Deep Space Network VLBI Processor (DVP)

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Summary

- VLBI at Deep Space Network
- DSN VLBI Processor –DVP- Overview
- Required DVP functionality: non-DSN customers support
- DVP tests in the EVN

DVP effort working group

- **JPL group:** Robert Navarro, Steven Rogstad, Eric Clark, Chuck Naudet, Chris Jacobs, Chuck Goodhart, Les White, Joseph Trinh, Melissa Soriano, Doug Wang, Elliot Sigman
- **DSN operations** (ITT Exelis Systems Division): Norm Baker, John Luvalle, George Martinez
- **Canberra DSCC station:** Shinji Horiuchi, Phil Pope
- **Goldstone DSCC station:** Larry Snedeker
- **Madrid DSCC station:** Cristina Garcia-Miro, Francisco Gallardo, Ioana Sotuela, Juan Lobo

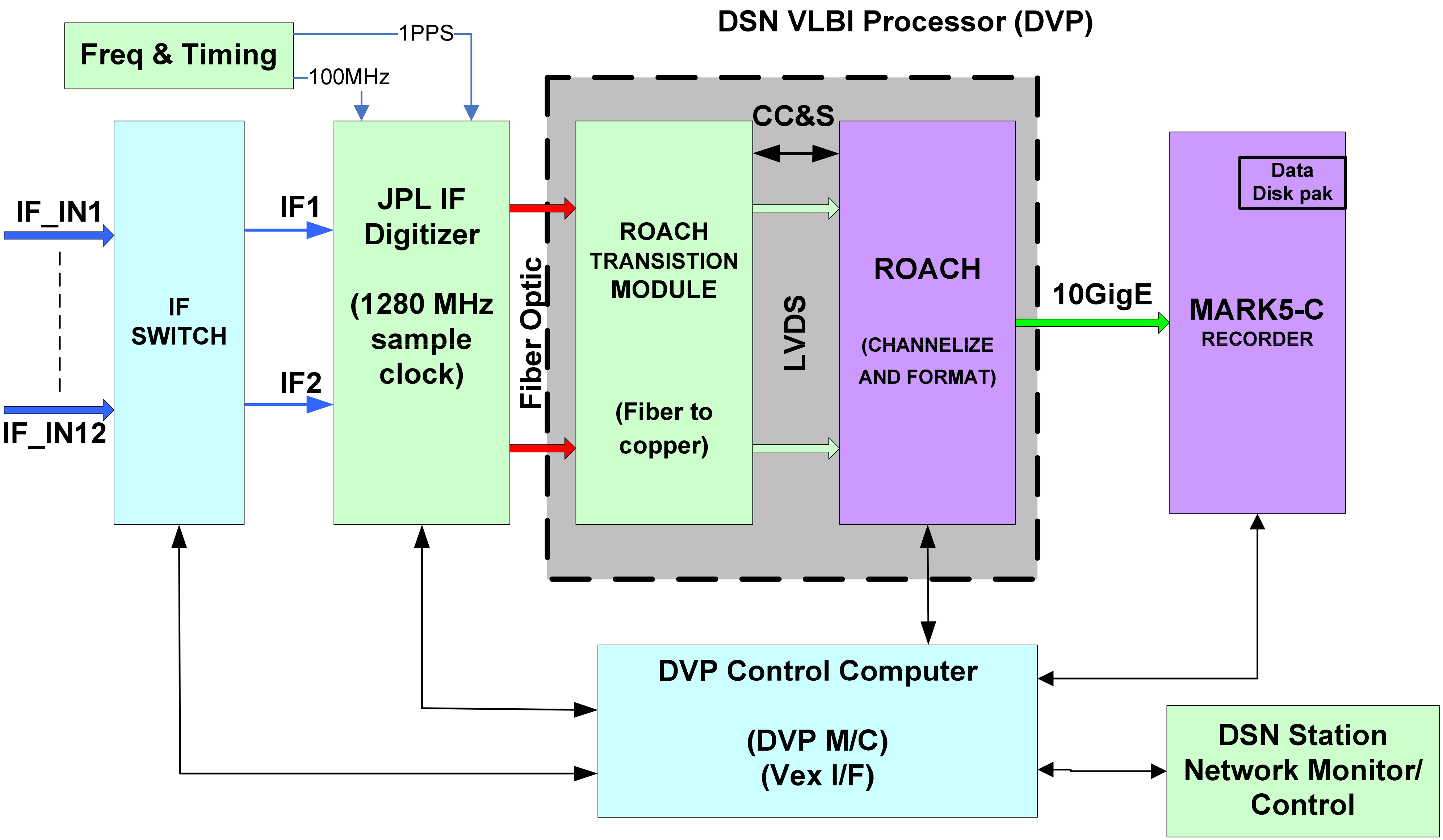
VLBI at the DSN

- **Internal customers:**
  - JPL Reference Frame Calibration project:
    - Earth Orientation Parameters determination: JPL TEMPO experiments, once every two weeks
    - Maintenance of inertial celestial reference frame for JPL navigation: S/X and X/Ka bands
  - JPL Delta Differential One-way Ranging (DDOR): support JPL navigation group
  - Proof-of-concept of VLBI applications for navigation: phase referencing, same beam interferometry, etc.
- **External customers:**
  - EVN + global observations: DSN is an associate member of the EVN
  - IVS Geodesy and Astrometry observations
  - Australian VLBI observations: Australian Long Baseline Array –LBA-
  - RadioAstron co-observing
- **Other non-VLBI customers:**
  - GBRA Host Country groups: single dish spectroscopy
  - GBRA Guest Observe Programs: pulsars, DSN transient observatory, etc.

Aim of the DVP

- Replace aging VLBI Data Acquisition Terminal hardware (MarkIV DAT) with modern Digital Backend system based on JPL Wideband VLBI Science Receiver (WVSR).
- Replace PCFS computer by *Dell PowerEdge R210 server as Data Processor and Controller (DPC) computer (debian linux)*. Replace Field System application by *driver, command, modeling and monitor and control WVSR based s/w.*
- Upgrade to Mark5C recorder for data recording.
- Make incremental improvements to JPL VLBI Software Correlator to support Mark5C hardware and data formats.
- Maintain compatibility with other VLBI centers for DSN support of international VLBI and Host Country activities.

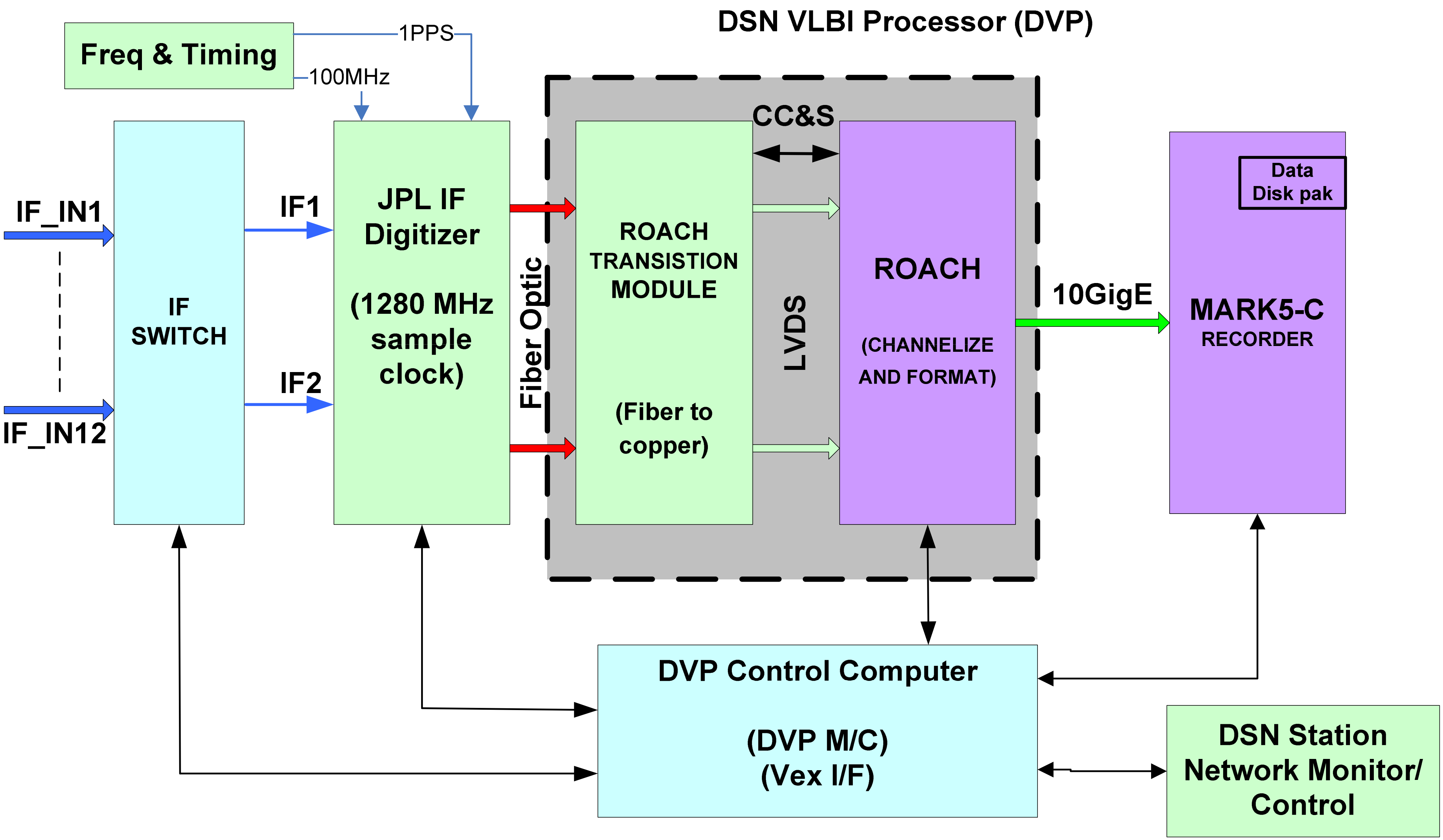
DVP overview



DVP overview

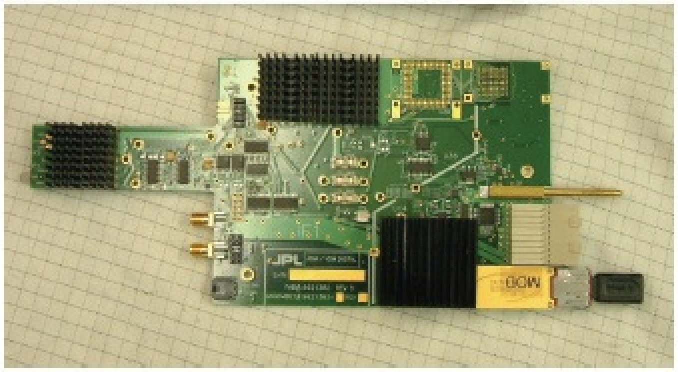
- IF switch up to 12 IF inputs from DSN antennas (at least 3 antennas at each complex support VLBI)
- Two IF inputs, each covering up to 500 MHz of bandwidth.
- Accepts DSN IF input band of 100-600 MHz. Good for L band (1.4-1.9 GHz), S band (2.3 GHz), X band (8.4 GHz), K band (18-26 GHz), Ka band (31.2 GHz) and Q band (38-50GHz).
- Uses JPL IF sampler module and CASPER ROACH board for Digital Processing and Channelization.
- Interfaces to JPL Deep Space Network monitor & control infrastructure.
- Records up to 32 upper/lower or 16 complex channels (in-phase and quadrature-phase). Channel max BW is 32 MHz (or 64 MHz for complex channels). Supported bits per channel = 8, 4, 2 or 1 bits.
- Phase calibration signal real time detection.
- Mark5C recorder used for data recording. Data stored on Mark5 modules in VDIF format.
- VEX 2.0 files used for input.
- Compatible with other digital developments (DBBC, RDBE, etc.)

DVP overview



DVP: JPL IF digitizer module

- Already in operational use at the DSN.
- A/D samples 8 bits at 1280 MHz.
- Digitally controlled built-in attenuator.
- Optically isolated from digital processing back ends:
  - Spurious signals attenuated 97 dB below A/D saturation level: S/C tracking
  - Enables use for spectral line work.
- Generates 1280 MHz sampling clock from 100 MHz reference.
- Uses interface module to connect to ROACH Board.



DVP channelization and sub-band filtering

- JPL VLBI DAT Digital Backend Channelization broken up into two stages:
  - **First stage:**
    - polyphase filterbank breaks input signal up into 7 fixed bands of data, each 160 MHz (complex).
    - Channels centered at 80, 160, 240, 320, 400, 480 and 560 MHz.

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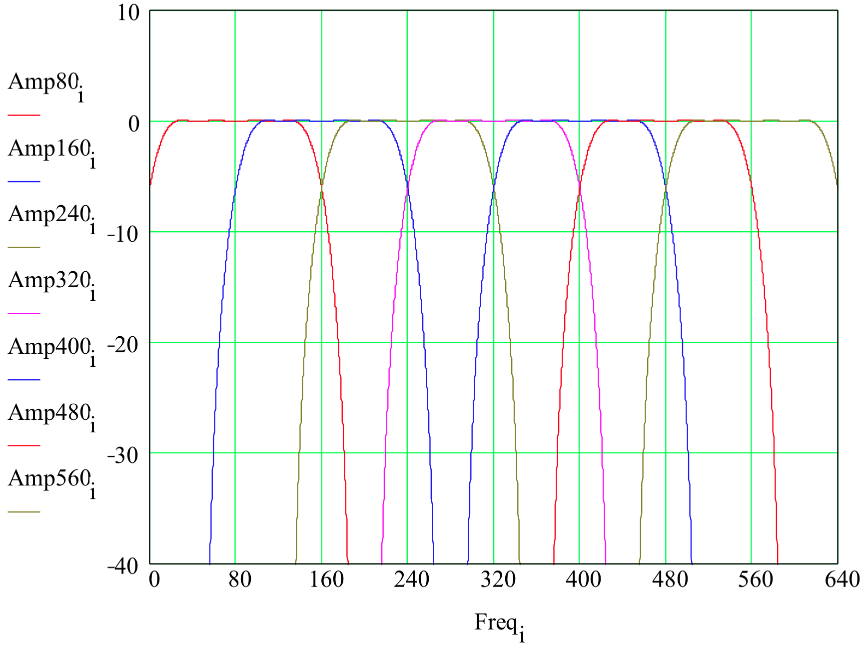
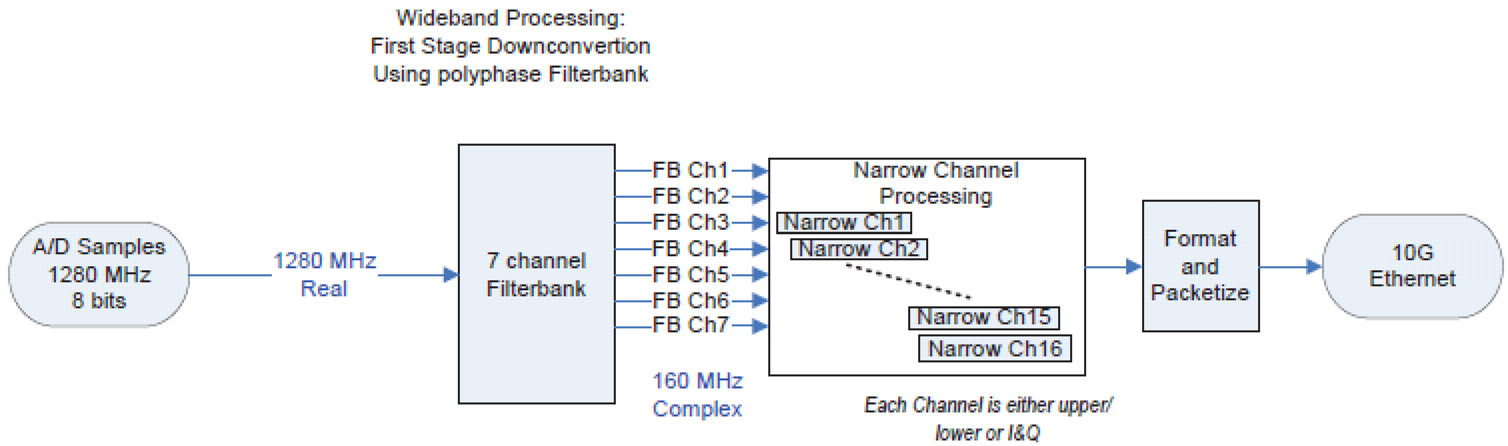
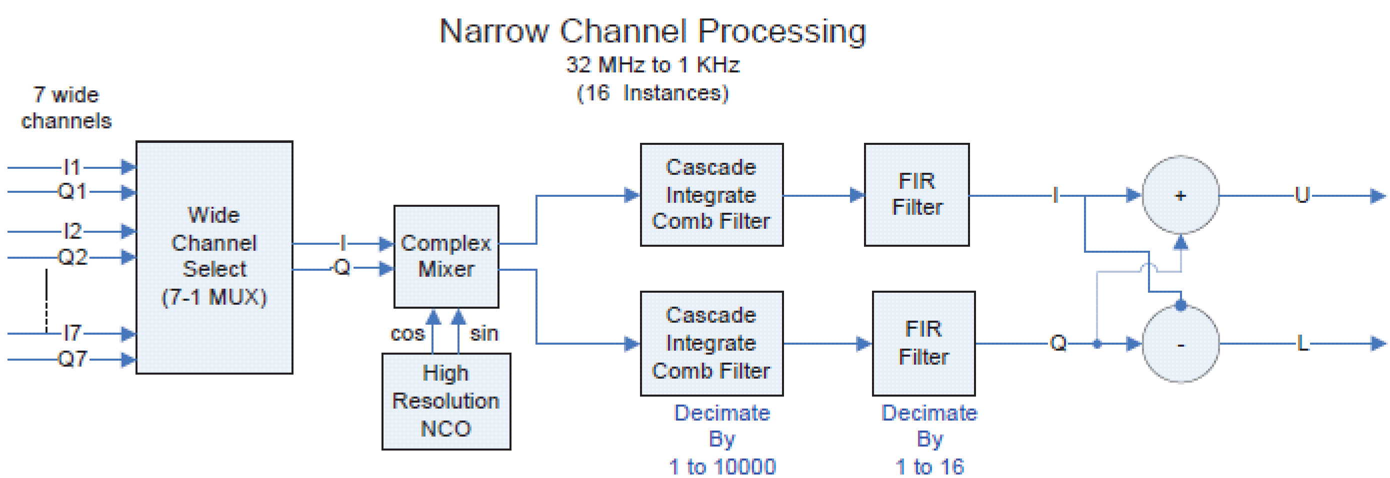


DVP channelization and sub-band filtering

- JPL VLBI DAT Digital Backend Channelization broken up into two stages:
  - **Second stage:**
    - selects one of seven first stage wideband inputs.
    - applies digital mixer for precise channel location selection.
    - Cascade of downconverting filters (CIC & FIR) provides variable output bandwidth per channel.
    - A total of 16 complex sub-channels can be formed (32 MHz to 1 KHz).
    - Changed to upper/lower representation using Hilbert transforms. Processing organization means upper/lower channels always occur in contiguous pairs.

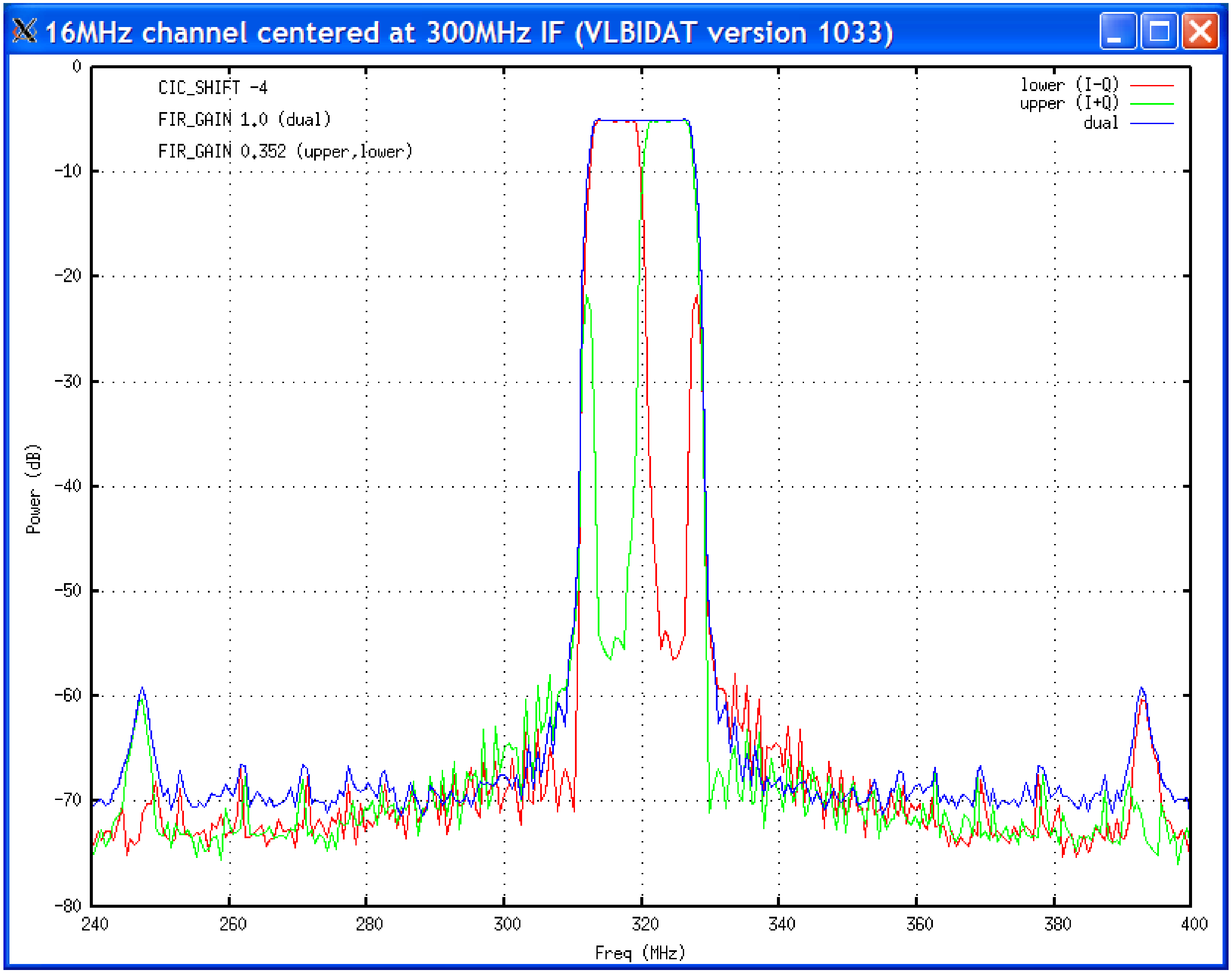
Sub-band filtering stages





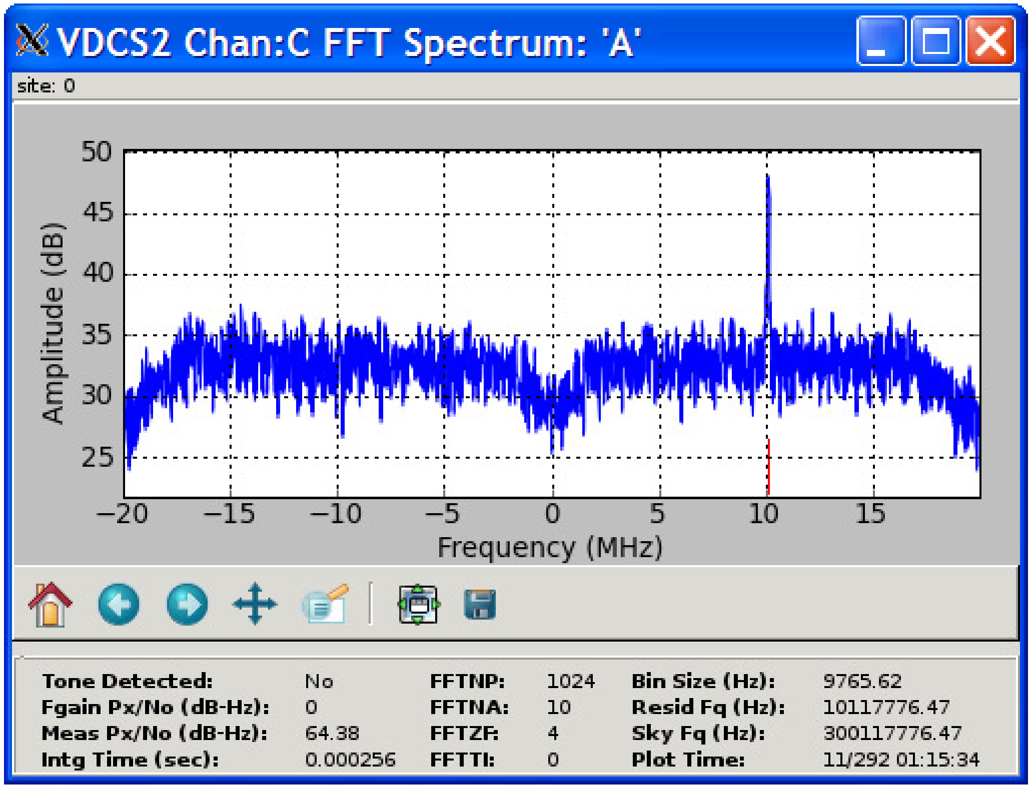
Sub-band filter performance

- Aim is to get 0.1 db ripple in passband and at least 40 db attenuation in stopband.



SubChannel output

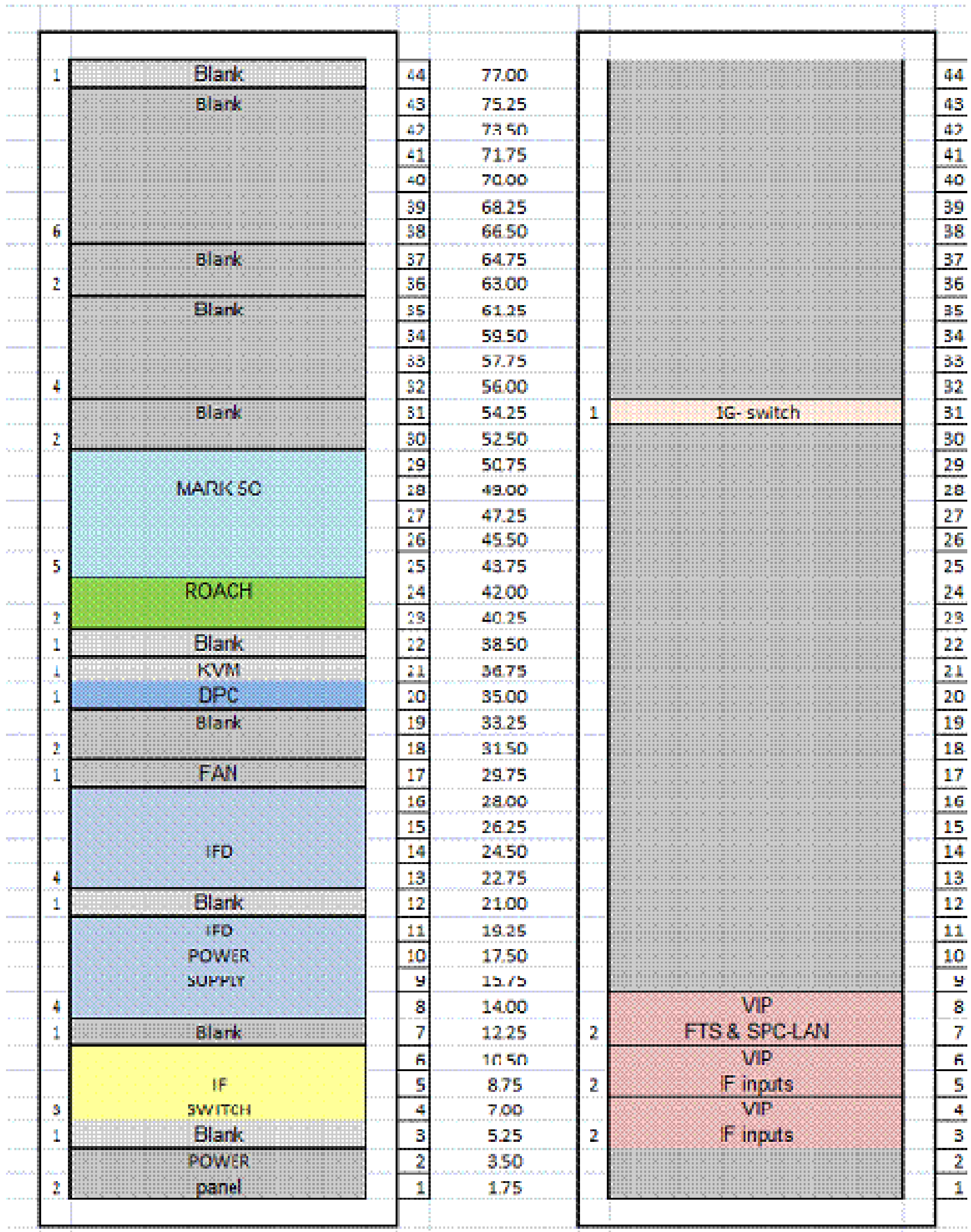
- Actual data from tone buried in noise shown below. Sub-channel is 16 MHz upper / 16 MHz lower.
- Cutoffs of Upper and Lower bands apparent at edges.



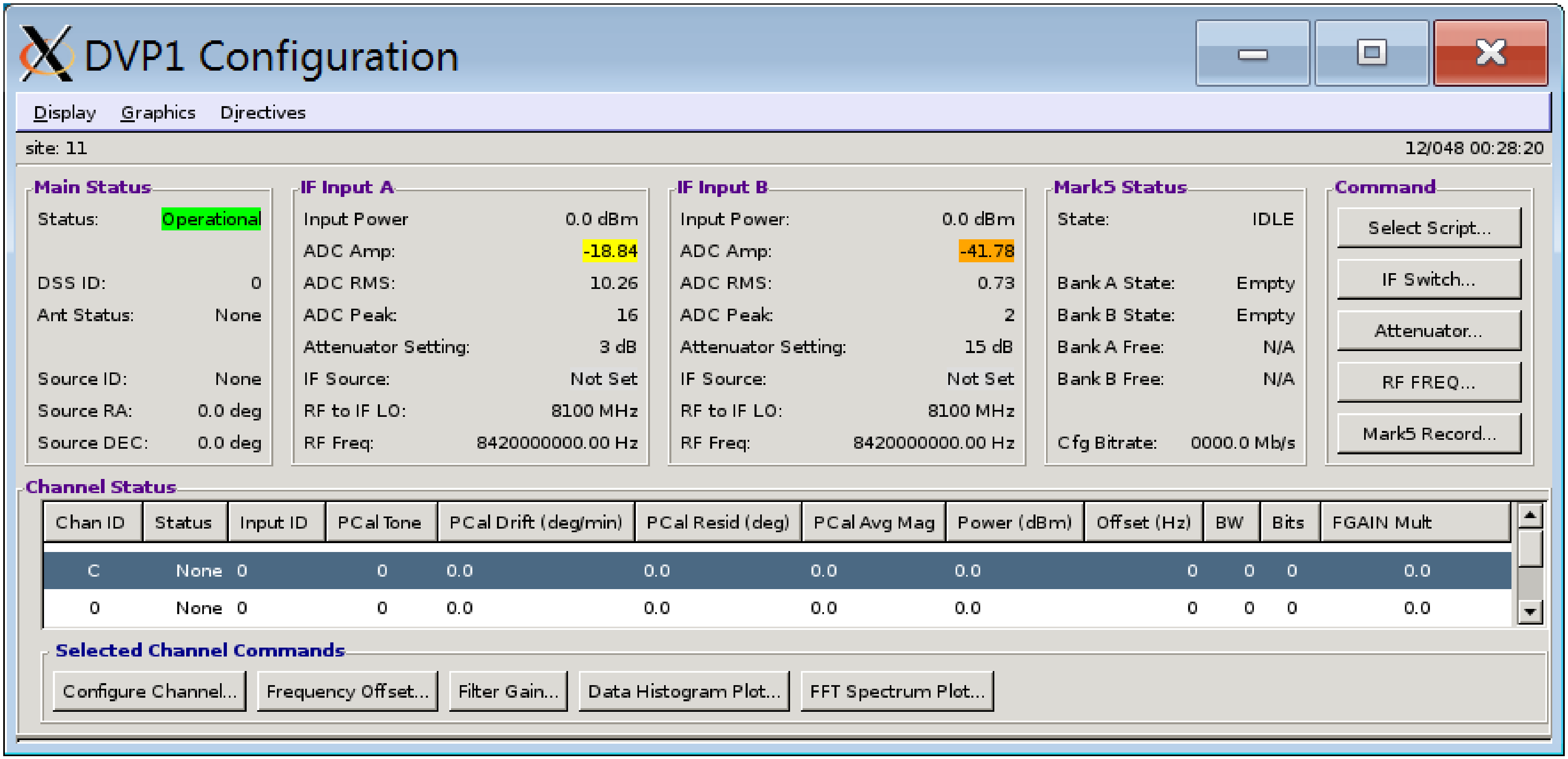
DVP overview

- First prototypes installed at the end of 2012 at Ro & Go
- Recording tests @ 3 Gbps
- DVP successful piggyback recording until Oct. 2013 for DSN projects
- DVP will become operational April 2014
- Mark5A will be upgraded to a Mark5C, MarkIV DAT will be decommissioned and remove

DVP overview



DVP GUI


DVP1 Configuration
Display Graphics Directives
site: 11
12/048 00:28:20
Main Status
Status: Operational
DSS ID: 0
Ant Status: None
Source ID: None
Source RA: 0.0 deg
Source DEC: 0.0 deg
IF Input A
Input Power 0.0 dBm
ADC Amp: -18.84
ADC RMS: 10.26
ADC Peak: 16
Attenuator Setting: 3 dB
IF Source: Not Set
RF to IF LO: 8100 MHz
RF Freq: 8420000000.00 Hz
IF Input B
Input Power: 0.0 dBm
ADC Amp: -41.78
ADC RMS: 0.73
ADC Peak: 2
Attenuator Setting: 15 dB
IF Source: Not Set
RF to IF LO: 8100 MHz
RF Freq: 8420000000.00 Hz
Mark5 Status
State: IDLE
Bank A State: Empty
Bank B State: Empty
Bank A Free: N/A
Bank B Free: N/A
Cfg Bitrate: 0000.0 Mb/s
Command
Select Script...
IF Switch...
Attenuator...
RF FREQ...
Mark5 Record...
Channel Status
Chan ID Status Input ID PCal Tone PCal Drift (deg/min) PCal Resid (deg) PCal Avg Mag Power (dBm) Offset (Hz) BW Bits FGAIN Mult
C None 0 0 0.0 0.0 0.0 0.0 0 0 0 0.0
0 None 0 0 0.0 0.0 0.0 0.0 0 0 0 0.0
Selected Channel Commands
Configure Channel...
Frequency Offset...
Filter Gain...
Data Histogram Plot...
FFT Spectrum Plot...

Required DVP functionality: non-DSN customers support

- VEX 2.0 files used for input, should contain appropriate $blocks for DVP configuration and precess coordinates for observing date. Script builder generates DVP recording script.
- DVP log XLATOR to Field System type log:
  - System temperature calibration: total power on each channel calculated at digital stage, IF total power measured using power meters. Output in ANTAB format.
  - Phase calibration signal: real time tone extraction, in /pcald/ notation.
  - Antenna status: provide /onsource/ and /flagr/ status.
  - Weather: provide /wx/ notation.
  - Mark5C monitor data.
  - Equivalent gps-fmout: DVP digitizer does not provide 1pps output from internal clock.
- Automatic delivery of logs to users (IVS servers, vlbeer, etc).
- Antenna calibration performed using custom built DSN tools (ACME): gain curve, DPFU and noise diode versus frequency measurements substitute onoff / gnplt / rxgfiles.
- VDIF format:16 bytes header and single data thread carrying multi-channels data frames.

Required DVP functionality: VDIF

- **data frame header:** legacy header length 16 bytes (4x32bits words).

Bit 30 =1

Bit 31 (MSB) Bit 0 (LSB)

Byte 3 Byte 2 Byte 1 Byte 0

Word 0	I_1	L_1	Seconds from reference epoch$_{30}$	
Word 1	Un-assigned$_2$	Ref Epoch$_6$	Data Frame # within second$_{24}$	
Word 2	V_3	$\log_2$(#chns)$_5$	Data Frame length (units of 8 bytes)$_{24}$	
Word 3	C_1	bits/sample-1$_5$	Thread ID$_{10}$	Station ID$_{16}$
Word 4	EDV$_8$		Extended User Data$_{24}$	
Word 5	Extended User Data$_{32}$			
Word 6	Extended User Data$_{32}$			
Word 7	Extended User Data$_{32}$			

Not present

DiFX is being modified to cope with legacy headers (by Chris Phillips, CSIRO)

Bit 31 Bit0

Bit 63 **Bit 32**

Required DVP functionality: VDIF

- **data frame array:** single data thread with multi-channel data frames, 64 bits for a single sample time, 8000 bytes

Bit 32 Bit 0

C15l	C14u	C13l	C12u	C11l	C10u	C9l	C8u	C7l	C6u	C5l	C4u	C3l	C2u	C1l	C0u
C31l	C30u	C29l	C28u	C27l	C26u	C25l	C24u	C23l	C22u	C21l	C20u	C19l	C18u	C17l	C16u

Bit 63 Bit 33

32 USB/LSB channels

cQ7	cI7	cQ6	cI6	cQ5	cI5	cQ4	cI4	cQ3	cI3	cQ2	cI2	cQ1	cI1	cQ0	cI0
cQ15	cI15	cQ14	cI14	cQ13	cI13	cQ12	cI12	cQ11	cI11	cQ10	cI10	cQ9	cI9	cQ8	cI8

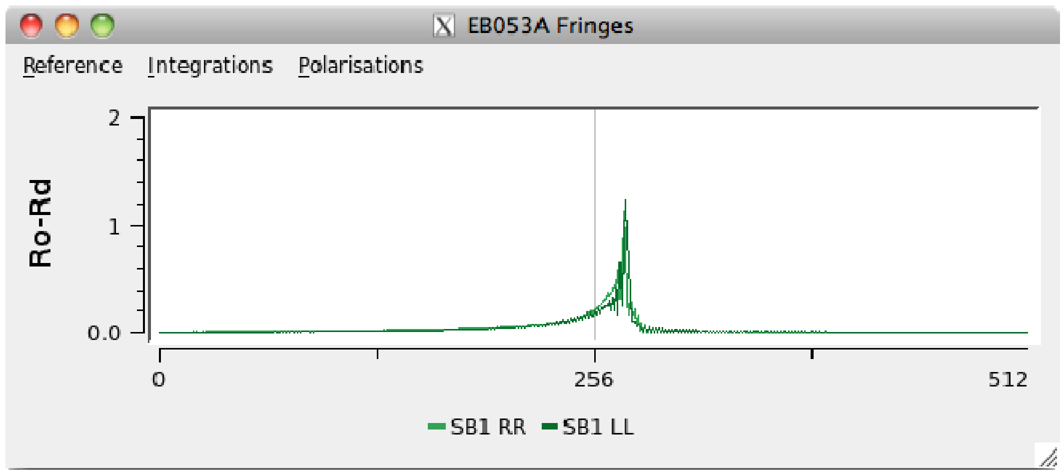
16 complex channels

DiFX is being modified to cope with multi-channels data frames
(by Chris Phillips, CSIRO)
Independently of number of channels configured DVP always records
16 or 32 channels: worse case scenario RadioAstron observations

256 Mbps (4x16x2x2) versus 2048 Mbps (32x16x2x2)

DVP tests within the EVN

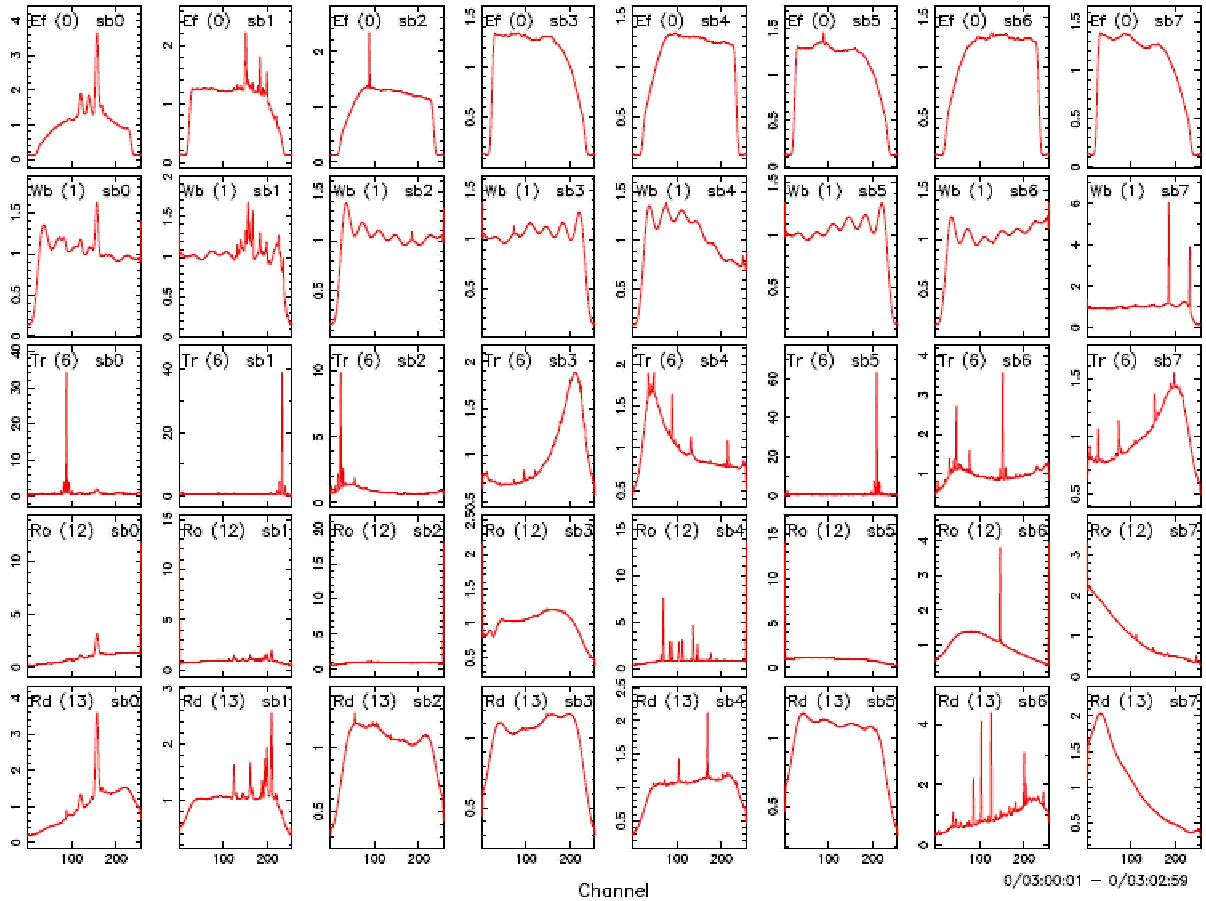
- EB053A (Jun 13): fringes between Robledo MarkIV DAT and DVP



Fringes between Robledo MarkIV DAT and DVP Mark5C with an offset of approximately 0.5 microsec between the two signals and good sampler statistics.

DVP tests within the EVN

- EP087E (Oct 13): first DVP fringes within EVN!!! But several LSB channels with no detection



Autocorrelation vs frequency

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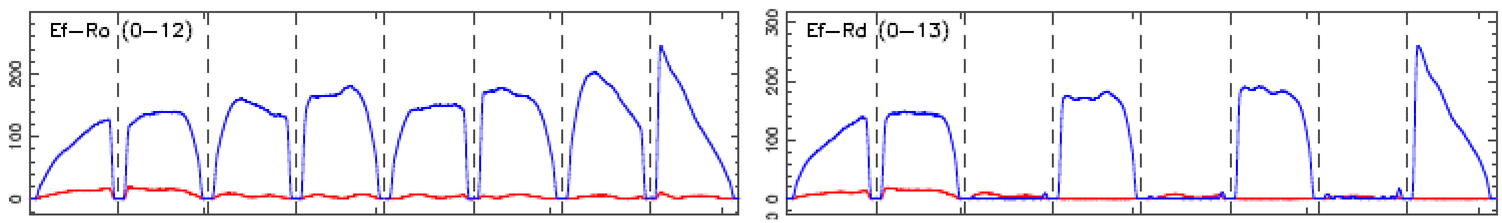
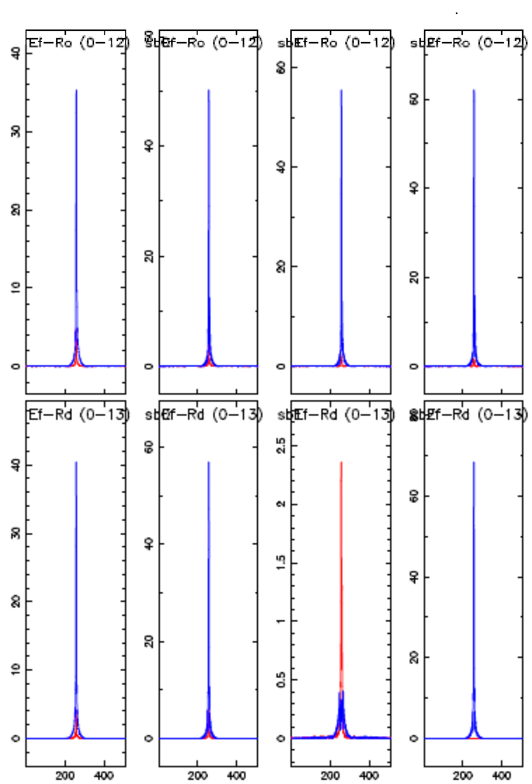
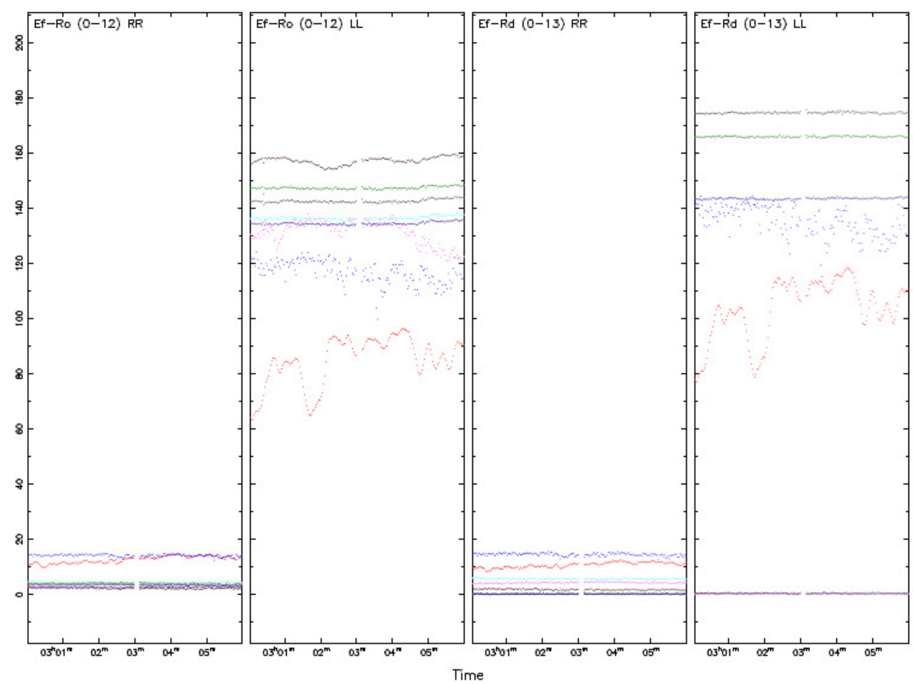


Amplitude vs frequency

Lag-based fringe





Amplitude vs time

DVP tests within the EVN

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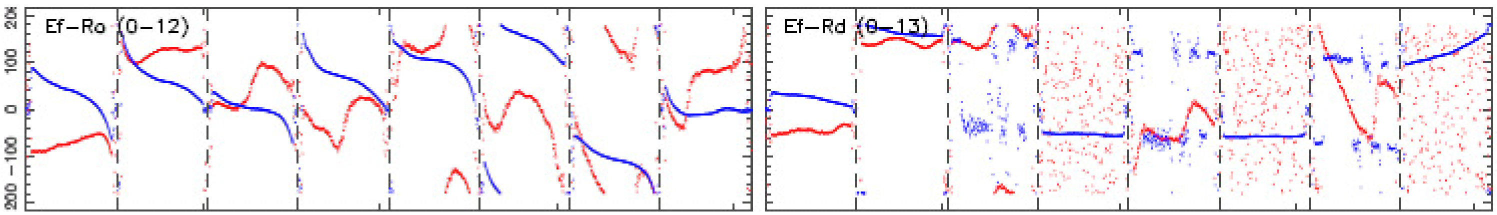
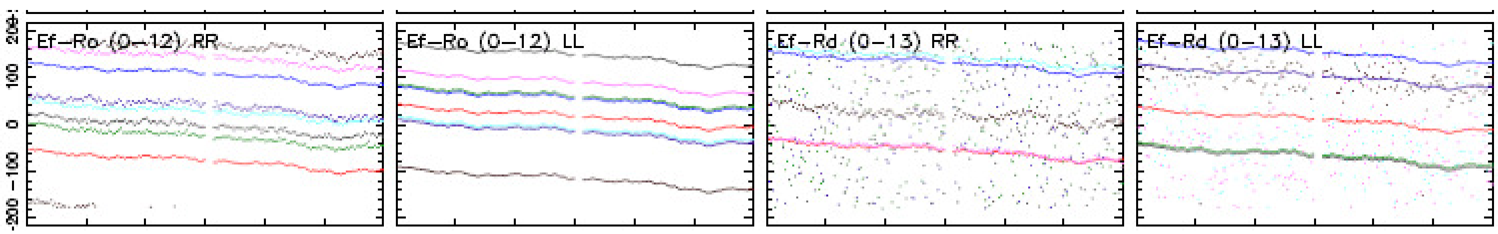


Phase vs frequency



Phase vs time

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Many thanks!

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