RFoF optical links for the K multi-feed receiver of the Sardinia Radio Telescope

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Introduction

Since the design phase of SRT it was investigated the possibility to use RF over fibre links in order to transfer the IF outputs of the receivers from the Elevation Equipment Room (EER) to the screened data processing room, for a total link length of about 500m [1]. In this document are reported the results of the acceptance test performed in the Medicina labs on the RFoF links purchased for the 14 double IF links of the K-band multi-feed receiver.

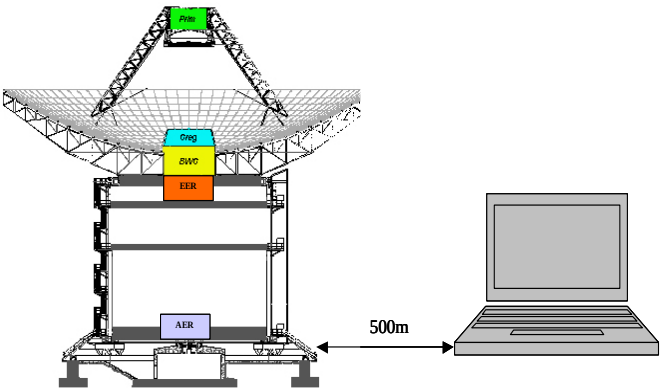


Figure 1 – SRT optical link.

Note on the optical attenuation

In order to emulate in the lab the overall optical attenuation from the EER and the data processing room without 500m of optical fibre, three patch cords have been used connected each other, because the attenuation due to connectors is dominant compared to that of the 500m of fibre.

The estimated optical loss between OTX and ORX is about 2.2dB (4xFC/APC connections + 500m of standard single mode fibre = 4x0.5dB + 0.2 = 2+0.2dB = 2.2dB) which corresponds to an RF loss of about 4.4dB.

The FC/APC connectors present an insertion loss that depends on their tightening [2]. In order to have a more repeatable situation, all the connectors inside the OTX and ORX racks were firmly tightened. **Note that this condition doesn't guarantee the minimum optical loss for all links but is the most repeatable one.**

In Figure 2 is shown the effect of the introduction of the three patch cords on the RF link gain. From this figure it can be derived the RF loss due to the connectors only, which is around 1dB (0.5dB of optical attenuation) for each optical connection.

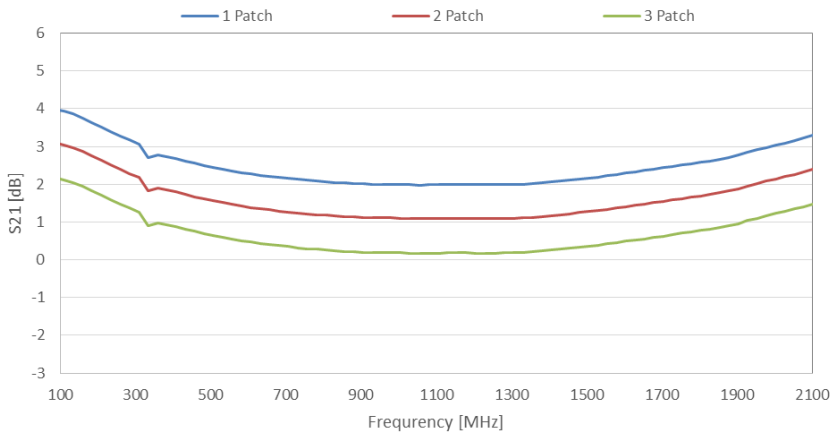


Figure 2 – Gain link with different number of patch cords.

Devices under evaluation

The devices under evaluation are from Optel s.n.c. (http://www.optelit.com). The technical and sales contact is Ing. Ferraresi (optel-info@optelit.com).

Link length (m)	500
Optical fibre	Single mode 9/125 G652D
Optical connectors	FC/APC
λ (nm)	1310

Table 1 – Optical specifications.

RF connectors	SMA
Input/Output impedance (Ohm)	50
Input/Output return loss (dB)	>15
RF Band (MHz)	100-2100
RF Gain (dB)	1
Gain ripple (dB)	+/- 1
OIP3 (dBm)	>+30
NF (dB)	≤40

Table 2 – RF specifications.

Figure 3 – Optel TX (bottom rack), RX (top rack) and example of bench test with VNA (right).

All 16 OTX and 16 ORX are hosted, respectively, in two 19” 3U racks which also accommodate two linear power supplies (230VAC input). Every module in both racks host 2 optical OTX or ORX each.

Measurements

Input 1dB Compression Point

The expected input P1dB is more than +14dBm. The HP 8753C Vector Network Analyser and the HP 85047 Test Set were used since the newer PNA-X N5249A is limited to +13dBm as maximum output RF power. Measurement bench set up is showed in Figure 4.

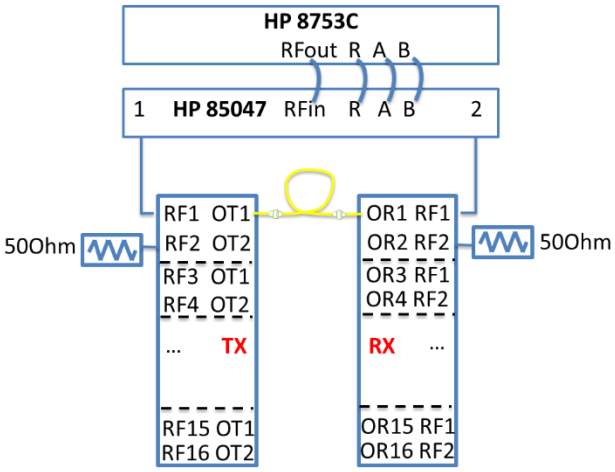


Figure 4 – P1dBin measurements bench set up.

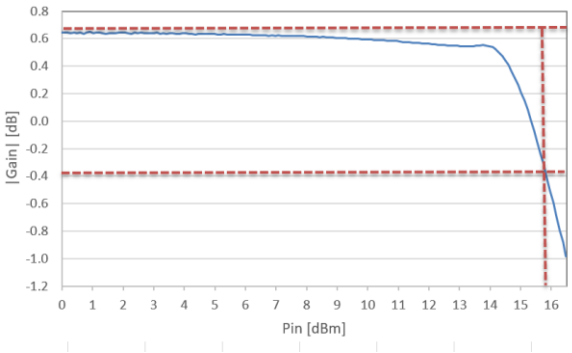


Figure 5 – P1dBin@900MHz measurements.

Only some sample measurements were performed at certain frequencies (100, 900 and 2100MHz). It was verified that the P1dB does not change in frequency for all the modules so, in Figure 5, is reported only one typical measurement (P1dB is +15.75dBm) at 900MHz.

S-parameters

S-parameters were measured with the PNA-X Vector Network Analyser. All measurements were performed under *FULL 2-PORT* calibration (with Ecal N4431-60008).

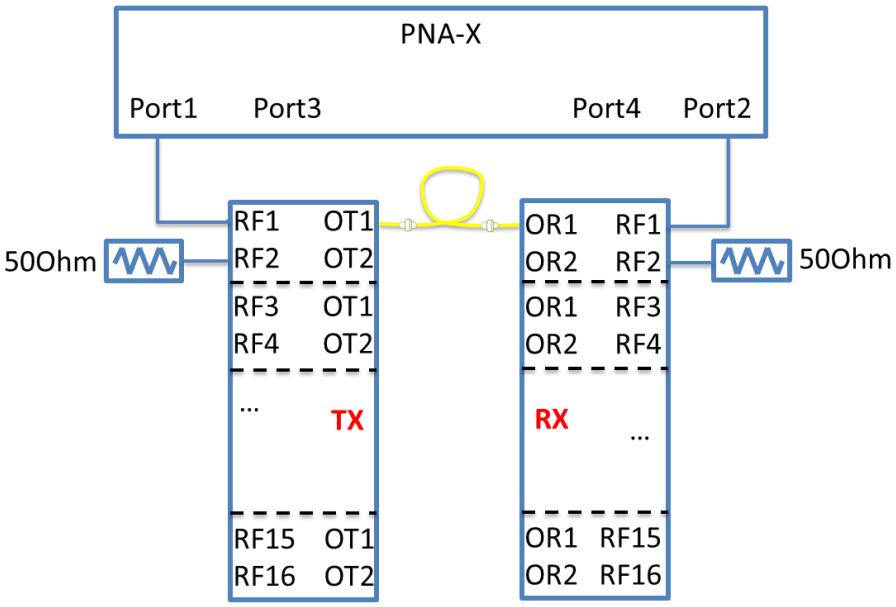
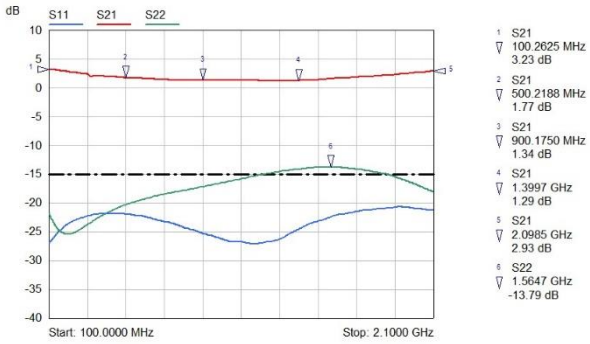


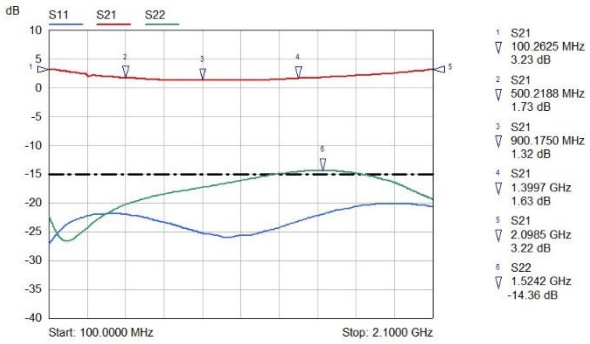
Figure 6 – S-parameters measurements bench set up.

RF Power [dBm]	-5
Number of Points	1601
Sweep Type	Linear Frequencies
IF BW [Hz]	300
F Start [MHz]	10
F Stop [MHz]	2500

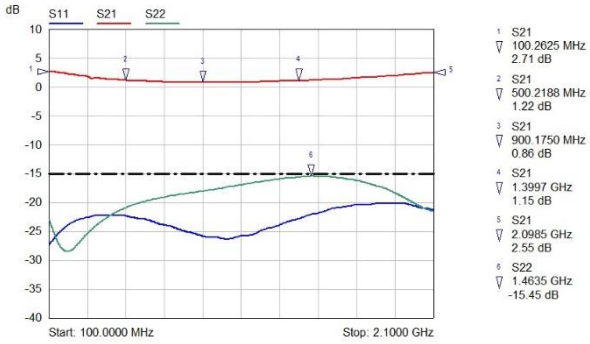
Table 3 – PNA-X configuration for S-parameters measurement.


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 3.23 dB
2 S21 500.2188 MHz 1.77 dB
3 S21 900.1750 MHz 1.34 dB
4 S21 1.3997 GHz 1.29 dB
5 S21 2.0985 GHz 2.93 dB
6 S22 1.5647 GHz -13.79 dB

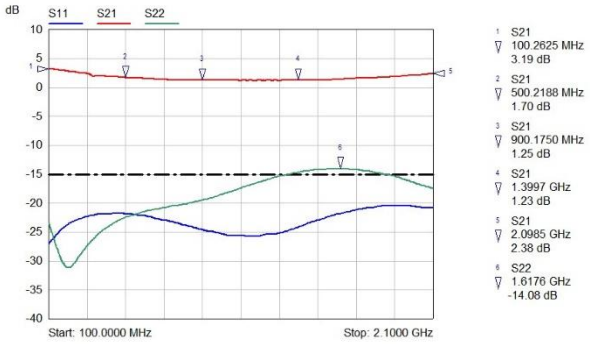
#1


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 3.23 dB
2 S21 500.2188 MHz 1.73 dB
3 S21 900.1750 MHz 1.32 dB
4 S21 1.3997 GHz 1.63 dB
5 S21 2.0985 GHz 3.22 dB
6 S22 1.5242 GHz -14.36 dB

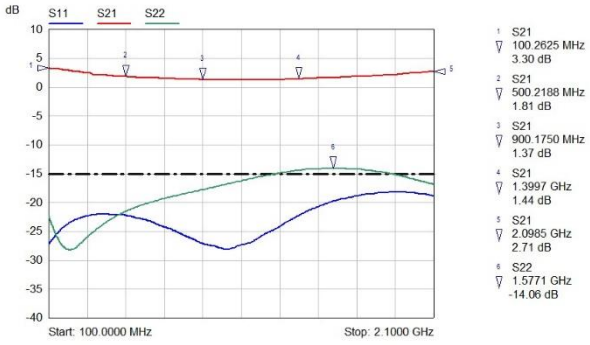
#2


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 2.71 dB
2 S21 500.2188 MHz 1.22 dB
3 S21 900.1750 MHz 0.86 dB
4 S21 1.3997 GHz 1.15 dB
5 S21 2.0985 GHz 2.55 dB
6 S22 1.4635 GHz -15.45 dB

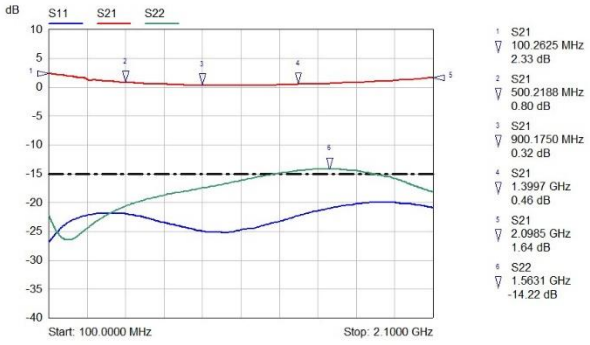
#3


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 3.19 dB
2 S21 500.2188 MHz 1.70 dB
3 S21 900.1750 MHz 1.25 dB
4 S21 1.3997 GHz 1.23 dB
5 S21 2.0985 GHz 2.38 dB
6 S22 1.6176 GHz -14.08 dB

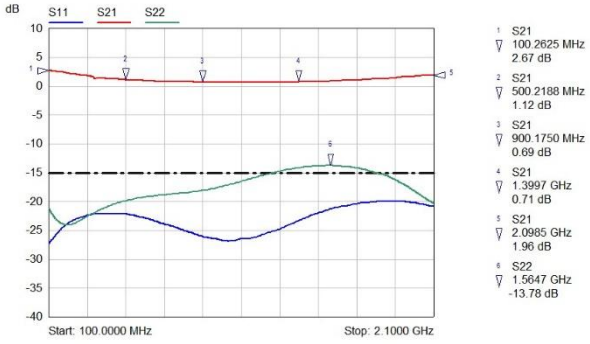
#4


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 3.30 dB
2 S21 500.2188 MHz 1.81 dB
3 S21 900.1750 MHz 1.37 dB
4 S21 1.3997 GHz 1.44 dB
5 S21 2.0985 GHz 2.71 dB
6 S22 1.5771 GHz -14.06 dB

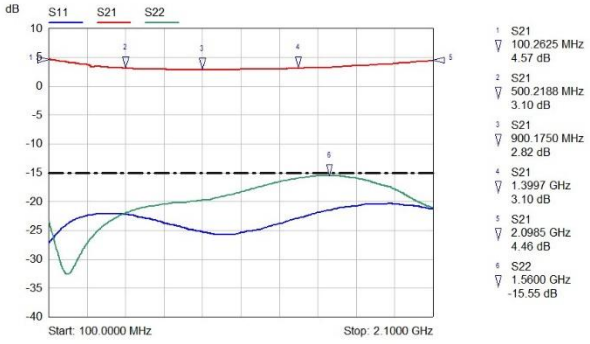
#5


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 2.33 dB
2 S21 500.2188 MHz 0.80 dB
3 S21 900.1750 MHz 0.32 dB
4 S21 1.3997 GHz 0.46 dB
5 S21 2.0985 GHz 1.64 dB
6 S22 1.5631 GHz -14.22 dB

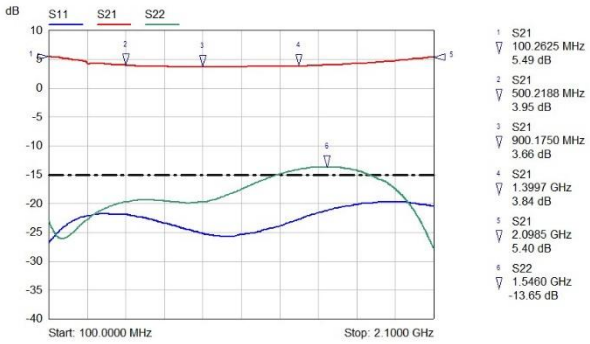
#6


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 2.67 dB
2 S21 500.2188 MHz 1.12 dB
3 S21 900.1750 MHz 0.69 dB
4 S21 1.3997 GHz 0.71 dB
5 S21 2.0985 GHz 1.96 dB
6 S22 1.5647 GHz -13.78 dB

#7


dB
S11 S21 S22
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Start: 100.0000 MHz
Stop: 2.1000 GHz
1 S21 100.2625 MHz 4.57 dB
2 S21 500.2188 MHz 3.10 dB
3 S21 900.1750 MHz 2.82 dB
4 S21 1.3997 GHz 3.10 dB
5 S21 2.0985 GHz 4.46 dB
6 S22 1.5600 GHz -15.55 dB

#8



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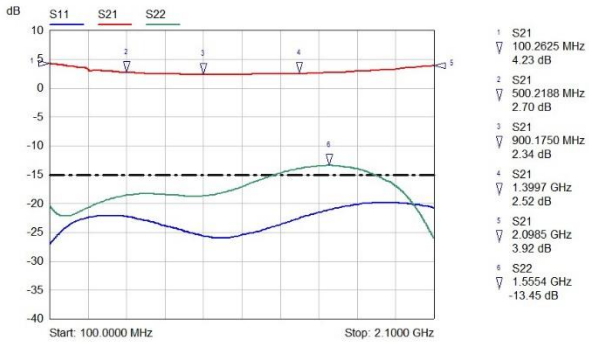

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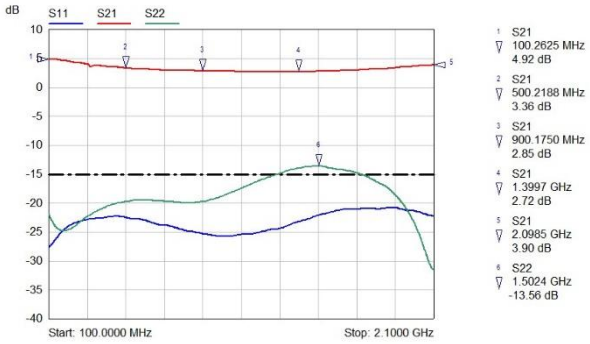

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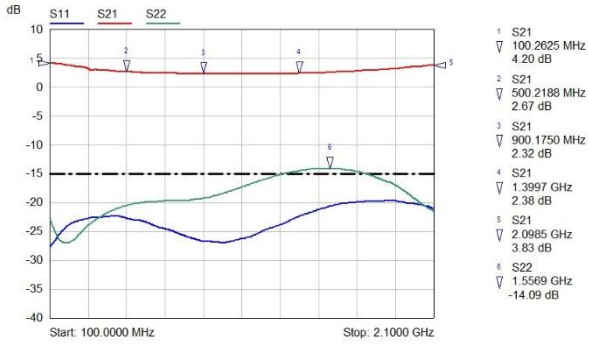

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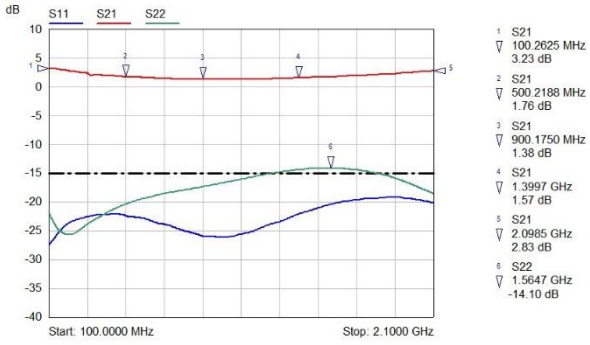

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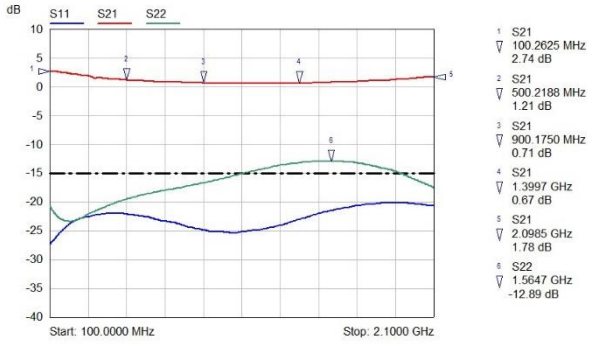

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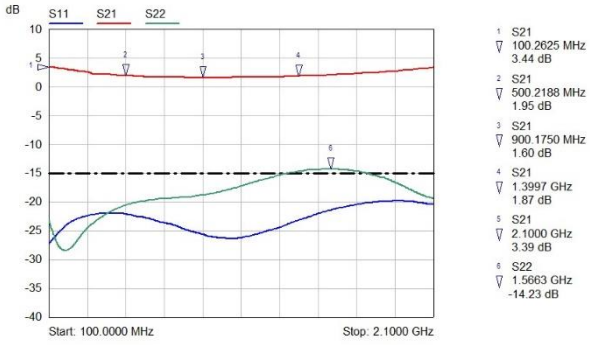

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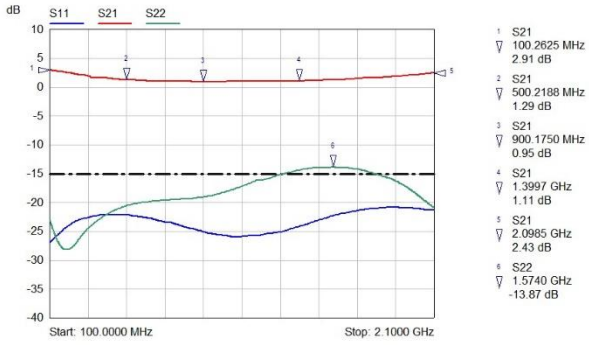

#16

Figure 7 – S-parameters measurements (black dashed line is the IRL/ORL specification of -15dB).

For all links, Input Return Loss fits the specification in the whole bandwidth whilst the Output Return Loss, between about 1.3 and 1.7GHz, exceeds the specifications of about 1-2dB maximum.

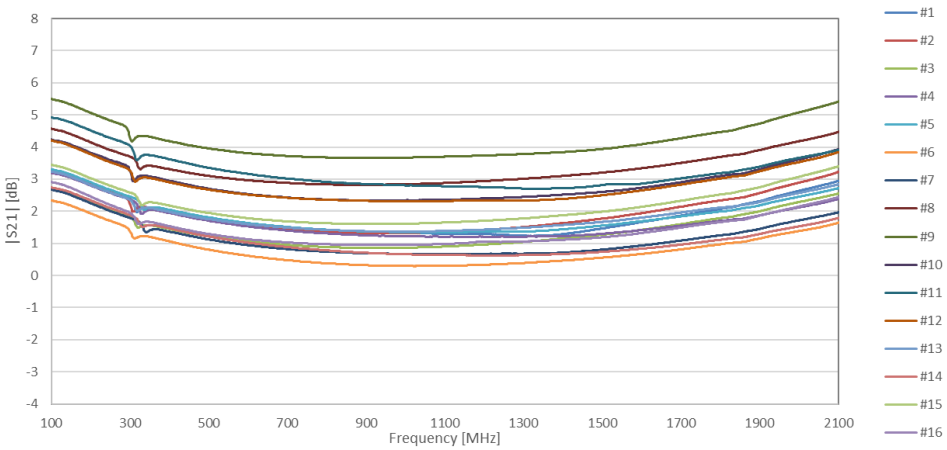

Figure 8 – Gain links measurements.

$$Gain\ ripple = \frac{\max(Gain_{link_{\#n}}) - \min(Gain_{link_{\#n}})}{2}$$

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
Gain ripple	1.00	0.96	0.93	0.99	0.98	**1.02**	1.00	0.88	0.92	0.95	**1.11**	0.94	0.93	**1.05**	0.92	0.98

Table 4 – Gain links ripple (in red are reported the values that exceed the specification) in the bandwidth 100-2100MHz.

From Figure 8 and Table 4 can be seen that gain's ripple remain under ±1dB except for 3 links but with an acceptable value.

Noise Figure

Measurement bench is showed in Figure 9. As the expected noise figure is higher than 30dB, isn't possible to use the Noise Figure Meter HP8970B (it can measure DUT with NF up to 30dB). For that reason the Spectrum Analyser Anritsu MS2726C was used.

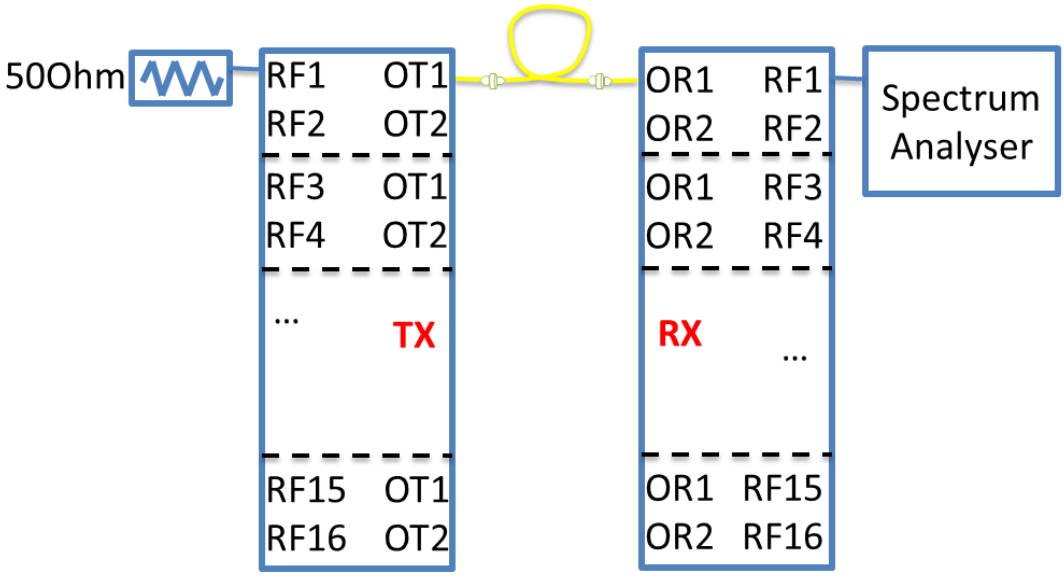

Figure 9 – Noise Figure measurement bench with Anritsu MS2726C Spectrum Analyzer.

Averaging	16
Span [kHz]	100
Attenuation [dB]	0
Reference Level [dBm]	-60
Resolution Bandwidth [Hz]	300
Video Bandwidth [Hz]	100
Marker [dBm/Hz]	Marker Noise
Preamp	ON
Detection	RMS/AVG

Table 5 – Spectrum analyser configurations for NF measurement.

F [MHz]	NF [dB]															
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
100	33.9	33.7	33.9	34.4	33.2	33.7	36.2	33.1	35.7	35.6	35.5	35.4	34.4	35.4	35.9	36.2
500	35.7	35.3	36.2	36.8	35.5	35.9	37.0	35.7	37.0	37.9	36.8	37.2	35.7	37.2	37.0	37.5
900	37.3	36.9	37.6	36.8	36.4	36.8	38.9	36.5	38.1	38.1	37.8	38.0	37	38.1	38.2	38.3
1400	37.9	37.1	38.5	37.4	37.4	37.3	39.1	37.9	37.7	38.9	38.5	38.7	37.6	39.5	38.1	**40.0**
2100	38.5	38.5	39.1	38.1	38.9	38.0	**40.9**	38.2	38.3	39.8	39.9	39.3	39.2	39.7	**40.4**	39.7

Table 6 – NF measurements (red values are above the specifications).

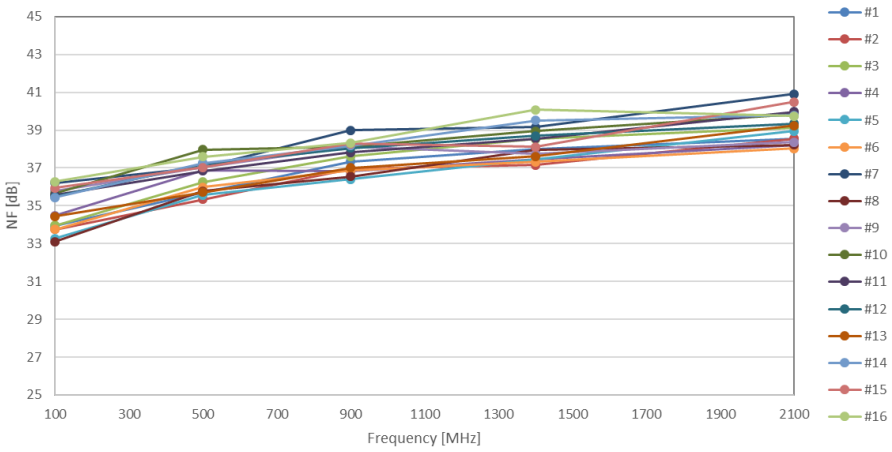

Figure 10 – NF measurements.

As can be noticed from the previous Table 6 and Figure 10, the NF remains under the specification (<40dB) for almost the entire bandwidth and never exceed 41dB.

Output IP3 and IP2

Measurement bench is showed in Figure 11. No filters were adopted due to the high quality of the internal PNA-X signal generators. The two signals generated by the PNA-X were combined using the Minicircuits ZAPD-21 RF combiner. With the Spectrum Analyser has been verified that the spurious and harmonics distortions of the sources were under the noise floor with the same SA configuration used for the link IP measurements.

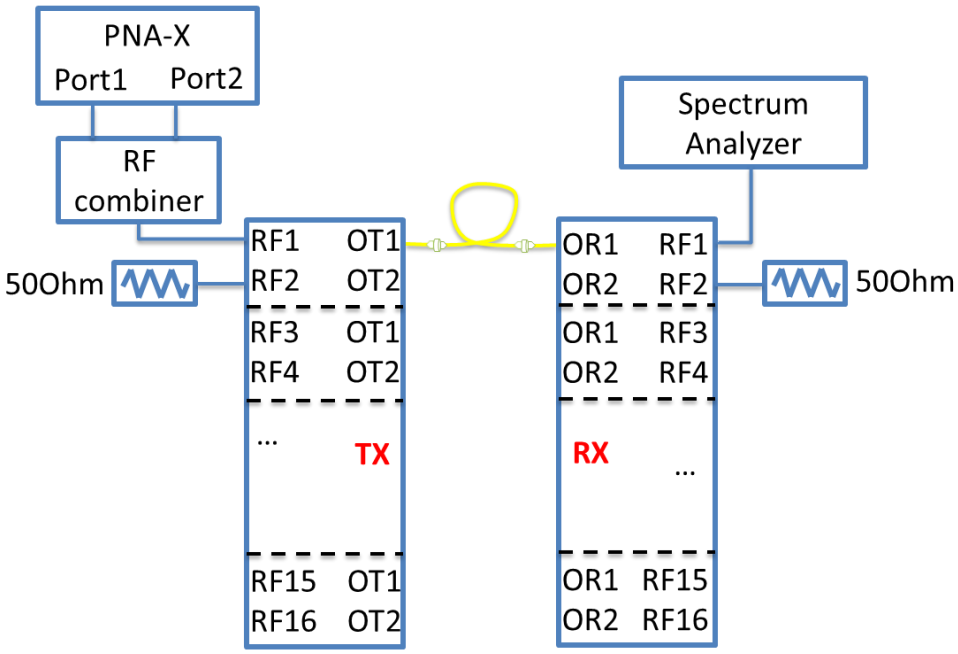

Figure 11 – IP2 and IP3 measurement bench set up.

Span [MHz]	4
Attenuation [dB]	30
Reference Level [dBm]	10
Resolution Bandwidth [Hz]	300
Video Bandwidth [Hz]	100
Preamplifier	OFF
Sweep type	Performance
Detection	Peak

Table 7 – Spectrum analyzer configurations for IP3 measurements.

F [MHz]	OIP3 [dBm]															
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
100	30.6	32.7	30.1	32.2	32.8	30.9	30.1	32.8	31.1	30.5	30.9	31.6	32.6	32.7	33.3	32.2
500	30.6	32.6	30.3	31.8	32.8	30.9	30.3	33.3	31.5	30.7	30.5	31.9	32.7	33.0	33.6	32.9
900	30.3	32.7	30.8	31.5	32.6	30.6	30.2	33.1	31.1	30.3	30.6	32.4	32.9	32.7	33.3	32.2
1400	30.4	33.3	32.7	31.7	33.2	31.1	31.6	33.7	30.8	30.6	30.4	35.3	34.9	32.5	34.3	32.7
2100	29.6	34.8	35.1	32.5	35.1	32.3	33.2	33.9	31.2	31.1	31.3	36.3	36.6	34.1	34.7	34.3

Table 8 – Measured optical links OIP3. IRA specification is OIP3>+30dBm.

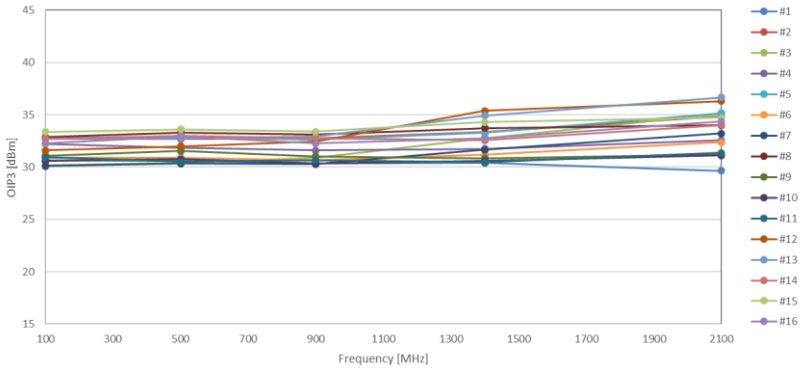

Figure 12 – OIP3 measurements.

F [MHz]	OIP2 [dBm]															
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
100	40.5	43.8	50.3	43.2	44.6	41.2	40.0	46.6	41.1	40.3	41.3	44.7	45.1	44.2	44.6	42.8
500	41.4	44.3	50.8	43.8	45.0	41.9	41.1	46.9	42.6	42.4	43.2	46.5	46.2	45.9	46.4	44.4
900	40.9	42.8	49.5	42.2	42.4	40.8	38.6	45.6	41.9	41.6	42.0	43.3	43.8	45.8	43.6	42.4

Table 9 – Measured optical links OIP3.

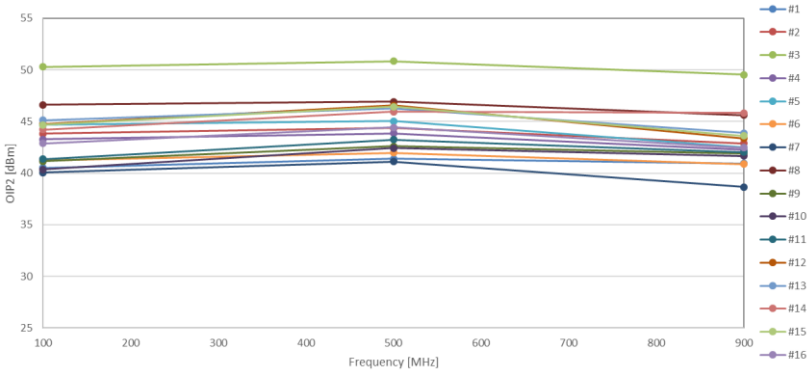

Figure 13 – OIP2 measurements.

SFDR

The Spurious Free Dynamic Range (SFDR) of a system is the range between the smallest signal that can be detected in a system (i.e., a signal just above the noise level of the system) and the largest signal that can be introduced into a system without creating detectable distortions (typically second and third order) in the bandwidth of concern.

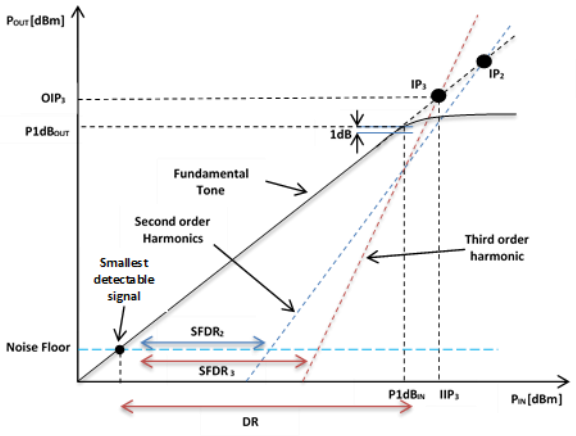

Figure 14. IP_n graphic explanation.

$$SFDR_2 = \frac{1}{2}(IIP_2 - 174 - 10\log_{10}(BW) - NF) = \frac{1}{2}(IIP_2 - EIN)\ \left[dB \cdot Hz^{1/2}\right]$$

$$SFDR_3 = \frac{2}{3}(IIP_3 - 174 - 10\log_{10}(BW) - NF) = \frac{2}{3}(IIP_2 - EIN)\ \left[dB \cdot Hz^{2/3}\right]$$

Equation 1 – $SFDR_2$ and $SFDR_3$ formulas.

where:

- $IIP_n = OIP_n - G_{LINK}$, $n = 2$ for IIP_2 and $n = 3$ for IIP_3
- -174 = Noise floor = $10\log_{10}(kT_0)$
- BW = System bandwidth (fixed at 1 Hz)
- $EIN = NF/kT_0$ (Equivalent Input Noise)

F [MHz]	SFDR3 [dBm*Hz$^{2/3}$]															
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
100	111.6	113.1	111.6	112.3	113.5	112.5	110.1	112.8	109.2	109.8	109.6	110.6	112.6	112.3	112	111.4
500	111.4	113.0	111.2	111.5	113.0	112.1	110.7	112.3	109.7	109.4	109.5	110.7	112.8	112.3	112.4	112
900	110.4	112.3	110.9	111.6	112.5	111.6	109.7	111.8	108.8	109.2	109.3	110.7	112.3	111.9	111.6	111.3
1400	110.0	112.3	111.4	111.3	112.2	111.5	110.5	111.1	108.8	108.7	108.7	112.2	113.1	110.9	112.2	110.4
2100	108.1	111.3	111.6	110.6	111.6	111.1	109.5	110.2	107.6	107.5	107.6	111.4	112.4	110.9	109.9	110.8

Table 10 – SFDR3 values.

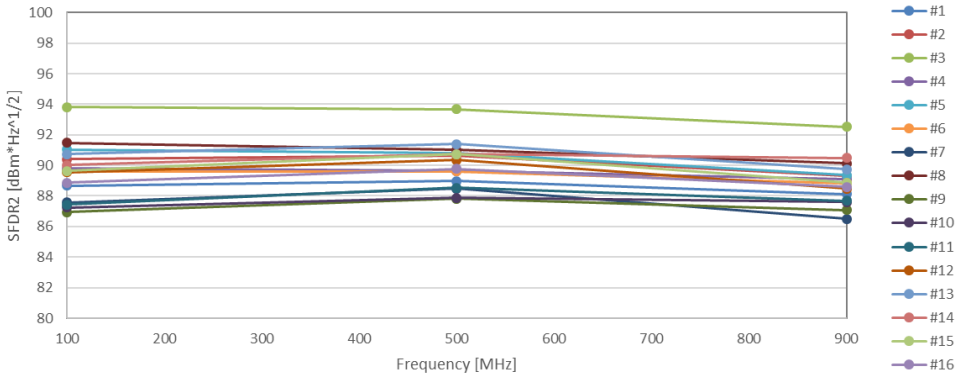

Figure 15 – SFDR$_2$ measurements.

F [MHz]	SFDR2 [dBm*Hz$^{1/2}$]															
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
100	88.6	90.4	93.8	89.8	91	89.5	87.5	91.4	86.9	87.2	87.4	89.5	90.7	90	89.6	88.8
500	88.9	90.6	93.6	89.6	90.8	89.6	88.4	91	87.8	87.8	88.5	90.3	91.4	90.7	90.7	89.8
900	88.1	89.3	92.5	89.1	89.3	88.8	86.4	90.1	87.1	87.6	87.6	88.5	89.7	90.5	88.8	88.6

Table 11 – SFDR2 values.

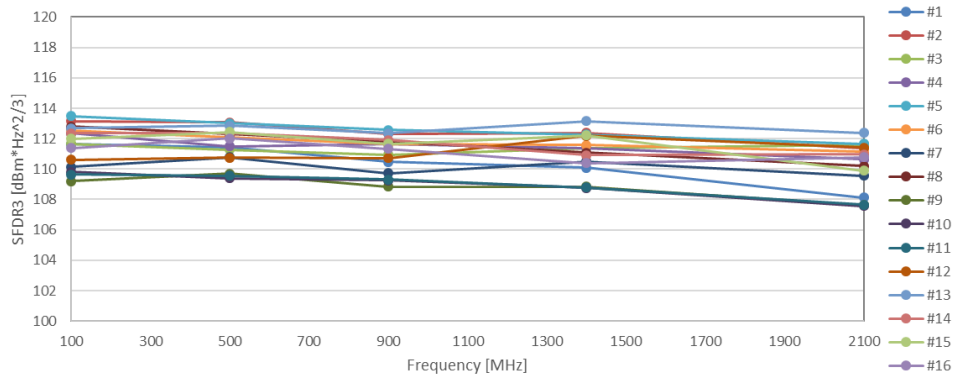

Figure 16 – SFDR$_3$ measurements.

Conclusions

The 16 RFoF links provided by Optel for the use with the K-band multifeed receiver for SRT have been tested in the Medicina labs with INAF/IRA instrumentations. All the links tested meet all the specifications with just few, not significant, exceptions. They are so suitable to remote the SRT receivers, carrying the IF frequency band (0.1-2.1GHz) from the Elevation Equipment Room (EER) on the antenna, to the remote control and data processing room.

Bibliography

[1] "SRT optical links prototypes characterization", F. Perini, IRA Technical Report N° 444/11

[2] http://www.dbmoptics.com/appnotes/010%20Minimizing%20FC-APC%20connector%20variation.pdf