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Mixed-Mode Correlation

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Outline

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- Pre-requisites and basic needs
- Configuration and setup
- Setting clocks
- Conversion to mk4 format

Pre-requisites

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Essential system requirements

- Cluster with DiFX 2.5[a], and DiFX 2.6.2 (for difx2mark4).
- HOPS (fourfit, alist, etc.)
- Storage (Mark6, RAID, etc.)

[a] Special build, more on this later.

Input needed

- The raw station data (.vdif)
- The session .vex (schedule, sources, etc.)
- Frequency setup information
- EOP data
- The station clock info (ΔGPS, peculiar offsets for SX and VGOS stations)
- Both a VGOS and mixed-mode template fourfit control file.

Station Data

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- SX stations typically e-transfer their data as MK5B format.
- VGOS stations are a mixture of both modules and e-transfer of VDIF.
- For VGOS stations which e-transfer, we expect them to gather their data first.
- Other e-transfer and playback details will be correlator specific.
- VDIF format comes in a variety of flavors listed below:

Back-end	Sample type	Media	Format
RDBE-G/R2DBE-G	complex	Mark6 scatter/gather	VDIFC/0:1:2:3/8224/2
RDBE-G/R2DBE-G	complex	RAID (gathered)	VDIFC/32800/2
DDBC2	real	Mark6 scatter/gather	VDIF/0:1:2:3/8224/2
DDBC3	real	RAID (gathered)	VDIF/65568/2
ADS3000	real	RAID (gathered)	VDIF/5152/2

VGOS station formats encountered.

Assembling a correlator .vex file

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Need the session .vex file to describe various aspects of the experiment:

- Assorted meta-data
- Stations involved, properties, and positions
- Frequency, channel and p-cal set-up
- EOP and station clocks
- Schedule and sources

Where to collect this information:

- Some is available from an IVS provided .skd or .vex file.
- Some follows a standard 'template'. This is for settings that do not typically change from session-to-session.
- Some information must be crafted by correlator operator.

Crafting the .vex file for mixed-mode sessions is not yet quite as stable from session to session as VGOS or SX.

Various .vex sections

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Ranked in order of level of effort:

Low - proceed as you would with VGOS and/or SX session

- $EXPER - define experiment meta data
- $STATION and $ANTENNA - participating station and antenna meta data
- $SCHED, $SOURCE, and $SITE - schedule, source, and location information

Medium - combination of SX and VGOS definitions, but exact contents may change depending on which stations participate

- $MODE $FREQ, $BBC, $IF, and $TRACK - maps the frequency/channel set up of each station (varied but individual components mostly stable, could be templated)
- $EOP - Earth orientation parameters, constructed as per usual.

High - varies from session to session

- $CLOCKS

vex2difx – .v2d file

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Needed to configure additional DiFX details:

- Processing details:
  - point to .vex file
  - stations involved
  - machines, threads, cores
  - N spectral points
  - Zoom bands to extract
- Data format for each station:
  - data location: machine and filelists
  - data format
  - phase-cal interval: 1MHz for SX, 5MHz for VGOS, (10MHz Yj-VGOS)

Zoom Bands

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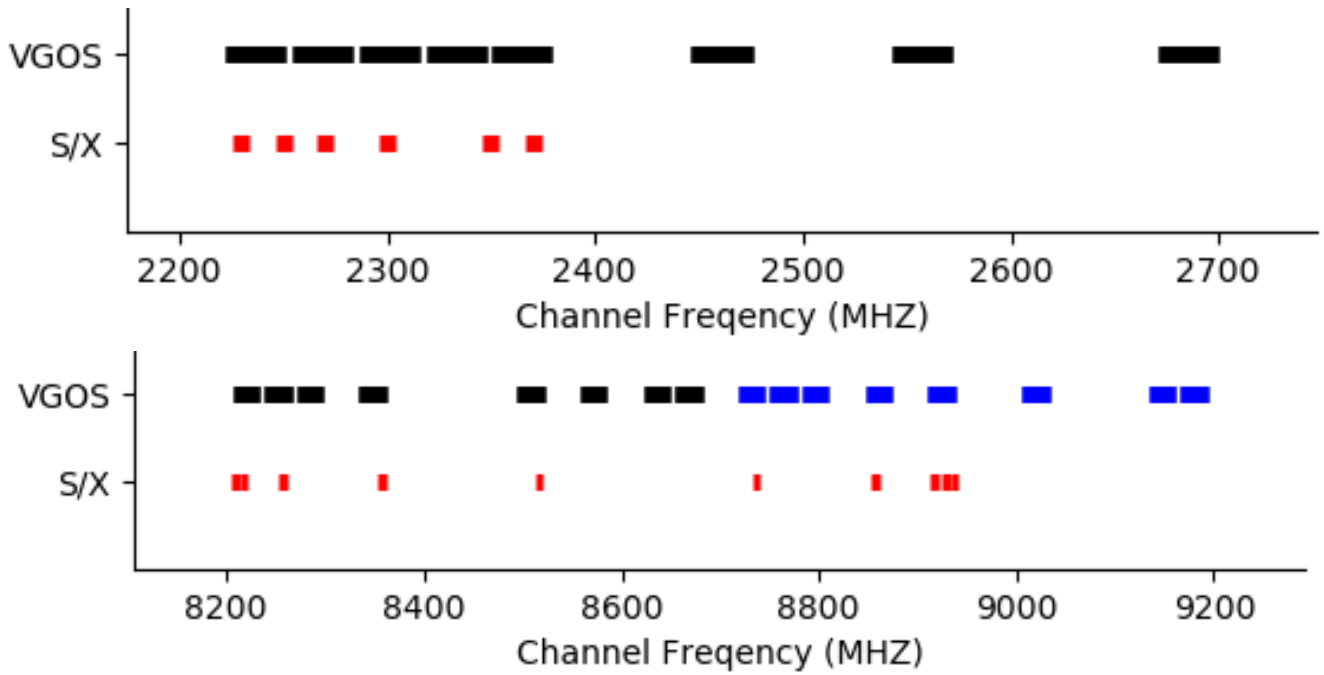
- SX and VGOS stations do not share same channel width (8 and 32 MHz respectively)
- DiFX Zoom bands feature is required to extract the appropriate overlapping slices.
- DiFX will correlate zoom-bands as well as the native 32 MHz channels on VGOS-VGOS baselines.



The frequency set-up of VGOS and S/X stations channels for mixed-mode.

Zoom Bands

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- Applied to the VGOS stations.
- Zoom bands selected are the following 8MHz chunks:

```
ZOOM zoom
{
    addZoomFreq = freq@8212.99/bw@8.0/noparent@false
    addZoomFreq = freq@8252.99/bw@8.0/noparent@false
    addZoomFreq = freq@8352.99/bw@8.0/noparent@false
    addZoomFreq = freq@8512.99/bw@8.0/noparent@false
    addZoomFreq = freq@8732.99/bw@8.0/noparent@false
    addZoomFreq = freq@8852.99/bw@8.0/noparent@false
    addZoomFreq = freq@8912.99/bw@8.0/noparent@false
    addZoomFreq = freq@8932.99/bw@8.0/noparent@false
    addZoomFreq = freq@2225.99/bw@8.0/noparent@false
    addZoomFreq = freq@2245.99/bw@8.0/noparent@false
    addZoomFreq = freq@2265.99/bw@8.0/noparent@false
    addZoomFreq = freq@2295.99/bw@8.0/noparent@false
    addZoomFreq = freq@2365.99/bw@8.0/noparent@false
}
```

vex2difx: data formats

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- Data `format` depends on site (see table 1).
- `format` needed for VGOS stations, but not strictly needed for legacy SX (Mark5B).
- Note phaseCalInt.

Example snippet for GGAO12M (note 'zoom' must be present):

```
ANTENNA Gs
{
  machine = rc19
  format = VDIFC/0:1:2:3/8224/2
  mark6filelist = rd2005_gs.filelist
  sampling = COMPLEX
  phaseCalInt = 5
  toneSelection = all
  zoom = zoom
}
```

Example snippet for Fortaleza

```
ANTENNA Ft
{
  machine = rc18
  filelist=rd2005_ft.filelist
  phaseCalInt = 1
  toneSelection = all
}
```

Clock setting procedures: legacy-only vs. VGOS-only sessions

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- Commonalities:
  - Apply known peculiar offsets to 'fmout' clock models.
  - Adjust $CLOCK offsets as needed to get |residual SBD| $< \sim$0.03 μs.
  - In legacy session, if S and X residual SBDs differ, apply |residual SBD| $< \sim$ 0.03 μs condition to X.
- Differences:
  - VGOS peculiar offsets are biased relative to legacy offsets by $+1.0 \pm 0.1$ μs.
    $\rightarrow$ UT1 estimated from VGOS-only and legacy-only sessions differ by $\sim$1 μs.
  - In VGOS-only ff control file, part of clock delay is contained in sampler delay.
- In mixed-mode sessions, follow legacy-only procedure as closely as possible.
  - Use legacy peculiar offset "clock frame."
  - Sampler delay is not used in mixed-mode control file.
    $\rightarrow$ Sampler delay is absorbed into $CLOCK.

```
if station G
 sampler_delay_x -160 160 160 160
 sampler_delay_y -160 160 160 160
```

Mixed-mode clock-setting procedure

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- Determine $CLOCK models for legacy sites using standard legacy procedure & cf.
  - Apply known peculiar offsets to 'fmout' clock models.
  - Adjust $CLOCK offsets as needed to get |residual SBD| $<\sim$0.03 μs at X.
- Determine $CLOCK models for VGOS sites using standard VGOS procedure & cf.
  - Check that cf sampler delays match fringe plot PC delays to <50 ns.
  - Apply known peculiar offsets to 'fmout' clock models.
  - Adjust $CLOCK offsets as needed to get |residual SBD| $<\sim$ 0.03 μs.
- Bring VGOS $CLOCK models into legacy "clock frame."
  - To $CLOCK offset for each VGOS site, add (mean of bands C & D s.d.) – 1 μs. (= 0.07 – 1 μs = – 0.93 μs for station Z)

```
 if station Z
sampler_delay_x 80   30   80   60
sampler_delay_y 80   30   80   60
```

- With legacy-style cf (i.e., no sampler delays), adjust VGOS $CLOCK offsets as needed to get X-band |residual SBD| $<\sim$ 0.03 μs on VGOS baselines.
  - Adjustments should be $<\sim$ 0.1 μs. With luck!

Notes on mixed-mode clocks and residual SBD

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- Instead of steps 2-3 on previous slide, one could simply adjust $CLOCK offset for each VGOS site as needed to get small X-band residual SBD on VGOS-legacy baselines.
  - These adjustments could be as large as many μs.
  - Advantage of steps 2-3 is that final adjustments should be $\ll 1$ μs.
- Band A sampler delays differ from band C & D delays by 100-300 ns at Gs, K2, & Mg.
  $\rightarrow$ S-band residual SBDs on baselines to those sites may be as large as 0.3 μs
- Because broadband processing is done in same correlator pass as mixed-mode, $CLOCK models for broadband are same as for mixed-mode.
  - Consequently, broadband residual SBDs on VGOS-VGOS baselines will be offset from zero by station difference in the band C & D sampler delays.
  - This offset may be as large as $\sim$200 ns.

DiFX output

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- After correlation, the DiFX output will contain data of the follow types:
  - Native 8MHz SX-SX (RR circular pol).
  - 8MHz zoom-banded VGOS against native 8MHz SX channels (mixed linear-circular pols: RX, RY).
  - 8MHz zoom-banded VGOS-VGOS (linear-linear pols: XX, YY, XY, YX).
  - 32MHz native VGOS-VGOS (linear-linear pols: XX, YY, XY, YX).
- The 8MHz channel data contains circular, linear, and mixed linear-circular pol data (hence...mixed-mode).
- The 32MHz channel data is VGOS only, and is essentially treated like a concurrent independent VGOS session.

Conversion to Mk4-types

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- Use difx2mark4 (v2.6.2) to convert DiFX output to Mk4 type-1 and type-3 files for HOPS processing.
- Need to do this twice!
- First to convert the VGOS-only broad-band correlation (32MHz channels) as "X" band:

```
difx2mark4 --override-version -v -d -w 32 -b X 2300 14000 -e XXXX -s <codes>
```

- Second to convert the SX-SX, SX-VGOS, and VGOS-VGOS mixed-mode correlation (8MHz channels) (both S and X-band):

```
difx2mark4 --override-version -v -d -w 8 -e XXXX -s <codes>
```

- The mixed-mode post-processing and the broad-band post-processing can then proceed (mostly) separately.
- Beware of empty 'root' files! They can cause hiccups in post-processing and may need to be removed manually.
- Single letter station codes vary from typical SX/VGOS choices due to conflicts.

Backup: vex2difx warnings...

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- Much of mixed-mode processing is predicated on DiFX features which are experimental.
- `vex2difx` needs to run with `-force` flag

```
Warning: Currently correlation of rec bands that are parents to globally defined
    zoom bands is not supported. Results will be unpredictable.
....
Warning: Currently correlation of rec bands that are parents to globally defined
    zoom bands is not supported. Results will be unpredictable.
Warning: Unsupported pulse cal interval of 10 MHz requested for antenna Yj.
Warning: Unsupported pulse cal interval of 10 MHz requested for antenna Yj.
start date: 2020y190d18h00m00s
stop date: 2020y191d18h00m00s
Warning: both linear and circular polarizations are listed in the .vex file. Very
     partial support exists for such modes within DiFX. Use at your own risk!
Note: Proceeding even though there were 16 warnings.
Warning: differing correlation channel bandwidths found. You can correlate this
    data, but won't be able to convert to FITS!
....
```