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 photo of an actual Band 1 prototype QRFH, along with the simulated aperture efficiency and spillover noise temperature versus frequency are shown in **Figure 2**.

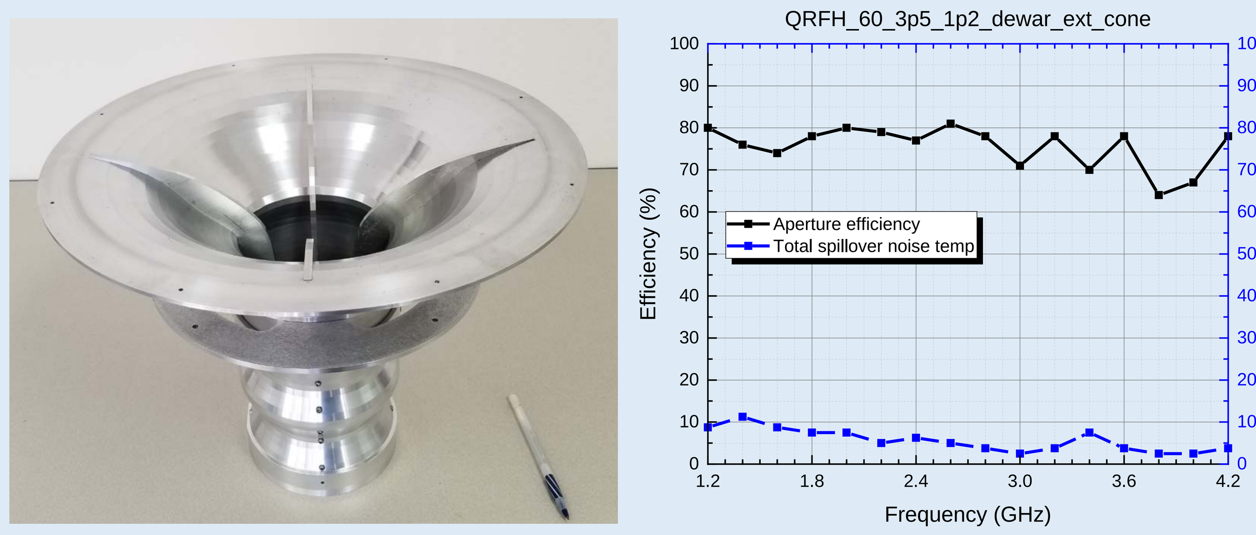

Figure 2: Band 1 Quad-ridge feed horn, with plotted aperture efficiency, and spillover noise

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 (~55º half-angle), based on a design by G. Cortes and L. Baker [1], are proposed 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 and noise. A machined prototype of this feed [4] scaled to Q-band is shown in **Figure 3**, along with a plot of the simulated aperture efficiency versus normalized frequency.

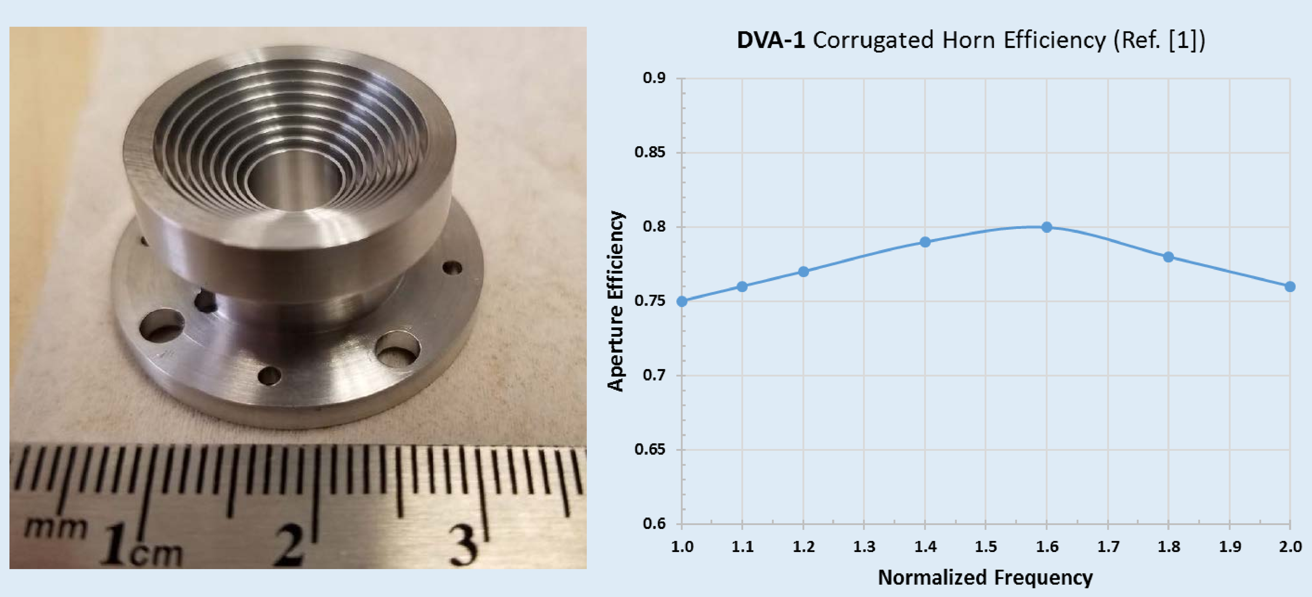

Figure 3: Axially-corrugated Q-band feed horn, and aperture efficiency vs. frequency

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, 6 mm PWV) are assumed for Bands 1-5; however, a best-case 1 mm 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.

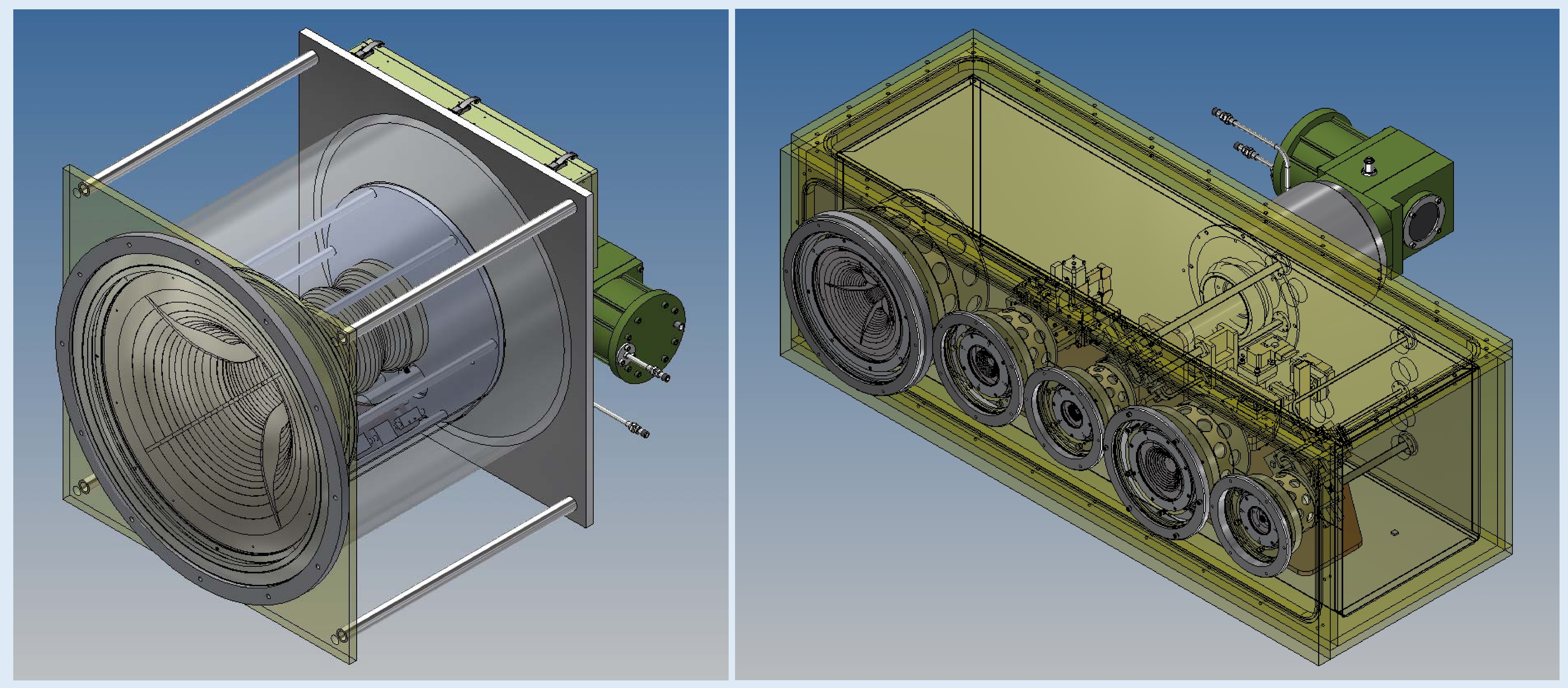

Figure 1: ngVLA Two-cryostat Front End concept: (a) Band 1 (1.2 - 3.5 GHz); (b) Bands 2-6 (3.5 – 116 GHz)

Summary of Estimated Performance, Front End Concept [5]

Band #	f_L GHz	f_M GHz	f_H GHz	BW 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	2	0.78	0.79	0.74	10	7	5	11.8	12.1	13.6
2	3.5	6.6	12.3	8.8	0.78	0.79	0.70	10	6	4	12.9	13.1	19.8
3	12.3	15.9	20.5	8.2	0.84	0.87	0.86	4	4	4	13.8	14.7	16.6
4	20.5	26.4	34	13.5	0.83	0.86	0.83	4	4	4	16.9	17.9	22
5	30.5	39.2	50.5	20	0.81	0.82	0.78	4	4	4	21.8	25.4	27
6	70	90.1	116	46	0.68	0.61	0.48	4	4	4	61.2	51.4	73.2

Band #	T_{FEED} K	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	80	4.4	4.5	4.6	**26**	**24**	**23**	34	30	31	**1.70**	**1.51**	**1.59**
2	20	4.6	4.7	5.3	**28**	**24**	**29**	35	30	42	**1.79**	**1.53**	**2.11**
3	20	5.3	6.3	13.6	**23**	**25**	**34**	28	29	40	**1.39**	**1.46**	**2.02**
4	20	13.6	12.1	12.4	**35**	**34**	**38**	42	40	46	**2.10**	**2.02**	**2.34**
5	20	11.1	16.9	70.3	**37**	**46**	**101**	45	56	129	**2.30**	**2.85**	**6.56**
6	20	68	15	112	**134**	**71**	**190**	196	116	395	**9.94**	**5.86**	**20.02**

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] Akgiray, A. and Zhong, W., "ngVLA Spillover Temperature Calculations", November 2017. Photo courtesy S. Weinreb, Caltech.

[4] Locke, L. et. al., "ngVLA Community Studies Report: Feed and Receiver Development at NRC Herzberg", ngVLA Memo #32, November 2017.

[5] Grammer, W. et. al., "ngVLA Front End Reference Design Description", Doc# 020.30.03.01.00-0003-DSN, NRAO, June 2018

Cryogenic Subsystem

The ngVLA cryogenic subsystem reference design assumes the use of modern but mature technology, with predictable system performance and cost. For cryocoolers, a two-stage Gifford-McMahon (GM) type refrigerator is proposed, like a CTI model 350. It can cool to temperatures below 20K for optimum receiver noise performance, has sufficient cooling capacity for the estimated loading, 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.

Ongoing/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.

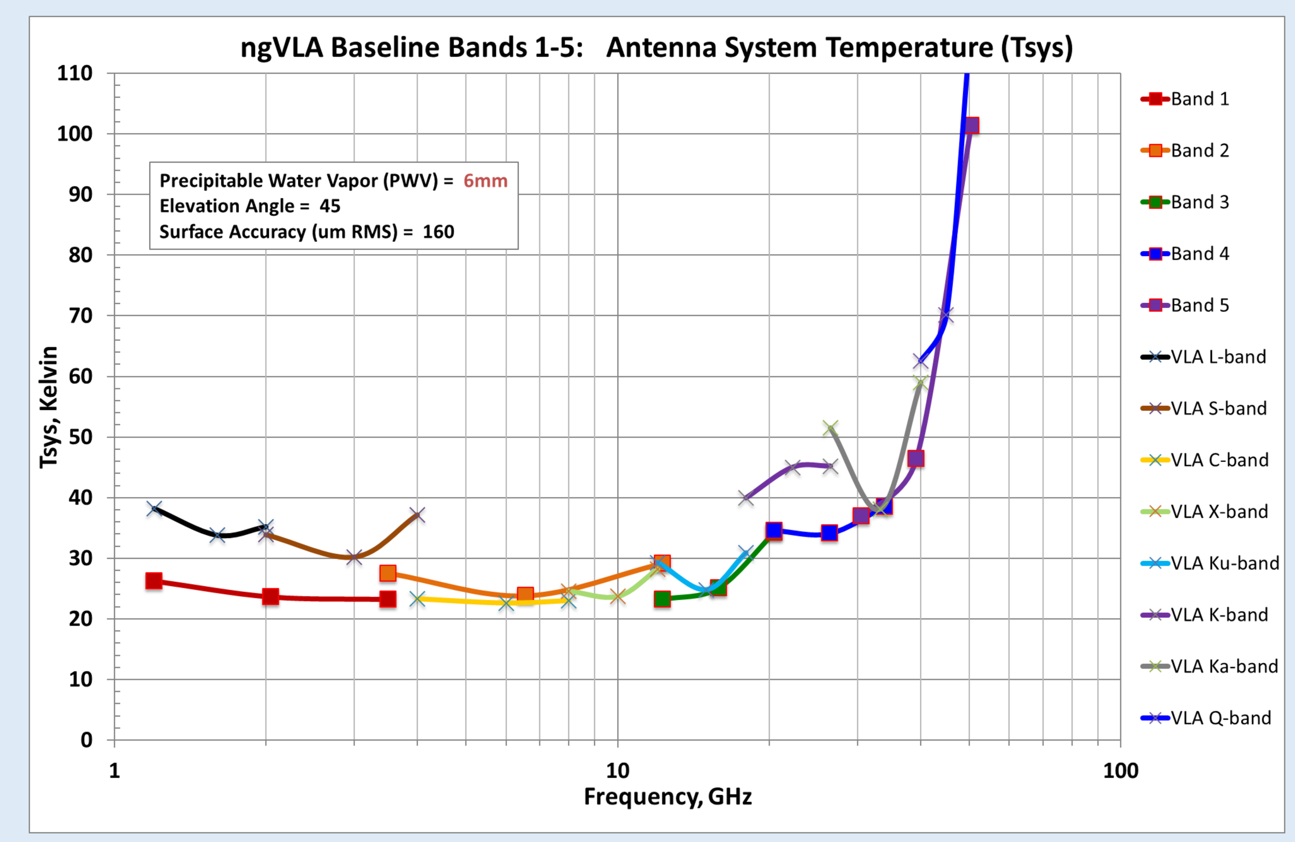

Figure 4: Antenna System Temperature (Tsys), ngVLA Bands 1-5, versus VLA L-Q bands

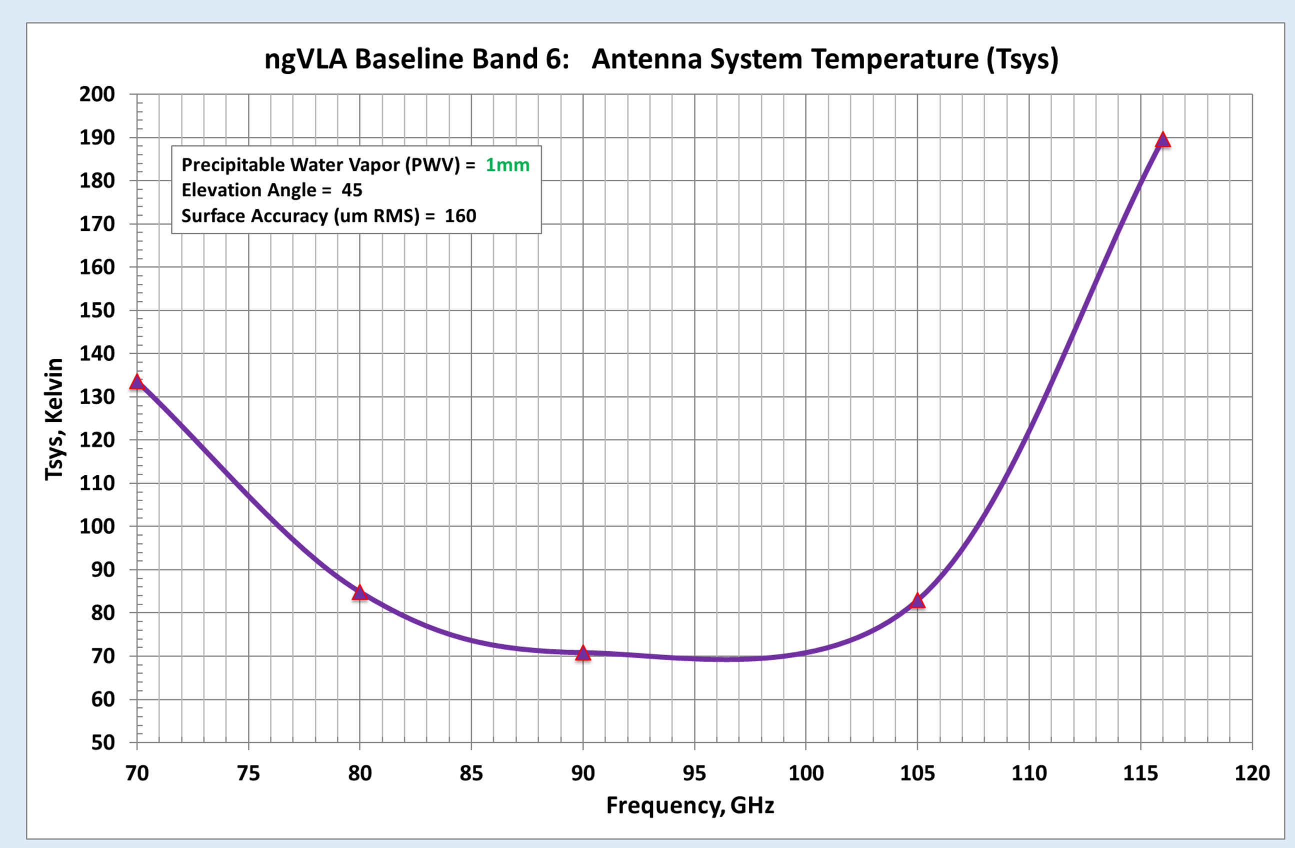

Figure 5: Antenna System Temperature (Tsys), ngVLA Band 6

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