VGOS MEMO #042

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August 22, 2016

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To: Space Geodesy Project

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Subject: Failure and repair of the GGAO broadband cryogenics and receiver

The GGAO broadband cryogenics failed on the night of 13 June 2016, as indicated by the Monitoring and Control Infrastructure (MCI) data. The problem was discovered the morning after. After retracting the feed to assess the problem, it was noted that the Mylar vacuum window had also failed. Upon repair of the cryogenics and Mylar vacuum window, pointing checks were performed on standard calibration sources, and it was noted that excessive System Equivalent Flux Density (SEFD) values were being obtained. The observed SEFD values were 75-100% higher than normal in band A and 50-100% above normal in bands B, C, and D. In this memo, we investigate the potential cause of the failures and put forward a set of recommendations on how to prevent this from reoccurring in the future for all broadband VGOS sites.

1. GGAO cryogenics failure and repair

The GGAO broadband receiver uses a Model 350CS cryogenic refrigerator that is produced by several companies using a common design. The refrigerator uses a staged Gifford-McMahon (GM) cycle refrigerator that utilizes a rotary motor to move a displacer up and down a cylinder, as well as to open and close the high-pressure supply and the low-pressure return helium ports. A common indicator of impending issues is a characteristic knocking noise. This indicates either contaminants in the displacer cylinder or issues with the crosshead. (The latter converts the drive motor motion from rotary to linear.)

During a visit by MIT Haystack engineering to GGAO in February 2016, it was noted that the refrigerator was knocking. The action to take is to purge the helium refrigerant to attempt to purge the displacer of potential containments. If the knocking still continues after the purge, a visual inspect of the crosshead is required. However, a replacement of the refrigerator is typically required if purging does not solve the problem. The GGAO site personal did purge the refrigerator but the knocking remained

Four months later, on 14 June 2016, GGAO site personal came to the site to find that the cryogenics system had failed. When the Dewar was retracted they found that the Mylar vacuum window also had a catastrophic failure. Understanding the root cause of the receiver warm up was critical. Data from the Monitoring and Control Infrastructure (MCI) were logged throughout the failure providing various system metrics such as Dewar temperature, helium supply pressure, and Dewar vacuum.

The MCI data showed that the refrigerator locked up and stopped turning during the early evening of 13 June 2016. When this happened, the Dewar gradually warmed to ambient temperature, the Dewar pressure slowly rose to above the MCI sensor range, and the helium pressure spiked to the bypass pressure the instant the lock up occurred.

The cause of the failure of the Mylar window, cryogenics or retraction, is surmised to be not related to the cryogenics failure but to the retraction of the Dewar out of radome. Because the radome is sealed, the Dewar retraction causes a suction between the radome and the Dewar that is released when the Dewar finally pulls out of the sealing ring. A fast retraction rate can cause a sudden pressure release, and Mylar implosion. The rate of retraction of the Dewar is believed to have been the root cause of the Mylar window failure at GGAO.

On 21 June 2016, MIT Haystack engineers traveled to the GGAO site to rebuild the damaged IR window and replace the Mylar vacuum window. Upon inspection of the failed refrigerator, it was concluded that the internal failure mode was the migration of the main crosshead bearing and its subsequent jamming against the case wall. This bearing is held in place by a circle clip that was unable to be located. It is unknown if this clip was omitted when rebuilt last or simply unable to be found. Additionally, because the refrigerator motor is cooled by helium flow the motor windings burned depositing a thick coating of carbon throughout the refrigerator.

2. Degraded GGAO receiver performance and repair

Subsequent to the repair of the GGAO cryogenics, now functioning correctly, the performance of the telescope degraded. Specifically, pointing checks on standard calibration sources resulted in excessive System Equivalent Flux Density (SEFD) values. (Observed values were about 7500-9700 Jy in band A, or 75-100% higher than normal, and about 3000-5500 Jy in bands B, C, and D, or 50-100% higher than normal).

During 18-20 July 2016, it was found that the excessive SEFD issue was caused by a mismatch between the QRFH feed and the LNA probes. The problem and the solution are described below. Calibration data taken after repair on 21 July 2016 revealed good receiver performance over all the four bands.

2.1 QRFH-feed probes mismatch

The first step in the debug process was to acquire pointing and aperture efficiency data on a few standard radio sources. System temperature data showed a large ripple, and aperture efficiencies were very low. The possibility of ice buildup inside the probes was ruled out by first warming up the Dewar under vacuum over a weekend and cooling the receiver back down. This confirmed good cryogenics performance but showed no improvement in the RF performance. At this point, it was clear the problem originated inside the Dewar.

The Dewar was opened and the feed brought inside the trailer for further analysis. Using a network analyzer it was quickly evident that there were large impedance mismatches in both the vertical (V) and horizontal (H) polarization channels. Figure 1 indicates mismatch (i.e., poor return loss) across the (2-14 GHz) broadband in both polarizations.

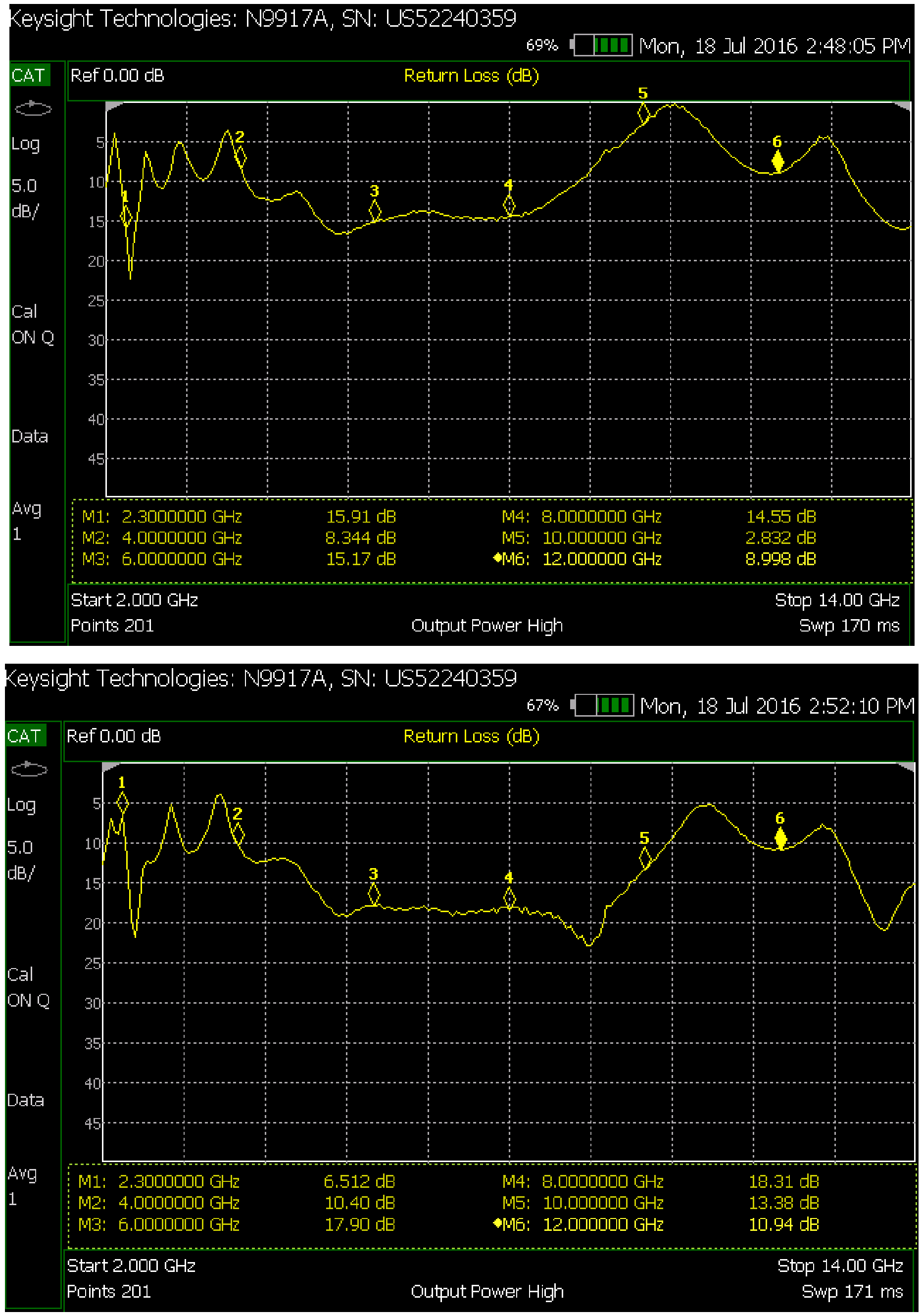


Figure 1 Return loss in the QRFH feed for (top) vertical and (bottom) horizontal polarization before tuning.

Visual inspection found positioning misalignment on the receiver probes. Figure 2 is a zoom into the receiver probes to illustrate positioning misalignment.

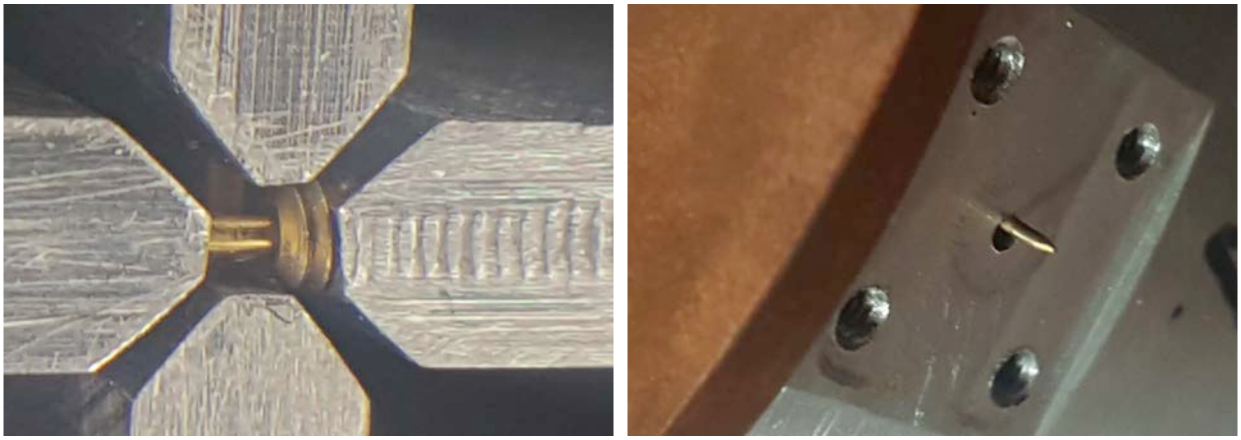


Figure 2 Close-up view of (left) probe and set screw, showing misalignment, and (right) end of the probe connector, showing over extension.

Retuning of the probes was initiated and the results (Figure 3) show very good broadband match over the entire band after re-tuning the probes for proper positioning. (No part of the set screw should show up inside the waveguide cavity.) It was also noted that the second set of jam screws that lock the set screw with the probes were initially loose leading to the inward movement of the probe during multiple vacuum cycles contributing to the problem.

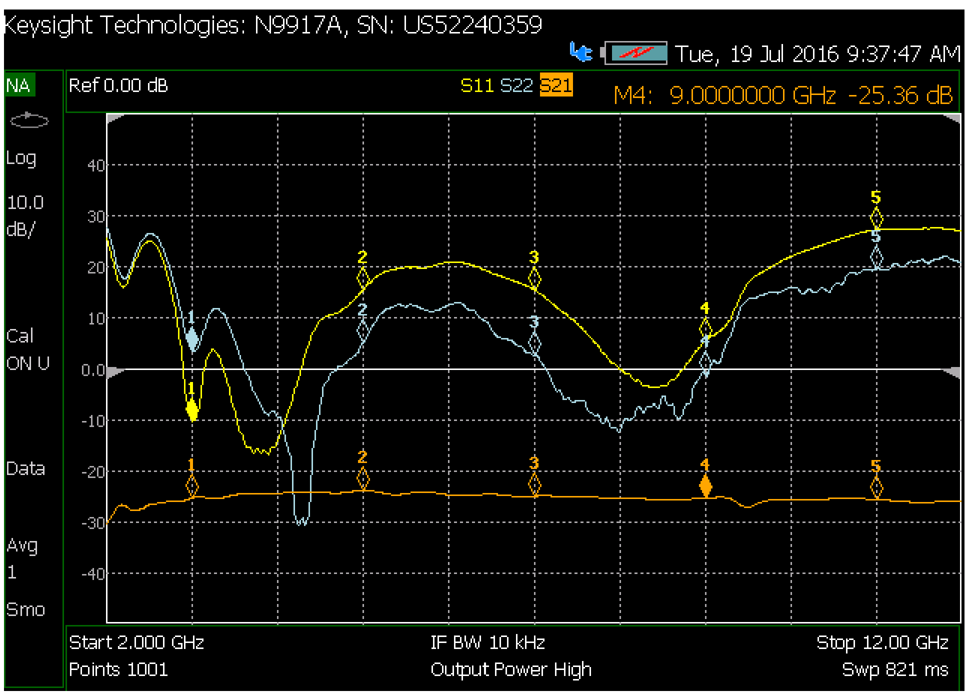


Figure 3 Post-tuning performance of (yellow) the V- and (blue) H-polarization channels.

2.2 GGAO receiver-calibration coupler mismatch

Network analyzer measurements showed that the 20-dB directional couplers that inject the phase calibration tones and the noise calibration signal had a bad match at the coupler ports. Both couplers were replaced using spares components from the Westford station.

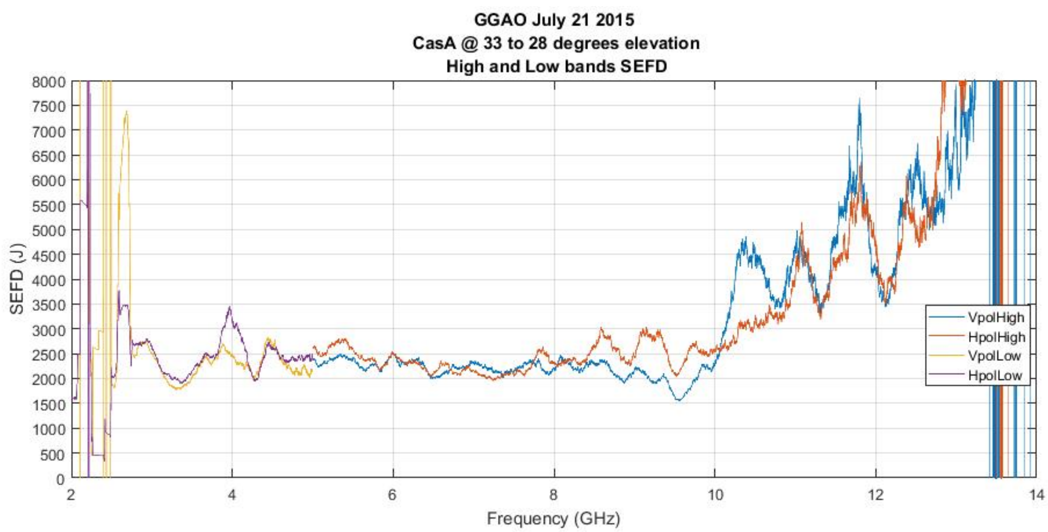
Analysis of the couplers, opened to trace the cause for the poor match, found that the 50-ohm terminations at the fourth port had failed. The possible cause is assumed to be multiple cool downs. The MELF-type (cylindrical) resistor values were 235 ohms and 480 ohms. Suitable replacements are being sourced to determine the viability of fixing the couplers.

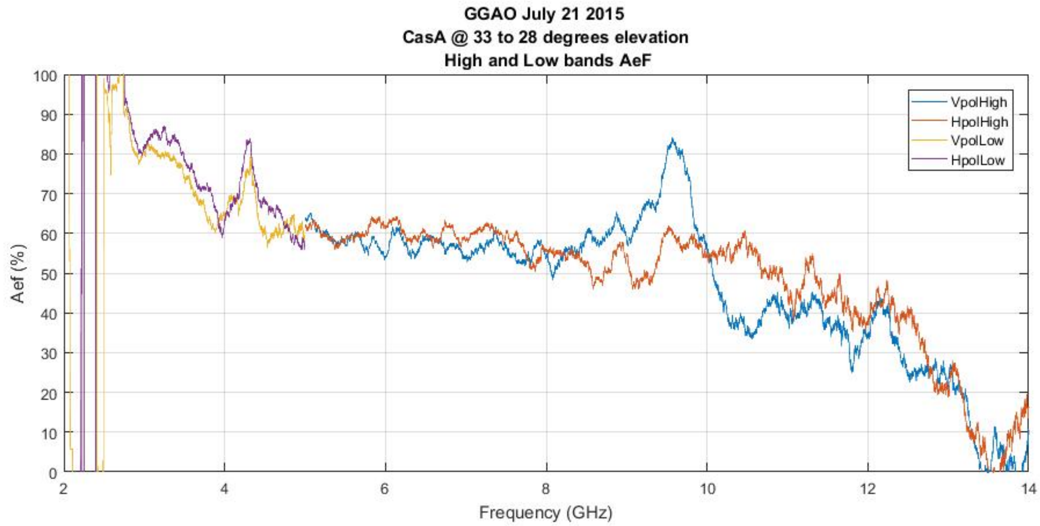
2.3 Band-A post-amplifier gain and dynamic range

The low-band signal levels received inside the trailer were down by several dBs due to increased losses in the LMR400 coax cables. The attenuators in front of the second post amplifiers were adjusted but a better solution is to get a higher dynamic range amplifier with less gain to eliminate the need for these attenuators. These attenuators in front of the second post amplifiers prevent them from being saturated by strong RFI from DORIS and cellular band transmissions.

2.4 System performance comparison from the February 2016 visit

Figures 4 and 5 show SEFD, aperture efficiency, and system temperature of GGAO to compare performance between (pre-failure) February and (post-repair) July 2016. The overall improvement in flat performance up to 10 GHz can clearly be seen.





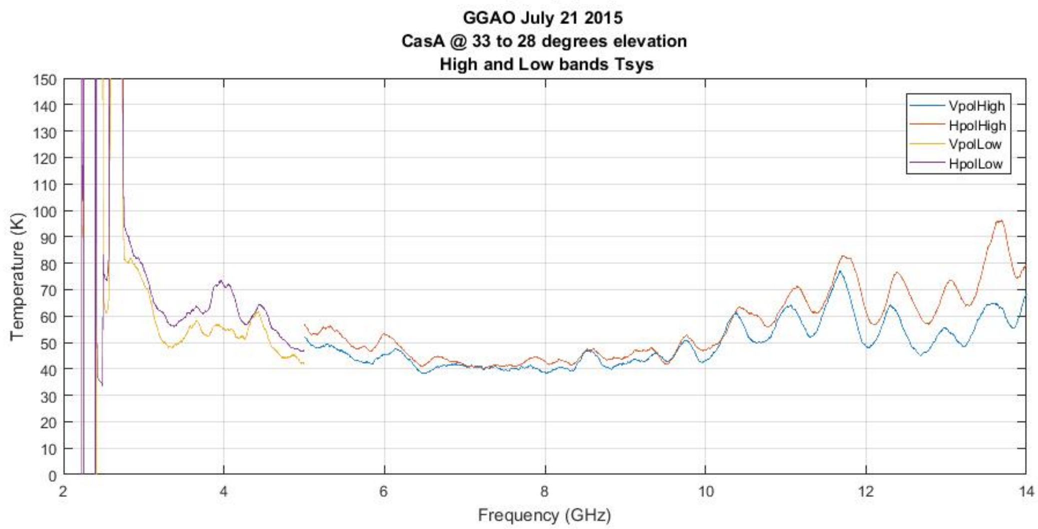
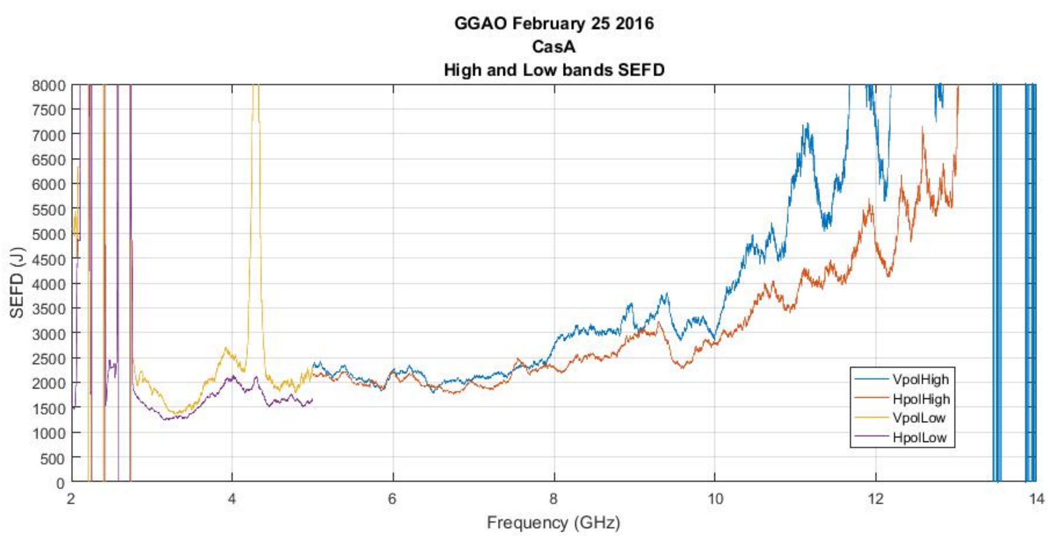


Figure 4 GGAO post-repair (top) SEFD, (middle) antenna efficiency, and (bottom) system temperature measured on CasA on 21 July 2016 (note typo in the title year).



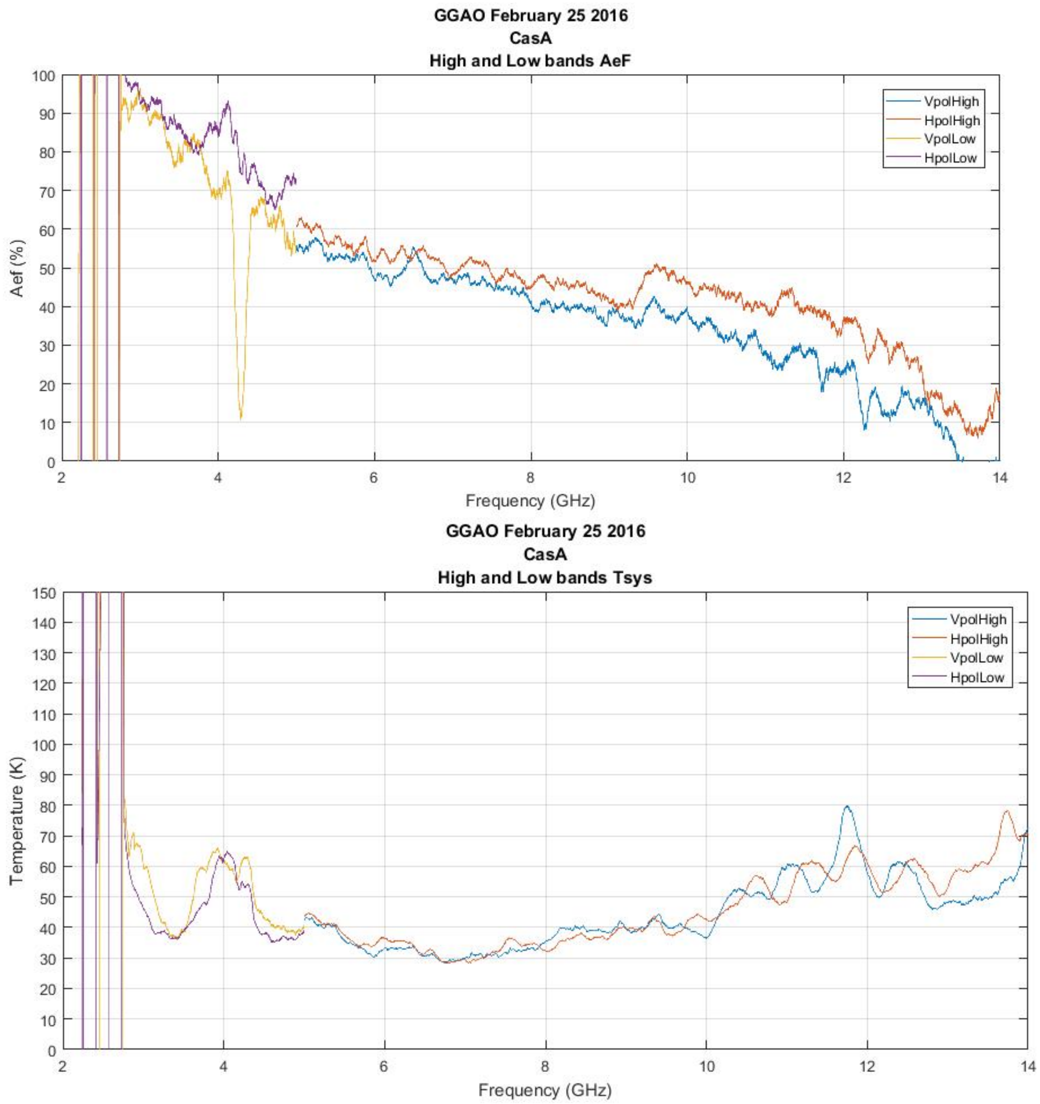


Figure 5 Same as Figure 4 but here on (pre-failure) 25 February 2016.

3 Recommendations

After analysis of the failure and procedures in place, the following set of recommendations can be made:

- General preventive maintenance and periodic replacements, in particular the cryopump, should be performed. A maintenance plan that includes MCI data is being generated.
- A MCI interface should be simplified to bring to the front potential failures. This data should be displayed independently and also available to the PC Field System (PCFS).
- MIT Haystack is in discussions with Caltech on improving the design of the probes and the procedure to lock them once tuned. Future feed probes may incorporate this new design to eliminate the need for a second jam screw inside the cavity thus preventing failure of the device. The existing 20-dB calibration couplers should be replaced with 30-dB couplers for improved performance.

- The post-amplifiers in the low-band channels (i.e., Minicircuits ZX60-5916M-S+) should be replaced with lower noise figure and higher dynamic range amplifiers (e.g., Minicircuits ZX60-83LN+) for improved performance.