EVLA Memo 167
Clock leakage into the EVLA baseband datastream

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During observations with the EVLA at very high spectral resolution, a forest of narrowband spurious features (also nicknamed “grass”) has been observed - see Figure 1.

A variety of tests and checks has established that the primary cause of this is leakage of a 64-MHz system clock, and its harmonics, into the astronomical signal datapath somewhere between the last tuneable LO and the samplers. As there are 64-MHz clock signals in the sampler module, it is presumed that the leakage is happening just before the samplers[1]. This is leading to clock leakage at fixed baseband frequencies. We have seen all the odd harmonics of 64 MHz in the 1024 MHz WIDAR baseband spectrum.

We have not looked at the even harmonics: these correspond to the gap between each of the 128-MHz WIDAR subbands, and are thus not a region which is easily observable. However we note that even harmonics are seen in EVLA Memo 98 (Figure 5). Although the test setup for this memo is unclear, it is possible there is leakage at even harmonics in the EVLA systems.

Because this leakage is happening at baseband, not at sky frequencies, the sky frequencies affected are shifted by changes in the front-end local oscillator settings. A remedy to the issue is thus straightforward for spectral line observations: ensure that the front-end local oscillators are set so that observing band is more than a few spectral window bandwidths away from any of the 64-MHz harmonics. The clock leakage is unlikely to be significant effect for continuum observations, because the effect is heavily diluted by the large bandwidth used.

We note that in practise this issue will only be seen when the WIDAR subband mixer is used. To get the spectral resolutions needed to see the effect, the 8-MHz filter stages will need to be used. If the subband mixer is not used, the clock harmonics fall in the gap between 8-MHz filters.

Normally this clock leakage will not correlate between antennas: the leakage is occurring between where the astronomical signal is shifted by $f_{\rm shift}$ at the front-end, and where this shift is removed in the correlation process. Consequently the leakages at the antennas are at a slightly different sky frequencies and thus do not correlate. The normal fringe frequency will also prevent the leakages from correlating. This means that the response in cross-correlations will integrate down at $1/\tau$ (not the square root of this). However the leakage will contribute to system noise, which will integrate down at the $1/\sqrt{\tau}$ rate.

In addition to the harmonic of 64 MHz, we have seen a secondary feature a few kilohertz to a few 10s of kilohertz

[1] An early hypothesis was that the 64-MHz harmonics were a characteristic of the samplers. The 8-bit samplers, where the issue was noted, have a “flash” sampler architecture. This architecture is not expected to generate subharmonics of the 2048-MHz sampling frequency, and so the sampler itself is unlikely to be the cause. This is not necessarily the case with other sampler architectures which use time multiplexing to achieve high sampling rates.

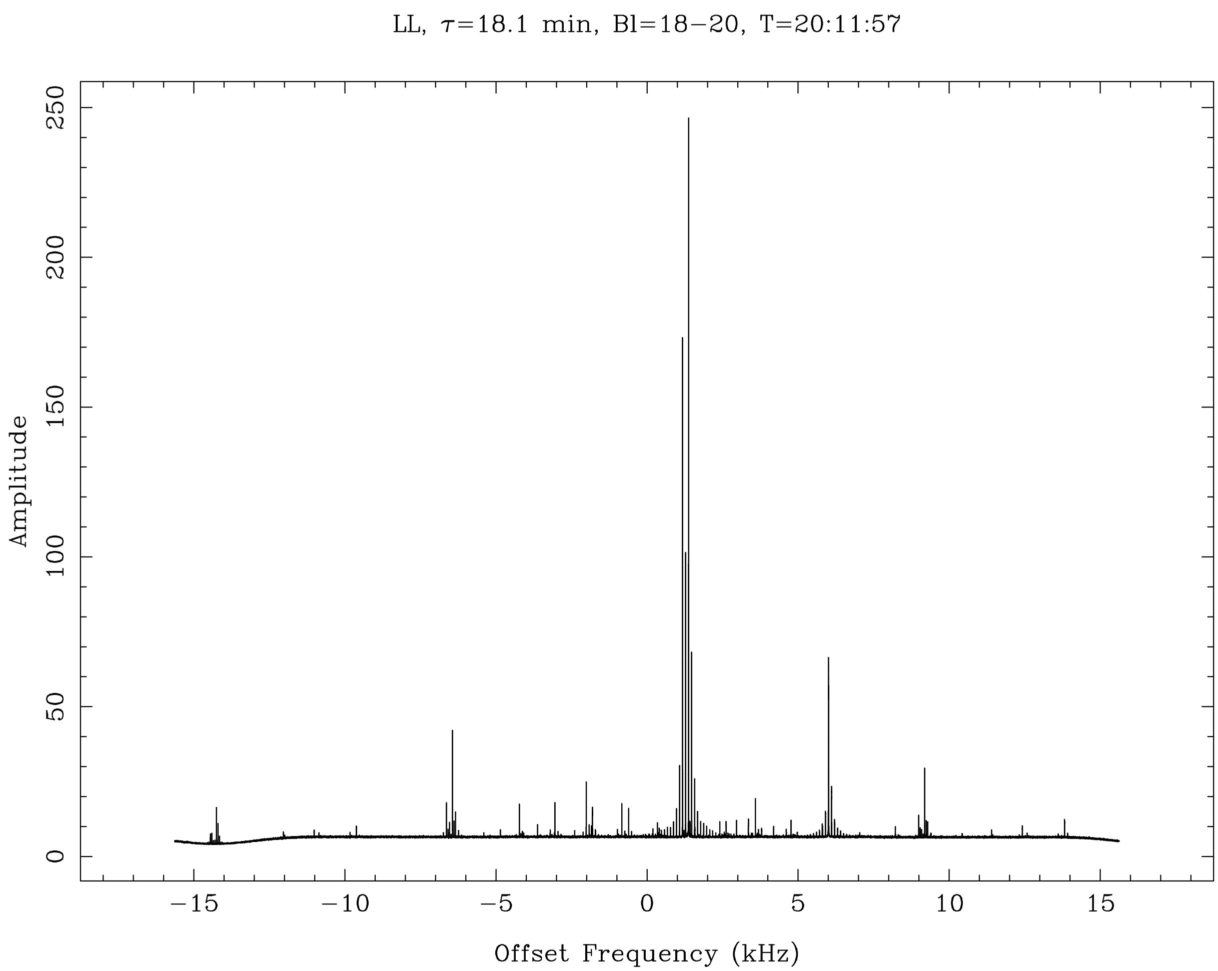

Figure 1: A forest of spurious narrowband features. The center frequency corresponds to 448 MHz ($= 7 \times 64$) in the WIDAR baseband. The shift of the features from the center frequency is caused by the $f_{\rm shift}$ frequencies for antennas 18 and 20 (1.4 and 1.2 kHz respectively). Note that spurious features occur at the $f_{\rm shift}$ frequencies of the individual antennas - not the difference frequency.

away from the multiple 64 MHz. This secondary feature is significantly weaker, is typically at slightly different frequencies for the R and L channels, and does not appear to be completely coherent with the system clock. We do not know its origin.

The clock leakage on its own does not generate the "forest" of spurious features. The forest is generated from the clock leakage from the following two effects:

- The clock leakage is shifted by f_{shift} in the final output. Also satellite lines at harmonics of f_{shift}, caused by the three-level fringe rotator, are seen around the main feature.
- A flaw[2] was found in configuring WIDAR when observing in spectral bandwidths of 62.5 and 31.75 kHz. This flaw caused a discontinuity in the phase model every 10 ms. This in turn leads to a 100 Hz comb of satellite lines around other features.

These two effects combine to give a quite complex forest of spurious features.

The strength of the spurious features is obviously of interest: Table 1 gives the approximate strength of the worst harmonic in the WIDAR baseband for each 8-bit sampler on each antenna. These are in units of MJy·Hz. To determine the strength of the spurious response in an autocorrelation, divide these by the channel width (in Hz). For a channel width of ≈50 kHz, the strength of the worst clock leakage (sampler 25D) is comparable to system noise of ≈300 Jy. This greatly overestimates the response in cross-correlation because the response integrates down rapidly.

Our investigation has been limited to the 8-bit samplers. It is quite plausible (indeed highly likely at some level) that the 3-bit samplers will experience similar issues. They, too, have 64-MHz clock signals in close proximity to the samplers. Characterization of the 3-bit samplers is called for. However this issue is probably a less important effect for the 3-bit systems: generally high spectral resolution observations will use the 8-bit system, whereas the use of 3-bit samplers will be used in continuum modes.

[2] A digression into details of the subband mixer is warranted. The mixer implementation allows 32-bit phase and phase-dot registers to be updated at each correlator 'tick', which is 100 Hz. If the desired mixer frequency is a multiple of the 100 Hz 'tick' and constant, then the mixer control can be simplified to an initial setting of phase-dot and an arbitrary, constant choice for phase, which can be taken to be zero. The station board configuration takes this simplification and enforces it by coercing the requested center frequency of the subband to be a multiple of 100 Hz. This fails for the two narrowest subband bandwidths – 62.5 and 31.75 kHz – where the center frequency of the subband is not a multiple of 100 Hz. It also has the unpleasant side effect of making the frequency labeling in MCAF incorrect. We propose to remedy this by

1. no longer coercing the requested center frequency; and
2. correctly updating the phase register of the mixer at each correlator tick.

This work is in progress at the writing of this memo. It should be noted that if it is intended to use the mixer to remove the WIDAR f_{shift} frequency, or the natural fringe frequency, then care must be taken to set the initial phase for the mixer when the station board is configured.

Antenna	A	B	C	D
1	0.62	0.37	0.98	3.77
2	1.65	2.36	1.43	1.53
3	9.94	1.20	0.74	3.57
4	4.07	3.55	0.58	0.49
5	2.31	3.56	3.74	0.48
6	6.16	0.80	0.93	2.25
7	1.79	1.38	1.69	4.50
8	0.97	6.43	0.57	6.60
9	1.13	0.79	1.36	2.25
10	0.47	1.20	4.01	1.88
11	0.71	1.96	4.32	1.19
12	1.68	4.43	0.87	2.56
13	7.82	0.66	1.00	2.22
14	0.46	1.76	1.20	0.41
15	0.93	9.18	0.87	2.81
16	1.36	6.48	2.64	3.73
17	1.25	3.54	2.93	2.35
18	1.13	1.75	1.71	0.36
19	0.63	0.54	1.30	1.53
20	0.63	0.86	2.44	2.40
21	1.46	1.34	2.21	0.64
22	0.76	0.80	0.41	3.00
23	0.46	2.28	0.84	5.60
24	1.96	0.97	0.77	1.13
25	0.84	3.97	0.65	14.14
26	4.49	6.61	4.49	4.63
28	1.89	0.21	0.76	1.06

Table 1: Strength of sampler leakage signal in MJy·Hz. The table is for the 8-bit samplers, and gives the case of the worst harmonic within the WIDAR 1024-MHz baseband.