VLBA Sensitivity Upgrade Memo 53

Priority tuning options for L404B synthesizers

Walter Brisken

18 Oct 2022

1 Introduction

The L104 synthesizers (the ones originally installed in the VLBA) can tune to setpoints of $500n \pm 100$ MHz, for integer n, within the 2 to 16 GHz range.[1] This coarse tuning generally allows the intermediate frequencies (IFs) to be set with alternating 200 and 300 MHz values.[2] This granularity can limit the total observing bandwidth or interfere with custom tunings where a specific range of frequencies is desired. As part of the VLBA Back-End Retrofit (VBER) project, a new synthesizer, the L404B, is being introduced which will relax the tuning restrictions. The introduction of this increased capability is somewhat at odds with the existing scheduling software, NRAO's Sched[3] program, which was designed with the assumption that the local oscillator (LO) tunings could be enumerated. This memo details some specific important applications of the increased tuning flexibility offered by the L404B synthesizers for implementation in the standard frequency setups contained within Sched. Advanced users will be able to take full advantage of the L404B flexibility through explicit setting of local oscillators, which could be complicated, especially when observing with a combination of VLBA and non-VLBA stations, without any changes to Sched or its catalogs. This memo also describes a small change that needs to be made to Sched to allow the updated catalogs to work without being rejected. However, a mechanism is in place that will allow initial testing of new LO settings with current Sched versions. Further improvements in tuning flexibility will come with the VLBA New Digital Architecture (VNDA) project. VNDA-related changes will be covered by future documentation.

2 High priority additions to the frequency catalog

This section contains an explicit list of a small number of additional local oscillator settings that should be added to Sched's `freq_rdbe.dat` file to allow for more convenient tuning of some important capabilities that will be enabled by the L404B. Per the VBER schedule, updates to the sched catalogs for these should be complete by Jan 6, 2023. This is well in advance of the anticipated Sched 12.0 release, which is targeting Sep 29, 2023. At the time of writing, information about the VBER project, including more detailed project schedules with additional relevant milestones, can be found online at https://staff.nrao.edu/wiki/bin/view/NMOps/Electronics/VBERproject.

It should be noted that all Sched setups using the proposed new LO settings must invoke the `modetest` parameter (see Sec. 4) to prevent a built-in VLBA-specific check from disqualifying the setup.

[1] See VLBA Technical Report 15A for more information on the VLBA's timing and tuning systems: https://library.nrao.edu/public/memos/vlba/tech/VLBATR_15A.pdf.

[2] The high-frequency receivers use multiple LOs, meaning there is some reduction in tuning granularity in the higher frequencies.

[3] See http://www.aoc.nrao.edu/software/sched/index.html .

2.1 Options to allow more simultaneous bandwidth at L-band

The VLBA L-band has nominal tuning range of 1265 to 1835 MHz, with some antennas allowing some additional tuning range. The existing tuning options are:

LO setting (MHz)	Sky frequency range (MHz)	Comments
2100	1076 – 1588	only 323 MHz usable
2400	1376 – 1888	only 459 MHz usable
2600	1576 – 2088	only 259 MHz usable

Three new LO settings are suggested that provide access to the full 512 MHz IF bandwidth. One is centered in the nominal receiver band and the other two each abut one of the band edges. Two other tunings are included as well; one which allows for 512 MHz starting at the lowest frequency accessible by any of the VLBA antennas (1180 MHz) and one which ends at the highest frequency accessible by any of them (1850 MHz). See comments in Sched's `freq_RDBE.dat` for details on tuning ranges of individual antennas.

LO setting (MHz)	Sky frequency range (MHz)	Comments
2286	1262 – 1774	bottom of nominal band
2320	1296 – 1808	center of nominal band
2350	1326 – 1838	top of nominal band
2204	1180 – 1692	access to lowest tuning frequency
2362	1338 – 1850	access to highest tuning frequency

For the "bottom" and "top" of band options, the tunings extend an additional 3 MHz beyond the bottom/top of the band to allow for reasonably unattenuated channels even at the extreme frequencies. The 2286 MHZ LO setting is well positioned to allow three 128 MHz DDC channels per polarization that avoid the worst RFI.

In addition to including these five new LO settings in the `RDBE_freq.dat` file, it is recommended here that new standard setups for continuum be created that offers 512 MHz of bandwidth.

DDC A new 3 Gbps mode (to be supported starting with DiFX version 2.8) that avoids the worst RFI could be based on the 2286 MHz LO with dual-polarization channels at 1262-1390 MHz, 1390-1518 MHz, and 1646-1774 MHz. A fourth channel pair (increasing data rate to 4 Gbps) could be added from 1518-1646 MHz with the understanding that the entire channel may be discarded due to RFI.

PFB The 2320 MHz LO setting is well positioned to allow a range of good PFB setups that avoid the worst RFI at L-band (roughly 1520 MHz to 1635 MHz). Some experimentation will be required to identify the best options, but a dual-polarization setup with eight channel pairs at the following frequencies might be a good starting point: 1312-1344 MHz, 1344-1376 MHz, 1376-1408 MHz, 1408-1440 MHz, 1440-1472 MHz, 1697-1728 MHz, 1728-1760 MHz, 1760-1792 MHz.

2.2 Options to improve RFI avoidance when using the PFB personality at S-band

The polyphase filter-bank (PFB) personality is widely used for geodetic astrometry (enabling 16 separate channels) and for some astronomy. The S-band (nominally 2200-2400 GHz as implemented

at the VLBA) is prone to severe radio frequency interference (RFI). The PFB tuning restrictions combined with limited S-band LO options makes avoiding RFI nearly impossible. Some specific LO tunings can be used to avoid the worst known offenders. In particular, it is best to avoid channels that include the 2182-2198 MHz and 2320-2352 MHz portions of the band. It is here proposed to offer two new tuning options at S-band for the PFB personality and one for the DDC:

LO setting (MHz)	Sky frequency range (MHz)	Comments
3030	2022 – 2502	only 480 MHz of the IF is useful for the PFB
3068	2006 – 2518	centers the DDC 256 MHz tuning zone on 2300 MHz
3158	2150 – 2630	only 480 MHz of the IF is useful for the PFB

The above sky frequencies for two of the setups are restricted to the 480 MHz of useful bandwidth that can be accessed by the PFB personality. Since the S-band nominal range is less than 200 MHz, the primary use of the PFB personality at S-band is in conjunction with X-band using the dual-band mode. While two of these are motivated by the PFB use case and one by the Digital Down-Converter (DDC) use case, nothing locks a LO setting to a specific RDBE personality.

All three tunings ascend well above the 2400 MHz nominal cutoff. There is hope that removing a band-limiting filter will allow some access above 2400 MHz. But, most critically, the two tunings above offer some likely improved tuning options even within the nominal band.

Some or all of these three new S-band LO setups should be added to the S/X portion of the frequency catalog as well. This could amount to approximately 20 additional entries.

2.3 Options to improve coverage with known radar bands

The International Telecommunication Union (ITU) has established some specific radar bands (see for example https://copradar.com/chapts/chapt7/ch7d1.html). The NRAO and GBO have active interest in pursuing planetary radar with wide bandwidths. Some radar bands within the VLBA tuning capability are centered at 2400, 5670, 8750, and 13700 MHz. Previous test observations using a prototype transmitter installed on the GBT operated with up to 200 MHz bandwidth centered at 13900 MHz. It is thus proposed to include the following LO settings to support possible planetary radar observations:

LO setting (MHz)	Sky frequency range (MHz)	Comments
3168	2144 – 2656	S-band radar
6440	5416 – 5928	C-band radar
7982	8494 – 9006	X-band radar
13132	13644 – 14156	Ku-band radar (previous experience)
12932	13444 – 13956	Ku-band radar (future options)

3 Medium priority additions to the frequency catalog

This section contains suggestions for additional tunings that will likely have general value in support of wide-band (e.g., full IF bandwidth of 512 MHz for one or both polarizations) observations of a specific frequency range. These should be implemented if time and resources allow.

3.1 Universal 100 MHz granularity

The proposal here is to provide tuning options for all bands at all multiples of 100 MHz. Rather than enumerate each one, a table below shows the quantity of new setups that would be needed.

Band	Lowest LO (MHz)	Highest LO (MHz)	Sideband	Number of new LO settings
20cm	2000	2600	Lower	4
13cm	2800	3600	Lower	6
6cm	3400	4400	Upper	6
6cm	5400	6400	Lower	6
6cm	5100	6100	Upper	6
6cm	7400	8600	Lower	7
4cm	7100	7900	Upper	5
4cm	9000	9600	Lower	4
2cm	11100	14900	Upper	23
1cm	20000	24500	Upper	22
7mm	37000	45400	Upper	61
7mm	39700	46800	Lower	52
3mm	79200	95200	Upper	81

A listing of currently supported LO settings and background on how to create Sched frequency setups can be found in VLBA Sensitivity Upgrade Memo 51[4].

Note that 6cm is especially complicated due to three factors: 1. there is a wide tuning range in this band, 2. two independent LOs can be used simultaneously, and 3. there are four tuning zones within this band using alternating sidebands. The multiple-LO option for 6cm means that there are hundreds of combinations of the two LO settings. Creation of the exhaustive list of setting for 6cm (and likely other bands) should be done by software, not by hand! 4cm can also use two simultaneous LO settings, but that receiver has considerably narrower bandwidth.

Observing with the 3mm system is already considered an expert mode of operation, so it would be reasonable to exclude the multitude of 3mm options.

Each of the LO settings in the `freq_RDBE.dat` file has an associated priority. Often there are multiple LO settings that can achieve a given desired channel set. This priority is used to choose amongst the options. A priority of 0 implies highest priority. Priority values up to 5 are present in the file. A lower priority will be given to settings that result in having known internally-generated in-band RFI (e.g., due to an LO or its harmonic being in the band) or those that may have reduced useful bandwidth due to filtering.

It is unclear at this time if Sched will experience problems should the number of `freq_RDBE.dat` entries be greatly increased.

4 Fully general setups from Sched

Sched comes with an example file, `newsyn.key` which shows how to allow a single VLBA antenna to use a different (and non-legacy-compliant) synthesizer setting. This file can be generalized as needed. Some experimentation indicates that when proceeding using this approach, the total LO, all three synthesizers, and all baseband converter frequencies must be explicitly provided and all front-end IF assignments must made as well.

[4] https://library.nrao.edu/public/memos/vlba/up/VLBASU_51.pdf.

Below is one of the example setups from `newsyn.key` that has been simplified to be used across the entire VLBA.

```
setini = stdz2.2cm /
  station = VLBA modetest
  firstlo = 14620.50
  dbe = rdbe_ddc  netside= U  sideband= U
  bbfilt= 16      nchan= 4    pol= dual    bits= 2
  pcal = 'off'
  bbsyn= 648.75,648.75, 664.75,664.75
  synth = 14.62050, 15.6, 15.6
  ifchan = B, D, B, D  pol = dual
  fe='omit', '2cm', 'omit', '2cm'
  /
endset /
```

It is highly recommended that users of this technique carefully look at the sched output files (`.sum` and `.vex`) files to ensure the files are as expected.

The use of `modetest` in this setup allows a validity check to be bypassed. This line will not be needed once a minor sched change (see below) is implemented.

5 Suggested change to Sched

Prior to users being given access to the new tuning capabilities, a check in the Sched program needs to be removed that currently prevents use of tuning outside the legacy setpoints: $500n \pm 100$ MHz. In source file `chkvlba.f`, near line 183, the following code block exists

```
      IF( MODETEST(KS) .AND. ( I .EQ. 1 .OR. I .EQ. 2 ) ) THEN
         IF( BADLO( 'SYNTH X 1000.', R8FREQ(I), 0.01D0, 0, 0.D0,
     1          0.D0, 2000.0D0, 16000.D0, MSGTXT ) ) ERRS = .TRUE.
      ELSE
         IF( BADLO( 'SYNTH X 1000.', R8FREQ(I), 500.D0, 1, 100.D0,
     1          0.D0, 2000.0D0, 16000.D0, MSGTXT ) ) ERRS = .TRUE.
      END IF
```

This should be modified as follows:

```
      IF( BADLO( 'SYNTH X 1000.', R8FREQ(I), 0.01D0, 0, 0.D0,
     1       0.D0, 2000.0D0, 16000.D0, MSGTXT ) ) ERRS = .TRUE.
```

Essentially this change always enforces a multiple-of-10 kHz LO setting rather than enforcing the legacy limitations.

6 Acknowledgements

Thanks to Amy Mioduszewski for helping unravel some of the secrets of Sched. Thanks to Emmanuel Momjian and Chris Hales for useful comments on draft versions.