MIT Haystack Observatory Technology Development Center

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Abstract Technology development activity at MIT Haystack Observatory was focused on the following areas in 2015–2016: (1) KPGO 12-m Signal Chain, (2) calibration system's CDMS, (3) VGOS-compliant signal chain backend R2DBE, and (4) updates to the Mark 6.

1 KPGO 12-m VGOS Signal Chain

MIT Haystack Observatory (MIT/HO) has been responsible for the design, fabrication, deployment, and commissioning of the signal chain for the new KPGO 12-m VGOS system at Kokee Park, HI. In January 2016 the signal chain, which is comprised of three separate sub-systems — Frontend (FE), Backend (BE), and Calibration (VCS), was deployed, and the commissioning phase was completed. Reports on the step-by-step progress are available on the KPGO (Kokee Park Geophysical Observatory) blog at https://space-geodesy.nasa.gov/blogs/KPGO/index.html.

The FE contains the very sensitive low-noise electronics and QRFH feed, which were integrated with the Intertronics Solutions Inc. 12-m antenna. The system equivalent flux density was measured to be $<$ 2,500 Jy. The FE includes all supporting infrastructure (e.g., networking, power supply distribution, and monitor/control) necessary to operate the dual-linearly polarized cryogenic receiver. The calibration antenna unit (Section 2) provides the phase and noise calibration signals that are injected directly into the frontend to provide for instrumental delay and gain correction in post-correlation processing. Within the frontend the signals out of the cryogenic Dewar are amplified to drive the microwave-over-fiber link that is used to transmit the higher frequency of the spectrum to the BE. To conserve dynamic range in the link, the RFI-afflicted S-band portion of the frontend frequency range is sent separately over a coaxial downlink, which possesses significantly more dynamic range in order to be able to support observing in this frequency band. A block diagram of the signal chain FE and a photograph of the KPGO 12-m focal point can be found in Figure 1 and Figure 2, respectively.

The BE receives and distributes the microwave signals downlinked from the FE for further processing. A block diagram of the BE and a photograph of the sub-system in the KPGO control room are shown in Figure 3 and Figure 4, respectively. The low- and high-band signals from the FE are split and fed into four independently tunable 2—14 GHz Up-Down Converters (UDCs). The UDCs are currently equipped with filters for the second Nyquist zone and provide access from 2—13.5 GHz. To access the final 512 MHz of the VGOS range, 13.5—14 GHz, a filter for the third Nyquist zone will be required. The UDC supports 2.5-GHz baseband output with LO tuning resolution of 10 KHz to accommodate compatibility with other VGOS frequency conversion schemes.

In the KPGO implementation, 512-MHz Nyquist zone filters are incorporated in the UDCs to support the sample rate of the RDBE-G (ROACH Digital BackEnd-Geodetic) (1024 MHz). Following the polyphase filter bank (PFB) processing by the RDBE-G, the digitized data are transmitted over standard 10G Ethernet and recorded onto disk modules of a Mark 6

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recorder. The Mark 6 is capable of either continuous recording of a sustained 4 Gbps per disk module or 30-second bursts of 8 Gbps onto a single disk module, assuming the ratio of 50% being on source and another 50% slewing to the next source.

2 VGOS Calibration System

MIT/HO has developed a calibration system to address the VGOS challenge of 4 picoseconds uncertainty in the group delay observable. The new VGOS Calibration System (VCS) incorporates a Cable Delay Measurement Sub-system (CDMS) with upgraded versions of the existing noise and phase/delay calibration sub-systems. Components of the VCS are located in both the BE and FE of the VGOS Signal Chain (SC). The BE houses the CDMS Ground Unit (CDMS-GU), and the FE houses the Calibration Antenna Unit (Cal-AU), which contains the phase calibration generator, the noise diode, and the CDMS Antenna Unit (CDMS-AU) (Figure 5).

2.1 Cable Delay Measurement Sub-system (CDMS)

The purpose of the CDMS is to measure variations of the delay in the cable carrying the reference frequency from the Hydrogen maser to the phase calibration generator. This is needed because these variations are included in the total VLBI delay but are not experienced by the quasar signal path and thus must be removed to obtain accurate geometric delays.

A significant source of these variations, in addition to thermal changes, is mechanical stress on the reference frequency cable imparted by the motion of the antenna.

On time scales relevant to geodetic observations the CDMS is designed to meet the following delay stability requirements (Allan standard deviation):

- 1.8e-14 at 30 s
- 5.5e-15 at 100 s
- 9.0e-16 at 600 s
- 1.0e-16 at 50 min

The CDMS ground sub-system is based on Software Defined Radio (SDR) and was developed and deployed at KPGO to address this requirement.

The initial design of the CDMS, deployed at KPGO, provides correction for transmission of the reference frequency over a coaxial cable. A subsequent modification to the design allows for support of optical fiber in place of the coax, but it is presently supplied for research purposes only and requires a different version of the Cal-AU CDMS board.

3 Upgrade from RDBE-G to R2DBE-G

A digital backend (DBE) based on the ROACH2 is being developed at MIT/HO to extend the performance and cost advantages of digital processing using commercially available hardware from the CASPER collaboration.

The ROACH2 DBE leverages the ADC code base from the Event Horizon Telescope R2DBE (ROACH Version 2 Digital BackEnd) and improves on the ROACH1 DBE by processing two inputs of 2,048 MHz bandwidth, compared to 512 MHz previously, Figure 5. The design uses both VHDL and CASPER blocks to maximize performance and reduce design time. The CASPER filterbanks channelize the input signals, which are then re-quantized to two bits, and the data are output in complex format in standard VTP protocol (UDP / Packet serial number / VDIF) through the 10 GigE outputs.

The R2DBE components will be installed in the same rack-mounted 2U RDBE-G chassis modified to accommodate the ROACH2 and support components, Figure 6 and Figure 7. It supports two IFs, requiring two ADC samplers in the system and is presently undergoing verification, consisting of zero-baseline correlation with an RDBE-G. Operational R2DBE-G units are expected to be available by late 2017.

4 Mark 6 Developments

In 2016, an investigation of the internal temperatures of the Mark 6 host chassis was initiated and was conducted while data were recorded at a sustained 16 Gbps. The investigation was prompted by failures of the 10 G Ethernet NIC hardware at altitudes greater than 3,048 meters. The result of the study was a modification kit for the Mark 6 that reduced the internal temperature by using increased fan speeds, fan ducts, and an air flow deflector plate. A poster summarizing the study was presented at the IVTW at Haystack (http://www.haystack.mit.edu/workshop/ivtw2016/presentations/cruszczyk_poster_ivtw2016.pdf).

Lastly, Mark 6 software v1.3 was developed with added features and bug corrections. The corrections focused on strengthening the resiliency of the Mark 6 software. This software release is available at http://www.haystack.edu/tech/vlbi/mark6/software.html.

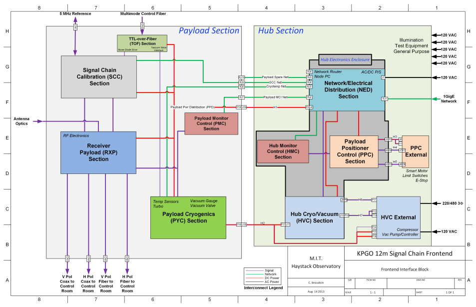

Fig. 1 Block diagram of the signal chain frontend sub-system.

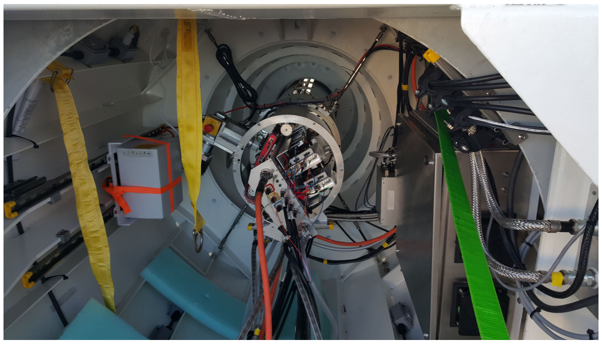

Fig. 2 Signal Chain frontend deployed at KPGO (focus cone).

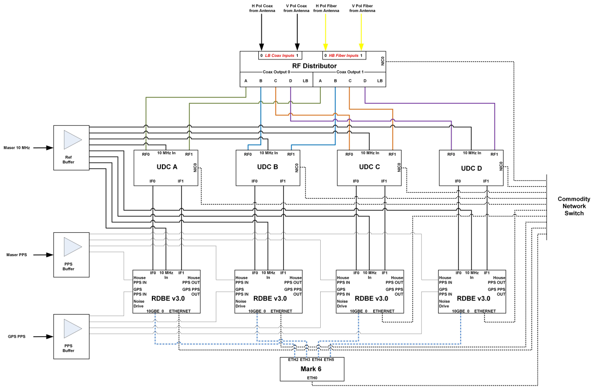

Fig. 3 Block diagram of the signal chain backend sub-system. External connections into the backend from the top represent those to the frontend sub-system. External connections into the frontend from the left/right represent those from the site's general infrastructure (not provided by Haystack).

Fig. 4 Signal Chain backend sub-system as deployed at KPGO control room.

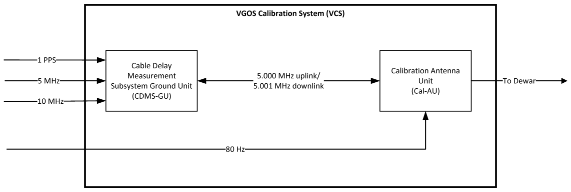

Fig. 5 Block diagram of the cable delay measurement system.

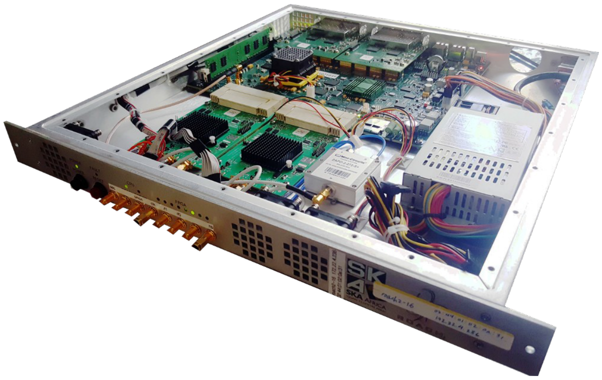

Fig. 6 Roach2 in EHT 1U chassis.

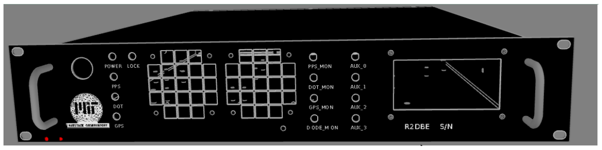

Fig. 7 R2DBE-G front panel.

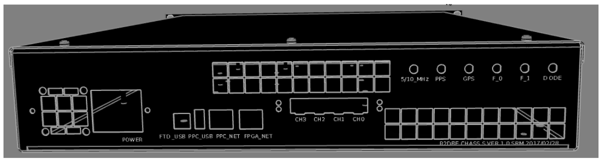

Fig. 8 R2DBE-G back panel.