# *TOW 2009 Correlator Operations*

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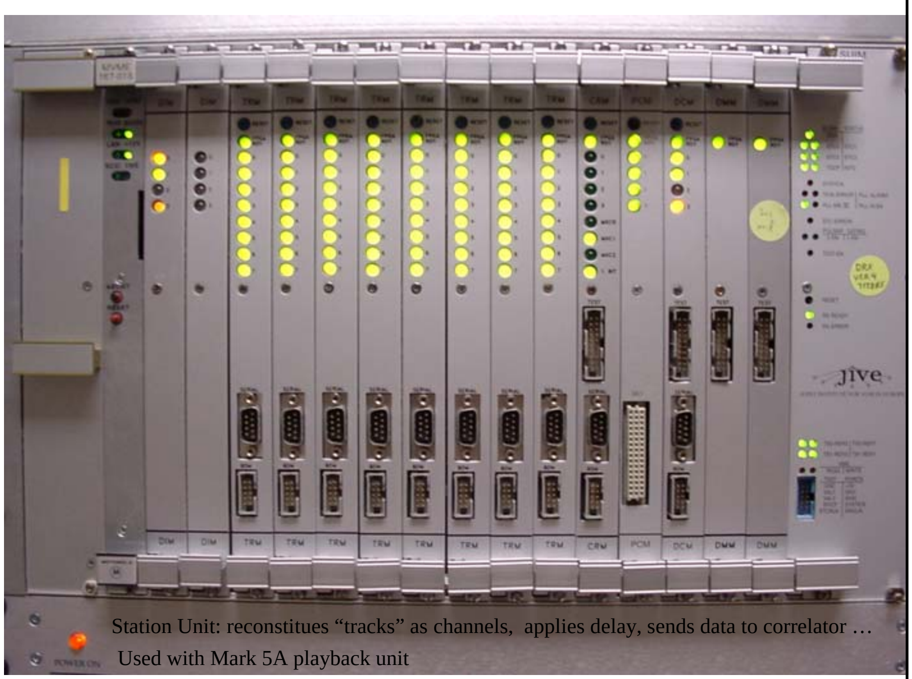
# *Introduction*

- Brief outline of an experiment’s life cycle
- What you can do for us
- Correlator report discussion
- What we can do for you (and how!)

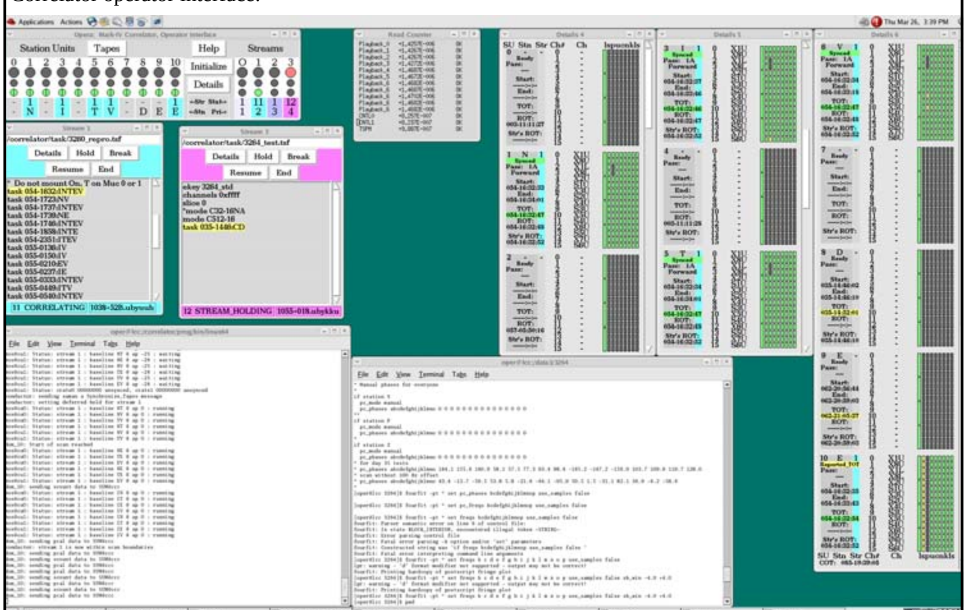
Bonn

Washington



Station Unit: reconstitues “tracks” as channels, applies delay, sends data to correlator …
Used with Mark 5A playback unit

Mark 5B DOM playback unit and Correlator Interface Board (CIB – just below)
Mark 5B Data Output Module (DOM) generates channels/applies model
CIB sends data to correlator …


Correlator operator interface:



## *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 …*

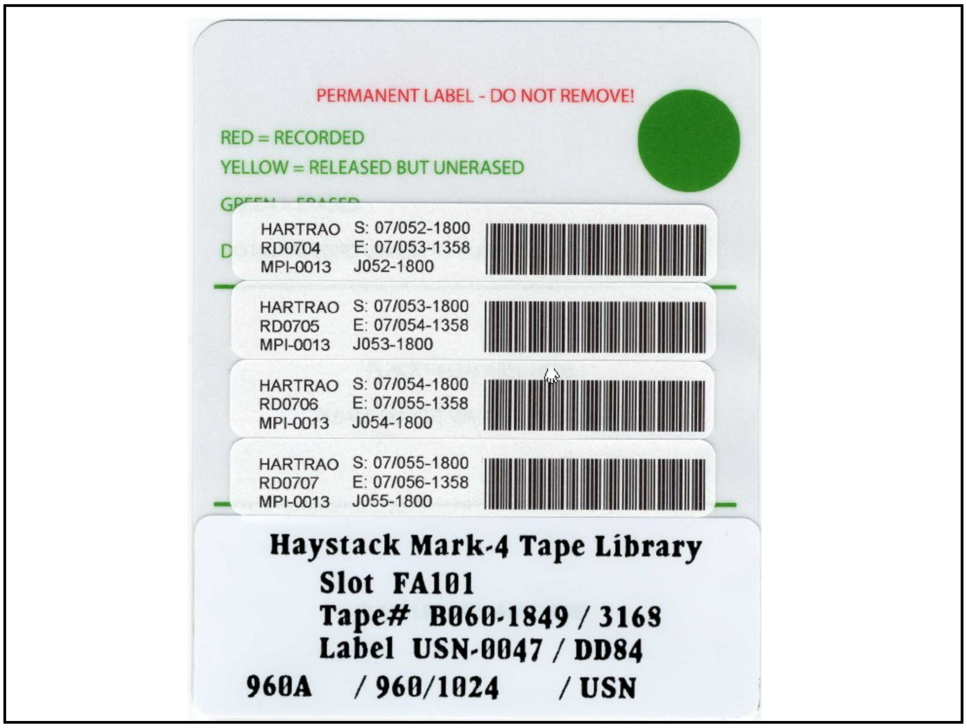
- Construct processing/fourfit control files
- Schedule/production process/cleanup
- Analyze results/evaluate stations
- Export
- Release disks

## *What you can do for us*

- Ship the disks 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


PERMANENT LABEL - DO NOT REMOVE!
RED = RECORDED
YELLOW = RELEASED BUT UNERASED
HARTRAO S: 07/052-1800
RD0704 E: 07/053-1358
MPI-0013 J052-1800
HARTRAO S: 07/053-1800
RD0705 E: 07/054-1358
MPI-0013 J053-1800
HARTRAO S: 07/054-1800
RD0706 E: 07/055-1358
MPI-0013 J054-1800
HARTRAO S: 07/055-1800
RD0707 E: 07/056-1358
MPI-0013 J055-1800
Haystack Mark-4 Tape Library
Slot FA101
Tape# B060-1849 / 3168
Label USN-0047 / DD84
960A / 960/1024 / USN


SDK8
Please mark your module if it is > SDK 6
SDK 7 !!
Haystack Mark-4 Tape Library
Slot BA112
Tape# K049-1800 / 3259
Label USN-0180 / BD90
2000D / 2000/1024 / USN
USN-0180/2000/1024
Haystack Mark-4 Tape Library
Slot BA206
Tape# N351-1730 / 3251
Label BKG-0065 / 523E
2000D / 2000/1024 / BKG
BKG-0065/2000/1024
Mark 5 VLBI Data System

## *More details on documentation*

- Put it in OPS messages - they are read first!
- Media 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

```
Nice starting message:

Session k09075 ready message for Ny -Alesund.
--------------------------------------------
Comments:
VC04 bad, some snow in antenna

First source: 0955=476 at 07:00  UT
GPS-FMOUT: 26.44 microseconds
Wx:  Temperature (C): -11.55  Pressure (mBar): 998.2  Humidity (%): 85.6
Sky Conditions: Overcast and some wind
Cable difference is: longer cable makes the reading larger by
                     672.9 microseconds and is nominal
Pointing values:
SEFD  X/S       Source          Az/El      Offset1  Offset2
   1473/1749    taurusa           4/11      0.012    0.014
   1166/1505    cygnusa         135/49      0.0104   0.0017
   1309/1655    casa             76/58      0.0059   -0.0007

Tsys (x1/s/x2): 43/33/42
_____________________________________________
IVS-ops mailing list
IVS-ops@ivscc.gsfc.nasa.gov
http://ivscc.gsfc.nasa.gov/mailman/listinfo/ivs-ops
```

Nice ending message:

The log from experiment r1370 has been copied to:
ivsopar.obspm.fr:/pub/ivsincoming/
-----------------------------------------------------
Formatter (H-maser) leads GPS by 11.5147 microsec at 2009.076.16:55:59.16
Cable difference: Longer cable makes reading smaller by 761.4 microsec
and is nominal.

Additional experiment notes:
We recorded to module BKG-0015/1480/1024 sent to Bonn using DHL AWB#
3443214121
Media stock: We have 1 size A, 1 size B, 2 size C, 1 size D and zero
larger modules remaining at Hobart after this experiment. We also
received an additional 5 modules today and we are yet to identify the
size of these modules.

Started 6.5 hours late because of making repairs to X2 motor encoder wiring.
First scan on mark5 module is with the antenna slewing.
Good data commences with scan 075-2325a.

Observers: Brett, Eric, Shari
Observer comments follow:
2009.075.23:23:56.87;"first scan for Hobart26 will be 075-2325 following
repairs to X2 motor encoder cabling and earthing
2009.075.23:24:21.93;"missed first 6.5 hours of experiment
2009.075.23:24:37.40;"weather is overcast
2009.076.01:11:43.96;"weather: calm and overcast
2009.076.03:12:46.64;"weather: calm, 80% cloud cover
2009.076.05:03:05.51;"weather: calm, 30% cloud cover
2009.076.09:45:06.22;"weather: calm, mostly clear
2009.076.17:00:07.84;"weather: calm, mostly clear

Regards,
Brett

*More details on severe problems*

## *Possibly recoverable problems*

- 1-2 Mark5 disk failures (in 8 pack)
- Bad playback (e.g. cable crosstalk at Gb/sec data rate)
- 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

## *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!
- Covered in part 2 …
- Provide correlator reports upon completion.
  - Contains summary/evaluation

# *Annotated Correlator Report*

For discussion

**A sample annotated correlator report**
**MAT/BEC/KAK/AB/DH 032709**
Below is a sample correlator report with comments in ***bold italics*** explaining each section:
*******************************************************************

WACO Correlator Report for R4368 (exp# 4368)
Obs: 05 Mar. to 06 Mar. 2009 doy 064/065
Correlated: 16 Mar. 2009 to 17 Mar. 2009
Exported: done

***This introductory section identifies the correlator, the experiment and the dates of observation and correlation.***

| Qcode | % of Total scans | % of Correlated scans |
|---|---|---|
| 5-9 | 54% | 94% |
| 0 | 1% | 1% |
| B-H | 3% | 5% |
| Removed | 43% | (Ft, Ny) |

***This is an overall fringe quality code summary. This section gives you a sense of how much usable data was extracted from the observation. The first column is fringe quality codes; these will be covered later in this document. Suffice to say here that the Qcode 5-9 row represents data which will be accepted in the final results. Qcode 0 represents non-detections. B-H represents various problems which mean the data will not be accepted even though fringes were detected. 'Removed' means scans which were removed before correlation due to problems reported by the station during record time.***

Station notes:

BADARY (Bd/B): Phase offsets applied with respect to WETTZELL
Spurious signals at BADARY.
X1 (BBC01, 8212.99) -19dBc
X2 (BBC02, 8252.99) -19 dBc
X3 (BBC03, 8352.99) -18 dBc
… etc

ZELENCHK (Zc/Z): Station reports BBC06 was removed from VLBA4 rack for repair BBC11 no signal. Scans 064-2146 and 065-1826 failed due to antenna problems.
Channels X6 (BBC06, 8852.99) and S3 (BBC11, 2257.99) removed from fringe fitting. Spurious signals at ZELENCHK:
. . . etc ..

***The section above contains specific comments related to the performance of each station participating in the experiment. You should read carefully any comments for your station and ask the correlator if there is anything you do not understand in those comments. More importantly, you should fix any problems identified in the report if that is possible!***

Clocks: WACO

| Station | fmout-gps [usec] | Used [usec] | rate [sec/sec] |
|---|---|---|---|
| Bd | -1.87 | -1.10 | 0.0 |
| Kk | -0.34 | 0.08 | -0.4e-12 |
| Ma | -26.62 | -25.37 | -0.6e-12 |
| Tc | 0.85 | 1.03 | 0.0 |
| Wz | -13.26 | -13.01 | 0.0 |
| Zc | -0.76 | -0.43 | 0.0 |

Date: 2009/03/05

***These are the clock offsets used for each station. The second column is the value reported in the station logs, the third is the value actually used at the correlator and the fourth is any clock drift rate applied. There are fixed offsets applied at the correlator to correct for different instrumental offsets at different stations.***

| Qcodes | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | G | H | N | - | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BI:X | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 24 | 124 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 165 |
| BI:S | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 53 | 92 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 165 |
| BZ:X | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 88 | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 147 |
| BZ:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 145 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 147 |
| VK:X | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 14 | 66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 |
| VK:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 |
| Totals | 38 | 0 | 0 | 0 | 0 | 0 | 4 | 43 | 407 | 2313 | 0 | 0 | 0 | 0 | 2 | 0 | 133 | 0 | 0 | 2188 | 5128 |

***This is a table of fringe quality codes on a baseline basis (using the single letter station codes), with totals at the bottom. This table can give you more information about how your station is performing. See below for an explanation of the codes:***

Legend:
QC = 0  Fringes not detected.
= 1-9  Fringes detected, no error condition. Higher number = better quality.
= B  Interpolation error in fourfit.
= D  No data in one or more frequency channels.
= E  Maximum fringe amplitude at edge of SBD, MBD, or rate window.
= F  "Fork" problem in processing.
= G  Fringe amp in a channel is <.5 times mean amp (only if SNR>20).
= H  Low Phase-cal amplitude in one or more channels.
= N  No valid correlator data.
Tot  Total number of scans in schedule.
Minus  Scans in original schedule file for which correlation was not attempted, usually because of known station problems.

Processed in one pass

MEAN RATIOS = Observed SNR / Predicted SNR for exp no. 4368

...by baseline, over all sources:

| bl | X | n | S | n |
|---|---|---|---|---|
| BK | 0.52 | 127 | 1.09 | 128 |
| BI | 0.36 | 153 | 0.76 | 162 |
| BO | 0.00 | 0 | 0.00 | 0 |
| BV | 0.59 | 176 | 1.16 | 177 |
| BZ | 0.48 | 144 | 1.02 | 146 |

etc …

***This is a table of the actually measured vs. predicted (by sked) signal to noise ratios (snr) over the course of the whole experiment, by baseline. This table shows whether your station is as sensitive as it is predicted to be by sked. Ratios below 1 indicate the station is not as sensitive as expected, or better than expected if above 1.***

***bl = baseline***
***X = X band snr ratio***
***n = number of scans included in calculation***
***S = S band snr ratio***
***n = number of scans included in calculation***

CF File

```
***
* 4fit control file for R4368
*
  max_parity 0.02
  sb_win -1.0 1.0 mb_win -1.0 1.0 dr_win -3.0e-5 3.0e-5
  start -3 stop -1
*
  if f_group X
    ref_freq 8212.99
    pc_freqs ghijklmn  0010  0010  0010  0010  0010  0010  0010  0010

etc …
```

***This is the fourfit control file used at the correlator, which is the place where many parameters are set and adjusted (one example, this is where any station specific channel deletions would be made) before fringe fitting the correlated data. This file is mostly of interest to those who use fourfit (like, people who might re-fringe fit the data later in the analysis process), so it will not be explained here. Most likely all of what is documented here is explained in the section where specific station issues are summarized, if there is an issue of concern to the station. If you are curious to know more about this file, please ask a fourfit guru.***

Dave: David Hall dmh@usno.navy.mil

***This is the person (or persons) who wrote the report above. It is probably best to direct any questions related to the report to the person listed here.***

***As of May 2009, the correlator analysts are as follows:***

***Bonn:***

***Alessandra: Alessandra Bertarini abertari@mpifr-bonn.mpg.de***
***Arno: Arno Mueskins amueskin@mpifr-bonn.mpg.de***

***Haystack:***

***Mike: Mike Titus mike@haystack.mit.edu***
***Brian: Brian Corey bec@haystack.mit.edu***

***Washington:***

***Dave: David Hall dmh@usno.navy.mil***
***Kerry: Kerry Kingham kingham.kerry@usno.navy.mil***

## *End of part 1*

Now comes the good part …

## *Supplemental Slides*

If needed, for discussion

# *Hardware and software structure*

...of current Mark IV correlator

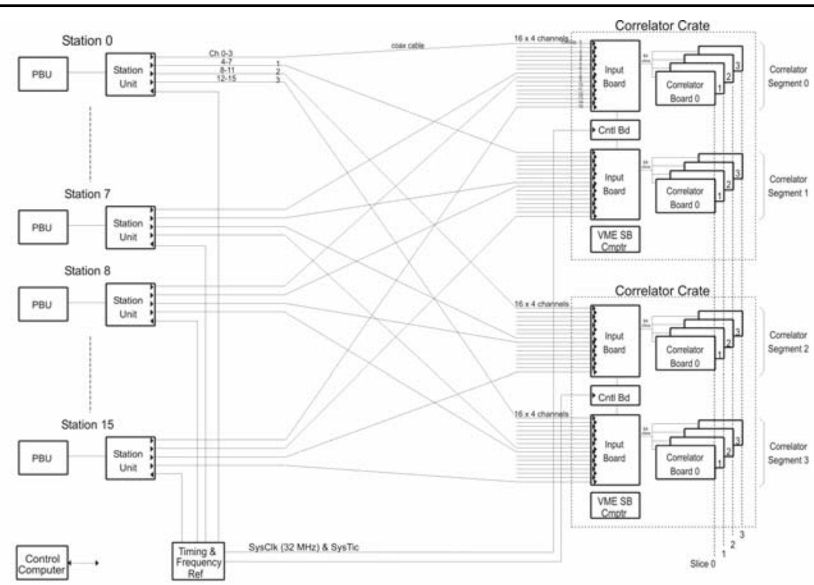



Figure 1: Correlator Block Diagram

SYSTEM5.DRW

ARW
23 Nov 99

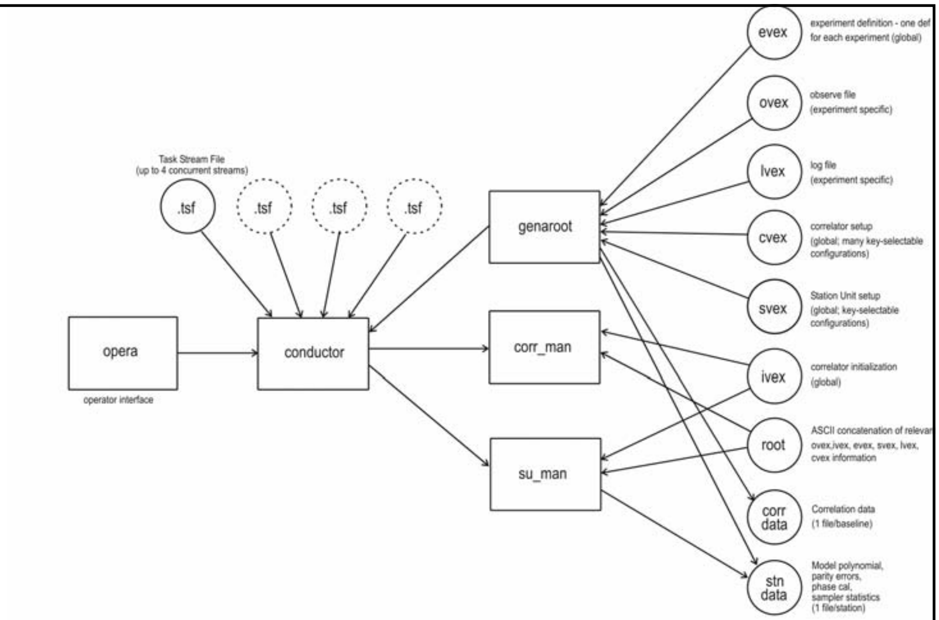



Figure 13: Simplified Mark 4 Correlator Software Block Diagram

ARW 981104

```
* tgen run on 2006 June 16 14:13 LT
ekey 3151_std
* Reading file /correlator/sysvex/global.evex
* Experiment number is 3151
* Using 8 SUs
channels 0xffff
slice 0 2
mode C32-16NA
* DRIVE RECIPE  Station    X   P   K   F/O U   V   L
*               Drive #    0   1   2   3   4   5   6
* Using only stations FOKUVLXP
* Reading file /correlator/data/3151/3151.ovex
*     and file /correlator/data/3151/3151.lvex
* New disc set X USN-0073
* New disc set O cmva-004
* New disc set K USN-0141
* New disc set U USN-0067
* New disc set V CMVA-012
* New disc set L BKG-0018
task 143-1730:OKUVLX
* New disc set F IAA-0017
task 143-1745:OKUX
task 143-1749:OUV
task 143-1753:OUV
task 143-1804:OUVL
task 143-1810:OUV
```

# Notes for 2009 IVS TOW Meeting Correlator Operations Class

MAT/AB/KAK/DH/AM/BEC/DRS/RJC 041009

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## Part 1 – Introduction

In this lecture, we hope to accomplish the following:

- 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.
- Discuss correlator reports and the feedback loop between the stations and correlator.
- Show some of the tools we use, and how we might use them to help you.

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

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## Part 2 – 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
- 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, 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

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## Part 3 – What the stations can do for the correlator

### *Ship the disks 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: all the stations should use TRACK regularly. The usage of TRACK is important for correlators, especially since the responsibility for 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

- 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.
- Note any physical damage upon arrival, and be sure to package disks properly for shipping.
- Be sure to label the module if it is recorded using a Conduant SDK version greater than 6.

### 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)
- Pointing/SEFD Info

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

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

### III) playback quality

- Be sure to erase the disk and check and correct (if necessary) the disk's VSN **before recording**.
- 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 (like apparently slow disks in a pack).

### 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.
- Degraded Mark 5 recording at Gb/sec data rates due to cable interference.
- 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 playback problems (like cable interference problems at Gb/sec data rates).
- 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)
- offsets larger than 8 seconds

- 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.

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## Part 4 – 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 and the fringe fitting of the trial correlation detects the rest. Checking lights on the operator interface, SUs and DOMs while correlation is in progress can also reveal problems quickly.

***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 data, IF problems, wrong frequency setup, wrong polarization, antenna failure, system problem that can degrade the sensitivity, SEFD, warm receivers, wrong formatter setting, difference between the expected and the observed SNR, data formatting problems, clock performance.

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## Part 5 – 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, observing lights on the operator interface/SUs and DOMs 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 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.

# A sample annotated correlator report

**MAT/BEC/KAK/AB/DH 041009**

Below is a sample correlator report with comments in ***bold italics*** explaining each section:

*****************************************************************

```
WACO Correlator Report for R4368  (exp# 4368)
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Correlated:  16 Mar. 2009 to 17 Mar. 2009
Exported: done
```

***This introductory section identifies the correlator, the experiment and the dates of observation and correlation.***

```
Qcode   % of Total   % of Correlated
          scans          scans

 5-9       54%           94%
  0         1%            1%
 B-H        3%            5%
Removed    43% (Ft, Ny)
```

***This is an overall fringe quality code summary.  This section gives you a sense of how much usable data was extracted from the observation.  The first column is fringe quality codes; these will be covered later in this document.  Suffice to say here that the Qcode 5-9 row represents data which will be accepted in the final results.  Qcode 0 represents non-detections. B-H represents various problems which mean the data will not be accepted even though fringes were detected. 'Removed' means scans which were removed before correlation due to problems reported by the station during record time.***

```
Station notes:

BADARY   (Bd/B):   Phase offsets applied with respect to WETTZELL
                   Spurious signals at BADARY.
                   X1 (BBC01, 8212.99) -19dBc
                   X2 (BBC02, 8252.99) -19dBc
                   X3 (BBC03, 8352.99) -18dBc
                   X4 (BBC04, 8512.99) -21dBc
                   X5 (BBC05, 8732.99) -19dBc
                   X6 (BBC06, 8852.99) -20dBc
                   X7 (BBC07, 8912.99) -19dBc
                   X8 (BBC08, 8932.99) -19dBc

                   Phase offsets applied with respect to WETTZELL.

FORTLEZA (Ft/F):   FORTLEZA had no media and was unable to participate
                   in the session.

KOKEE    (Kk/K):   Manual phasecal at KOKEE

MATERA   (Ma/I):   Low pcal/fringe amplitude in channel S4 (BBC12, 2312.99)
                   leading to nearly all G-codes.  Additional low pcal/fringe
```

amplitude in channels S1 (BBC09, 2227.99),
S2 (BBC10, 2237.99) and S3 (BBC11, 2257.99) throughout the experiment leading to many G-codes. Channel S4 dropped, channels S1, S2 and S3 not dropped.

NYALES20 (Ny/N): Station was unable to participate due to ongoing repairs on the receiver.

TIGOCONC (Tc/O): -

WETTZELL (Wz/V): -

ZELENCHK (Zc/Z): Station reports BBC06 was removed from VLBA4 rack for repair BBC11 no signal. Scans 064-2146 and 065-1826 failed due to antenna problems.

Channels X6 (BBC06, 8852.99) and S3 (BBC11, 2257.99) removed from fringe fitting. Spurious signals at ZELENCHK:
X1 (BBC01, 8212.99) -15dBc
X2 (BBC02, 8252.99) -17dBc
X3 (BBC03, 8352.99) -18dBc
X4 (BBC04, 8512.99) -24dBc
X5 (BBC05, 8732.99) -28dBc
X7 (BBC07, 8912.99) -22dBc
X8 (BBC08, 8932.99) -18dBc
S1 (BBC09, 2227.99) -24dBc
S2 (BBC10, 2237.99) -22dBc

$

***The section above contains specific comments related to the performance of each station participating in the experiment. You should read carefully any comments for your station and ask the correlator if there is anything you do not understand in those comments. More importantly, you should fix any problems identified in the report if that is possible!***

Clocks: WACO

| Station | fmout-gps [usec] | Used [usec] | rate [sec/sec] |
|---|---|---|---|
| Bd | -1.87 | -1.10 | 0.0 |
| Kk | -0.34 | 0.08 | -0.4e-12 |
| Ma | -26.62 | -25.37 | -0.6e-12 |
| Tc | 0.85 | 1.03 | 0.0 |
| Wz | -13.26 | -13.01 | 0.0 |
| Zc | -0.76 | -0.43 | 0.0 |

Date: 2009/03/05

*

***These are the clock offsets used for each station. The second column is the value reported in the station logs, the third is the value actually used at the correlator and the fourth is any clock drift rate applied. There are fixed***

***offsets applied at the correlator to correct for different instrumental offsets at different stations.***

| Qcodes | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | G | H | N | - | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BF:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 13 |
| BF:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 13 |
| BI:X | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 24 | 124 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 165 |
| BI:S | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 53 | 92 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 165 |
| BN:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 200 | 200 |
| BN:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 200 | 200 |
| BZ:X | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 88 | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 147 |
| BZ:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 145 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 147 |
| BO:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BO:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BV:X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 171 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 177 |
| BV:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 176 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 177 |
| BK:X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 11 | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 128 |
| BK:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 128 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 128 |
| FI:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 43 | 43 |
| FI:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 43 | 43 |
| FN:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 18 |
| FN:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 18 |
| FZ:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 17 |
| FZ:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 17 |
| FO:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 75 |
| FO:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 75 |
| FV:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 40 |
| FV:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 40 |
| FK:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 20 |
| FK:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 20 |
| IN:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195 | 195 |
| IN:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 195 | 195 |
| IZ:X | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 26 | 133 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 164 |
| IZ:S | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 51 | 62 | 0 | 0 | 0 | 0 | 2 | 0 | 34 | 0 | 0 | 1 | 164 |
| IO:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| IO:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| IV:X | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 12 | 250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 267 |
| IV:S | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 90 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 68 | 0 | 0 | 0 | 267 |
| IK:X | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 62 |
| IK:S | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 62 |
| NZ:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 129 | 129 |
| NZ:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 129 | 129 |
| NO:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 |
| NO:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 |
| NV:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 209 | 209 |
| NV:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 209 | 209 |
| NK:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 126 | 126 |
| NK:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 126 | 126 |
| ZO:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 |
| ZO:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| ZV:X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 155 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 161 |
| ZV:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 160 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 161 |
| ZK:X | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 9 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 |
| ZK:S | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 |
| OV:X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| OV:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OK:X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 |
| OK:S | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 |
| VK:X | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 14 | 66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 |
| VK:S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 |
| Totals | 38 | 0 | 0 | 0 | 0 | 0 | 4 | 43 | 407 | 2313 | 0 | 0 | 0 | 0 | 2 | 0 | 133 | 0 | 0 | 2188 | 5128 |

***This is a table of fringe quality codes on a baseline basis (using the single letter station codes), with totals at the bottom. This table can give you more information about how your station is performing. See below for an explanation of the codes:***

Legend:

| | | |
|---|---|---|
| QC | = 0 | Fringes not detected. |
| | = 1-9 | Fringes detected, no error condition. Higher number = better quality. |
| | = B | Interpolation error in fourfit. |
| | = D | No data in one or more frequency channels. |
| | = E | Maximum fringe amplitude at edge of SBD, MBD, or rate window. |
| | = F | "Fork" problem in processing. |
| | = G | Fringe amp in a channel is <.5 times mean amp (only if SNR>20). |
| | = H | Low Phase-cal amplitude in one or more channels. |
| | = N | No valid correlator data. |
| Tot | | Total number of scans in schedule. |
| Minus | | Scans in original schedule file for which correlation was not attempted, usually because of known station problems. |

***More explanation of each code would be interesting, but would make this paragraph very long …***

Processed in one pass

***If there are more stations participating in the experiment than the correlator has playback units on which to put them, the experiment has to be processed in more than one pass in order to correlate all the data. This is documented here.***

MEAN RATIOS = Observed SNR / Predicted SNR for exp no. 4368

...by baseline, over all sources:

| bl | X | n | S | n |
|---|---|---|---|---|
| BK | 0.52 | 127 | 1.09 | 128 |
| BI | 0.36 | 153 | 0.76 | 162 |
| BO | 0.00 | 0 | 0.00 | 0 |
| BV | 0.59 | 176 | 1.16 | 177 |
| BZ | 0.48 | 144 | 1.02 | 146 |
| KI | 0.58 | 56 | 1.17 | 60 |
| KO | 1.13 | 48 | 1.25 | 48 |
| KV | 1.01 | 82 | 1.69 | 82 |
| KZ | 0.85 | 46 | 1.44 | 46 |
| IO | 0.66 | 9 | 0.99 | 9 |
| IV | 0.71 | 265 | 1.00 | 265 |
| IZ | 0.56 | 163 | 0.84 | 159 |
| OV | 1.08 | 11 | 1.48 | 11 |
| OZ | 0.83 | 4 | 1.23 | 4 |
| VZ | 0.96 | 159 | 1.31 | 160 |

***This is a table of the actually measured vs. predicted (by sked) signal to noise ratios (snr) over the course of the whole experiment, by baseline. This table shows whether your station is as sensitive as it is predicted to be by sked. Ratios below 1 indicate the station is not as sensitive as expected, or better than expected if above 1.***

***bl = baseline***
***X = X band snr ratio***
***n = number of scans included in calculation***
***S = S band snr ratio***
***n = number of scans included in calculation***

CF File

```
***
* 4fit control file for R4368
*
  max_parity 0.02
  sb_win -1.0 1.0 mb_win -1.0 1.0 dr_win -3.0e-5 3.0e-5
  start -3 stop -1
*
  if f_group X
    ref_freq 8212.99
    pc_freqs ghijklmn  0010  0010  0010  0010  0010  0010  0010  0010
*
  if f_group S
    dr_win -3.0e-5 3.0e-5
    ref_freq 2227.99
    pc_freqs abcdef  0010  0010  0010  0010  0010  0010
*
*
  if f_group S and station I
    dr_win -3.0e-5 3.0e-5
*
  if station O or station Z or station K
  lsb_offset 280.
*
  if station F
  lsb_offset  30.
*
  if station C
  lsb_offset  20.
*
  if station Y
  lsb_offset 230.
*
  if station B
  lsb_offset 100.
*
*
  if f_group S and baseline IZ and scan 064-183000 to 065-030000
   mb_win   0.04700  0.05700
*
  if f_group S and baseline IZ and scan 065-030100 to 065-100000
   mb_win   0.05300  0.06200
*
  if f_group S and baseline IZ and scan 065-100100 to 065-183000
```

```
   mb_win   0.05500  0.06600
***
  if station K and f_group X
    pc_phases ghijklmn  144  52  92  151  83  110  93  138
    pc_mode manual
*
  if station K and f_group S
    pc_phases abcdef   0  60  74  20  40  45
    pc_mode manual
**
  if station B and f_group X
    pc_mode ap_by_ap
*
  if station B and f_group S
    pc_mode ap_by_ap
*
  if station B and f_group X
    pc_phases ghijklmn     22  -9  -28  -20  -9  24  0  2
*
  if station B and f_group S
    pc_phases abcdef       7  17  -32  7  0  2
*
*
  if station Z and f_group X
    freqs g h i j k   m n
*
  if station Z and f_group S
    freqs a b   d e f
*
*
  if station I and f_group S
    freqs a b c   e f
*
*
**
```

***This is the fourfit control file used at the correlator, which is the place where many parameters are set and adjusted (one example, this is where any station specific channel deletions would be made) before fringe fitting the correlated data. This file is mostly of interest to those who use fourfit (like, people who might re-fringe fit the data later in the analysis process), so it will not be explained here. Most likely all of what is documented here is explained in the section where specific station issues are summarized, if there is an issue of concern to the station. If you are curious to know more about this file, please ask a fourfit guru.***

Dave

***This is the person (or persons) who wrote the report above. It is probably best to direct any questions related to the report to the person listed here.***

***As of May 2009, the correlator analysts are as follows:***

***Bonn:***

***Alessandra: Alessandra Bertarini  abertari@mpifr-bonn.mpg.de***
***Arno:       Arno Mueskins         amueskin@mpifr-bonn.mpg.de***

***Haystack:***

| | | |
|---|---|---|
| ***Mike:*** | ***Mike Titus*** | ***mike@haystack.mit.edu*** |
| ***Brian:*** | ***Brian Corey*** | ***bec@haystack.mit.edu*** |

***Washington:***

| | | |
|---|---|---|
| ***Dave:*** | ***David Hall*** | ***dmh@usno.navy.mil*** |
| ***Kerry:*** | ***Kerry Kingham*** | ***kingham.kerry@usno.navy.mil*** |

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# What the Correlators Can Do For You!
## Diagnosis of station performance (and more) using Fourfit & Aedit

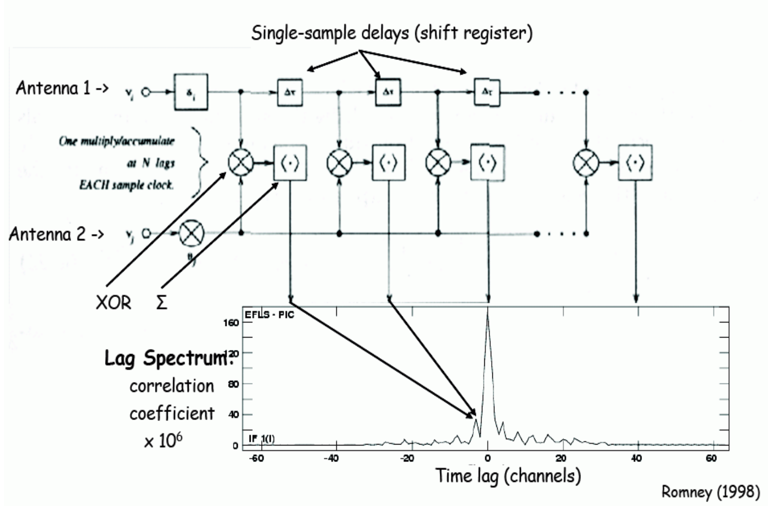
Alessandra Bertarini – Bonn

Mike Titus – Haystack

Kerry Kingham – Washington

Dave Hall – Washington

# A Lag Correlator




The correlator applies the *correlator model* to align the bit streams before the correlation and then it calculates the cross-corr. coeff. (phase & amp = fringe visibility) for every lag and for every accumulation period (AP).



Slide 1 – lag correlator:

One way to measure the delay ( = geodetic observable) is to cross-correlate the sky signal and see at what lag (= time offset) the maximum cross-correlation coefficient is located.

The output of a lag (Mark IV) correlator is a temporal series of correlator coefficients. The correlator coefficients are expressed as a series of sine and cosine because we want to reconstruct the phase and the amplitude (known as visibilities) of the sky signal.

The correlator applies a *correlator model* to the data: additional delay is inserted into the data streams, effectively moving the stations to be in the same wavefront.

The process of *fringe fitting* the data reveals where the maximum of the cross-correlator coefficient is located.

For more info on the Mark IV correlator:

"Mark 4 VLBI correlator: Architecture and algorithms", A.R. Whitney et al. (2004), Radio Sci., 39, RS1007

## Fringe Search

In reality fourfit solves also for the MBD, producing a 4D (!) plot

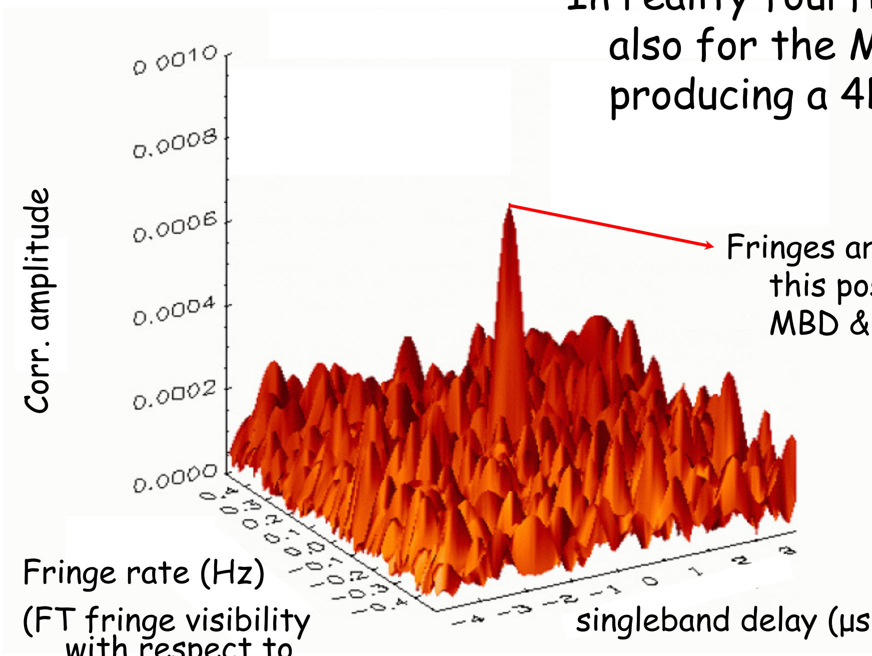



Image courtesy of K. Kingham



Slide 2 – Fringe search:

The program *fourfit* solves simultaneously for singleband delay (SBD), delay rate (DR) and multiband delay (MBD).

For every coordinate triplet (SBD, DR, MBD) there is a corresponding value of the correlator coefficient amplitude. Where this value is maximum, we have *fringes* (it is a sort of 3D image).

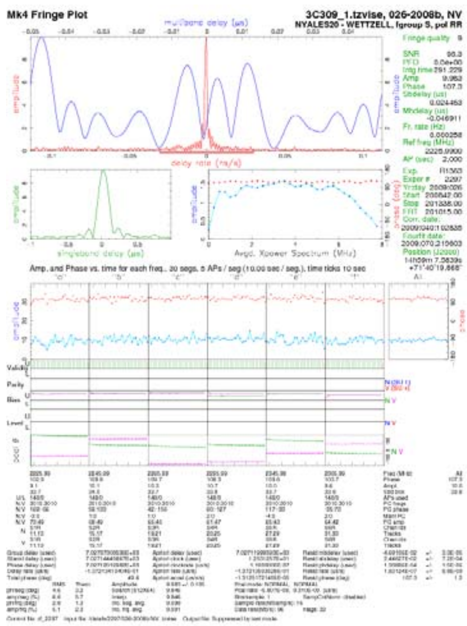
The fringes should be located at the (0,0,0) position because the correlator applied the *correlator model* . This, though, is not generally the case because the correlator model leaves some *residual* errors, which are corrected by fringe fitting the data.

For more info on the fringe fit algorithm:

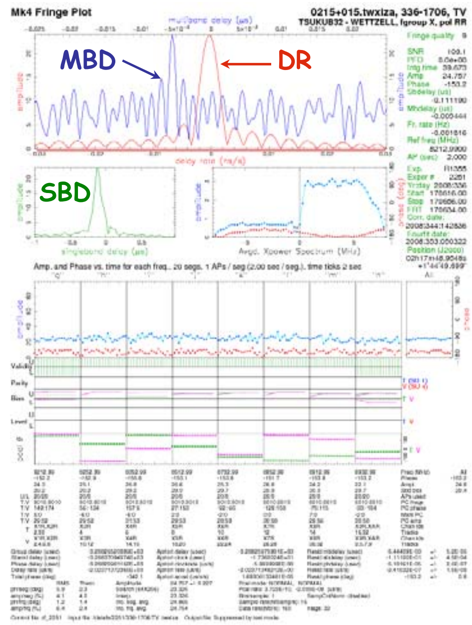
"Precision Geodesy Using the Mark-III Very-Long-Baseline Interferometre System", T. A. Clark et al., 1985, IEEE Transactions on Geoscience and Remote sensing, vol. GE-23, no. 4.

# Fourfit - Overview

S-Band:




X-Band:






Slide 3 – Fourfit - Overview

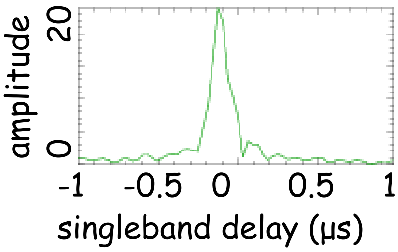
The logic flow is the following: fourfit will take the correlator output (lag spectrum) Fourier transform it in the frequency domain (power spectrum), averages over frequency to give a single amplitude and phase value for every accumulation period (AP, no. of seconds of accumulation after which the correlator writes a correlator coefficient) and in parallel it plots the amplitude and phase vs time and Fourier transform this data into phase rate (fringe rate); The data are averaged over the whole Aps to give a single phase and amplitude for every BBC channels that are used to calculate the MBD.

In the slide there are examples of the graphical outputs of fourfit. Instead of having one 4D plot(!!) we see slices through it: the SBD vs correlator amplitude, the DR vs correlator amplitude and the MBD vs correlator amplitude. In the plots we see other features (described above) that will be explained in the following slides.

One plot represents one scan one baseline one polarization and one band.

For a typical R1 session we have ~8000 plots.

# Singleband Delay




- Lag spectrum: output of the correlator integrated over the scan duration.
- Lag spectrum shown is lag spectra of all BBC stacked.
- 8 MHz/BBC => 16 Ms/s => sample period = 1 / 16 Ms/s = 0.0625 μs => 0.0625 μs * 32 lags = 2 μs SBD window width.
- Indicates residual correlator model errors, part of which can be absorbed in the clock offset.

4

Slide 4 – Singleband Delay

The singleband delay is the output of the correlator integrated over the scan duration.

The correlator amplitude is plotted against lag expressed in microseconds.

A correlator amplitude of '20', as shown in the slide, is in reality an amplitude of $20 \times 10^{-4}$, which means that after correlating 10000 bits from each station there is an excess of 20 bits with the same value at the two stations (e.g. both zeroes or both ones) over that expected by chance.

In absence of source position or station position errors, the correlator model shifts the fringes within 32 lags (which means 2 μs for a 8 MHz/BBC bandwidth).

The peak of the SBD should be centered at 0 μs. If there are residual errors, we can adjust them by changing the clock offset (gps-fmout) in the files controlling the correlation.

Normally we run a 'trial correlation' before starting the stream correlation, in which we check that the SBD and DR are centered (within 0.1 μs) at zero lag. If not, we change the clock offset and rate and after that start the correlation.

## Singleband Delay Errors

Causes:

- Often: resetting of the formatter.
- Sometimes: gps-fmout values not reported either in the FS logs or in the ivs-ops messages.
- Rare: bad gps-fmout values reported in the logs.

Cures?

- Curable: gps –fmout not reported, bad counter reading (we use an old value to start with).
- Painful: resetting of the formatter.
- Not curable: offsets larger than 8 s.

5

Slide 5– Singleband Delay Errors

Sometimes we see the peak located at the edge of the SBD window, or worse, we do not see it at all.

The cause is often found to be formatter resetting.

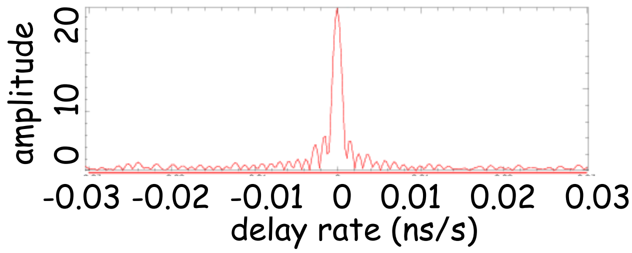
Please do not reset the formatter during an observation unless it is really necessary (more info in E. Himwich's presentation at the TOW), but report it to the correlators, even if it is logged in the FS log file.

As described in the previous slides, our search windows are preatty small. We can enlarge them up to 1024 lags (i.e. 64 µs), but you can imagine what it means to find a clock value that is off by 1 s stepping by 64 µs at the time! It means to repeat the search for 15625 times… not really practical ☺.

Keep also in mind that the correlator cannot cope with an offset nominally larger than 5 s (though, a station with an offset of 8 s was correlated at Bonn).

Clock offsets are mostly recoverable at the correlator BUT they damage the geodetic measurables.

# Fringe Rate (FR) & Delay Rate




- FR is the Fourier transform of fringe visibility with respect to time.
- DR = FR / Observing frequency.
- DR window = [1 /(2 * AP)] / Obs. Freq.
- DR tells how fast the fringes move away from the phase centre due to correlator model error. It can be absorbed in the clock rate.



Slide 6 – Fringe Rate (FR) & Delay Rate

The FR tells us how fast the fringes are moving away from the phase centre (i.e. 0 lag) due to correlator model errors.

It is the Fourier transform of the fringe visibility (cross-correlation coefficients averaged in frequency) with respect to time.

The FR is frequency independent. What fourfit is plotting is the delay rate (DR) which is the FR divided by the observing frequency.

The DR can be absorbed in the clock rate: the gps-fmout value is drifting because the masers are drifting (normally between $0.1 \times 10^{-12}$ s/s to $10 \times 10^{-12}$ s/s). Any other drift is added to the station clock drifts in the correlator control file.

## Fringe Rate - Delay Rate Errors

Causes:

- Often: wrongly calculated clock drifts.
- Seldom: wrong Earth orientation parameters (EOP).
- Rare: wrong sky frequency (not xxxx.99 MHz).
- Very rare: station position errors.
- Almost never seen: maser problem.

Cures?

- Curable: wrongly calculated drifts, wrong EOP, station positions.
- Not curable but still valid: wrong sky frequency.
- Not curable: wrong frequency offset bigger than 500 kHz.



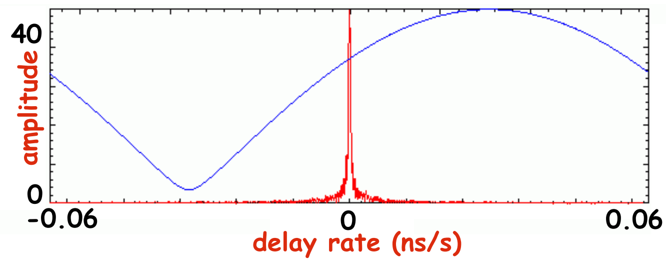
Slide 7 – Fringe Rate – Delay Rate Errors

The errors in the DR are mostly due to errors in calculating the station clock drifts or Earth orientation parameters (= parameters describing the motion of the Earth poles and the universal time), but these are our mistakes at the correlator!

Sometimes it happens that the tuning of the frequency is wrong: instead of observing at xxxx.99 MHz, the stations observe at xxxx.98 Mhz.

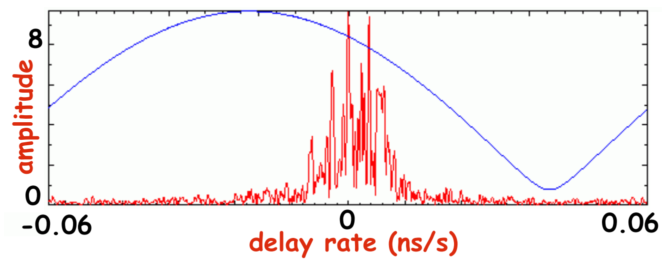
If the error is caused by wrong EOP or wrong clock drift, we can correct the values in the correlator files. If we have an offset in frequency (if the offset is not larger than 500 kHz) we follow the fringes throughout the observation (the clock drift is accordingly corrected), but we cannot cure the tuning. The price to pay for offset in frequency is a loss in SNR and the phase cal is not usable.

## Fringe Rate - Delay Rate Errors: Maser




hydrogen maser – hydrogen maser.

Stability: $3x10^{-15}$ over 1000 s.




hydrogen maser – rubidium.

Stability: $1x10^{-12}$ over 1000 s.

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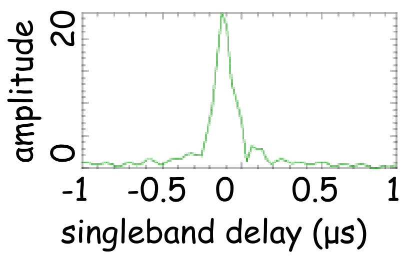
Slide 8 – Fringe Rate – Delay Rate Errors: Maser

We had only once that a station used a rubidium instead of a maser, but the change in the DR precision due to maser vs rubidium is pretty dramatic!

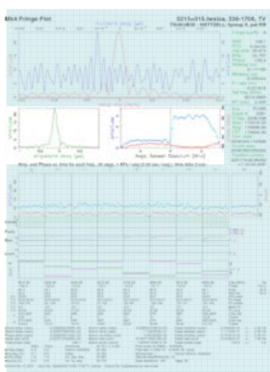
The rubidium is less stable ($3x10^{-12}$ s over 1000 s). The maser is a factor 1000 more stable than the rubidium clock.

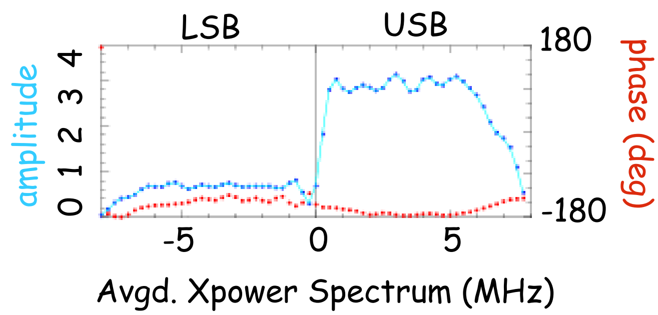
## Transform from Lag to Frequency




Fourier Transform

$$V(u,v,\tau) = \int V(u,v,\nu)e^{2\pi i\tau\nu}d\nu$$






The data are already fringe fitted.



Slide 9 – Transform from Lag to Frequency

To correct the residual slope in phase vs frequency, which would cause error in the delay (a phase slope vs frequency = delay) the data are Fourier transformed from lag spectrum to frequency for applying the correction.

Whilst in the time domain fourfit plots only the amplitude of the correlator coefficient, in the frequency domain it plots both phase and amplitude.

The phase vs frequency needs to be flat: fourfit removes any residual slopes remaining in the data due to imperfection of the correlator model.

The amplitude is a measure of the correlated filter response at the two stations.

The bottom right plot shows the spectrum integrated over the scan length.

## Effects Visible from the Power Spectrum

The correlator can be used as a very expensive spectrum analyzer: the power spectrum is a measure of the correlated filter responses at the two stations.

We see:

- Pcal tones (should be there!)
- RFI (should not be there!)
- USB/LSB offsets (to be removed when stations using two different DAR are cross-correlated. E.g. Mk4/VLBA).



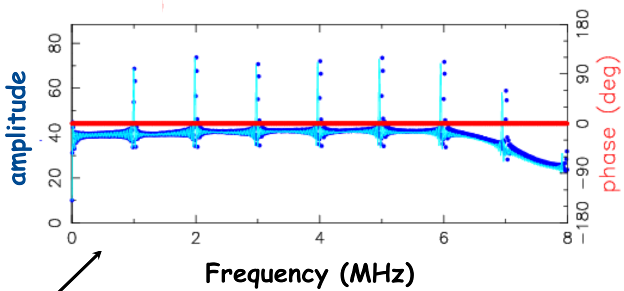
Slide 10 – Effects Visible from the Power Spectrum

We use the correlator as spectrum analyzer:

If we correlate using a big enough no. of lags (e.g. 512 lags => 32 µs) we have a big enough no. of spectral channels (in this case: 512) to see the pcal tones (a small no. of lags will wash out the pcal tones due to noise in the wider frequency channels) and, in some unfortunate cases, to see also radio frequency intereference (RFI).

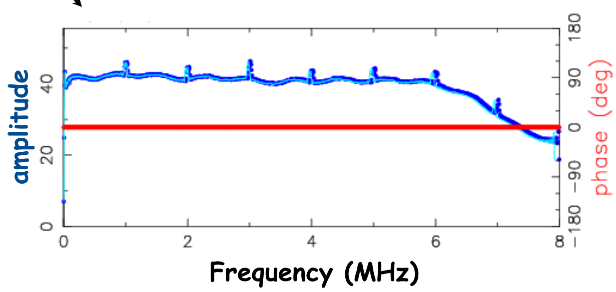
We can use 512 lags in the trial correlation, whereas we use 32 lags during the stream correlation. By using 512 lags, we can correlate only one baseline per time (for a standard geodetic setup using 16 BBCs).

# Effects Visible from Power Spectrum: Pcal




The amplitude of the pcal tones is visible (enough power) at every MHz.

Autocorrelation plots (512 lags)




The amplitude of the pcal tones is too low (not enough power). Tones not usable for calibration.

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Slide 11 – Effect Visible from the Power Spectrum: Pcal

The pcal tones are visible in the autcorrelation plots (correlation of the station against itself. The data are 100 % correlated, because also the noise is the same).

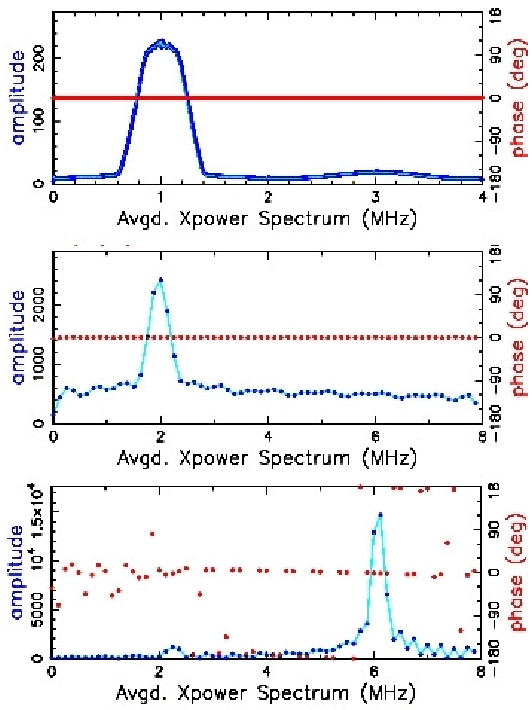
In the plot above is shown a good case: the tones are at every MHz and their amplitude is high enough to be detected, but at the same time, not too high to corrupt the signal.

In the plot below is shown a case in which the pcal tones will not be usable although present. The software will recognize that the tones are too weak in power and flag the scan as *"H-code"* (we can recover the station by using manual pcal).

Sometimes weak pcal tones might indicate the presence of RFI. To discover that, we need to look at the spectrum of every single BBC.

Please, if at the station you see an RFI, report it. It helps us to diagnose why the pcal levels are low (for example).

## Effects Visible from Power Spectrum: RFI




Internal RFI, better known as *spurious signals*.

Spurious signal are narrow-band signals coherent with the true pcal and have the same frequency.

Corrupt the visibility phases.

Causes & Cures: see B. Corey memo : "Spurious Phase Calibration Signals: How To Find Them and How To Cure Them".

(class offered at the TOW. Memo in the folder)



Slide 12 – Effects Visible from the Power Spectrum: RFI

We can divide the RFI in three subgroups: internal (better known as spurious signals), external and very external.

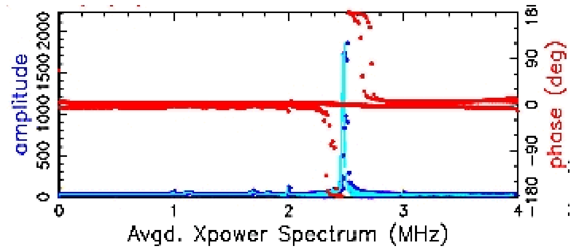
In this slide, there are three examples of spurious signals. In all the cases they corrupt the visibilities and make them unusable.

The RFI has the same frequency as the pcal (in the case of the plots the RFI is respectively at 1 MHz, 2 MHz and 6 MHz) and will make the pcal tone that it hits unusable.

Fortunately the Mark 4 correlator can extract two pcal tones, therefore in most of the cases the data are recoverable by using the other tone to calibrate the data.

The spurious signals are treated in detail in the TOW class of B. Corey and are written in the TOW notes.

## Effects Visible from Power Spectrum: RFI




External RFI (microwave oven in the observatory kitchen??).

They are time variable and spatially localized.

If they enter in the radio band observed, they affect the visibility and the pcal amplitude (amplifier saturation).

Cure: the correlator staff flags the affected channels.

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Slide 13 – Effects Visible from the Power Spectrum: RFI

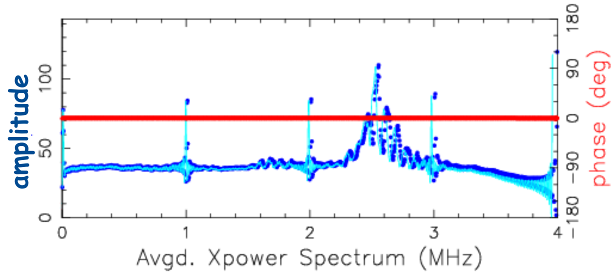
In this slide there is an example of external RFI.

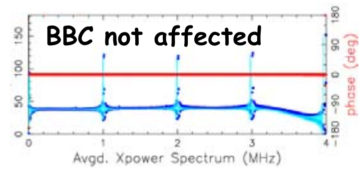
This kind of RFI is spatially localized (direction dependent) and time variable, which means that we will not necessarily see them throughout the whole observation, but only when the telescope is pointing at a precise location and maybe at precise times (e.g. pointing in the direction of the observatory kitchen, when someone is heating the coffee ☺).

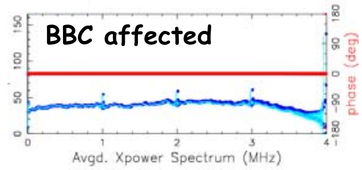
They are cause of concern only if they enter in the radio band: as shown in the picture, they dominate the noise power in the band (they can also saturate the amplifier) and badly affect the visibility and pcal amplitude. In the plot there is a spike between 2 MHz and 3 MHz and has an amplitude of ~ 1500 units, much larger than the rest of the band.

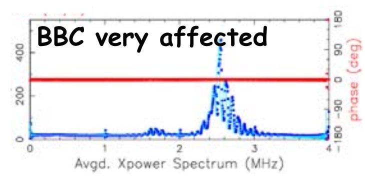
Fourfit has no RFI excision: if RFI is present, we have to flag the affected channel.

## Effects Visible from Power Spectrum: RFI




Very external RFI (mostly satellites at S-Band).

The signals are broadband => affect more than one BBC/VC channel.

Corrupt the visibility and pcal amplitude.

Cure: flag the affected channels.



Slide 14 – Effect Visible from the Power Spectrum: RFI

In this slide there is an example of a very external RFI (normally due to satellites transmitting at S-band).

The RFI signals are broadband therefore they affect more than one BBC.

On the right side there are plotted three single BBC channels while the plot on the left is the sum of the three channels.

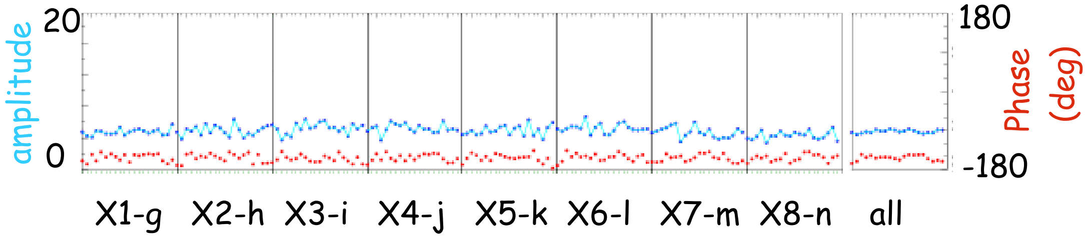
In the plot at the top right there is no sign of RFI: the pcals are visible and the visibility amplitude vs frequency is flat.

The middle plot is a channel that is affected by the RFI: the pcal tones are washed out by the RFI.

The bottom plot is a channel where the RFI is stronger: it is wideband (affects 1 MHz out of the 4 MHz of the BBC band) and both pcal and visibility amplitude are affected.

The two channels (middle and bottom right plots) are unusable for data reduction and are flagged at the correlators.

## Amplitude & Phase vs Time




- Every dot represents the phase (red) and amplitude (blue) of the visibility for every segment (~ AP).
- Data are already fringe fitted and pcal has been applied.
- Every BBC/VC channel is represented.



Slide 15 – Amplitude & Phase vs Time

Another useful way to look at the data is by plotting the phases and amplitudes of the frequency spectrum after averaging over frequency from every accumulation period (AP = no. of seconds of accumulation after which the correlator writes a correlation coefficient).

The data are flat in phase: the data have already been fringe fitted: no residual phase slope vs time remains (i.e. the DR has been fitted) and the pcal has already been applied, removing the inter-BBC phase offsets.

The amplitude is also flat (Tsys is fairly constant across the radio band observed and the source is emitting about the same power within the observed band), but it is still in arbitrary units: fourfit does not perform amplitude calibration.

In this way we can see better BBC by BBC whether there are problems. RFI, for example, is visible also in these plots, it will corrupt both phase and amplitude in the BBC in which they are located.

## Amplitude & Phase vs Time: Visible Effects

- RFI.
- BBC/VC specific problem (unlock, wrong sky freq…).
- LO instabilities (loss of coherence).
- IF problems (e.g. mixer setup "in" or "out").
- Low/absent pcal phase signal.
- Pointing (if one scan is compared with an old scan on the same source observed at the same sidereal time = same elevation).
- Source structure (bad news, geodesy likes pointlike sources).
- Atmosphere (ionosphere & troposphere).

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Slide 16 – Amplitude & Phase vs Time: Visible Effects

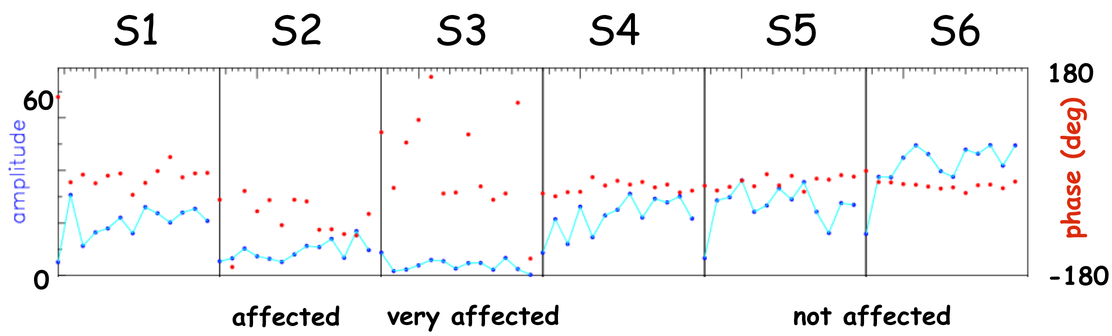
The amplitude and phases vs time are sensitive to every problem present in the BBC channels. If RFI is present, the amplitude of the affected channels will be visibly lower than the amplitude of the other channels. The same will be true for an unlocked BBC or wrong sky frequency (see the next slides for graphical examples).

There are also other effects that can be diagnosed with the help of these plots, like LO instability, low/absent pcal signal, pointing, atmosphere, IF problems…

These plots might show a problem, but only by processing all the information available from the power spectrum and other things that will be mentioned later on, we can nail down what the problem is (sometimes!).

In this notes only the station-related issue will be presented.

## Amplitude & Phase vs Time: RFI




Broadband RFI in S-band.

The amplitude is low (almost zero in S3) and the phase is noisy.

Channels S2 and S3 need flagging.



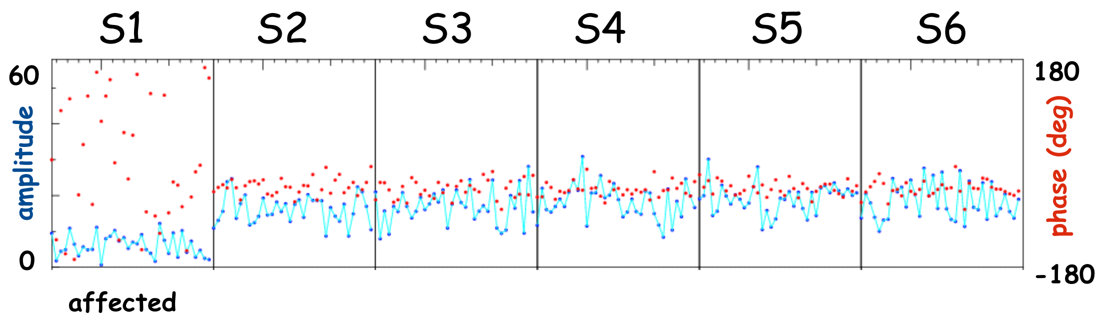
Slide 17 – Amplitude & Phase vs Time: RFI

This plot shows the effects of a very external RFI (satellites transmitting TV for mobile phones over Italy).

The channels called S1 , S4, S5 and S6 are not affected. The channel S2 is affected: the amplitude (blue line) is lower than the amplitude in the good channels and the phase (red line) is noisier. The channel S3 is completely corrupted by the RFI; the amplitude is at almost 0 units and the phase is spread over 360°.

The channels S2 and S3 were flagged during the data analysis.

## Amplitude & Phase vs Time: Unlocked VC/BBC




The phase of S1 is spread over 360°

The amplitude is low.

S1 needs to be flagged

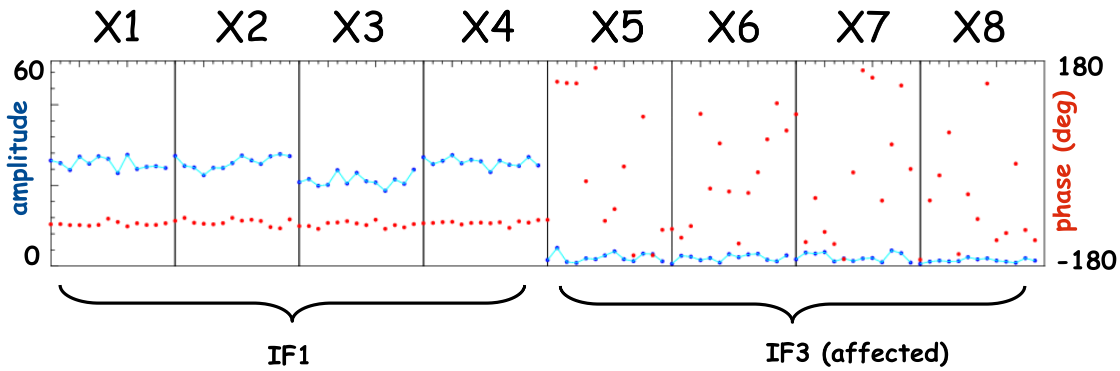
Wrong sky frequency would give an analogous result.



Slide 18 – Amplitude & Phase vs Time: Unlocked VC/BBC

This plot shows the effects of an unlocked BBC. Unlocked BBCs are normally reported in the FS log files. In the example plotted on slide 18, the affected channel is S1. Also in this case, as for the RFI, the phase is spread over 360° and the amplitude is almost zero. Apart from the fact that this specific case was reported in the log, we could exclude RFI because the amplitude vs frequency did not show any RFI symptoms as described in the slides 13, 14 and 15.

## Amplitude & Phase vs Time: IF Problems




The IF3 distributor was set "in" although it should have been set to "out".

Last four channels need flagging.

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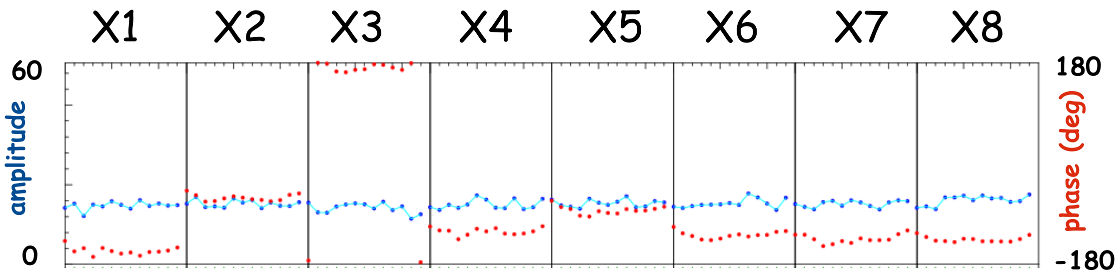
Slide 19 – Amplitude & Phase vs Time: IF Problems

These kinds of problems are very rare and can be discovered and corrected quite soon by the station personnel during the observations.

In this specific case the IF setup was left as for an R1 (wideband), while observing a EURO experiment. The last four channels: X5, X6. X7 and X8 (the one connected to the IF3) have no signal: the amplitude is zero and the phase is spread over 360°. This specific case was reported in the ivs-ops messages and in the FS log file.

The last four channels need to be flagged.

## Amplitude & Phase vs Time: Pcal Problems




Every BBC/VC has its own electronics which add a constant phase to the signal.

The phase within one BBC/VC is flat, but the phases across the RF band are not.

Manual pcal is required.



Slide 20 – Amplitude & Phase vs Time: Pcal Problems

Fourfit will correct the phase slope vs time, but will leave any offsets due to the BBC electronics, which will add a constant phase to the visibility and will be specific for every BBC.

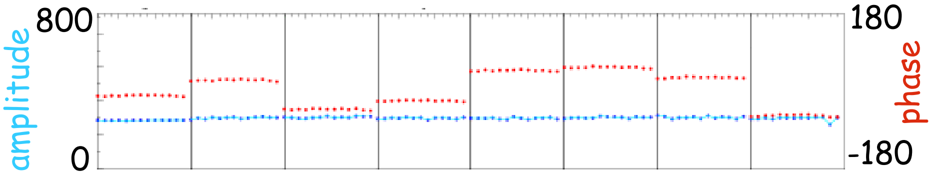
The task of the pcal phase is to remove this offset: the pcal passes through the same electronics as the signal, but the pcal is of known character and therefore can easily be used to eliminate any inter-BBC offsets.

The figure in the slide shows a fringe fit plot where one of the two stations had no pcal injected. The phase (red line) within every BBC is flat (e.g. in X1 is at about -180°, in X2 is at about -30°…) but it is not flat across the entire radio band.

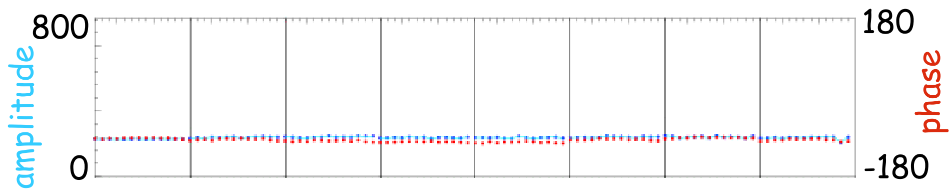
In this case we need to apply manual pcal: we choose one scan (typically 30 s of data) with relatively stable phase and (therefore) high SNR and use that only scan to calibrate the whole 24 hours. If the station electronics are stable enough, that is OK. If the electronics were not stable, we would select a second scan a bit later and re-apply the manual pcal. This causes jumps in the delay and corrupts the geodetic measurable.

## Amplitude & Phase vs Time: Pcal Phase

without pcal:




Phase cal phase flattens the phases across the band.



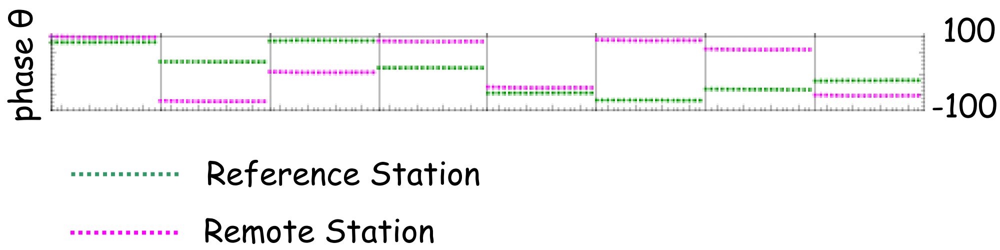



Slide 21 – Amplitude & Phase vs Time: Pcal Phase

As an example the slide 21 shows in the plot above, the data without pcal phase applied (no error condition in this plot, just demo): the phases are flat within every BBC, but not across the whole radio band.

The plot below is the same as above, but with the pcal phases applied to the data: now the phases are flat across the band, as is required for doing precision geodetic measurements.

## Pcal Phase Plot




Phase cal phases are plotted whilst only the value of the mean coherent pcal amplitude (PC amp.) is written for each channel.



Slide 22 – Pcal Phase Plot

The fourfit program also plots the pcal phases vs time for the two station in the baseline and for every channel. Color coding will distinguish the two antennas (green and pink).

They give an idea of how stable is the system: the plot in the slide shows very stable phases.

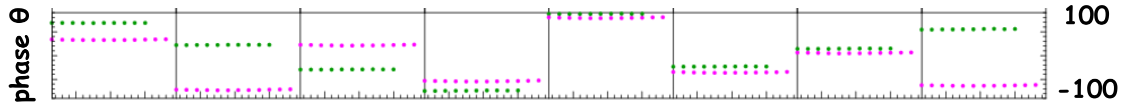
The phases for both the antenna drawn in green and pink are flat across the BBC. They can, and normally have, a different level among the different BBCs due to the electronics of the BBCs: this is the effect that pcal phases correct.

The pcal amplitudes are not plotted by fourfit. In the plot is reported only the value of the mean coherent amplitude for each BBC.

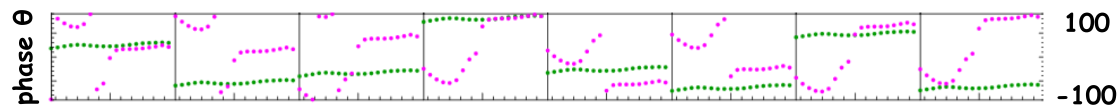
To plot the pcal amplitude values we have to extract them with aedit (see later on in the talk).

## Pcal Phase Plot

Stable pcal phases at both antennas:




Unstable pcal phases at antenna "pink" and stable at antenna "green":




Pcal phases are sensitive to the delays caused by the electronics from receiver (pcal injection point) to the recorder.

Want more? Follow Brian's pcal lesson ☺



Slide 23 – Pcal Phase Plot

In this slide there are two examples of pcal plots: the top one shows stable pcal phases at both antennas, while the bottom one shows unstable pcal phases for the antenna whose pcal phase is drawn in pink.

The pcal phases should be straight lines within one BBC and have an inter-BBC offset. In the plot below, the pcal phases of the pink antenna are not flat and this might indicate a problem in the system.

The pcal phases of the pink antenna might still be usable, if they follow an effect that is also present in the visibility phases. In this case, they will correct for the effect and remove it from the data.

Pcal phases are sensitive to the delay caused by the electronics from the pcal injection point to the recorder.

## Multiband Delay

- Geodesy wants the delay to measure UTC, continental drift…
- To improve the delay resolution we use bandwidth synthesis: observations sample small part of a wider band (e.g. 720 MHz) and the delay resolution function is calculated almost as if the whole band was observed. **(Rogers, 1970 "VLBI with Large Effective Bandwidth", Radio Science, Vol 5, p. 1239 -1247).**
- Every BBC/VC is tuned to a different frequency and by cross-correlating pairwise all BBC/VCs at the two stations we measure the visibility amplitude and phase at each frequency.
- Fourfit Fourier transforms the visibilities from frequency domain to time domain -> MBD.



Slide 24 – Multband Delay

The geodesists use the delay measurement to calculate station poistions, EOP, UT, continental drifts….

The Bandwidth Synthesis Technique was developed in the '70 by A. Rogers to increase the precision of the delay determination for a given recording rate.

The basic idea is to increase the obsereved bandwidth, by sampling small part of it, and from that synthesize the whole band.

That's why in X-band we span 720 MHz, sampling the band using 8 BBCs.

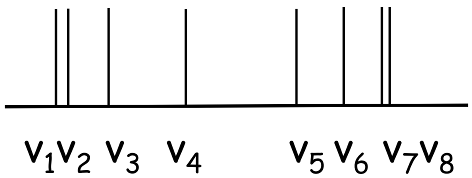
Every BBC is tuned to achieve non-redundant frequency spacings. By cross-correlating pairwise all BBCs at the two stations we measure the mean visibility amplitude and phase at each frequency.

Fourfit then Fourier transforms the data from frequency domain to time domain to recontruct the MBD .

For more info on Bandwidth Synthesys:

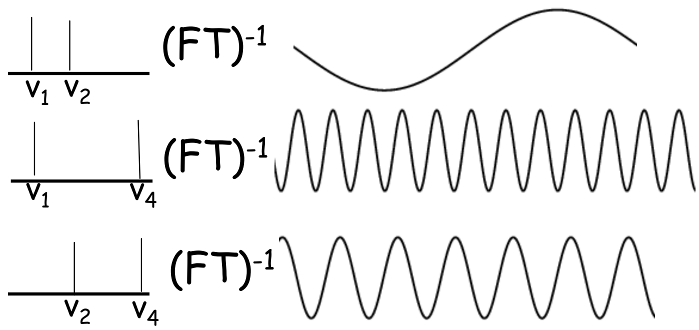
"Very Long Baseline Interferometry with Large Effective Bandwidth", A.E.E. Rogers (1970), Radio Science, Vol 5, p. 1239 – 1247.

## Multiband Delay




One frequency per BBC yields one mean phase per BBC.

Eight BBC/VC yield 28 non-redundant frequency spacings.




The Fourier transform of every phase difference between frequency pairs produces a sinusoid with a specific period



Slide 25 – Multband Delay

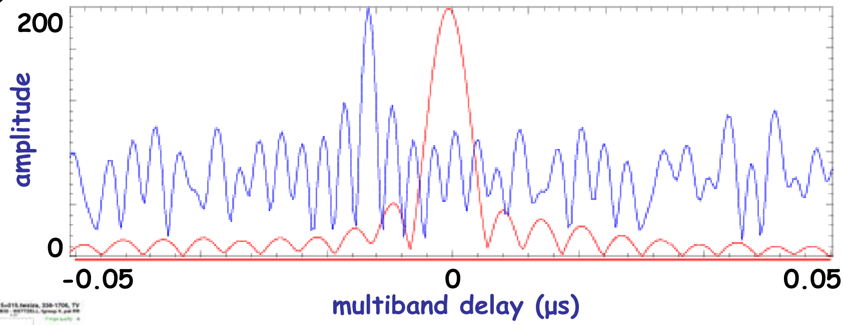
In this slide are represented the eight BBCs that geodesy uses in X-band. The spacing between BBCs is a scaled version of the real case (wideband setup). For every BBC the mean frequency of the BBC band is indicated as a delta function. Associated with this mean frequency there is a mean amplitude and mean phase calculated by cross-correlating the signal from this BBC against the signal from the matching BBC at the other station.

For every pair of BBC a Fourier transform is performed and depending on the spacing between the BBC mean frequencies we have a sinusoid with different frequency (the larger the spacing between frequencies, the higher the sinusoid frequency).

The sinusoids are all added together to form the MBD function.

# Multiband Delay

The sum of all the sinusoids produces the MBD function (in blue):




From here you can understand how important it is to have the whole 14 BBC/VC observing: loss of channels => loss of resolution



Slide 26 – Multband Delay

The sum of all the sinusoids gives the MBD function, and is the blue curve in the fourfit plot (top). Being a sum of sinusoids the function repeats itself when the sinusoids align (ambiguities).

The absence of one or more BBC will degrade the MBD, the main peak will be not recognizable and the ambiguities become closer to the main peak and lie inside the MDB window.

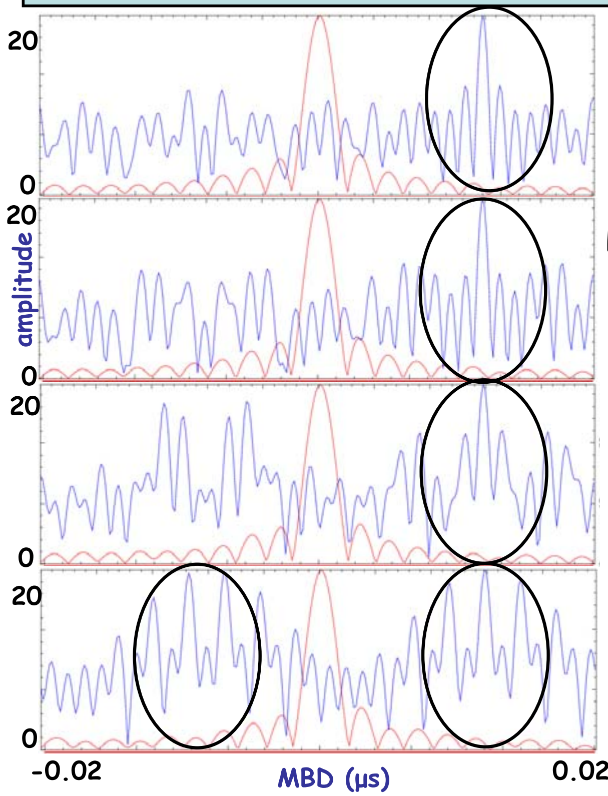
Fourfit can, in this worst case, latch to the wrong peak and the geodetic analysis is completely falsified.

The effect is even worse if two station participating in the observation lose different BBCs.

Please if you know you have a BBC that is not working, contact the network coordinator and let him/her suggest to you which channel to drop first. Note that the choice of the channels is dependent on which frequency setup is used for the observation. The frequency spacings vary from setup to setup and so the does the MBD function.

In the next slide there are four MBD plots taken from the same scan, same band (X-band), but gradually removing BBCs from it.

## Multiband Delay: Loss of Channels




All BBCs: the MBD peak is clearly distinguishable from the side lobes.

BBC06 removed: MBD very similar as above.

BBC04, BBC06 and BBC08 removed: the sidelobes grow, ambiguities still out of the window.

BBC03, BBC05, BBC07 and BBC08 removed: MBD peak hardly seen.



Slide 27 – Multiband Delay: Loss of Channels

In the top MBD plot, all the eight BBCs are present: the MBD peak is clearly distinguishable (the peak in the oval) from the side lobes, which have almost half of the peak's amplitude. The ambiguities are not visible and well outside the window.

In the second plot, from above, BBC06 has been removed. Still seven BBCs are contributing. The MBD is similar to that with all the BBCs present. BBC06 is the first channel to be dropped in case of a broken BBC (at least for the R1 frequencies !!!!).

The third plot has three BBC (BBC04, BBC06 and BBC08) removed. The MBD is calculated using the remaining five BBCs. The sidelobes increased in amplitude, but the ambiguities are still out of the window.

The fourth plot has four BBCs removed: the real MBD peak is hardly distinguishable from the sidelobes, and the ambiguities are within the window (second oval on the left of the plot): fourfit has to decide to latch to one of the two peaks and has no information on which one is the right one.

## Aedit

- Import the fringe fitted data
- Check the data quality by plotting
- Check pcal phase and amplitude
- Check SBD: clock jumps?
- Check closure quantities for the SBD, MBD and DR
- Export the visibility phases to calculate phase offsets (mostly to compensate the error between the feed and the pcal injection unit).
- Others… depending in the purpose of the analysis (polarization, source…)



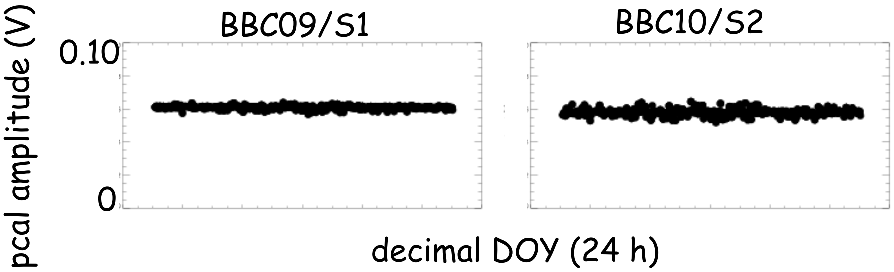
Slide 28 – Aedit

Aedit is another piece of software used at the correlator after fourfit has run. It gives us the possibility to check the data all at once (it has a nice graphical display) and offers the possibility of extracting parameters like the pcal phases and amplitudes and of plotting them over the whole observation instead of having them scan bys scan.

In aedit it is possible also to check the MBD, SBD and DR values for every baseline throughout the whole experiment. This will help us to detect eventual clock jumps that are small enough not to corrupt the fringe quality, but enough to corrupt the delay calculation (in the SBD plot). It can reveal station position errors (drift in the DR) and show the effects of errors in the clock model (MBD).

We can also check other things that I will not explain in this talk (but if you are interested, I will gladly tell you about them ☺).

## Phase Cal Data – Amplitude vs Time




- Every station pcal amplitude vs time is checked
- Amplitude variations should be proportional to the inverse square root of Tsys. If not, the variation within one BBC/VC or different BBC/VC might indicate a problem: RFI, unlocked BBC/VC…

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Slide 29 – Phase Cal Data – Amplitude vs Time

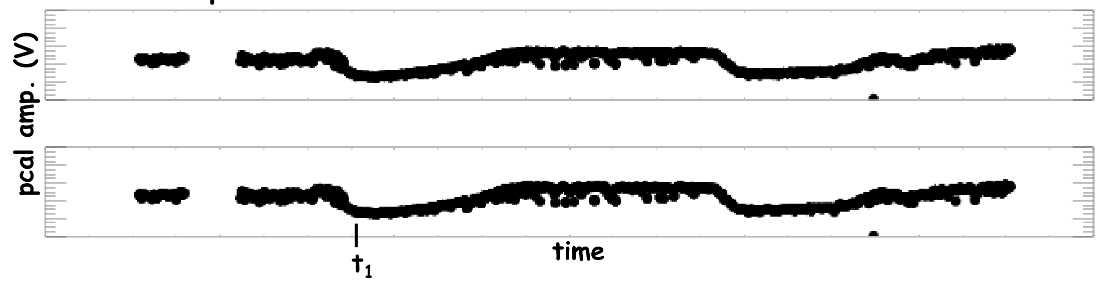
As already said, aedit permits us to extract the pcal data and plot them. In this slide there are two example of pcal amplitude (expressed as the ratio between the rms pcal voltage and the rms noise voltage) against time (expressed in decimal day of the year (DOY)), coming from the BBC09 (first S-band channel) and BBC10 (second S-band channel).

The pcal amplitude is checked for all the stations and every variation should be proportional to the inverse of the square root of the Tsys. If this is not the case, this can represent the symptom of a problem like RFI or unlocked BBCs…

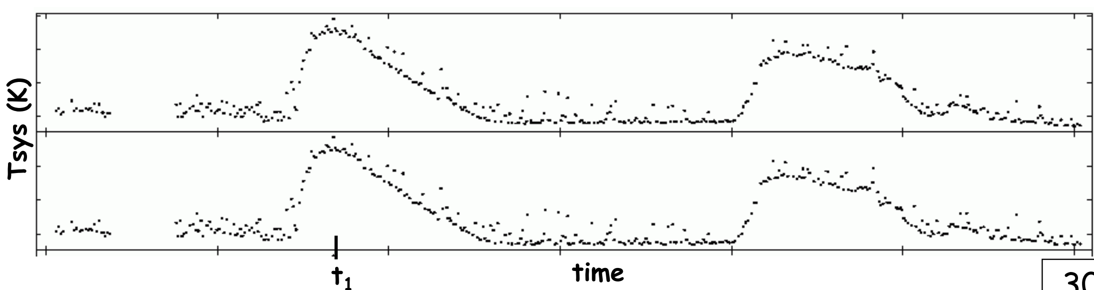
Note that the pcal amplitude units as extracted with aedit are $10^{-3}$ times those read from the fringe plot!

## Phase Cal Data – Variation $\alpha$ sqrt (1/Tsys)

Pcal amplitude vs time:




Tsys vs time:






Slide 30 – Phase Cal Data – Variation $\alpha$ sqrt(Tsys)

In the plots above are shown the pcal amplitude vs time of two BBCs: instead of being flat they have some drop in voltage.

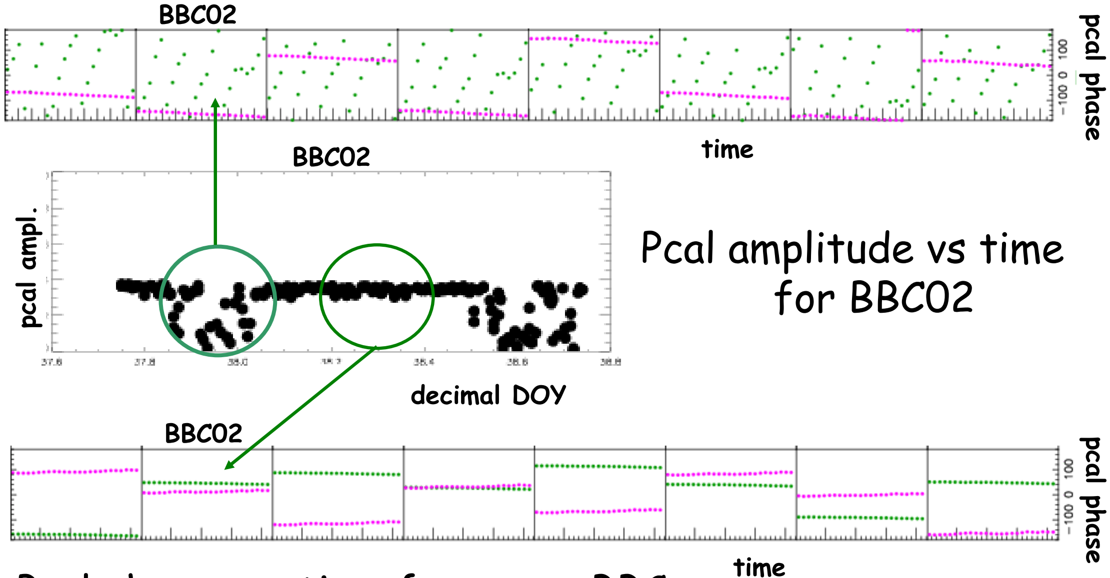
By looking (using plotlog… yes we use it too!) at the Tsys, we see that the variations in pcal correspond to the variations in Tsys and are inversely proportional to the square root of the Tsys.

The pcal in this case are perfectly fine and usable for calibration purposes.

Note that the abscissa in the two plots is a period of 24 hours, but the scaling factor is different because the two plots were created using two different plotting packages.

# Phase Cal Data – Unstable LO

Pcal phases vs time for every BBC




Pcal phases vs time for every BBC



Slide 31 – Phase Cal Data – Unstable LO

The middle image in this slide is the pcal amplitude vs time over 24 hours. In this case where there are present two periods of instability, recognizable because the pcal amplitude is scatterd instead of being a flat line.

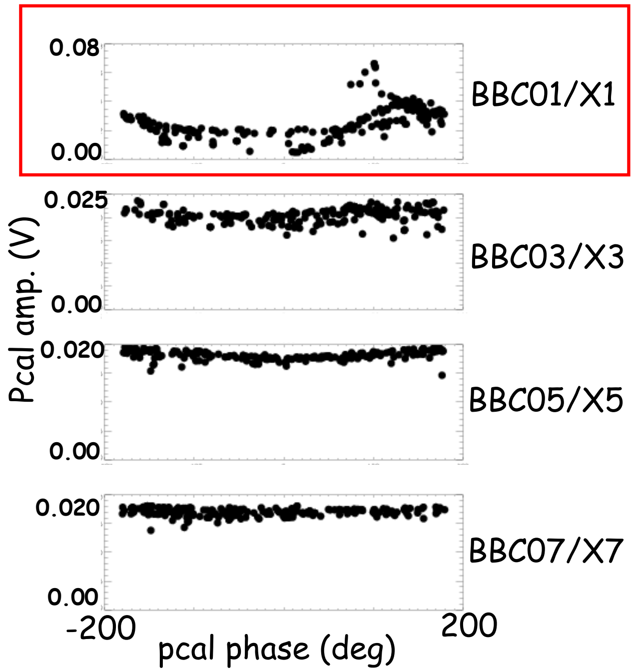
The top plot is a zoom in on one scan selected during the period of time in which the pcal amplitude was unstable and shows how the pcal phase was also unstable (green dots).

The bottom plot is a zoom in on one scan selected during the period of time in which the pcal amplitude was stable and, in fact, the pcal phase is also flat across the BBC as it should be.

The scattered pcal amplitude indicate a coherence loss.

The same behavior is present in the visibility phases and the visibility amplitudes are also smaller than they should be (for the same source at the same elevation).

## Phase Cal Data – Amplitude vs Phase




- From these plots we find the spurious signals (sinusoid).
- Spurious signals are narrowband signals coherent with the true pcal and have its same frequency.
- Corrupt the visibility phases.

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Slide 32 – Phase Cal Data – Amplitude vs Phase

We have already introduced the concept of spurious signal: it is a narrowband signal coherent with the true pcal and has its same frequency. The spurious signals are not always avoidable, but should be below -50 dBc.

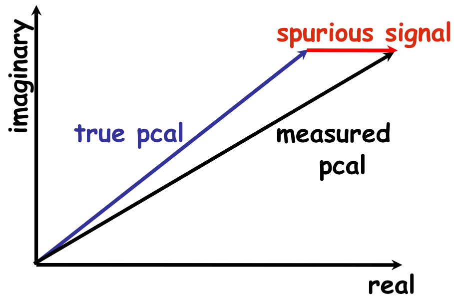
The spurious signals corrput the visibility phases, and therefore they corrupt the delays and the geodetic observable.

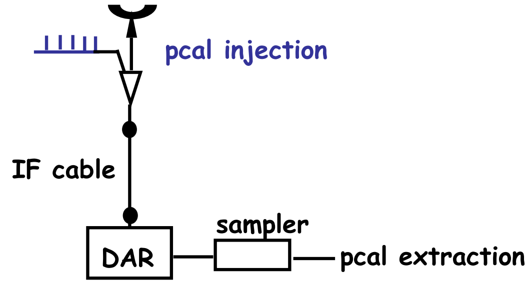
In this slide there are four plots of the pcal amplitude (V) vs the pcal phase (deg) for four BBCs of one station.

The signature of the spurious signals (often shortened – spur) is a sinusoid. The first plot shows an affected BBC, the others are 'clean'.

Why the signature of the spurious signals is a sinusoid will be explained in the following slides.

## Phase Cal Data – Spurious Signals & Pcal




The true pcal phases can rotate due effects happening between the telescope and the control room (cable length change, temperature change..)

If the spurious signal is coupling to the pcal signal in the DAR => its phase does not rotate since it does not go through the cables.

If there are reflections (due to mismatch) in the system the spurious signal can be the tone itself.

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Slide 33 – Phase Cal Data – Spurious Signal & Pcal

If we plot the pcal signal in a Real / Imaginary plane (instead of seeing the pcal as phase and amplitude), the pcal would be represented by a vector starting from the origin and having a certain length, direction and sense. The spurious signal will add vectorially to the true pcal signal, corrupting its length, direction and sense.

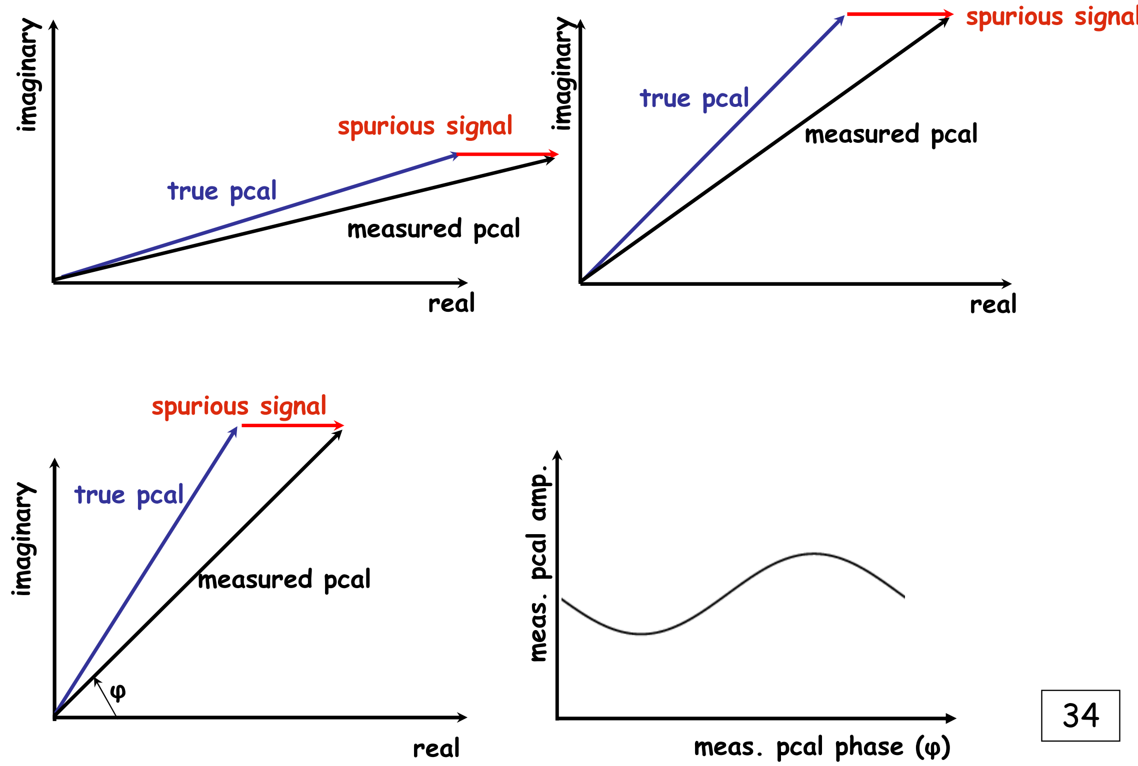
If the spurious signal gets into the system in the data acquisition rack (DAR), it will not be sensitive to whatever is happening in the IF cable (cable length change, temperature changes..). The true pcal, though, is injected at the top of the IF cable, therefore its phase will rotate due to the effects happening in the IF cables.

The spurious signal phase will not rotate as the the true pcal phase does.

The pcal itself can generate a spurious signal if there is a mismatch in the system (cable reflections). In this case the spurious signal is the tone itself.

Let's see how the two effects are visible in the pcal amplitude vs pcal phases plots and why it is like that.

# Phase Cal Data – Spurious Signal in DAR & Pcal

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Slide 34 – Phase Cal Data – Spurious Signal in DAR & Pcal

Case One: the spurious signals are generated in the DAR.

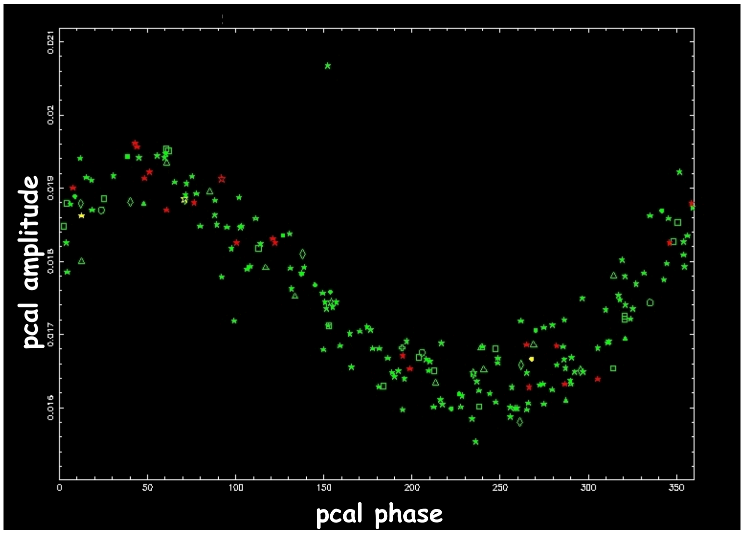
The top left plot show the true pcal + the spurious signal at an instant of time $t_1$. The top right plot shows the true pcal + the spurious signal one instant of time later $t_2$. In this case the true pcal phase is rotated by a bit (due to, e.g., IF cable length change), but the spurious signal is not. The measured pcal will also undergo a rotation. The bottom left plot shows the same scenario at an instant of time $t_3$: again the true pcal rotates, but the spurious signal does not.

If we plot the measured pcal amplitude vs measured pcal phase while varying as described above, we have a sinusoid with a single period in 360° (bottom right plot).

Note: pcal_amp = sqrt(Real$^2$ + Img$^2$)

pcal_phase = arctg (Img/Real)

## Phase Cal Data – Spurious Signal in DAR & Pcal




"Single" sinusoid: the spurious signal coupled to the pcal in the DAR

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Slide 35 – Phase Cal Data – Spurious Signal in DAR & Pcal

Plot of real pcal extracted by aedit.

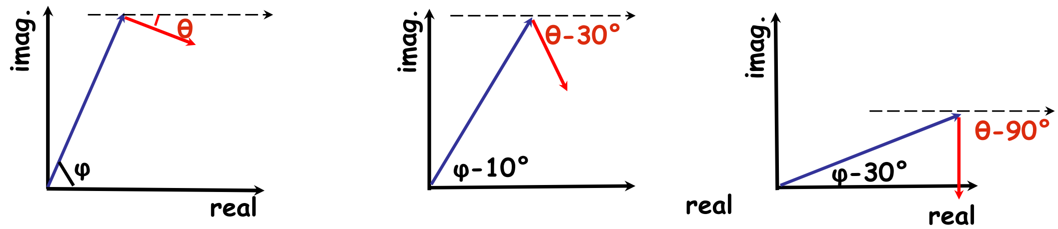
We see a single sinusoid therefore we can tell precisely enough that the spurious signal is coming from the DAR.

Typically the formatter would emit at 4 MHz and its harmonics can hit a pcal tone. The 4 MHz harmonics are known and are avoided by the correlators: we extract and use tones that are not harmonics of 4 MHz.

In general these kinds of spurious signals are not present in all tones and not in all BBC channels in one band (they are frequency dependent). The correlator extracts two tones, therefore we can change tone and so avoid the spurious signal.

If the pcal is badly contaminated, then we use manual pcal rather than the pcal tones.

# Phase Cal Data – Spurious Sig. Due to Refl.& Pcal

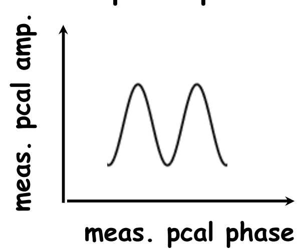


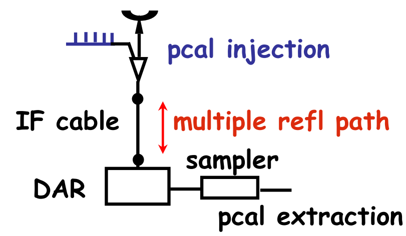

$\varphi_{pcal} = 2\pi \times (\text{cable length} / \lambda_{pcal\ IF})$ rad

$\theta_{spur} = 2\pi \times (2\times \text{cable length} / \lambda_{spur\ IF}) + \varphi_{pcal}$ rad

Variation of phases due to cable length (l) change ($d\theta/dl$):

1 turn of pcal phase = 3 turn of spur phase.

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Slide 36 – Phase Cal Data – Spurious Sig. Due to Refl. & Pcal

Case Two: the spurious signals are the pcal tone itself due to reflections in the system.

A bit of simple math:

$$\varphi_{pcal} = 2\pi \times \frac{l}{\lambda_{pcal\ IF}} \text{ rad}$$

$$\theta_{spur} = 2\pi \times \underbrace{\frac{2 \times l}{\lambda_{spur\ IF}}}_{\text{reflection}} + \varphi_{pcal} \text{ rad}$$

$\varphi_{pcal}$ is the phase of the true pcal signal

$\theta_{spur}$ is the phase of the spurious signal

$l$ is the cable length

$\lambda_{pcal}$ is the IF wavelength of the pcal

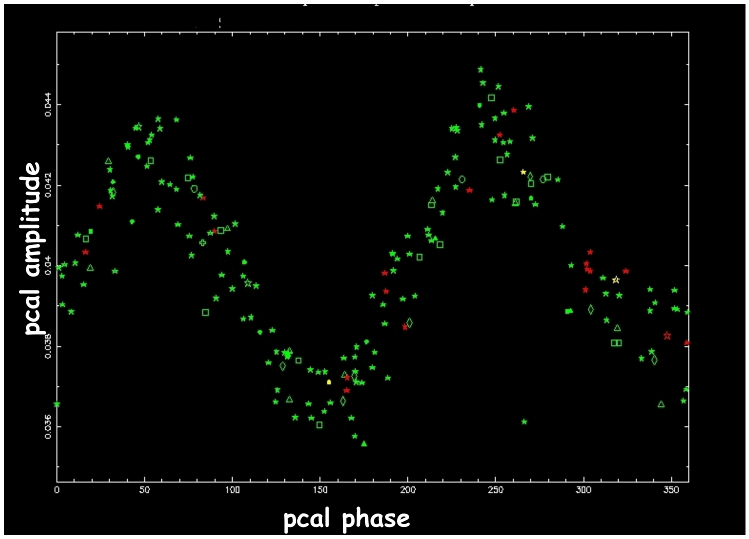
$\lambda_{spur}$ is the IF wavelength of the spur

The phase of the spurious signal is equal to the phase of the pcal plus a term due to the reflection (underlined in red in the equation above).

If we consider the variation in phase (for the spurious signal) due to cable length variation (which means to take the derivative of the phase against length variation: $d\theta/dl$), we see that for every turn of phase of the pcal, the spurious signal will have three turns of phase.

The three top plots are as for case one, considering that, e.g., if $\varphi_{pcal} = 30°$ then $\theta_{spur} = 90°$. In this case the sinusoid described by the measured pcal amplitude vs pcal phase is double in 360°.

## Phase Cal Data – Spurious Sig. Due to Refl.& Pcal




"Double" sinusoid: mismatch in the system.



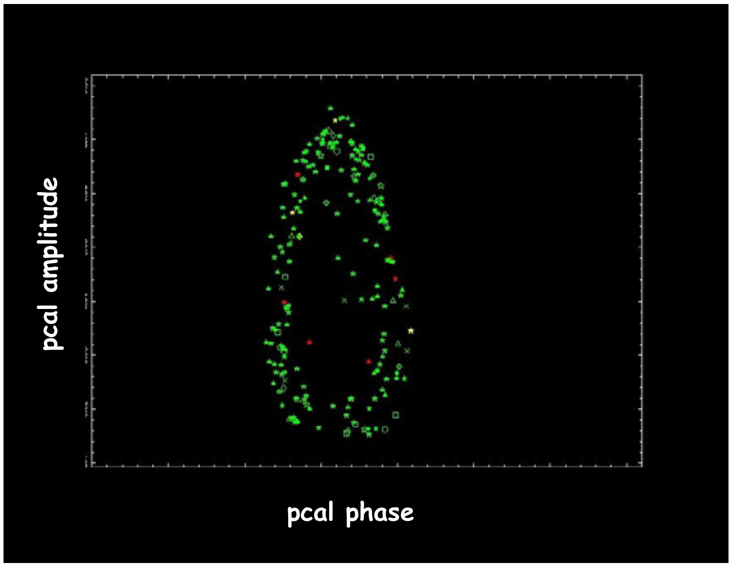
Slide 37 – Phase Cal Data – Spurious Sig. Due to Refl. & Pcal

Plot of real pcal extracted by aedit.

We see a double sinusoid therefore we can tell precisely enough that the spurious signal is due to mismatch in the system.

In general these kinds of spurious signals are present in all of the tones (although with different intensities) and in all the BBCs for a given band (the mismatch affects all frequencies) . In this case, the correlators use manual pcal to calibrate the data.

## Phase Cal Data – Spurious Signal Oddities & Pcal




The spurious signal is stronger than the true pcal signal !!!



Slide 38 – Phase Cal Data – Spurious Signal Oddities & Pcal

Plot of real pcal extracted by aedit.

If one follows the same reasoning done for case one and case two and considers that the spurious signal is stronger than the true pcal signal, the result is an oval for the spurious in the DAR and two ovals for the reflections.

The cases in which the spurious signal is stronger than the pcal itself happen rarely, but the other two cases of spurious signals happen often.

If the correlator reports spurious signal please check! Spurious signals can corrupt the geodetic analysis and make the observation useless.

The spurious signals are treated also in other courses offered during this TOW and therefore further information about them can be found also elsewhere in this folder.

## Aedit: SBD,MBD & DR

Aedit can plot the SBD, MBD and DR for the whole observation baseline per baseline, for both bands:

- Singleband Delay -> checks the clock model. Clock jumps result in delay jumps => corrupt the geodetic measurables.
- Multiband Delay -> checks for drifts. Bad clock model corrupts the delay.
- Delay Rate -> if not flat, mostly station position error (can also be source position error or wrong EOP).



Slide 39 – Aedit: SBD, MBD & DR

Aedit permits us to plot the SBD, MBD and DR for every baseline both bands for the whole observation.

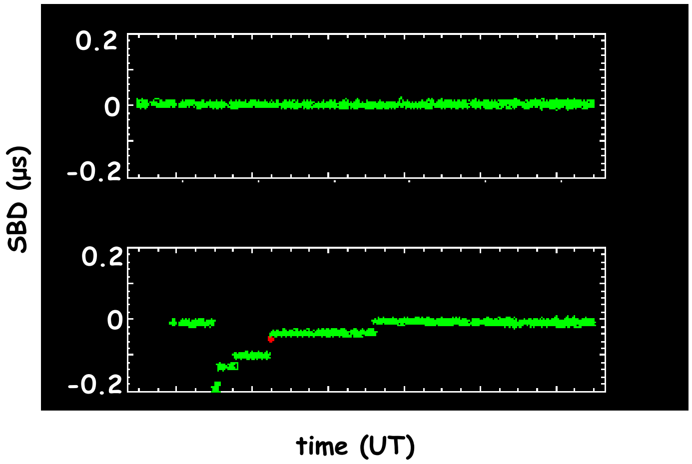
The SBD vs time plot can reveal clock jumps which corrupt the delay and therefore the geodetic measurables.

The MBD vs time plots show possible drift of the delay vs time that can be caused by bad clock model.

The DR vs time can reveal station position errors, source position errors or wrong EOP.

All of the above quantities, if plotted against time should be flat. Any deviation from being flat normally represents a problem.

## Singleband Delay – Clock Jumps




good baseline

bad baseline

Clock jumps cause jumps in the delay => geodetic measurable are corrupted.

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Slide 40 – Singleband Delay – Clock Jumps

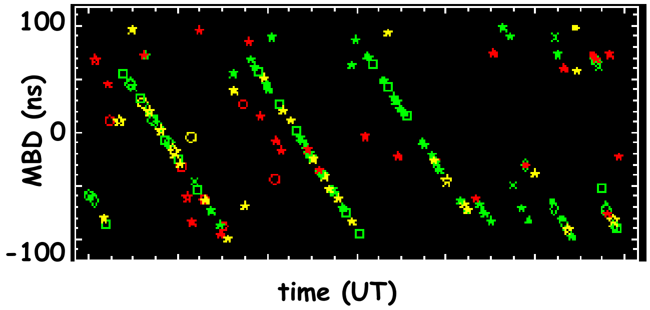
Aedit plots of the SBD vs time for two baselines.

The top plot has no visible jumps, the SBD is at 0 µs.

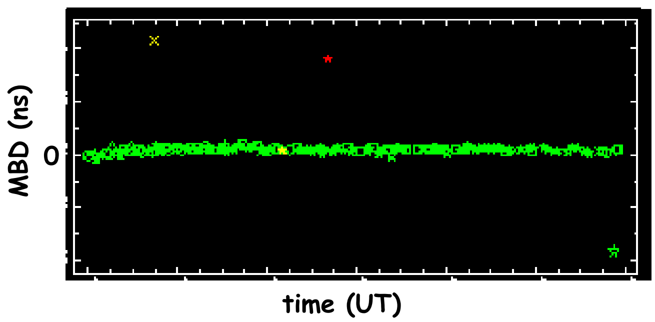
The bottom plot has six jumps, which are small enough to keep the SBD within its fourfit search window (no loss of fringes), but are big enough to disturb the geodetic analysis.

Sometimes the clock jumps are bigger than the SBD window and are therefore corrected introducing a clock break in the correlator control files. The correlation will continue normally, but the jump will influence the precision of the delay measurements.

# Multiband Delay – Bad Clock Model




bad baseline: the ambiguities are visible.




good baseline

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Slide 41 – Multiband Delay – Bad Clock Model

Aedit plots of the MBD vs time for two baselines.

The top plot shows the MBD delays ambiguities: the MBD is not flat vs time, but has a slope. The -100 ns to +100 ns jumps are due to the delay peak moving out of the bottom of the window and the ambiguity enter from the top of the window. This effect will be unwrapped during the delay calculation at the analysis centers.

The bottom plot is flat as it should.

## Database Submission - Conclusion

- The data are re-fringe fitted using the additive phases and bad channels (e.g. RFI) flagged.
- The data are re-checked using aedit.
- Correlator report is written.
- Stations with problems are notified.
- Database is submitted.
- Please read the correlator reports and ask us if there is something not clear! We report any errors at the stations that you might not have noticed and you might find errors that we made and we did not notice ☺



Slide 42 – Database Submission - Conclusion

The work at the correlators is finished after a second round of fringe fit, where all the recognized solvable problems have been dealt with.

The data are then re-checked in aedit before submitting the database.

We write the correlator report (M. Titus talk and notes for this TOW) where we describe the problems encountered during the correlation.

Please read the reports! There might be written something vital for your station that can save other observations.