

Correlation and Post-Processing for VLBI2010

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Overview

New VLBI2010 system driving transition to new processing capabilities

Hardware

Mk4 correlator → DiFX cluster
Mk5a & Mk5b → Mk5c & Mk6

Software

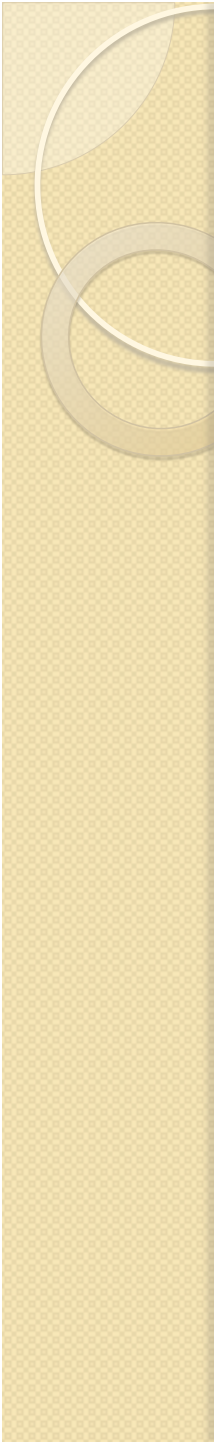
Enhanced VLBI2010 characteristics

- DiFX
- New post-correlation modes and features



VLBI2010 drivers

- Dual linear polarization
 - Combined fringe fit (pseudo Stokes I) from all 4 products
- Aggregate data rates of 8 Gb/s, channelized as 64 streams
- Phase-delay across 6-8 GHz of sky bandwidth requires removal of 2π ambiguities
 - multiple phase cal tones link different bands
 - differential ionosphere a significant effect
- Mark 6
 - VDIF support
- Support of legacy equipment
 - Mismatched video BW's
 - Mixed circular/linear fringe fitting



Other (e.g. EHT) drivers

- High data rates (16+ Gb/s)
- Single channel BW's as high as 512 MHz
- Coherent combination of Nyquist bands (without pcal) to maximize *snr*



DiFX Software Correlator

- FX correlator, originally written by Adam Deller to facilitate his PhD research in 2006
- Now improved & maintained by an international team of ~12 developers
- Widely used (VLBA, LBA, MPIfR, ...)
- Executes on a cluster of high-performance servers, using MPI and Intel's IPP library
- Extremely flexible:
 - Multiple phase centers within FOV
 - Pulsar binning
 - eVLBI
 - Phase cal and Tsys extraction
 - Input data formats: LBA, Mk4, VLBA, VDIF
 - Complex samples
 - Output datasets to FITS-ID1 or Mk4/fourfit

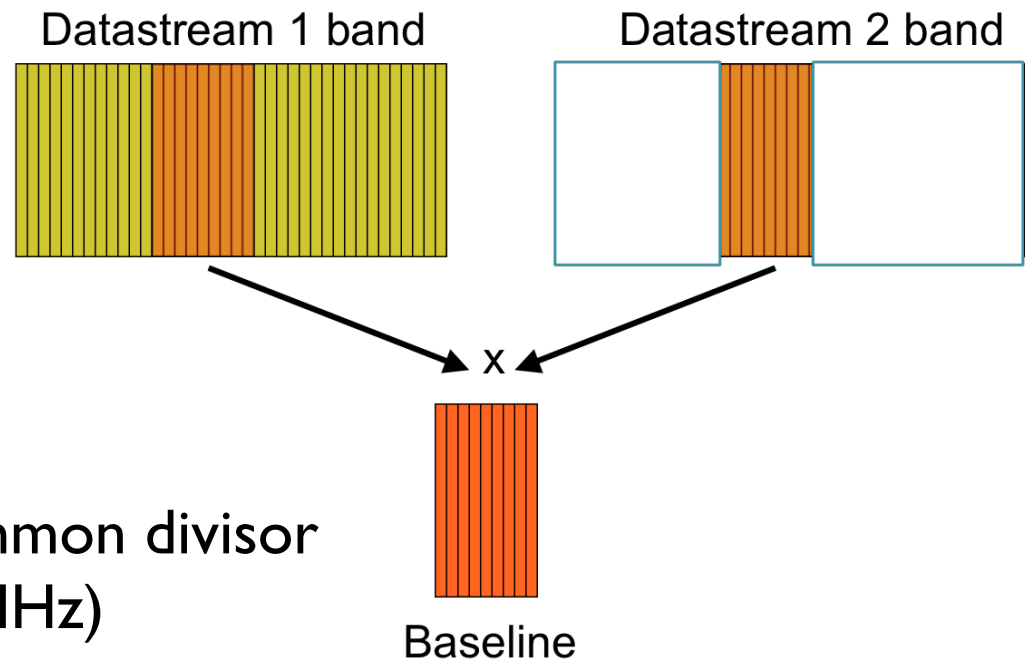
Software correlator = flexibility

DiFX Development at Haystack

- DiFX to HOPS interface software
- DiFX-specific modifications to HOPS
 - Spectral domain visibilities, pcal extraction, etc.
- HOPS distribution with DiFX
- ~100 core cluster
40 Gb/s Infiniband
- Hosted annual meeting last December



Example of DiFX Flexibility: correlating 32 MHz x 8 MHz ch

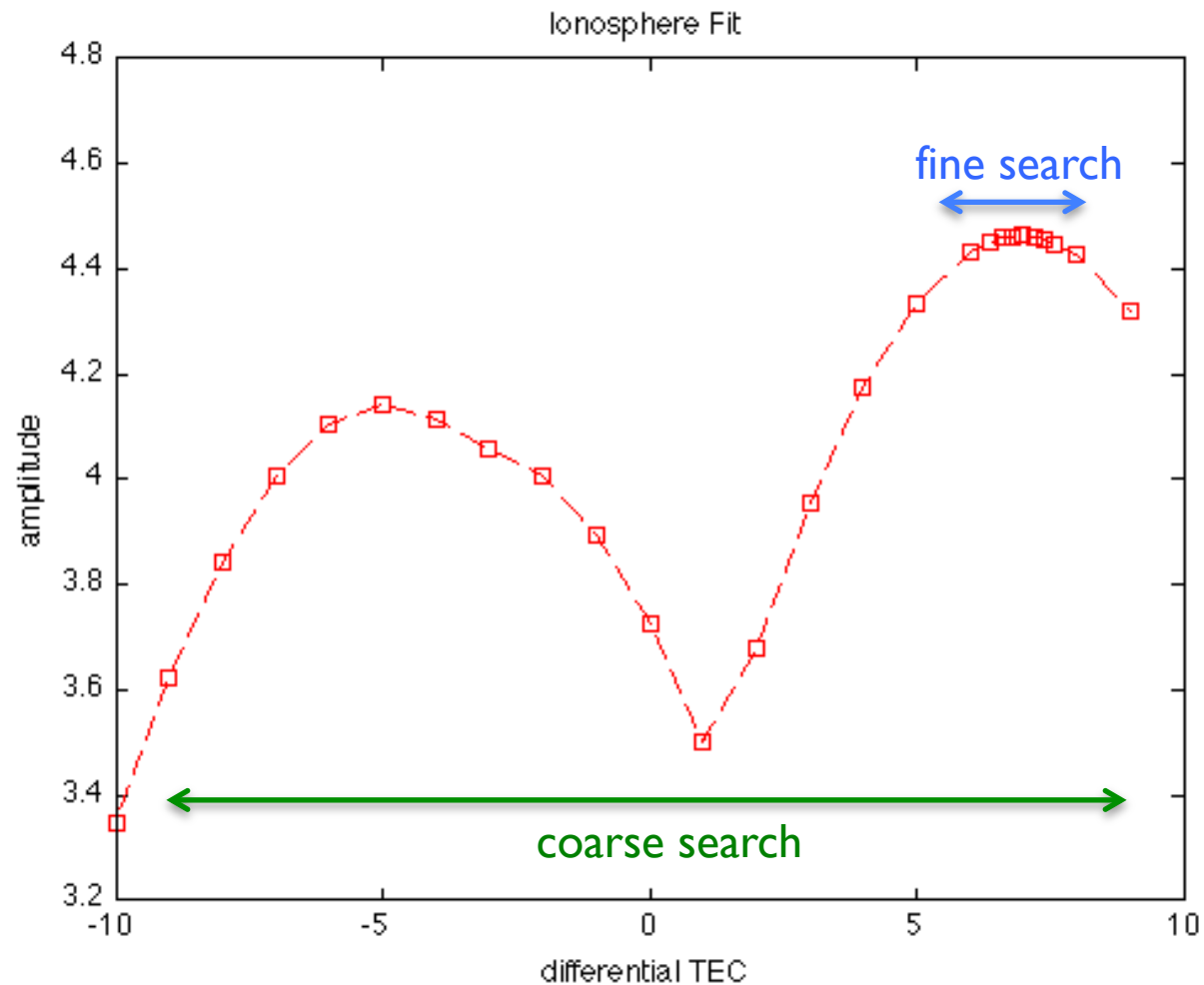


- Channelize to a common divisor frequency (e.g. 0.5 MHz)
- Match corresponding channels prior to XY^* multiply

Ionosphere

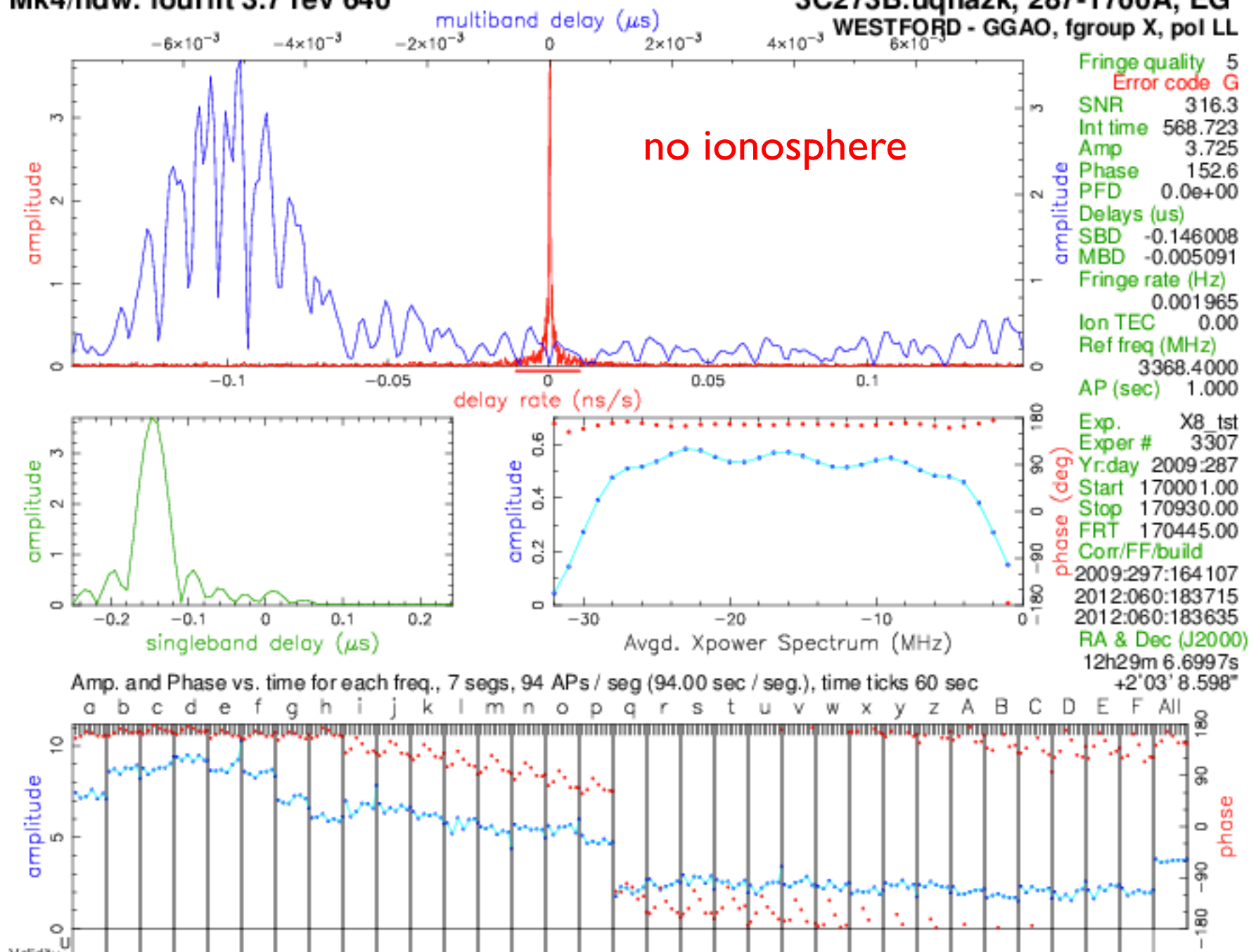
- differential TEC can be fit and/or specified *a priori*
 - all-sky models from GPS available, but not yet used
 - fit made difficult by nonlinearity
- *fourfit*
 - search for delay & rate that maximizes coherent sum over all t 's and f 's
 - now do multiple passes with different values of ΔTEC , and find maximum

Fourfit Ionosphere Fit



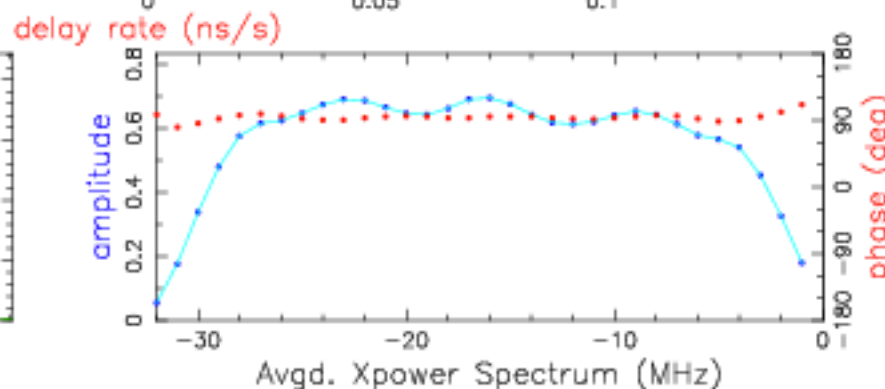
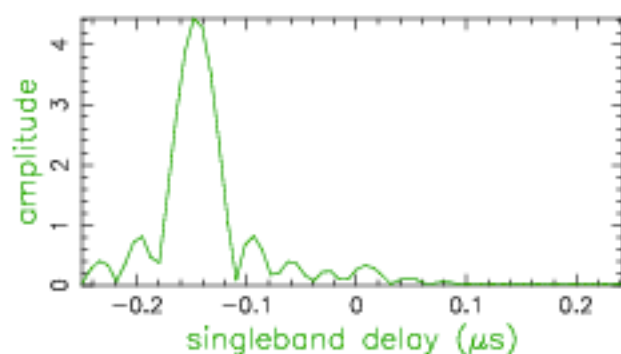
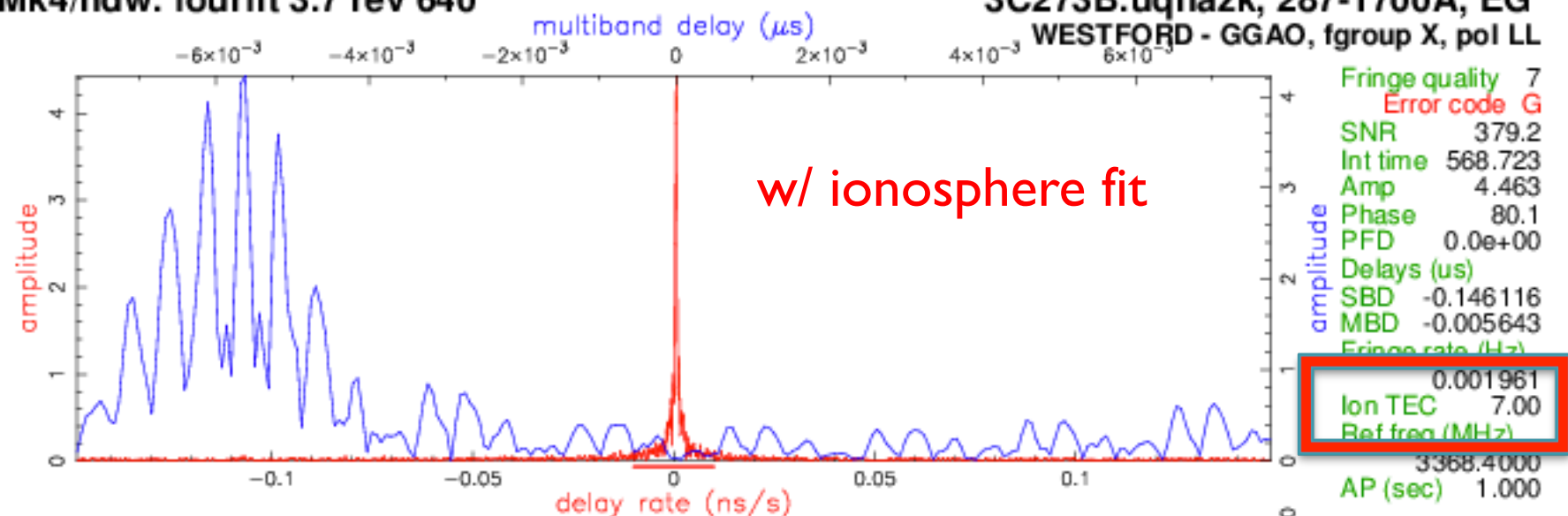
Mk4/hdw. fourfit 3.7 rev 640

3C273B.uqnazk, 287-1700A, EG
WESTFORD - GGAO, fgroup X, pol LL



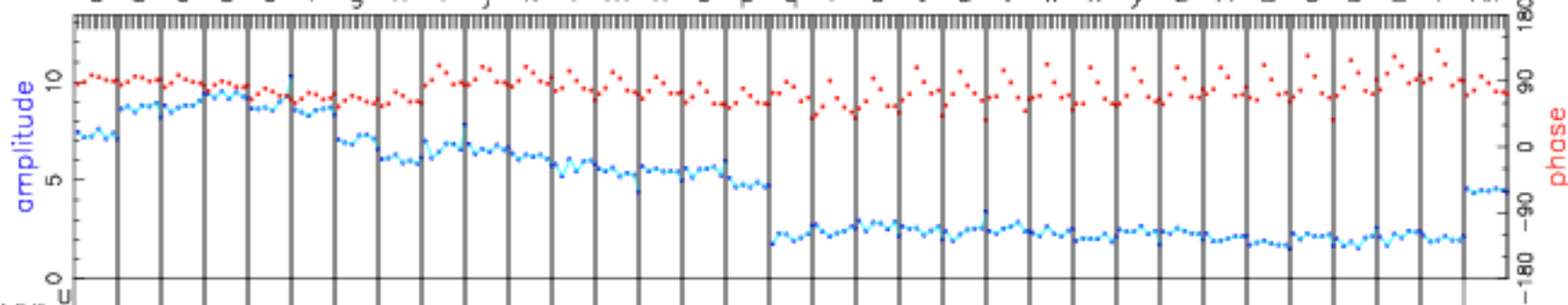
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3C273B.uqnazk, 287-1700A, EG
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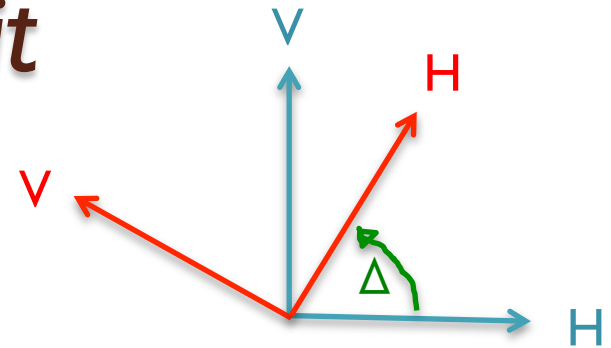


Amp. and Phase vs. time for each freq., 7 segs, 94 APs / seg (94.00 sec / seg.), time ticks 60 sec

a b c d e f g h i j k l m n o p q r s t u v w x y z A B C D E F All



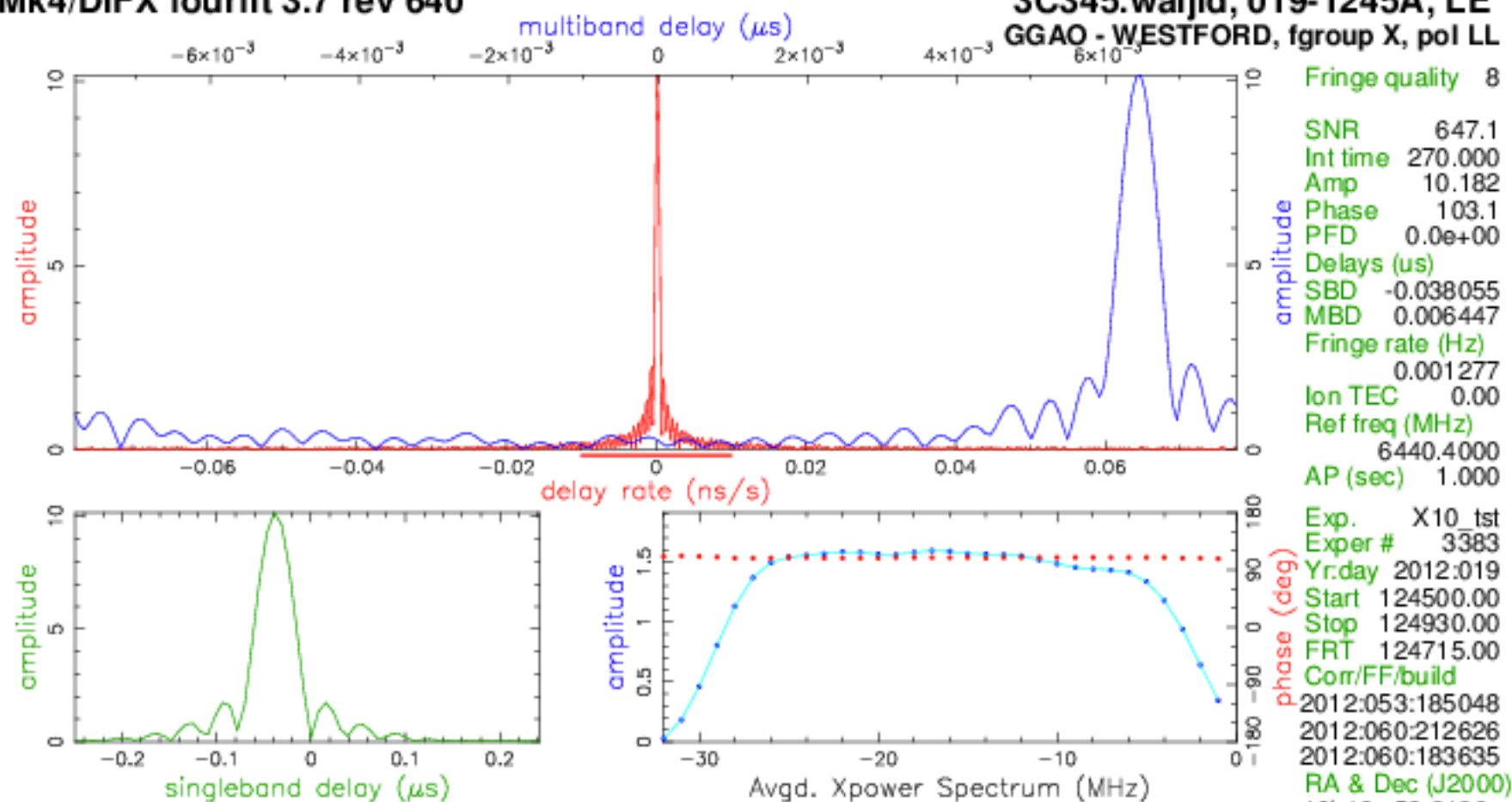
Polarization in *fourfit*



- Maximize sensitivity in τ_g by combining all 4 Stokes polarization products
- Form an approximation to Stokes I:
 - from the 4 correlation products form
$$I \cong (H_{\text{red}} \times H_{\text{blue}} + V_{\text{red}} \times V_{\text{blue}}) \cos \Delta + (H_{\text{red}} \times V_{\text{blue}} - V_{\text{red}} \times H_{\text{blue}}) \sin \Delta$$
$$\Delta = \text{differential parallactic angle}$$
 - correct to first order in the D terms

Mk4/DiFX fourfit 3.7 rev 640

3C345.waljid, 019-1245A, LE
GGAO - WESTFORD, fgroup X, pol LL



Fringe quality 8

SNR 647.1

Int time 270.000

Amp 10.182

Phase 103.1

PFD 0.0e+00

Delays (μ s)

SBD -0.038055

MBD 0.006447

Fringe rate (Hz)

0.001277

Ion TEC 0.00

Ref freq (MHz)

6440.4000

AP (sec) 1.000

Exp. X10_tst

Exper # 3383

Yr.day 2012:019

Start 124500.00

Stop 124930.00

FRT 124715.00

Corr/FF/build

2012:053:185048

2012:060:212626

2012:060:183635

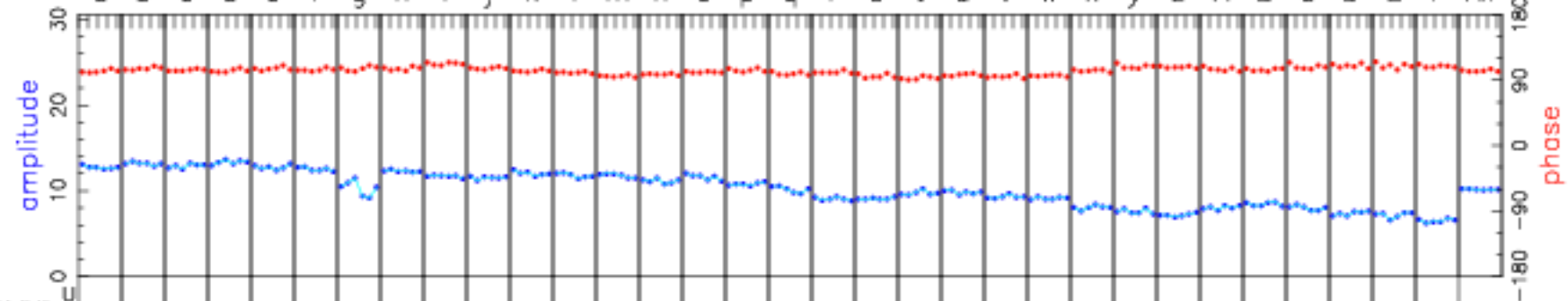
RA & Dec (J2000)

16h42m58.8100s

+39°48'36.994"

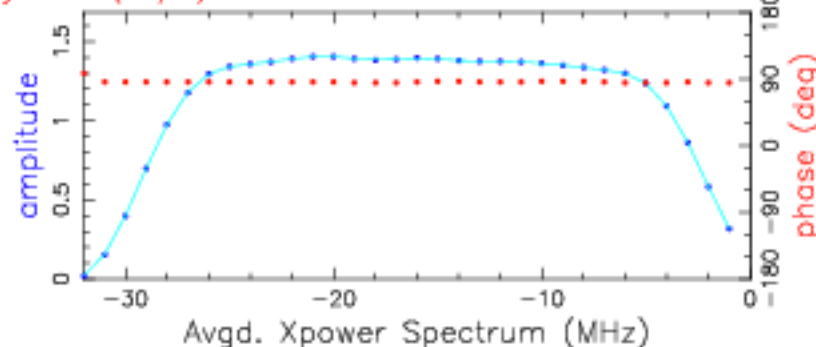
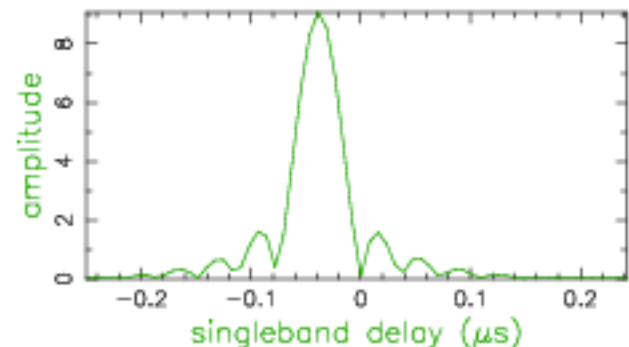
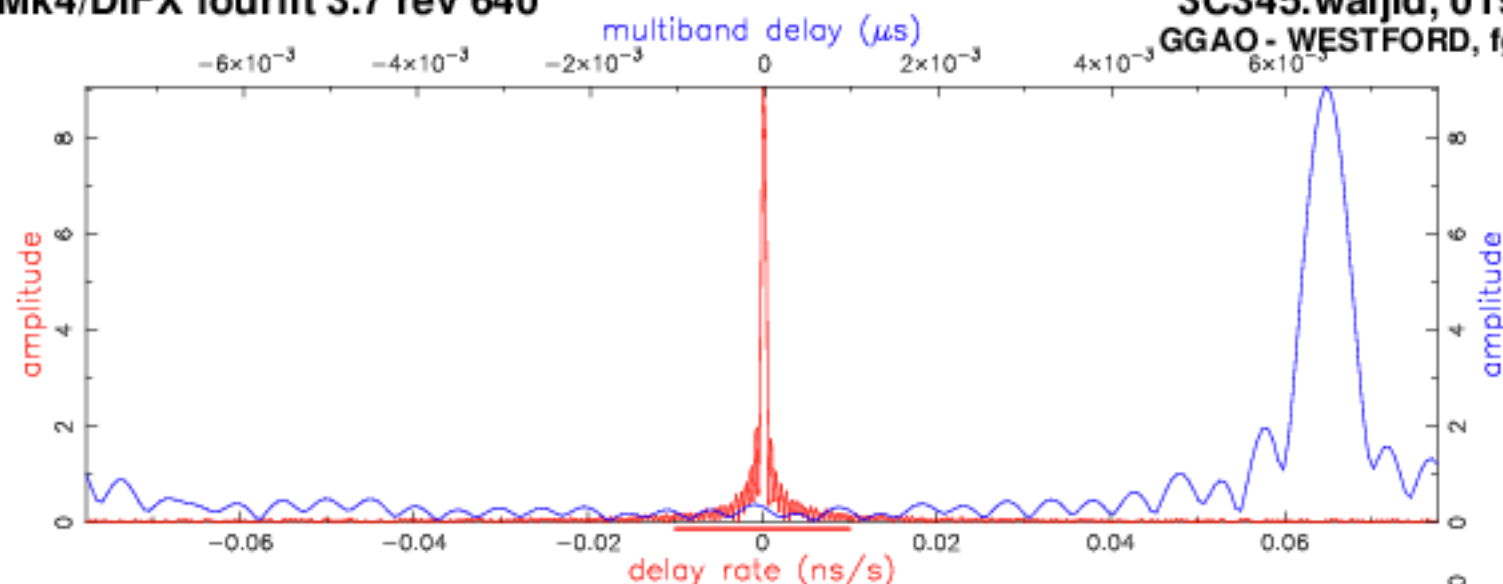
Amp. and Phase vs. time for each freq., 6 segs, 45 APs / seg (45.00 sec / seg.), time ticks 60 sec

a b c d e f g h i j k l m n o p q r s t u v w x y z A B C D E F All



Mk4/DiFX fourfit 3.7 rev 640

3C345.waljid, 019-1245A, LE
GGAO - WESTFORD, fgroup X, pol RR



Fringe quality 8

SNR 577.5

Int time 270.000

Amp 9.089

Phase 81.5

PFD 0.0e+00

Delays (us)

SBD -0.038307

MBD 0.006479

Fringe rate (Hz)

0.001259

Ion TEC 0.00

Ref freq (MHz)

6440.4000

AP (sec) 1.000

Exp. X10_tst

Exper # 3383

Yr.day 2012:019

Start 124500.00

Stop 124930.00

FRT 124715.00

Corr/FF/build

2012:053:185048

2012:060:212727

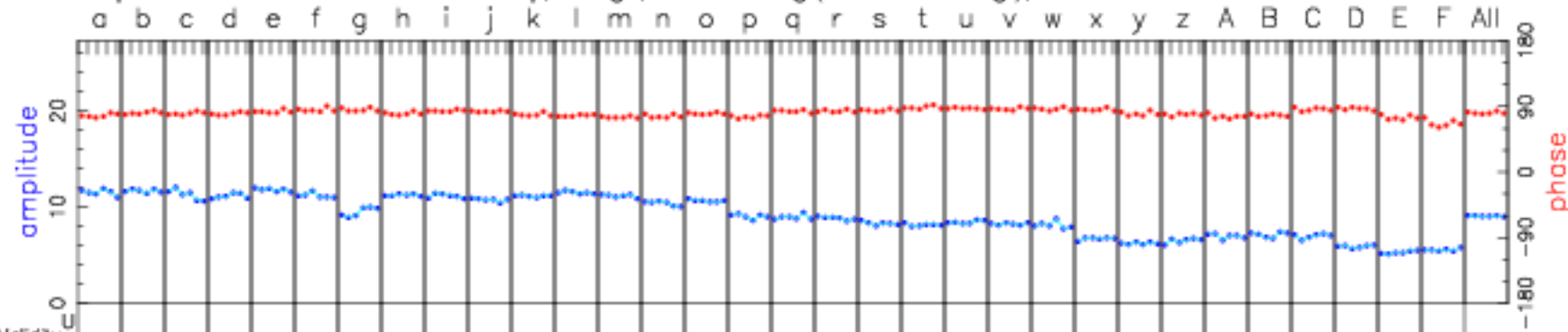
2012:060:183635

RA & Dec (J2000)

16h42m58.8100s

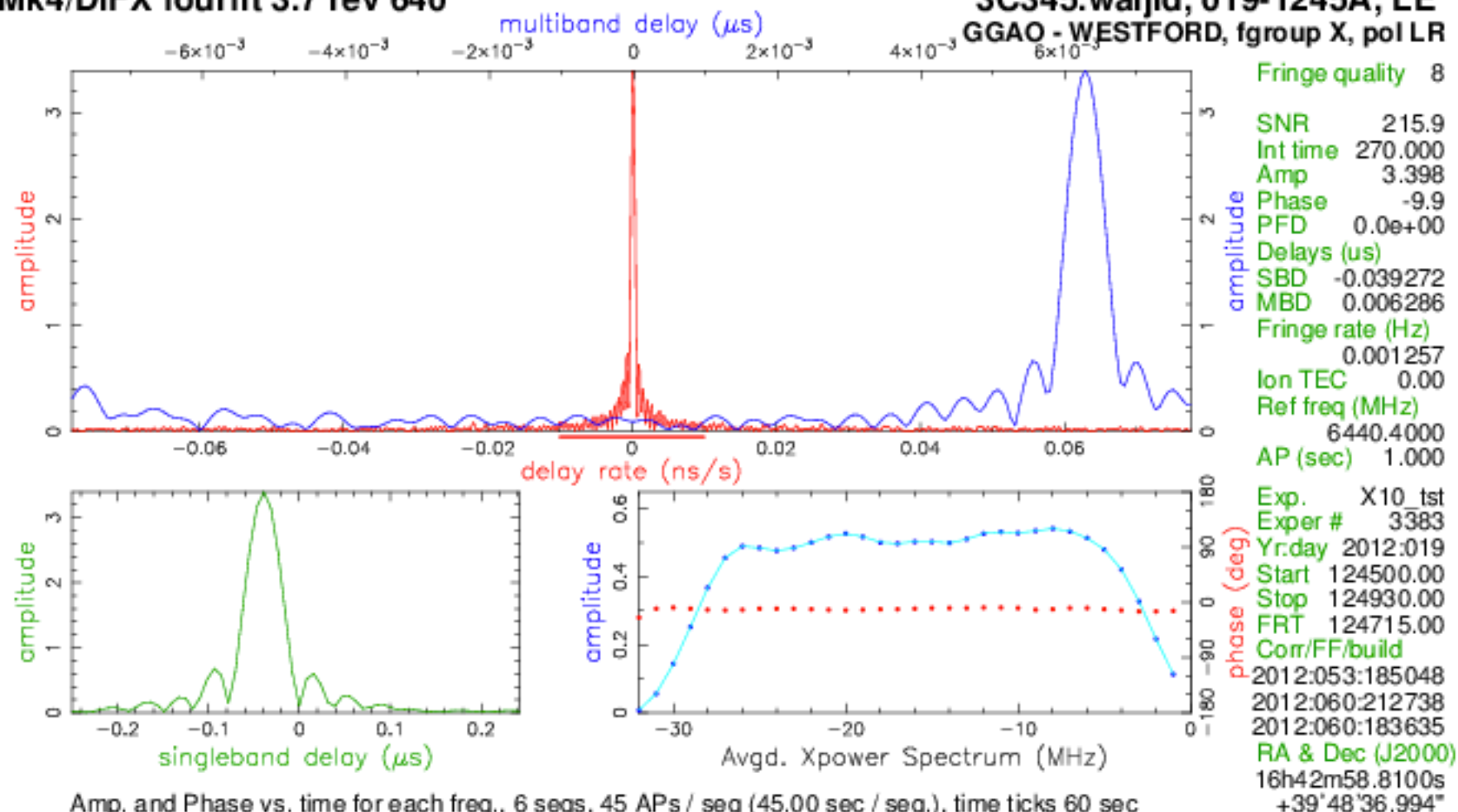
+39°48'36.994"

Amp. and Phase vs. time for each freq., 6 segs, 45 APs / seg (45.00 sec / seg.), time ticks 60 sec

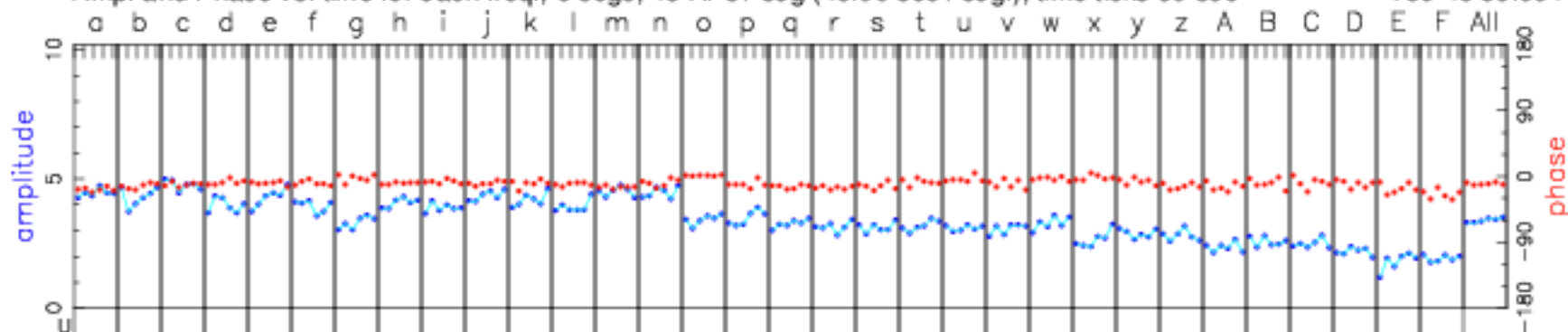


Mk4/DiFX fourfit 3.7 rev 640

3C345.waljid, 019-1245A, LE

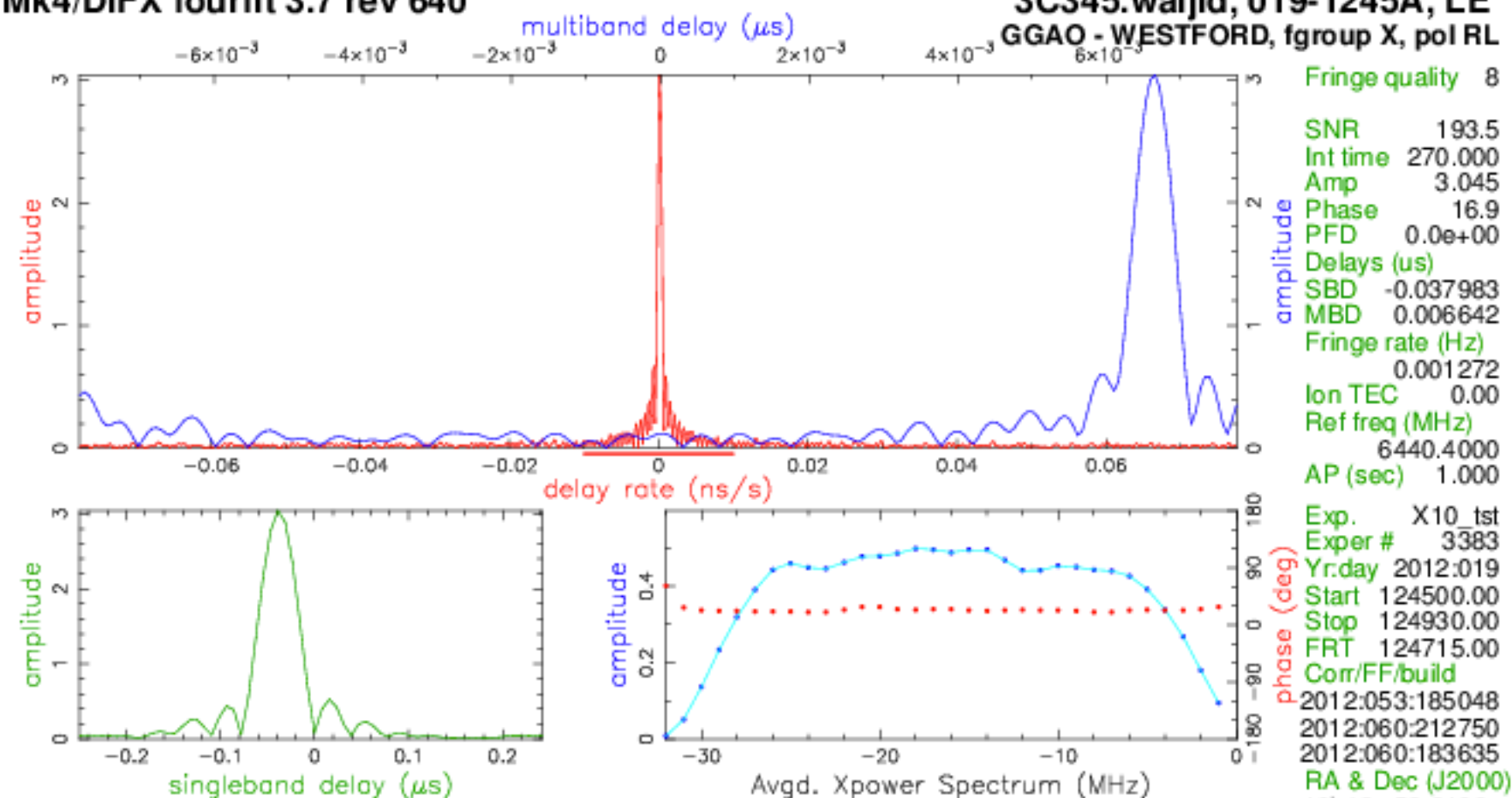


Amp. and Phase vs. time for each freq., 6 segs, 45 APs / seg (45.00 sec / seg.), time ticks 60 sec

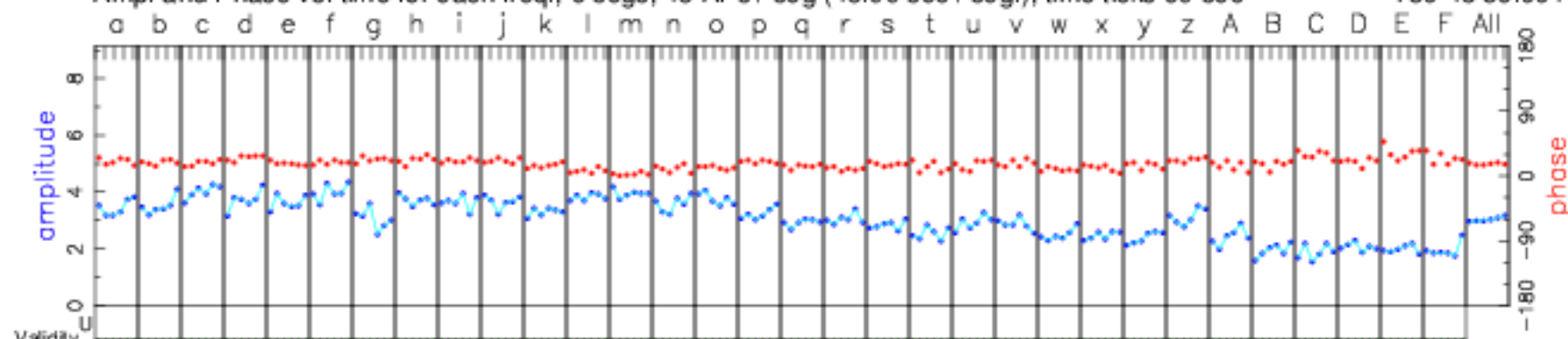


Mk4/DiFX fourfit 3.7 rev 640

3C345.waljid, 019-1245A, LE
GGAO - WESTFORD, fgroup X, pol RL

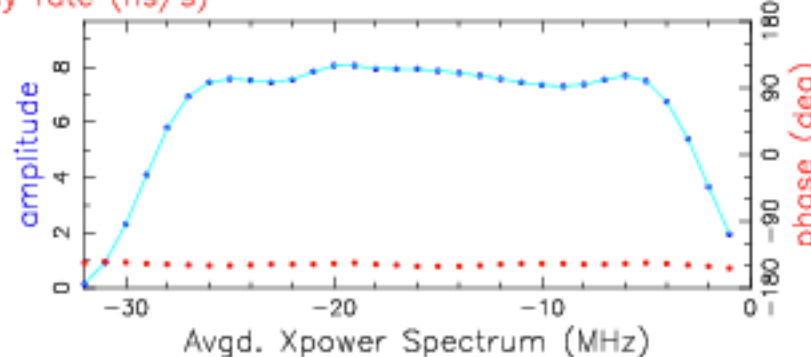
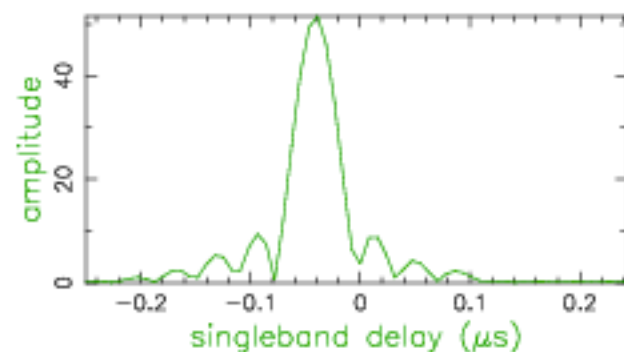
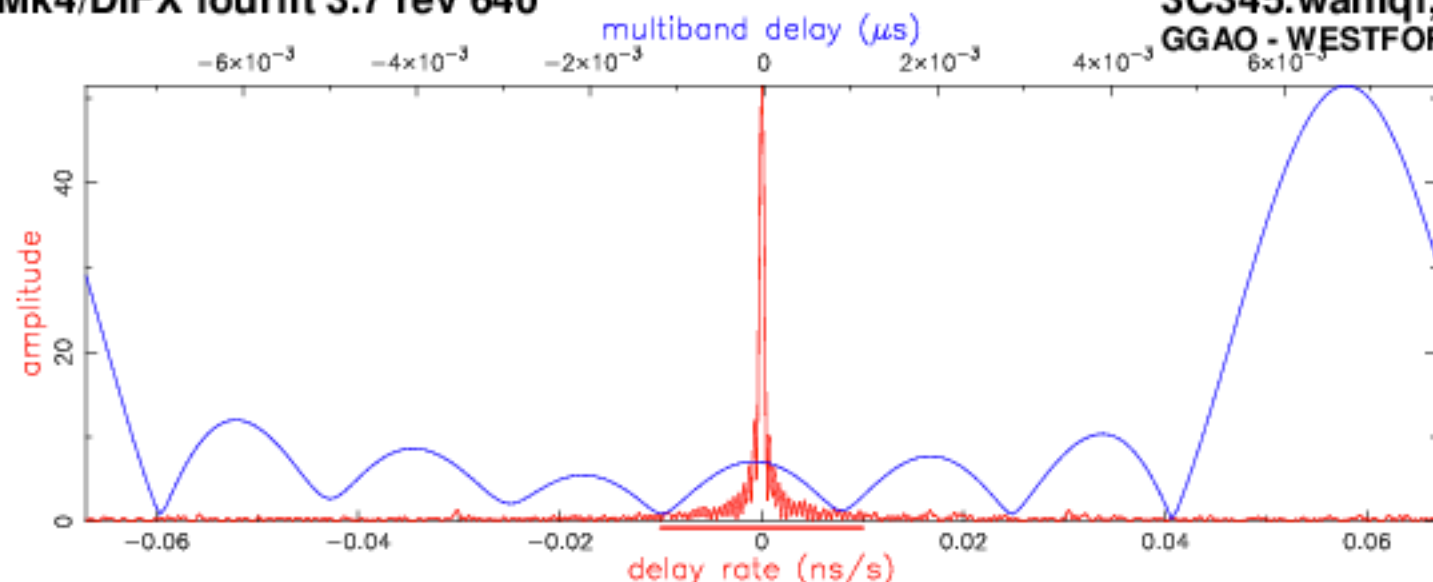


Amp. and Phase vs. time for each freq., 6 segs, 45 APs / seg (45.00 sec / seg.), time ticks 60 sec



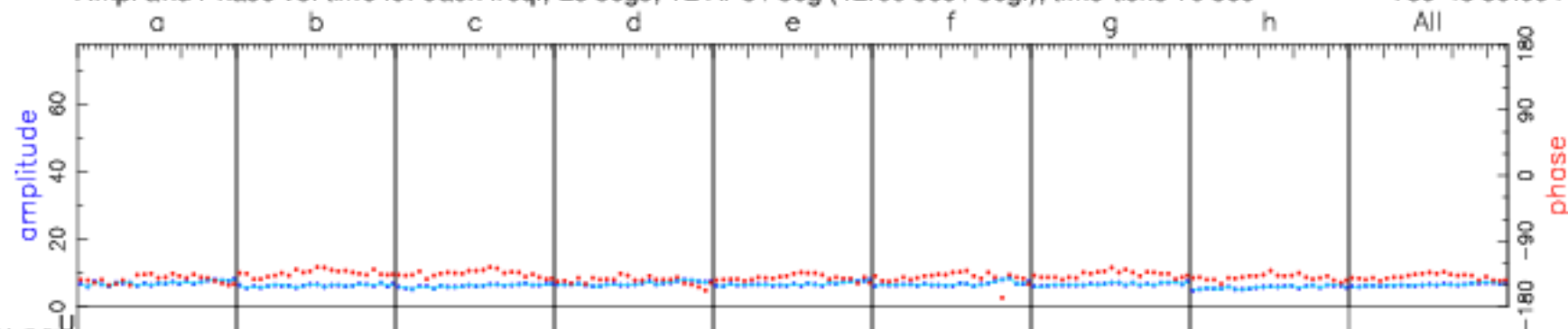
Mk4/DiFX fourfit 3.7 rev 640

3C345.wahlqf, 019-1320B, LE
GGAO - WESTFORD, fgroup, pol lxy

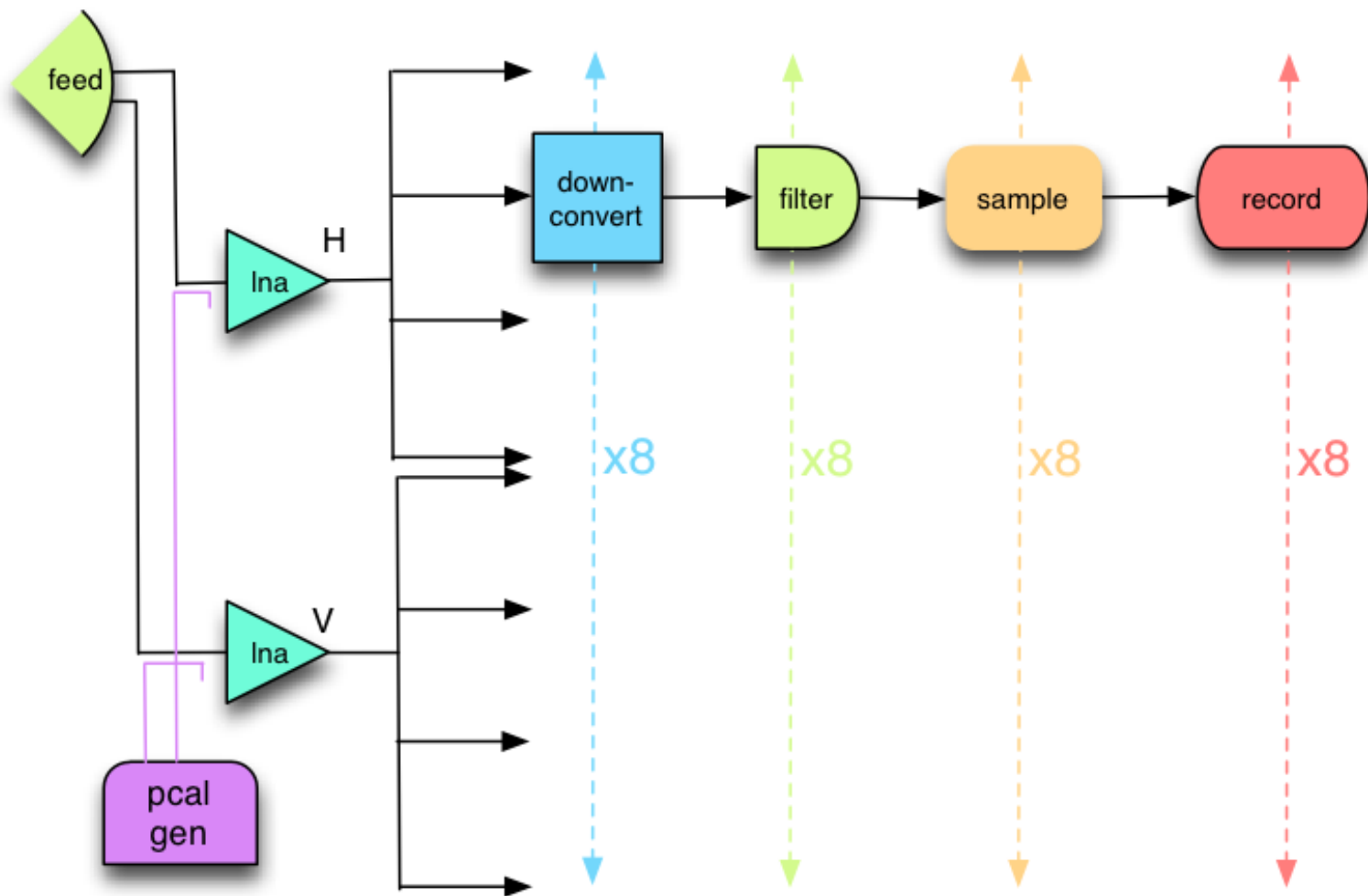


Fringe rate (Hz)
Error code G
SNR 578.8
Int time 67.500
Amp 25.854
Phase -139.0
PFD 0.0e+00
Delays (μs)
SBD -0.040779
MBD 0.006712
Fringe rate (Hz)
0.000321
Ion TEC 0.00
Ref freq (MHz)
7464.4000
AP (sec) 1.000
Exp. X10_tst
Exper # 3383
Yr.day 2012:019
Start 132500.00
Stop 132930.00
FRT 132715.00
Corr/FF/build
2012:039:122148
2012:060:214130
2012:060:183635
RA & Dec (J2000)
16h42m58.8100s
+39°48'36.994"

Amp. and Phase vs. time for each freq., 23 segs, 12 APs / seg (12.00 sec / seg.), time ticks 10 sec



VLBI2010 Signal Path



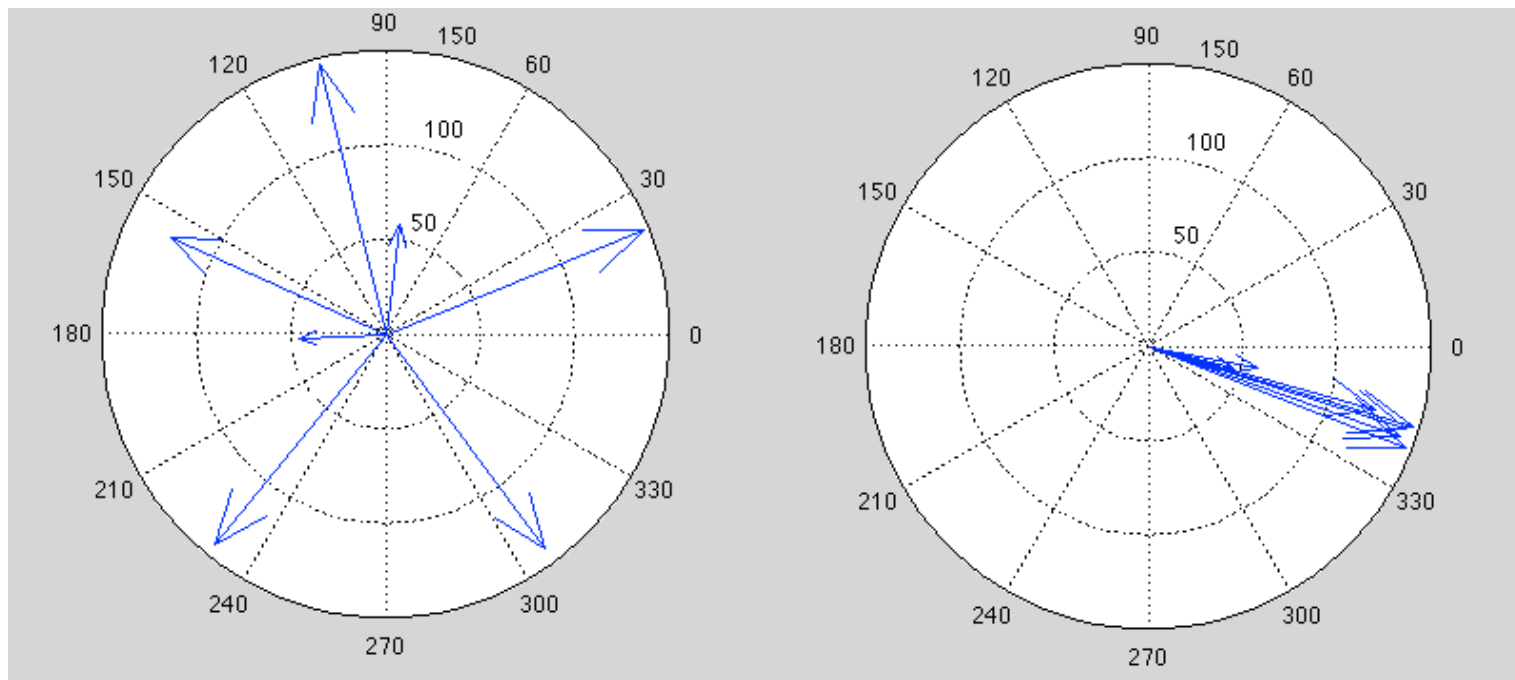


Increased Postprocessing Setup Complexity

- Now have 4 frequency bands and 4 polarization products
- 4 passes need to be merged (*fourmer*)
- Need to correct for separate delays and phases in each signal path
- pcal has a delay ambiguity of 200 ns

fourfit features for VLBI2010

- Multitone phasecal extraction uses all (desired) tones in each band to derive instrumental delay for groups of chan/pols sharing a sampler



fourfit features for VLBI2010

- If necessary, apply explicit delay and phase offsets per:
 - station
 - channel
 - polarization

```
if station A
  pc_mode multitone
  pc_period 30
  pc_tonemask abcdefgh 0 0 8 0 4 0 5 0
  pc_phases_l abcdefgh 12 13 11 12 24 -6 38 110
  pc_phases_r abcdefgh 11 29 14 11 64 -2 44 132
  samplers 2 abcd efgh
  delay_offs bdh 2.7 -3.65 4.778
```

For the Future

- Grow the existing cluster at Haystack to better match observing data rates
- Continually refine post-processing software, e.g.:
 - operational efficiency improvements
 - automated selection of pcal masks
 - $\phi(f)$ due to source structure
 - handle mixed polarization combinations to legacy stations, such as {RxV, RxH, LxV, LxH}