

How to Tune the VLBA

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This document describes the capabilities and constraints in the tuning of the VLBA. In order to keep this memo short and as simple as possible some rarely used modes of operation that are exceptions to the normal rules have been left out. More details can be found in the VLBA Observational Status Summary or by contacting the NRAO helpdesk. This document describes the state of VLBA as of the date of publication except where projections are explicitly made. There will be some evolution in capabilities offered over time.

1 Background definitions and facts

1. A frequency band (or just band) is a contiguous range of sky frequencies made available through the use of a single receiver. The VLBA offers 10 frequency bands ranging from 300 MHz to 90 GHz.

2. An IF (Intermediate Frequency) is a contiguous chunk in frequency space of one polarization that is carried on a single wire from the antenna to the backend electronics. Each IF is 512 MHz wide in the current VLBA system. Each IF is characterized by three quantities: a local oscillator (LO) frequency, a sideband, and a polarization.

The polarization for the VLBA is either Right Circular (RCP) or Left Circular (LCP). The VLBA offers 4 IFs, labeled A, B, C and D. The details of the system of IF switches in the VLBA determine which IFs can attach to which receivers. In most cases only one particular IF can attach to a particular polarization of a particular receiver. In most cases IFs A and B will carry RCP signals and C and D will carry LCP. This means that in most cases a maximum of two IFs can contain useful data. There are a couple notable exceptions. In the case of S/X observations, both the S-band (13cm = 2.15–2.35 GHz) and the X-band (4cm = 7.7–9 GHz) receivers can be used simultaneously with the help of a frequency selective reflector. Both polarizations of each receiver can be used at the same time. In the case of 6cm (4–8 GHz) observing, two separate polarization-pairs of IFs can be attached, allowing, for example, simultaneous dual-polarization access to different, generally discontinuous, portions of the 6cm band.

Note that an IF in AIPS is not the same as an IF as described here.

3. A personality is a configuration of the wideband system that involves a specified set of FPGA firmware and control software. VLBA users can currently select from two personalities: the Polyphase Filterbank (PFB) and the Digital Downconverter (DDC). The properties of each will be described below.

4. A data channel¹ is a contiguous piece of an IF that is sampled and recorded onto magnetic media for transport to the correlator. Multiple data channels can be produced from a single IF. The current observing system can produce data channels between 1 and 128 MHz in factors of 2. Note that in some places in this document data channel will be abbreviated as “channel”. A “channel pair” is a set of two data channels with identical tunings but opposite polarizations.

5. A ROACH Digital Back End (RDBE) is an FPGA-based replacement for the legacy baseband converters, samplers, and formatter. Each RDBE takes as input two 512 MHz bandwidth IF signals and produces a digitized output through a 10 Gb Ethernet port. The choice of personality dictates the channelization that happens in the FPGA.

6. The wideband observing system consists of two RDBEs, a fully general matrix switch capable of switching any IF to any of the 4 RDBE inputs (with possible duplication), a 10 Gb Ethernet switch used to merge

¹NOTE: The term “data channel” replaces the older term “baseband channel”; SCHED still uses the older terminology.

outputs of two RDBEs into a single 10 Gb Ethernet stream, and a Mark6 recorder capable, in the VLBA’s mode of use, of recording rates as high as 4096 Mbps.

2 VLBA IF configuration

Compared to radio telescopes used for VLBI that also function as single dish antennas the VLBA has rather coarse granularity in configuring its IFs. As will be seen below, the wideband observing system stresses the IF tuning limitations even more, so some understanding of this system is needed if one is to gain mastery in tuning the VLBA.

For observing up through 15.9 GHz the frequency range for an IF is determined entirely by a single synthesizer. This synthesizer can tune between 2.1 and 14.9 GHz in alternate steps of 300 and 200 MHz. That is, they can tune to 2.1, 2.4, 2.6, 2.9, 3.1, . . . , 14.9 GHz. Some of the observing bands are configured so that this LO frequency is always higher than the sky frequency being observed (which results in a lower sideband IF) and in some the LO frequency is always lower (for an upper sideband IF). Some can make use of either. The following table divides the sky frequencies (in MHz) reachable by the VLBA into blocks, indicating in each case the IF sideband and the available synthesizer choices. Note: this is a concentration/generalization of information available in the `freq_rdbe.dat` file that comes with SCHED². Also note that the 90cm and 50cm bands are not discussed here. It is assumed here that polarization pairs are always being observed together at the same frequency. Usually this is desired when using dual polarization. The case for single polarization can be considered a degenerate version of this where one IF is just ignored.

Band	Freq range (MHz)	IFs	Sideband	LO choices (GHz)
20cm	1180–1850	A,C	Lower	2.1, 2.4
13cm	1920–2840	A,C	Lower	2.9, 3.1, 3.4
6cm	3900–5400	Any	Upper	3.4, 3.6, 3.9, 4.1, 4.4
6cm	4400–5900	Any	Lower	5.4, 5.6, 5.9, 6.1, 6.4
6cm	5600–7100	Any	Upper	5.1, 5.4, 5.6, 5.9, 6.1
6cm	6400–7900	Any	Lower	7.4, 7.6, 7.9, 8.1, 8.4, 8.6
4cm	7700–8900	B,D	Upper	7.1, 7.4, 7.6, 7.9
4cm	8100–9050	B,D	Lower	9.1, 9.4, 9.6
2cm	11800–13000	B,D	Upper	11.1, 11.4, 11.6, 11.9, 12.1
2cm	12800–14000	B,D	Upper	12.1, 12.4, 12.6, 12.9, 13.1
2cm	13800–15000	B,D	Upper	13.1, 13.4, 13.6, 13.9, 14.1
2cm	14700–15900	B,D	Upper	14.1, 14.4, 14.6, 14.9

Note that for 6cm, any two IF pairs (A,C and B,D) can be used and set with any combination of LO choices. In doing this, please heed warnings you may see regarding internally generated interference from the synthesizers leaking in-band. 13cm, except at three VLBA stations (MK, PT, and FD), is heavily filtered such that the actual usable portion of the band is limited to 2150–2350 MHz due to RFI.

For frequency bands above 15.9 GHz, an additional synthesizer and downconverter are used in series. The presence of two synthesizers (with one possibly multiplied to a higher frequency) means that the number of combinations of net sum local oscillator frequency is quite a bit greater. Without additional explanation, the above table continues as follows:

²The `freq_rdbe.dat` file is also posted online at http://www.aoc.nrao.edu/software/sched/catalogs/freq_rdbe.dat

Band	Freq range (MHz)	IFs	Sideband	LO choices (GHz)
1cm	20500–25300	B,D	Upper	20.0, 20.2, 20.5, 20.7, 20.8, 21.0, 21.2, 21.3, 21.5, 21.7, 21.8, 22.0, 22.3, 22.5, 22.7, 22.8, 23.0, 23.2, 23.3, 23.5, 23.7, 23.8, 24.0, 24.3
7mm	37600–46200	A,C	Upper	37.1, 37.3, 37.7, 37.9, 38.6, 38.8, 39.2, 39.4, 40.1, 40.3, 40.7, 40.9, 41.6, 41.8, 42.2, 42.4, 43.1, 43.3, 43.7, 43.9, 44.6, 44.8, 45.2, 45.4
7mm	38700–46200	A,C	Lower	39.7, 39.9, 40.6, 40.8, 41.2, 41.4, 42.1, 42.3, 42.7, 42.9, 43.6, 43.8, 44.2, 44.4, 45.1, 45.3, 45.7, 45.9, 46.6, 46.8
3mm	79700–96200	B,D	Upper	79.2, 79.3, 79.5, 79.8, 80.0, 80.2, 80.3, 80.5, 80.8, 81.0, 81.2, 81.3, 81.5, 81.8, 82.0, 82.2, 82.3, 82.5, 82.8, 83.0, 83.2, 83.3, 83.5, 83.8, 84.0, 84.2, 84.3, 84.5, 84.8, 85.0, 85.2, 85.5, 85.8, 86.0, 86.2, 86.3, 86.5, 86.8, 87.0, 87.2, 87.3, 87.5, 87.8, 88.0, 88.2, 88.3, 88.5, 88.8, 89.0, 89.2, 89.3, 89.5, 89.8, 90.0, 90.2, 90.3, 90.5, 90.8, 91.0, 91.2, 91.3, 91.5, 91.8, 92.0, 92.2, 92.3, 92.5, 92.8, 93.0, 93.2, 93.3, 93.5, 93.8, 94.0, 94.2, 94.3, 94.5, 94.8, 95.0, 95.2

Note that some LO choices may seem missing. Usually that is due to desired avoidance of internally generated interference or cases where a filter boundary cannot be crossed.

3 The Polyphase Filterbank (PFB) personality

The wideband system PFB personality is relatively simple in its configuration and is thus also quite limited in its utility. In all cases the PFB personality produces 16 data channels, each of 32 MHz bandwidth, and always quantizes data to 2 bit per sample, leading to a constant data rate of 2048 Mbps. The data channels to record are selected from a total of 30 valid channels that are synthesized from the two digitized 512 MHz wide IFs. Each input is digitally divided into 17 frequency ranges. The first and last are each 16 MHz wide and don't contain calibratable data. The inner 480 MHz is divided evenly into 15 valid channels. The center of this 480 MHz band is 768 MHz above (for upper sideband observing) or 768 MHz below (for lower sideband observing) the LO.

Taking 20cm as an example, one can use the 2.1 GHz or 2.4 GHz LO options to create for each polarization channels centered on $2100 - 768 + N \times 32$ MHz or $2400 - 768 + N \times 32$ respectively where N ranges from -7 to $+7$, resulting in the following channel options:

N	2.1 GHz LO channel (MHz)	2.4 GHz LO channel (MHz)
-7	1092-1124	1392-1424
-6	1124-1156	1424-1456
-5	1156-1188	1456-1488
-4	1188-1220	1488-1520
-3	1220-1252	1520-1552
-2	1252-1284	1552-1584
-1	1284-1316	1584-1616
0	1316-1348	1616-1648
1	1348-1380	1648-1680
2	1380-1412	1680-1712
3	1412-1444	1712-1744
4	1444-1476	1744-1776
5	1476-1508	1776-1808
6	1508-1540	1808-1840
7	1540-1572	1840-1872

Often one would pair up polarizations and choose 8 of these data channel frequency ranges that falls inside the receiver passband (i.e., not below 1180 MHz or above 1850 MHz, in this particular case). Note that the first and last channel options for any given LO tuning tend to be affected by filter roll-off and are best avoided when not required. Figure 1 shows two PFB configurations with selected channels shown in cyan. The first is for 2 blocks of contiguous frequency coverage, and the second alternates the channels. The SCHED setups for these are shown in SCHED Setups 1 and 2.

A peculiarity of the PFB personality not shared by the DDC personality is that the data channels it produces are always of the opposite sideband sense as the IFs that are fed into it. The net sideband sense is not a concern for the DiFX correlator so this issue will not be discussed in more detail.

SCHED Setup 1 *PFB system setup for 20cm receiver and 2.1 GHz LO* — Two blocks of contiguous frequency coverage.

```

setinit=pfb20cm1 /
  station=VLBA
  dbe=rdbe_pfb      ! select the personality
  nchan=16 pol=dual ! generate 8 data channels from each of RCP and LCP
  bits=2            ! this is the only allowed value
  bbfilter=32      ! data channel bandwidth is 32 MHz
  firstlo=2100     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  netside=U        ! for PFB with a lower sideband IF, this is the only option
  freqoff=1188,1188,
                1220,1220,
                1252,1252,
                1284,1284,
                1380,1380,
                1412,1412,
                1444,1444,
                1476,1476 ! the sky frequencies of data channels in pairs (MHz)
/
endset /

```

SCHED Setup 2 *PFB setup for 20cm receiver and 2.4 GHz LO* — Alternating frequency channels. Note that the 1840–1872 MHz channel straddles the upper edge of the receiver band so may provide sub-optimal performance.

```

setinit=pfb20cm2 /
  station=VLBA
  dbe=rdbe_pfb      ! select the personality
  nchan=16 pol=dual ! generate 8 data channels from each of RCP and LCP
  bits=2            ! this is the only allowed value
  bbfilter=32      ! data channel bandwidth is 32 MHz
  firstlo=2400     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  netside=U       ! for PFB with a lower sideband IF, this is the only option
  freqoff=1392,1392,
                1456,1456,
                1520,1520,
                1584,1584,
                1648,1648,
                1712,1712,
                1776,1776,
                1840,1840 ! the sky frequencies of data channels in pairs (MHz)
/
endset /

```

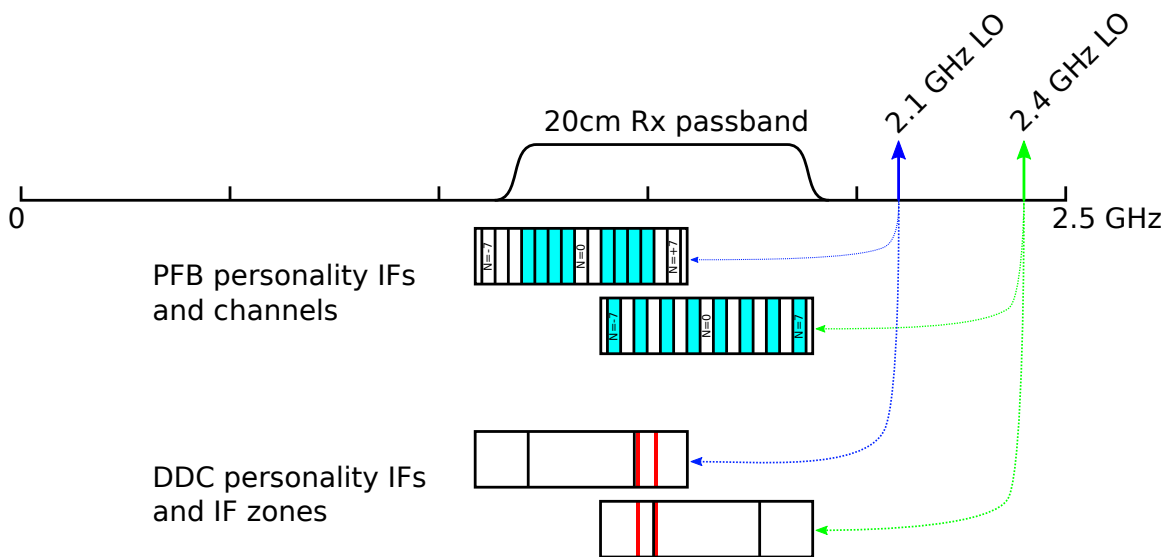


Figure 1: *Tuning options within the 20cm receiver.* The top curve shows the approximate passband of the 20cm VLBA receivers and the location on the same spectrum of the two LO settings that can be used to tune within the band. Below that are two pairs of IF options. The first pair of IF options is for the PFB personality. With this configuration data channels are hardwired as indicated by the black vertical dividers. Usable channels are labeled from $N = -7$ to $+7$. Between the two polarizations a total of 16 of these data channels may be selected. Some likely choices for channel selection are shown in cyan, corresponding to SCHED Setups 1 and 2. The second pair of IF options is for the DDC personality. Within each IF option the IF zone boundaries are indicated by the black vertical dividers. Data channels may be placed anywhere within the selected IF but may not cross one of these IF zone boundaries. Here, the DDC setups only record two channels with 8 MHz of bandwidth each (red vertical lines in the DDC IFs). The DDC setups can be found in SCHED Setups 3 and 4.

4 The Digital Downconverter (DDC) personality

The DDC wideband system personality supports a wide range of bandwidths. As with the PFB, the IF is 512 MHz wide and is centered 768 MHz from the LO. A single RDBE using the DDC personality can produce 1, 2, or 4 channels selectable from either of the two IF inputs. Using both RDBEs allows for either 4 or 8 channels. Channel bandwidths supported by the DDC range from 1 to 128 MHz. All channels must use the same bandwidth within an observing scan. Only 2-bit quantization is supported at the present time.

The 512 MHz IF is divided into 3 IF zones. Relative to the LO frequency these zones span the following frequency ranges: 512–640 MHz, 640–896 MHz, and 896–1024 MHz with zone boundaries at 640 and 896 MHz. The important thing about these boundaries is that a data channel cannot cross them. This leads to some additional constraints in the tuning of the DDC. In particular, when using 128 MHz channels in the outer zones, there is only one tuning option for each. The digital filtering used in the DDC has significant passband roll-off in the outer 3% of each side of the band. This means that when using 128 MHz channels there are gaps of about 7.68 MHz centered on each of the zone boundaries where observations of spectral lines will be hampered.

The current total data rate for the DDC personality ranges from 4 to 4096 Mbps (a.k.a., “4 Gbps”) with the Mark6 recorders.

As a first example of DDC personality use, one can create a setup to observe with 2 polarization pairs of data channels at 1476–1484 and 1512–1520 MHz. In contrast to the PFB personality, the DDC can record just the regions of interest. However, care must be taken to avoid crossing the two IF zone boundaries. For the 2.1 GHz LO 20cm IF configuration the IF spans 1076–1588 MHz and has IF zone boundaries at 1204 and 1460 MHz. For the 2.4 GHz LO, the IF spans 1376–1888 MHz and the IF zone boundaries are at 1504 and 1760 MHz. Since both desired data channel pairs individually are wholly within a single IF zone both LO settings can be used. The DDC personality SCHED setups for this narrow-band observation are shown in SCHED Setups 3 and 4. Graphical representations of these setups are presented in Figure 1.

As a less trivial example of DDC tuning, consider the case where water masers within two velocity ranges, $4650 \pm 150 \text{ km s}^{-1}$ and $4120 \pm 100 \text{ km s}^{-1}$, are to be observed. These velocities correspond to frequency ranges 21879–21901 MHz and 21922–21937 MHz respectively. The center of the IF must be no higher than $21879 + 256 = 22135$ MHz and no lower than $21922 - 256 = 21666$ MHz. Within the 1cm band only upper-sideband IFs are an option so the LO is 768 MHz lower in frequency than the center of the IF, so must be in the range 20898–21367 MHz. The options include 21.0, 21.2, and 21.3 GHz. For these three choices the IF zone boundaries would be at (21640 and 21896), (21840 and 22096), and (21940 and 22196) MHz respectively. The first of these options won’t work because 21896 MHz is within one of the desired passbands. The other two options can be used (see SCHED Setups 5 and 6), but the 21.2 GHz option would be preferred as the upper frequency range gets quite near an IF zone boundary so some signal attenuation may occur. Figure 2 illustrates some of the tuning considerations discussed for this example.

SCHED Setup 3 *DDC personality setup for 20cm receiver and 2.1 GHz LO* — This is one way to configure data channels spanning 1476–1484 MHz and 1512–1520 MHz.

```
setinit=ddc20cm1 /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=4 pol=dual   ! generate 2 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=8        ! data channel bandwidth is 8 MHz
  firstlo=2100      ! LO in MHz
  freqref=0         ! so the freqoff below corresponds to actual sky frequency
  netside=U         ! so freqoff represents the lower edge of each band
  freqoff=1476,1476,
                  1512,1512 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 4 *DDC personality setup for 20cm receiver and 2.4 GHz LO* — This is another way to configure data channels spanning 1476–1484 MHz and 1512–1520 MHz.

```
setinit=ddc20cm2 /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=4 pol=dual  ! generate 2 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=8       ! data channel bandwidth is 8 MHz
  firstlo=2400     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=1476,1476,
                  1512,1512 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 5 *DDC personality setup for 1cm receiver and 21.2 GHz LO* — This is one way to configure data channels spanning 21879–21901 MHz and 21922–21937 MHz.

```
setinit=ddc1cm1 /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=4 pol=dual  ! generate 2 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=32       ! data channel bandwidth is 32 MHz
  firstlo=21200     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=21876,21876,
                  21914,21914 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 6 *DDC personality setup for 1cm receiver and 21.3 GHz LO* — This is another way to configure data channels spanning 21879–21901 MHz and 21922–21937 MHz. It is less optimal because of the proximity of the second channel pair to an IF zone boundary.

```
setinit=ddc1cm2 /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=4 pol=dual  ! generate 2 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=32       ! data channel bandwidth is 32 MHz
  firstlo=21300     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=21876,21876,
                  21908,21908 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

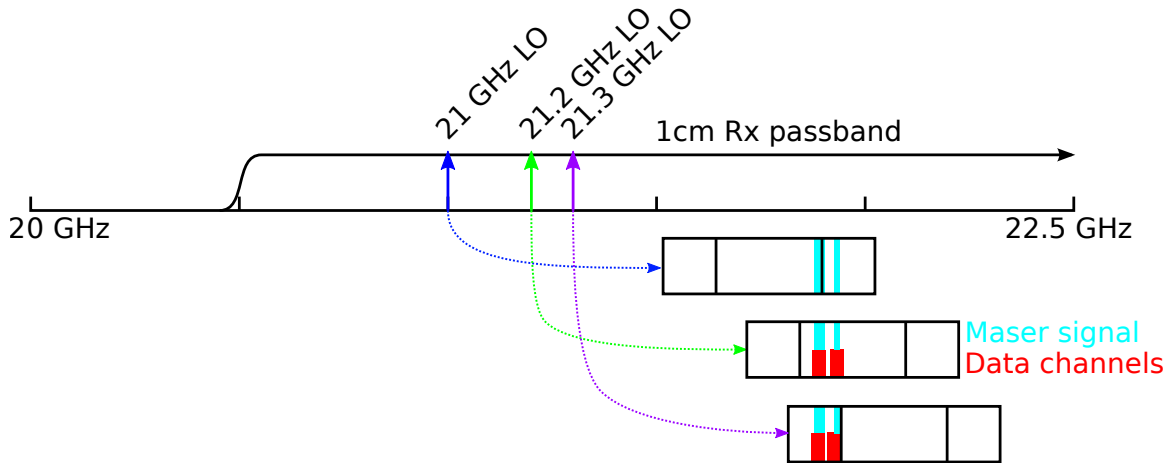


Figure 2: *Water maser example tuning options.* Observations of two maser lines spanning frequency ranges 21879–21901 MHz and 21922–21937 MHz are desired (shown in cyan). There are three LO tunings that place the full frequency range within an IF. The first of these (21 GHz) causes an IF zone to be placed directly within the first of these channels and is thus not useful. Both of the other two options can be made to work. 32 MHz data channels spanning the desired frequency ranges are shown in red. Note that for the 21.3 GHz LO option an IF zone boundary gets very close to the desired signals and the data channel needs to be nudged off center. SCHED Setups 5 and 6 contain details of these configurations. Note that compared to the 20cm tuning diagram shown in Figure 1 the IF sidebands are inverted.

5 Final notes

This document has given a fairly simplistic overview of the tuning situation at the VLBA. There are several factors that have been omitted such as avoiding RFI (including internally generated), receiver and IF filters that may vary a bit from site to site, and in the case of the 90cm/50cm system the extra mixing stage used to place the two receiver passbands in convertible frequency ranges. SCHED’s `freq.dat` and internal logic embody much of this knowledge. It is recommended that once a setup has been identified to run it through SCHED both with and without an explicit LO setting (i.e., `firstlo` in the setup). Look at the summary file that SCHED produces (ending in `.sum`) for each and watch for comments indicating potential problems. In some cases it may be *lesser of two evils* compromise.

Additional primary documentation includes the SCHED manual (<http://www.aoc.nrao.edu/software/sched/sched.html>) and the VLBA Observational Status Summary (<http://www.vlba.nrao.edu/astro/obstatus/current/>).

If additional help is required, please contact the NRAO helpdesk (<https://help.nrao.edu/>).

5.1 Acknowledgements

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A Acronyms

DDC = Digital Downconverter

FPGA = Field-Programmable Gate Array

IF = Intermediate Frequency

LCP = Left Circularly Polarized

LO = Local Oscillator

OSS = Observational Status Summary (Note: The VLBA and VLA each maintain a separate OSS)

PFB = Polyphase Filterbank

RCP = Right Circularly Polarized

RFI = Radio Frequency Interference

ROACH = Reconfigurable Open Architecture Computing Hardware

RDDBE = ROACH Digital Backend

Rx = Receiver

VLA = Very Large Array (officially, the Karl G. Jansky Very Large Array)

VLBA = Very Long Baseline Array

VLBI = Very Long Baseline Interferometry

B Creating a DDC Setup

Creating a DDC setup from scratch can be confusing. Here are some steps to follow that will (hopefully) make it easier.

1. Decide on the desired center frequency. This will determine the receiver and limit the options for the LO. For example, observing near 13.5 GHz will require using the 2cm receiver and either the 12.6 GHz or 12.9 GHz LO. The 12.6 GHz LO has access to 13.1–13.6 GHz; the 12.9 GHz LO has access to 13.4–13.9 GHz.
2. Determine where the IF zone boundaries are with respect to the LO. For example, the 12.6 GHz LO band is centered at $12600 \text{ MHz} + 768 \text{ MHz} = 13368 \text{ MHz}$ (“+” because this LO only uses the upper sideband). The IF boundaries are at $12600 \text{ MHz} + 640 \text{ MHz} = 13240 \text{ MHz}$ and $12600 \text{ MHz} + 896 \text{ MHz} = 13496 \text{ MHz}$. The 12.9 GHz LO band is centered at 13668 MHz with boundaries at 13540 and 13796 MHz.
3. Determine the polarization mode and total bandwidth needed for the observation. This has implications for the number of data channels and the data channel bandwidths. For example, if a continuum observation will be dual polarization and the total bandwidth needed is 128 MHz, the options are eight 32 MHz channels (four channels per polarization), four 64 MHz channels (2 channels per polarization), or two 128 MHz channels (1 channel per polarization). Choosing more data channels with smaller bandwidths makes it easier to fit the channels around the IF zone boundaries. However, there will be significant roll-off at the edges of the data channels which may have negative impacts on the observation.
4. Determine the frequencies for the data channels and create the setup (see SCHED Setup 7 below).

SCHED Setup 7 *DDC personality for 2cm receiver and 12.9 GHz LO* — Example of 128 MHz of continuous coverage centered near 13.5 GHz.

```
setinit=ddc.2cm.13.5ghz /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=4 pol=dual  ! generate 2 data channels from each of RCP and LCP
  bits=2           ! for DDC personality this is the only legal value
  bbfilter=64     ! data channel bandwidth is 64 MHz
  firstlo=12900   ! LO in MHz
  freqref=0       ! so the freqoff below corresponds to actual sky frequency
  sideband=U      ! uses the lower sideband of the IF
  netside=U       ! so freqoff represents the upper edge of each band
  freqoff=13412,13412,
                13476,13476 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

5. Put the setup in a SCHED .key file and run it through SCHED to make sure it does not have any errors.

C The freq_RDBE.dat File

The `freq_RDBE.dat` file, located in the `catalogs` directory of the SCHED installation, contains a large amount of useful information about the VLBA receivers and possible setups. SCHED checks all user-generated setups against setups in `freq_RDBE.dat` for possible issues or errors. The file also contains a large amount of human-readable information in comments, including frequency filters installed on specific antennas. It is a good place to look for details on the actual limits of each antenna.

Each entry in `freq_RDBE.dat` may contain the following parameters:

NAME: the name of the frequency entry
STATION: Stations covered by the group
PRIORITY: Lower values are favored groups, with 0 being the most favored
RF1: The lower limit of the IF (the lowest frequency available using that LO)
RF2: The upper limit of the IF (the highest frequency available using that LO)
POL: The polarization of the IF
LO1: The sum of all LOs other than the data channel (for frequencies ≥ 1 GHz, this is the LO used)
IFNAME: The name of the IF as used by control software
FE: The front end name (mainly VLBA)
SYN: The 3 VLBA front end synthesizer settings
DUALX: Use the wide band X-band system on the VLBA
CHIRF1: The lower hard limit for channel 1 (mainly for 2cm VLBA)
CHIRF2: The upper hard limit for channel 1 (these select the filter for 2cm VLBA)
RCP50CM, LCP50CM: 50cm VLBA filter (NARROW or BROAD)

Here is an example of an entry in the `freq_RDBE.dat`:

```
Name = vc_bh      Station = VLBA      Priority = 1
  rf1   = 4112., 4112., 4876., 4876.  ifname = A, C, B, D
  rf2   = 4624., 4624., 5388., 5388.  fe   = '6cm', '6cm', '6cm', '6cm'
  syn(2) = 3.6   syn(1) = 5.9
  pol   = RCP,  LCP,  RCP,  LCP      lo1  = 3600., 3600., 5900., 5900.
/
```

The entry is named “vc_bh”, it is valid for the VLBA, and it is a relatively favored group. The entry uses both the 3600 MHz and 5900 MHz LOs, each in dual polarization. The 3600 MHz LO uses the upper sideband, so the lowest frequency available to it (rf1) is $3600 + 512 = 4112$ MHz and the highest frequency (rf2) is $3600 + 1024 = 4624$ MHz. The 5900 MHz LO uses the lower sideband, so the lowest frequency available to it is $5900 - 1024 = 4876$ MHz and the highest frequency is $5900 - 512 = 5388$ MHz.

An example of an entry which uses the 13/4-cm dichroic system is:

```
Name = vsx_13    Station = VLBA      Priority = 4
  rf1 = 1876, 1876, 8412, 8412  ifname = A,      C ,  B ,  D
  rf2 = 2388, 2388, 8924, 8924  fe   = '13cm', '13cm', '4cm', '4cm'
  pol = RCP,  LCP,  RCP,  LCP  lo1  = 2900, 2900, 7900, 7900
  syn(1) = 7.9   syn(2) = 2.9
  note='Poor LO choice at 4cm - LO in receiver RF - consider 9.4 GHz'
/
```

This entry specifies that both the 13cm and 4cm front ends are used. Observers should note that using this entry is discouraged. The priority is very low and the note indicates there are better options available.

D Additional Example Setups

SCHED Setup 8 *DDC personality 4 Gbps setup for 20cm receiver and 2.4 GHz LO* — Note that the 20cm receivers have a maximum bandwidth of 400 MHz, so they will not take full advantage of the 512 MHz bandwidth in this setup.

```
setinit=4gb_ddc.20cm /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=2400     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=L       ! uses the lower sideband of the IF
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=1376,1376,
                 1504,1504,
                 1632,1632,
                 1760,1760 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 9 *DDC personality 4 Gbps setup for 6cm receiver and 4.1 GHz LO* — 512 MHz of continuous coverage centered near 5 GHz.

```
setinit=4gb_ddc.6cm /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=4100     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=U       ! uses the upper sideband of the IF
  netside=L        ! so freqoff represents the upper edge of each band
  freqoff=4740,4740,
                 4868,4868,
                 4996,4996,
                 5124,5124 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 10 *DDC personality 4 Gbps setup for 6cm receiver using both the 3.9 GHz and 5.9 GHz LOs* — 2 widely-separated blocks of 256 MHz of coverage each; one centered near 4.5 GHz and the other centered near 6.7 GHz (methanol maser).

```
setinit=4gb_ddc.6cm.split /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=3900,3900,
                 3900,3900,
                 5900,5900,
                 5900,5900 ! the LOs for each data channel
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=U       ! both LOs use the upper sideband of the IF
  netside=U        ! so freqoff represents the upper edge of each band
  freqoff=4412,4412,
            4540,4540,
            6540,6540,
            6668,6668 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 11 *DDC personality 4 Gbps setup for 4cm receiver and 7.6 GHz LO* — note that the last data channels extend slightly beyond the edge of the IF.

```
setinit=4gb_ddc.4cm /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=7600     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=U       ! uses the upper sideband of the IF
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=8112.25,8112.25,
            8240.25,8240.25,
            8368.25,8368.25,
            8496.25,8496.25
                    ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 12 DDC personality 4 Gbps setup for 2cm receiver and 14.4 GHz LO.

```
setinit=4gb_ddc.2cm /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=14400    ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=U       ! uses the upper sideband of the IF
  netside=L        ! so freqoff represents the upper edge of each band
  freqoff=15039.75,15039.75,
                15167.75,15167.75,
                15295.75,15295.75,
                15423.75,15423.75
                        ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 13 DDC personality 4 Gbps setup for 1cm receiver and 22.8 GHz LO.

```
setinit=4gb_ddc.1cm /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=22800    ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=U       ! uses the upper sideband of the IF
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=23312,23312,
                23440,23440,
                23568,23568,
                23696,23696
                        ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 14 DDC personality 4 Gbps setup for 7mm receiver and 42.4 GHz LO.

```
setinit=4gb_ddc.7mm /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=128     ! data channel bandwidth is 128 MHz
  firstlo=42400    ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=U       ! uses the upper sideband of the IF
  netside=U        ! so freqoff represents the lower edge of each band
  freqoff=42912.75,42912.75,
                43040.75,43040.75,
                43168.75,43168.75,
                43296.75,43296.75
                ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 15 PFB system setup for 13cm receiver and 3.1 GHz LO — One block of continuous frequency coverage. Note that this extends beyond both the bottom and top of the 13cm receiver range of 2200–2400 MHz.

```
setinit=pfb13cm /
  station=VLBA
  dbe=rdbe_pfb     ! select the personality
  nchan=16 pol=dual ! generate 8 data channels from each of RCP and LCP
  bits=2           ! this is the only allowed value
  bbfilter=32     ! data channel bandwidth is 32 MHz
  firstlo=3100    ! LO in MHz
  freqref=0       ! so the freqoff below corresponds to actual sky frequency
  sideband=L      ! use the lower sideband of the IF
  netside=U       ! for PFB with a lower sideband IF, this is the only option
  freqoff=2188,2188,
                2220,2220,
                2252,2252,
                2284,2284,
                2316,2316,
                2348,2348,
                2380,2380,
                2412,2412 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 16 *PFB system setup for 6cm receiver and 7.6 GHz LO* — One block of continuous frequency coverage.

```
setinit=pfb6cm /
  station=VLBA
  dbe=rdbe_pfb      ! select the personality
  nchan=16 pol=dual ! generate 8 data channels from each of RCP and LCP
  bits=2            ! this is the only allowed value
  bbfilter=32       ! data channel bandwidth is 32 MHz
  firstlo=7600      ! LO in MHz
  freqref=0         ! so the freqoff below corresponds to actual sky frequency
  sideband=L        ! use the lower sideband of the IF
  netside=U         ! for PFB with a lower sideband IF, this is the only option
  freqoff=6624,6624,
                  6656,6656,
                  6688,6688,
                  6720,6720,
                  6752,6752,
                  6784,6784,
                  6816,6816,
                  6848,6848 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 17 *DDC personality for 13cm receiver and 3.1 GHz LO* — 128 MHz of continuous coverage centered around 2274 MHz. Note that the top 18 MHz in this setup will be affected by RFI from the SiriusXM satellites, which operate between 2320 and 2345 MHz.

```
setinit=ddc.13cm /
  station=VLBA
  dbe=rdbe_ddc     ! select the personality
  nchan=8 pol=dual ! generate 4 data channels from each of RCP and LCP
  bits=2           ! for DDC personality this is the only legal value
  bbfilter=32      ! data channel bandwidth is 32 MHz
  firstlo=3100     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=L       ! uses the lower sideband of the IF
  netside=U        ! so freqoff represents the upper edge of each band
  freqoff=2210,2210,
                  2242,2242,
                  2274,2274,
                  2306,2306 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```

SCHED Setup 18 *DDC personality for 6cm receiver and 7.6 GHz LO* — 256 MHz of continuous coverage centered near 7 GHz.

```
setinit=ddc.6cm.7ghz /
  station=VLBA
  dbe=rdbe_ddc      ! select the personality
  nchan=8 pol=dual  ! generate 4 data channels from each of RCP and LCP
  bits=2            ! for DDC personality this is the only legal value
  bbfilter=64      ! data channel bandwidth is 64 MHz
  firstlo=7600     ! LO in MHz
  freqref=0        ! so the freqoff below corresponds to actual sky frequency
  sideband=L       ! uses the lower sideband of the IF
  netside=U        ! so freqoff represents the upper edge of each band
  freqoff=6832,6832,
                6896,6896,
                6960,6960,
                7024,7024 ! the sky frequencies of data channels in pairs (MHz)
/
endset /
```
