Overview of the NASA/Haystack VLBI2010 Receiver Frontends

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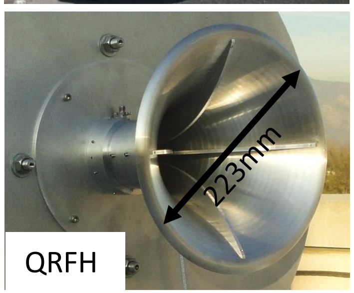
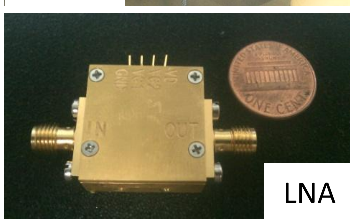
Overview

1. Description of NASA Broadband VLBI Receiver Frontend
2. Receiver Performance
3. Calibration Signal Injection
4. Procurement Logistics

NASA Broadband VLBI Receivers

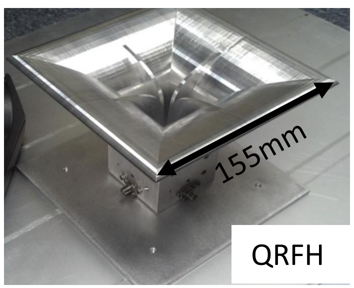




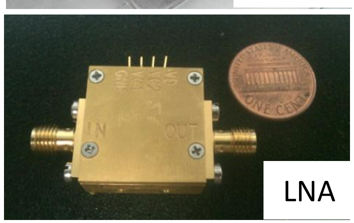
- Reflector optics are shaped
  - Feed optical half-angle width of 50°
- Major frontend components comprising 2-14 GHz receiver frontend :
  - Quadruple-ridged flared horn (QRFH) design – Ahmed Akgiray
  - Feed designed for optimal illumination of 12m optics
  - CRYO1-12 low noise amplifier (LNA) – Sandy Weinreb
- QRFH frontend installed early 2011
  - Initial sensitivity was poor owing to subreflector misalignment
  - After alignment, sensitivity was improved significantly
  - Pointing model developed for the antenna
    - Scatter in pointing offsets < 0.010° rms
- Calibration signal injection via stripline coupler

NASA Broadband VLBI Receivers

Westford 18m



QRFH



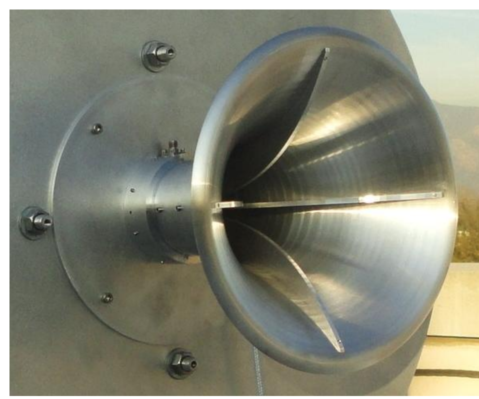
LNA

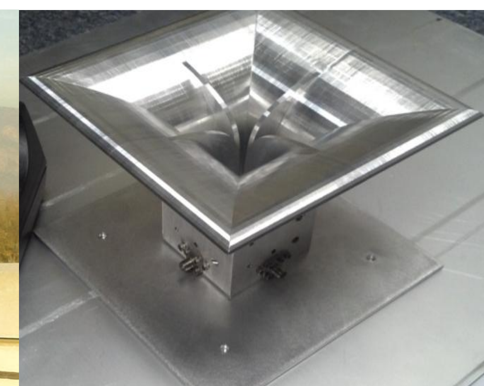
- Standard Prime Focus
  - Feed optical half-angle width: 80°
- Major frontend components comprising 2-14 GHz receiver frontend:
  - New QRFH design
  - Optimized for Westford and cuts off at 2.2 GHz
  - CRYO1-12 low noise amplifier
- Frontend diagnostics currently underway at Haystack
- Calibration signal injection via stripline coupler

NASA Broadband VLBI Receivers

QRFH Description

- A feed design methodology with different hardware realizations
- Designs available for good broadband matching of a wide range of reflector antenna optics:
  - 40° half-angle beamwidth feed achieves 6:1 bandwidth (e.g. 2-12 GHz)
  - 70° half-angle beamwidth feed achieves 4:1 bandwidth
- Single SMA port per polarization
  - One LNA per polarization
  - Direct phase and noise cal injection is feasible
- Dual linear polarization
- Excellent match to 50 ohms
- Easily maintained and cooled





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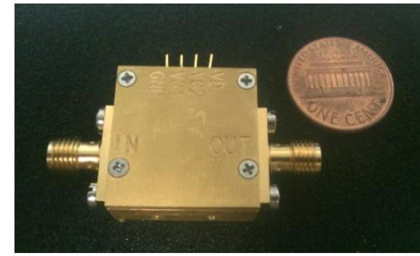
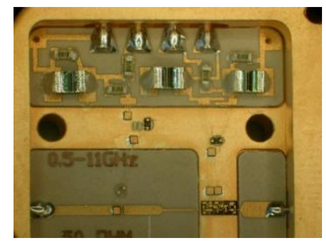
LNA Description

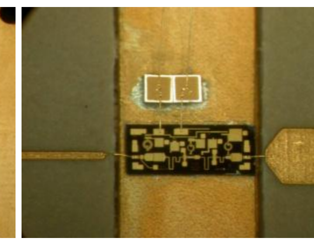


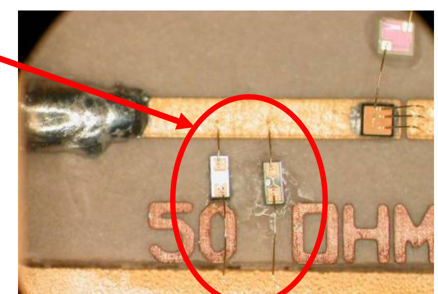
Only known hardware source are in academic fab from Caltech

- Model Number CRYO1-12
- Designed by Sandy Weinreb
- MMICs are fabricated by NGST
- ITAR restricition lifted - can now be exported from US
- Noise temperature ~12K at 12 GHz and 20K physical temperature
- VERY sensitive to ESD, take ESD precautions when handling!
- Installation of diode limiters highly recommended
- Bias regulator also required to properly operate the device
- Input 1dB compression ~-40 dBm,

  Total input power should not exceed -50 dBm to avoid fringe loss

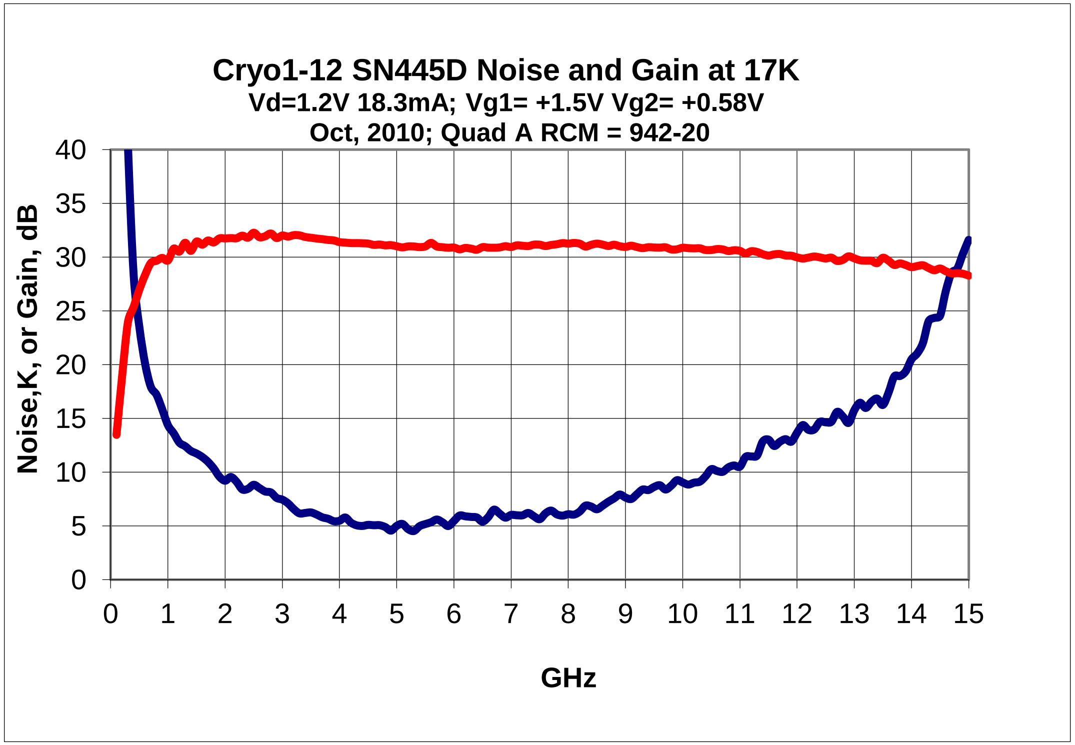


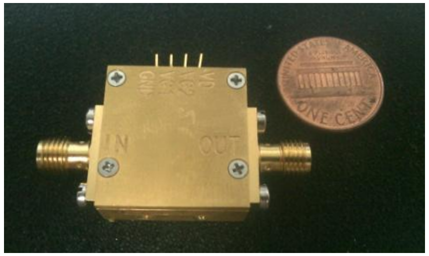




NASA Broadband VLBI Receivers

LNA Description



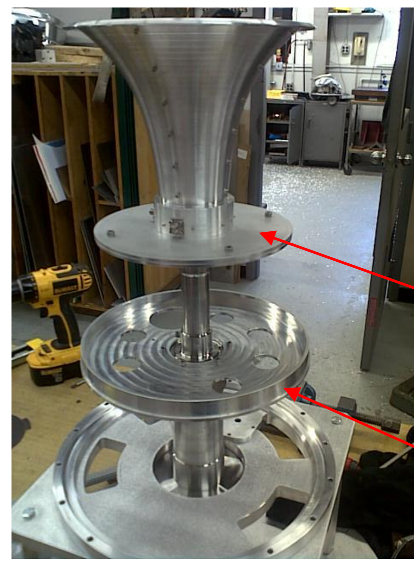


NASA Broadband VLBI Receivers

Dewar/Cryostat - Internal Construction

IR Filter: 16 layers of 25-μm-thick Teflon film separated by a mesh of fine tissue/veil

70K Shield

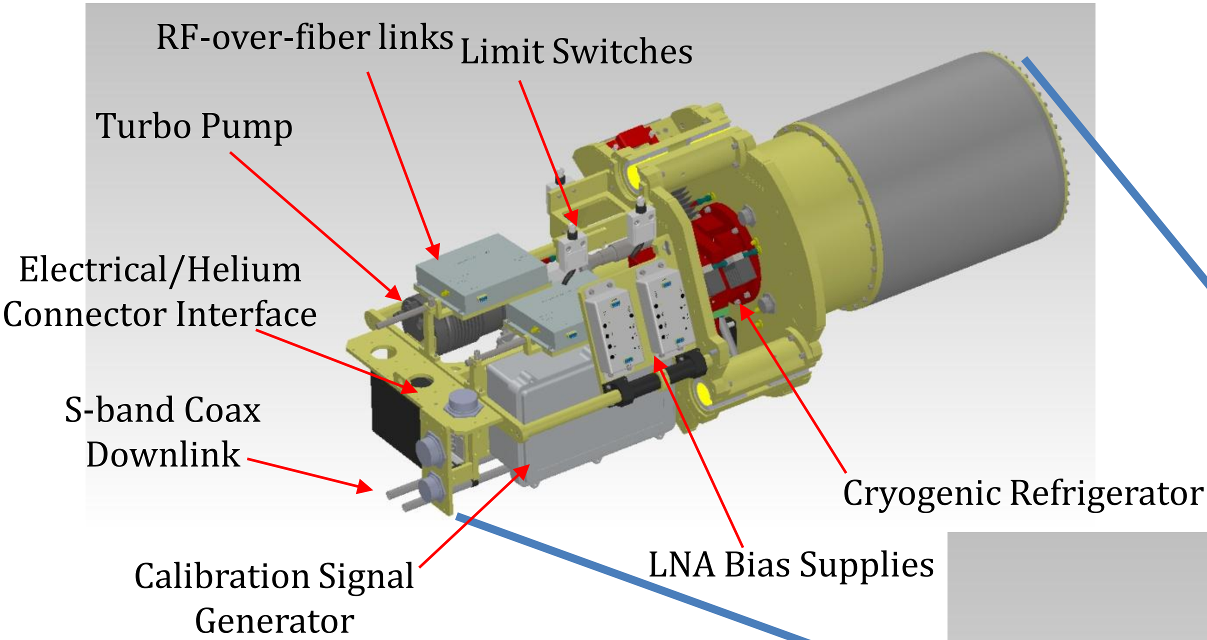


20K Station

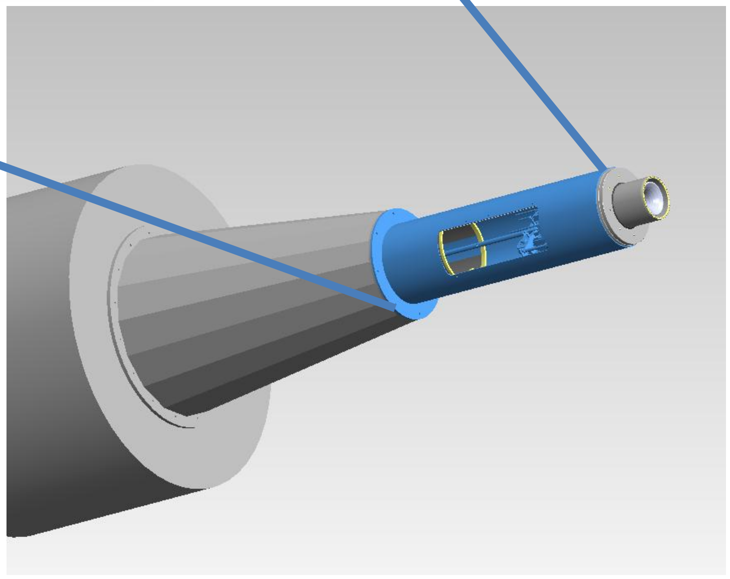
70K Station

NASA Broadband VLBI Receivers

Operational System



- Motorized positioner, remote pump down
- Design was developed for Patriot/Cobham 12m feed tower
- Adaptable to other Cassegrain telescopes



Receiver Performance

- Sensitivity of a VLBI receiver is generally characterized by System Equivalent Flux Density (SEFD)

$$SEFD = \frac{2kT_{sys}}{A_{eff}} 1 \times 10^{26} \quad Jy - Janskys \qquad A_{eff} = \frac{\lambda^2}{4\pi} 10^{\frac{G}{10}}$$

k: Boltzmann's Constant 1.3807×10^{-23}
T_{sys}: system temperature (K)
A_{eff}: antenna effective area (m^2)
λ : wavelength (m)
G: antenna gain (dB)

- VLBI2010 simulated performance is based on *2500 Jy* SEFD for 12m antenna
  - 50K T_{sys} : includes all sources of noise
  - 50% aperture efficiency → $A_{eff} = (0.5)\pi 6^2$

- Often times the sensitivity of an reflector antenna is specified as A_{eff}/T
  - If $T = T_{sys}$ then the conversion from A_{eff}/T to SEFD is trivial
  - Sometimes vendor will refer to T as just noise due to ground pickup so receiver noise must be added to T before converting to SEFD

Receiver Performance

- Total System Temperature < 50K
  - Cosmic Blackbody radiation: 2.7 K
  - Atmospheric Noise: 10K

Frequency Dependent Contributions (GGAO 12m Example)

2.2 GHz	8 GHz	14 GHz
Zenith Ground Noise*: 20K	Zenith Ground Noise*: 8K	Zenith Ground Noise*: 8K
Frontend Noise: 15K	Frontend Noise: 11K	Frontend Noise: 26K
• LNA: 10K	LNA: 6K	LNA: 20K
• Coupler Loss**: 1K	Coupler Loss**: 2K	Coupler Loss**: 3K
• Injected***: 3K	Injected***: 3K	Injected***: 3K
Total Noise: 47.7K	Total Noise: 31.7K	Total Noise: 46.7K

*12m/QRFH antenna ground noise contributions computed by Bill Imbriale/NASA-JPL.

**Based on insertion loss measurement of coupler

***Noise injected through 20 dB coupler from 50 Ohm/300K impedance of calibration generator. Larger coupling factor reduces this contribution

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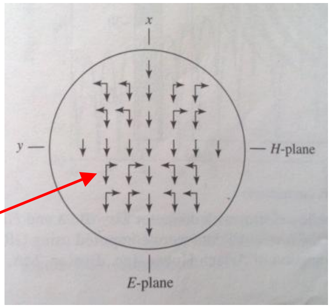
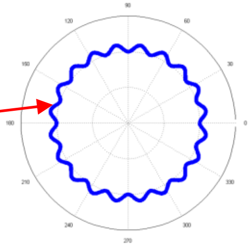
Receiver Performance

- 12m antenna operating with efficiency > 50%
  - Illumination
  - Spillover
  - Blockage
  - Phase center
  - Polarization
    - x and y polarizations of feed pattern are not perfectly balanced
    - loss of aperture area due to field cancellation
    - Not a metric of receiver cross-polarization contamination for on-axis fed antennas



  - n > 1 azimuth modes (BOR1)
    - Higher order modes generate more sidelobes
    - Less power collected from desired direction
    - Can increase ground noise contribution



Receiver Performance

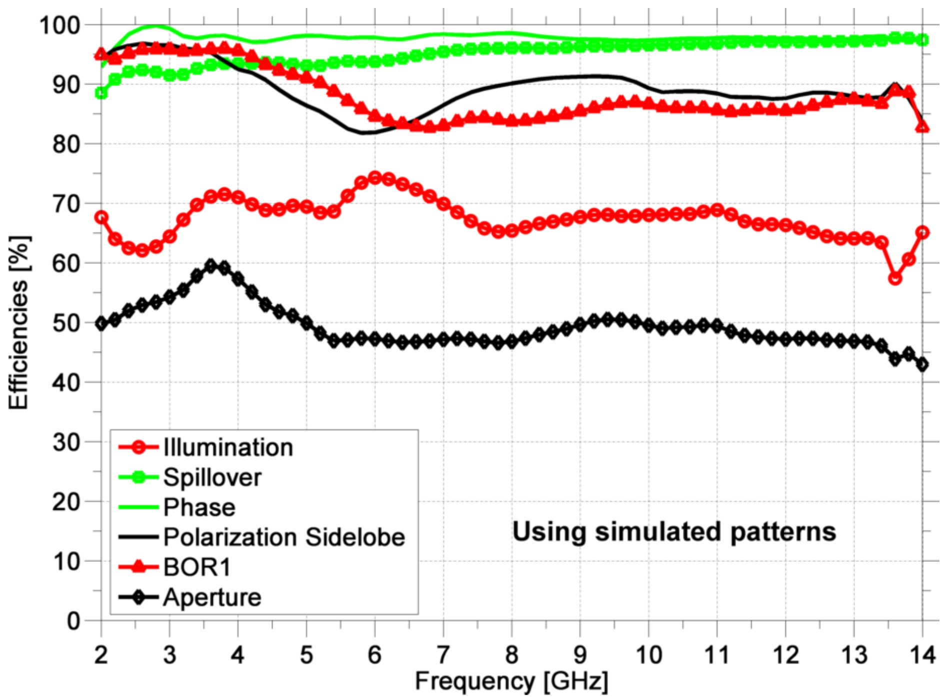
- Feed performance must be qualified by specification of reflector optics
  - W. Imbriale, “Comparison of Prime Focus and Dual Reflector Antennas for Wideband Radio Telescopes”, IEEE Aerospace Conference, Big Sky, Montana, March 3-10, 2012
  - W.A. Imbriale, L. Baker, and G. Cortes-Medellin, “Optics Design for the U.S. SKA Technology Development Project Design Verification Antenna”, 6th European Conference on Antennas and Propagation, Prague, CZ, March 26-30, 2012

- Good reference for computing antenna ground noise pickup:
  - W. Imbriale, "Faster antenna noise temperature calculations using a novel approximation technique," IEEE Ant. Prop. Society International Symposium, Toronto, ON, July 2010

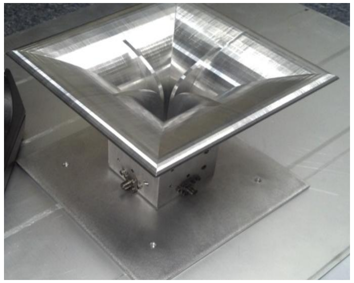
- Good reference on antenna feed efficiency factorization computations:
  - P.-S. Kildal, “Factorization of the Feed Efficiency of Paraboloids and Cassegrain Antennas,” IEEE Trans on Antennas and Propagat., vol. AP-33, iss. 8, pp. 903-908, Feb. 1985.

Receiver Performance

Westford 18m Expected Aperture Efficiency

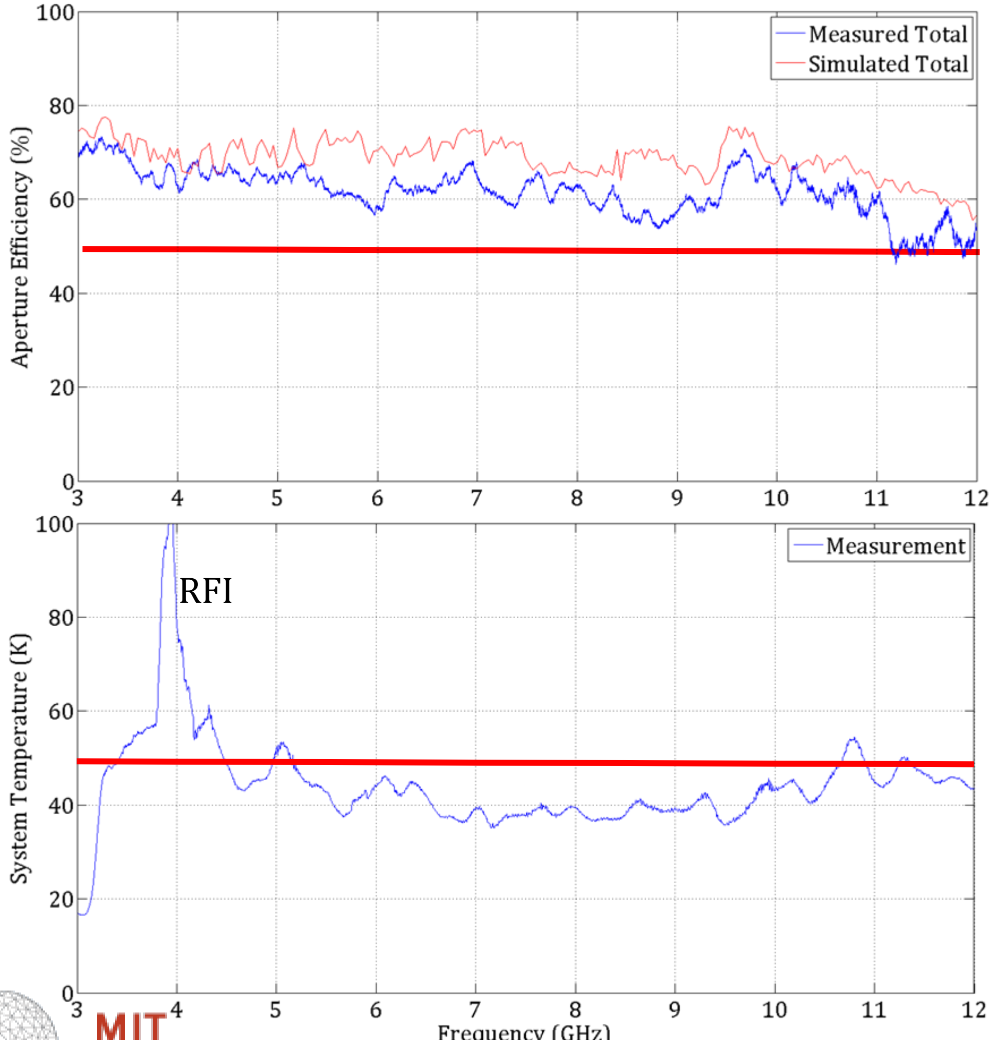


- Westford requires low gain feed
  - Half-angle 80° BW
- Difficult to match with any currently available broadband feed.
  - Can afford lower Aeff on Westford
- QRFH designed to cutoff at 2.2 GHz
  - 10% smaller than 2 GHz feed
  - More defense against S-band RFI



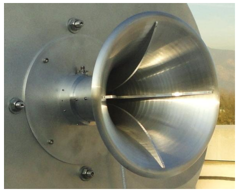
Receiver Performance

GGAO 12m Sensitivity



- Aperture efficiency “simulation” computed by Bill Imbriale (JPL) using custom PO solver. Blockage/Thermal/Gravitational deformations not considered by solver

- Aperture efficiency “measurement” obtained using single-dish observations of TaurusA and estimated by on/off-source/Y-factor method.



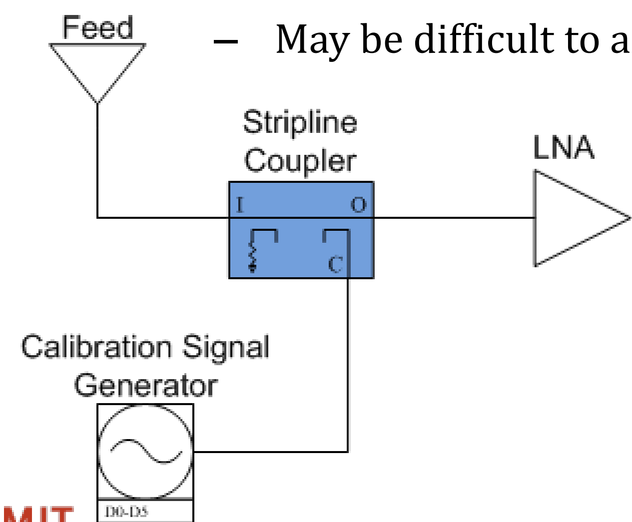
Calibration Signal Injection

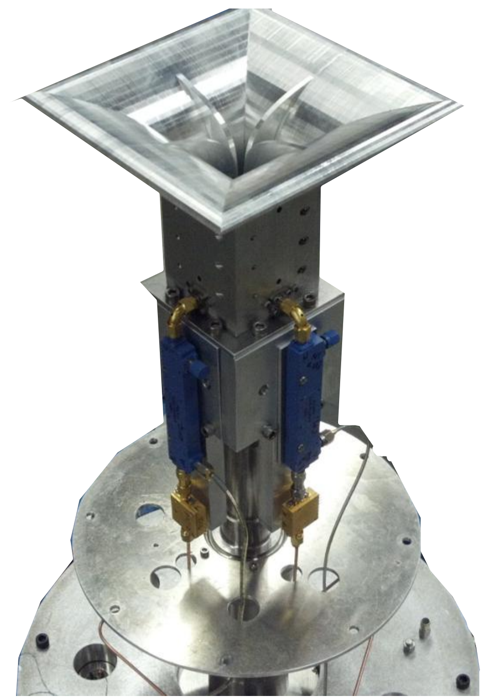
- VLBI2010 receivers must inject phase and noise calibration signals into receiver frontend
- Phase cal signals are easily corrupted by spurious signals
- Two primary injection methods proposed for VLBI
  - Direct injection
  - Radiative injection

Calibration Signal Injection

Direct Injection

- Uses commercial microwave components to inject the calibration signals so implementation is not difficult
- Spurs (~-40 dBc) will arise but they should be time-invariant
- Some receiver performance is sacrificed
  - ~1-8K increase at 20K physical temperature
  - May be difficult to adequately cool the coupler





To receiver backend

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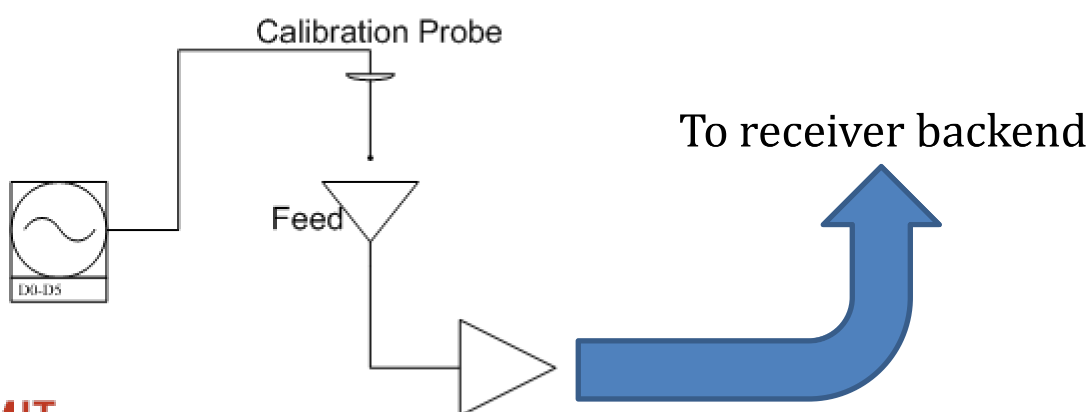
Calibration Signal Injection

Radiative Injection

- Uses a small broadband probe to radiate calibration signals into the receiver frontend
- No receiver performance is lost since the probe is external
- Multipath spurs can arise and may be time-variant and can be difficult to detect



Procurement Logistics

- QRFH and LNAs can be ordered through Caltech
  - QRFH
    - 10,000 USD (7,500 EUR) for the GGAO 12m and Westford designs
    - For cost of a new design consult Sandy Weinreb
  - CRYO1-12 LNA
    - 5,000 USD (3,800 EUR) for amplifier module
    - 1,000 USD (760 EUR) for bias regulator
    - Also contact Sandy Weinreb
- Stripline couplers for calibration signal injection
  - Pulsar Microwave: 530 USD (400 EUR)
- Haystack can provide integrated frontend solution
  - Contact Arthur Niell