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DOCUMENT NUMBER: **V081500003/LND/AS/001**

DOCUMENT REVISION: **03**

DATE: **25/11/2016**

CAGE CODE:

Customer: INAF

Design of performance improvements and industrial process of SKA-LFAA receiver

Technical Report

Contract N.: 18862/2014

No. pagine / Nr. of pages	Classificazione / Classification
	NON CLASSIFICATO / UNCLASSIFIED
	NON CLASSIFICATO CONTROLLATO / UNCLASSIFIED CONTROLLED
	RISERVATO / RESTRICTED
	RISERVATISSIMO / CONFIDENTIAL
	SEGRETO / SECRET
37	**No. totale delle pagine / Total nr. of pages**

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REVISION RECORD

Rev.	Modification N.	Date	Description	Author/s
00		11/10/2016	First Issue	Luigi Pierno
01		15/12/2016	Second Issue: This issue has been delivered following the INAF remarks	Luigi Pierno
02		11/5/2017	Third Issue: This issue has been delivered following the INAF remarks and new enhancements about the proposed solution	Luigi Pierno
03		16/10/2017	Forth Issue: This issue has been delivered following the INAF remarks and new enhancements about the proposed solution	Luigi Pierno, Alberto Sperandini

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1 INTRODUCTION

The subject of this Technical Report is the description of the industrialization aspects including design improvements of the FE optical transmitter and optical receiver PREADU sub-assemblies in the LFAA RX chain. For RX chain means a complete RF block from the output of LNA to the input of ADC. Also the mass-manufacturability and testing study, the reliability and maintenance study and the product baseline of the sub-assembly are provided. The study has been performed starting from a prototype initially provided by INAF (INAF prototype).

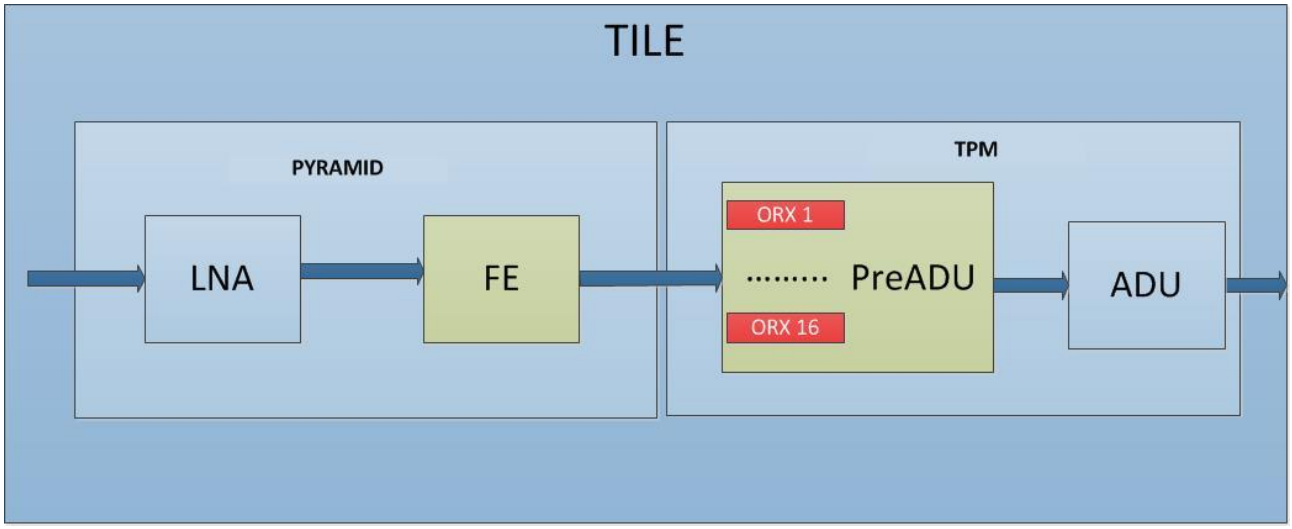


Figure 1 – Block diagram of RF chain

The two signals corresponding to the two polarizations of each array antenna element are transported by one optical fiber by using WDM technique (Wave Division Multiplex).

The FE subassembly is the optical transmitter placed on each antenna, while the PREADU board consists of an array of 16 optical receivers ORX in a single subassembly.

Such improvements have two goals:

- Make the v2.1 prototype whose project has been acquired by LeonardoCompany in partnership with INAF, ready to be mass-produced;
- Reduce the costs of the complete tested and maintained optical transmitter FE and receiver ORX sub-assemblies to a target cost around € 60 per unit for a hypothetical production of about 130.000 or 1 Million complete chains (+ 10% spare parts).

2 REFERENCE DOCUMENTS

2.1 Applicable Documents

Ref.	Identifier	Title
A1.	Contract n. 18862/2014	SERVIZIO DI INGEGNERIZZAZIONE E INDUSTRIALIZZAZIONE DI UN SISTEMA RICEVENTE PROTOTIPALE NELL'AMBITO DEL PROGETTO

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Ref.	Identifier	Title
		SKA-LFAA (Low Frequency Aperture Array)
A2.	Addendum to Contract n. 18862/2014	SERVIZIO DI INGEGNERIZZAZIONE E INDUSTRIALIZZAZIONE DI UN SISTEMA RICEVENTE PROTOTIPALE NELL'AMBITO DEL PROGETTO SKA-LFAA (Low Frequency Aperture Array)

2.2 Referenced Documents

Ref.	Number	Title
R1.	INAF Document	Collaudo TX009-RX001 (Optel receiver final test)
R2.		Electrical Diagram
R3.		Parts List
R4.		Package Diagram
R5.		PCB assembly diagram

3 DEFINITIONS & ACRONYMS

3.1 Definitions

Terms	Description
ADU	Analog to Digital Unit
APIU	Analogue Power Interface Unit
EMI	Electro Magnetic Immunity
FE	Front End
INAF	Istituto Nazionale di Astrofisica
LFAA	Low Frequency Aperture Array
LNA	Low Noise Amplifier
OTX and ORX	Optical transmitter and optical Receiver subassembly
PRE ADU	Pre Analog to Digital Unit
SKA	Square Kilometer Array
WDM	Wavelength division multiplexing

3.2 Acronyms

Acronym	Description

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4 INDUSTRIALIZATION AND COST REDUCTION

4.1 Cost objectives and reliability requirements

As mentioned before, the cost of the optical link composed of FE and ORX per each antenna unit (double polarization signal) is estimated to be less than 60 € by INAF, considering a production volume of around 144.000. pieces (2^{17} + 10% of spares based on RAMT Analysis considerations).

The required reliability foresees an acceptable performance degradation: an out of use of the 0.3% of the array receiver chains is the acceptability limit of the array operation under the operating conditions. The Planned maintenance period is 1 year. Therefore, the reliability will be much higher than the 99.7% whereas the receiver chain also includes other parts as well as FE and PRE ADU.

The operating conditions are:

- FE -10 : +70 °C
- PREADU +15 : +30 °C

4.2 SELECTION OF CRITICAL OPTICAL COMPONENTS

Optical components are critical both for the value and for the integration aspects. Fiber optic pigtail does not allow for SMT temperature soldering that is applicable to the rest of the components.

Their soldering lead should be locally heated to solder.

The objective is to get control of the chain supply up to the far east telecom manufacturer in order to optimize logistic costs, and in order to obtain a proper selection of the laser chip based on the IL curve performance and repeatability, and on monitoring PD tracking.

The device selected is a double Transmitter custom device packaged within a standard Optical subassembly typical for B-OSA. The same applies for the double Receiver. These packages are commonly adopted for BiDI links. Selected wavelengths are typical of Coarse WDM and uncooled for low cost and wide diffusion on the market. Highly integrated photodiodes array solutions in second and third optical window have been discarded as they are not cost effective.

On the market, especially in Far East, manufacturing players for telecom own the required technology and know-how for the special B ROSA and B TOSA required for the project; in this study many suppliers have been compared, so the chain supply is guaranteed also in case of obsolescence of the selected supplier product.

4.3 Integration, Maintenance, installation and RAMT assessment

Integration and test of PCBs of FE and PREADUs will be realized based on three possible solutions:

- Leonardo assembly lines
- Italian Leonardo subcontractors
- Far East low cost Leonardo subcontractors.

The choice is the second because of cost and quality considerations.

Integration of the FE in the pyramid assembly together with the 2 LNAs (provided by suppliers engaged by SKA LFAA consortium) is a mechanical assembly and electrical testing activity that will be performed in factory assembly line (i.e. Leonardo premises), the complete pyramid assembly will be then delivered to the radiotelescope installation place to be mounted on each antenna mast.

The PREADU =ORX16 will be connected to the ADU board inside the basket suitable for the rack 19”, this integration operation will be done in in factory assembly line (i.e. Leonardo premises).

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The Central Processing Facility (CPF) will host the array of 16 PREADUs and ADUs; the array of 16 PREADUs will be assembled and tested in factory, and afterward will be shipped to the radiotelescope installation place to be placed in the rack 19" placed in the CPF.

An RF testing bench to test the RF chain of 16 FE assembly + 1 PREADU subassembly will be setup in factory.

The strategy of maintenance is based on level of maintenance 3 (in factory maintenance), so no maintenance activity will be performed on the radio telescope installation site except mounting and dismounting of pyramid assembly (composed of LNA and FE) and of PREADU array in the rack 19" subrack in the CPF.

The Least Replaceable Unit (LRU) will be the whole pyramid assembly and the PREADU = ORX array x16).

The maintenance will be based on the replacement of each LRU at the installation site, particularly at the antenna mast for the pyramid assembly and at the subrack in rack 19" in the CPF for the PREADU.

The maintenance and logistics management during the operating life of the assembly are described in Attachment A.

In order to implement this maintenance logistics principles a BITE of FE and PREADU is required and hereafter proposed. For each antenna, an indirect FE monitoring is proposed to be based on laser optical power monitor inside the PREADU and DC power supply current monitor inside the APIU (BITEs are foreseen in the APIU). This will implement a remote sensing of the FE so that no wireless BITE data transmission would be perturbing the LFAA receiving functionality.

The MTBF of the components: two LNAs, single FE, single PREADU and single motherboard have been calculated by Prof. Catelani of "Università di Firenze - Dipartimento Ingegneria delle Informazioni" and the results of calculation based on the TELCORDIA SR332 have been reported in Attachment C – Part 1.

The calculation based on the MIL HDBK 217 have also been performed, but, due to the telecom nature of most of the components, this reliability assessment is less accurate and less suitable in this case. The MTBF analysis has been performed on the components of the INAF prototype, therefore the results have to be considered the worst case as the new industrialized product is simpler than the prototype.

The design of a PCB that contains 16 ORX, allows to reduce costs with respect to single PCB per each ORX unit, but its MTBF is a factor of 16 lower than the MTBF of the single ORX unit.

Optical connectors show a reliability based on the maximum number of mating iterations, its data are referred to a proper mating and unmating procedure implemented by the operator in a clean and dust free environment while usually the mating unmating does not happen in this conditions.

In this application they are mated and unmated a very limited number of times by a skilled operator and only during installation and maintenance of the PREADU and FE. Particularly the FE connection and disconnection is made in the antenna installation environment that can be very harsh due to the presence of dust and moisture that affect the optical fibre "end fire" (fibre tip). So the number of mating and unmating operations available should be downscaled considering the installation environment.

The MTBCF calculation of the LFAA subsystem is covering only the chain LNA/FE and ORX, so only the contribution to the LFAA of this assembly is considered. This info needs to be complemented by the MTBCF contribution from different part of the chain as APIU and ADU systems.

The reliability will be verified also by specific environmental and aging tests on samples of the whole receiving chain done by the "Università di Firenze" that shall complement the reliability estimations reported in Attachment C - RAMT Calculation – Part 2.

4.4 Disposal and ROHs / REACH analysis

The analysis of RoHS and REACH compliance for each component of the assembly of the INAF prototype (not yet industrialized) is reported in Attachment B.

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The delivered product will be free from the hazardous substances according to the European RoHS Directive 2011/65/EU. Therefore, the product and its parts may be disposed as any standard, not critical electronic equipment.

5 ELECTRICAL CIRCUIT IMPROVEMENT

The most important changes to the components in schematics have been validated through simulation, consequently the improvement criterion has been to have a minimum impact on the functionalities of the rest of the circuit, in particular minimum impact on impedance matching, signal levels, and compression points of the rest of the chain.

5.1 Manual Adjustment elimination

The adjustment of the laser injection current in the FE is implemented in a potentiometer, the adjustment of the single chain countermeasures the tolerances of the IL curve of a commercial laser diode and in particular for the threshold current. Therefore the adjustment sets the injection current to values of around 30 mA, while the control loop is of type Automatic Power Control APC of the laser during the operating life. It utilizes the photodiode of the monitor. The requirement for the dissipation of the FE is 750mW @ + 50 ° C.

The cost of the manual adjustment is huge, therefore, the potentiometer is replaced by a resistive divider. However the arithmetical average over 10 samples of the resistance ratio will be adopted to define the resistive divider nominal value. In this regard a better selection of the laser from the manufacturer to reduce the tolerances is required. Nonetheless the value of the resistor could change to achieve the set optical power and will be selected based on the IL curve of the laser production batch.

5.2 Elimination of high band filter 350-650 MHz in PRE ADU

The high band filter was conceived to extend the applicability of the receiver in radio telescopes in that band, the SKA Organisation has reduced the bandwidth only to the low band 50-350MHz, so it has been possible to remove the high band, hence complexity and cost of this feature has been reduced accordingly.

5.3 Low band filter design

The low pass filter has been simulated to align the simulation with the measurement of the actual filter in the initial prototype provided by INAF, then some improvements have been adopted to match the following requirement:

- 3dB cut-off frequency: 350 MHz
- Rejection @ 450 MHz ≥ 50 dB

Simulations have been made in AWR environments with actual s parameters; the linear simulation results for the initial prototype filter are quite close to the measured receiver chain response.

The values of the passive filter components have been optimized, maintaining the same original structure, to improve the response @ 450MHz.

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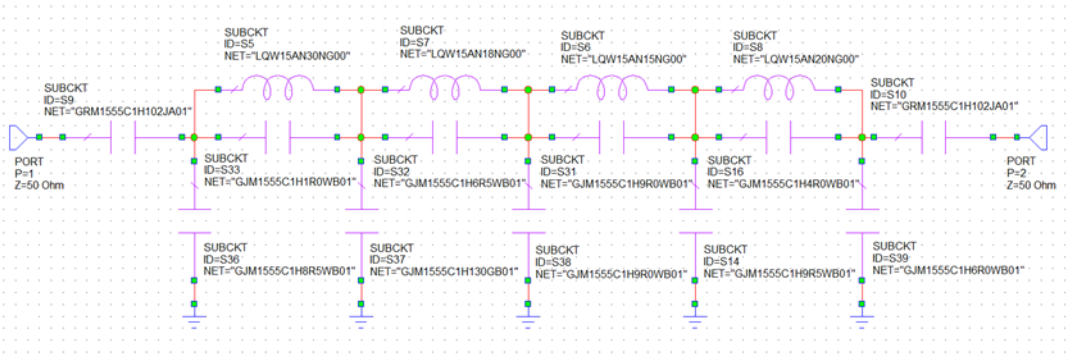


Figure 2 – Optimized filter

In the following figure, the results of the simulation of the original filter and the optimized one are shown.

It is worth noting that the E.M. simulation (green line) yields no improvements with respect to linear simulation (red line) if we compare the results with the measurement (grey lines).

On the other hand, it is quite evident the improved rejection of the optimized filter (blue line): the response within the signal band is almost the same, while the rejection at @ 450Mhz increases by about 5dB.

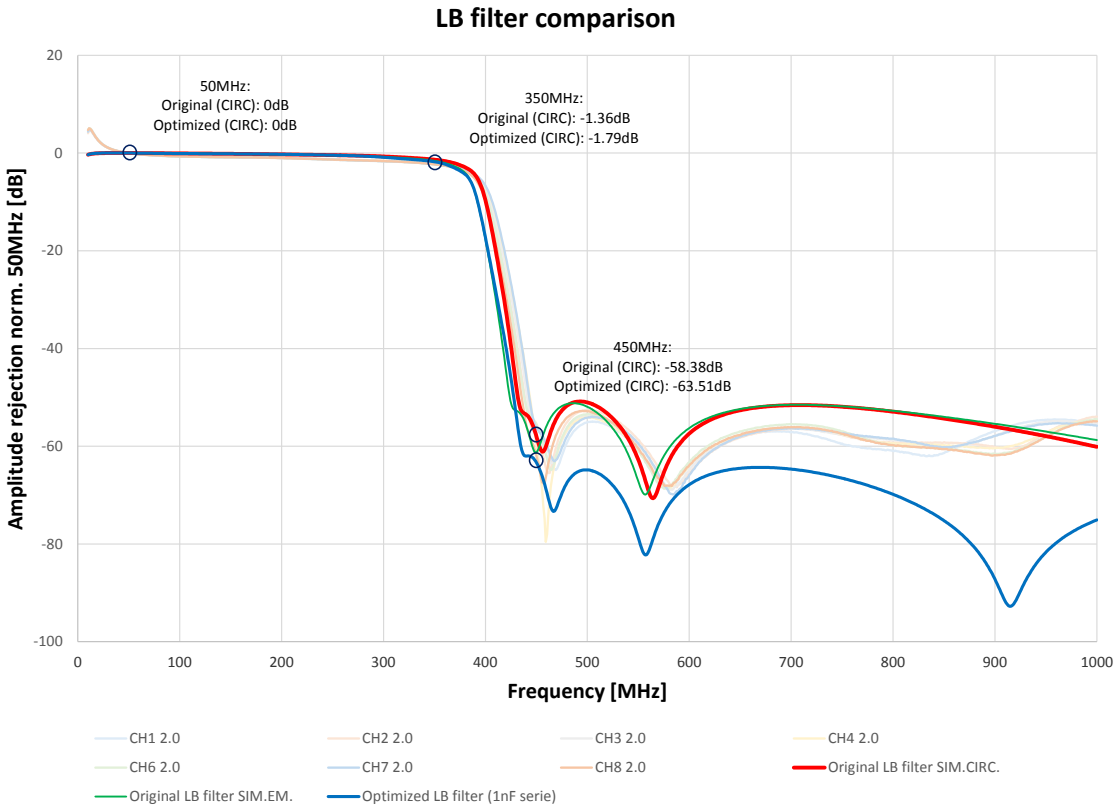


Figure 3 – LB filter optimization

Eliminating SPDT switches generates an increase in the RF chain gain of approximately 1.8 dB.

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5.4 Fixed resistances for the setting of the laser bias

The potentiometer has been replaced by 2 fixed resistors to avoid any manually tuning for each devices. During the assembly phase the laser production batch will be analyzed, on a statistics base, in terms of I-L curve and the resistor value will be selected accordingly to this analysis. The tolerance of FE absorbed current will be minimized in the range of some mA, based on the supplier production quality management.

5.5 Optical components

WDM Double laser and double photodiode are semicustom component for this application. The manufacturing volume is small so that a complete qualification environmental and reliability has not been done by manufacturers.

They guarantee to fullfill these requirements by analysis of components and by similarity to Bosa mass manufactured Telecom devices. Qualification is planned before the 1st batch release, also to verify the tolerances in the biasing curve of diodes and thresholds. The Rohs and reach are certified forum such components.

5.6 Replacement of the amplifier in the FE

The AWG0123E replaces the AWG0023 as the manufacturer claims the former to be more stable, improved 50 Ohm matching at the RF input and with a higher suppression of second harmonics wrt the latter. The 2 LDCL015 LDOs provide the 3V references to feed directly the AWG00123E amplifiers.

5.7 FE EMI Filter

A pass through EMI filter from Tusonix has been included in the package of the FE in order to reject conducted RFI from APIU.

5.8 DC blocks in PREADU

After some tests the first DC block capacitor at the output of the digital step attenuator has been replaced from 1 nF to 150pF. The replacement of the capacity value has no impact on the overall chain response, but the second one has greater rejection of low frequency (50 Hz harmonics) spurious due to negative internal DC-DC regulator.

5.9 ON-OFF RF Switch in PRE ADU

The option to load the input of the RF receiver chain using an RF switch is no longer necessary so it can be eliminated.

5.10 FE 20 MHz filter simplification

The DC-20 MHz filter in FE can be realized with a smaller number of filtering stages as it is required to be less selective by the AADC requirements.

The LNA amplifier before it already implements a sufficient RFI rejection in this band range.

5.11 Modified FE package for EMI filter

The package has included the EMI filter Tusonix 4400-095LF for the power supply filtering.

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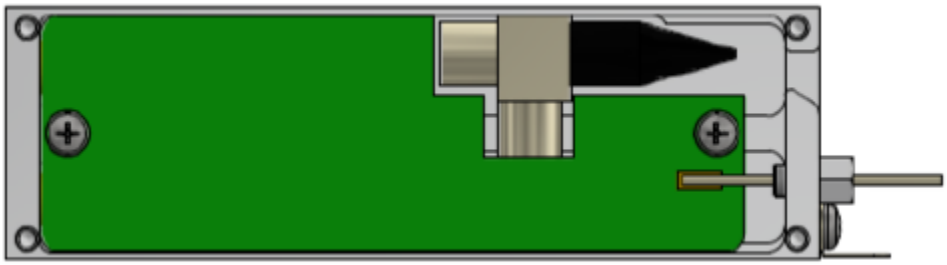


Figure 4 - FE metallic box including the feedthrough EMI filter

5.12 Simulation results

Several AWR simulations have been performed on the entire receiver chain: FE - RFoF (OTX + ORX) - PREADU.
The linear response (s parameters) has been simulated in MWO: the chain has been simulated using the linear models provided by each component manufacturer.

In addition, a system level simulation has been performed to evaluate overall linear and nonlinear features of the chain (OIP1dB, OIP2, OIP3, NF).

In this case too, each component has been modeled according to manufacturer data (touchstone files).

5.12.1 MWO SCHEMATIC (“TO_RFoF_PREADU chain”)

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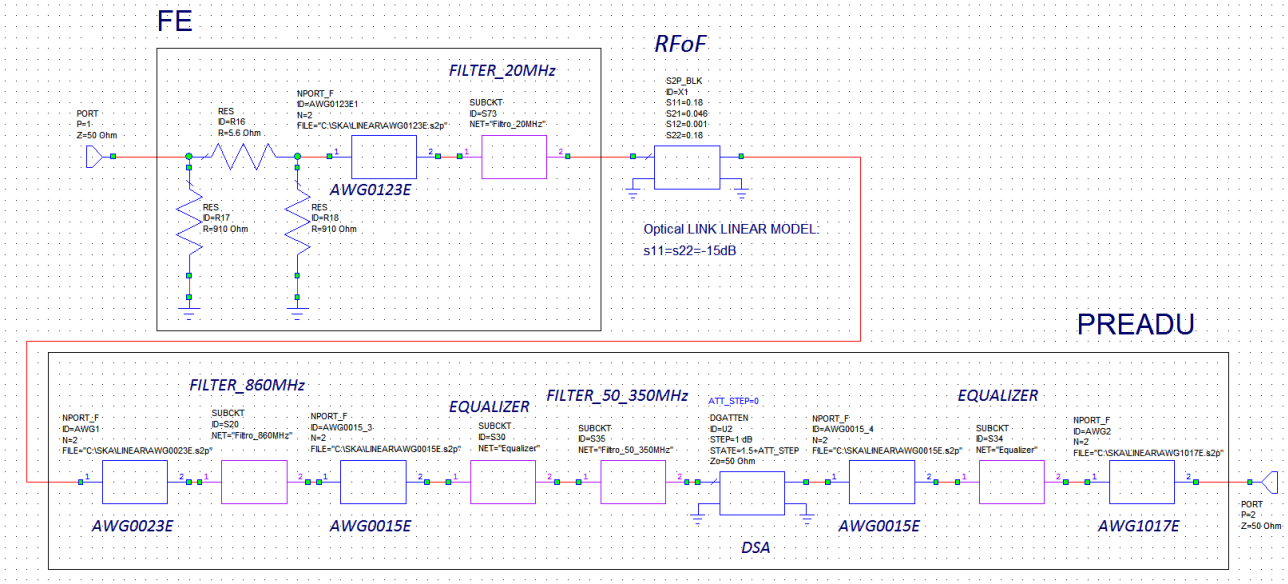


Figure 5 - MWO schematic receiver chain

The following figures show the filters and the equalizer details.

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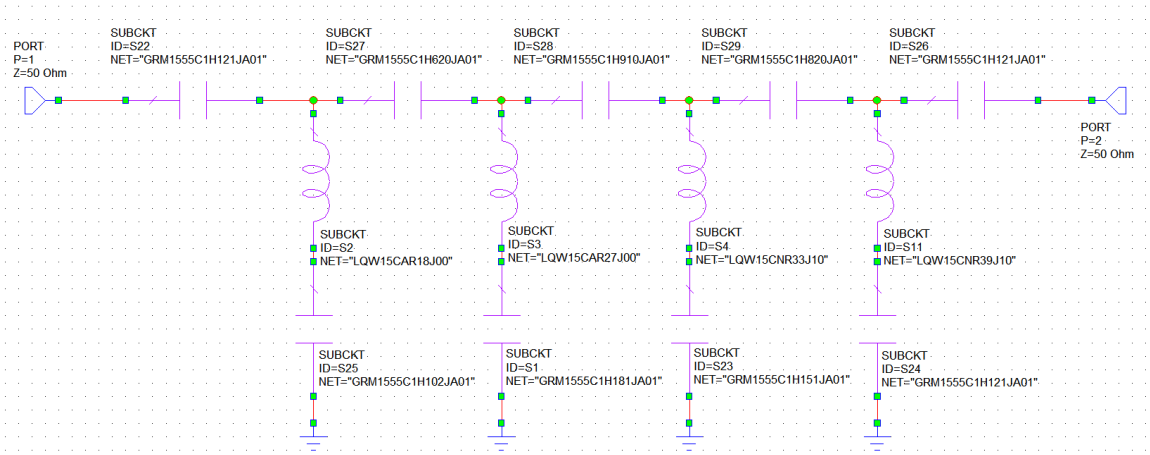


Figure 6 - FILTER 20MHz

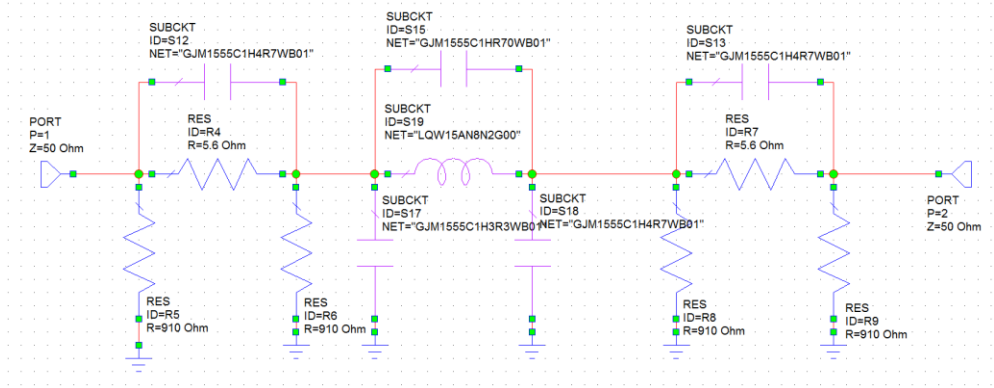


Figure 7 - FILTER 860MHz

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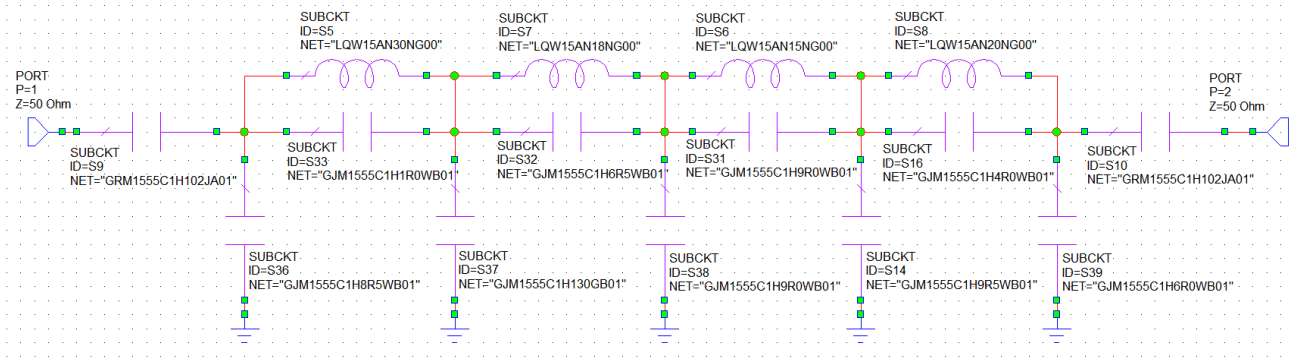


Figure 8 - FILTER 50_350MHz

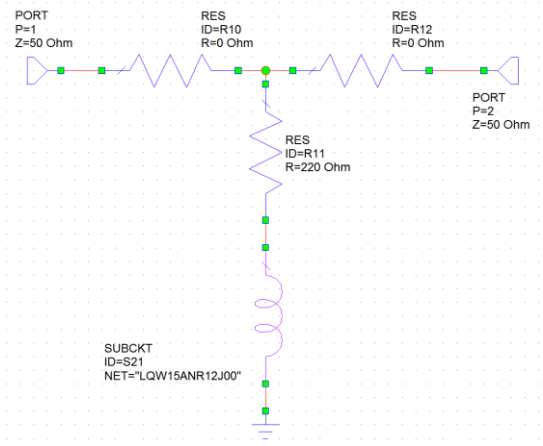


Figure 9 - Equalizer

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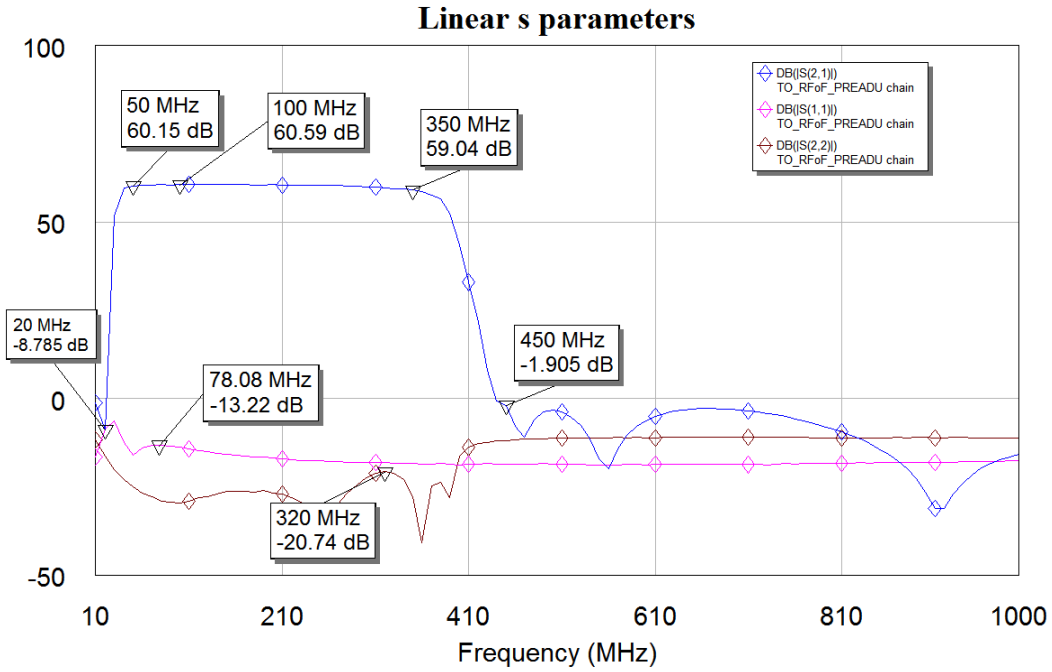


Figure 10 - Receiver chain linear s parameters

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5.12.2 VSS CHAIN (“RF chain”)

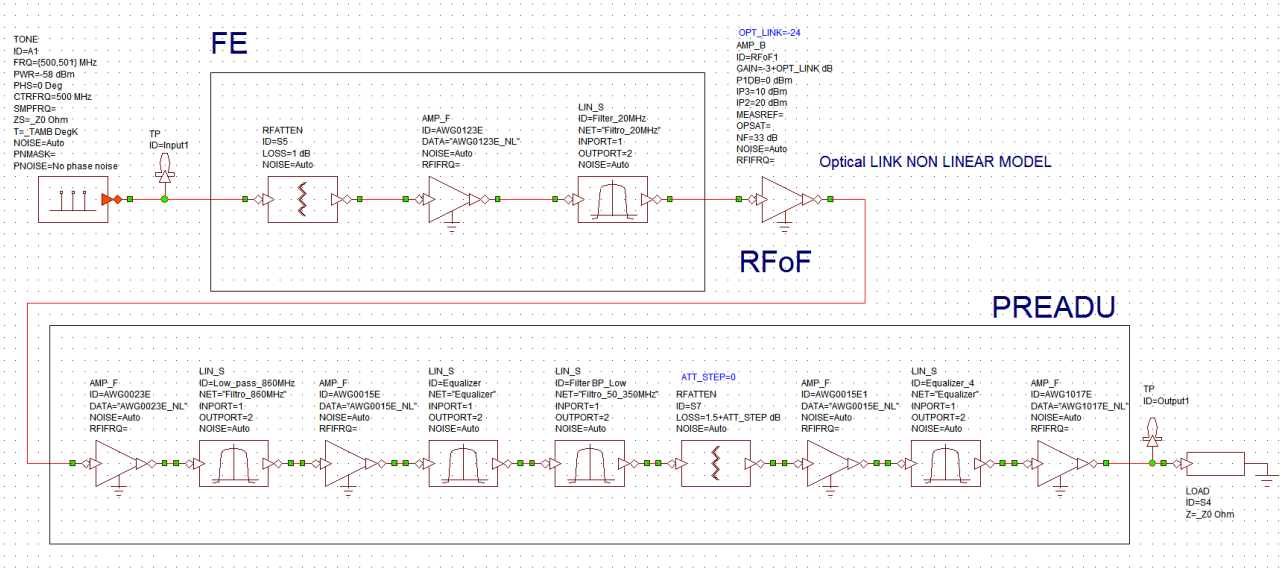


Figure 11 - VSS schematic receiver chain

The gains of the entire simulated receive chain in MWO and VSS are compared: the obtained values are compatible with each other.

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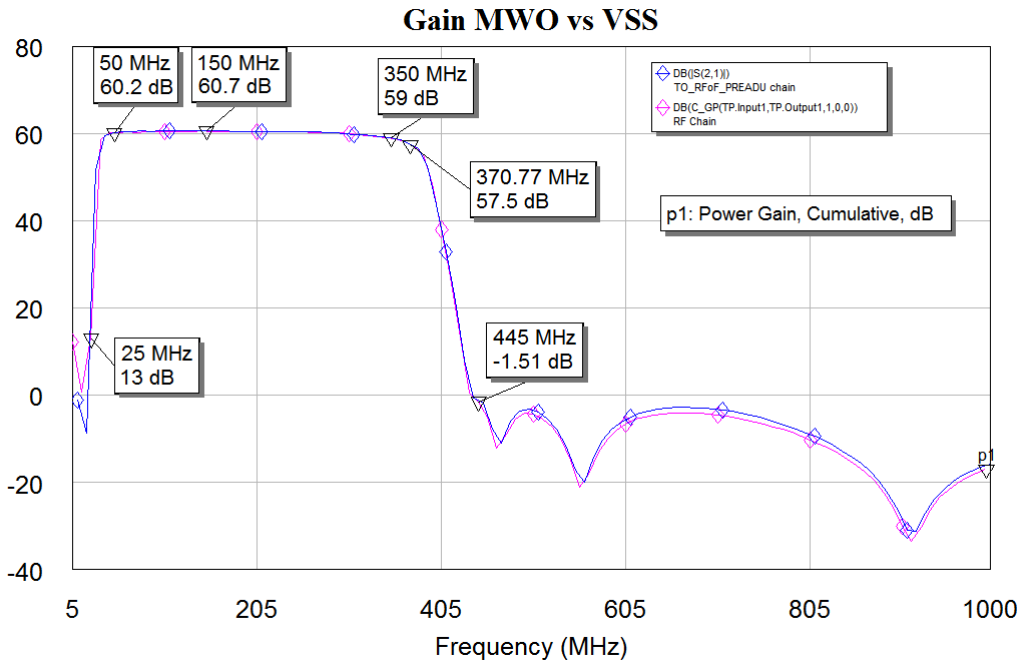


Figure 12 - Gain comparison of MWO and VSS simulation

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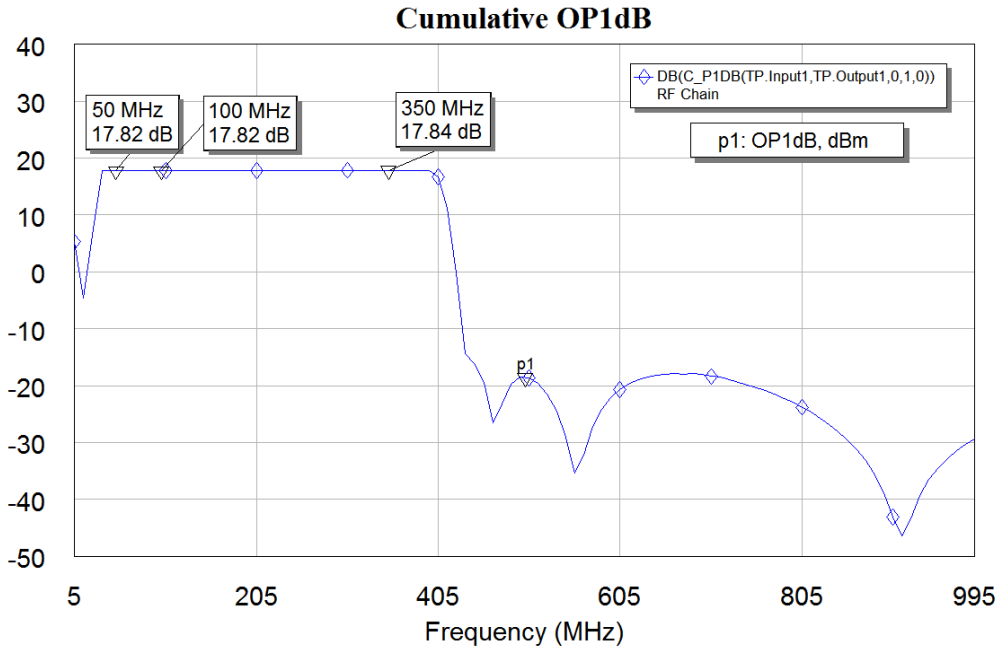


Figure 13 - VSS OP1dB receiver chain

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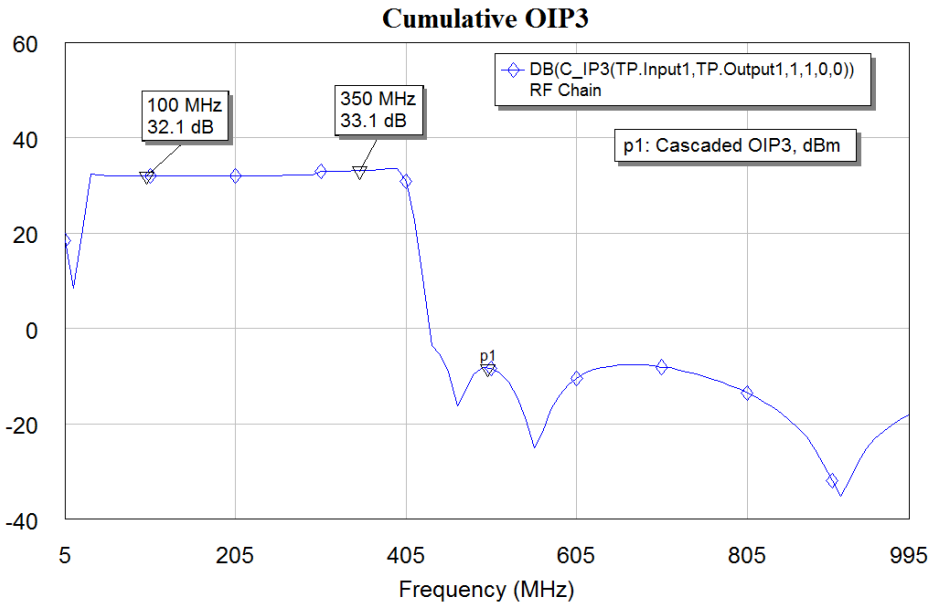


Figure 14 - VSS OIP3 receiver chain

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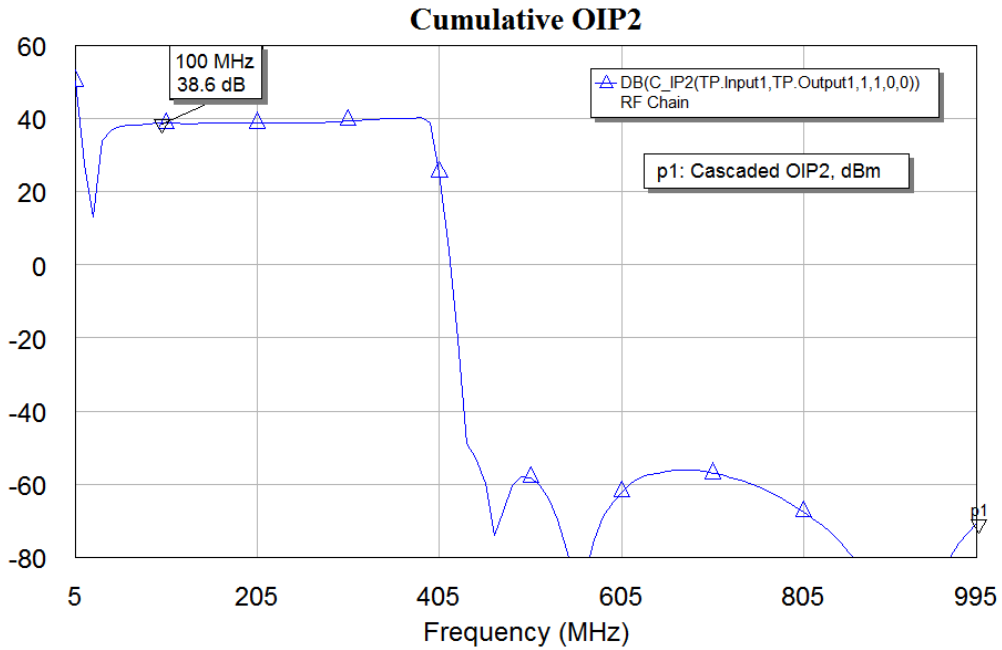


Figure 15 - VSS OIP2 receiver chain

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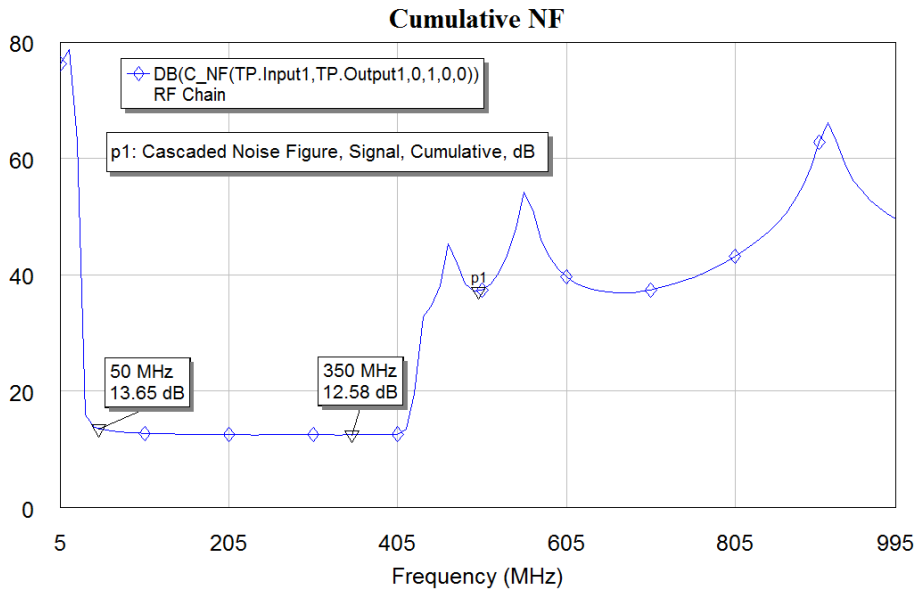


Figure 16 - VSS NF receiver chain

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5.12.3 Simulations Results

RF Parameter	Simulation Result	Range, notes	Simulation environment	Ref.
Flatness	+/-0.85 dB	[50 ÷ 350] MHz	MWO	Figure 10
High pass filter Rejection	> 45 dB	f ≤ 20MHz, +/-5MHz	MWO	
Low pass LB filter Rejection	> 60 dB	f ≥ 450MHz, +/-5MHz	MWO	
Gain	60.5 dB	[50 ÷ 350] MHz I.L. RFoF (OTX + ORX) 27dB, DSA at minimum attenuation	MWO	
IRL	> 13 dB	[50 ÷ 350] MHz, at the input of FE	MWO	
ORL	> 20 dB	[50 ÷ 350] MHz at the output of PREADU	MWO	
OP1dB	> +17 dBm	[50 ÷ 350] MHz I.L. RFoF (OTX + ORX) 27dB, DSA at minimum attenuation	VSS	Figure 13
OIP3	> +30 dBm	[50 ÷ 350] MHz I.L. RFoF (OTX + ORX) 27dB, DSA at minimum attenuation	VSS	Figure 14
OIP2	>+38 dBm	[50 ÷ 350] MHz I.L. RFoF (OTX + ORX) 27dB, DSA at minimum attenuation	VSS	Figure 15
NF	< 13.65 dB	[50 ÷ 350] MHz I.L. RFoF (OTX + ORX) 27dB, DSA at minimum attenuation	VSS	Figure 16

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6 DESIGN OPTIONS FOR COST SAVING AND SIMPLIFICATION

The following changes wrt prototype v2.1 are presented and discussed as possible options.

6.1 PREADU amplification chain

The Low Band filter can be also distributed in sections so that a part of the filter stages shall be implemented in between the amplifiers AWG 23 and AWG 15. This part would play the role of harmonics suppression for oscillation avoidance of the amplifying chain.

6.2 Variable step attenuator elimination

The function of signal dynamic range matching with the ADC full scale can be implemented by selectable gain amplifiers ADA 4961 that can be employed in the new ADU subassembly then the 16 commands step attenuator can be suppressed.

This implies that the PREADU will be simplified as all the latch registers and Dip-switches (for manual switch option) could be eliminated. Considering this option also SPI signals from ADU 1017 to PREADU can be avoided.

7 IMPROVEMENTS IN THE MECHANICS

7.1 Edge to edge between PRE ADU and ADU

The PREADU circuitry will not be embedded in the ADU. As the former PCB contains a small number of routing layers with respect to the acquisition system board. So the cost saving driver suggests not to merge the 2 PCBs in one.

The two boards are connected to each other, edge to edge, using low cost MH 113 RF cables pairs and SMT mount coax connectors OSMT type RSP-122811-01 by SAMTEC.This will allow also to accept tolerances in the 2 boards alignment. Also the Partron connectors and cables have been considered as second supplier for cost reduction action.

7.2 Mechanical package and PCB for 16 PREADU array

The PCB of the PREADU can be redesigned to host 16 double chains (16 antennas) on a single face. All of the components will fit into a 233 X235 mm board due to the electrical circuit simplification described in chapter 5 (considering the simplifying options in chapter 6, the size of the PREADU can still be reduced), also the RF test points and the Dip-switches for the manual setting of the programmable attenuator have been eliminated. The mechanical lid on the top is a single item as depicted in the following figure.

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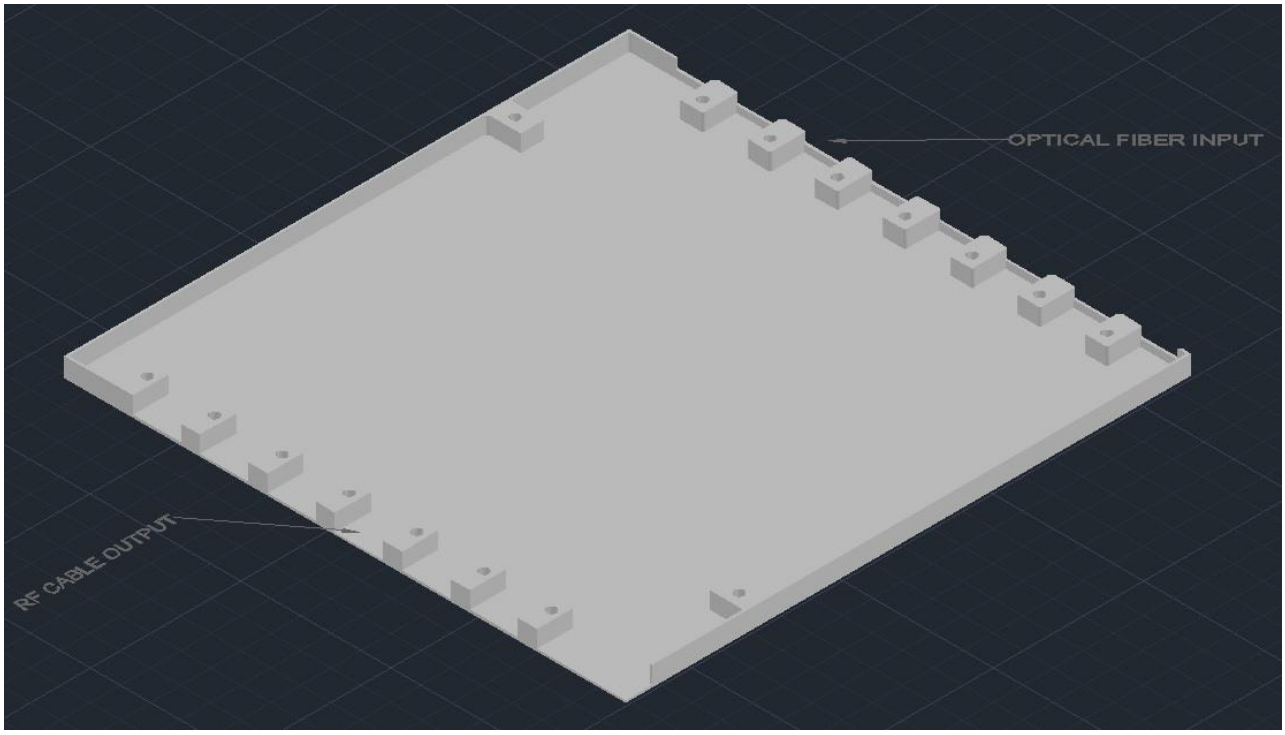


Figure 17 - Mechanical lid

In order to achieve a low cost production, it will be realized based on Aluminium cast molding or on mechanical milling with numerical control milling machines. The finish will be based on Chromatisation. The assembly company will select the most cost effective solution.

The septa for isolation of the parallel RF chains on the PCB could be not necessary. If the RF isolation would not be sufficient then suitable septa will be introduced into the mechanics.

7.3 Hybrid electrical optical connector option and integrated FE

In order to avoid the fibre optic cable deployment at each installation /replacement of the Pyramid assembly, then to simplify the maintenance and shipping of components, a hybrid connector should be placed at the input the pyramid assembly, so that the cable is a separate unit from the pyramid.

A possible implementation of the cable and FE hybrid connector is depicted in the following picture. This solution has to be validated by a proper mechanical design of the Pyramid.

In this case the G.657 fibre with small curvature radius has to replace the G652D for the LASER pigtail. This because inside the trumpet the available space to loop the fiber is below 4cm so only G657 allows to avoid extra losses due to eccesive fiber bending

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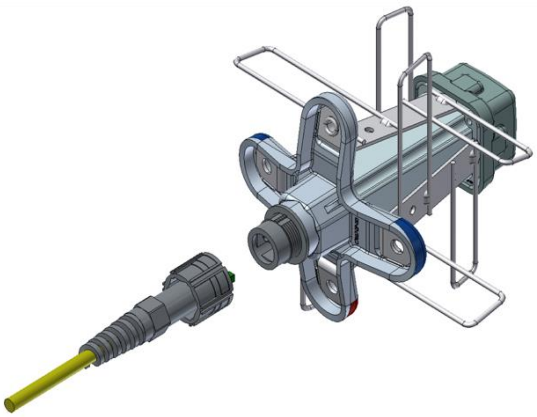


Figure 18 – Hybrid electrical optical connector

In a follow up of this study the whole FE subassembly can be suitably integrated in a Small Form Factor SFF package, with a suitable PCB design.

7.4 Optical connectors

It is proposed that the FE will be including an hybrid electrical optical connector. Then the native optical connectors of the double laser and double photodiode (LC/APC) will be not part of the final FE and PREADU subassemblies. Anyway, during the test of the FE and PREADU these LC/APC connector will be used. The FE final connector choice depends on the finalization of the design of the Hybrid connector for the Pyramid assembly.

8 TEST PLAN AND PROCEDURES

The test of the LFAA receiver chain will be fully automated and performed including an spool of LC/APC connectorised fibre (10km of SMF G652D) that emulates the real link in the application, this will allow to consider the effects of Optical loss and Dispersion in the RF chain.

The operating tests will be made based on the following test bench and applied to every sample.

The equipment consists in an automated Aeroflex 4 ports network, this is a low frequency DC 1 GHz testing bench, a dedicated mechanical fixture will implement the connectorisation of RF input and output for both the polarisations receive chains, a dedicated algorithm shall put all the tests in a sequence so that the DUT will be mounted and dismounted only one time. The Aeroflex testing machine model will be defined by the assembly company.

An array of 16 FE (each with 2 polarizations channels) and 1 PRE ADU card containing array of 16 ORX optical receiver will be tested simultaneously on the test bench.

The following test benches are then implemented in a parallel X16 test bench. The Aeroflex equipment will have 32 RF input and 32 RF output so that 16 double polarization chains will be tested simultaneously.

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8.1 S parameters and P1dB

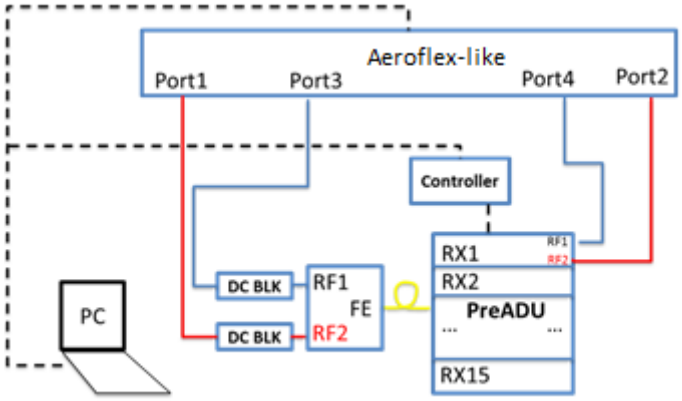


Figure 19 – Test bench for S parameters and P1dB of the PREADU and FE

A computer driven algorithm will sequence the tests of the 4 S parameters and of the P1dBc, for all of the configurations of the variable step attenuators. Test data are recorded in part no. files and pass /fail test report is automatically released.

Typical settings are:

f start	10	MHz
f stop	1.01	GHz
no of points	1000	
P RF	-10	dBm
Attenuation	50	dB
IFBW	300	Hz
Sweep Type	Linear Frequency	
Calibration	Full4port	
Calibration kit	TBD	

Sweep type	Power sweep	
P start	-50	dBm
P stop	-35	dBm
f	CW@100	MHz
no of points	101	
IFBW	1	kHz
Calibration	Full4port	
Calibration kit	TBD	

Table 1 - Settings of Aeroflex equipment for S parameters (left) and P1dB (right)

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8.2 NF and intermodulation products test

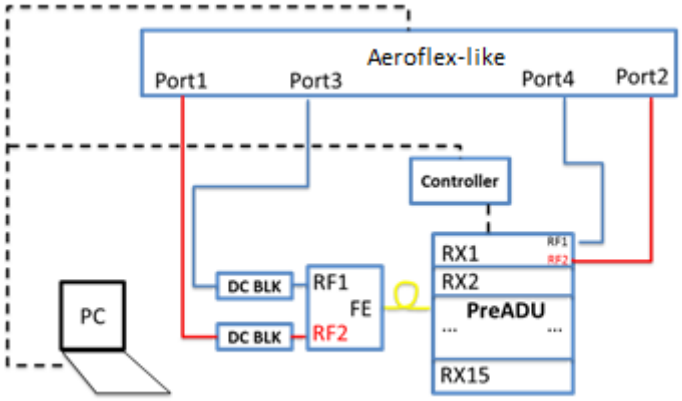


Figure 20 - Test bench schematic for NF and intermodulation test for the single FE

Typical settings are:

f start	10	MHz
f stop	1.01	GHz
N of points	100	
P RF	-30	dBm
Attenuation	20	dB
IFBW	300	Hz
Sweep Type	Linear Frequency	
Noise BW	4	MHz
Averaging factor	16	
Calibration	Scalar Noise	
Calibration kit	TBD	

f start	50	MHz
f stop	1	GHz
N of points	201	
P RF	-10	dBm
Attenuation	50	dB
IFBW	300	Hz
Sweep Type	Linear Frequency	
Calibration	Source & Receiver Power	
Calibration kit	TBD	

Table 2 - Aeroflex configuration for NF test (left) and IM products (Right)

8.3 Environmental tests

The environmental and reliability tests :

- Operating Temperature range for the FE (-10 : +70 °C);
- Aging (reliability) (800 h, 85°C, DUT powered on);

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- Humidity; IP Test (IP55) for the receiver Front End : Operation Humidity and Sand & dust (if needed: salt spray for connector oxidation) (Testing procedure MIL STD 883- damp heat)
- Wind vibrations for the FE Wind gusts and galloping according to EN 12368 “Traffic control equipment – Signal heads”
- Solar Exposure for the receiver Front End

The tests will be carried on randomly selected production samples on statistical basis (one over 1000).

9 PRODUCT BASELINE

The documents necessary for the production of a high number of LFAA receiving chain have been produced:

- The schematic drawing and mechanical drawings for the FE, PREADU X16 array (Attachment E)
- The routing gerber file (Attachment F)
- The Part List (Attachment D)
- The Acceptance test procedure and report (Attachment G)

It is also proposed some suggestions about the following issue:

- Maintenance Philosophy;
- Reliability, Availability, Maintainability and Testability (RAMT) analysis ;
- In Service Support (ISS);

reported in Attachment A

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ATTACHMENT A - Maintenance Policy

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ATTACHMENT B - Detailed Analysis of RoHS / REACH

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ATTACHMENT C - RAMT Calculation

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ATTACHMENT D - Part List of industrialized Receiver Chain

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ATTACHMENT E - Electrical Schematics and Mechanical Drawings of FE and PREADU

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ATTACHMENT F - Routing of the FE and Preadu

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ATTACHMENT G - Acceptance Test Report

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