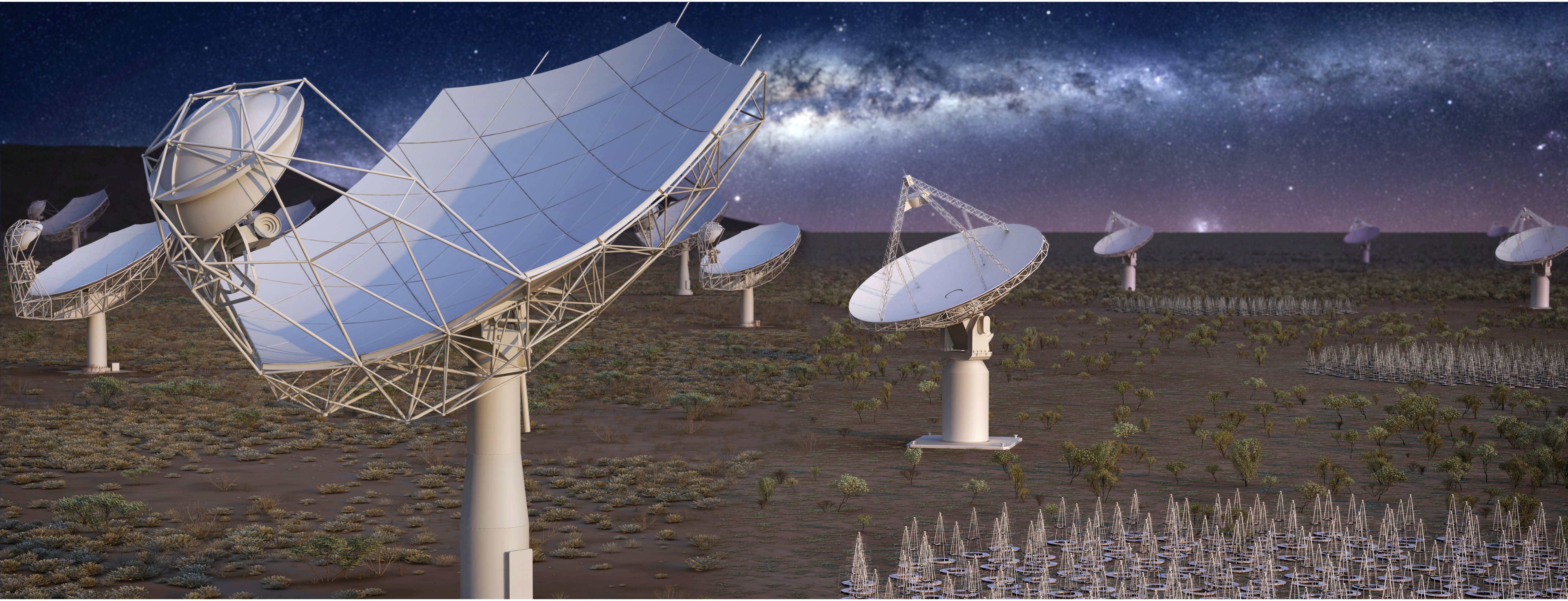
SKA Signal Chain Performance



SQUARE KILOMETRE ARRAY

B. Alachkar

26/11/2019

Topics

1. Scope of the Signal Chain Analysis
2. Performance of the Low Signal Chain
3. Performance of the Mid Signal Chain
4. Signal Chain Models

Two Teams - Contributors

SKA Signal Chain for Low	
SKAO INAF CSIRO UMAN Swinburne MDA	

SKA Signal Chain for Mid	
SKAO SARAO Chalmers NRC CSIRO UMAN Swinburne MDA	

Low and Mid Signal Chain

System CDR Documents

Signal Chain for Low:
SKA-TEL-SKO-0000793

SKA1 SIGNAL CHAIN FOR THE LOW TELESCOPE

Document Number SKA-TEL-SKO-0000793
Document Type .... DRE
Revision 01
Author .... B. Alachkar
Date 2019-10-15
Document Classification .... FOR PROJECT USE ONLY
Status .... Released

Name	Designation	Affiliation	Signature
Authored by:			
B. Alachkar	Domain Specialist	SKAO	Date: 2019-10-16
Owned by:			
L. Stringhetti	Project Engineer	SKAO	Date: 2019-10-16
Approved by:			
L. Stringhetti	Project Engineer	SKAO	Date: 2019-10-16
Released by:			
J. McMullin	Head of Project	SKAO	Date: 2019-10-17

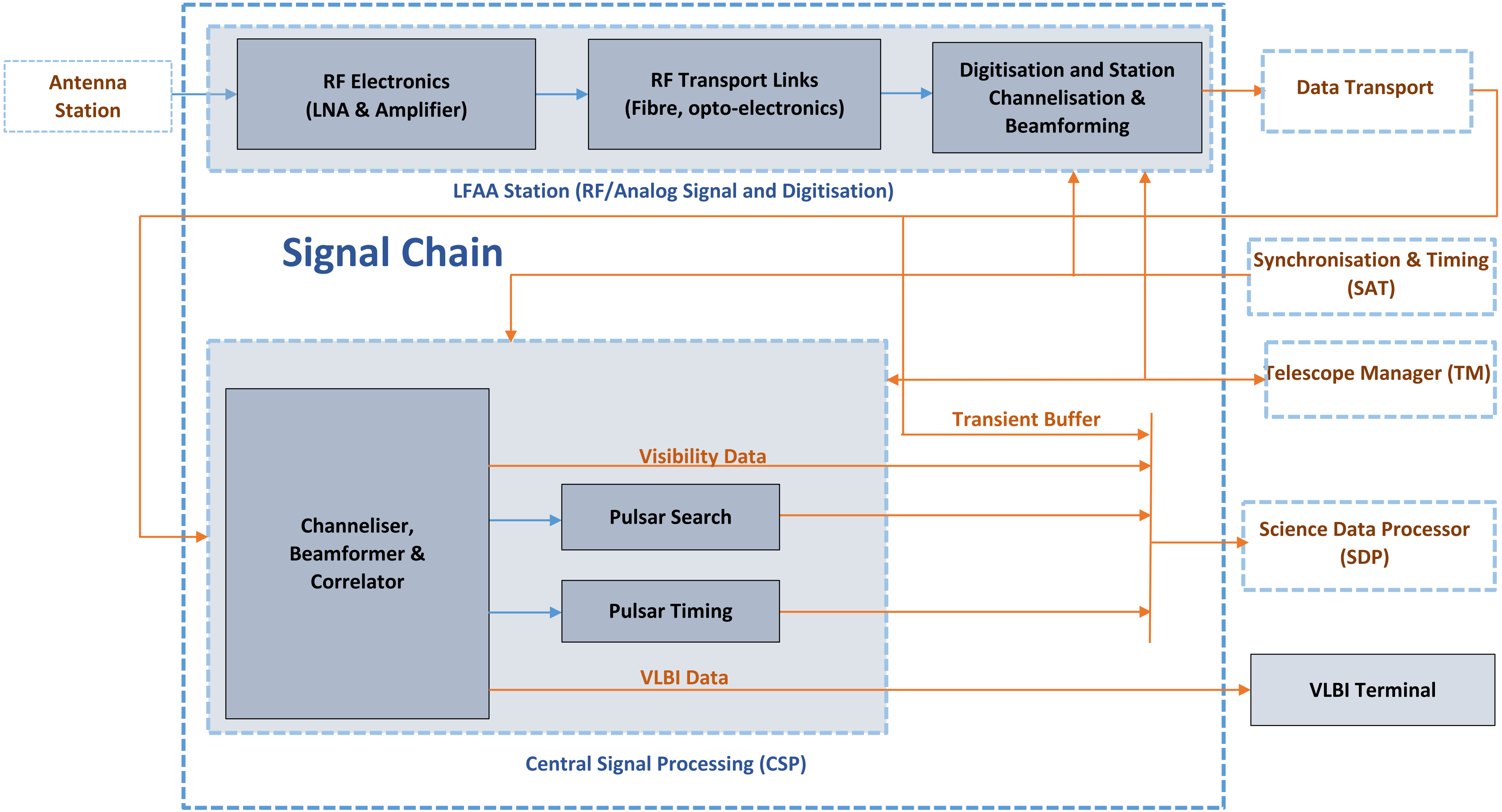
Signal Chain for Mid:
SKA-TEL-SKO-0000790

SKA1 SIGNAL CHAIN FOR THE MID TELESCOPE

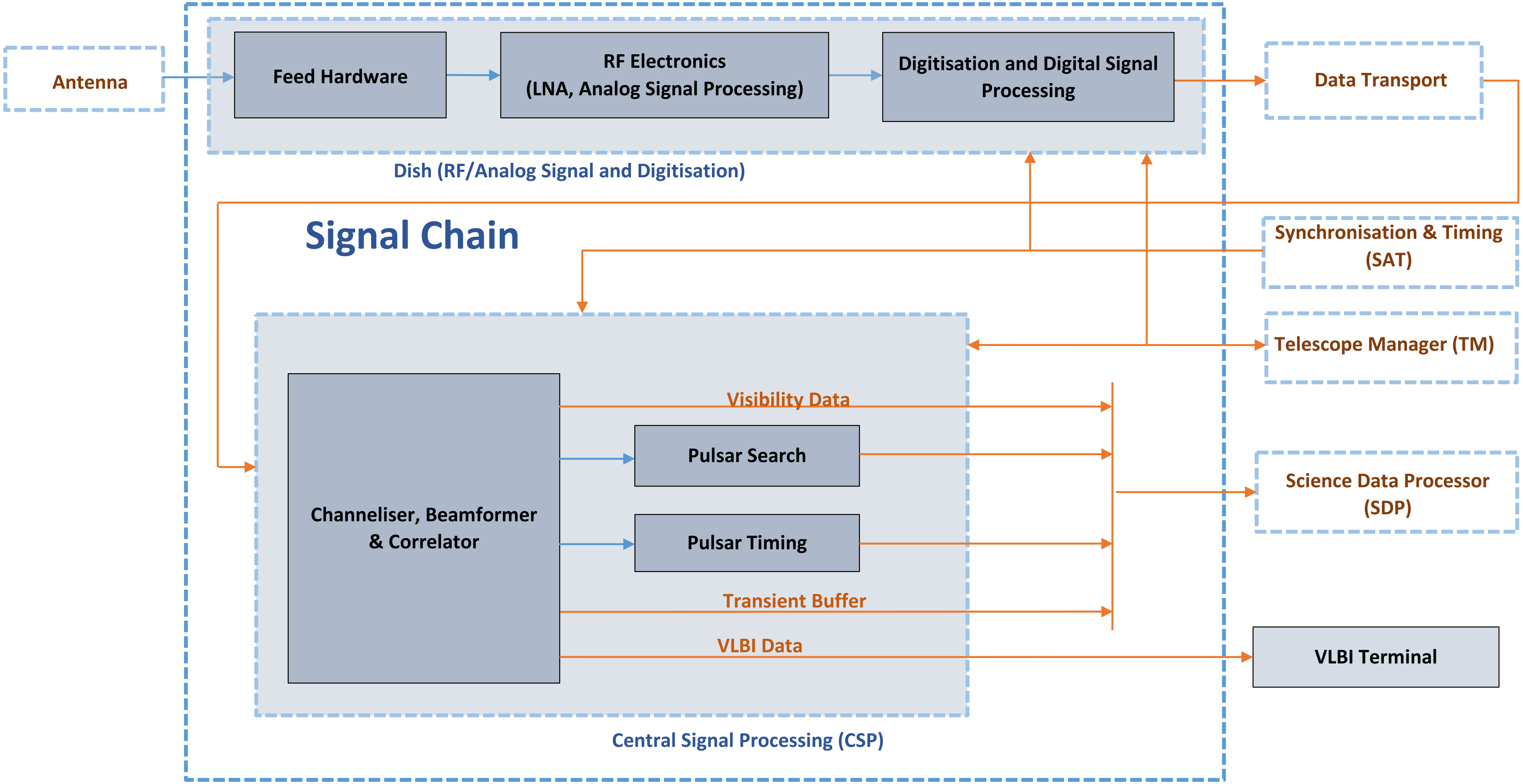
Document Number SKA-TEL-SKO-0000790
Document Type .... DDR
Revision 01
Author .... B. Alachkar
Date 2019-10-17
Document Classification .... FOR PROJECT USE ONLY
Status .... Released

Name	Designation	Affiliation	Signature
Authored by:			
B. Alachkar	Domain Specialist	SKAO	Date: 2019-10-18
Owned by:			
L. Stringhetti	Project Engineer	SKAO	Date: 2019-10-18
Approved by:			
L. Stringhetti	Project Engineer	SKAO	Date: 2019-10-18
Released by:			
J. McMullin	Head of Project	SKAO	Date: 2019-10-19

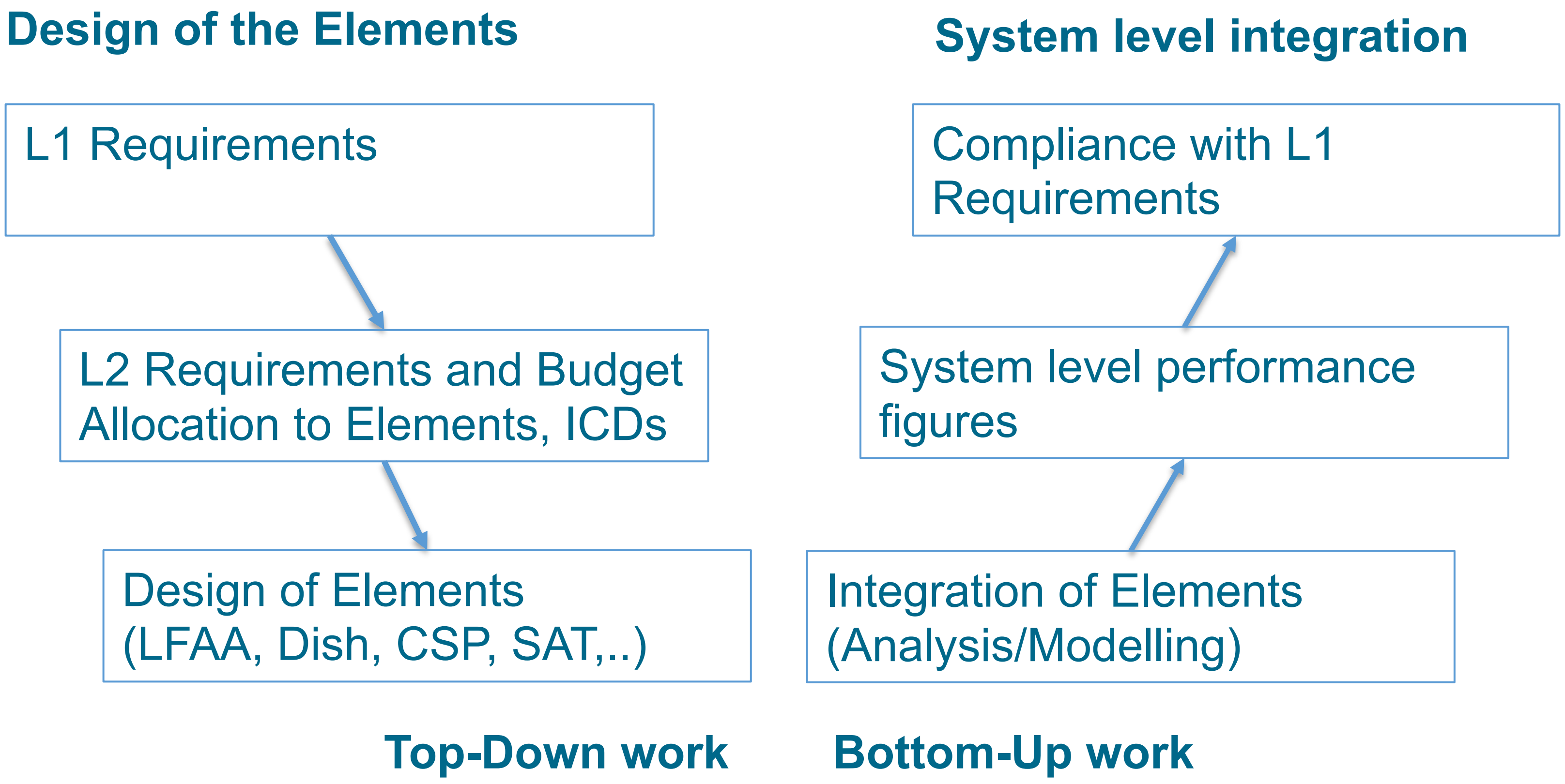
Signal Chain Scope (Low)



Signal Chain Scope (Mid)



System View of the Signal Chain



The Work Approach

Grouping the L1 Signal Chain performance Requirements in Performance Categories

→

Integrating Analysis and Modelling For each Performance Category

→

Compliance with the L1 requirements?

Performance categories:

- Linearity
- Frequency response
- Impulse response
- Coherence, Timing Accuracy, and Jitter
- Signal to Noise Ratio
- RFI Effects and Flagging
- Cross Polarisation
- Systematic Errors and Stability

The outcome of the Analysis and Modelling:
Numerical figures describing the Signal Chain Performance
Based on the Design of the Elements, results of Testing of some parts of the elements, Simulation, and Integrating the Element Models.

Compliance based on the Analysis

The results will be validated by verification and testing on integrated prototypes
These activities are already taking place

General Assessment

- **No critical issues of non compliance with the L1 requirements** relevant to the Signal Chain.
- Some L1 requirements involve aspects that are beyond the scope of the Signa Chain analysis:
  - The analysis **does not consider directional effects** (pointing and beam pattern)
  - The analysis **does not include the calibration process**.
- Some **assumptions** made are to be considered in the L1 Rev 12. This includes some interpretation of the current requirements.
- The results will be **validated by more testing on prototypes** on integrated parts.

Performance of the Low Signal Chain

Low Signal Chain Performance

Linearity

Non-linearity (as other errors and imperfections on the Signal Chain) affects the Dynamic Range and Sensitivity of the telescope.

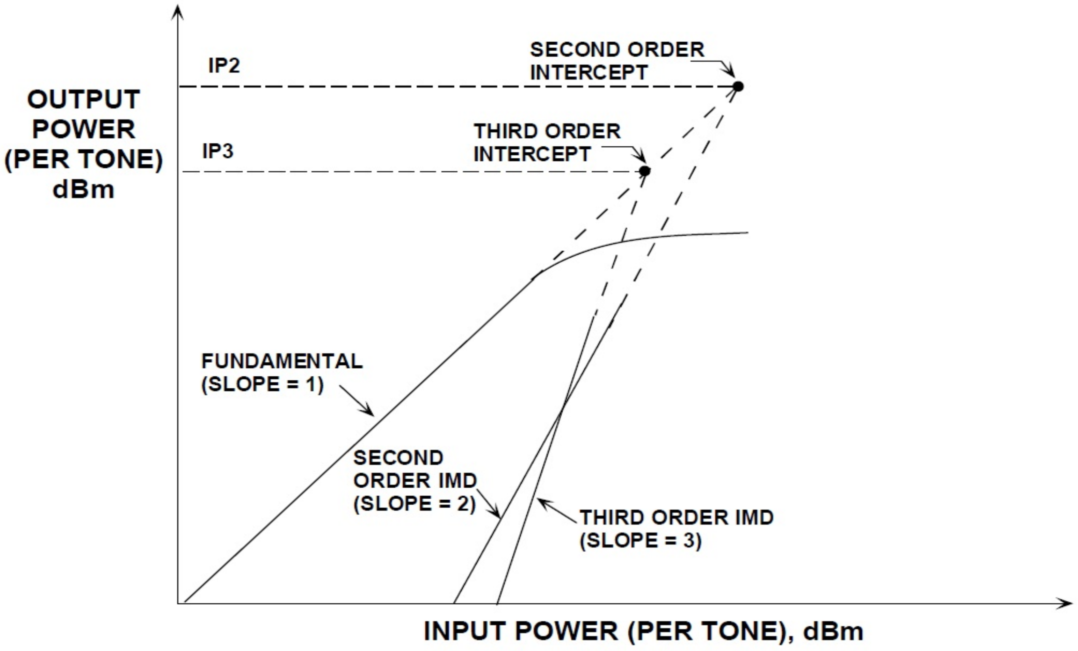
Non-linearities are manifested in:

- Intermodulation products generated in the analogue chain (LNA, other amplifiers, and RFoF) and in the digitisation (ADC: clipping and quantisation).
- Nonlinear behaviour in the correlation (generated by the digitization and requantisation, offsets in the correlation process generated by rounding processes).

Low Signal Chain Performance

Linearity

- Nonlinearities are usually described in terms of the IP2 and IP3 parameters which are linked respectively to the quadratic and cubic terms in the transfer function.
- The 1 dB compression point describes the gain dependency on the signal power level. All components in the chain are operated well below the compression, and gain variations are negligible.



Nonlinearity parameters for the LFAA analogue chain

Total gain (100 MHz)	84	dB
Output level (operating, typical)	-2.7	dBm
OIP2	49	dBm
OIP3	33	dBm
1 dB compression point	18	dBm

Low Signal Chain Performance

Linearity and RFI

The L1 Linearity requirement **SKA1-SYS_REQ-2653** ("The level of spurious products generated by the SKA1_Low, in the presence of signals representative of the expected RFI environment, shall degrade the expected thermal noise floor of a 1000 hour integration by no more than 10%.")

The system must behave linearly when RFI is present, with data flagged when RFI power exceeds the linearity region. This depends on RFI statistics. RFI flagging should not **clip (flag)** more than 5% of the data (SKA-SYS_REQ-2639) .

Analysis on RFI use cases derived from site observations showed that the noise induced by intermodulation products of RFI signals is close to the requirement limit and exceeds it by a small margin in some portions of the spectrum.

Compliance is also dependent on adequate flagging of RFI in SDP.

Low Signal Chain Performance

Flagging

- Detecting when the signal level increases to a point when nonlinear effects become likely
- Flagged samples are set to the most negative value in the signed representation used (-128 for 8 bit), with remaining values representing an unbiased set of valid values (-127:+127 for 8 bit).
- This leaves an equal number of positive and negative values in the representation avoiding a possible bias.

Clipping

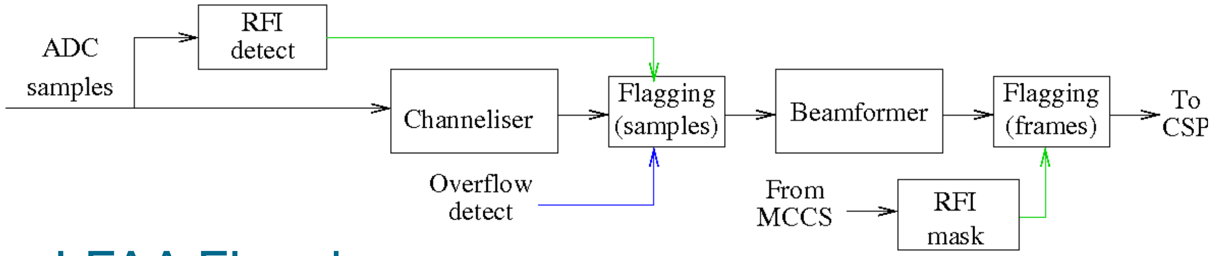
- The signal is clipped if its value exceeds the representable range.
- At the output of the LFAA, samples are clipped (set to the maximum or minimum representable value) when they exceed the range which can be represented with the integer representation used.
- In LFAA and CBF, where there is a reduction in bit width, for example to the correlation function (16 to 8 bits) the data may be clipped. If this occurs the data is flagged.

Low Signal Chain Performance

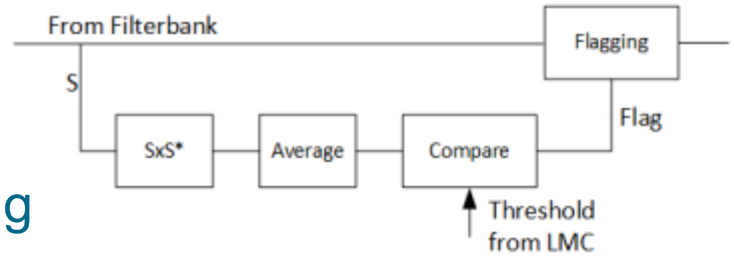
RFI Effects and Flagging-Flagging Mechanisms

4 levels of RFI Flagging :

- Detection of total power excess in data digitised by the ADC in LFAA
- Coarse channel power in the LFAA (for hard truncation/clipping).
- Detection of total power excess in Fine channel power in the CSP-CBF (adjustable parameters).
- Fine channel data transport (to correlator and beamformer) (for hard truncation only/clipping).



LFAA Flagging



CSP Flagging

Adjustable thresholds defined by TM

Low Signal Chain Performance

RFI Effects and Flagging

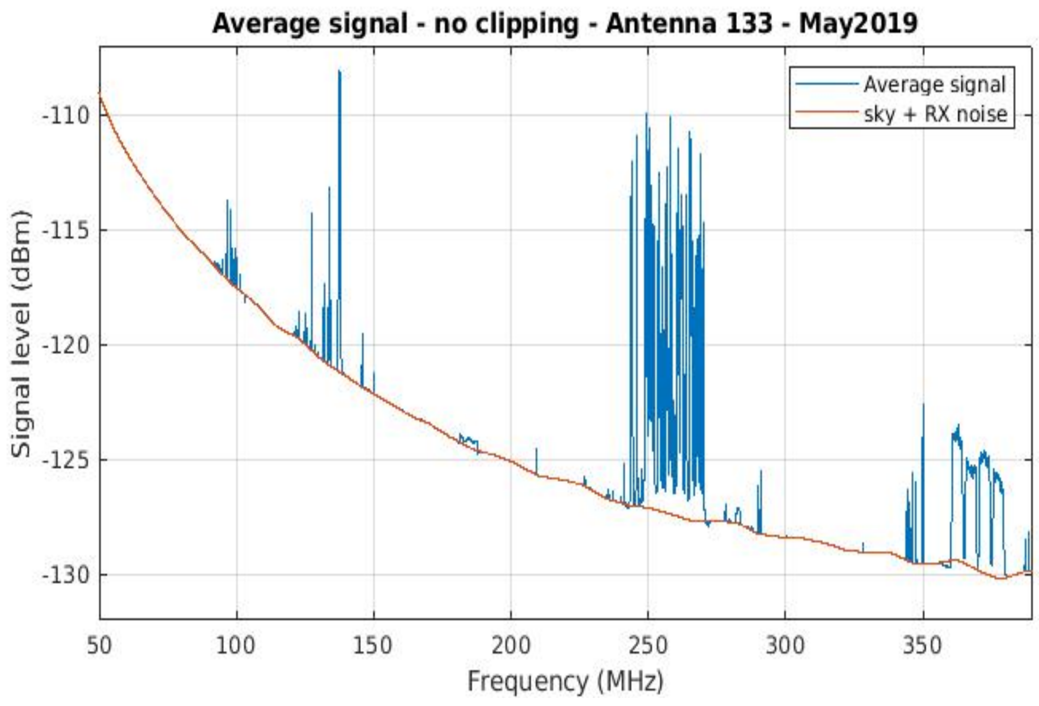
Three main types of RFI:

- **Persistent RFI** on the time scales of 1 second or more, e.g. satellites, ducted broadcast emission and airplane communications (bandwidth of the order of the resolution bandwidth and greater).
- **Transient RFI** on time scales less than 1 second, (e.g. lightning).
- **Narrow band RFI** which is normally due to leakage of clock internal to the telescope (bandwidth much less than the resolution bandwidth).

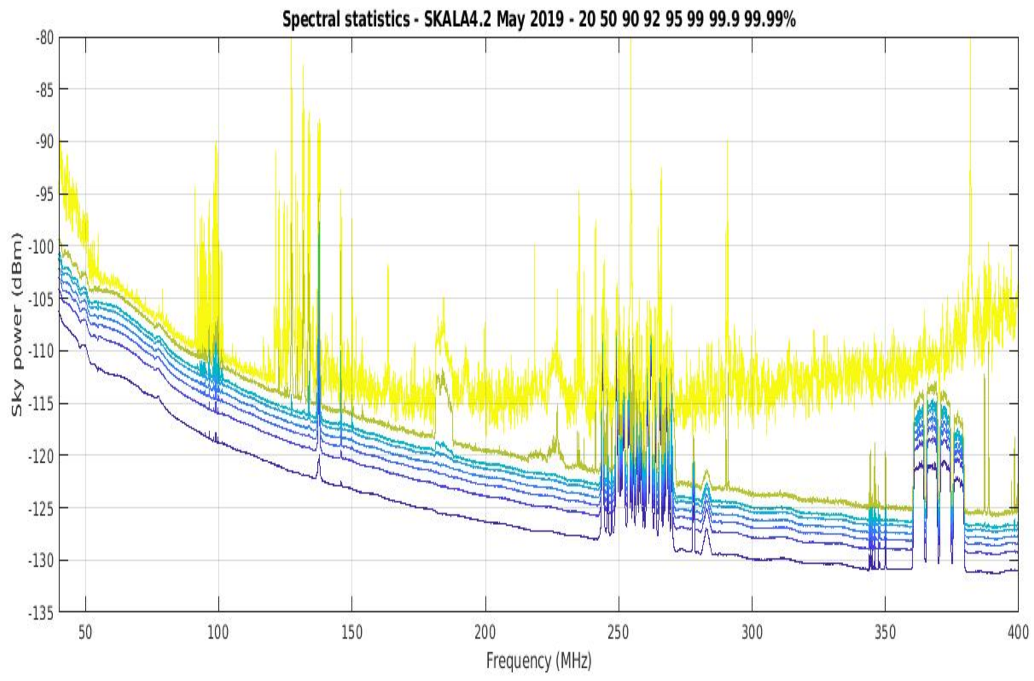
Low Signal Chain Performance

RFI Effects and Flagging- RFI Environment

The RFI environment in the SKA1_Low site description is based on several measurements conducted in recent years.



Average spectrum of sample segments not exceeding clipping value - X polarisation.



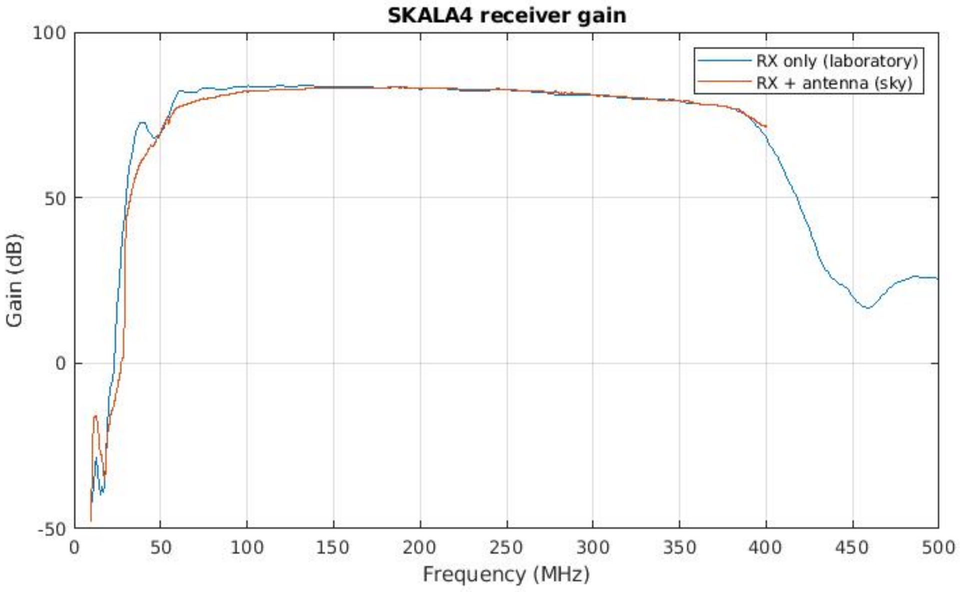
RFI levels at Percentiles: Spectra of signal level at 20%, 50% , 90% ,95%, 99%, 99.9% and 99.99% probability.

Low Signal Chain Performance

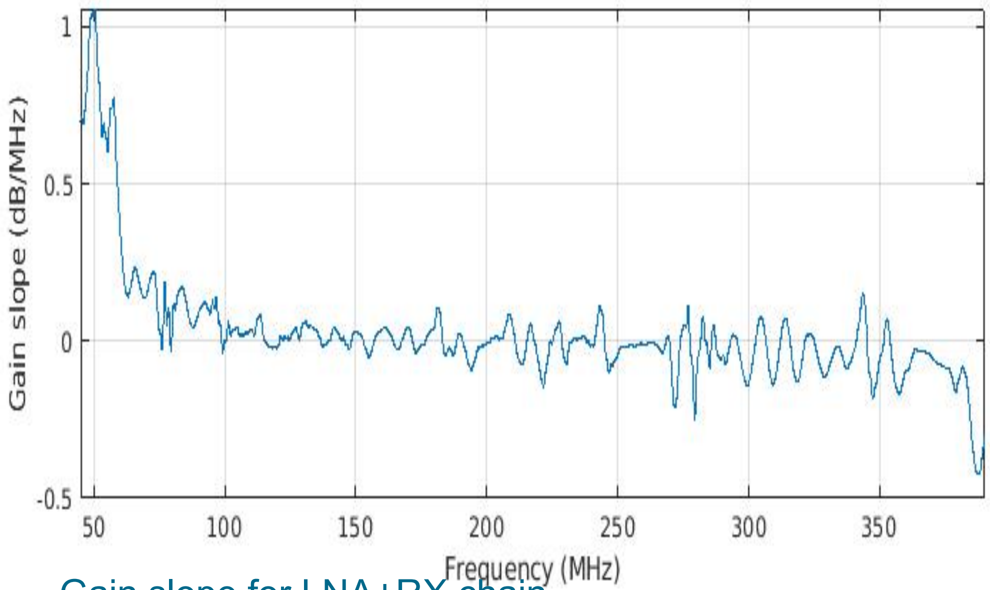
Frequency Response

Frequency response is determined by the cascaded responses of:

- LNA, high-pass filter to remove unwanted shortwave RFI, and the anti-aliasing low-pass filter.
- LFAA polyphase filterbank frequency response.
- CSP channelisers frequency response. Separate channelisers are used for imaging, Pulsar Search, Pulsar



Gain of the RX chain and of the whole SKALA4 antenna-receiver



Gain slope for LNA+RX chain

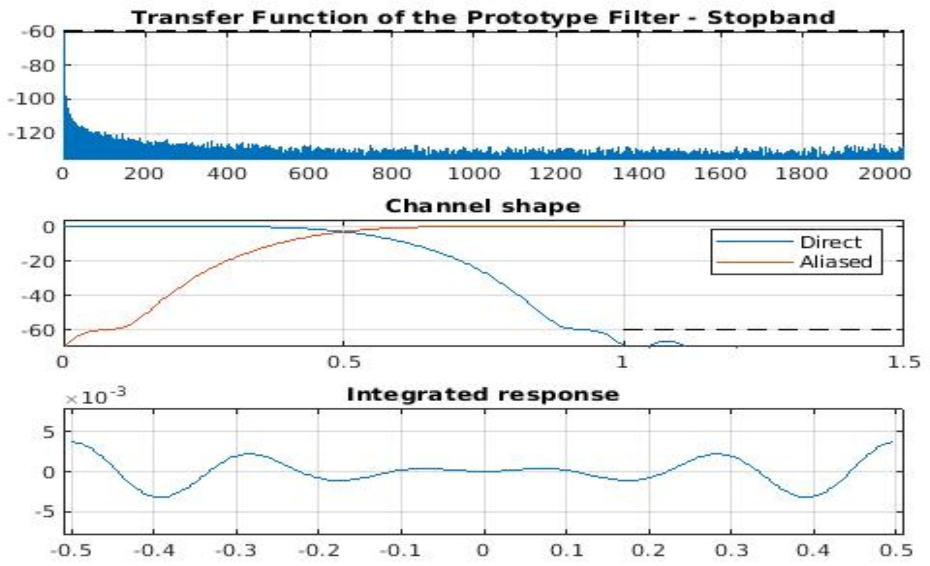
Low Signal Chain Performance

Frequency Response - Channelisation frequency response

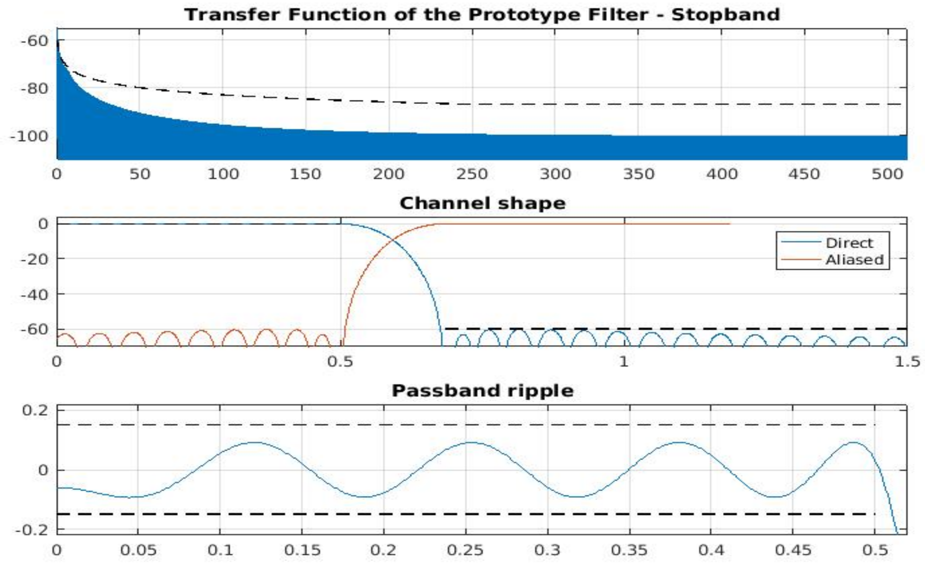
Imaging channeliser: minimum **stopband attenuation is 65dB**, at the middle of the adjacent channel, 100dB after a few channels. **Spectral flatness +/- 0.005dB**.

PSS channeliser minimum **stopband attenuation is 85dB**, **spectral flatness +/- 0.04dB**.

PST channeliser minimum **stopband attenuation is 79dB.**



Frequency response of the LFAA



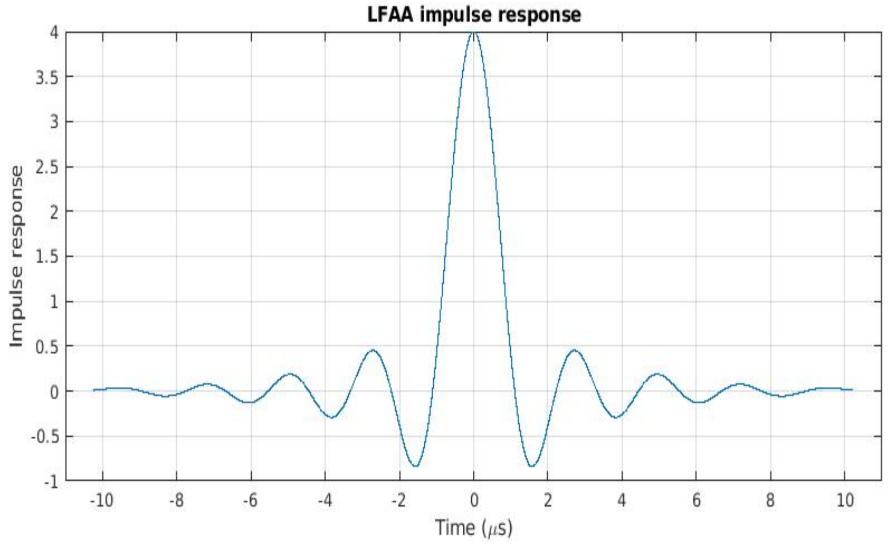
Frequency response CSP imaging channeliser

Low Signal Chain Performance

Impulse Response

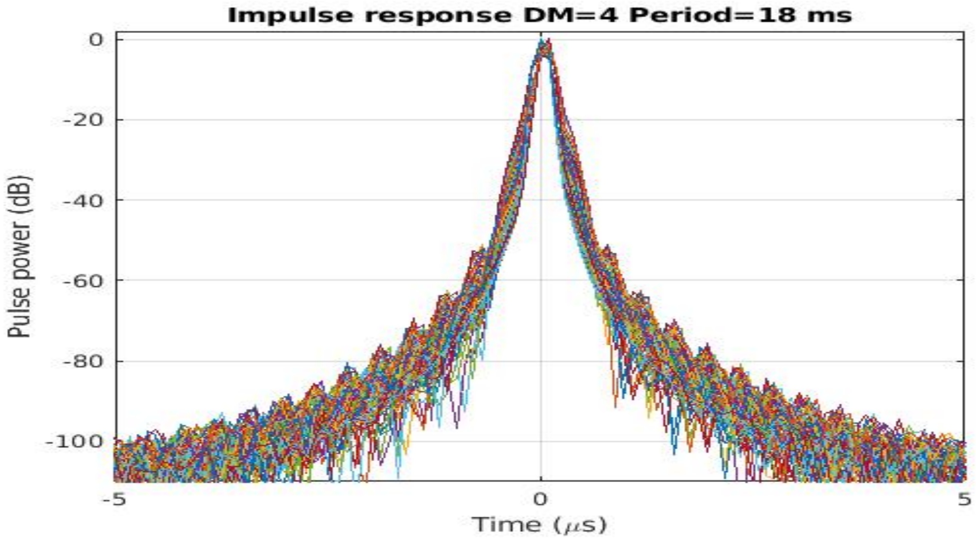
Impulse response is relevant for time domain analysis. This applies to Pulsar Search, Pulsar Timing, and transient analysis.

Impulse response is mainly determined by the CSP PSS and PST channeliser



LFAA Impulse Response

Most of the power (90%) is contained in the central $\pm 0.7\ \mu s$of the response.

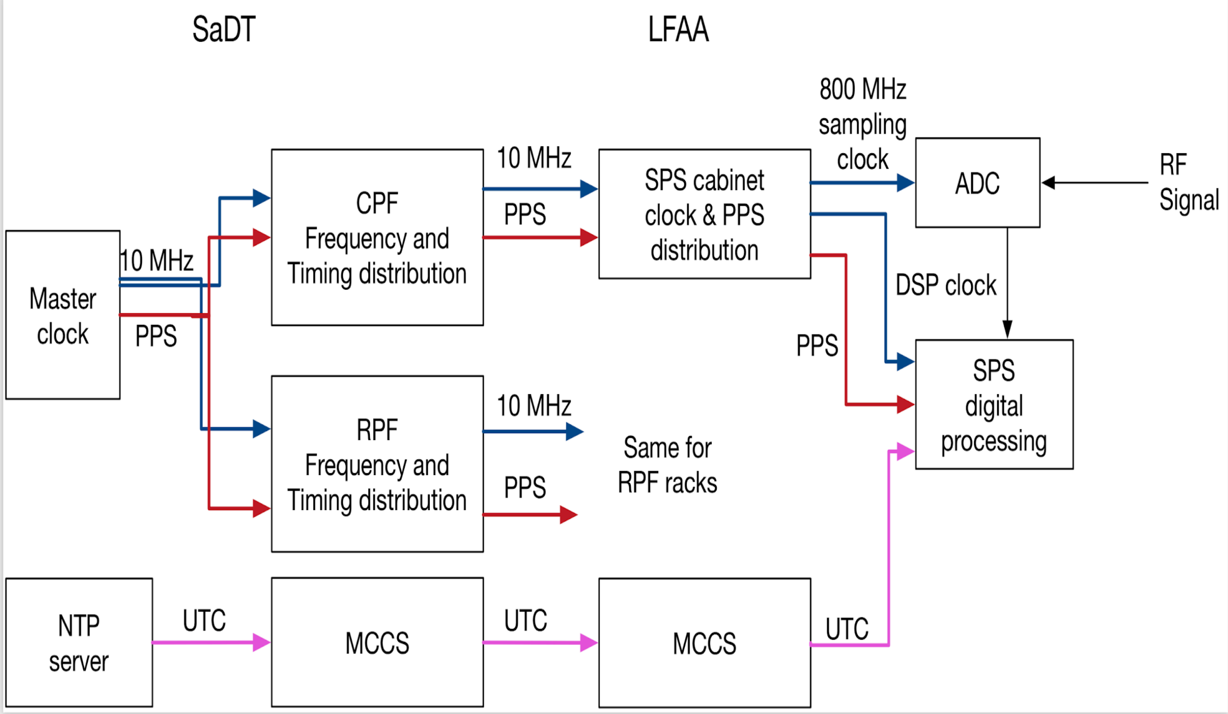


Simulated PST impulse response (folded pulses) synthesized bandwidth of 9 MHz, DM=4 $cm^{-3}pc$

Low Signal Chain Performance

Coherence, Timing Accuracy, and Jitter

The Synchronisation and Timing (SAT) system provides frequency and timing signals to the LFAA stations.



Frequency and Time distribution

Expected Performance of Coherence Loss and Jitter

Coherence Loss 1s	<0.001%
Coherence Loss 60s	<0.01%
Linear Phase Drift 10min	3.5 millirad over 30km link
Sampling Clock Jitter	308 fs

Low Signal Chain Performance

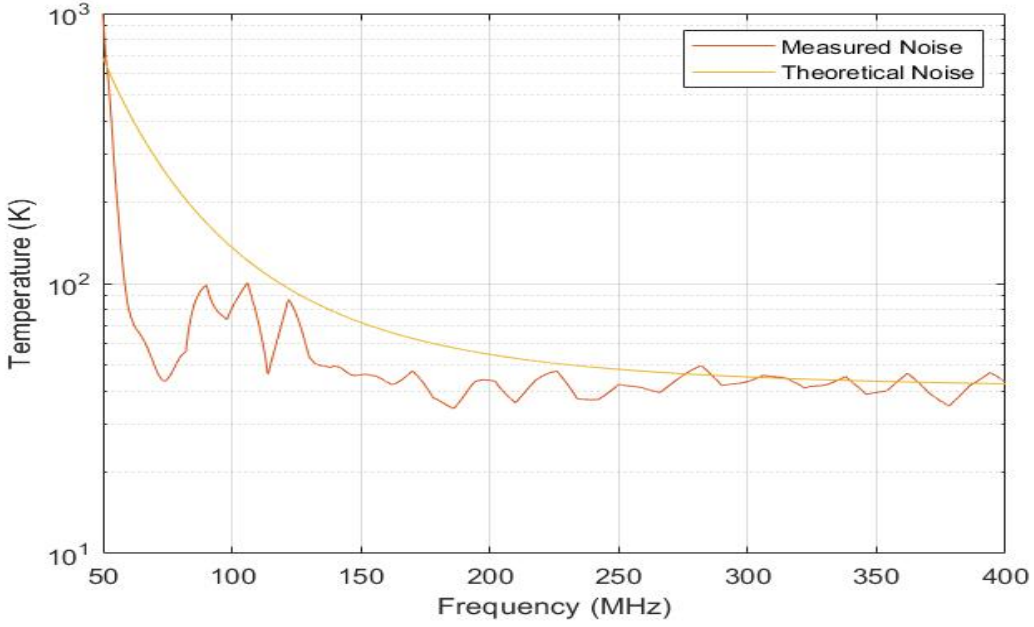
Signal to Noise Ratio

Sources of noise along the Signal Chain include:

- Front-end noise (LNA, RFoF, and other elements of the analogue chain)
- Quantisation noise, truncation and correlation related noise
- Jitter induced noise
- RFI-induced noise

	50 MHz	350 MHz
ADC	0.03	1.00
Polyphase filter	0.01	0.12
FFT	0.00	0.03
Equalisation	0.01	0.01
Beamforming decorrelation	0.33	0.33
Tile beamformer requantisation	0.01	0.01
Station beamformer requantisation (8 bit)	0.15	0.15
TOTAL (excluding ADC)	0.5	0.75

Added noise in the LFAA digital processing (%)



Receiver noise for SKALA4 receiver chain

Low Signal Chain Performance

Signal to Noise Ratio- Correlation Efficiency

Correlation Efficiency:

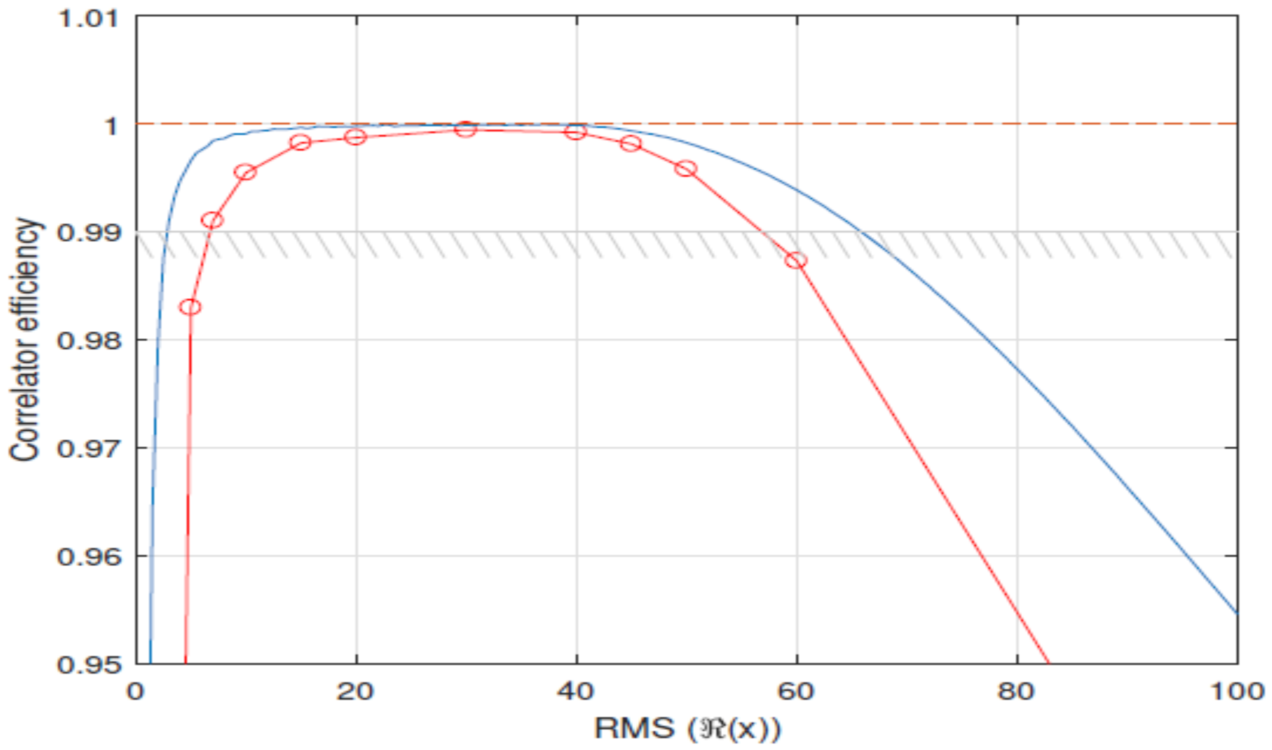
SNR of the correlation between two quantised signals relative to the SNR of the correlation of the original, unquantised signals.

At signal low levels, efficiency is lower because of the quantisation noise

At high levels, efficiency is lower due to clipping

ADC: 8 bits

with an ENOB of 7.93



The Blue curve: the effect of the quantisation stage (ADC)

The Red curve: The effect of all stages of quantisation (including CSP)

The RMS value of the input signal level is in ADC units (8 bits)

Low Signal Chain Performance

Cross Polarisation Purity of the Signal Chain

- Channel-to-channel (between the two polarisations) isolation is negligible. Testing measures showed channel isolation better than ~70 dB.
- The size of the calibration coefficients (complex Jones Matrix values) representation is be enough to support the dynamic range of the correction values. These are presented on 18 bits offering ~108 dB dynamic range.
- The limitation on the accuracy of calibration will be caused by the accuracy of the determination of the calibration coefficients.

The impact of the Signal Chain on the purity of cross polarisation is minor. Testing and simulation work is still taking place on the antennas that are used in AAVS1.5 (and AAVS2).

Low Signal Chain Performance

Systematic Errors and Stability

- The systematic errors are not reduced by time integration. They are mitigated by calibration.
- Time stability requirements are strongly related to the calibration procedure.
- The time interval between calibrations depends on the behaviour time variation of the elements of the telescope (including the Signal Chain), and on its environment. This is also constrained by the timescales of the atmospheric variations.
- The timescales considered for calibration are in minutes (~10 minutes**): reviewing of these timescales in the L1 Rev 12.**
- The Signal Chain complex gain (amplitude and phase) must be ‘sufficiently’ stable over the intervals between calibrations.
- The time variations of the Signal Chain complex gain are essentially caused by variation in temperature. These are mainly in the analogue parts in the LFAA (**LNA and RFoF**).

Low Signal Chain Performance

Systematic Errors and Stability

LNA Stability

- The testing on the LNA of the SKALA4-ST shows that its **gain amplitude** variation with temperature is smaller than **-0.03 dB/°C**. The **phase variation** is less than **0.16 deg/°C**.

- Relative temperature measurements with spatial separation distances of 35 m in the MRO site in 2015 found that **1.1 °C** is the maximum relative temperature difference within a **10-minute windows**. The standard deviation of gain amplitude and phase are below **0.01 dB** and **0.1 deg** over the whole passband.

- Recent measurements on an LNA on the SKALA4-AL in a thermal chamber showed variations of gain over the whole passband, with changes in temperatures from **10 to 80 °C, less than 1 dB in amplitude and less than 1 degree in phase.**

Low Signal Chain Performance

Systematic Errors and Stability

RF over Fibre (RFoF) Stability

Frequency (MHz)	100	160	200
Relative gain variation between two links (within 600 seconds)			
Max over windows 600 sec (dB)	0.023	0.024	0.024
std over windows 600 sec (dB)	0.006	0.006	0.006
Relative phase variation between two links (within 600 seconds)			
Max over windows 600 sec (deg)	0.051°	0.071°	0.088°
std over windows 600 sec (deg)	0.013°	0.019°	0.023°
Maximum absolute gain drift (within 600 seconds)			
Max over windows 600 sec (dB)	0.017	0.017	0.017
std over windows 600 sec (dB)	0.004	0.004	0.004

Relative gain and phase variation between two links (1310 nm) from different fibre ribbons (11 km buried).

Frequency (MHz)	100	160	200
Relative gain variation between two links (within 600 seconds)			
Max over windows 600 sec (dB)	0.027	0.028	0.028
std over windows 600 sec (dB)	0.007	0.007	0.007
Relative phase variation between two links (within 600 seconds)			
Max over windows 600 sec (deg)	0.045°	0.056°	0.070°
std over windows 600 sec (deg)	0.011°	0.014°	0.017°
Maximum absolute gain drift (within 600 seconds)			
Max over windows 600 sec (dB)	0.022	0.022	0.022
std over windows 600 sec (dB)	0.006	0.006	0.006

Relative gain and phase variation between two links (1310 nm) from the same fibre ribbon (11 km buried).

Performance of the Mid Signal Chain

Mid Signal Chain Performance

Linearity

Band	RF Frequency (GHz)	Nom Atten. A_{nom} [dB]	$T_{eq,avg}$ [K]	IIP3 [dBm]	IIP2 [dBm]	ENOB @A_{nom} [bits]
B1	0.35 – 1.050	6	15 – 17	-60 – -55	-42 – -37	8.5
B2	0.95-1.76	4	5 – 6	-67 – -61		8.0
B3	1.65-3.05	10	10	-63 – -58	-37 – -24	7.8
B4	2.8-5.18	0	14 – 15	-74 – -70		4.3
B5a	4.6-8.5	1	9 – 10	-77 – -70	-65 – -57	3.0
B5b	8.3-15.4	5	11 – 13	-74 – -70	-62 – -57	3.0

DISH total signal chain simulation results with attenuation ranging from "Cold sky" nominal, to nominal+8dB

Mid Signal Chain Performance

RFI Effects

- An integrated DISH+CSP time-domain model exists. It is to be updated with the final DISH CDR models.

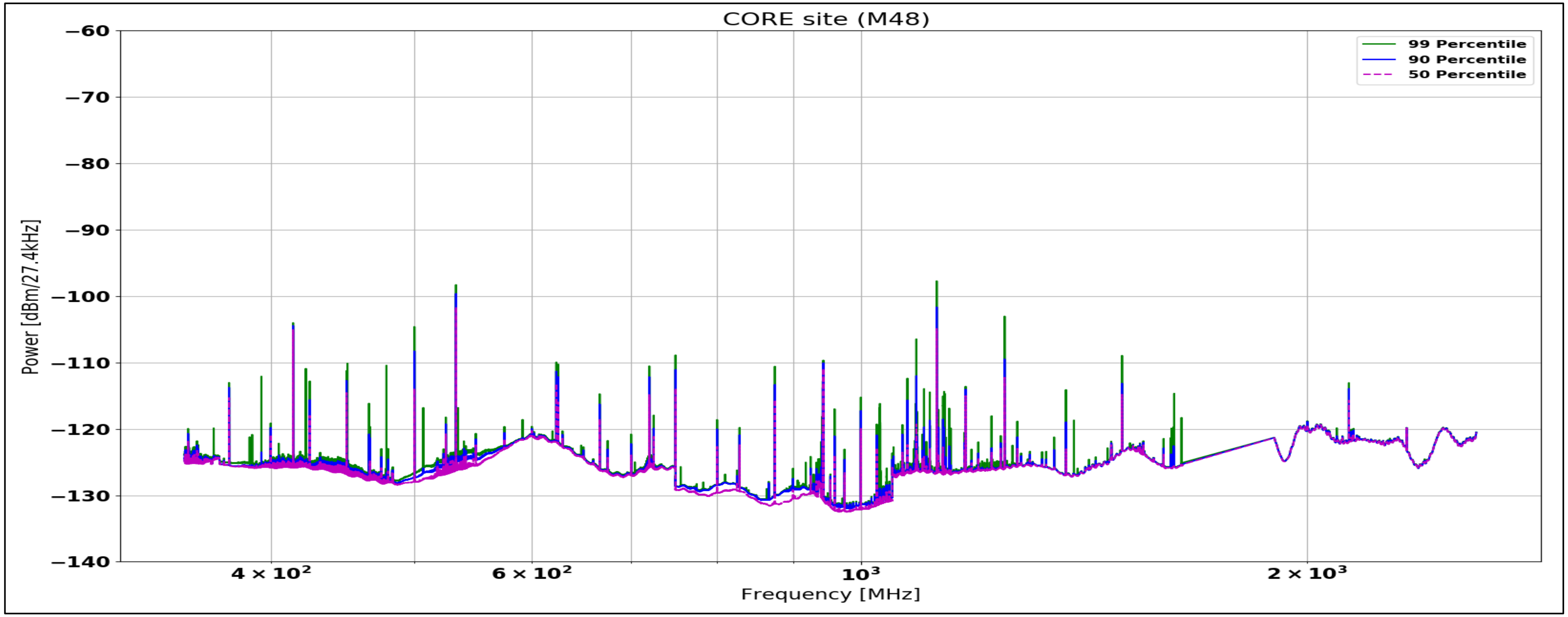
- Some simulation of the performance of the Signal Chain in the presence of RFI signals (e. g. DME of Aircraft Navigation) has been carried out. To be completed.

- RFI test vectors have been implemented and will be updated and validated.

- The RFI sources and signal types are identified. Some statistics exist. To be completed/validated.

Mid Signal Chain Performance

RFI Environment



An example of the RFI spectrum. Received power percentiles from 2016 survey in the core site time resolution 1 second, spectral resolution 27.4 KHz.

Mid Signal Chain Performance

Frequency Response

Dish frequency response flatness <6.5 dB p-p for bands B1-B4, and < 4 dB p-p for bands 5a-5b.

Qualification results available for SPF B1 and SPF B2.

The frequency response of the combined transfer functions (Dish + CSP) gives the passband flatness and out of band attenuation required (e.g. for zoom windows imaging, **±0.05 dB flatness** and **-60dB out of band attenuation**).

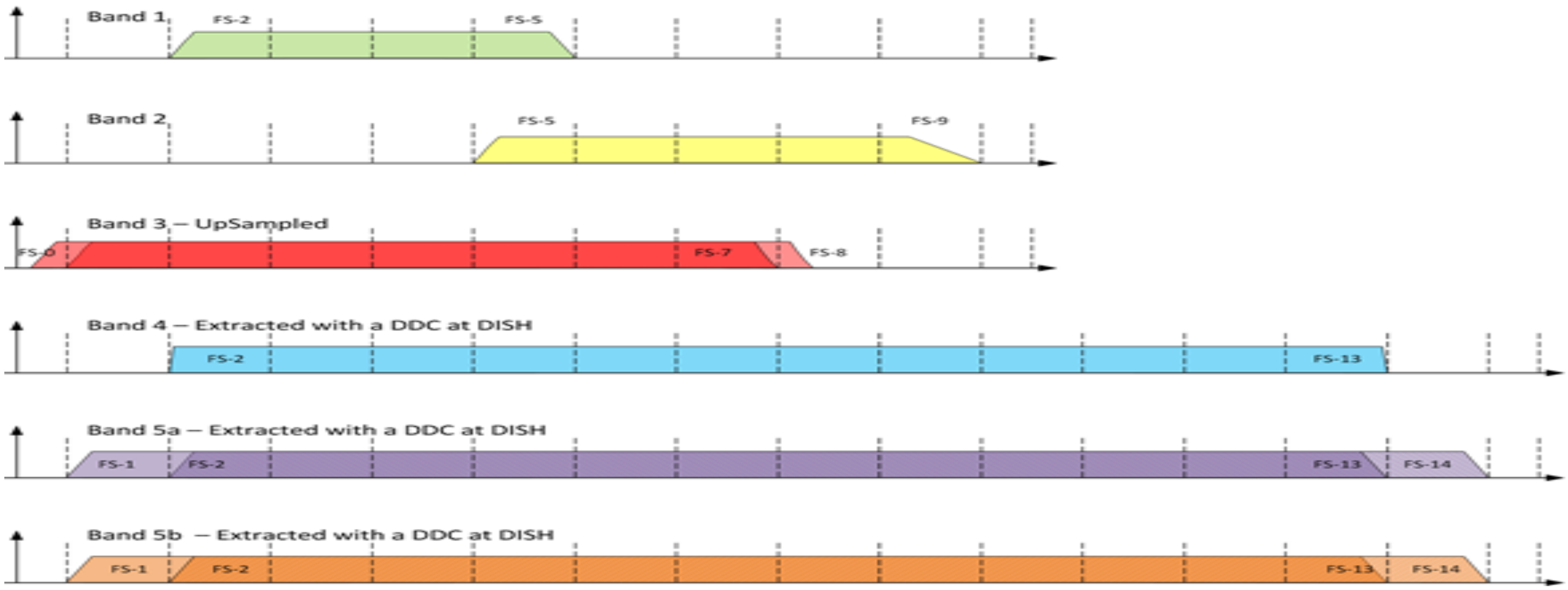
Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation:

The observation bandwidths are segmented into Frequency Slices (FSs) containing ~200 MHz of ‘spectrally pure’ bandwidth.

The Mid.CBF segments each FS into 16,384 channels, each of width 13,440 Hz.

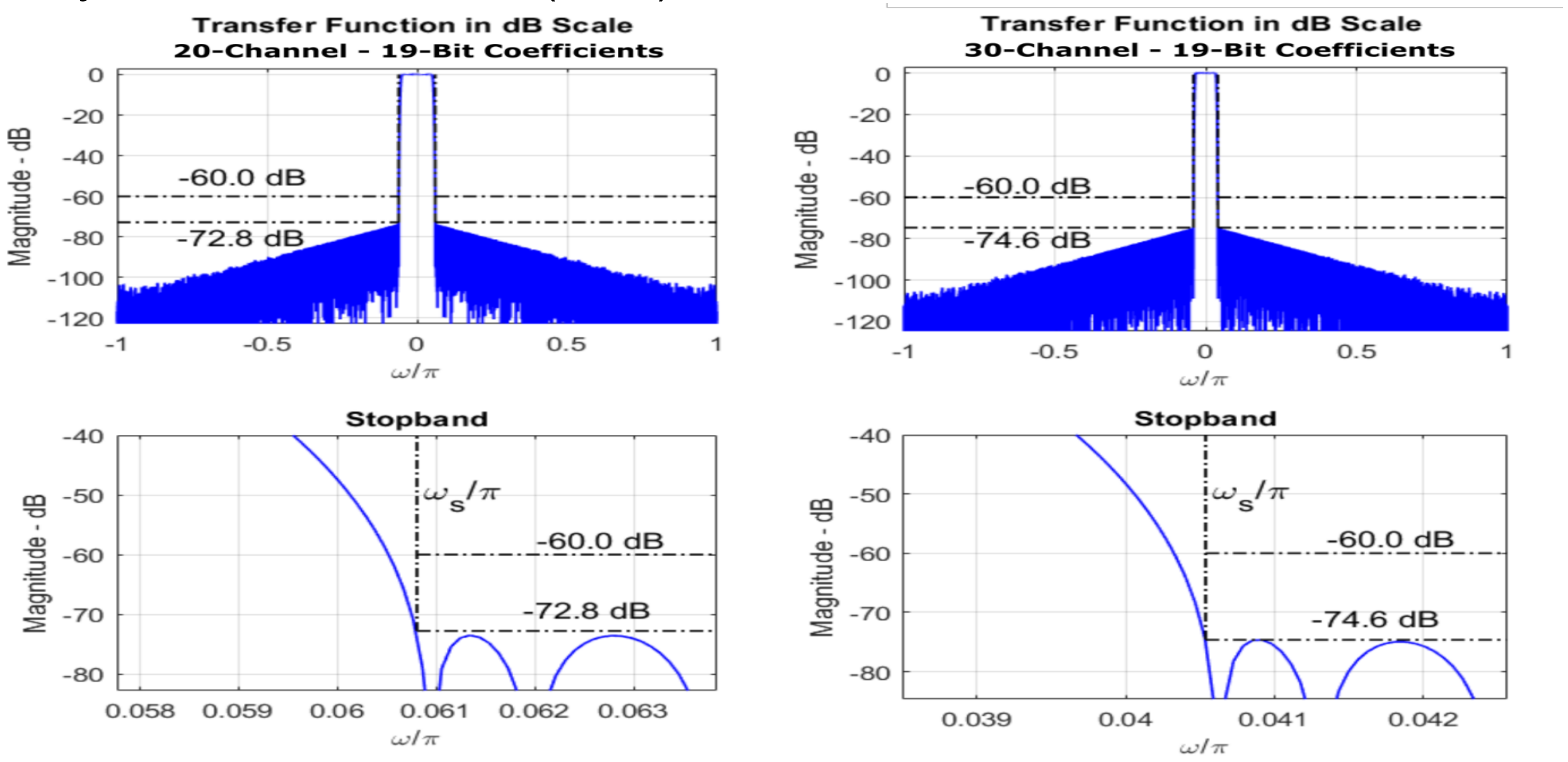


The spectral occupancy of FSs for SKA1_Mid observation bands.

Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation-Very Coarse Channeliser (VCC):

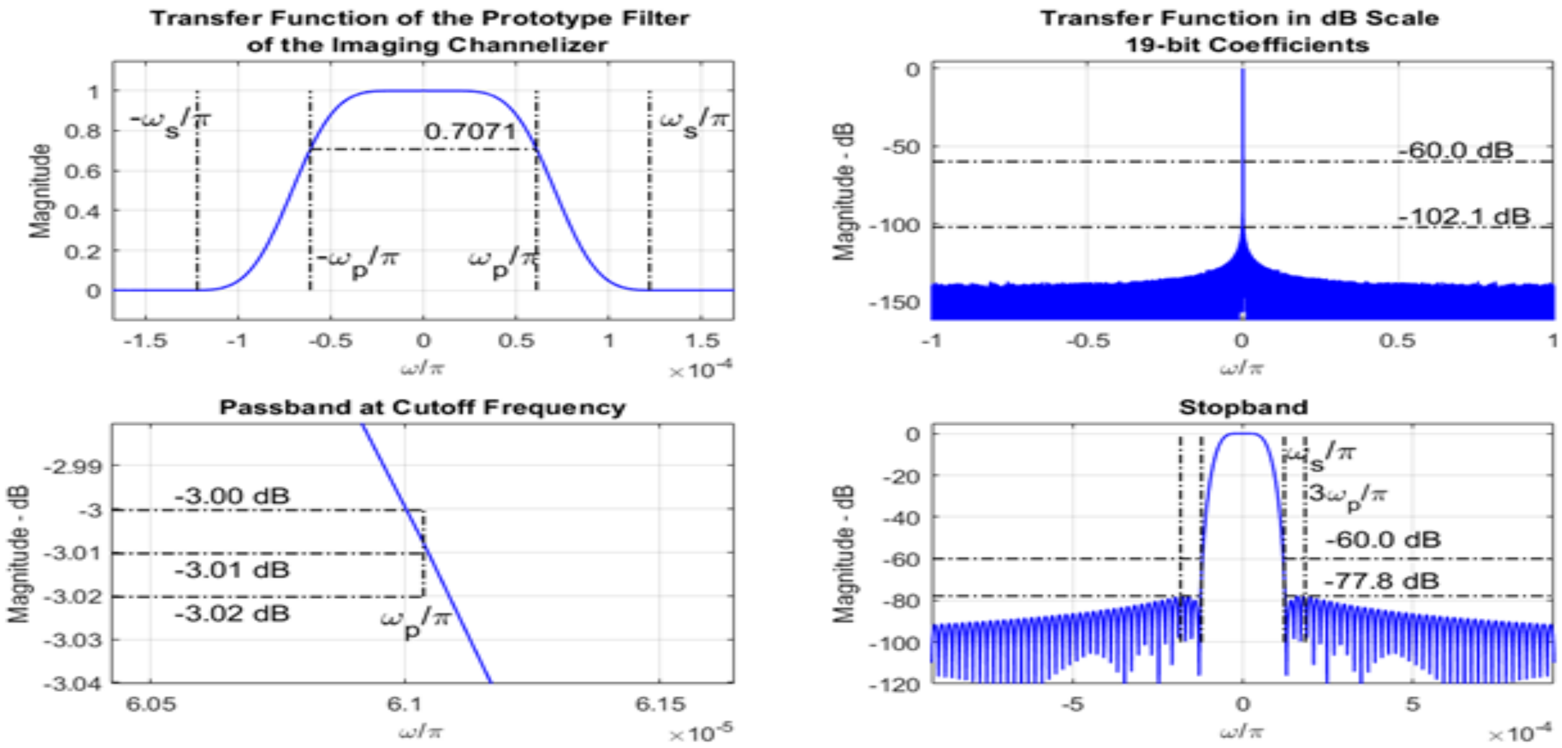


The magnitude responses of the prototype filters of the 20- and 30- channel configurations of the Very Coarse Channeliser (VCC). The coefficients are normalised and quantised to 19-bits.

Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation- Imaging Channeliser (IC):

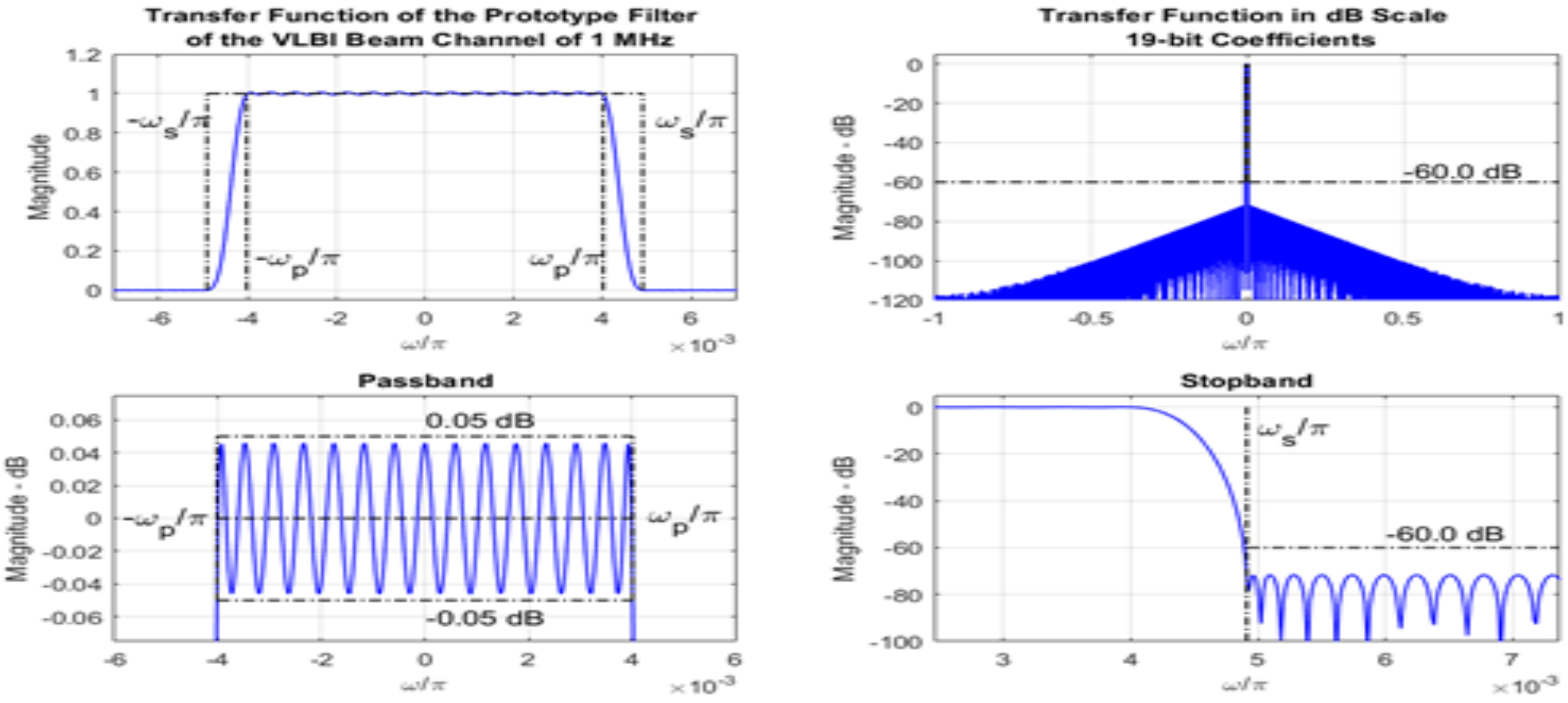


The magnitude responses of the prototype filter of the Imaging Channeliser (IC). The coefficients are normalised and quantised to 19-bits.

Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation- VLBI beam-channel:

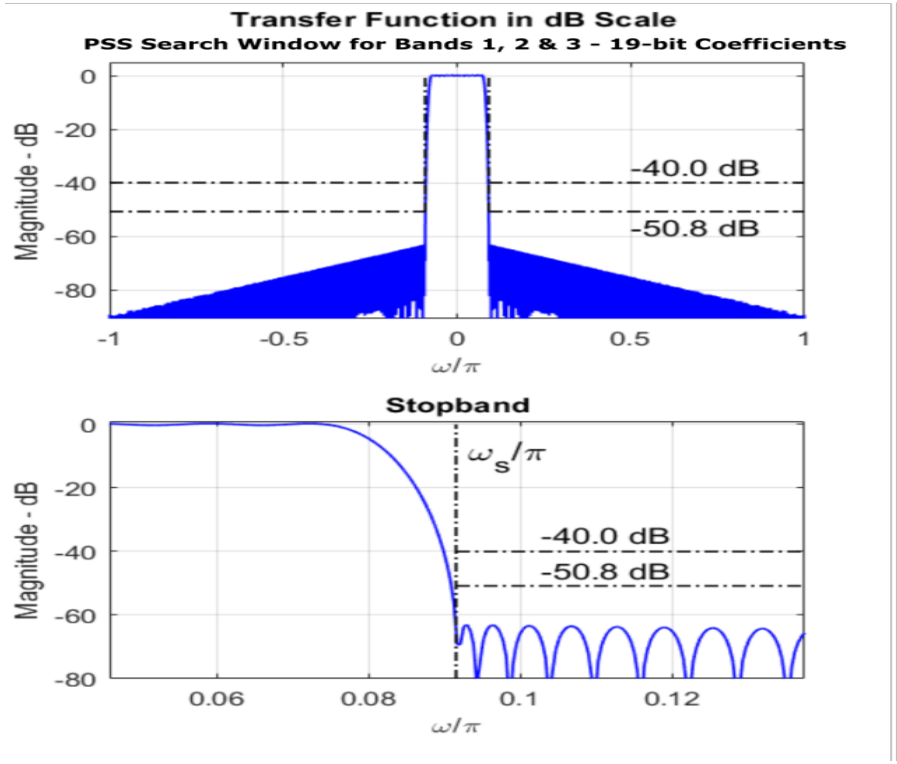


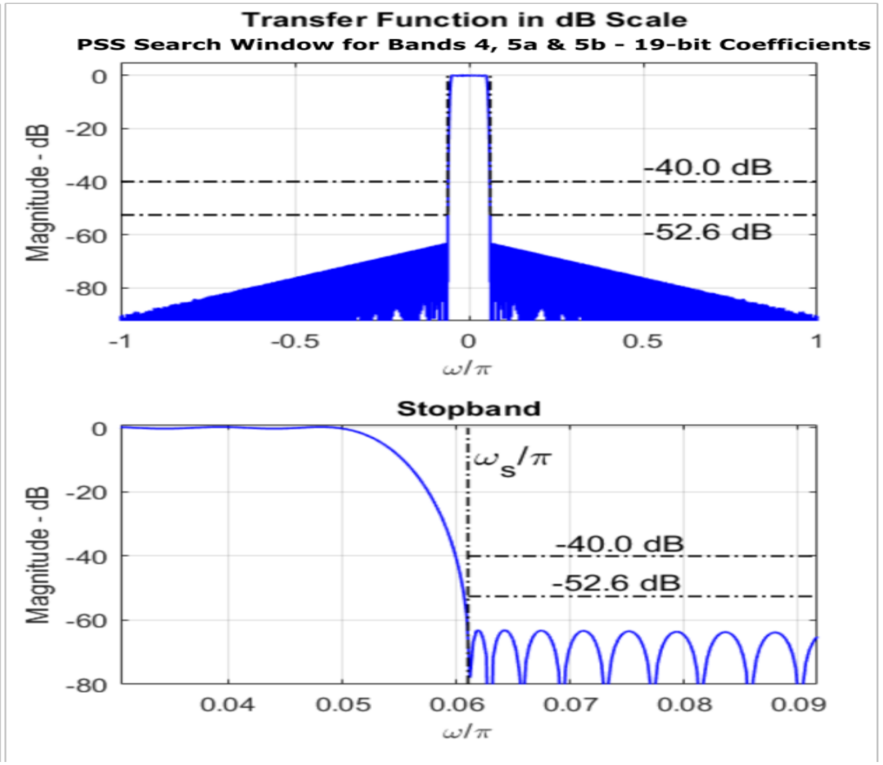
Magnitude transfer function of the Digital Down Converter (DDC) prototype filter for VLBI beam-channel of bandwidth 1 MHz (19-bit coefficients).

Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation- PSS-DDC-channel:



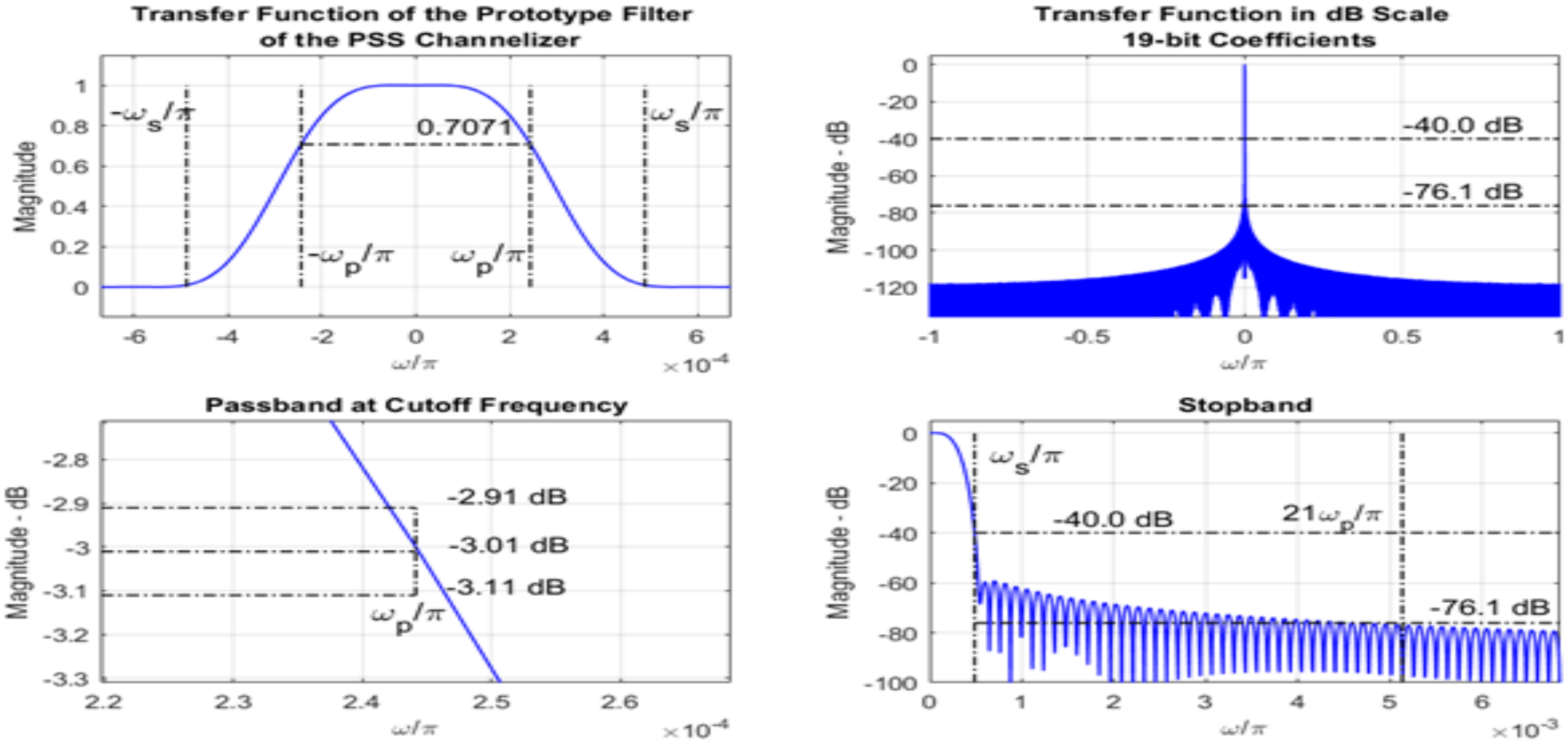


Magnitude transfer functions of the prototype filters for the PSS Search Window extraction DDCs (19-bit coefficients).

Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation- PSS-channeliser:

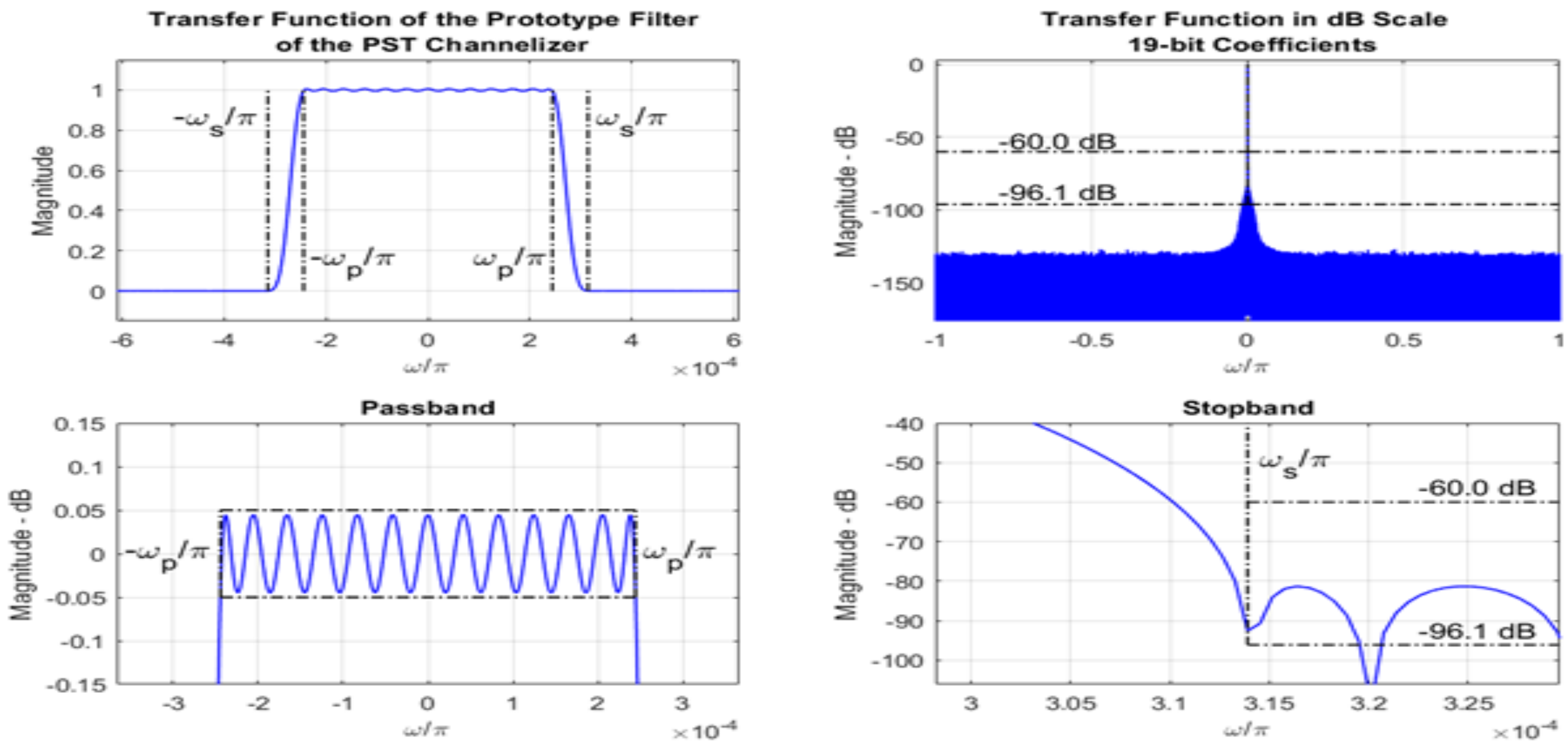


Magnitude transfer function of the PSS channeliser prototype filter (19-bit coefficients).

Mid Signal Chain Performance

Frequency Response (CSP)

Channelisation- PST-channeliser:

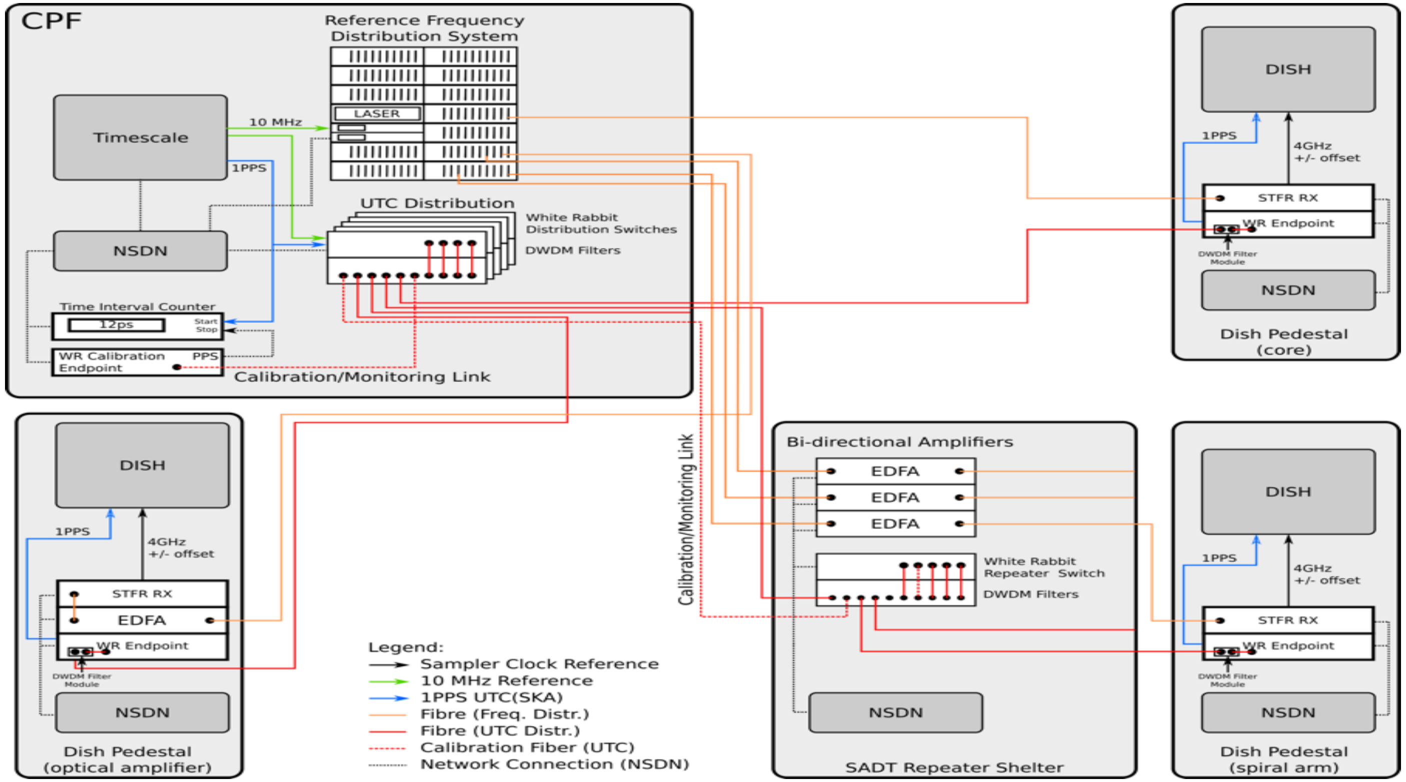


Magnitude transfer function of the PST channeliser prototype filter (19-bit coefficients).

Mid Signal Chain Performance

Coherence, Timing Accuracy, and Jitter

The Synchronisation and Timing (SAT) system provides frequency and timing signals to the Antennas.



Frequency and Time distribution

Expected Performance Coherence Loss, and Jitter

Coherence Loss 1s	<0.3% (Band 5)
Coherence Loss 60s	<0.4% (Band 5)
Linear Phase Drift 10min	0.08 rad over 77km link
Sampling Clock Jitter	<250 fs

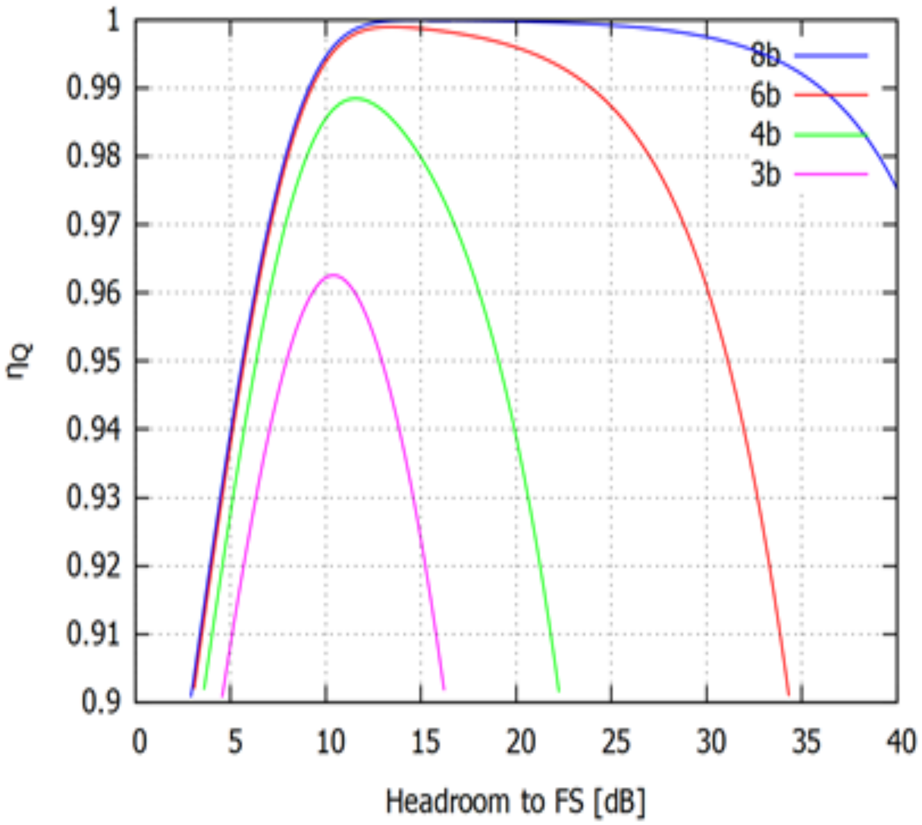
Mid Signal Chain Performance

Signals and Noise (DISH)

Sources of noise along the Signal Chain include:

- Noise in the analog part.
- Quantisation noise
- Jitter induced noise
- RFI-induced noise

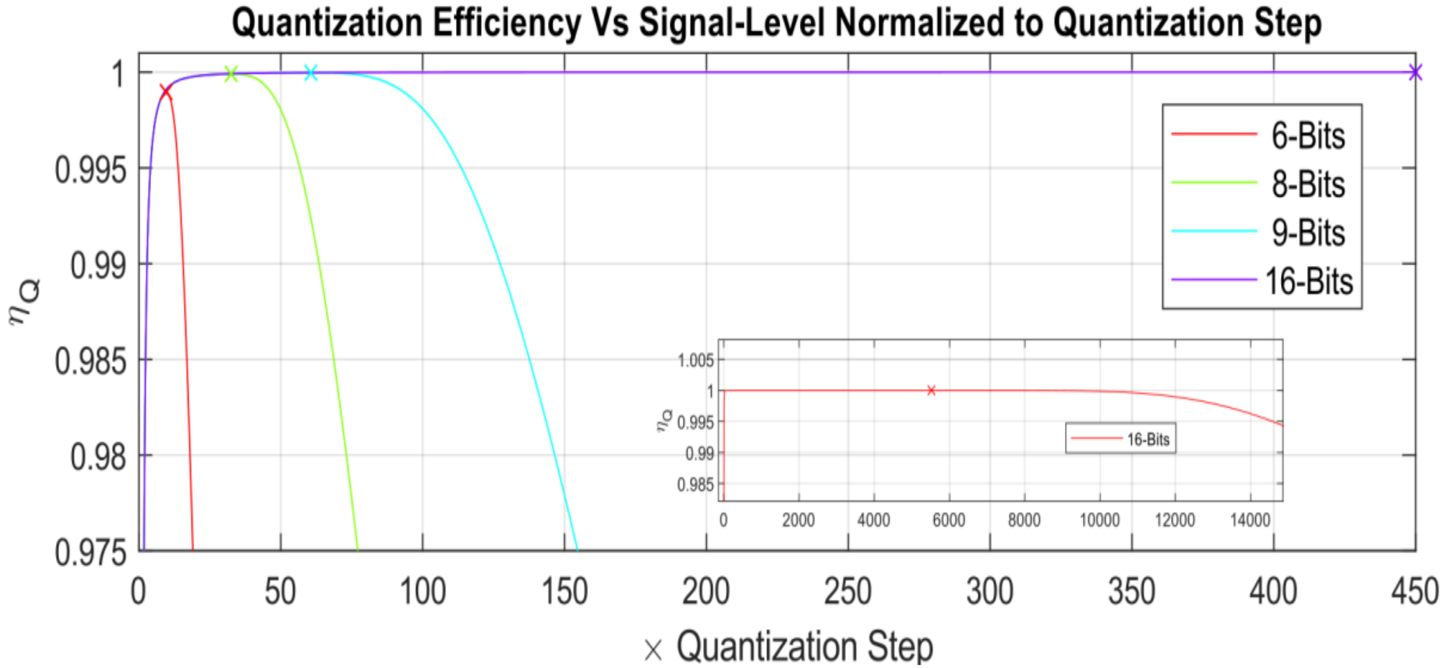
Quantisation efficiency vs. the headroom between ADC input power and full scale power, for various numbers of bits.



Mid Signal Chain Performance

Signals and Noise (CSP)

Quantisation efficiency (SNR) and number of bits



The quantisation efficiency curves for 6, 8, 9 and 16-bit representation for rms signal level normalised to the quantisation steps.

Mid Signal Chain Performance

Signals and Noise (CSP)- numbers of bits for compliance with the S/N requirements

The word lengths of the signal processing modules.

Signal Processing Module	Input Word Length bits	Output Word Length bits
Wideband Bulk Delay Corrector (Just a memory buffer no change to the signal values)	8 (Bands 1, 2 & 3) 4 (Bands 4, 5a & 5b)	8 (Bands 1, 2 & 3) 4 (Bands 4, 5a & 5b)
Wideband (WB) Frequency Shifter (Not in for Bands 5a & 5b)	8 (Bands 1, 2 & 3) 4 (Bands 4)	8+8
Very Coarse Channeliser (VCC-OSPFB)	8+8 (Bands 1, 2, 3 & 4) 4 (Bands 5a & 5b)	16+16
ReSampler, Integer and Fractional Delay Tracker, Fringe Phase & Doppler Shift Corrector	16+16	16+16
Imaging Channeliser/ Zoom Channeliser	16+16	9+9
Complex-Cross Multiply and Accumulator (C-XMAC)	9+9 (non-VLBI) 6+6 (VLBI)	32-bit [Single] precision floating point
Configurable Zoom Window DDC	16+16	16+16
PST Channeliser	16+16	16+16
Per-Beam Per-Antenna Jones Matrix Corrector	16+16	16+16
PST Beamfomer	16+16	8+8
VLBI Beamformer (ReSampler)	16+16	16+16
VLBI Beamformer (Beam Sum)	16+16	8+8
VLBI Beam-Channel Extraction DDC/ Complex-to-Real Transformer	8+8	8+8
VLBI Channeliser	16+16	6+6
PSS Digital Down Convertor (DDC)	8 (Bands 1, 2, 3 & 4) 4 (Bands 5a & 5b)	16+16
PSS Channeliser	16+16	8+8
PSS Beamformer	8+8	8+8

Mid Signal Chain Performance

Signals and Noise- Sensitivity

MID Sensitivity= (Ndishes).(per DSH Ae/Tsys).(correlator efficiency)

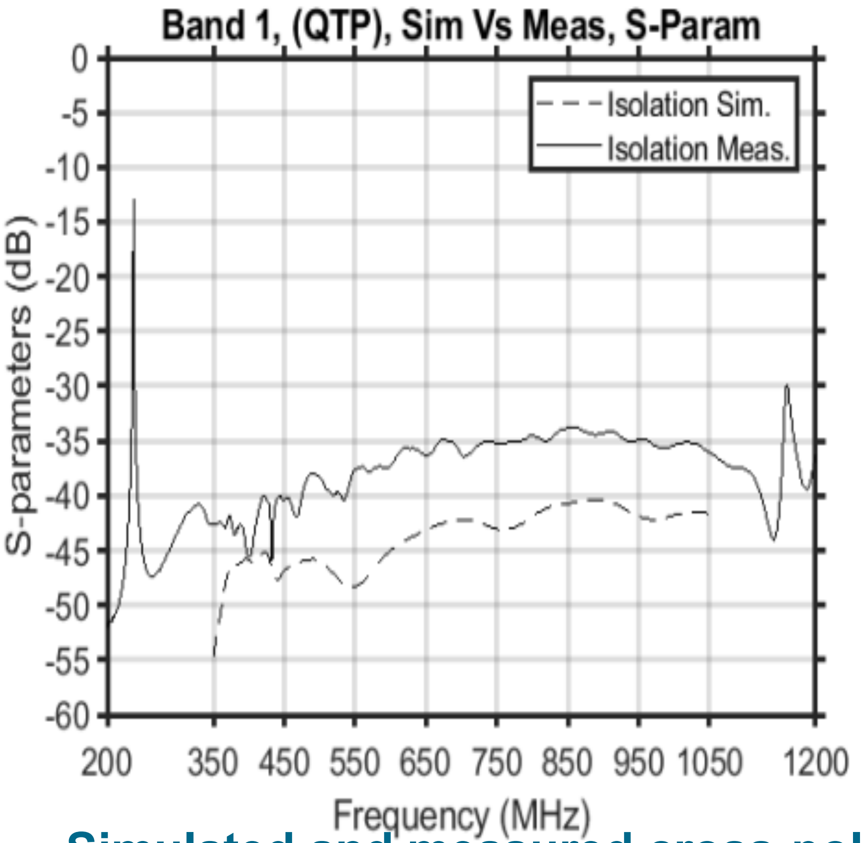
Simulation showed, for the correlation efficiency, figures better than 99%

Band	Frequency (GHz)	Sensitivity Requirement (m^2/K)			Compliance	
		Array (L1)	Dish (L2)	Feed (L3)	Feed (L3)	Method
1	0.35 – 0.650	272 – 545	2.1 – 4.2	2.1 – 4.2	2.4 - 5.0	Test
	0.65 – 1.050	545	4.2	4.2	5.4	
2	0.95 – 1.760	916	7.0	7.1	10.9	Test
3	1.65 – 3.050	916	7.0	7.1		Design
4	2.80 – 5.180	833	6.4	6.6		Design
5a	4.60 – 8.500	1110	8.70	8.86	9.52	Analysis
5b	8.30 – 15.40	805	6.31	6.74	7.93	Analysis

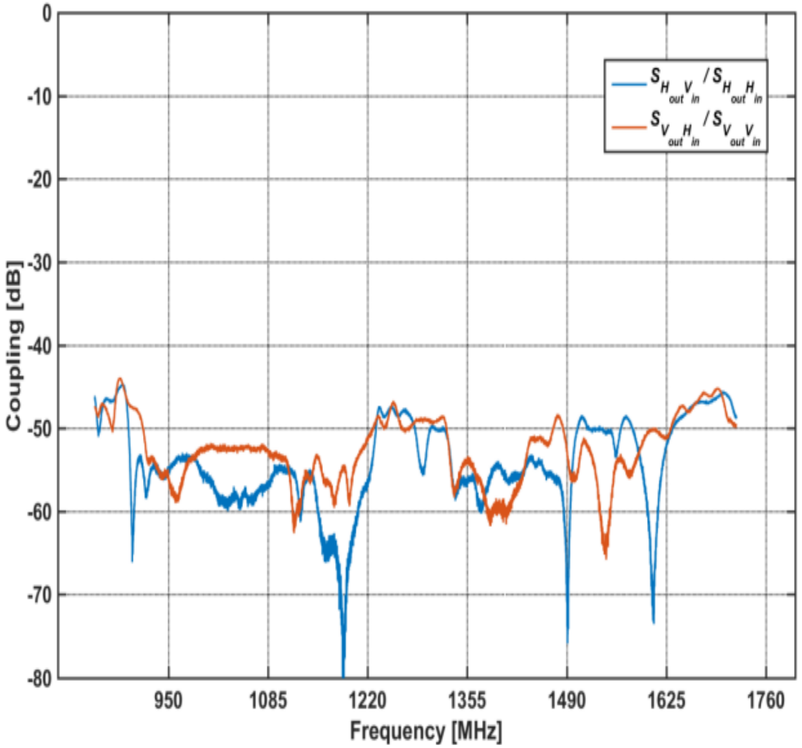
Dish Sensitivity

Mid Signal Chain Performance

Cross Polarisation Purity



Simulated and measured cross-polarisation coupling of the Band 1 feed package.



Measured cross-polarisation coupling of the Band 2 feed package.

Mid Signal Chain Performance

Systematic Errors and Stability-SPF Stability

The SPF Band 1 qualification results yield:

gain stability **< 0.05%.**

Verification over **5 minutes** of the **phase stability p-p** showed values **<<1°**, and **phase stability RMS < 0.5°**.

The SPF Band 2 qualification Results yield:

gain stability **< 0.04%**.

Variations over **30 minute**s and temperature change of more than 7 degrees showed variation in gain amplitude of about **0.023 dB**.

Verification over 5 minutes of the **phase stability p-p** showed values less than **0.16°**, and **phase stability RMS** << **0.05°**.

More validating testing and verification results are expected.

Follow up

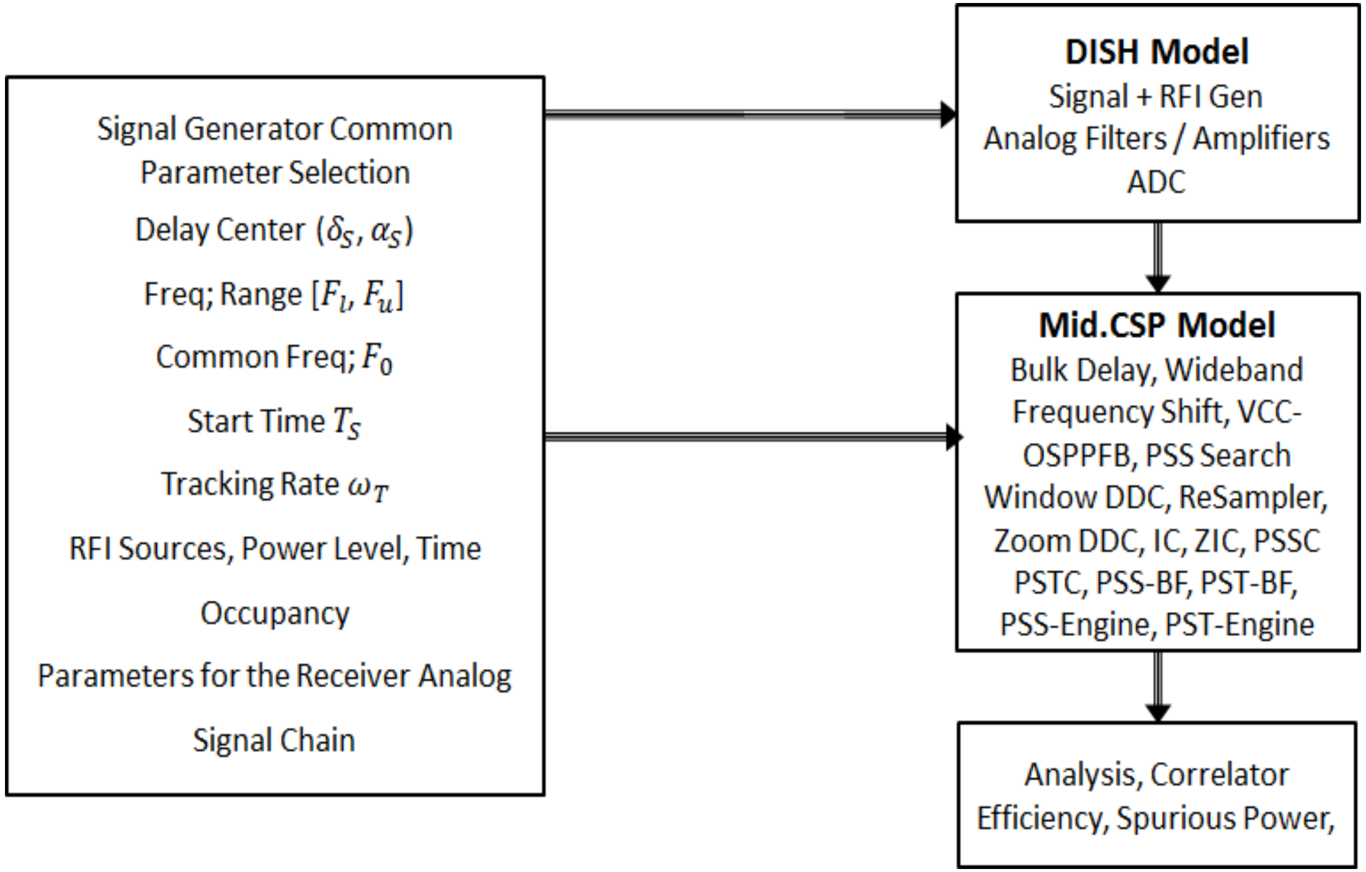
- RFI use cases: Important analysis and simulation has been performed for Low and Mid Signal Chains based on measurements from sites. This is to be completed by a more comprehensive analysis.
- Validation of the results of the analysis by verification and testing results on prototypes.
- Reviewing some L1 requirements such as the 10 minutes timescale stability and calibration.

Signal Chain Models

Modelling and Analysis

- System performance has been evaluated for the entire chain, integrating elements models.

- Based on measurements for the RFI environment, some representative use cases have been included in the Signal Chain performance evaluation.



Mid DISH, CSP integration (Exchange of data files between element models)

Similar way for Low between LFAA and CSP

Low Signal Chain Models

Modelling and Analysis

- System performance has been evaluated for the entire chain, integrating elements of the LFAA and CSP models.

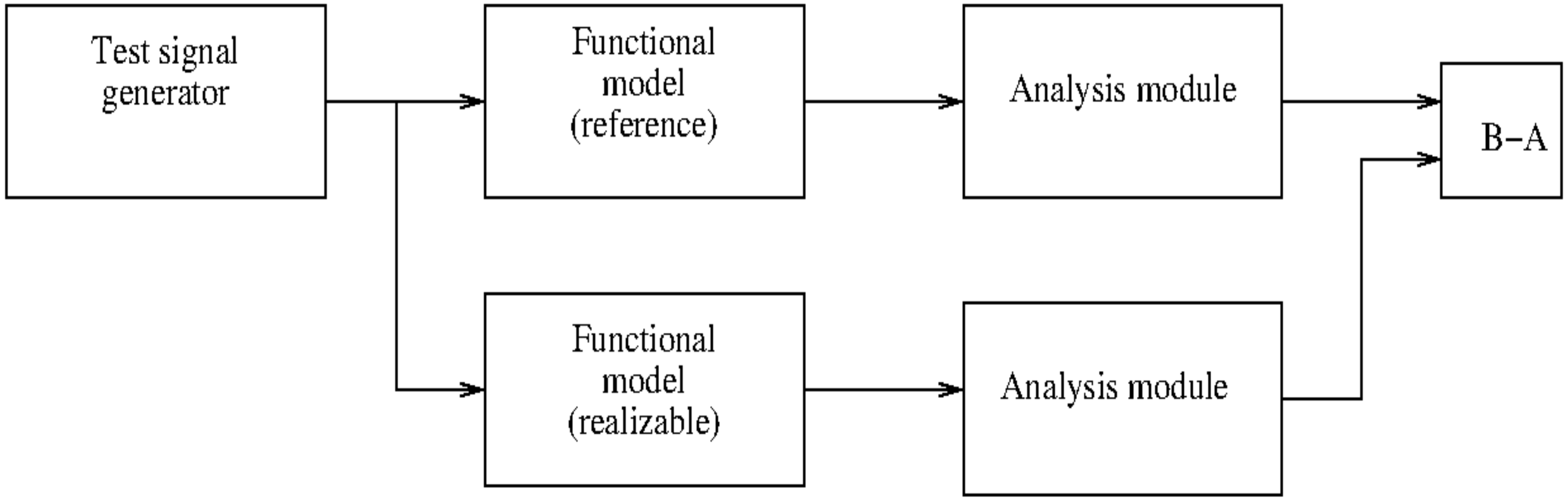
- For CBF and PSS elements, the combined frequency response of LFAA and CSP channelisers has been computed.

- The performance of the PST sub-system has been evaluated including the LFAA contribution both in the frequency and time domains.

- New measurements for the RFI environment have been made available. This allowed some representative use cases to be included in the Signal Chain performance evaluation.

Low Signal Chain Models

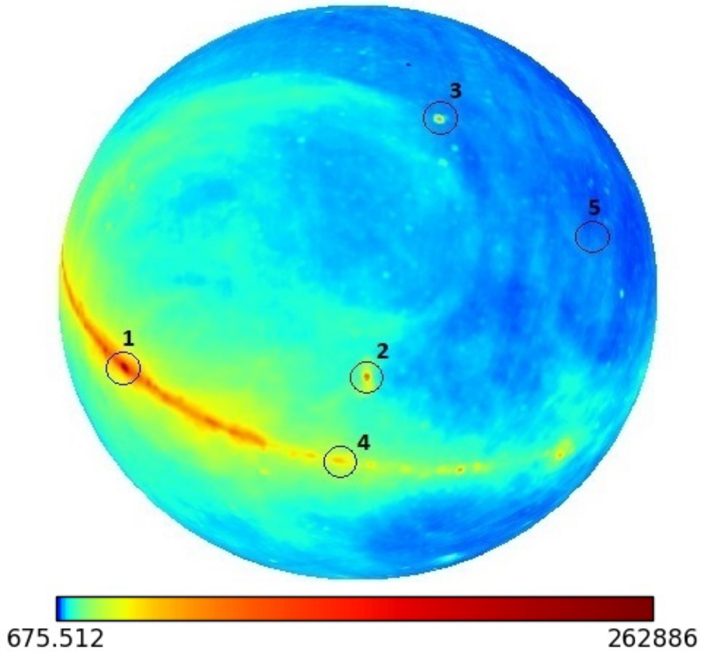
Models –LFAA modelling

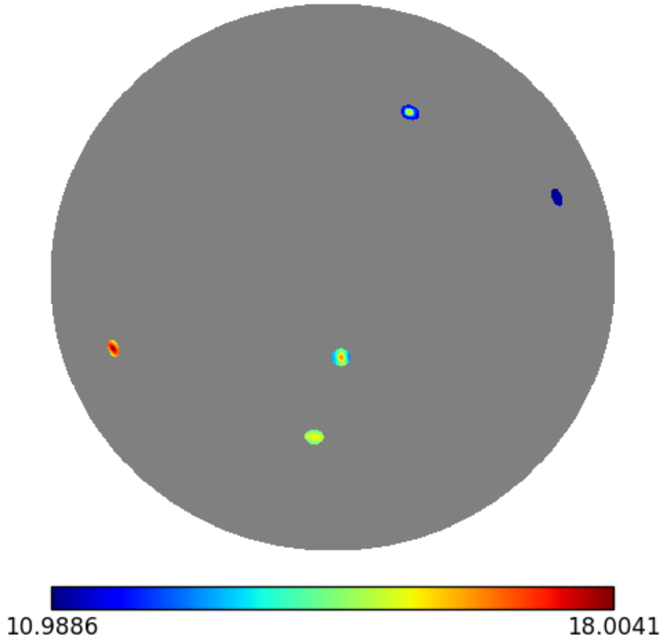


Model for quantisation effects. Same signal is sent to reference (floating point) and realizable (including quantisation) models. Difference between the two models is quantisation contribution.

Low Signal Chain Models

Models –LFAA modelling





Sky model. Left: actual visible sky (Oliveira-Costa, 2008).

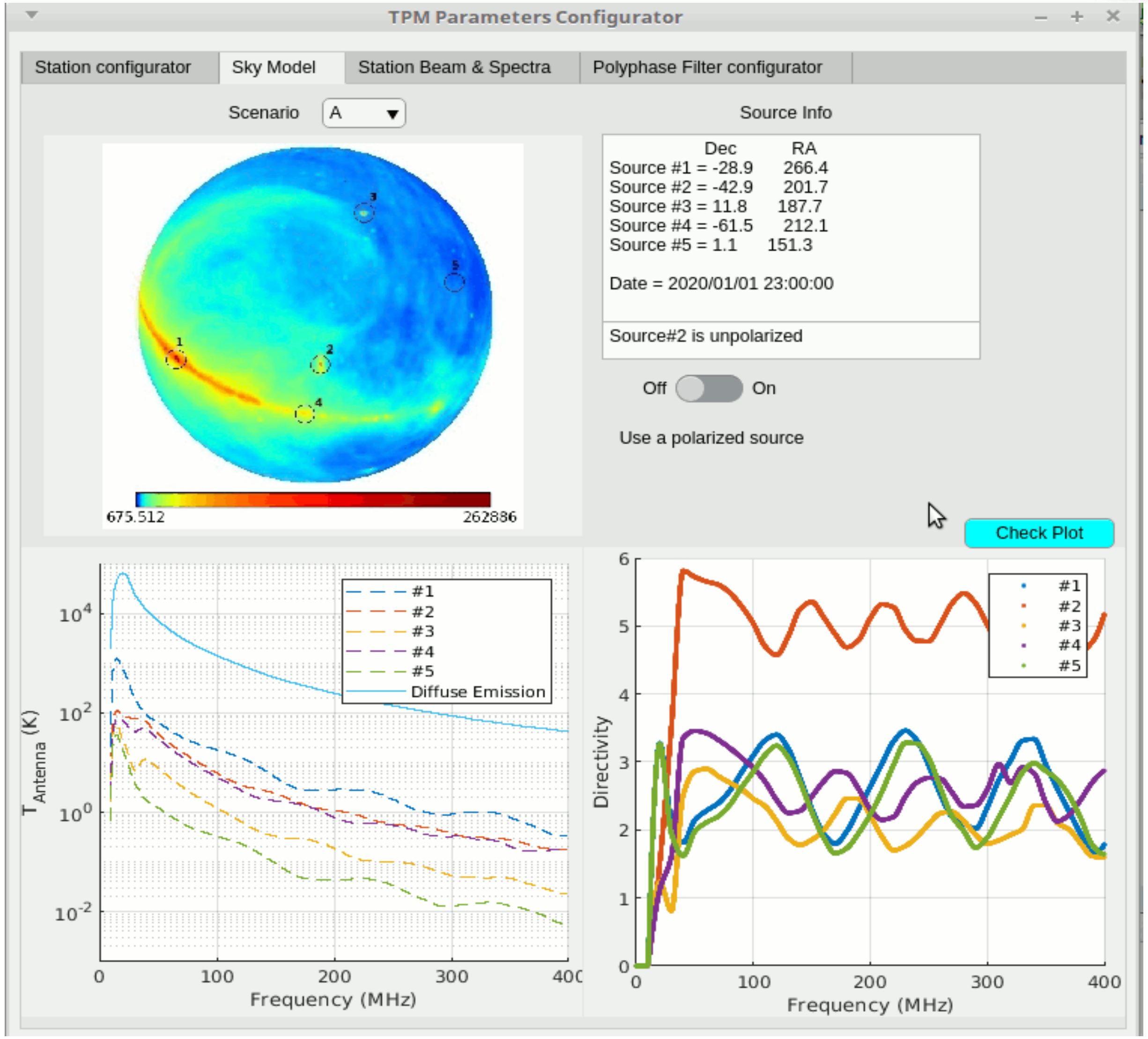
Right: Simulated sky. Grey area is simulated using an incoherent signal, with intensity derived by convolving the sky model with the typical antenna response.

Low Signal Chain Models

Models –LFAA modelling

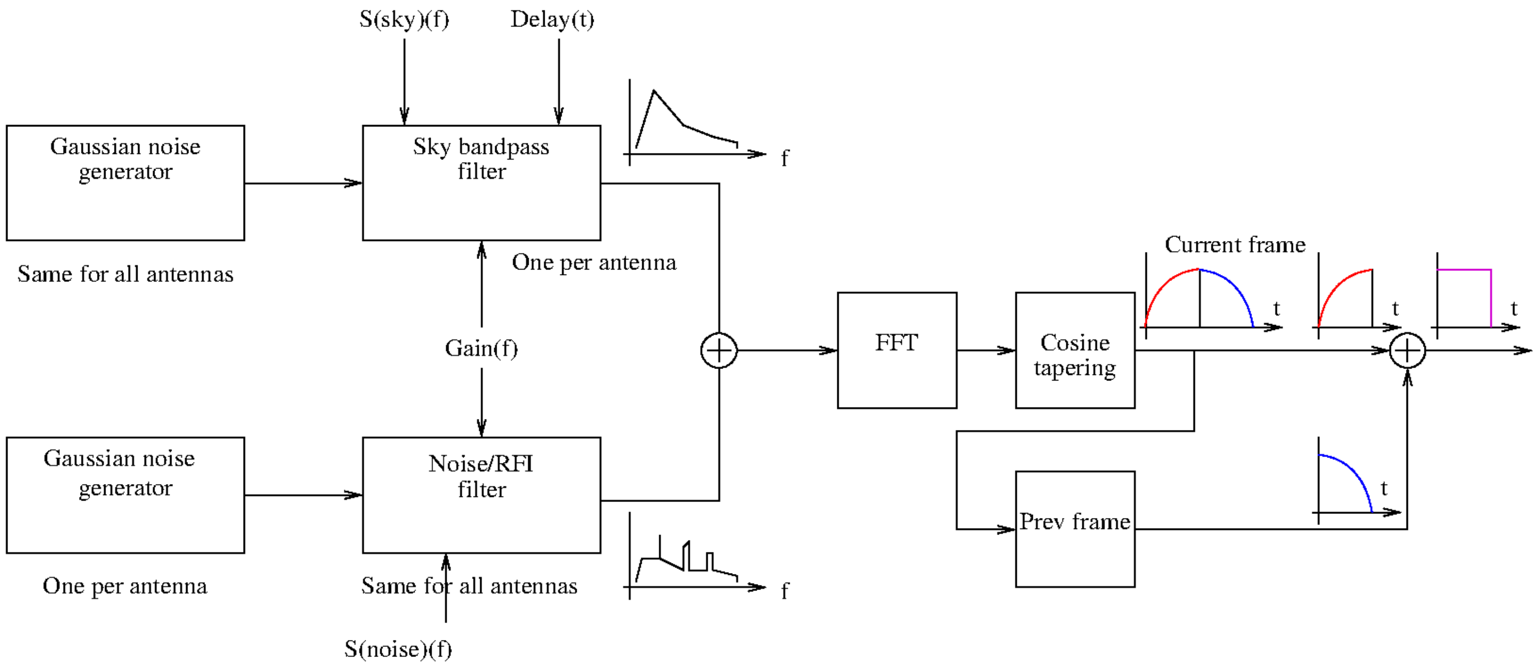
GUI Sky Model Set-up page.

In this page, the interface computes the spectra of diffuse and individual sources (lower left) using sky model (upper left) and antenna model (lower right).



Low Signal Chain Models

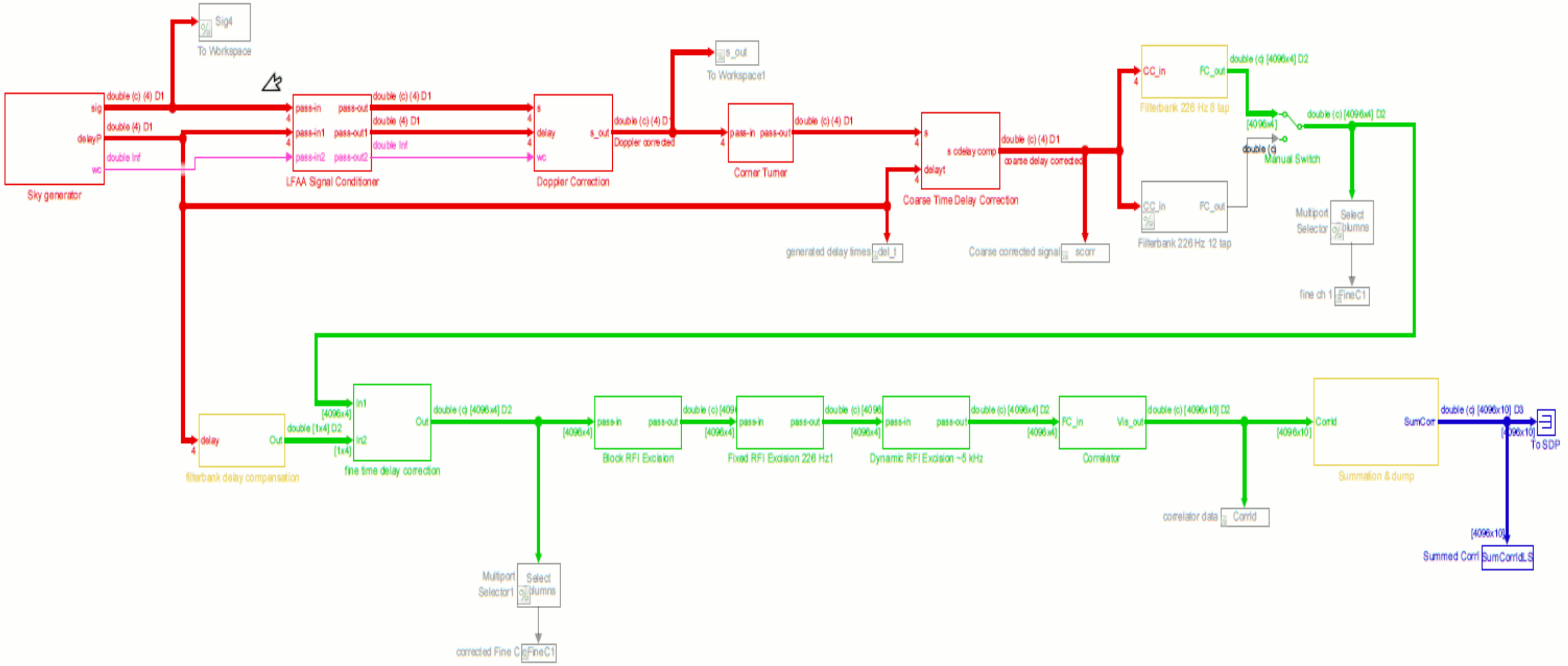
Models –LFAA modelling



Structure of the signal generation block. Signal is composed of uncorrelated noise (different noise for each antenna) plus a correlated source (same noise, different amplitude and phase response for each antenna). Signal is composed of overlapped segments, with cosine tapering.

Low Signal Chain Models

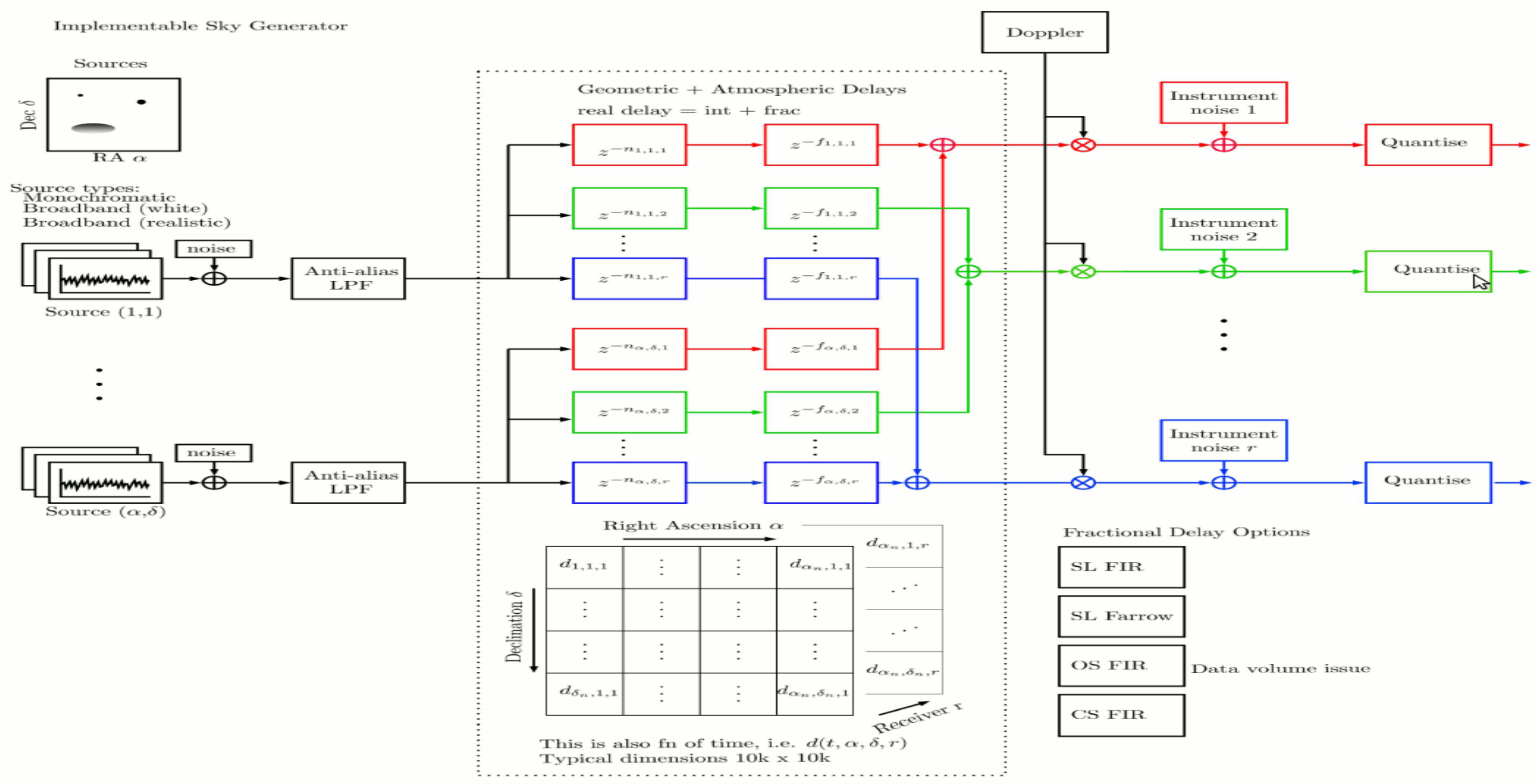
Models –CSP modelling



Imaging Simulink Model

Low Signal Chain Models

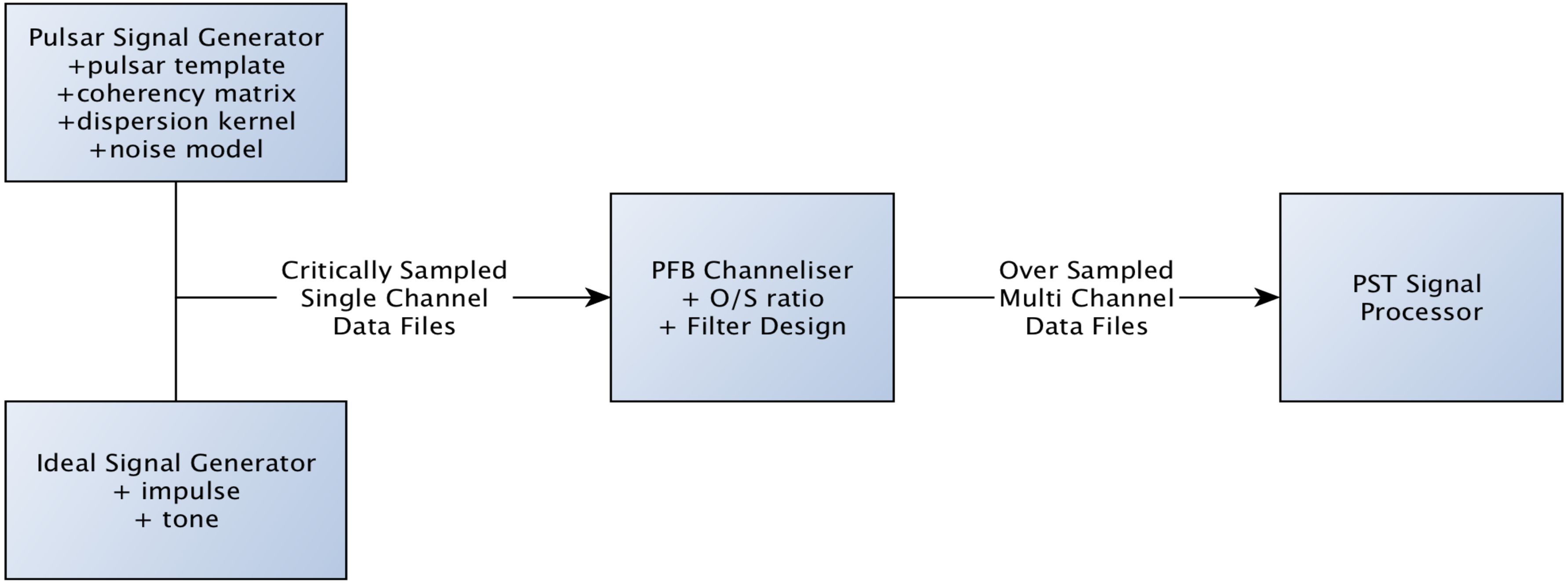
Models –CSP modelling



Model with true Sky, array configuration mode, and atmospheric delays to test imaging algorithms.

Low Signal Chain Models

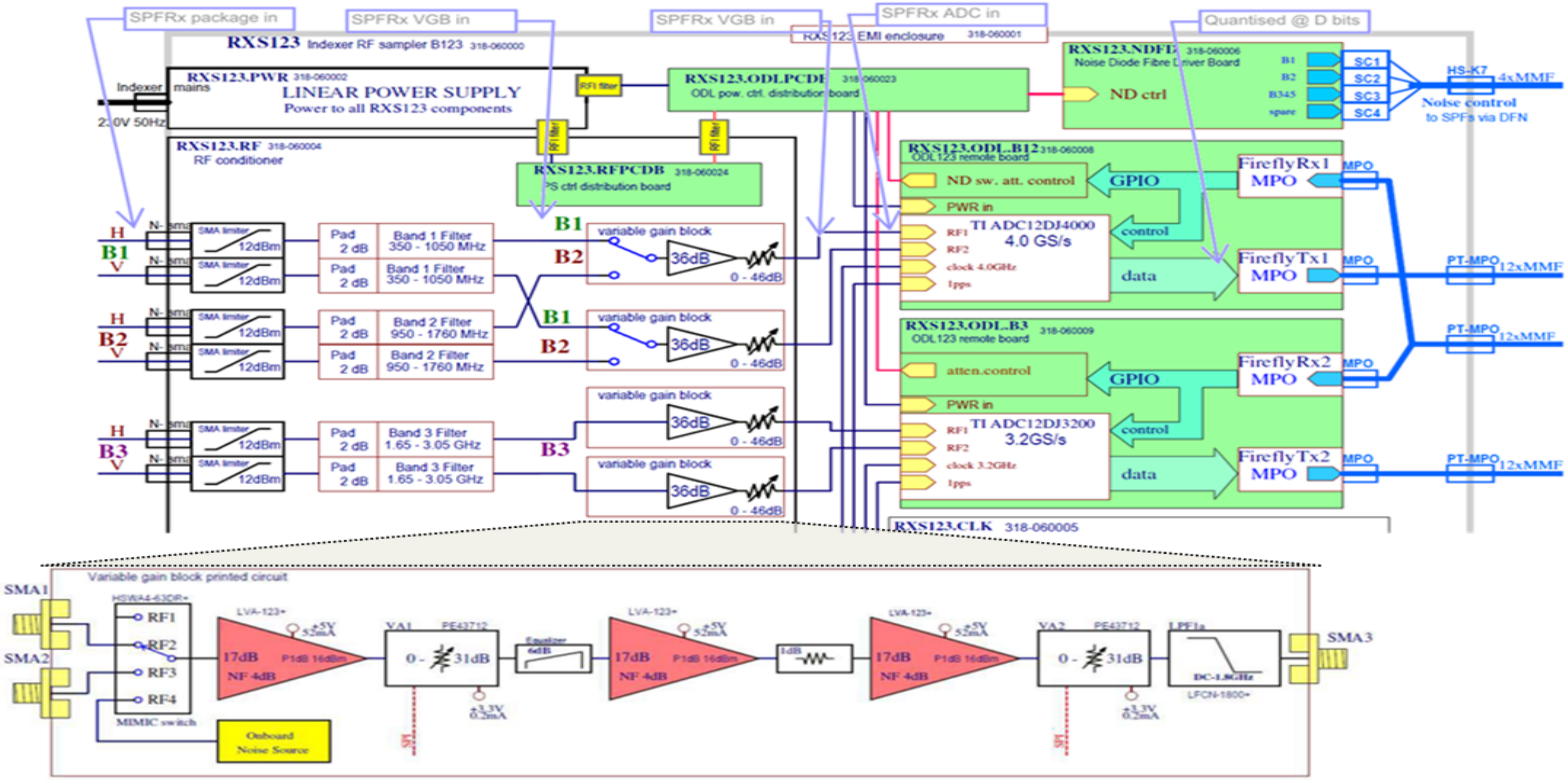
Models –Pulsar Processing



Block diagram of the pulsar timing signal processing Model.

Mid Signal Chain Models

DISH Models (SPFRx)

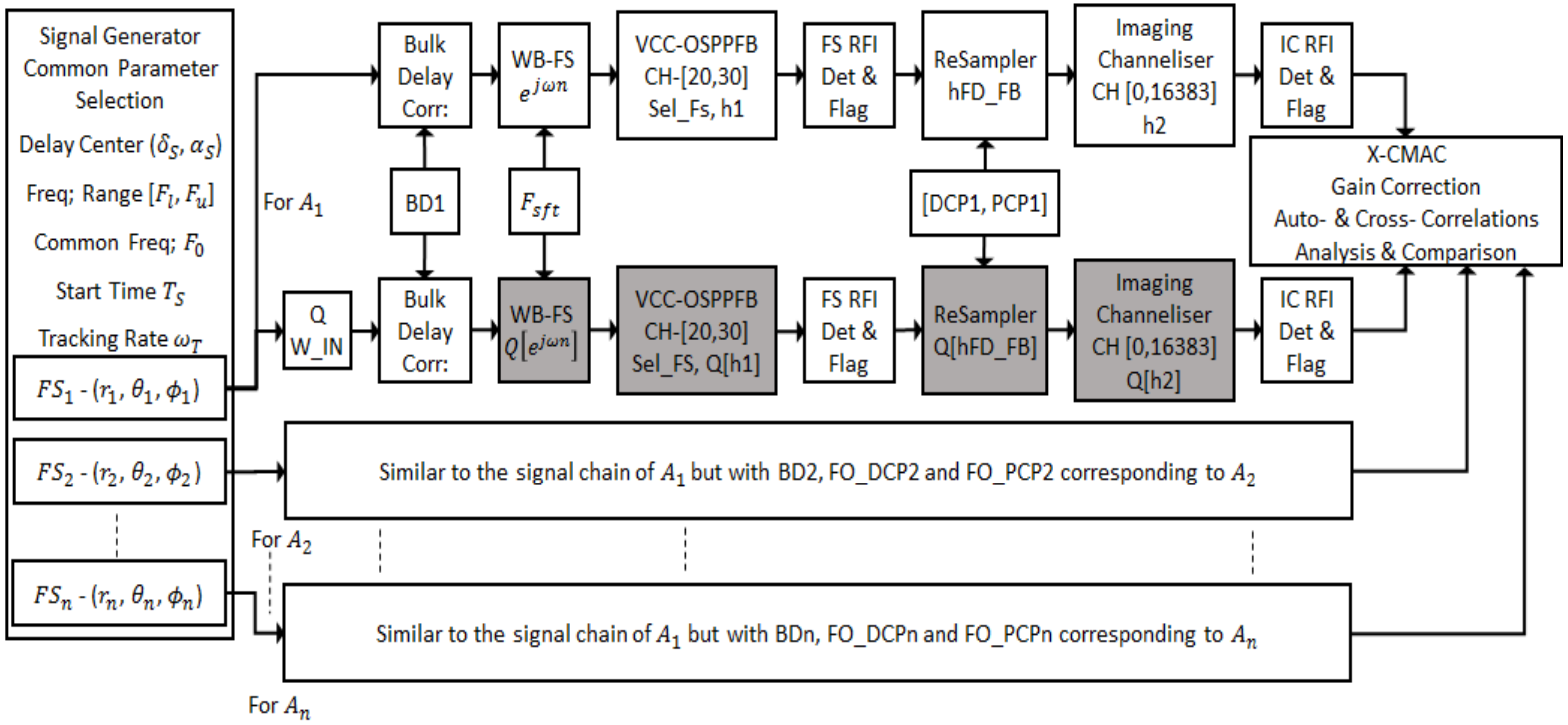


SPFRx B123 line-up (top).

Detail of the “integrated Variable Gain Block” (bottom)

Mid Signal Chain Models

CSP Models



The signal flow graph of the model to verify the signal chain of the CSP_Mid for normal imaging.

SKA1 Multinational Project

Thank you