Notes for May 2005 IVS TOW Meeting Correlator Class

MAT/KAK/AM/BEC/DRS/RJC 042605

Part 1 – Introduction

In this lecture/demonstration, we hope to accomplish the following:

- Give you a basic idea of how the correlator works.
- Briefly outline the life cycle of an experiment at the correlator.
- List some of the most important things a station can do to make our job easier.
- Show how we might make your job easier, and solicit your feedback for other ways in which we can do that for you.
- Demonstrate the correlator in action.

We hope too that along the way, you feel free to ask questions and make suggestions.

Part 2 – What does a Correlator do?

Roger Cappallo will present a description of how a VLBI Correlator works. See the accompanying slides for his presentation.

Part 3 – Overview of the Life Cycle for an experiment at the correlator

To give you some idea of what happens to your data when it leaves the station, here is a summary of the basic steps we go through when processing an experiment:

- gathering of logs and schedules upon recording completion
- tapes and disks come in - inspected physically and put into library
- compile logs and schedule in format correlator likes
- based on info in the logs and ops messages, pick scan(s)to find fringes and tweak clocks
- also based on info in logs (after clock tweaks), select a small sample of scans interspersed throughout the schedule to check clock stability, playback quality, tape quality etc ... throughout experiment. These scans are called “pre-passes”. based on pre-pass results, make any appropriate corrections to production processing parameters.
- construct fourfit control files and production processing lists based on results from pre-passes
- schedule/production process
- analyze results of production processing – re-fourfit and/or re-process any scans which need it
- evaluate station performance
- export data to analysis center
- possible re-processing on request from analysis center

- release disks and tapes

Part 4 – What the stations can do for the correlator

Ship the disks or tapes fast!!

Some notes on facilitating the shipping process:

- We look at the experiment as soon as all stations arrive, so ship them right away.
- Feedback on TRACK usage: not all the stations use TRACK regularly. The usage of TRACK is important for correlators, especially since the responsibility for tape/disk shipment has been given to correlators/stations.
- Customs declarations: some stations do not add to the shipment a declaration for the customs or the value declared for customs is too high. Both cause delays in delivery.
- Couriers: some are faster and more reliable than others.
- Correlators require e-mail addresses of station personnel who can be contacted. In case of stations where shifts are made we require an e-mail address for each shift.

Provide good documentation!

- Note that at the correlator, **ops messages are read first**. The logs are delved into only if problems encountered (other than comments). Document the routine stuff well, and document *anything* that could be considered out of the ordinary. Here are a few categories of things you should be sure to document well:

I) physical disk or tape

- Make sure Mark5 modules are labeled and shipped in accordance with the "**Mark5A Disk-Module Labeling and Management Procedures"** memo which is available on the Haystack Mark5 web site at http://web.haystack.edu/mark5/operations.html.
- For tape, accurately and precisely log damage/splices needed etc ... . Make sure tapes are properly packed for shipping, especially glass reels which have been known to break in transit.

II) ops messages

- Log everything carefully and put into ops messages (see above). Check all BBCs periodically. Note periods of poor antenna tracking etc … Here are some further notes on OPS messages:

a) information we focus on in the OPS messages:

- Session comments in the stop message (especially scans missed/problem scans (please give times **not** line numbers)/unusual conditions/equipment problems/start-stop times of problems/other comments)
- Weather Info
- Clock Info (offset from GPS/drift rates - whatever appropriate)

- Recorder Humidity
- Pointing/SEFD Info

b) information we focus on in TRACK and follow up OPS messages:

- Log Placement Info
- Disk/Tape Shipping/Inventory info (including labels & AWB number if known)

III) playback quality

a) mark5 disks

- Note if a disk or disks went bad during the course of recording. Note any unusual behaviors of the Mark5 system, or any other anomalies.

b) tapes

- Make sure head calibration and record current setting are properly done. Make sure drive is physically in good shape.
- Watch PER checks during experiment and note any problems / clean heads frequently.
- Note any changes in station drive which will change speed (mainly capstan replacement).
- Make sure footage counter is correct. Note missed scans. If a tape is bad (e.g. keeps losing vacuum), change it!
- Watch out for badly wound tapes (see next point) - they can influence the quality of the data.
- The tapes that correlators send to the stations should always be prepassed before recording. Tapes might be damaged during transport, and thus not necessarily well wound, or possibly well degaussed.

IV) clock/maser (timing)

- Give offset in standard format - note any possible ambiguities. Check that formatter is synced to correct whole second.
- Log all jumps and/or equipment changes which might cause them.
- State any rates/instabilities as clearly as possible.

V) phase cal

- Log any known problems with anything in the LO chain which might affect phase cal behavior or problems with the phase cal itself. Be sure to note replacing or re-setting of any BBC.

VI) other data quality issues

- Don't check the cable cal during an experiment, and don't remove the extender during the experiment if it has been left in by mistake. If either of these things do happen though, please note them.
- Check locally & inform correlator about *any* unusual problems you are aware of. Don't hesitate to ask the correlator for feedback!!

Avoid Severe Problems

There are a host of situations where problem data might be recoverable by efforts which go beyond the normal level of demand for corrective action (i.e. ones which if done would greatly degrade correlator efficiency or require extraordinary efforts or intervention). Under these circumstances a value judgement is made (usually by Goddard people) as to whether or not the unusual efforts and their cost is worth the effort to recover the data. A few examples of this might be:

- 1-2 Mark5 disk failures in an 8 pack after the data has been successfully recorded.
- severe tape tracking problems which are only recovered through manual intervention
- bad tape playback on multiple stations requiring special drive assignments which add additional passes
- formatter/decoder/rack errors which require special software patches to correct

Finally, there are a host of problems that cannot by any method be salvaged by tricks at the correlator. A short list of the most common ones might include:

- Multiple disk failures in a Mark5 module (more than two in an 8 pack) after the data has been successfully recorded
- no fringes (for reasons unknown to anyone - all likely problems tested) rare nowadays for geodetic stations
- any antenna/system problem at record time which degrades system sensitivity
- really bad tape playback/tracking problems
- unpatchable data formatting problems (i.e. stuck bits, wrong times in nasty places, missing CRCC)
- wrong polarization
- formatter +-30 milliseconds away from integer second (see special Mark IV considerations below)
- wrong schedule observed (it happens!)
- ?? too many more to list

The main point behind all this is to make sure however possible that the data you send to the correlator is a good as it possibly can be.

Note Special Considerations for the Mark IV Correlator

There are a few limitations of the Mark IV correlator which need to be kept in mind in order to avoid conditions which might result in uncorrelatable data, but which at recording time might seem like minor problems:

- The range of clock offsets we can correct for is limited (see other comments above). This is very important, as falling outside of this range may result in our inability to correlate. It is safest to make sure your clock is close to GPS and you report it accurately (especially correct sign).
- Logs are more important to us. The Mark IV correlator uses log information extensively and making "fake" logs in absence of a real log is much less desirable and more difficult. Please be extra careful that you write proper logs and send them promptly.
- The use of barrel rolling and fan out modes makes it a bit more difficult for us to diagnose problems. If you know about a problem and are going to run an experiment before being able to fix it, please describe it well in the closing OPS message.

Part 5 – What the correlator can do for the stations

Fringe fitting after the production correlation reveals most of the problems that arise at the stations. Control file preparation detects some problems too (e.g. wrong footage) and the fringe fitting of the trial correlation detects the rest (e.g. by checking oscilloscopes and SUs).

Stations should always read the correlator reports and are invited to ask if something is not clear. In the reports there is a short summary of the problems encountered during the correlation and the fringe fitting like: RFI, bad and/or missing tracks, IF problems, wrong frequency setup, wrong polarization, antenna failure, system problem that can degrade the sensitivity, SEFD, warm receivers, wrong formatter setting, wrong head calibrations, wrong footage, difference between the expected and the observed SNR, data formatting problems, clock performance.

Part 6 – Conclusion

You might realize, given all this, that the correlator is something like a oracle when it comes to assessing station data (i.e. in many respects the quality of the data reveals itself immediately upon the first sync-up and first examination of fourfit plots). Most problems are revealed by examining fourfit plots from resultant correlations; but many others are discovered/diagnosed also by observing the pre-passes in action (i.e. observing sync-up times, examining eye patterns on scope - observing lights etc ...). Usually after a few scans the quality of station data is fairly well known. Thus, please report your problems, as they cannot hide from the correlator!

We hope that the lecture portion of this class gives you a better idea of what is done with your data once it leaves the site. We also hope that we have given you good feedback on how you can help us, and that we have received feedback on how we can help you.

Part 7 - Correlator Demonstration

Since many of you may not have seen a Mark IV correlator run, if we have time after the talk/discussions, we will walk down to the correlator for sample scan demo.

TOW 2005 Correlator Class

Mike Titus
Roger Cappallo
MIT Haystack Observatory

Introduction

- Basic idea of how the correlator works
- Brief outline of an experiment's life cycle
- What you can do for us
- What we can do for you
- Demo

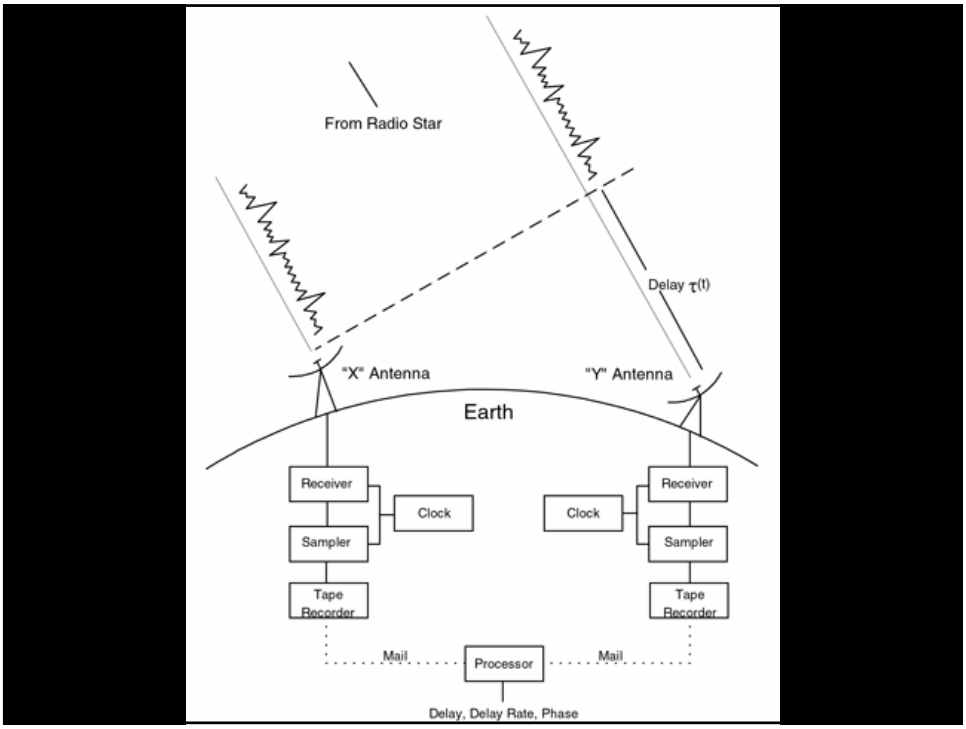
What Does a Correlator Do (and how does it do it)?

Roger Cappallo
May 2005

Why Correlate?

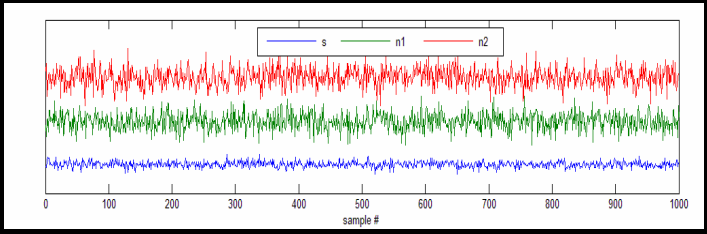
- If we had a high snr, we could just difference the arrival times (e.g. pulse)
- Unfortunately, quasar signals are ~10^3 weaker than the noise in our best receiving systems
- The correlater allows us to magically pull this weak signal out of the noise and measure its delay (and rate) between two sites

DeLay and Raitt



Cross-correlation of weak signals

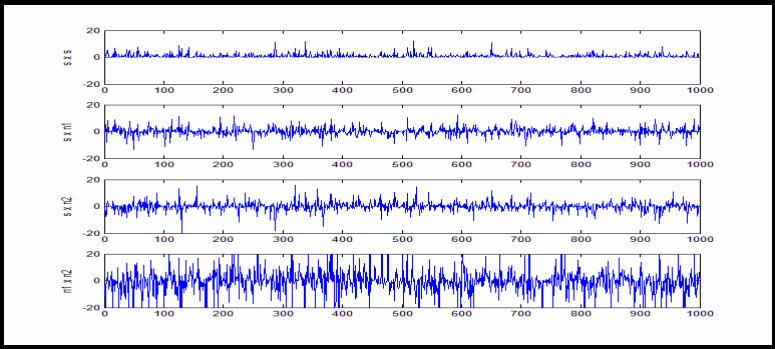
- Let s(t) be a weak astronomical signal, and $n_1(t)$ and $n_2(t)$ be noise signals at sites 1 & 2



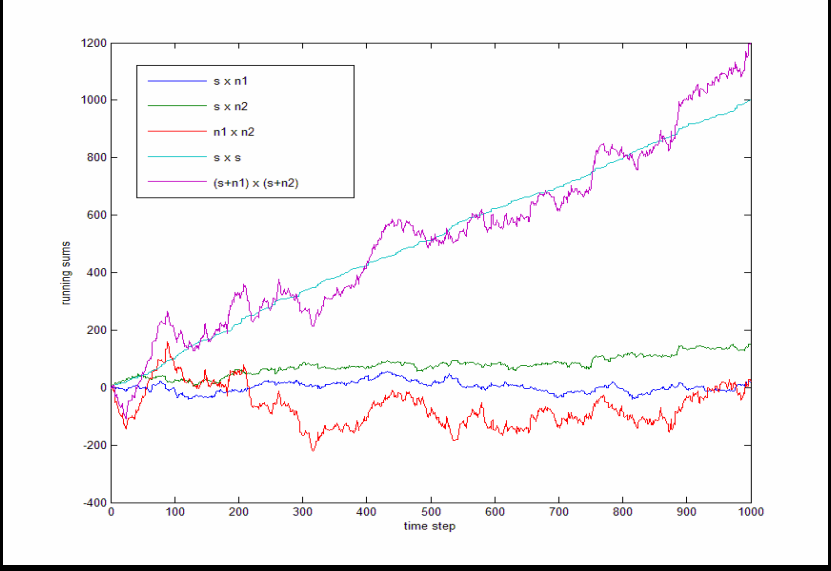
Correlation of weak signals (cont'd)

- Product of signals is:

$$(s + n_1)(s + n_2) = s^2 + n_1 s + n_2 s + n_1 n_2$$



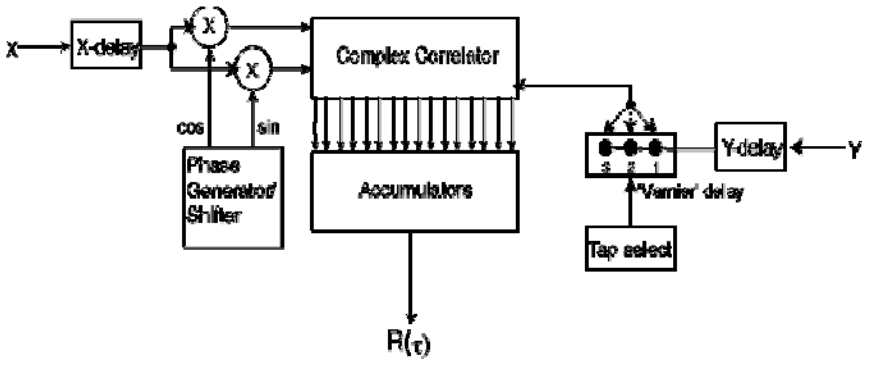
Summed Correlation Components



Correlation Hardware

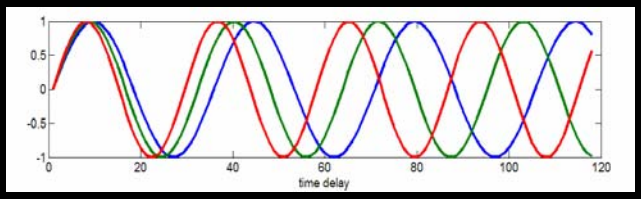
- If done at the original RF, a delay model by itself would produce the correct Doppler shift
- Since we process at baseband, we need to have separate delay and phase models

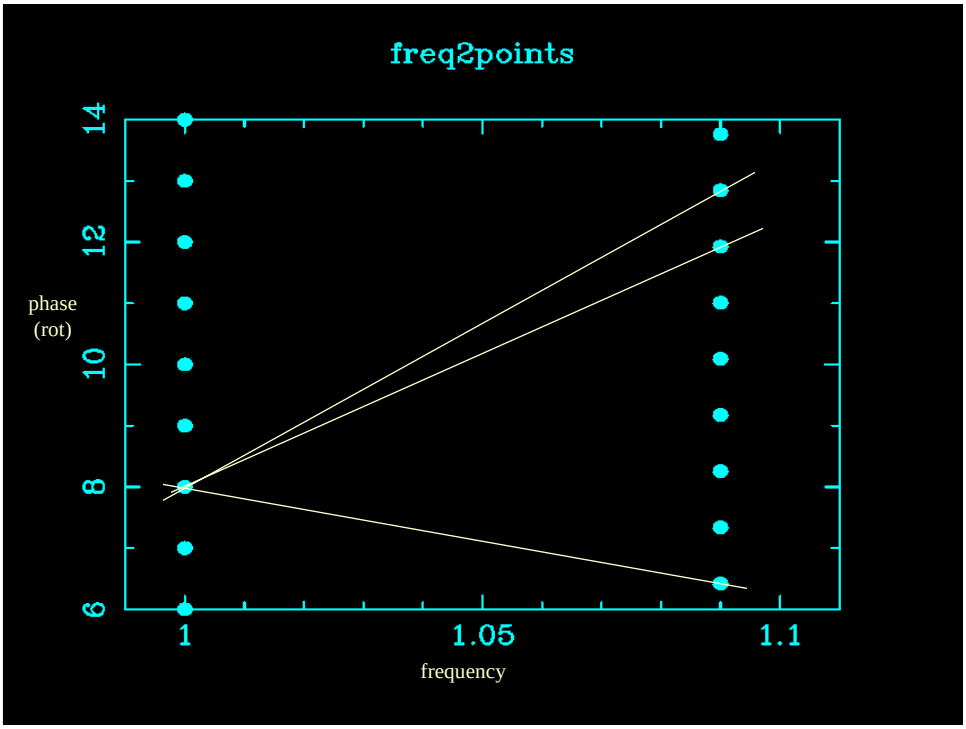
Correlator Channel

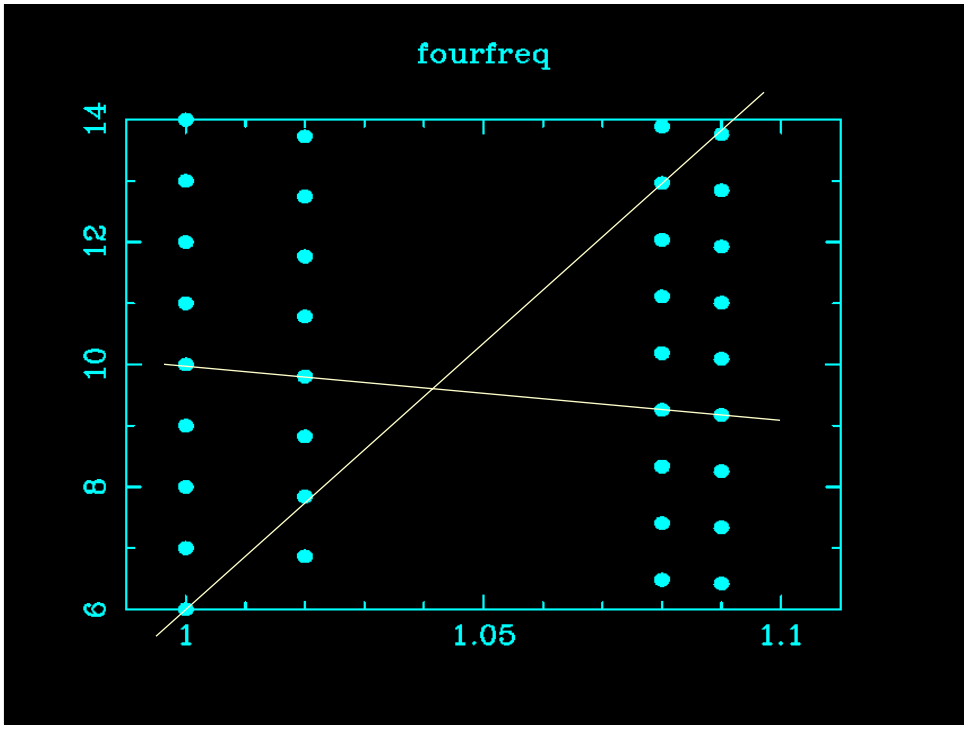


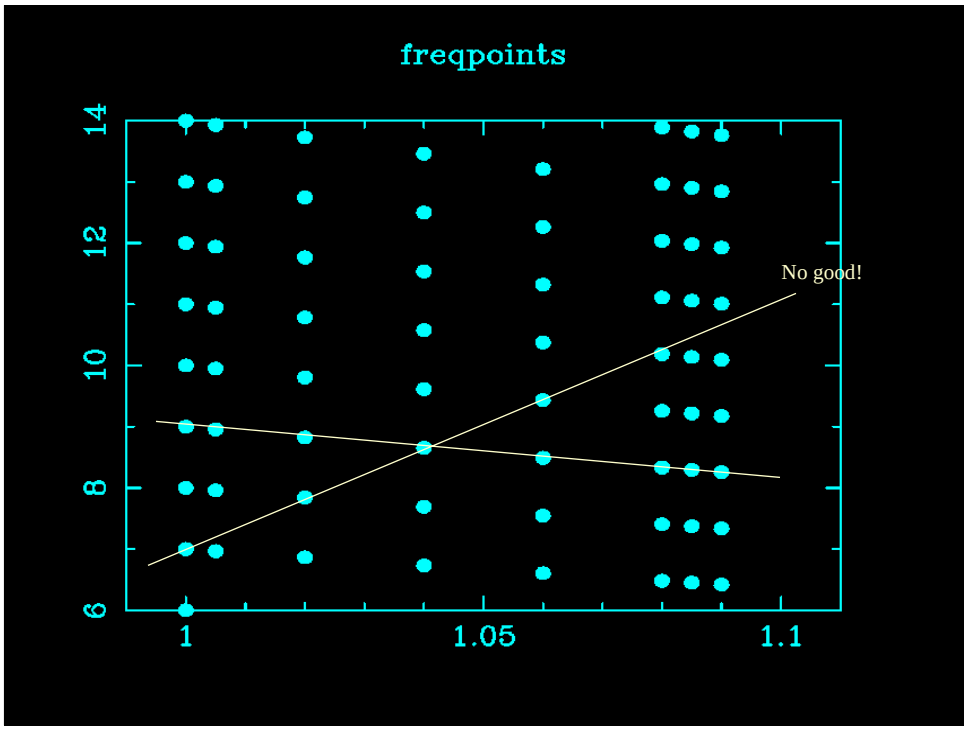
Bandwidth Synthesis

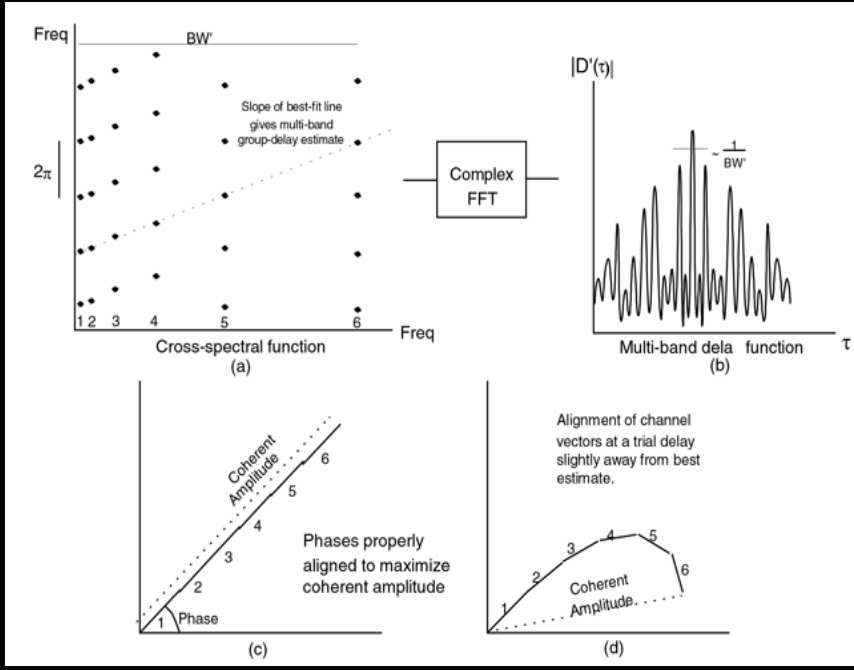
- We measure delay by observing phase differences at different frequencies
- For a given delay, the higher the frequency, the greater the change in phase:






fourfreq
14
12
10
8
6
1
1.05
1.1

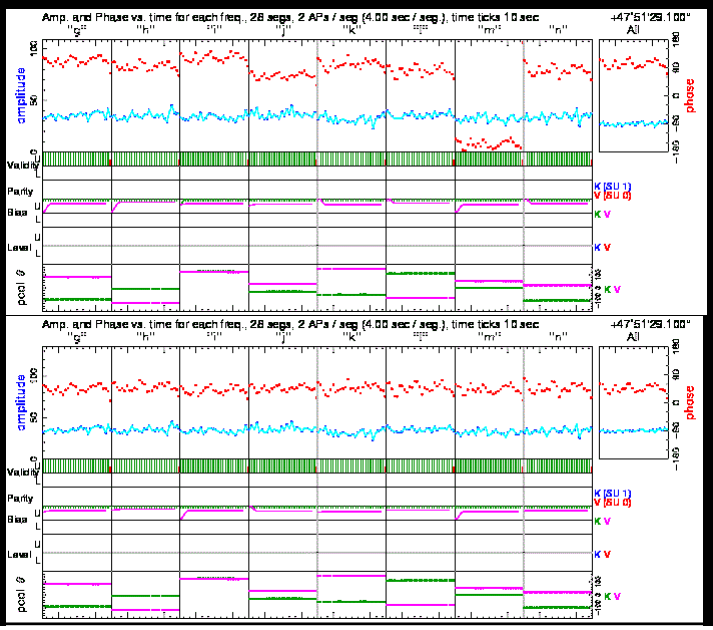

freqpoints
No good!
14
12
10
8
6
1
1.05
1.1



Optimizing Coherence

- In addition to the linear phase change due to frequency, there is a contribution to each channel's phase from the instrumentation
- e.g. the filters in each VC have slightly different delays
- The phase cal subsystem injects tones into the front end every MHz with the same phase (at the start of each second).
- The correlator detects each tone, and adjusts the phase of the corresponding channel.

Phase-cal aligns the channels:



Hardware and software structure

...of current Mark IV correlator

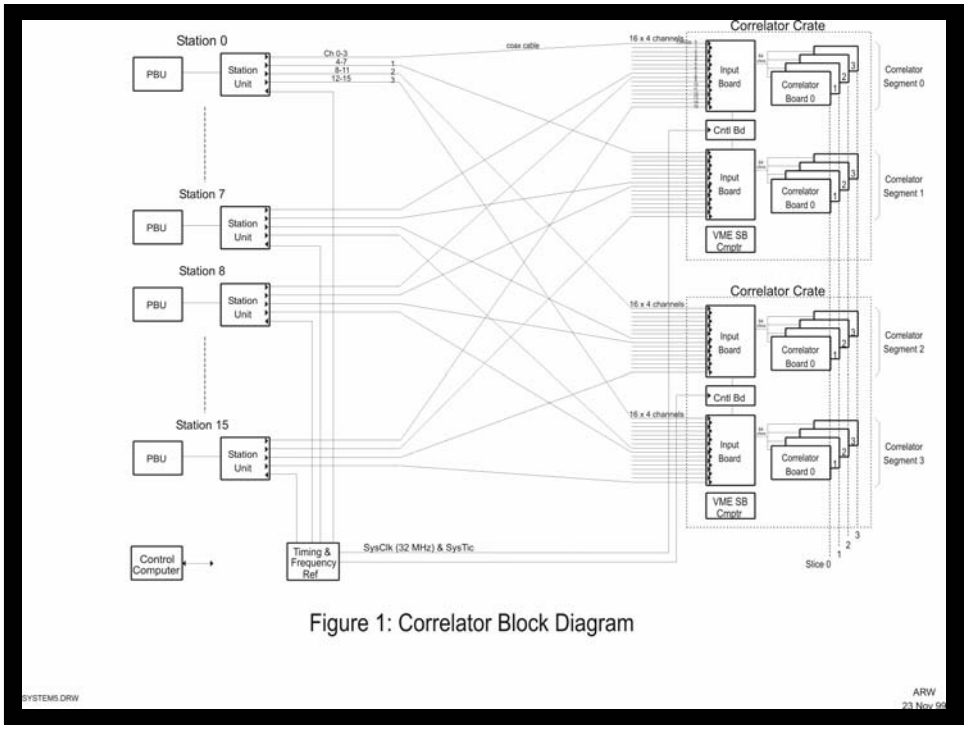


Figure 1: Correlator Block Diagram

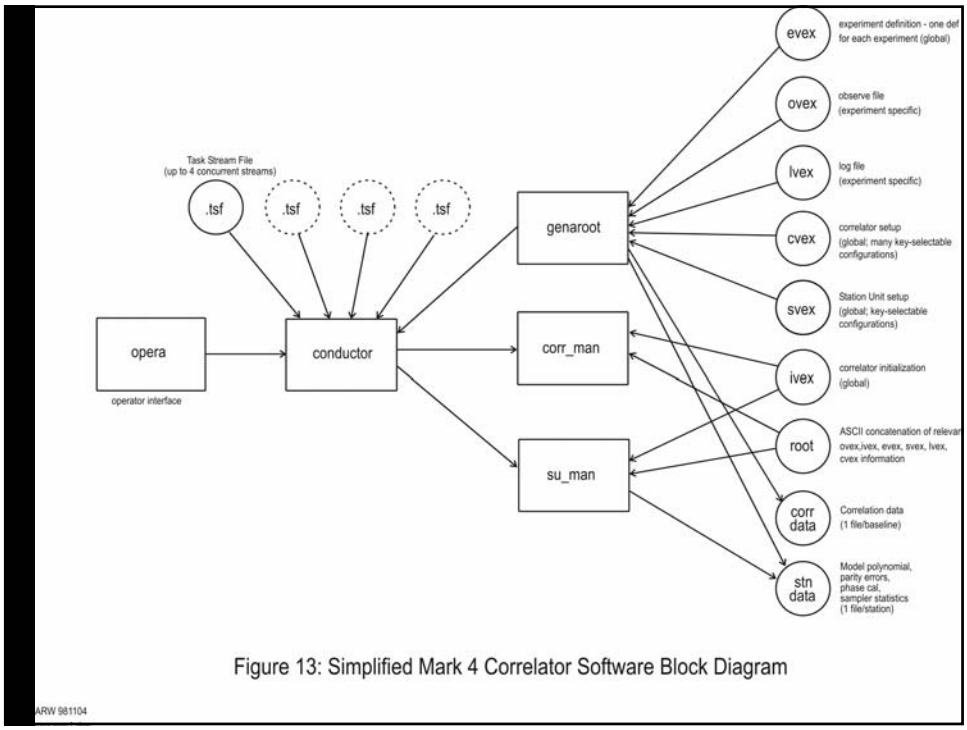
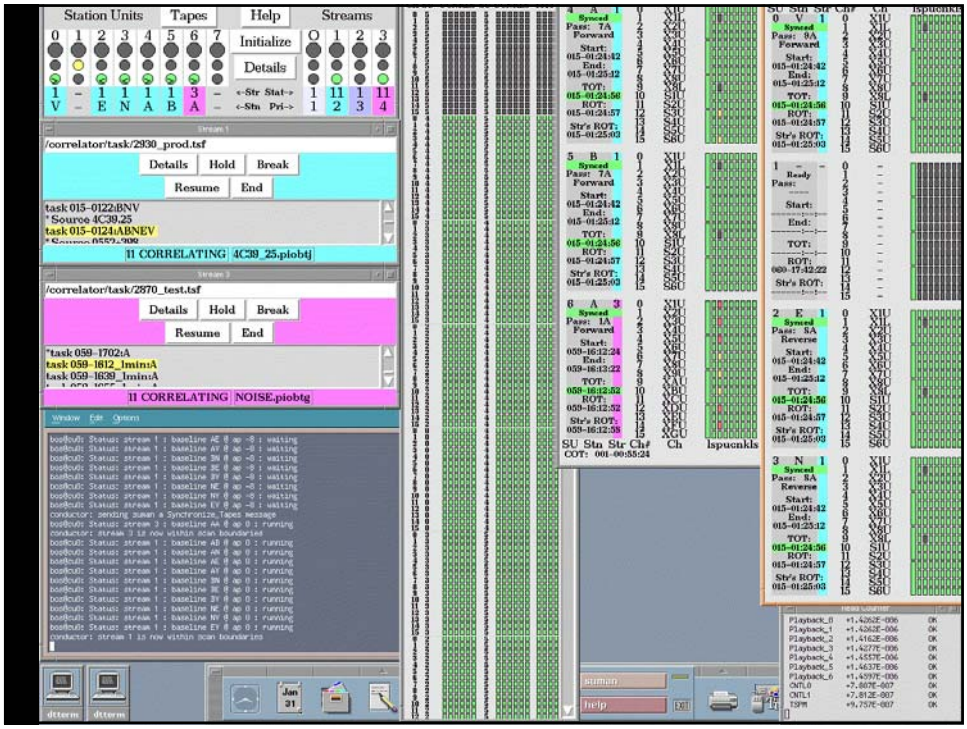


Figure 13: Simplified Mark 4 Correlator Software Block Diagram



Overview of the life cycle for an experiment at the correlator

- Gather logs and schedules
- Inspect incoming media - put into library
- Compile logs and schedule in correlator format
- pick scans to find fringes
- select and run “pre-pass” scans

Overview continued …

- Construct processing/fourfit control files
- Schedule/production process/cleanup
- Analyze results/evaluate stations
- Export
- Release disks/tapes

What you can do for us

- Ship the disks or tapes fast!!
- Provide good documentation
- Avoid/fix severe problems before session
- Note special considerations for correlator

More details on shipping

- Ship right away
- Use TRACK
- Declare customs properly
- Use a good Courier
- Provide email notification

More details on documentation

- Put it in OPS messages - they are read first!
- Media (Disk/Tape) physical integrity
- Playback quality
- Clock/Maser
- Other regarding data quality, like
  - phase cal (LO OK?)/cable cal (don’t change)
  - any system performance issue
- Other issues

More details on severe problems

Possibly recoverable problems

- Mild to moderate tape tracking problems
- 1-2 Mark5 disk failures (in 8 pack)
- Bad playback other than tracking
- Errors which require special software patches

Unrecoverable severe problems

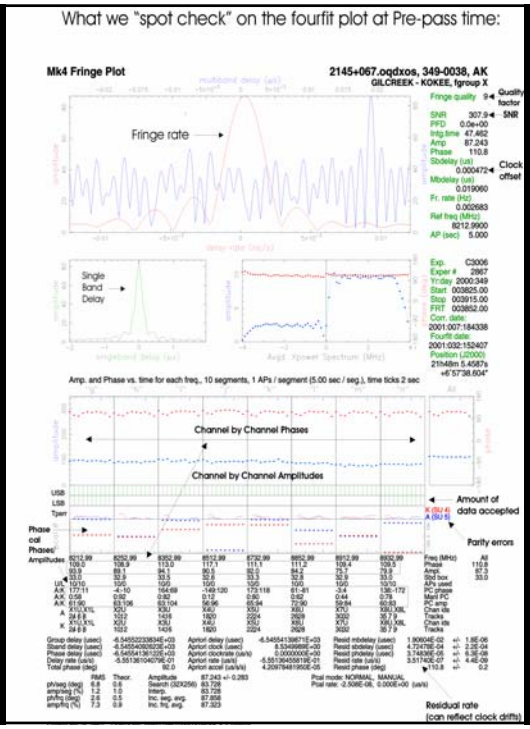
- Multiple (>2 of 8) Mark5 disk failures
- no fringes - for unknown reasons
- antenna/system performance/sensitivity
- unpatchable formatting problems
- wrong polarization
- formatter +- 30 milliseconds from int. sec.
- etc etc etc … (too many to list!)

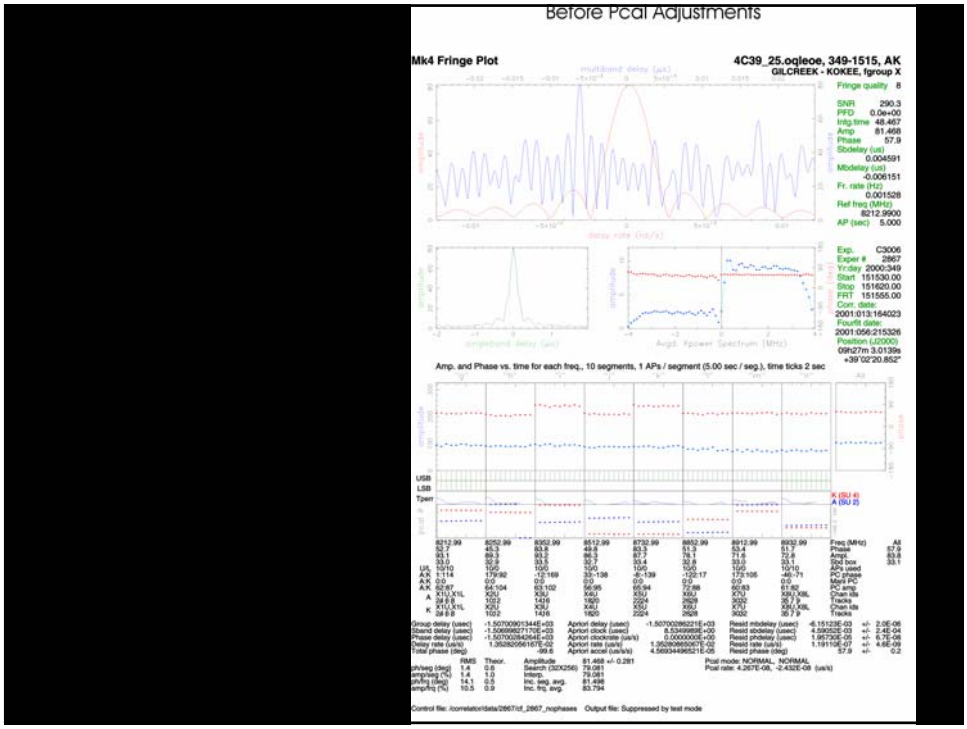
Special considerations

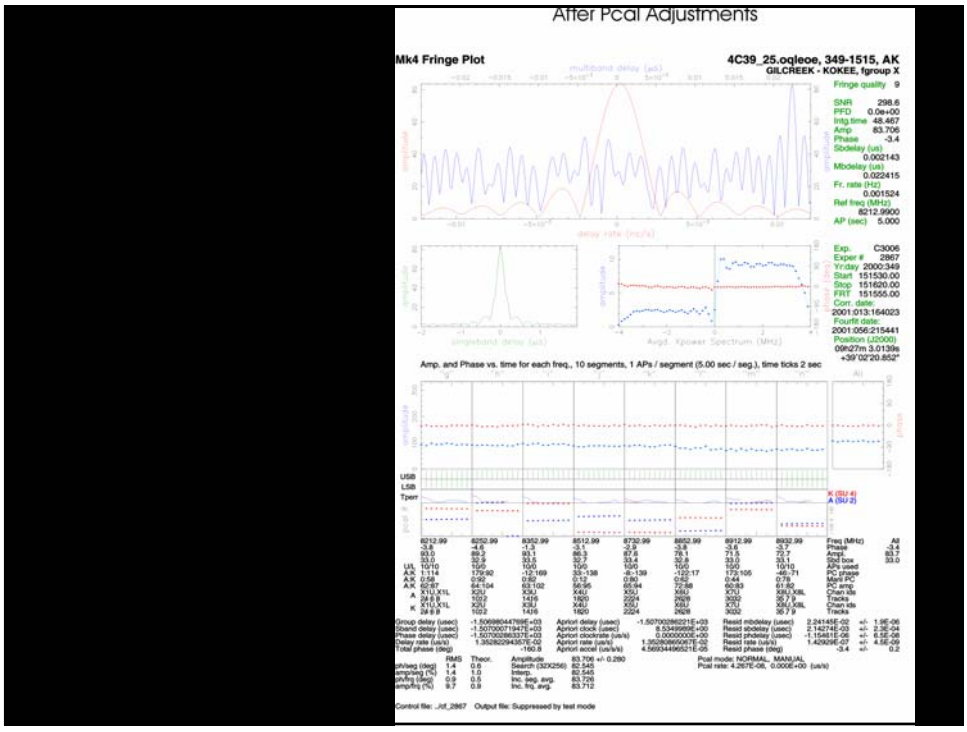
- Clock offset limitations
- Machine readable logs
- Barrel rolling/fan out effects

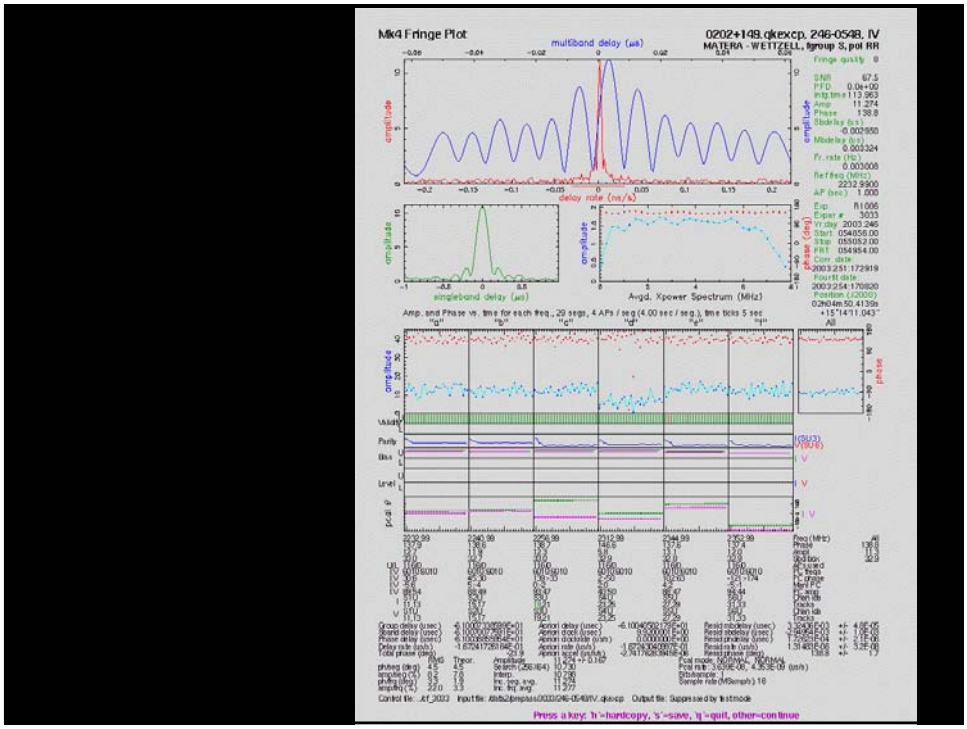
Analysis tools

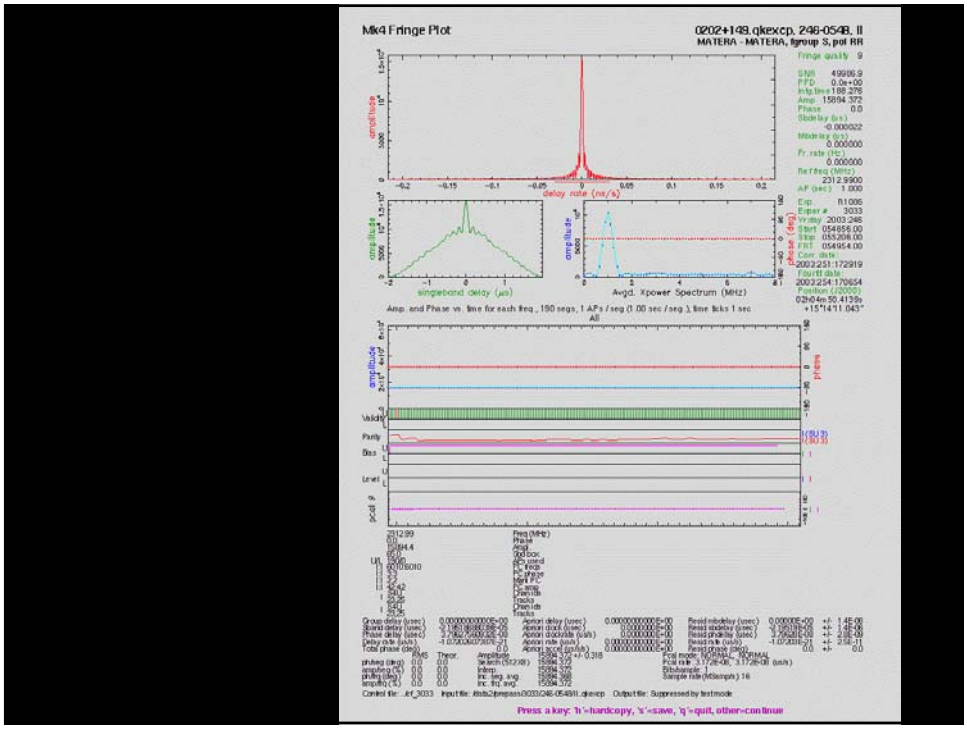
Fourfit plots and aedit

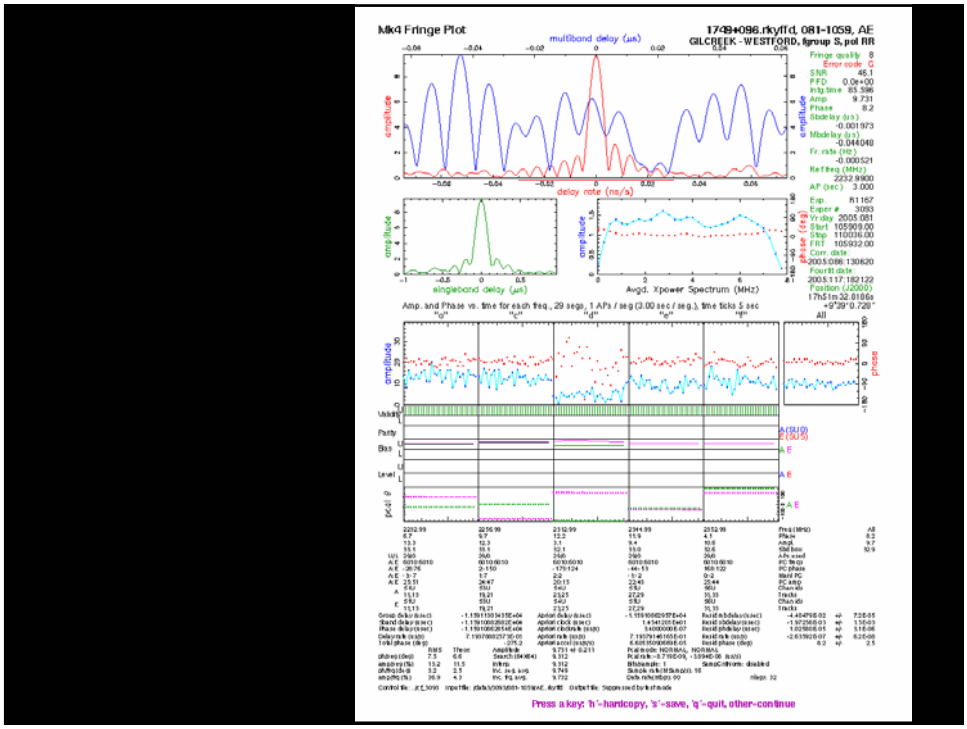


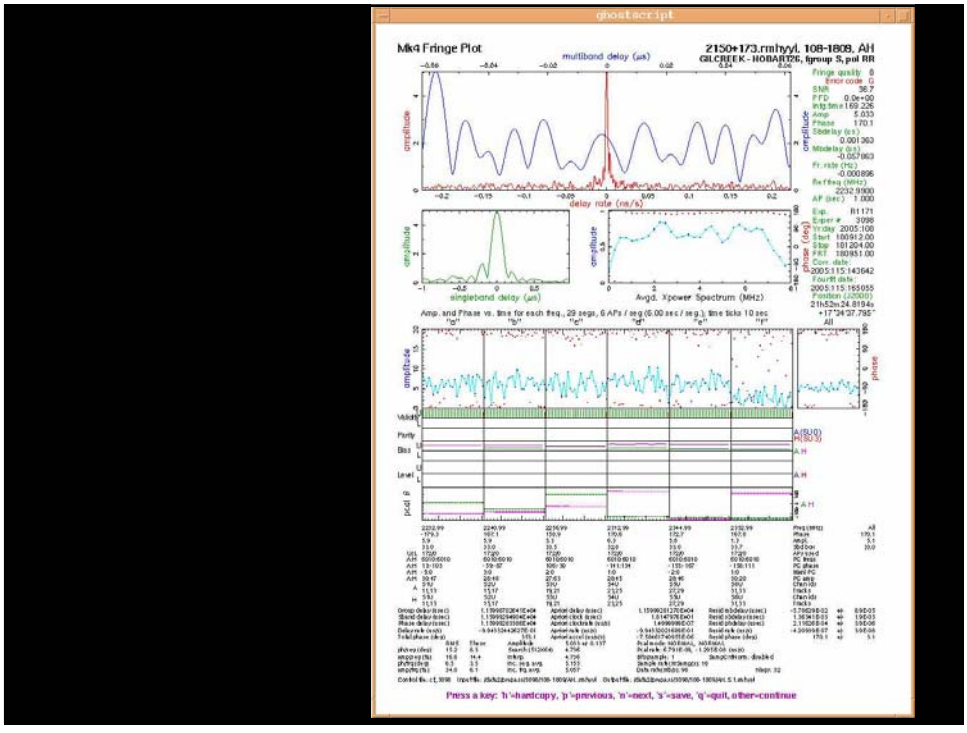

Before Pcal Adjustments
Mk4 Fringe Plot
4C39_25.oqleoe, 349-1515, AK
GILCREEK - KOKEE, fgroup X
Amp. and Phase vs. time for each freq., 10 segments, 1 APs / segment (5.00 sec / seg.), time ticks 2 sec

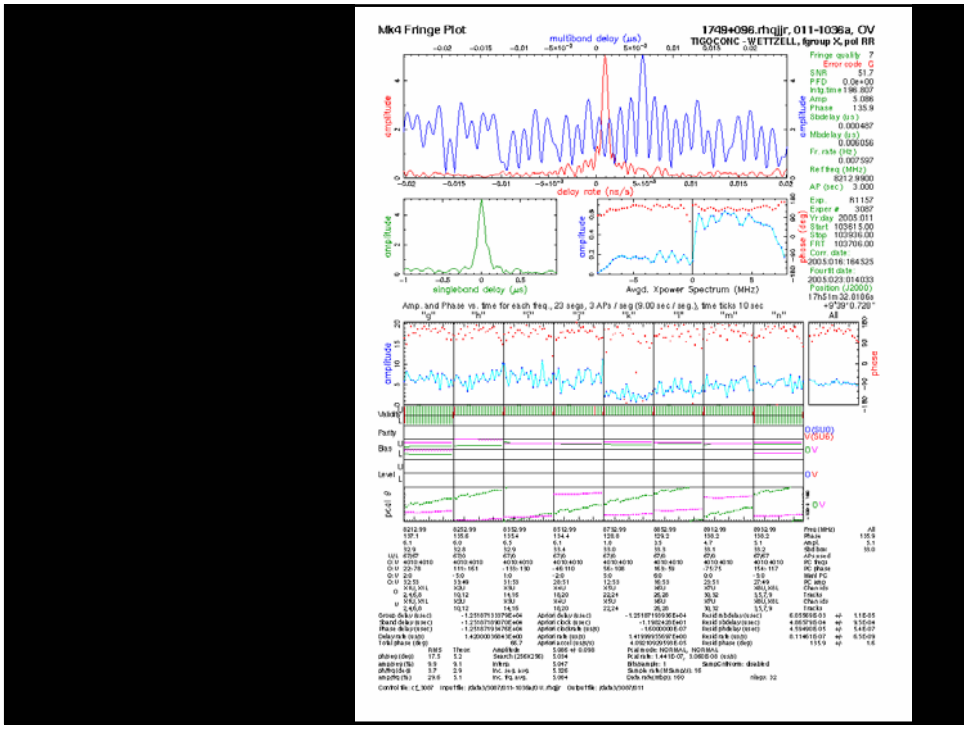

After Pcal Adjustments
Mk4 Fringe Plot
4C39_25.oqleoe, 349-1515, AK
GILCREEK - KOKEE, fgroup X
Amp. and Phase vs. time for each freq., 10 segments, 1 APs / segment (5.00 sec / seg.), time ticks 2 sec

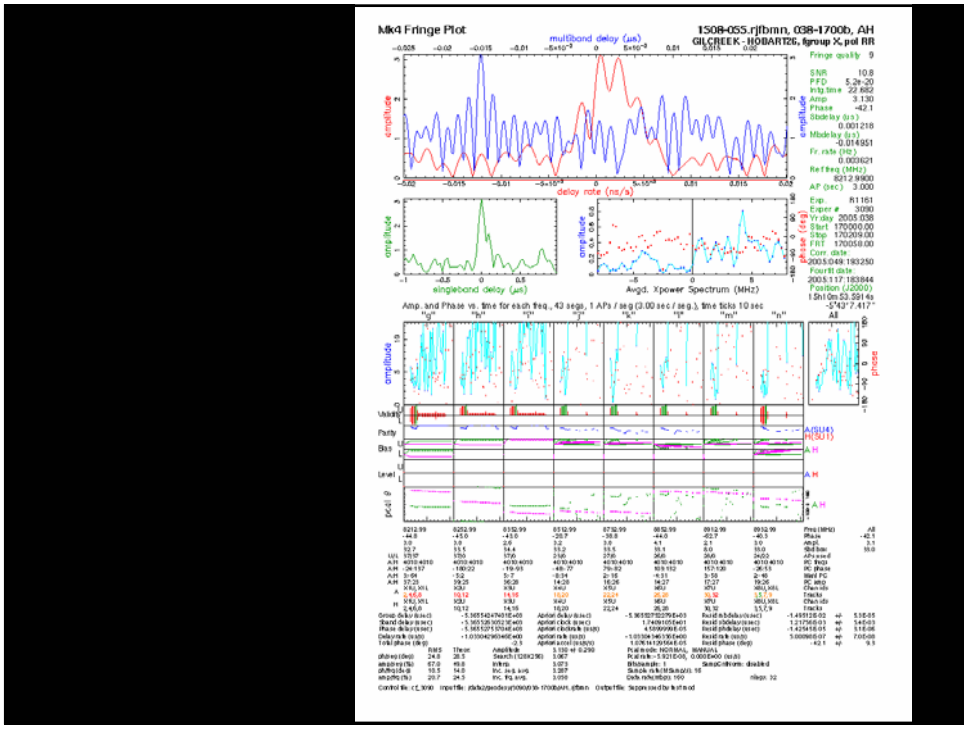

Mk4 Fringe Plot
0202+149.qkexcp, 246-0548, IV
MATERA - WETTZELL, fgroup S, pol RR
multiband delay (μs)
amplitude
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 29 segs, 4 APs / seg (4.00 sec / seg.), time ticks 5 sec
All
Press a key: 'h'=hardcopy, 's'=save, 'q'=quit, other=continue


Mk4 Fringe Plot
0202+149.qkexcp, 246-0548, II
MATERA - MATERA, fgroup S, pol RR
amplitude
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 190 segs, 1 APs / seg (1.00 sec / seg.), time ticks 1 sec
All
Press a key: 'h'=hardcopy, 's'=save, 'q'=quit, other=continue

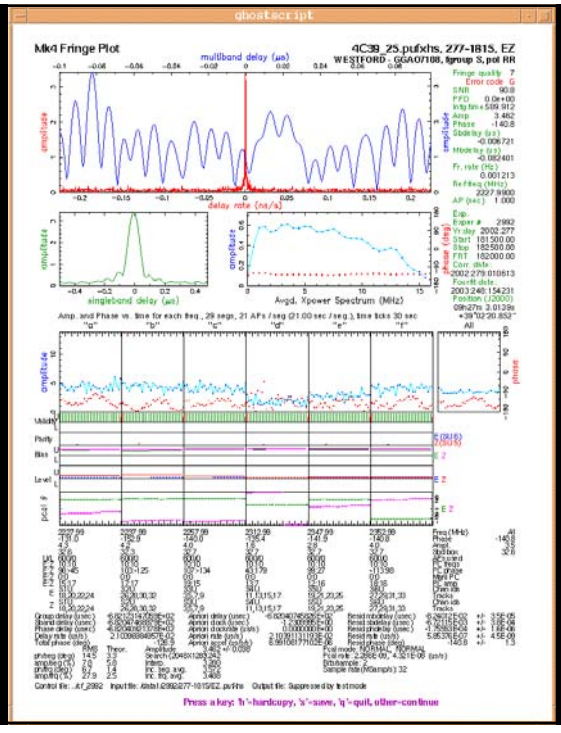

Mk4 Fringe Plot
1749+096.rkyffd, 081-1059, AE
GILCREEK - WESTFORD, fgroup S, pol RR
multiband delay (μs)
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 29 segs, 1 APs / seg (3.00 sec / seg.), time ticks 5 sec
Press a key: 'h'=hardcopy, 's'=save, 'q'=quit, other=continue

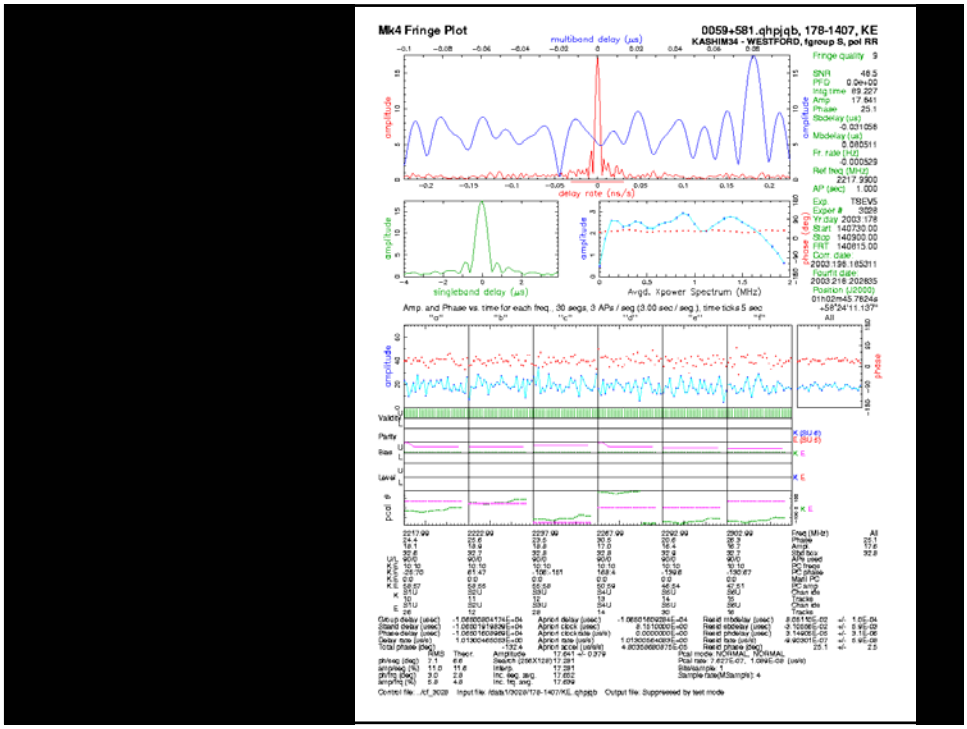

ghostscript
Mk4 Fringe Plot
2150+173.rmhyyl, 108-1808, AH
GILCREEK - HOBART26, fgroup S, pol RR
multiband delay (μs)
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 29 segs, 6 APs / seg (6.00 sec / seg.), time ticks 10 sec
Press a key: 'h'=hardcopy, 'p'=previous, 'n'=next, 's'=save, 'q'=quit, other=continue

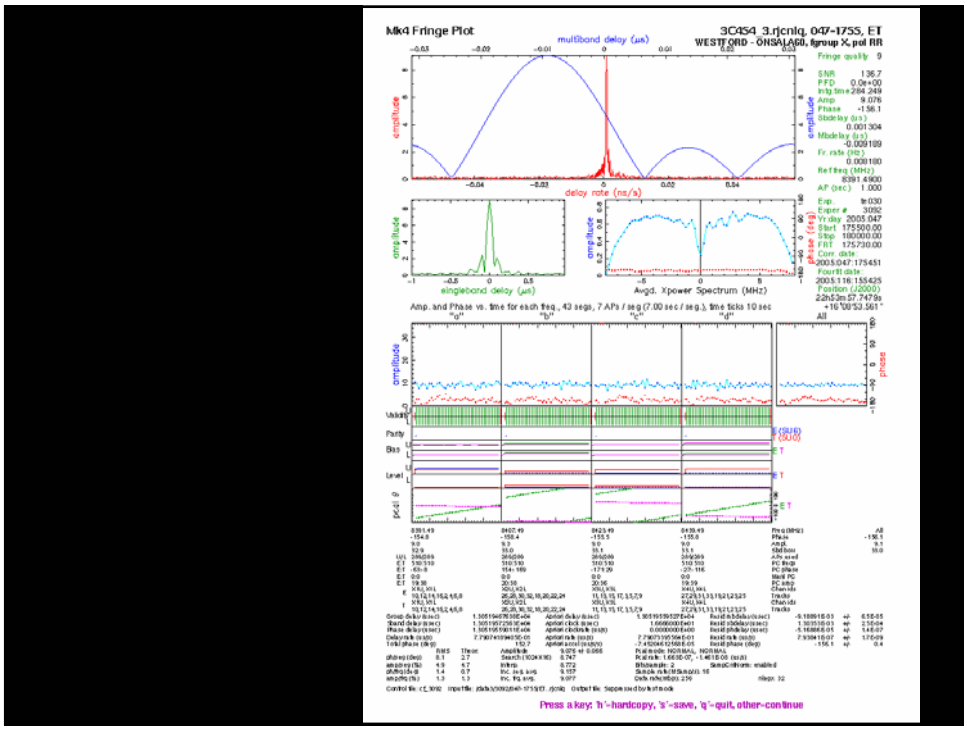

Mk4 Fringe Plot
1749+096.rhqjjr, 011-1036a, OV
TIGOCONC - WETTZELL, fgroup X, pol RR
multiband delay (μs)
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 23 segs, 3 APs / seg (9.00 sec / seg.), time ticks 10 sec
amplitude
phase
Validity
Parity
Bias
Level
pcal
O(SU0)
V(SU6)
OV

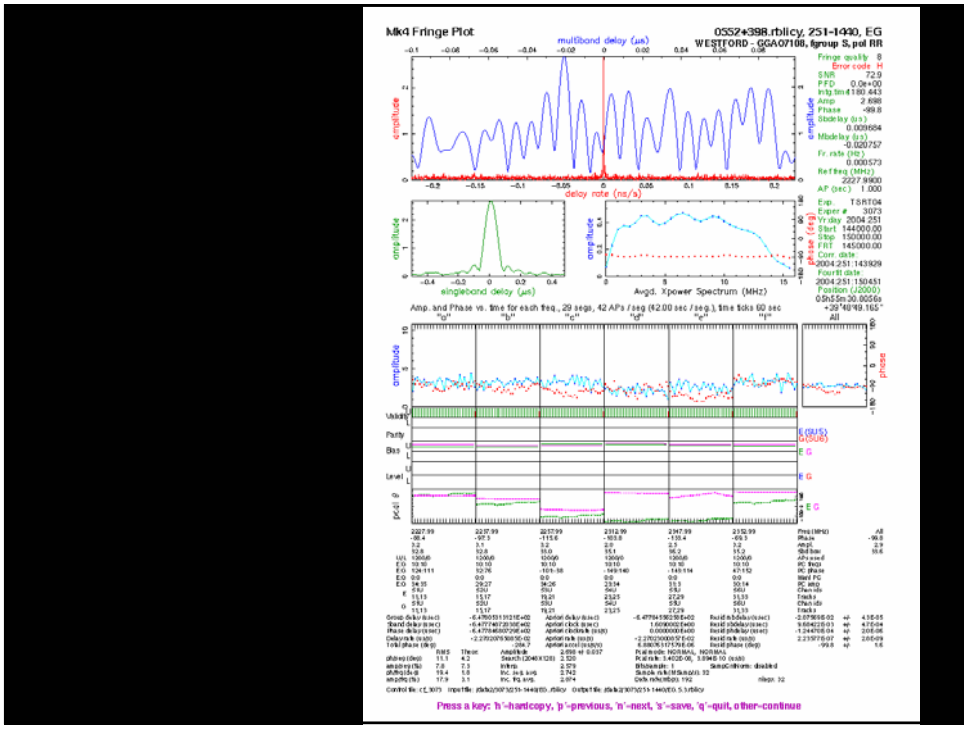

Mk4 Fringe Plot
1508-055.rjfbmn, 038-1700b, AH
GILCREEK - HOBART26, fgroup X, pol RR
multiband delay (μs)
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 43 segs, 1 APs / seg (3.00 sec / seg.), time ticks 10 sec
amplitude
phase
Validity
Parity
Bias
Level
pcal
A(SU4)
H(SU1)
AH

Some eVLBI examples

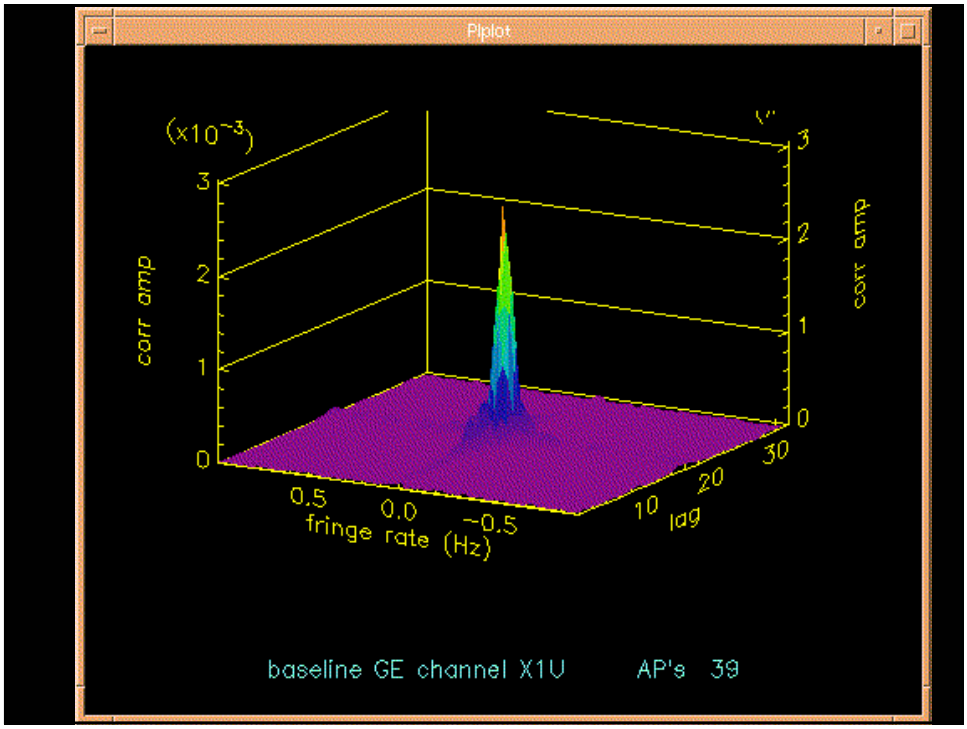



Mk4 Fringe Plot
0059+581.qhpjqb, 178-1407, KE
KASHIM34 - WESTFORD, fgroup S, pol RR
multiband delay (μs)
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 30 segs, 3 APs / seg (3.00 sec / seg.), time ticks 5 sec
amplitude
phase
Fringe quality 9
SNR 46.5
PFD 0.0e+00
Intg time 89.297
Amp 17.841
Phase 25.1
Sbdelay (us) -0.031058
Mbdelay (us) 0.080511
Fr. rate (Hz) -0.000529
Ref freq (MHz) 2217.9900
AP (sec) 1.000
Exp. T6EV5
Exper # 3028
Yr.day 2003.178
Start 140730.00
Stop 140900.00
FRT 140815.00
Corn. date 2003.198.185211
Fourfit date 2003.216.202835
Position (J2000) 01h02m45.7624s +58°24'11.137"

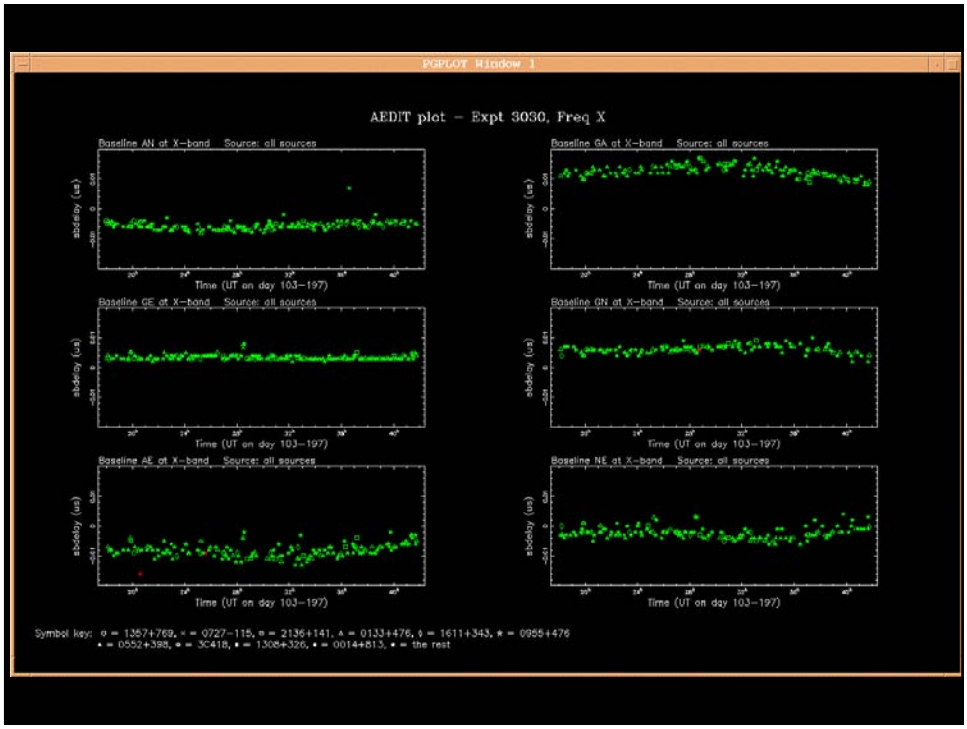

Mk4 Fringe Plot
3C454.3.rjcnlq, 047-1755, ET
WESTFORD - ONSALA60, fgroup X, pol RR
multiband delay (μs)
delay rate (ns/s)
singleband delay (μs)
Avgd. Xpower Spectrum (MHz)
Amp. and Phase vs. time for each freq., 43 segs, 7 APs / seg (7.00 sec / seg.), time ticks 10 sec
amplitude
phase
Fringe quality 9
SNR 136.7
PFD 0.0e+00
Intg time 284.249
Amp 9.076
Phase -156.1
Sbdelay (us) 0.001304
Mbdelay (us) -0.009189
Fr. rate (Hz) 0.000180
Ref freq (MHz) 8391.4900
AP (sec) 1.000
Exp. tr030
Exper # 3052
Yr.day 2005.047
Start 175500.00
Stop 180000.00
FRT 175730.00
Corn. date 2005.047.175451
Fourfit date 2005.116.155425
Position (J2000) 22h53m57.7479s +16°08'53.561"
Press a key: 'h'=hardcopy, 's'=save, 'q'=quit, other=continue

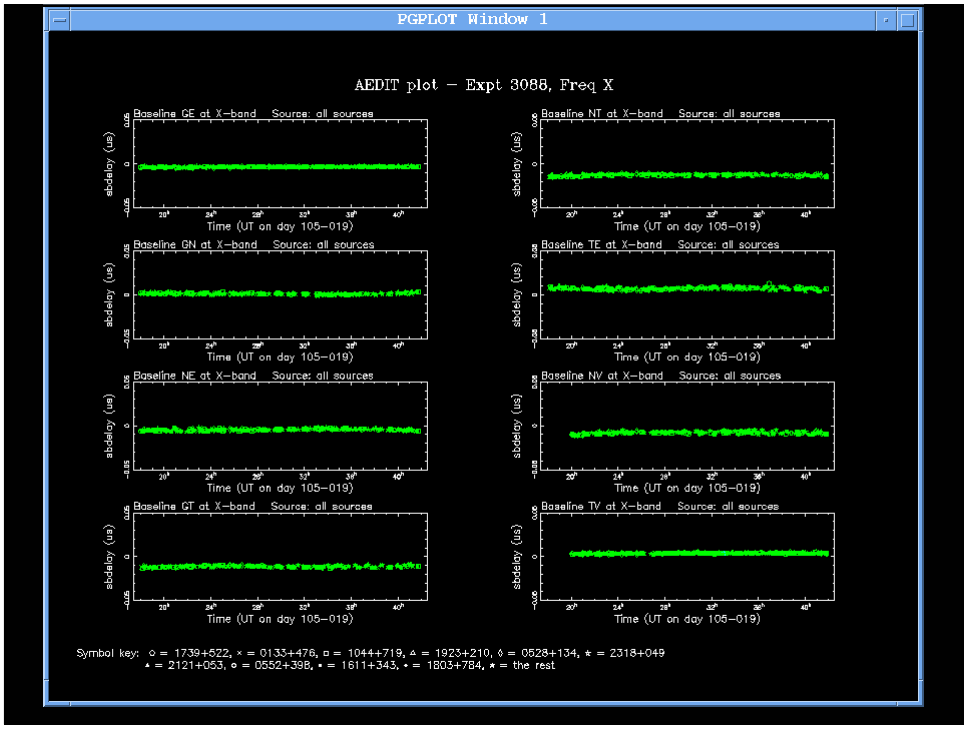


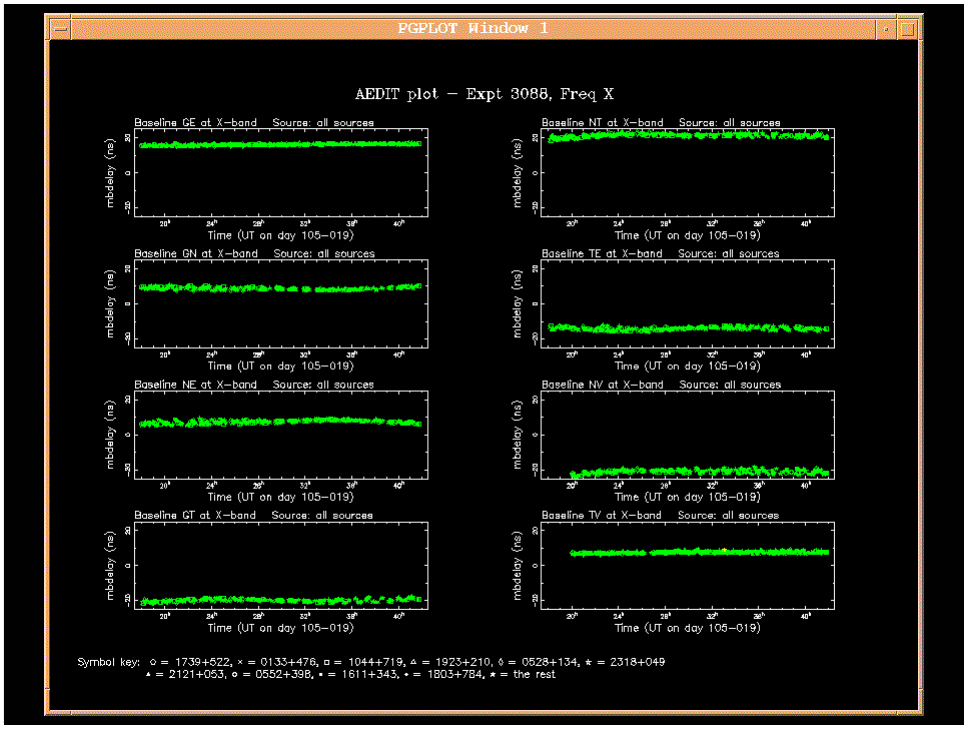
Real Time Display

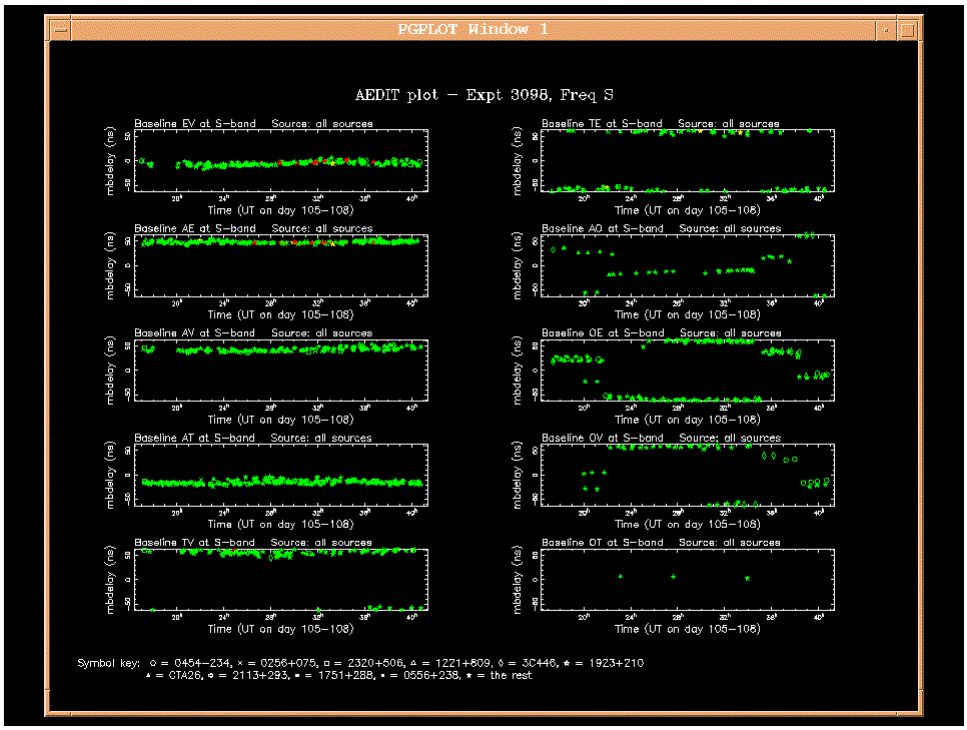

Piplot
(x10^-3)
corr amp
3
2
1
0
0.5
0.0
-0.5
fringe rate (Hz)
10
20
30
lag
corr amp
baseline GE channel X1U
AP's 39

Aedit plots


PGPLOT Window 1
AEDIT plot – Expt 3030, Freq X
Baseline AN at X-band Source: all sources
Baseline GA at X-band Source: all sources
Baseline GE at X-band Source: all sources
Baseline GN at X-band Source: all sources
Baseline AE at X-band Source: all sources
Baseline NE at X-band Source: all sources
sbdelay (us)
Time (UT on day 103–197)
Symbol key: ○ = 1357+769, × = 0727–115, □ = 2136+141, △ = 0133+476, ◊ = 1611+343, ☆ = 0955+476
• = 0552+398, ⊕ = 3C418, ▪ = 1308+326, ▪ = 0014+813, ▪ = the rest


PGPLOT Window 1
AEDIT plot – Expt 3088, Freq X
Baseline GE at X-band Source: all sources
Baseline NT at X-band Source: all sources
Baseline GN at X-band Source: all sources
Baseline TE at X-band Source: all sources
Baseline NE at X-band Source: all sources
Baseline NV at X-band Source: all sources
Baseline GT at X-band Source: all sources
Baseline TV at X-band Source: all sources
sbdelay (us)
Time (UT on day 105–019)
Symbol key: ○ = 1739+522, × = 0133+476, □ = 1044+719, △ = 1923+210, ◊ = 0528+134, ☆ = 2318+049
▪ = 2121+053, ⊕ = 0552+398, • = 1611+343, ▪ = 1803+784, ▪ = the rest


PGPLOT Window 1
AEDIT plot – Expt 3088, Freq X
Baseline GE at X-band Source: all sources
Baseline NT at X-band Source: all sources
Baseline GN at X-band Source: all sources
Baseline TE at X-band Source: all sources
Baseline NE at X-band Source: all sources
Baseline NV at X-band Source: all sources
Baseline GT at X-band Source: all sources
Baseline TV at X-band Source: all sources
mbdelay (ns)
Time (UT on day 105-019)
Symbol key: ◇ = 1739+522, × = 0133+476, □ = 1044+719, △ = 1923+210, ◊ = 0528+134, ★ = 2318+049
▲ = 2121+053, ○ = 0552+398, • = 1611+343, + = 1803+784, ★ = the rest


PGPLOT Window 1
AEDIT plot – Expt 3088, Freq S
Baseline EV at S-band Source: all sources
Baseline TE at S-band Source: all sources
Baseline AE at S-band Source: all sources
Baseline AQ at S-band Source: all sources
Baseline AV at S-band Source: all sources
Baseline QE at S-band Source: all sources
Baseline AT at S-band Source: all sources
Baseline QV at S-band Source: all sources
Baseline TV at S-band Source: all sources
Baseline QT at S-band Source: all sources
mbdelay (ns)
Time (UT on day 105-108)
Symbol key: ◇ = 0454-234, × = 0256+075, □ = 2320+506, △ = 1221+509, ◊ = 3C446, ★ = 1923+210
▲ = CTA26, ○ = 2113+293, • = 1751+288, + = 0556+238, ★ = the rest

What we can do for you

- Provide feedback after checkout
  - IF/freq./pol./clock/LO/pcal performance
  - antenna/system/setup/formatter performance
  - RFI/recording problems
  - any/many other issues!
- Provide correlator reports upon completion.
  - Contains summary/evaluation

Conclusion

Correlator is a powerful diagnostic tool!

Correlator Demonstration