NRC-HAA Cryogenic Radio Receiver Development

Sara Salem Hesari, Doug Henke, Lewis Knee, Vlad Reshetov, Bruce Veidt,

Frank Jiang, Alireza Seyfollahi, Ivan Wevers, Neal Kelly

www.nrc-cnrc.gc.ca
NRC Herzberg Astronomy and Astrophysics Research Centre, Victoria, BC, Canada
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Presenter: Sara Salem Hesari, Ph.D.
RF Engineer
Email: sara.salemhesari@nrc-cnrc.gc.ca

Agenda

- RIT Research Activity

- Q-band/ngVLA Band-5 receiver development
  - System design
  - Feed horn
  - OMT
  - Vacuum window
  - LNA
  - Cryostat model

- Octave band receiver development
  - Feed horn
  - OMT
  - Vacuum window
  - LNA

RIT Research Activity

- Design and development of a cryogenic receiver for ngVLA band-5
- Design and development of an Octave band radio receiver

- Feed horns → Corrugated feed; Quad-ridge horn; Clover-leaf horn (D. Henke, S. Salem Hesari)
- OMT → Linear polarization; Circular polarization; Compact structure (D. Henke)
- Vacuum window → Anti-reflection layers; Noise analysis; Optical analysis; Mechanical analysis (S. Salem Hesari, B. Veidt, V. Reshetov)
- Mixer → A. Seyfollahi
- Cryostat design → V. Reshetov
- IR filters → Thick IR filters with AR layers; Multi layer IR filters; Optical analysis; Mechanical analysis (S. Salem Hesari, B. Veidt, V. Reshetov)
- LNA/ MMIC → Hybrid LNA; MMIC; GaAs LNA; InP LNA (F. Jiang, A. Seyfollahi, A. Densmore)
- Noise calibration module → S. Salem Hesari, D. Henke
- Receiver noise analysis → S. Salem Hesari, D. Henke
- Material characterization → S. Salem Hesari, D. Henke
- System engineering → S. Salem Hesari, D. Henke
- Thermal analysis → V. Reshetov
- Project management → Q-band receiver project; Octave band receiver project (S. Salem Hesari, D. Henke, L. Knee)

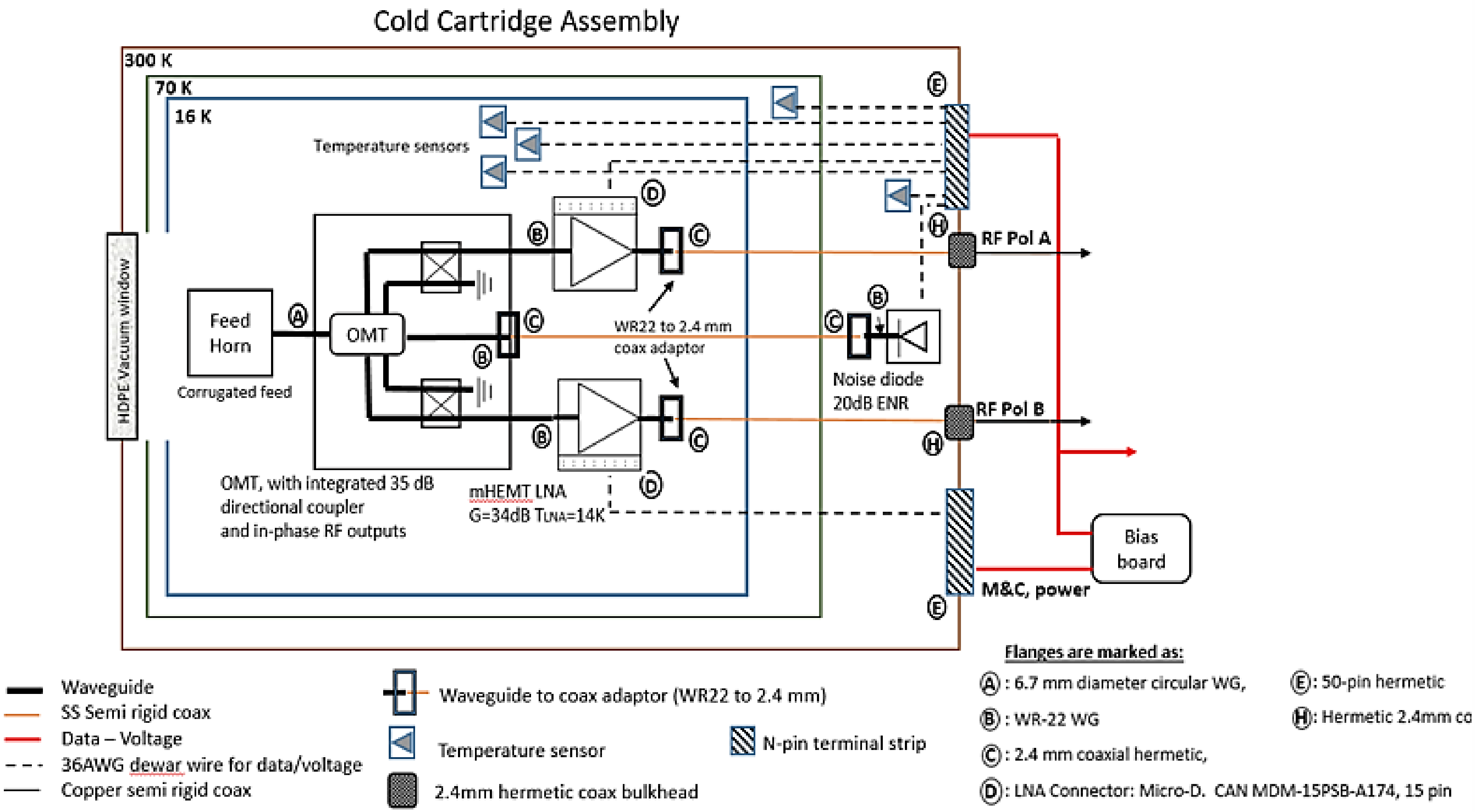
ngVLA Band-5 Receiver

➢ Q-band receiver specification

RF frequency range	30.5 - 50.5 GHz
Polarization	Dual-linear
Receiver noise temperature	T_{RX} < 25 K over entire band
Optics	Optimized for ngVLA
LNA noise temperature	T_{LNA} < 14 K (GaAs mHEMT LNA) T_{LNA} < 12 K (InP LNA)
Calibration	Noise injection
Monitoring	Remote monitor and control
Cryogenic environment	2-stage Gifford-McMahon cryopump system (16 K and 70 K stages)

System description

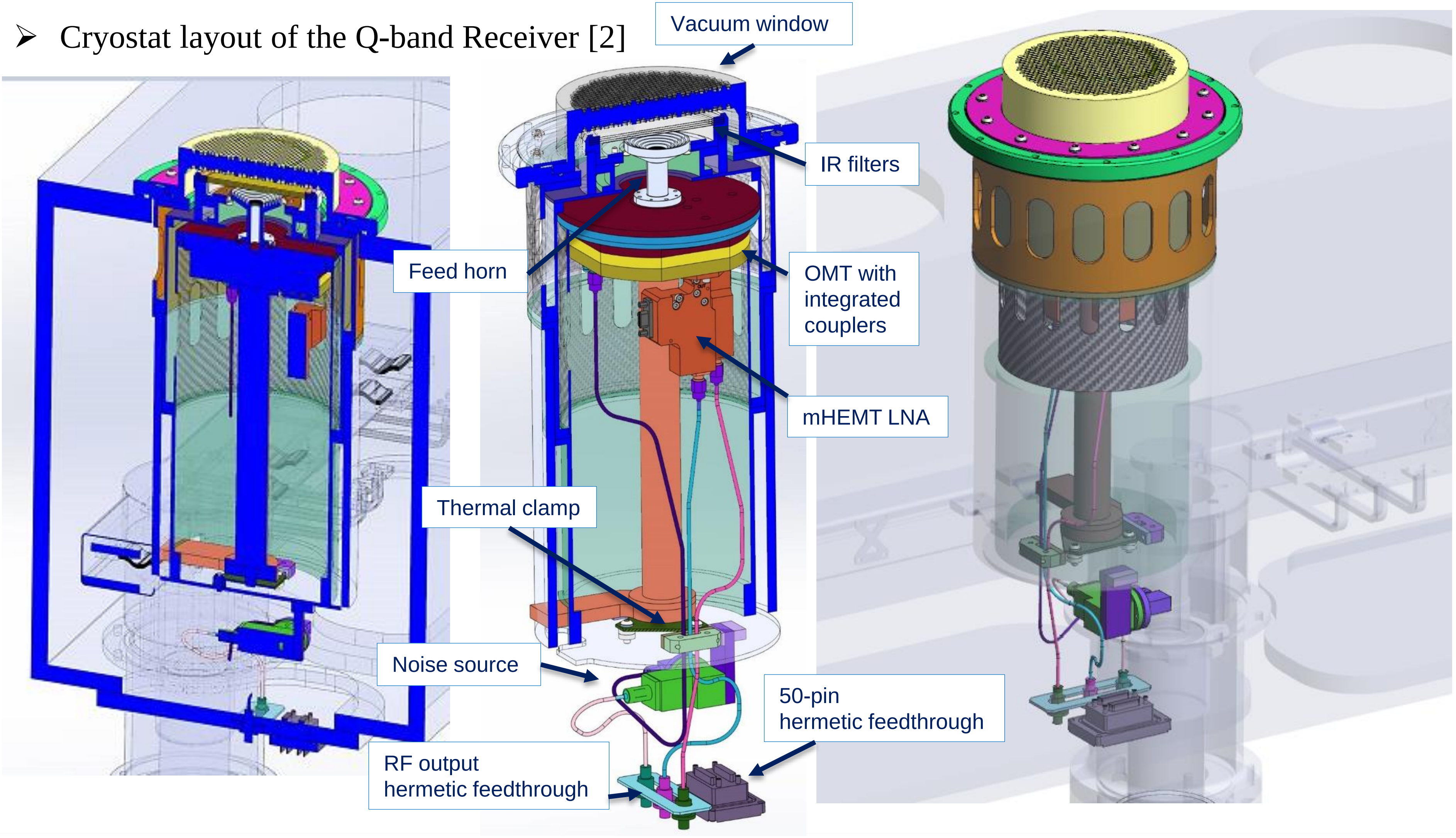
➢ Front-end Q-band Receiver Electrical Block Diagram [1]



[1] S. Salem Hesari, et al, "Q-band receiver system design for the Canadian DVA-2 radio telescope", SPIE, 2020

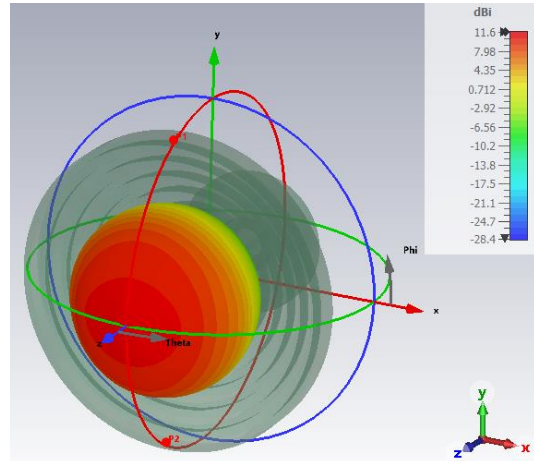
System description

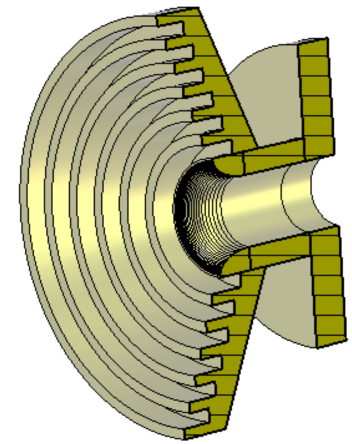
➢ Cryostat layout of the Q-band Receiver [2]

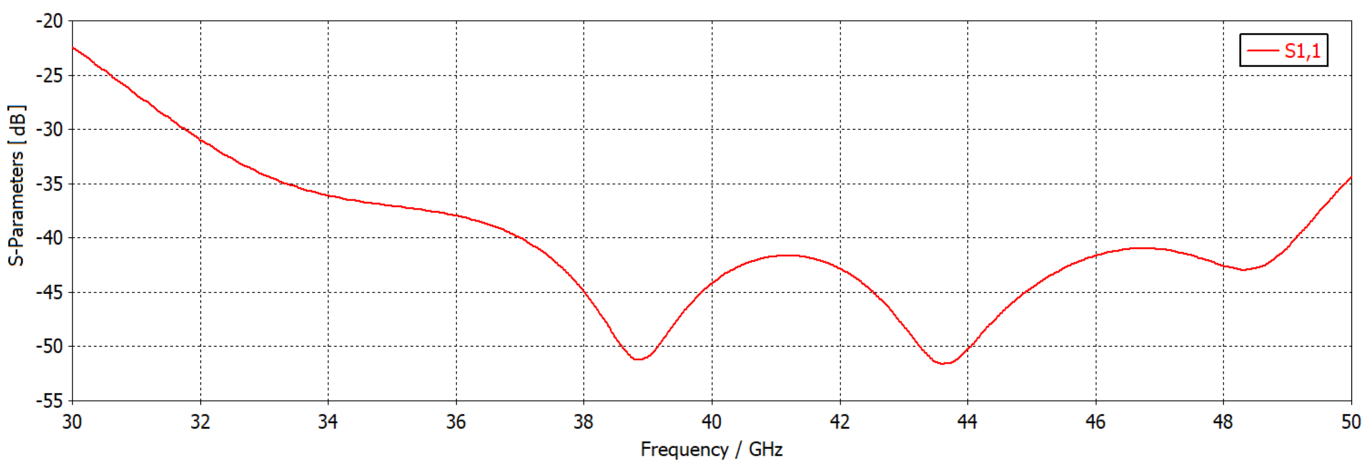


Feed Horn

- Corrugated feed horn with logarithmic flare
- Compact structure
- Suitable candidate for all ngVLA bands
- Machinable features
- Could consider for 3D printing
- Symmetric pattern

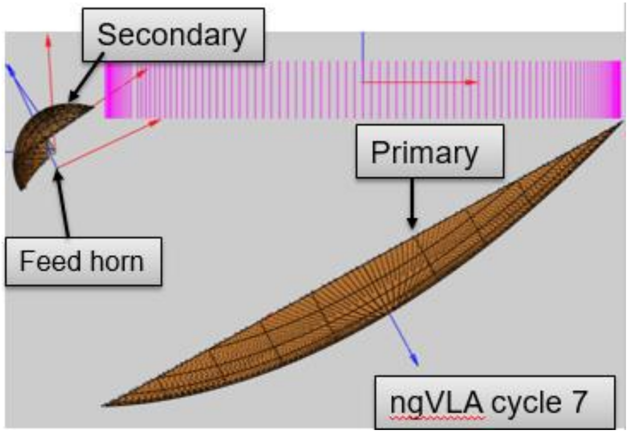


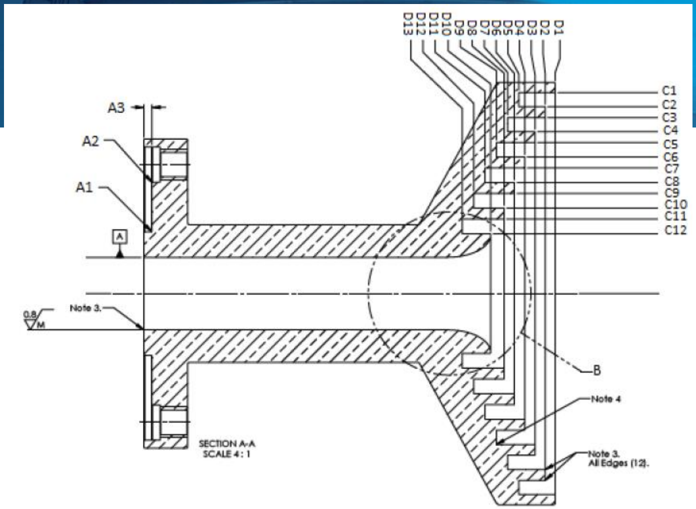




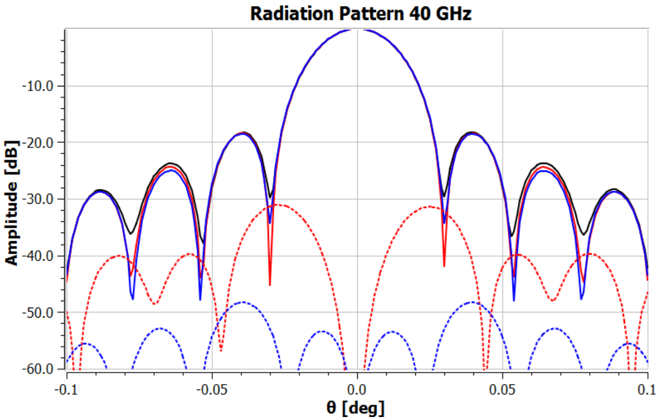
[3] D. Henke, et al, “Axial Ring Feed Horn with Logarithmic Flare for Offset Gregorian Optics,” URSI GASS, 2021.
[4] S. Salem Hesari, at al, “A Compact Axial-Ring Feed Horn and Vacuum Window Model for a Cryogenic Q-band Receiver”, IEEE ANTEM, 2021

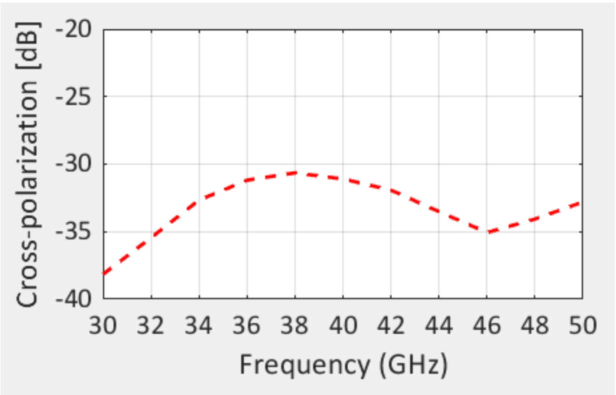
Feed Horn

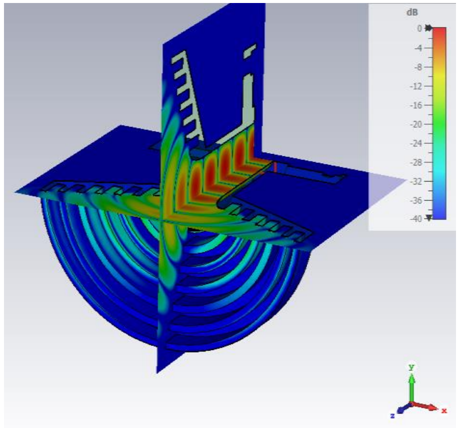




Frequency (GHz)	30	34	40	44	50
Aperture efficiency of a Gaussian feed (55°, 16dB)	95.8	95.9	96	96	96.1
Aperture efficiency of the Feed horn	95.6	95.5	95.5	95.3	96.3



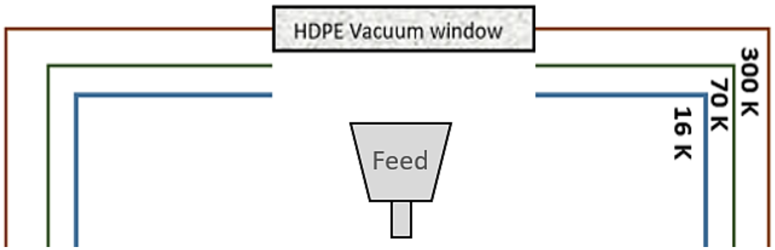


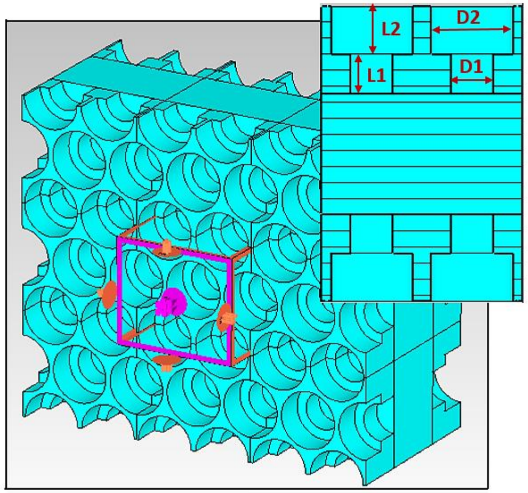


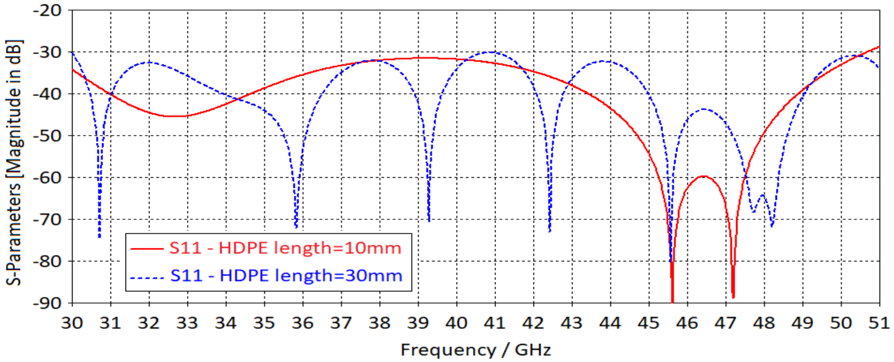
[3] D. Henke, et al, “Axial Ring Feed Horn with Logarithmic Flare for Offset Gregorian Optics,” URSI GASS, 2021.
[4] S. Salem Hesari, at al, “A Compact Axial-Ring Feed Horn and Vacuum Window Model for a Cryogenic Q-band Receiver”, IEEE ANTEM, 2021

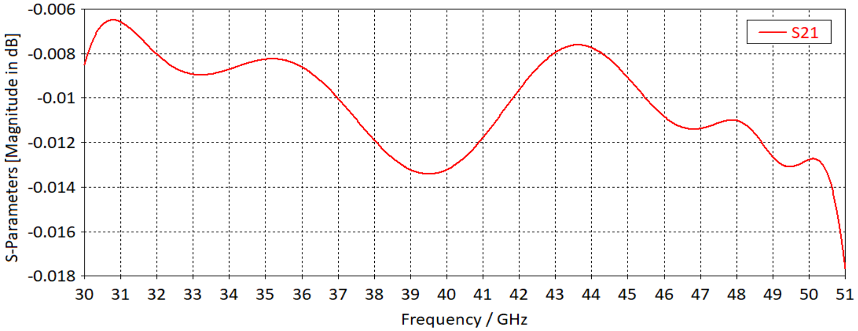
Vacuum window / IR filters

- Vacuum window is the first optical component of the cartridge









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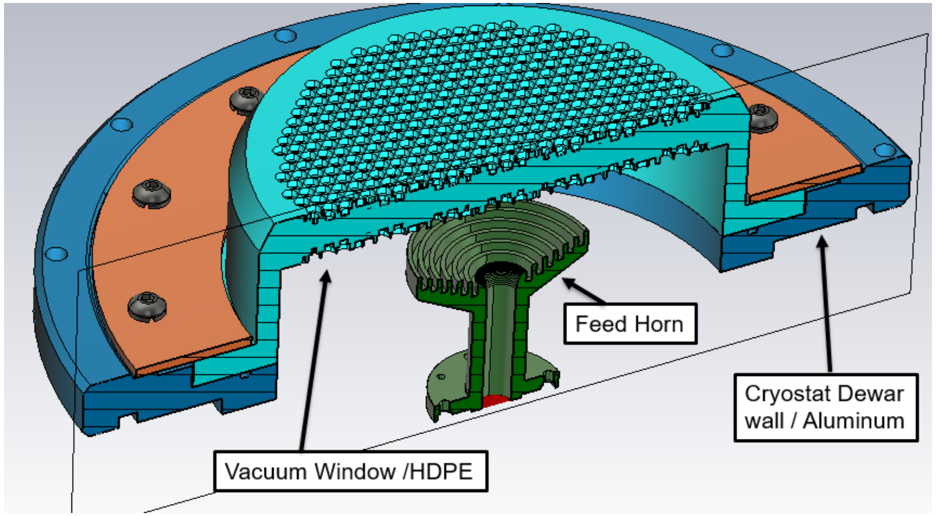
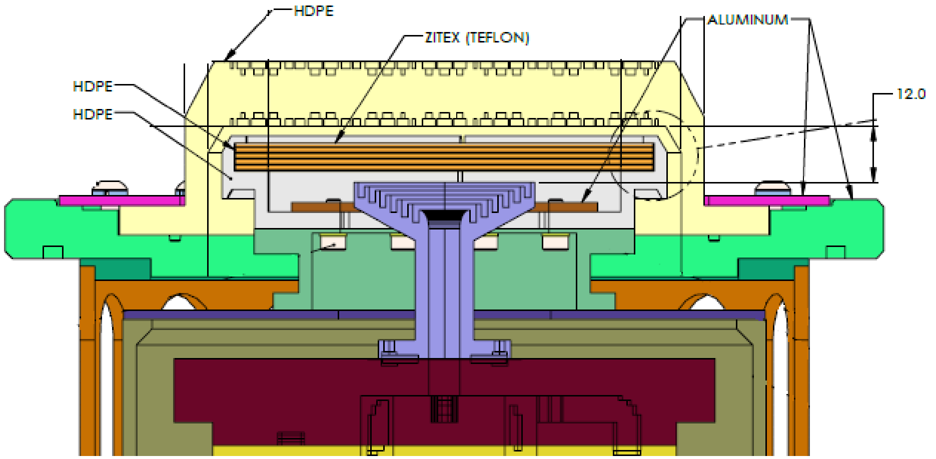
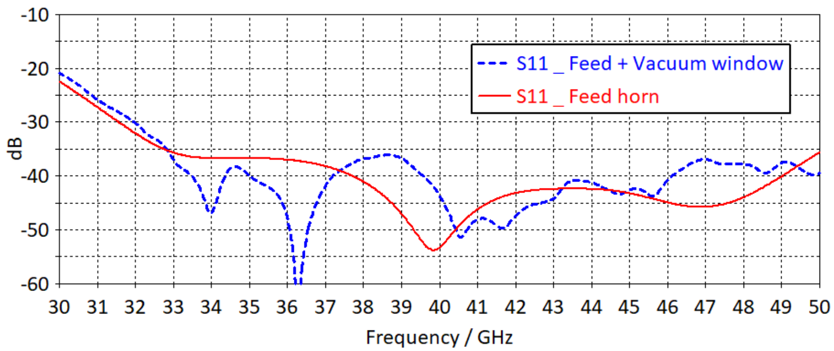




Aperture efficiency (%)					
Frequency (GHz)	30	34	40	44	50
Gaussian feed (55°, 16dB)	95.8	95.9	96	96	96.1
Feed horn	95.6	95.5	95.5	95.3	96.3
Feed horn + vacuum window	94.5	95.1	95.3	95.5	95



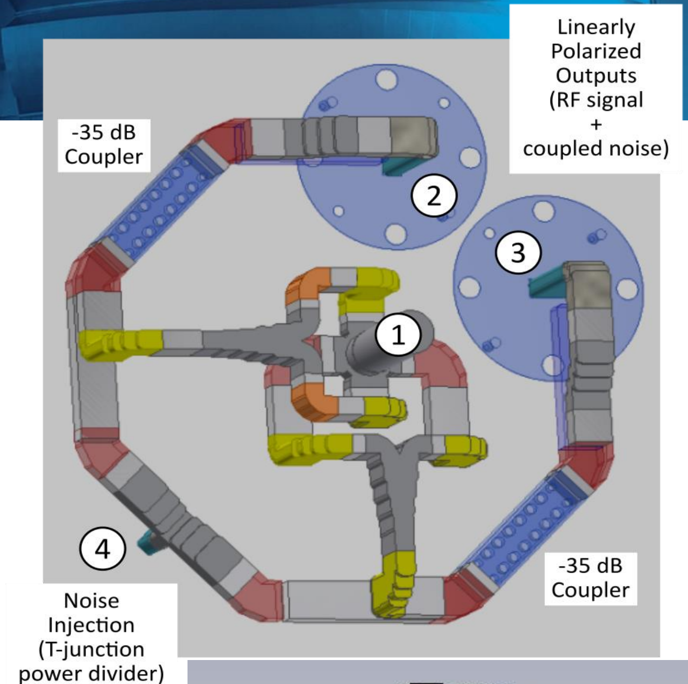
OMT + NC

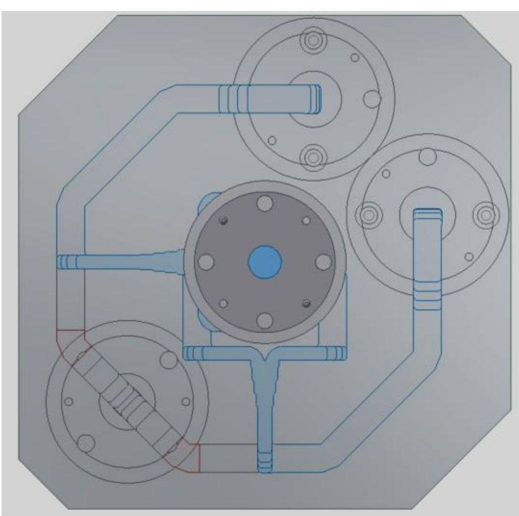
- Ortho-Mode transducer (OMT)

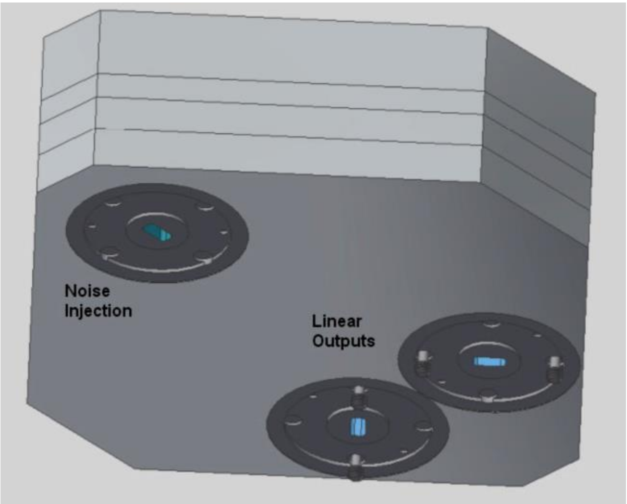
  Port-1: input from feed horn circular waveguide

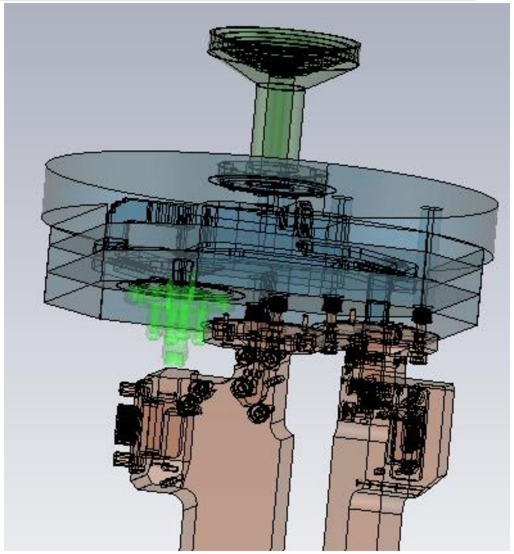
  Ports 2 and 3: linear X and Y output WR-22

  Port-4: coupled noise injection input WR-22



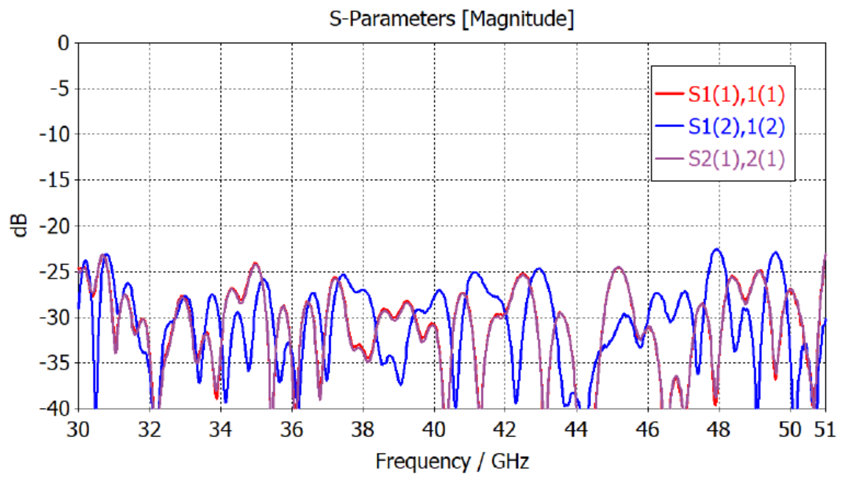


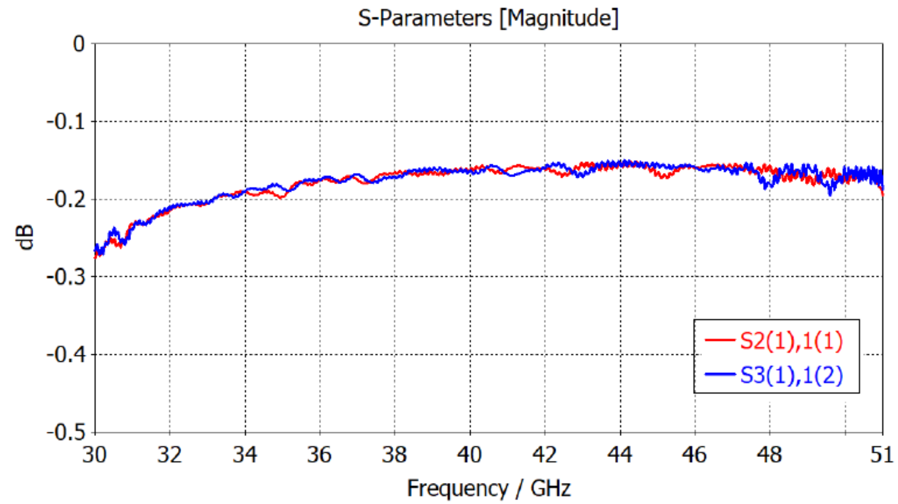


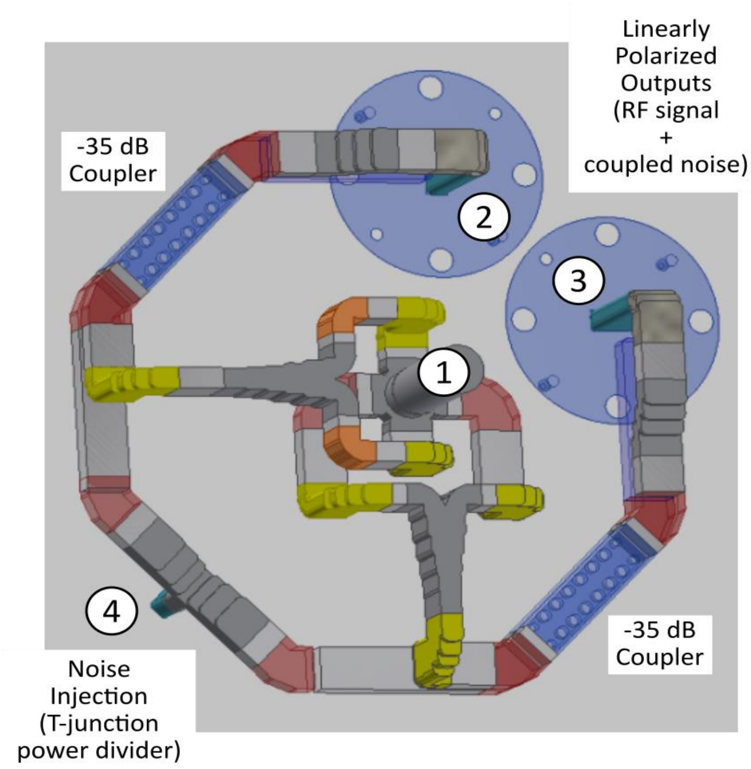


OMT + NC

- Ortho-Mode transducer (OMT)







[5] D. Henke, "OMT Data-Pack for ngVLA," NRC Herzberg, no. HAA-RIT-NGVLA-001-DSN-A, May 14, 2021.

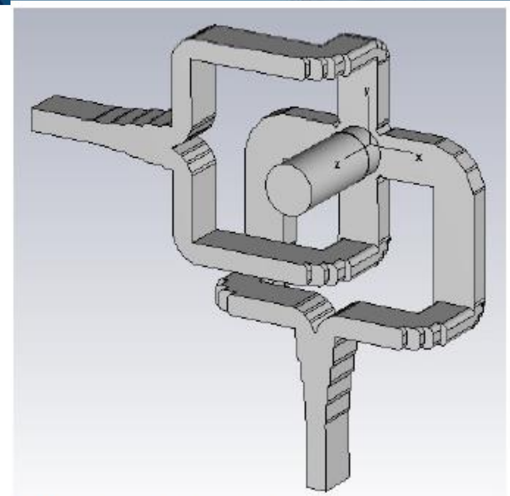
OMT + NC

- **OMT Data-Pack for ngVLA [5]**

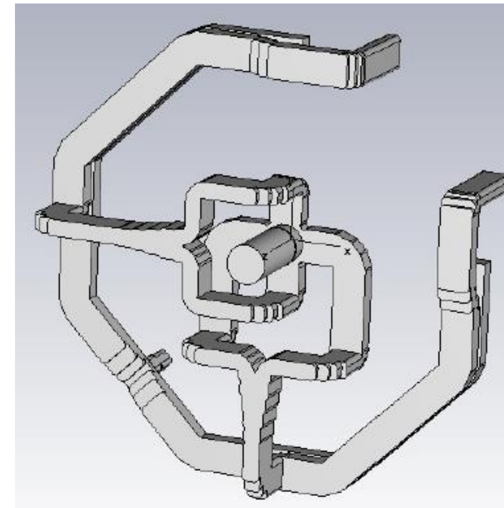
  4 variations of possible OMT models for ngVLA.

  EM designs have been optimised for Band 5 using WR-22.

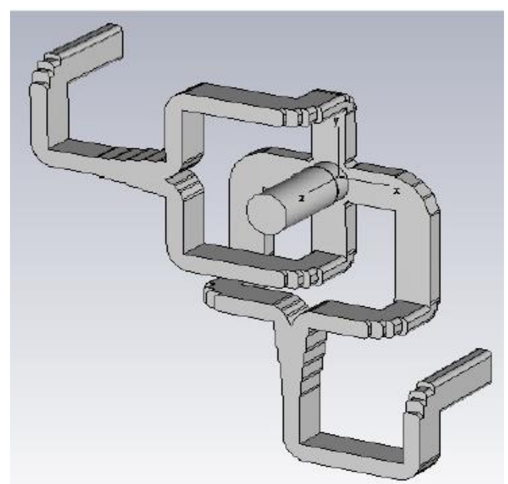
  Note that the dimensions are generally scalable across Bands 3–6.



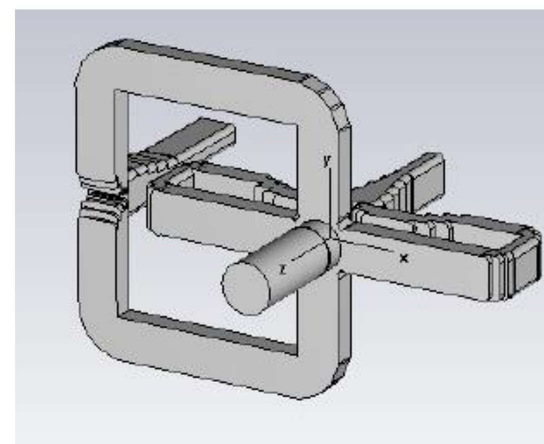
NRC-1a: 3-Pc, Side Ports



NRC-1c: 4-Pc, with Couplers



NRC-1b: 3-Pc, Bottom Ports



NRC-2: Compact

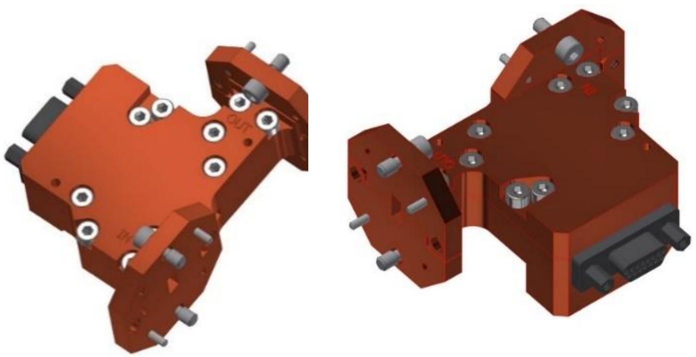
[5] D. Henke, “OMT Data-Pack for ngVLA,” NRC Herzberg, no. HAA-RIT-NGVLA-001-DSN-A, May 14, 2021.

Cryogenic LNA

➢ One of the most critical building blocks in a radio telescope is LNA.

$$T_{CASCADE} = T_{LNA} + T_{POST\_LNA} / G_{LNA}$$

An mHEMT MMIC LNA design with WR-22 waveguide input and output ports:



Q-band low noise amplifier chassis

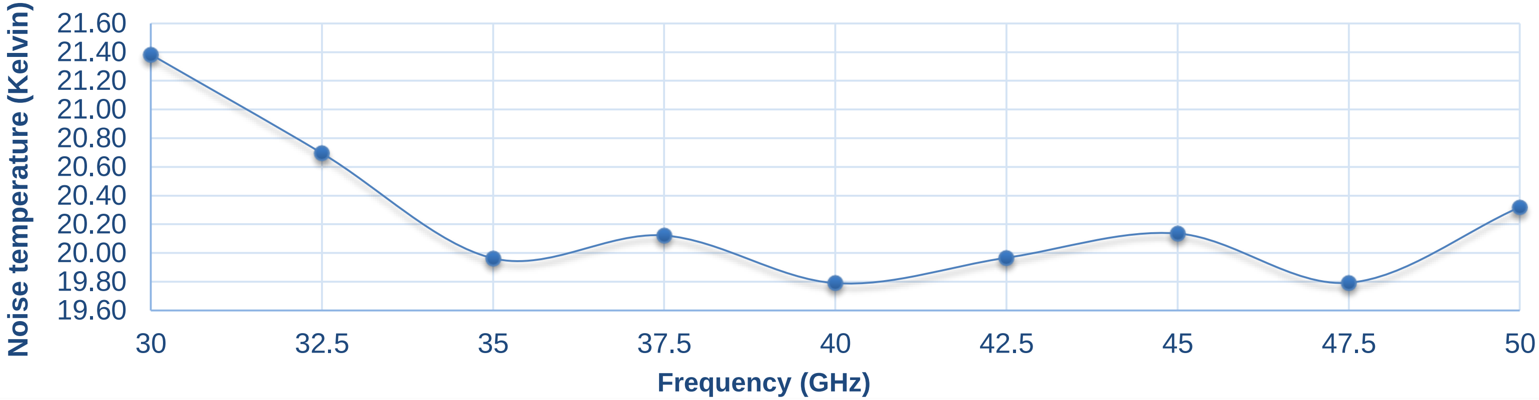
Frequency	30 – 50 GHz
Gain, S21	≥ 34 dB
Input match, S11	≤ -10 dB
Output match, S22	≤ -10 dB
Isolation	50 dB
Noise temperature	≤ 14 K
Gain flatness	± 1.5 dB

[6] F. Jiang, et al, “Cryogenic LNA Development for ngVLA Band 1, 3, 4, and 5 Receivers,” NRC Herzberg, HAA-RIT-NGVLA-003-REP-A, Oct. 1, 2021.
[2] S. Salem Hesari, et al, “NRC Q-band/Band-5 Receiver Development for the ngVLA,” NRC Herzberg, HAA-RIT-NGVLA-001-REP-A, Oct. 1, 2021.

Cascaded Noise Analysis

Component	Gain [dB]	Cum. Gain [dB]	$T_{comp.}$ (K)	T_{rx} (K)	Phys. Temp (K)
Vacuum window	-0.014	-0.01	0.96	0.96	300
Feed Horn	-0.018	-0.03	0.06	1.03	16
OMT(integrated coupler)-thru path	-0.3	-0.33	1.14	2.18	16
Calibration coupler-coupled path	0	-0.33	0.09	2.29	300
WG to WG flange	-0.05	-0.38	0.18	2.49	16
LNA	30	29.6	13	16.6	16
WG to coax adaptor	-0.5	29.1	1.95	16.6	16
Stainless steel coax cable	-2	27.1	87.7	16.7	150
Coax cable to noise diode	-1	26.1	77.6	16.9	300
BPFilter (35-50GHz)	-2	24.1	175.4	17.3	300
Post amplification	25	49.1	527.3	19.4	300
Mixer	6	55.1	1716	19.4	300
Back-end cables	-5	50.1	648.6	19.4	300

Values are simulated or estimated, not measured.



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Octave Band Receiver

➢ System Overview Comparison

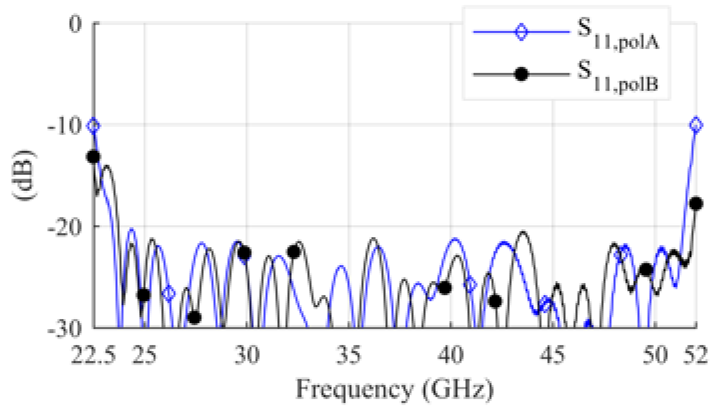
	Standard band	Octave band
Bandwidth	1.66:1	**2:1** (20% instantaneous bandwidth increase)
Frequency range	30.5 -50.5 GHz	25-50 GHz
Window	Reflected power < -30dB (2-stepped hole AR, UHMWPE)	Reflected power < -25dB (2-stepped hole AR, UHMWPE)
Feed horn	Reflected power < -25dB Aperture efficiency > 95% Cross-pol < -30dB Phase efficiency > 99.5%	Reflected power < -25dB Aperture efficiency **> 92%** Cross-pol **< -25dB** Phase efficiency **> 99.3%**
OMT	Reflected power < -26dB Cross-pol isolation < -50dB Insertion gain > -0.25dB	Reflected power **< -21dB** Cross-pol isolation **< -40dB** Insertion gain **> -0.35dB**
LNA	Input reflected power < -10dB Output reflected power < -14dB Gain > 30dB	Input reflected power < -10dB Output reflected power **< -10dB** Gain > 30dB

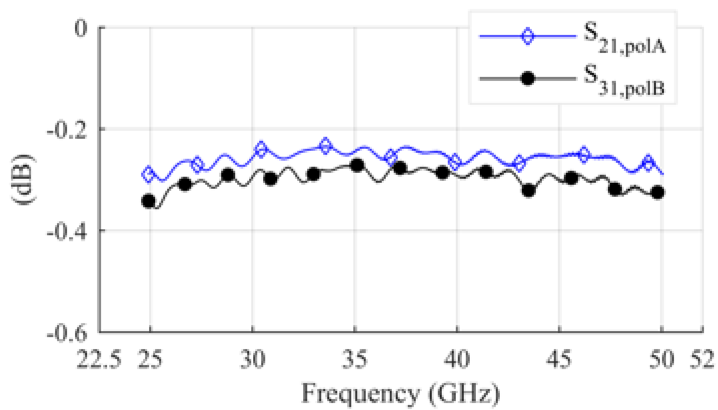
Values are simulated or estimated, not measured.

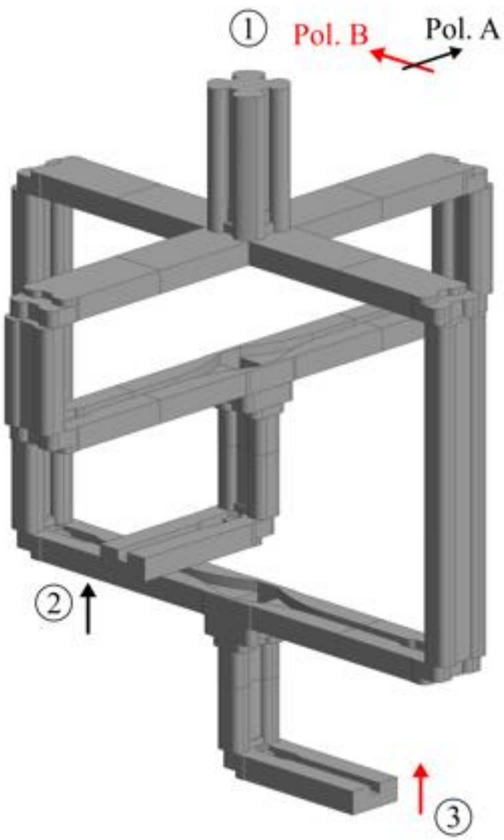
[7] D. Henke, et al, "Octave Band Receiver for ngVLA," NRC Herzberg, HAA-RIT-NGVLA-002-REP-A, Oct. 1, 2021.

Octave Band Receiver _ OMT

- The complete assembly of ridge waveguide features that comprise the OMT, including a turnstile junction, E-bends, and a T-junction combiner.





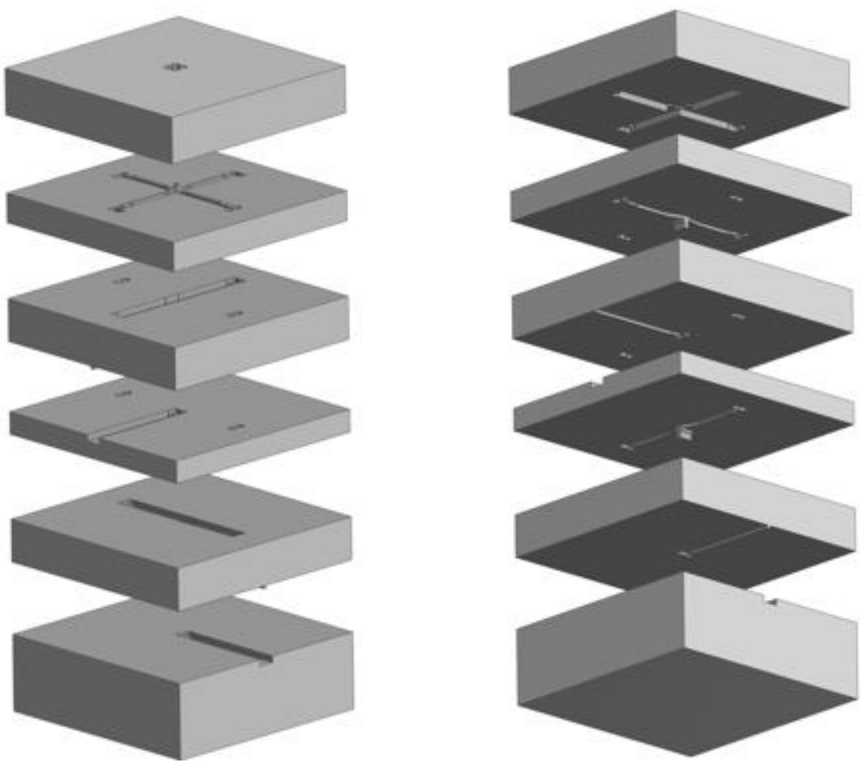


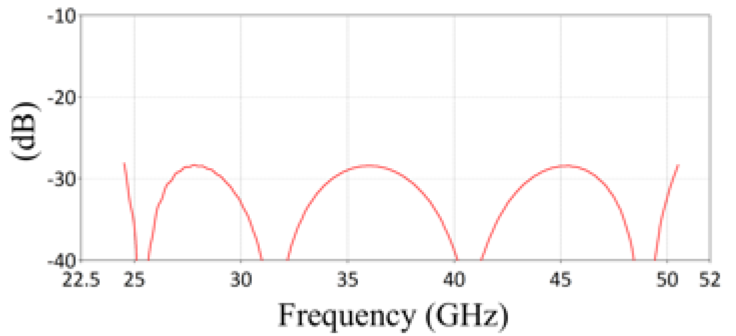
[7] D. Henke, "A Full Octave-Band OMT for Millimetre-Wave Receivers," in Proc. 31st Int. Symp. Space Terahertz Technol., Tempe, Arizona, Mar. 2020, http://www.nrao.edu/meetings/isstt/papers/2020/2020000046.pdf

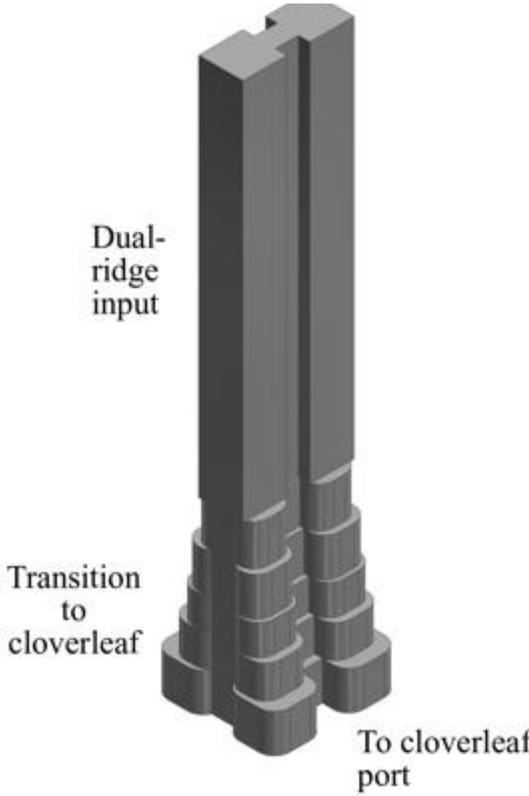
NRC·CNRC

Octave Band Receiver _ OMT

- Mechanical assembly showing the six layer stack-up.



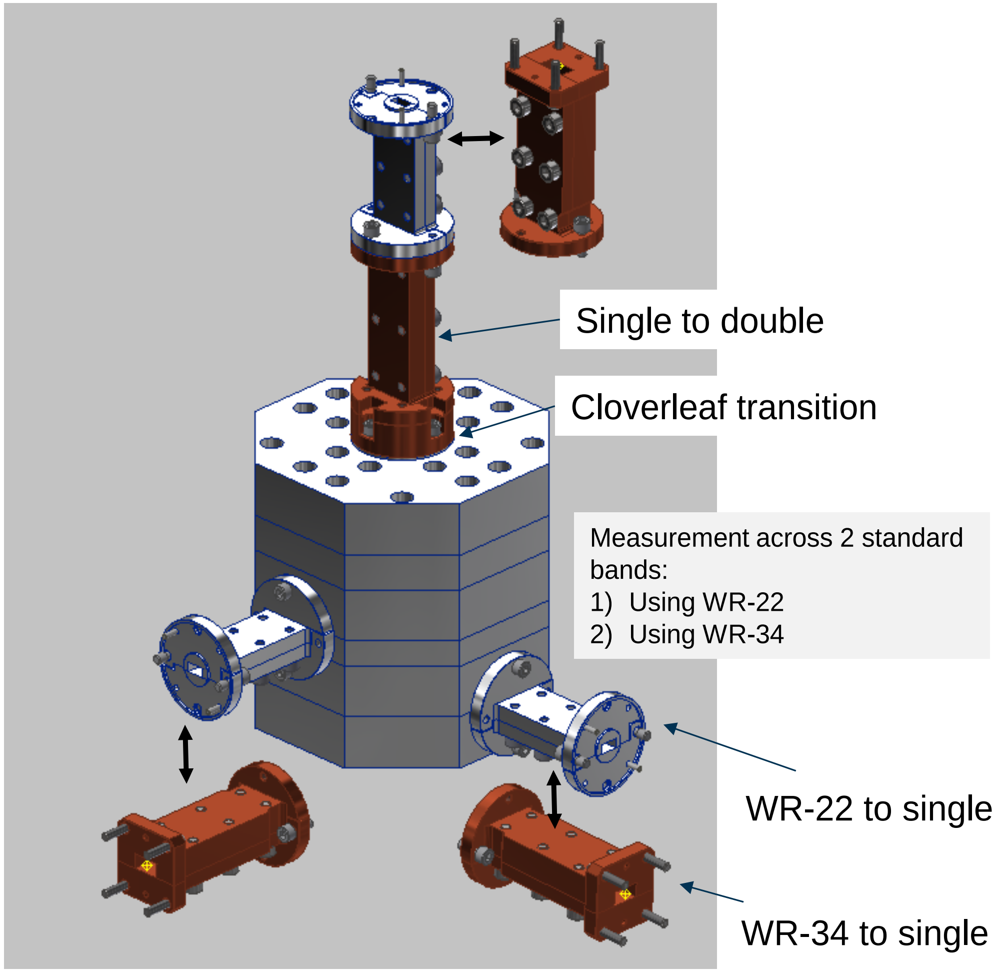




Octave Band Receiver _ OMT

Required for full testing of OMT

- WR-22 to single (qty. 3)
- WR-34 to single (qty. 3)
- Single to double ridge
- Cloverleaf transition
- OMT



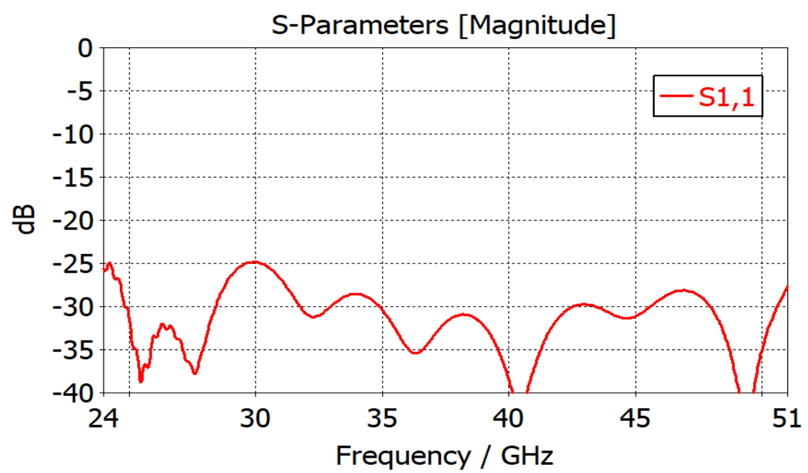
Measurement across 2 standard bands:
1) Using WR-22
2) Using WR-34

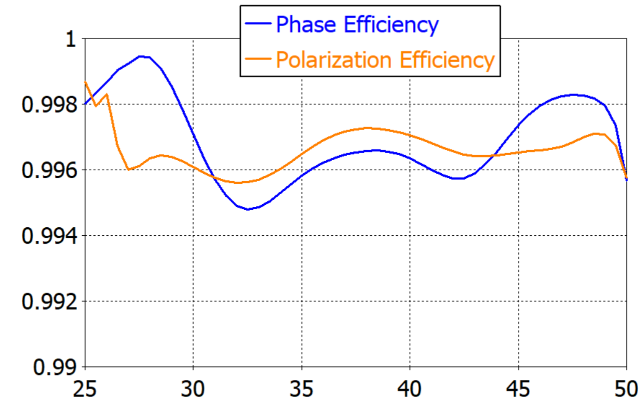
Octave Band Receiver _ OMT

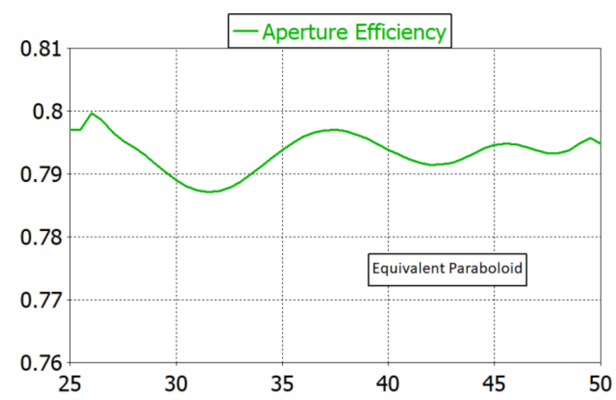
- Pictures showing progress of machined adapters and transitions for measuring the octave band OMT.

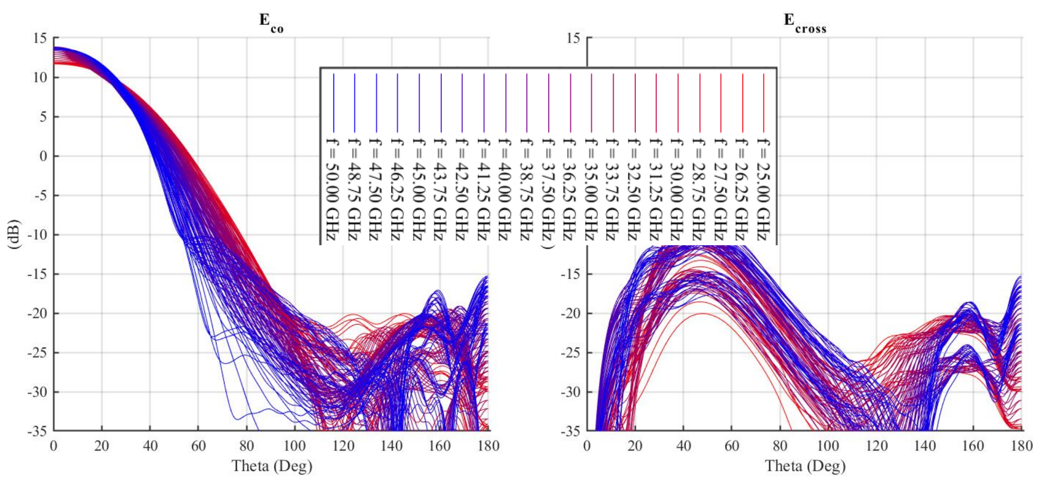
Octave Band Receiver _ Feed Horn

- **Quad-Ridge with Axial Grooves**





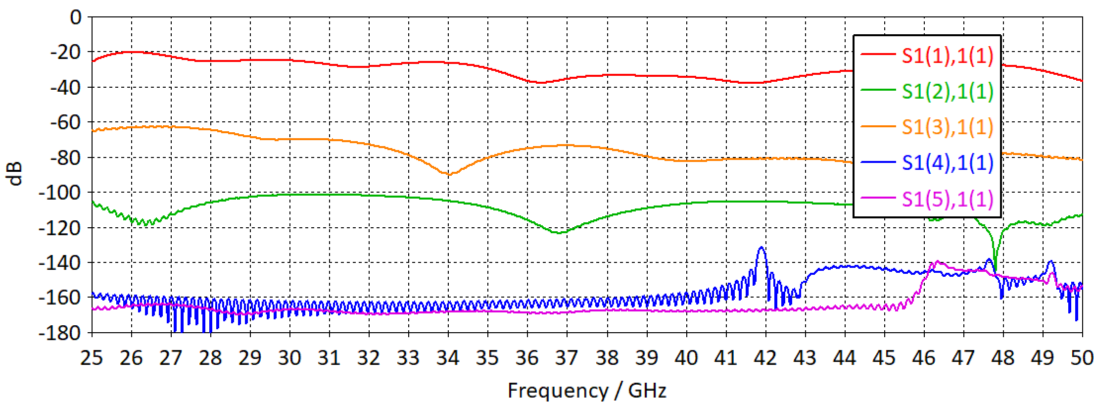


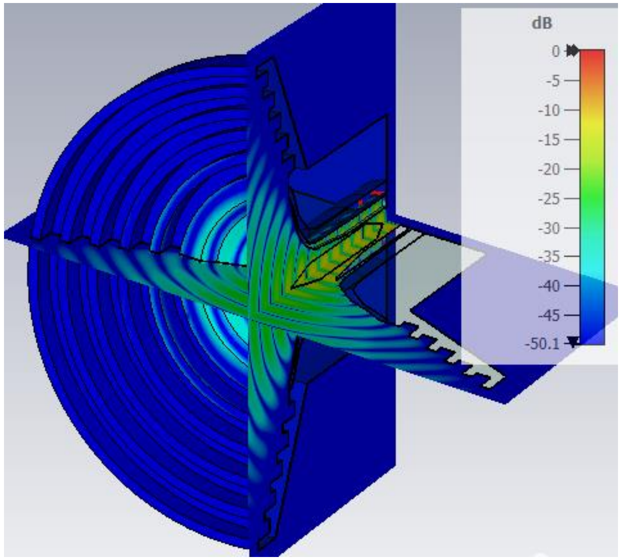


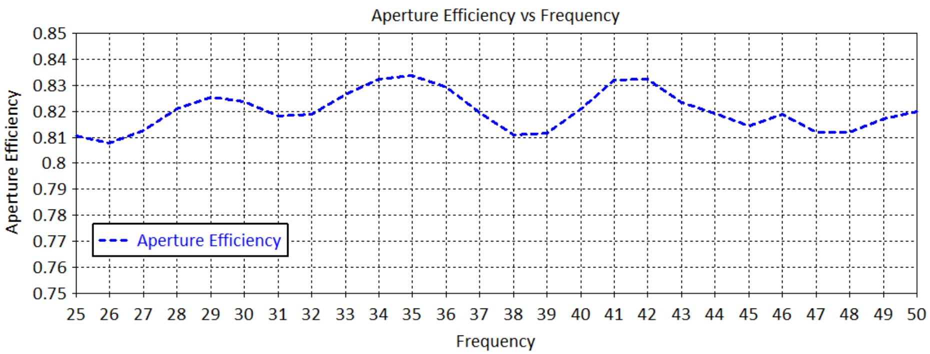
[7] D. Henke, et al, "Octave Band Receiver for ngVLA," NRC Herzberg, HAA-RIT-NGVLA-002-REP-A, Oct. 1, 2021.

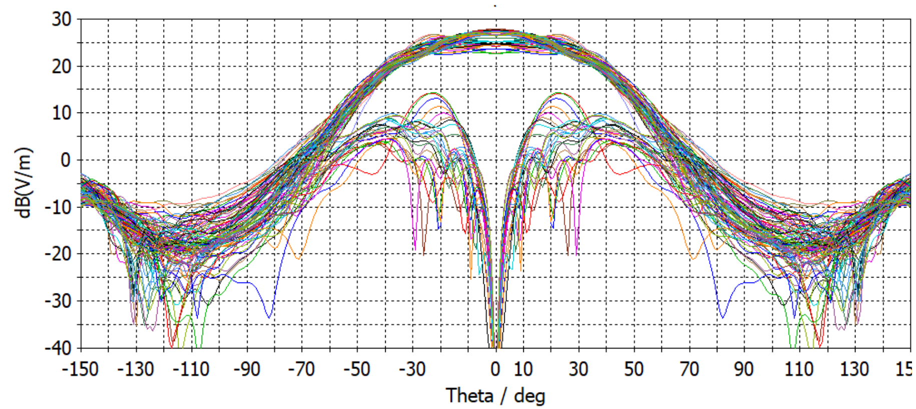
Octave Band Receiver _ Feed Horn

- Quad-Ridge with Axial Groove and a dielectric rod



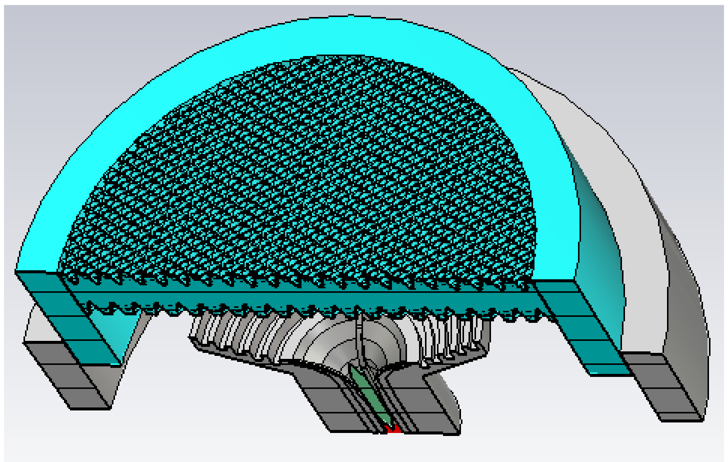


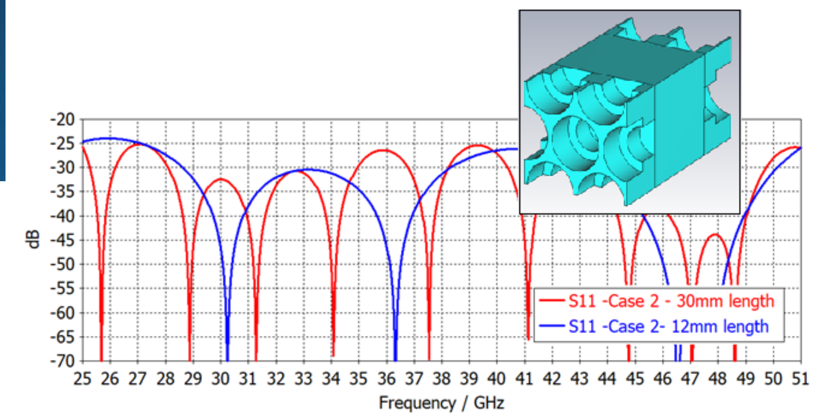


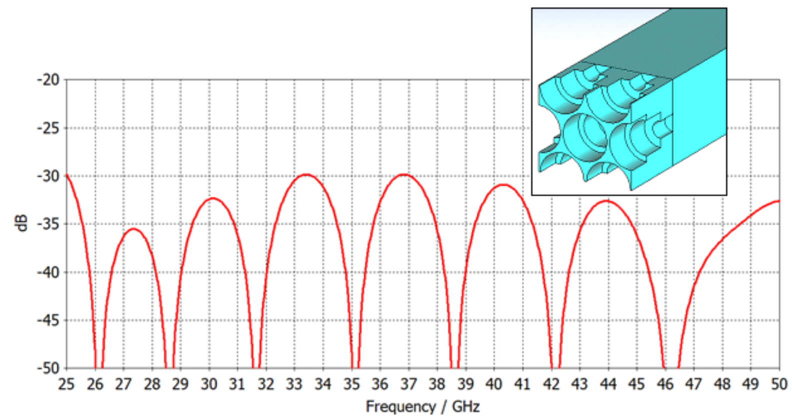


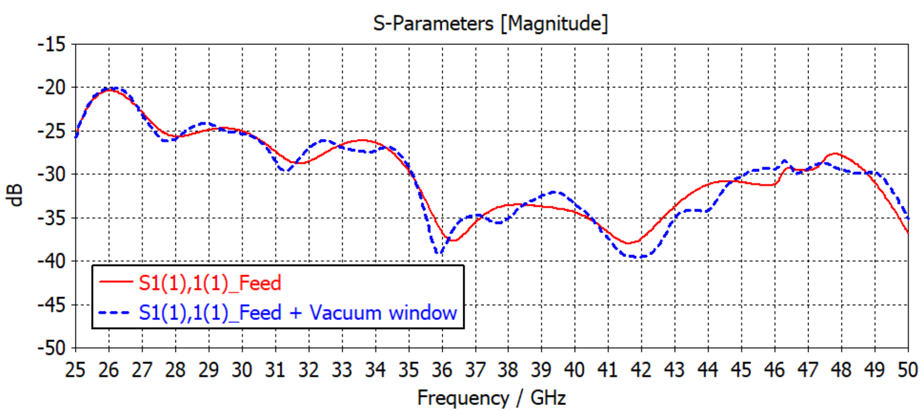
Octave Band Receiver _ Vacuum Window

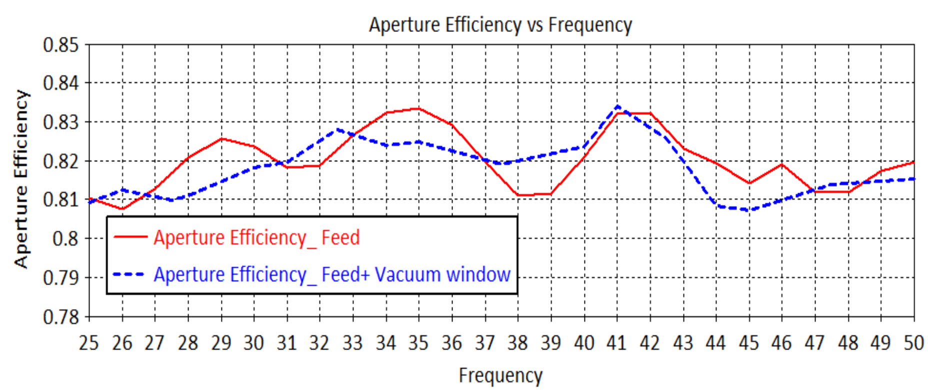
➢ **Cryostat Vacuum Window**







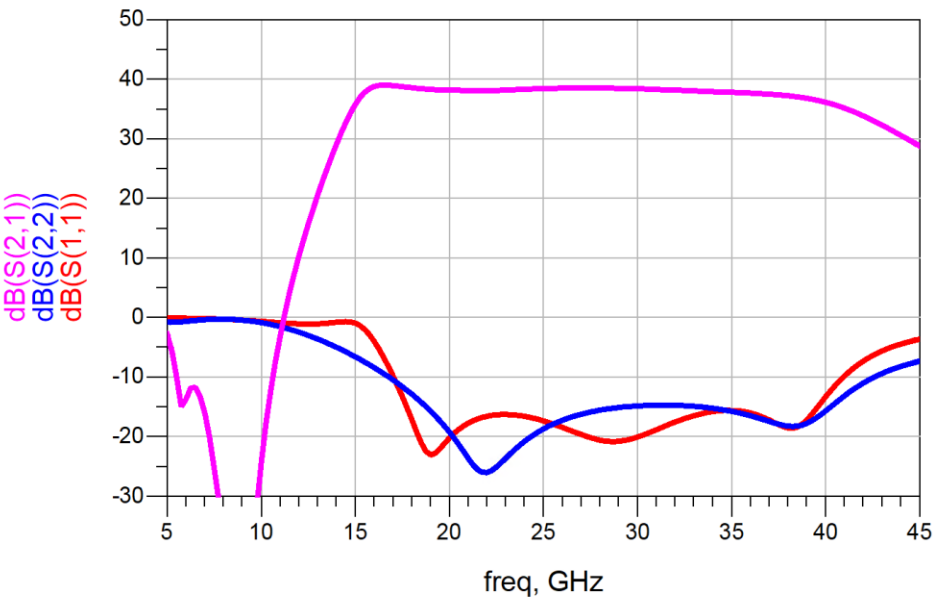




Octave Band Receiver: LNA

- **GaAs mHEMT MMIC design covering 18–36 GHz**

(widened octave bandwidth for ngVLA Band 4)



S-parameter simulation at room temperature for 18–36 GHz MMIC chip

Estimated cryogenic performance: ~38 dB, 7–12 K

[6] F. Jiang, et al, "Cryogenic LNA Development for ngVLA Band 1, 3, 4, and 5 Receivers," NRC Herzberg, HAA-RIT-NGVLA-003-REP-A, Oct. 1, 2021.
[7] D. Henke, et al, "Octave Band Receiver for ngVLA," NRC Herzberg, HAA-RIT-NGVLA-002-REP-A, Oct. 1, 2021.

THANK YOU

Sara Salem Hesari, Ph.D.

RF Engineer

Email: sara.salemhesari@nrc-cnrc.gc.ca

NRC Herzberg Astronomy and Astrophysics Research Centre, Victoria, BC, Canada

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