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Development Upgrades of the Atacama Large
Millimeter/submillimeter Array

Band 3 Cold Cartridge Assembly Magnet and Heater Installation for Deflux Operation

Cycle 2 Final Report

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1 Summary

During the Front End qualification in the ALMA antennas, power variations were observed during azimuth rotations. Such power variations were found on other bands and later reduced by tuning the electromagnets. In addition, mini-warmups of the mixers are found to be necessary to eliminate some instability found while the Band 3 receiver is operated. These mini warmups are currently done by turning the cold head off until the mixers have warmed up from 4 K to 10 K. For other ALMA bands, a heater is installed and powered up before each use as part of a deflux procedure.

The Band 3 design does not have heaters and magnets and no need for them were found during testing. Indeed, SIS mixers are sensitive to external magnetic field and operating them with an external local oscillator will generate resonances (Josephson effect) that can be removed by adding the right amount of magnetic flux. Josephson effects are frequency dependent (the higher the frequency the stronger the resonance) and at the low operating frequency of Band 3, the effect is normally negligible. Indeed, the same mixers have been operated at other mm-radio telescope (CARMA and ARO) without any deflux heater or magnets.

A joint study between ALMA and NRC was conducted in order to find a solution to the power variations with azimuth rotation. Electromagnetic perturbation from the antenna or from the earth magnetic field could be due to the power variation. At the NRC laboratory, a strong magnet was moved around the receiver and power variations were observed. It was found that in the presence of permanent magnets located near the mixers (like on the Band 4 cartridge), the power variations were partially suppressed.

A method to retrofit the magnet without affecting the cartridge integrity was proposed by NRC. In addition, a way to install mixer block deflux heaters and way to enable their operation was developed and tested. Extensive testing at NRC and at the ALMA observatory of both the permanent magnets and the mixer heater options were made and it was concluded that the former approach resulted in inconsistent and variable cartridge performance. The latter approach of periodically defluxing the mixers by temporarily bringing the mixer blocks to above their superconducting transition temperature, was found to be more reliable and resulted in much more consistent and repeatable performance.

NRC then finalized the design, procurement, and assembly of the mixer heater parts kits and delivered these upgrade kits, one for each cold cartridge, to ALMA for installation. Comprehensive documentary and video instructions were also delivered to ALMA in order that the local staff at the OSF can upgrade Band 3 cartridges as they cycle through the Front End laboratory.

This complex, multi-year effort is documented in this report.

Section 2 describes the discovery and investigation of the hysteresis phenomenon which affects the Band cartridge mixers caused by magnetic flux trapped in the mixers, leading to degraded receiver performance. Experimental results showing how mixer heating can clear the trapped flux and improve the mixer performance are also described. Some tests with installed magnets were made on NRC's prototype cartridge CCA3-999. Although the presence of magnets did protect the mixer IF power from external magnetic fields, it was unclear that they helped to reduce or prevent trapped flux, or even might contribute to the problem of trapped flux. However, it was decided that more extensive testing of cartridges with permanent magnets installed needed to be made in order to confirm these impressions.

In Section 3, the promising technique of mixer deflux using heaters was further explored at NRC with a series of experiments focusing on what improvements there might be on the receiver noise temperature as a result of defluxing. Although results varied (likely to the degree of flux trapped before defluxing), measurements showed that defluxing did not degrade the noise temperature and might even improve it by perhaps 2 K or so.

In Section 4, further testing of the mixer heater system was performed under field operational conditions at the ALMA observatory, using cartridge CCA3-33. Although ALMA had some difficultly in setting the optimal SIS bias points, extensive testing confirmed the conclusions made from testing at NRC that mixer deflux considerably improved the stability of the receivers without degrading noise performance.

In Section 5, testing of cartridge CCA3-66 with permanent magnets at ALMA are presented. Again, this was a large-scale follow-up to the earlier magnet tests performed in the laboratory at NRC. Although (as in the earlier tests), there was some suppression of IF power variations due to the masking effect to the permanent magnets, once again it was clear that the magnets on their own did not improve the medium- to long-term stability of the cartridge and likely led to a noise deterioration. This confirmed the impression of the relative usefulness of mixer heaters versus permanent magnets, and in conjunction with the NRAO ALMA Front End management, it was decided that the optimum strategy for the upgrade to Band 3 would be to retrofit mixer heaters to all cartridges but not to install permanent magnets.

In Section 6: since the mixer heaters needed to be controlled through the external cartridge bias box circuitry in order be controllable by the observatory control system, a way needed to be found to implement monitor and control by means of the least intrusive method, both on the hardware side and on the software side. A few options were proposed and investigated for providing this capability (which had not been envisioned for the Band 3 system), and all but one were ruled out as being problematic from either the technical or software point of view. However, NRC proposed a new solution that necessitated minimally invasive technical procedures on the cartridge (no extensive reassembly which could be problematic from the safety and alignment point of view) and would not require changes to the ALMA control software for Band 3 beyond simply activating dormant code for controlling the heaters. It would however, require a replacement of the main cryogenic pigtail wiring assembly and a small modification to the bias box. Modified bias boxes could be used on unmodified cartridges, but a modified bias box was needed to enable heater control on a modified cartridge. This modification is described and demonstrated in this section.

In Section 7 we present the detailed procedure for installing the mixer heater system in the cartridge using the upgrade parts kit supplied by NRC, in Section 8 the procedure for modifying the bias box, and finally in Section 9 a recommended test procedure for confirming correct operation of the heater system.

2 Mixer Heater Deflux Laboratory Tests

NRC Herzberg in Victoria investigated techniques for improving the power stability (gain stability) of the Band 3 cartridges under varying antenna AZ/EL position. Two possible solutions have been pursued: installation of permanent magnets to the mixer blocks and implementation of heaters to magnetically deflux the SIS mixers. Detailed investigations of the effect of permanent magnets and/or heater defluxing for cartridges CCA3-18, 33, 53, 55, 66, and 999 (the undelivered prototype) have been documented in a number of ALMA and internal NRC documents. NRC concluded that installation of permanent magnets is not beneficial for the overall gain stability of the suite of Band 3 cartridges but did recommend that the cartridges be upgraded with defluxing systems.

During Band 3 cartridge testing at NRC Herzberg some of the pumped IV (PIV) curves showed a phenomena which was referred to as 'hysteresis'. A hysteresis is formed when the mixer IV curve for a forward voltage sweep between a small range of mixer voltages (from 0 to 20 mV) around a mixer bias voltage of 10 mV is slightly different from that when a reverse sweep (from 20 to 0 mV) is made. When the two curves are plotted on the same graph, they form a 'hysteresis', as shown in Figure 1.

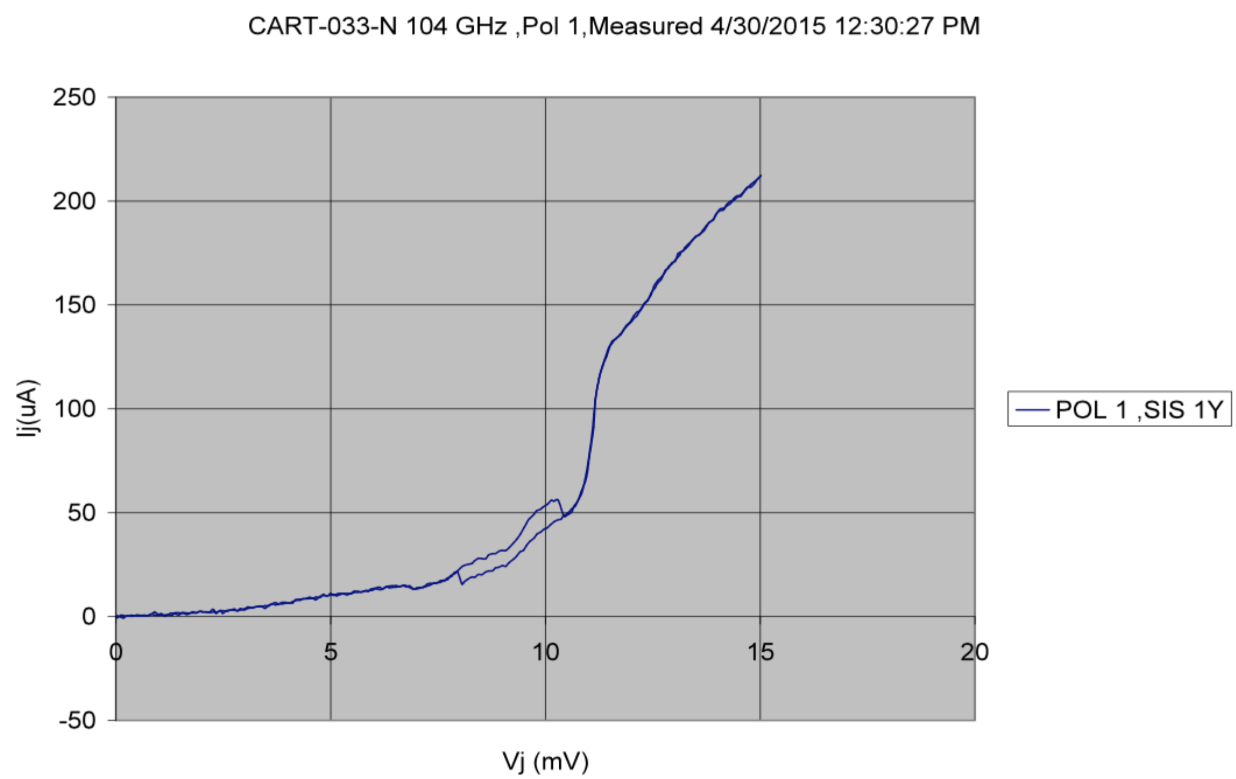


Figure 1: IV Curve Hysteresis for Pumped Mixer

The location of the hysteresis differs from mixer to mixer. When the location of the hysteresis is around the bias region, the mixer current has the potential to change during normal operation, resulting in gain variations. It is highly likely that trapped magnetic flux within the superconductor is the cause of the hysteretic behaviour and it is known that changes in the local magnetic environment have detrimental impacts on the performance of other ALMA bands. Thus, it seems clear that eliminating the hysteresis by periodically defluxing the mixers, as is done for other ALMA bands, is a relatively risk-free way to improve the gain stability of the Band 3 receivers.

2.1 Creating Hysteresis

The hysteresis shows up usually between 6.0 to 11.0 mV, right in the bias region of the Band 3 mixers (a typical mixer bias voltage is 9.8 – 10.6 mV). Hysteresis occurs at different LO frequencies for different mixers and can change over time for an individual mixer as it encounters different thermal and magnetic environments. We discovered that a slow partial warm-up (to about 15 K) of the cartridge by turning off the cryocooler in the presence of a strong external magnetic field would increase the likelihood of occurrence of hysteresis. We used this technique to create hysteresis in SIS mixers in Band 3 cartridge CCA3-33 installed in the NRC Band 3 test cryostat. We then used prototype heaters to rapidly warm up the cartridge to about 11 K (well above the SIS superconducting temperature) to get rid of the hysteresis. We carried out numerous partial warm-ups. During this extensive experiment, we acquired IV curves after each partial warm-up to look for the presence/disappearance of hysteresis. Each set of PIV curves consists of 10 curves (5 LO frequencies times 2 polarizations).

2.2 Method of Deflux Using Heaters

1. Turn off LO power to SIS mixers by setting PA-B, and PA-A to 0 V.
2. Set all four SIS mixers voltages to 0 mV (at this point, all four mixer currents should read 0 microA).
3. Turn off SIS/LNA/LO monitoring.
4. Set Pol 0-Magnet1 Current to 100 mA.
5. Set Pol 0-Magnet2 Current to 100 mA.
6. Set Pol 1-Magnet1 Current to 100 mA.
7. Set Pol 1-Magnet2 Current to 100 mA.
8. Leave the four heaters on for 3 minutes, and then turn them all off.
9. Allow 10 minutes for mixer temperatures to cool down to 4 K (or whatever steady state temperature the mixers were operating prior to deflux) before resuming operation or observing.

Note that the times and temperatures above are those appropriate to the NRC Band 3 test cryostat, and would need revision for the environment of the ALMA cryostat. The magnet current limit of 100 mA is a result of the ~ 4 V hardware limit on the magnet supply voltage.

2.3 Deflux Effects

As the SIS mixers warm up, they lose the superconductivity. By checking the PIV curve, one could easily determine whether a mixer has lost its superconductivity (or has been de-fluxed). A typical PIV curve at 4 K and 10 K are shown in Figure 2.

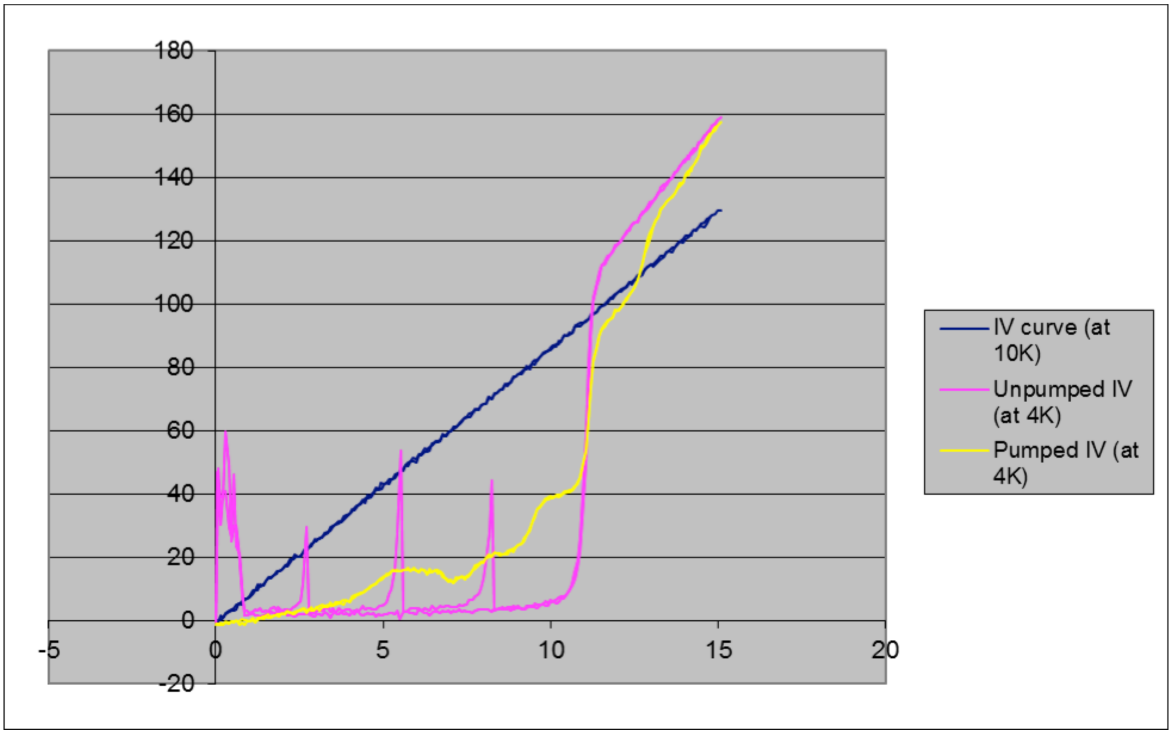


Figure 2: Unpumped and Pumped IV Curves at 4 K and 10 K

2.4 Improvements

Our experiments show that a number of improvements in mixer behaviour result from defluxing, as summarized below. Note that since NRC Herzberg does not have a cryostat tilt table, experiments on mixer behaviour as a function of cryostat orientation could not be made.

1. Mixer current imbalance around mixer bias point decreases (two closely matched mixers are required for best sideband separation performance).

Before Deflux	After Deflux

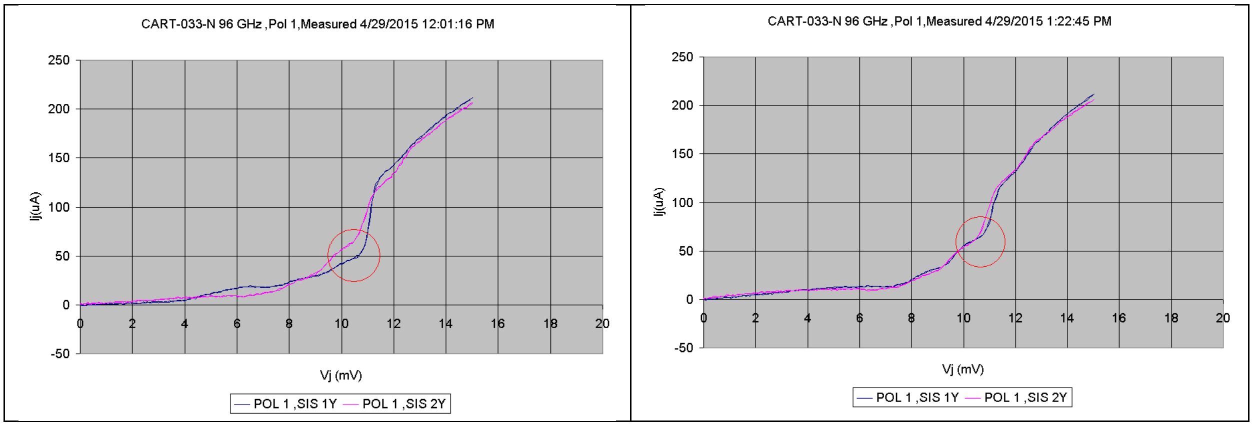


Figure 3: Wide Current Imbalance around Bias Point Decreases

2. Removal of hysteresis in PIV curves.

Before Deflux	After Deflux

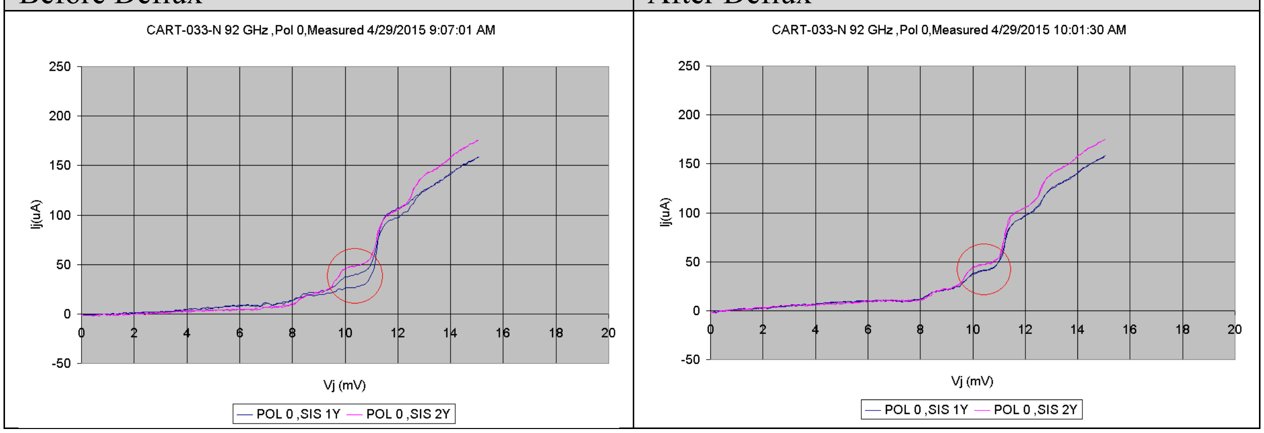


Figure 4: Hysteresis Disappears

3. Flat (zero slope) or negative slope photon step disappears (a photon step with positive slope is expected).

Before Deflux	After Deflux

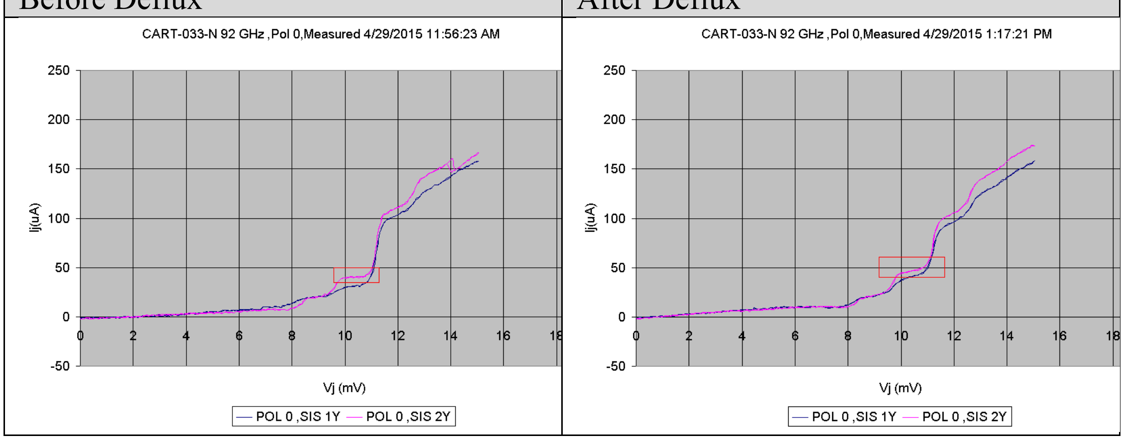


Figure 5: Flat Photon Step Slope Becomes Positive

2.5 <u>Experiments</u>

The NRC experiments on magnets and heaters comprised three different experiments. We tested the effect of heaters and on two cartridges:

1. CCA3-999 with heaters (aka "CART-998-A"; undelivered NRC prototype).
2. CCA3-33 with heaters (aka "CART-033-N").
3. CCA3-999 with magnets and heaters (aka "CART-997-A").

2.6 <u>CCA3-33 With Heaters</u>

In this experiment, CCA3-33 was fitted with four heaters. The four heaters ranged from 22 to 28 ohms (four different values were chosen to determine the best resistance value for maximum power-heat transfer). These four heaters raised the mixer temperature from 3.5 K to 11.1 K within 3 minutes in the NRC test cryostat.

Table 1 summarizes the results of testing CCA3-33. In this table, a qualitative metric of enumerating the number of times an improvement or degradation occurred was used. Three tests were carried out, and in each test, ten (5 LO times 2 mixer pairs) IV curves were compared. The numbers in red indicate the number of IV curves that did not improve substantially after deflux.

Table 1: Summary of CCA3-33 Testing

Test	Performance Characteristic	Improvements	Degradations
1	Wide current imbalance at bias point	7	0
	Hysteresis	2	0
	Flat or negative slope photon step	0	0
2	Wide current imbalance at bias point	5	0
	Hysteresis	4	0
	Flat or negative slope photon step	1	0
3	Wide current imbalance at bias point	4	2
	Hysteresis	2	0
	Flat or negative slope photon step	0	0

2.7 <u>CCA3-999 With Heaters</u>

In this experiment CCA3-999 was fitted with four 33 ohm heaters. The four heaters raised the mixer temperature from 3.8 K to 10.0 K within 3 minutes. The 33 ohm resistors are not the optimum for maximum power-heat transfer.

Table 2 summarizes the results of testing CCA3-999. In this table, the statistics on the improvements and degradations in performance characteristics are listed. Four tests were carried out, and in each test, ten (5 LO times 2 mixer pairs) IV curves were compared. The numbers in red indicate the number of IV curves that did not improve substantially after deflux.

Table 2: Summary of CCA3-999 Testing

Test	Description	Improvements	Degradations
1	Wide current imbalance at bias point	3	0
	Hysteresis	4	0
	Flat or negative slope photon step	0	0
2	Wide current imbalance at bias point	2	3
	Hysteresis	3	0
	Flat or negative slope photon step	0	0
3	Wide current imbalance at bias point	0	2
	Hysteresis	4	0
	Flat or negative slope photon step	0	0
4	Wide current imbalance at bias point	1	1
	Hysteresis	6	2
	Flat or negative slope photon step	0	0

2.8 CCA3-999 With Heaters and Magnets

The IV curves in the presence of permanent magnets (attached to the mixer blocks) are not normal as they show a strong hysteresis between 11 to 15 mV, just above the standard bias point. About half of the curves we looked at had this anomaly. Although the presence of magnets makes the cartridge's IF power somewhat immune to external magnetic field, it is very doubtful that these magnets have helped to reduce or prevent trapped flux, with the indications being that they themselves can contribute to the problem of trapped flux.

Furthermore, the magnets increase the noise temperature. This depends on the strength of the magnet and our tests indicate doubling the magnet flux increase the noise from ~ 0.5 K to ~ 2.0 K. Shown below are some standard IV curves without permanent magnets (left) and curves seen to be affected by the magnets (right). The heater based rapid partial warm-up does not get rid of the hysteresis induced by the magnets.

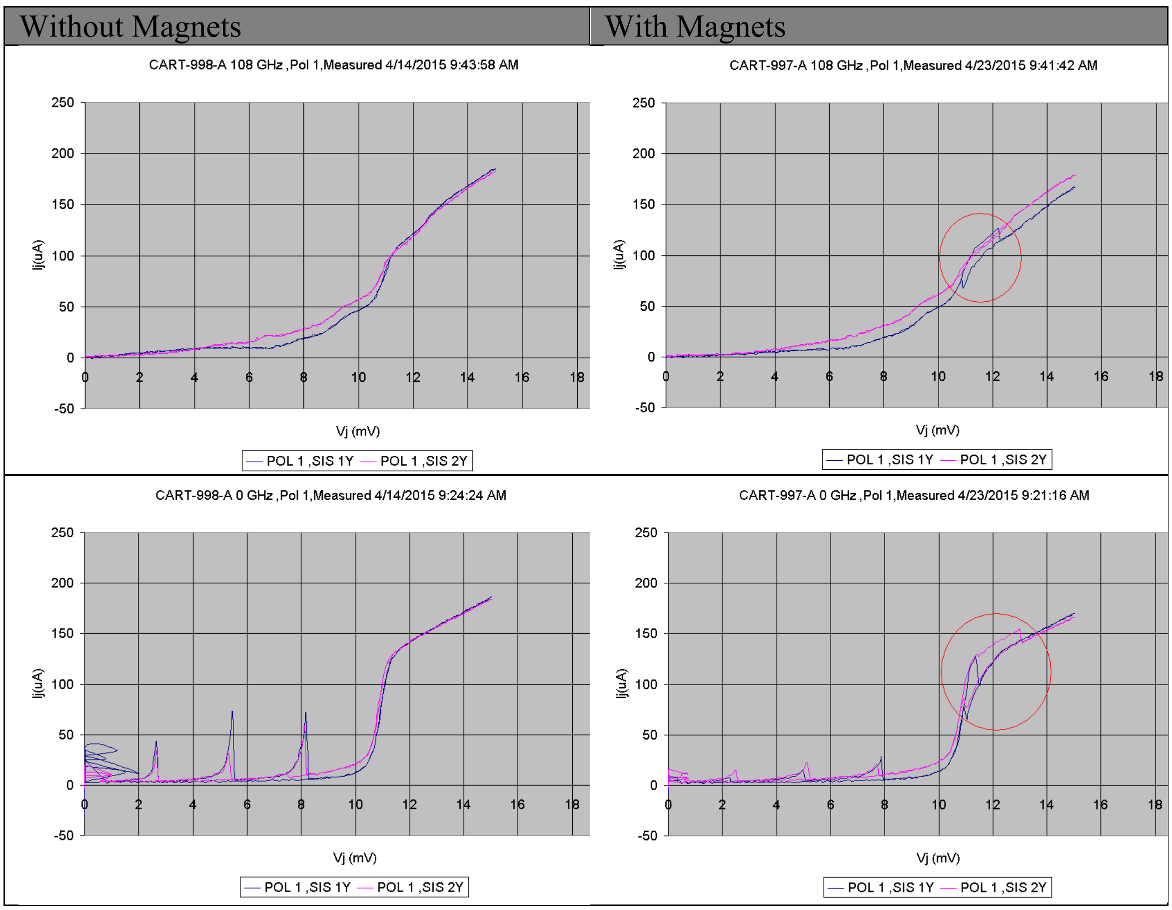


Figure 6: IV Curves (Pumped on Top, Unpumped on Bottom) With and Without Permanent Magnets

2.9 <u>Limitations</u>

The magnet circuitry can deliver only 100 mA in each of the four lines. This limitation does not allow the cartridge to be (partially) warmed up well past the superconducting temperature of 9.6 K. Instead, it can elevate the temperature from 3.5 K to 11.1 K, which is still sufficient to deflux the mixers. A slightly higher temperature, say 15 K, would provide much greater confidence of a successful deflux, and heater performance in the production ALMA cryostats would need to be characterized.

2.10 Testing at ALMA

At a minimum, defluxing and gain stability performance of a Band 3 cartridge retrofitted with heaters should be tested at ALMA on a tilt table, as described below. Our understanding is that there are IF power variations due to cable flexure on the tilt stage, and therefore cannot easily be used to test the stability of a cartridge. We recommend that SIS mixer current measurements can be used as a proxy for gain stability in tilt table tests, and strongly advocate full testing in an ALMA cryostat mounted on an antenna.

Proposed test sequence:

1. Cool cartridge to operating temperature.
2. Tune mixers.
3. Take IV curves of all four mixers at 92 and108 GHz (and other LO frequencies if time permits). Both forward and reverse voltage sweeps are recommended. Record SIS mixer currents and other parameters.
4. Rotate FE cryostat to another position. Note the position for repeating this measurement later. Repeat step 3.
5. Rotate FE cryostat to another position. Note the position for repeating this measurement later. Repeat step 3.
6. Plot the PIV curves of each mixer on the same graph and note any changes in performance characteristics.
7. Deflux mixers.
8. Repeat steps 3 to 6.

2.11 Summary

Heater deflux, when performed as described above, removed anomalies (hysteresis, etc) in most cases. This conclusion was derived after performing numerous defluxes. In some cases, most notably when warming the mixer to only 10 K during the deflux process, a higher percentage of performance degradations relative to improvements could be seen. This is presumably due to incomplete defluxing at a lower maximum mixer temperature. The question of the highest temperature which can be achieved in the ALMA cryostat is an important one and the NRC is exploring ways to boost the heating capacity within the current bias board design.

The heater deflux changes the SIS characteristic and therefore affects the noise temperature. Some LO frequencies/channels showed improvement in noise, while some were degraded. These changes (both positive or negative) are within ~ 2 K. However, the noise temperature in all LO frequencies/channels could be improved by means of a new mixer fine tuning after defluxing.

The deflux is most effective if the mixer plate temperatures are brought to 11.0 K or higher, although in theory reaching the superconducting theoretical limit of 9.6 K should be sufficient. The success of deflux was evident on CCA3-33 (deflux raised the mixer plate temperature to 11.1 K) but less so on CCA3-999 (deflux raised the mixer plate temperature to 10.0 K). The maximum mixer plate temperature achievable depends on the initial temperature of the mixer plate (or cooling capacity of the cooler).

Unlike permanent magnets, proper defluxing by heaters cannot cause any degradation in cartridge performance. Considering this, the success in suppressing hysteresis with defluxing, and the uneven and unreliable effect of permanent magnets, our recommendation is to use only heaters as a means to improve Band 3 cartridge power stability.

3 Noise Improvement Due to Heater Deflux

During our investigation into improving Band 3 cartridge stability, the effectiveness of heater deflux was measured using a simple qualitative metric of enumerating the number of times an improvement occurred to IV curves. Three broad categories were chosen for this comparison – wide current imbalance at the bias point (implies that the match between the two SIS mixers of the same polarization is poor), presence of hysteresis, and zero or negative photon step. This method is a quick way of identifying, and quantifying improvements.

A better, but tedious, and time-consuming method, is to measure noise temperature. The noise temperature measurement comparison was performed only on handful occasions. Here we present the noise temperature improvement due to heater deflux, along with pumped IV curves that show how the anomalies identified prior to deflux improved after deflux. CCA3-33 was used throughout this investigation, and was tested in NRC's Cartridge Test Set 1 (CTS1).

3.1 Procedure

- Set mixer plate temperature to 4.0 K, and perform a mixer fine tune.
- Measure broadband noise temperature.
- Deflux mixers using heaters.
- Allow mixer temperature to drop to 4.0 K.
- Perform a mixer fine tune.
- Measure broadband noise temperature.
- Compare the two measurements.

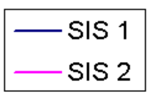
3.2 Measurement Results – IV Curves and Noise

A color code is being used to highlight an IV curve anomaly that falls into one of the three categories identified above. They are listed below once again.

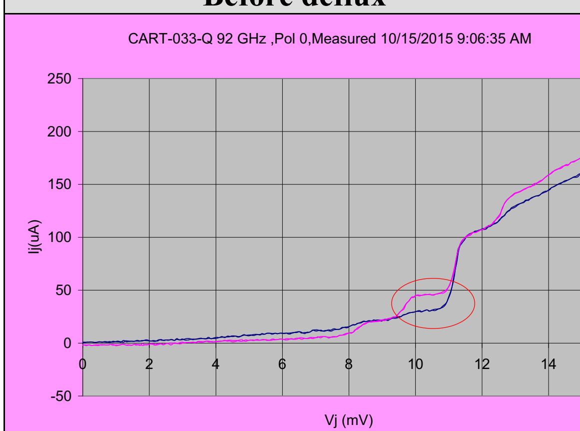
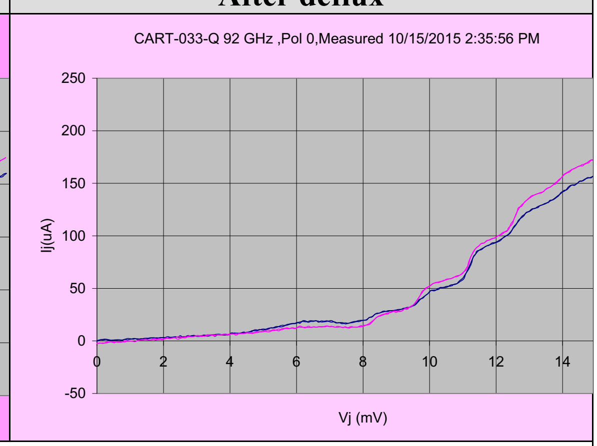
	Anomaly	Before	After
1	Significant wide current imbalance at the bias point		
2	Presence of hysteresis		
3	Zero or negative photon step		
	Very little or no improvement		

As noted before, the numbers in the left column were obtained after a mixer fine tune, but before deflux (noise temperature is higher, as expected.). The numbers in the right column were obtained after deflux, and after a mixer fine tuning (noise temperature has improved. The improvements are highlighted in green.

The following legend applies to IV curves:

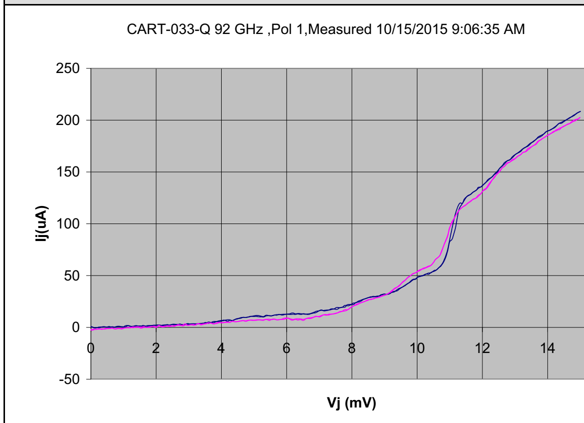
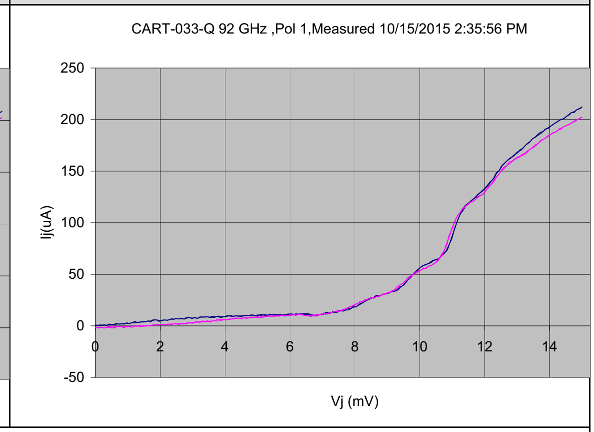


3.3 92 GHz-Pol 0

Before deflux	**After deflux**
	
Comment: The current imbalance between SIS1 and SIS2 mixers is abnormal (left). A well matched pair of mixers will have identical mixer currents at the bias point. A typical mixer bias is 10.2~10.5 mV.	

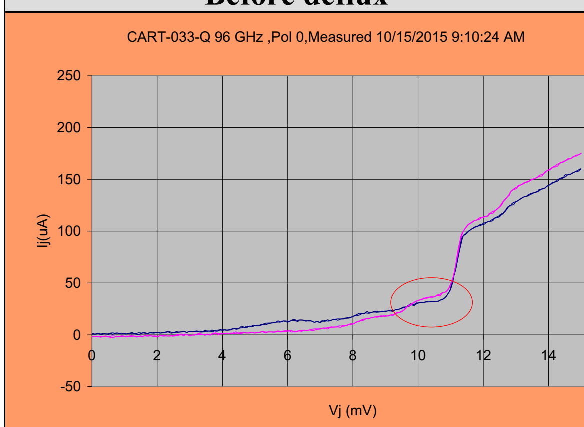
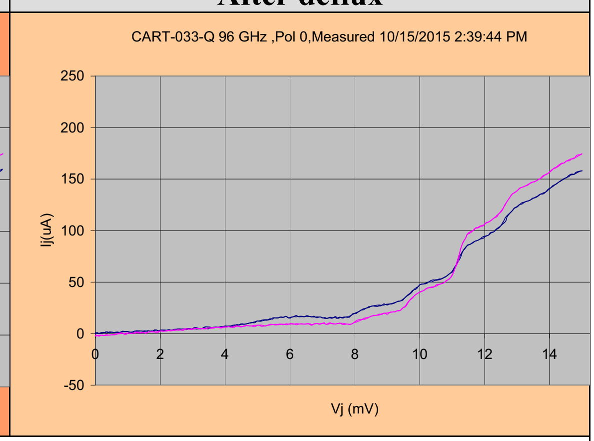
	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	34.5	33.5	34.0
After deflux	29.1	33.4	**31.2**

3.4 <u>92 GHz-Pol 1</u>

<table>
<tr><th>Before deflux</th><th>After deflux</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Comment: Slight current imbalance is noted but, is not ‘significant’ enough to categorize this case as an ‘improvement’</td></tr>
</table>

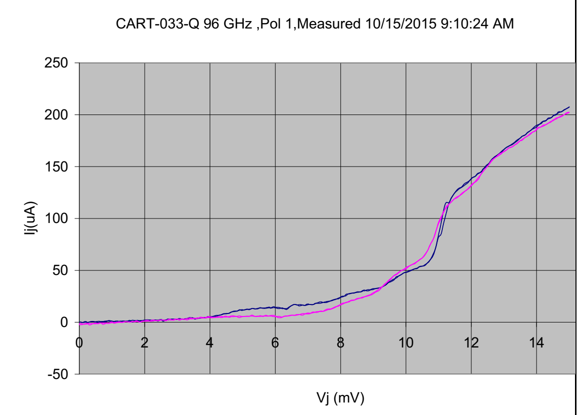
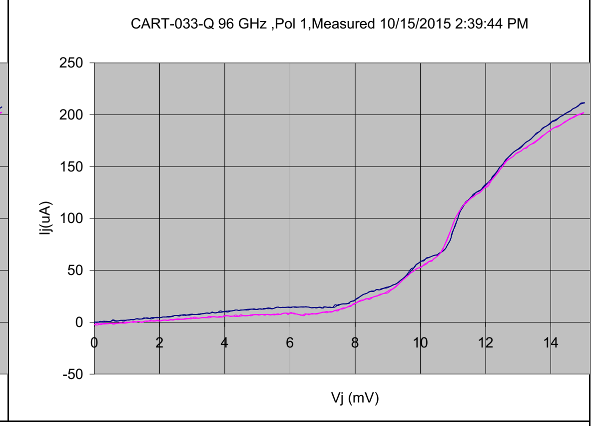
	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	41.6	38.9	40.2
After deflux	36.6	38.1	**37.4**

3.5 <u>96 GHz-Pol 0</u>

<table>
<tr><th>Before deflux</th><th>After deflux</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Comment: SIS1 mixer has zero photon step.</td></tr>
</table>

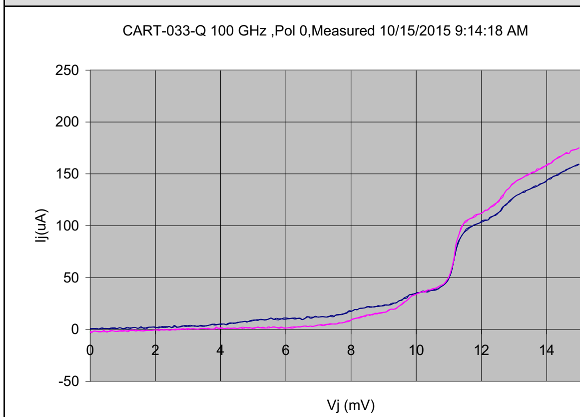
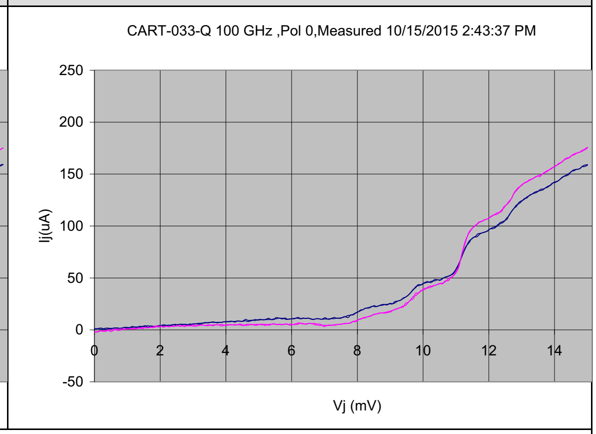
	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	36.9	31.9	34.4
After deflux	32.1	35.5	**33.8**

3.6 <u>96 GHz-Pol 1</u>

Before deflux	After deflux
	
Comment: Slight current imbalance is noted but, is not ‘significant’ enough to categorize this case as an ‘improvement’	

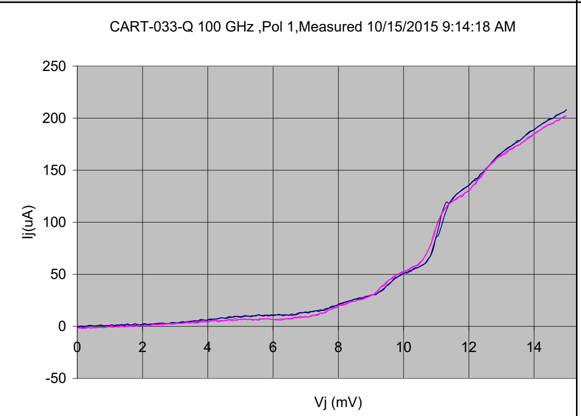
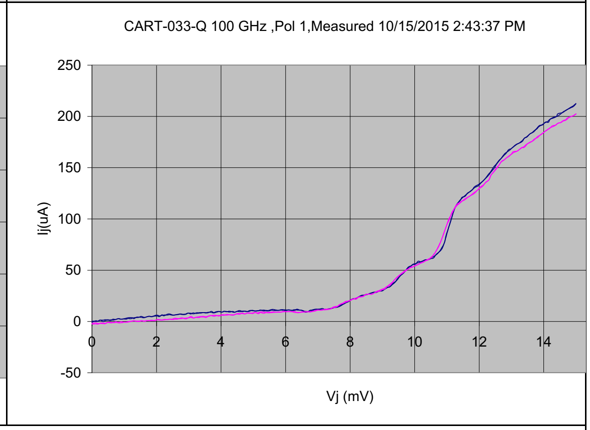
	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	38.1	37.0	37.5
After deflux	33.6	36.0	**34.8**

3.7 <u>100 GHz-Pol 0</u>

Before deflux	After deflux
	
Comment: IV curves do not show any imperfection.	

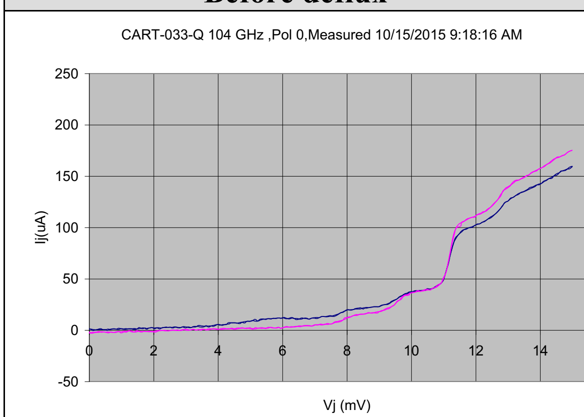
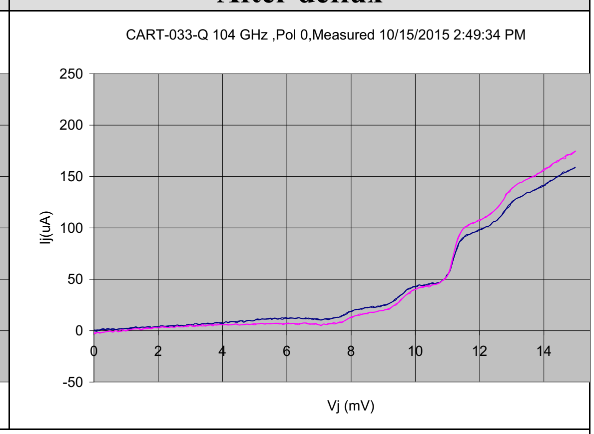
	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	36.6	35.7	36.1
After deflux	31.5	34.8	**33.2**

3.8 100 GHz-Pol 1

Before deflux	After deflux
	
Comment: IV curves do not show any imperfection.	

	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	34.8	38.9	36.9
After deflux	31.2	37.7	**34.4**

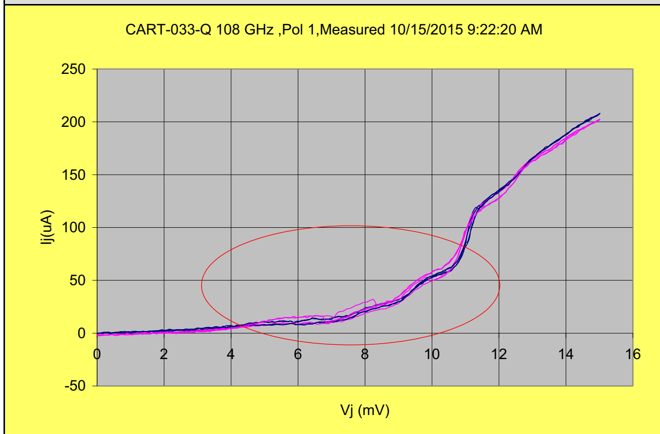
3.9 104 GHz-Pol 0

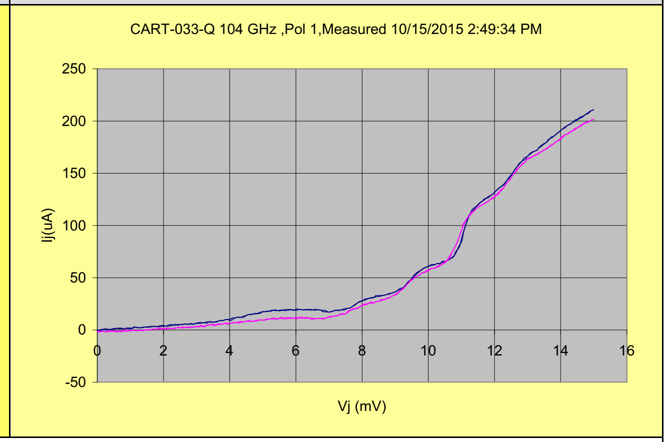
Before deflux	After deflux
	
Comment: IV curves do not show any imperfection.	

	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	31.9	31.5	31.7
After deflux	28.9	32.9	**30.9**

3.10 <u>104 GHz-Pol 1</u>

Before deflux	After deflux



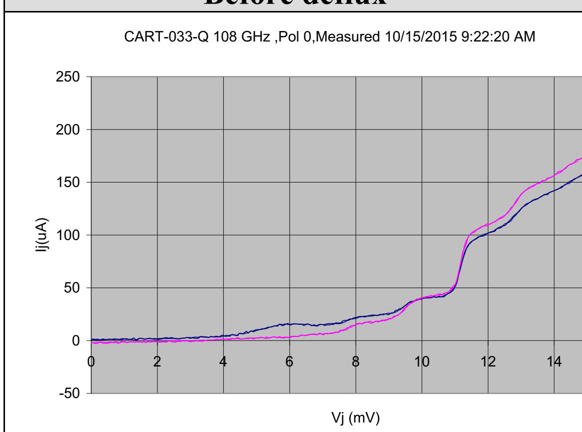


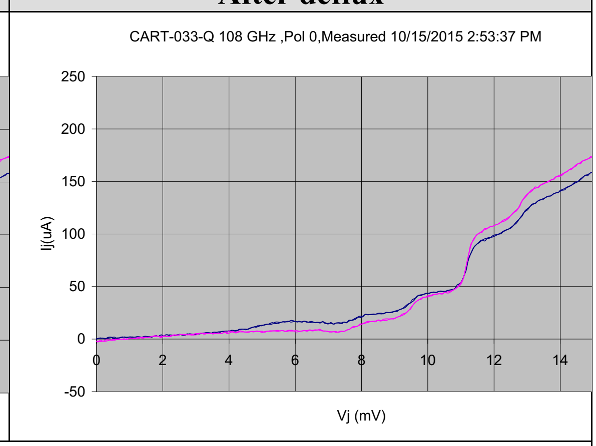
Comment: SIS2 is affected by hysteresis

	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	34.6	38.1	36.4
After deflux	30.3	37.0	**33.7**

3.11 <u>108 GHz-Pol 0</u>

Before deflux	After deflux



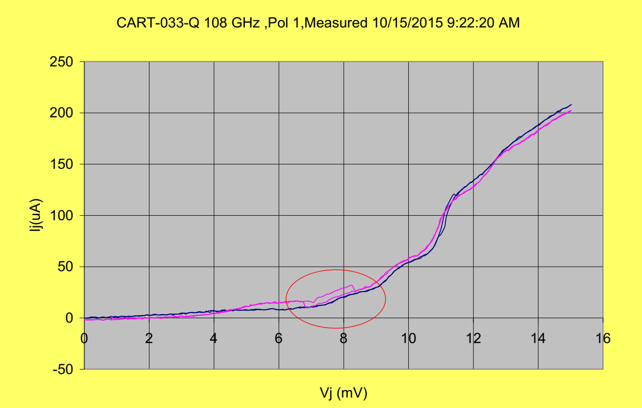


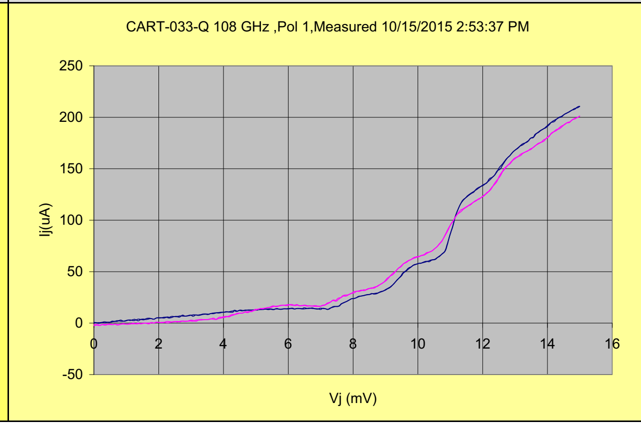
Comment: IV curves do not show any imperfection.

	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	28.8	33.6	31.2
After deflux	27.6	34.0	**30.8**

3.12 108 GHz-Pol 1

Before deflux	After deflux





Comment: SIS2 is affected by hysteresis

	LSB Noise (K)	USB Noise (K)	Ave Noise (K)
Before deflux	34.9	41.5	38.2
After deflux	31.0	40.1	**35.6**

3.13 Measurement Results – Noise

Two different methods were used to deflux CCA3-33 during our investigation to improve band3 cartridge stability. Initially, magnet circuits were used to power up heaters. Due to limitation of the power capability of the magnet circuit (4 V/100 mA per mixer), and the reluctance of ALMA to approve such a modification, this idea was later abandoned. The deflux seemed effective in our cryostat (though there was some apprehension as to how effective it would be on a real ALMA cryostat). Later, the proper heater circuits were used to power up heaters. This circuit has ample power to perform the deflux (24 V/200 mA per two mixers).

The charts below compare the noise improvement due to deflux. We have included both defluxes – heater circuit and magnet circuit - in order to provide a complete picture. Please note the date of the experiment in each chart’s legend – an indication that some of the results are from different ‘cooling cycles’.

In our experience, the noise improvement is best compared if the average noise of USB & LSB (of each pol) is considered together, as opposed to individual channel comparisons. This ‘averaging’ will offset the worsening of one channel noise to the improvement in the other channel. The chart below is using this approach. The yellow line (noise before deflux) shows that the noise temperature is much higher compared to noise after deflux.

The data for the magenta was from the final qualification of CCA3-33 before shipping to ALMA. A 58 ohm resistor per mixer was used (the earlier run used 29 + 30 ohm resistors in place of the 58 ohm resistor).

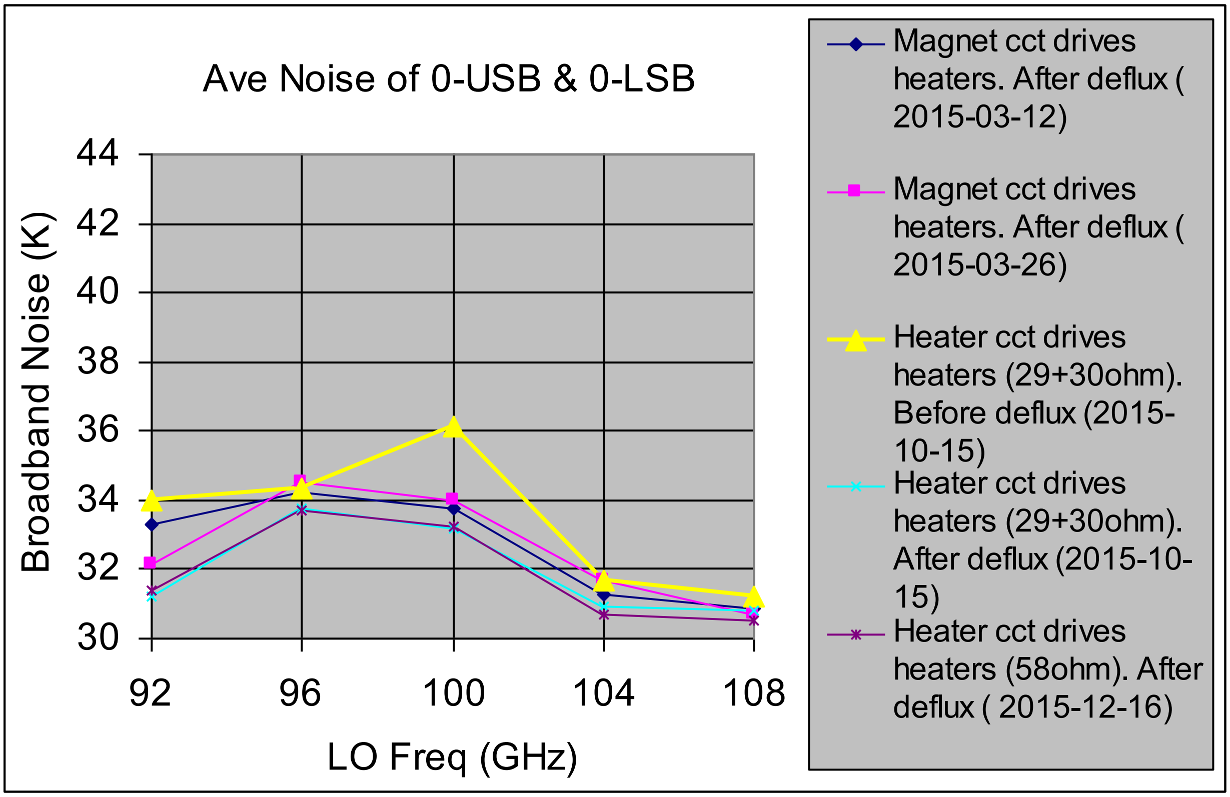


Figure 2: Noise improvement due to various methods of deflux (Pol 0)

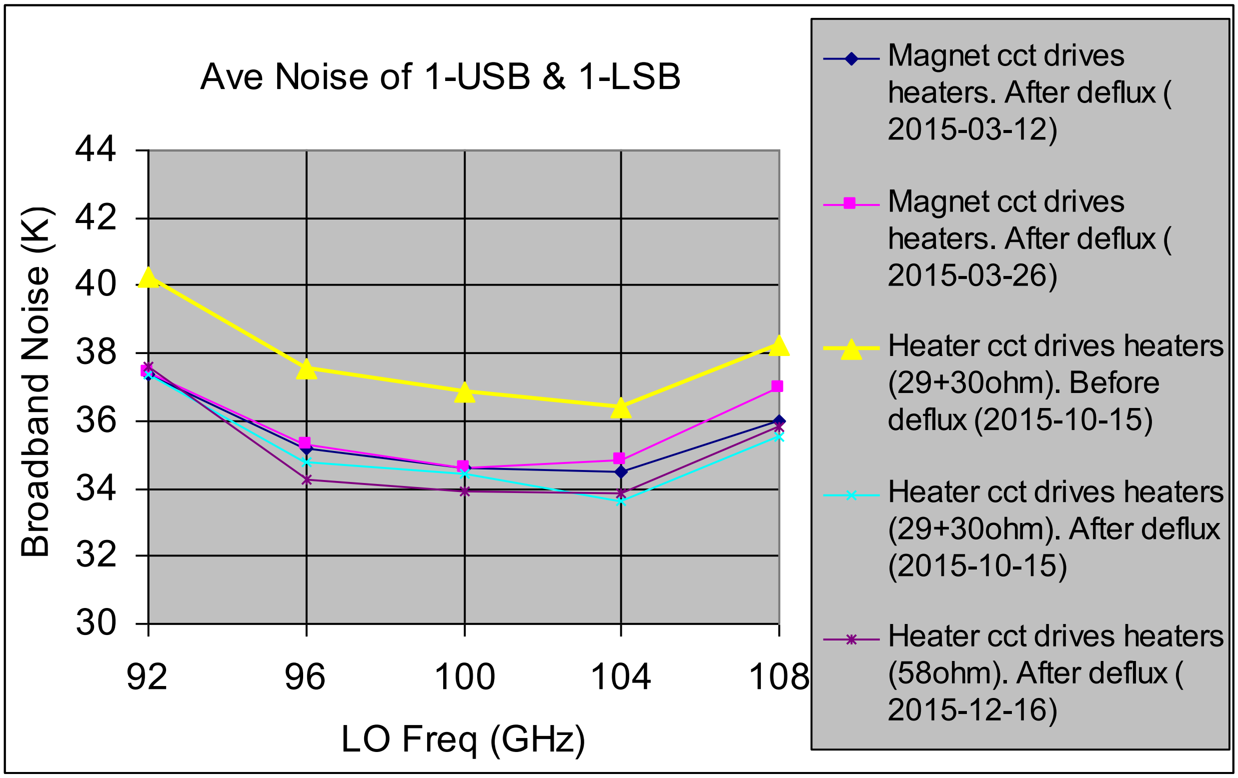


Figure 3: Noise improvement due to various methods of deflux (Pol 1)

3.14 Conclusion

We note a 2 K improvement on Pol 1 due to deflux but much less in Pol 0. It must be pointed out though that the noise improvement (in kelvin terms) depends on how severe the trapped flux was prior to deflux. Some 2SB assemblies are less prone to trapped flux, and in those assemblies, the improvement is marginal.

4 Tests of CCA3-33 at ALMA

CCA3-33 was installed with prototype mixer heaters at NRC and shipped back to ALMA and the performance of the cartridge tested under field operational conditions, as described in the JIRA ticket http://jira.alma.cl/browse/FENCR-629. From that ticket, the findings were:

1. **IV curves** did not show sign of hysteresis, before or after the deflux. This could be an indication that the mixers did not have any significant trapped magnetic field from the beginning.
2. **Trx**: the receiver noise shows almost identical behavior, within the measurement errors, in all tests, before or after the deflux. It seems that at this insignificant level of trapped magnetic field we are not able to see any difference by defluxing.
3. **AmbDip and AzSlew** always show some small fluctuations. The screening level used in engineering verification tests is 0.2 dB peak-to-peak. We see here that the

fluctuations are always below that level (with only one exception, see later), one more indication of insignificant trapped magnetic field. There is only one case where the fluctuations are slightly above 0.2 dB: it happened after the first deflux test. However, there is a drift in the TP, the number given for the fluctuations in the plot is actually mostly reflecting the drift rather than intrinsic fluctuations from the mixers.

Notice that these tests are all done at the same LO1 frequency of 92.2 GHz and same BB assignment (85.225, 87.175, 97.225, 99.175) with BB0, BB1 on SB1 and BB2, BB3 on SB2. Differences between BBs are likely introduced by the cabling, calibration of the TP detectors in the IFProcs, LO2, and other reasons, all of them not directly related to the SIS mixers. Maybe could be better to measure the power at the SB TP detectors rather than at the BB TP detectors. We could think of adding the results of the two BBs on the same SB (BB0 + BB1 --> SB1, BB2 + BB3 --> SB2).

4. **Y-factor**: the curves measured by "yfsis.py" script are similar before and after the defluxing, as also happens with the IV curves. However I noticed some differences, jumps in some cases, between the curves taken with different loads. Maybe due to the bias module, needs additional investigation. The latest results (after the 2nd deflux) will be used to perform an all-band optimization of this receiver.

4.1 IF Power Drifts

1. Bias points appear to be wrong for all LO. For example, at 92 GHz, our bias points are 10.5/10.5/10.4/10.2 mV, whereas theirs are 10.1/10.1/10.0/10.0 It is important to bias the mixers at its optimum point (IF power peak). At this optimum point, the receiver IF power is least susceptible to mixer bias point drift (for whatever reasons).

2. Unable to compare the NRC noise temperature with ALMA's due to the above mentioned point (using wrong bias points). ALMA should have done a mixer fine tune, and use those values. The red circled noise temperatures are questionable.

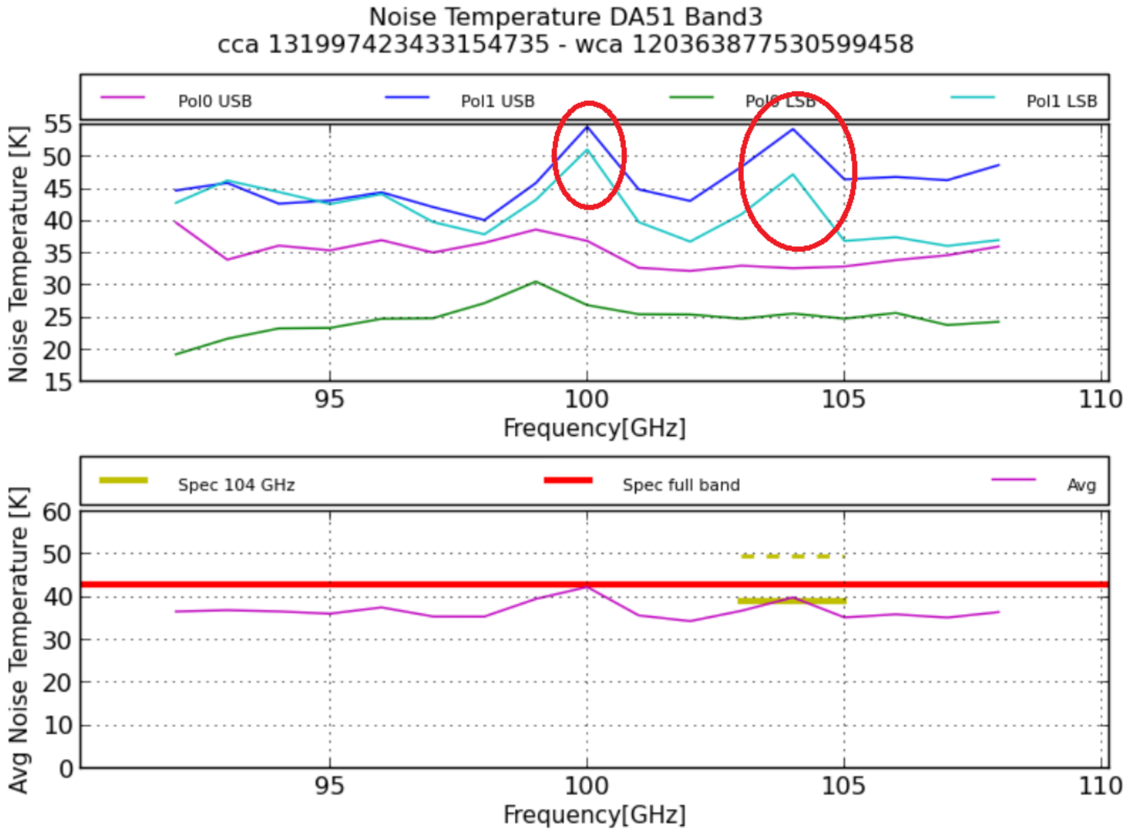


Figure 4: Noise increase deu to wrong bias points

3. During AmbDip, the 15 K (indicated by green arrow) shows a strong angular dependency. It is hard to estimate from the chart below, but it is about 1K peak-peak. If the 15 K stage exhibits angular dependency, then it is likely that the 4 K stage (red arrow) will also show similar dependency. This could lead to IF power variation.

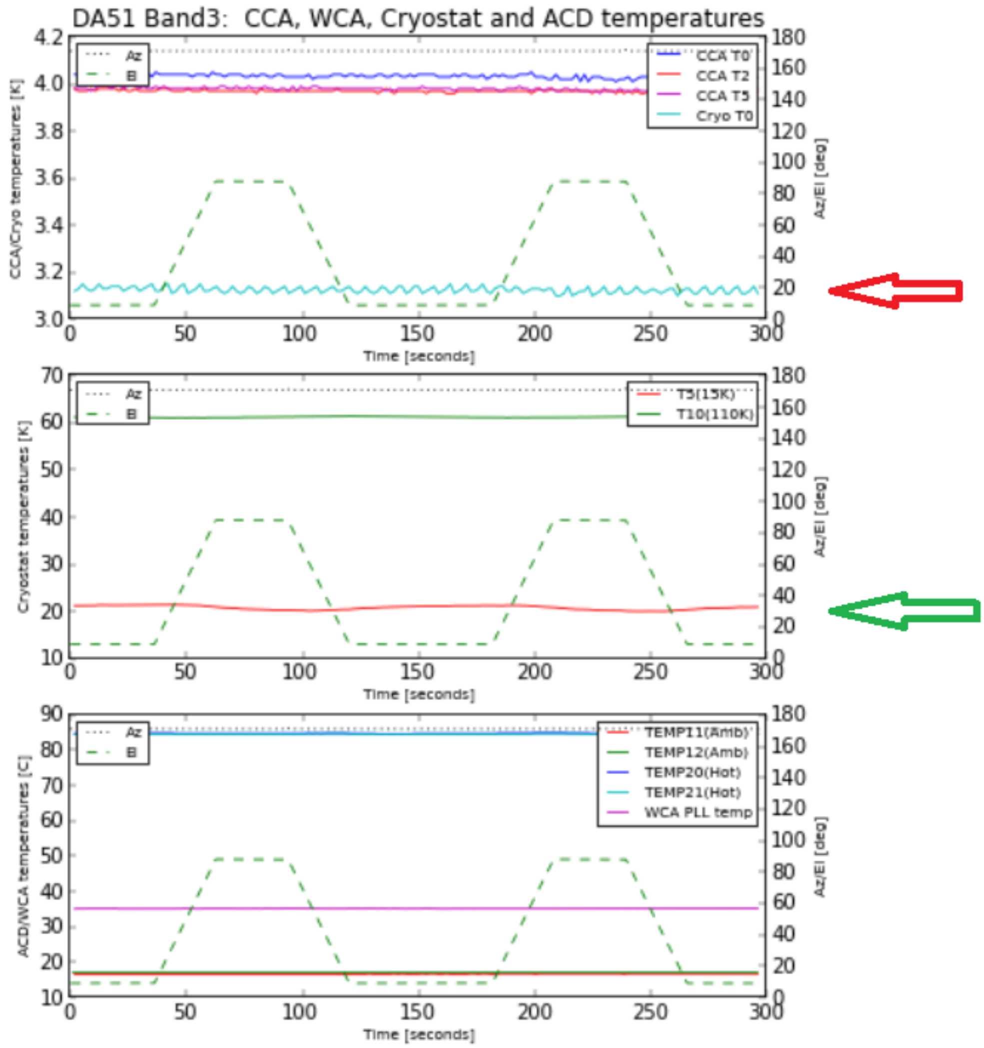


Figure 5: Front end temperatures

4. The IF power drift is unacceptable when trying to quantify IF power variation improvement due to deflux. They have shown better IF power drift in other JIRA tickets (for example: http://jira.alma.cl/browse/FENCR-611). Figure 3 shows a 'no drift' chart from this ticket.

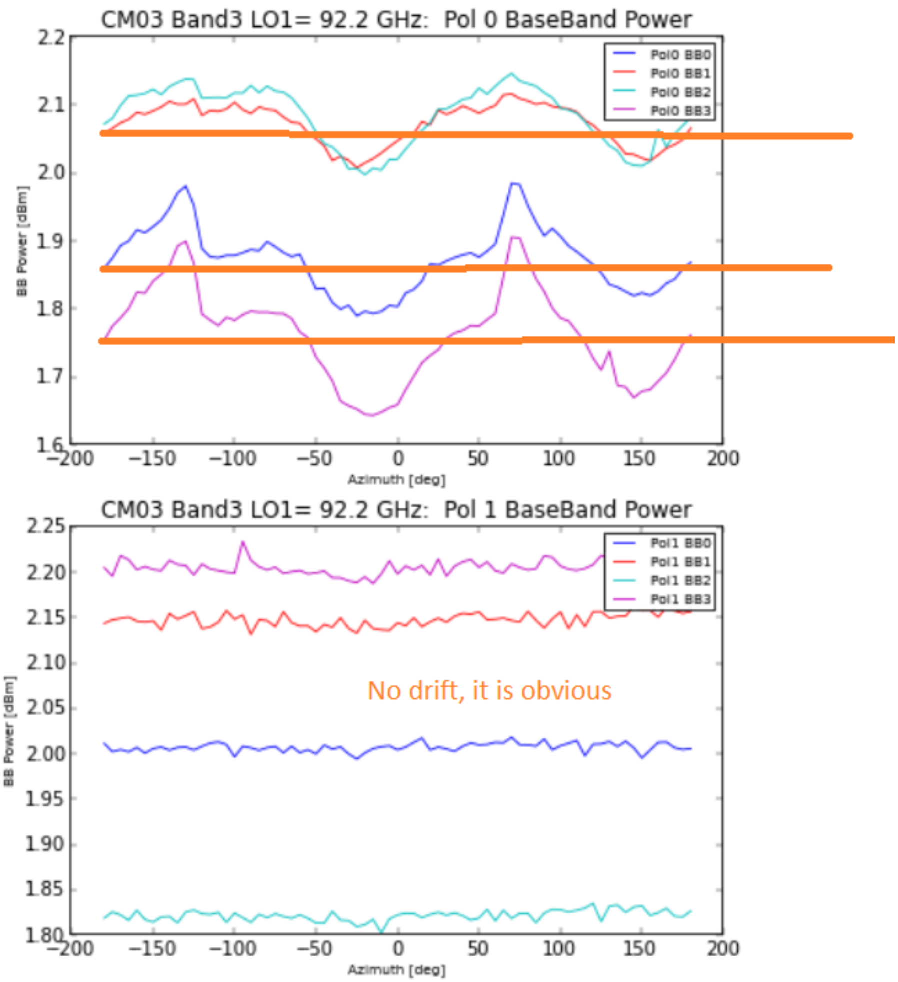


Figure 6: No drift example

5. It would have been better to see the entire IV sweep from 0 to 15 (or 20 mV). The IV curves posted are from 9.6 ~ 10.8 mV. The anomalies of CCA3-66 circled in black were detected at 11 mV, just outside the current sweep range. This chart is also from FENCR-611. Probably a full sweep is needed to detect hysteresis.

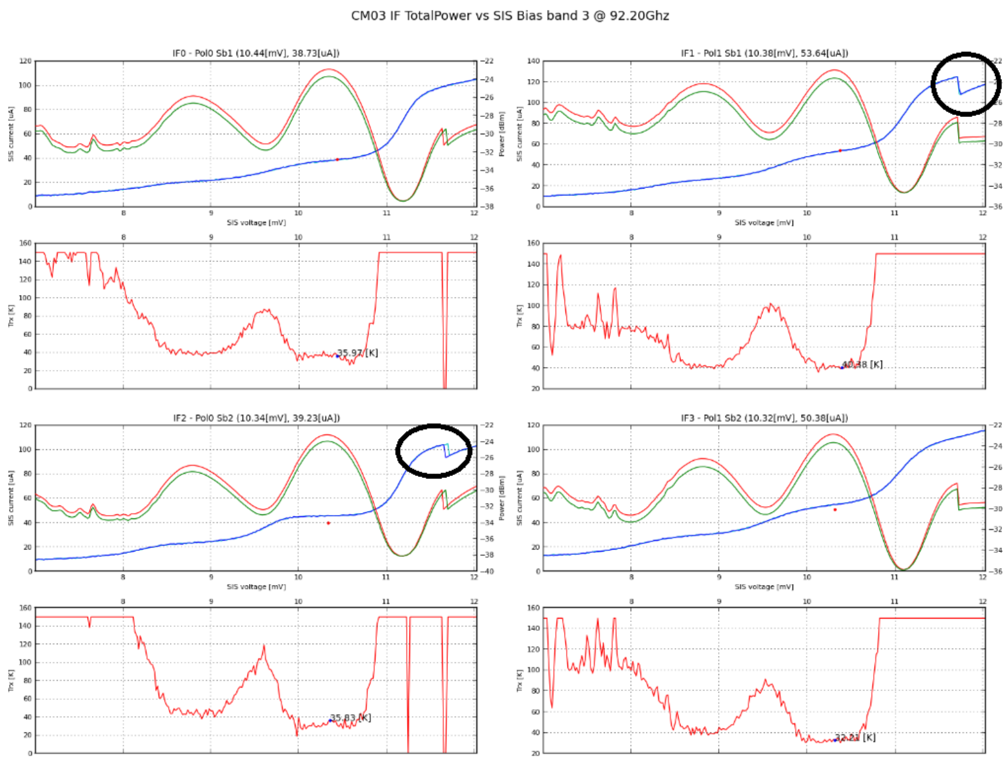


Figure 7

6. Mixer current changes considerably between hot and cold measurements in some plots (IF1 and IF3 in Figure 12, IF1 and 3 in Figure 13). Consequently, the calculated noise temperatures are 'off the scale'.

7. The AzSlew curves (before and after deflux) show curves becoming 'smoother' from 'being ripply'. This is a sign of improvement. The improvement after 2^{nd} deflux is much better than the one after the first which may be an indication that each deflux, in its present form, is 'not deep enough' to rid of trapped flux. Compare Figure 18 (before deflux) with Figure 20 (after 2^{nd} deflux).

8. The AmbDip curves (before and after deflux) show curves becoming 'smoother' from 'being ripply'. This is a sign of improvement. The improvement after 2^{nd} deflux is much better than the one after the first which may be an indication that each deflux, in its present form, is 'not deep enough' to rid of trapped flux. Compare Figure 15 (before deflux) with Figure 17 (after 2^{nd} deflux).

9. Deflux duration - We recommended in *Band 3 Cartridge Procedure for Retrofitting Heater Circuit* (FEND-40.02.03.00-0788-A-PRO):

   "The heater circuit delivers pulses of 200 mA current of 1 sec duration. Our experiments in our cartridge test set show that 60 pulses of 1 sec duration with 20ms dead time in between is sufficient to deflux the cartridge. In our system, the first 30 pulses elevated the mixer plate temperature to about 15 K. The remaining

30 pulses resulted in an additional 1 K rise. The number of pulses/duration required in an ALMA front end system is likely to be different than it is for our system given the different cooling capacity, mass, and thermal load of the former. We suggest that a 15 K rise in mixer plate temperature, and 1 min duration would be a good starting point. Please note that the superconducting temperature of Band 3 mixers is 9.8 K, and a deflux requires a temperature much higher than this."

In light of this, it is likely that deflux needs to be applied longer than the present 4 sec duration (beginning with 2 doses of 10 s or 15 K mixer temperature whichever comes first).

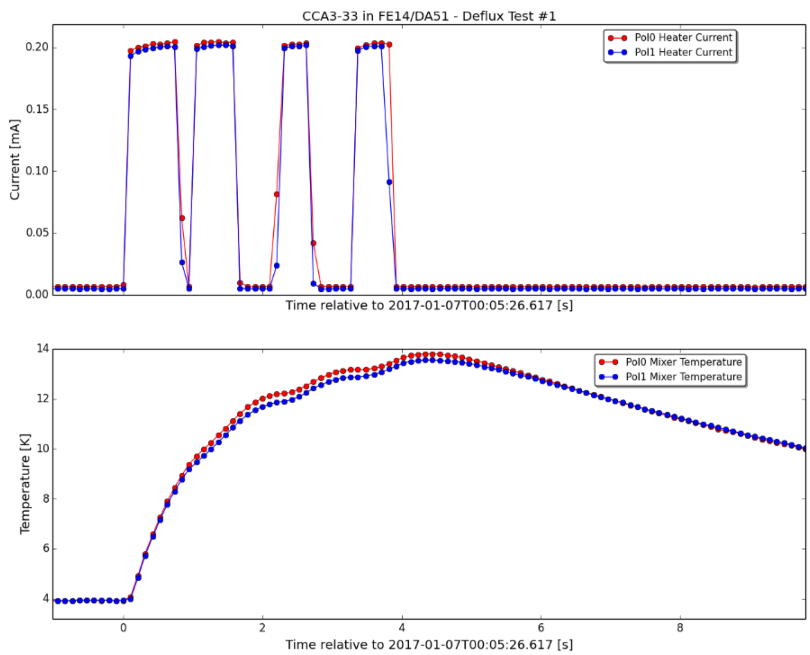


Figure 8: Mixer deflux test

4.2 IV Curves, Bias Point, Noise Temperature

NRC measurements (just prior to shipping the cartridge to ALMA)

Freq (GHz)	Pol	Date Stamp	Vj SIS 1 Set	Vj SIS 2 Set	Ij SIS 1 Mon	Ij SIS 2 Mon	T_LSB	T_USB
92	0	2015-12-16 14:43:16	10.5	10.5	43.1	45.5	29.3	33.5
92	1	2015-12-16 16:12:08	10.4	10.2	56.0	47.2	37.8	37.3

Before Deflux

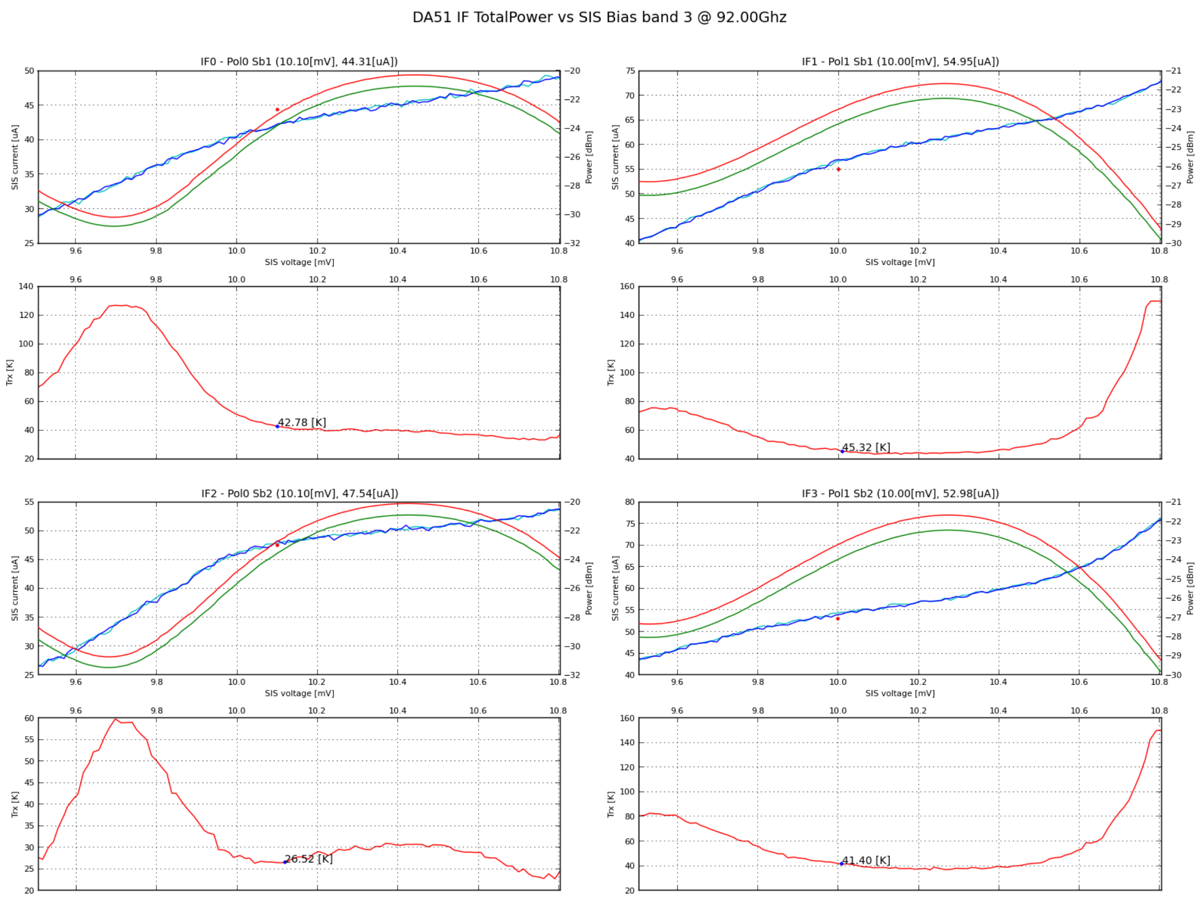


Figure 9

After Deflux

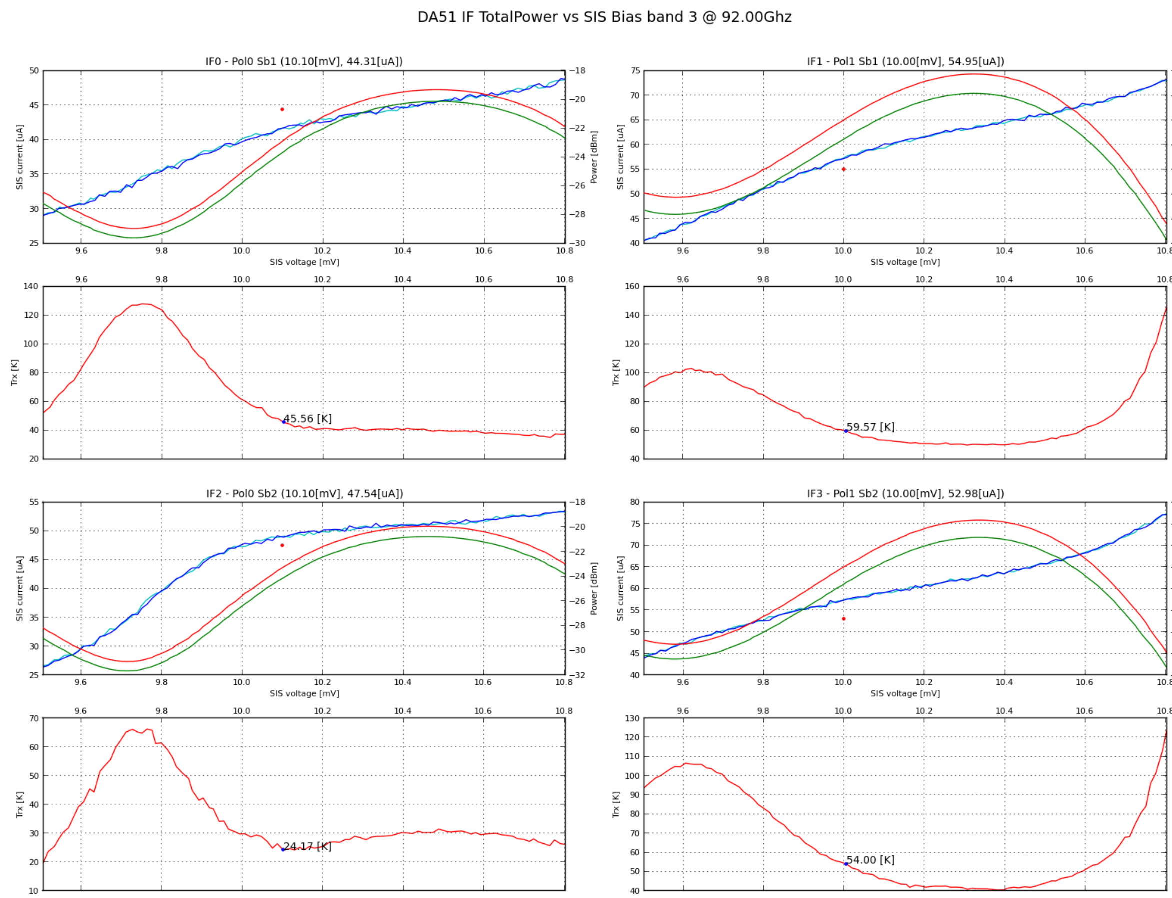


Figure 10

NRC measurement (just prior to shipping the cartridge to ALMA)

Freq (GHz)	Pol	Date Stamp	Vj SIS 1 Set	Vj SIS 2 Set	Ij SIS 1 Mon	Ij SIS 2 Mon	T_LSB	T_USB
100	0	2015-12-16 15:25:22	10.5	10.5	41.4	38.8	31.6	34.9
100	1	2015-12-16 16:49:59	10.4	10.2	55.6	53.6	33.3	34.5

Before Deflux

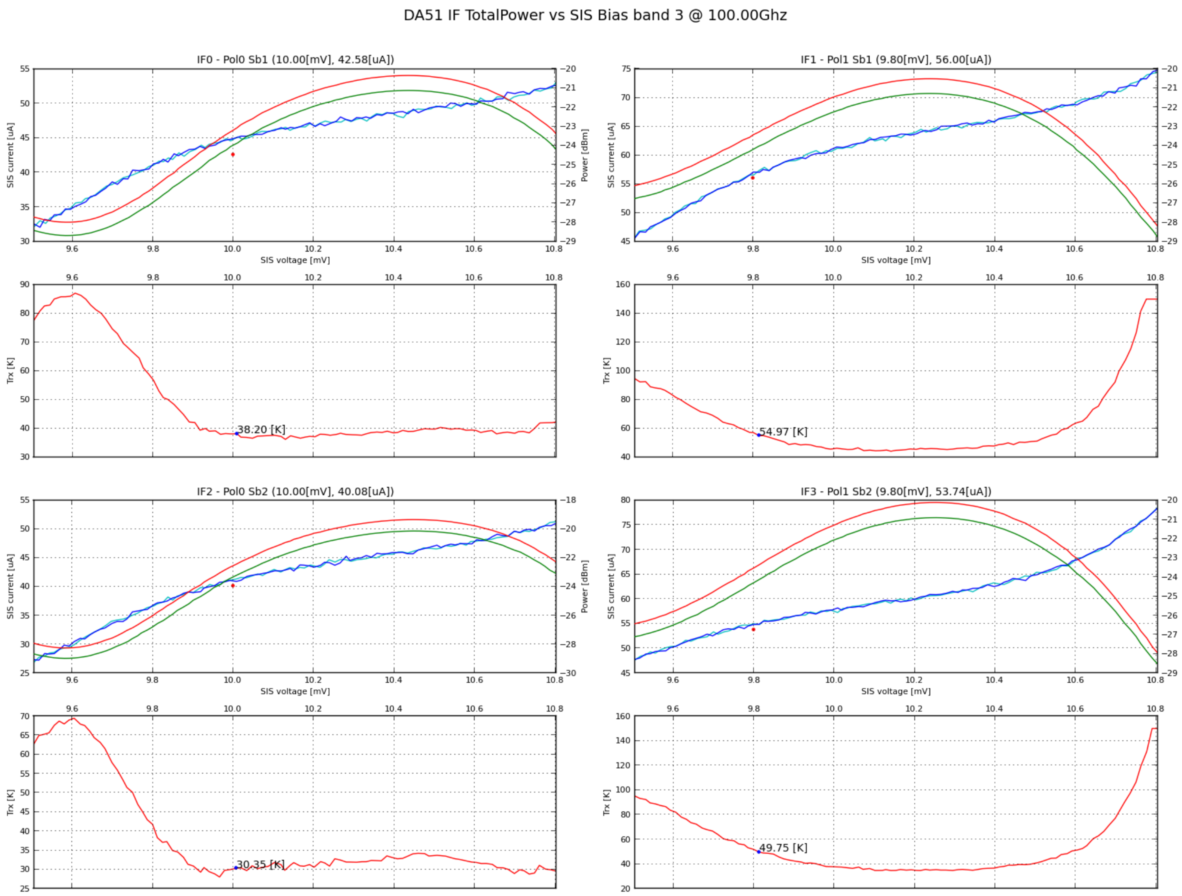


Figure 11

After Deflux

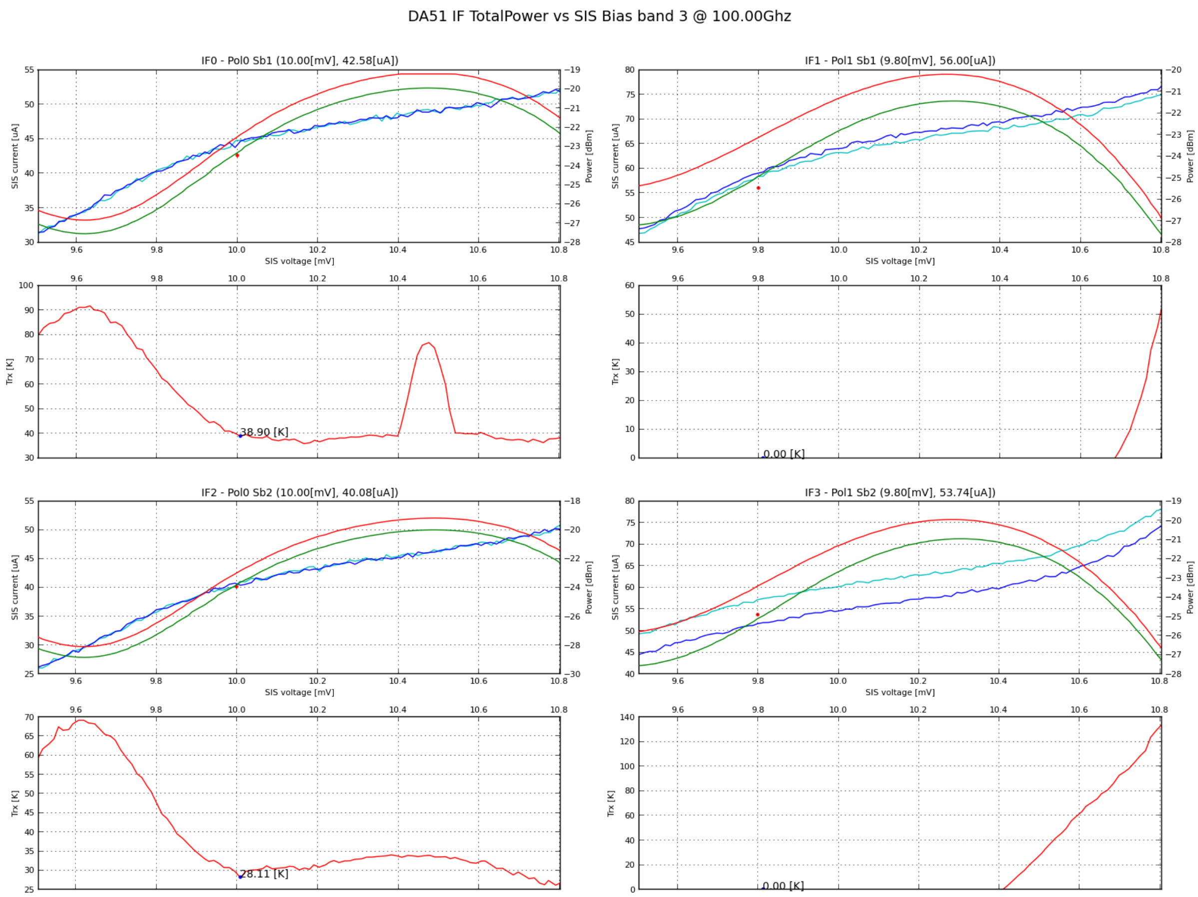


Figure 12

NRC measurement (just prior to shipping the cartridge to ALMA)

Freq (GHz)	Pol	Date Stamp	Vj SIS 1 Set	Vj SIS 2 Set	Ij SIS 1 Mon	Ij SIS 2 Mon	T_LSB	T_USB
108	0	2015-12-16 16:01:25	10.4	10.4	39.4	40.7	27.3	33.7
108	1	2015-12-16 17:26:37	10.3	10.1	54.4	57.5	32.5	39.1

Before Deflux

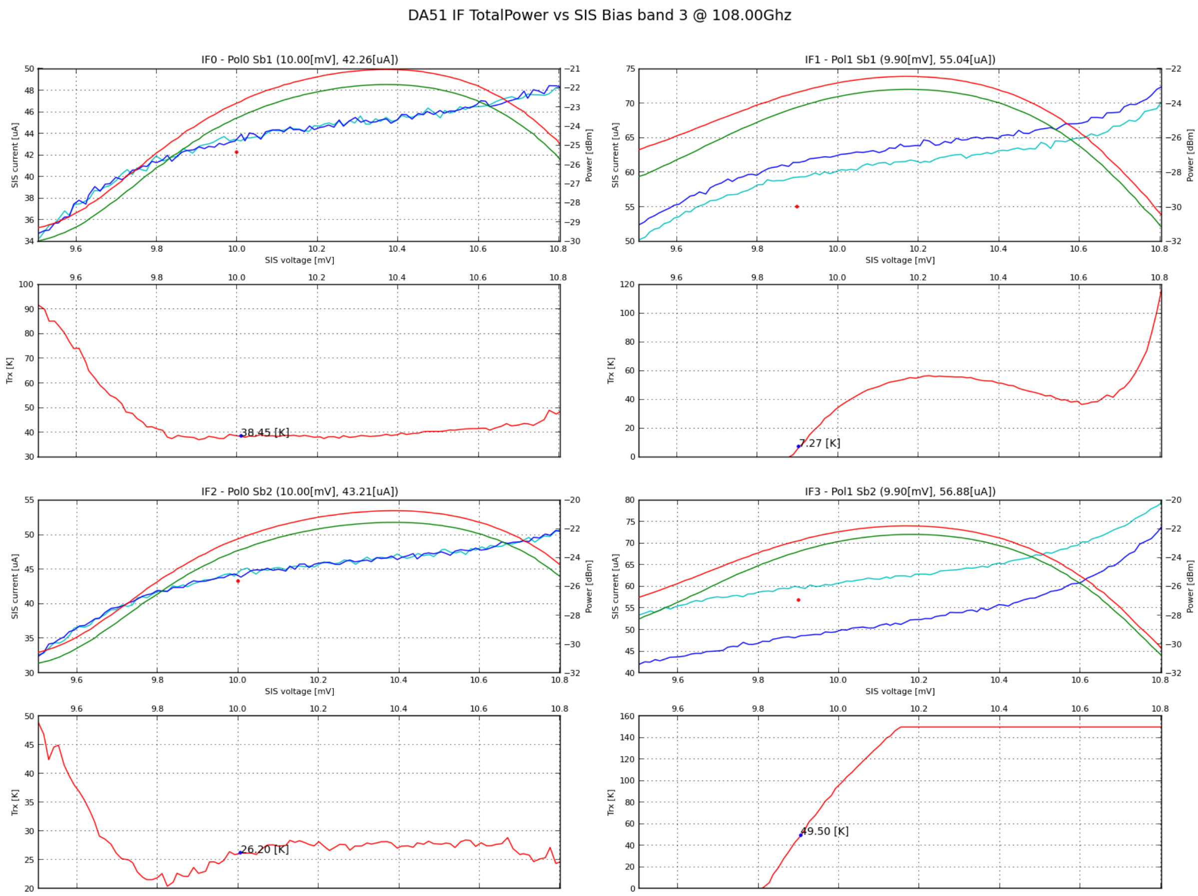


Figure 13

After Deflux

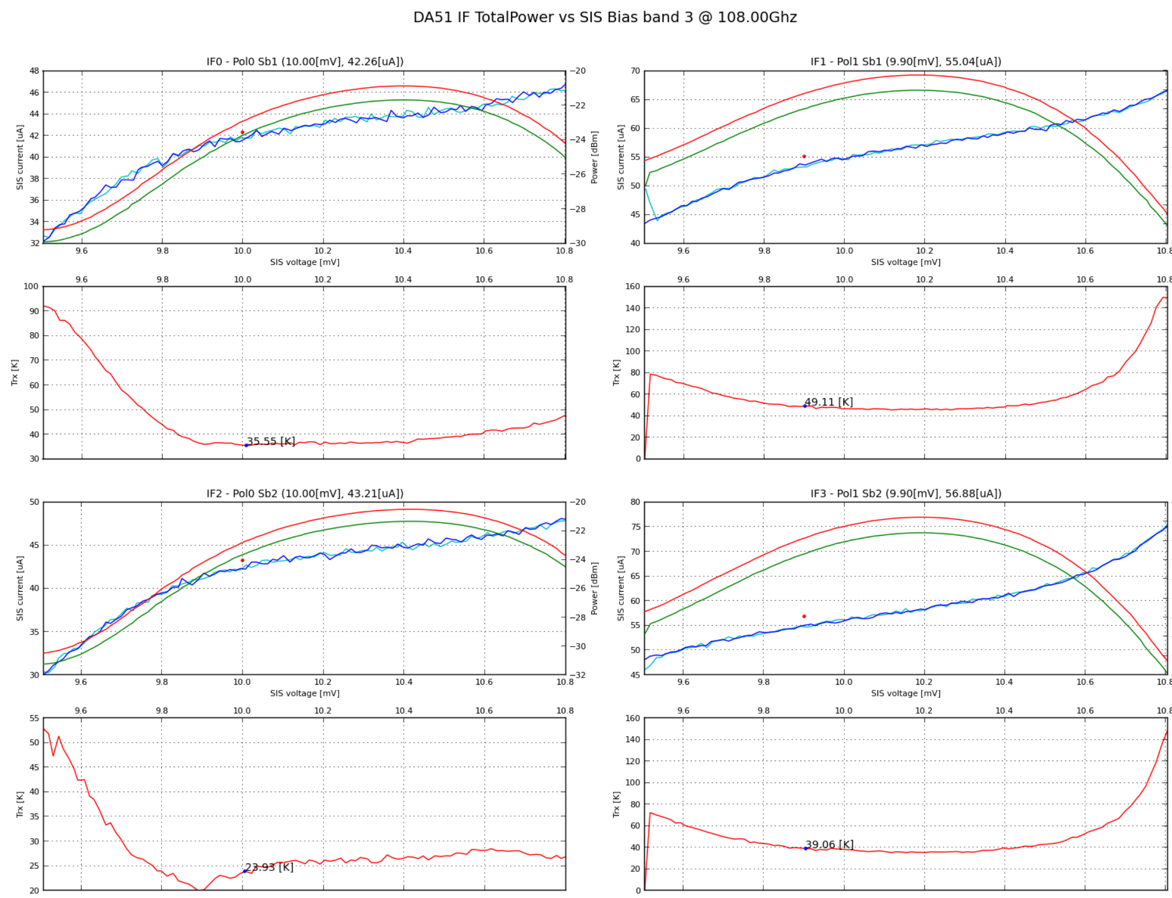


Figure 14

4.3 AmbDip

AmbDip before deflux

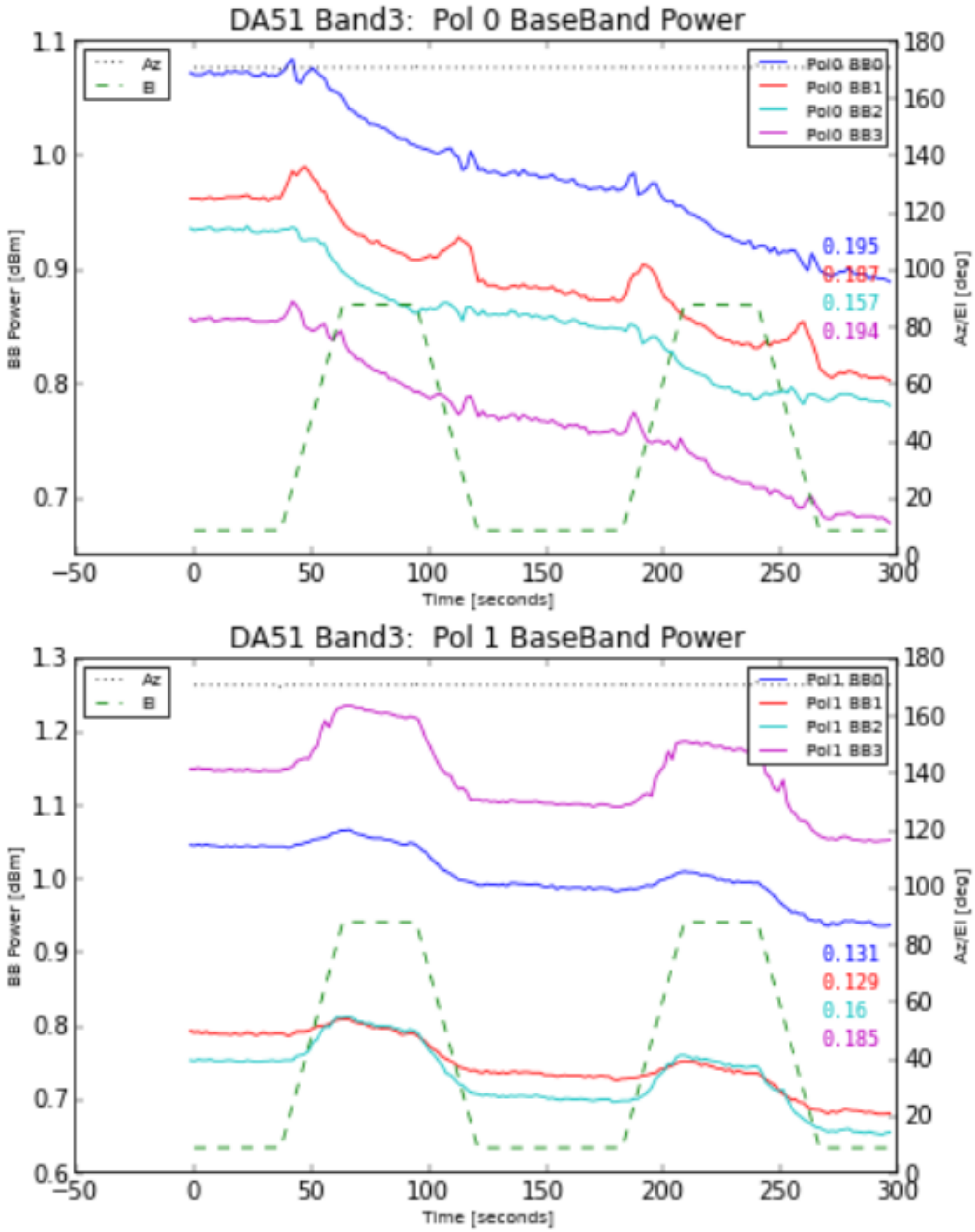


Figure 15

AmbDip after 1st dip

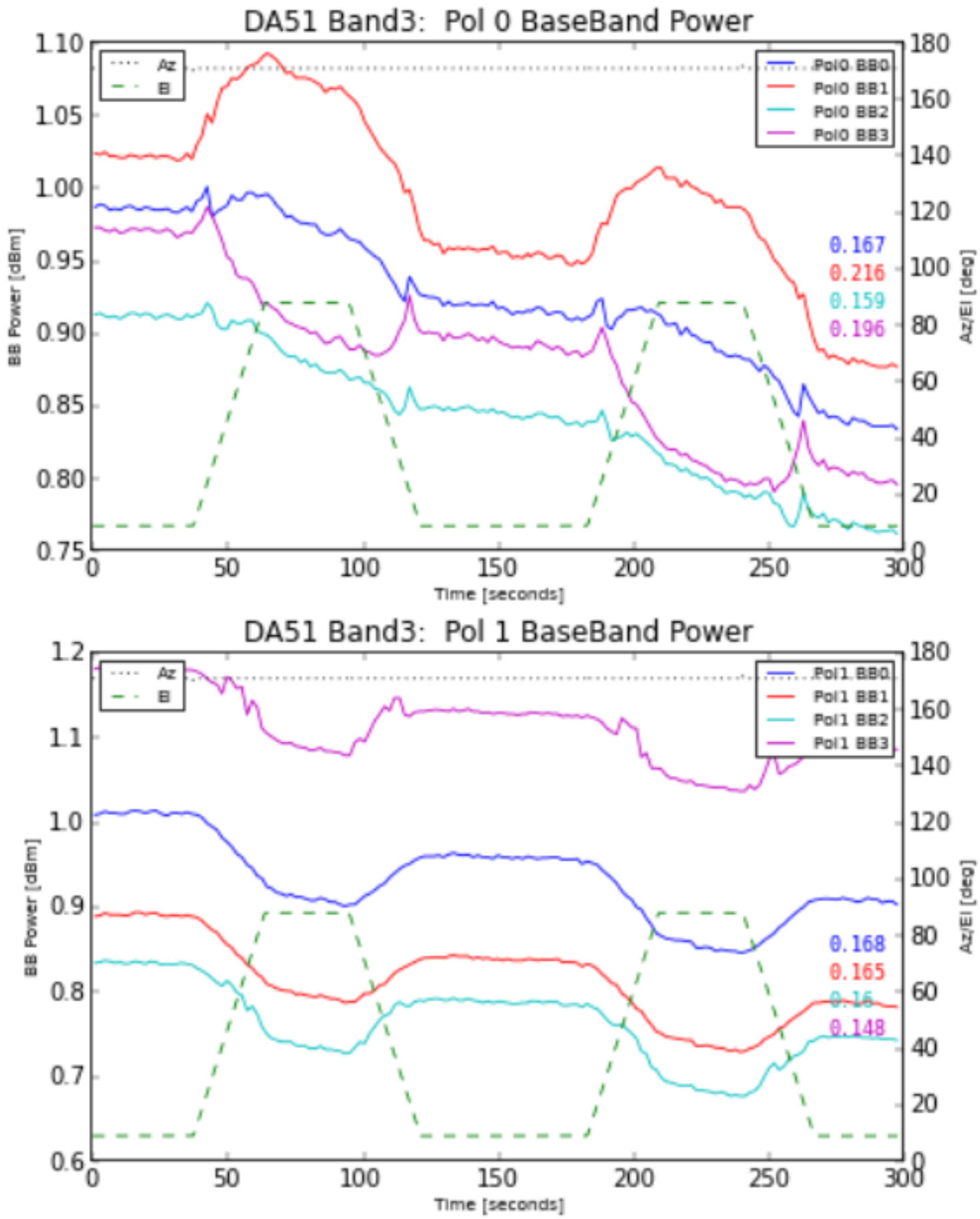


Figure 16

AmbDip after 2nd dip

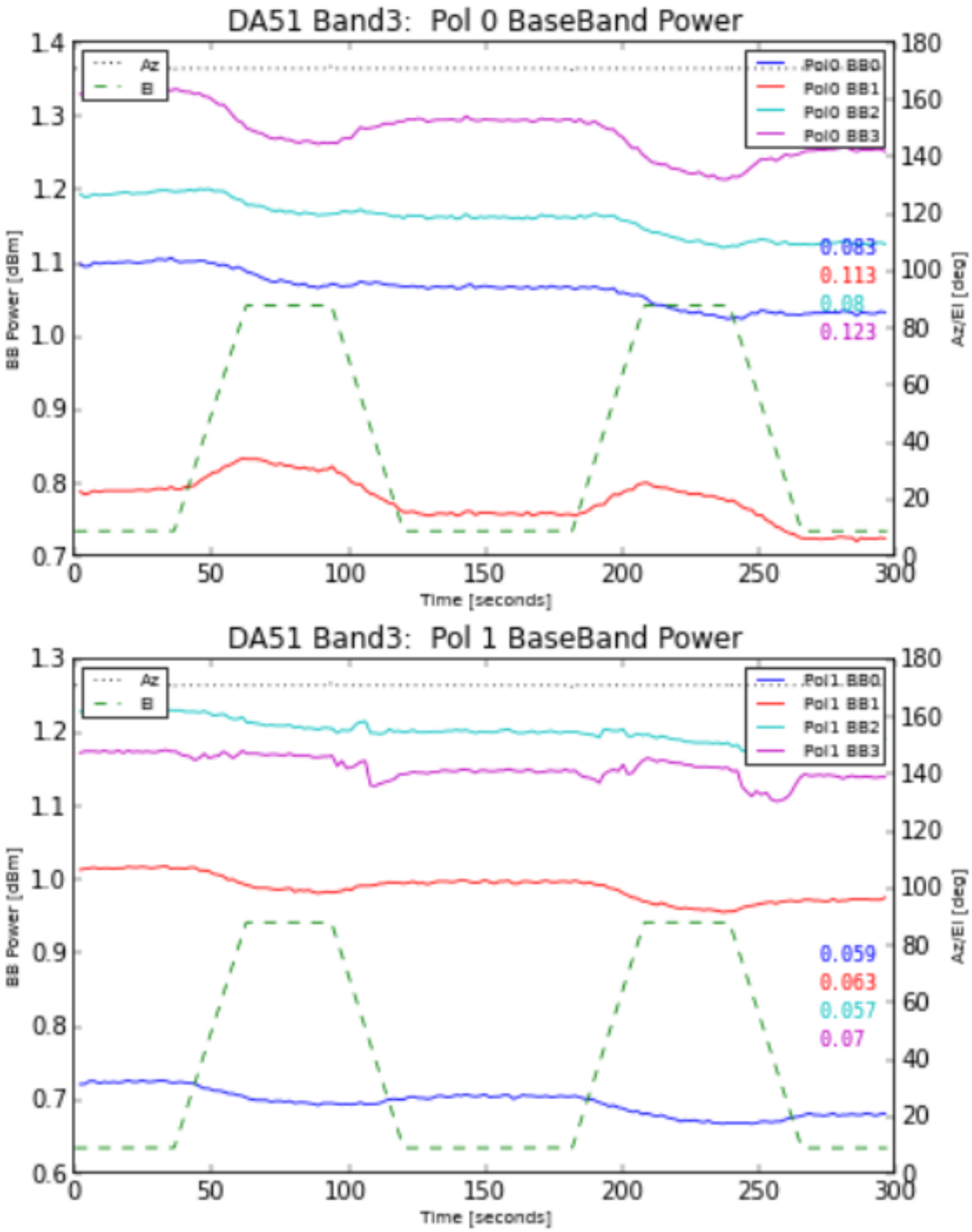


Figure 17

4.4 AzSlew

AzSlew before deflux

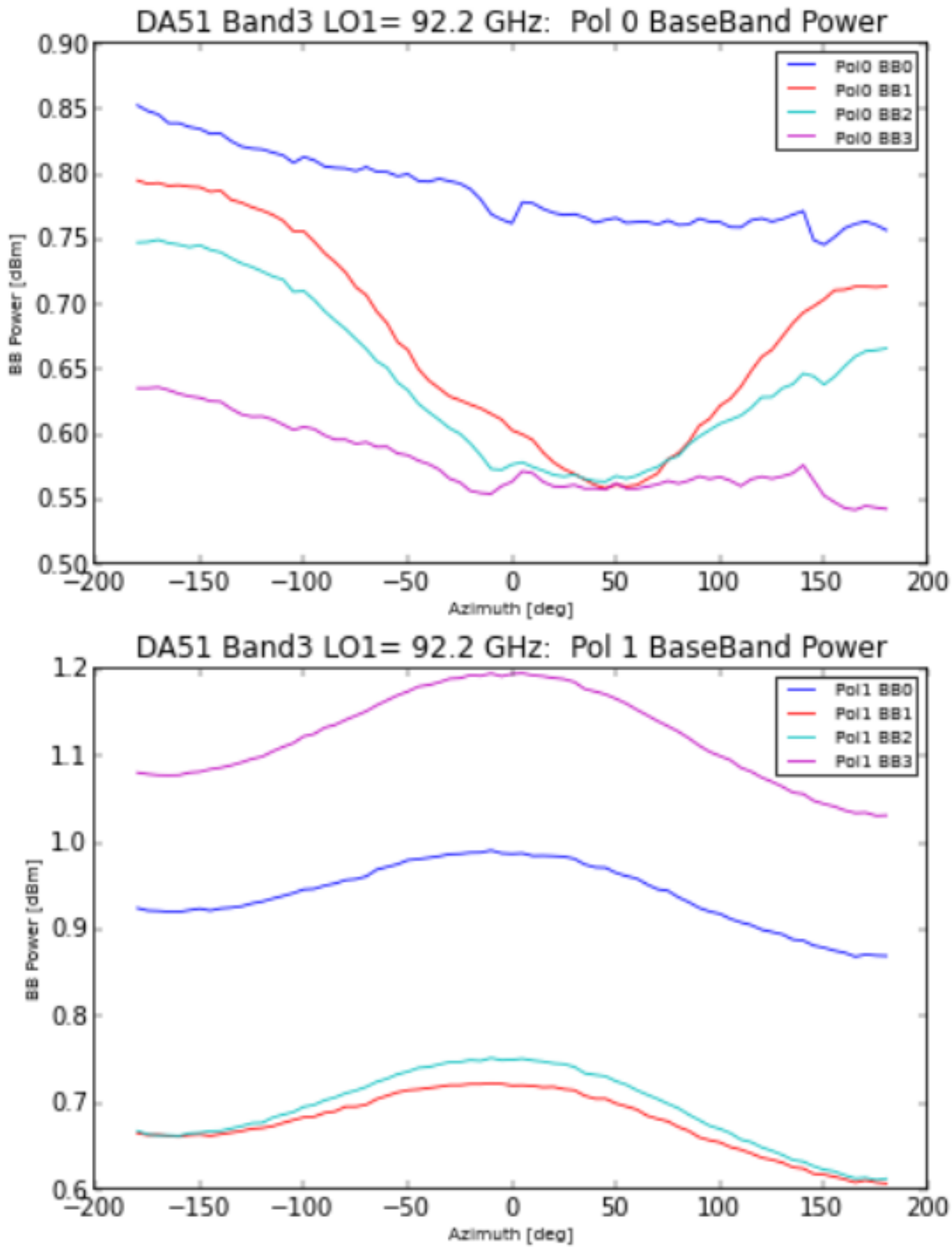


Figure 18

AzSlew after 1st deflux

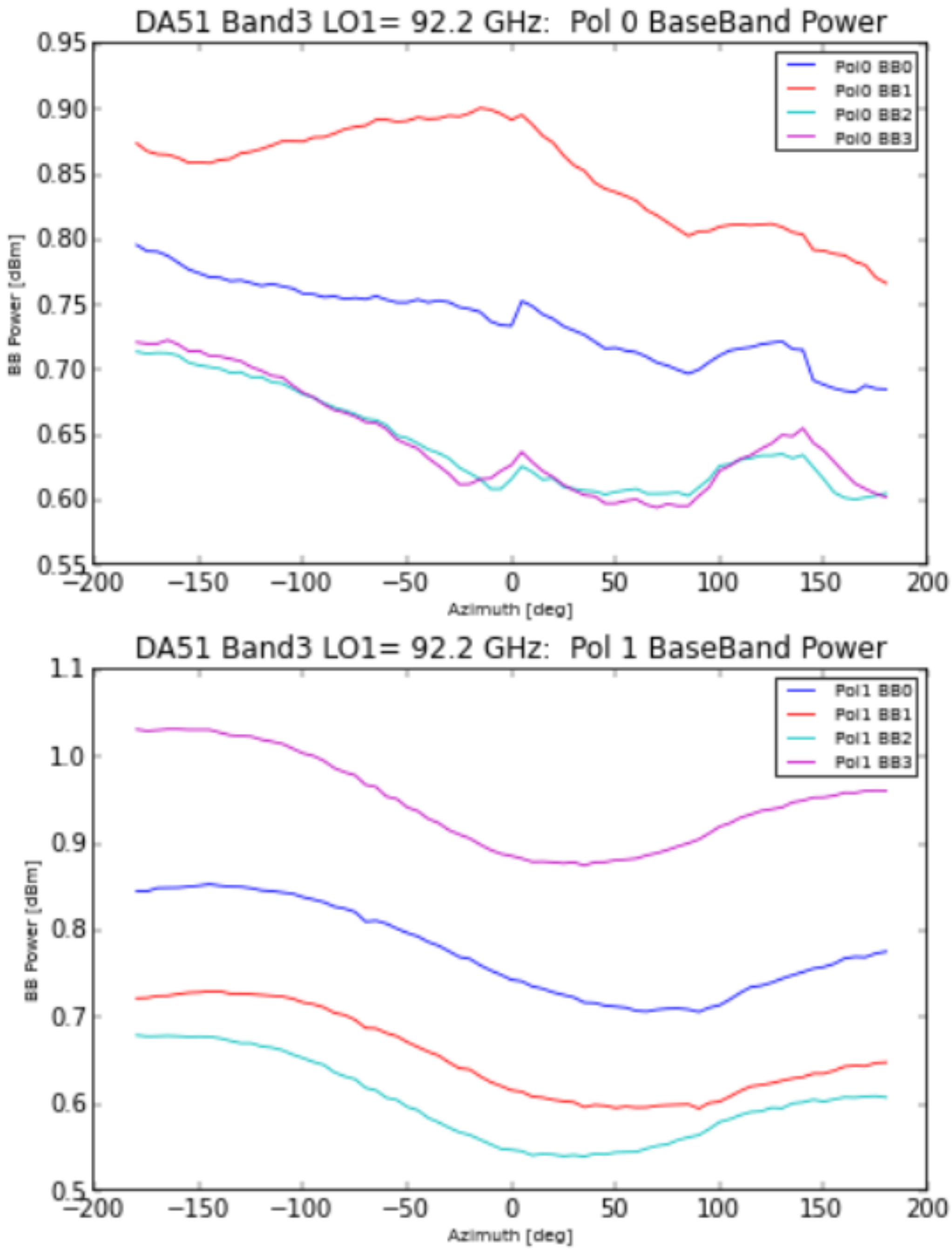


Figure 19

AzSlew after 2nd deflux

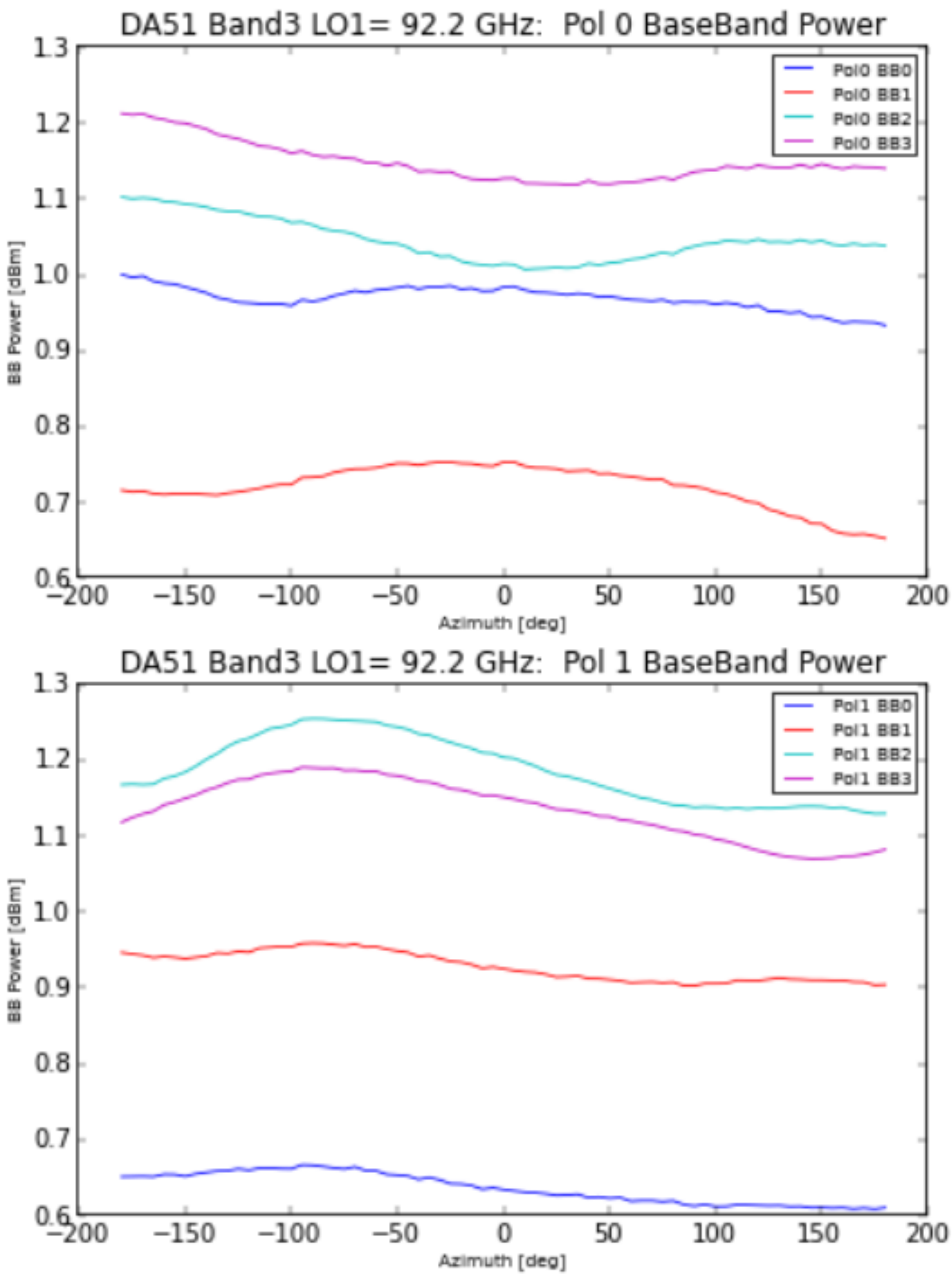


Figure 20

5 <u>Tests of CCA3-66 at ALMA</u>

Here we summarize an analysis of the total power stability of Band 3 cartridge CCA3-66 when installed in antennas at ALMA during 2012, and in early 2014 after permanent magnets and new Pol0 mixers had been installed. This analysis is based on data collected during a number of azimuth and elevation slews of the antenna. The primary scope was a quantitative measurement of the overall change in cartridge stability resulting from the magnet installation. However, there are a few qualitative comments made on the detailed (i.e., on the level of individual measurements) behaviour which could provide a starting point for a detailed analysis aimed towards a more fundamental understanding of the cartridge behaviour. The main findings of the present analysis are:

(1) The baseband power stability of the cartridge with magnets is a factor ~ 3 better for azimuth slews and a factor ~ 2 better for elevation slews. In the original cartridge the baseband powers varied by substantially more than 0.2 dBm with antenna orientation, and after refit generally below 0.2 dBm.

(2) The SIS current stability of the cartridge with magnets is about a factor of 3.5 - 4.0 better than without magnets (and by a factor ~ 9.5 for Pol1SB2).

(3) In the original cartridge, the current stability under azimuth slews was ~ 6% better than for elevation slews. In the refit cartridge, stability for azimuth slews has improved more than for elevation slews, and is now ~ 42% better.

(4) The baseband power stability shows the opposite trend to the current stability: the power is more stable for elevation slews than for azimuth slews in the original cartridge by ~ 58%, and in the refit cartridge by ~ 40%, consistent with point (3).

(5) The baseband power during elevation slews is generally correlated with the antenna elevation, and during azimuth slews is typically sinusoidal with azimuth. There is sometimes evidence for a correlation of power with the horizontal component of the Earth's magnetic field, but the power variations in azimuth and elevation are often more complex than that, suggesting more than one effect is at work (the obvious candidate being variable magnetic flux trapping).

(6) Combined azimuth/elevation slews have a complex power variation but is often very repeatable over short time scales, suggesting that the baseband power output is tightly coupled to the antenna orientation.

(7) Mini-warmups do not have a consistent effect on the stability of the original cartridge, and transient effects on the stability can sometimes be seen one or more days after a mini-warmup, making a reliance on stability measurements taken immediately afterwards unwise. There is probably not enough data to make any conclusions of the effect of mini-warmups on the refit cartridge.

5.1 <u>Test Measurements</u>

CCA3-66 in its original condition without permanent magnets was installed in FE-55 on antenna DA48 in 2012. Between late May and late June of 2012, 14 elevation slews and 18 azimuth slews were made by ALMA staff. Not every data set found in the on-line system at ALMA appears to be documented in the JIRA system, although an exhaustive search of JIRA was not performed. A standard "AZ Slew" measurement moves the antenna from AZ = -180 degrees to AZ = +180 degrees at a fixed EL = 45 degrees, with the front end observing the ambient load of the ACD. A standard elevation slew measurement (also known as an "AmbDip", an EL dipping of the antenna while observing the ambient load) cycles the antenna twice between EL = 9 and EL = 88 degrees at a fixed AZ = +171 degrees. Table 1 summarizes the AZ Slew and AmbDip data sets found for the original CCA3-66. The data sets can be found in the OSF on-line system in date-stamped folders under the following paths:

/groups/engineering/data/BackEnd/AmbDip/DA48
/groups/engineering/data/BackEnd/TpAzslew/DA48

It is difficult to get a picture of the steady-state performance of the original cartridge because of numerous interventions: five mini-warmups, one complete FE thermal cycle, a bias module replacement, compressor monitor and control (M&C) work, and low LO1 power tests, were all made during the test period of one month. Additionally, different LO1 frequencies were apparently used and some I-V curve sweep mixer optimizations were made instead of using the established tuning tables, but we do not have full documentation.

The refit cartridge CCA3-66 with prototype magnets and new Pol0 mixers was installed in FE-52 on antenna CM03 in 2014. In January - February 2014 more AmbDip (11) and AZ Slews (25) were made. Most were standard slews, but some AmbDips were made while stepping in EL and some AZ Slews were done in a number of different fixed EL positions. Only one mini-warmup and one low SIS mixer current test were made over the test period of two weeks, and it appears that a single LO1 frequency was used most of the time, so it is easier to get a picture of the steady-state performance in the new cartridge configuration. These data sets are summarized in Tables 1 and 2 below and can be found online at ALMA at:

/groups/engineering/data/BackEnd/AmbDip/CM03
/groups/engineering/data/BackEnd/TpAzslew/CM03

5.2 <u>Analysis Overview</u>

The focus of this analysis is on the SIS mixer voltages and currents and the baseband (BB) powers. There are four BB channels of width 2 GHz in the IF in each of polarization 0 and 1. In each polarization, BB0 and BB1 are placed in the LSB and BB2 and BB3 in the USB. Within one polarization, the two BBs have centres spaced 1.95 GHz apart, providing for 50 MHz of overlap. The LO1 frequency was usually 92.2 GHz, in which case the centres of the BBs were BB0: 85.225 GHz, BB1: 87.175 GHz, BB2: 97.225 GHz, and BB3: 99.175 GHz.

However, we cannot rule out that some observations may have used different baseband/sideband arrangements.

The focus of the analysis was to concentrate on the overall trends of the cartridge performance, particularly in comparing the original cartridge with the refit cartridge. All of the data collected was visually inspected, and this showed that there was sometimes quite a bit of variation in the shape of the power versus azimuth/elevation curves over time, particularly for the original cartridge.

Very broadly, the AmbDips for the original cartridge tended to show a correlation between power and elevation which was usually in the sense of increased power with increased elevation. However, the opposite trend or an apparent mixture of both trends was sometimes seen. Although voltages and currents were generally stable, there were some instances in which there was some variation in mixer current with elevation. The final AmbDip taken in the original cartridge showed voltage spikes correlated with changes in mixer current. AZ Slews taken on the same day (20120624) showed the same phenomenon, but they disappeared when measurements were made after a pair of mini-warmups and have not reappeared in the refit cartridge to date. AZ Slews in the original cartridge seemed to vary less in their power versus azimuth curves, and were roughly sinusoidal in azimuth.

In the refit cartridge, AmbDips mostly returned to their typical power versus elevation dependence except in the case of combined AZ-EL slews where a more complex variation was observed. For AZ Slews in the refit cartridge a much attenuated variation of power with azimuth was still commonly seen, but with some variations and power jumps when AZ Slews at different elevations were made.

Date Stamp	Time Stamp	Observation	Ticket	Notes
20120527	044237	AmbDip 0	None	Pre-AIV testing
20120601	072028	AmbDip 1	AIV-9816	Original AIV processing on DA48/FE-55
20120601	190057	AmbDip 2	AIV-9816	
20120602	163236	AmbDip 3	AIV-9816	After first mini-warmup
20120604	135753	AmbDip 4	None	Unknown if bias module replacement and compressor M&C system work was complete
20120604	174631	AmbDip 5	None	Unknown if bias module replacement and compressor M&C system work was complete
20120604	180135	AmbDip 6	AIV-9816	After bias module replacement and compressor M&C system work
20120608	005723	AmbDip 7	None	
20120608	215007	AmbDip 8	AIVNCR-191	
20120608	221208	AmbDip 9	None	
20120609	122556	AmbDip 10	AIVNCR-191	Low LO1 power test
20120610	001059	AmbDip 11	AIVNCR-191	After second mini-warmup (with HVAC off)
20120611	061139	AmbDip 12	AIV-9816	
20120624	162257	AmbDip 13	None	After full thermal cycle of FE and third mini-warmup (with HVAC off)
20120527	045252	AZ Slew 0	None	Pre-AIV testing
20120601	073017	AZ Slew 1	AIV-9816	Original AIV processing on DA48/FE55
20120601	191050	AZ Slew 2	AIV-9816	
20120602	164227	AZ Slew 3	AIV-9816	After first mini-warmup
20120604	140736	AZ Slew 4	None	Unknown if bias module replacement and compressor M&C system work was complete
20120604	181100	AZ Slew 5	AIV-9816	After bias module replacement and compressor M&C system work
20120606	122907	AZ Slew 6	None	
20120608	010714	AZ Slew 7	None	

20120608	215956	AZ Slew 8	AIVNCR -191	
20120609	123545	AZ Slew 9	AIVNCR -191	Low LO1 power test
20120610	002048	AZ Slew 10	AIVNCR -191	After second mini-warmup (with HVAC off)
20120611	062127	AZ Slew 11	AIV-9816	
20120620	035852	AZ Slew 12	None	
20120624	003443	AZ Slew 13	AIVNCR -191	After full thermal cycle of FE
20120624	161238	AZ Slew 14	AIVNCR -191	After third mini-warmup (with HVAC off)
20120624	163235	AZ Slew 15	None	
20120625	005548	AZ Slew 16	AIVNCR -191	After fourth mini-warmup (with HVAC off)
20120625	223736	AZ Slew 17	AIVNCR -191	After fifth mini-warmup (with HVAC off)

Table 1: Tests with Original Cartridge

Date Stamp	Time Stamp	Observation	Ticket	Notes
20140118	150850	AmbDip 14	None	
20140118	153333	AmbDip 15	AIV-15688 FENCR-611	
20140119	152019	AmbDip 16	None	
20140123	150850	AmbDip 17	None	Simultaneous AZ steps
20140123	162130	AmbDip 18	None	Simultaneous AZ steps
20140124	122514	AmbDip 19	AIV-15634 FENCR-611	After mini-warmup
20140201	214018	AmbDip 20	None	
20140201	214651	AmbDip 21	None	Simultaneous AZ steps
20140201	220345	AmbDip 22	None	Simultaneous AZ steps
20140202	153506	AmbDip 23	FENCR-611	
20140202	155005	AmbDip 24	FENCR-611	Simultaneous AZ steps
20140118	151936	AZ Slew 18	None	
20140118	154420	AZ Slew 19	AIV-15688 FENCR-611	
20140119	153108	AZ Slew 20	None	
20140123	014637	AZ Slew 21	FENCR-611	
20140123	015223	AZ Slew 22	FENCR-611	
20140123	015806	AZ Slew 23	FENCR-611	
20140123	144424	AZ Slew 24	FENCR-611	EL = 5
20140123	145026	AZ Slew 25	FENCR-611	EL = 10
20140123	145604	AZ Slew 26	FENCR-611	EL = 30
20140123	150141	AZ Slew 27	None	EL = 45
20140123	150718	AZ Slew 28	None	EL = 60
20140123	151258	AZ Slew 29	None	EL = 75
20140123	151817	AZ Slew 30	None	EL = 88
20140123	152353	AZ Slew 31	None	EL = 5
20140124	123625	AZ Slew 32	AIV-15634 FENCR-611	After mini-warmup

20140202	161214	AZ Slew 33	FENCR-611	EL = 5
20140202	162447	AZ Slew 34	FENCR-611	EL = 15
20140202	163039	AZ Slew 35	FENCR-611	EL = 30
20140202	163633	AZ Slew 36	FENCR-611	EL = 45
20140202	164223	AZ Slew 37	FENCR-611	EL = 60
20140202	164809	AZ Slew 38	FENCR-611	EL = 75
20140202	165344	AZ Slew 39	FENCR-611	EL = 88
20140202	165938	AZ Slew 40	FENCR-611	EL = 5
20140202	172836	AZ Slew 41	FENCR-611	
20140202	181310	AZ Slew 42	FENCR-611	Low Pol0 SIS current test

Table 2: Tests with Reworked Cartridge

5.3 SIS Voltages

SIS mixer average voltages are shown in Figure 1 for the AmbDips and in Figure 2 for the AZ Slews. The four mixer voltages in an observation generally fall into two different groups about 0.02 - 0.03 mV apart. Most instances of these occurred in 2012. This is almost certainly due to different look-up table voltages, suggesting that at least two different LO1 frequencies were used during the observations. In some cases it is known that mixer re-optimization was done using I-V curve sweeps, which might also modify the mixer voltage from the look-up value.

In Figures 3 and 4 are plotted the standard deviation of the voltages during each observation. Note that the voltage data for the AmbDips was recorded with 0.01 mV precision and the AZ Slews with 0.001 mV precision. The very large standard deviation for AmbDip 13 in Pol0SB1, and for AZ Slew 14 and 15 in Pol0SB1 are caused by voltage spikes which occurred during those observations. The large standard deviation for AZ Slew 42 in Pol1SB1 and Pol1SB2 is caused by noisier voltages. AZ Slew 42 was made with the Pol0 mixer currents deliberately set low as a test and the procedure to achieve that might have had a deleterious side effect on the Pol1 voltages.

There is a small systematic difference in the standard deviations of the voltages between the AmbDips and the AZ Slews (see Table 3). Individual AmbDip observations have voltage standard deviations of ~ 6.5 μV and AZ Slews have ~ 5.9 μV. This may be an artifact caused by the differing data precision in the two cases. In any case, the mixer voltages are very stable during an observation and no significant changes were seen after the magnet refit. No voltage spikes were seen after the refit. The stability of the voltages is displayed in the standard deviation plots in Figures 3 and 4.

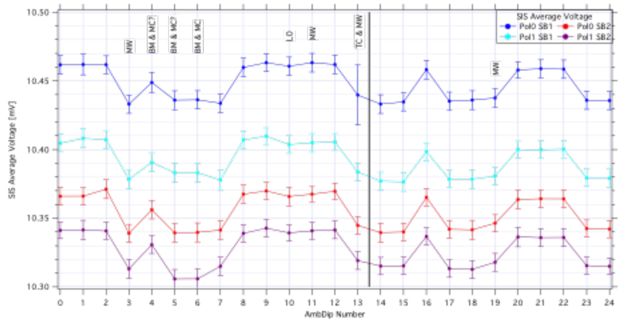


Figure 1. SIS average voltage for AmbDips. The vertical black bar divides the original cartridge measurements (left) from the refit cartridge (right). MV = measurement made immediately after a mini-warmup. BM = during or after bias module replacement. MC = during or after work done on cryostat monitor and control system. LO = LO1 low power test. TC = after thermal cycle of cryostat. Error bars are standard deviation from the mean.

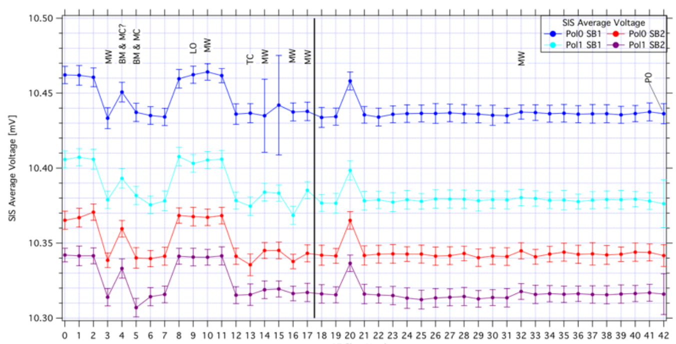


Figure 2. SIS average voltage for AZ Slews. P0 = low Pol0 SIS mixer current test. Other markings and labels as in Figure 1.

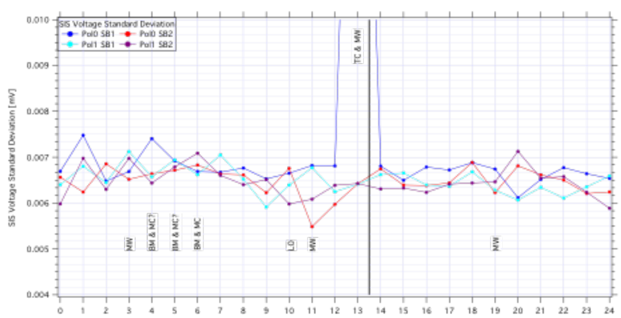


Figure 3. SIS voltage standard deviations for AmbDips. Markings and labels as in Figure 1.

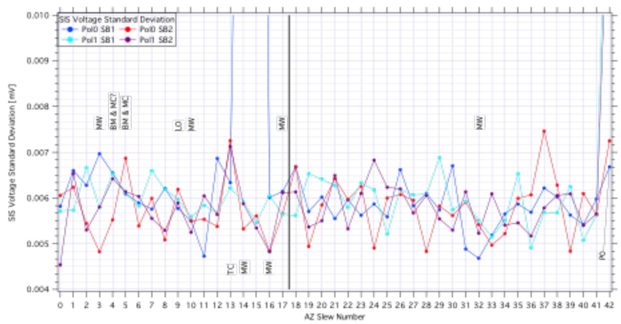


Figure 4. SIS voltage standard deviations for AZ Slews. Markings and labels as in Figure 1.

	Standard Deviation AmbDips Original [μV]	Standard Deviation AmbDips Refit [μV]	Standard Deviation AZ Slews Original [μV]	Standard Deviation AZ Slews Refit [μV]	Standard Deviation AmbDips All Data [μV]	Standard Deviation AZ Slews All Data [μV]
Pol0 SB1	6.82	6.64	6.09	5.83	6.73	5.94
Pol0 SB2	6.46	6.50	5.70	5.86	6.48	5.79
Pol1 SB1	6.59	6.41	5.97	5.88	6.51	5.92
Pol1 SB2	6.50	6.42	5.76	5.80	6.46	5.78
Mean	6.59	6.49	5.88	5.84	6.54	5.86

Table 3: SIS Mixer Voltages

5.4 <u>SIS Currents</u>

SIS mixer average currents are shown in Figure 5 for the AmbDips and in Figure 6 for the AZ Slews. The mixer current standard deviations are in Figures 7 and 8. Note that in the analysis we omit when appropriate the problematic observations noted earlier and AmbDip 10 and AZ Slew 9 (low LO1 power tests). The current standard deviation for AmbDip 0 in Pol0SB1 and Pol1SB2 are anomalous because of unusual behaviour in their mixer current curves which vary strongly with elevation. These have also been excluded from the standard deviation analysis.

As can be seen in Table 4, the average currents changed by < 3 μA after the cartridge rework except for Pol0SB2, which changed by > 9 μA. In the original cartridge, the current stability is ~ 2 - 5 μA depending on the mixer. The current stability for AZ Slews in the original cartridge appears to be ~ 6% better than for AmbDips. Addition of the magnets improves the current stability for all mixers to ~ 0.3 - 1.0 μA, by factors of ~ 3.5 - 4.0 in general, but by ~ 9.5 for Pol1SB2. The stability for the AZ Slews has improved more than for the AmbDips, and so the stability in the AZ Slews is now better by ~ 20% (Pol0) and by ~ 65% (Pol1) compared to the AmbDips.

In addition to AmbDip 0, there were six additional AmbDips which resulted in SIS mixer currents showing a small variation correlated with elevation (AmbDips 4, 5, 6, 7, 10, and

12). It was usually the Pol0SB2 mixer showing the variation, but occasionally Pol1SB2 would also show a weak variation (for AmbDip 0 all mixers were varying substantially). This intermittent behaviour vanished after the cartridge rework. The AZ Slews never showed this behaviour. AZ Slew 9 showed azimuth dependent mixer currents, but it should be noted this observation was a low LO1 power test and the mixer currents were much lower than normal.

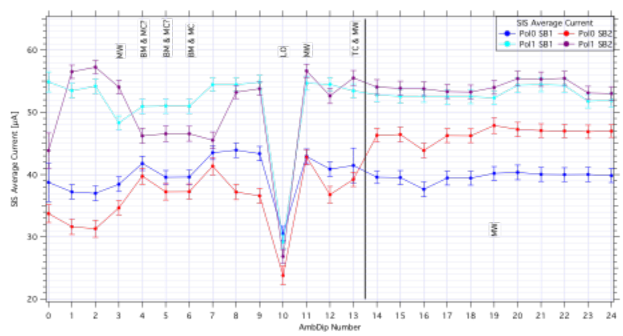


Figure 5. SIS average current for AmbDips. Markings and labels as in Figure 1.

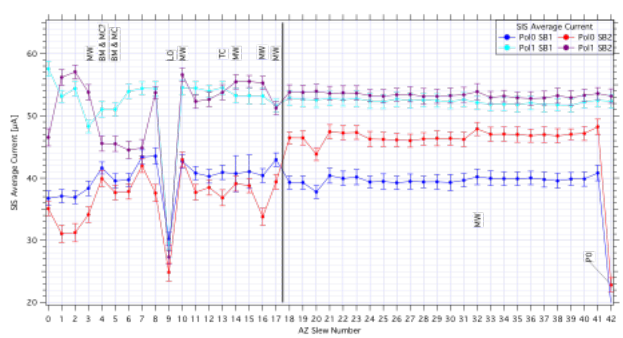


Figure 6. SIS average current for AZ Slews. Markings and labels as in Figure 1.

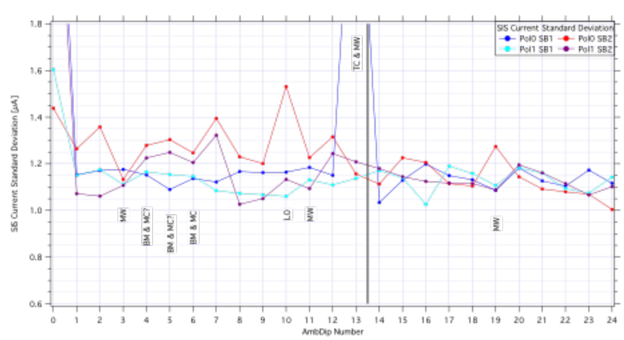


Figure 7. SIS current standard deviations for AmbDips. Markings and labels as in Figure 1.

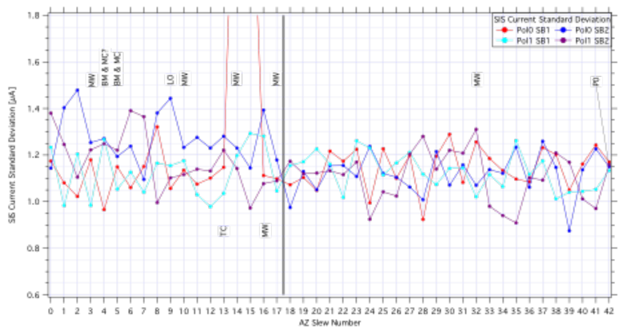


Figure 8. SIS current standard deviations for AZ Slews. Markings and labels as in Figure 1.

Table 3 - SIS Mixer Voltages						
	Standard Deviation AmbDips Original [µV]	Standard Deviation AmbDips Refit [µV]	Standard Deviation AZ Slews Original [µV]	Standard Deviation AZ Slews Refit [µV]	Standard Deviation AmbDips All Data [µV]	Standard Deviation AZ Slews All Data [µV]
Pol0 SB1	6.82	6.64	6.09	5.83	6.73	5.94
Pol0 SB2	6.46	6.50	5.70	5.86	6.48	5.79
Pol1 SB1	6.59	6.41	5.97	5.88	6.51	5.92
Pol1 SB2	6.50	6.42	5.76	5.80	6.46	5.78
Mean	6.59	6.49	5.88	5.84	6.54	5.86

5.5 Baseband Powers

Figures 9 - 16 show the standard deviation and peak-to-peak variation in each baseband channel for the AmbDip and AZ Slews. Before the magnet installation, the average IF power in each BB was ~ +1 dBm. Afterwards, it was ~ +2 dBm. Measurements at NRC Herzberg show that the increase in IF power is not due to the magnets (the magnets caused a ~ -1 dB change in IF power), and it seems more likely it is due to a change in the BB settings in the software used to make the observation. The BB power target for total power (no correlator) observations should be +2.0 dBm (2-bit correlator modes should use +3.8 dBm and 3-bit modes +2.4 dBm). It appears that the BB powers were set 1 dB lower than optimum when testing the original cartridge.

Various observations are omitted from analysis as appropriate: AZ Slew 4 and 5 are problematic since they were observed around the time that work was being done (bias module replacement and compressor work), and AZ Slew 9 was a low LO1 power test. AZ Slew 14 and 15 (Pol0) was also omitted due to very strange behaviour probably related to the voltage spikes mentioned earlier. AZ Slew 42 was the low Pol0 mixer current test. AmbDip 13 (Pol0) also suffered from voltage spikes.

Before refit, AmbDips in Pol1 (~ 0.029 dBm) gave a factor of ~ 3 better power stability than Pol0 (~ 0.096 dBm). Comparing sidebands, LSB and USB had roughly similar stability (USB/LSB ~ 1.14). AZ Slews showed a different pattern, with LSB (~ 0.122 dBm) a factor ~ 1.5 more stable than USB (~ 0.184 dBm) and the polarization channels having exactly the same stability (Pol0/Pol1 ~ 1.0).

The AZ Slew results give the clearest picture of the effect of the cartridge refit (see Table 5). The power stability (standard deviations) in the refit cartridge are a factor ~ 3.2 better, going from 0.152 dBm to 0.047 dBm averaged across both polarizations and sidebands. There is some evidence that the Pol1 channels have improved more than the Pol0 channels: before the refit the stability ratio (Pol0/Pol1) ~ 1.0 and after refit (Pol0/Pol1) ~ 1.2, suggesting Pol1 has improved ~ 13% more than Pol1. Before the refit (USB/LSB) ~ 1.5 and after (USB/LSB) ~ 1.4, suggesting that the USB channels have improved ~ 12% more than the LSB channels.

Identifying trends in the AmbDip results is more difficult. The overall stability has improved by a factor ~ 2.1, from 0.062 dBm to 0.029 dBm. Unlike the AZ Slews, the AmbDips in the original and refit cartridge do not have consistent (Pol0/Pol1) or (USB/LSB) stability ratios. It is not immediately obvious why there is this difference between the AZ Slew and AmbDip data.

Comparing AmbDips and AZ Slews, the cartridge is more stable with AmbDips than with AZ Slews. Before the refit the stability ratio (AZ Slew/AmbDip) ~ 1.5 - 6.5, with Pol1 being significantly worse than Pol0. With magnets, the ratio is ~ 1.2 - 4.2, again with Pol1 being worse. It seems that the refit improved the stability of AZ Slews more than it did for AmbDips. Since the pre- and post-refit stability of the AZ Slews is worse than that of the AmbDips, it is clear the power stability is more sensitive to AZ Slews than AmbDips (for mixer current stability the opposite is the case). However, the AmbDips seem to give less consistent results.

Table 6 and 7 tabulate the BB power peak-to-peak statistics, included since the JAO engineering team have been using an informal peak-to-peak power threshold (of 0.2 dBm) as an indicator of cartridge performance. Considering the mean (i.e. averaged over all observations) value of the peak-to-peak power, we can see that both AmbDips and AZ Slews exceeded the 0.2 dBm limit in Pol0 (~ 0.20 - 0.47 dBm) but were under the threshold in Pol1 (~ 0.08 - 0.13 dBm) in the original cartridge. AZ Slews showed worse stability than AmbDips. With the magnets, the cartridge is under the threshold in all sidebands and polarizations. For AmbDips Pol0 improved by a factor of ~ 2 while the Pol1 channel was broadly unchanged. For AZ Slews, both polarizations improved by a factor of ~ 2 - 3. This is more or less consistent with the earlier conclusion that while the AmbDips showed the best power stability, the AZ Slews showed the most improvement with the magnets.

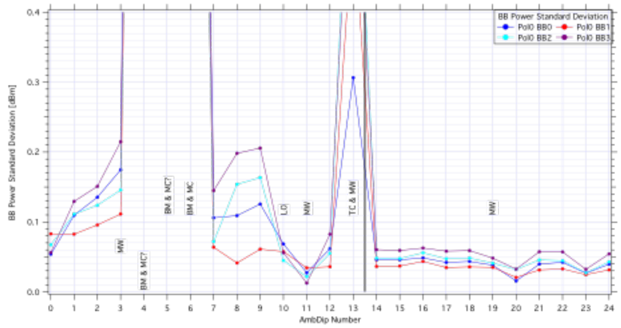


Figure 9. Baseband power standard deviations in Pol0 for AmbDips. Markings and labels as in Figure 1.

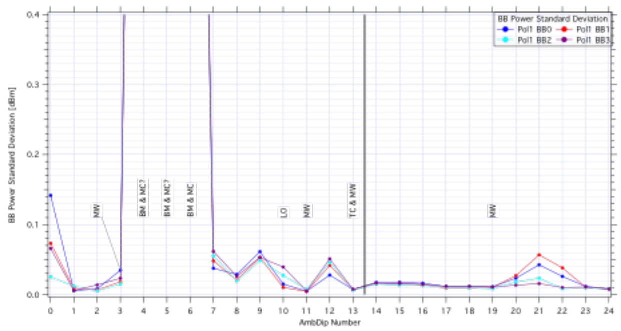


Figure 10. Baseband power standard deviations in Pol1 for AmbDips. Markings and labels as in Figure 1.

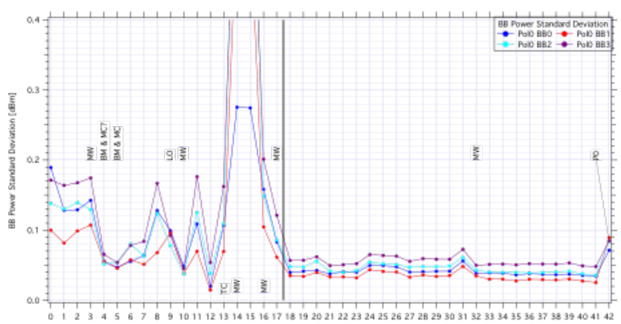


Figure 11. Baseband power standard deviations in Pol0 for AZ Slews. Markings and labels as in Figure 1.

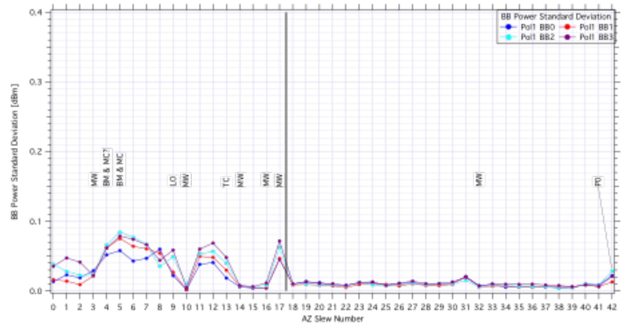


Figure 12. Baseband power standard deviations in Pol1 for AZ Slews. Markings and labels as in Figure 1.

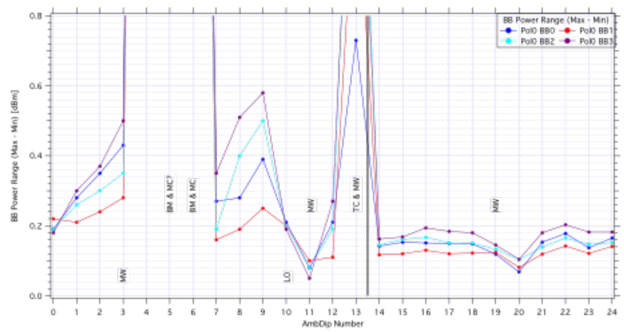


Figure 13. Baseband power peak-to-peak range in Pol0 for AmbDips. Markings and labels as in Figure 1.

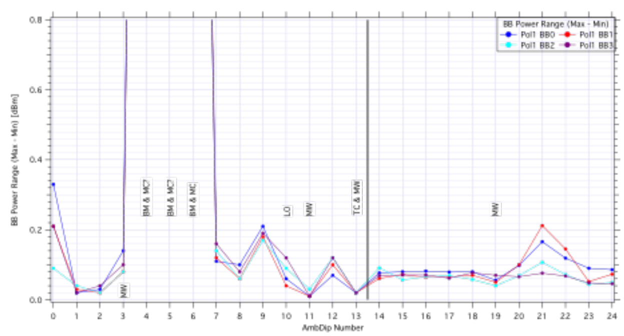


Figure 14. Baseband power peak-to-peak range in Pol1 for AmbDips. Markings and labels as in Figure 1.

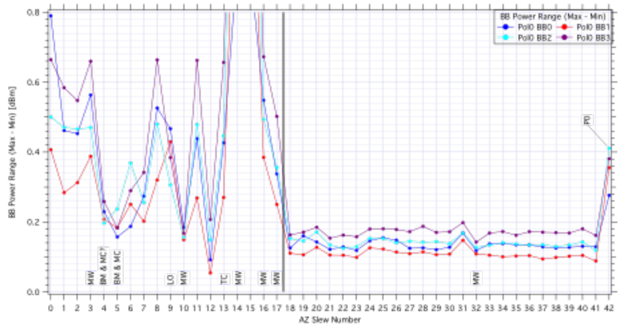


Figure 15. Baseband power peak-to-peak range in Pol0 for AZ Slews. Markings and labels as in Figure 1.

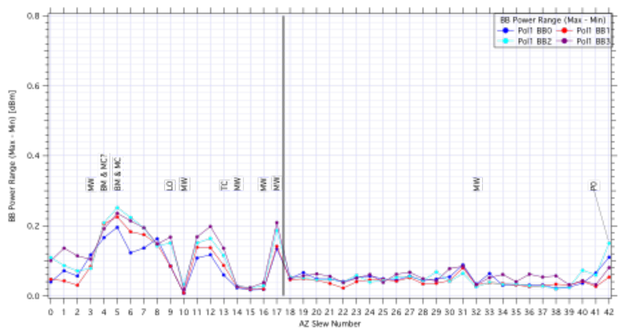


Figure 16. Baseband power peak-to-peak range in Pol1 for AZ Slews. Markings and labels as in Figure 1.

	Standard Deviation Original, AmbDips [dBm]	Standard Deviation Refit, AmbDips [dBm]	Refit/Original	Standard Deviation Original, AZ Slews [dBm]	Standard Deviation Refit, AZ Slews [dBm]	Refit/Original
Pol0 BB0	0.097	0.039	0.40	0.117	0.048	0.41
Pol0 BB1	0.067	0.033	0.49	0.129	0.039	0.30
Pol0 LSB	0.082	0.036	0.45	0.123	0.043	0.36
Pol0 BB2	0.096	0.044	0.46	0.182	0.052	0.29
Pol0 BB3	0.125	0.053	0.42	0.190	0.065	0.34
Pol0 USB	0.110	0.048	0.44	0.186	0.058	0.31
Pol1 BB0	0.034	0.018	0.53	0.117	0.041	0.35
Pol1 BB1	0.027	0.020	0.74	0.124	0.034	0.27
Pol1 LSB	0.030	0.019	0.64	0.120	0.037	0.31
Pol1 BB2	0.024	0.012	0.50	0.175	0.045	0.26
Pol1 BB3	0.032	0.013	0.41	0.187	0.056	0.30
Pol1 USB	0.028	0.012	0.45	0.181	0.050	0.28
Pol0/Pol1 LSB	2.71	1.93		1.02	1.16	
Pol0/Pol1 USB	3.93	3.87		1.03	1.16	
USB/LSB Pol0	1.35	1.34		1.52	1.35	
USB/LSB Pol1	0.93	0.67		1.50	1.35	

Table 5: BB Power Standard Deviations

	Peak-to-Peak Mean Value Original [dBm]	Peak-to-Peak Mean Value Refit [dBm]	Refit/Original	Peak-to-Peak Maximum Original [dBm]	Peak-to-Peak Maximum Refit [dBm]	Refit/Original
Pol0 BB0	0.27	0.14	0.53	0.43	0.18	0.41
Pol0 BB1	0.20	0.12	0.62	0.28	0.14	0.51
Pol0 LSB	0.23	0.13	0.57			
Pol0 BB2	0.27	0.15	0.55	0.50	0.17	0.33
Pol0 BB3	0.33	0.17	0.52	0.58	0.20	0.35
Pol0 USB	0.30	0.16	0.53			
Pol1 BB0	0.10	0.09	0.95	0.33	0.17	0.50
Pol1 BB1	0.08	0.09	1.11	0.21	0.21	1.01
Pol1 LSB	0.09	0.09	1.02			
Pol1 BB2	0.08	0.07	0.84	0.17	0.11	0.63
Pol1 BB3	0.10	0.07	0.68	0.21	0.08	0.37
Pol1 USB	0.09	0.07	0.75			

Table 6: BB Power Peak-to-Peak for AmbDips

	Peak-to-Peak Mean Value Original [dBm]	Peak-to-Peak Mean Value Refit [dBm]	Refit/Original	Peak-to-Peak Maximum Original [dBm]	Peak-to-Peak Maximum Refit [dBm]	Magnet/Original
Pol0 BB0	0.38	0.13	0.35	0.79	0.17	0.21
Pol0 BB1	0.27	0.11	0.40	0.43	0.15	0.34
Pol0 LSB	0.33	0.12	0.37			
Pol0 BB2	0.36	0.14	0.39	0.50	0.17	0.34
Pol0 BB3	0.47	0.17	0.37	0.67	0.20	0.29
Pol0 USB	0.41	0.16	0.38			
Pol1 BB0	0.09	0.05	0.51	0.20	0.09	0.45
Pol1 BB1	0.10	0.04	0.39	0.23	0.08	0.35
Pol1 LSB	0.10	0.04	0.45			
Pol1 BB2	0.12	0.04	0.36	0.25	0.07	0.29
Pol1 BB3	0.13	0.05	0.39	0.24	0.08	0.36
Pol1 USB	0.13	0.05	0.37			

Table 7 – BB Power Peak-to-Peak for AZ Slews

5.6 Sample Plots

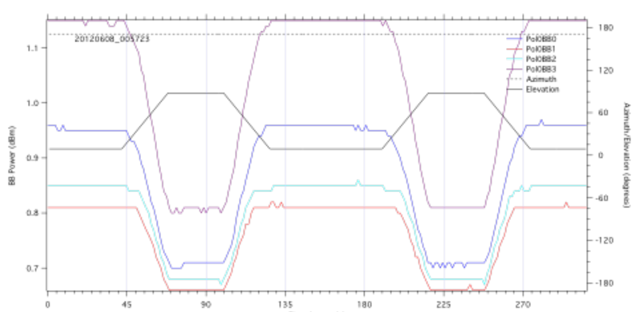


Figure A1. Typical baseband power plot in Pol0 for AmbDips in the original cartridge. The black solid trace/dotted trace is the elevation/azimuth slew profile as a function of time. Date/time stamp is at upper left. The elevation dependence in the power is evident.

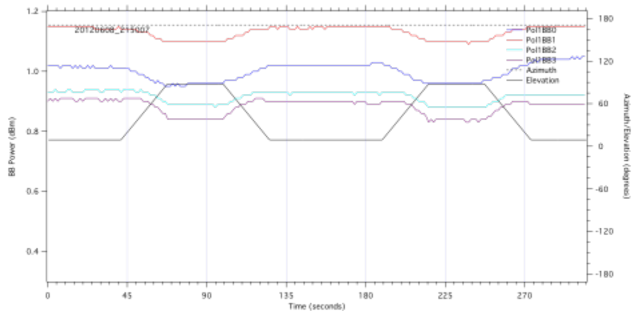


Figure A2. Baseband power plot in Pol1 for an AmbDip in the original cartridge observed 20 hours after Figure A1. Note that the elevation dependence of the power appears to have changed sign.

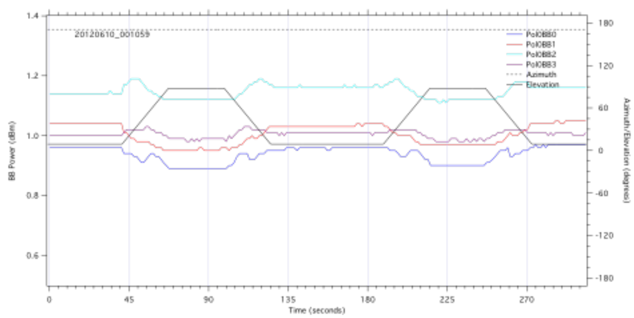


Figure A3. Baseband power plot in Pol0 for an AmbDip in the original cartridge. Note that the elevation dependence of the power is now more complex, with both positive and negative dependences on elevation in different elevation ranges.

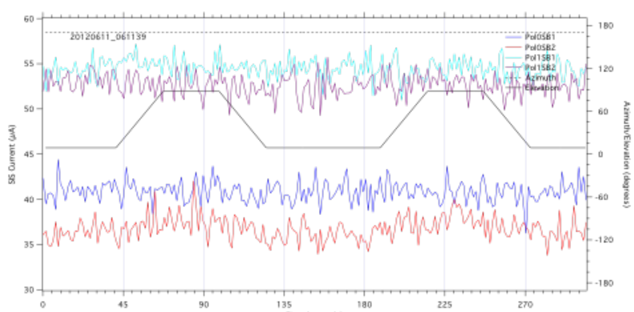


Figure A4. SIS current plot for an AmbDip in the original cartridge. Note that, unusually, there is a small but definite correlation of Pol0SB2 current with elevation.

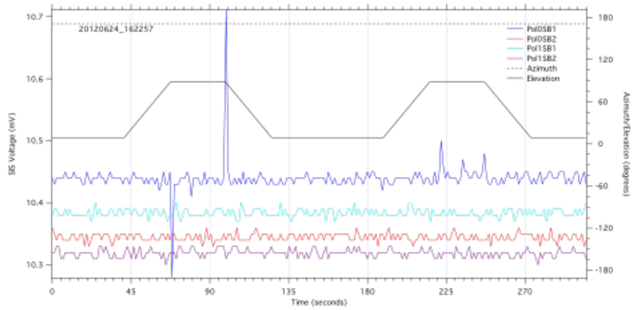


Figure A5-a. SIS voltage plot for an AmbDip in the original cartridge. Note that, unusually, there are spikes (two large, two small) in Pol0SB1. See Figure A5-b and A5-c for the behaviour of the current and power for this observation.

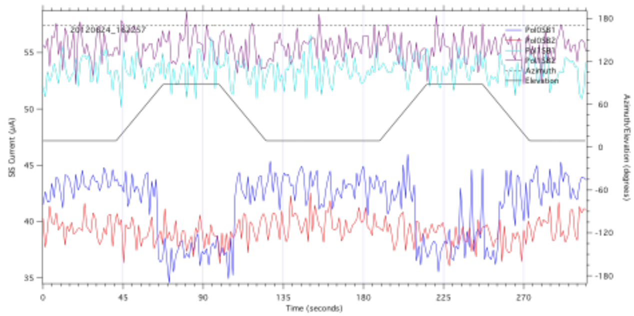


Figure A5-b. SIS current plot for the AmbDip in Figure A5-a. The current in Pol0SB1 drops just before the first voltage spike and recovers just after the second spike. A similar pattern is repeated when the second pair of voltage spikes occurs.

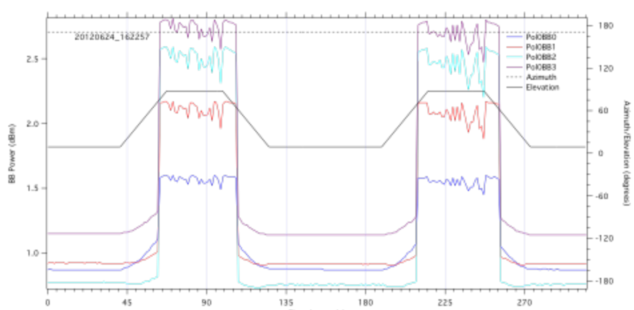


Figure A5-c. Baseband power plot in Pol0 for the AmbDip in Figure A5-a. This profile is very unusual.

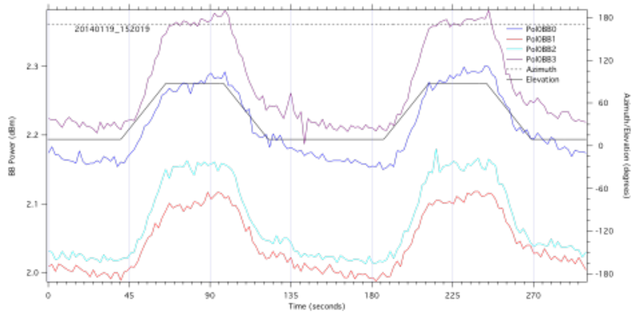


Figure A6-a. Baseband power plot in Pol0 for a typical AmbDip with the refit cartridge.

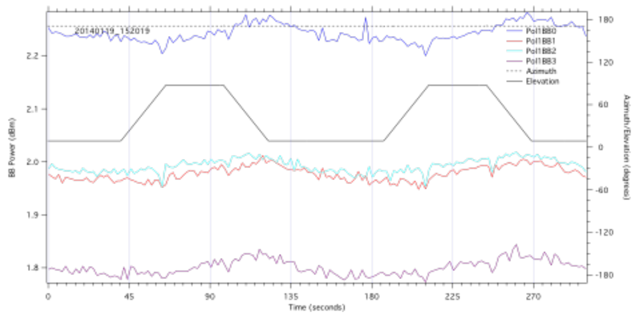


Figure A6-b. Baseband power plot in Pol1 for a typical AmbDip with the refit cartridge.

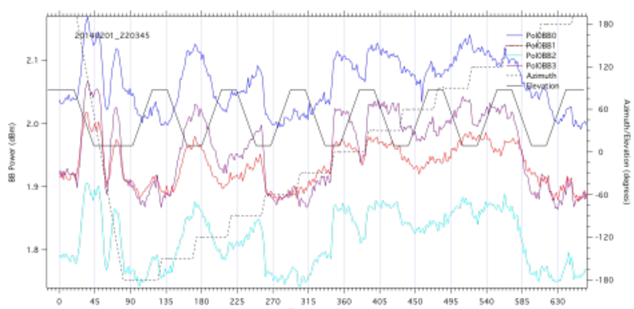


Figure A7-a. Baseband power plot in Pol0 for a combined AZ/EL slew with the refit cartridge. Note that the power curves are much more irregular than for standard AmbDips or AZ Slews, but is repeatable.

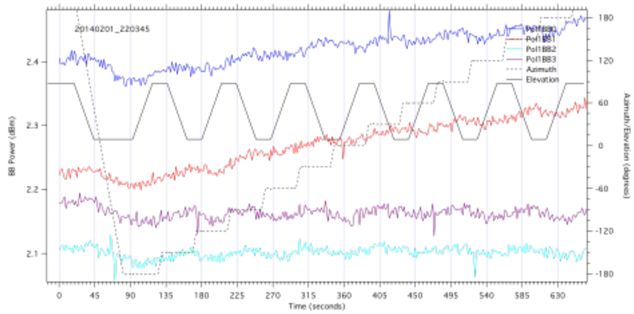


Figure A7-b. Baseband power plot in Pol1 for the same combined AZ/EL slew with the refit cartridge as in Figure A7-a. Note the drift in the two LSB Pol1 basebands.

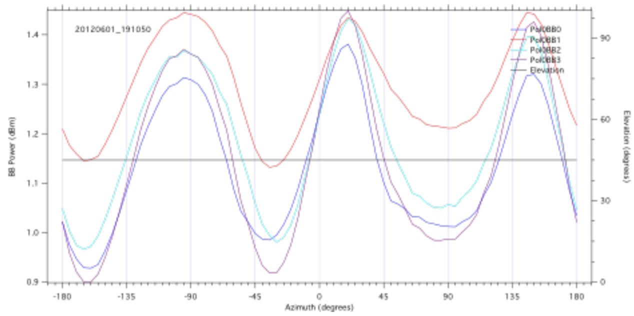


Figure A8-a. Baseband power plot in Pol0 for an AZ Slew in the original cartridge. The periodicity is roughly 120 degrees in azimuth.

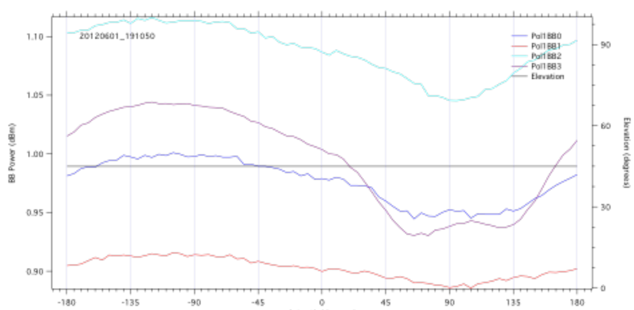


Figure A8-b. Baseband power plot in Pol1 for an AZ Slew in the original cartridge (same observation as Figure A8-a). The behaviour is different from Pol0.

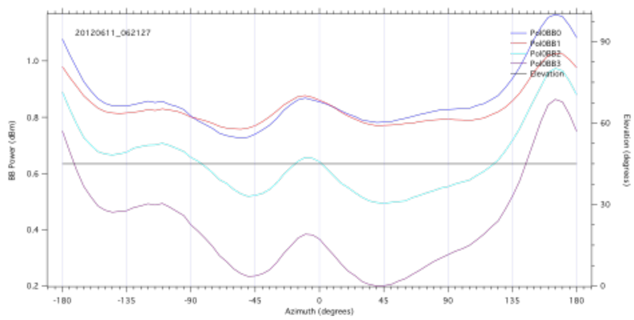


Figure A9-a. Baseband power plot in Pol0 for an AZ Slew in the original cartridge.

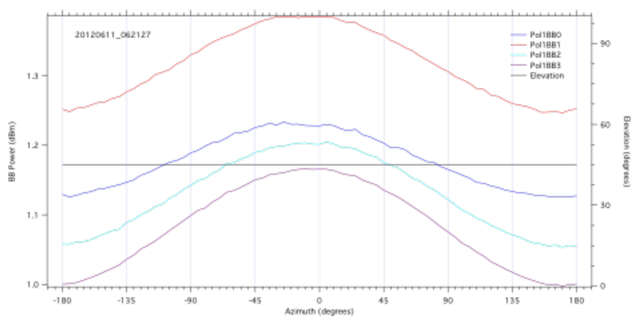


Figure A9-b. Baseband power plot in Pol1 for an AZ Slew in the original cartridge (same observation as Figure A9-a. In this observation there is a strong correlation with the direction of the Earth's magnetic field (field direction in the horizontal plane is AZ ~ -5 degrees).

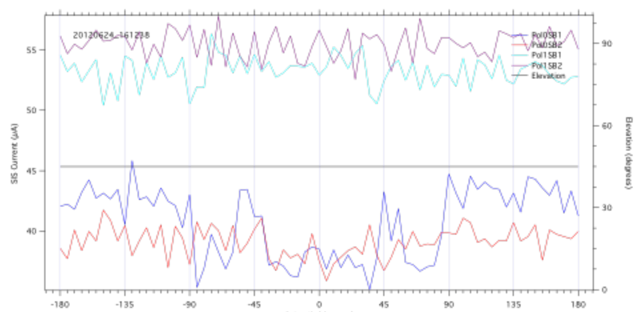


Figure A10-a. SIS current for an AZ Slew in the original cartridge (taken on the same date as the AmbDip of Figure A5). Similar to the AmbDip, the current in Pol0SB1 drops for an extended period of time (from about AZ = -90 to +90).

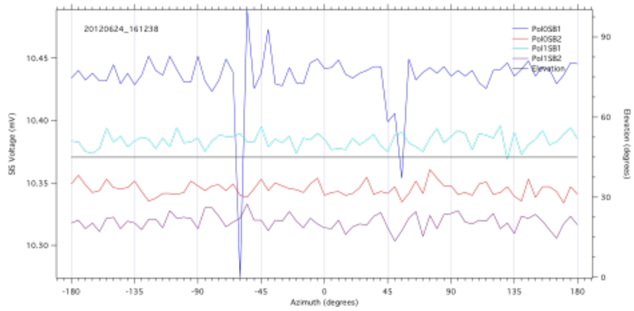


Figure A10-b. SIS voltages in the original cartridge (same observation as Figure A10-a). The voltage spikes just after the current dropped and spike again just before the current recovers.

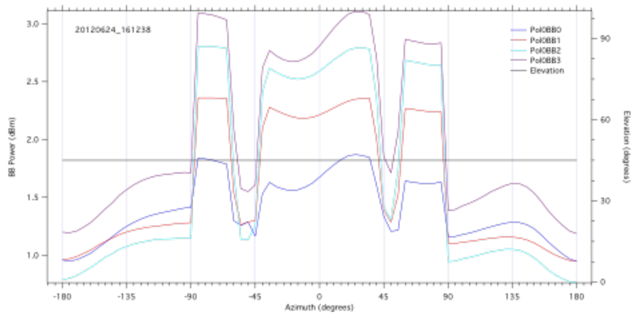


Figure A10-c. Baseband powers in Pol0 for the same observation as Figure A10-a. There are power jumps correlated with both the voltage spikes and the current drops.

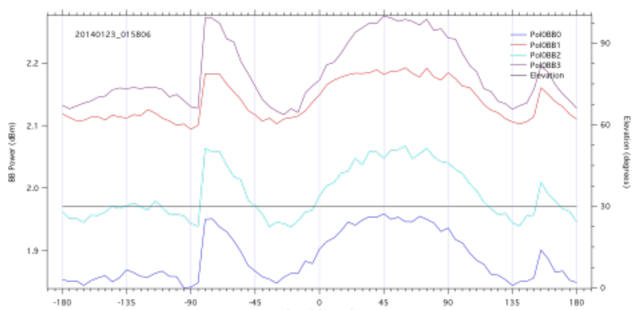


Figure A11-a. Baseband powers in Pol0 for an AZ Slew in the refit cartridge. Note the abrupt jump around AZ = -80. There appears to be a weaker jump ~ 240 degrees later.

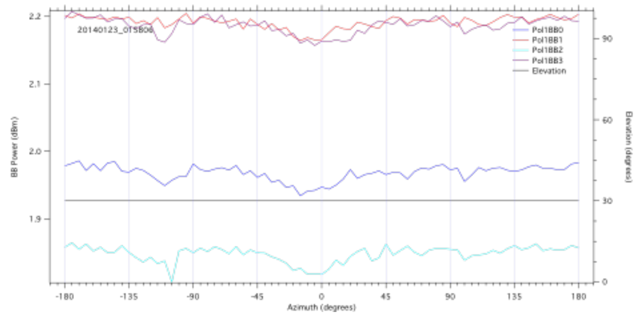


Figure A11-b. Baseband powers in Pol1 for the same AZ Slew as Figure A11-a.

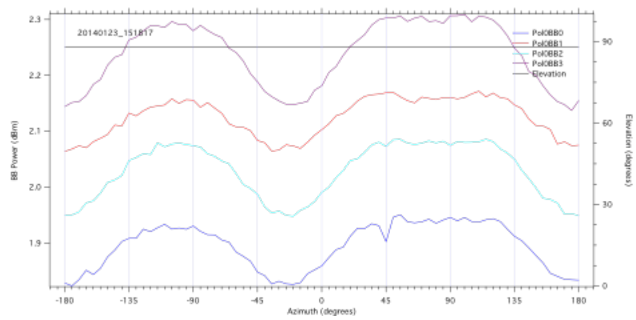


Figure A12-a. Baseband powers in Pol0 for an AZ Slew at EL = 88 in the refit cartridge.

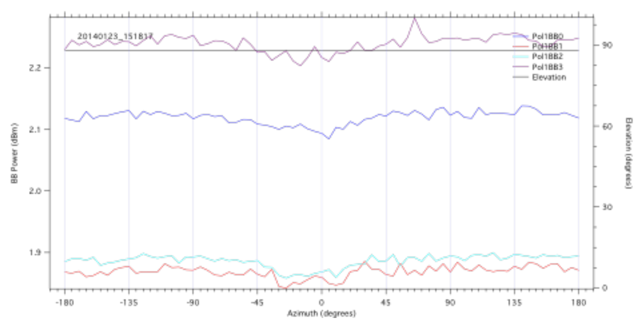


Figure A12-b. Baseband powers in Pol1 for the same observation as Figure A12-a.

5.7 Supplementary Measurements

In order to extend the time monitoring of the cartridge stability (with magnets) after the end of the main monitoring campaign, 6 additional AmbDips and 5 AZ Slews were performed between 20140226 and 20140304. This extended the measurements by 31 days past the end of the main test campaign, and provided a check on the long term stability. Table A1 summarizes these measurements. Figures A13 to A20 are updated versions of the baseband power peak-to-peak and standard deviation plots. Inspection of these plots confirms that the cartridge remained stable over that month.

Date Stamp	Time Stamp	Observation	Ticket	Notes
20140226	172040	AmbDip 25	FENCR-611	After “mini-warmup” (short term power failure)
20140227	073623	AmbDip 26	FENCR-611	
20140228	090959	AmbDip 27	FENCR-611	
20140303	034823	AmbDip 28	FENCR-611	
20140304	052909	AmbDip 29	FENCR-611	
20140305	101904	AmbDip 30	None	
20140226	173132	AZSlew 43	FENCR-611	After “mini-warmup” (short term power failure)
20140227	074719	AZSlew 44	FENCR-611	
20140228	093246	AZSlew 45	FENCR-611	
20140303	041203	AZSlew 46	FENCR-611	
20140304	054633	AZSlew 47	FENCR-611	

Table A1: Supplementary Measurements

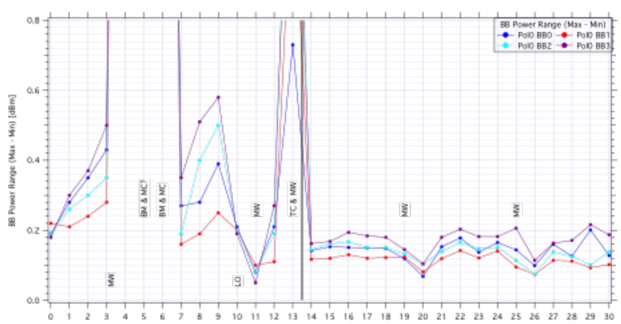


Figure A13. Baseband power peak-to-peak range in Pol0 for AmbDips. Markings and labels as in Figure 1.

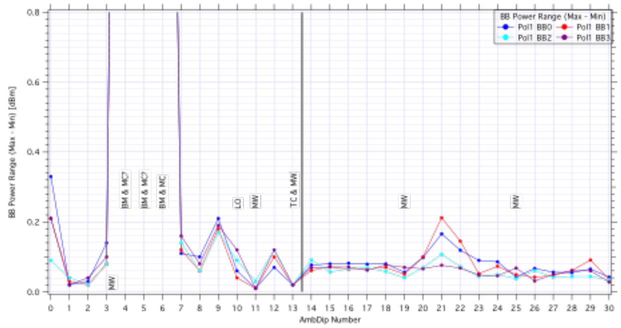


Figure A14. Baseband power peak-to-peak range in Pol1 for AmbDips. Markings and labels as in Figure 1.

6 Options for Bias Box Modification

This section describes how to enable the heater circuitry in Band 3 cartridges without re-designing the ESD cards. It also discusses the issues surrounding the different options for deflux.

6.1 Introduction

In May 2015 the NRC presented to ALMA a possible solution to deflux Band 3 mixers. This approach was to power up heaters using magnet circuits (without using the conventional heater circuits). This approach was discussed extensively by NRC, ALMA, and NRAO representatives during their telecon of 6 July 2015. A number of issues arose from the magnet circuit proposal:

1. Heater control by means of the magnet circuits, while technically simple, may have an impact on existing software safety features, specifically the automatic cutoff of heater current in the case of loss of software control.
2. This solution would require Band 3-specific software and operational modifications and was considered by JAO to be problematic from this point of view.

It was agreed that NRC would continue to explore and test other possible solutions keeping in mind the above issues. One possible approach is to modify the ESD cards in order to control the heater current through the heater lines. Such an approach would dispense with the issues mentioned above, but raises concerns of its own:

1. This solution would require re-design of the ESD cards. This would be a costly solution. Apart from the (unknown) cost of re-design, manufacturing alone costs CAD$600 for a pair of ESD cards (2 cards per cartridge), and the cost of testing a pair of ESD cards is the equivalent of 2 hours of labour.
2. Each cartridge would have to be dis-assembled and re-assembled with the new ESD cards installed. This is costly in terms of labour and presents technical risk to the cartridge (as described in more detail below). NRC estimated dis-assembly of the cartridge to require about 7.5 hours and re-assembly 30 hours.

3. Following re-assembly, the cartridge must undergo RF testing at 4 K, which would require 22.5 hours of test time. For logistical and cost reasons, steps 2 and 3 would have to be done at ALMA by JAO staff.

The main technical risks to the cartridge identified by NRC stemming from the requirement to dis-assemble and re-assemble at ALMA are:

1. The risk of introducing a mismatch and/or gain slope change at the IF outputs.
2. The risk of causing misalignment of the feed horn
3. The general risk of damage to components, wiring, cables, feed-throughs, etc, through the dis-assembly/re-assembly procedure.

JAO had suggested that it might be possible to remove and install ESD cards without having to perform a complete dis-assembly/re-assembly of the cold cartridge. NRC review of their experiment in one cartridge suggests a very significant risk of not maintaining the proper torque values on screws and SMA connectors, which could lead to damage and/or decreased performance of the cartridge. NRC does not recommend partial dis-assembly of Band 3 cartridges and advocates avoiding complete dis-assembly if at all possible. In addition, the particular cartridge used in their experiment was an early cartridge in which there was an accidental rotation of the 300 K fibreglass cylinder with respect to the cartridge body relative to all other cartridges. This error made it easier to access the waveguide flange screws, ESD mounting screws, and SMA connectors only in that cartridge, an access that would be far more difficult or impossible in all other Band 3 cartridges using torque tools.

Here we present alternate approaches for using the bias box heater circuits instead of the magnet circuits. This approach has the advantage of not requiring software changes and does not compromise safety. NRC considers that the modified bias boxes (envisioned in one option discussed below) could be used without risk to or requiring changes in the control of cartridges in other bands (noting, however, that Band 3 cartridges would require the modified boxes in order for heating to work for them). The second option would not require bias box changes. These two options were:

1. Modify the bias box to re-route the heater circuit lines to unused lines in the Band 3 cartridges. Pol0 and Pol1 heater circuits would both become functional.

2. Install jumper wires on the Pol0 ESD card in-situ through the window on the 300 K fiberglass cylinder. Only the Pol0 ESD card is accessible. This jumper will re-route the Pol0 heater circuit lines from the bias box to unused lines in the Band 3 cartridges. Only the Pol0 circuit will be functional in this option.

6.2 <u>Modify Bias Box</u>

This approach uses both the heater power supplies and jumpering over to the spare traces that are connected (but unused) in both the ESD boards. In this case the modification is done on the output connectors P1 of both of the bias supply boards in the Band 3 bias box.

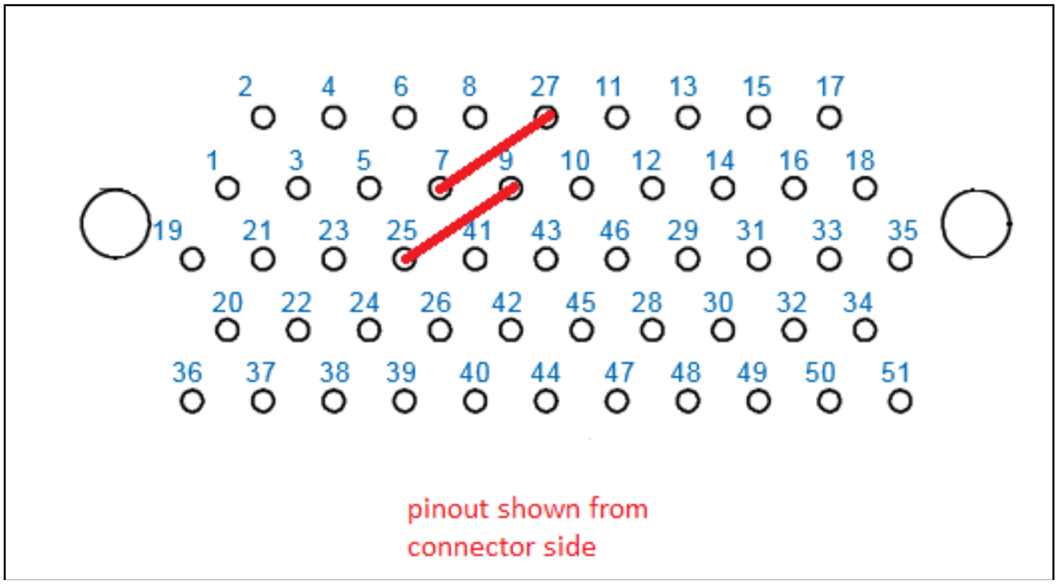


Figure 1: Pinout of bias card

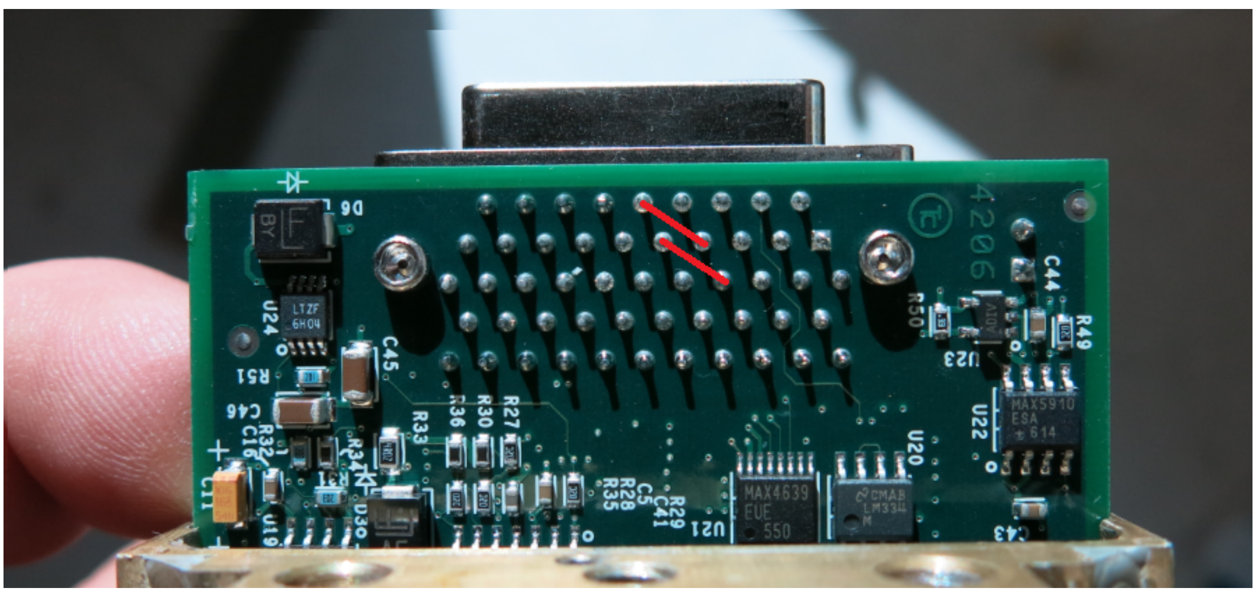


Figure 2: Solder side of bias card (modification is shown by red lines)

VHTR- P1-7 and VHTR+ P1-25 are used and jumpered at P1, 9-25 and P1, 7-27 and using spare traces on the ESD card J1 9, 27 to J2 1, 14 and the new wires in two of the new pigtails GN-YL. Some dis-assembly of the bias box is required but two short traces per heater can be added to the PCB at connectors P1 (Pol0, Pol1). The connector is numbered such that these are adjacent pins. The new traces are soldered to the exposed through-hole pins, creating a reliable rework. Putting two 56 ohm resistors in series in each pigtail we can dissipate 2.25 W per heater. Note that the available power from each heater is 2.4 W, and the difference is dissipated on the 300 K to 4 K wiring harness (Tek-data cable). The heaters are controlled separately for each polarization.

6.3 Modify Pol0 ESD Card

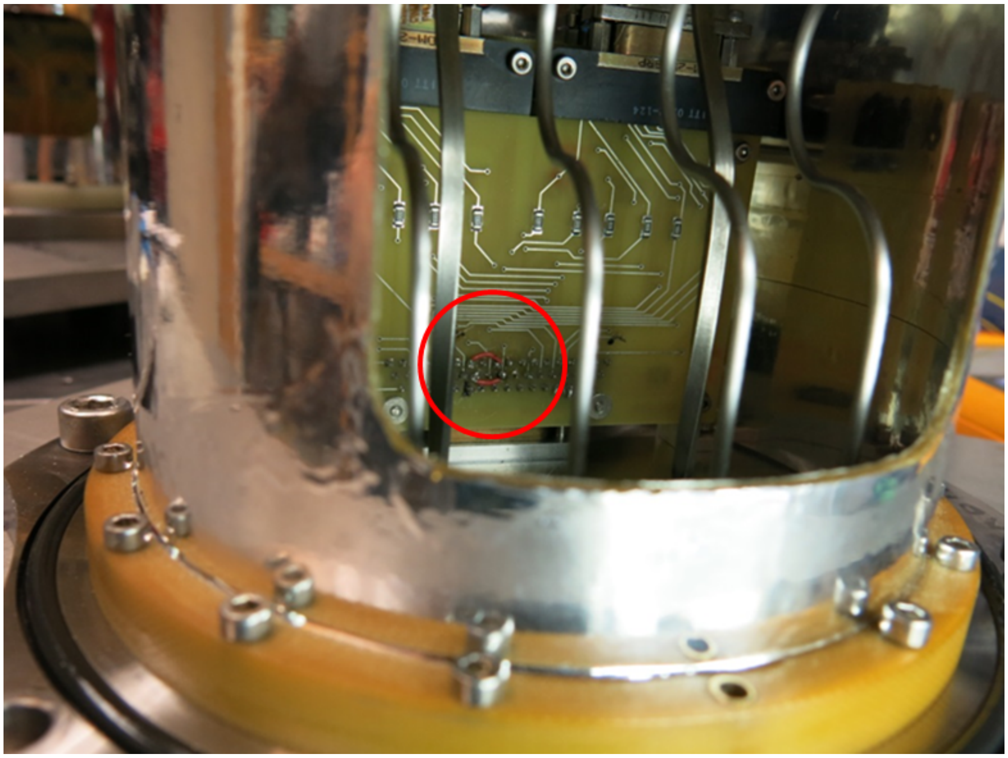


Figure 3: Jumper wires on Pol0 ESD card

This option uses the Pol0 heater power supply and jumpering over to spare traces that are connected but unused in the outer (Pol0) ESD board. The modification is internal to the Band 3 cartridge (vacuum side). Without removing the ESD boards from the CCA, we can get to one J1 connector, and it's just possible using a long thin soldering iron and tweezers to add two short jumper wires (circled in red in Figure 3). VHTR- J1-7, VHTR+ J1-25 are used and using spare traces on the ESD card J1 1, 19 or J1 9, 27 to J2, J3 1 -14 and the new wires in one of the new pigtails GN-YL. Then putting four 28 ohm resistors in series we can dissipate 1.1 W per heater.

6.4 Improvements

The improvements due to deflux are summarized below:

1. Mixer current imbalance around the mixer bias point improves (two closely matched mixers are a must for best sideband separation).

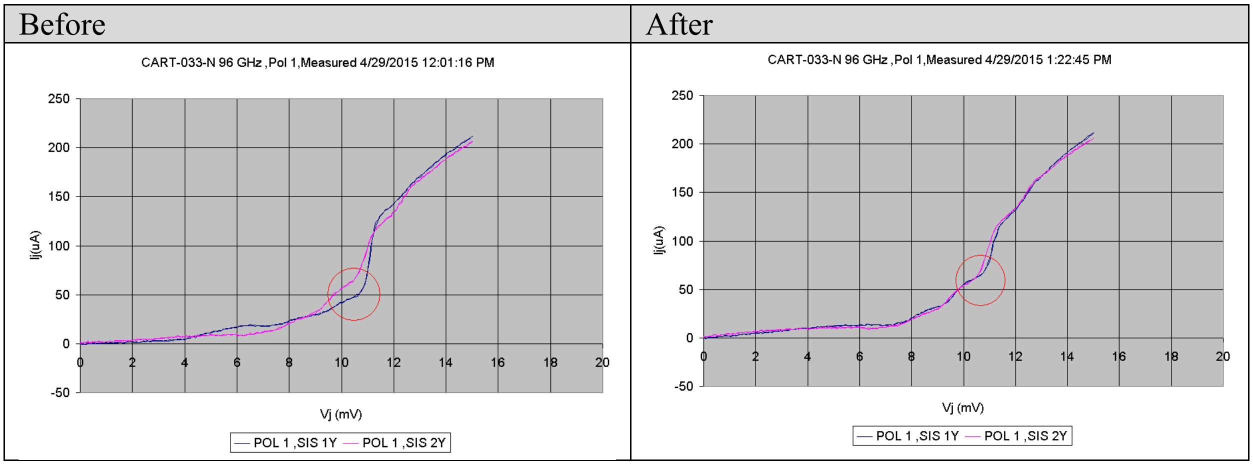


Figure 4: Current imbalance around bias point improvement

2. Removal of hysteresis.

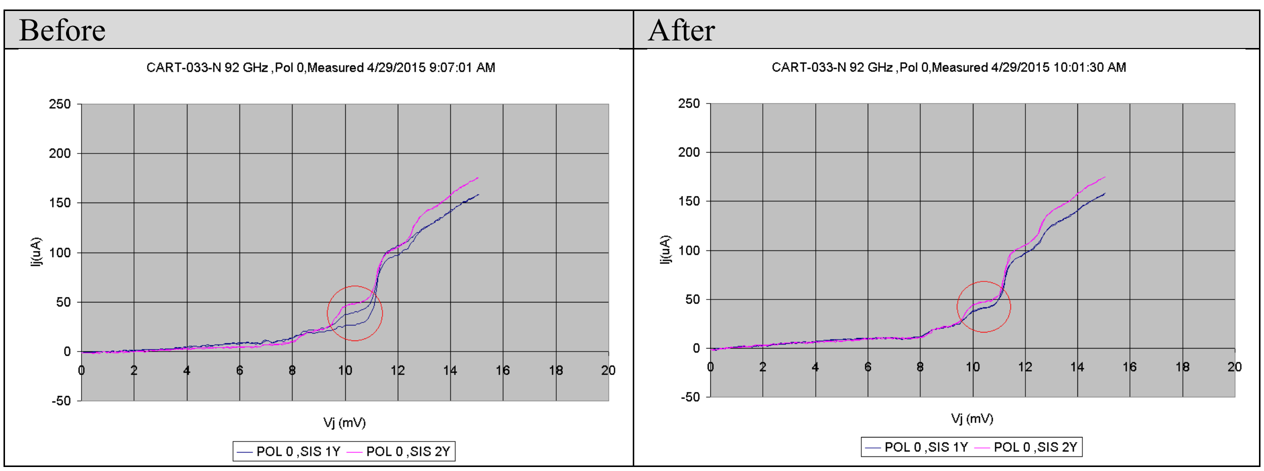


Figure 5: Hysteresis disappearance

3. Flat (zero slope) or negative slope photon step improves (a photon step with positive slope is expected).

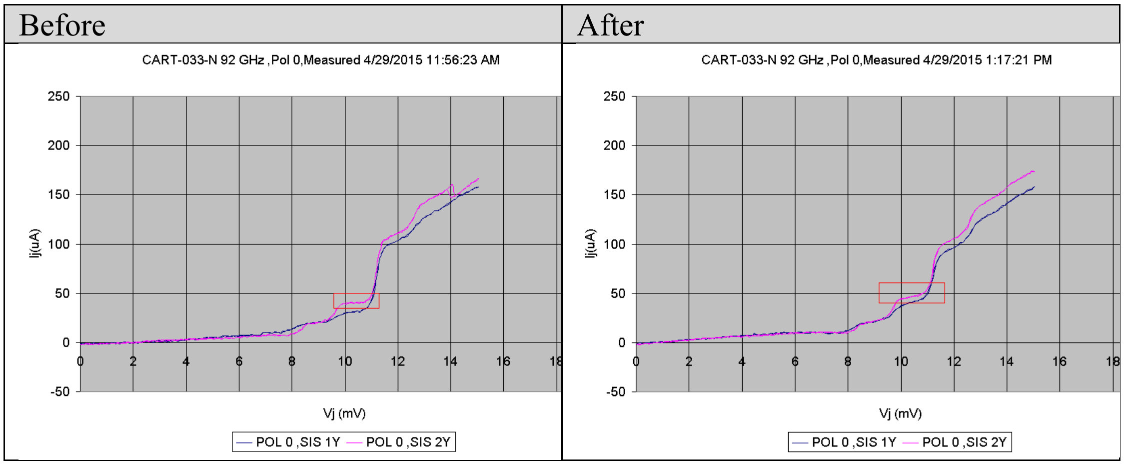


Figure 6: Flat photon step becomes positive

6.5 Experiments

Three different experiments were conducted. They were:

1. CCA3-999 (our prototype cartridge) with Pol0 heater only – modify ESD card approach.
2. CCA3-999 with Pol0 and Pol1 heaters – modify bias box approach.
3. CCA3-33 with Pol0 and Pol1 heaters – modify bias box approach.

6.6 CCA3-999 with Pol0 Heater Only

In this experiment, CCA3-999 was fitted with four 28 ohm resistors in series – one resistor per each mixer block. The available power from the Pol0 heater circuit (24 V x 0.2 A = 4.8 W, ignoring loss in cables) is split among the four mixers, thus each mixer receiving 1.2 W. The resistors are mounted onto the mixer block as shown in Figure 7.

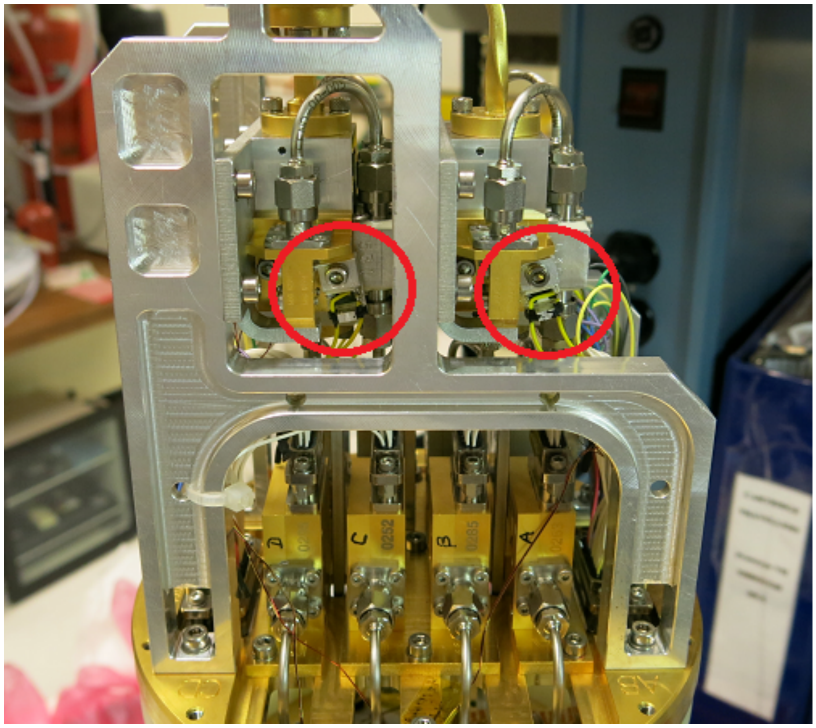


Figure 7: Heater blocks mounted onto the mixer blocks.

The NRC CTS1 control software was modified to deliver 120 pulses, each with a pulse width of 1000 ms on – 50 ms off. The total heat time was just over 2 minutes. The following table summarizes the results of this experiment. In this table the improvements and degradations are listed. Three tests were carried out and in each test ten (5 LO x 4 mixers) IV curves were compared (see Table 1). The numbers in red indicates the number of IV curves that did not improve substantially by the deflux.

Table 3 Summary of CCA3-999 testing with Pol0 heater only

Test	Impairments	Improvements	Degradations
1	Wide current imbalance at bias point	6	0
	Hysteresis	4	1
	Flat (zero slope) or negative slope photon step	0	0
2	Wide current imbalance at bias point	5	1
	Hysteresis	7	2
	Flat (zero slope) or negative slope photon step	0	0

6.7 CCA3-999 with Pol0 And Pol1 Heaters

In this experiment, the CCA3-999 Pol0 and Pol1 heaters are alive. Each heater circuit powers up two 56 ohm resistor in series – one resistor per each mixer block. The available power from each heater circuit (24 V x 0.2 A = 4.8 W, ignoring loss in cables) is split among the two mixers, thus each mixer receiving 2.4 W. The resistors are mounted onto the mixer block as shown in Figure 7. The CTS1 control software was modified to deliver 120 pulses, each with a pulse width of 1000 ms on – 50 ms off. The total heat time was just over 2 minutes. Table 2 summarizes the results of this experiment.

Table 4 Summary of CCA3-999 testing with Pol0 and Pol1 heaters

Test	Description	Improvements	Degradations
1	Wide current imbalance at bias point	0	0
	Hysteresis	6	2
	Flat (zero slope) or negative slope photon step	0	0
2	Wide current imbalance at bias point	0	0
	Hysteresis	6	2
	Flat (zero slope) or negative slope photon step	0	0
3	Wide current imbalance at bias point	5	0
	Hysteresis	0	1
	Flat (zero slope) or negative slope photon step	0	0
4	Wide current imbalance at bias point	1	0
	Hysteresis	5	0
	Flat (zero slope) or negative slope photon step	0	0

6.8 <u>CCA3-33 with Pol0 And Pol1 Heaters</u>

In this experiment, the CCA3-33 Pol0 and Pol1 heaters are alive. The resistors are mounted onto the mixer block as shown in Figure 7. The CTS1 control software was modified to deliver 120 pulses, each with a pulse width of 1000 ms on – 50 ms off. The total heat time was just over 2 minutes. During this time, the mixer temperature sensor (mounted on the back of the mixer plate) reached 14 - 15K. The results are summarized in Table 3.

Table 3 Summary of CCA3-33 testing

Test	Description	Improvements	Degradations
1	Wide current imbalance at bias point	1	0
	Hysteresis	5	0
	Flat (zero slope) or negative slope photon step	1	0
2	Wide current imbalance at bias point	2	0
	Hysteresis	1	0
	Flat (zero slope) or negative slope photon step	0	0

6.9 Summary

We have presented two options for mixer deflux using the Band 3 cartridge heater circuitry. They are:

1. Modify the bias box – allows each polarization's mixers to be defluxed at the maximum available power of 4.8 W (24 V x 0.2 A per circuit) per polarization (2.4 W per mixer, ignoring the heat loss in cables).

2. Modify the Pol0 ESD card – allows each polarization's mixers to be defluxed at half the available power (1.2 W per mixer).

Our recommendation was to modify bias box thus harnessing the full available heater power. Note that this would require that modified bias boxes only would have to be used with Band 3 cartridges. However, assuming that the additional pins are not used in the cartridges in the other ALMA bands, modified bias boxes could be used safely in other bands.

7 Procedure for Upgrading Cartridge

Here the procedure for retrofitting the mixer block deflux heater circuit into the Band 3 cold cartridge is described in detail. To operate the heaters a modified bias box must be used, and the procedure for modifying the bias box is also described. Note that an un-modified bias box will work with a retrofitted Band 3 cartridge but the deflux heating system will not function.

7.1 Parts

The heater circuitry is rated 24V/200mA per polarization. Given the Tek-Data ribbon cable loss at 4K is 4.1 ohm each way, two 220 ohm (at 4 K) resistors in parallel will maximize the power drawn.

1. 4 K wiring harnesses (Pigtails)
   A new pigtail, as per FEND-08-005 Rev R04, was ordered from Glenair Inc. This new pigtail has some additional wires brought out from the MDM connector (4K plate end) that were not present in the earlier version. These extra wires are for heaters and magnets (circled in black), but only heater wires will be used.

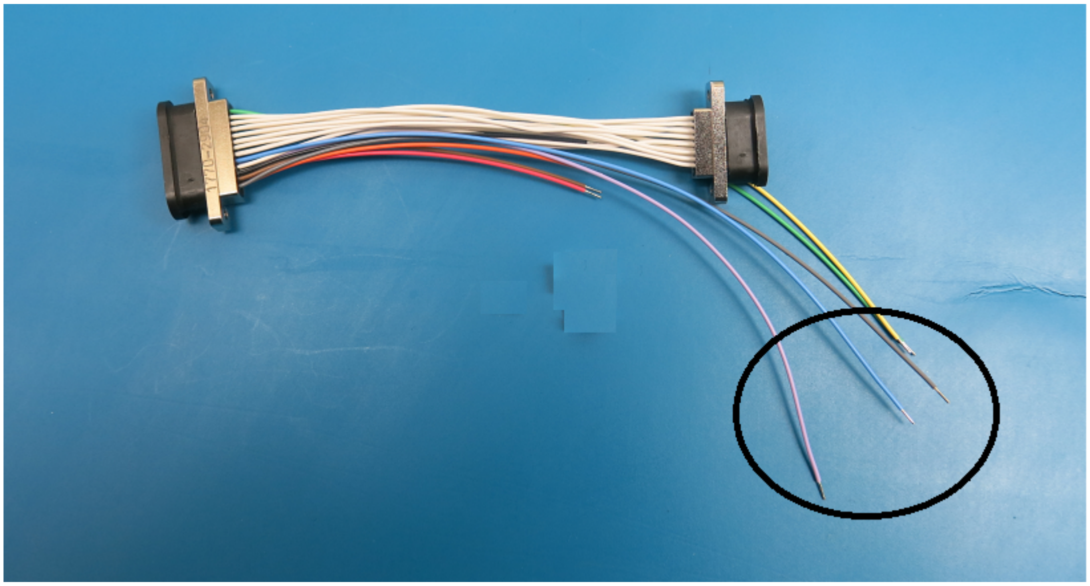


Figure 21: New Pigtail

2. Resistors
   210 ohm flange mount type resistors from ATC Ceramics. Part number is FR10302N0210GBK. Our experiments show that a 210 ohm resistor (rated at room temperature) will measure approx. 220 ohm at 4 K.

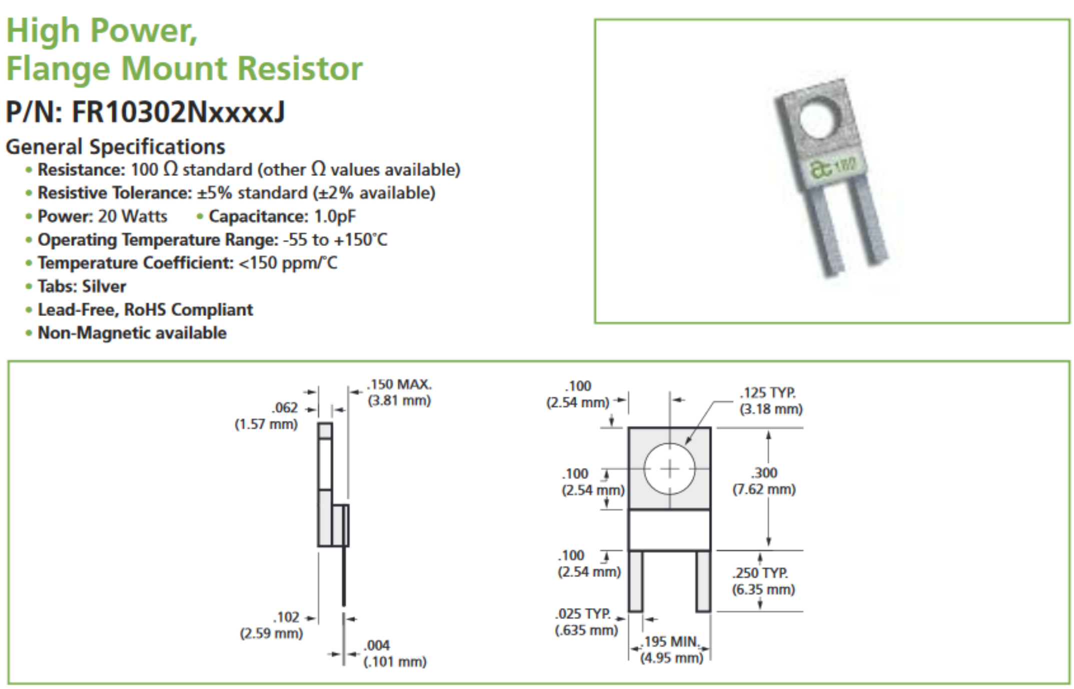


Figure 22: Flange mount resistor

3. #4-40 Captive screws
   These are not the standard waveguide screws, but a modified version of the same. A standard screw's shaft length is 7.3 mm, and the thread length is 3.2 mm. Compare these to the modified screws' dimensions of 10.0 mm and 2.5 mm respectively. See Figure 23.

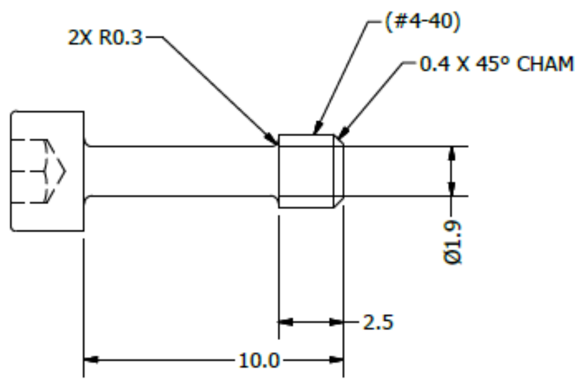


Figure 23: #4-40 captive screw (modified)

7.2 Kit

For each cartridge the following items are included in the kit:

1. Pigtail (pol 0) with heaters attached (Figure 24)	x 1
2. Pigtail (pol 1) with heaters attached (Figure 24)	x 1
3. #4-40 screws (modified) and washers	x 4
4. Zip ties	x 4
5. Heat shrink tubes, 8mm long	x 6

Note: Pol 0 and 1 pigtails are NOT identical. Pol 1 pigtail's yellow/green wires are bit longer than those of Pol 0 (to facilitate easy assembly given Pol 1 mixers are harder to reach).

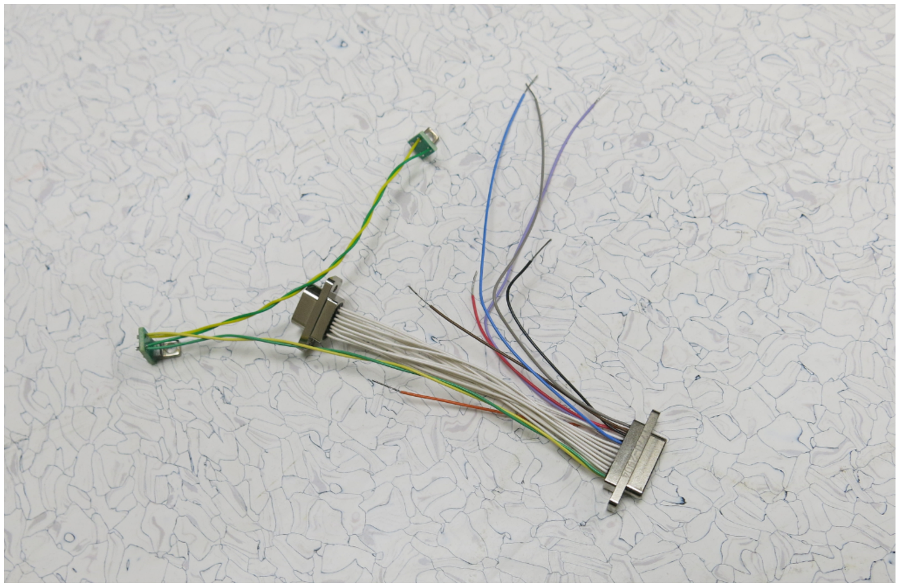


Figure 24: Pigtail with resistors soldered (per pol)

7.3 Resistors

There are two 2SB assemblies (Pol 0 and Pol 1) in a cartridge, and each 2SB assembly consists of two mixers. Therefore, four resistors are needed per cartridge. The bias box has two heating circuitries, one for each polarization. The two resistors (per pol) are connected in parallel as in Figure 25.

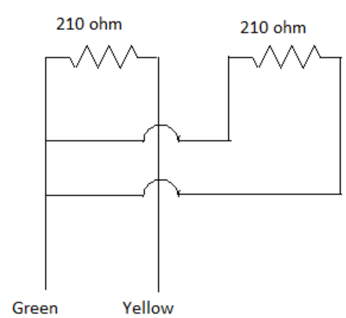


Figure 25: Resistor Wiring Scheme (per pol)

The yellow and green wires of pigtail B are used for Pol 0 heaters. Likewise, the yellow and green wires of pigtail D are used for Pol1 heaters.

7.4 Mixer – RF Hybrid Assembly

The RF hybrid and Mixer both have #4-40 threads which poses a challenge when attaching or removing a #4-40 fastener from the assembly. There is a pocket at the interface which is free of any threads. When removing a #4-40 fastener, the threads on the fastener disengages from the RF hybrid first, enters the 'pocket', and then re-engages the threads on the mixer, before coming off completely.

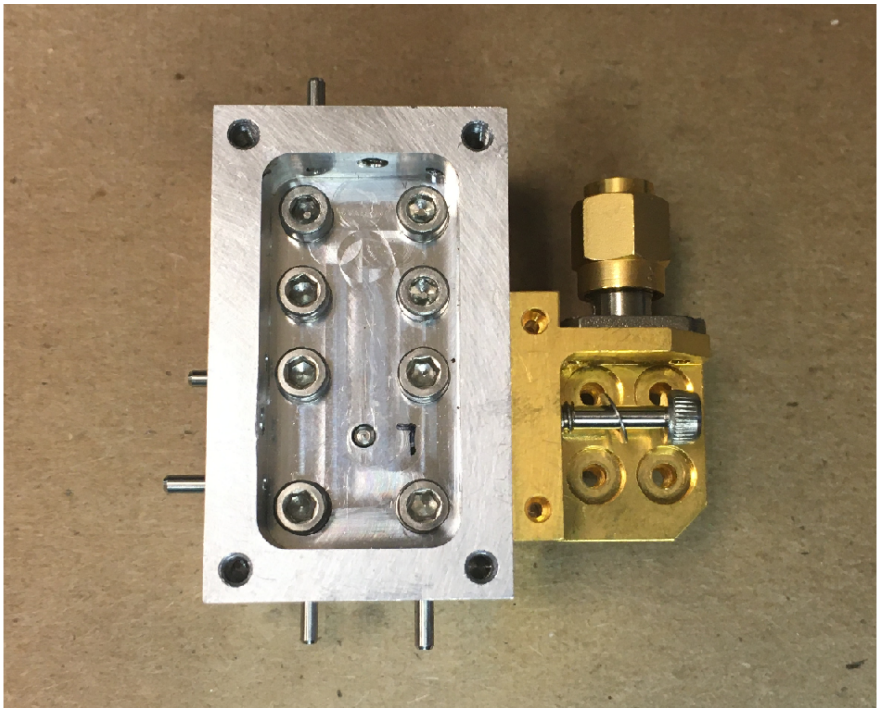


Figure 26: RF Hybrid (left) – Mixer (right)

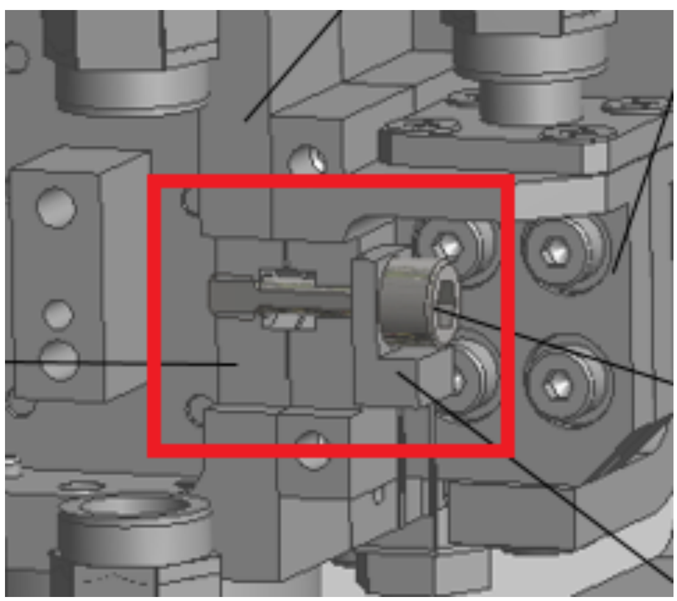


Figure 27: Mixer – RF Hybrid Interface Close-up View

When removing the fastener care should be taken to not to strip threads on the mixer.

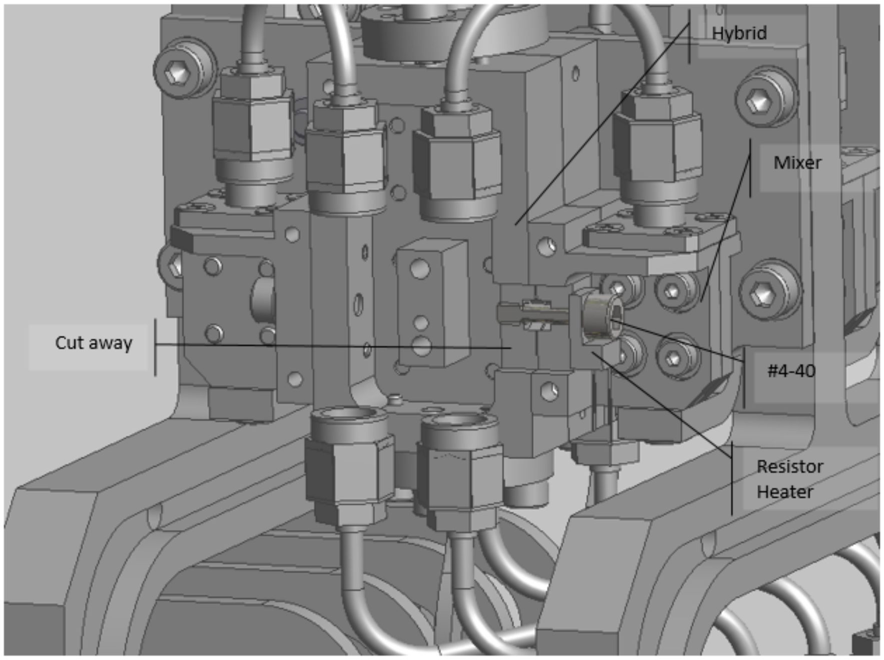


Figure 28: Mixer – RF Hybrid Cross Sectional View

7.5 ESD

Please take appropriate ESD prevention measures before attempting this retrofit.

7.6 Tools Needed

1. Torque wrench with 3/32 hex driver bit. This is for removing #4-40 fasteners. Torque used 78 N cm (110 oz-in). Find a suitable one with this value in the middle of its range (eg: 40 ~ 120 N cm)
2. Torque wrench with 5/64 hex driver bit. This is for removing fasteners on the MDM connectors (LNA and 4 K plate ends). Torque used 8 N cm. Find a suitable one with this value in the middle of its range (eg: 0 ~ 30 N cm)
3. Soldering iron
4. Zip ties (blue)
5. Tweezers

7.7 ESD Precautions

Warning: Take necessary ESD precautions before attempting the following steps (Foot straps or ESD shoes and wrist straps)

7.8 Remove Pigtails

1. We shall replace pigtails B & D only (B & D are used for heaters).

2. Pigtail B:

De-solder the lakeshore temperature sensor of 4 K plate from pigtail B. <u>Do not remove the 4 K sensor from the 4 K plate</u>. Undo pigtail's MDM connectors from their sockets, and gently remove the pigtail from the cartridge. Save this pigtail as a 'spare' for pigtail A.

3. Pigtail D:
   De-solder the lakeshore temperature sensors of 15 K, and 90 K plates from pigtail D. <u>Do not remove the sensors from their respective plates</u>. Undo pigtail's MDM connectors from their sockets, and gently remove the pigtail from the cartridge. Save this pigtail as a 'spare' for pigtail C.

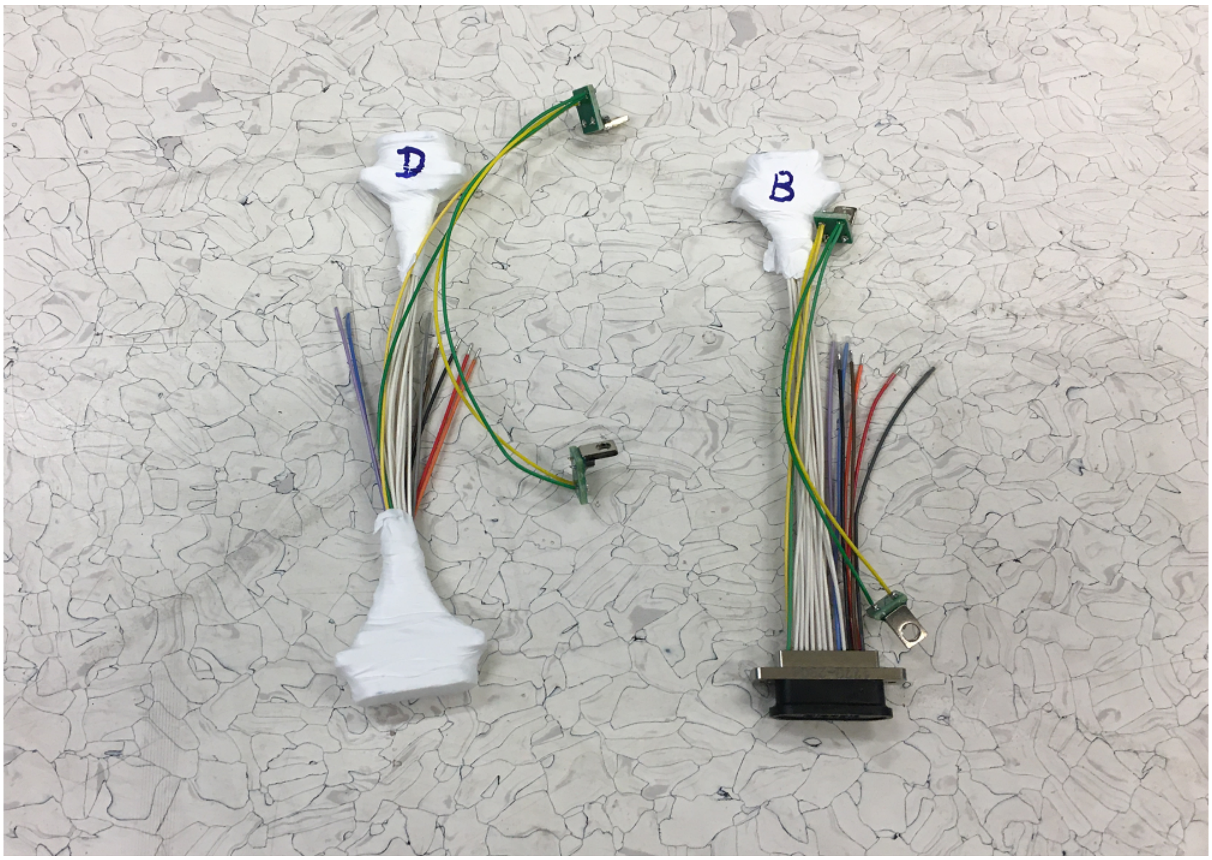


Figure 29: Pigtail B and D

7.9 Install New Pigtails

Warning: Excessive torque can strip threads. Use recommended torque only

Install two new pigtails in positions B and D. Seat the MDM connector on the 4 K plate end first followed by the LNA end. Fasten the screws. Use the following torque:

LNA end:
Use 8 N cm torque when tightening the #2-56 fasteners. If you cannot get a torque wrench in comfortably, then a 'finger tight' is sufficient.

4 K plate end:
Use 8 N cm torque when tightening the #2-56 fasteners. If you cannot get a torque wrench in comfortably, then a 'finger tight' is sufficient.

7.10 Attach Heaters to Mixer Blocks – Pol0

Warning: Excessive torque can strip threads. Use recommended torque only

The mixer block is made of very soft 1100 Aluminum. Therefore, proper torque must be used when attaching resistors to the mixer block. The recommended torque is 110 oz-in. As said before, this material is very soft and the thread will strip very easily if over torqued.

1. Set the torque driver to 110 oz-in (78 N cm).
2. Remove one #4-40 screw from the left mixer (discard or save the screw for your lab use).
3. Attach the left resistor to the mixer block using the #4-40 screw in the kit (remember that this screw is a bit longer). Do not forget to include a Bellville washer for each mixer. Avoid the dowel pin (shown by red arrow in Figure 31) by angling the resistor. When angling, try to keep the contact area as large as possible (the larger the contact area, the faster the heat transfer is).

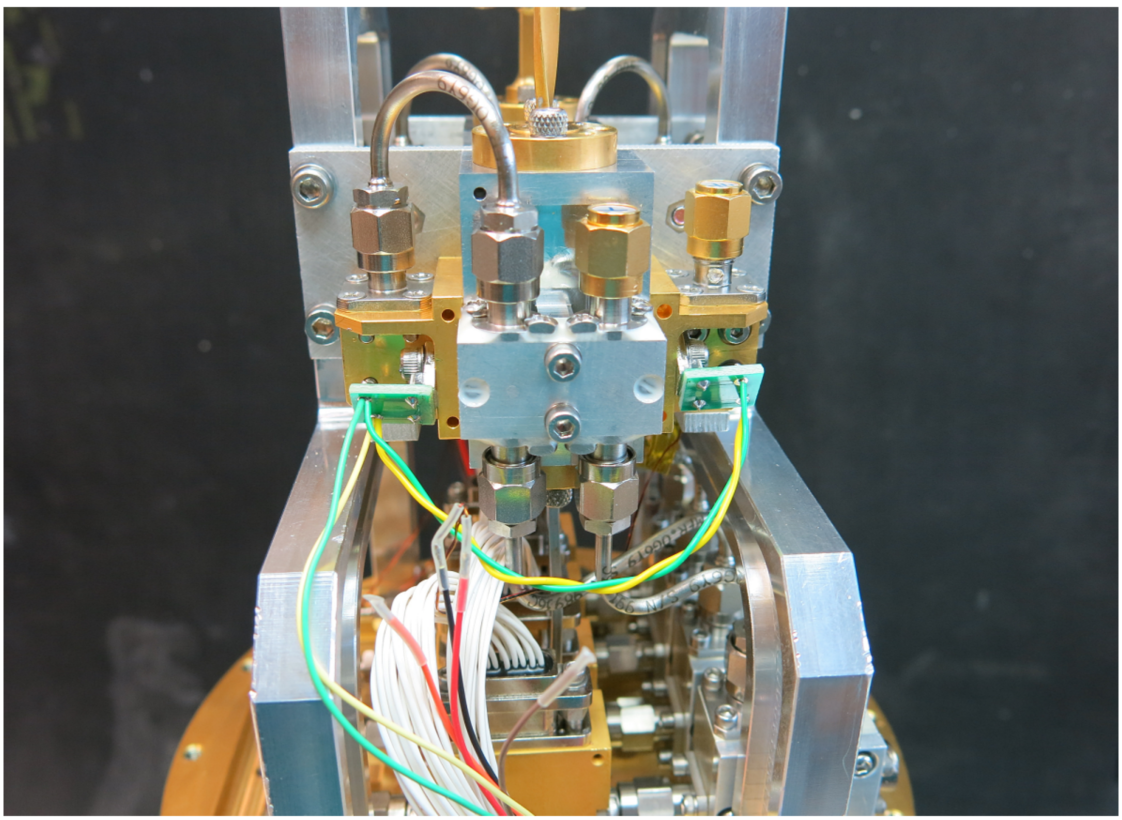


Figure 30: Resistors on Pol0 2SB

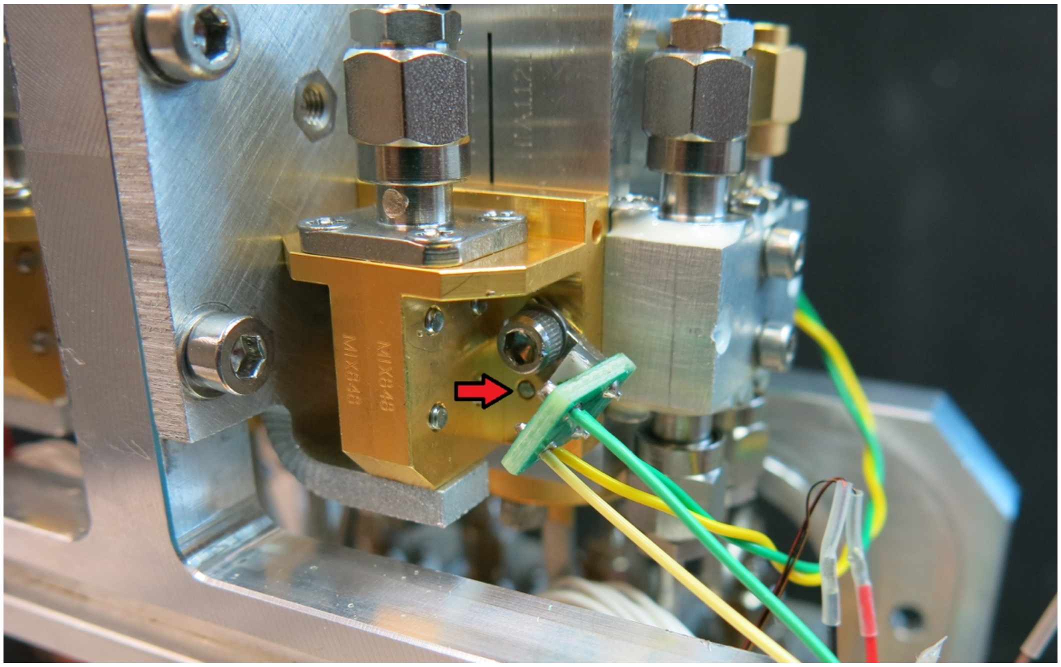


Figure 31: Left Resistor on Pol0 2SB (note the dowel pin)

4. Tighten the #4-40 to 110 oz-in.
5. Remove one #4-40 screw from the right mixer (discard or save the screw for your lab use).
6. Attach the right resistor to the mixer block using the #4-40 screw in the. Do not forget to include a Bellville washer. Avoid the dowel pin as before.
7. Tighten the #4-40 to 110 oz-in.

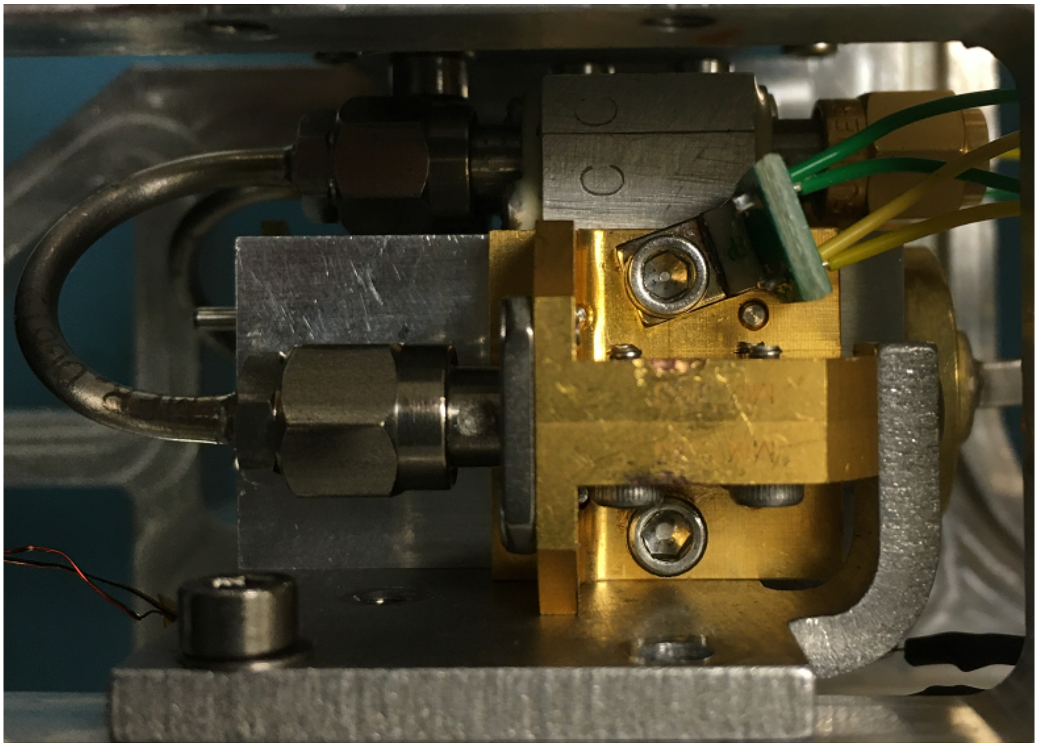


Figure 32: Correctly installed Resistor (for max heat transfer)

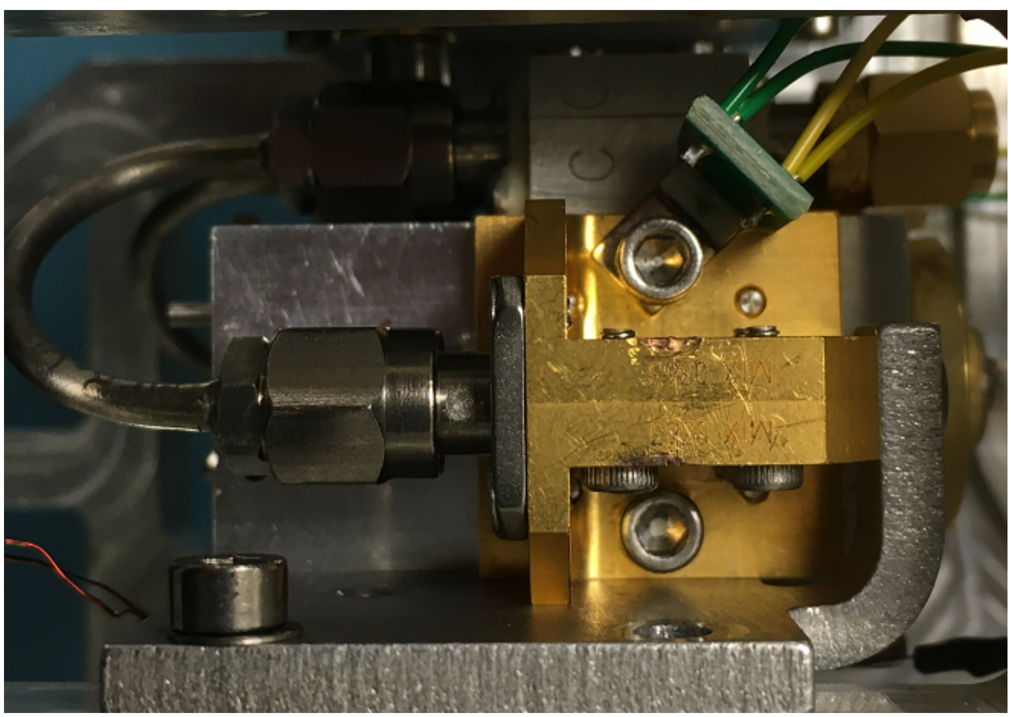


Figure 33: Incorrectly installed Resistor (heat transfer is not optimal)

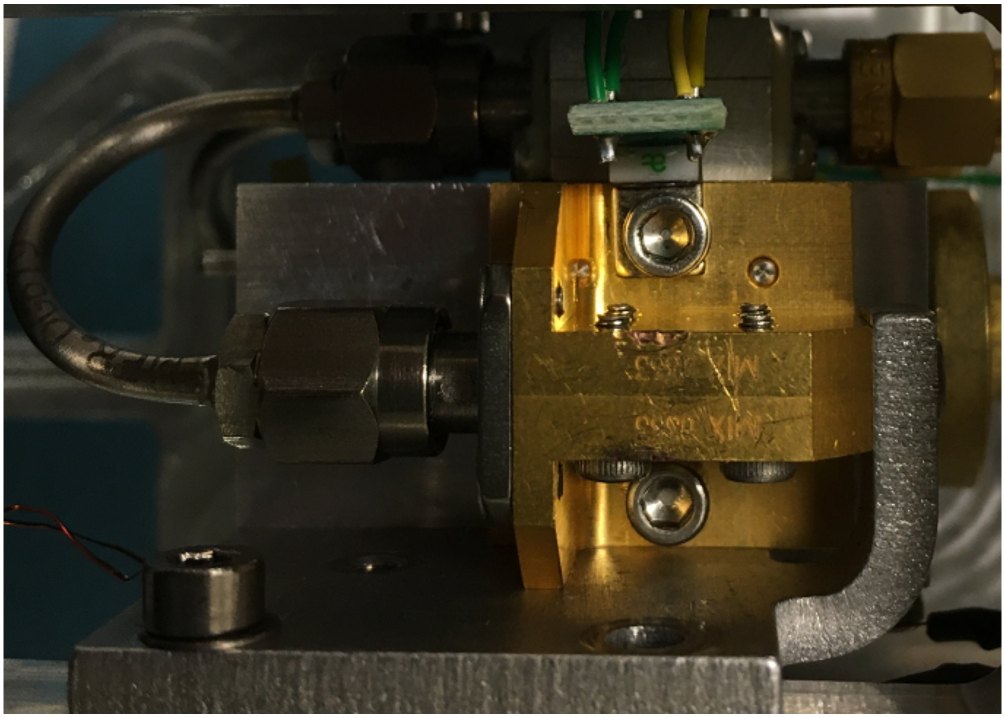


Figure 34: Incorrectly installed Resistor (heat transfer is not optimal)

7.11 Attach Heaters to Mixer Blocks – Pol1

Warning: Excessive torque can strip threads. Use recommended torque only

1. Attaching resistors is more difficult for this polarization.
2. Repeat the same steps as in Pol 0.

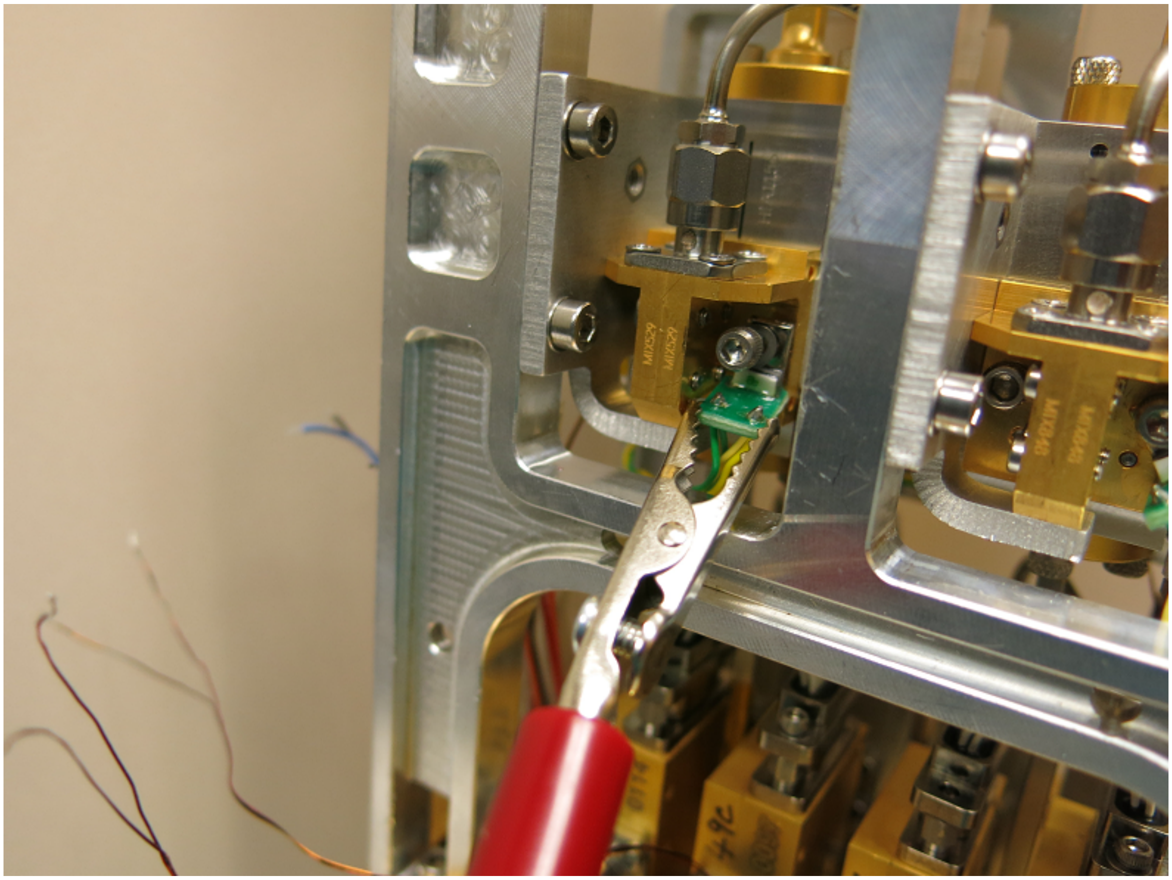


Figure 35: Jig to hold resistor

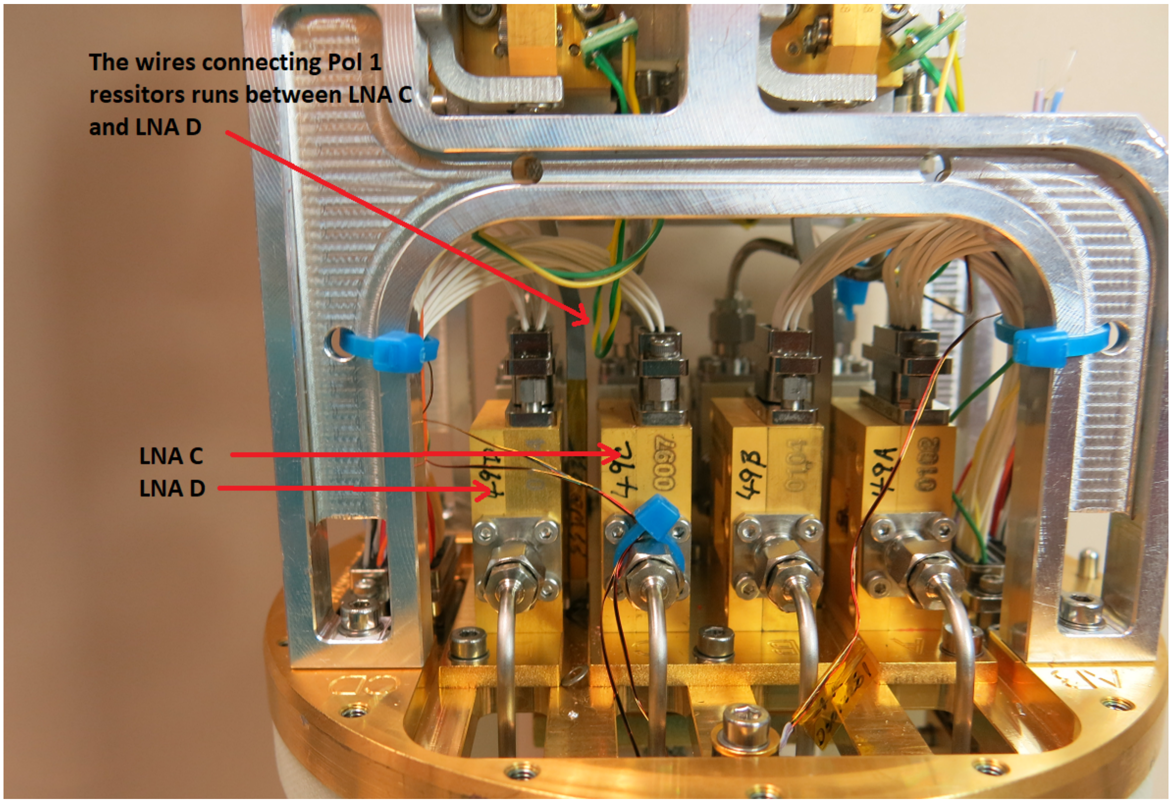


Figure 36: Proper routing of Pol 1 resistors

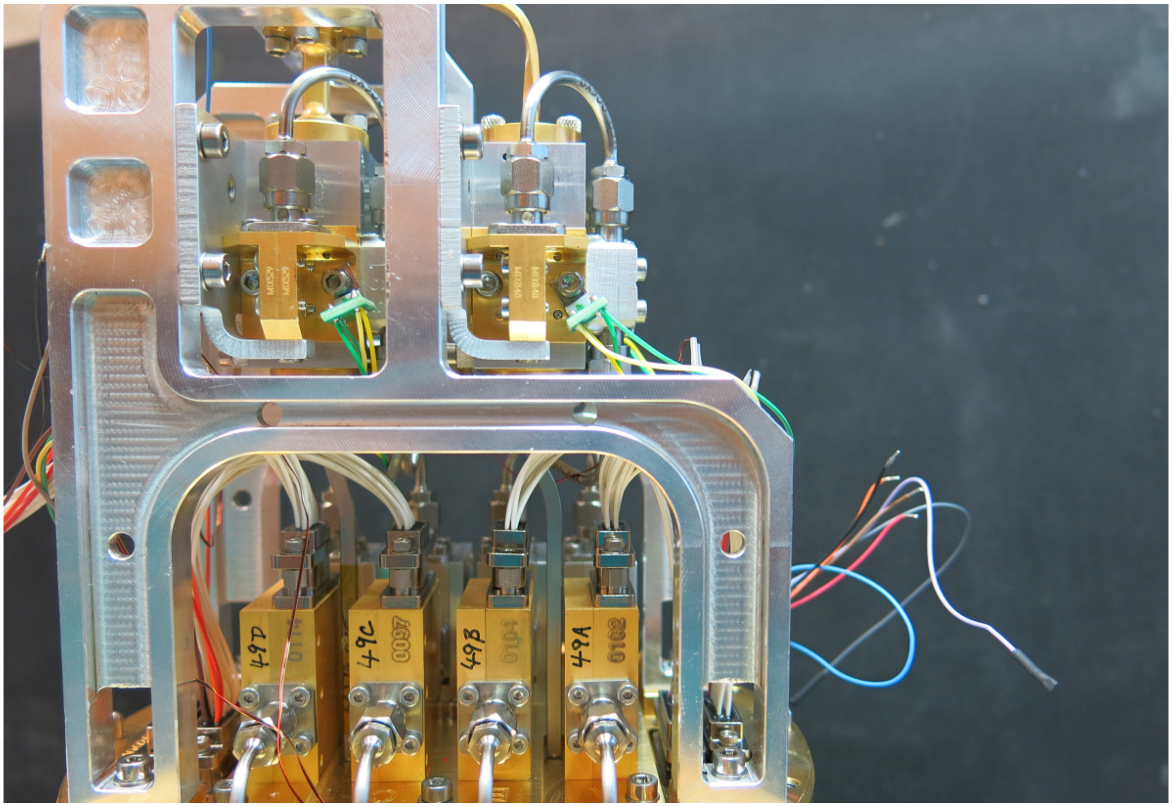


Figure 37: Left side (LNA end) Resistors on Pol0 and Pol 1

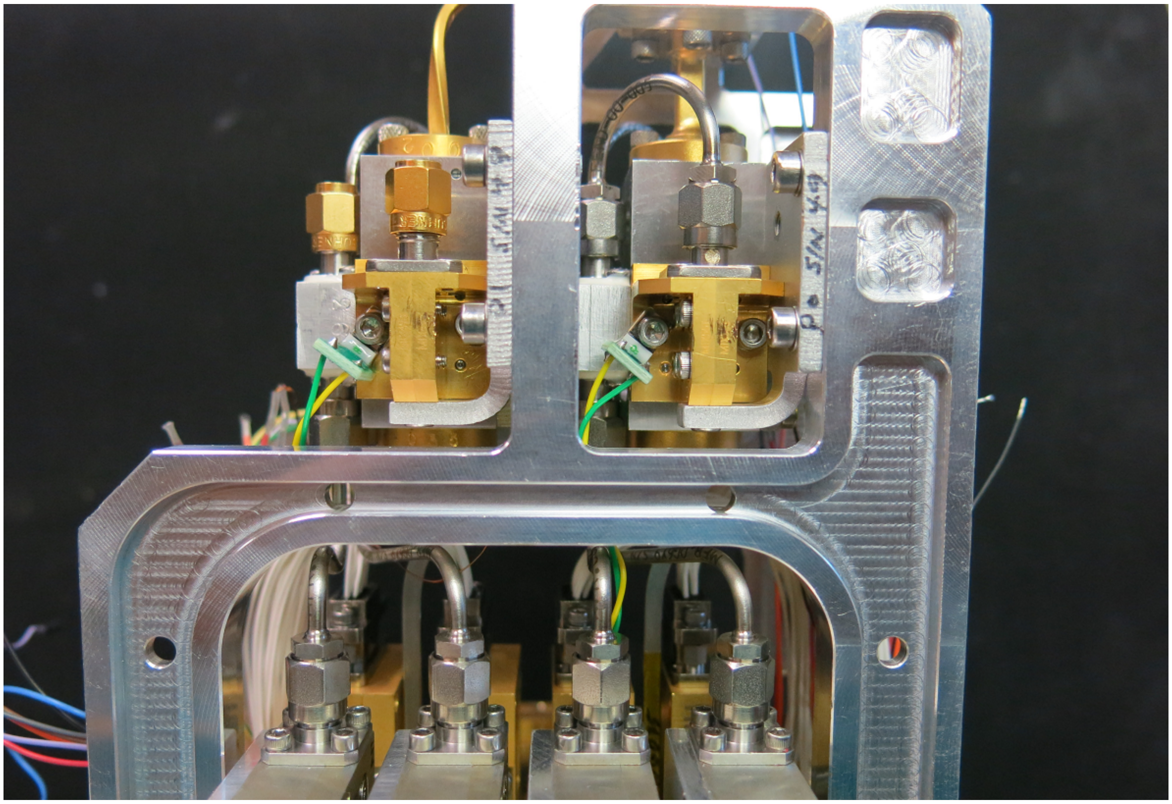


Figure 38: Right side (isolator end) Resistors on Pol0 and Pol 1

7.12 Attach Temperature Sensors to New Pigtails

Solder back the removed 4 K sensor to the new pigtail B. Please note the polarity when soldering the wires back (use Table 5 for guidance).

Wire harness	Sensor end	Pigtail end	Sensor location
A	Gold/black	Red	Pol0 Mixer
	Red/green	Black	
B	Gold/black	Orange	4K plate
	Red/green	Brown	
C	Gold/black	Red	Pol1 Mixer
	Red/green	Black	
D	Gold/black	Red	15K plate
	Red/green	Black	
	Gold/black	Orange	90K plate
	Red/green	Brown	

Table 5

Solder back the removed 15 K and 90 K sensors to the new pigtail D. Please note the polarity when soldering the wires back (use Table 5 for guidance).

7.13 <u>Tie the Wires and Clean Up</u>

Install the supplied heat shrinks over unused/exposed wires. Tie the wires of each pigtail to the left side structure using the provided blue zip ties as shown in Figure 39. Make sure wires are contained well within the 4 K plate footprint.

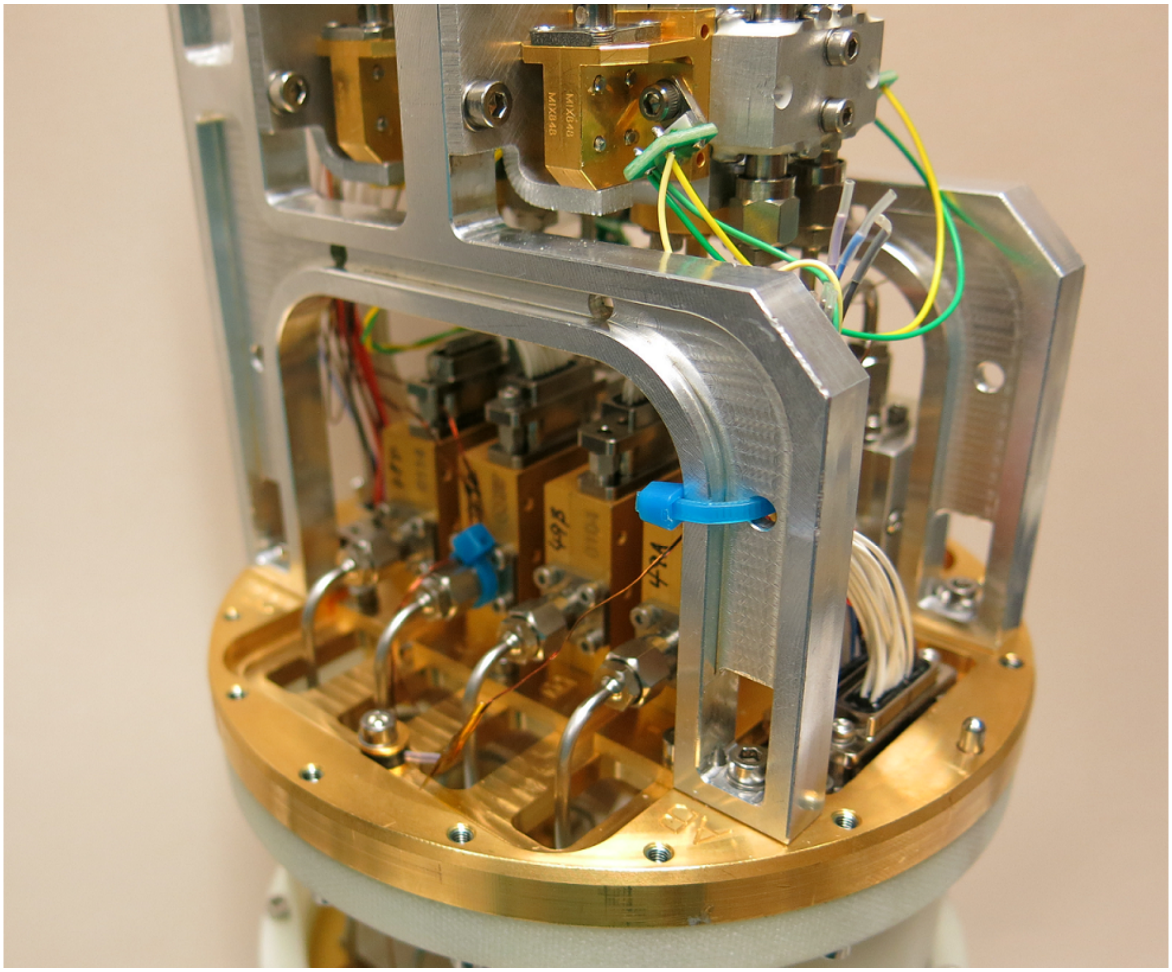


Figure 39: Tie the wires

Clean up the cartridge to remove any debris (solder drops, dropped washers, etc.) that may have accumulated during assembly. Use pressurized air for this. If you have touched any of the cartridge parts or surfaces with bare hands, use alcohol to wipe off any grease/finger prints left behind. Note: The heater assembly will not disturb the feedhorn assembly, and therefore, a feedhorn alignment check is unnecessary.

7.14 Testing

Warning: Take necessary ESD precautions before attempting the following steps (Foot straps or ESD shoes and wrist straps)

The installed resistors should be tested using a multi-meter before cooling the cartridge. The resistance should measure 112 ~ 114 ohm.

Please note that the nominal resistance is 113 ohm as calculated below:

Lead resistance from 4K MDM to 300K MDM	= 4 ohm
Two 210 ohms in parallel	= 105 ohm
Lead resistance from 300K MDM to 4K MDM	= 4 ohm
Total (nominal)	= 4 + 105+ 4 = 113 ohm

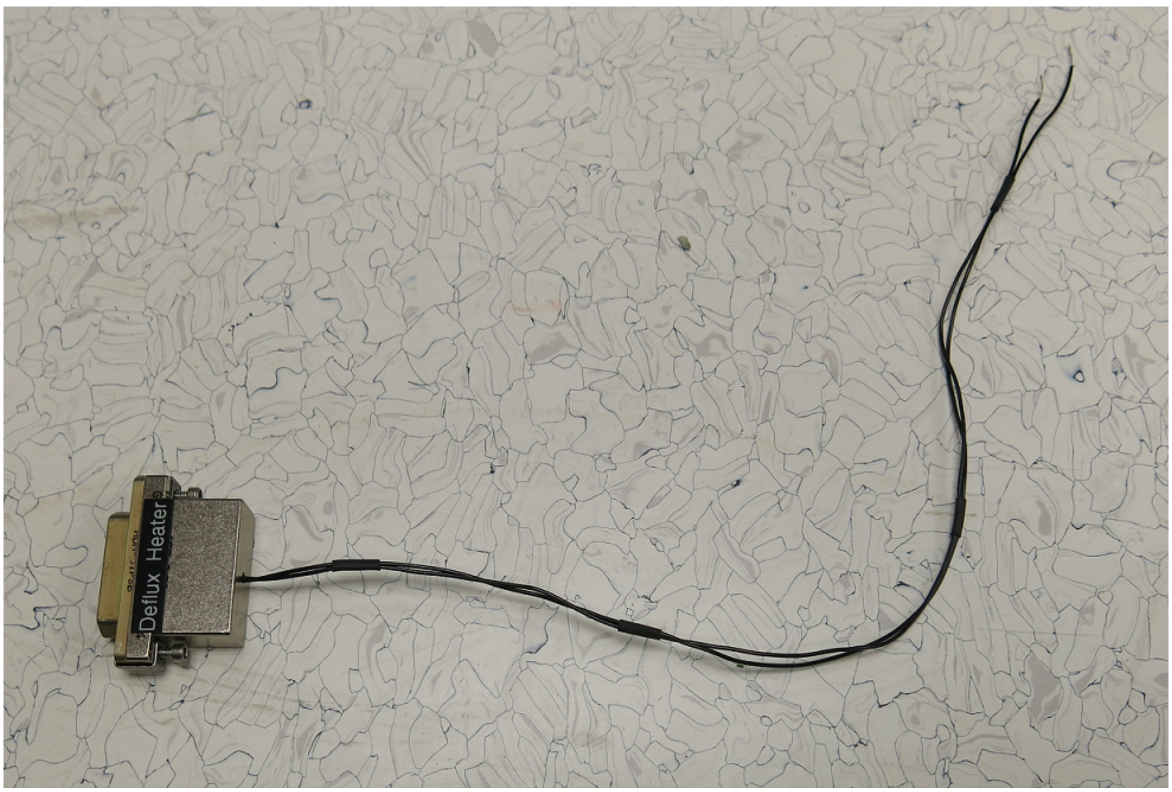


Figure 40: Test Jig

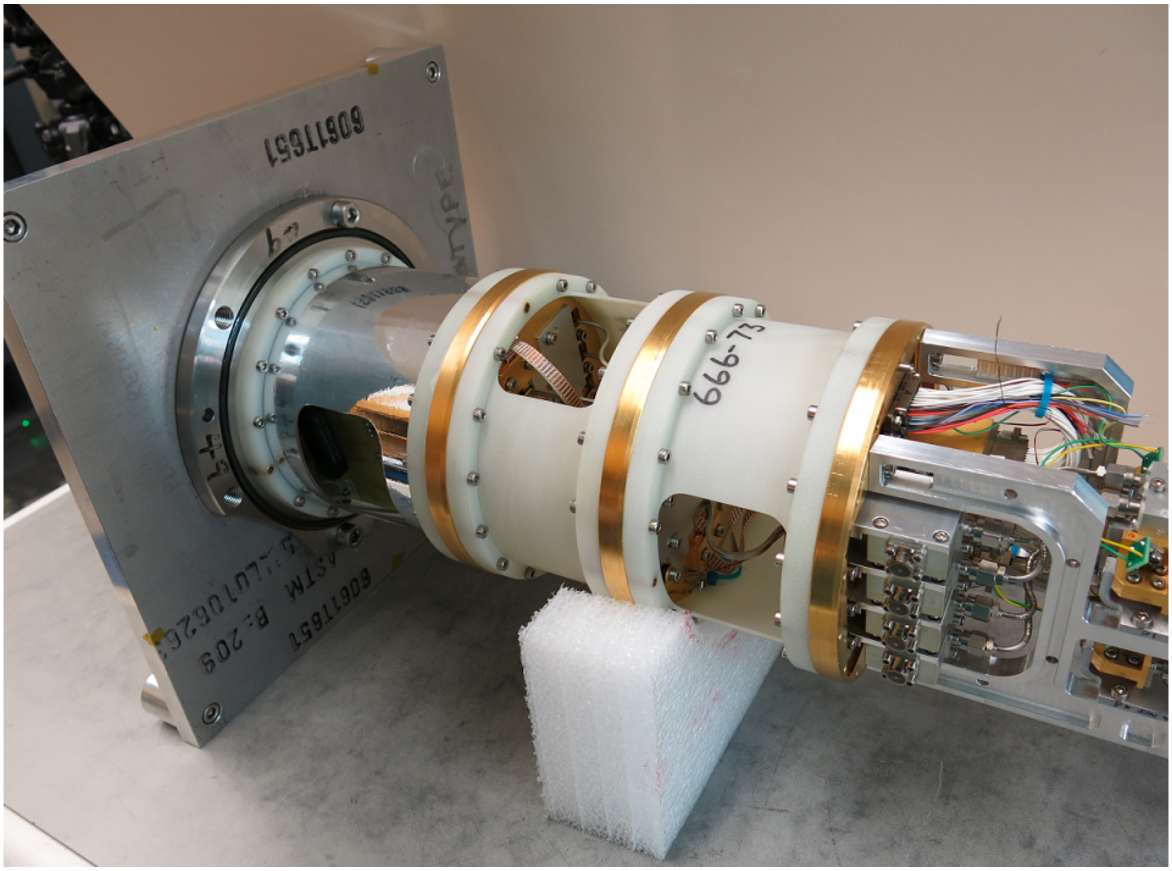


Figure 41: Cartridge on its side

Figure 42: Valid Reading (112.7 ohms)

8 Procedure for Retrofitting Bias Box

For the heaters to work, the bias box must be modified. The modification is done on the output connectors P1 of both of the bias supply boards in the Band 3 bias box.

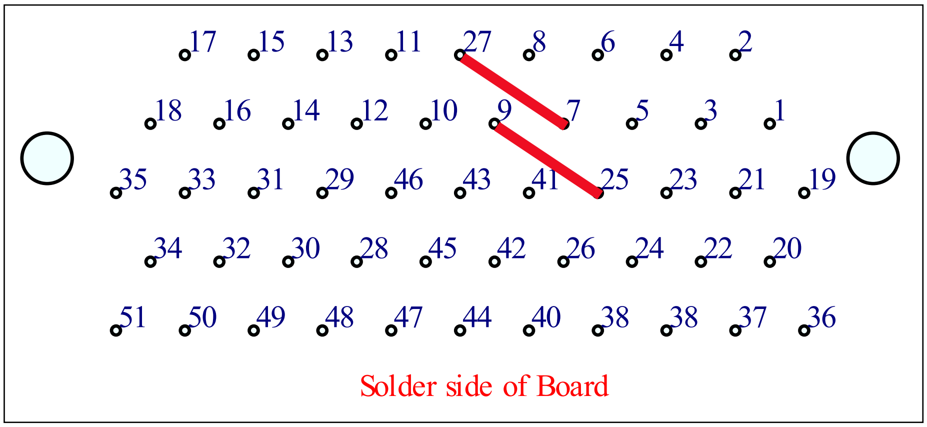


Figure 43: Pinout of bias card connector P1

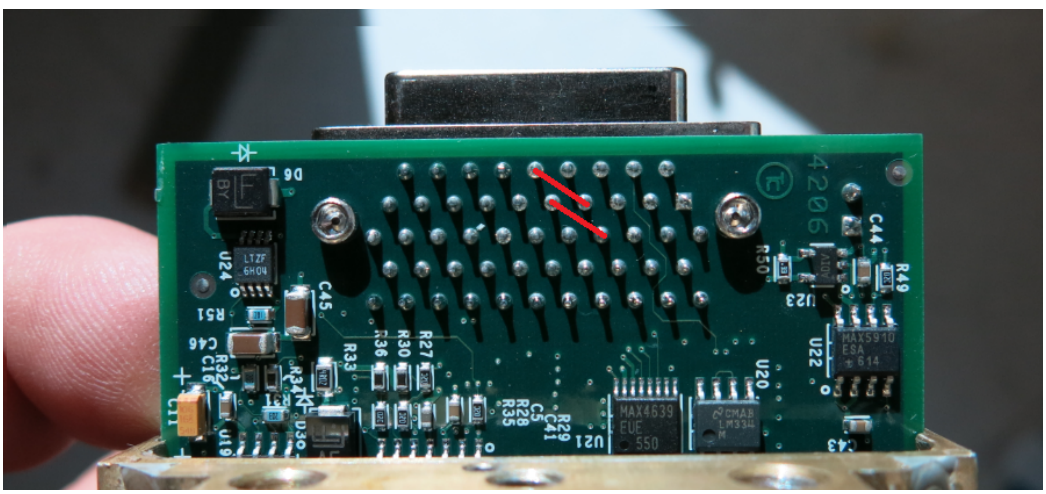


Figure 44: Solder side of bias card (intended modification is shown by red lines)

VHTR- [P1-7], VHTR+ [P1-25] are jumpered at P1, 9-25 and P1, 7-27.

Disassembly of the bias supplies is required, two short traces (per heater) are added to the PCB at connectors P1 (Pol0, Pol1). The new traces are soldered to the exposed through-hole pins, creating a reliable rework.

8.1 Tools Required

Figure 45: Before starting

1. 3 mm Allen wrench.
2. 1.5 mm Allen wrench.
3. 10 mm wrench.
4. Soldering iron.
5. Copper repair tape or pad frame.
6. Tweezers and dental type pick.
7. Alcohol and small brush or swab.
8. Microscope or magnifying light.
9. Solder sucker (ESD type).
10. ESD strap.
11. PCB repair pads such as CP050060AS https://www.all-spec.com/Catalog/Soldering-Rework/PCB-Board-Assembly-and-Repair/Circuit-Board-Assembly-Repair-Kits/CP050060AS-10123.
12. These instructions.

8.2 Remove the Bias Boards Screws and Hardware

1. Wash hands to remove any hand sanitizer. It is conductive and will leave a residue.
2. Remove the two M3 screws (Figure 46).
3. Using the 10mm wrench remove the two custom support bars and metal plate (Figure 47).
4. Remove the six M2 back plate screws (Figure 48).

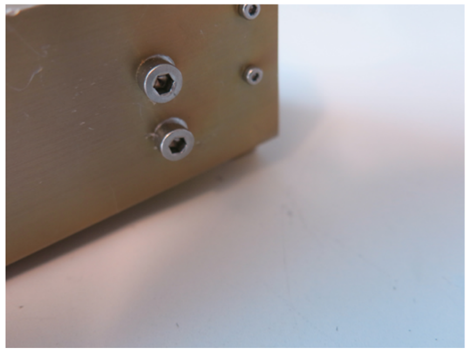


Figure 46: M3 screws

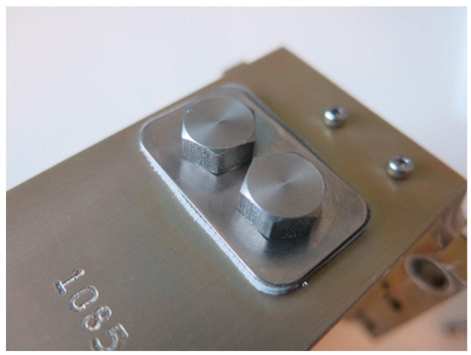


Figure 47: custom support bars

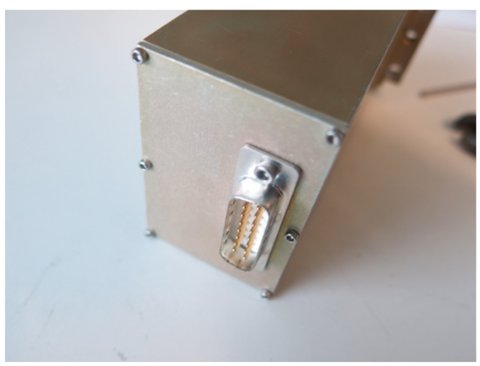


Figure 48: M2 screws

8.3 Removing the Bias Boards from the Enclosure

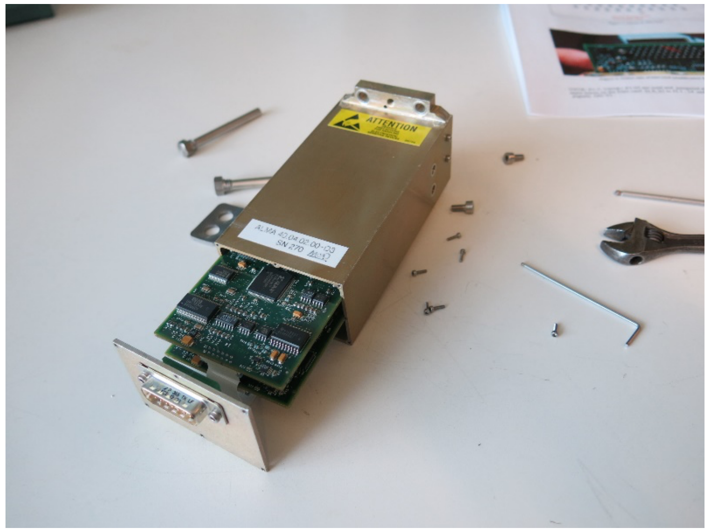


Figure 49: Slide boards out from rear

Slide boards out from the rear of the enclosure. To disconnect the ribbon cables, release the dark blue catches and slide out the ribbon cable. This is shown in the video as it is quite fiddly. Mark the boards/cables with a marker pen so they go back in the same order. Top/Bottom, or 1-2 etc. Do not remove the four card guide stop screws.

8.4 Adding Repair Copper Tape to the Boards

Cut small pieces [3mm x 0.5mm] of self-adhesive copper PCB repair tape. Alternatively, use pre-cut PCB repair pads such as CP050060AS.

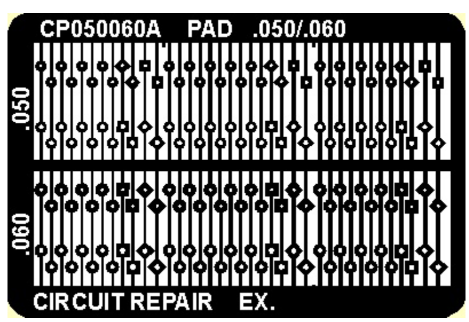


Figure 50: PCB repair frame

Using the solder pump remove the solder from around pins P1, 9-25 and P1,7-27, wetting the pin with fresh solder will make removing the solder easier as a layer of flux will be deposited (see Figure 31 and 32). Removing the existing solder allows the repair tape or pads to be laid flat up to the pin.

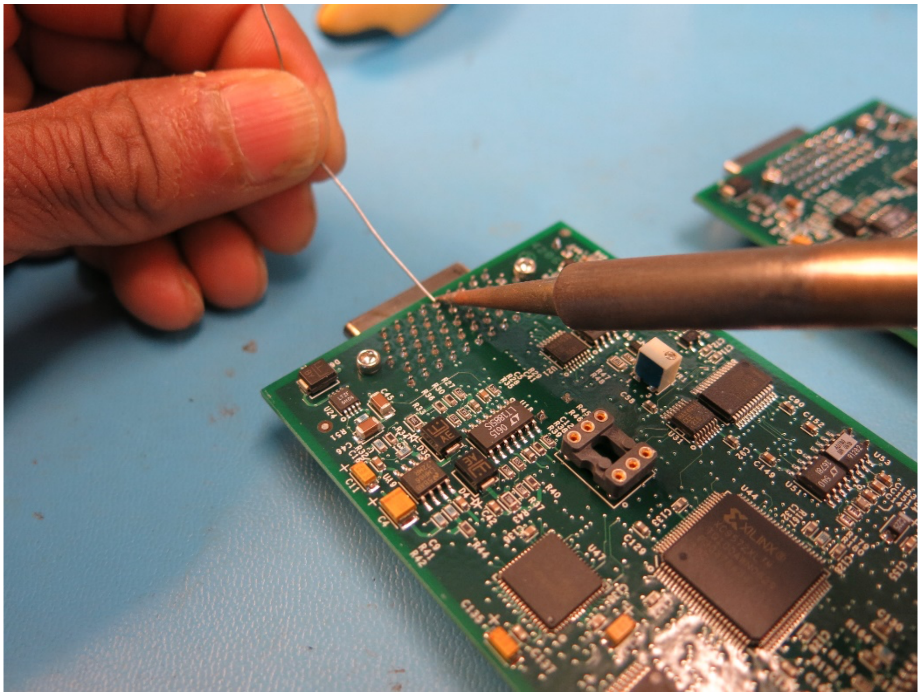


Figure 51: Wetting the solder pin

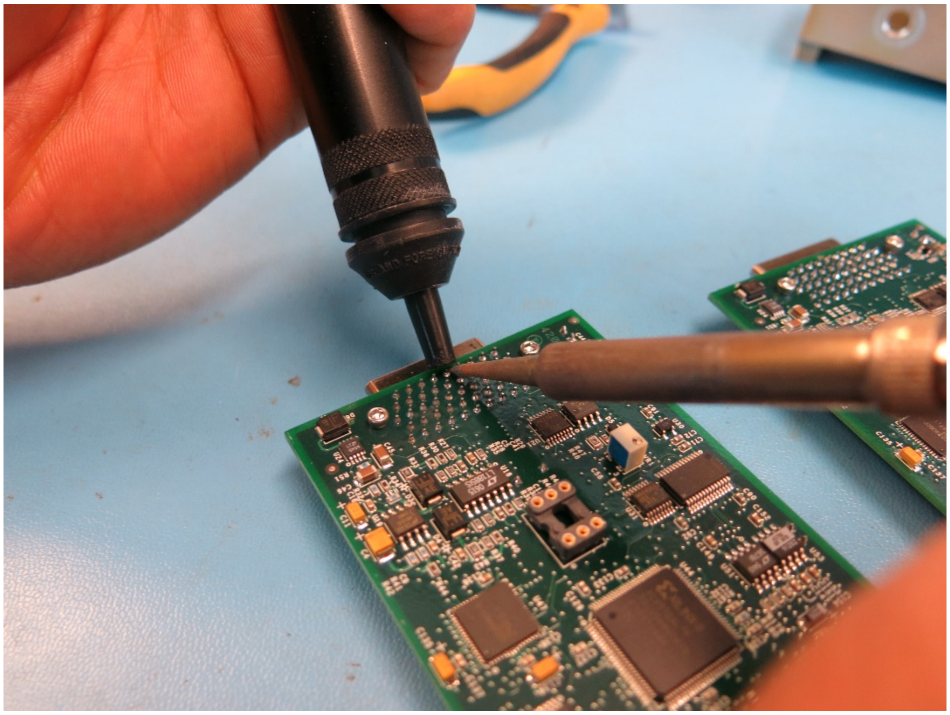


Figure 52: Correct placement of solder sucker and iron

.

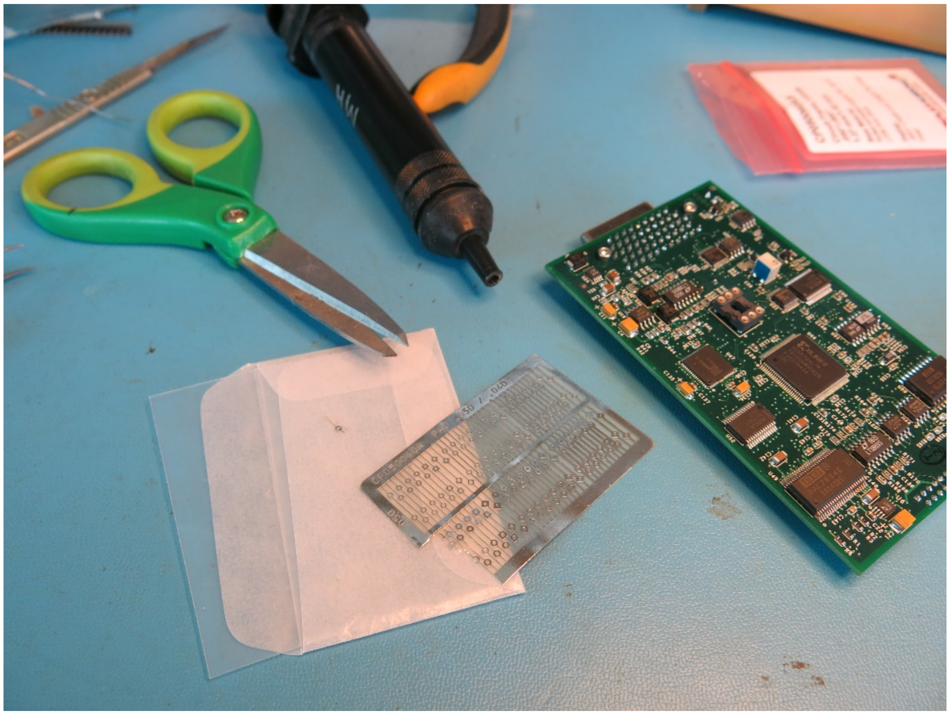


Figure 53: A scalpel or scissors may be used to cut out and select trace

After a suitable piece of trace is cut, use the tweezers or a pick to poke a hole through the center of the new pad. This will make it easier to locate the trace over the existing pad that already contains the connector pin. Using tweezers apply to board as shown in Figure 55. Use the dry soldering iron to press the trace to the board in a way similar to spot-welding. Then gently use the soldering iron tip to heat the new trace to activate the heat sensitive adhesive. Clean off the plastic carrier using alcohol and tweezers and the brush. Do this before making the solder joint. Once clean, solder the tape and pad to the connector pins. The finished first trace after cleaning with alcohol and a small brush is shown in Figure 55.

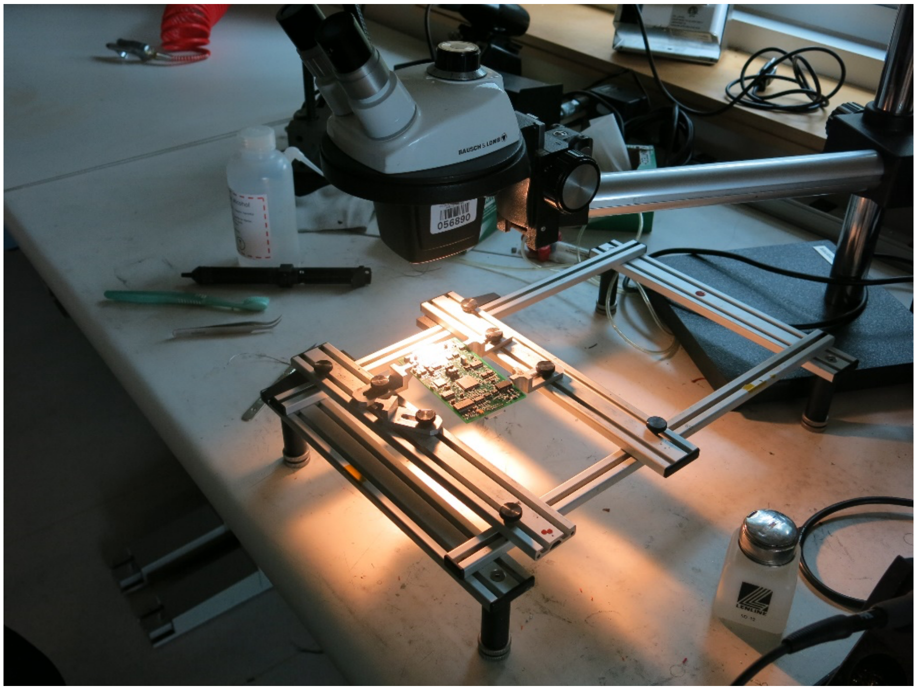


Figure 54: A microscope may also be used to aid

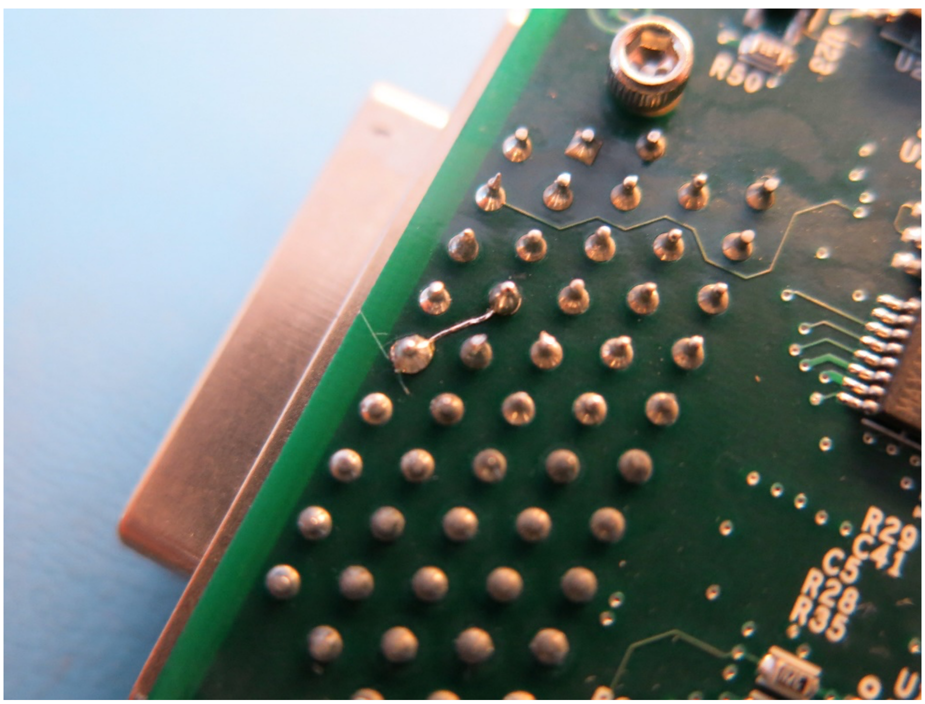


Figure 55: Shows first trace added to board

Repeat for the second pin.

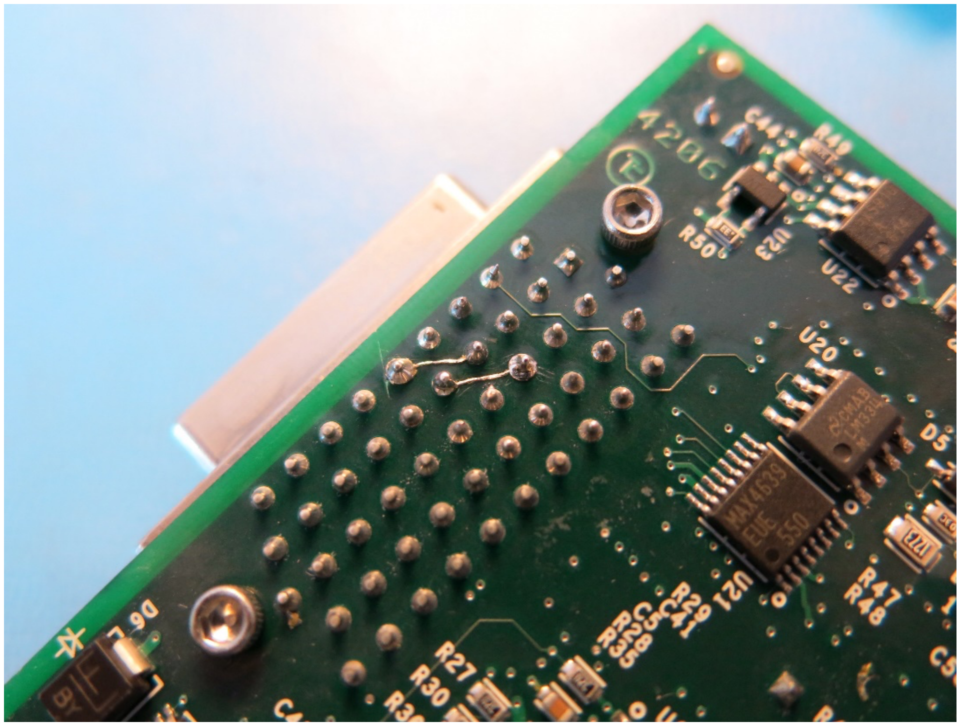


Figure 56: Second trace added and cleaned

A layer of epoxy can be applied over the new traces after they have been checked for continuity, if felt necessary.

9 Testing the Upgrade at Room Temperature

During this retrofit, the heaters and temperature sensors were removed and/or installed. Therefore, these two must be tested at room temperature prior to cooling a modified cartridge.

9.1 Heater Resistors

The heater circuit delivers pulses of 200 mA current of 1 sec duration. Apply one pulse to Pol 0 heater and note the heater current. Repeat this step to Pol 1 heater as well. The screenshots (Figure 57 and Figure 58) on the left were taken when heaters are off. The screenshots on the right were taken just when the software's heater current readings had peaked. Note the 200 mA.

The screenshots on the left show some residual current readings (approx. 5 - 6 mA) when the heaters are off, instead of 0 mA. This non-zero value seems typical of un-modified bias boards. Bias boards that have been modified seem to be consistent as well. It is thought that the residual 'current' to be pickup/measurement error in the monitoring circuitry.

Pol0 Heater

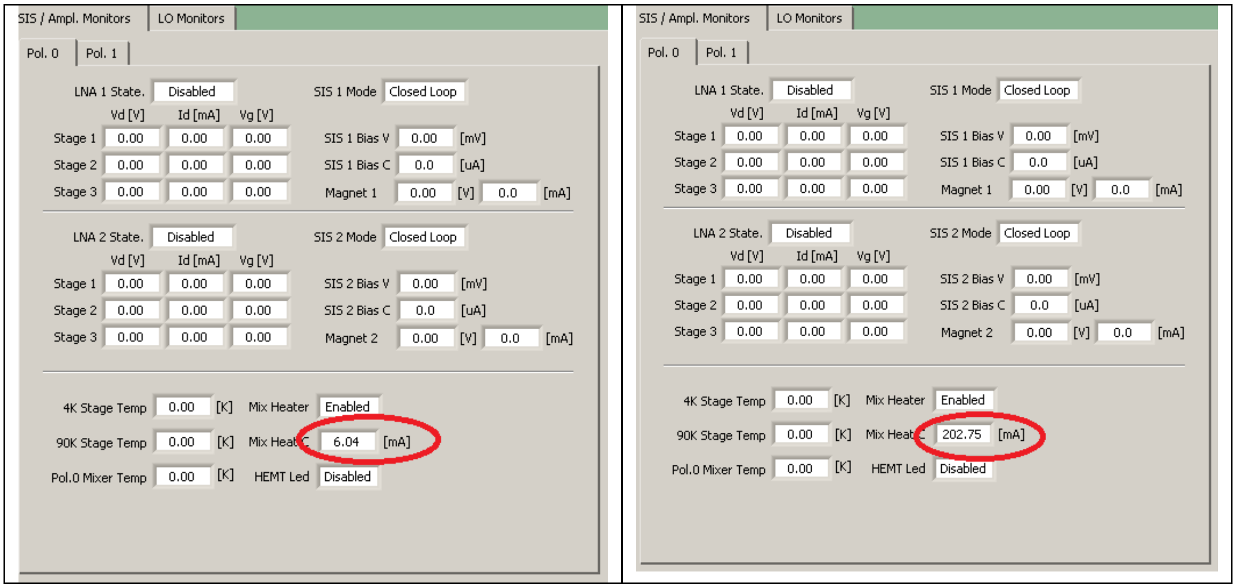


Figure 57: Pol0 heater –Off (left), On (right)

Pol1 Heater

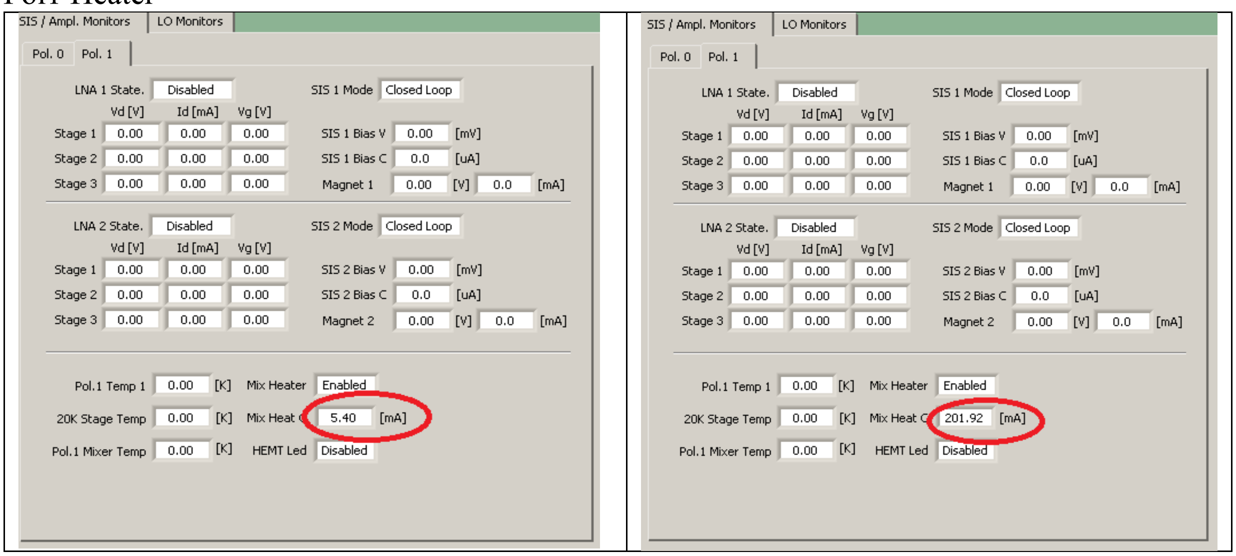


Figure 58: Pol1 heater –Off (left), On (right)

9.2 <u>Temperature Sensors</u>

The 4 K, 15 K, and 90 K sensors were removed and re-installed during this retrofit. These sensors are circled in green in Figure 59 and Figure 60. Make sure the readings are close to 295 K (room temperature). As an additional step, please check mixer sensor readings as well (circled in blue).

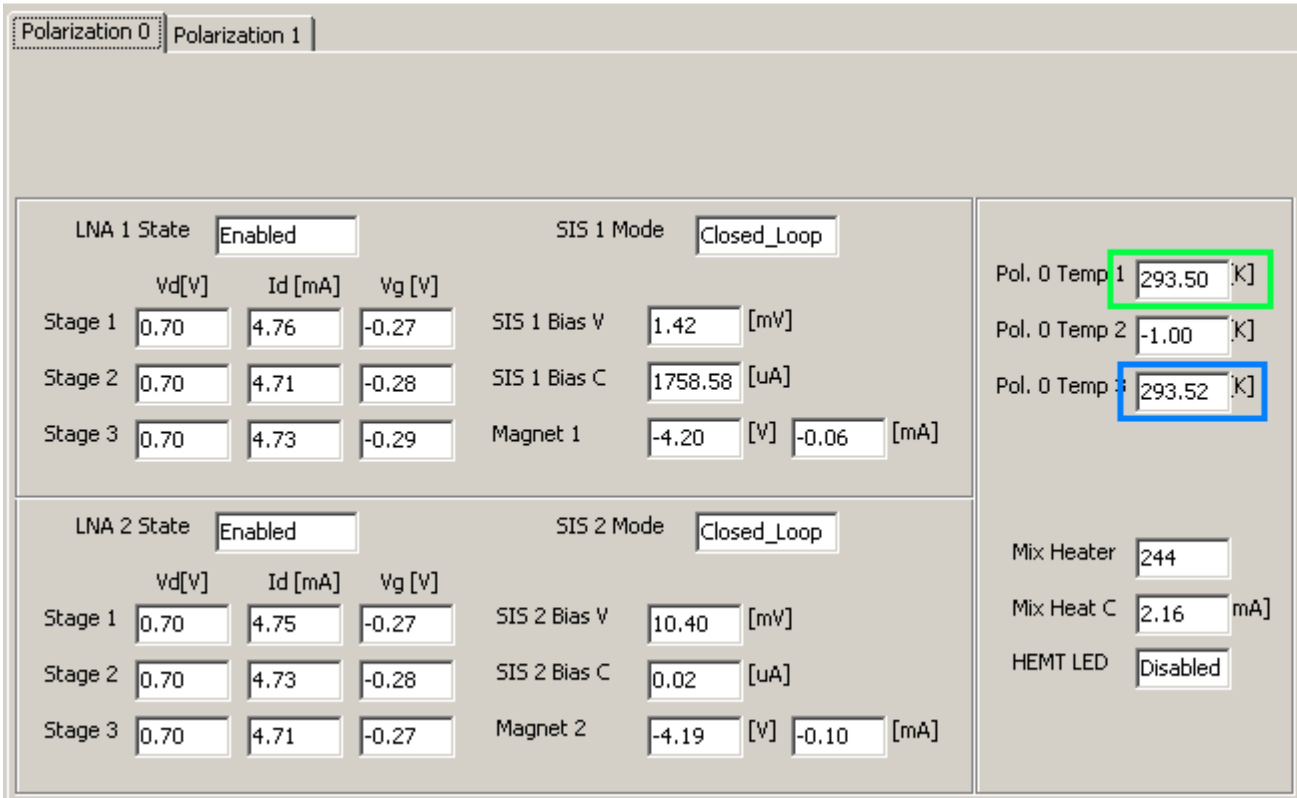


Figure 59: Pol 0 Temperature Sensors

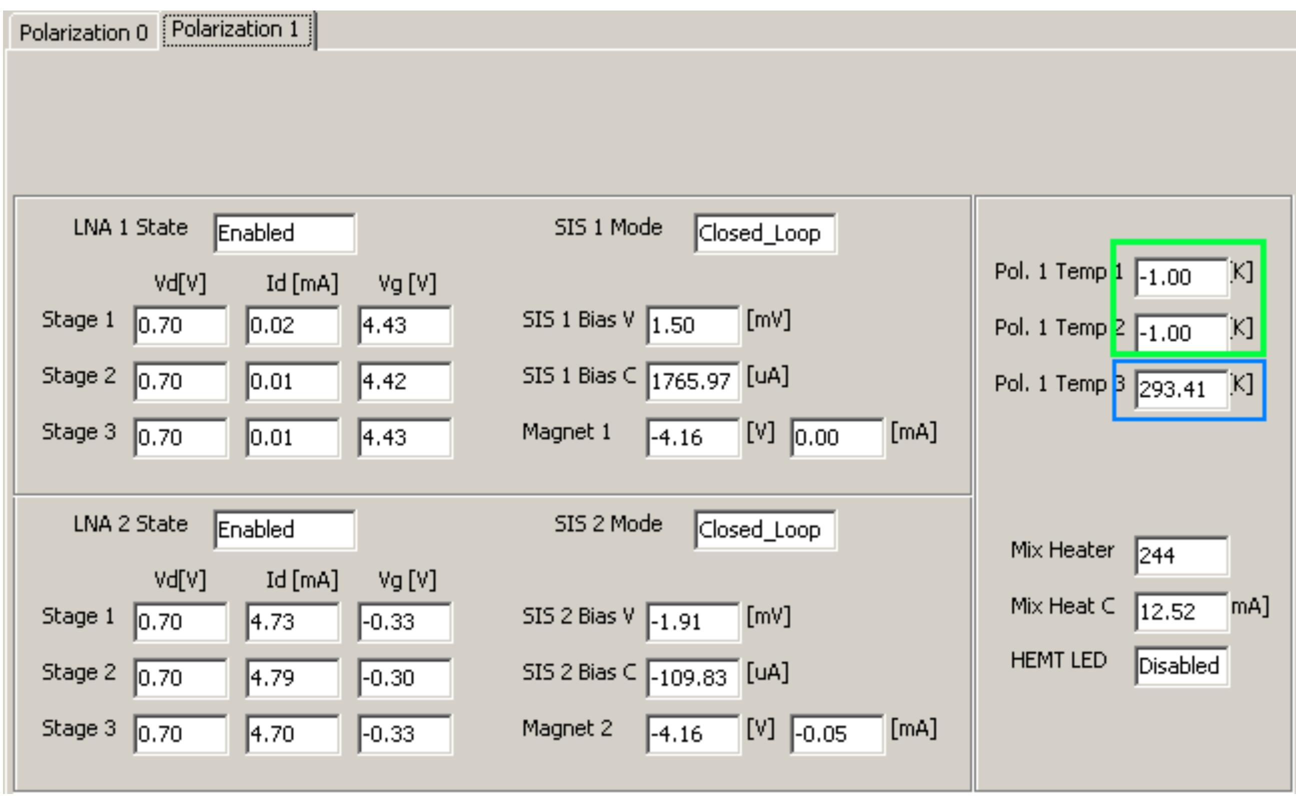


Figure 60: Pol 1 Temperature Sensors

9.3 Cartridge Deflux at 4 K

The heater circuit delivers pulses of 200 mA current of 1 sec duration. Our experiments in our cartridge test set show that 10 pulses of 1 sec duration with 20 ms dead time in between is sufficient to deflux the cartridge (to elevate the mixer plate temperature to about 15 K). Please note that the super conducting temperature of Band 3 mixers is 9.8 K, and a deflux requires a temperature much higher than this. The number of pulses/duration required in an ALMA front end system is likely to be different than it is for the NRC system given the different cooling capacity, mass, and thermal loads.

10 Dedication

With great sincerity, the authors acknowledge the contribution that our late colleague and friend, Dr. Stéphane Claude, made to the technical leadership of the ALMA Band 3 project at NRC from its very beginning. It was under his direction that this ALMA Upgrade Project was initiated, but to everyone's sorrow and regret, he did not live to see completed. We dedicate this report to his memory.