VLBA Frequency Coverage

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This memo specifies the frequency coverage of the VLBA. It represents the plan currently being implemented, rather than a proposal or suggestion. It will remain current unless specifically revised at a later date.

The choices of the bands to be covered and the limits of each result from several interacting considerations. There are the limitations of antenna optics, which produce upper and lower bounds to the frequency coverage; there is a desire to make continuum observations at spacings no larger than a factor of three over the available range; there is a need to cover certain spectral lines; and there is a need to have most receivers include a protected band, in case the interference environment becomes severe. Furthermore, there is a desire to obtain compatability with systems other than the VLBA, including the VLA, the NASA network at 2.3 and 8.6 GHz, and other VLB stations at various frequencies. The bandwidth achievable in a low noise receiver is typically 10% of its center frequency (although sometimes careful design allows more), and this determines the number of separate receivers needed. At the higher frequencies, the processor, recorder, or IF transmission system will limit the usable bandwidth to much less than 10%.

Nine separate dual-polarization receivers, with separate feeds, are now planned; they cover wavelengths from 90 to 0.7 cm. In addition, two receivers are planned as options to be considered near the end of the project; these are each close in frequency to one of the nine primary bands. Finally, space will be reserved for a possible future receiver at 86 GHz.

There are several ways of considering the frequency coverage. Let me define three of these: (a) Tunability is the ability to cause a given single frequency to appear in the band processed by the correlator. (b) Bandwidth is the amount of the spectrum which can be instaneously observed. (c) Frequency diversity is the range of frequencies which can be instanteously observed, even though this range may not be continuously covered. Sufficient tunability will be provided to reach any frequency covered by a feed and front end. In fact, the planned first L.O. synthesizers allow continuous coverage from 1.1 to 16.9 GHz. The bandwidth provided by each receiver, including I.F. transmission and conversion to baseband, will be 500 MHz in each polarization, except for the two lowest frequency bands. This greatly exceeds the capacity of the recorders and processor. The frequency diversity will normally also be 500 MHz, and is limited by the I.F. bandwidth. However, this can be extended in two ways: dual band operation will be possible on certain pairs of bands (initially only 3.6 cm and 13 cm); and a split-polarization mode will be provided on one band (3.6 cm), wherein the two polarization channels can be tuned to opposite ends of the band.

The general choice of frequency coverage is discussed below for each band separately. In some cases, the quantization of the first L.O. tuning affects the exact range covered (the first L.O. will have 100 MHz steps except for the multiples of 500 MHz). All of the specified band edges are then set by the bandwidth of the feed, polarizer, and front end. In many cases, there will be an "accessible band" which is somewhat larger than this; this is the band which appears in the I.F. and which is not rejected by any filters. (Filters are required in most front ends for image rejection and interference protection.) For some experiments, it may be possible to operate outside the specified band, but within the accessible band, by accepting higher noise temperatures and higher cross-polarization.

The bands to be covered, including the optional ones, are:

<u>90 cm (.312-.342 GHz):</u> This is a 10% bandwidth centered on the protected band (.3220 to .3286 GHz). The band will be upconverted to the 0.5-1.0 GHz I.F. band.

<u>50 cm (.580-.640 GHz):</u> This is also a 10% bandwidth centered on the protected band (.608-.614). Here the signal is already in the "I.F." band, so no conversion is needed.

<u>20 cm (1.35-1.75 GHz; 1.30-1.80 accessible):</u> Red-shifted HI through OH line frequencies are covered. The NRAO FET amplifiers allow low-noise coverage of this range in a single band. LSB conversion with a fixed LO at 2.3 GHz is planned; this keeps the LO out of the IF band, and also allows use of the same 2-16 GHz synthesizer which is planned to provide LOs for most of the other bands.

<u>13 cm (2.15-2.35 GHz; 2.10-2.60 accessible):</u> Included for NASA compatability. Actually, the NASA band is 2.20 to 2.32, but limiting the bandwidth with a higher-Q R.F. filter would degrade the phase and delay stability. Narrower filters may be needed in the I.F. for interference rejection. The L.O. is fixed at 3.1 GHz, with LSB conversion.

<u>6 cm (4.60-5.10 GHz):</u> Included for VLA compatability and for coverage of the protected band at 4.8-5.0 (4.990-5.000 primary). The LO could be either at 4.1 or 5.6 GHz, with 4.1 prefered for better LO phase stability.

<u>5 cm (5.90-6.40 GHz) [Optional]:</u> This band was proposed in early discussions as part of the 6 cm receiver, but this no longer seems feasible. If this range is to be covered, a separate receiver would have to be built, with a separate feed. The L.O. would be fixed at 5.4 GHz. This receiver will be considered an option, to be pursued if sufficient funds exist late in the project.

3.6 cm (8.0-8.8 GHz; 7.9-8.9 accessible): Included for NASA compatability. In this and other bands where the R.F. bandwidth is between 500 and 1000 MHz, tuning of the entire band while maintaining good image rejection requires that the lower half be covered by USB conversion (in this case with the L.O. at 7.4 GHz), and that the upper half be covered by LSB conversion (L.O. at 9.4 GHz). Normally, both polarization channels would be driven by the same synthesizer, giving 500 MHz of frequency diversity. However, this band is excpected to be used extensively for astrometric and geodetic measurements via bandwidth synthesis, where maximum frequency diversity is desired. Therefore, a special "geodesy mode" will be provided, in which one polarization would be driven from a fixed L.O. at 9.4 GHz, providing LSB conversion of the upper half of the band, while the other would be driven from the synthesizer, which could be set to cover the lower half.

2.8 cm (10.2-11.2 GHz) [Optional]: This is another 10% bandwidth centered on a protected band (10.69-10.70). The need for this receiver is somewhat in doubt, considering that the nearby 3.6 cm band is available. But the latter contains no protected frequencies, and it is desired to have coverage of a protected band in this region. Therefore, this receiver is considered an option, to be pursued later if time and funds permit. If built, the 2.8 cm receiver would obtain 1.0 GHz coverage by USB conversion of the lower half and LSB conversion of the upper half, but would not include the split-polarization mode planned for the 3.6 cm receiver.

2 cm (14.4-15.4 GHz): This is the same as a VLA band, and covers the formaldehyde line at 14.489 GHz on one end, and a protected band at 15.35-15.40 GHz on the other. The 1.0 GHz coverage is obtained in the same way as at 3.6 cm, but without the split-polarization mode. This band produces the most severe requirements for the image rejecting filters, since the fractional separation of the signal and image bands is getting small. Nevertheless, ordinary lumped-element filters can provide 30 dB image rejection with phase sensitivity of .002 radian/deg C, and this will be acceptable (assuming ± 1 deg C temperature stability).

1.3 cm (22.2-24.6 GHz; 21.0-26.0 accessible): This band covers the water line at 22.235 GHz, where there is some protection; the primary protected band at 23.6-24.0 GHz, which includes the ammonia line; and the VLA band at 22.0-24.0 GHz. Additional coverage above 24 GHz is desired for continuum, in order to get further from the peak atmospheric water absorption, and also for additional ammonia lines. Once the tuning range exceeds 1.0 GHz, an additional frequency conversion is needed to provide image rejection (alternatively, a tunable filter or an image-rejecting mixer might be considered, but these are technically less attractive at this time). This is accomplished by having a tunable first L.O. at 11.10 to 15.60 GHz, and a fixed second L.O. at 9.4 GHz (the latter being the same oscillator as is needed for geodesy mode at 3.6 cm). Image filtering is easy, and the tuning range could actually be extended slightly if necessary. But below 22.1 GHz, a spurious response of the first mixer ($3\ f_1 - f_s$) will fall in the band, and this may also limit the usable coverage.

<u>0.7 cm (42.3-43.5 GHz)</u>: This covers the protected band at 42.5-43.5, which includes the silicon monoxide maser line. This is the only band which requires an L.O. outside the 2 to 16 GHz range. To ease the image rejection problem, two conversions will be used to get to the 0.5-1.0 GHz I.F. To cover more than 0.5 GHz, the first of these L.O.s must be tunable. The specified range is obtained for first L.O.s of 32.4, 32.6, 32.9, and 33.1 GHz and a fixed second L.O. at 9.4 GHz (also used at 1.3 and 3.6 cm). The first L.O. should be obtainable using a voltage-tuned Gunn oscillator locked to references at 0.5 and 0.1 GHz; the available reference frequencies and the tuning range of this oscillator determine the exact band edges.