Using 1 GHz wide frequency setups at X-band
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Abstract: *The use of wide spanned bandwidth for applications that utilize group delay is discussed. Optimal sequences for the cases of using 8, 5, and 4 IFs in the band are presented. An example of using the capability of the VLBA X-band hardware to set up a spanned bandwidth of 1 GHz is presented.*

1 The use of widely spanned bandwidth

The VLBA hardware limits the bandwidth of the signal sent from antenna to the data acquisition hardware to 500–1000 MHz. Thus the spanned bandwidth of the recorded signal is limited to 500 MHz for most of the receiver bands. However, the IF converter at X-band supports a special mode: it allows the right circular polarization signal from the receiver to be split and mixed with two local oscillator (LO) signals. The X-band receiver has good performance in the range of frequencies [7900, 8900] MHz. Thus, recording a spanned bandwidth of 1000 MHz is feasible. Although that feature was implemented when the VLBA was built, it has received very little use.

Using wide spanned bandwidth allows group delay to be determined more precisely. Applications that use group delays, such as absolute astrometry and geodesy, benefit from an increase of the spanned bandwidth because the uncertainty of group delay determination is the reciprocal of the root mean square (rms) of frequencies of the channels used during fringe fitting. The hardware upgrade of a number of geodetic VLBI stations in 1990s that made it possible to extend the spanned bandwidth from 360 MHz to 720 MHz gave a sizeable improvement in accuracy of site positions and the Earth orientation parameters.

Since the bandwidth of the of the full signal from the antenna is too large to be recorded completely (at least before the ongoing enhancements are done), several narrower baseband channels are extracted that are distributed across the spanned bandwidth. The precise distribution of those basebands in frequency affects the performance for delay measurements. For a long time the same sequence of X-band basebands was used for all geodesy and absolute astrometry observations using the X/S bands: `8405.99 + (0, 2, 11, 14)*35.0` MHz with 8 MHz wide baseband channels. The availability of the 512 Mbps recording mode, that required a change to the use of 16 MHz wide baseband channels, has prompted us to revisit the issue of the optimal frequency setup and to reconsider use of the special wide-band mode available at X-band.

Note that the 500 MHz wide signal from the antenna is commonly called the Intermediate Frequency (IF) when discussing telescope signals. But that same term is used for the baseband channels once they are in the post-processing software. In the rest of this memo, an IF is what is called a baseband channel above, following the AIPS convention.

The following considerations have to be taken into account for selecting the frequency sequence for applications that utilize precise estimates of group delays:

- Precision of group delay at a given SNR (the higher, the better);
- Group delay ambiguity spacing (the larger, the better);
- Level of secondary maximum in the delay resolution function (the smaller, the better);
- Radio interference.

The uncertainty of the group delay caused by random thermal noise for a received signal with the same variance across the band is

$$\sigma(\tau_{gr}) = \frac{1}{2\pi} \frac{1}{\mathrm{SNR}} \frac{N_i}{\sqrt{\sum (f_k - \bar{f})^2}} \tag{1}$$

where N_i is the number of IFs, f_k is the IF frequency, and $\bar{f}$ is the arithmetic mean over intermediate frequencies.

The group delay ambiguity spacing depends on the algorithm used for fringe search. In the past, group delay was evaluated in two steps (Rogers, 1970): first the fringe rate and the incoherent sum of group delays across each individual IF (the so-called single-band or narrow-band delay) were found. Using estimates of the single-band delay and delay rate, the cross-spectrum was averaged across each IF and the phase of the averaged spectrum related to the nominal IF frequency was computed. Then a group delay over the entire band was found using the phases and amplitudes of the averaged fringe phases of each individual IF (task MBDLY in AIPS). See Takahashi et al. (2000) for more details. This algorithm is thereafter called "narrow-band fringe fitting". An alternative approach is to evaluate group delay over the entire wide band in one step without computing single band delay (Petrov et al., 2011), the so-called "wide-band fringe fitting" approach. This approach is much more computationally intensive and was not feasible in the 20th century.

In both approaches, group delay is evaluated by a search for the global maximum of the two-dimensional Fourier-transform of the cross-spectra over frequency and over time. For a signal with a flat spectrum over the band and with aligned IF phases, the one-dimensional Fourier-transform of the cross-spectrum of the observed signal over frequency is proportional to the Fourier-transform of a synthetic signal with a rail of 1 at frequencies for which the spectrum is provided by the correlator and 0 otherwise. Therefore, the procedure for group delay determination can be easily investigated by examining the Fourier-transform of the synthetic spectrum.

The wide-band fringe search algorithm uses the Fourier-transform of the cross-spectrum directly. The result folds with the period of folding (also called group delay ambiguity spacing) which is the reciprocal of the frequency separation of the spectral channels within IFs, typically several microseconds. The narrow-band fringe search algorithm at the last step uses the Fourier-transform of the averaged spectrum over IF frequencies with the the period reciprocal to the minimum frequency separation between IFs scaled by the maximum common denominator of IF frequencies if it is different from 1. A typical group delay ambiguity for the narrow-band algorithm, is in the range 1–200 ns. Strictly speaking, a fringe search algorithm determines not the group delay, but a combination $\tau_{gr} + N * S_g$, were S_g is the group delay spacing and N is an arbitrary integer number.

The Fourier-transform has many maxima and minima. The amplitude of the secondary maximum expressed as the share of the amplitude of the main maximum is an important characteristic of the frequency sequence. If the Fourier-transform of the synthetic spectrum has secondary maxima with high amplitudes, in the presence of random noise the fringe fitting procedure may converge to a secondary maxima, i.e. the fringe fitting procedure will provide a

wrong result. If the number of observations with incorrectly determined group delays is significant (say more than 10%), and the magnitude of errors is not so large that it dominates other errors of group delays (say, less than 20 ns), identifying wrong values of group delays may become problematic. Without cleaning for observations with group delays that correspond to secondary maxima, the dataset it is useless for further analysis.

Crafting a good frequency sequence is a non-trivial problem if ones tries to solve it analytically. The use of fast computers allows us to do it by a brute force approach.

For computing the level of secondary maxima and group delay uncertainties at a given SNR, we generated a synthetic spectrum with 1 at the frequencies that correspond to a sequence of intermediate frequencies under consideration and 0 elsewhere. This is for the narrow-band fringe fitting algorithm. For the wide-band fitting algorithm the simulated spectrum has $N_i * N_s$ non-zero components at all frequencies that the correlator generates. Here N_s is the number of spectral channels in the individual IF. Then we compute the Fourier transform of the simulated spectrum, divide its amplitude by the amplitude of the main maximum, and find the amplitude of the secondary maximum. It should be noted that we set the imaginary part of the synthetic spectrum to zero, i.e. we assume the phase of the synthetic spectrum is constant over the band. The data acquisition system may cause a frequency-dependent phase distortion. If the phase of the complex bandpass is not properly calibrated and this distortion is not entirely compensated, the amplitude of the secondary maximum may change, usually increase.

The number of frequency channels in an individual IF was set to 64 in the following computations. Although the VLBA hardware allows one to set the IF frequencies with the step of 0.01 MHz, in the following computations we considered all frequency sequences with spacings that are a multiple of 16 MHz — the maximal width of the analog IF.

2 Case of 8 IFs

If the frequency bandwidth of 992 MHz is forced by fixing IF1 and IF8, then there are 50,063,860 non-overlapping sequences with a step which is a multiple of 16 MHZ. All these sequences have been analyzed.

Table 1: Selected sequences of 8 IF frequency channels 16 MHz wide spread over (61+1)*16=992 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitude of the secondary maximum is computed for the narrow-band fringe fitting algorithm. Group delay ambiguity spacing is shown in the last column. In total, 50,063,860 sequences were analyzed.

#F	Multipliers								$\sigma_{gr}(ns)$	A_s	S_{gr} (ns)
8	0	1	2	3	58	59	60	61	0.342	0.992	62.500
8	0	20	23	27	28	37	39	61	0.607	0.519	62.500
8	0	1	3	16	34	53	59	61	0.398	0.617	62.500
8	0	1	2	22	47	56	60	61	0.383	0.695	62.500
8	0	1	2	8	41	59	60	61	0.369	0.792	62.500

Table 1 shows some results of computations for the case of using the narrow-band fringe search algorithm. The first sequence has the minimum group delay uncertainty but it has the secondary maximum of its Fourier transform with amplitude 0.992 at spacing 1000/(16*58) = 1.077 ns, which makes it unacceptable. The second sequence has the minimum amplitude of the secondary maximum, 0.519, but the precision of the group delay is 1.77 times worse. We can find a sequence between these two extremes that has a small group delay uncertainty and a low level of the amplitude of the secondary maximum. For instance, we can set the following constraints: 1) the amplitude of the secondary maximum is no more than 20% greater than the amplitude of the secondary maximum of the sequence that provided the minimum, 2) the group delay ambiguity spacing is greater than 20 ns, and search for the sequence that has the minimum group delay uncertainty under these conditions. That sequence is shown in the 3rd row of the table. We can raise the limit on the amplitude of the secondary maximum further to 0.7 (sequence 4) and 0.8 (sequence 5). This reduces the group delay uncertainties by a small amount, but the reduction is not significant.

Table 2 shows similar results for the wide-band algorithm. The group delay ambiguity spacing of 4000 ns is very large and it is not a factor for selecting the sequence. The second sequence has the minimum amplitude of the secondary maximum. Similarly, we varied the upper limit of the allowed amplitude of the secondary maximum and searched for a sequence that minimizes group delay uncertainty. Results are very similar to the sequence optimized for the narrow-band algorithm. The recommended sequence is emphasized by bold font.

Table 2: Selected sequences of 8 IF frequency channels 16 MHz wide spread over (61+1)*16=992 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitude of the secondary maximum is computed for the wide-band fringe fitting algorithm.

#F	Multipliers								$\sigma_{gr}(ns)$	A_s
8	0	1	2	3	58	59	60	61	0.342	0.990
8	0	20	23	27	28	37	39	61	0.607	0.451
8	**0**	**1**	**3**	**16**	**35**	**54**	**60**	**61**	**0.393**	**0.618**
8	0	1	2	22	47	56	60	61	0.383	0.695
8	0	1	2	8	41	59	60	61	0.369	0.791

Similarly, we considered the case when observations are made within a spanned bandwidth of 496 MHz. Results for the narrow-band fringe fitting algorithm are shown in table 3 and results for the wide-band fringe fitting algorithm are shown in table 4. Starting with the 3rd row, the maximum allowed level of the secondary maximum was raised, keeping the minimal group delay ambiguity spacing over 20 ns (for the narrow-band algorithm only). The recommended sequence is shown in bold. We see that, for a given SNR, the group delay over 1000 MHZ bandwidth is determined with an uncertainty smaller by a factor of 2.

Table 3: Selected sequences of 8 IF channels 16 MHz wide spread over (30+1)*16=496 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitude of the secondary maximum is computed for the narrow-band fringe fitting algorithm. Group delay ambiguity spacing is shown in the last column. In total, 475020 sequences have been checked.

#F	Multipliers								$\sigma_{gr}(ns)$	A_s	S_{gr} (ns)
8	0	1	2	3	27	28	29	30	0.734	0.967	62.500
8	0	3	6	9	12	15	21	30	1.076	0.315	20.833
8	0	1	7	10	15	26	28	30	0.879	0.479	62.500
8	0	1	3	9	17	27	29	30	0.823	0.598	62.500
8	0	1	3	8	17	27	29	30	0.819	0.618	62.500
8	0	1	2	6	18	28	29	30	0.791	0.699	62.500
8	0	1	2	3	19	28	29	30	0.771	0.791	62.500

Table 4: Selected sequences of 8 IF channels 16 MHz wide spread over 30+1)*16=496 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitude of the secondary maximum is computed for the wide-band fringe fitting algorithm.

#F	Multipliers								$\sigma_{gr}(ns)$	A_s
8	0	1	2	3	27	28	29	30	0.734	0.967
8	0	3	8	9	11	13	15	30	1.169	0.376
8	0	1	6	10	17	26	28	30	0.870	0.499
8	0	1	2	8	16	26	29	30	0.821	0.599
8	**0**	**1**	**2**	**14**	**22**	**26**	**29**	**30**	**0.819**	**0.614**
8	0	1	2	6	18	28	29	30	0.791	0.697
8	0	1	2	3	19	28	29	30	0.771	0.791

3 Case of 4 IFs

During dual-band S/X observations the pool of eight IFs have to be split between S and X bands, for instance 4 IFs at X-band and 4 IFs at S-band. Table 5 shows the sequence with the minimum amplitude of the secondary maximum (1st row) for the narrow-band fringing fitting algorithm. Starting with the 2nd row, the maximum allowed level of the secondary maximum was raised, keeping the minimal group delay ambiguity spacing over 20 ns.

Table 5: Selected sequences of 4 IF frequency channels 16 MHz wide spread over (30+1)*16=496 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitude of the secondary maximum is computed for the narrow-band fringe fitting algorithm. In total, 406 sequences have been analyzed.

#F	Multipliers					$\sigma_{gr}(ns)$	A_s	S_{gr}
4	0	5	10	15	30	0.906	0.409	12.500
4	0	3	18	24	30	0.850	0.600	20.833
4	0	2	10	26	30	0.809	0.669	31.250
4	0	1	11	27	30	0.787	0.747	62.250

Table 6 shows two sequences for the wide-band fringe fitting algorithm. The first one has the minimum level of the secondary maximum, and the second sequence has the minimum group delay uncertainty keeping the amplitude of the secondary maximum under 0.8.

Table 6: Selected sequences of 4 IF frequency channels 16 MHz spread over (30+1)*16=496 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitudes of the secondary maximum were computed for the wide-band fringe search algorithm.

#F	Multipliers				A_s	$\sigma_{gr}(ns)$
4	0	2	22	30	0.775	0.797
4	0	14	19	30	0.923	0.757

Spreading the frequencies over 1 GHz makes it problematic to find a good sequence. There are two sequences spread over the band of 972 MHz shown in table 7 that have the amplitude of the secondary maximum for the narrow-band algorithm 0.72 and 0.83 respectively. The second sequence has the minimum amplitude of the secondary maximum among those sequences that have group delay ambiguity spacing above 20 ns.

Table 7: Selected sequences of 4 IF frequency channels 16 MHz wide spread over (60+1)*16=976 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitudes of secondary maximum were computed for the narrow-band fringe search algorithm. In total, 1711 sequences have been analyzed.

#F	Multipliers				$\sigma_{gr}(ns)$	A_s	S_{gr}
4	0	12	18	60	0.440	0.720	10.417
4	0	9	24	60	0.435	0.832	20.833

Table 8 shows two best sequences for the wide-band fringe fitting algorithm. The first one has the minimum amplitude of the secondary maximum. The second sequence has the amplitude of the secondary maximum 1% higher, but 11% smaller uncertainty of group delay at a given SNR.

Table 8: Selected sequences of 4 IF frequency channels 16 MHz spread over (60+1)*16=976 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitudes of secondary maximum were computed for the wide-band fringe search algorithm. In total, 1771 sequences have been analyzed.

#F	Multipliers				$\sigma_{gr}(ns)$	A_s
4	0	12	39	60	0.426	0.826
4	0	5	47	60	0.383	0.835
4	**0**	**19**	**52**	**60**	**0.410**	**0.839**

When we have to select between sequences with high amplitudes of secondary maximum, the placement of the secondary maxima is becomes important. For example, as it seen in figure 1, the sequence `(0, 19, 52, 60)` is preferable with respect to `(0, 5, 47, 60 )`, since the first sequence has the major secondary maximum at delay 1.2 ns, while the second sequence has the major secondary maximum at delay 6.2 ns.

4 Case of 5 IFs

The difficulty to find a good sequence using only 4 IFs prompts us to consider using 5 IFs at X-band and 3 IFs at S-band. Table 9 demonstrates that there exist good sequences spread over 972 MHz (but not 992 MHz) with the amplitude of the secondary maximum below 0.7 level and group delay ambiguity spacings greater than 20 ns. The recommended sequence for the wide-band fringe search algorithm is shown in table 10 by bold font. It has the amplitude of the secondary maximum 0.73 and group delay uncertainty 0.39 ns for SNR=1.

5 A trial VLBI experiment

The new sequence was tried in absolute astrometry experiments. under BC191/BC196 program in 2010/2011 that used 8 IFs in X-band.

Figure 1: The normalized amplitude of its Fourier-transform of the sequence `(0, 5, 47, 60)` *left* and sequence `(0, 19, 52, 60)` *right* for the wide-band fringe fitting algorithm. Although, the amplitude of the secondary maximum at the left plot is slightly less, it is located very close to the main maximum. The second sequence is preferable.

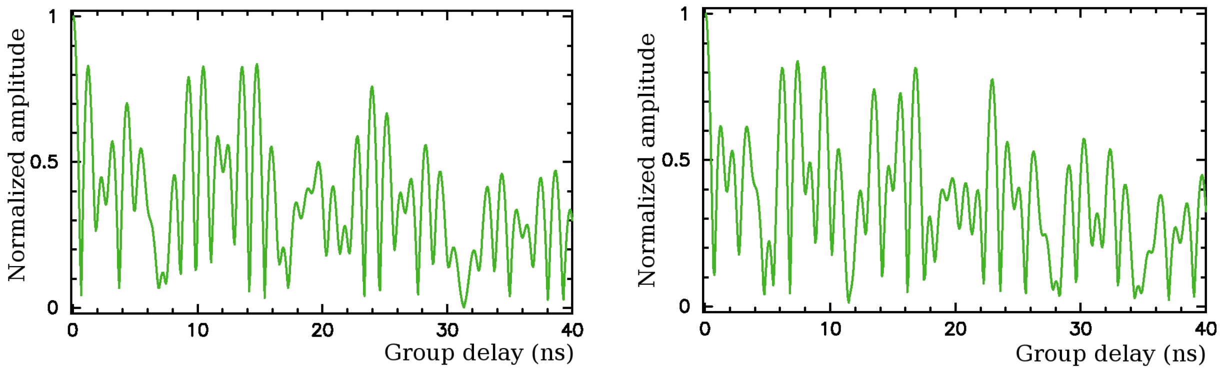


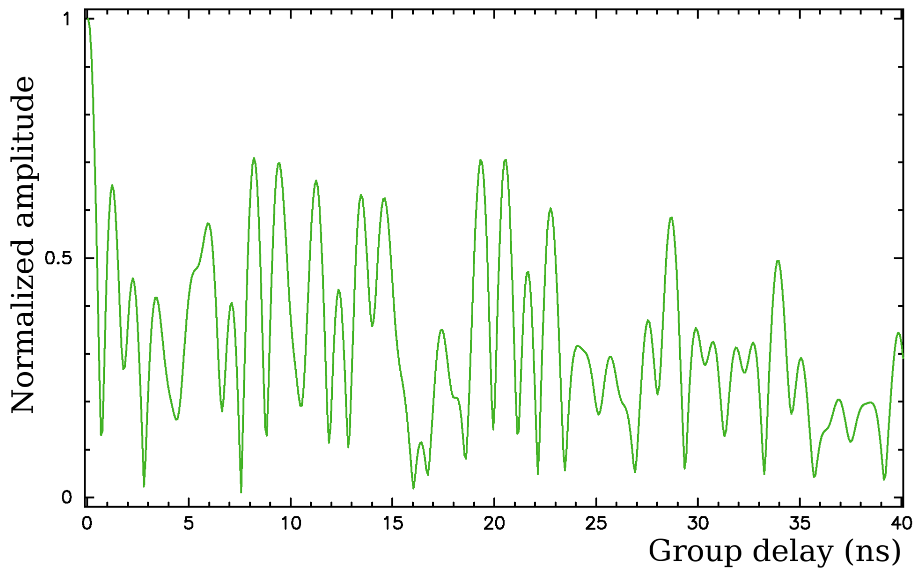
Table 9: Selected sequences of 5 IF frequency channels 16 MHz wide spread over (60+1)*16=972 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitudes of secondary maximum were computed for the narrow-band fringe search algorithm. In total, 34220 sequences were examined.

#F	Multipliers					$\sigma_{gr}(ns)$	A_s	S_{gr}
5	0	5	15	35	60	0.451	0.551	12.500
5	0	1	21	36	60	0.508	0.644	20.833
5	0	3	21	38	60	0.415	0.695	20.833
5	0	3	21	38	60	0.393	0.740	20.833

Table 10: Selected sequences of 5 IF frequency channels 16 MHz wide spread over (61+1)*16=992 MHz bandwidth with frequencies set to be a multiple of 16 MHz. The amplitudes of secondary maxima were computed for the wide-band fringe search algorithm.

#F	Multipliers					$\sigma_{gr}(ns)$	A_s
5	0	12	19	28	61	0.482	0.677
5	0	4	11	37	61	0.430	0.683
5	**0**	**6**	**39**	**52**	**61**	**0.407**	**0.708**
5	0	2	16	56	61	0.377	0.796

Figure 2: The normalized amplitude of its Fourier-transform of the sequence (0, 6, 39, 52, 60)*16.0 MHz for the wide-band fringe fitting algorithm.



In experiment BC191 the following sequence spanning 496MHz was used: `8405.99 + (0 1 7 10 15 26 28 30)*16.0 MHz`. It had the maximum amplitude of the secondary maximum 0.478 and the group delay uncertainty 0.879 ns for observations with SNR=1.

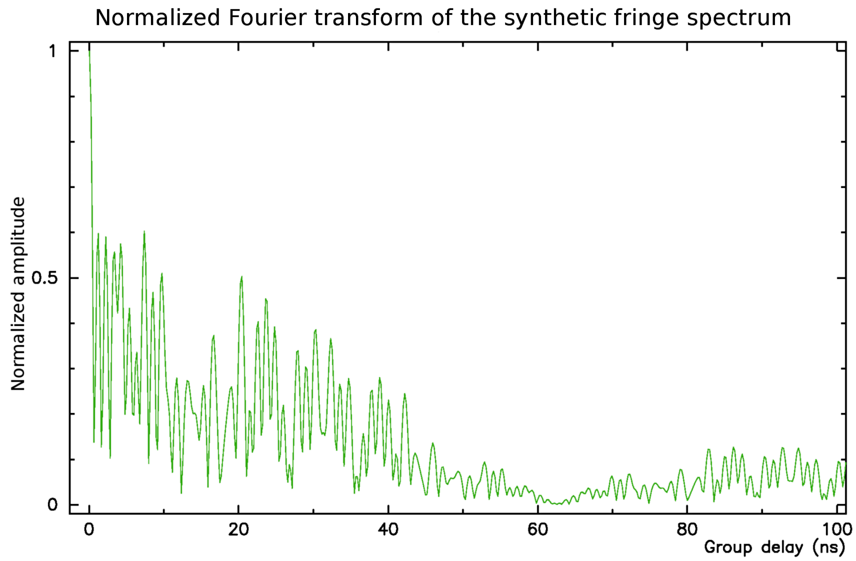
In experiment BC196 the sub-optimal sequence `7900.99 + (0 1 3 16 34 53 59 61)*16.0 MHz` was used. The normalized amplitude of its Fourier-transform for the variant of the wide-band fringe fitting algorithm is shown in figure 3. The maximum secondary maximum has the amplitude 0.605, and the group delay uncertainty at the SNR=1 is equal to 0.398 ns.

The sequence was defined in the key-file the following way:

```
setinit = astromet-512-16-2-R-wide /
!
!  (0   1   3  16  34  53  59  61) x 16 MHz  (max sidelobe level: 0.605)
!   0  16  48 256 544 848 944 976
!
! Sky frequencies
!
!   7900.990
!   7916.990
!   7948.990
!   8156.990
!   8444.990
!   8748.990
!   8844.990
!   8876.990
!
  nchan    = 8
  bits     = 2
  bbfilter = 16.0
  freqref  = 8380.99
```

```
  pcal     = '1MHz'
  freqoff  =  -480.0, -464.0, -432.0, -224.0,  64.0, 368.0,  464.0,   496.0
  netside  =     U,      U,      U,      U,     U,     U,      U,      U
  pol      = rcp
  station  = VLBA /
endset /
setup=astromet-512-16-2-R-wide
```

Figure 3: The normalized amplitude of Fourier transform of the sequence `7900.99 + (0 1 3 16 34 53 59 61)*16.0 MHz` for the wide-band fringe fitting algorithm.



VLBA experiments with 992 MHz wide spanned bandwidth were successful. Figures 4–5 show no abnormalities in plots of residual fringe phase and fringe amplitude of one of the bright sources used as a calibrator in that experiment.

Some sources were observed in one scan in different experiments that used sequences spread over 496 and over 992 MHz. Due to different weather conditions, different LST observing time and other factors, the number of observations used in the astrometric solution varies. We found seven sources that had about the same number of used observations in experiments with 496 MHz and 992 MHz spanned bandwidth. Formal position uncertainties from observations made with the two sequences are shown in table 11. In general, position uncertainties with the use of the wide spanned bandwidth are smaller, although they are not simply scaled with the bandwidth, since other factors, such as geometry of observations play a certain role.

Figure 4: The residual fringe phase of the calibrator 0106+013 on the baseline KP-VLBA/PIETOWN in experiment bc196a that used the wide-band frequency sequence `7900.99 + (0 1 3 16 34 53 59 61)*16.0 MHz`

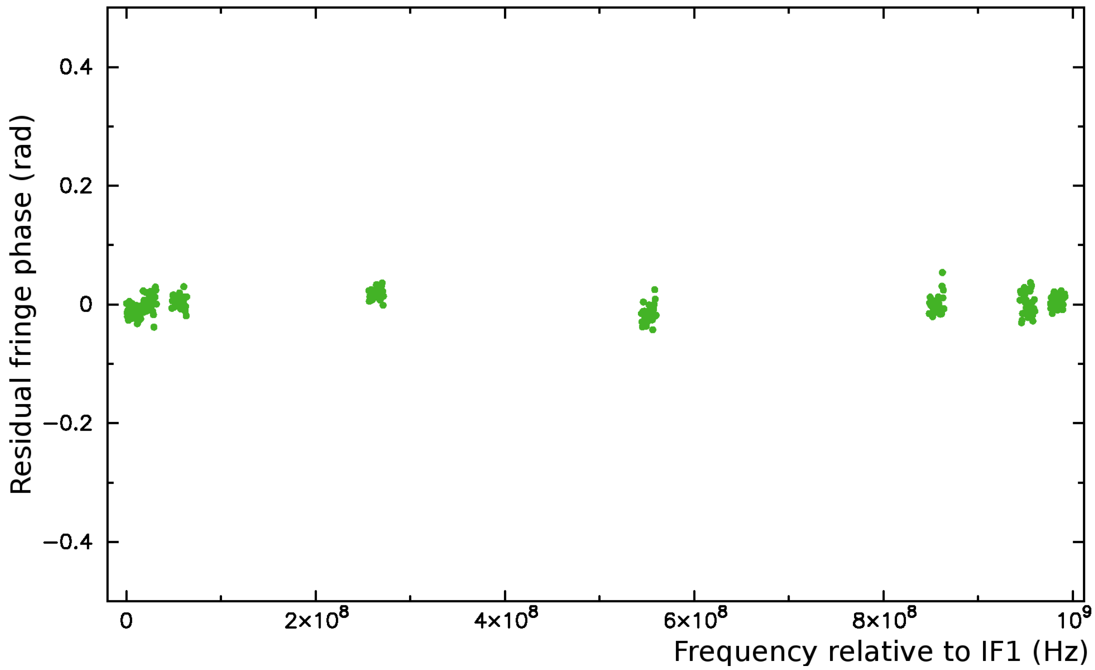


Figure 5: Fringe amplitude of calibrator 0106+013 on the baseline KP-VLBA/PIETOWN in experiment bc196a that used with wide-band frequency sequence `7900.99 + (0 1 3 16 34 53 59 61)*16.0 MHz`

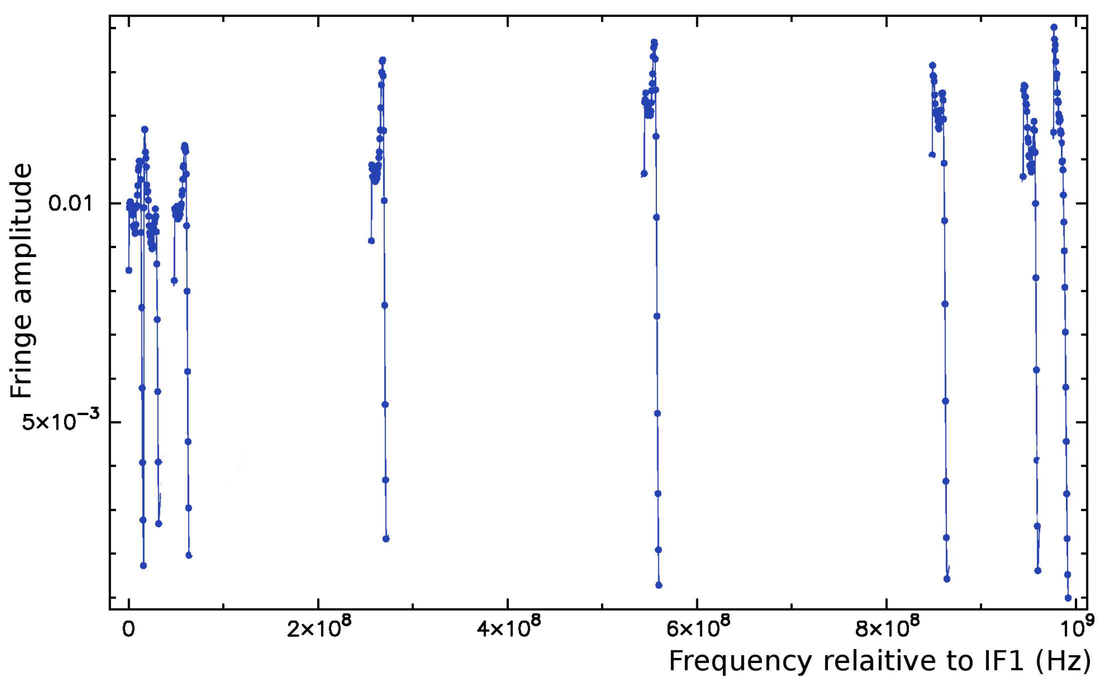


Table 11: Comparison of source position uncertainties in mas observed at the VLBA in one scan in two experiments that used bandwidth 492 and 992 MHz.

Source	496 MHz bandwidth			992 MHz bandwidth			F_{corr}
	#Obs	$\sigma(\alpha)$	$\sigma(\delta)$	#Obs	$\sigma(\alpha)$	$\sigma(\delta)$	mJy
$0221-029$	19	1.3	3.3	17	0.7	1.6	12
$0242+510$	10	2.3	2.9	10	1.4	1.5	10
$0306-237$	13	1.5	3.7	12	1.3	2.8	12
$0336-177$	45	0.2	0.5	10	0.2	0.4	45
$0448+519$	43	0.8	1.0	45	1.0	0.6	16
$0636+335$	44	0.5	0.7	45	0.4	0.6	16
$0718+277$	45	0.4	0.6	45	0.2	0.3	55

6 Using the wide-band capability

The wide-band capability at X-band (4cm) on the VLBA is provided by some extra cabling, splitters, and switches in the X-band IF converters. The incoming RCP signal from the receiver is split. One path then goes to the usual mixers and amplifiers for the RCP data path. There is a switch on the input of the left circular polarization (LCP) data path that can select either the LCP signal from the receiver or the other right circular polarization (RCP) output from the splitter. In the other IF converters, and in the normal mode for this one, both the RCP and LCP signals are downconverted using the same LO signal. But for the wide-band mode, the LO used on the LCP side, when it is carrying an RCP signal, can be from a different LO synthesizer, allowing a different segment of the RF to be sent to the backend. Thus it is possible to place the two 500MHz IFs, both carrying RCP in different parts of the RF signal from the receiver. The same IF converter is used for the K-band (1cm) signals, but the wide-band mode cannot be used because the extra LO synthesizer is also required for the first downconvert that happens in that receiver.

An implication of this design is that, when the wide-band capability is being used, the LCP signal is not available for recording. Thus the capability cannot be used when dual polarization is desired. Another implication is that 2 of the IFs (B and D - note these are the 500 MHz wide IFs on the telescopes, not the AIPS ”IF”s) are required to use the full spanned bandwidth. If both S and X band signals are desired, signals from at least 3 IFs must be processed. This is not a problem with the old analogue backend system used since 1992 where each baseband converter can chose from any of the 4 IFs. For the new RDBE/Mark5C system used since 2011, each RDBE can only process signals from 2 IFs. The initial implementation in 2011 only uses one RDBE, so wide X with S will not be possible. But the hardware for a second RDBE at each station is in hand and the necessary switches to use both are being acquired so the ability to do wide X with either single or dual polarization S-band will return soon after the conversion to the new digital backend system: late in 2011 or 2012.

Table 12: Summary of limitations of the capability to record 1 GHz spanned bandwidth at X-band

Equipment	X-band only	X & S band	RCP	LCP	RCP & LCP
Analogue	yes	yes	yes	no	no
one RDBE	yes	no	yes	no	no
two RDBEs	yes	yes	yes	no	no

The wide-band mode can be invoked in a schedule simply by specifying the desired frequencies and only requesting RCP at X-band. SCHED will find the necessary mode in the *freq.dat* file. The `DUALX` parameter in a SCHED setup file can also be used to request the wide-band mode.

7 Conclusions

The ability of the VLBA to record signal in a bandwidth spread over 1 GHz within [7.9, 8.9] GHz has been successfully tested. The uncertainty of group delay for the same SNR was reduced by a factor of 2, which is important for observing weak sources in the absolute astrometry mode. Using all 8 IFs, makes it easy to select a sequence of IFs that has a small amplitude of the secondary maximum of the fringe spectrum based on a Fourier transform.

Using only 4 IFs 16 MHz wide over 1 GHz is problematic, since the frequency sequence has a secondary maximum with an amplitude of 0.83, which may be too high.

Using 5 IFs over 1 GHz lifts this problem. There exist frequency sequences with the level of secondary maximum of their Fourier-transform in the range 0.68–0.73.

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