Reference Receiver Concept for a Next-Generation Very Large Array

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Front End Reference Design

The proposed receiver configuration will be implemented as six independent single-pixel receiver bands, each with its own feed. The upper five bands (2-6) will be integrated into a single compact cryostat, while the lowest-frequency band (1) occupies a second cryostat of similar volume and mass. Due to its large size, the Band 1 feed is cooled only to 80K, while the feeds for Bands 2-6 are cooled to 20K. A mechanical concept for these two receiver cryostats is shown in **Figure 1**.

For continuous coverage between 1.2 – 12.3 GHz, waveguide or even octave-bandwidth receivers are not cost-effective, given the > 10:1 frequency range. For these bands, wideband (3.5:1) LNAs mated to a Caltech-designed quad-ridge feed horn (QRFH) are proposed [2]. These feeds are highly compact, and are cryogenically cooled to reduce losses ahead of the LNAs. Aperture efficiency, spillover and LNA noise temperature may be somewhat less than optimum: however, there would be significant cost savings by effectively halving the number of receivers and cryostats required per antenna. A cross-sectional view of the QRFH profile, with the simulated aperture efficiency and spillover versus frequency are shown in **Figure 2**.

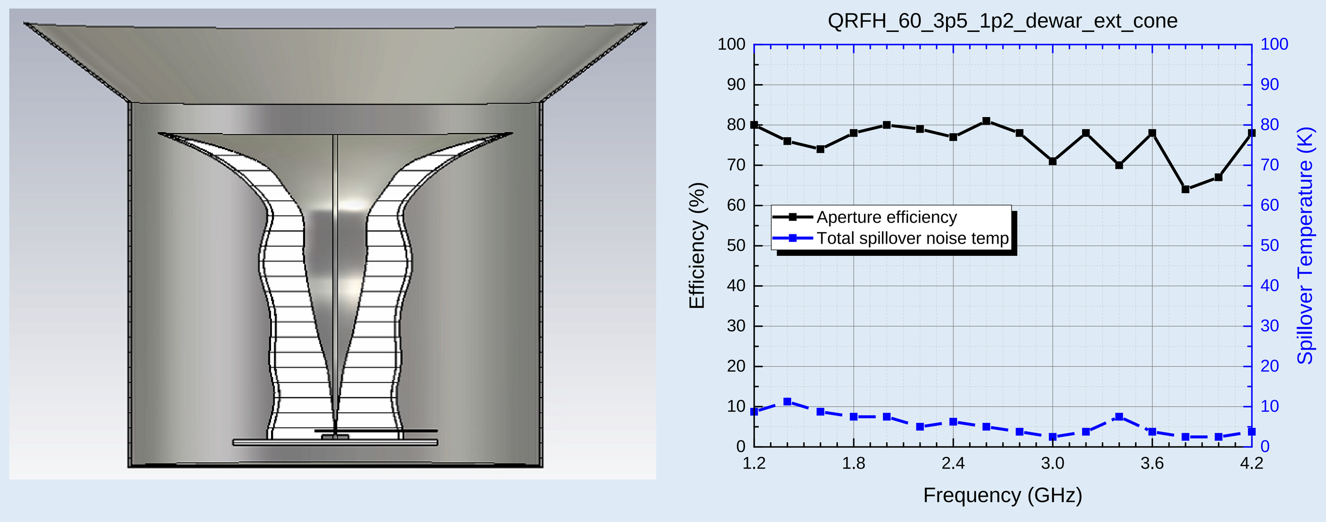

Figure 2: Quad-ridge feed horn profile, aperture efficiency, and spillover performance

For optimum performance at the higher frequencies, waveguide-bandwidth (~1.66:1) receivers are proposed to cover 12.3 – 50.5 GHz and 70 – 116 GHz in four separate bands, integrated into a single cryostat. Excellent LNA noise performance is readily achievable, and using waveguide throughout the signal chain reduces losses and their associated noise contributions, without adding undue size or weight.

An axially-corrugated conical feed horn with wide flare angle (~55^0 half-angle), based on a design by G. Cortes and L. Baker [1], is being considered for the waveguide bandwidth receivers. This design is extremely compact, with very good aperture efficiency (75-80%), excellent RF match and low loss over an octave of bandwidth. However, unlike the QRFH it does require an external polarization separator or OMT, which adds a small amount of additional loss. A 3D rendering of this feed, with a plot of simulated aperture efficiency over frequency are shown in **Figure 3**.

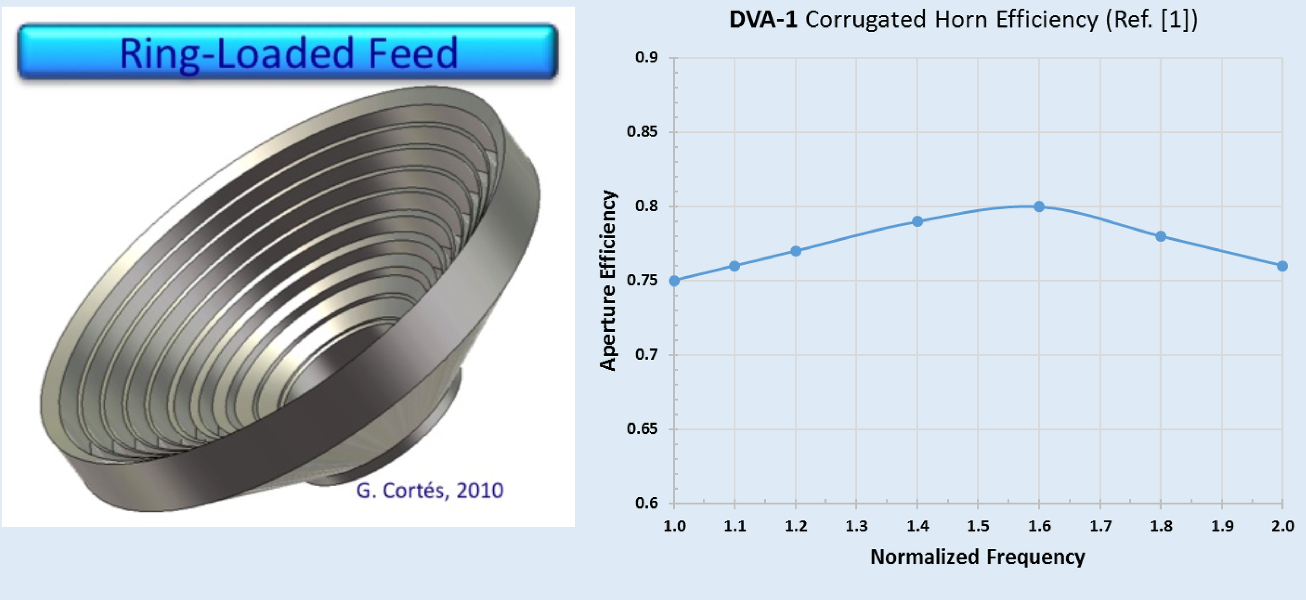

Figure 3: Axially-corrugated feed horn rendering, and aperture efficiency (normalized for L-band)

Plots of the estimated Tsys versus frequency for all six receiver bands are shown in **Figures 4 and 5**. Nominal observing conditions for the VLA site (45 degree elevation angle, 6mm PWV) are assumed for Bands 1-5; however, a best-case 1mm PWV is assumed for Band 6. Where applicable, the nominal Tsys for each of the current VLA receivers are included on the plot as well, for comparison purposes.

Abstract

The Next Generation Very Large Array (ngVLA) is envisioned to be an interferometric array with 10 times the effective collecting area and spatial resolution as the current VLA, operating over a frequency range of 1.2-116 GHz. Achieving these goals will require 214 antennas of nominal 18m diameter, on baselines of 300km. Maximizing sensitivity for each receiver band, while also minimizing the overall operating cost are the primary design goals. Therefore, receivers and feeds will be cryogenically cooled, with multiple bands integrated into a common cryostat to the greatest extent possible. Using feed designs that yield broad bandwidths and high aperture efficiencies are key to meeting these goals.

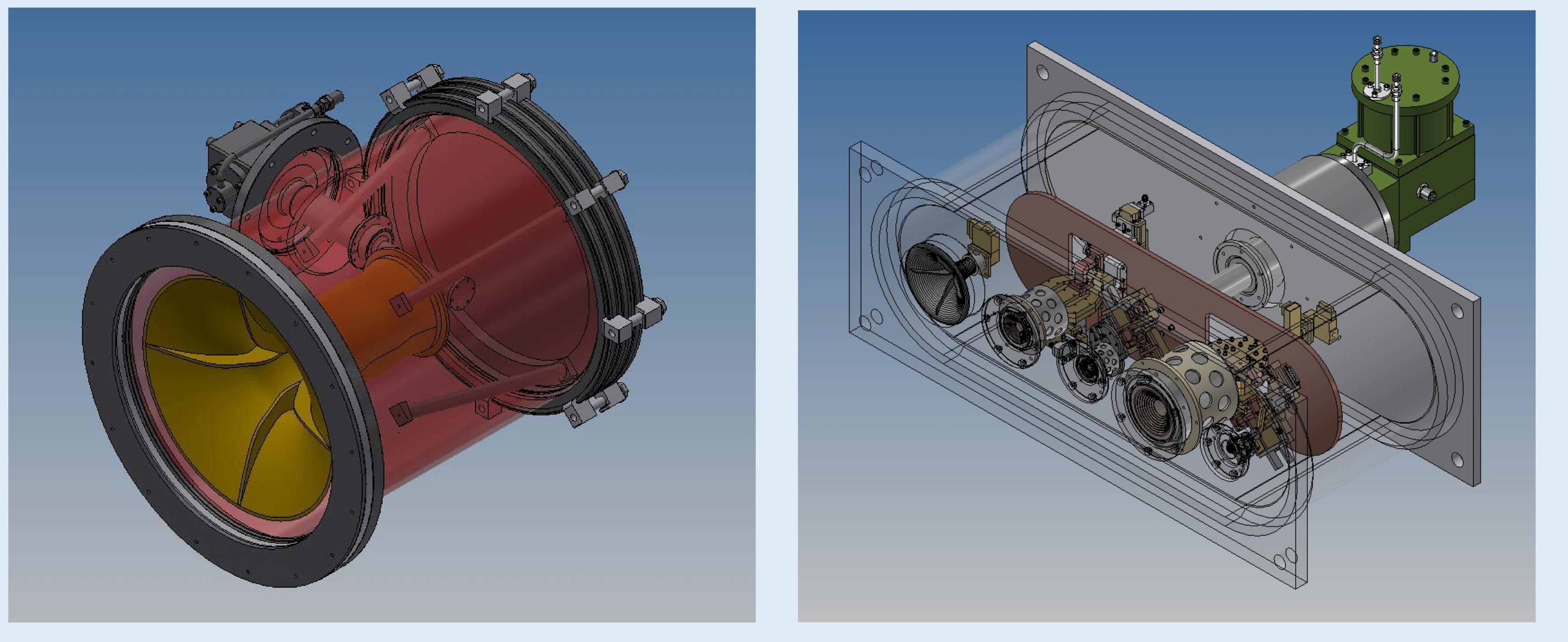

Figure 1: ngVLA Two-cryostat Front End concept: (a) Band 1 (1.2 - 3.5 GHz); (b) Bands 2-6 (3.5 – 116 GHz)

Summary of Estimated Performance, Front End Concept [3]

Band #	f_L GHz	f_M GHz	f_H GHz	Aperture Eff., η_A @ f_L	@ f_M	@ f_H	Spillover, K @ f_L	@ f_M	@ f_H	T_{RX}, K @ f_L	@ f_M	@ f_H
1	1.2	2.0	3.5	0.78	0.79	0.74	10	7	5	7	8	8.5
2	3.5	6.6	12.3	0.78	0.79	0.70	10	6	4	9	10	13
3	12.3	15.9	20.5	0.76	0.78	0.78	3	3	3	9	10	11
4	20.5	26.4	34	0.76	0.77	0.75	3	3	3	11	13	18
5	30.5	39.2	50.5	0.74	0.74	0.70	3	3	3	17	21	27
6	70	90.1	116	0.62	0.55	0.43	3	3	3	39	41	60

Band #	T_{SKY}, K @ f_L	@ f_M	@ f_H	**T_{SYS}, K** @ f_L	@ f_M	@ f_H	(T_{SYS}/η_A), K @ f_L	@ f_M	@ f_H	**Array SEFD, Jy** @ f_L	@ f_M	@ f_H
1	4.4	4.5	4.6	**21**	**20**	**18**	27	25	24	**1.39**	**1.25**	**1.24**
2	4.6	4.7	5.3	**24**	**21**	**22**	30	26	32	**1.53**	**1.33**	**1.61**
3	5.3	6.3	13.6	**17**	**19**	**27**	22	24	35	**1.13**	**1.23**	**1.79**
4	13.6	12.1	12.4	**27**	**28**	**33**	36	36	44	**1.83**	**1.84**	**2.24**
5	11.1	16.9	70.3	**31**	**41**	**100**	42	55	142	**2.11**	**2.79**	**7.20**
6	68	15	112	**110**	**59**	**175**	178	108	406	**9.03**	**5.46**	**20.57**

References

[1] Baker, L. and Veidt, B., "DVA-1 Performance With An Octave Horn From CST & GRASP Simulations", Internal Report, March 2014. Excerpted content used with permission from the authors.

[2] Weinreb, S. and Mani, H., "Low Cost 1.2 to 116 GHz Receiver System – a Benchmark for ngVLA", ngVLA Science Workshop presentation, June 2017. Excerpted content used with permission from the authors.

[3] Parameter table from Excel file, ngVLA_band_configs_Ver4.2_2017-12-13.xlsm, W. Grammer, NRAO

Cryogenic Subsystem

The ngVLA cryogenic subsystem reference design assumes the use of modern but mature technology, with predictable system performance and cost. For the cryocoolers, a two-stage Gifford-McMahon (GM) type refrigerator is retained, as it can cool to temperatures below 20K for optimum receiver noise performance, and has proven reliability and low maintenance cost. The helium compressor is an efficient, scroll-type unit, with sufficient capacity to cool down both receiver cryostats.

Unlike the VLA, both cryocoolers and the compressor will have variable-speed capability, to allow the helium flow and cryocooler capacity to be matched to the actual thermal loads in the cryostats. This will optimize system efficiency, reduce electrical power consumption and improve reliability.

Future Work

- Optimize QRFH profile to reduce backlobe response (lower Tspill) and flatter aperture efficiency over frequency.
- Optimize the corrugated feed horn profile to maximize aperture efficiency over the 1.67:1 bandwidth, in conjunction with the shaping profile chosen for the antenna reflectors.
- Obtain accurate pattern measurements of both types of reference feed horns.
- Development of Band 1 concept by the Caltech group (S. Weinreb et. al.)
- Detailed Band 2-6 mechanical design/modeling, test dewar construction.

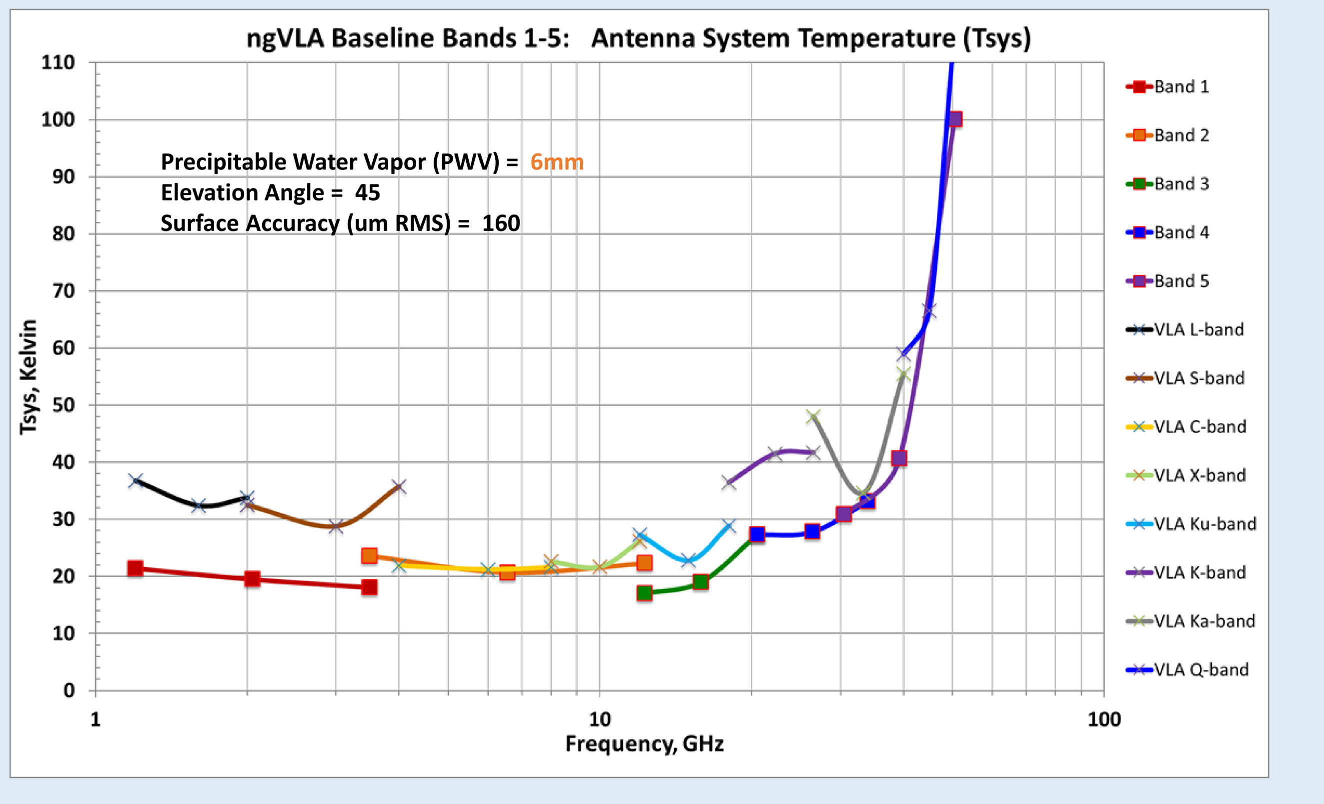

Figure 4: Antenna System Temperture (Tsys), ngVLA Bands 1-5, versus VLA L-Q bands

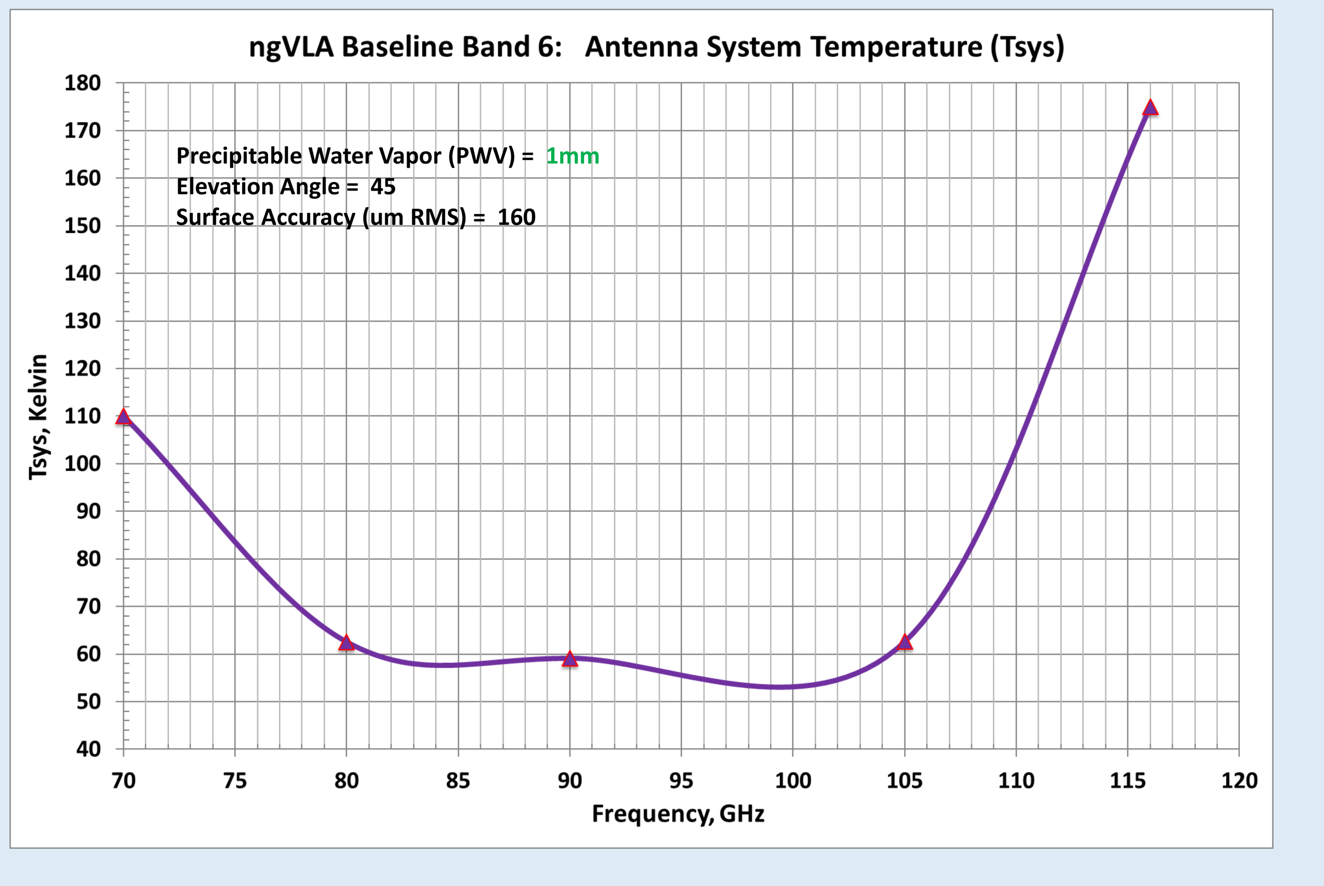

Figure 5: Antenna System Temperture (Tsys), ngVLA Band 6

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