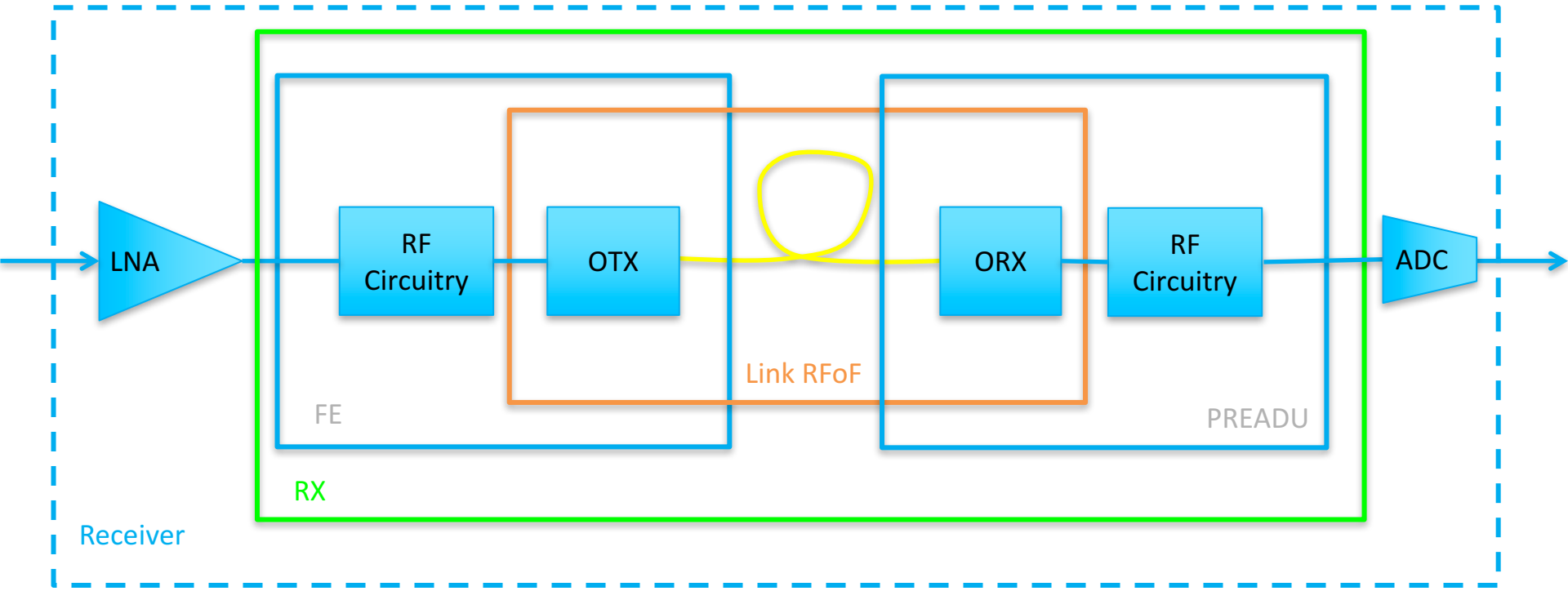
Definition Receiver, RX, RFoF



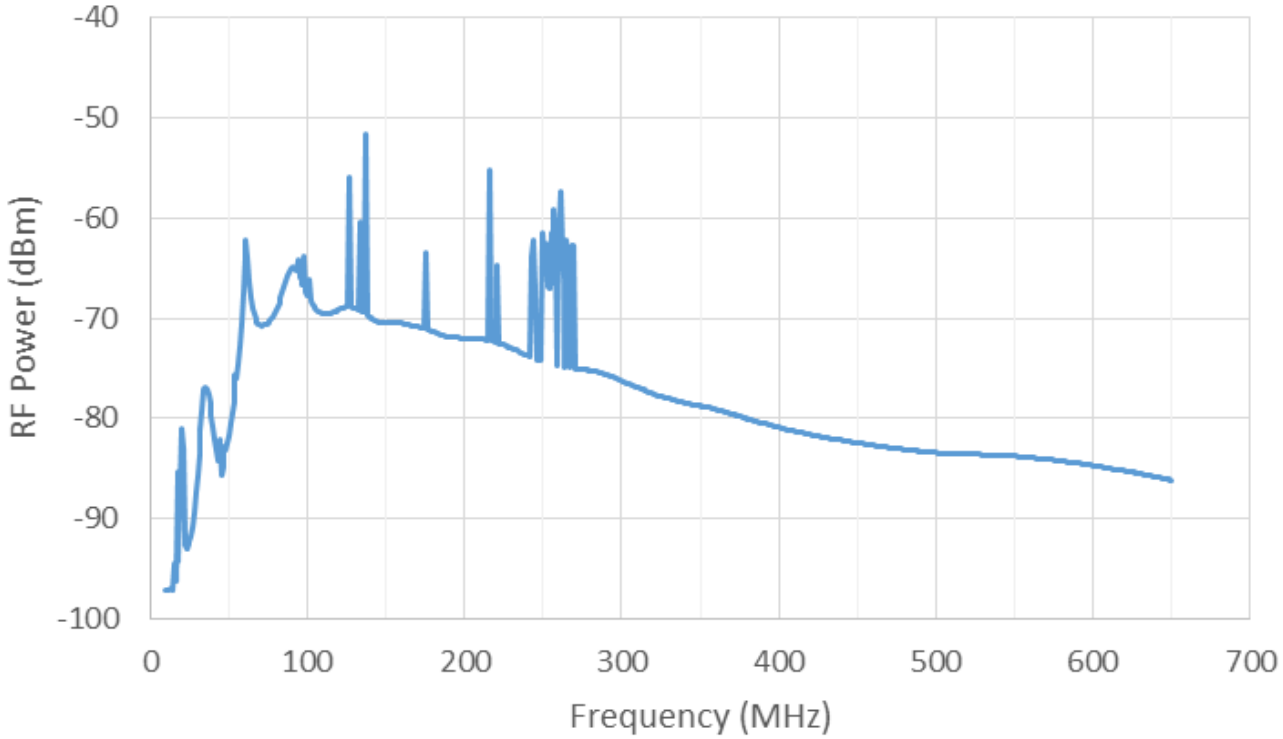
RX WP input data – Input RX Level

$$T_{sky} = 60 \cdot \lambda^{2.55}$$

RFI levels ML corrected

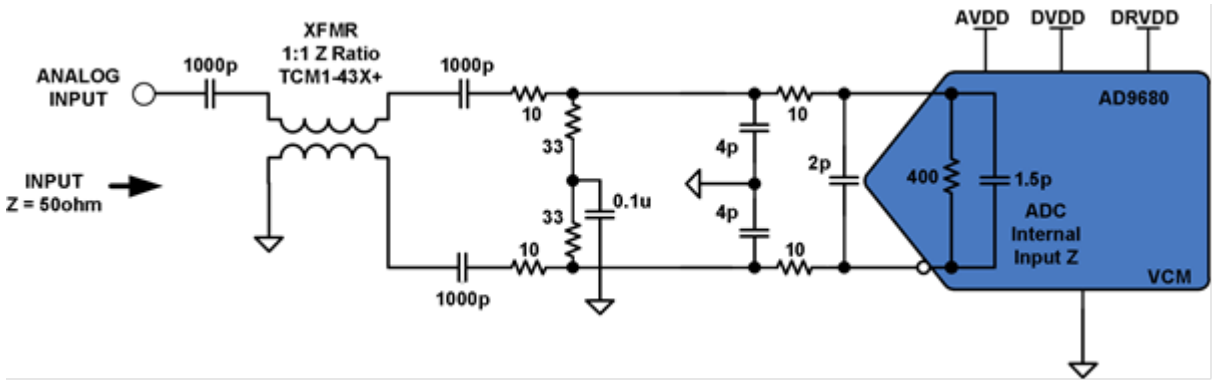
Transducer gain
Antenna+LNA

RF spectrum at RX input (50-350MHz):
-43.6dBm (SKY would be -46.7dBm)



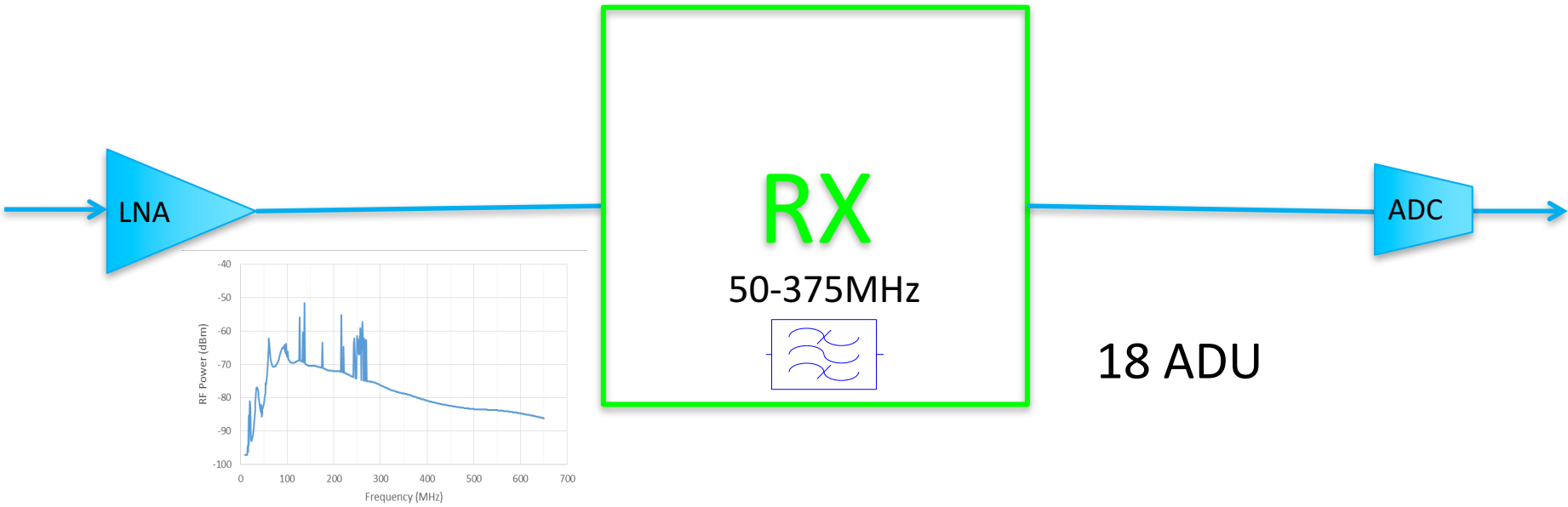
RX WP input data – ADC end

As outcomes by Comoretto *et*. *al*. the optimal power level at the ADC input is 17.5 ADU rms (Analogue Digital Units) which corresponds to -14.7dBm assuming an impedance of 400Ω and a full scale voltage of $1.7V_{pp}$ for our specific ADC.



Considering the aforementioned power level of -14.7dBm at the ADC input, this means that the PREADU board has to deliver an RF power, on a 50Ω load of -2.7dBm (12dB is the loss conversion due to matching and single-ended/differential conversion)

RX Analysis - Gain



$$RX_{Gain}(dB) = TotalPower_{ADC\_input} - TotalPower_{LNA_{output}} = -2.7dBm - (-43.6dBm)$$
$$= 40.9dB$$

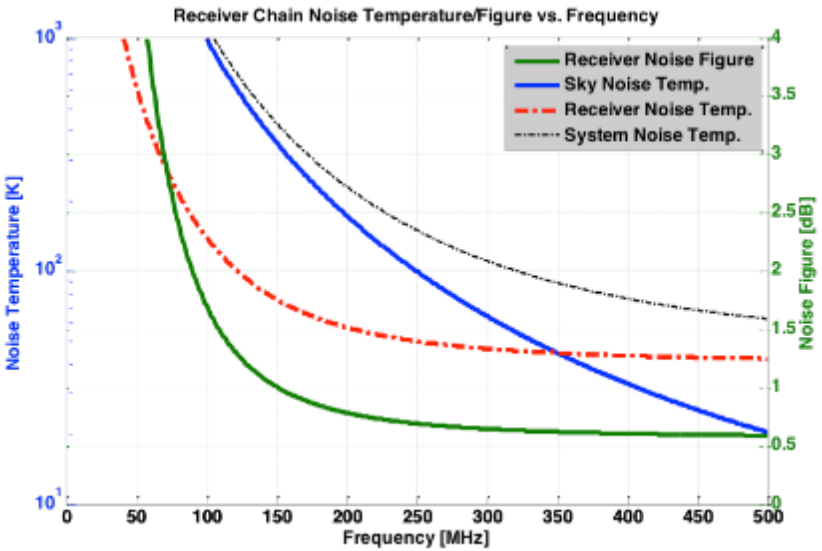
Receiver Analysis - Noise Figure

Baseline assumptions

$$T_{sky} = 60 \cdot \lambda^{2.55}$$

$$T_{\mathrm{Re}ceiver} = 10\% T_{sky} + 40K = 44K$$

Calculation performed @350MHz



RX WP assumption

$$T_{\mathrm{Re}ceiver} = T_{LNA} + 10\% T_{LNA} = 1.1 \cdot T_{LNA} = 44K$$

$$T_{LNA} = \frac{T_{\mathrm{Re}ceiver}}{1.1} = 40K$$

$$NF_{LNA} = 0.56 \text{ dB}$$

Maximum LNA NF@350MHz allowed to reach specs

RX Analysis - Noise Figure

$$T_{\mathrm{Re}ceiver} = T_{LNA} + \frac{T_{RX}}{G_{LNA}} + \frac{T_{ADC}}{G_{LNA}G_{RX}} < 44K$$

Considering AD9680 case

$$NF_{ADC} = P_{ADC\_FS} + 174dBm - SNR_{ADC} - 10\log(BW) =$$

$$= 4.5dBm + 174dBm - 61.4dB - 10\log(300MHz) = 32.3dB \rightarrow T_{ADC} = 490kK$$

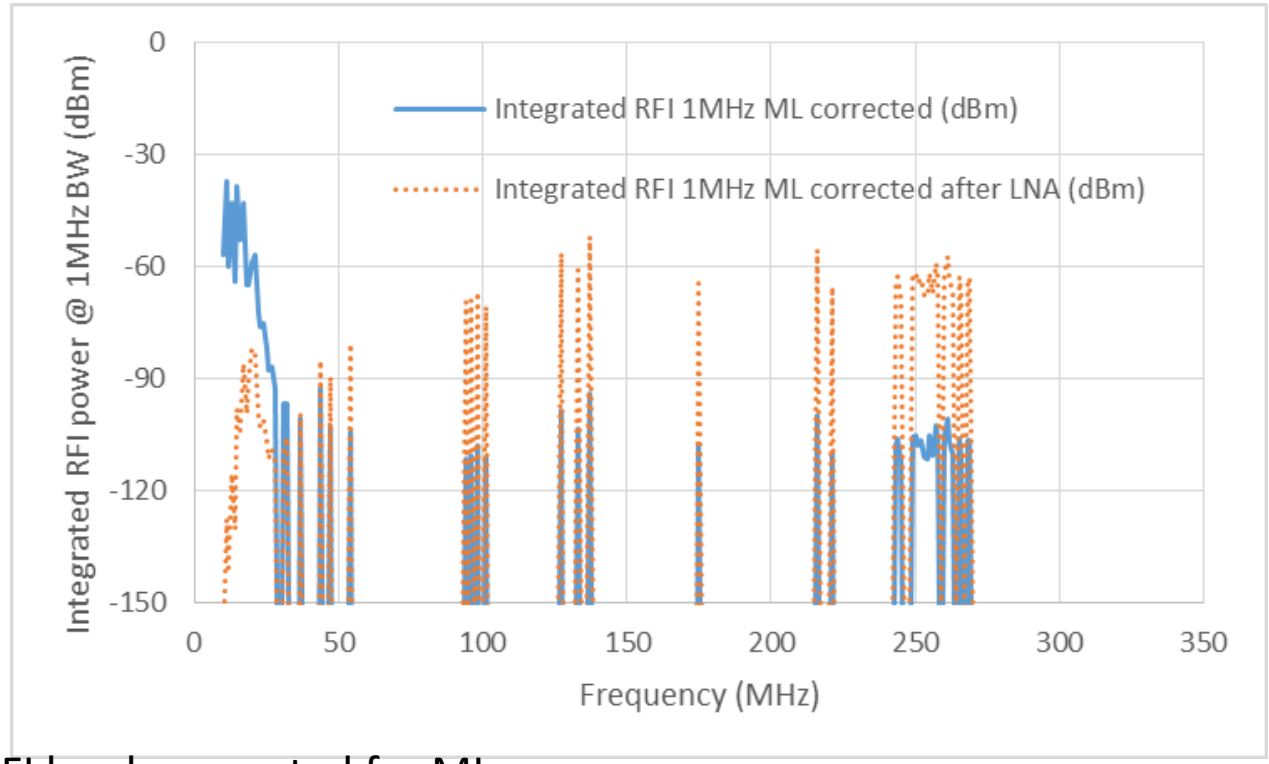
$$T_{RX} < (T_{Receiver} - T_{LNA} - \frac{T_{ADC}}{G_{LNA}G_{RX}})G_{LNA}$$

$$T_{RX} < (44K - 40K - \frac{490kK}{G_{LNA}G_{RX}})G_{LNA} = 39842K$$

$$NF_{RX} = 21.4dB$$

RX Analysis – Linearity

REF- REQ SKA #2653: The level of spurious products generated by the SKA1_Low, in the presence of signals representative of the expected RFI environment [AD2], shall degrade the expected thermal noise floor of a 1000 hour integration by no more than 10%.



RFI levels corrected for ML and LNA transducer gain

RX Analysis – IMs and HDs

RFI RX input (dBm)	RFI (MHz)	IM3 (MHz)	IM2 (MHz)	HD3 (MHz)	HD2 (MHz)
-56	127[A]	117/147	10/264	381	254
-51	137[B]			411	**274**
-64	175	79[A]/99[B] 134[C]/257[C]	302[A]/312[B]	525	350
-55	216[C]	**305[A]/295[B]** 38[A]/58[B]	**343[A]/353[B]** 89[A]/79[B]	648	432
-62	240-270	210÷300	0÷30 480÷540	>720	>480

Table 1: RFI, Harmonics and Intermodulation products.

RX Analysis – IIP2 and IIP2

$$P_{IMD3} = 3P_{RFI} - 2IIP3 \le P_{N-System} \qquad P_{IMD2} = 2P_{RFI} - IIP2 \le P_{N-System}$$

$$\Rightarrow \quad IIP3 \ge \frac{3P_{RFI} - P_{N-System}}{2} \qquad \Rightarrow \quad IIP2 \ge 2P_{RFI} - P_{N-System}$$

$$P_{N-System}(305_{MHz}) = k_B \cdot T_{system}(305_{MHz}) + BW_{\min\_dB} + G_{LNA}$$
$$\Rightarrow -179.6dBm + 30.7dB + 43.1dB_{LNA} = -105.8dBm$$

$$P_{N-System}(350_{MHz}) = k_B \cdot T_{system}(350_{MHz}) + BW_{\min\_dB} + G_{LNA}$$
$$\Rightarrow -180.7dBm + 30.7dB + 41.9dB_{LNA} = -108.1dBm$$

$$IIP3_{RX} \ge \frac{3(-51dBm) - (-105.8dBm)}{2} = -23.6dBm$$

$$IIP2_{RX} \ge 2(-51dBm) - (-108.1dBm) = +6.1dBm$$

RX Analysis – Linearity

	Gain (dB)	NF (dB)	IIP3 (dBm)	IIP2 (dBm)	P1dBin (dBm)
RX 1.0 Simulation	41	16.5	-7.7	-8.3	-22.4
Revised RX L3 specs	41	<22	>-23.6	>+6.1	>-22.6

Considering all RFI 100% persistent

RX Analysis – Linearity

The statistics of low frequency radio interference at the Murchison Radio-astronomy Observatory

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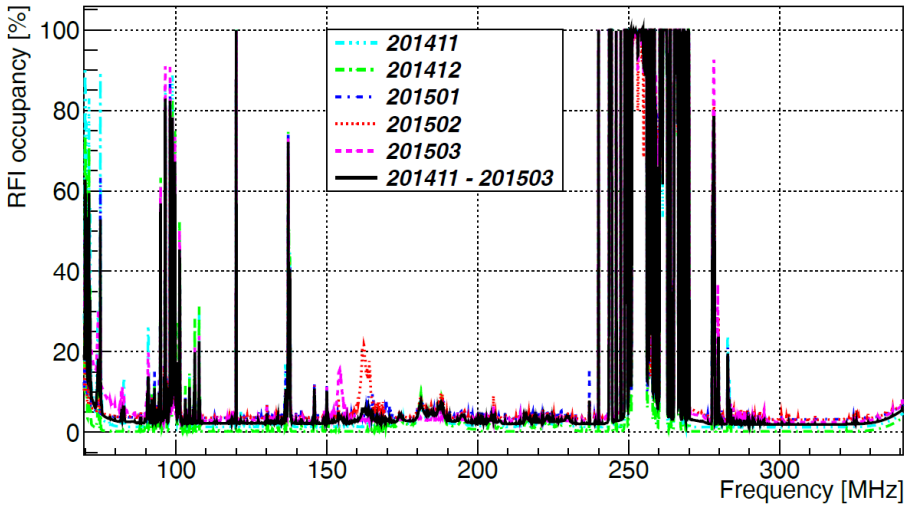


Persistant (100%) satellites based 242-272MHz

Intermittent Orbcom (137MHz) 70%

3 FM 80%, 3 FM 40% and 4 FM 20%

and

216MHz only during (rare) strong ducting events

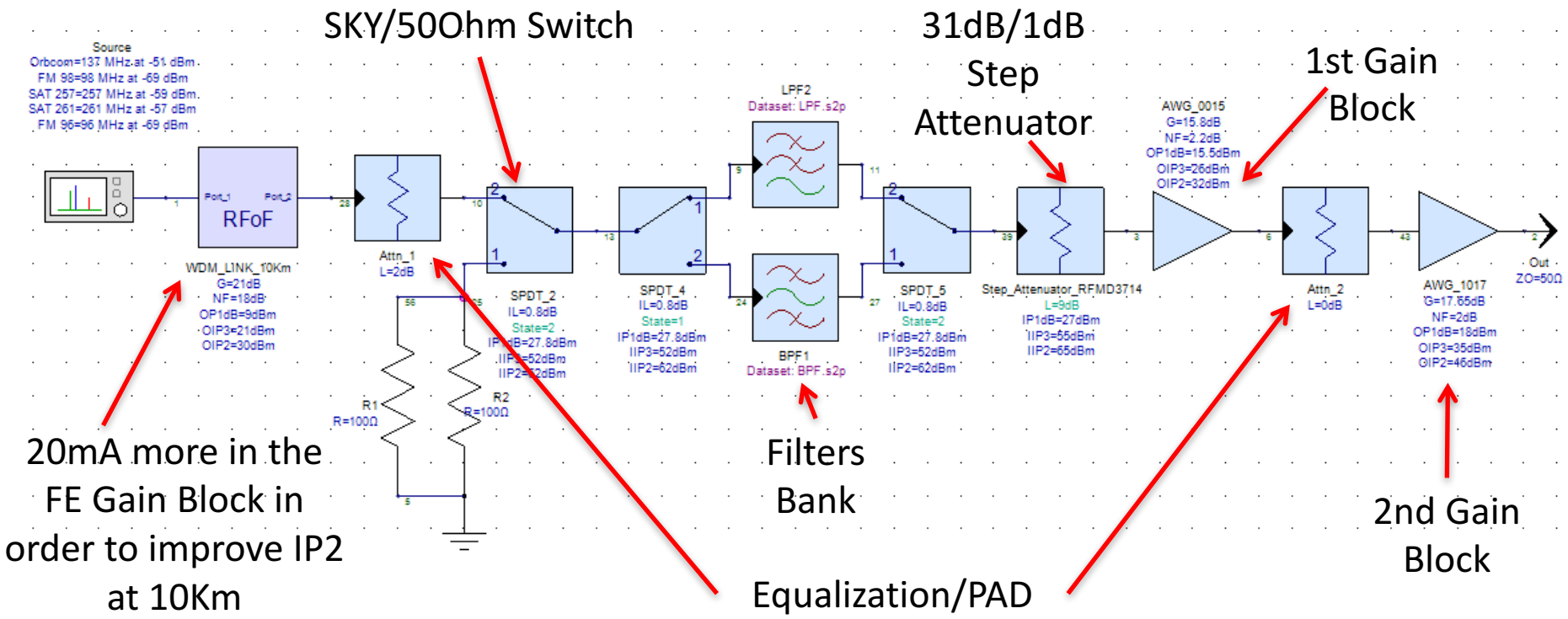
$IIP2_{RX} \geq -3.1dBm$

R163 AAVS1 requirement

AAVS1 shall be designed such that 95% of the time the performance of the system will not be affected by ***terrestrial*** electromagnetic radiation at any frequency.
Parent requirement: SKA1-SYS_REQ-2467

The worst RFI in terms of in-band power/intermodulations/harmonics comes from space (Orbcom Satellite at 137MHz)

RX Chain



New RF switches from Peregrine (PE4251) and new DSA from RFMD (RFSA3714): cheaper and easier to procure than Hittite and Minicircuits ones

	Gain (dB)	NF (dB)	IIP3 (dBm)	IIP2 (dBm)	P1dBin (dBm)
RX 2.0 Simulation	40.7	18	-7.1	-2.1	-22.1
Revised RX L3 specs	41	<22	>-23.6	>-3.1	>-22.6

RX Linearity

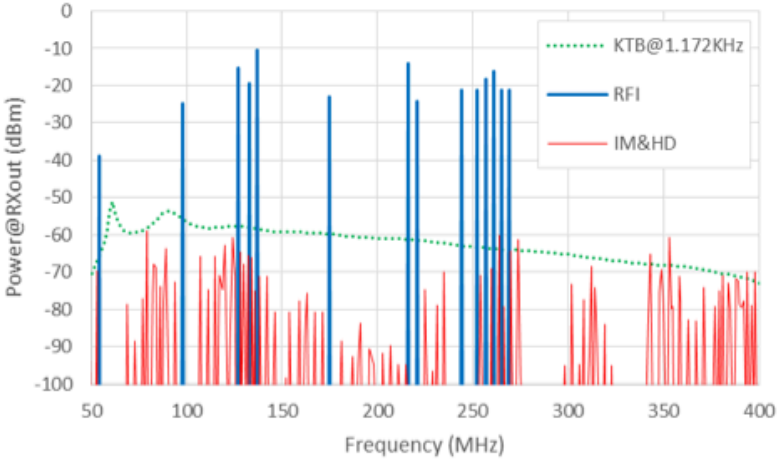


Figure 8: Receiver output spectrogram (BW = 1.172 KHz at correlator).

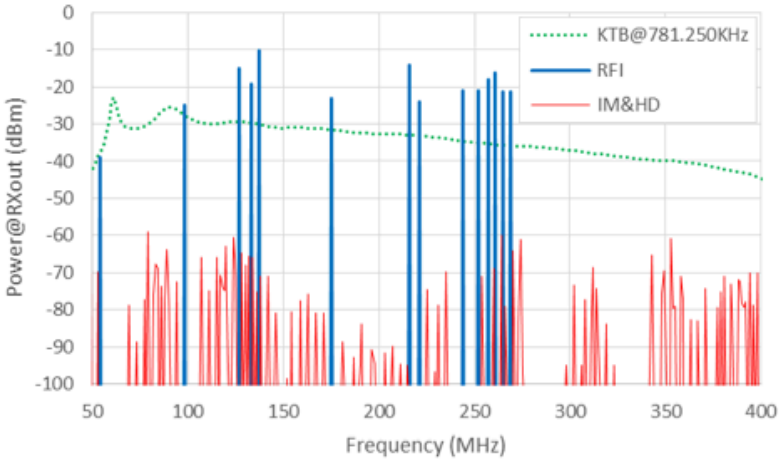


Figure 9: Receiver output spectrogram (BW = 781.25kHz at TPM).

In order to check the performance of the system in terms of dynamic range, with Genesys we computed the spectrum at the RX output considering the strongest RFI peaks present at its input.

RX Relevant Specifications

DC specifications (at 25°C unless otherwise noted).

Parameter	Value	Notes / Conditions
Vin FE PCA	3.5-5VDC	
Power FE PCA	<750mW	At 50°C with Vin=3.5V and without the LNA boards connected and biased.
Vin PREADU PCA	3.5VDC	
Power PREADU PCA	<1300mW	Two PREADU channels.
LNA Power Supply	3.5-5VDC >150mA	The FE module shall bias the LNA through the RF connectors.

Optical specifications.

Parameter	Value	Notes / Conditions
Nominal WDM optical wavelengths	1270nm / 1330nm	

RF requirement specifications (0-10Km of G652D SMF).

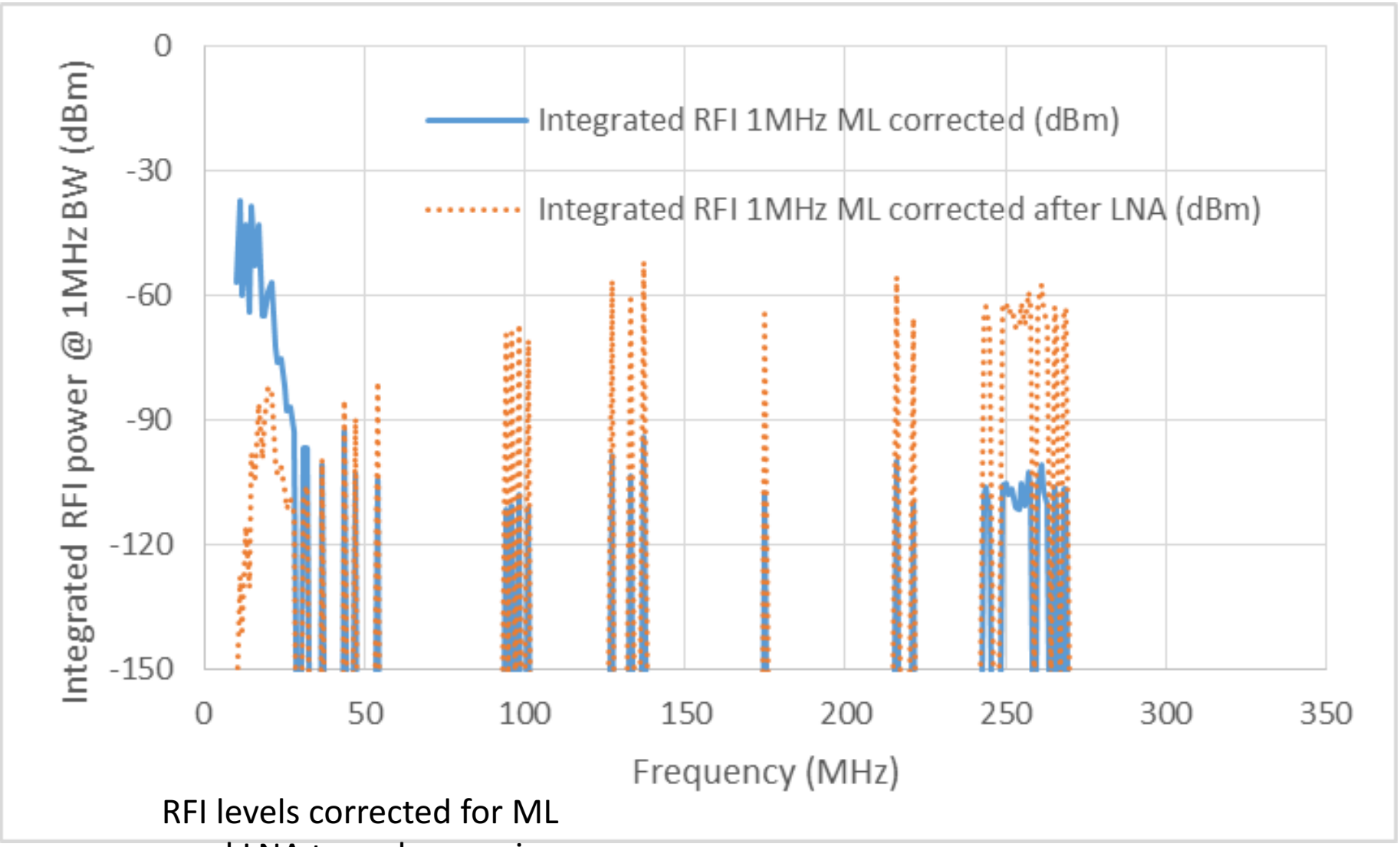
Parameter	Value	Notes
RF band	50-650MHz	Overall frequency band
Low Band (LB)	50-375MHz	3dB cut frequency
High Band (HB)	375-650MHz	3dB cut frequency
Flatness	+/-1.5dB	Measured in the two separate sub-bands LB and HB
HP filter rejection	≥45dB	Freq≤20MHz, HP filter integrated in the FE PCA
LB filter rejection	≥45dB	Freq≥450MHz, LB filter integrated in the PREADU PCA
HB filter rejection	≥45dB	Freq≤325MHz & Freq≥750MHz, HB filter integrated in the PREADU PCA
Gain	41dB	See Simulation report.
IRL	>12dB	Measured at both FE inputs on the overall RF band 50-650MHz.
ORL	>12dB	Measured at both ORX+RF outputs on the two sub-bands LB and HB.
NF	<22dB	See PDR report.
RF channels isolation	>30dB	Defined as the difference of the gains measured at the two PREADU PCA outputs with the same FE PCA input on both LB and HB bands.
OP1dB	>+17.3dBm	20dB below P1dB at nominal output power of -2.7dBm.
OIP3	>+18dBm	See Simulation report.
OIP2	>+38dBm	Updated spec considering RFI statistic.

Environmental specifications.

Parameter	Value	Notes
FE PCA operational temperature	-10 ÷ +70°C	See "Testing consideration for outdoor RF subsystems" report.
PREADU PCA	+15 ÷ +30°C	

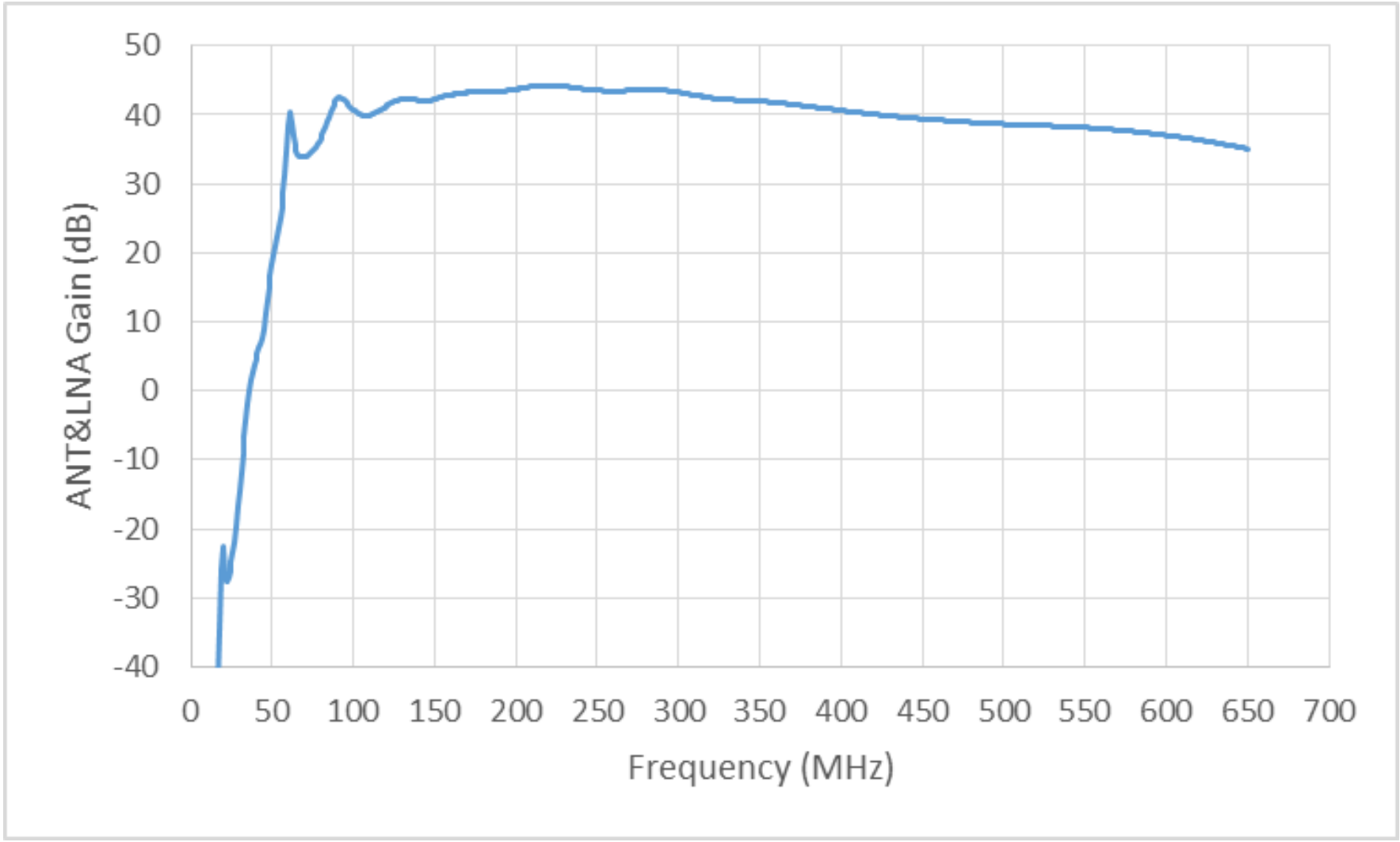
Slides di riserva

Receiver WP input data – RFI

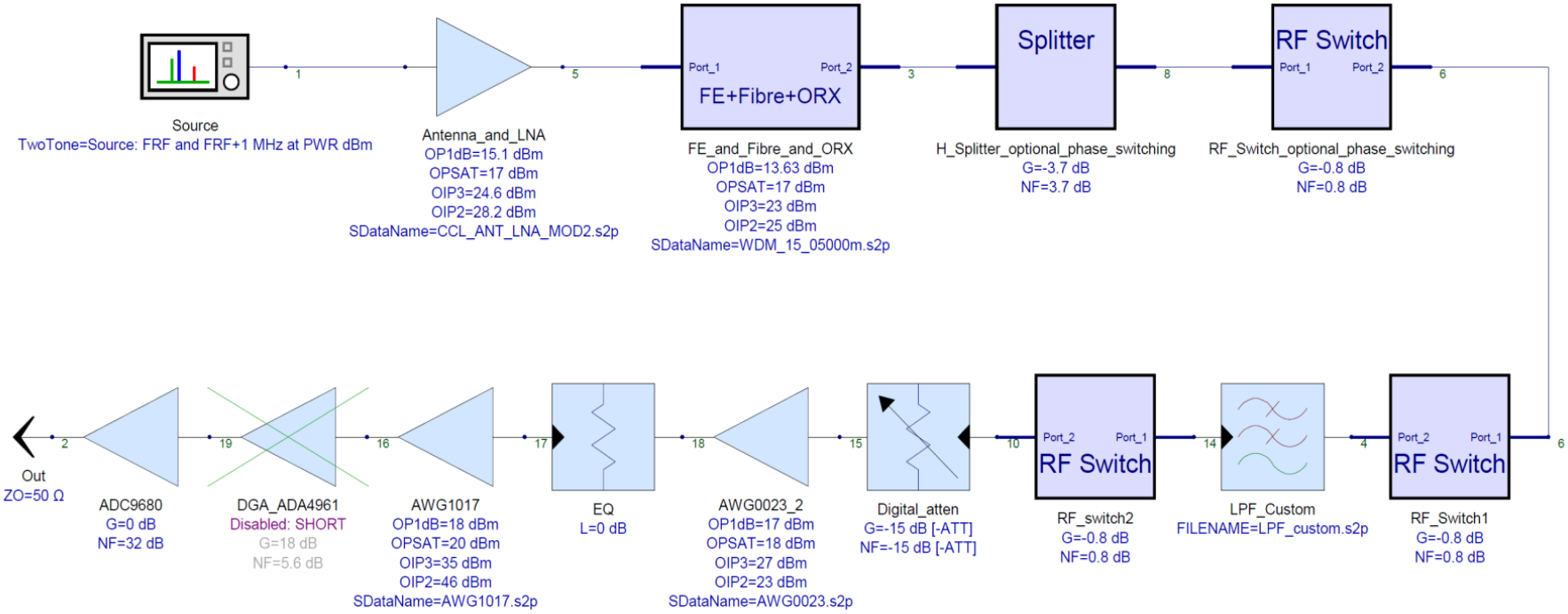


RFI levels corrected for ML and LNA transducer gain

Receiver WP input data – Trasducer Gain



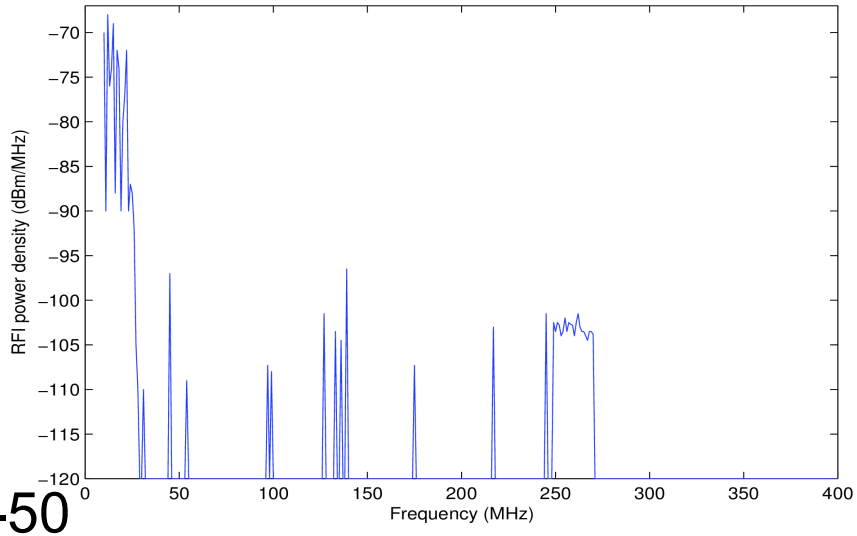
Block Simulation (only RX)

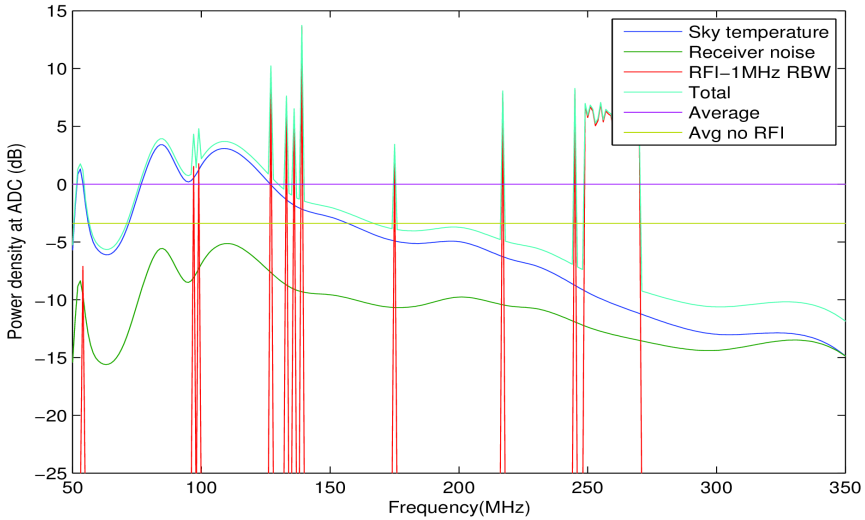


ADC resolution and quantization noise

ADC requirements:

- Immunity to RFI
  - RFI integrated power > sky power
- Good linearity
  - Deviations from linearity < -50 dB
- Low added noise
  - Goal < 0.5% of total, at all frequencies
  - Requirements on spectral flatness



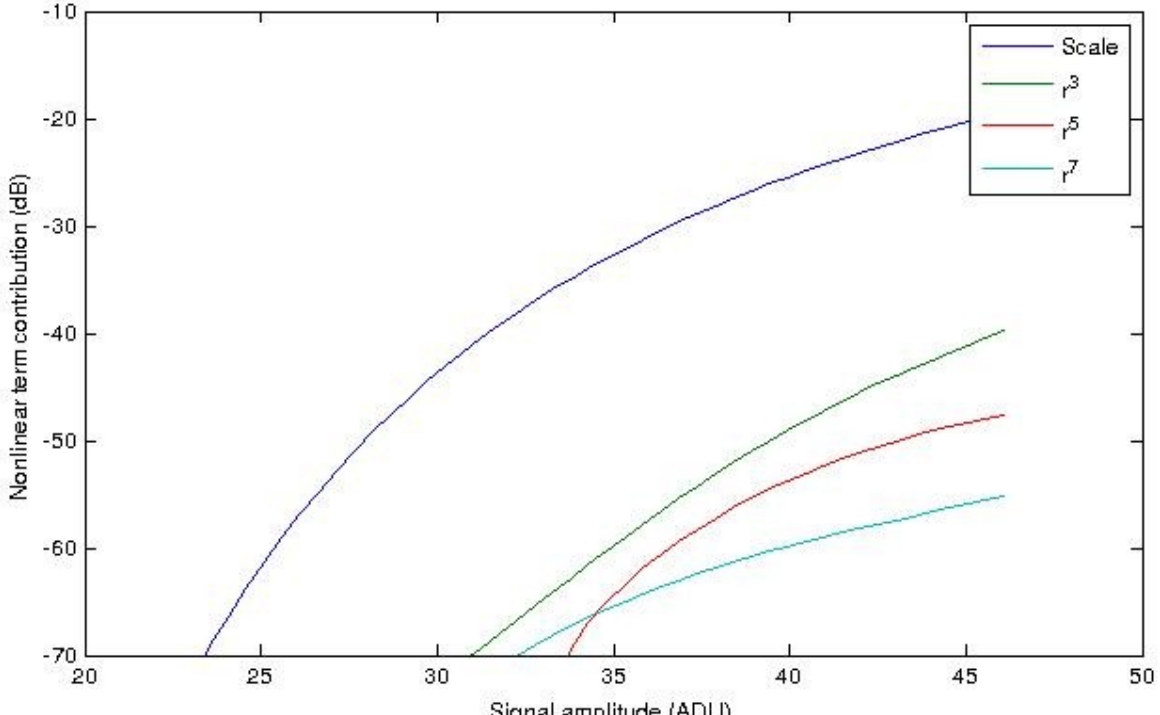


ADC linearity

Response of an interferometer to a Gaussian correlated signal

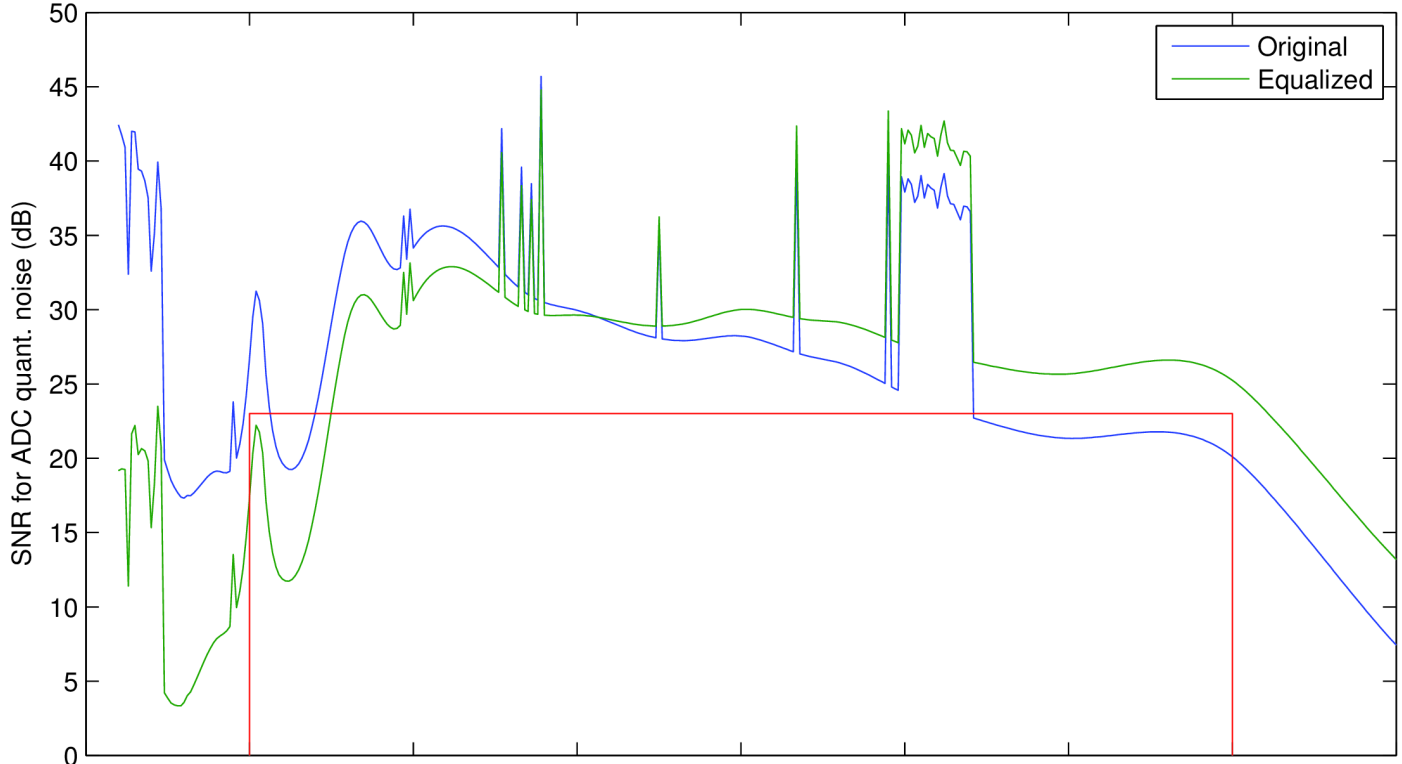
- Gain variations (mainly clipping) for input RMS < 14% full range
- Distortion of the cross correlation for input RMS < 16% full range
- For 8 bit ADC: RMS < 37 ADU
- Added noise: 1/12 ADU^{2-} larger for less eff. Number of bits

Scale (gain) error and cross correlation nonlinear terms as a function of input level



ADC linearity

- Input optimal level ~ 18 ADU to leave room for RFI variations
- Spectral slope causes ~ 1% added noise at > 250 MHz
- “Whitening” 1/f2 network can correct the sky spectral slope
- Receiver chain bandshape should be flat at ± 6 dB



Quantized spectrum
total SNR