Simultaneous X- and Ka-Band Receiver for Astrometry and Navigation

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Advanced Celestial Reference Frames**

Objectives

The objectives of this proposal are to develop a wideband cryogenic monolithic microwave integrated circuit (MMIC)-based receiver, to cover 8-36 GHz, simultaneously covering X and Ka band, for potential use in developing an X-Ka reference frame for astrometry and navigation. The receivers are needed to provide reference frames to navigate, including determining positions of quasars for navigation beacons, measuring station locations, and measuring earth orientation to the nano-radian level or better. The measurements of X and Ka band simultaneously allows for calibrations of both the Earth's ionosphere and solar plasma at the exact time and direction of the observations. The acquisition of data in the 8-36 GHz range consolidates several receiver systems (X, Ku, K, and Ka) into one receiver package (Fig 1a), which saves space, power, minimize maintenance cost, and allows for additional receivers in VLBI systems. The instrument is being designed and built at JPL. Members of the Strategic Initiative team have been in discussions with personnel from NRAO, regarding development of a wideband X-Ka receiver for potential use at the VLBA. The discussions include suggestions for receiver interfaces and requirements.

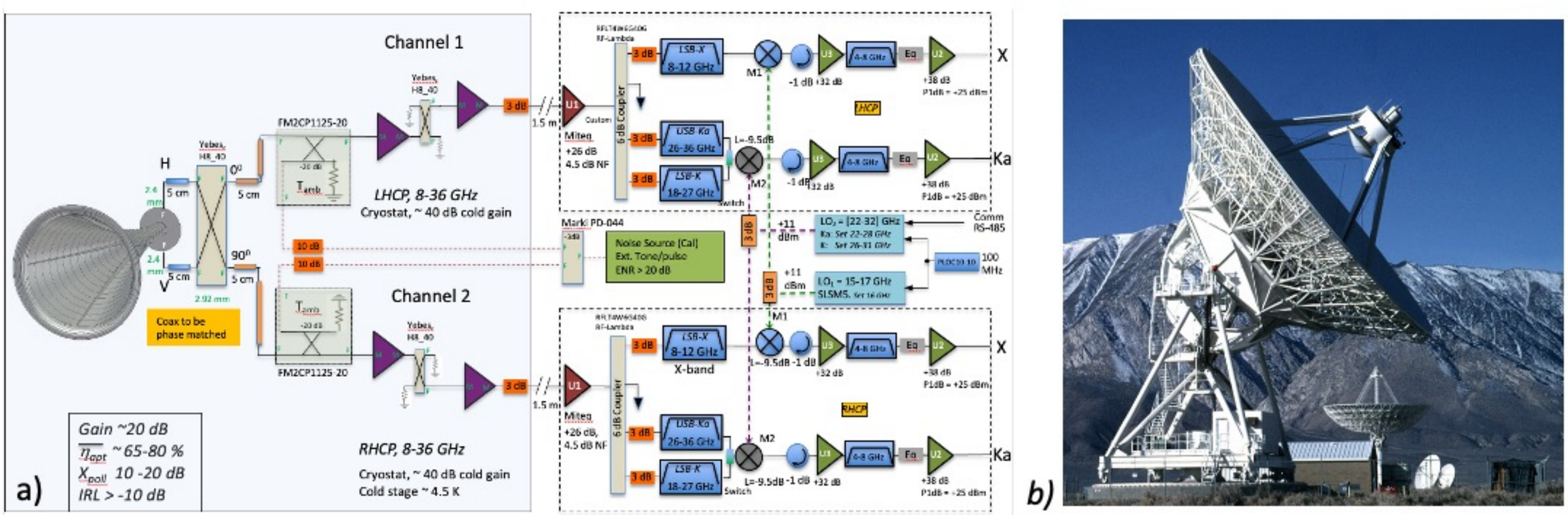

Figure 1a) Schematic diagram of the new simultaneous X-Ka Band receiver under development. On the left is the front-end, which utilizes three key components developed under this task: a Quad-Ridge Feedhorn, Wideband LNAs, and the 90 degree quadrature hybrids from YEBES Observatory, Spain. To the right is the IF processor / IF downconverter. To interface to the VLBA antenna the IF output is down converted into the 4-8 GHz frequency range. b) Owens Valley VLBA antenna at which the X-Ka band receiver will be installed.

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Background

This Strategic Initiative is designed to strengthen JPL's leadership in defining the next-generation of celestial reference frames. As part of its vision to be a world leader in deep space telecommunications, the Interplanetary Network Directorate (IND) has invested in higher radio frequency (Ka-band, 36 GHz). The traditional means of navigating deep space spacecraft relies on the use of their radio telecommunications equipment—measuring the relative separations between the spacecraft and reference sources on the sky. As part of the effort to transition to Ka-band systems, JPL has developed a reference frame based on measurements of quasars at X band (8 GHz) and Ka band (the X/Ka reference frame). We note that the International Astronomical Union, motivated in part by the upcoming Gaia optical catalog release (ca. 2022), may adopt a new International Celestial Reference Frame (ICRF-4) in the next few years which would seamlessly integrate the new Gaia optical frame with the current multi-wavelength radio frames at the S/X, K, and X/Ka radio bands. This proposal enables JPL to continue the leadership in this area that was established by having a JPL chair of the ICRF3 working group, thus ensuring that the next generation international standards meet JPL's navigation needs.

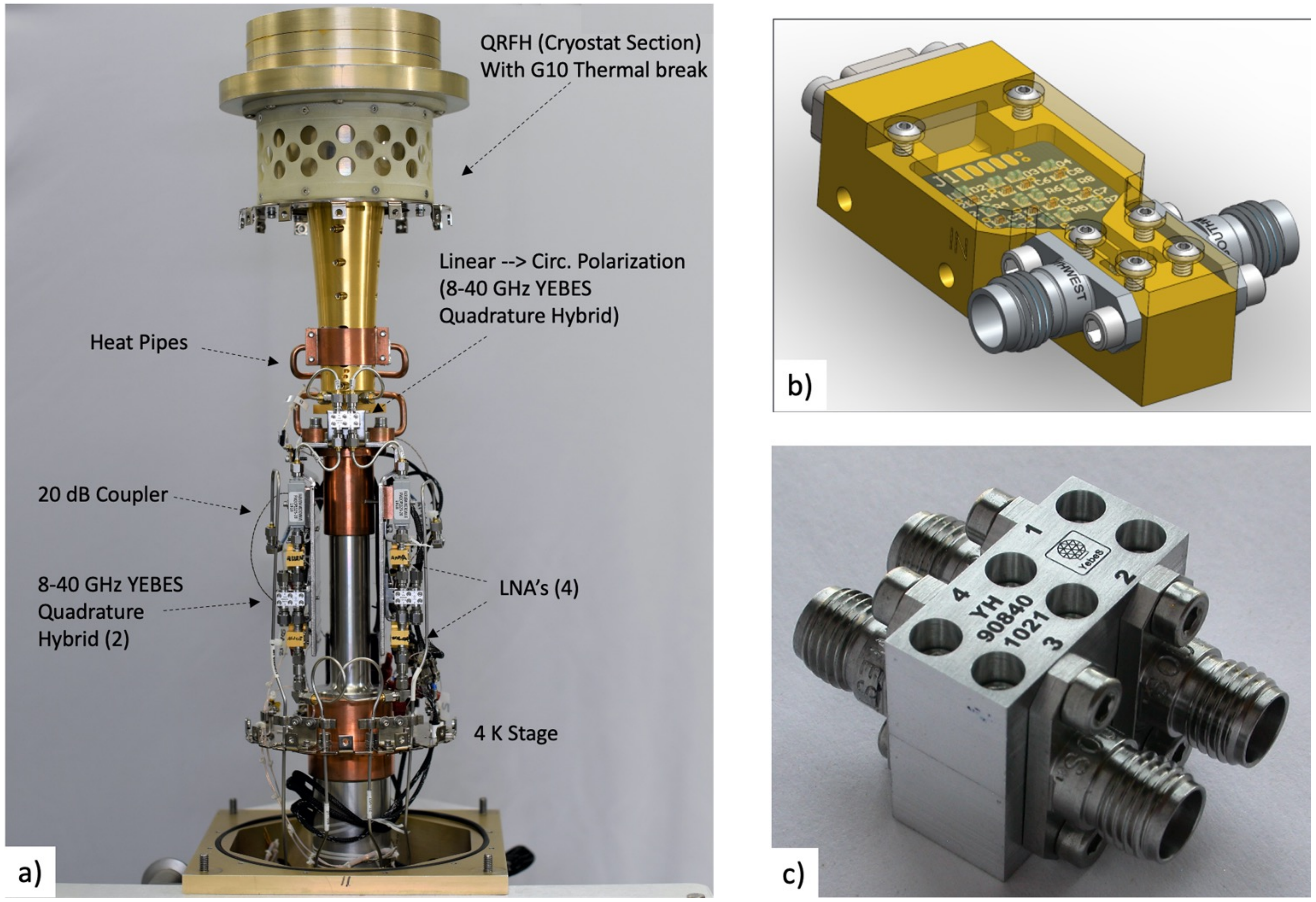

Figure 2a) Fully assembled 'circular' polarized X-Ka band receiver. b) Standard 8-40 GHz LNA Housing, and c) YEBES Observatory 8-40 GHz Cryogenic Quadrature Hybrid.

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Approach and Results

This work leverages the design and development work conducted under a prior strategic initiative, Technology for the North American Array.

Comparison with State of the Art: A prior LNA designed in NGC's 35 nm InP process by then-graduate student Ahmed Akgiray, has achieved between 13-20 K from 8-40 GHz [PhD dissertation, Caltech 2013], in a chip designed for 8-50 GHz. Similar results were obtained at JPL in a design using OMMIC, again intended for the wider 8-50 GHz frequency range. Both of these chips, with their wider bandwidth, have compromised noise performance in order to obtain the gain up to 50 GHz.

Technical Approach: By reducing the bandwidth requirement to 8-36 GHz, the LNA performance is expected to improve substantially. In addition, new designs being evaluated using NGC and OMMIC, have newly developed 4-finger HEMT transistors with drain air-bridges, previously demonstrated to improve stability associated with larger gate periphery 4-finger devices [Moschetti, 2016]. We have been evaluating the new chips as part of this program.

After evaluation of the prior designs, we have designed new, optimized 8-36 GHz LNAs in a commercial OMMIC foundry process. OMMIC offers an affordable shared foundry process, and we have procured 30 MMICs of three different designs (Samoska, Fung, Akgiray) for a total of 90 chips in 2019. It is envisioned that in future research we will investigate MMIC funds with the Swiss company Diramics who at the present time have the lowest noise transistors on the market. As part of year 2 we have cryogenic wafer probed these chips at the Caltech Radio Astronomy Lab (CRAL) for noise, gain, and input return loss (S-parameter) performance. The cryogenic wafer probed results show very high yield (> 90%) and broad-band performance to 40 GHz ((Fig. 4), consistent with computer simulation models. To facilitate, and optimize performance above ~18 GHz, we have also reworked (HFSS) the LNA block input and output 50 Ohm Coax-Microstrip transition to a 50 Ohm Coax-Coplanar wave (CPW) transition (Fig. 2b). The latter configuration is consistent with the very broadband ~40 GHz 'Pico probe' CPW mode transition of the probe station which provided excellent performance.

Innovation: No other wideband 8-36 GHz LNAs exist covering the full frequency range, in industry or on any radio telescope. The JVLA achieves excellent noise performance in separate LNA designs for 8 different bands.

Achieving only a 20% increase in noise over the JVLA performance specs (Fig. 4) in such a wide bandwidth represents a revolutionary capability that can be used in multiple telescope projects in the US.

In addition, a 8-36 GHz Quad Ridged Feedhorn (Fig 3a) was designed to interface with optimal aperture efficiency (Fig. 3c) to the VLBA antenna(s). The feed (Fig. 2a) is an integral part of the cryostat that houses the task's front-end low noise amplifiers. With the feed assembled, the beam patterns were measured on an antenna range at 8-, 20- and 36 GHz. Measured beam patterns (Fig. 3b) and horn input return loss (Fig 3d) agree well with the computer simulations.

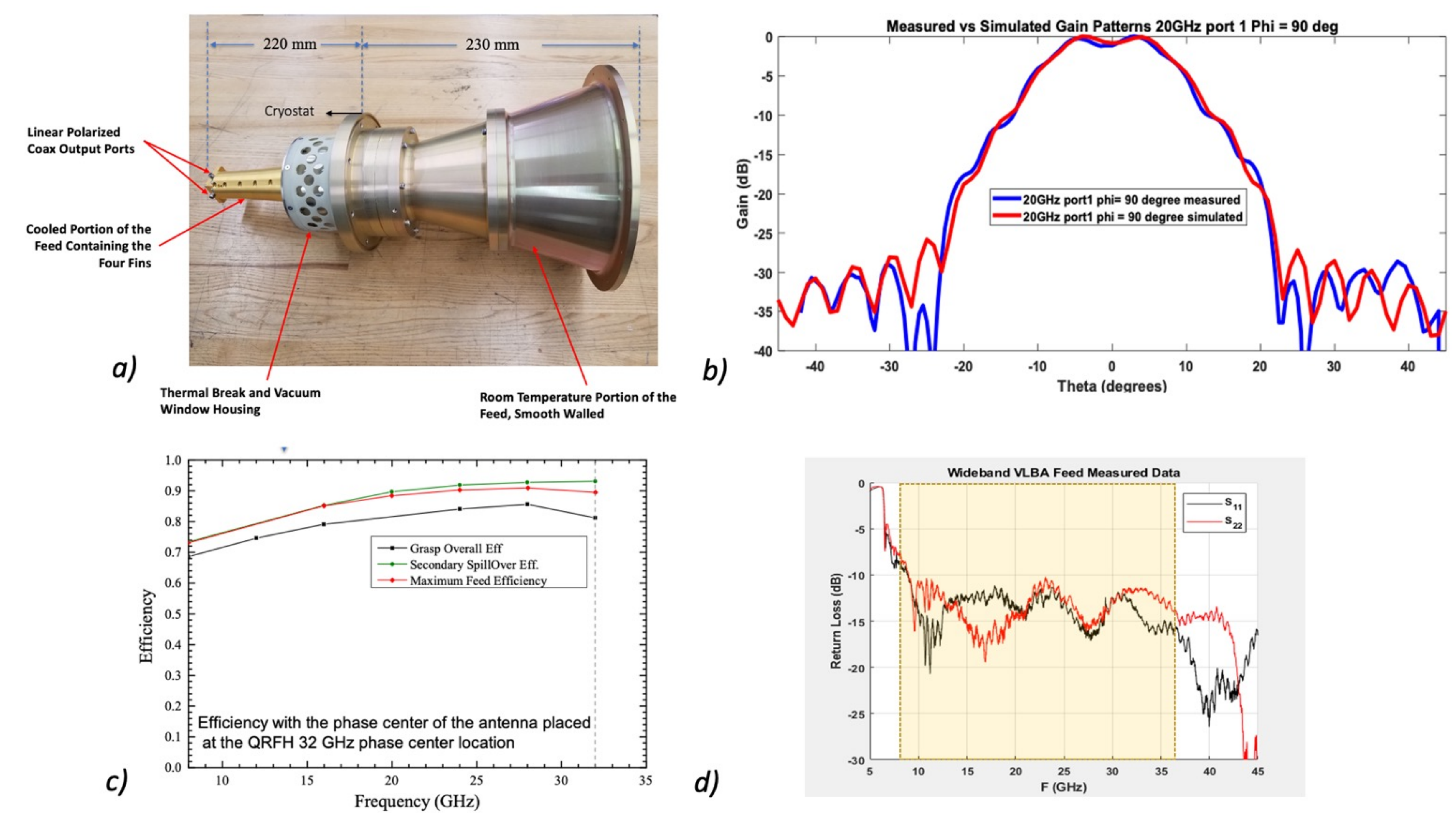

Figure 3a) Quad-ridge flare horn (QRFH) designed to illuminate the (Owens Valley) 25m VLBA antenna from 8-36 GHz, *b)* Measured and modeled beam pattern at 20 GHz*, c)* Calculated efficiency from 8-32 GHz with the phase center of the VLBA antenna placed at the feedhorn 32 GHz phase position*. d)* Measured (RT) QRFH input return loss on both linear channels.

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Significance/Benefits to JPL and NASA

We have successfully demonstrated in the lab, and on the sky (by putting the instrument (Fig 2a) on the roof of building 238), a 8-36 GHz circular polarization receiver that in allows simultaneous detection in the X, Ku, K, Ka microwave bands. The instrument baselines a four finger 35 nm NGC MMIC (AJ50LN2N4) and meets by and large all the programatic technical and scientific requirements.

In FY 2019 an 8-36 GHz wideband feed (QRFH) was designed to interface with optimal aperture efficiency (Fig. 3c) to the VLBA antenna(s). The feed (Fig. 3a) is an integral part of the cryostat that houses the task's front-end low noise amplifiers (Fig. 2a). Beam patterns measured on an antenna range at 8-, 20- and 36 GHz show excellent agreement between simulation and measurement (Fig. 3b). In addition measured input return loss (Fig 3d) agrees well with the computer simulations.

Development of a X, Ka band IF processor / downconverter (Fig 1a right side). Because of it's flexible nature, it is also possible observe in K (18-27 GHz) band. The latter facilitates interferometry observations with the VLBA.

In collaboration with YEBES Observatory in Spain we developed a unique 8-40 GHz low-loss Quadrature Hybrid (Fig. 2c).

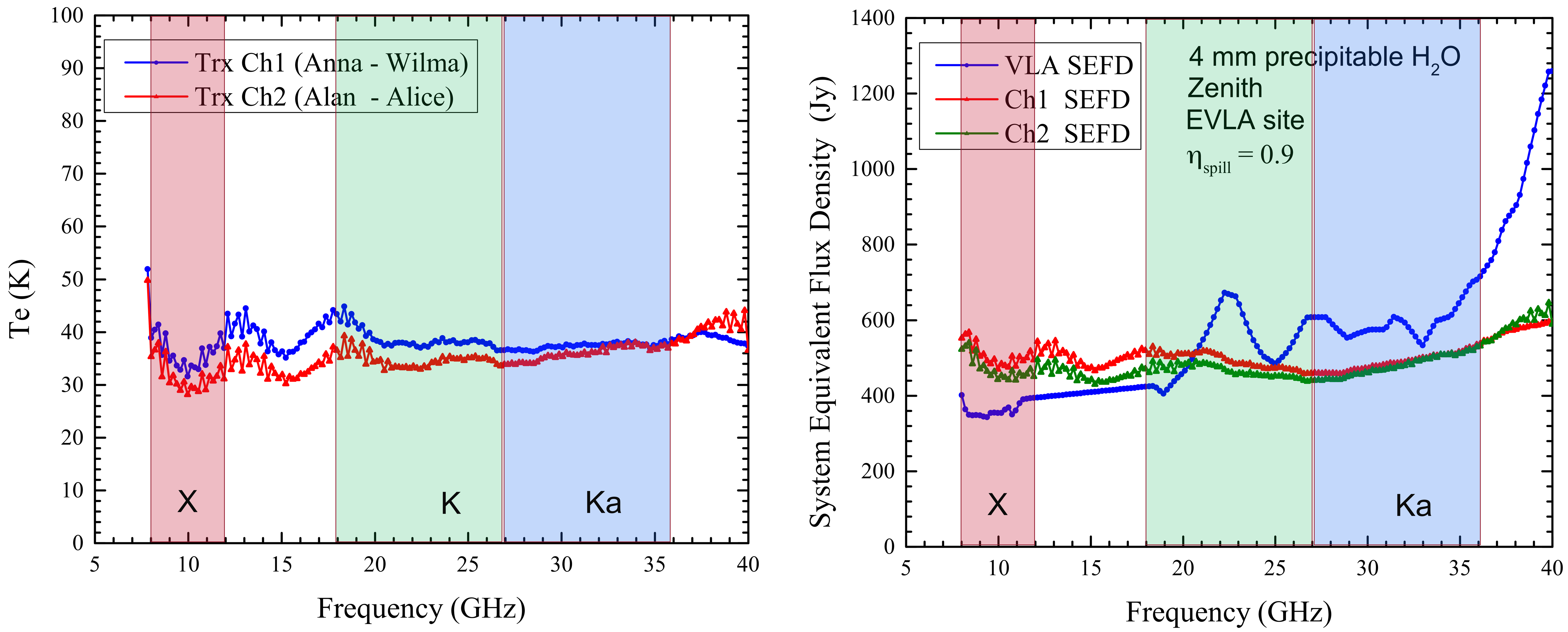

Figure 4a) Receiver system noise temperature, and *b)* Wideband Receiver System Equivalent Flux Density. The goal of the task is to be no greater than 20% in excess of the narrowband VLBA system, which is met everywhere except at between 8-10 GHz. Future MMIC design/fabrication with updated transistor models is likely to make the instrument fully compatible.

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Publications

"Simultaneous X- and Ka-Band Receiver for Astrometry and Navigation", Jacob W. Kooi, Melissa Soriano, James Bowen, Andy K. Fung, Dan Hoppe, Raju Manthena, Zubair Abdulla, Lorene Samoska, Andrew Janzen, Daniel Gallego, Inmaculada Malo, Bekka Bekari, Alex Choi, Kieran Cleary, Chris Jacobs, and Joseph Lazio, In preparation for IEEE-MTT Int. Microwave Symp.

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