SRT optical links prototypes characterization

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IRA Technical Report N° 444/11

Reviewed by: Alessandro Orfei

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SRT link specifications

The SRT optical links will be installed between the Elevation Equipment Room (EER in Figure 1) on the antenna and the remote control and data processing room. The total link length is about 500m.

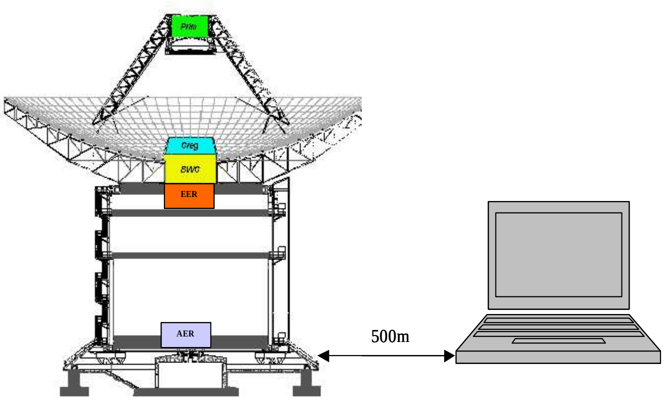

Figure 1 – SRT optical link.

In order to simplify the design of the receiver chains, a RF "transparent" solution was decided to be adopted. That means a RF gain of 0dB and an OIP3 which must not worse the OIP3 of the RF chain. Regarding the RF gain, an overall optical link loss of about 0.8-1dB seems to be a reasonable value (2x Fiber Patch Cables+500mt SMF@1310nm = 2x 0.3dB+0.2dB=0.8dB) which corresponds to an RF loss of about 1.6-2dB. For this reason an intrinsic RF gain of the optical links of about 2dB has to be considered normal when direct links (i.e: no fibre link between TX and RX) are considered during the characterization in labs.

Link length (m)	500
Optical fibre	Single mode 9/125
Optical connectors	FC/APC
λ (μm)	1.3

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)	0
Gain ripple (dB)	+/- 1
OIP3 (dBm)	>+30
NF (dB)	≤40

Table 2 – Electrical specifications.

Devices under evaluation

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

RF connectors	SMA
Input/Output impedance (Ohm)	50
Optical connectors	FC/APC
Output optical power (dBm)	+3
RF Band (MHz)	100-2400
Gain @ 0dBopt (dB)	0
λ (µm)	1.3
Gain ripple (dB)	+/- 1
OIP3 (dBm)	>+30
NF (dB)	≤38

Table 3 – Nominal link specifications.

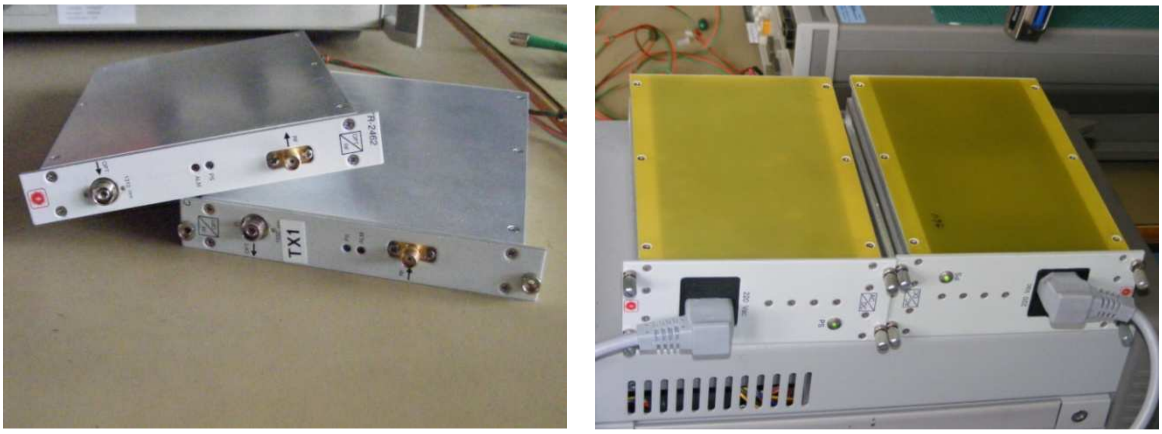

Figure 2 – Optel TX and RX (left) and the relative power supplies (right).

Measurements

Optical power

The measure was done with an optical power meter Fotec, model M710, serial number 910213, Power Range: +3 To -50 dBm (+33 To -20 dBµ).

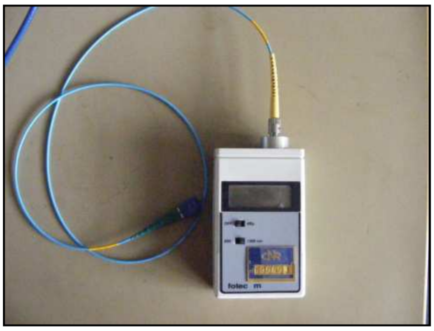

Figure 3 – Optical power meter.

To avoid the saturation of the optical power meter, a 10dB optical attenuator was inserted between the optical transmitters and the meter itself.

TX-O	Serial number	Optical power meter reading [dBµ]	Aopt [dB]	Pout [dBm]	Pout [mW]
Optel1	OTR-2422	+22.8	10	+2.8	1.91
Optel2	OTR-2422	+25.1	10	+5.1	3.24

Table 4 – TX1 and TX2 measured optical power.

The optical power, in dBm, is obtained from the reading on the instrument, which is expressed in dBµ, through the following formula:

$$Pout[dBm] = Pout[dB\mu] - 30 + Aopt$$

S-parameters

The S-parameters measurements were done with a HP8753C vector network analyser equipped with the HP85047 test set. All measurements were performed under FULL 2 PORTS calibration.

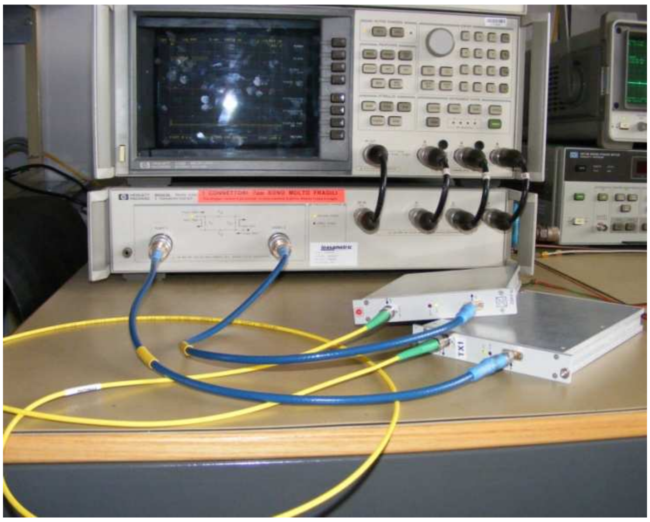

Figure 4 – S-parameters measurement set up.

Power	0 dBm
Attenuator port 1	10 dB
Attenuator port 2	0dB
Number of Points	801
Sweep Type	Lin Freq
IF BW	1KHz
Start	300 KHz
Stop	3 GHz

Table 5 – VNA configuration.

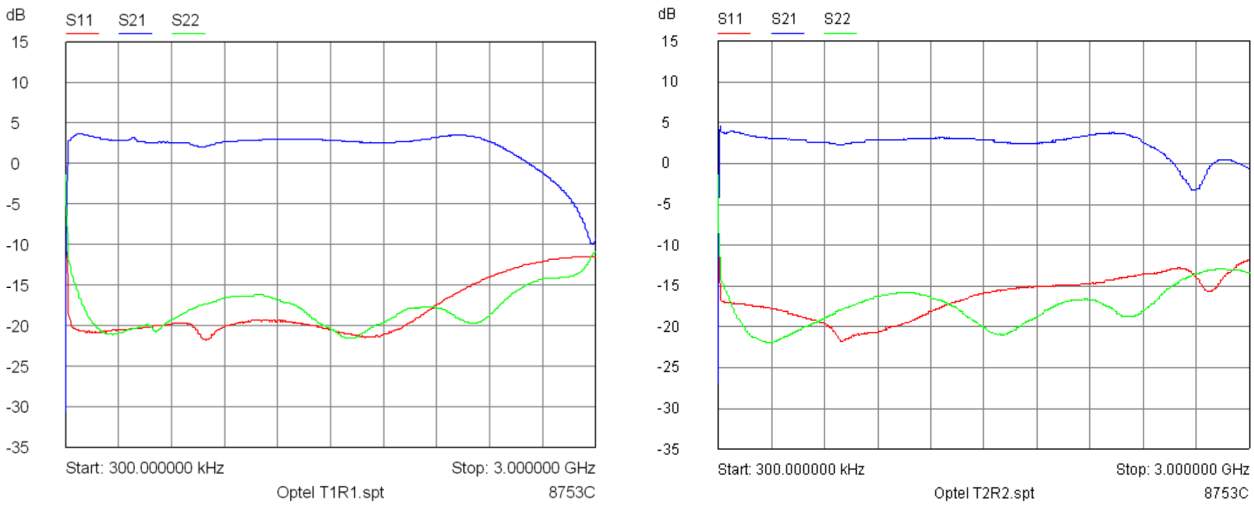

Figure 5 – S-parameters measurements.

Gain

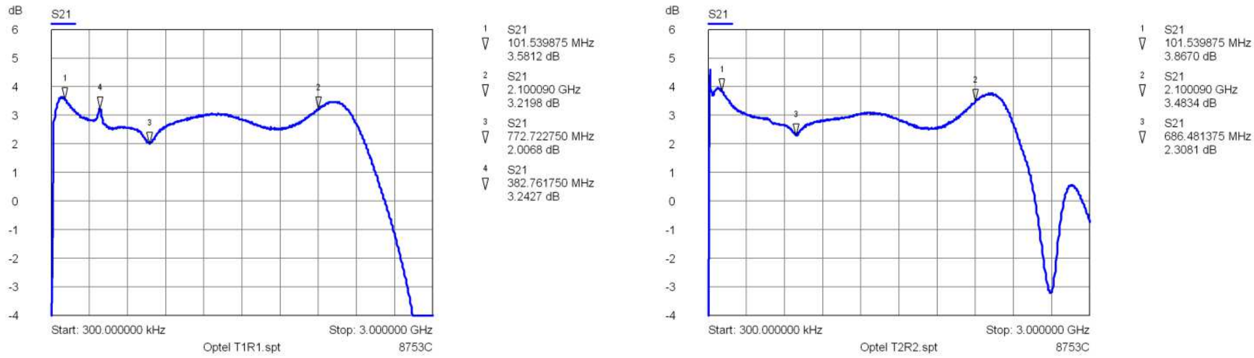

Figure 6 - Gain (S21): Optel1 (left) and Optel2 (right).

The mean gain and the gain variation, or ripple, have been evaluated, respectively, as: $\mathrm{G_{mean}} = (\mathrm{G_{max}} + \mathrm{G_{min}})/2$ and $\Delta\mathrm{G} = (\mathrm{G_{max}} - \mathrm{G_{min}})/2$.

	Optel1	Optel2	IRA Specifications
G mean (dB)	2.28	3.12	0
ΔG (dB)	+/-0.8	+/-0.78	+/-1

Table 6 – Mean RF link gain and gain ripple.

It is worth to notice that the gain of Optel1 presents a peak at 382 MHz (see fig.6 on the left). In order to identify the cause, some tests have been done with different combinations of TX and RX. In particular, both images of Figure 7 are relative to combination with Optel TX1 and, respectively, Optel RX1 and a passive RX by Andrew Wireless Systems. They show gain traces with the peak only for RX1. These comparisons suggest that the gain peak is generated only by Optel RX1. This hypothesis is reinforced also considering Figure 8, where Optel TX1 -2 and RX1 -2 are exchanged: here again the peak is only in the combination with RX1. The effect of the gain peak affects also the group delay, as clearly recognizable in Figure 9.

Optel TX1-Optel RX1 Optel TX1-Andrew RX

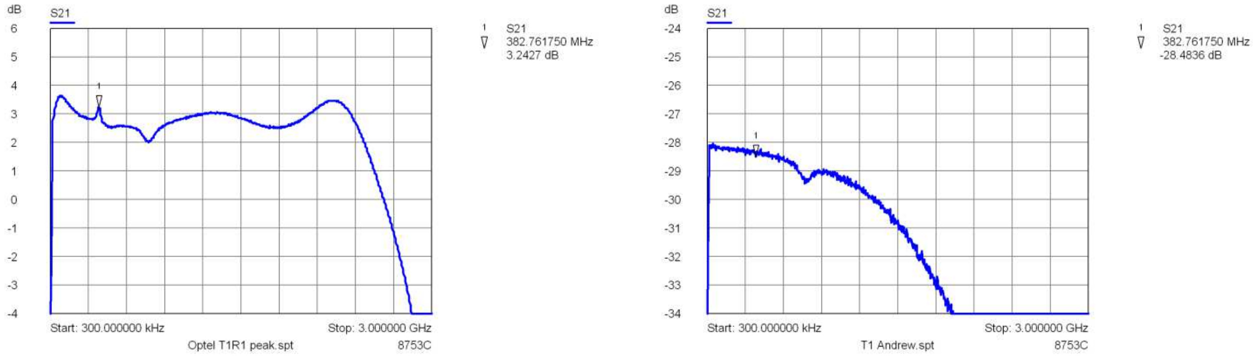

Figure 7 – Gain traces: Optel TX1- Optel RX1 (left) and Optel TX1- Andrew RX (right).

Optel TX2-Optel RX1 Optel TX1-Optel RX2

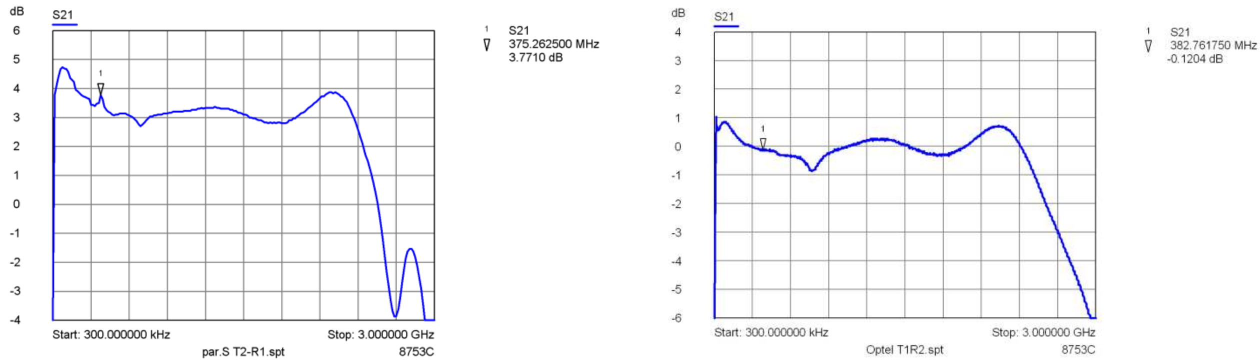

Figure 8 – Gain traces: Optel TX2- Optel RX1 (left) and Optel TX1- Optel RX2 (right).

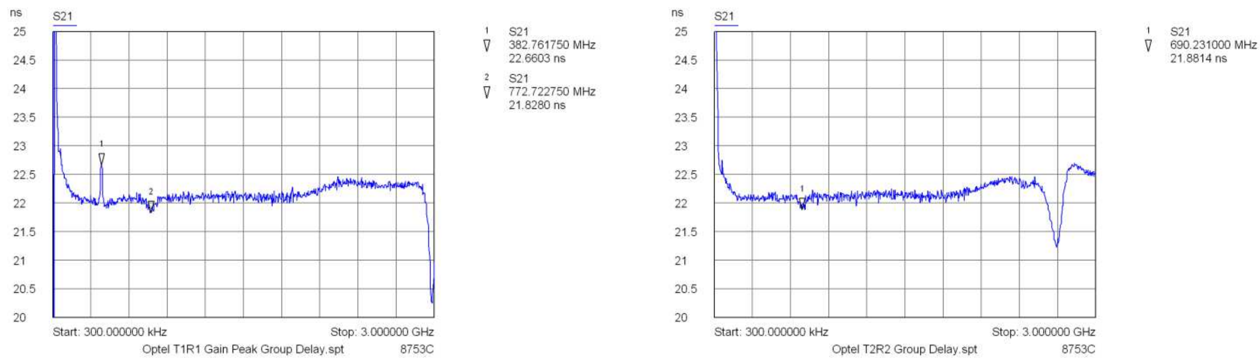

Figure 9 – Optical link group delay: Optel 1 (left) and Optel 2 (right).

Input and output matching

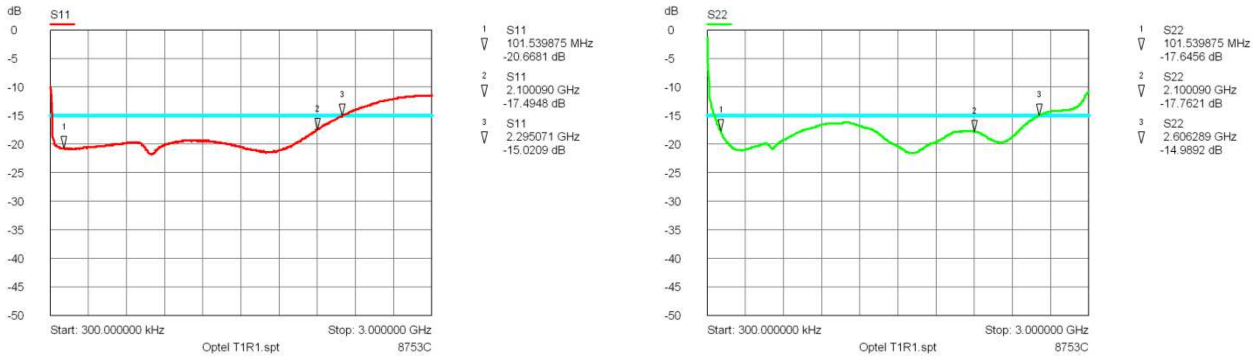

Figure 10 – Optel1 input (left) and output (right) matching (horizontal sky blue line = IRA goal specification).

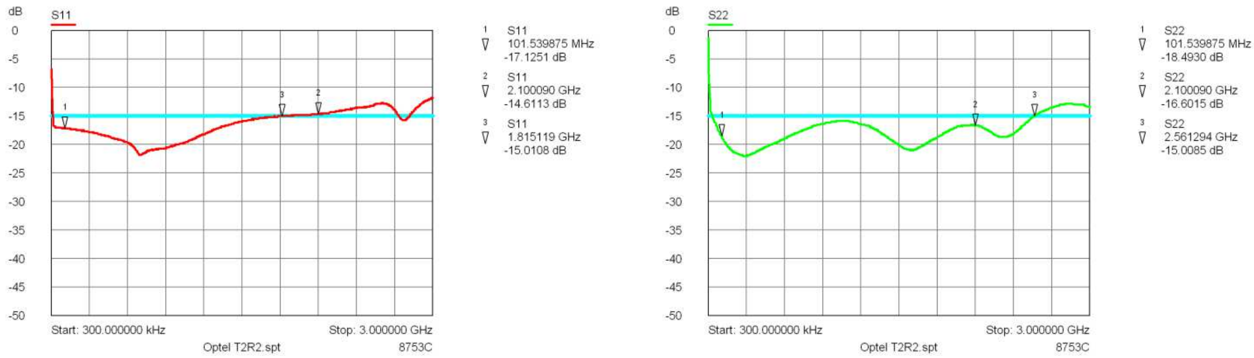

Figure 11 – Optel2 input (left) and output (right) matching (horizontal sky blue line = IRA goal specification).

Output IP3

In order to increase the accuracy of the OIP3 measurements, some filters to reject the harmonics of the RF generators and some attenuators to increase the matching and isolation between the RF generators and DUT have been used. The low pass filters were selected for each frequency where the OIP3 has been measured.

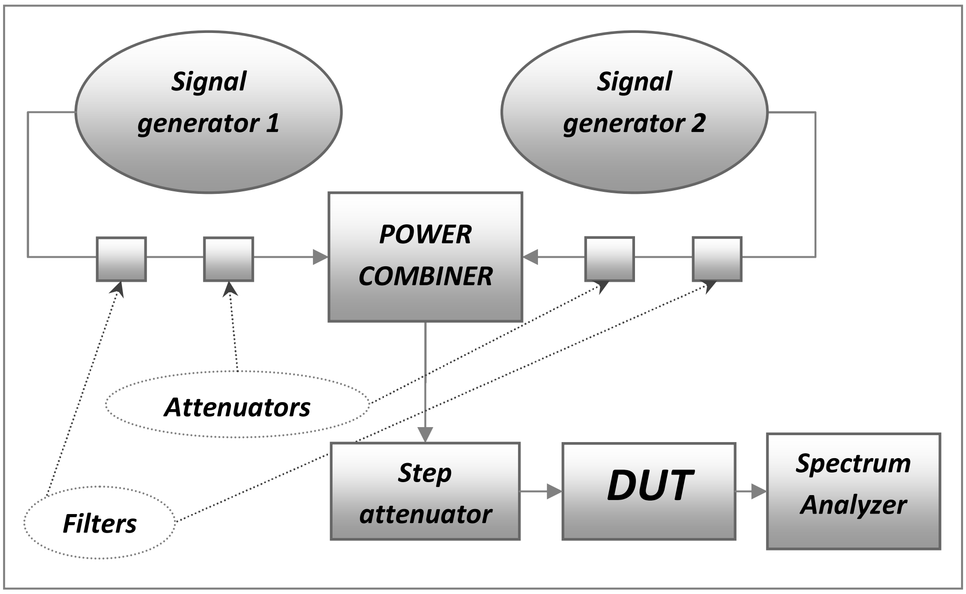

Figure 12 – IP3 measurement set up block diagram.

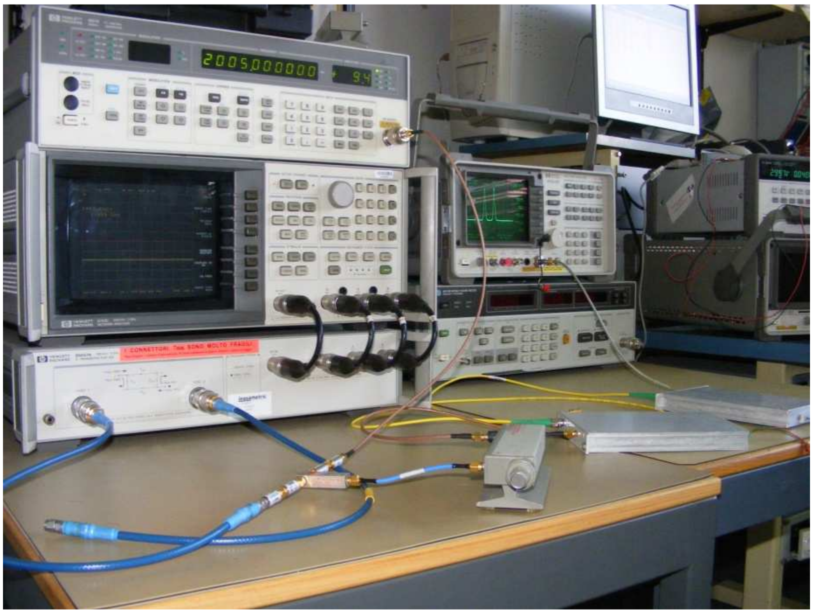

Figure 13 – IP3 measurement set up.

To choose the right filter at the frequency f_0, the criteria adopted was to have both IL@f_0<1dB and IL@$2f_0$>20dB in order to have the minimum signal attenuation at the fundamental tones and a good rejection of the harmonics.

RF Generators 1	HP 8657B (0.1-2060 MHz)
RF Generators 2	VNA (CW mode) HP 8753C (300KHz – 3GHz) with test set HP 85047
Power combiner	Mini-Circuits ZFSC-2-2-S (100-1000MHz) RLC Electronics D-05180-2 (1000-2100MHz)
Attenuators	Mini-circuits VAT-3+
Filters	See Table 9
Step attenuator	HP8494B, 11dB, 1dB step

Table 7 – Instrumentation for IP3 measurement.

	HP 8564E (9 KHz-40 GHz)	**HP 8591A** (9 KHz-1.8 GHz)
Span	50 MHz	50 MHz
Attenuation	30dB	20dB
Reference Level	10 dBm	10 dBm
Resolution Bandwidth	300 KHz	100 KHz
Sweep Time	500 mS	500 mS
Video Bandwidth	1 KHz	300 KHz

Table 8 – Spectrum analyzer configurations for IP3 measurements.

Frequency (MHz)	Second harmonic (MHz)	Minicircuits Filter model
100	200	SLP-100+
200	400	SLP-250
300	600	VLF-320+
400	800	SLP-550+
500	1000	SLP-550+
600	1200	SLP-1000+
700	1400	SLP-1200+
800	1600	SLP-1200+
900	1800	SLP-1200+
1000	2000	SLP-1200+
1100	2200	VLF-1400+
1200	2400	VLF-1400+
1300	2600	VLF-1400+
1400	2800	VLF-1400+
1500	3000	VLF-1400+
1600	3200	VLF-2250+
1700	3400	VLF-2250+
1800	3600	VLF-2250+
1900	3800	VLF-2250+
2000	4000	VLF-2250+
2100	4200	VLF-2250+

Table 9 – Filters adopted for IP3 measurement.

For each IP3 measurement, the power of the RF generators was adjusted in order to have the same level at the link output for both tones: $\mathrm{P_{out}(f_1) = P_{out}(f_2)}$. Also, we checked that the measurements were performed in linear regime. To do that, we verified that for each increment (decrease) of 1dB of the amplitude of the tones, the level of the intermodulation products, $\mathrm{P_{out}(2f_1 - f_2)}$ and $\mathrm{P_{out}(2f_2 - f_1)}$, was incremented (decreased) by 3dB. To control the amplitude of the tones a stepper attenuator in front of the DUT was used.

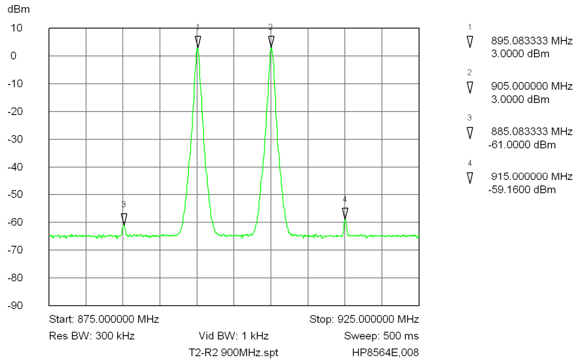

Figure 14 – Fundamentals tones and their relative third order intermodulation products.

OIP3 was obtained by:

$$OIP3 = P + {}^{\Delta}/_{2} = {}^{3}/_{2} \times \left(P_{out}(f_1)\right) - {}^{1}/_{2} \times \left(P_{out}(2f_2 - f_1)\right)$$

where Δ is the suppression, expressed in dB, of the intermodulation products respect to the fundamental tones and P is the power, in dBm, of the tones.

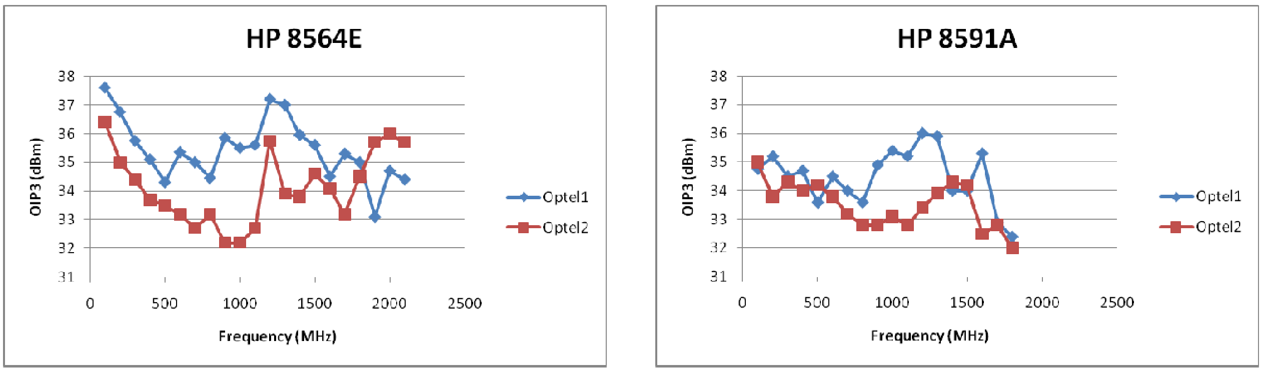

Figure 15 – OIP3 link measurements with HP 8564E (left) and HP 8591A (right) spectrum analysers.

The measurement performed with the HP8591A at 1800MHz was actually made at 1790MHz (Tone$_1$=1785MHz, Tone$_2$=1795MHz), because the spectrum analyzer frequency range is 9KHz-1.8GHz.

Frequency (MHz)	HP 8564E (9 KHz-40 GHz)		HP 8591A (9 KHz-1.8 GHz)	
	Optel 1 OIP3 (dBm)	Optel 2 OIP3 (dBm)	Optel 1 OIP3 (dBm)	Optel 2 OIP3 (dBm)
100	37.6	36.4	34.75	35
200	36.75	35	35.2	33.8
300	35.75	34.4	34.5	34.3
400	35.1	33.7	34.7	34
500	34.3	33.5	33.6	34.2
600	35.35	33.2	34.5	33.8
700	35	32.7	34	33.2
800	34.45	33.2	33.6	32.8
900	35.85	32.2	34.9	32.8
1000	35.5	32.2	35.4	33.1
1100	35.6	32.7	35.2	32.8
1200	37.2	35.75	36	33.4
1300	37	33.9	35.9	33.9
1400	35.95	33.8	34	34.3
1500	35.6	34.6	34	34.2
1600	34.5	34.1	35.3	32.5
1700	35.3	33.2	32.9	32.8
1800	35	34.5	32.4	32
1900	33.1	35.72		
2000	34.7	36		
2100	34.4	35.72		

Table 10 – OIP3 measured with HP 8564E (left) and 8591A (right). IRA specification is OIP3>+30dBm.

Since the IP3 parameter was one of the most important of the link specification requested, we compared, in order to check their consistency, the IP3 measurements obtained with two spectrum analysers available in the Medicina laboratories (see Figure 16 for link Optel1 as example).

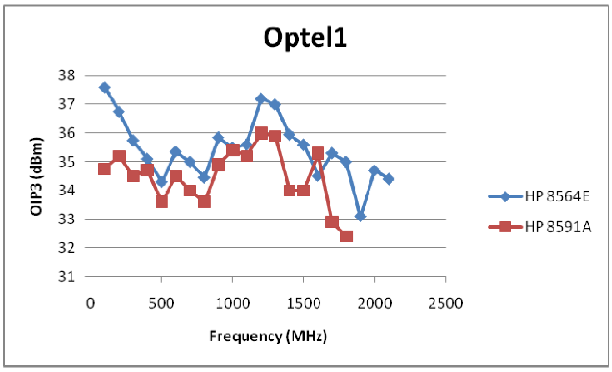

Figure 16 – OIP3 link measurements: comparison between the spectrum analysers.

Noise Figure

To increase the measurement accuracy a low noise amplifier (LNA), to mask the high noise figure of the spectrum analyser, was inserted between the DUT and the analyser itself.

The link noise figure, NF_{OL} , was obtained considering the measurement of the level of the spectral noise power of the entire chain (50Ohm load+optical link+LNA+spectrum analyser), $N_{out,TOT}$, and the expression of the noise factor of a 2 stages chain, $F_{TOT} = F_{OL} + (F_{LNA} - 1)/G_{OL}$, so:

$$NF_{OL}[dB] = 10 \times log_{10}\left(F_{TOT} - \frac{F_{LNA} - 1}{G_{OL}}\right)$$

where:

- $F_{TOT} = \left(N_{out,TOT}/N_{in}\right) \times (1/G_{TOT})$, total noise factor
  - $N_{out,TOT}$ is the Marker Noise reading of the spectrum analyser, espressed in W/Hz, and $N_{in} = kT$
- F_{LNA}, LNA noise factor
- G_{OL}, optical link gain
- $G_{TOT} = G_{OL} + G_{LNA}$, total gain

SA1	HP 8564E (9 KHz-40 GHz)
SA2	HP 8591A (9 KHz-1.8 GHz)
Power Supply	Agilent E3631A
LNA	Minicircuits ZX60-33LN-S+ (50-3000 MHz)

Table 11 – Instrumentation for NF measurement.

	HP 8564E (9 KHz-40 GHz)	HP 8591A (9 KHz-1.8 GHz)
Span	10 MHz	10 MHz
Attenuation	0 dB	0 dB
Reference Level	-30 dBm	-30 dBm
Resolution Bandwidth	100 KHz	100 KHz
Sweep Time	1 sec	3 sec
Video Bandwidth	300 Hz	100 Hz
Marker	Marker Noise [dBm/Hz]	Marker Noise [dBm/Hz]

Table 12 – Spectrum analyser configurations for NF measurement.

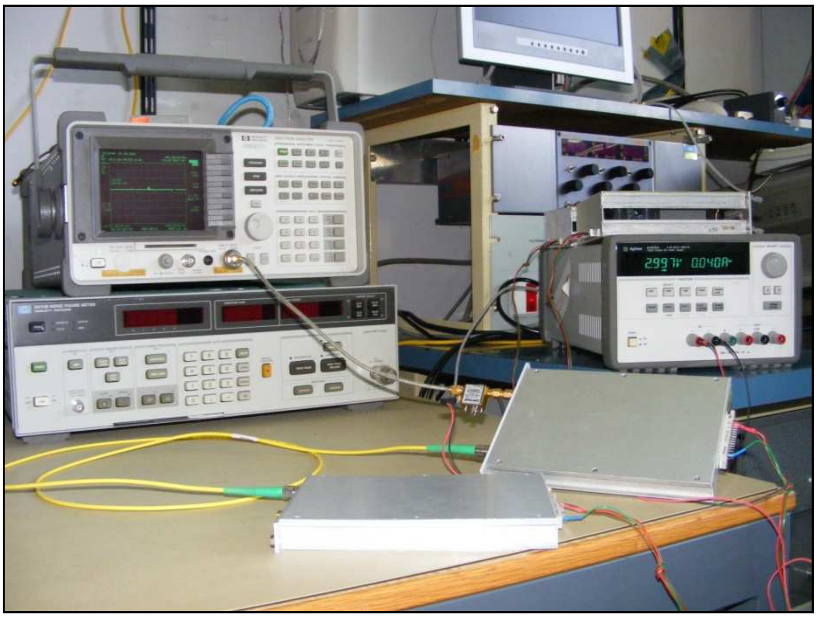

Figure 17 – NF link measurement set up.

Freq [MHz]	Gain_link [dB]	Gain_link	Gain_LNA [dB]	Gain_LNA	NF_LNA [dB]	NF_LNA	Marker [dBm/Hz]	Marker [dBW/Hz]	Marker [W/Hz]	NF_tot [dB]	NF_tot	NF_Link [dB]
100	3.07	2.03	21.31	135.21	0.92	1.24	-114.45	-144.45	3.59E-15	35.15	3271.32	**35.15**
200	2.59	1.82	21.2	131.83	0.8	1.20	-115.15	-145.15	3.05E-15	35.04	3189.50	**35.04**
300	2.33	1.71	21	125.89	0.86	1.22	-115.65	-145.65	2.72E-15	35.00	3160.26	**35.00**
408	2.22	1.67	20.75	118.85	0.91	1.23	-116.05	-146.05	2.48E-15	34.96	3131.29	**34.96**
500	2.03	1.60	20.5	112.20	0.89	1.23	-116.2	-146.2	2.4E-15	35.25	3347.52	**35.25**
600	2.07	1.61	20.14	103.28	0.87	1.22	-116.7	-146.7	2.14E-15	35.07	3211.61	**35.07**
700	1.88	1.54	19.66	92.47	0.91	1.23	-116.5	-146.5	2.24E-15	35.94	3923.95	**35.94**
800	1.67	1.47	19.38	86.70	0.83	1.21	-116.2	-146.2	2.4E-15	36.73	4706.77	**36.73**
900	2.1	1.62	18.96	78.70	0.78	1.20	-116.1	-146.1	2.45E-15	36.82	4805.33	**36.82**
1000	2.28	1.69	18.53	71.29	0.82	1.21	-116	-146	2.51E-15	37.17	5208.62	**37.17**
1100	2.41	1.74	17.94	62.23	1.01	1.26	-116.5	-146.5	2.24E-15	37.13	5160.87	**37.13**
1200	2.48	1.77	17.75	59.57	0.87	1.22	-116.75	-146.75	2.11E-15	37.00	5008.68	**37.00**
1300	2.54	1.79	17.37	54.58	0.85	1.22	-116.75	-146.75	2.11E-15	37.32	5391.67	**37.32**
1400	2.53	1.79	16.97	49.77	0.84	1.21	-117.2	-147.2	1.91E-15	37.28	5342.23	**37.28**
1500	2.35	1.72	16.58	45.50	0.85	1.22	-116.65	-146.65	2.16E-15	38.40	6913.90	**38.40**
1600	2.16	1.64	16.2	41.69	0.89	1.23	-116.75	-146.75	2.11E-15	38.87	7704.12	**38.87**
1700	2.07	1.61	15.82	38.19	0.95	1.24	-117	-147	2E-15	39.09	8104.44	**39.09**
1800	1.99	1.58	15.52	35.65	0.97	1.25	-116.7	-146.7	2.14E-15	39.77	9478.14	**39.77**

Table 13 – Optel1 NF measured with HP8591A (red values are taken from datasheet).

Freq [MHz]	Gain_link [dB]	Gain_link	Gain_LNA [dB]	Gain_LNA	NF_LNA [dB]	NF_LNA	Marker [dBm/Hz]	Marker [dBW/Hz]	Marker [W/Hz]	NF_tot [dB]	NF_tot	NF_Link [dB]
100	3.87	2.44	21.31	135.21	0.92	1.24	-113.6	-143.6	4.37E-15	35.20	3309.20	**35.20**
200	3.27	2.12	21.2	131.83	0.8	1.20	-114.2	-144.2	3.8E-15	35.31	3394.09	**35.31**
300	3.03	2.01	21	125.89	0.86	1.22	-115	-145	3.16E-15	34.95	3124.09	**34.95**
408	2.88	1.94	20.75	118.85	0.91	1.23	-115.2	-145.2	3.02E-15	35.15	3271.32	**35.15**
500	2.75	1.88	20.5	112.20	0.89	1.23	-115.4	-145.4	2.88E-15	35.33	3409.75	**35.33**
600	2.66	1.85	20.14	103.28	0.87	1.22	-116	-146	2.51E-15	35.18	3293.99	**35.18**
700	2.34	1.71	19.66	92.47	0.91	1.23	-115.7	-145.7	2.69E-15	36.28	4243.49	**36.28**
800	2.71	1.87	19.38	86.70	0.83	1.21	-115.4	-145.4	2.88E-15	36.49	4453.72	**36.49**
900	2.81	1.91	18.96	78.70	0.78	1.20	-115.3	-145.3	2.95E-15	36.91	4905.95	**36.91**
1000	2.89	1.95	18.53	71.29	0.82	1.21	-115.3	-145.3	2.95E-15	37.26	5317.69	**37.26**
1100	2.93	1.96	17.94	62.23	1.01	1.26	-115.8	-145.8	2.63E-15	37.31	5379.26	**37.31**
1200	3.05	2.02	17.75	59.57	0.87	1.22	-116	-146	2.51E-15	37.18	5220.63	**37.18**
1300	3.09	2.04	17.37	54.58	0.85	1.22	-116	-146	2.51E-15	37.52	5645.77	**37.52**
1400	3	2.00	16.97	49.77	0.84	1.21	-116.5	-146.5	2.24E-15	37.51	5632.78	**37.51**
1500	2.82	1.91	16.58	45.50	0.85	1.22	-116	-146	2.51E-15	38.58	7206.48	**38.58**
1600	2.66	1.85	16.2	41.69	0.89	1.23	-116	-146	2.51E-15	39.12	8160.62	**39.12**
1700	2.55	1.80	15.82	38.19	0.95	1.24	-116.3	-146.3	2.34E-15	39.31	8525.56	**39.31**
1800	2.59	1.82	15.52	35.65	0.97	1.25	-116	-146	2.51E-15	39.87	9698.91	**39.87**

Table 14 – Optel2 NF measured with HP8591A (red values are taken from datasheet).

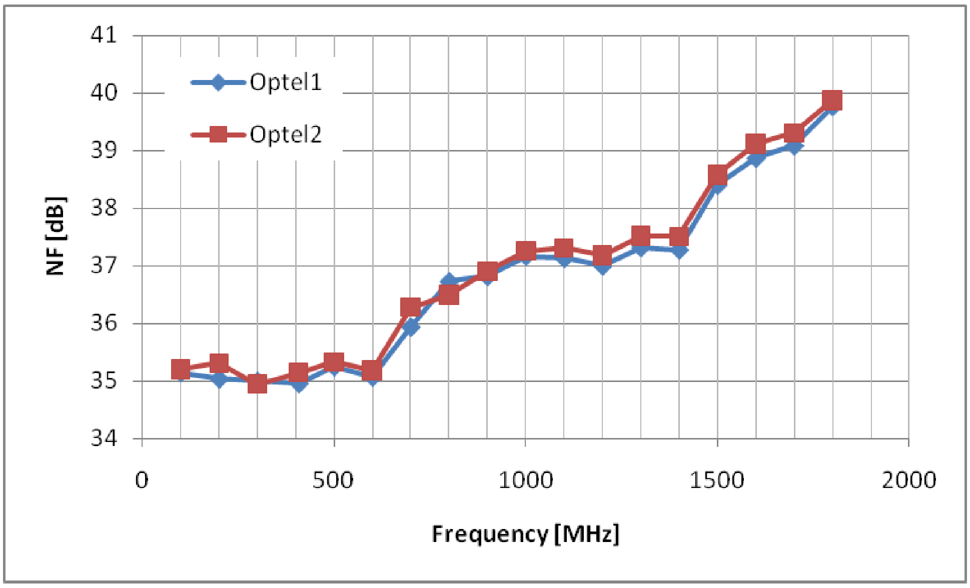

Figure 18 – Optel1 and Optel2 NF link measurements (with 8591A).

Freq [MHz]	Gain_link [dB]	Gain_link	Gain_LNA [dB]	Gain_LNA	NF_LNA [dB]	NF_LNA	Marker [dBm/Hz]	Marker [dBW/Hz]	Marker [W/Hz]	NF_tot [dB]	NF_tot	NF_Link [dB]
100	3.07	2.03	21.31	135.21	0.92	1.24	-114.7	-144.7	3.39E-15	34.89723	3088.324	**34.90**
200	2.59	1.82	21.2	131.83	0.8	1.20	-115.2	-145.2	3.02E-15	34.98723	3152.992	**34.99**
300	2.33	1.71	21	125.89	0.86	1.22	-116	-146	2.51E-15	34.64723	2915.566	**34.65**
408	2.22	1.67	20.75	118.85	0.91	1.23	-116.3	-146.3	2.34E-15	34.70723	2956.126	**34.71**
500	2.03	1.60	20.5	112.20	0.89	1.23	-116.5	-146.5	2.24E-15	34.94723	3124.086	**34.95**
600	2.07	1.61	20.14	103.28	0.87	1.22	-116.5	-146.5	2.24E-15	35.26723	3362.969	**35.27**
700	1.88	1.54	19.66	92.47	0.91	1.23	-116.7	-146.7	2.14E-15	35.73723	3747.338	**35.74**
800	1.67	1.47	19.38	86.70	0.83	1.21	-116	-146	2.51E-15	36.92723	4928.593	**36.93**
900	2.1	1.62	18.96	78.70	0.78	1.20	-116.2	-146.2	2.4E-15	36.71723	4695.944	**36.72**
1000	2.28	1.69	18.53	71.29	0.82	1.21	-115.8	-145.8	2.63E-15	37.36723	5454.098	**37.37**
1100	2.41	1.74	17.94	62.23	1.01	1.26	-116.3	-146.3	2.34E-15	37.32723	5404.094	**37.33**
1200	2.48	1.77	17.75	59.57	0.87	1.22	-116.3	-146.3	2.34E-15	37.44723	5555.497	**37.45**
1300	2.54	1.79	17.37	54.58	0.85	1.22	-116.5	-146.5	2.24E-15	37.56723	5711.141	**37.57**
1400	2.53	1.79	16.97	49.77	0.84	1.21	-117	-147	2E-15	37.47723	5594.006	**37.48**
1500	2.35	1.72	16.58	45.50	0.85	1.22	-116.7	-146.7	2.14E-15	38.34723	6834.754	**38.35**
1600	2.16	1.64	16.2	41.69	0.89	1.23	-116.5	-146.5	2.24E-15	39.11723	8160.615	**39.12**
1700	2.07	1.61	15.82	38.19	0.95	1.24	-116.7	-146.7	2.14E-15	39.38723	8684.062	**39.39**
1800	1.99	1.58	15.52	35.65	0.97	1.25	-116.3	-146.3	2.34E-15	40.16723	10392.57	**40.17**
1900	2.12	1.63	15.19	33.04	1	1.26	-116	-146	2.51E-15	40.66723	11660.65	**40.67**
2000	2.38	1.73	14.84	30.48	1.05	1.27	-115.3	-145.3	2.95E-15	41.45723	13986.95	**41.46**
2100	2.69	1.86	14.5	28.18	1.05	1.27	-114.7	-144.7	3.39E-15	42.08723	16170.48	**42.09**

Table 15 – Optel1 NF measured with HP8564E (red values are taken from datasheet).

Freq [MHz]	Gain_link [dB]	Gain_link	Gain_LNA [dB]	Gain_LNA	NF_LNA [dB]	NF_LNA	Marker [dBm/Hz]	Marker [dBW/Hz]	Marker [W/Hz]	NF_tot [dB]	NF_tot	NF_Link [dB]
100	3.87	2.44	21.31	135.21	0.92	1.24	-113.8	-143.8	4.17E-15	35.00	3160.26	**35.00**
200	3.27	2.12	21.2	131.83	0.8	1.20	-114.7	-144.7	3.39E-15	34.81	3024.98	**34.81**
300	3.03	2.01	21	125.89	0.86	1.22	-115.3	-145.3	2.95E-15	34.65	2915.57	**34.65**
408	2.88	1.94	20.75	118.85	0.91	1.23	-115.7	-145.7	2.69E-15	34.65	2915.57	**34.65**
500	2.75	1.88	20.5	112.20	0.89	1.23	-116	-146	2.51E-15	34.73	2969.77	**34.73**
600	2.66	1.85	20.14	103.28	0.87	1.22	-116	-146	2.51E-15	35.18	3293.99	**35.18**
700	2.34	1.71	19.66	92.47	0.91	1.23	-116.3	-146.3	2.34E-15	35.68	3695.92	**35.68**
800	2.71	1.87	19.38	86.70	0.83	1.21	-115.5	-145.5	2.82E-15	36.39	4352.34	**36.39**
900	2.81	1.91	18.96	78.70	0.78	1.20	-115.8	-145.8	2.63E-15	36.41	4372.43	**36.41**
1000	2.89	1.95	18.53	71.29	0.82	1.21	-115.5	-145.5	2.82E-15	37.06	5078.35	**37.06**
1100	2.93	1.96	17.94	62.23	1.01	1.26	-116.2	-146.2	2.4E-15	36.91	4905.95	**36.91**
1200	3.05	2.02	17.75	59.57	0.87	1.22	-116.3	-146.3	2.34E-15	36.88	4872.18	**36.88**
1300	3.09	2.04	17.37	54.58	0.85	1.22	-116.3	-146.3	2.34E-15	37.22	5268.94	**37.22**
1400	3	2.00	16.97	49.77	0.84	1.21	-116.8	-146.8	2.09E-15	37.21	5256.82	**37.21**
1500	2.82	1.91	16.58	45.50	0.85	1.22	-116.7	-146.7	2.14E-15	37.88	6133.71	**37.88**
1600	2.66	1.85	16.2	41.69	0.89	1.23	-116.5	-146.5	2.24E-15	38.62	7273.16	**38.62**
1700	2.55	1.80	15.82	38.19	0.95	1.24	-116.8	-146.8	2.09E-15	38.81	7598.41	**38.81**
1800	2.59	1.82	15.52	35.65	0.97	1.25	-116.5	-146.5	2.24E-15	39.37	8644.16	**39.37**
1900	2.74	1.88	15.19	33.04	1	1.26	-116.2	-146.2	2.4E-15	39.85	9654.35	**39.85**
2000	3.09	2.04	14.84	30.48	1.05	1.27	-115.5	-145.5	2.82E-15	40.55	11342.87	**40.55**
2100	3.48	2.23	14.5	28.18	1.05	1.27	-114.8	-144.8	3.31E-15	41.20	13174.16	**41.20**

Table 16 – Optel2 NF measured with HP8564E (red values are taken from datasheet).

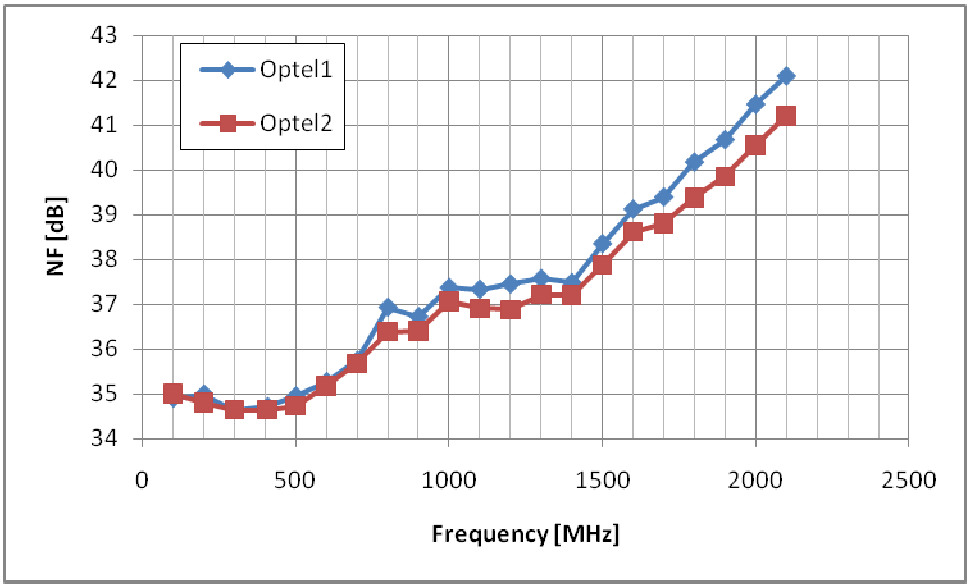

Figure 19 – Optel1 and Optel2 NF link measurements (with HP8564E).

As can be noticed from the previous figures and tables, the NF exceeds the specification (<40dB) above 1.8GHz. The measurements done with both spectrum analysers are well in agreement in the common frequency range (100-1800MHz).

Notes on NF measurements made by spectrum analyser.

To measure the noise figure with the spectrum analyser, the method adopted is to get the noise spectral density power using the marker noise option, which provide directly the value expressed in dBm/Hz. Different NF values are obtained if the noise spectral density has been got dividing the power of the marker, expressed in dBm, by the resolution bandwidth, expressed in Hz. The latter method leads to underestimate the NF of about 2dB. The reasons are well explained in the Agilent application note n.1303 "Spectrum Analyzer Measurements and Noise". As examples, here are reported the NF measurements of the Optel links obtained with both methods.

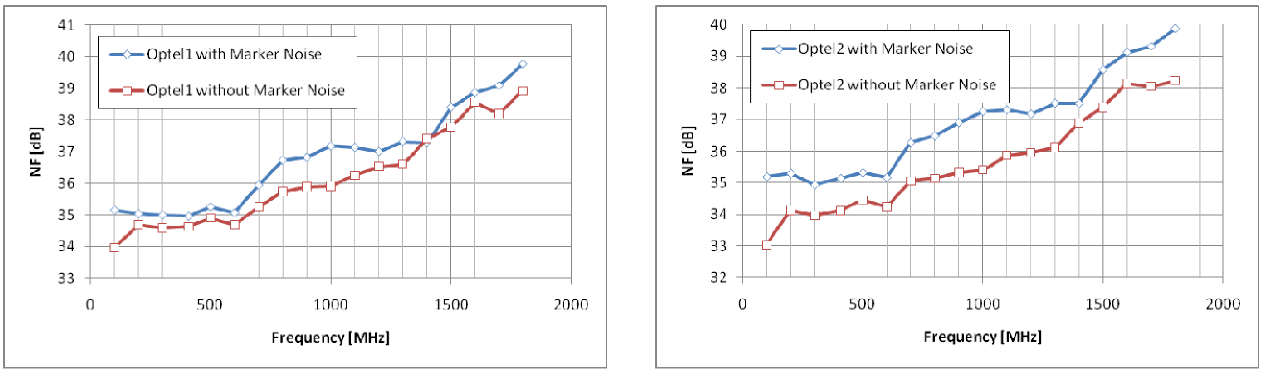

Figure 20 – NF measurements comparison: with and without Marker Noise.

Gain Compression Point (P1dB)

The measurement set up is shown in the following figures.

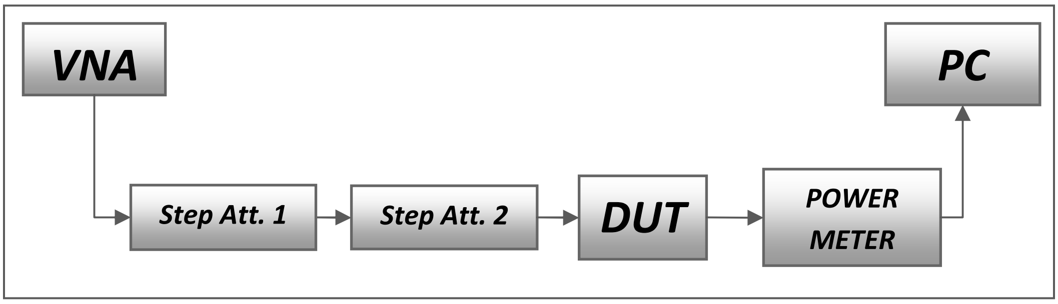

Figure 21 – P1dB measurement set up block diagram.

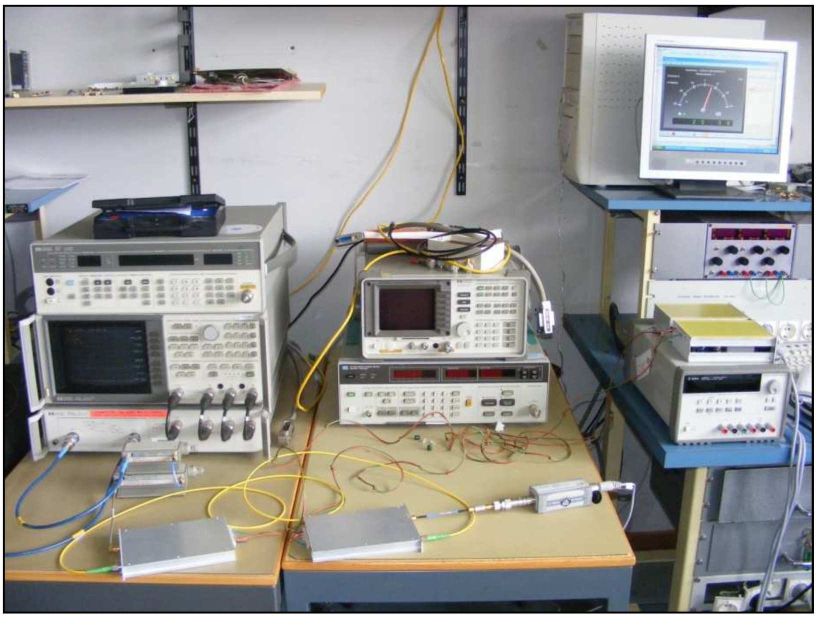

Figure 22 – P1dB measurement set up.

RF Generators	VNA (CW mode) HP 8753C (300KHz – 3GHz) with test set HP 85047
Step attenuator 1	HP8494B, 70dB, 10dB step, DC-18GHz
Step attenuator 2	HP84955B, 11dB, 1dB step, DC-18GHz
Attenuator	Mini-circuits VAT-10+
Power Meter	Agilent U2004A USB Average Power Sensor [9KHz-6GHz; -60 to + 20dBm (1mW-100mW)]

Table 17 – Instrumentation for P1dB measurement.

To control the power level at input of the DUT, two step attenuators were inserted between the VNA, used as signal generator in CW mode and with constant output power, and the DUT itself.

As starting point, for each measurement step (for each frequency), the power at the DUT input was attenuated by 30dB. With the first attenuator (HP 8495B/70dB, 10dB step), the level was attenuated by 20dB and with the second one (HP 8494B/11dB, 1dB step), by further 10dB. Then the power meter was set in relative measurement mode and the DUT input power increased step by step lowering the attenuation of the step attenuators.

When the Output 1dB compression point was found, the power meter was set in absolute measurement mode in order to get the power levels, both at the DUT output and input. The instrument readings were then corrected adding 10dB because, to protect the power meter, a 10dB attenuator was inserted in front of the meter itself.

Figure 23 – Agilent Power Meter with 10dB attenuator.

Frequency (MHz)	OutP1dB [dBm]	InP1dB [dBm]
100	17,70	15,63
200	18,01	16,42
300	18,45	17,12
400	18,58	17,36
500	18,92	17,89
600	18,91	17,84
700	19,10	18,22
800	18,99	18,32
900	18,77	17,67
1000	18,91	17,63
1100	19,23	17,82
1200	19,37	17,89
1300	19,17	17,63
1400	18,92	17,39
1500	18,65	17,30
1600	18,47	17,31
1700	18,43	17,36
1800	18,63	17,64
1900	18,92	17,80
2000	19,39	18,27
2100	20,00	18,88

Table 18 – Optel1 Input and Output 1dB compression point.

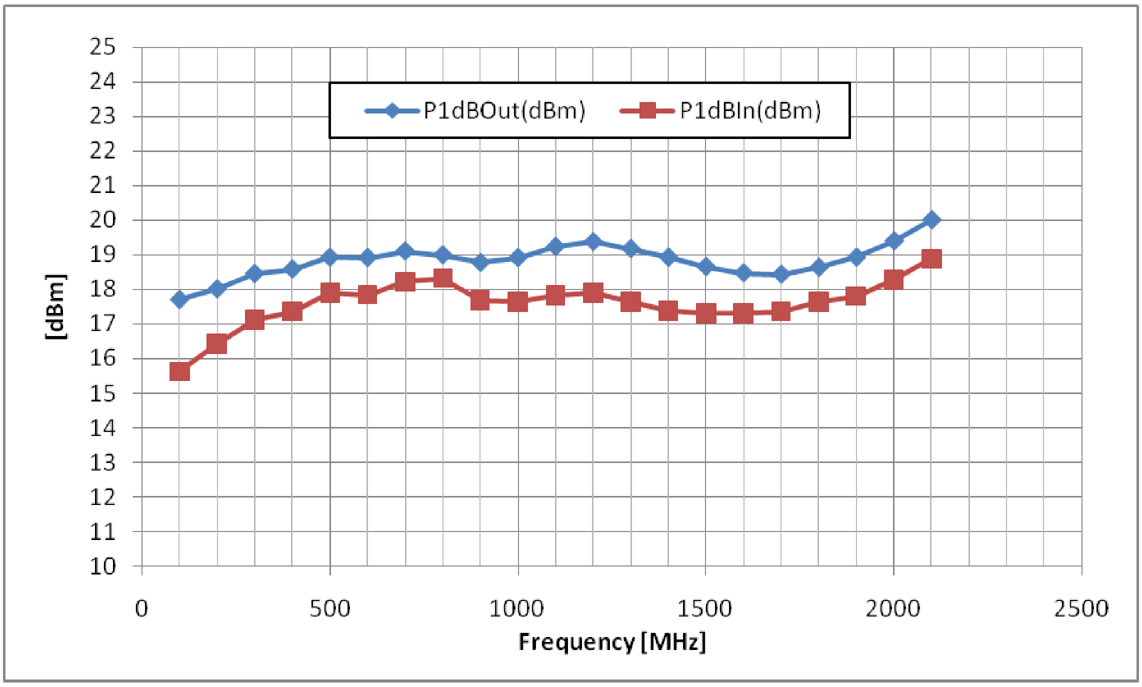

Figure 24 – Optel1 Input and Output 1dB compression point.

Frequency (MHz)	OutP1dB [dBm]	InP1dB [dBm]
100	19,13	16,26
200	19,16	16,89
300	19,49	17,46
400	19,61	17,73
500	20,41	18,66
600	20,72	19,06
700	20,20	18,86
800	20,07	18,36
900	20,43	18,62
1000	19,81	17,92
1100	20,65	18,72
1200	21,11	19,06
1300	20,73	18,64
1400	20,77	18,77
1500	20,50	18,68
1600	20,03	18,37
1700	20,00	18,45
1800	20,30	18,71
1900	20,44	18,70
2000	21,01	18,92
2100	21,38	18,90

Table 19 – Input and Output 1dB compression point for Optel2.

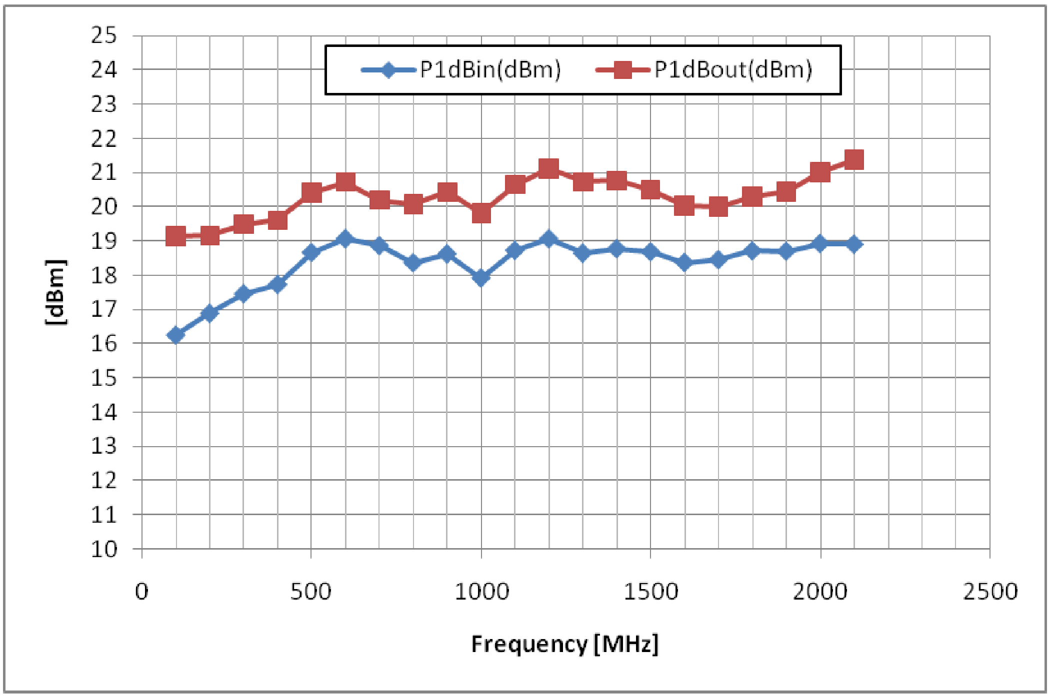

Figure 25 – Optel2 Input and Output 1dB compression point.

Link gain ripple versus temperature variation of the optical transmitter.

At the Medicina radio telescopes, the Radio over Fibre (RoF) technology has been applied since 2004, when four new receivers, developed in the frame of the SKA project, were installed on a single reflector of the N/S arm of the Northern Cross Radiotelescope. Those receivers were composed by a three stages LNA developed by IRA/INAF and a commercial optical transmitter (by Andrew Wireless Systems). During some astronomical observation made with this system (called BEST-1), a ripple on the detected traces of some radio sources has been noticed (see Figure 26).

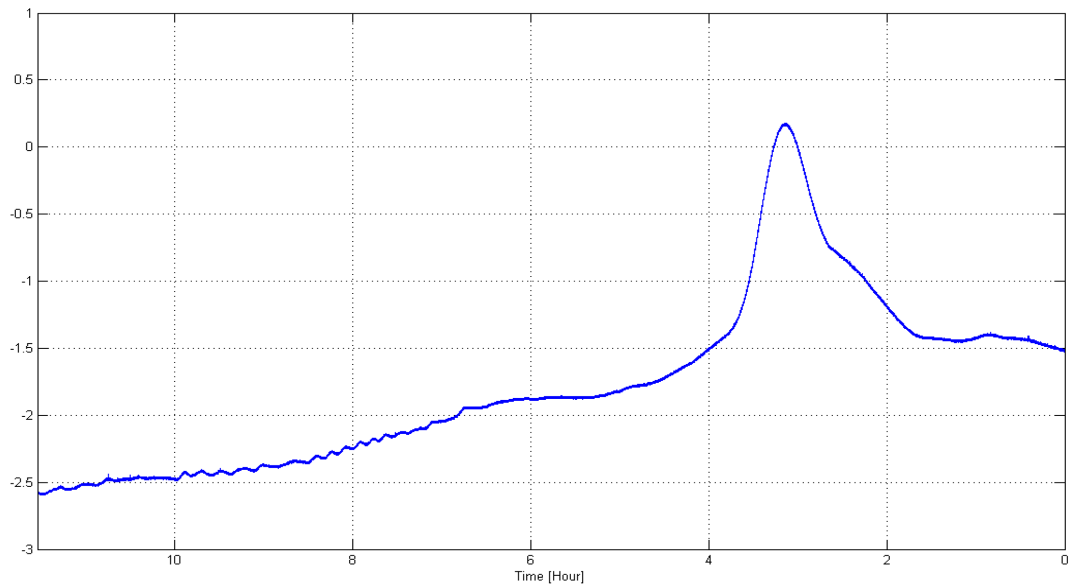

Figure 26 – Total power ripple on a detected transit of Cas-A with a single BEST-1 RX.

Thanks to a measurement system able to reproduce the slow environmental temperature variations, similar to the one where electronics mounted on the antennas generally operate, and after several tests of various optical links by different company (Andrew Wireless Systems, Miteq, Tekmedia,…), we have found the origin of the ripple is the LASER, and in particular it depends to the LASER quality. Optical TX equipped with LASER selected for analogue applications show minor ripple effects than optical TX equipped with lower cost devices namely for digital applications but used in analogue applications.

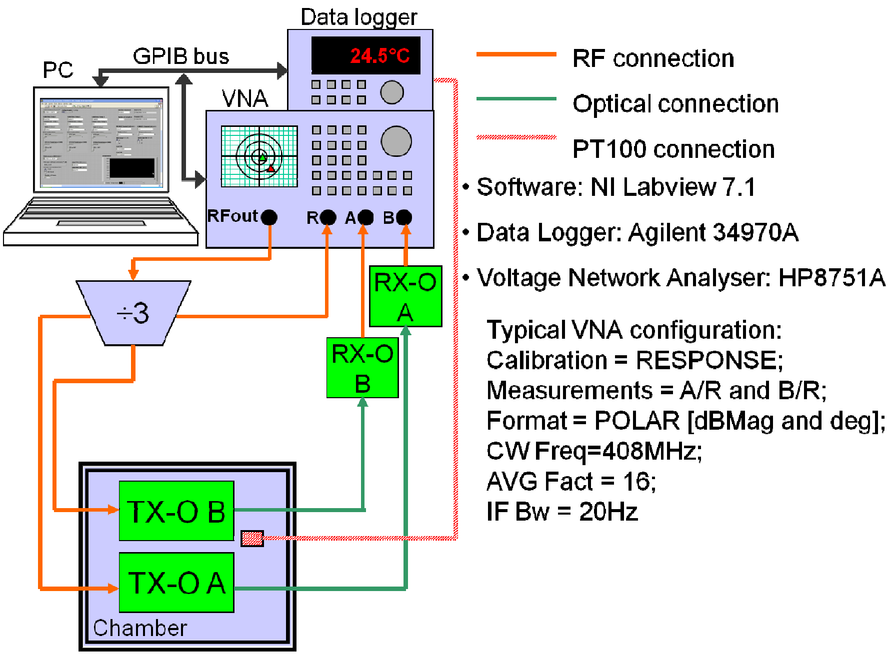

Figure 27 – Ripple measurement block diagram set up.

Figure 28 – Ripple measurement set up.

Figure 29 – Optical TXs inside the chamber.

CW frequency	408 MHz
Attenuator port A	0 dB
Attenuator port B	0 dB
Attenuator port R	10 dB
Number of Points	2
Sweep Type	Power sweep
Center	-5 dBm
Span	0 dBm
IF BW	200 Hz
Averaging factor	128
Calibration	Response

Table 20 – VNA configuration for ripple measurements.

The optical transmitters have been tested from 50°C to ambient temperature, which is easily obtainable simply switching off the heater of the chamber after a steady state at 50°C. Thanks to the not perfect thermal isolation of the chamber, the cooling phase from 50° to about 30°C takes 6-8 hours, which is similar to a day/night thermal transition.

The following graphs report the collected data. Values are normalised respect to the max. For that reason, the measurement units are [dB rel] and [deg rel], respectively, for gain and phase. As is possible to notice, TX2 seems not show any ripple on the gain while TX1 shows a ripple of small entity (compared to other commercial optical TX). Regarding phase, TX2 shows a strange behaviour since its trace appears extremely noisy, probably due to a bug in the measurement set-up.

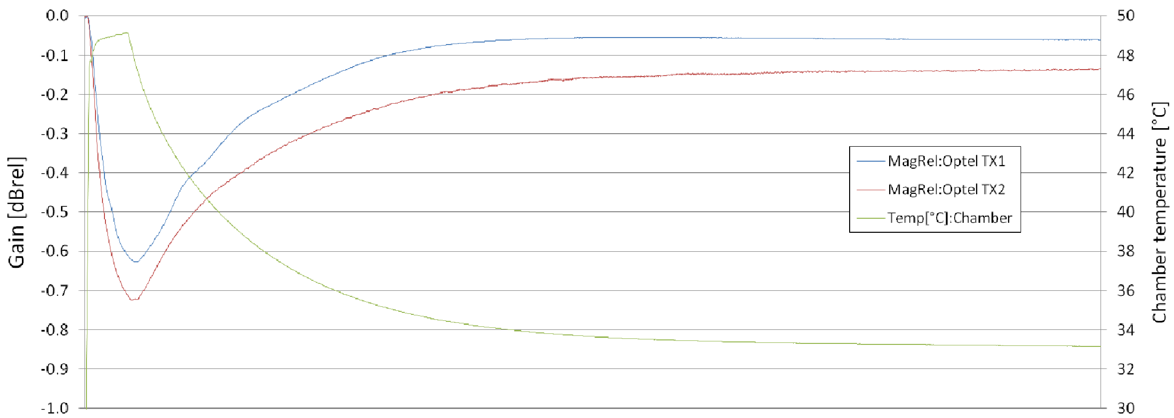

Figure 30 – Optel TX1 and TX2 gain variation vs temperature (horizontal axes is time, not showed).

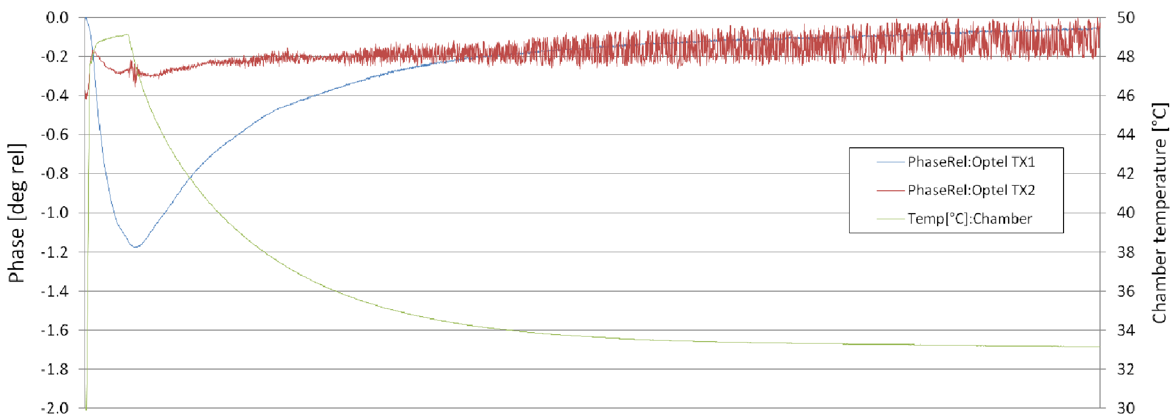

Figure 31 – Optel TX1 and TX2 phase variation vs temperature (horizontal axes is time, not showed).

Conclusion

An optical link suitable for the remotisation of the SRT receivers has been identified. The link is produced by the Italian company “Optel”, based in Milan. In late 2009-early 2010 some commercial samples have been tested in the Medicina labs and then, in mid 2010, a couple of customised links have been purchased by INAF/IRA and deeply tested and measured. The solution identified allows the signal transportation of 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. The total link length is about 500m. Moreover, thanks to a link gain of 0dB associated with an OIP3>+30dBm on full band, this solution guarantees to not affect the overall receiver specifications.