VLBI2010 Feed Comparison

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Introduction.

VLBI2010 requires a feed that simultaneously has high efficiency over the full 2.2−14 GHz frequency range. The simultaneity requirement implies that the feed must operate at high efficiency over the full frequency range without the need to adjust its focal position to account for frequency dependent phase centre variations. Two feeds meet this specification:

- The Eleven Feed developed at Chalmers University. (For more information, contact Miroslav Pantaleev, miroslav.pantaleev@chalmers.se. The Eleven Feed, integrated with LNA's in a cryogenic receiver, is available as a product from Omnisys Instruments, info@omnisys.se).
- The Quadruple Ridged Flared Horn (QRFH) developed at the California Institute of Technology. (For more information please contact Ahmed Akgiray, aakgiray@ieee.org or Sander Weinreb, sweinreb@caltech.edu)

Although not VLBI2010 compliant, two triband S/X/Ka feeds are also being developed for the commissioning of VLBI2010 antennas, for S/X observations during the VLBI2010 transition period, and to support X/Ka CRF observations. The two feeds are:

- The Twin Telescopes Wettzell (TTW) triband feed developed by Mirad Microwave. (For more information please contact Gerhard Kronschnabl, Gerhard.Kronschnabl@bkg.bund.de)
- The RAEGE (Spain) triband feed developed at Yebes Observatory. (For more information please contact Jose Antonio Lopez Perez, ja.lopezperez@oan.es)

Broadband Feed Comparison.

The Eleven and QRFH broadband feeds are compared in Table 1. [See also appended notes describing table parameters.] In addition one of the most important feed parameters, the aperture efficiency was compared via simulation in a Cassegrain reflector system. The results are shown in Figure 1. There are three notable differences between the feeds:

LNAs per Polarization. Due to the differential port configuration of the Eleven Feed, each polarization output requires a network to combine the output from four antenna ports. To avoid noise degradation from the combining network, LNA's are required directly on each antenna port for a total of 4 LNA's per polarization or 8 LNA's per Eleven feed. Furthermore, since mismatches in the LNA's degrade feed performance, it is necessary that the LNA's be matched within specified limits. In contrast, the QRFH requires no combining network, only one LNA per polarization, and no LNA matching. [Note: The total number of LNA's for the Eleven Feed could be reduced to four through the use of broadband baluns. Although a broadband balun is under development at Onsala Observatory, it is not yet ready for use.]

Calibration Signal Injection. For both feeds it is possible to radiate the calibration signal directly into the feed or to couple it into the signal chain after the LNA. [See Table 1 notes for more details.] However, due to the combining network and multiple LNAs needed for the Eleven Feed, it is not practical when using this feed to inject calibration signals between the feed and LNA.

Design adaptability. The QRFH design can be optimized to match a variety of antenna optics whereas the Eleven Feed has a fixed 10-dB half-beamwidth of about 65°. To be fair, the performance of the Eleven Feed does not degrade quickly as antenna optics change so it is in fact compatible with a fair range of antenna optics. However, for the case of legacy IVS antennas requiring 10-dB half-beamwidths that are significantly different from 65°, the adaptability of the QRFH design will likely lead to improved performance.

	Eleven	*QRFH*
VLBI2010 Compatibility	Yes	Yes
Frequency range (GHz)	1.2–14	2.2–14
Polarization	Dual-Linear	Dual-Linear
Port Configuration	Differential	Single-Ended
LNAs per Polarization	4	1
LNAs per Feed	8	2
LNA Balance Requirements	1.6 dB amp 14° phase	None
Calibration Signal Injection	Radiated or post-LNA	Radiated, pre-LNA, or post-LNA
Aperture Efficiency (F/D ~ 0.375)	See Figure 1	
Ground Noise Contribution (F/D ~ 0.4)	Preliminary 10–20K, but more research is needed	< 20K (2.2–5 GHz) < 10K (5–14 GHz)
F/D Range	0.35–0.5	Adaptable for nominal 0.3–2.5
Feed 10-dB half-beamwidth	65°	Adaptable for nominal 15°–70°
Size (Half-beamwidth ~ 65°)	Diameter 210 mm height 65 mm	diameter 160 mm height 150 mm
Cost (USD)	33K (TBC)	15K

Table 1. VLBI2010 Broadband Feed comparison. Although the QRFH design is adaptable, note that the QRFH table entries for aperture efficiency, ground noise contribution, and size assume its design has been optimized for a half-beamwidth of 65°.

Notes on table parameters:

Aperture Efficiency: This is the total aperture efficiency for each feed feeding reflector optics that are nominally 0.4 F/D (65° feed half-angle). In addition to the impact of return loss, all feed sub-efficiencies including those related to beamwidth and phase center variations with frequency are accounted for in this parameter. If the feed is to be considered for an antenna system having significantly different optics, the aperture efficiency needs to be recomputed. Note that phase center variations have not been broken out as a separate table entry since, due to the directional nature of VLBI antennas, they do not impact VLBI geometric products.

Figure 1 compares the feeds as they would perform in a 12m shaped reflector system like the one manufactured by Intertronics Solutions. The version of the QRFH used in the comparison was designed specifically for these optics assuming a frequency range of 2−12 GHz; hence no data were available for a comparison in the 12−14 GHz range. [Note however that the QRFH design can easily be scaled to cover the 2.2−14 GHz range with similar performance.] The efficiency plot for the QRFH was calculated using Physical Optics software at JPL while the efficiency plot for the Eleven feed was calculated using GRASP software at Onsala Observatory. In both cases measured far field patterns were used as input. Real-world complications such as feed leg scattering have not been taken into account. From figure 1 it can be seen that the performance of the feeds is comparable with the Eleven feed having slightly higher efficiency over the 3−5 GHz band and the QRFH having slightly higher efficiency over the 9−11 GHz band.

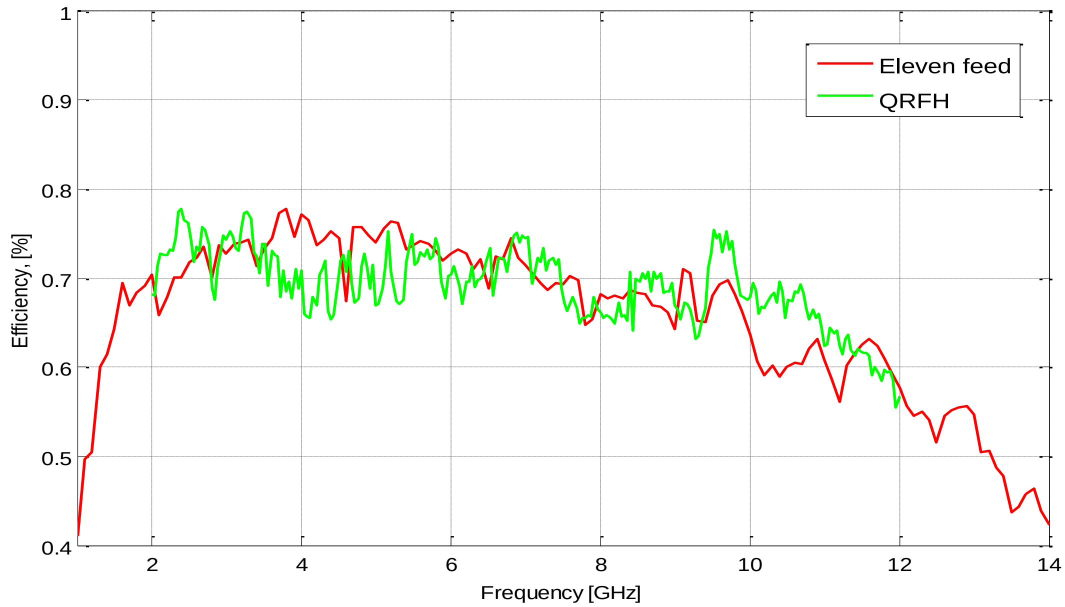

Figure 1: Comparison of the aperture efficiencies of the Eleven feed and the QRFH in a 12m Cassegrain shaped reflector antenna system. The result for the Eleven feed, red curve, is calculated with GRASP software while the result for the QRFH, green curve, is calculated with Physical Optics software. In both cases measure far field patterns were used as input. Real-world complications such as feed leg scattering have not been taken into account.

Ground Noise Contribution: This is a computation of the expected ground noise pickup when a dual-reflector antenna system is pointed at Zenith; this contribution will increase at lower elevation angles or for prime focus optics. This does not include LNA noise or thermal losses in the feed hardware.

Calibration Signal Injection: Mode of injecting calibration signals into the receiver.

- Radiated – signal is radiated into the feed via a small transmitting probe. This mode calibrates the entire signal chain but is susceptible to phase cal antenna-orientation-dependent multipath interference.
- Pre-LNA – signal is injected via microwave hardware preceding the LNA. This mode calibrates the entire signal chain and does not suffer from antenna-orientation-dependent multipath like the radiated technique but instead incurs a slight increase (~5K) in the receiver temperature.
- Post-LNA – signal is injected after the LNA so that multipath and receiver temperature increase need not be considered. However, the entire signal chain is not calibrated

Triband Feed Comparison

The Raege and Mirad feeds are compared in Table 2.

	Raege Triband	***Mirad Triband***
VLBI2010 Compatibility	No (for compatibility with S/X and X/Ka and for antenna commissioning)	No (for compatibility with S/X and X/Ka and for antenna commissioning)
Frequency range (GHz)	S: 2.2–2.7 X: 7.5–9 Ka: 28–33	S: 2.15–2.8 X: 7.0–9.5 Ka: 26.5–33
Polarization	Dual-Circular	Dual-Circular
Port Configuration	Single-Ended (use of hybrids to combine ports)	Single-Ended (use of hybrids to combine ports)
LNAs per Polarization	1	1
LNAs per Feed	6 (3 bands x 2 Pols)	6 (3 bands x 2 Pols)
LNA Balance Requirements	None	None
Calibration Signal Injection	Radiated, pre-LNA, or post-LNA	Radiated, pre-LNA, or post-LNA
Aperture Efficiency	> 70%	> 70% (70-83%)
Ground Noise Contribution	< 20 K S-band < 10 K X-band < 5K Ka-band	< 20 K S-band (17K@60°) < 10 K X-band (12K@60°) < 5K Ka-band
F/D Range	0.4	0.29
Feed 10-dB Half- Beamwidth	65°	55°
Size (DxH – mm)	190x245	Feed alone: 190x400 Feed + Waveguide: (500-900)x1250
Operating Temp (°K)	20	room temp
Cost (USD)	25K (including hybrids and Ka-band septum)	250K (including feed, waveguide and feed cone)

Table 2. Comparison of Triband Feeds.