Memo: FFT size for VGOS correlation

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DiFX correlator allows to select an arbitrary FFT size. However, transitionally FFT size of the power two was used. There are several reasons of this choice. The initial FFT implementation supported FFT size a power two, since this simplifies the algorithm. Hardware correlators supported only the power two choice. VLBI hardware supported the bandwidth that is the power two of 1 MHz. Therefore, spectral resolution that is the power two of 1 MHz was provided.

The intermediate frequency lower end is usually set to -0.01 MHz of an integer MHz for geodetic experiments and some astronomical experiments and to an integer Megahertz for most continuum astronomical experiments. Apparently, 0.01 MHz offset was required for Mark-3 correlator to extract phase calibration. Haystack team suggested to shift the frequency by 0.4 MHz of an integer MHz arguing that this mitigates the impact of internal RFI on phase calibration signal. It would be nice to check to which extent this mitigation is efficient.

VLBI hardware emits parasite signals that are a harmonics of 1 MHz. They can be regarded as internal RFI. Phase calibration signal that has a spectrum in a form of a rail of 1 or 5 or 10 MHz can be considered as an internal RFI as well. When the phase rate is significant and is away from the fringe rate search window, internal RFI are decorrelated. When the fringe rate is low, there are chances the fringe search procedure will pick up these signals since they may be the strongest. Correlation between phase calibration or other internal RFI is not that the scientist needs. Such “data” are later flagged out as outliers and discarded. A chance that an observation will have a small phase rate are much higher at short baselines or at baselines with short equatorial baseline projection (f.e. BR-VLBA/OV-VLBA baseline).

In a case if the pcal signal falls exactly at the central frequency bin of the discrete Fourier Transform, all power of it signal propagates to that spectral constituent, and not power goes to another frequency beam. Therefore, the contribution of internal RFIs is confined to certain spectral constituents. Flagging them out by a applying a mask on the spectral with 0 at affected frequency bins and 1 otherwise, eliminates their contribution on the cross- and auto-fringe spectrum entirely. When data at 32 MHz wide IFs are correlated with spectral resolution 256, 1/8th the data are lost due to masking which results in 6.5% SNR reduction, which is acceptable.

A shift of the IF frequency by 0.01 MHz does not cause big problems, but a shift at 0.4 MHz does. 0.4 MHz is 1/80 of 32 MHz, and therefore FFT size of power two has frequency bins away from pcal and other internal RFI tones. In that case **the internal RFIs affect the entire spectrum**. Figure 1 shows an example. VGOS experiment vo1007 was correlated with FFT size 128. Spectral resolution is 0.25 MHz. We see that pcal and over internal RFI affects most of the spectrum. **All** observations at that baseline and that band turned out useless because the fringe fitting procedure selected signal from phase calibration, not from extragactic sources.

DiFX has a flexibility to use any FFT size. Although using a prime number, f.e. 127, would noticeably affect performance, using radix 3,5,7 does not. Bonn has re-correlated vo1007

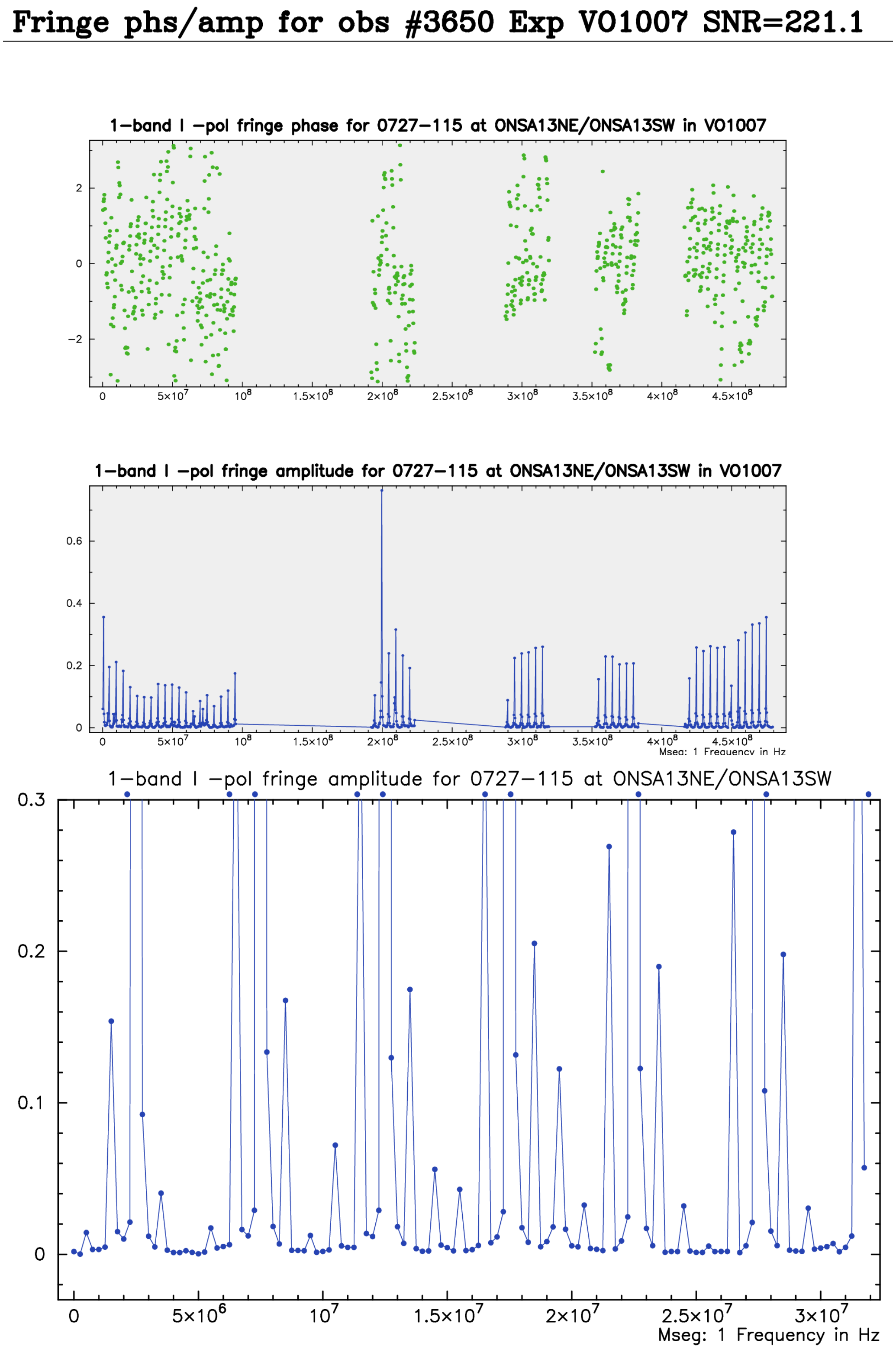


Figure 1: Fringe plot of VGOS experiment v01007 correlated with a spectral resolution of 0.25 MHz (FFT size 128) at band 1 (3000.4–3408.4 MHz). Top plot: fringe phase. Middle plot: fringe amplitude. Mask with step 1 MHz the closest an integer MHz + 0.4 MHZ has been applied. Bottom plot: zoom of fringe amplitude in IF #2 without mask applied.

experiment with FFT size 320, which provide spectral resolution 0.1 MHz. Phase calibration tones and other internal RFI that are harmonics of 1 MHz fall exactly at the frequency bins. Figure 2 shows the same scan correlated with FFT size 320. Masking entirely eliminated the contribution of the internal RFI. The observation is usable. With fft size 80% observations at shrtot baseline ONSA13NE/ONSA13SW, band 1 have been recovered. Remaining 20% were affected by external RFI and were not cleaned. Phase dealy solution have been. Its wrms fit is 10.4 ps at band 1 and at 1.8 ps at band 4 (see Figure 4).

NB: the fringe plots shows not only the contribution of phase calibration that has spacing 5 MHz, but other parasite signals with a step of 5 MHz. We can also see the contribution of external RFI that affects a range of 19–20 MHz with respect to 3032.4 MHz. Dodging these RFI requires a different technique that are routinely used for processing connected interferometer data.

As it was mentioned, internal RFI affects not only scans at short baselines, but at long baselines as well, although not that often. Figure 3 shows fringe plots of the same scan at a long baseline correlated with FFT size 128 and 320.

Using finer spectral resolution increases file size and processing time. The vo1007 dataset correlated with FFT size 128 is 79.1 Gb long and correlated with FFTS size 320 is 197 Gb long. Final fringe fitting run took 45 minutes when processing the dataset correlated with FFT 128 and 8.5 hours when correlated with FFT size 320 at AMD 3990X. Masking causes losses of 5% SNR. Correlating with the FFT size 160 causes losses of 10.5% SNR. Though masking can be applied only to affected scans. $\mathcal{PIMA}$ has such an option.

I ran correlation of about 100 scans of a VGOS intensive experiment with the FFT size 128 and 160 and did not notice any difference in wall execution time at all. Although this test may be affected by I/O bottleneck, it still shows that the slowdown in correlation, it it exists, is not substantial.

Conclusion

When using the frequency setup with the low intermediate frequency shifted by 0.4 MHz from an integer MHz, correlation with the FFT size 160 or 320 should be used, especially for experiments with short baselines or baselines with short equatorial baseline projections. Correlation with the FFT size of power two, such as 128 and 256, should be avoided.

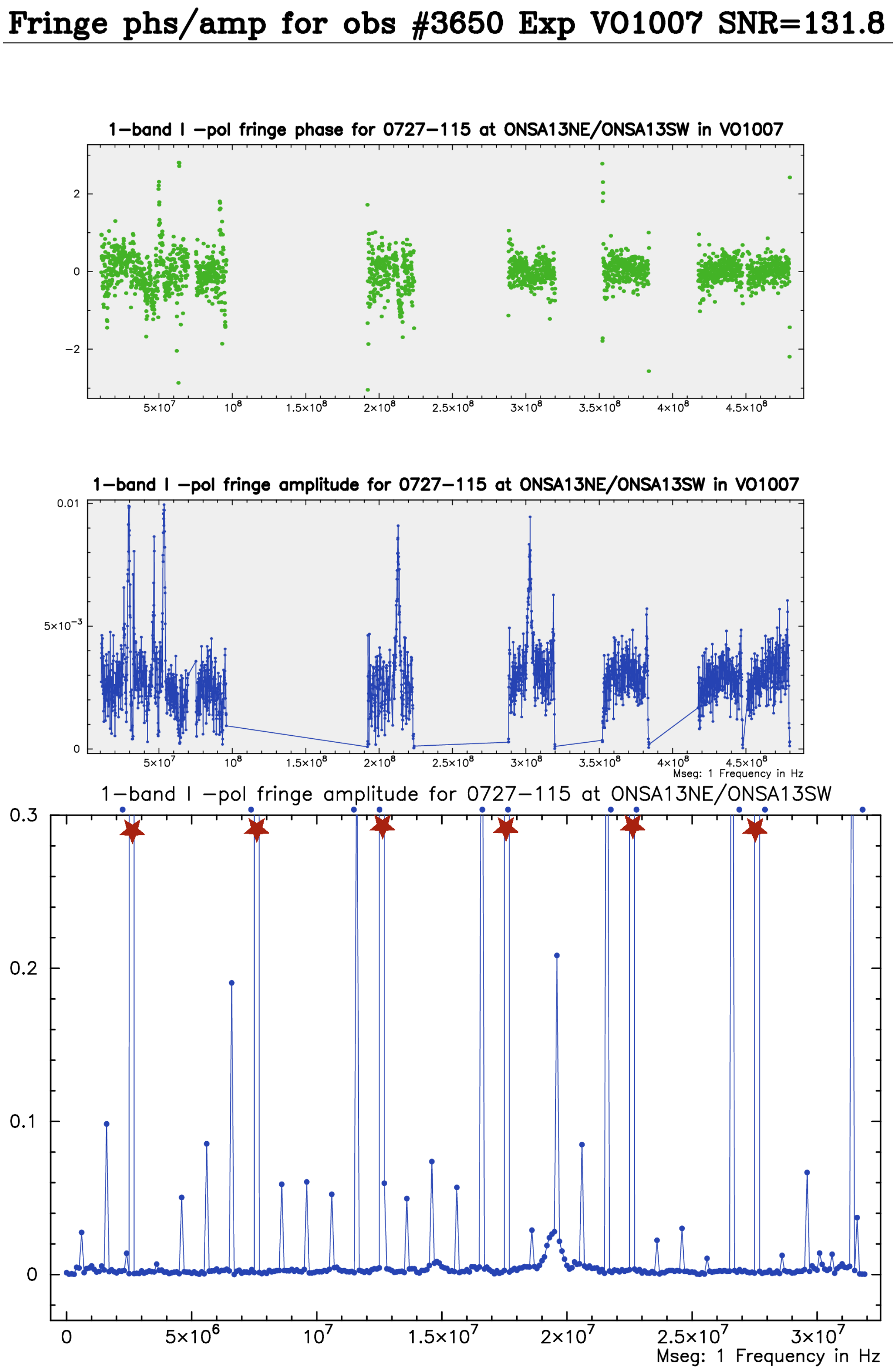
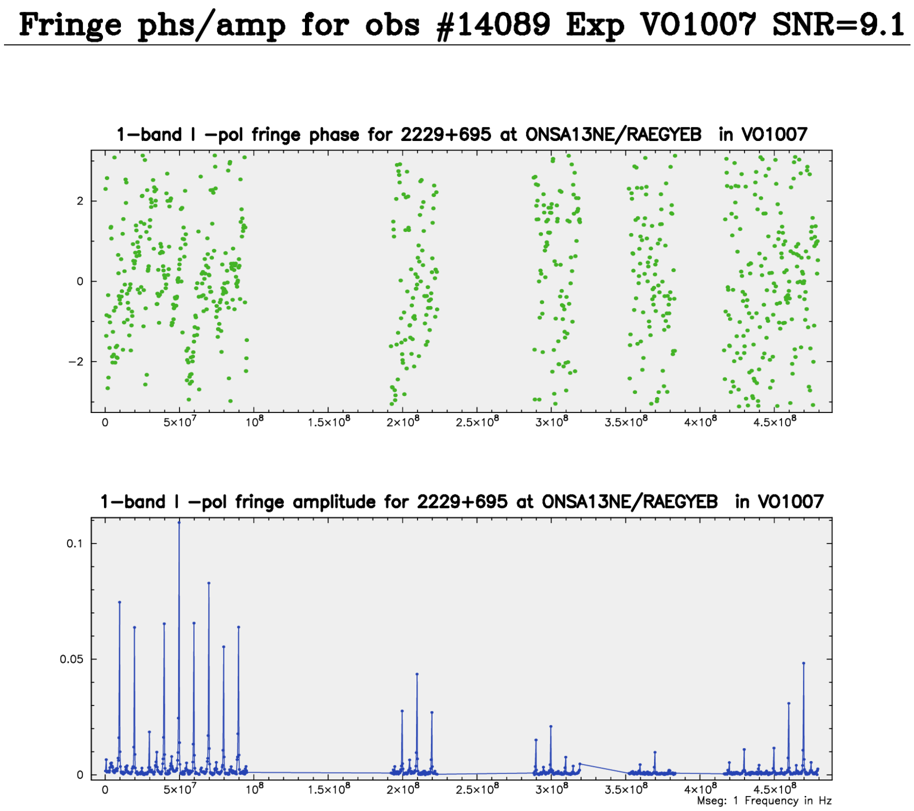


Figure 2: Fringe plot of VGOS experiment v01007 correlated with a spectral resolution 0.10 MHz (FFT size 320) at band 1 Top plot: fringe phase. Middle plot: fringe amplitude. Mask with step 1 MHz the closest an integer MHz + 0.4 MHz has been applied. Bottom plot: zoom of fringe amplitude in IF #2 without mask applied.



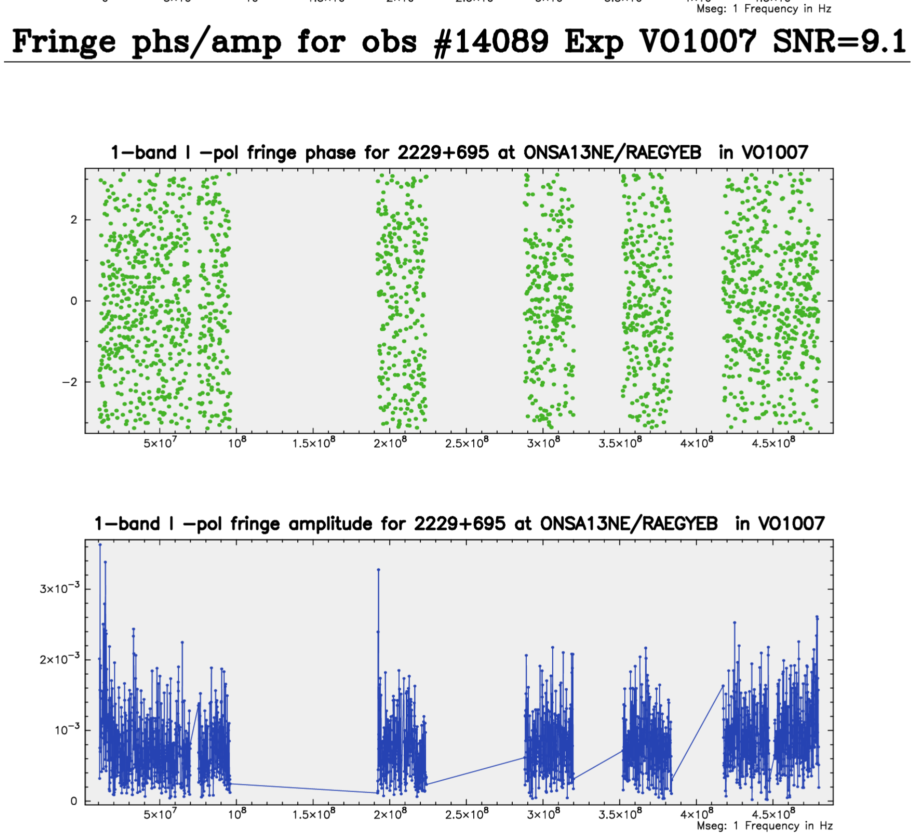


Figure 3: Fringe plots of same scan from a VGOS experiment at a long baseline correlated FFT size 128 (top) and 320 (botton) at and 1 (3000.4–3408.4 MHz).

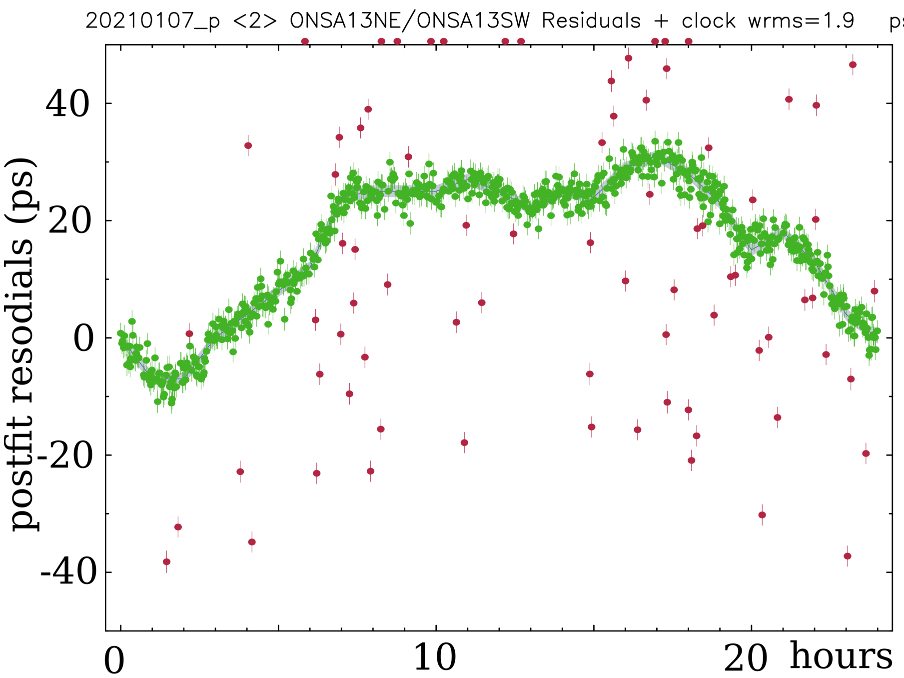


Figure 4: A sum the phase delay residuals from phases at band 4 and the clock function from processing vo1007 experiment processed with FFT size 320.