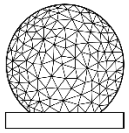
RDBE-G / R2DBE–G /DBEv5 Setup and Operations

Chet Ruszczyk / Russ McWhirter

IVS TOW 2025



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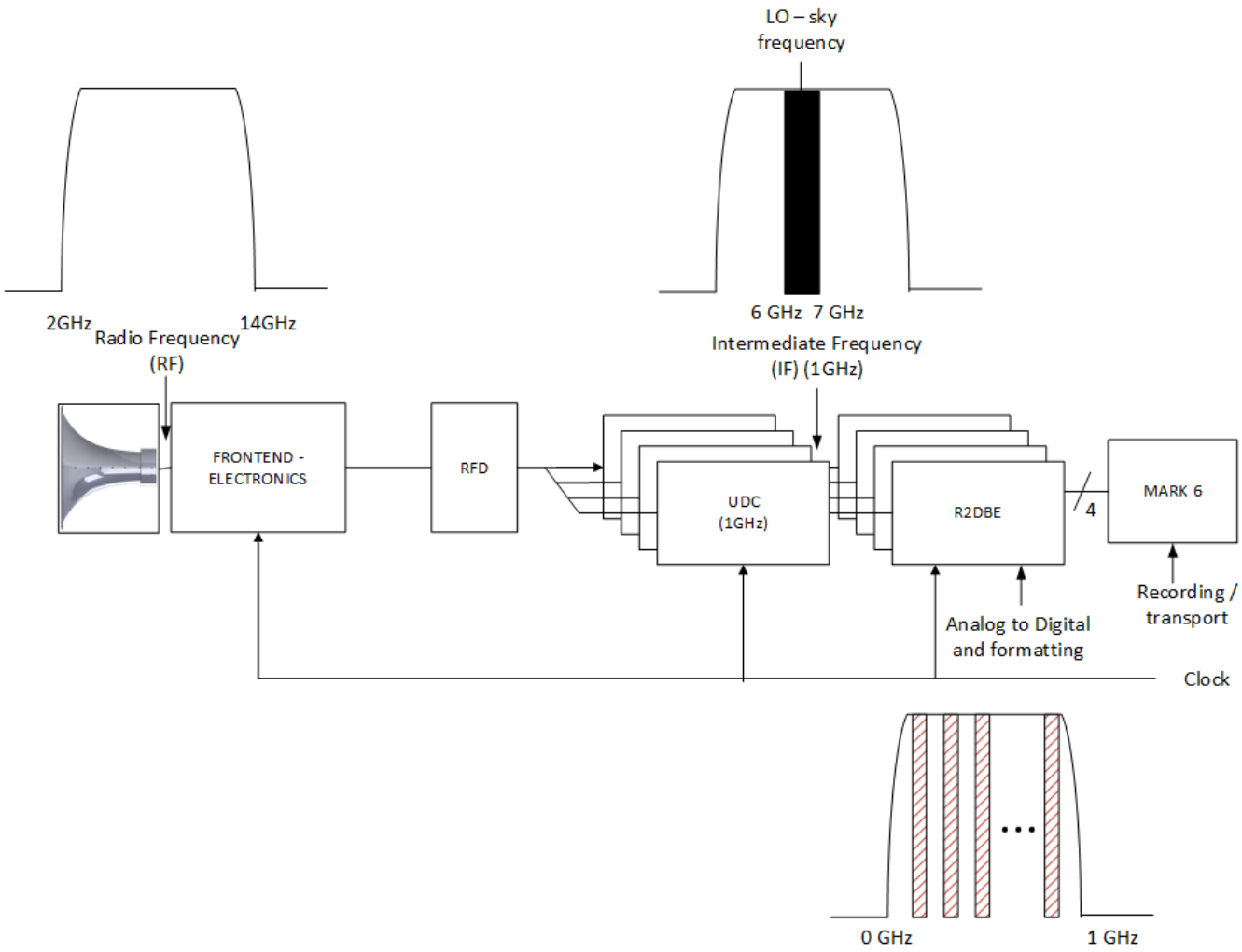
Overview

- Role of Haystack Digital Backends (DBEs)
- History of Haystack DBEs
- Capabilities
- State of operations
- Next steps
- General operational questions

Role of Digital Backend (DBE)



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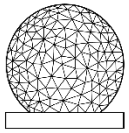
DBE Systems

- VGOS systems consist of:
  - 1 DBE / band for both polarizations
    - 4 DBE's per signal chain
  - A Backend (BE) computer
- The DBEs are embedded systems
- BE computer
  - NFS mount computer for all DBE's
  - OS is Debian Stretch (EoL)
  - OS updated to Ubuntu
    - Expect the next 2 months it will be released for stations

Digital Backend

- Receives two Intermediate Frequencies (IFs)
  - Horizontal and vertical polarization
  - Up to 1.5GHz of bandwidth from Up Down Converter
    - Based on filter installed
- Converts IF from analog to digital domain
- Filters the data thru poly phase filter bank
- Packetizes the data in VDIF format
  - With a timestamp
    - Integer second and frame count of when the data was received
  - Thread ID
- Transmit the packet over 10G Ethernet
  - IPv4/UDP/VTP



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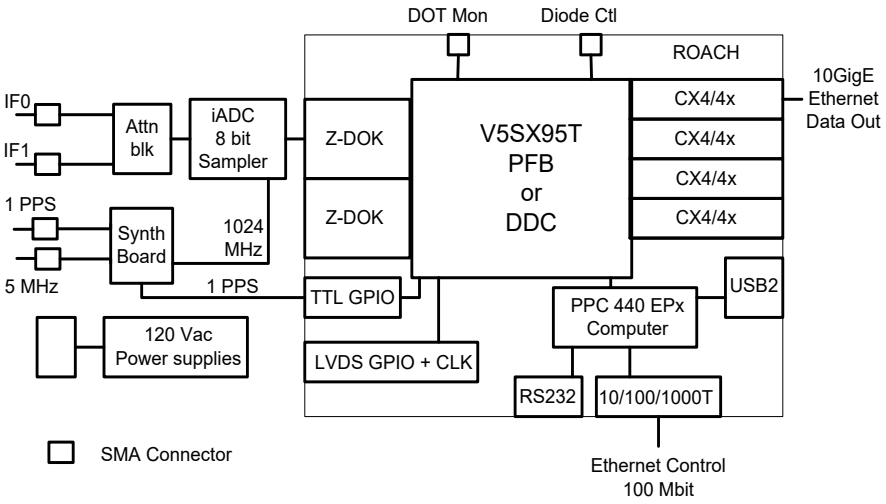
History of Haystack DBE's

System	Input IF BW	Personality	Data Rates	Usage	VGOS Compliant
Vers. 1 – Ibob	512 MHz	DDC (Casper)	2 Gbps (real)	Astronomy	No
Vers. 2 - RDBE-H*	512 MHz	DDC / PFB (VHDL)	2 | 4 Gbps (Real)	Astronomy / Geodesy	No
Vers. 3 - RDBE-G	512 MHz	PFB (Casper)	2 | 4 Gbps (complex)	Geodesy	No
Vers. 4 - R2DBE-G	2 GHz	PFB (Casper)	2 | 4 | 8 Gbps (complex)	Geodesy	Yes
Vers. 5 – DBEv5	2.5 GHz	PFB (Casper) / ?	2 |4 | 8 | Gbps	Geodesy	Yes

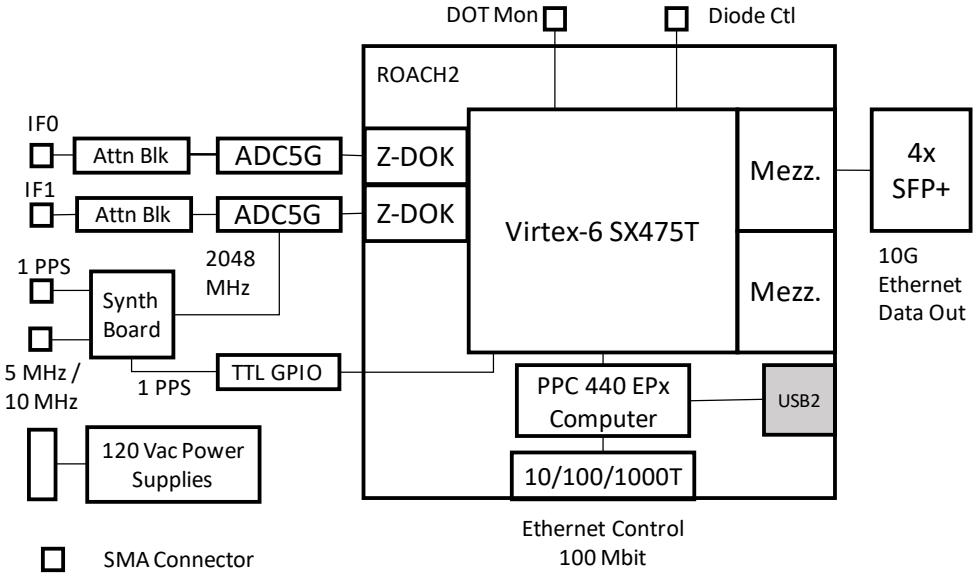
* Joint project NRAO / Haystack

Block Diagram(s)

RDBE-G Block Diagram (Version 3)



R2DBE-G Block Diagram (Version 4)



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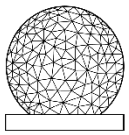
Overview

- RDBE-G was the 3rd Generation DBE system (Roach1 based unobtainium)
  - Emerged from a joint NRAO / MHO collaboration (Version 2)
  - Case, LCD display, attenuation, synthesizer board
  - CX4 - 10G Ethernet
- R2DBE-G is a 4th generation DBE (Roach2 based)
  - Leveraged from SAO's EHT system
    - ADC card initialization routine
  - Mezzanine board allows specification of 10G interface (SFP+)

System	Input IF BW	Output Channels[1]	Data Rates	Boot Options	VGOS Compliant
RDBE-G	512 MHz	16 | 32	2 | 4 Gbps (complex)	NFS, USB, SDRAM	No
R2DBE-G	2 GHz	16 | 32| 64	2 | 4 | 8 Gbps (complex)	NFS	Yes

Note 1: Configuration of ½ the output channels per polarization for the total number of output channels



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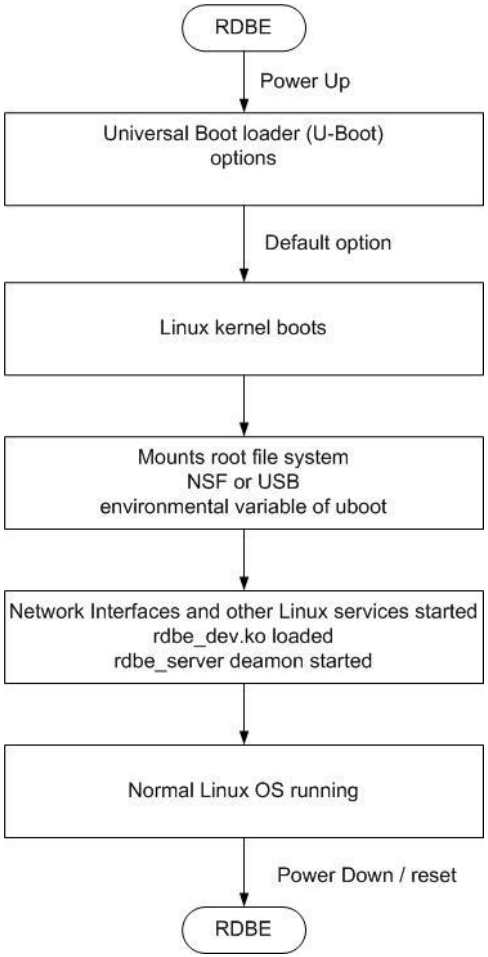
Bootup



- U-Boot options
  - Environment variables defining what the boot loader will execute
    - location of the kernel in flash (address)
    - location of the root file system
      - USB
      - NFS
      - SDRAM
      - bootp
    - Network configuration
      - Static
      - Dynamic
  - Details are beyond the scope of this talk
    - Detail documentation available if needed

Boot Up

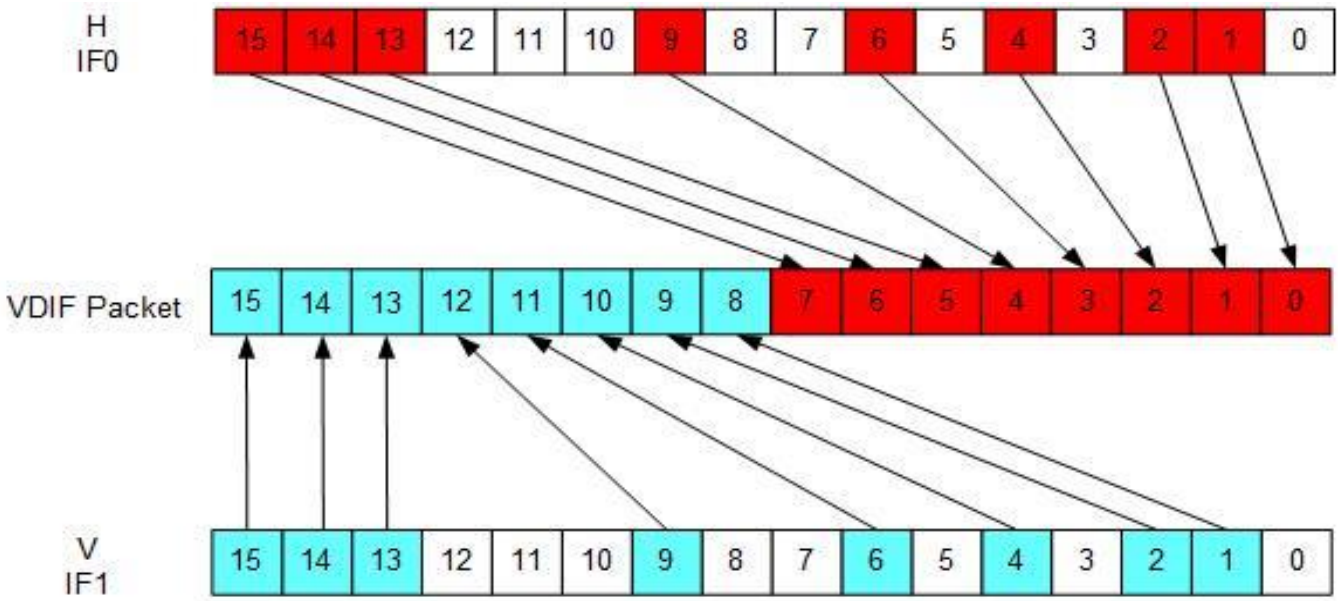
- RDBE
  - Boots from NFS, USB, SDRAM, bootp
  - rdbe_server loads and configures the FPGA personality
- R2DBE
  - ***Must*** boot from NFS
  - katcp used to load personality and calibrate FPGA
    - Performed manually at present
    - Automated configuration is being developed
  - Load the personality and configure
    - Channel selection

Operational Features

- RDBE-G is a standalone system that boots into a known operation configuration
  - Communication to the outside world is enabled
  - NTP daemon started
  - FPGA loaded
  - Persistent configuration for:
    - Interfaces (10G, network stack)
    - VDIF headers are configured
  - DOT time is synchronized
  - Data is enabled
- PCFS configures
    - Channels and other observation dependent parameters
    - Enables multicast

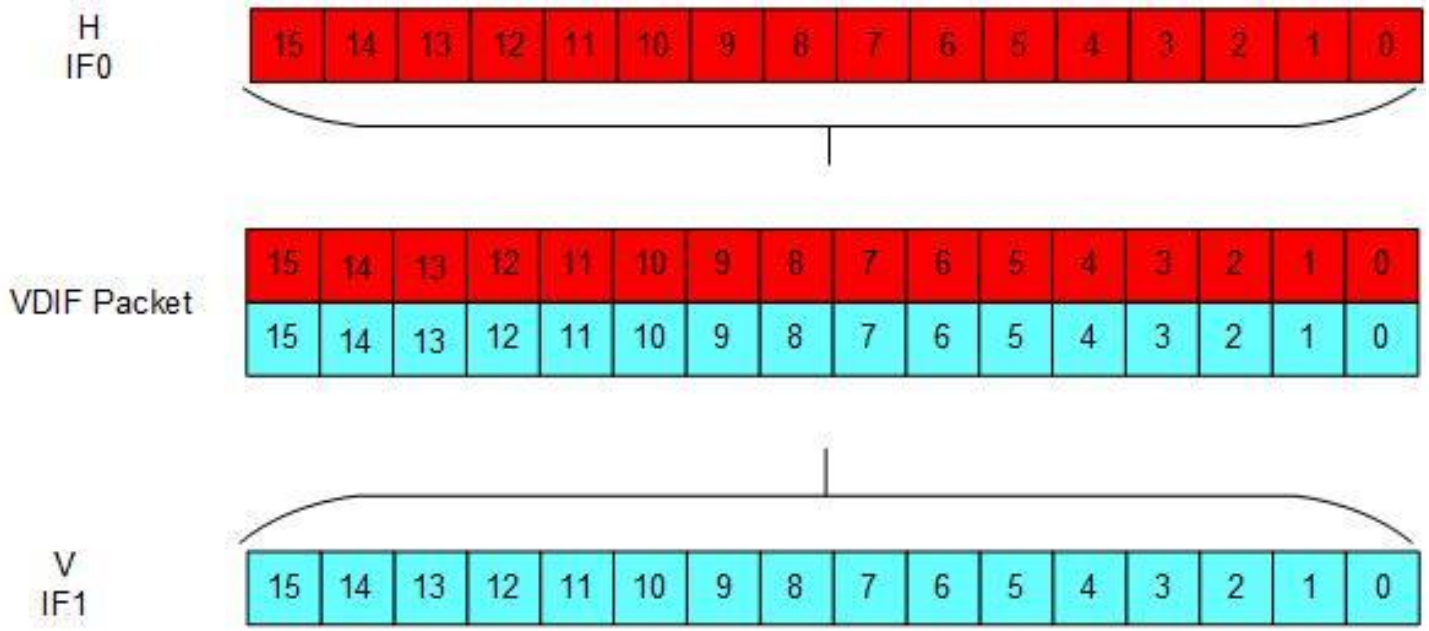
Legacy or RDBE-G Channel Output Configuration

- 16 channels total / IF
- 2 Gbps data rate / DBE resulting in 8 Gbps aggregate per scan (4 DBE's)

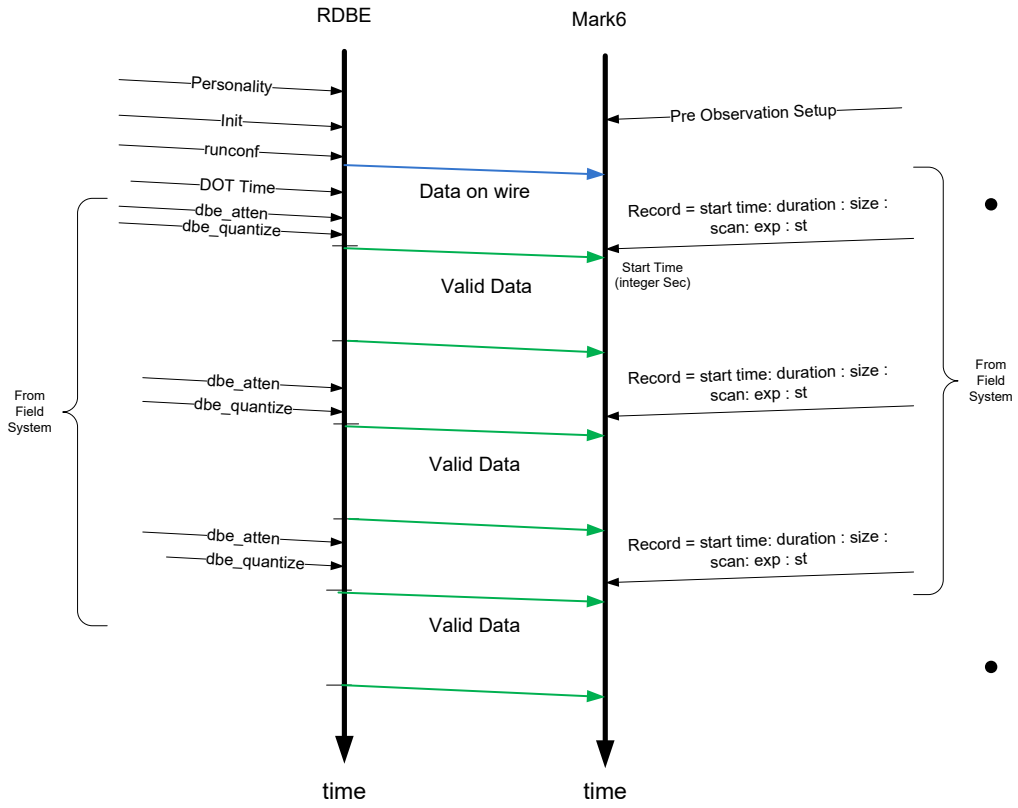


Legacy 32 RDBE-G Channel Configuration

- Disabling channel select results in all channels selected
  - 16 channels total / IF
  - 4 Gbps data / RDBE-G resulting in 16 Gbps per scan



RDBE-G Operation command / control flow



- Loading the FPGA personality
  - Located where the root file system is mounted
  - /home/roach/personalities
- Initialization
  - Setting the FPGA registers
  - Setting the DOT time
    - system time
    - manually
  - Quantization
    - Formats the filter bank channels at 2 bits / sample
  - Monitoring capabilities
- Set for normal operations
  - Transmitting data out CX4 interface
  - Status / etc.

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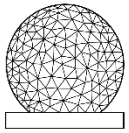
Operational Features

- R2DBE-G
  - Communication to the outside world is enabled
  - NTP daemon started
  - Requires user interaction (a script executed)
    - Loading personality
    - Synchronization of the ADC's
    - Persistent configuration 10G interface and VDIF headers
  - PCFS configures
    - Channels and other observation dependent parameters
    - Enables multicast
  - All commands related to channel information return full 64 channels for IF
- VSI-S software interface to system
  - RDBE-G Command set -> 3.0
  - R2DBE-G Command set -> 1.1.1



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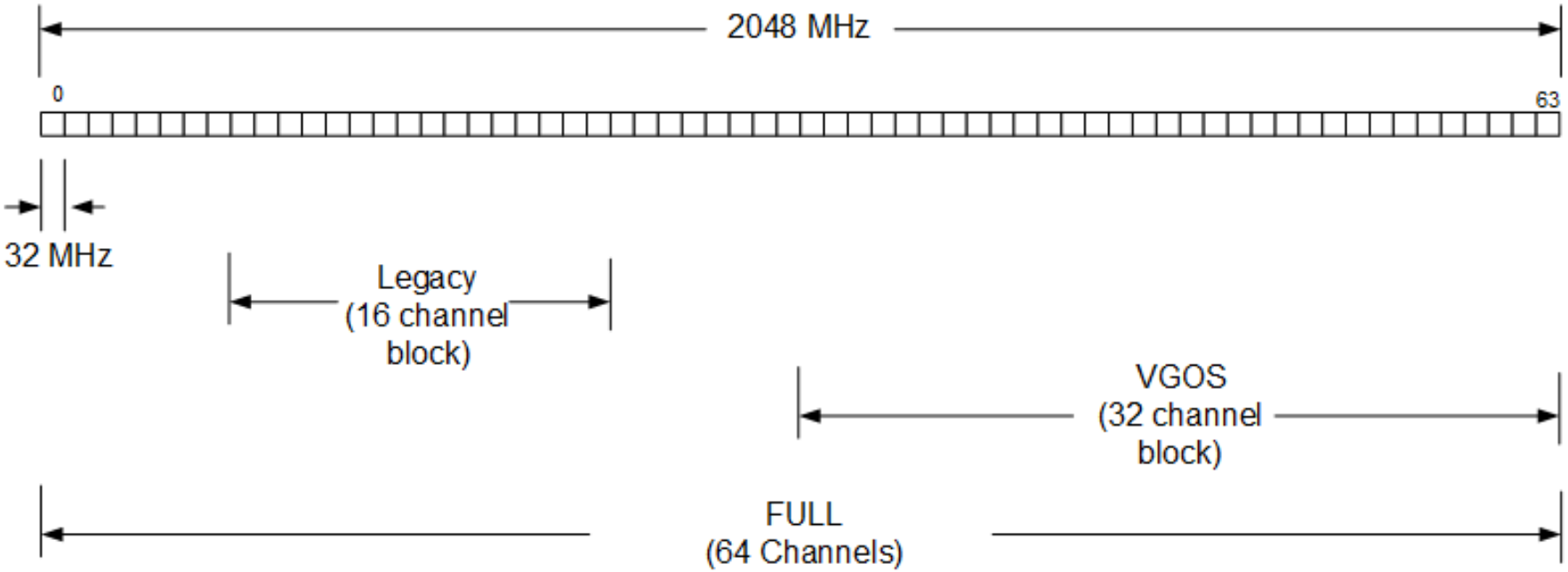
R2DBE-G Channel Configuration



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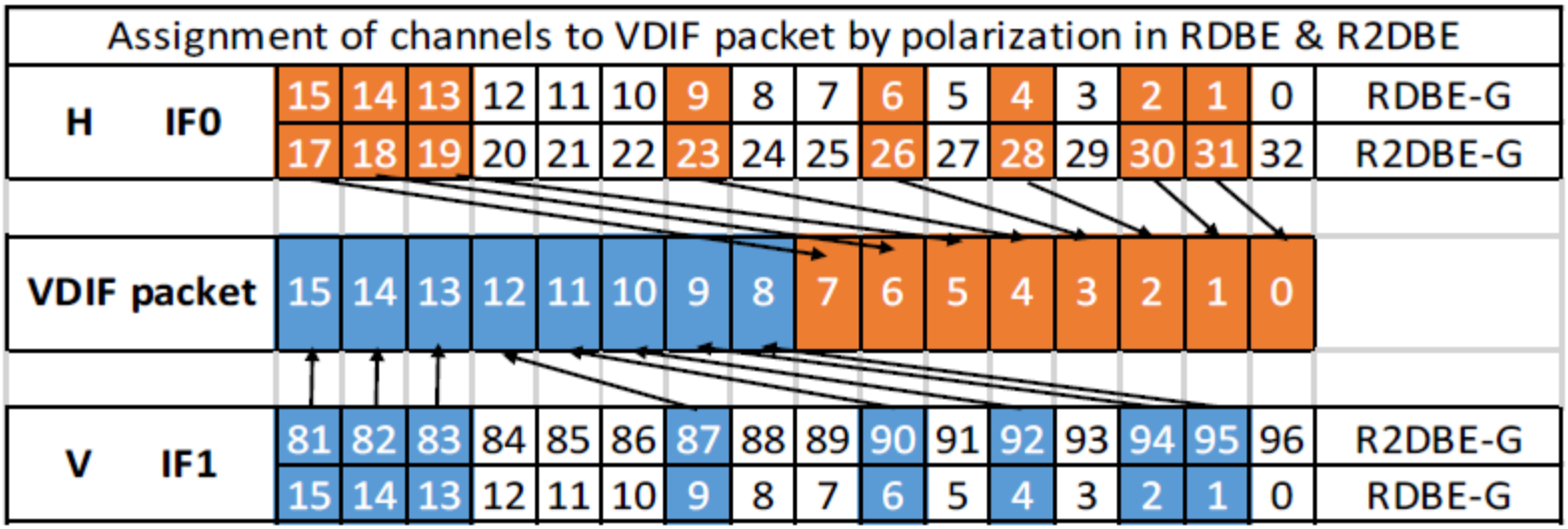
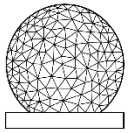
R2DBE Firmware

- 1 Personality type (FPGA code)
  - Polyphase filter bank
    - Input is two 2048MHz BW IFs
    - Output selects 16/32/64 of 128 possible 32-MHz channels (2Gbps/4Gbps/8Gbps)
    - Output is a 8224 byte VDIF data format
    - **Complex Data**
      - Standard 32 byte header
    - eVLBI VTP protocol available

Channel Selection Configuration



Band D	Start Sky Freq (MHz)	Stop Sky Freq (MHz)	1st LO Freq (MHz)	LO1 Synth Freq (MHz)	netLO (MHz)					
MGO RDBE	10200.4	10680.4	31172.4	7793.1	9672.4					
Westford R2DBE	10200.4	11208.4	32172.4	8043.1	9672.4					
	MGO RDBE (IF filter 528-1008 MHz & ADC sampling at 1024 MHz)					Wf R2DBE (IF filter 512-1536 MHz& ADC sampling at 4096 MHz)				
IF	Start Sky Freq (MHz)	Stop Sky Freq (MHz)	RDBE Start IF (LSB) MHz	RDBE Stop IF (LSB) MHz	RDBE PFB Channel Select	R2DBE Start IF (USB) MHz	R2DBE Stop IF (USB) MHz	R2DBE PFB Channel Select	Start Sky Freq (MHz)	Stop Sky Freq (MHz)
H pol 0	10696.4	10680.4	1024	1008	0	1008	1040	32	10680.4	10712.4
0	10680.4	10648.4	1008	976	1	976	1008	31	10648.4	10680.4
0	10648.4	10616.4	976	944	2	944	976	30	10616.4	10648.4
0	10616.4	10584.4	944	912	3	912	944	29	10584.4	10616.4
0	10584.4	10552.4	912	880	4	880	912	28	10552.4	10584.4
0	10552.4	10520.4	880	848	5	848	880	27	10520.4	10552.4
0	10520.4	10488.4	848	816	6	816	848	26	10488.4	10520.4
0	10488.4	10456.4	816	784	7	784	816	25	10456.4	10488.4
0	10456.4	10424.4	784	752	8	752	784	24	10424.4	10456.4
0	10424.4	10392.4	752	720	9	720	752	23	10392.4	10424.4
0	10392.4	10360.4	720	688	10	688	720	22	10360.4	10392.4
0	10360.4	10328.4	688	656	11	656	688	21	10328.4	10360.4
0	10328.4	10296.4	656	624	12	624	656	20	10296.4	10328.4
0	10296.4	10264.4	624	592	13	592	624	19	10264.4	10296.4
0	10264.4	10232.4	592	560	14	560	592	18	10232.4	10264.4
0	10232.4	10200.4	560	528	15	528	560	17	10200.4	10232.4
The 8 channels selected for VGOS correlation are accented by color										
*H-pol RDBE Channel 0 & corresponding R2DBE channel 32 are not used due to RDBE PFB#0 being only halfband										
	MGO RDBE (IF filter 528-1008 MHz & ADC sampling at 1024 MHz)					Wf R2DBE (IF filter 512-1536 MHz& ADC sampling at 4096 MHz)				
IF	Start Sky Freq (MHz)	Stop Sky Freq (MHz)	RDBE Start IF (LSB) MHz	RDBE Stop IF (LSB) MHz	RDBE PFB Channel Select	R2DBE Start IF (USB) MHz	R2DBE Stop IF (USB) MHz	R2DBE PFB Channel Select	Start Sky Freq (MHz)	Stop Sky Freq (MHz)
V pol 1	10696.4	10680.4	1024	1008	0	1008	1040	96	10680.4	10712.4
1	10680.4	10648.4	1008	976	1	976	1008	95	10648.4	10680.4
1	10648.4	10616.4	976	944	2	944	976	94	10616.4	10648.4
1	10616.4	10584.4	944	912	3	912	944	93	10584.4	10616.4
1	10584.4	10552.4	912	880	4	880	912	92	10552.4	10584.4
1	10552.4	10520.4	880	848	5	848	880	91	10520.4	10552.4
1	10520.4	10488.4	848	816	6	816	848	90	10488.4	10520.4
1	10488.4	10456.4	816	784	7	784	816	89	10456.4	10488.4
1	10456.4	10424.4	784	752	8	752	784	88	10424.4	10456.4
1	10424.4	10392.4	752	720	9	720	752	87	10392.4	10424.4
1	10392.4	10360.4	720	688	10	688	720	86	10360.4	10392.4
1	10360.4	10328.4	688	656	11	656	688	85	10328.4	10360.4
1	10328.4	10296.4	656	624	12	624	656	84	10296.4	10328.4
1	10296.4	10264.4	624	592	13	592	624	83	10264.4	10296.4
1	10264.4	10232.4	592	560	14	560	592	82	10232.4	10264.4
1	10232.4	10200.4	560	528	15	528	560	81	10200.4	10232.4
The 8 channels selected for VGOS correlation are accented by color										
*V-pol RDBE Channels 0 & corresponding R2DBE channel 96 are not used due to RDBE PFB#0 being only halfband										



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R2DBE-G Software Updates

- Originally the R2DBE-G was not backward compatible
  - 64 channel information / IF
  - Limited resources resulted in support not available for:
    - Pointing (Tsys)
    - Multicast processing
- New FPGA personality (under test)
  - dbe4t_2025_Mar_30_1622.bof
    - Tsys update – how it is generated (the number of bits)
  - Fringe test with GGAO completed
  - Executed for V05120 observing session
    - Waiting for correlation report of session

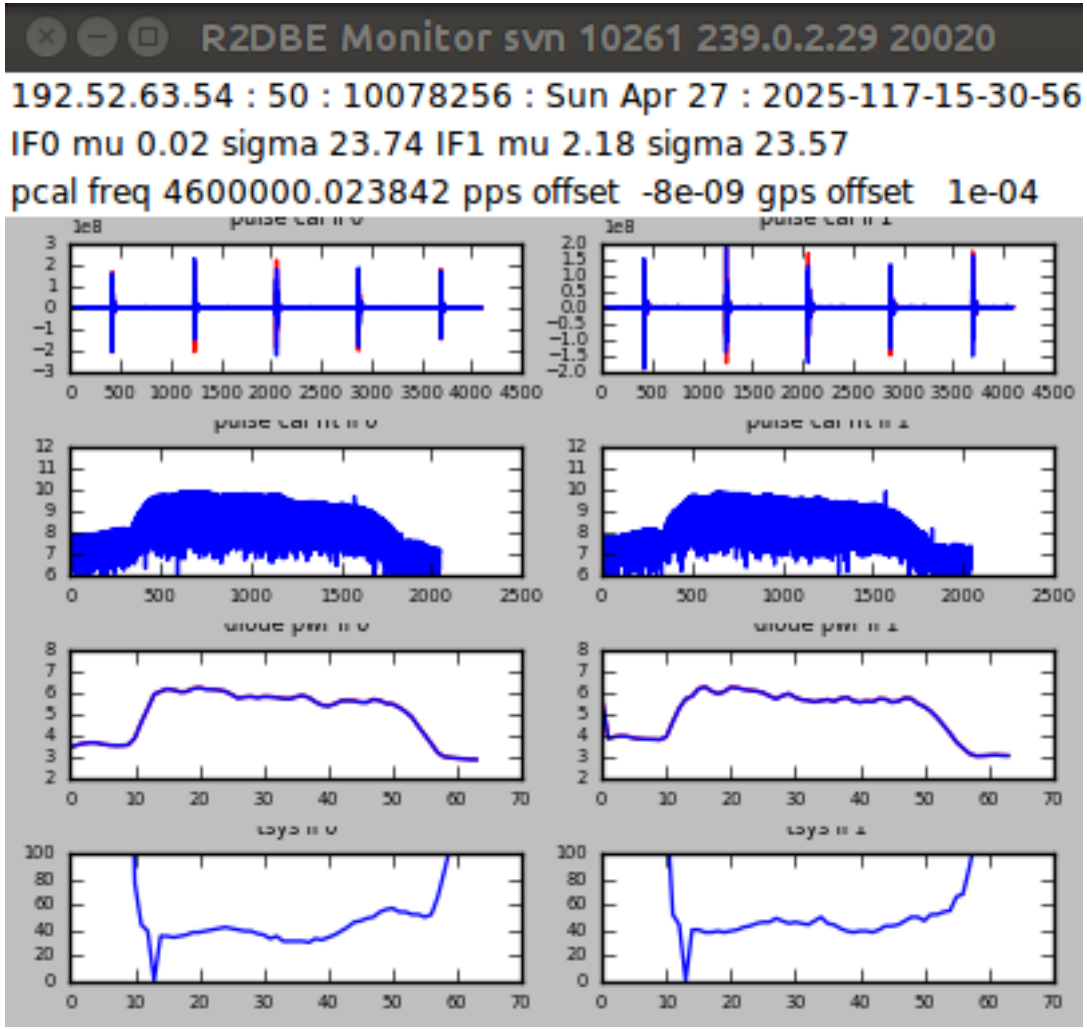
R2DBE-G Software Updates

- New rdbe_server code
  - Version 3.2 (SVN 10190)
    - Update for tsys
    - Multicast updated
- Requires new version (10.3 or 10.4) of FS
  - Provides SEFD for all 4 bands
  - Pointing check
  - Testing required for full release – in discussions with Ed Himwich
- R2DBE documentation and release package under construction
  - **Release date Mid June 2025**

Monitoring Capabilities

- 1pps monitoring
  - Multcast monitoring data broadcast 1 per second (1pps)
  - dbe_1pps_mon = <enable> : <multicast IP address> : <port>;
  - Use r2dbe_mon.py on a system attached to same network to receive multicast data
    - Working with PCFS for processing information
  - Tsys monitoring
    - System temperature measurement all 64 channels / pol
    - On power / off power of the receive chain
    - tsys data is summed every second
  - ***Raw Capture Mode – Removed from R2DBE***

R2DBE multicast monitoring



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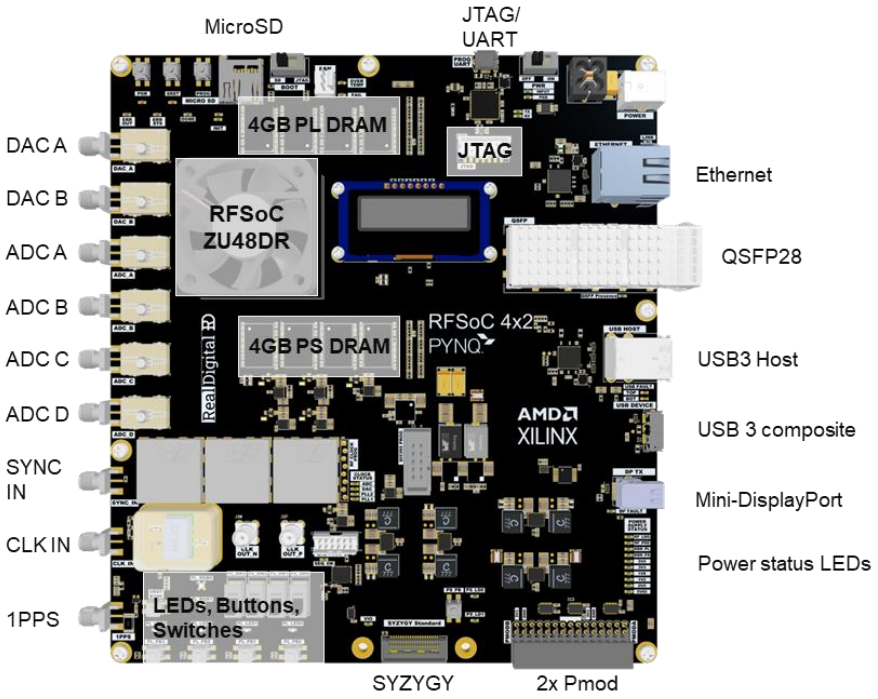
Next steps - DBE Version 5

- DBEv5 was developed to be a drop-in replacement for DBEv4 (R2DBE)
- Based on the RF system on a chip (RFSoC) 4x2 chip set
- Utilizes a ported:
  - R2DBE FPGA personality
  - rdbe_server
- Requires 100Gbps / 10Gbps network switch between existing Mark6's



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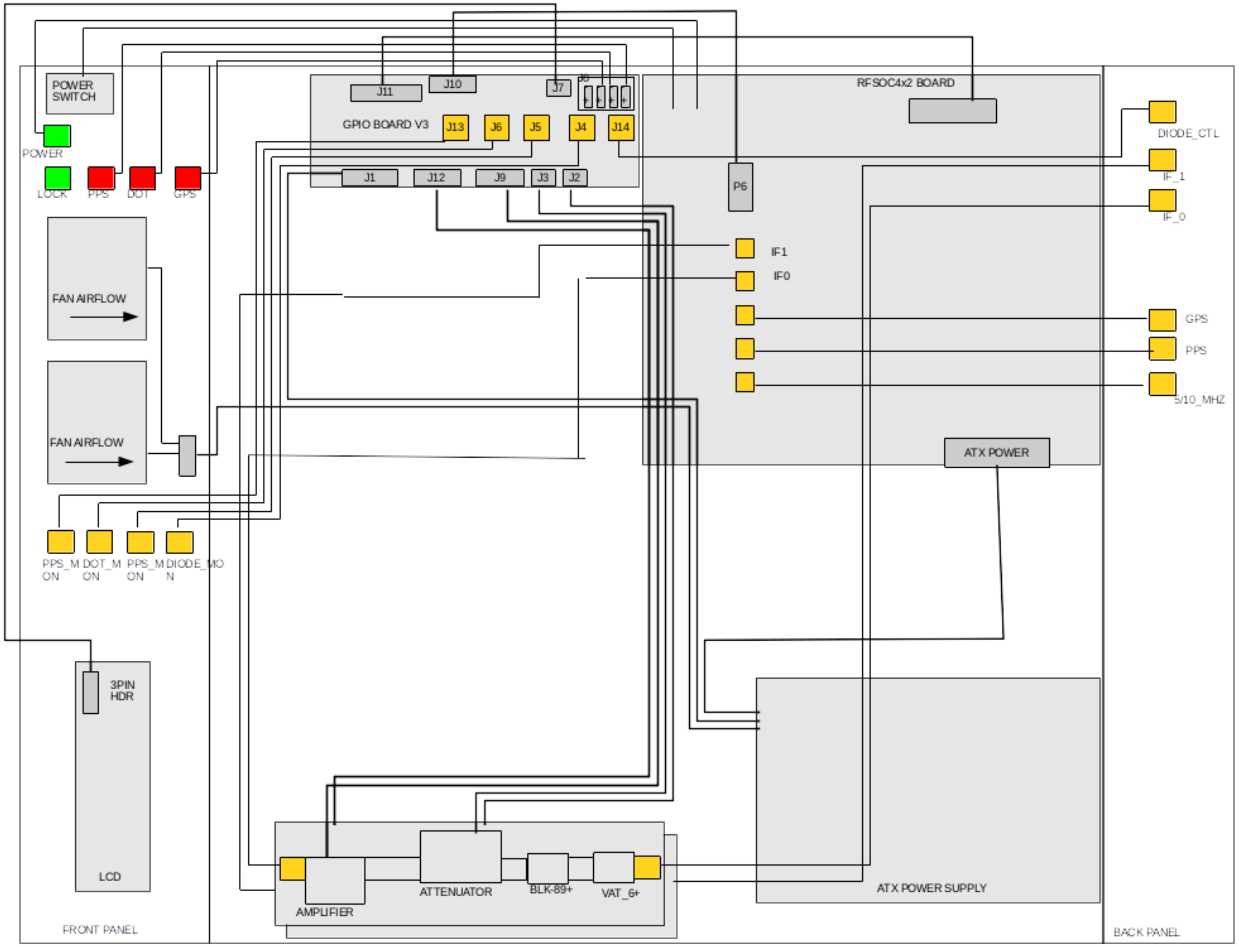
DBEv5 Layout



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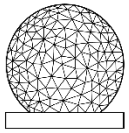
DBEv5 (cont)

- Engineering prototype built
  - On display at the front with V3 (RDBE) / V4 (R2DBE) / V5
  - Single RFSOC / chassis
    - Can update to 2 per chassis
- Expanded FPGA features expected
  - To support other NASA programs
- Will work with Digicom for release to general public
  - Date and Cost TBD

Questions on presentation or operational problems?

Thank you



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