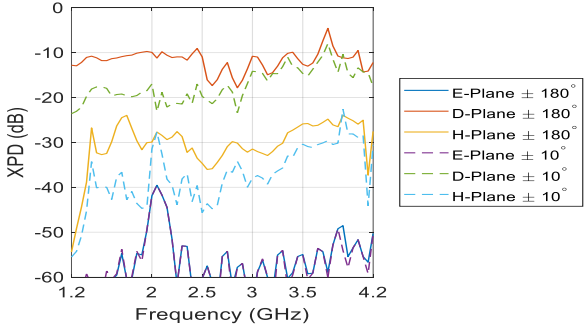
Feed (+10mm) in dewar + cone



Feed (+20mm) in dewar + cone

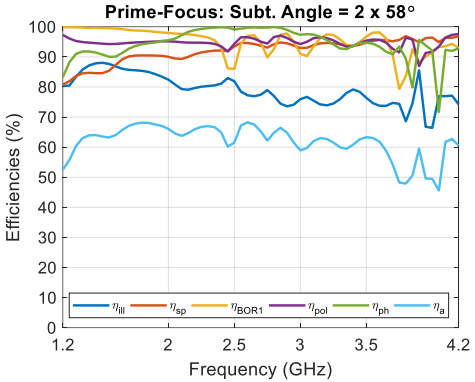


Feed (+30mm) in dewar + cone



Sub efficiencies, Prime-focus

Feed



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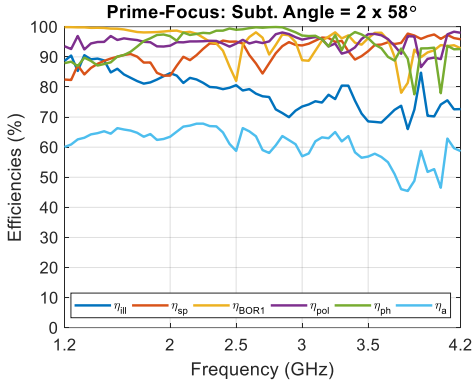
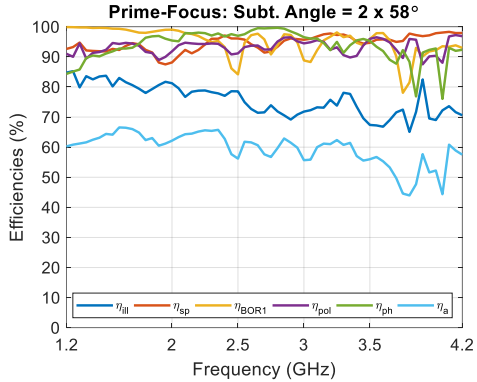
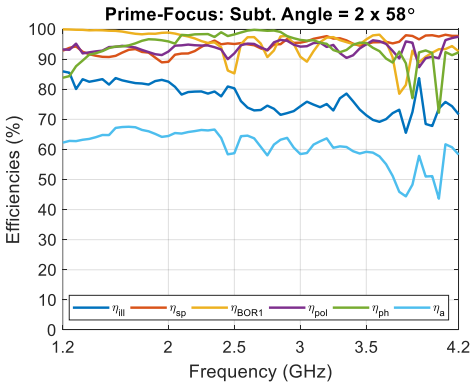


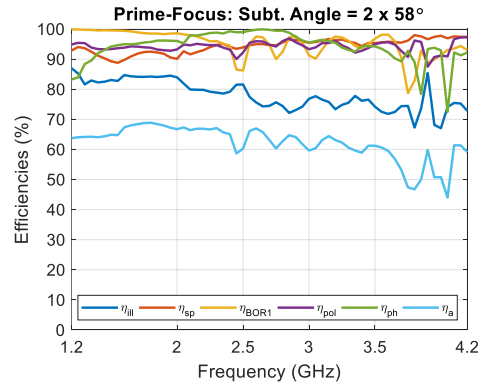
Feed in dewar + cone



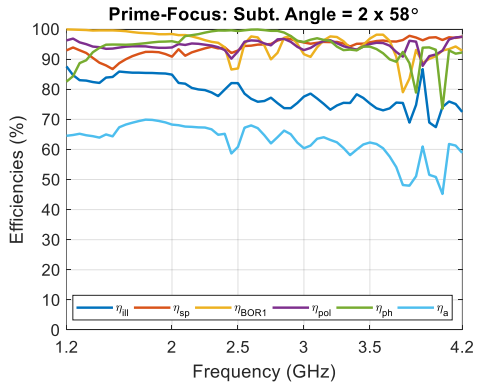
Feed (+10mm) in dewar + cone



Feed (+20mm) in dewar + cone

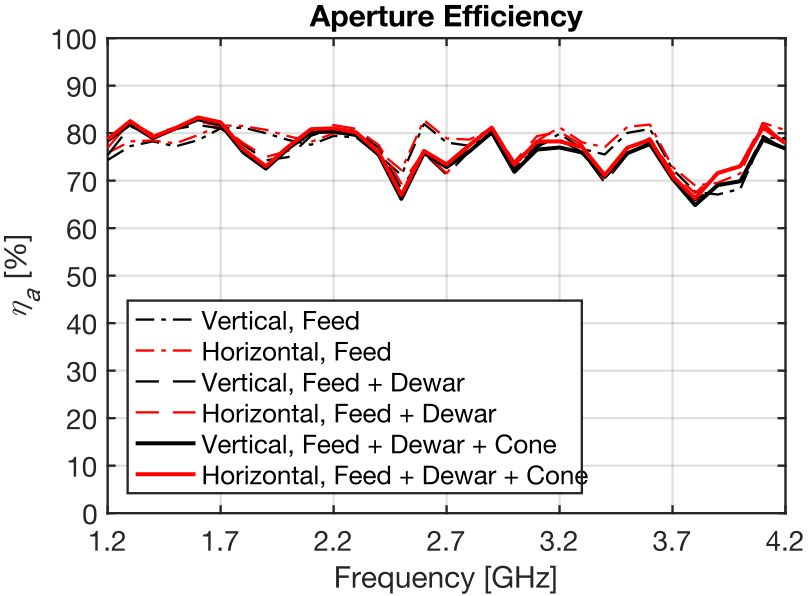


Feed (+30mm) in dewar + cone

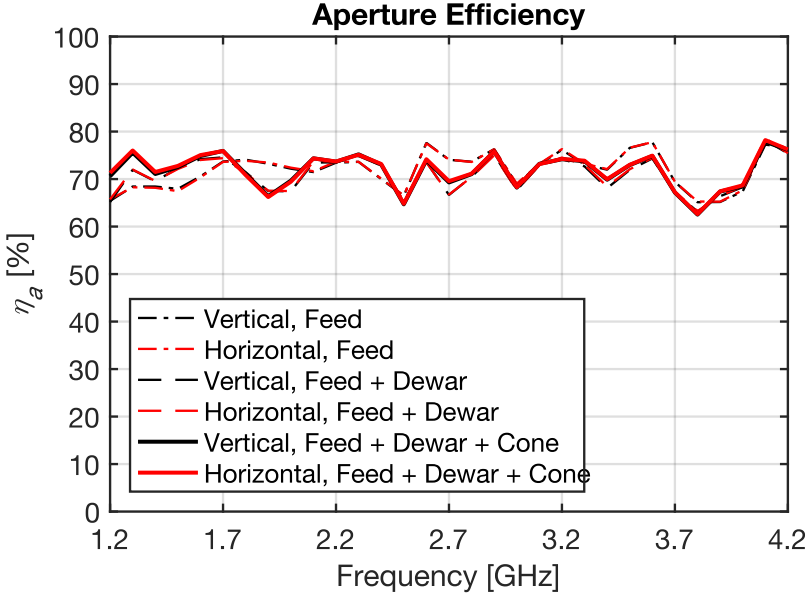


η_a, SKA vs DVA

SKA Dish



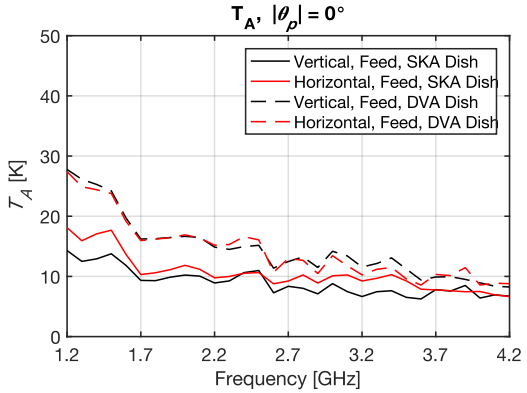
DVA Dish

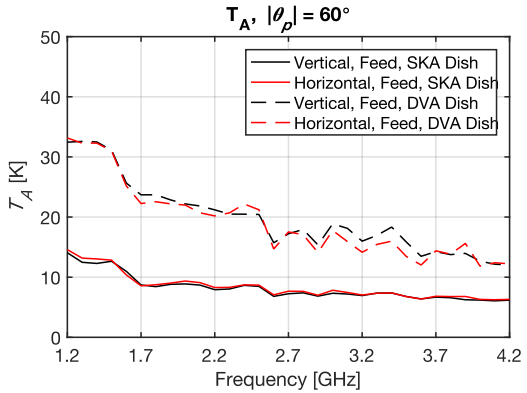


	Feed	Feed + Dewar	Feed + Dewar + Cone
SKA	77,4 %	76,5 %	76,4 %
DVA	71,9 %	71,0 %	71,8 %

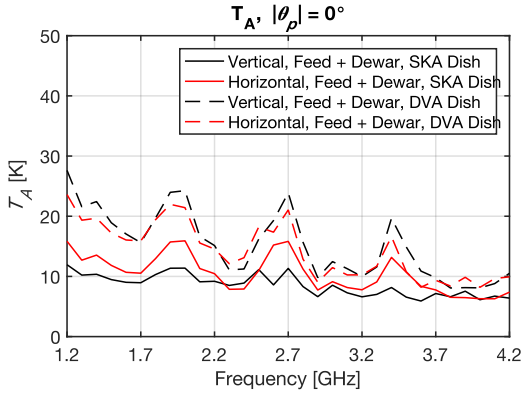
T_A, SKA vs DVA

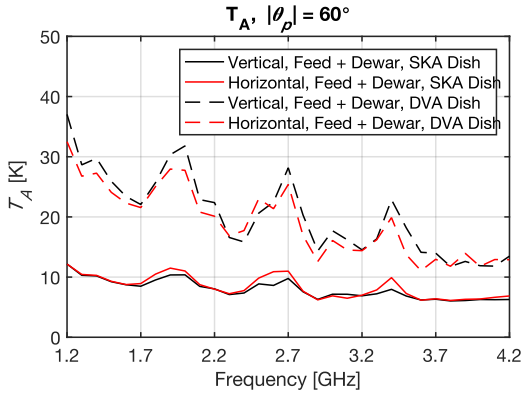
Feed



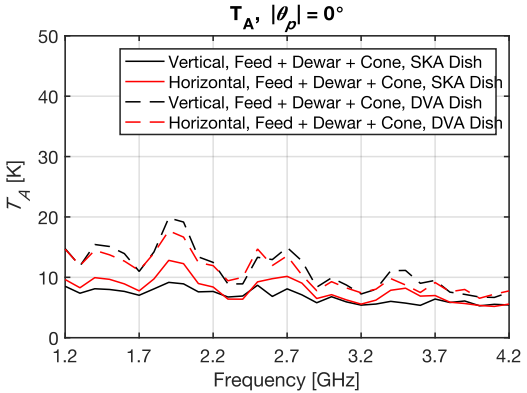


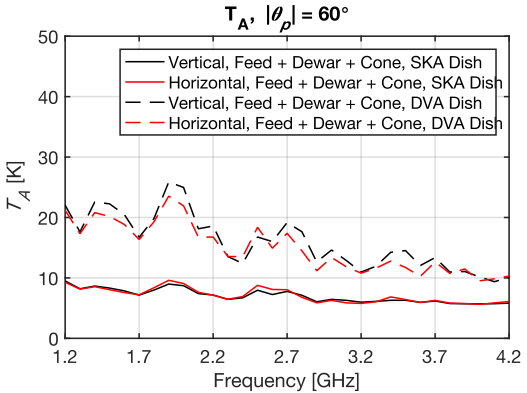
Feed in dewar





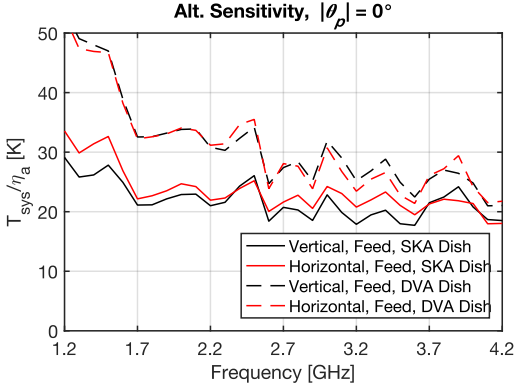
Feed in dewar + cone

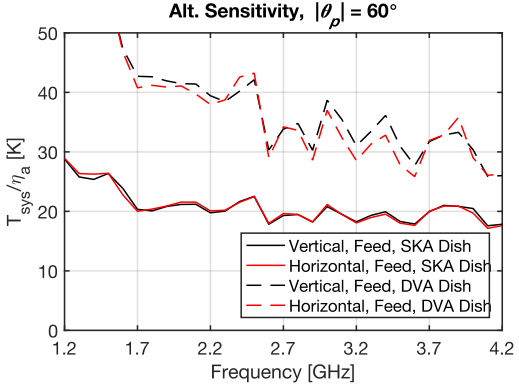




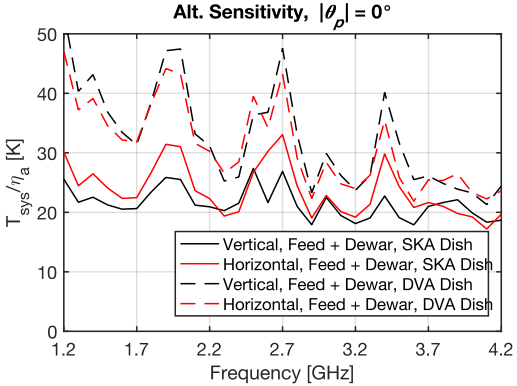
T_{SYS}/η_a, SKA vs DVA

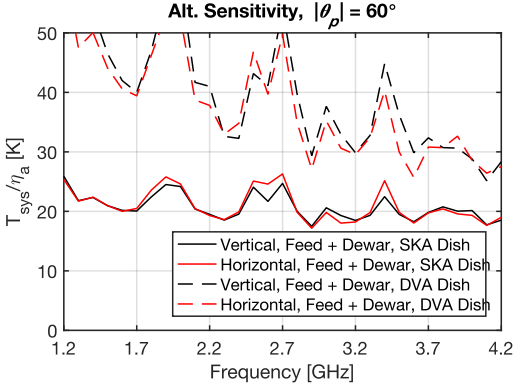
Feed



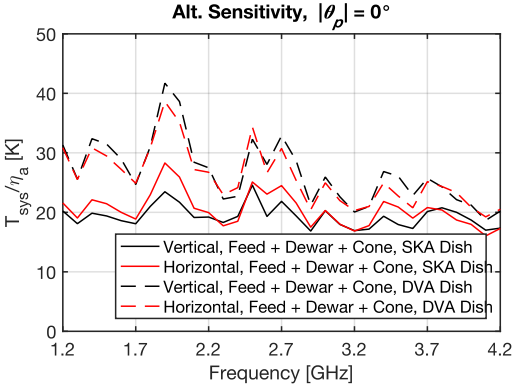


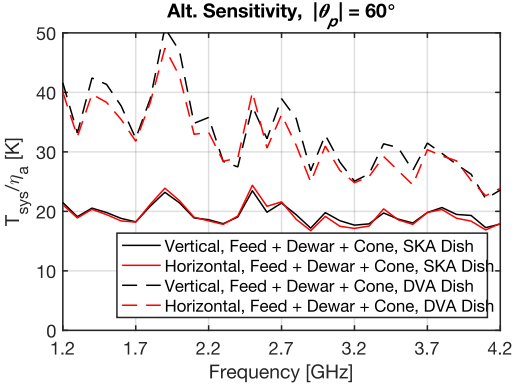
Feed in dewar





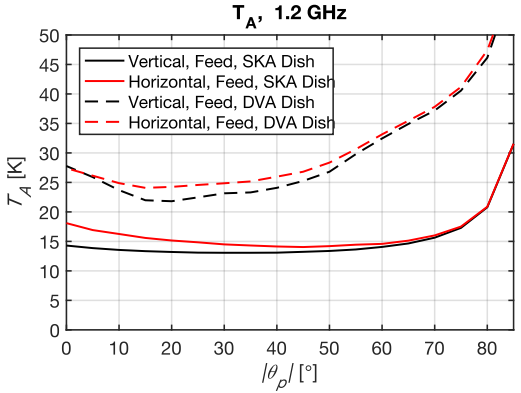
Feed in dewar + cone

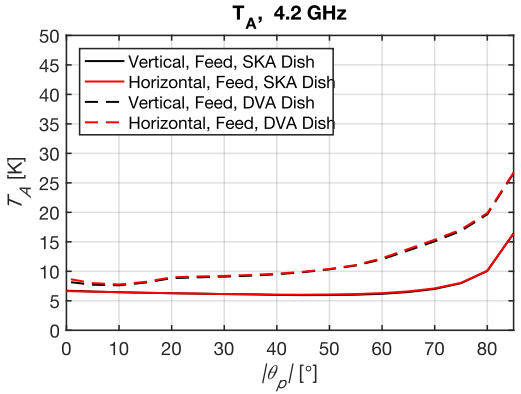




T_A, SKA vs DVA

Feed





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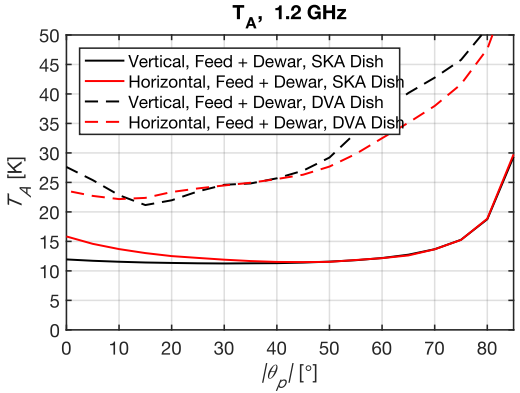
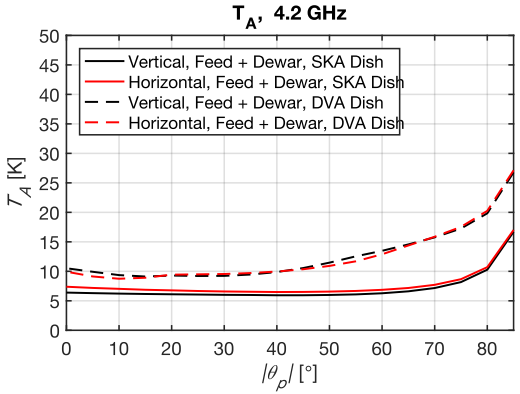
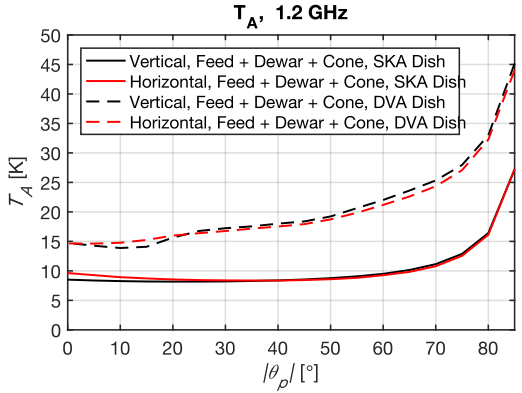
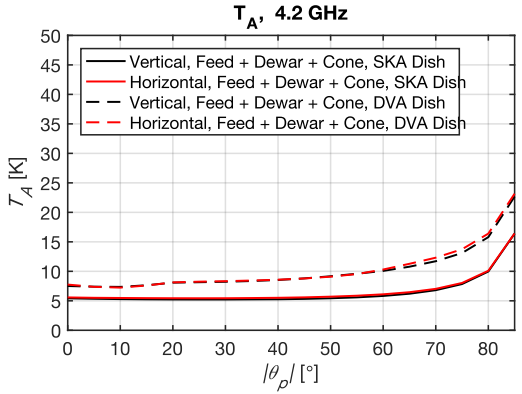




Feed in dewar + cone





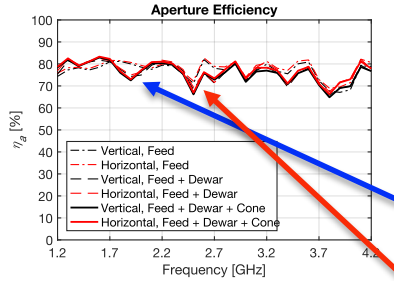
SKA Dish
(Feed down, shaped, spill-over shield Gregorian Offset, $\theta_e = 58°$)

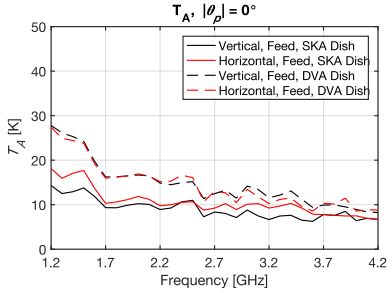
	ApEff	Ta 0	Ta 60	Tsys 0	Tsys 60	Tsys/Ap Eff 0	Tsys/Ap Eff 60	SEFD 0	SEFD 60	IXR
Feed	77,4	9,8	8,3	17,5	16,1	22,6	20,8	353,7	324,6	13,5
Feed + Dewar	76,5	9,5	8,2	17,3	15,9	22,6	20,9	353,2	326,1	14,7
Feed + Dewar + Cone	76,4	7,4	7,1	15,2	14,8	19,9	19,4	311,0	303,5	15,1

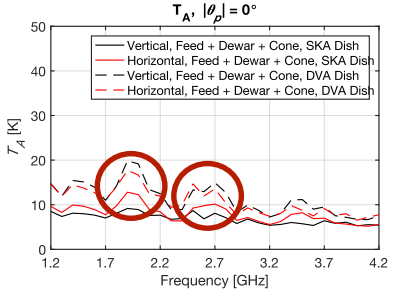
DVA Dish
(Feed up, shaped Gregorian Offset, $\theta_e = 55°$)

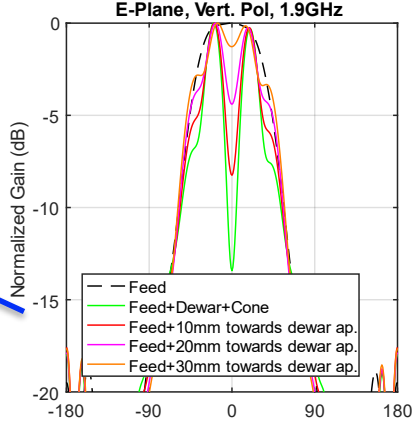
	ApEff	Ta 0	Ta 60	Tsys 0	Tsys 60	Tsys/Ap Eff 0	Tsys/Ap Eff 60	SEFD 0	SEFD 60	IXR
Feed	71,9	14,5	21,1	22,2	28,8	31,2	40,4	487,0	631,6	13,9
Feed + Dewar	71,0	14,8	21,2	22,5	29,0	31,9	41,1	498,5	641,8	14,3
Feed + Dewar + Cone	71,8	11,1	15,7	18,8	23,4	26,3	32,7	410,6	511,3	14,6

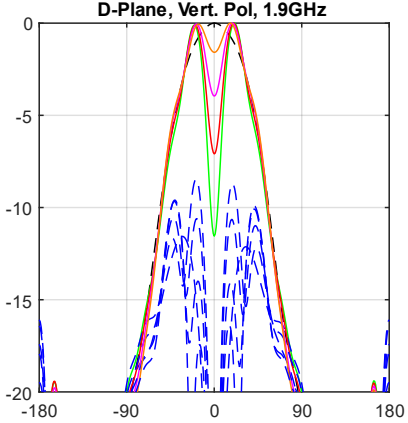
Dewar beam split effect

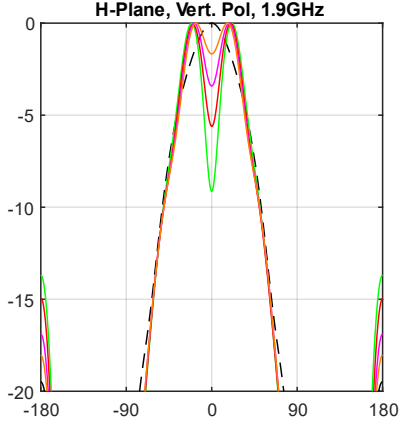


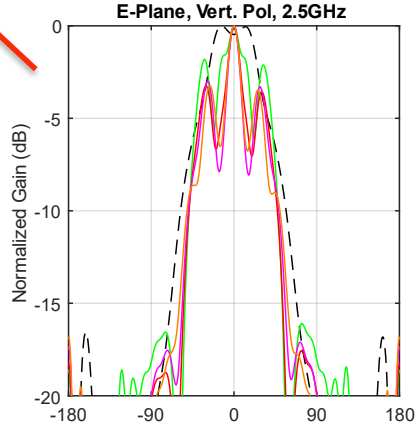


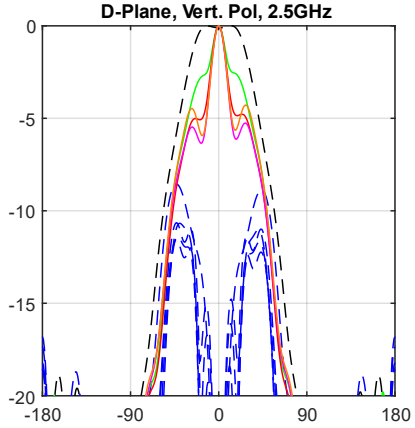


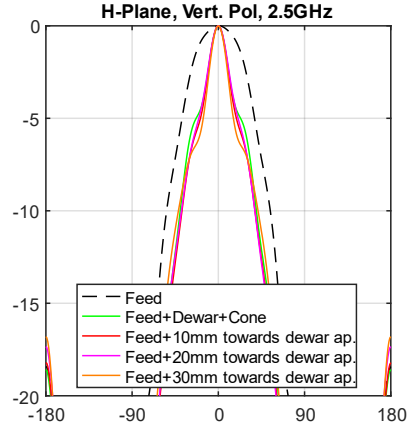


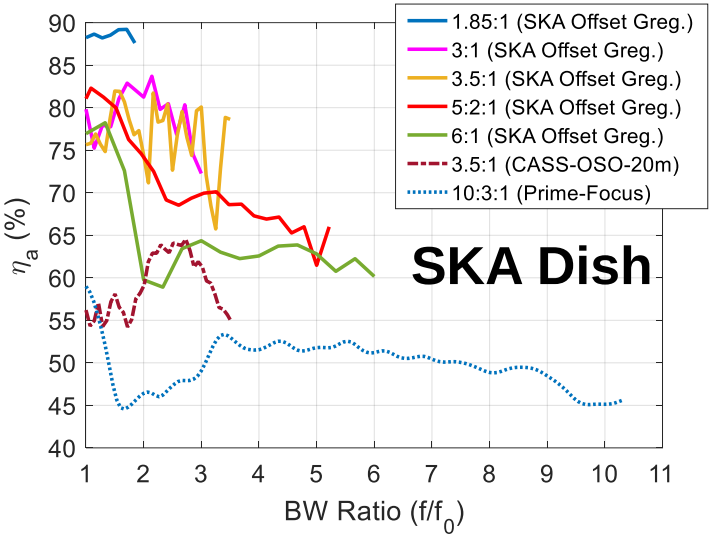


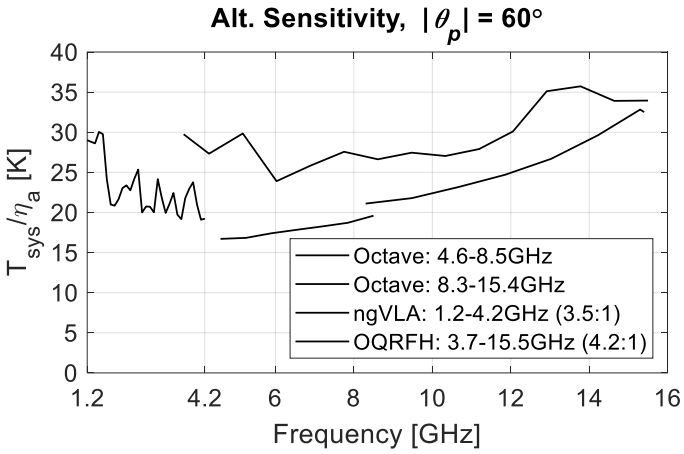


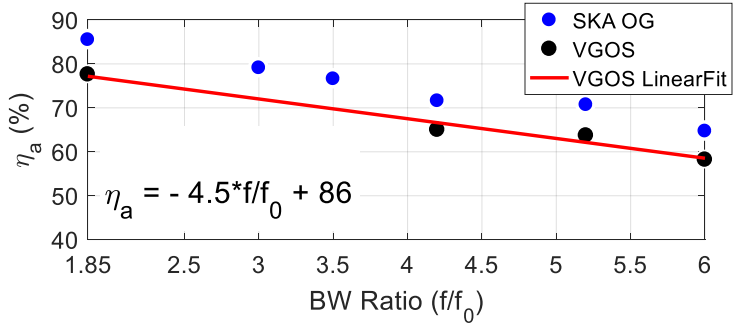








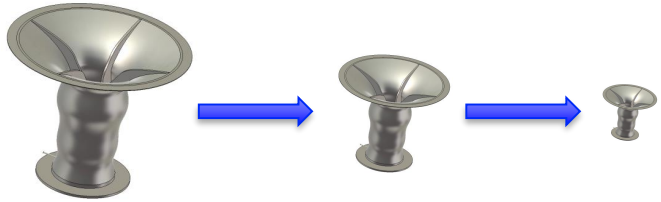


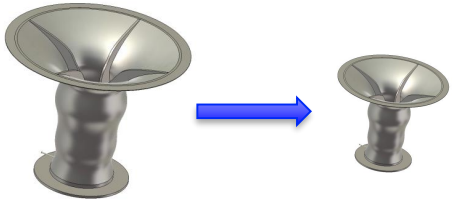


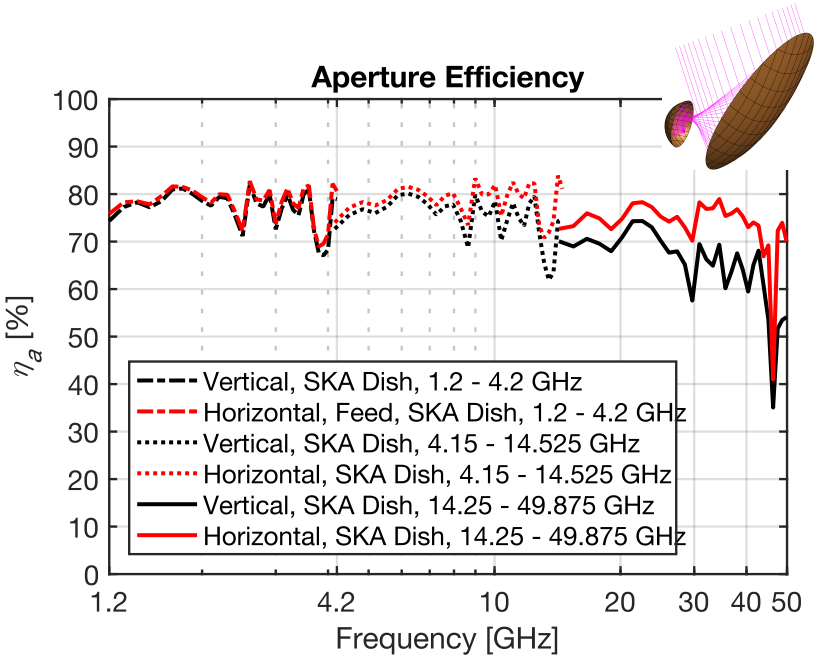
$$\eta_a = (D\lambda^2)/(4\pi A_{phy})$$
$$\eta_{ant} = \eta_{rad}\eta_a$$
$$A_{eff} = \eta_{ant}\eta_{dish}A_{phy}$$
$$SEFD = 2k_B(T_{sys}/A_{eff})$$

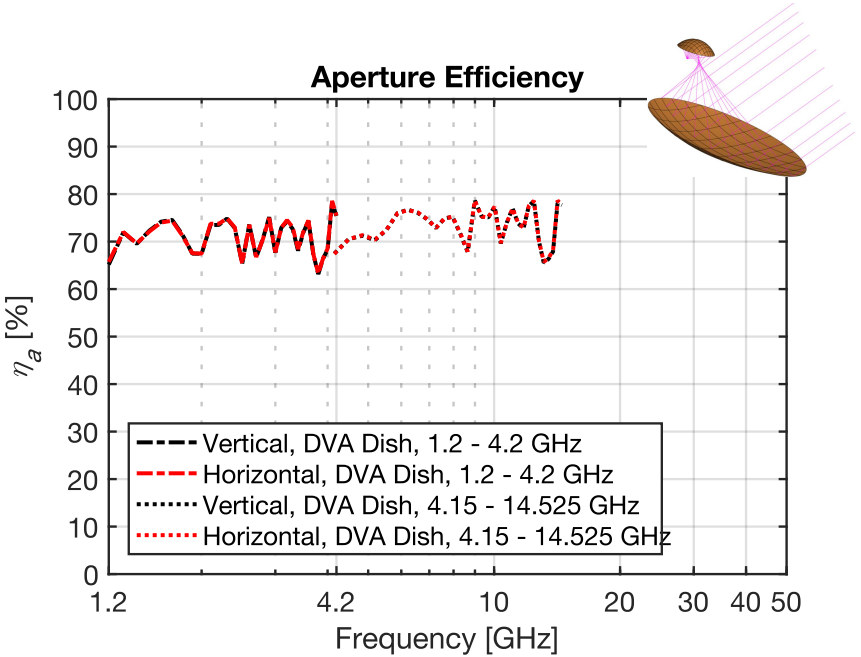
BW	η_a (%) (SKA OG)
1.85:1	85,5
3:1	79,1
3.5:1	76,6
4.2:1	71,6
5.2:1	70,7
6:1	64,7

Frequency scaling

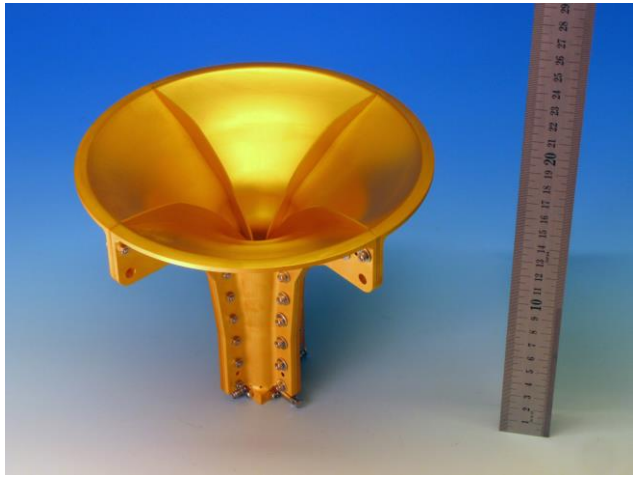








- WBSPF SKA: 4.6 – 24 GHz
- Spillover improved with cone



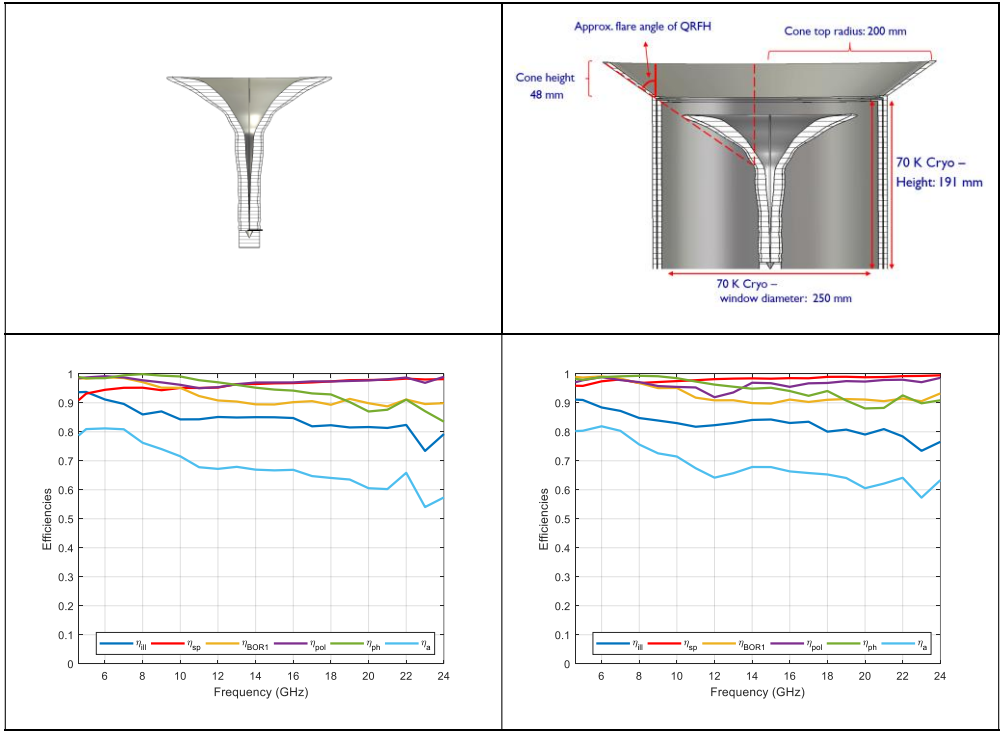
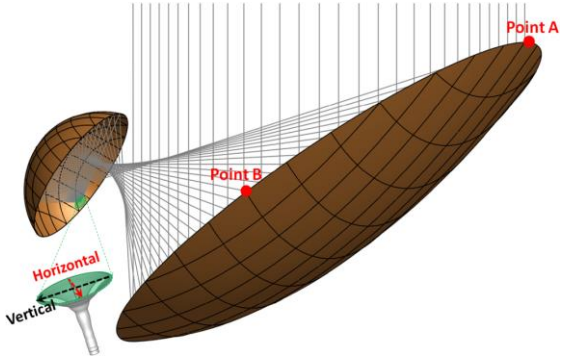


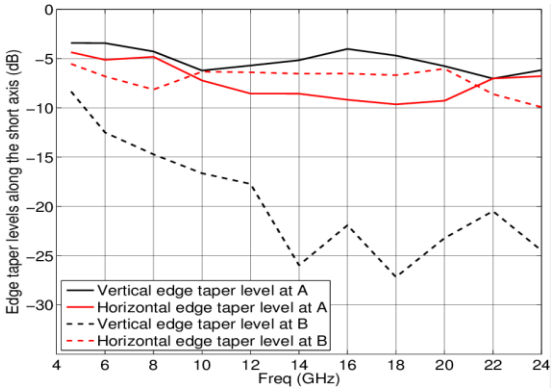
Figure 1: Aperture, spillover and polarization efficiency in the θ_e = 58° SKA Dish for the Band B QRFH in free space (left) and the Band B QRFH inside the cryostat (250 mm diameter IR window) with spillover cone (right). Especially notice the improved spillover efficiency (red) with the cone mounted.

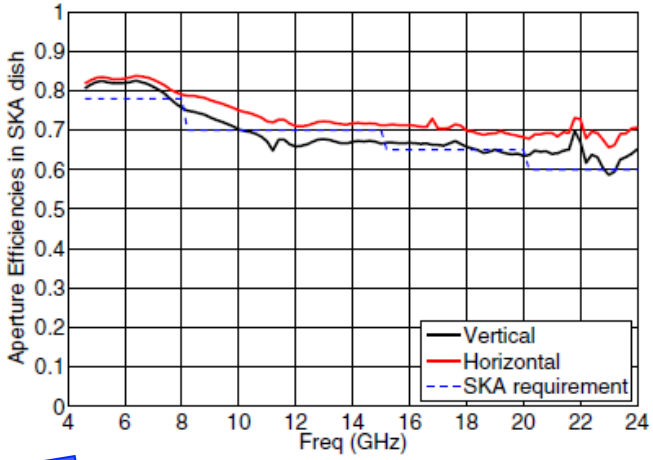
Credit: F. Mokhupuki

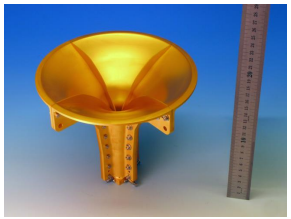
Polarization discrepancy – SKA Dish

- High-frequency, 4.6 – 24 GHz.
- Vertical taper at point B decreasing with frequency
  - Efficiency follows

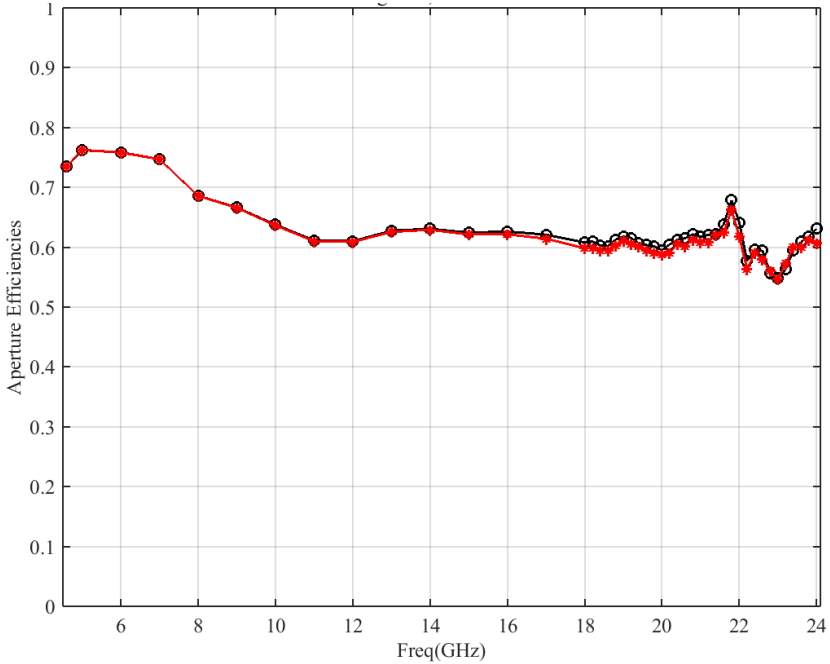




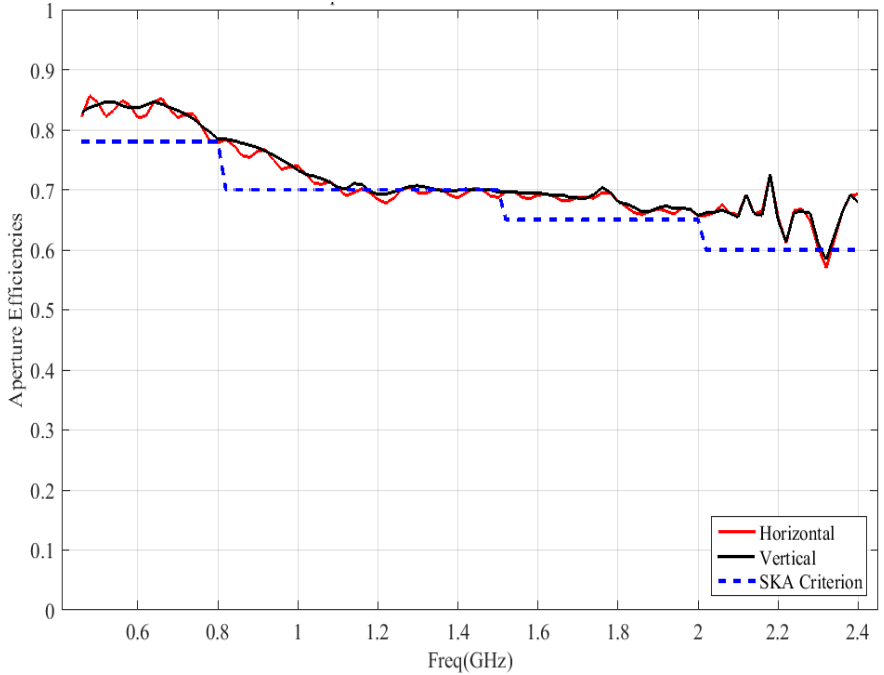




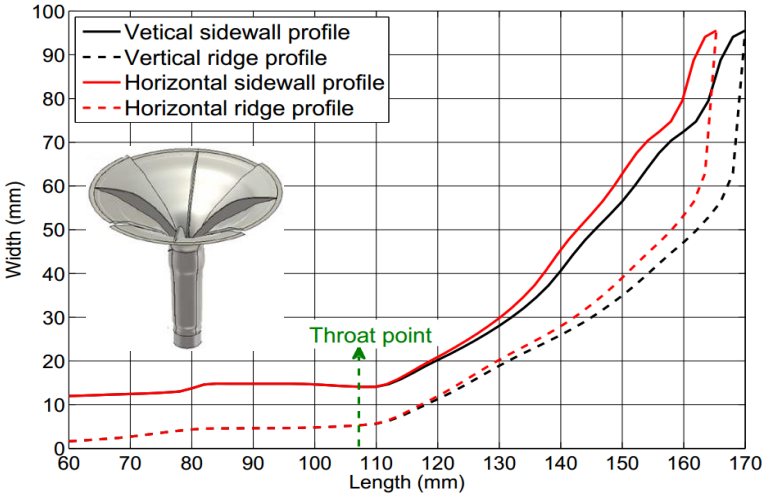
Band-B feed in a primary-dish: No discrepancy



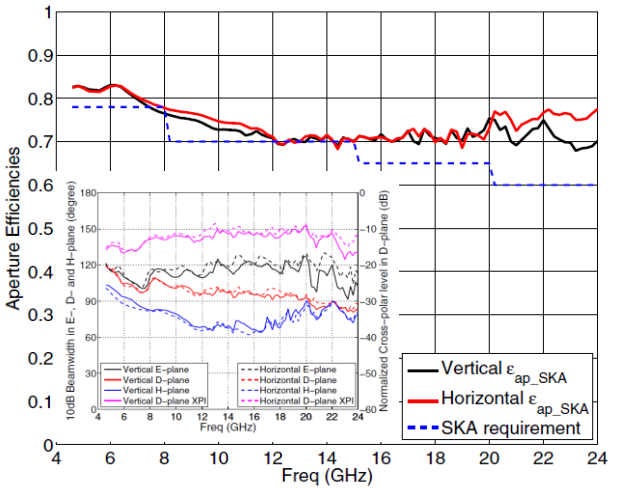
Scaled to 0.46-2.4GHz: No discrepancy



Assymetric QRFH solution



➢ Profiles' difference begins only from the "throat point" where the feed opens up;



➢ Asymmetry caused **resonance** at high band.

➢ Discontinuity gives slightly worse S11

Solution is Elliptical QRFH

Future Work

- Feed was optimized for SKA Dish, should be re-optimized for new ngVLA dish
- Re-Opt for sensitivity (spill-over reduction)
- “Smoother” efficiency
- Optics specification 55°, feed up?
- Scale Band B feed to 4 – 21 GHz for midrange feed?
- Implement fixed dewar dimensions for optimization to mitigate split-beam effect
- Implementation of spill-over cone on dish? Effects on indexer rotation of feeds?

References

"BRAND: Ultra-Wideband Feed Development for the European VLBI Network - A Dielectrically Loaded Decade Bandwidth Quad-Ridge Flared Horn"
J. Flygare, M. Pantaleev, and S. Olvhammar
12th European Conference on Antennas and Propagation (EuCAP), London 2018 April.

"Cryogenic 1.2 to 116 GHz Receiver for Large Arrays"
S. Weinreb, H. Mani, W. Zhong, J. Flygare, B. Billade, A. Akgiray, L. Dong.,
12th European Conference on Antennas and Propagation (EuCAP), London 2018 April.

"Design of an Asymmetrical Quadruple-ridge Flared Horn Feed: a Solution to Eliminate Polarisation Discrepancy in the Offset Reflecting Systems"
B. Dong, J. Yang, M. Pantaleev, J. Flygare, B. Billade
12th European Conference on Antennas and Propagation (EuCAP), London 2018 April.

"The design of the MeerKAT dish optics"
I. P. Theron, R. Lehmensiek, D.I.L. de Villiers, ICEAA'12

"Deriving an Optimum Mapping Function for the SKA-Shaped Offset Gregorian Reflectors,"., R. Lehmensiek, I. P. Theron, and D. I. L. De Villiers. *IEEE Trans. Antennas Propag.*, vol. 63, no. 11, pp. 4658–4666, 2015.

"A wide-band feed system for SKA band 1 covering frequencies from 350 - 1050 MHz,"
B. Billade, J. Flygare, M. Dahlgren, B. Wästberg, and M. Pantaleev, in *Proceedings of the 10th European Conference on Antennas and Propagation, EuCAP2016, 10-15 April*, 2016.

"Development of the Dish Verification Antenna-1 for the Square Kilometre Array,"
G. Hovey, G. Lacy, P. Byrnes, J. Fitzsimmons, and M. Fleming, *Published in 2014 16th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), Victoria, BC, Canada, 2014*

"Optimization and Realization of Quadruple-ridge Flared Horn with New Spline-defined Profiles as a High-efficiency Feed for Reflectors over 4.6– 24 GHz"., B. Dong, J. Yang, J. Dahlstr¨om, J. Flygare, M. Pantaleev, and B. Billade, *IEEE Transactions on Antennas and Propagation, September 2017 (Submitted).*

"Ultrawideband square and circular quadridge horns with near-constant beamwidth,"
A. Akgiray and S. Weinreb, *in International Conference on Ultra-Wideband (ICUWB), Syracuse, NY, USA, September 2012, pp.518–522.*

"Circular quadruple-ridged flared horn achieving near-constant beamwidth over multioctave bandwidth: Design and measurements," A. Akgiray, S. Weinreb, W. A. Imbriale, and C. Beaudoin, *IEEE Transactions on Antennas and Propagation, vol. 61, no. 3, pp. 1099–1108, March 2013.*

"An optimal beamforming strategy for wide-field surveys with phased-array-fed reflector antennas," M. Ivashina, O. Iupikov, R. Maaskant, W. van Cappellen, and T. Oosterloo, *Antennas and Propagation, IEEE Transactions on, vol. 59, no. 6, pp. 1864–1875, June 2011*

http://ngvla.nrao.edu

https://www.skatelescope.org