The ngVLA Front End Reference Design

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Front End Reference Design

The proposed receiver configuration will be implemented as six independent single-pixel receivers, 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. Because of its large size, the Band 1 feed is cooled only to 80 K, while the feeds for Bands 2-6 are cooled to 20 K. A mechanical concept for these two receiver cryostats is shown in **Figure 1**.

For continuous coverage from 1.2 – 12.3 GHz, even octave-bandwidth receivers are not cost-effective, given the > 10:1 frequency range. For Bands 1 and 2, wideband (3.5:1) LNAs mated to a Caltech-designed quad-ridge feed horn (QRFH) are proposed [1]. These feeds are 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 prototype Band 1 QRFH built by Caltech, with plots of simulated aperture efficiency and spillover as a function of frequency are shown in **Figure 2**.

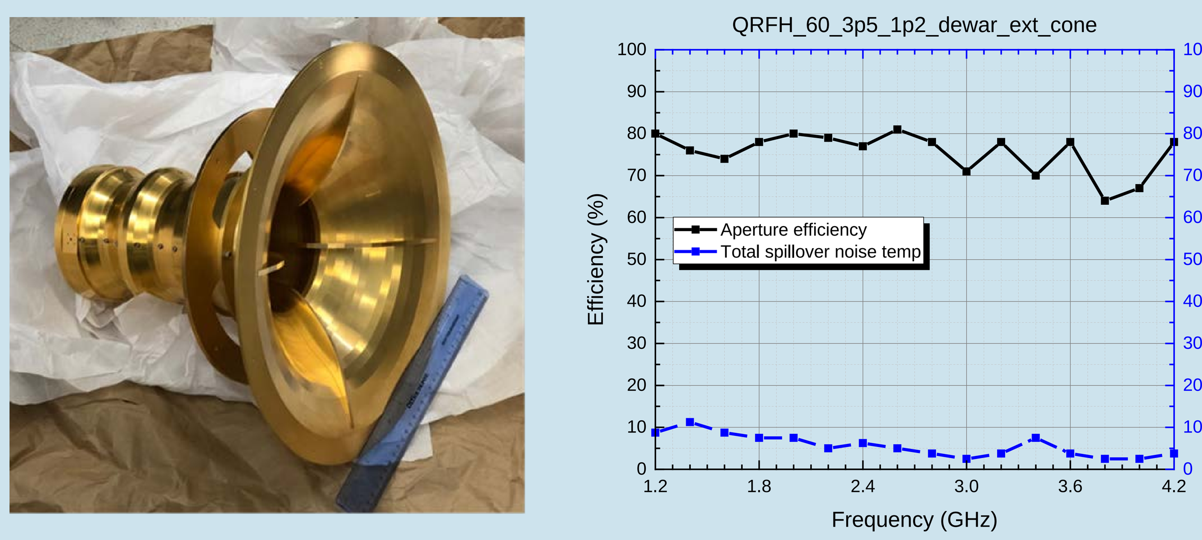

Figure 2: Quad-ridge feed horn prototype, aperture efficiency, and spillover performance.

For optimum performance at the higher frequencies, receivers with bandwidth ratio of ~1.65:1, 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 waveguides throughout the signal chain reduces losses and their associated noise contributions, without adding undue weight.

An axially-corrugated conical feed horn with wide flare angle (55° half-angle), based on a design by L. Baker and B. Veidt [2], is being considered for the Band 3-6 receivers. This design is extremely compact, with good aperture efficiency (75%) and RF match. However, unlike the QRFH it does require an external polarization separator or orthomode transducer [3]. A prototype feed was built at C-band and measured. Simulated and measured patterns at 6 GHz are shown in **Figure 3** and there is good agreement of the patterns up to ±90°.

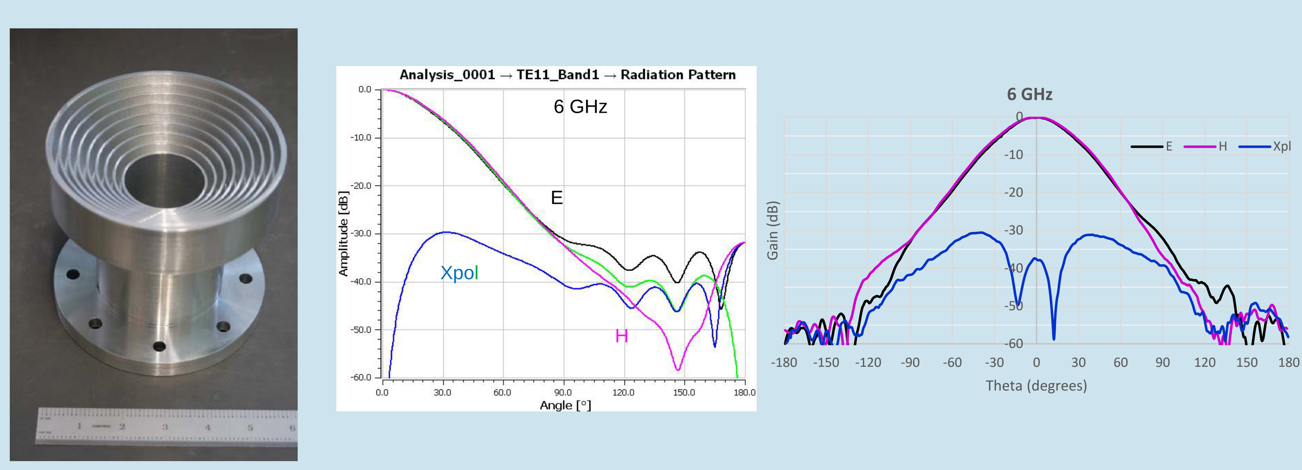

Figure 3: Axially-corrugated feed horn at C-band, simulation and measurement.

Plots of the estimated T_{sys} versus frequency for all six receiver bands are shown in **Figures 4 and 5**. Nominal observing conditions for the VLA site (45° 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 T_{sys} for each of the current VLA receivers is included on the plot for comparison purposes.

Abstract

The Next Generation Very Large Array (ngVLA) is a future interferometric array, a major U.S. radio astronomy facility following the legacy of the VLA, VLBA and ALMA. The array will operate nominally from 1.2-116 GHz. In order to achieve the goal of 10 times the effective collecting area of the VLA at 40 GHz, the main array will be comprised of 214 18 m antennas. An additional 19 6 m antennas will form a short baseline array, sensitive to a portion of the undetected larger angular scales. In 2018 the Long Baseline Array consisting of 30 18 m antennas was included to fully define the ngVLA. 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.

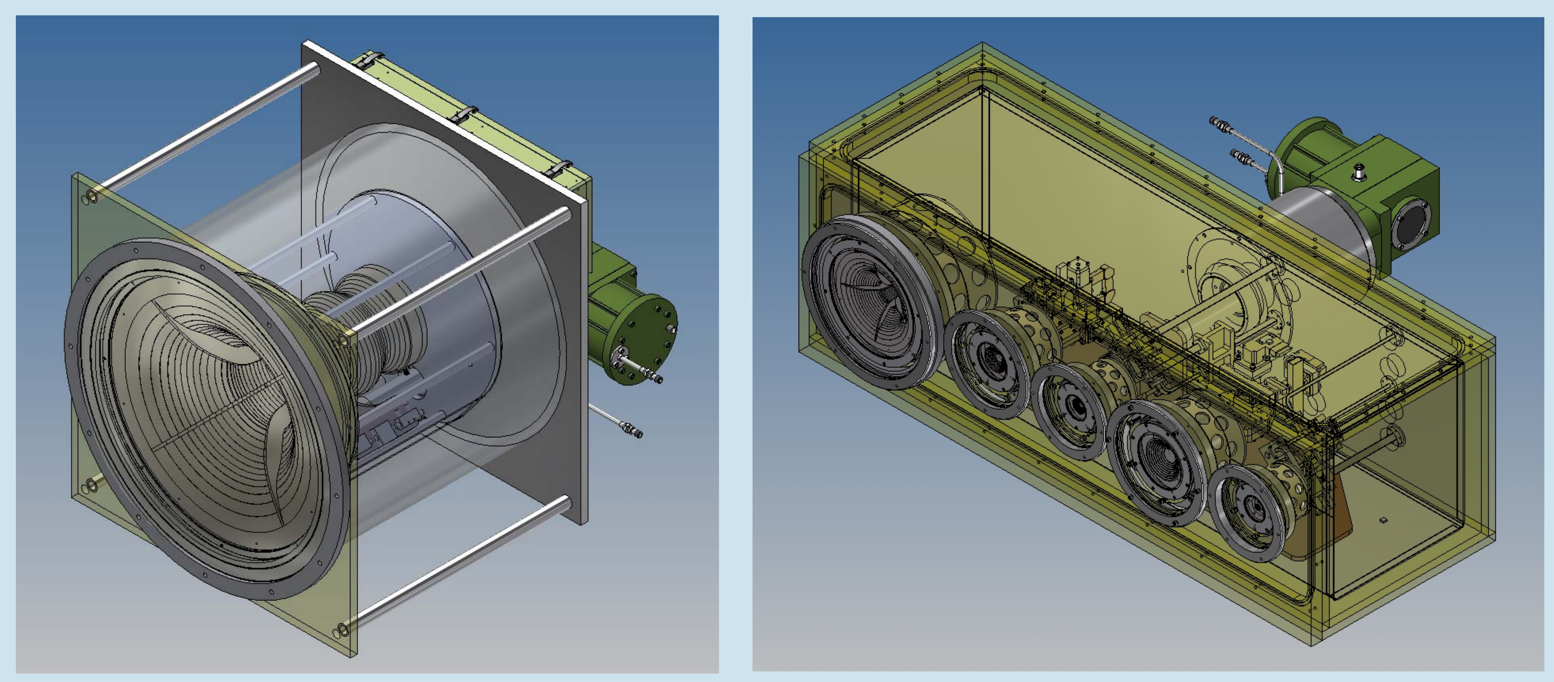

Figure 1: ngVLA Two-cryostat Front End concept: (a) Band 1 (1.2 - 3.5 GHz); (b) Bands 2-6 (3.5 – 116 GHz).

Summary of Estimated Performance, Front End Concept [4]

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	0.80	0.79	0.74	13	10	4	9.9	10.3	13.8
2	3.5	6.6	12.3	8.8	0.80	0.78	0.76	13	7	4	13.4	15.4	14.4
3	12.3	15.9	20.5	8.2	0.84	0.87	0.86	4	4	4	13.9	16.9	18.6
4	20.5	26.4	34	13.5	0.83	0.86	0.83	4	4	4	15.4	16.2	19.5
5	30.5	39.2	50.5	20	0.81	0.82	0.78	4	4	4	19.1	20.4	26.5
6	70	90.1	116	46	0.68	0.61	0.48	4	4	4	50.6	49	72.6

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	**28**	**26**	**23**	35	33	32	**1.55**	**1.44**	**1.39**
2	20	4.6	4.7	5.3	**32**	**28**	**25**	40	36	32	**1.75**	**1.59**	**1.42**
3	20	5.3	6.3	13.6	**24**	**28**	**37**	29	32	43	**1.27**	**1.43**	**1.91**
4	20	13.6	12.1	12.4	**34**	**33**	**37**	41	39	44	**1.80**	**1.72**	**1.95**
5	20	11.1	16.9	70.3	**35**	**42**	**102**	43	51	130	**1.91**	**2.27**	**5.73**
6	20	68	15	112	**123**	**68**	**189**	181	112	394	**7.96**	**4.92**	**17.36**

References

[1] 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.

[2] 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.

[3] Srikanth, S. and Solatka, M., "Widband Orthomode Transducer for Millimeter Wave Bands", 2013 Asia-Pacific Radio Science Conference, Taipei, September 2013.

[4] Grammer, W., "ngVLA Front End Reference Design Description", ngVLA Internal Document # 020.30.05.00.00-0003-DSN

Cryogenic Subsystem

The ngVLA cryogenic reference design assumes the use of modern but mature technology, with predictable system performance and cost. For the cryocooler, a two-stage Gifford-McMahon (G-M) type is retained, as it can cool to temperatures below 20 K for optimum receiver noise performance, and has a well-defined maintenance cost and reliability. However, cryostat designs based around a 3-stage Stirling-type pulse-tube cryocooler are under active consideration in the conceptual design phase, as a more reliable and efficient alternative. 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 design to reduce backlobes (lower T_{spill}) and flatter aperture efficiency, and carry out pattern measurements to verify improvements.
- Refinement of the Band 1 cryostat concept at Caltech / ASU (S. Weinreb / H. Mani)
- Detailed Band 2-6 mechanical design and thermal modeling, and test-dewar construction.
- Design, fabricate Band 6 feed horn that is easier to machine/mill, and validate performance.

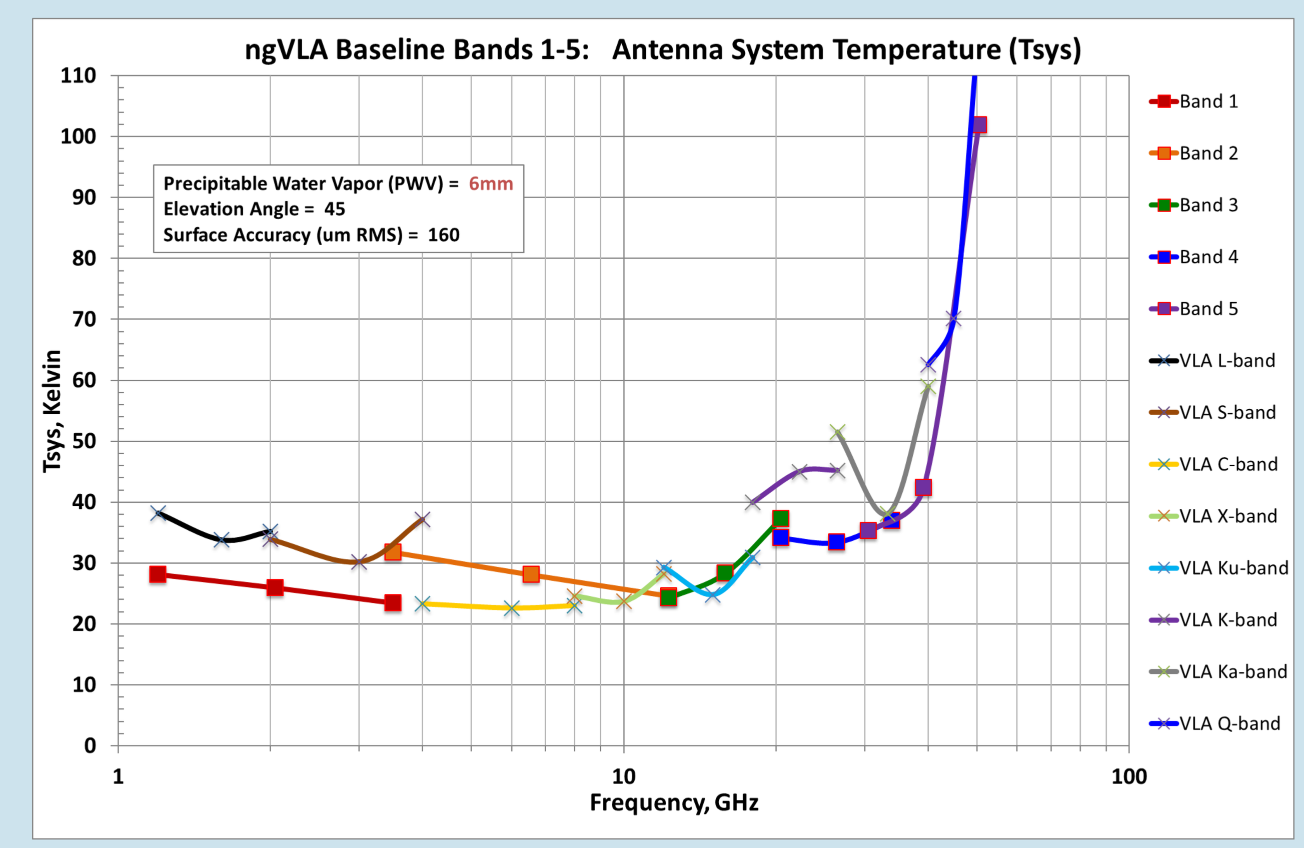

Figure 4: Antenna System Temperture (T_{sys}), ngVLA Bands 1-5, versus VLA L-Q bands.

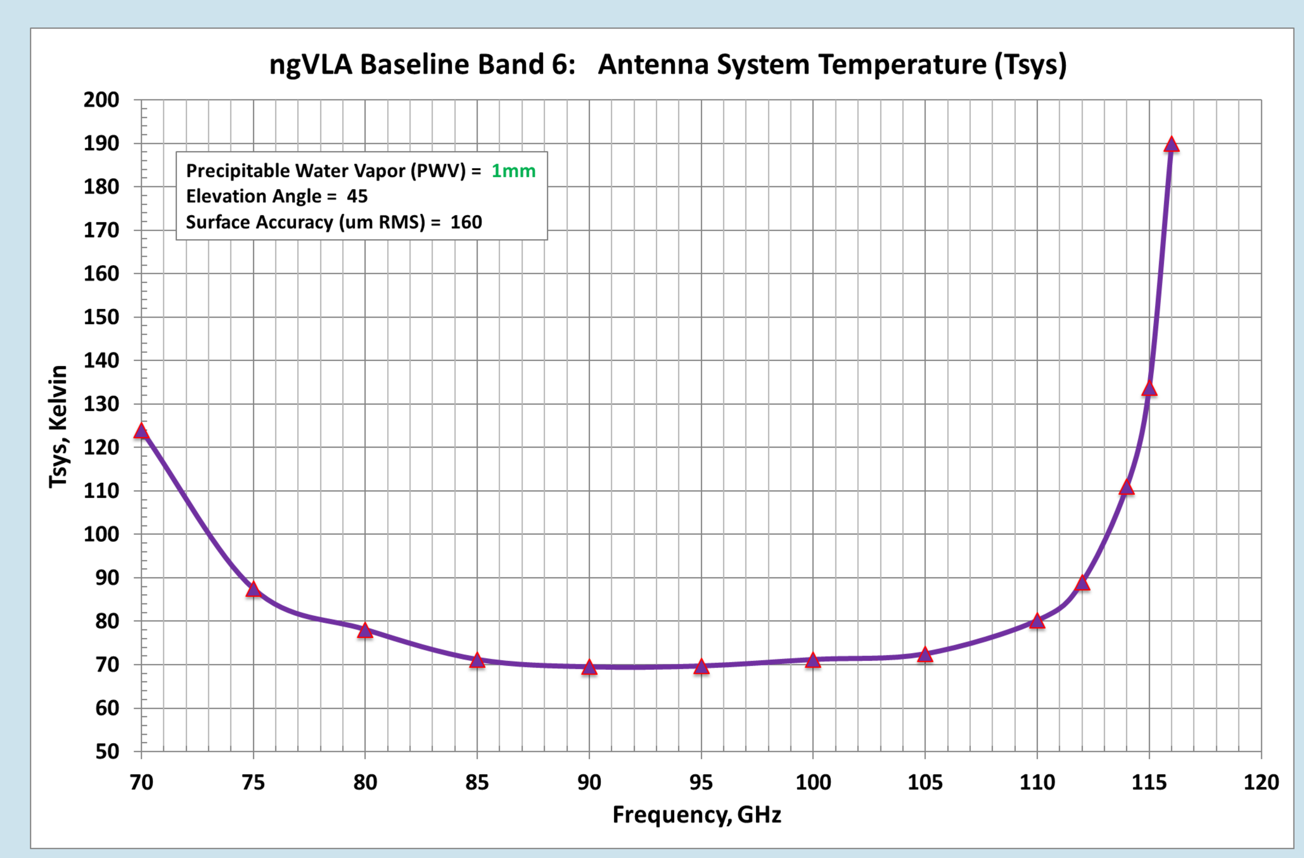

Figure 5: Antenna System Temperture (T_{sys}), ngVLA Band 6.

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