MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

2022 October 18

Telephone: 617-715-5400

To:	VGOS Signal Chain RF Engineering
From:	G. Rajagopalan
Subject:	Electrical delay measurements along various segments of the VGOS signal chain of the GGAO antenna

1 Summary

Electrical delays for various segments of the signal chain of the VGOS station at GGAO were measured. The delay measurements were made using an Agilent FieldFox and an Anritsu Optical Time Domain Reflectometer (OTDR). The measurement approach is applicable to the signal chain of other VGOS stations. Results are summarized in Table 1.

2 VGOS signal chain delay measurements up to the antenna feed

To illustrate the various delay paths that are measured, Figure 1 shows a simplified block diagram of the VGOS signal chain at GGAO. The end points of the segments that are involved in each delay measurement are identified as P1, P2, …, P9.

2.1 P1-to-P2: The unambiguous electrical length of the 5-MHz reference cable

The length was measured at GGAO using a FieldFox in CAT/TDR mode. (With thanks, the measurement was made by Hudson and Redmond on 2022 October 6.) The delay for the measured 256.56 foot-long LMR400 cable was calculated using the characteristic 1.2 ns per foot of the LMR400 cable (see Table 1).

2.2 P2-to-P3: The phase relationship of the phase-calibration pulse output to the 5-MHz input

By design, the phase-calibration generator maintains phase coherence between the 5-MHz input and output pulse train within VGOS requirements (Appendix A) for the single-band delay (SBD) and the multi-band delay (MBD) determination. (We do not currently have precision measurements on the phase relationship.)

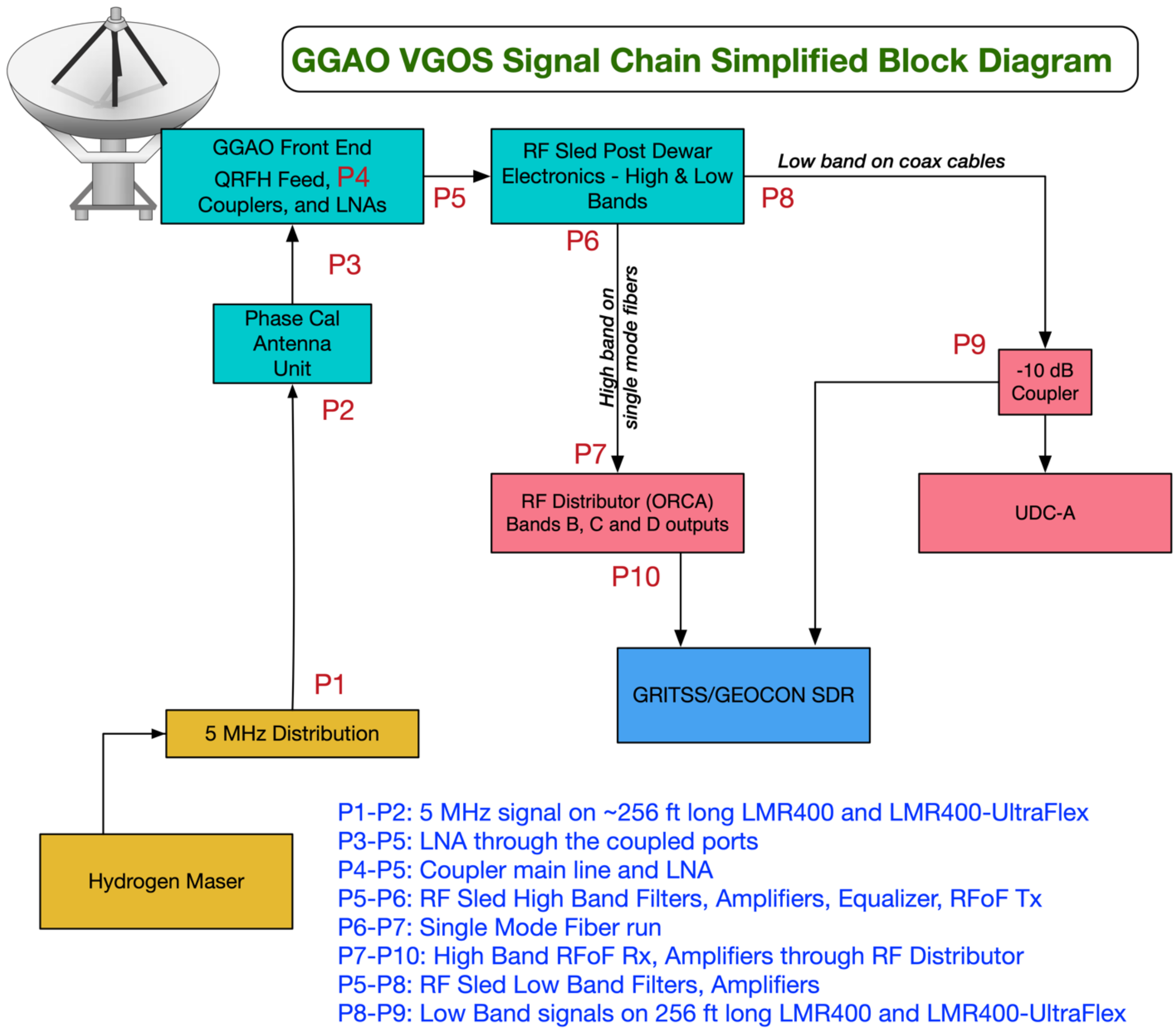


Figure 1: Simplified block diagram of the VGOS signal chain at GGAO.

3 VGOS signal chain delay measurements down from the antenna feed

The S-parameters of various sub-systems of the GGAO signal chain were measured at room temperature during refurbishment of the GGAO receiver at the MIT/HO lab using Vector Network Analyzer (VNA) mode of Agilent FieldFox N9917A after eCal kit calibration. After receiver cooldown, the frequency response through the coupled ports of horizontal (H-) and vertical (V-) polarization channels were also measured. The following sections describe the group delay derived from these S-parameter measurements.

3.1 P3-P5: LNA through the coupled ports

Measurements were made at room temperature and at cryogenic temperature after receiver cool down. Figures 2 and 3 show the frontend coupled gain, match, and group delay at room temperature for the H- and V-polarization channels, respectively. And Figures 4 and 5 show the same measured parameters as Figures 2 and 3 but at cryogenic temperature.

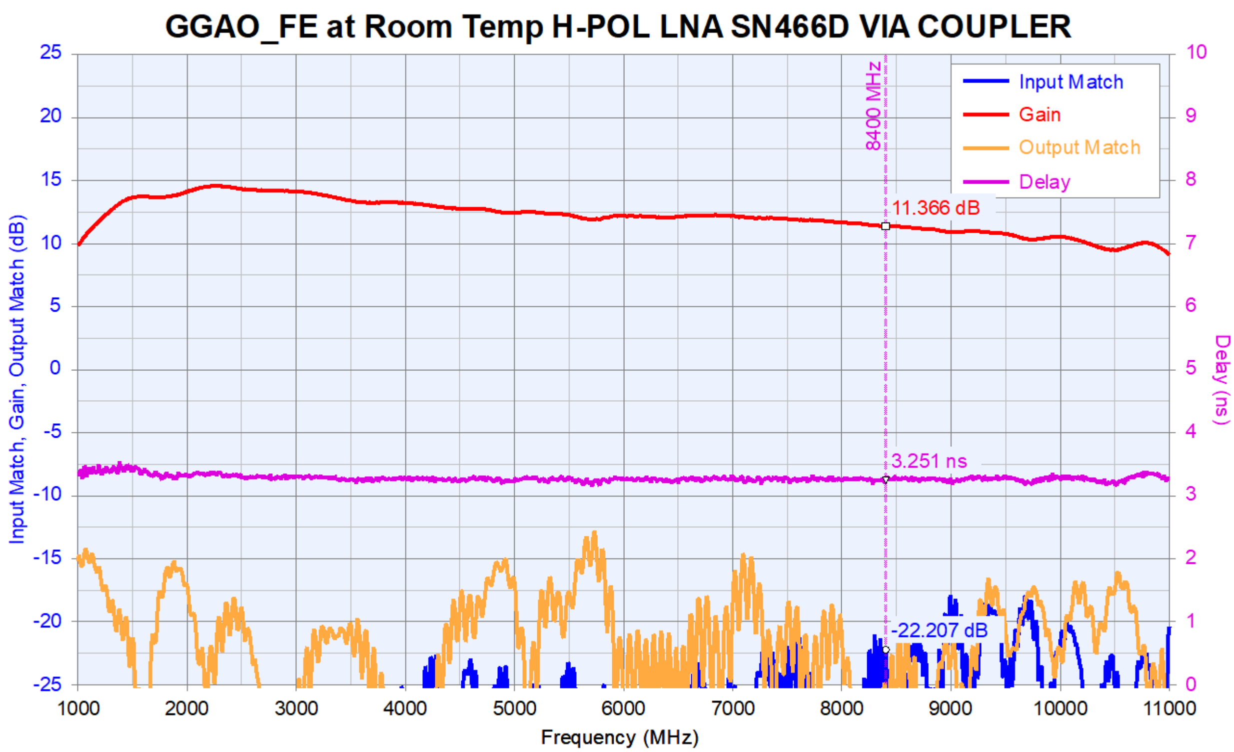


Figure 2: Measured frontend (left axis) coupled gain, input/output match, and (right axis) group delay at room temperature for the H-polarization channel.

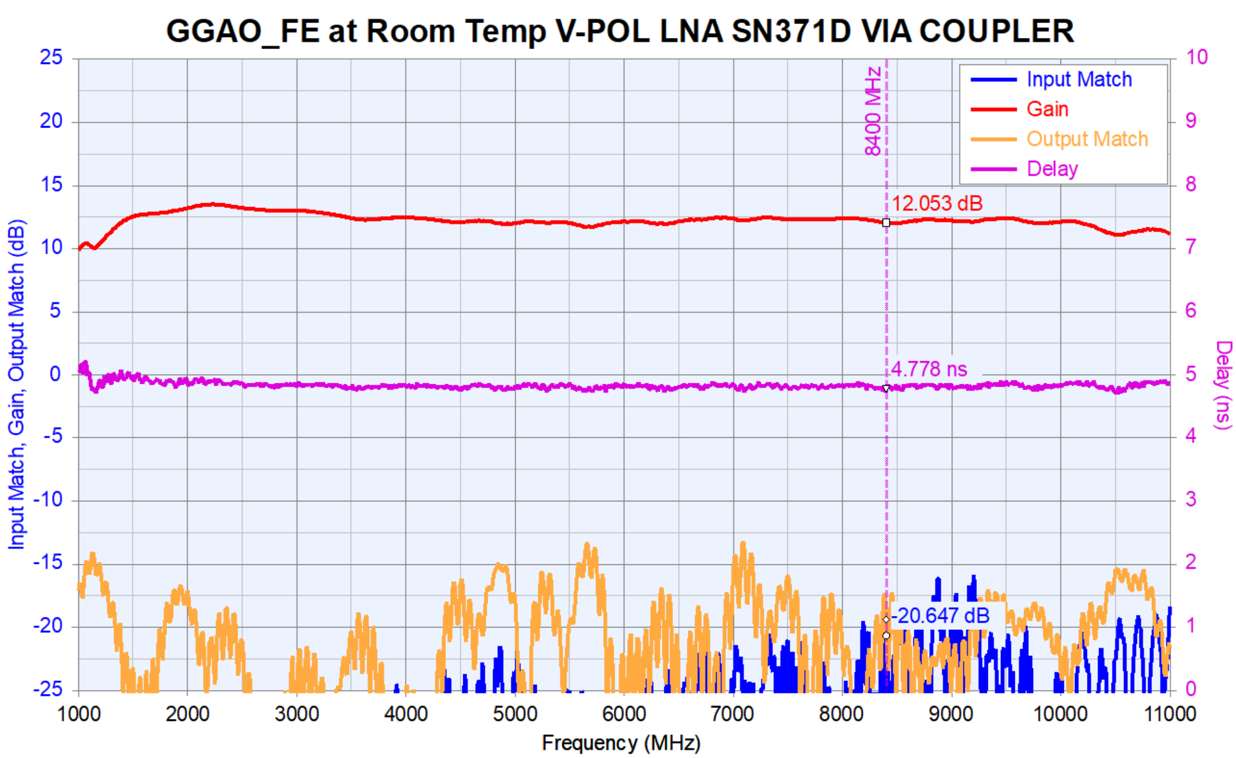


Figure 3: Same as Figure 2 but here for the V-polarization channel.

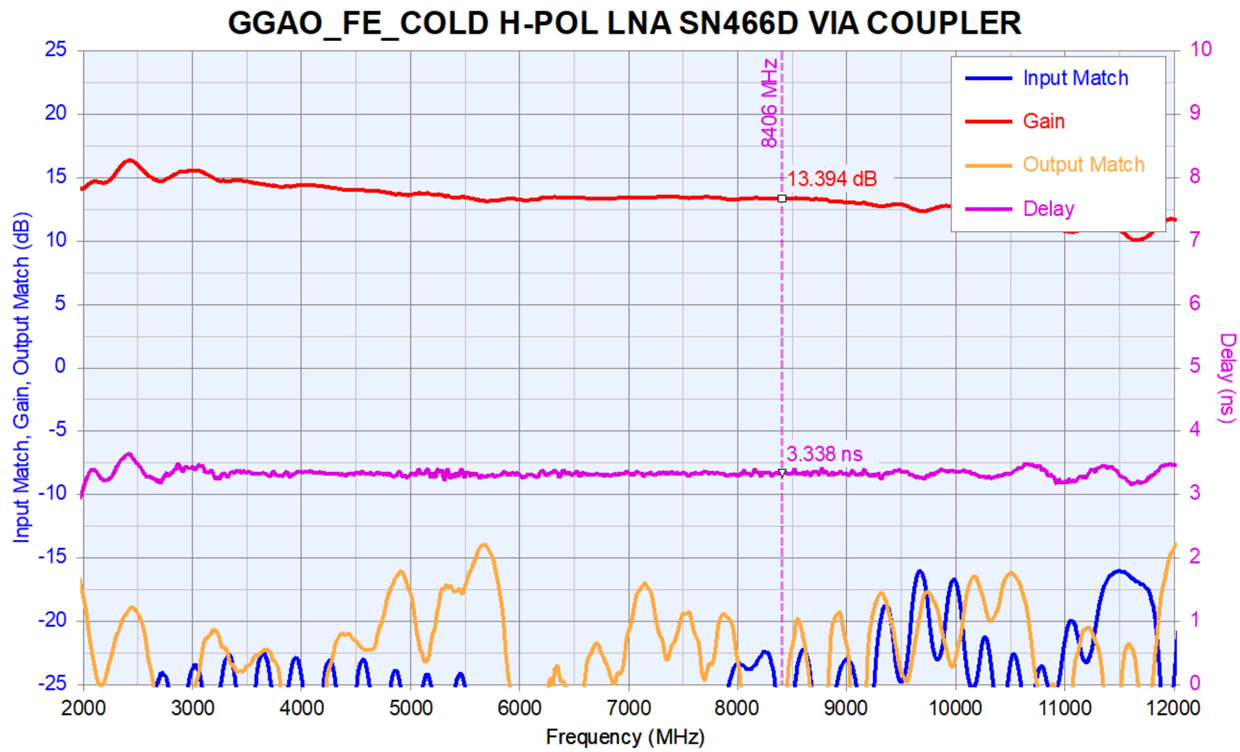


Figure 4: Same as Figure 2 but here at cryogenic temperature.

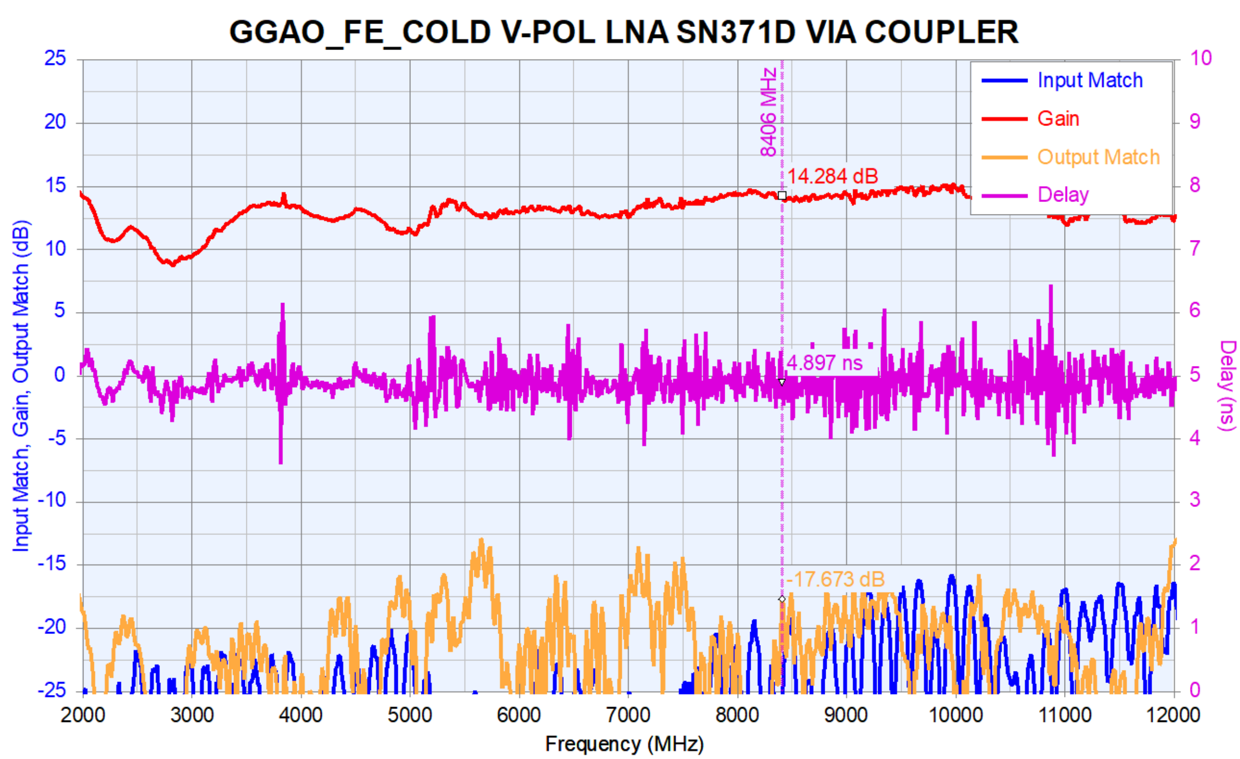


Figure 5: Same as Figure 3 but here at cryogenic temperature, noisier due to lack of averaging.

3.2 P4-P5: Frontend coupler main line and LNA at room temperature

Figures 6 and 7 show the frontend straight-through gain, match, and group delay measurements at room temperature for the H- and V-polarization channels, respectively.

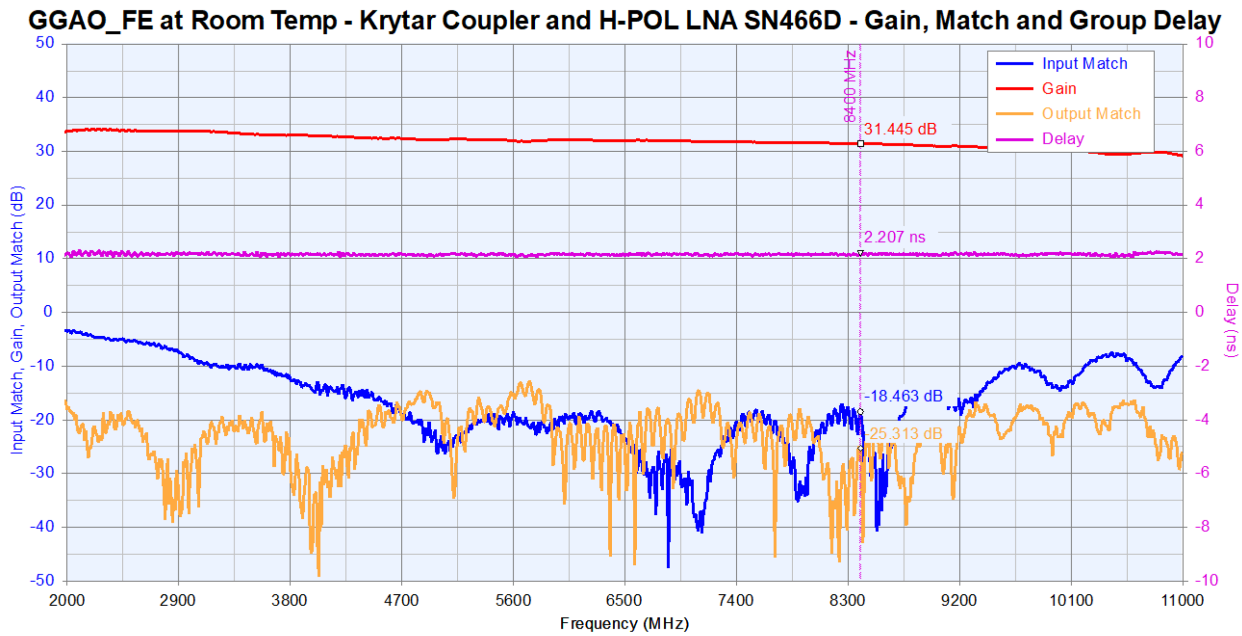


Figure 6: Measured frontend (left axis) straight-through gain, input/output match, and (right axis) group delay at room temperature for the H-polarization channel.

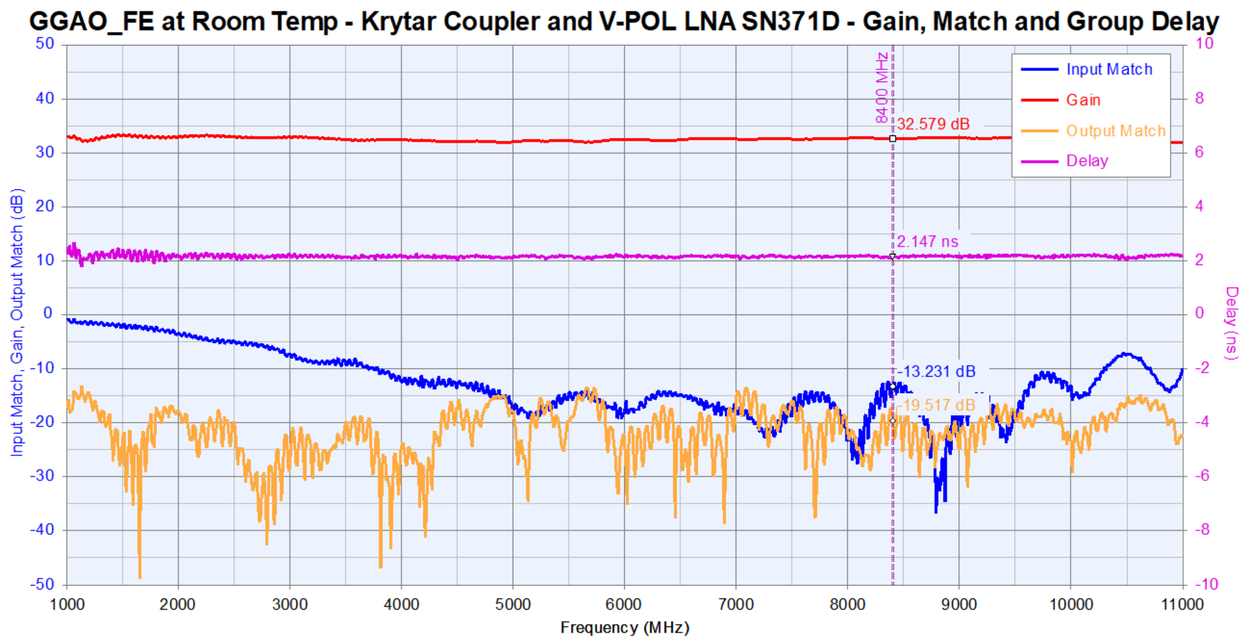


Figure 7: Same as Figure 6 but here for the V-polarization channel.

3.3 P5-P6: RF sled high-band filters, amplifiers, and equalizers

Figures 8 shows the high-band response (i.e., gain and group delay) of the filters, amplifiers, and equalizers in the RF sled in the H- and V-polarization channels. Note that these measurements do not include the response of the RF-over-fiber (RFoF) transmitter (see next).

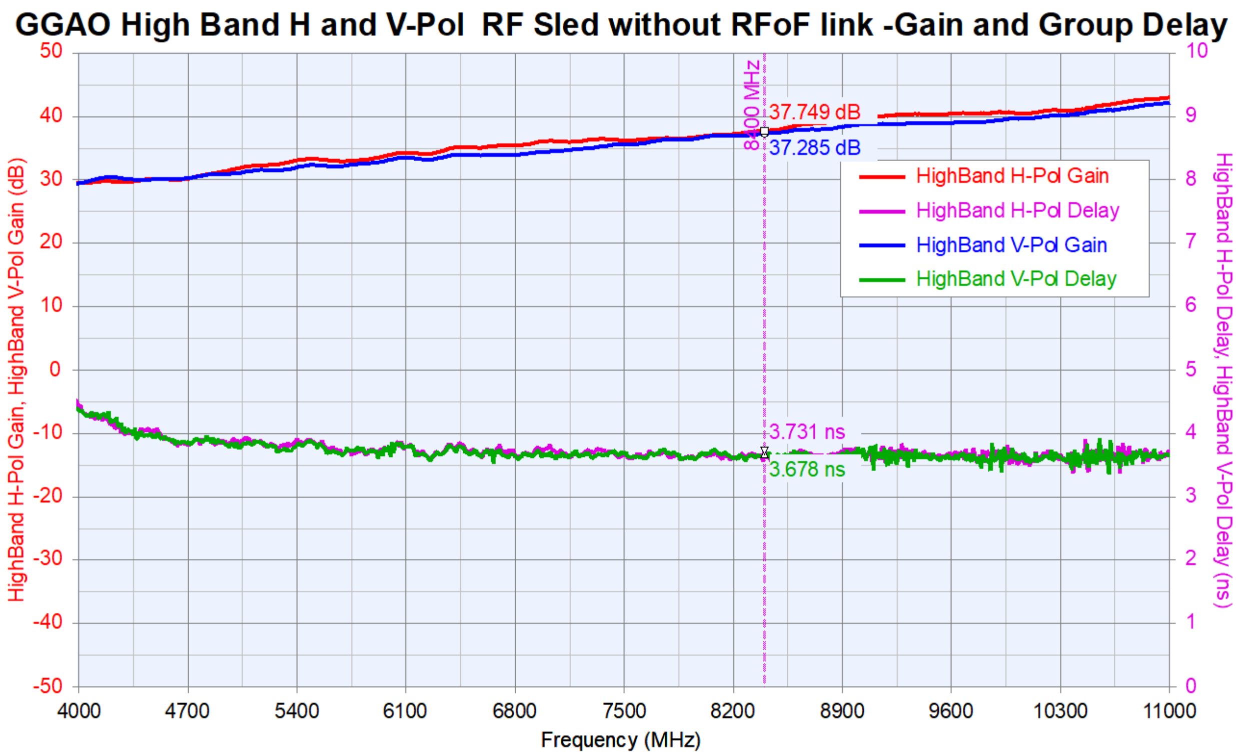


Figure 8: Response of the H- and V-polarization high-band filters, amplifiers, and equalizers in the RF sled.

The high-band response of the RFoF transmitter, fiber patch chord, RFoF receiver, and amplifiers in the RF distributor of both the H and V-polarization is shown in Figure 9. In the Figure, note that the negative group delay extracted from the phase versus frequency relationship of the S-parameter “S21”is an artifact of the insufficient resolution for an unambiguous determination. That is because the FieldFox Analyzer was set to 1-15 GHz in 1001-point sweeps, giving 14-MHz steps. This corresponds to a delay ambiguity range of +/–35.714 ns, which is less than the total delay through these RF-over-Fiber link and the amplifiers in the RF-Distributor plus the fiber patch cord. Therefore, the actual delay is, e.g., 71.428 – 24.616 = 46.812 ns. Corrected group delay values are listed in Table 1.

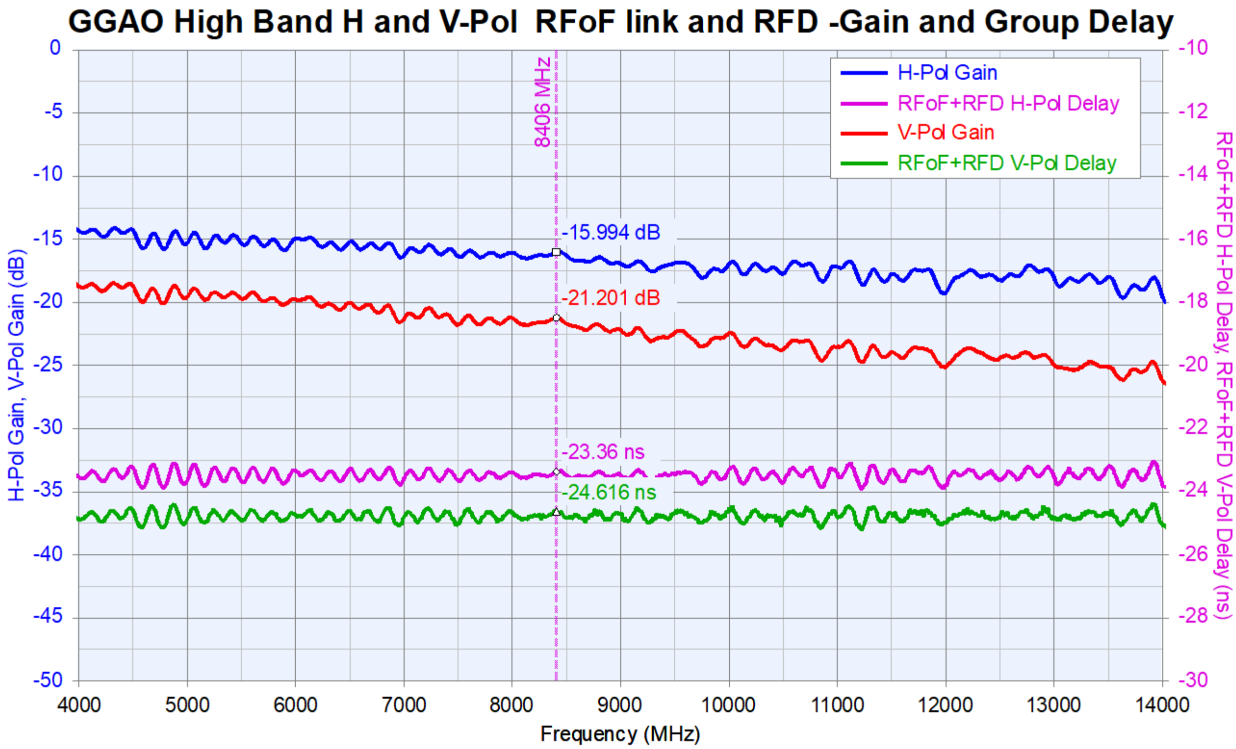


Figure 9: Response of the H- and V-polarization RF-over-Fiber links, amplifiers, and power dividers in the RF distributor.

3.4 P6-P7: Single-mode fiber run

The total length of the pair of single mode fiber (SMF) runs through various junctions was measured at GGAO using an Anritsu OTDR- Optical Time Domain Reflectometer. (With thanks, the measurement was made by Hudson and Redmond on 2022 October 6.) The delays for the measured 126.7 m (H-polarization) and 126.5 m (V-polarization) were calculated using the characteristic 4.9 ns per meter propagation constant of the optical fiber (see Table 1).

3.5 P5-P10: High-band RF sled filter input

This measurement includes the RFoF transmitter, a short fiber patch cord, the RFoF receiver, and the amplifier through RF Distributor front panel output. That is the total high-band path in the lab minus the long fiber run at GGAO. Figure 10 shows the high-band response for both the H- and V-polarization.

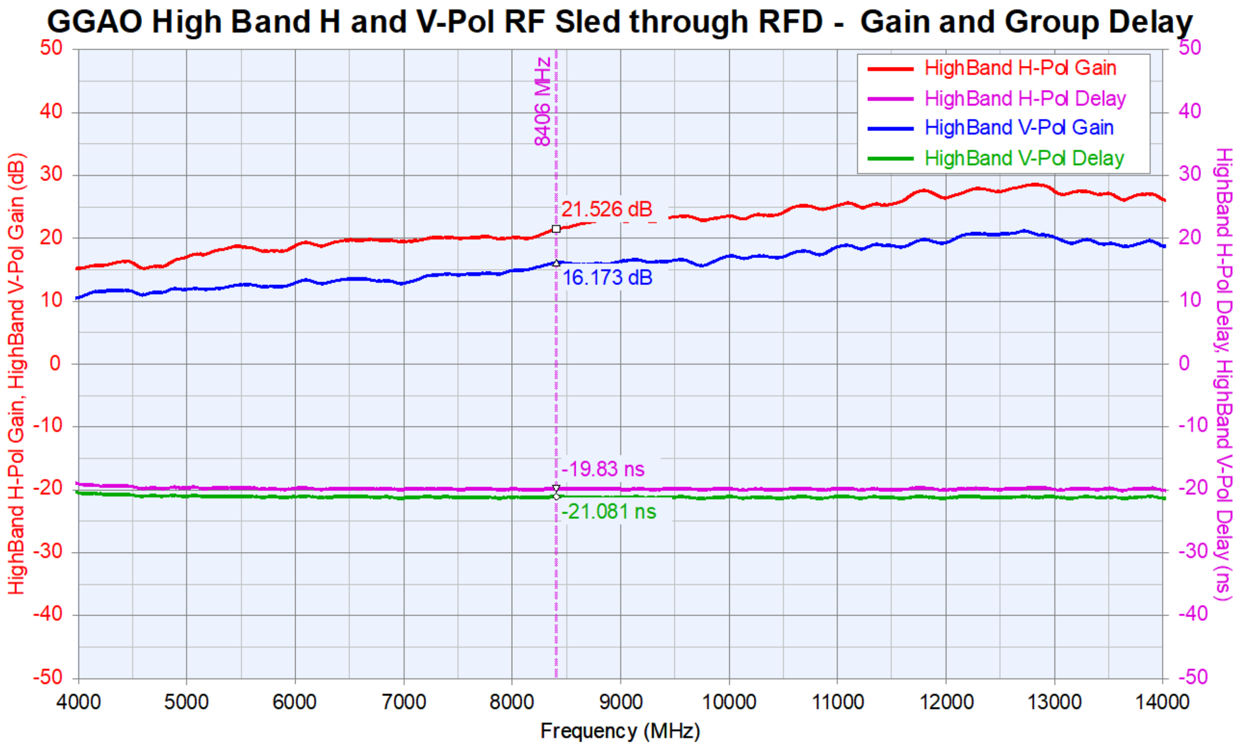


Figure 10: Response of the high-band H- and V-polarization post-dewar through the RF Distributor.

As noted above for Figure 9, here in Figure 10, the negative group delay extracted from the phase versus frequency relationship of the S-parameter “S21” is an artifact of the insufficient resolution for an unambiguous determination. (The FieldFox Analyzer was set to 1-15 GHz in 1001-point sweeps, giving 14-MHz steps. This corresponds to a delay ambiguity range of +/- 35.714 ns, which is less than the total delay through all the high-band components plus the fiber patch cord. This delay ambiguity error was eliminated in subsequent measurements of the long LMR400 cable lengths by changing the step size to 1 MHz.) Therefore, the actual group delay is, e.g., 71.428 – 19.830 = 46.812 ns. Corrected delay values are listed in Table 1.

3.6 P5-P8: RF Sled low-band filters and amplifiers

Figure 11 shows the low-band response (i.e., gain and group delay) on the RF sled in the H- and V-polarization channels.

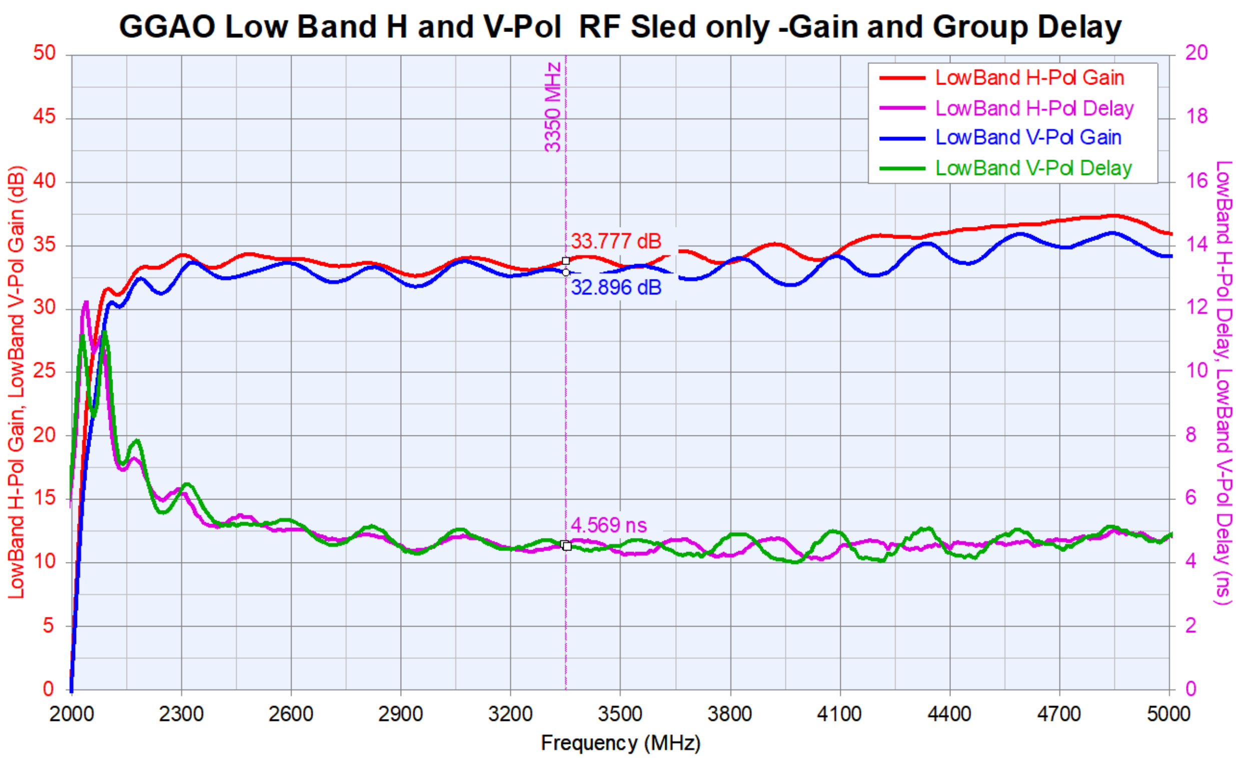
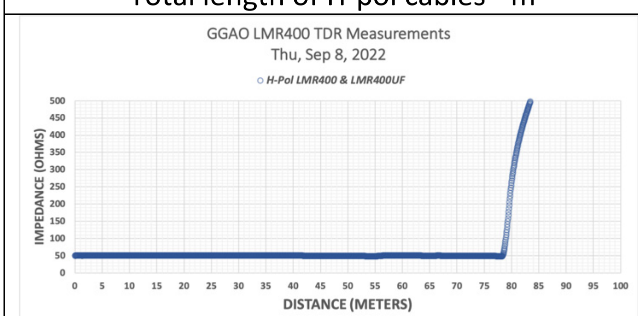


Figure 11: Response of the low-band H- and V-polarization on the RF sled.

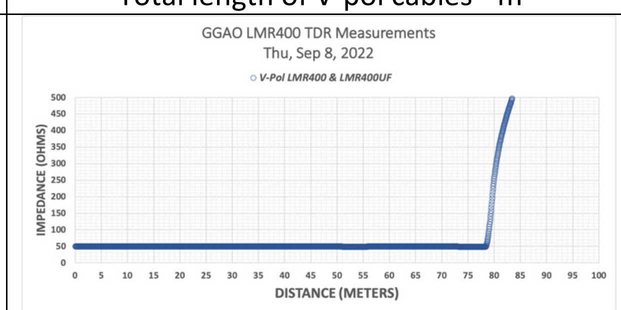
3.7 P8-P9: Low-band signals on 256-foot-long LMR400 and LMR400-UltraFlex

Figure 12 shows the measured length of the LMR400 and LMR400Ultra-Flex cables used for the low-band signals. The total lengths are approximated to 256 feet, with 181 feet outside and 75 feet inside through the cable wraps of the azimuth and elevation angles. The S-parameters through a looped back pair of these H and V-polarization cables were also measured to confirm the group delay estimates. (With thanks to Hudson, Hilliard, and Redmond for the S-parameter measurements made on 2022 September 23.)

Total length of H-pol cables - m



Total length of V-pol cables - m



	DTF (m)	DTF (FT)		DTF (m)	DTF (FT)
Total	78.4125	257.26	Total	78.30625	256.91
LMR400	55.14375	180.92	LMR400	55.25	181.27
LMR400UF		76.34	LMR400UF		75.64

Checks very well with 181' for LMR400 and 75' for LMR400UF provided by Katie in 2012

Figure 12: Electrical length measurements of the low-band LMR400/UF cables.

4 Results

Table 1 is a summary of all the measurements made and presented above. In the Table, group delays are calculated for the specific (GRITTS/GEOCON) frequencies of 3200 MHz and 10200 MHz, but any frequencies could obviously be used.

Table 1: Summary of electrical length measurements.

Delay Table (in nano seconds)					
5 MHz Cable Delay from Distributor to Antenna Unit (ns)	P1-P2	307.87			
Signal Chain- Common	**Ports**	**Delay @3200 MHz (ns)**		**Delay @10200 MHz (ns)**	
		H-Pol	**V-Pol**	**H-Pol**	**V-Pol**
LNA through the coupled ports- Room Temp	**P3-P5**	**3.25**	**4.78**	**3.25**	**4.78**
LNA through the coupled ports- Cryogenic Temp	**P3-P5**	**3.34**	**4.90**	**3.34**	**4.90**
Coupler main line and LNA- Room Temp	**P4-P5**	**2.21**	**2.15**	**2.21**	**2.15**
Signal Chain - High Band				**Delay @10200 MHz (ns)**	
RF Sled High Band Filters, Amplifiers, Equalizer, minus RFoF Tx	**P5-P6**			**3.73**	**3.68**
High Band RFoF link and RFDistributor (ORCA)	**P7-P10**			**48.07**	**46.81**
Full High Band, RFoF Tx, Rx, Amplifiers through RF Distributor				**51.60**	**50.35**
Single Mode Fiber runs (TBC)	**P6-P7**			**620.83**	**619.85**
Signal Chain - Low Band		**Delay @3200 MHz (ns)**			
RF Sled Low Band Filters, Amplifiers	**P5-P8**	**4.57**	**4.57**		
Low Band signals on 256 ft long LMR400 and LMR400-UltraFlex	**P8-P9**	**308.71**	**308.29**		
Total Signal Delay estimate in Low Band	P4-P9	315.49	315.01		
Total Signal Delay estimate in High Band	P4-P10			674.64	672.35

4.1 Comparison to GGAO station delays used in the correlation/fourfit post-processing

As described in section 2.2, the phase calibration tones are used to determine the signal chain delays within the N*200 ns ambiguity given by the 5-MHz spacing, where N is an integer. The methodologies used in various delay estimations and station clock offsets are discussed in Corey and Himwich, 2018 and Corey, 2019.

From the recent correlation post-processing of the VGOS R&D 24-hr session VR2203 (2022/05/19), the GGAO sampler delays (ns) from the Correlation Report are:

- *sampler_delay_x -195 130 130 130*
- *sampler_delay_y -195 130 130 130*

with a peculiar offset of 371 ns, which had changed from an earlier value of 623 ns. This was change first noticed in VGOS session VR2201 (2022/01/20), but likely happened earlier (M. Titus, private communication).

References

Corey, B., and E. Himwich, "Setting correlator clocks for VGOS CONT17 processing," VLBI Broadband Memo Series (VGOS), memo #050, 2018 (https://www.haystack.mit.edu/haystack-memo-series/vgos-memos/memo_VGOS_050/).

Corey, B., "Phase-cal and sampler delay (dealing with phases, not amplitudes)," VGOS Correlation Workshop, 10th IVS Technical Operations Workshop, MIT Haystack, 2019

(https://www.haystack.mit.edu/conference-2/past-conferences/10th-ivs-technical-operations-workshop/; 7_PhaseCal_SamplerDelay_3.3bec.pdf).

Appendix A

VGOS Signal Chain Requirements pertaining to amplitude and phase calibration, from SGP-xxxx-Performance-Level3

VLP.15	VLBI Calibration	The VLBI system provide instrumental amplitude and phase calibration to assess system performance and compensate intrumental delay errors in post-correlation processing.

Number	Category	Type	Short Title	Description	Parent Rqmts	Element Allocation	Comment	Verification Method
SC0060	Frontend	Functional	Calibration	The Signal Chain shall inject a phase and amplitude calibration signal preceding its first active stage in the frontend	VLP.15			T