EVLA Memo # 194
EVLA Ka-band Receiver Down Converter Module Harmonics: The "Mega-Birdie" at 29440 MHz

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Abstract

Observations carried out using the Ka-band receivers of the EVLA show an extremely strong spectral feature (a birdie) at 29440 MHz. This frequency is the 230th harmonic of 128 MHz, and the 2nd harmonic of the L301-1 synthesizer. Our investigation shows that this feature is due to the leakage of the fundamental Local Oscillator (LO) frequency into the Intermediate Frequency (IF) of the Ka-band receiver block Down Converter Module (DCM). Reducing this LO leakage into the IF will require an expensive redesign of the DCM.

1. Introduction

This report is the conclusion of an investigation into the source of the 29440 MHz birdie. The frequency 29440 MHz is the 230th harmonic of 128 MHz, and the birdie is visible on all baselines and cross correlation products.

The spectrum in Figure 1 from the RFI spectral sweep shows the birdie prominently. The spectrum is a scalar average of all the baselines in the D-configuration of the array in RR, and has a channel separation of 125 kHz. Hanning smoothing was applied. The scale is logarithmic (in dB) with an arbitrary offset. The birdie is also seen in the LL correlation.

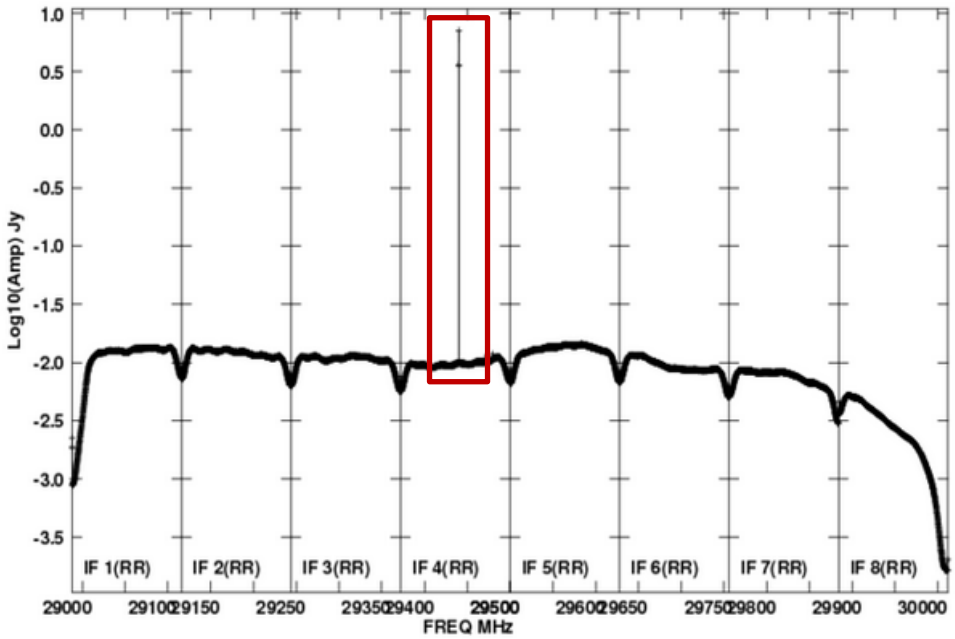

Figure 1: The 29440 MHz birdie. The spectrum is a scalar average of all the baselines in the D-configuration in RR. The scale is logarithmic, in dB, with an arbitrary offset.

2. Summary of Findings

The 29440 MHz birdie is the 2nd harmonic of 14720 MHz, which is the default (auto) tuning of the L301-1[1] for Ka-band observations centered at 34.5 GHz and below.[2] The RFI sweep script uses the automatic system tuning, and therefore would be tuned as such for the lower portion of the Ka-band utilizing the Intermediate Frequency (IF) pair B/D.

The harmonic is due to leakage of the fundamental Local Oscillator (LO) frequency into the IF path of the Ka-band receiver block Down Converter Module (DCM). When the fundamental LO is present in the IF, it will appear to the user as the second fundamental of the LO in the Radio Frequency (RF).

Based on laboratory tests of EVLA Ka-band DCM Serial Number (S/N) 32, the LO leakage power is -73dBm in to the IF. This is unfortunately the tuning with the worst rejection of the fundamental LO within the Ka-band DCM tuning range. Other legal tuning values have LO rejection of 80-100dB or more. The results are summarized in Table 1. The fundamental LO is shown in the first column. The leaked LO power in to the IF is shown in column 2. The second and third harmonic frequencies are shown in columns three and four, respectively. The range of the legal tunings for the Ka-band receiver's down converter is highlighted, with band edges shown in orange. See Table 2 for the full results.

f_{LO} (MHz)	$P_{LO \rightarrow IF}$ (dBm)	$f_{2 \times LO}$ (MHz)	$f_{3 \times LO}$ (MHz)
13952	< -100	27904	41856
14208	< -100	28416	42624
14464	-80	28928	43392
14720	**-73**	**29440**	44160
14976	-95	29952	44928
15232	< -100	30464	45696
15488	< -100	30976	46464
15744	-80	31488	47232
16000	< -100	32000	48000
16256	-96	32512	48768
16512	-93	33024	49536
16768	< -100	33536	50304

Table 1: The leaked LO power in to the IF in the Ka-band Down Converter Module Serial Number 32. The highlighted fields denote the range of the legal tunings for the Ka-band down converter, with band edges shown in orange.

The Ka-band DCM is built around a Monolithic Microwave Integrated Circuit (MMIC) which is not easily modified. Reducing LO leakage into the IF would require a redesign of this module, at significant expense in both dollars and manpower that is not recommended at this time.

Should a user have a spectral line or other features they wish to investigate in the vicinity of this spur, the spur can be moved to other frequencies shown in the third column of Table 1. E.g., tuning the fundamental LO to 14976 MHz would both reduce the amplitude of the spur and move it to 29952 MHz. A permanent

[1] The L301-1 is the synthesizer that is used for the Ka-band block down conversion.
[2] Tuning parameters were computed using the Tuning – Auto program ("Test Auto Config of EVLA") available on the SSS Test Programs page: Http://builder.aoc.nrao.edu/sssTestPgm.shtml

change in tuning would move the lower frequency limit for the IF pair AC from 32 GHz to 32.76 GHz. Since this is a feature advertised to users, a policy decision would be required.

2.1. Future Installations

Should the EVLA Ka-band receiver be installed at the VLBA or other sites, it is unlikely that the DCM would be reworked and/or redesigned to eliminate this spur. As an integrated MMIC module, any changes would involve prototyping and testing that is currently inconsistent with the 'crashed' schedules proposed for the VLBA Ka-band upgrade.

3. Investigated Hypotheses

Three possible ways this harmonic may be coupled into the signal path were identified and investigated:

1) Present at the output of the L301-1, and inadequately attenuated by existing filters in the LO path.
2) Present at the output of the L301-1, and radiated from the L301-1 and associated coaxial cables into the Ka-band feed.
3) Generated as a mixer product, or by a device in the LO path, of the Ka-band block Down Converter Module (DCM).

4. On-Antenna Tests

Tests were performed on antenna ea01 on May 7, 2015. A maintenance script was run to setup the antenna for Ka-band, the LO tuning was adjusted to the bandpass of interest, and the bandpass was plotted to confirm the presence of the 29440 MHz birdie (see Figure 2). A second, stronger birdie, at roughly 29480 MHz is also visible in the total power data. This feature may have also been seen in the RFI sweeps, but it is much weaker compared to the 29440 MHz birdie (see Figure 3).

The tuning of the L301-1 was changed to both 14464 MHz and 14976 MHz (the L301 is tuned in 256 MHz increments) to determine if the birdie moves with tuning. As expected, the birdie moves to 28928 MHz and 29952 MHz, respectively.

A follow up observation was performed on May 12, 2015. A sequence of four figures (Figure 4 – Figure 7) shows the birdie moving from 29400 MHz to 29952 MHz when the L301-1 is tuned to 14720 MHz and 14976 MHz, respectively. We note that the birdie previously seen at 29480 MHz is no longer visible in this observation.

Conclusion: The 29440 MHz birdie appears in the spectrum as the second harmonic of the L301-1. However, how this harmonic is coupled into the signal path is unclear.

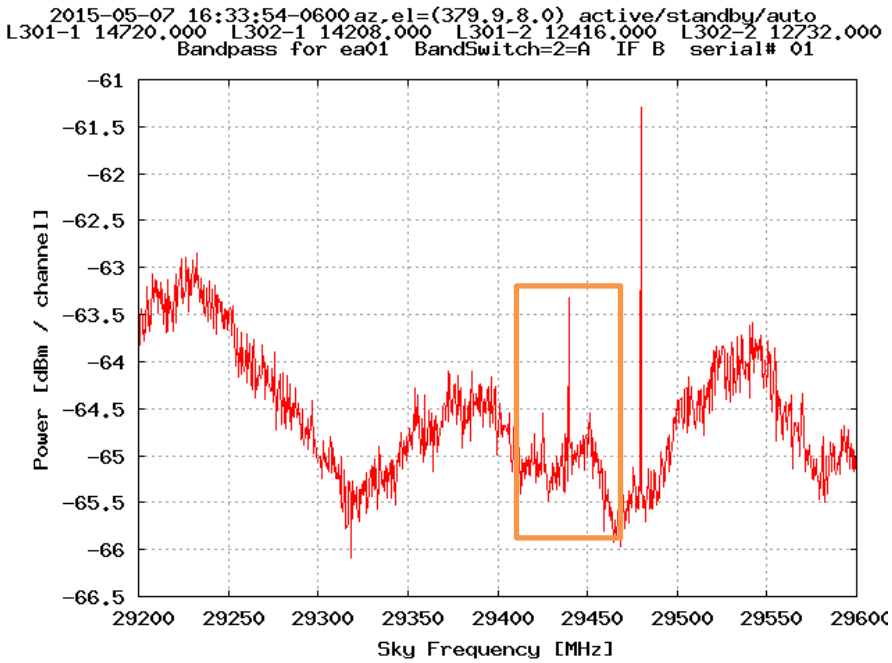

Figure 2: Bandpass plot using the default tuning from the Ka-band maintenance script. The observation was carried out on 2015-05-07. The 29440 MHz birdie (marked) is the weaker of the two visible in this plot. The 29480 MHz birdie may have been present during the RFI spectral sweep as can be seen in Figure 3.

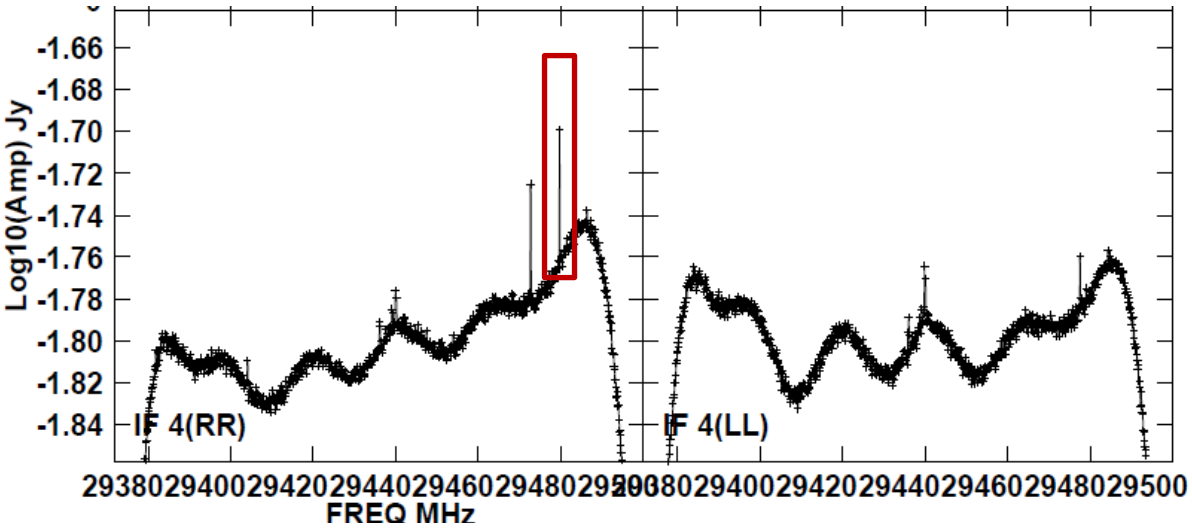

Figure 3: A spectrum at K-band from the RFI sweep showing weaker birdies. The 29480 MHz birdie (marked) may only be present in the RR polarization product.

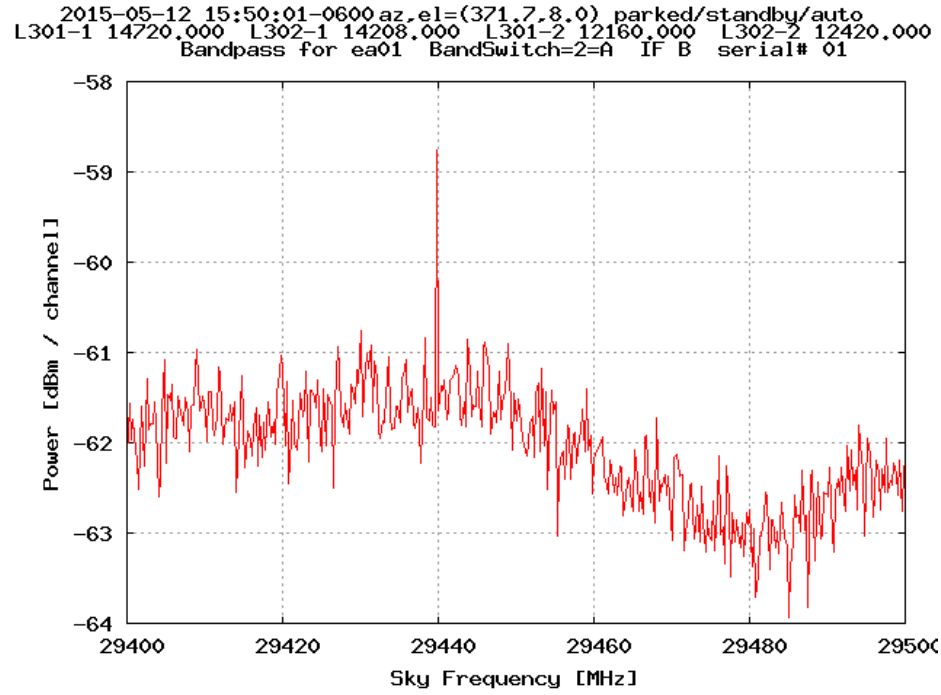

Figure 4: Follow up observation on 2015-05-12. The birdie is at 29440 MHz with the default L301-1 tuning.

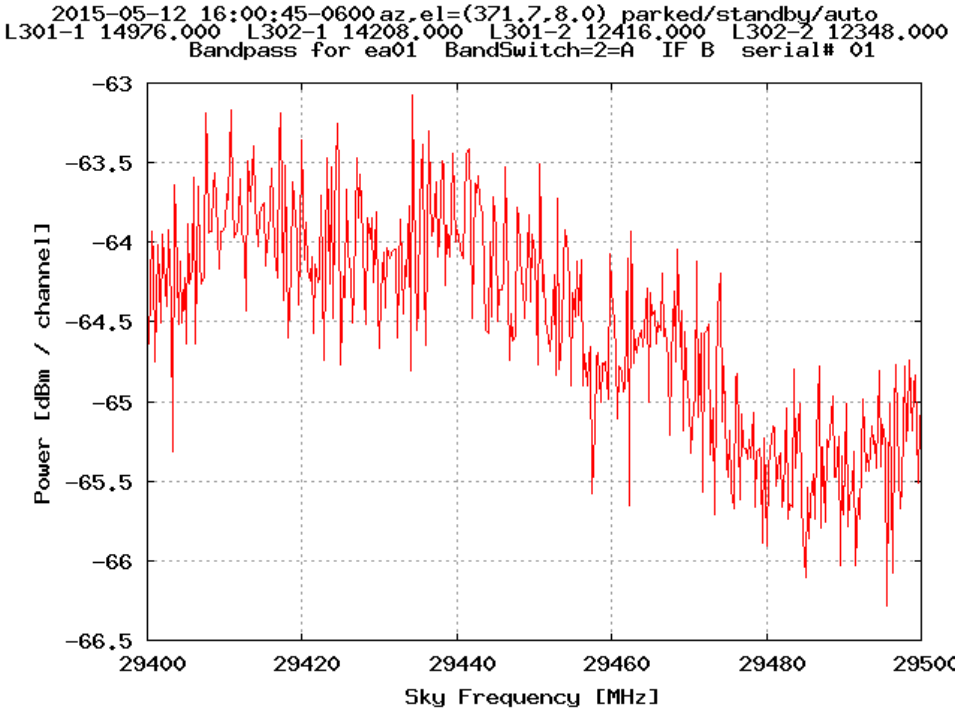

Figure 5: The birdie at 29440 MHz is not present once the fundamental LO, from the L301-1, is tuned away from 14720 MHz.

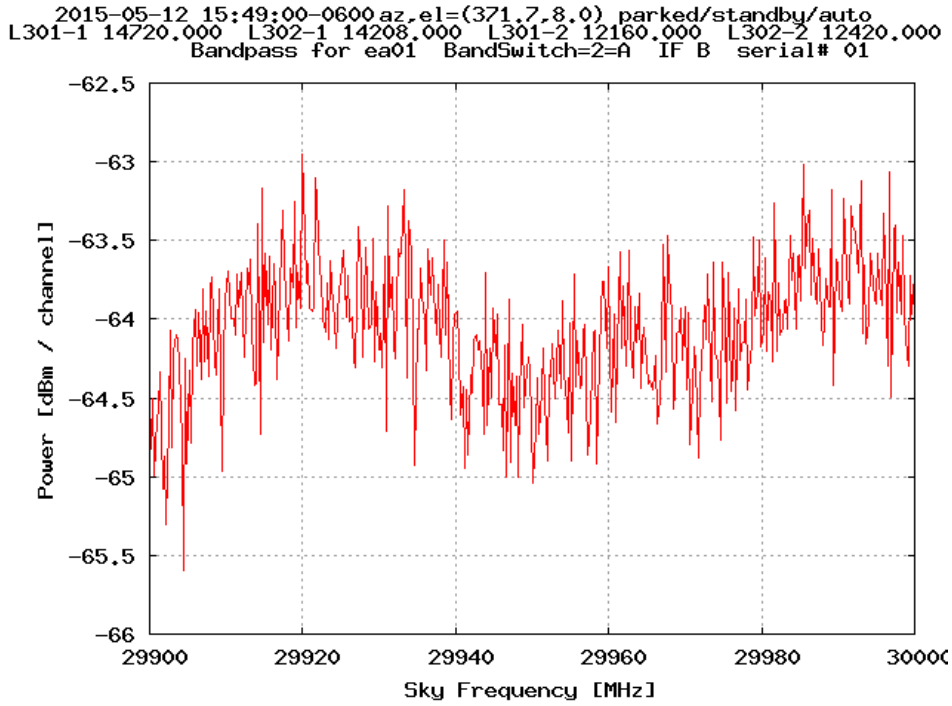

Figure 6: No birdie at 29952 MHz with the L301-1 tuned to 14720 MHz.

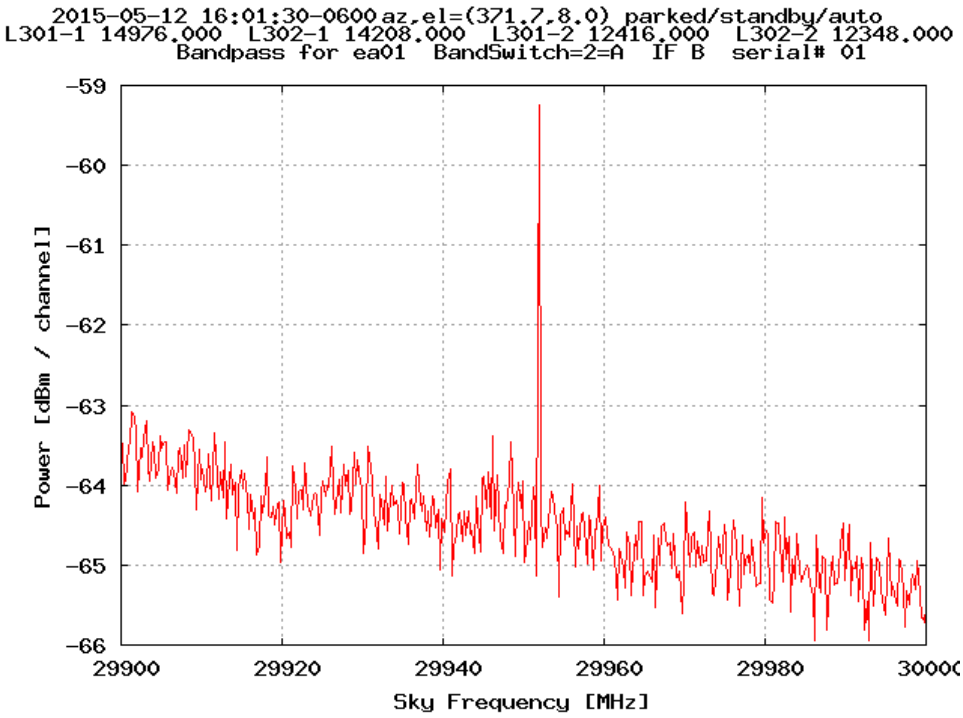

Figure 7: The birdie at 29952 MHz when the L301-1 is tuned to 14976 MHz.

5. L301-1 Characterization

The output level of the L301-1 was tested in the lab to determine the power of the second harmonic of the LO. Measurements are typically given in dBm with dBc in parenthesis. The L301-1 was set up with a short (~3 ft) section of heliax cable and no DC block to the input of an Agilent-8565 50 GHz spectrum analyzer. The L301-1 was tuned to 14720 MHz for the duration of the test.

The 2nd harmonic of the output (29440 MHz) has an output power of -72dBm (-83.5dBc). Other birdies are visible at odd multiples of 128 MHz:

- 29568 MHz (231st harmonic of 128 MHz), -66.8dBm (-78.3dBc).
- 29824 MHz (233rd harmonic of 128 MHz), -83.7dBm (-95.2dBc).
- 30080 MHz (235th harmonic of 128 MHz), -74.8dBm (-86.3dBc).

Note that the 512 MHz comb and its harmonics are not visible on the spectrum analyzer. Output power at 14848 MHz, the nearest comb line, was -86dBm (-97.5dBc), while at 29696 MHz it is below the noise level of the spectrum analyzer.

The power of these harmonics (with the marginal exception of 29568 MHz) meets the specifications for the L301-1. The specification, from the EVLA project book, is as follows:

- Output Power: +11dBm (Nominal and Adjustable)
- Output Spurious signal level: <-70 dBc (Except for harmonics of Ref (i.e., the 128 MHz reference)
- Output harmonics of Ref: <-80 dBc

The 128 MHz harmonics appear to be intermodulation products. Their composition is given by

$$(2 \times \text{nearest comb}) + (N \times 128\ \text{MHz})^{\ddagger}.$$

It is worth noting that the 231st, 233rd and 235th harmonics of 128 MHz are not present in the RFI spectral sweeps.

Conclusion: The 2nd harmonic of the output is not the highest power harmonic, and none of the nearby harmonics of comparable power are visible in the RFI spectral sweep data, therefore the L301-1 is not likely to be the cause of the 29440 MHz birdie visible in the IF.

There are also long coaxial cables, with high attenuation above 18 GHz, and filters within the IF path of the Ka-band receiver DCM, therefore the amplitudes of these spurs would be significantly attenuated before the block down converter mixer.

6. Ka-band Receiver LO Path

The frequency trippler in the LO path of the Ka-band receiver may be producing a second or a fourth harmonic of the fundamental LO supplied by the L301-1. A block diagram of the receiver can be seen in Figure 8.

Laboratory testing of EVLA Ka-band DCM S/N 32 confirms that that there is leakage of the fundamental LO into the IF port from the block down converter. When the fundamental LO is tuned to the default 14720 MHz, the LO leakage power is -73dBm in to the IF. Test results are summarized in Table 1 and the full test results are shown Table 2.

‡ The 128 MHz input to the L301-1 is used as a digital reference within the module, so it is clipped to a square wave. This may also be generating the additional harmonics, but is less likely than mixer products.

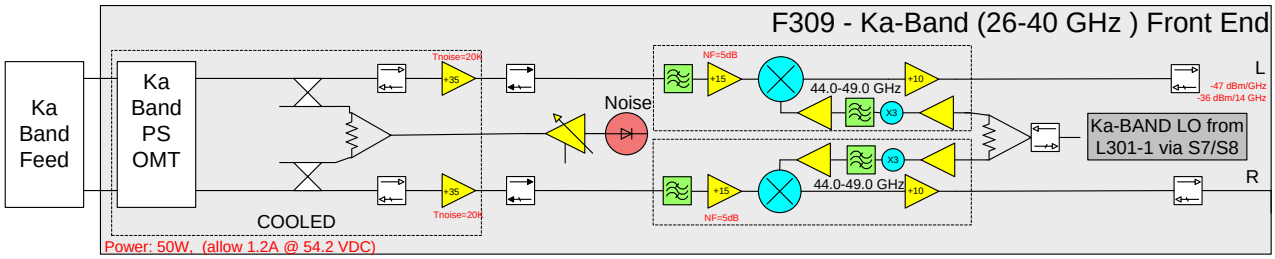

Figure 8: VLA Ka-Band Receiver Bock Diagram. Configuration of the DCM module is diagrammatic only. Actual schematic differs.

Due to the arithmetic of the down conversion process, when the fundamental LO is present in the IF, it will appear to the user as the second fundamental of the LO in the RF. Unfortunately, the LO tuning of 14720 MHz has the worst rejection of the fundamental LO within the Ka-band DCM tuning range. Other legal tuning values have LO rejection of 80-100dB or more.

The Ka-band DCM is an integrated MMIC module that is not easily modified. Reducing LO leakage into the IF would require a redesign of this module, at significant expense in both dollars and manpower.

f_{LO} (MHz)	$P_{LO \rightarrow IF}$ (dBm)	VMIX (V)	$f_{2 \times LO}$ (MHz)	$f_{3 \times LO}$ (MHz)	$f_{4 \times LO}$ (MHz)	$f_{5 \times LO}$ (MHz)	$f_{6 \times LO}$ (MHz)	$f_{7 \times LO}$ (MHz)	$f_{8 \times LO}$ (MHz)	$f_{9 \times LO}$ (MHz)
5248	-80	2.510	10496	15744	20992	26240	31488	36736	41984	47232
5504	-53	2.510	11008	16512	22016	27520	33024	38528	44032	49536
5760	-77	2.506	11520	17280	23040	28800	34560	40320	46080	51840
6016	-86	2.512	12032	18048	24064	30080	36096	42112	48128	54144
6272	-45	2.510	12544	18816	25088	31360	37632	43904	50176	56448
6528	-73	2.503	13056	19584	26112	32640	39168	45696	52224	58752
6784	-90	2.493	13568	20352	27136	33920	40704	47488	54272	61056
7040	-87	2.511	14080	21120	28160	35200	42240	49280	56320	63360
7296	-56	2.512	14592	21888	29184	36480	43776	51072	58368	65664
7552	-69	2.505	15104	22656	30208	37760	45312	52864	60416	67968
8064	-86	2.506	16128	24192	32256	40320	48384	56448	64512	72576
8320	-86	2.511	16640	24960	33280	41600	49920	58240	66560	74880
8832	-79	2.490	17664	26496	35328	44160	52992	61824	70656	79488
9088	-96	2.433	18176	27264	36352	45440	54528	63616	72704	81792
9344	-98	2.447	18688	28032	37376	46720	56064	65408	74752	84096
9600	-65	2.478	19200	28800	38400	48000	57600	67200	76800	86400
9856	-43	2.420	19712	29568	39424	49280	59136	68992	78848	88704
10112	-70	2.433	20224	30336	40448	50560	60672	70784	80896	91008
10368	-81	2.360	20736	31104	41472	51840	62208	72576	82944	93312
10624	-71	2.392	21248	31872	42496	53120	63744	74368	84992	95616
10880	< -100	2.406	21760	32640	43520	54400	65280	76160	87040	97920
11136	< -100	2.364	22272	33408	44544	55680	66816	77952	89088	100224
11392	< -100	2.297	22784	34176	45568	56960	68352	79744	91136	102528
11648	< -100	2.343	23296	34944	46592	58240	69888	81536	93184	104832
11904	< -100	2.257	23808	35712	47616	59520	71424	83328	95232	107136
12160	-85	2.219	24320	36480	48640	60800	72960	85120	97280	109440
12416	-98	2.289	24832	37248	49664	62080	74496	86912	99328	111744
12672	< -100	2.513	25344	38016	50688	63360	76032	88704	101376	114048
12928	< -100	2.513	25856	38784	51712	64640	77568	90496	103424	116352
13184	< -100	2.513	26368	39552	52736	65920	79104	92288	105472	118656
13440	< -100	2.513	26880	40320	53760	67200	80640	94080	107520	120960
13696	< -100	2.513	27392	41088	54784	68480	82176	95872	109568	123264
13952	< -100	2.503	27904	41856	55808	69760	83712	97664	111616	125568
14208	< -100	2.502	28416	42624	56832	71040	85248	99456	113664	127872
14464	-80	2.510	28928	43392	57856	72320	86784	101248	115712	130176
14720	-73	2.377	29440	44160	58880	73600	88320	103040	117760	132480
14976	-95	2.308	29952	44928	59904	74880	89856	104832	119808	134784
15232	< -100	2.219	30464	45696	60928	76160	91392	106624	121856	137088
15488	< -100	2.153	30976	46464	61952	77440	92928	108416	123904	139392
15744	-80	2.137	31488	47232	62976	78720	94464	110208	125952	141696
16000	< -100	2.196	32000	48000	64000	80000	96000	112000	128000	144000
16256	-96	2.110	32512	48768	65024	81280	97536	113792	130048	146304
16512	-93	2.084	33024	49536	66048	82560	99072	115584	132096	148608
16768	< -100	2.488	33536	50304	67072	83840	100608	117376	134144	150912
17024	< -100	2.509	34048	51072	68096	85120	102144	119168	136192	153216
17280	< -100	2.513	34560	51840	69120	86400	103680	120960	138240	155520
17536	< -100	2.513	35072	52608	70144	87680	105216	122752	140288	157824
17792	-99	2.513	35584	53376	71168	88960	106752	124544	142336	160128
18048	-98	2.513	36096	54144	72192	90240	108288	126336	144384	162432
18304	-94	2.513	36608	54912	73216	91520	109824	128128	146432	164736
18560	< -100	2.513	37120	55680	74240	92800	111360	129920	148480	167040

Table 2: Ka-band DCM LO leakage tests using the receiver S/N 32 with effective LO Leakage to IF output from ($n \times f_{LO} - (n-1) \times f_{LO}$). Legal LO tunings are highlighted in the red rectangle.