VLBA SENSITIVITY UPGRADE MEMO #14

IMPACT OF DBE CROSSOVER FREQUENCIES

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April 14, 2007

ABSTRACT: The new digital backends under design for the VLBA will use a polyphase filter to break the 512 MHz IF signal into two 256 MHz subbands. Further flexible digital baseband converters can create baseband signals anywhere within the subbands, but those basebands cannot span the crossover frequency between the subbands. That crossover frequency can only be moved, in terms of the corresponding RF frequency, by adjusting the front end synthesizers, which cannot be fine tuned. This memo explores the impact of the narrow region of reduced sensitivity at the crossover frequency. The conclusion is that the existence of the crossover frequencies does not present any insurmountable problems, but is a factor that the users and scheduling software must take into account when setting observing frequencies.

1. Introduction

The current VLBA backend, including the baseband converters (BBCs), samplers and formatters, limit the output bit rate to 512 Mbps. The VLBA has a goal of reaching 4 Gbps by 2011, which cannot be achieved with this hardware. A new Digital Backend (DBE) is being designed by NRAO and Haystack. With modern technology, all of the above equipment, with considerably increased capability, will be replaced with one or two boards containing two samplers, clocked at either 1024 or 2048 MHz, and a large FPGA. The FPGA will split the IF, now tightly filtered to 512-1024 MHz into two subbands of 256 MHz. The existing IFs are really 550 MHz wide so they can be used with just just the addition of a band limiting filter, avoiding the need for expensive LO/IF upgrades. From the within subbands, up to 16 basebands will be formed at whatever frequencies and bandwidths are desired. All of this will be done for rather modest cost – probably significantly less than the original cost of one BBC.

As with the EVLA, the initial FIR filters that create the 256 MHz subbands are constrained to fixed frequencies within the IF. There will be a crossover point centered at 768 MHz in the IF where the sensitivity will be reduced over approximately 4 MHz. Techniques for stitching the bands together, as used with the WIDAR, should also work here so those regions are not lost, but will be degraded. The high natural fringe rates of VLBI will play the roll of the offset frequencies in the EVLA to suppress correlation of aliased signals. With the EVLA/WIDAR system, those crossover regions can be kept away from any specific frequencies of interest because there is an ability to fine tune the LO signals used before sampling. The reason for this note is that the VLBA does not have that flexibility, so the implications of these reduced sensitivity regions of the spectrum need to be understood. There are options to increase the tuning capability to allow the crossover points to be shifted, but they add complexity in the hardware and software and should be avoided if possible.

2. Technical Details

Once the DBE is installed, the only LOs that come before the sampler on the VLBA will be the front end synthesizers which are constrained to lock points of N × 500 ± 100 MHz. The sampler clock also has the effect of an LO, but the preferred design has it running at a fixed 1024 MHz. Thus if the crossover point falls on a frequency of interest, the only options are to shift to another setting of the front end synthesizers, if possible, or live with the reduced performance. The question addressed here is whether there are circumstances where these options are not acceptable, forcing the implementation of some scheme to allow finer tuning of the LOs.

The tuning set points for the front end synthesizers are spaced by 200 and 300 MHz. That will set the tuning capability at 15 GHz and below. At higher frequencies, two synthesizers are used, with one of them multiplied by 1, 3, or 6 for the 1 cm, 7 mm, or 3 mm bands respectively. The resulting spacings between LO set points are between 100 and 300 MHz (with one of 400 MHz). For any setting where there is an adjacent setting that is less than 256 MHz different in frequency (ie 100 or 200 MHz), it will be possible to find an alternate LO setting to observe a frequency affected by the crossover. Thus the only situations where a crossover frequency cannot be observed with an alternate LO setup are those only bordered by 300 MHz or more steps. Fortunately, in practice, this never happens in the middle of an RF receiver band. It only happens when either the lowest or highest setting is offset from its nearest neighbor by 300 MHz. Those situations are summarized here:

20 cm: There is a crossover at 1332 MHz with the 2.1 GHz first LO that cannot be avoided. This frequency is already filtered at KP and FD because of the radar balloons in the vicinity. The main adverse affect of this crossover is likely to be on observations of redshifted hydrogen near z=0.066.

20 cm: There is a crossover at 1632 MHz with the standard 2400 MHz first LO setting that can be avoided using a 2.6 GHz LO setting. We've never used that for 20 cm but it should work. It puts the lower edge of the 512 MHz IF at 1576 MHz, which is a bit high. Mostly the 1632 MHz crossover will constrain continuum baseband settings, although anyone observing OH at a redshift near 0.02 will need to be aware of the issue and maybe use the 2.6 GHz synthesizer setting.

13 cm: There is a crossover at 2332 MHz that can only be avoided by using the 2.9 GHz first LO, which restricts the upper edge of the band to 2388 MHz, somewhat below the top of the RFI filter at 2400 MHz. But 2332 MHz is in the middle of the satellite radio frequencies so it is a bad place to observe in any case.

4 cm: There is a crossover at 7868 MHz that cannot be avoided. While that frequency is inside the maximum range for this receiver, it is outside the good performance range so will be used rarely if ever.

2 cm: There is a crossover at 11868 MHz that cannot be avoided. Like the one at 4 cm, this frequency is in the possible observing range but is well outside the good range for the receiver. It is unlikely to be used.

2 cm: Each of the 4 RF filters has a crossover at nn868 MHz, near the bottom of the filter band. But, except for the first noted above, that frequency can be reached by forcing the use of the next lower filter.

1 cm: There is a crossover at 25068 MHz in the highest possible LO setting. Again, that is in the maximum range, but not in the good range for the receiver.

6cm, 7mm, and 3 mm: No obvious problems

Note that, if a 200 MHz step is used to move away from a crossover, the signal will typically end up 56 MHz from the edge of the IF which may restrict placement of other baseband channels in wide band observations.

Of the above issues, the only ones that are likely to be of concern are at 20 cm. How much does it matter if redshifted hydrogen at 1332 MHz can only be observed at reduced sensitivity in the crossover region. I suspect this will be very rare. As for the 1632 MHz crossover region, that may set constraints on the frequencies for the basebands for continuum observations that are a bit awkward given the other RFI and instrumental constraints in the region. But they should not be impossible to work around.

I have attached three spreadsheets that show the impact of the crossover points. The first shows the impact on all of the spectral lines in the SCHED file *linefreq.dat*. For each line, all allowed options with different first LO settings are shown along with the location in the IF of the line. The final columns show the velocity offsets from the crossover and from the IF band edges. For these lines, there always appears to be an option that keeps the line separated from the crossover by significantly more than the usual maximum galactic velocities. Also for nearly all cases there is an alternative LO setup that can reach odd velocities. The exception near 25 GHz is very near the edge of the receiver band and outside the region of good performance.

The second spreadsheet shows the current standard continuum bands from SCHED and their location with respect to the band edges and the crossover. Mostly there shouldn't be problems, but for wide bandwidths we may want baseband channels from both sides of the crossover. In such cases, a gap can be left in the coverage, or the bands can be adjacent and stitched together as in the WIDAR with a small sensitivity loss. The biggest impact will probably be the requirement to shift the center frequencies in a few cases to align the crossover with baseband edges.

The third table shows all possible first LO settings and the RF locations of the band edges and the crossover. Crossovers that cannot be dodged are highlighted in red. The final column shows how close to the band edge the crossover frequency will be if the first LO is shifted to the best adjacent value.

3. Summary

The use of a digital backend provides many advantages for future operation of the VLBA. But it does introduce a new factor, namely the crossover frequency in the center of the 500 MHz band, that users and scheduling software must take into account when setting observing frequencies. This memo shows that the crossover frequency should not introduce any insurmountable problems, and for most projects, can be ignored. Only rather extreme spectral line observations will need to consider the effect. For wide bandwidth continuum observations, the individual baseband channel frequencies may need to be adjusted so that the baseband does not cross the crossover frequency. SCHED will need to be aware of the situation and warn users when it will be a problem. Care will also need to be exercised to make sure other digital backends in the VLBI world don't have the same effect, but at different frequencies that might make scheduling observations problematic.

Impact of a crossover frequency in the VLBA IF

A DBE design breaks the VLBA 512 MHz IF into two 256 chunks. Where they meet (Crossover), there is a region of reduced sensitivity about 4 MHz wide. This spreadsheed explores the impact of this on various spectral lines given the VLBA's limitedfront end tuning capability.

Sample clock 1024 MHz
Crossover in IF 768 MHz Width 4 MHz or less.
'NA' means that the VLBA cannot reach that frequency.
See the third spreadsheet for the actual crossover frequency values.

Line name	Line freq MHz	First LO MHz	Line freq in IF MHz	Offset from Crossover MHz	Offset from 512 Mhz km/s	Offset from Crossover km/s	Offset from 1024 Mhz km/s
HI	1420.41	2100	679.59	88.41	35371	18659	72691
HI	1420.41	2400	979.59	211.59	98688	44659	9372
OH1612	1612.23	2400	787.77	19.77	51277	3676	43927
OH1665	1665.40	2400	734.60	33.40	40069	6013	52096
OH1667	1667.36	2400	732.64	35.36	39670	6358	52386
OH1720	1720.53	2400	679.47	88.53	29180	15426	60032
OH4660	4660.42	3900	760.42	7.58	15980	488	16955
OH4660	4660.42	4100	560.42	207.58	3115	13353	29821
OH4765	4765.56	3900	865.56	97.56	22241	6137	9967
OH4765	4765.56	4100	665.56	102.44	9660	6444	22549
OH6030	6030.75	NA					
OH6035	6035.09	NA					
CH3OH	6668.52	NA					
CH3OH	12178.60	11400	778.60	10.60	6562	261	6041
CH3OH	12178.60	11600	578.60	189.40	1639	4662	10964
OH13	13441.42	12600	841.42	73.42	7347	1637	4072
OH13	13441.42	12900	541.42	226.58	656	5054	10763
NH3	18499.39	NA					
CH3OH	19967.40	NA					
H2O	22235.08	21300	935.08	167.08	5704	2253	1199
H2O	22235.08	21500	735.08	32.92	3008	444	3895
H2O	22235.08	21700	535.08	232.92	311	3140	6592
CH3OH	23121.02	22200	921.02	153.02	5303	1984	1335
CH3OH	23121.02	22300	821.02	53.02	4007	688	2632
CH3OH	23121.02	22500	621.02	146.98	1414	1906	5225
CH3OH	25124.87	24300	824.87	56.87	3733	679	2376
SiO425	42519.30	41600	919.30	151.30	2872	1067	738
SiO425	42519.30	41800	719.30	48.70	1462	343	2148
SiO428	42820.54	43600	779.46	11.46	1872	80	1712
SiO428	42820.54	42200	620.54	147.46	760	1032	2825
SiO428	42820.54	43800	979.46	211.46	3273	1480	312
SiO431	43122.03	42200	922.03	154.03	2851	1071	709
SiO431	43122.03	43800	677.97	90.03	1154	626	2406
SiO431	43122.03	42400	722.03	45.97	1460	320	2099
CH3OH	44069.43	43100	969.43	201.43	3112	1370	371
CH3OH	44069.43	43300	769.43	1.43	1751	10	1732
SiO862	86243.35	85300	943.35	175.35	1499	610	280
SiO862	86243.35	85500	743.35	24.65	804	86	976
SiO868	86846.89	86000	846.89	78.89	1156	272	611
SiO868	86846.89	86200	646.89	121.11	466	418	1302
SiO868	86846.89	86300	546.89	221.11	120	763	1647
CH3OH	97980.97	NA					
SiO1293	129363.26	NA					

Impact of the crossover frequency on default continuum bands.

Band	Center freq MHz	First LO MHz	Center freq In IF MHz	Offset from 512 Mhz Mhz	Offset from Crossover MHz	Offset from 1024 MHz MHz	
90cm	330.49	500	830.49	318.49	62.49	193.51	
50cm	610.98	0	610.98	98.98	157.02	413.02	
21cm	1465.49	2400	934.51	422.51	166.51	89.49	BW=128
21cm	1435.49	2400	964.51	452.51	196.51	59.49	BW=64
21cm	1416.49	2400	983.51	471.51	215.51	40.49	
18cm	1658.49	2400	741.51	229.51	26.49	282.49	
18cm	1658.49	2600	941.51	429.51	173.51	82.49	Alternate LO
18cm	1653.49	2400	746.51	234.51	21.49	277.49	With JB BW=32
18cm	1653.49	2600	946.51	434.51	178.51	77.49	Alternate LO
13cm	2295.49	3100	804.51	292.51	36.51	219.49	
13cm	2295.49	2900	604.51	92.51	163.49	419.49	
6cm	4990.49	4100	890.49	378.49	122.49	133.51	
4cm	8415.49	7600	815.49	303.49	47.49	208.51	
2cm	15285.49	14600	685.49	173.49	82.51	338.51	
1cm	22235.49	21500	735.49	223.49	32.51	288.51	
7mm	43135.49	42400	735.49	223.49	32.51	288.51	
3mm	Not in Sched.						

Bands and Crossover frequencies for most LO settings.

Orange background notches cannot be reached with alternate LO.

Receiver Max range.	LO MHz	Low edge MHz	Crossover MHz	High edge MHz	Offset from band edge if shifted MHz	
50/90 cm	Crossover outside observable bands					
20 cm	2100	1076	1332	1588		
1180 - 1850	2400	1376	1632	1888	56	
	2600	1576	1832	2088		
13 cm	2900	1876	2132	2388		
2200 - 2400	3100	2076	2332	2588		
6 cm	3900	4412	4668	4924	56	
4440 - 5240	4100	4612	4868	5124	56	
	4400	4912	5168	5424	56	
	4600	5112	5368	5624	56	
4 cm	7100	7612	7868	8124	-44	
7700 - 9050	7400	7912	8168	8424	56	
	7600	8112	8368	8624	56	
	9400	8376	8632	8888	56	
	9600	8576	8832	9088	56	
2 cm Filter 1	11100	11612	11868	12124	-44	
11820 - 12980	11400	11912	12168	12424	56	
	11600	12112	12368	12624	56	
	11900	12412	12668	12924	56	
	12100	12612	12868	13124	56	
2 cm Filter 2	12100	12612	12868	13124	-44	
12820 - 13980	12400	12912	13168	13424	56	
	12600	13112	13368	13624	56	
	12900	13412	13668	13924	56	
	13100	13612	13868	14124	56	
2 cm Filter 3	13100	13612	13868	14124	-44	
13820 - 14980	13400	13912	14168	14424	56	
	13600	14112	14368	14624	56	
	13900	14412	14668	14924	56	
	14100	14612	14868	15124	56	
2 cm Filter 4	14100	14612	14868	15124	-44	
14770 - 15630	14400	14912	15168	15424	56	
	14600	15112	15368	15624	56	
	14900	15412	15668	15924	-44	Crossover outside RF.
1 cm	20000	20512	20768	21024	56	
20500 - 25300	20200	20712	20968	21224	56	
	20500	21012	21268	21524	-44	
	20800	21312	21568	21824	56	
	21000	21512	21768	22024	56	
	21200	21712	21968	22224	156	
	21300	21812	22068	22324	156	
	21500	22012	22268	22524	56	
	21700	22212	22468	22724	156	
	21800	22312	22568	22824	156	
	22000	22512	22768	23024		
	Repeat pattern above					
	24000	24512	24768	25024	-44	
	24300	24812	25068	25324	-44	

Bands and Crossover frequencies for most LO settings (continued)

Receiver Max range.	LO MHz	Low edge MHz	Crossover MHz	High edge MHz	Offset from band edge i shifted MHz
7 mm	37100	37612	37868	38124	56
37.6 - 46.2	37300	37812	38068	38324	56
	37700	38212	38468	38724	56
	37900	38412	38668	38924	56
lsb	39700	38676	38932	39188	56
lsb	39900	38876	39132	39388	56
	38600	39112	39368	39624	56
	38800	39312	39568	39824	56
lsb	40600	39576	39832	40088	120
	39200	39712	39968	40224	192
lsb	40800	39776	40032	40288	192
	39400	39912	40168	40424	
	Repeat pattern (same each 1500 MHz)				
lsb	45700	44676	44932	45188	56
lsb	45900	44876	45132	45388	56
	44600	45112	45368	45624	56
	44800	45312	45568	45824	56
lsb	46600	45576	45832	46088	56
lsb	46800	45776	46032	46288	320
	45200	45712	45968	46224	320
	45400	45912	46168	46424	56
3 mm	79200	79712	79968	80224	156
79700 – 9620	79300	79812	80068	80324	156
	79500	80012	80268	80524	56
	79800	80312	80568	80824	56
	80000	80512	80768	81024	56
	80200	80712	80968	81224	
	Repeat pattern (same each 1000 MHz)				
	94800	95312	95568	95824	56
	95000	95512	95768	96024	56
	95200	95712	95968	96224	56