Spurious Responses From IF Signals Above 12 GHz

P.Napier, 11May2010

Summary

The issues discussed in this report are relevant only for FE Bands 6 and 9 which use the upper end of the 4-12 GHz IF range and are not relevant for Bands 3 and 7 which use an IF of 4-8 GHz. The impact of IF signals in the frequency range 12-14 GHz has been calculated. Signals in this range are not negligible because the response of the FE and BE electronic systems does not roll off rapidly enough above 12 GHz for Band 6 and Band 9. IF signals in this range are converted in-band via the USB response of the IFDC mixer when LO2 is in the range 10.5-11.5 GHz.

Signals of astronomical origin in the IF frequency range above 12 GHz will tend to degrade the spatial and spectral dynamic range. Such signals will always be present when observing a continuum source and may be present if observing a field rich in spectral lines. Here are some possible actions which ALMA can decide to take with respect to these spurious signals:

(1) Do nothing and accept the fact that Band 6 and Band 9 will have Image Dynamic Range and Spectral Dynamic Range degraded by up to 30 dB when LO2 is in the narrow frequency range 10.5-11.3 GHz. This may be more of an issue for Band 6 than Band 9 because it is not clear that Band 9 will have the sensitivity to achieve the dynamic ranges specified for ALMA (Image Dynamic Range 47 dB and Spectral Dynamic Range 40 dB).

(2) Do not use the LO2 frequency range 10.5-11.3 GHz when using Band 6 and Band 9. The Control Software group says that it is easy to exclude tuning solutions in this range from consideration. This should have a small impact on most science projects because the loss of this 800 MHz of LO2 tuning range will not prevent access to the whole of the available IF bandwidth for both Band 6 and band 9. The limitation will come when an observer wishes to observe a number of spectral lines simultaneously and wishes to place particular lines in particular basebands in order to utilize the available high-spectral-resolution resources in the correlator in an efficient way. I have discussed this with several astronomers but have not yet found an example that requires this range of LO2 tuning, but examples are almost certain to exist.

(3) Redesign the 8.5 GHz low pass filter in the IFDC so that its cutoff frequency is 9 GHz instead of 8.5 GHz. This will be expensive because this filter is printed on a complex

circuit board deeply imbedded in a vendor supplied module. About half of these modules have been delivered and the other half are under contract.

(4) Install an additional 12 GHz LPF which provides 35 dB of attenuation at 12.5 GHz on each input to the IFDC. The BE Filter Specialist (Chip Scott) says that this filter is very difficult to implement because of the requirement that it should have negligible insertion loss at 12.0 GHz.

A second example of a spurious signal entering in the 12-14 GHz IF range is the Band 6 WCA YIG leakage signal documented in JIRA AIV-2057. Additional tests are required to determine if this leakage signal is as strong above 12.5 GHz as it is in the measurement at 12.3 GHz on DV03. Under the assumption that the leakage does not reduce rapidly with increasing YIG frequency and the spurious signal is attenuated only by the roll-off in the IF response of the FE and IFDC, here are some possible actions which ALMA can decide to take with respect to this spurious signal.

(5) Take no action in which case there will be a very strong (several 10's of dB above spec) unresolved spurious CW signal in band 6 spectra whenever LO2 is in the range 10.5-11.0 GHz at the same time that the WCA YIG is above 12.5 GHz (LO1>225 GHz).

(6) Install a low pass filter on the Band 6 FE IF output that has negligible attenuation at 10.0 GHz and has 45 dB attenuation at 12.5 GHz. Note that if either of the IFDC filters described in (3) and (4) above are implemented then the attenuation requirements for this Band 6 filter are relaxed accordingly.

(7) Do not use the LO2 tuning range 10.5 to 11.0 GHz when Band 6 is selected and always operate Band 6 with LO1-LO2 frequency offsetting in place. This frequency offsetting is likely to be required always anyway in order to improve the sideband rejection of the FE SSB mixers. See point (2) above for a discussion of the impact of loosing this range of LO2 tuning.

1 Introduction

In this report we will examine spurious responses in the ALMA electronics system that result from signals in the 4-12 GHz IF that are slightly higher in frequency than the nominal 12 GHz upper frequency cutoff. Such signals are not negligible because the receivers that use the upper part of the 4-12 GHz IF, such as Band 6 (6-10 GHz IF) and Band 9 (4-12 GHz IF) do not have a very sharp roll-off in their IF response above 12 GHz. Similarly, the response of the IF Down-Converter (IFDC) to signals above 12 GHz is not sufficiently attenuated so that we can ignore signals in this range. The basic mechanism of the spurious response is shown in Figure 1 which shows the signals present at the input to the mixer in the IFDC when the second local oscillator (LO2) is set to 10.5 GHz.

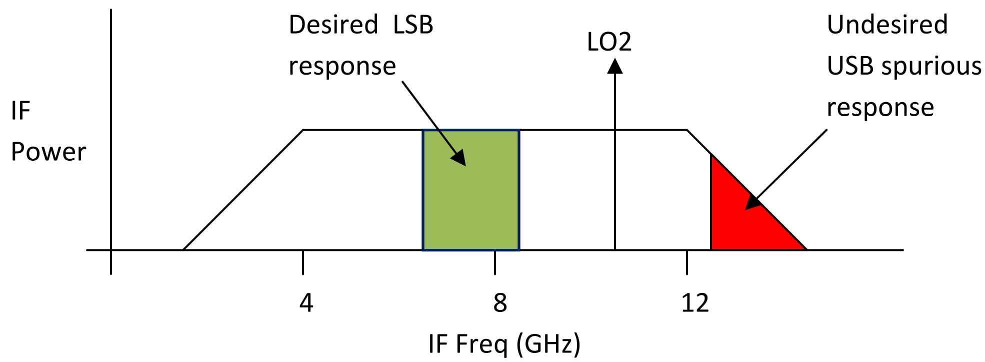

Figure 1 Desired and undesired response with LO2=10.5 GHz

The baseband 2-4 GHz desired response of the IFDC is the LSB response shown in green and the undesired spurious response is the USB shown in red. Note that when LO2 is below 10.5 GHz an 8.5 GHz Low Pass Filter is switched in before the IFDC mixer in which case the USB is adequately attenuated so the spurious responses discussed in this report are not significant for those FE's which use a 4-8 GHz IF (Bands 3, 7). As a further note, the filter switching frequency of 10.5 GHz was previously set to 10.0 GHz but will be changed to 10.5 GHz when Control Software Version 7.1 is installed in June 2010.

2.1 Spurious Response From the Sky

As explained above, signals above 12 GHz can be mixed into the 2-4 GHz baseband via the USB

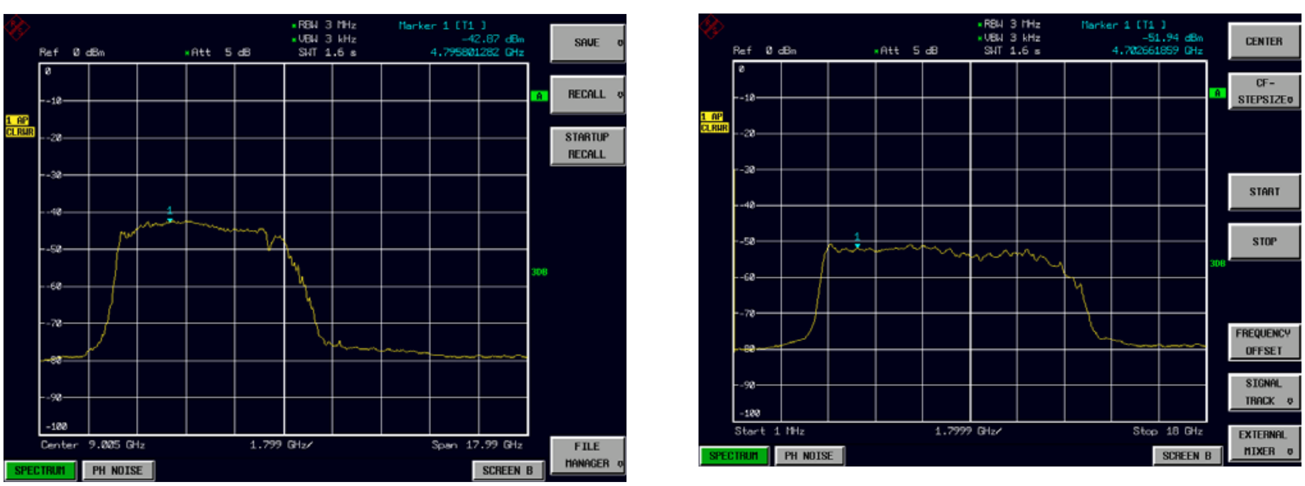

Figure 2 Measured IF response of FE 08. Left Band 6, Right Band 9

response of the IFDC mixer. The strength of this spurious response is determined by the rate of roll-off of the FE IF response and the IFDC response above 12 GHz. Measurement of the FE response is shown in Figure 2 which shows a Band 6 and a Band 9 IF response for FE 08

(http://edm.alma.cl/forums/alma/dispatch.cgi/iptfedocs/showFile/110537/d20100112134229/Yes/2009-12-14-FEND-40.00.00.00-222-A-REP.pdf).

These responses have been sampled by hand to give the response above 12 GHz as shown in Figure 3.

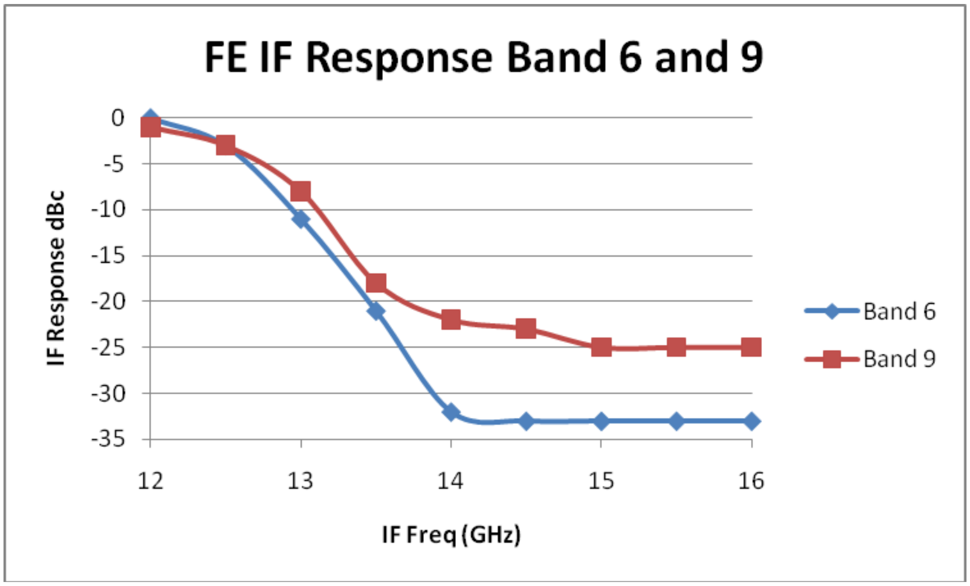

Figure 3 FE IF responses above 12 GHz from Figure 2

The dynamic range of the measurements in Figure 3, visible as the constant responses above ~ 14 GHz, is somewhat limited but is adequate for the analysis required for this report.

The end-to-end response of the IFDC is shown in Figure 4 for both the 8.5 GHz LP filter and 12 GHz LP filter paths. These response curves were measured by H. Malagon on 29Apr2010 in the Socorro lab on IFDC SN 163.

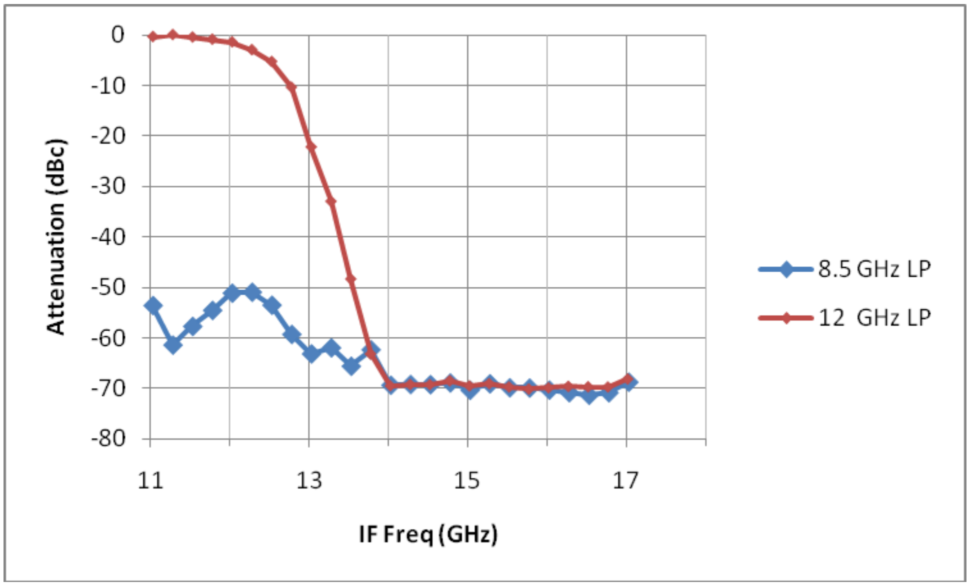

Figure 4. End-to-end response of an IFDC for the 8.5 GHz LP filter and 12 GHz LP filter paths. Attenuation values are with respect to a signal in the desired response band.

The dynamic range of the measurements in Figure 4 is limited to 70 dB and this is adequate for the calculations in this report.

Using the data in Figures 3 and 4 we can now calculate the strength of the undesired response as a function of LO2 frequency. The total attenuation experienced by a signal above 12 GHz is the sum (in dB's) of the attenuations shown in Figures 3 and 4. Table 1 shows the strength of the spurious response for 3 values of LO2.

Table 1 Calculated strengths of the USB spurious response

LO2 (GHz)	Spectral Line Spurious (dB)		Continuum Spurious (dB)	
	Band 6	Band 9	Band 6	Band 9
10.5	-8	-8	-17	-17
11.0	-33	-30	-42	-39
11.5	-69	-66	-78	-75

In Table 1 the "Spectral Line" spurious response is the strength of the response at an IF frequency of LO2+2.0 GHz and indicates the amount of attenuation expected for a spectral line located at this IF frequency; the "Continuum" spurious response is the average response integrated over the IF frequency range LO2+2 GHz to LO2+4 GHz.

How much attenuation of this spurious response is required? The numbers in Table 1 apply directly for single dish observations. For the interferometry case, with the fringe rotation and delay scheme used by ALMA, for a point source located at the array phase center on the sky there is no residual fringe rate associated with this spurious response . So the spurious response is not suppressed by fringe rotation. However, the phase of the spurious response due to astronomical origins such as source position or source structure will have the wrong sign and so this spurious response will tend to create a ghost image on the wrong side of the origin in the image plane and will therefore limit the spatial dynamic range of interferometric images. The spurious response is not suppressed by 180 degree Walsh phase switching and the amount of suppression provided by LO offsetting or 90 degree Walsh phase switching is limited to the sideband rejection provided by the FE mixer (ie no rejection for Band 9 which is DSB).

The important Science Requirements impacted by this spurious response are Image Dynamic Range 47 dB (Req 75) and Spectral Dynamic Range 40 dB (Req 70). From these considerations we should try to suppress the Continuum spurious response to -47 dB and the Spectral line spurious response to -40 dB. We can see from Table 2 that there is only a small range of LO2 values for which the spurious response is too strong. Here are some possible actions which ALMA can decide to take with respect to these spurious signals:

(1) Do nothing and accept the fact that Band 6 and Band 9 may have Image Dynamic Range and Spectral Dynamic Range degraded by up to 30 dB when LO2 is in the narrow frequency range 10.5-11.3 GHz. This may be more of an issue for Band 6 than Band 9 because it is not clear that Band 9 will have the sensitivity to achieve these high dynamic ranges.

(2) Do not use the LO2 frequency range 10.5-11.3 GHz when using Band 6 and Band 9. The Control Software group says that it is easy to exclude tuning solutions in this range from consideration. This should have a small impact on most science projects because the loss of this 800 MHz of LO2 tuning range will not prevent access to the whole of the available IF bandwidth for both Band 6 and band 9. The limitation will come when an observer wishes to observe a number of spectral lines simultaneously and wishes to place particular lines in particular basebands in order to utilize the available high-spectral-resolution resources in an efficient way. I have discussed this with several astronomers but have not yet found an example that requires this range of LO2 tuning.

(3) Redesign the 8.5 GHz low pass filter in the IFDC so that its cutoff frequency is 9 GHz instead of 8.5 GHz. This will be expensive because this filter is printed on a circuit board deeply imbedded in a vendor supplied module and about half of these modules have been delivered and the other half are under contract.

(4) Install an additional 12 GHz LPF which provides 35 dB of attenuation at 12.5 GHz on each input to the IFDC. The BE Filter Specialist (Chip Scott) says that this filter is very

difficult to implement because of the requirement that it should have negligible insertion loss at 12.0 GHz.

2.2 Band 6 Spurious CW Signals Due to WCA YIG

The postings to JIRA Ticket AIV-2057 indicate that in the Band 6 FE the WCA YIG, which has an allowable tuning range of 12.3-14.7 GHz, is leaking into the IF output of the FE. Note that this frequency range falls in the spurious response shown in Figure 1 so the WCA YIG signals can be seen in the 2-4 GHz baseband. It is not yet clear how the WCA YIG is leaking into the IF. The test reported by Nick Whyborn in the AIV-2057 posting of 16Apr2010 suggests that the YIG signal is leaking directly into the IF between the SIS mixer and the LNA's. This is surprising because this location should be RFI tight so this test should be repeated to confirm that the leakage mechanism really is direct leakage into the IF rather than a sideband on LO1.

Note that given the particular choice of IF bands and WCA YIG ranges in place for the various ALMA FE's Band 6 is the only current band which has this problem of WCA YIG leakage into the USB of the IFDC, although in the future Band 2 has potential for the problem. Let's see what, if any, changes are required to bring this Band 6 spurious response within specification. ALMA System Specification 295 requires IF narrow band spurious signals to be -40 dBc with respect to the system noise in 1 MHz bandwidth. The measurement of this spurious signal at an IF frequency of 12.3 GHz on DV03, reported in the 15Apr2010 posting to JIRA-2057, shows a signal strength of +14 dBc with respect to the system noise in a bandwidth of 1 MHz so it is out-of-spec by 54 dB. We will now assume that this signal strength is constant at the point of leakage over the allowable range of YIG frequencies, but it will be attenuated by the IF responses of the FE and IFDC. This assumption that the leakage is constant with YIG frequency needs to be checked by testing at YIG frequencies above 12.5 GHz. With this assumption we can use the FE and IFDC responses shown in Figures 3 and 4 to predict the strength of the spurious signal as a function of LO2 and WCA YIG frequency. Table 2 shows the predicted strength of the spurious signal expressed in dB with respect to the specification. For example, with an LO2 of 10.5 GHz and a WCA YIG at 12.5 GHz the spurious signal is predicted to be 46 dB above the specification.

Table 2 Strength of the WCA YIG spurious signal as a function of LO2 and WCA YIG frequency. The table entries show the strength of the signal in dB with respect to the specification.

	WCA YIG Freq (GHz)	12.5	13.0	13.5	14.0	14.5
LO2 Freq (GHz)						
10.5		+46	+21	-15	-47	-48
11.0			+21	-15	-47	-48
11.5				-15	-47	-48

The predicted strengths of the spurious signals shown in Table 2 apply directly to the autocorrelation spectrum used for single dish observations. For the interferometer case several other mechanisms will reduce the strength of the spur in cross-correlation data. The spur will be attenuated by the natural fringe rate of the astronomical source being observed, but the fringe rate goes to zero on the U axis in the UV plane so this attenuation is not always available. 180 degree Walsh function phase switching will suppress the spur if the leakage mechanism is direct leakage of the WCA YIG into the IF, but will not suppress it if the leakage mechanism is a sideband on LO1. LO Offsetting on LO1 will suppress the spur for either leakage mechanism but, because the spur will have a residual frequency offset of only (LO offset)/(Warm multiplier*Cold multiplier) = LO offset/18 , the amount of suppression may not be enough to bring the spur within the specification for the shortest integration times. The smallest value of LO offset is 30 KHz and for the shortest integration time of 16 ms the amount of suppression is of order (TMS eqn 15.5) $1/(\pi*1.7*10^3*16*10^{-3}) = -19$ dB.

Here are some possible actions which ALMA can decide to take with respect to this spurious signal. But no action should be taken until tests confirm that the spurs are present at the currently measured strength for WCA frequencies above 12.5 GHz.

(1) Take no action in which case there will be a very strong (several 10's of dB above spec) unresolved spurious CW signal in the band whenever LO2 is in the range 10.5-11.0 GHz at the same time that the WCA YIG is above 12.5 GHz (LO1>225 GHz).

(2) Install a low pass filter on the Band 6 FE IF output that has negligible attenuation at 10.0 GHz and has 45 dB attenuation at 12.5 GHz. Note that if either of the IFDC filters described in solutions (3) and (4) in section 2.1 above are implemented then the attenuation requirements for this Band 6 filter are relaxed accordingly.

(3) Do not use the LO2 tuning range 10.5 to 11.0 GHz when Band 6 is selected and always operate Band 6 with LO1-LO2 frequency offsetting in place. This frequency offsetting is

likely to be required always anyway in order to improve the sideband rejection of the FE SSB mixers. See point (2) of Section 2.1 above for a discussion of the impact of loosing this range of LO2 tuning.

3. Conclusions

The issues discussed in this report are relevant only for FE Bands 6 and 9 which use the upper end of the 4-12 GHz IF range and are not relevant for Bands 3 and 7 which use an IF of 4-8 GHz. The impact of IF signals in the frequency range 12-14 GHz has been calculated. Signals in this range are not negligible because the response of the FE and BE electronic systems does not roll off rapidly enough above 12 GHz for Band 6 and Band 9. IF signals in this range are converted in-band via the USB response of the IFDC mixer when LO2 is in the range 10.5-11.5 GHz.

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Acknowledgements:

Thanks to Darrel Emerson for helpful discussions concerning the impact of these spurious signals.