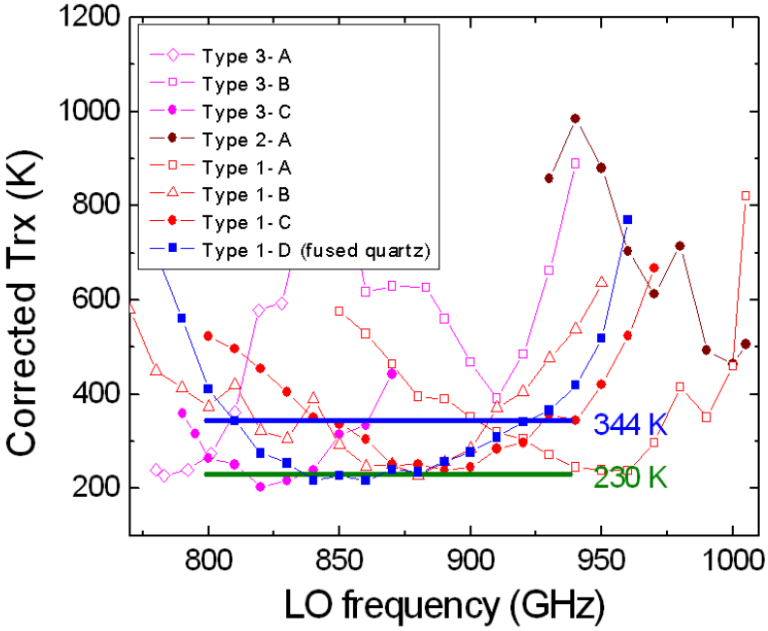
Band 10 – Noise Temperature Specification

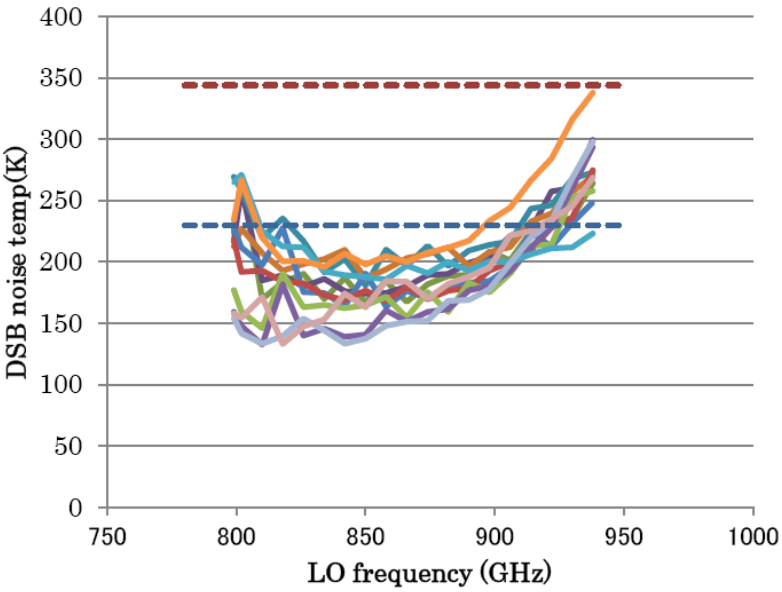
Those who have been on ASAC a long time will recall the discussion of this topic in May 2008 – see https://safe.nrao.edu/wiki/bin/view/ALMA/ASAC7May08Agenda. The situation then was that the initial development was giving encouraging results, but that it did not seem very likely that the ALMA specification for the single-sideband receiver temperature of $\alpha h\nu / k + 4$ K, where $\alpha = 10$ for the central 80% of the band and $\alpha = 15$ for the remainder of the band, could be met. Taking ν to be 950 GHz (i.e. the top end of the band) makes the values for the double-sideband temperatures (which are what is measured in the lab) 230 K and 344 K.

Here is the plot showing the performance data presented at that time.



I believe that the ASAC recommended at that time that the development work should continue with the emphasis on sensitivity rather than bandwidth, specifically that the team should aim to get the best performance possible in the part of the band where the atmospheric transmission is good and where most of the interesting lines lie.

Since then the Band 10 team at NAOJ has devoted an enormous amount of effort to this and has now produced the results shown in this plot for the first 6 dual-polarization cartridges:

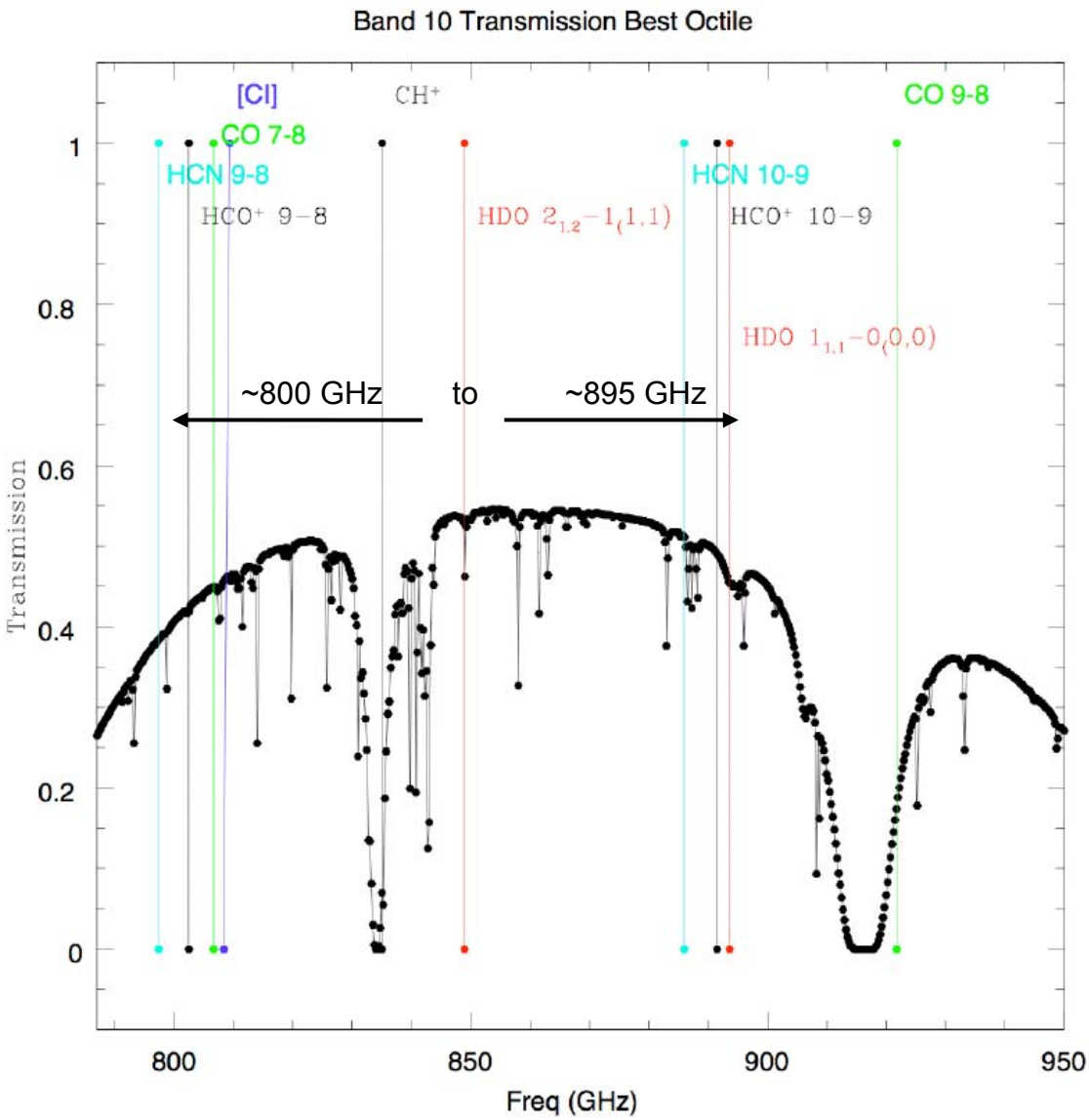


Note in particular the different vertical scale compared to the previous plot. This clearly represents a tremendous advance and I believe that we should congratulate the team on these results. It is important to take account of the fact that the frequencies in Band 10 lie

above the band-gap for Niobium, so the mixers have to be based on the much more difficult NbTiN technology instead of the all-Nb technology used in all the other ALMA bands. No allowance for this fact was made when the specifications were drawn up.

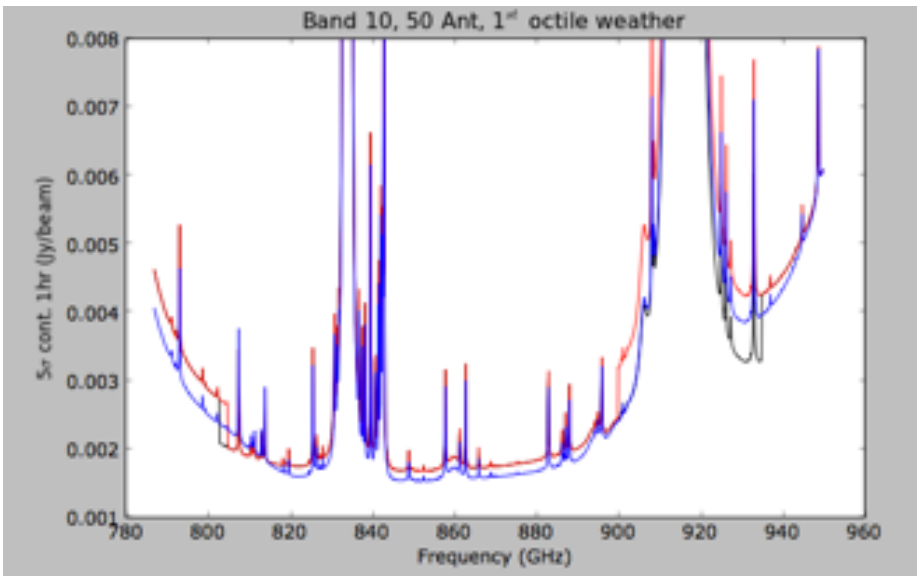
As explained in the attached draft change request, FEND-40.02.10.00-0000-A-CRE_Trx, there is no realistic prospect of reaching a viable yield of mixers if we insist on the original requirement, so some relief is now being sought. After some discussion, the proposed requirement is that the noise temperature should still be below 344 K over the whole band (787-950 GHz) but below 230 K only over 80% of a reduced range of 787 to 905 GHz, (instead of 80% of the whole band). This way of expressing it still allows some margin to allow for the fact that it is not possible to control the parameters of the junctions well enough to put the best spot at exactly the same place in every receiver. It nevertheless means that in practice we can expect that the overall performance of the array will be extremely good (in fact be rather better than that set by the original requirement) over at least the frequency range 800 to 895 GHz.

Al Wootten has provided this plot that shows the atmospheric transmission at zenith for about 0.5 mm of precipitable water vapour, together with the important lines, and I have marked the above range of frequencies.



It can be seen that, with the exception of the CO J = 9–8 transition, essentially all the lines are included. (HCN J = 9–8 falls just outside, but the J = 10–9 line is inside.) It is to be emphasized that, at < 344 K, the performance across the whole band will still be extremely good by any standards. The natural choice for continuum observing would be from ~850 to ~880 GHz, which is also inside the region where we would have the best performance.

It is important to appreciate at that these frequencies there is a large contribution to the system temperature, and hence to the overall system sensitivity, from the atmospheric emission and that therefore changes in receiver noise have less effect than one might expect. This plot by Andy Biggs illustrates that point. Here the black curve shows the sensitivity expected for a receiver which exactly met the original specification, the red curve the one that exactly meets the proposed revision and the blue curve shows the result for a simple smooth function that is a rough fit to the measured data shown above. This is again under very good conditions (about 0.5 mm of water vapour): the effect would be even smaller if there were more water.



One of the other important topics for this band is observations of red-shifted emission from the C^+ cooling line. For the whole band, the red-shift range over which this line can be studied is z = 1 to 1.41, but with some gaps due to the atmospheric absorption features. With the proposed specification we expect the best region to be from z of about 1.12 to 1.37 with a gap at about 1.275. Access to this line across the whole band will however not be lost by accepting the change request. The main effect is likely to be at about 930 GHz (z ~ 1.04), but even there the loss of sensitivity is modest, as can be seen above.

In addition to the limitations on performances arising from the SIS mixers themselves, the Band 10 group is also encountering problems with the Local Oscillator sources. These take two forms: a) excess noise arising in the LO source itself, and b) shortage of LO power at certain frequencies, which mean the mixers are not operating at the optimum level. The problem of excess noise has been encountered in several other bands. At present this is mainly affecting the performance at the lower end of the band where there are several significant spectral lines. There are separate internal specifications on the LO sources and this change request does not have a direct bearing on that problem. At these frequencies the technology of the LO sources (which are provided by NRAO) is again very challenging and it is not clear how much improvement can be made, but we will certainly continue to monitor this issue closely.

Conclusion

The noise temperature specifications are amongst the most critical in the whole project and we should only agree to relax them after it has been demonstrated that all reasonable efforts have been made in trying to meet them. If the ASAC is convinced that this is case, and that the reduced performance is acceptable given the pressures of costs and schedule, then the committee is requested to recommend that this change be adopted.

The draft change request (with a somewhat different version of the wording) is attached. More on this topic is at http://www.alma.cl/~science/docs/40_Front_End/Band_10/ .

Richard Hills 4th May 2012

	ALMA CHANGE REQUEST	**Date submitted**: 2012-04-30 **CRE #**:FEND-40.02.10.00-0000-A-CRE
	TITLE: Change Request for the Band 10 Cartridge Noise Performance (DRAFT!)	

(To be completed by CR Submitter/Initiator)

Description of change (detailed description of change proposed) and Justification:

This CRE requests changes in noise performance [FEND-40.02.10.00-00180-00 / T]

From 230 K over 80% of the frequency range

To 230 K over 60% of the frequency range

Although all pre-production cartridges are compliant with the requirement of less than 344 K for the bull-band, three cartridges out of six did not meet the specification of less than 230 K over 80% of the band as shown in Figure 1 [RD 01]. Figure 2 shows the noise performance in the worst case, which has 58% bandwidth below 230 K [RD 02].

These non-compliant performances happened due to the fact that the SIS junctions in the mixers have relatively low current density of 7-8 kA/cm^2, even though our target value is ~10 kA/cm^2 or higher. In our mixer design (and in general), the lower the current density, the lower the coupling efficiency between the SIS junctions and the waveguide feed, as described in Figure 6-9 on page 113 in Band 10 CDR design report [RD 03]. Instead, the mixer is supposed to offer wideband operation covering Band 10 frequency range with noise temperatures well below the full-bandwidth specification of 344 K. This is the case that the center frequency of the tuning circuit of the fabricated device is around the target value of 870 GHz (the center frequency of Band 10). In fact, the center frequency of the devices is shifted to lower or higher than the target value due to errors in definition of the junction sizes, variations in the complex conductivities (RF loss and kinetic inductance) of the NbTiN films, and so on, in the device fabrication process. These important parameters which directly-decide the tuning frequency of the devices can still not be well-controlled by current technologies, which is very difficult to overcome.

Another cause to increase the noise performance is thought to be excess LO noise. For example, in Figure 2, the noise increase at ~800 GHz can be seen, which may be due to the excess LO noise. The corresponding noise can be observed in measurements of noise temperature versus IF and LO frequency, as shown in Figure 3. This noise could be reduced by using a quasi-optical LO attenuator with a smaller diameter hole (larger attenuation). But simultaneously, the LO power to pump the SIS mixer will be decreased. Figure 4 shows an SIS pumped current as a function of LO frequency in full LO power operation as an example. The red line with closed squares shows optimum pumped currents for the receiver operation. The use of lager LO attenuation in the LO path would improve the receiver noise performance by decreasing the excess LO noise, but the noise performance at around 920 GHz is degraded due to a lack of LO power. Thus, it is difficult to improve the noise performance over all by changing the quasi-optical LO attenuator. More power-full LO sources will resolve this issue, as seen in the case of lower frequency bands. Or reduction of excess noise in the LO source will be necessary. However, the current LO technology limits these improvements.

Considering these situations mentioned above, the current noise requirement will need to be relaxed for the production cartridges as: The bandwidth for the 230 K noise requirement is relaxed to over 60% (instead of 80%). Another possibility has been discussed on JIRA [RD04], which is: The noise temperature requirement is relaxed to 250 K (instead of 230 K) over 80% bandwidth. The 100% bandwidth noise specification could stay the same. It should be noted that the proposed new specification or the second option would still be challenging.

Additional information in attached documents:

[RD01] FEND-40.02.04.00-0123-A-REP, “Band 10 Cartridge Manufacturing Readiness Review Technical Report”
[RD02] FEND-40.02.04.00-0110-A-REP, “Band 10 Cartridge S/N05 Acceptance Test Report”
[RD03] FEND-40.02.04.00-0039-A-REP, “Band 10 Cartridge CDR Design Report”
[RD04] http://jira.alma.cl/browse/FERFW-510

Impact: ☒Specifications ☒Science ☒Cost ☒Schedule ☐Safety ☐Technical ☐Other (specify):

Description of impact (technical, schedule, and cost):
Accepting the CRE will obviously lead to a possible negative impact on science. Rejection of the CRE on the other hand will impact on Band 10 cartridge delivery and cost. At this moment, about two years for completing the cartridge production are provisionally scheduled, assuming the acceptance of the CRE. If not accepted, it needs more

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than twice, and the production cost will increase, accordingly.		
Affected products to be modified: FEND-40.02.10.00 (Band 10 cartridge)		
Affected documents to be revised: FEND-40.02.10.00-0002-A-SPE, "Band 10 Cartridge Technical Specifications" ALMA-40.00.00.00-001-A-SPE, "Front-End Sub-System for the 12 m-Antenna Array Technical Specifications" ALMA-80.04.00.00-005-B-SPE, "ALMA System Technical Requirements for 12m array"		
Risk:		
Remarks:		
Date Submitted:	2012-04-30	**Date Decision Required:** 2012-06-08
CRE Initiator:	Yoshinori Uzawa (NAOJ)	

(To be completed by CCB)

Name	Signature	Date	App	Rej	Name	Signature	Date	App	Rej
EU FE sub-system engineer			☐	☐				☐	☐
NA FE sub-system engineer			☐	☐				☐	☐
EU FE IPT Lead			☐	☐				☐	☐
NA FE IPT lead			☐	☐				☐	☐
EU/NA/EA project manager	-- if necessary --		☐	☐				☐	☐

☐APPROVED
☐REJECTED Reason:

☐ All documents have been appropriately revised Doc Spec. Signature: Date:

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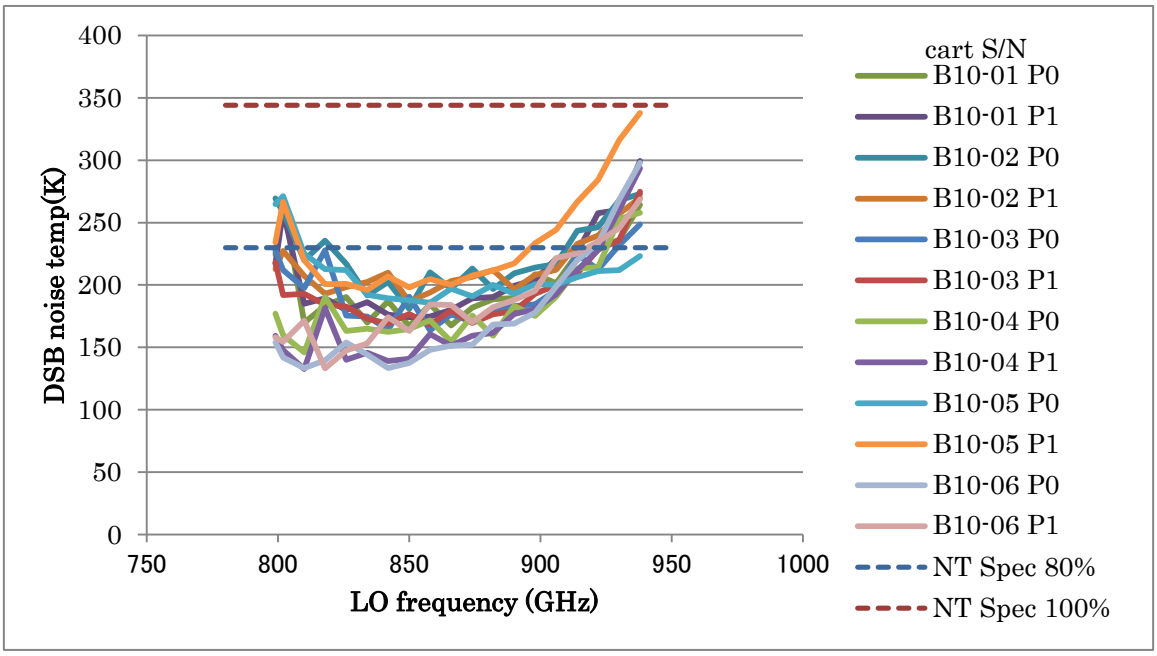

Figure 1. DSB noise temperatures of the first six Band 10 cartridges as a function of LO frequency. A blue dashed-line shows the noise performance specification of 230 K over 80% bandwidth.

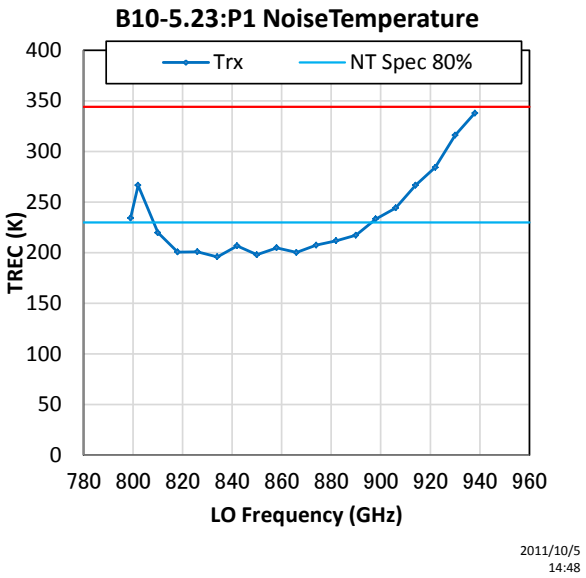

Figure 2. Noise performance of CCA10-05 Pol. 1 (the worst case of 58% bandwidth in the first six cartridges).

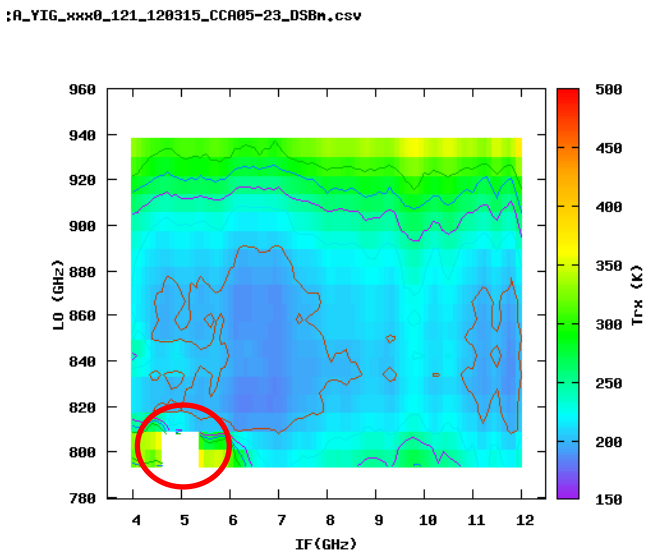

Figure 3. Noise temperature vs. IF and LO frequency of CCA10-05 Pol.1. Write region in a red circle has noise temperatures of higher than 500 K, which is attributed to excess noise from the Band 10 LO source.

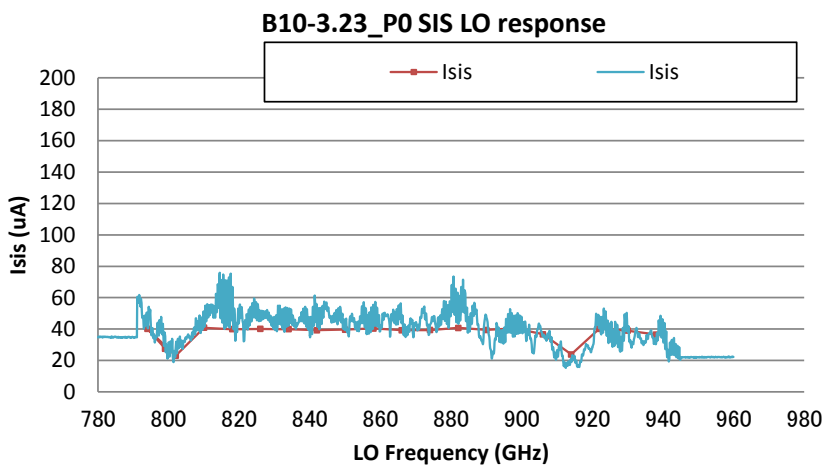

Figure 4. Measured SIS pumped current as a function of LO frequency in full power operation of CCA10-3 Pol.0. Also shown (red line with closed squares) is the pumped SIS current used for the cartridge operation.