Low Noise L-band RF-over-fiber Signal Transport for ALPACA on the GBT

Mitchell C. Burnett, Nathaniel Ashcraft, Spencer M. Ammermon, Brian D. Jeffs, Karl F. Warnick
Department of Electrical and Computer Engineering
Brigham Young University
Provo, Utah, USA
mitch.burnett@byu.edu

***Abstract*—After the catastrophic failure of the Arecibo Telescope on Dec. 1, 2020, the intended host telescope for the 69-element wide-field phased array feed ALPACA instrument was lost. Design of the RF-over-fiber (RFoF) signal transport link to the FPGA/GPU digital beamformer back end was revisited to accommodate the physical and operating requirements of a new host telescope. The equivalent noise temperature of the link must be below 850 K in order for signal transport to contribute no more than 1 K to the target system noise temperature performance of 27 K for the instrument. We present progress of the new design and report on its performance.**

I. Introduction

The ALPACA instrument is a fully cryogenic L-band wide-field 69-element phased array feed (PAF) and digital beamformer back end that was to be a user provided facility instrument on the Arecibo 305 m radio telescope prior to its decommissioning and subsequent collapse on Dec. 1, 2020. With its wide field of view, ALPACA will enable improved surveys for extra-galactic sources, pulsars, fast radio bursts and other radio transients. The Green Bank Telescope (GBT) in Green Bank WV, USA, is the best alternative host telescope to leverage the science capable with ALPACA.

In a radio astronomy application the design requirements for signal transport includes: minimal contribution to the system noise budget, sufficient dynamic range to detect the weak astronomical signals of interest and be resilient to any potential radio frequency interference, and—in the case of a PAF—stable gain and phase performance to permit calibrated array beamformer coefficients to be reused in digital signal processing for observations over many many days or weeks. ALPACA will use RF-over-fiber (RFoF) to transport antenna voltages from the cryostat to the digital back end to avoid the high loss of coaxial cable and allow for a low noise link without repeaters. Transitioning to the GBT as a facility instrument requires that the previous RFoF link for the Arecibo Telescope [1] be revisited in both its layout and design for placement as a prime focus receiver while maintaining its design requirements.

II. Signal Transport

The front end is fully cryogenic with two thermal stages: an 80 K stage at the ground plane followed by a 20 K stage for the array elements and cryo-LNAs. Semi-rigid coax cables (at 20 K) will carry the RF signal received by array elements from

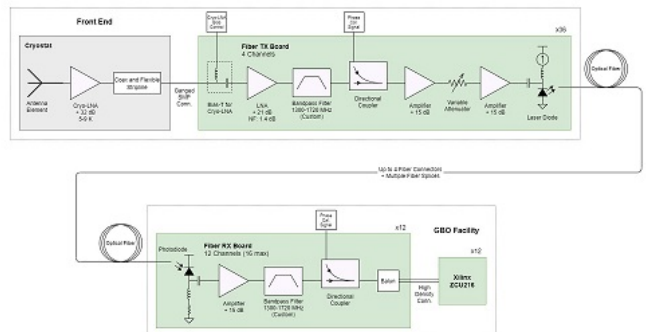

Fig. 1. Block diagram showing the ALPACA signal transport for a single antenna of the fully cryogenic array front end to an FPGA of the digital back end using RFoF for transport.

the cryo-LNA package to a multi-channel flexible stripline through the 80 K stage and exit the top plate of the cryostat. Here, 36 four-channel RFoF transmitter boards will be used for long-haul transport of all 138 RF signals from the front end at prime focus on the GBT over 3.5 km to the digital back end hardware located in the new Green Bank Observatory data center. The target system noise temperature of the instrument is 27 K. To meet this goal the RFoF portion of the full signal transport path must have an equivalent noise temperature less than 850 K. A diagram of the ALPACA front end with RFoF link to the FPGA of the digital back end is shown in Fig. 1.

The RF signals are received from the stripline connector and filtered with an instrument defining 1.3—1.72 GHz antialiasing bandpass filter. To reduce the noise contribution from the laser diode the transmitter uses three low noise amplifiers with sufficient RF isolation to prevent oscillations. A variable attenuator is also used to adjust gain and noise floor levels for the dynamic range of the link. The RF is then used to directly modulate a 5 mW, 1320 nm laser diode.

The RFoF transmitter boards will be installed in a ring on the top plate of the cryostat allowing for convenient servicing. This required all I/O connections of the transmitter be reoriented on the same edge of the PCB. The laser is therefore mounted in an end launch configuration within a cut-out of the PCB so the pigtail faces the same direction as the custom ganged SMP connector for the flexible stripline out of the

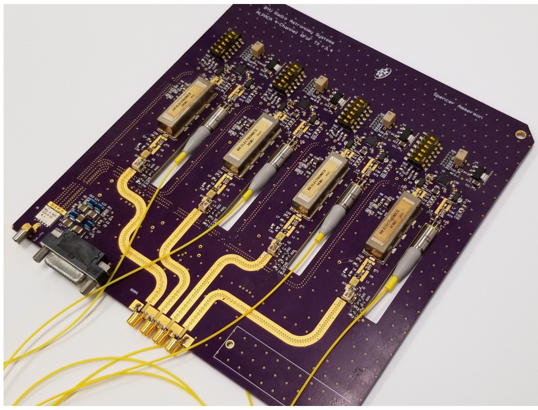

Fig. 2. One of 36 assembled four-channel transmitters with cryo-LNA power, monitoring, signal conditioning and laser diodes.

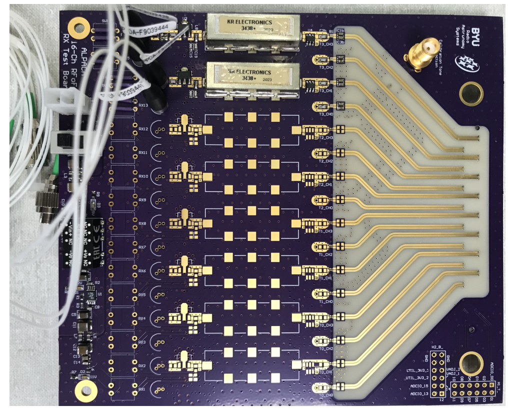

Fig. 3. Partial assembly of a 16-channel receiver board under test with an RFSoC of the digital back end.

cryostat. The fiber pigtail is secured by a custom fixture to make an SC/SC connection with the fiber to the downlink receiver. The remaining I/O on the transmitter are: a single SMP connector for calibration signal injection into each of the four transmit channels, and a single 25-pin micro D-sub connector for ±5 V power, ground, cryo-LNA power, and sense lines for the voltage and current on each cryo-LNA. A picture of an assembled four-channel transmitter board is shown in Fig. 2.

The 138 downlink fibers are distributed to 12 Xilinx ZCU216 boards each with a 16-channel RFoF receiver board to transfer the analog signals from the optical fibers to the ADCs on the RFSoC of the ZCU216. The first component on the RFoF receiver board is a photodiode converting the optical signal from the single-mode fiber to an electrical current. The RF signal out of the photodiode is amplified, filtered, and transformed through a balun to a differential pair matched to the 100 Ω differential inputs of the ADC of the ZCU216. A directional coupler is also included on each channel to inject a reference signal into the receive path at the balun as a test point or for calibrating ADC relative phase. The RFSoC includes a digital step attenuator at each ADC input allowing for gain leveling across all 138 inputs to maximize the dynamic range of the system. A partially populated 16-channel receiver board used for testing is shown in Fig. 3.

III. Link Performance

Fig. 4 shows the equivalent noise temperature of the link with different attenuation settings. Measurements were made using the Y-factor method with hot and cold voltage samples captured and processed using the ZCU216. The dashed line at 850 K is where signal transport contributes approximately 1 K to the total system noise temperature. Operating with 15 dB of total attenuation maximizes the dynamic range of the system at 142 dB Hz while still meeting the noise budget of 850 K. Operating with no attenuation decreases the dynamic range to 128 dB Hz but minimizes the equivalent noise temperature of the system to 174 K.

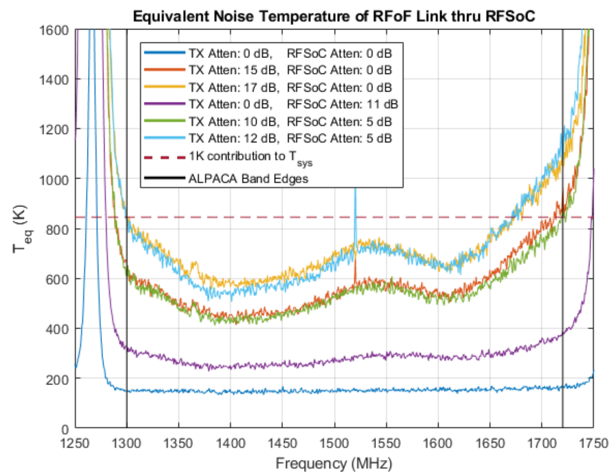

Fig. 4. Equivalent noise temperature of the RFoF through RFSoC system with different attenuator settings on the TX board and the digital step attenuator on the RFSoC.

IV. Conclusion

In anticipation for a transition of host telescope, the ALPACA RFoF link achieves its primary design goal with a minimum equivalent noise temperature of 174 K that maintains a linear dynamic range of more than 128 dB Hz at the digital back end hardware. Future work will evaluate long-term stability of the link and the repeatability of performance on multiple links.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. 1636645.

References

[1] M. Burnett, J. Kunzler, E. Nygaard, B. D. Jeffs, K. F. Warnick, D. B. Campbell, G. Cortes-Medellin, S. Parshley, A. Vishwas, P. Perillat, and D. A. Roshi, "Design and development of a wide-field fully cryogenic phased array feed for arecibo," in *2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS)*, 2020, pp. 1–4.