EMIR receiver: report of hardware installation and tests

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During the second week of March 2009 and after twelve years of successful operation, the old HDV-10 cryostats were stopped and removed from the receiver cabin of the 30m telescope. Then, one week later, the new single cryostat EMIR receiver was installed and its hardware and control software was successfully tested. Measurements in the cabin closely match previous data taken in the laboratory in Grenoble while first tests on the sky seems to indicate an excellent co-alignment of the beams and very good coupling to the telescope. For the first time in the life of the 30m telescope an helicopter flight was used to transport the receiver assembly to the observatory.

Figure 1. The EMIR cryostat in its way to the telescope just before sunrise.

1. EMIR installation sequence.

1.1 Removal of old equipment and cabin preparation. March 10th to 15th.

On March 10th the renewal of the 30m receiver cabin started by stopping the hybrid cryostats A, B, C and D and all the associated equipment. The Hera multibeam system was kept in stand-by mode while the Mambo-2 bolometer was maintained in a ready for operation status.

For more than three days the cabin was cleaned from the old stuff and prepared for the arrival of the new receiver. The four dewars and supporting frames, the old cold load cryostat and the beam splitter assembly were firstly removed to leave access to the cable distribution and the fixation to the telescope structure below the floor. All the unused signal and control cables were removed, the broken IF cables were also dismounted and replaced by a new type of coax cable. From the ten newly installed cables only four are to be used for EMIR, the rest are spares. All the cables from the receiver cabin to the backend room are split in two parts: one of 40 meter length, from the receiver cabin to the telescope tower and rest of 60 meters length, from the tower to the backend room. The four cables associated with the EMIR receiver are shown on the following table:

IF cable	40m label	60m label in tower	60m label in backend
1	S-7	60-F-2	60-F-1
2	S-8	60-I-2	60-I-1
3	S-9	60-L-2	60-L-1
4	S-10	60-D-2	60-D-1

Installation of the new coaxial lines in the cable spiral is a hard work so it took most of the time during the third day and required the help of more than six peoples from several technical groups.

Since 1997 he receiver cabin wasn’t that empty so it was decided to take the chance to paint it. The fourth, and part of the fifth day, were entirely devoted to the painting of the cabin - an activity with a non negligible risk for the remaining equipment in the cabin, as can be guessed from picture 2.

Figure 2. Painting over the Nasmyth mirrors.

Day sixth was scheduled as reserve for pending activities and for drying of the paint. The telescope time was used for radio-astronomy with bolometer. In fact, for most of the time scheduled for installation of the new EMIR receiver the bolometer instrument was efficiently used for observations during the night time.

1.2 Transport and installation of EMIR system. March 16th to 22nd.

On March the 16th the EMIR receiver and associated equipment were successfully transported by helicopter to the telescope. The flight was organized early in the morning in order to reduce to a minimum the safety risks and the impact on the operation of the ski station. All the material was transported from the parking in Pradollano on a total of three trips that did not last more than half an hour in total. On the way back from the telescope the spare Daikin compressor and cold head from the multibeam receiver were brought down from the telescope. All the transport went very smooth and no signs of shock or severe tilt was detected on any of the boxes, neither at the receipt from the truck driver nor at the arrival at the telescope, after the helicopter flight.
The rest of the transport day was used to open the boxes and visually inspect its content, for installation of the helium compressor on top of the receiver cabin (later moved to the other side of the roof) and for mounting the frame of the external optics. A problem on the support for the external optics was identified

and finally required the installation of the main plate 25mm away from the receiver cabin wall. The M5, M6 and M7 mirrors had to be shifted accordingly.

The following day was used to calculate the final position of the EMIR frame in the cabin and for installation of the external mirrors, M5, M6 and M7 on their supports. An unexpected change (respect to the available 3D drawings) on the size of the EMIR support was found, luckily before fixation of the beams to the telescope structure.

March 18th was mostly used for alignment of the receiver frame and external optics. The laser installed on the elevation axis is the main reference for optical alignment. Due to its importance a few hours were spent to verify and correct its position. The alignment of the rest of the flat mirrors was relatively straightforward and led to the final definition for the position of the frame and the later fixation to the floor.

Figure 3. View of M4 from the Hera input.

Once the alignment with the laser on the elevation axis was finished another laser, installed on the EMIR frame, was switched on and the global optical alignment was checked from the receiver up to the subreflector. While making the alignment of the external optics a possible vignetting problem of the Hera beam was identified. The position of M5, when closed, could be cutting part of the Hera beam. The mirror was carefully adjusted to reduce the problem to a minimum. Some more checks for truncation will be needed, anyway. Fig. 3 shows

a picture taken from the Hera input. The last activity during the day was the insertion of the EMIR cryostat in its frame and the connection to the vacuum pump.
On the following day the lines connecting the cryostat to the helium compressor on top of the cabin were installed. The cooling down process was started at 12H20. Then all the LO boxes and the rest of the electronics were installed in place.
Next day, the external wiring: DC, CAN cables, waveguides and semi-rigid cables between cryostat and various boxes, Ref 2 and PLL monitor cables was finished. The four ADRET synthesizers for the second PLL reference signal were connected in the following way:

Adret synthesizer	EMIR band	Hera part
1	1 (E0)	1
2	2 (E1)	2
3	3 (E2)	
4	4 (E3)	

In order to feed the two local oscillator boxes, for EMIR and Hera receivers, the first two Adret synthesizers are connected via powers splitter.
The PC to control the receiver was then connected and, approximately 30 hours after the start of the cool down process, the SIS junctions were finally tested. The operation of the mixer backshort motors and magnetic coils was also checked. The temperatures found on the cryostat are:

Stage	Cold head	Band 1	Band 3	Band 4	IF amps	Cold load
4K	3.82	4.25	4.22	5.25	-	-
15K	13.5	2	-	-	18.04	20.64
70K	57	-	-	-	-	-

That essentially match the temperatures found in the lab except for the 15K temperature on the cold head that is about 2 degrees lower.
On Saturday 21st the IF switch box and equalizer units were set in place. The semi-rigid cables, connecting the two boxes to the receiver were fabricated and later the first tests of the automatic tuning routines for LO, mixers and magnetic field for bands 1, 2 and 3 were performed.
Sunday 22nd was used to continue the tunings at different bands and to check the data files for the LOs and mixers at several frequencies. A problem on the automatic tuning of the coils for bands 3 and 4 was identified and a different method for tuning the magnetic field was explored and implemented by people from the software group.

1.3 First light and hardware tests on the sky. March 23rd to 30th.

The first tests on the sky were performed by using a laboratory power meter directly connected to the receiver output. Pointing scans on Venus provided the first indication of the very good performance of the receiver while initial estimations of the forward coupling efficiency at 3 and 1.3 mm wavelength demonstrated the correct alignment of the receiver beam. By the end of the day the control software for the Anritsu synthesizers was finished so the following day was already used for “real” observations of some planets. The training of the local staff on the operation of EMIR was then started and continued during the following three days, mostly in parallel with the rest of activities. While trying to tune to new frequencies a problem on the PLL circuitry, due to a low power level on the reference frequency, was found. It was decided to increase the level to 9 dBm for all frequencies.

On March 25th the packing of the old LO boxes and equipment was started. The boxes will be sent to Grenoble for modification so they can be used as spares for the actual ones.
Some water leaks (probably a mixture of water and glycol) falling on top of the new receiver, when the antenna was pointing to high elevations, were detected. A Plexiglas plate was installed to protect the electronics and the sensitive parts of the cryostat from the risk of corrosion and electrical problems.

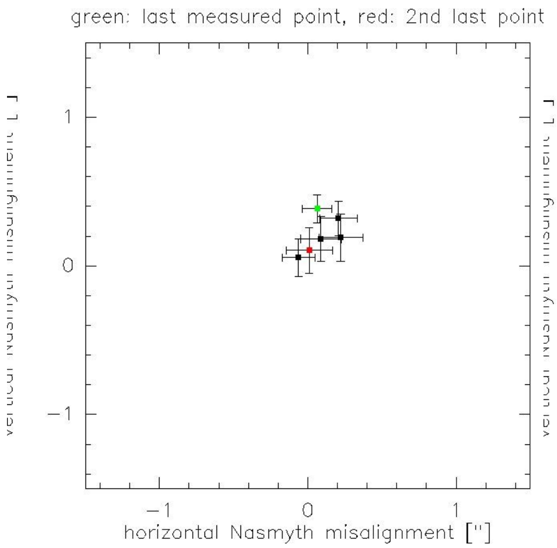
On the following days more measurements of co-alignment and forward efficiencies were carried out. Surprisingly the co-alignment between the H and V polarizations of band 1 were found to be much better than the values measured in the lab. While trying to characterize the continuum stability of the receiver a problem on one of the IF amplifier cards was found and corrected.

From March 26th on and to the rest of the installation slot the receiver was used most of the time for measurements of efficiencies, alignment and pointing model determination, measurement of Nasmyth offsets, beam shape characterization and tests of the automatic tuning software.

2. Verification and results

2.1 Co-alignment of H and V beams.

The co-alignment between the two polarizations on every band was checked by making pointing scans on planets. The best results were obtain on Monday the 30th on Mars and were also used to derive telescope efficiencies at several wavelengths. The following figures show the difference in arc seconds between the H and V channels for every band.



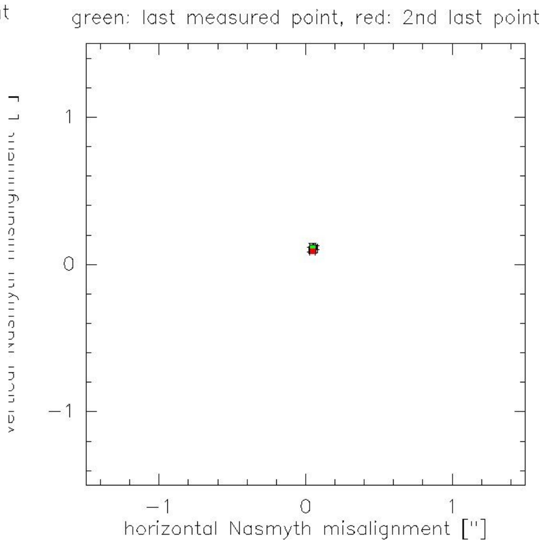
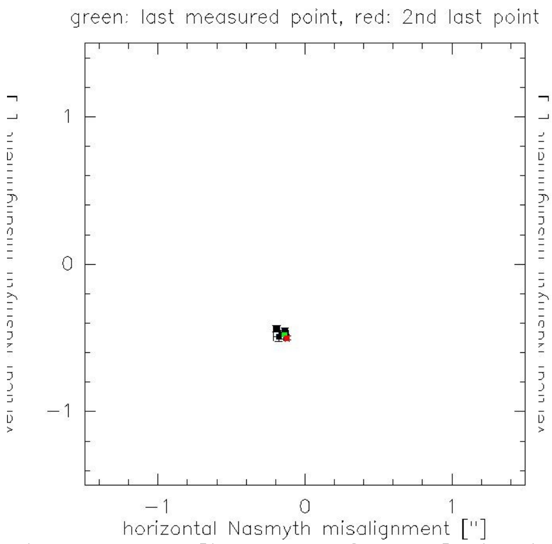


Figure 4. Co-alignment of E0 polarizations **Figure 5. Co-alignment of E1 polarizations**



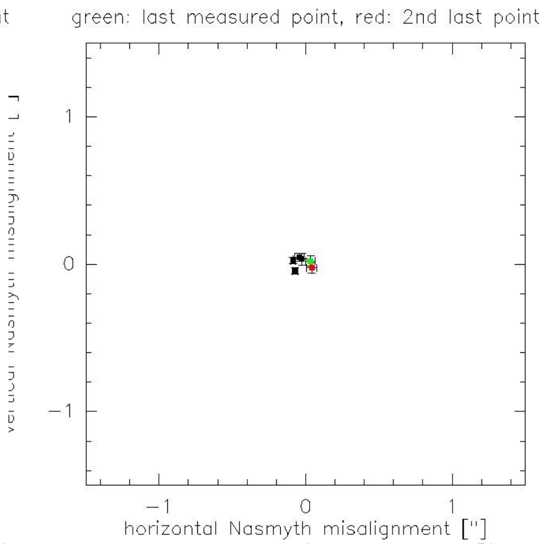


Figure 6. Co-alignment of E2 polarizations **Figure 7. Co-alignment of E3 polarizations**

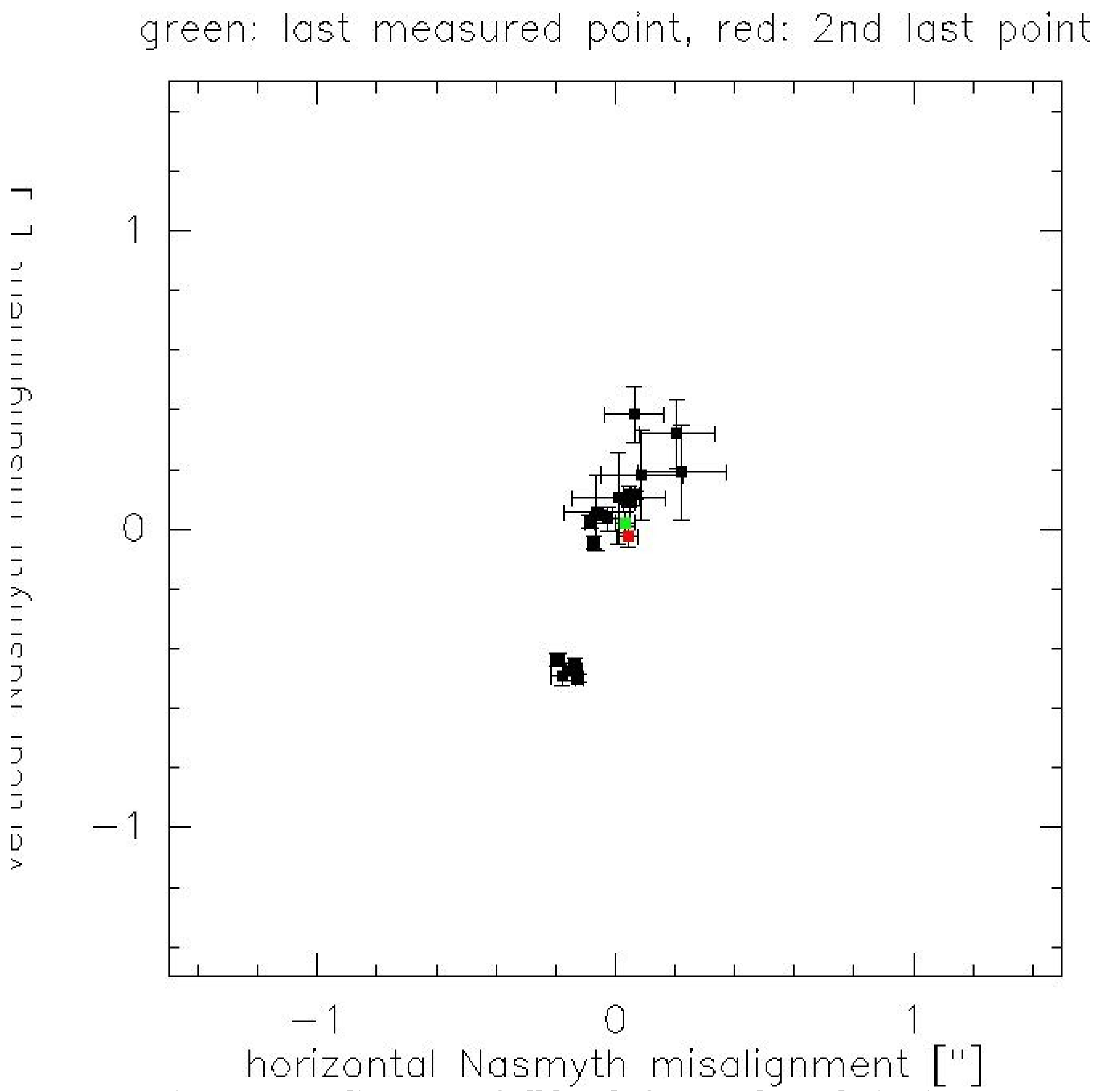


Figure 8. Co-alignment of all bands for V and H polarizations

2.2 Co-alignment between bands

The co-alignment between bands was checked for the three possible band combinations. The following table summarizes the results:

Band combination	Az difference	El difference
E0/E1	0.3	-0.3
E0/E2	-0.1	1.0
E1/E3	0.3	1.6

Where the difference on the pointing values are in arc seconds, first receiver minus the second.

2.3 Internal cold load values.

The equivalent temperature of the internal cold loads as a function of the sky frequency has been measured in the lab in Grenoble and their values have been fitted to the formulas:

- Band 1 Tc=0.01 f^2 - 2.25 f + 150
- Band 2 Tc = 26 + 0.08 * (f-130)
- Band 3 Tc = 26
- Band 4 Tc = 25 + 0.1 * (f-280)

A few measurements of the cold load were performed at the telescope while using the E0/E2 configuration and the receiver tuned at 104.2 LO LSB and 237 LO LSB GHz respectively. The values measured are compared with the values derived from the formulas on the following table:

Band	Polarization	Tcold telescope	Tcold fit
E0	H	25.6	26.1
	V	25.7	26.1
E2	H	25.2	26.0
	V	25.4	26.0

The few results we have show very little discrepancy. Anyway, it is clear that this table is not representative and more data is needed at different frequencies and receiver bands.

2.4 Optical alignment

The global optical alignment was checked from the receiver up the subreflector by using the laser installed on the EMIR frame. The alignment looks quite good: the laser spot on the subreflector moves from a 5 or 6 cm offset to the center at 0 degrees elevation, to 2 or 3 cm offset at 45 degrees and stays close to this offset up to 90 degrees. The values are estimated by eye from the receiver cabin by comparing with the size of the internal cone (Φ~130mm).

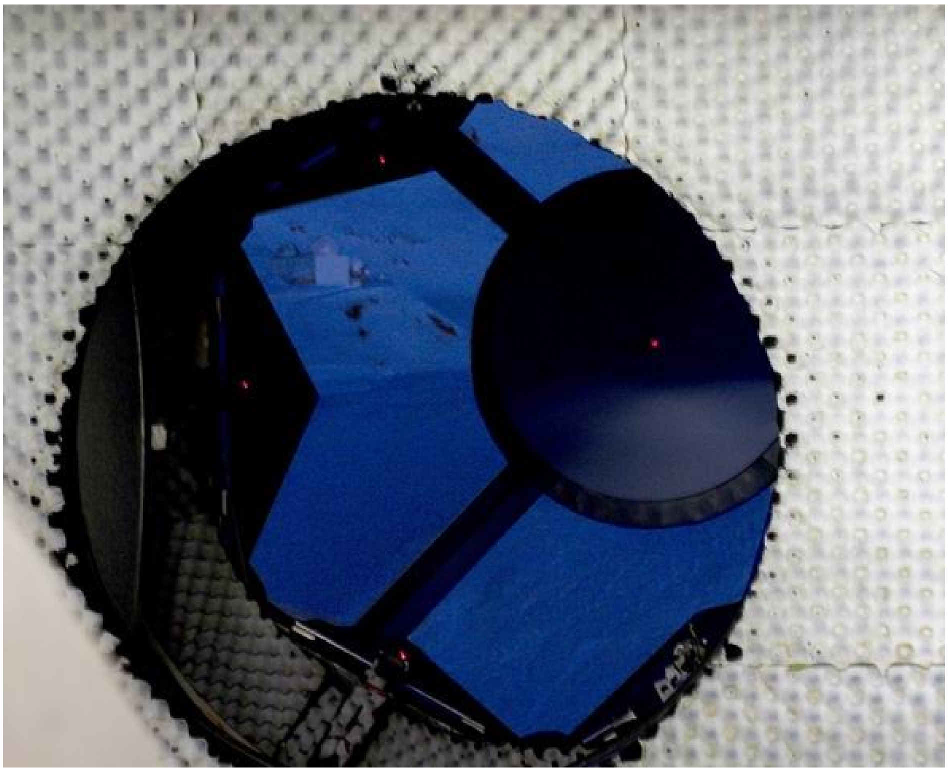


Figure 9. Laser spot on subreflector at zero degrees elevation (from B. Pissard)

2.5 Efficiencies

Results will be given on a different report

2.6 Forward coupling to the antenna

Results will be given on a different report

2.7 Total power stability measurements

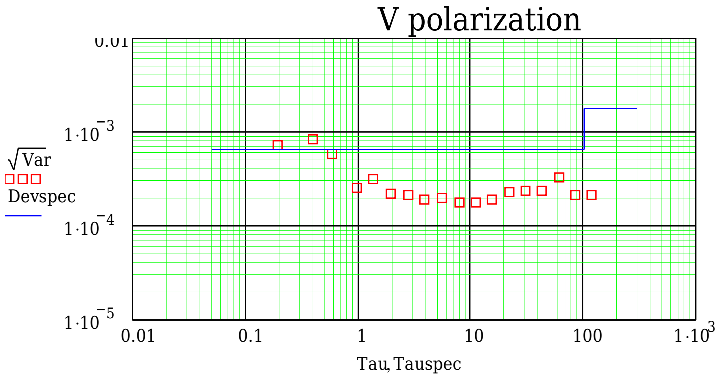
Stability measurements were performed at the output of the receiver's warm IF amplifiers. Using an Agilent E4419B dual-channel power meter, with two E9300A

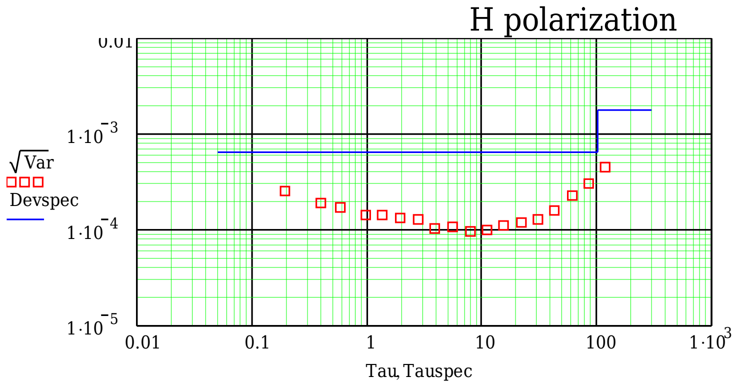
sensors. Two polarization channels were acquired in parallel. Total duration of data was 600s at a sampling of 200ms.
For each measurement, three graphs are displayed:

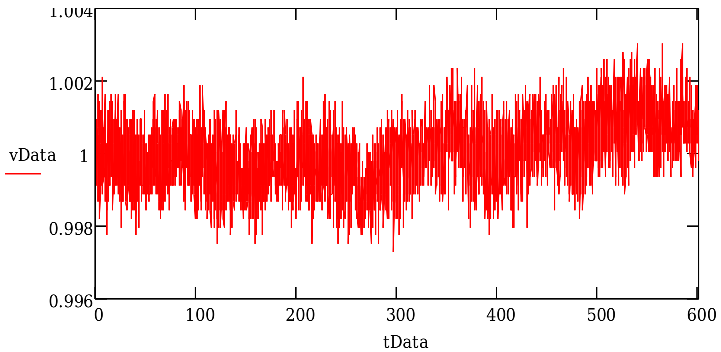
- Allan deviation ($\sqrt{\mathrm{var}}$) versus timescale; the blue line shows the ALMA specification for total power stability.
- Time plot
- Spectrum; resolution 1/600s, first two channels masked to better display low level features. The plotted quantity is *amplitude* (not power), on a scale such that the mean value (1) of the normalized power corresponds to a 0-Hz spectral component of amplitude unity.

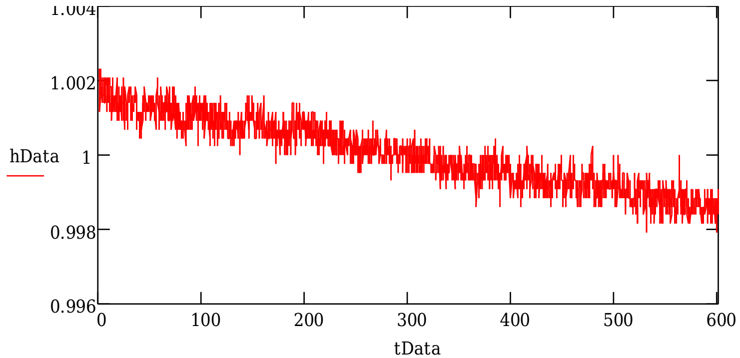
Plots are shown first for the V channel, then the H channel.

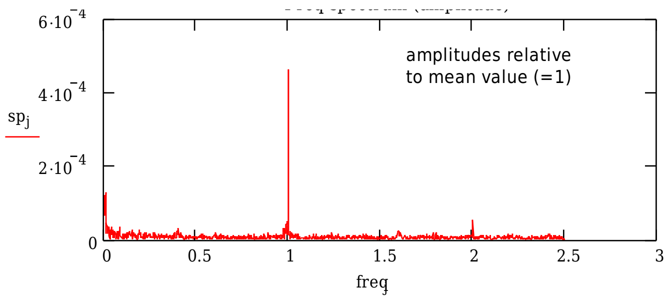
2.7.1 Band 1 (E0). 101 GHz LO USB.

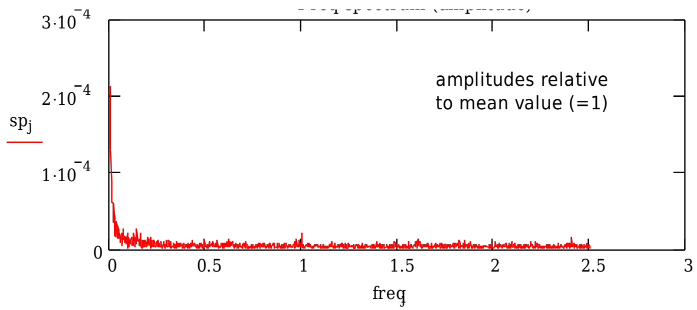








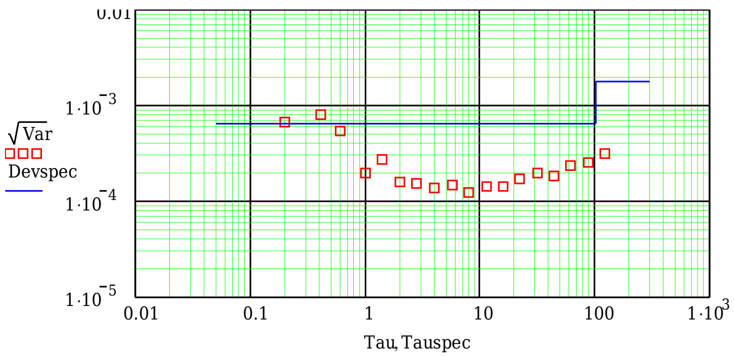


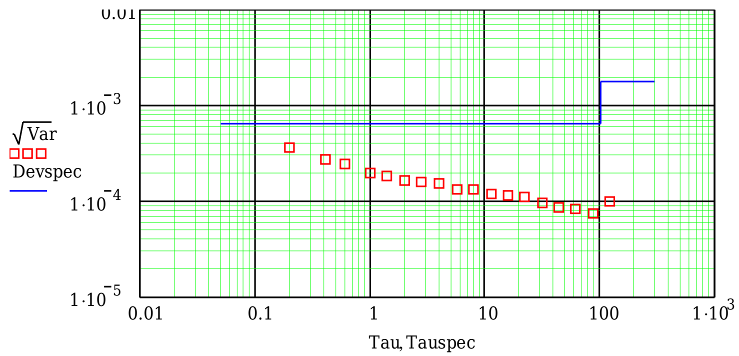


2.7.2 Band 1.(E0) 101 GHz LO LSB.

V polarization

H polarization


0.01
1·10^-3
1·10^-4
1·10^-5
√Var
Devspec
0.01
0.1
1
10
100
1·10^3
Tau, Tauspec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1·10^-3
1·10^-4
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√Var
Devspec
0.01
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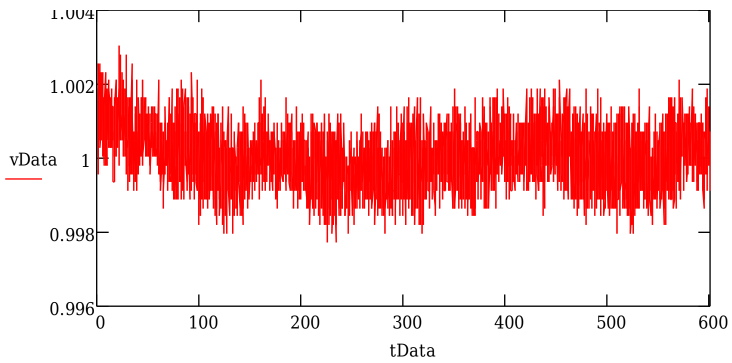
1
10
100
1·10^3
Tau, Tauspec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1.002
1
0.998
0.996
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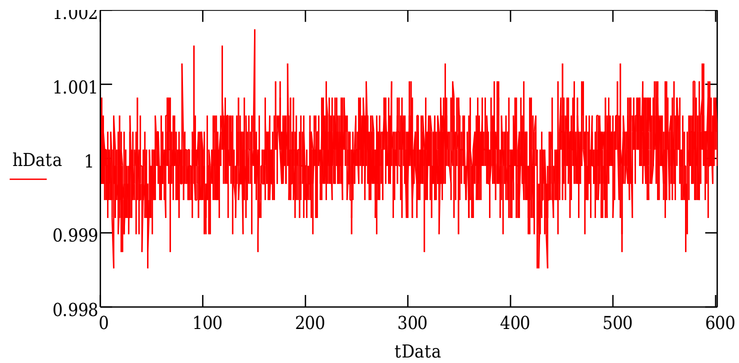
0
100
200
300
400
500
600
tData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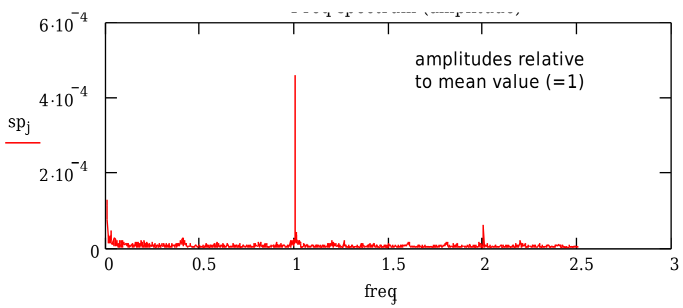
100
200
300
400
500
600
tData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4·10^-4
2·10^-4
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amplitudes relative
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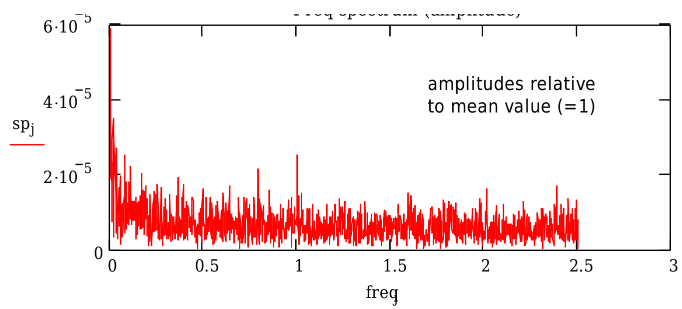
0.5
1
1.5
2
2.5
3
freq_j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4·10^-5
2·10^-5
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sp_j
amplitudes relative
to mean value (=1)
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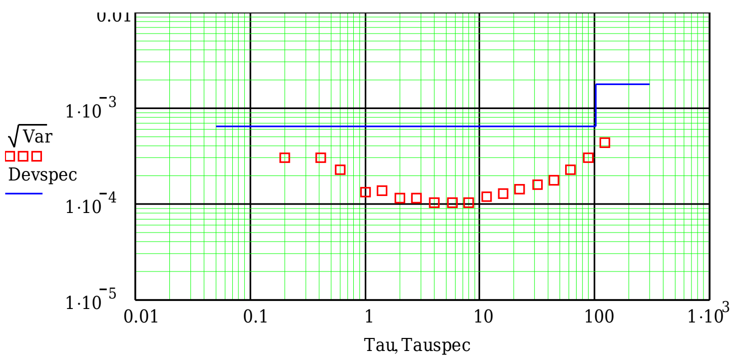
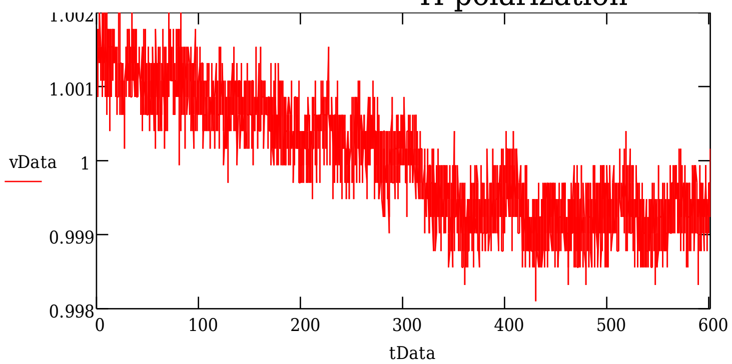
2
2.5
3
freq_j

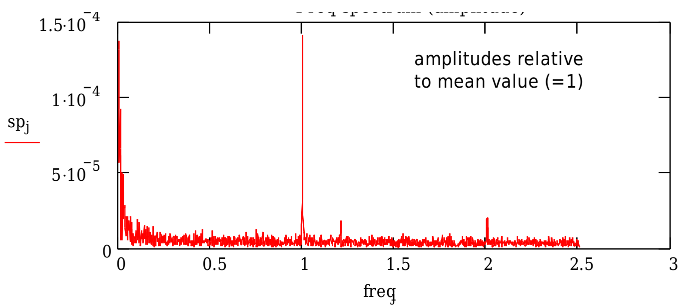
2.7.3 Band 2 (E1) 150.86 LO LSB

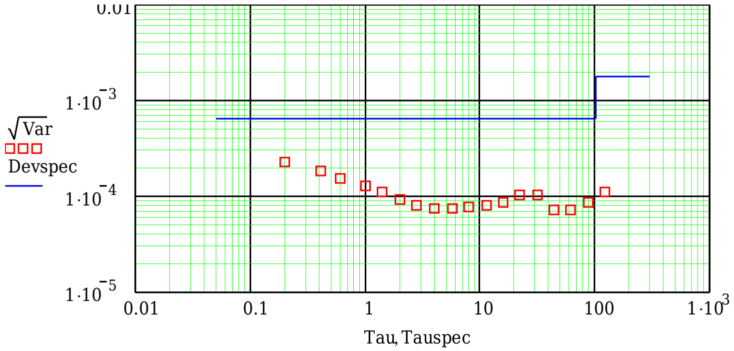
V polarization

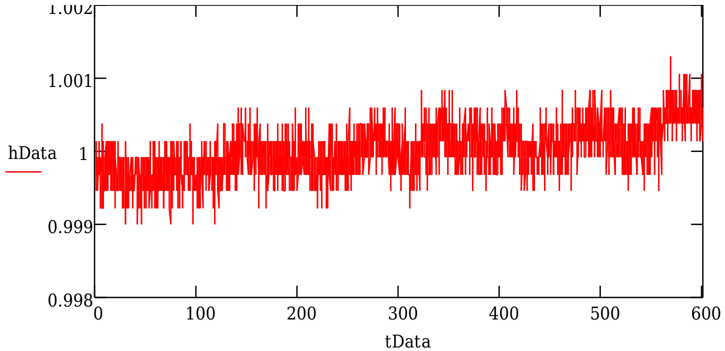


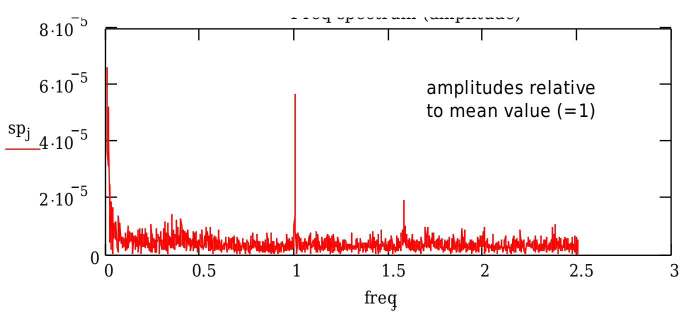
H polarization







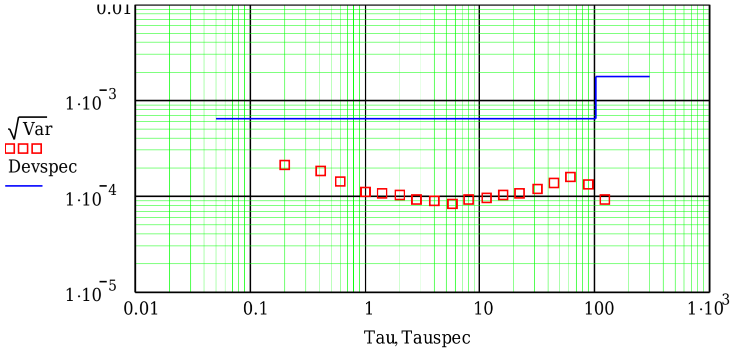


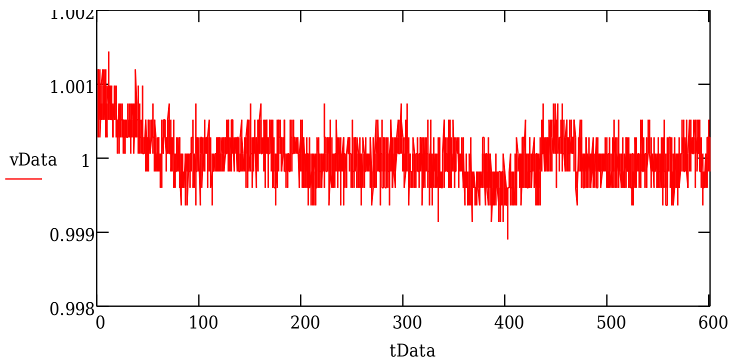


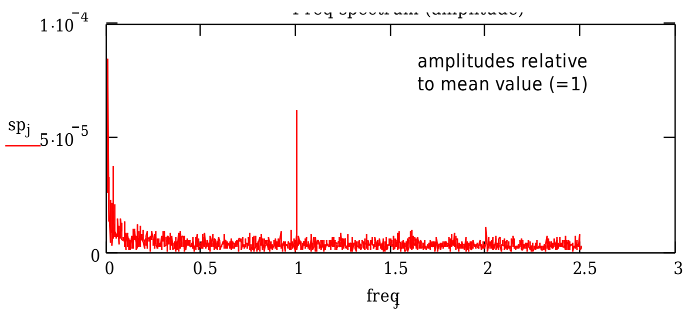
2.6.4 Band 3 (E2) 237 LO LSB

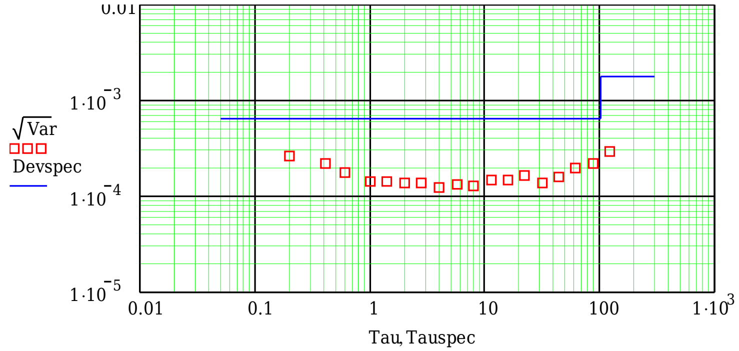
V polarization

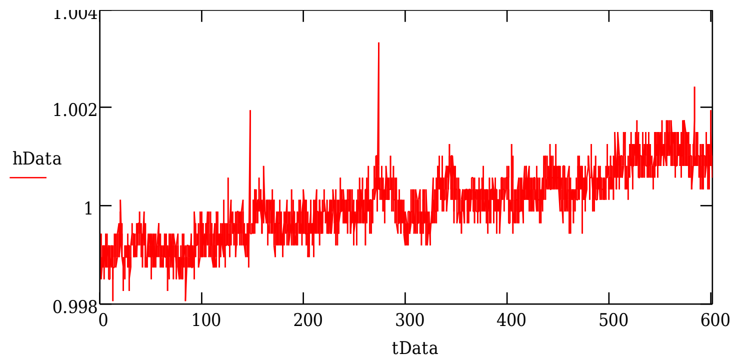
H polarization

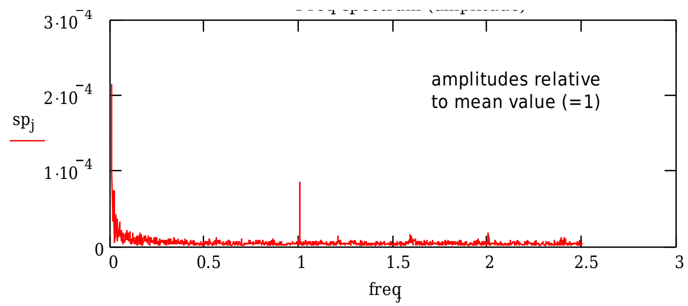








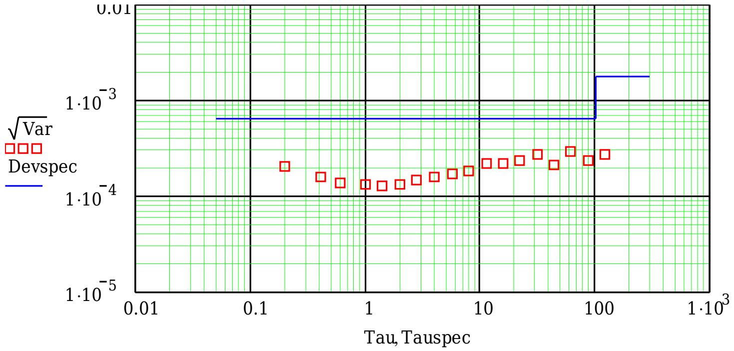


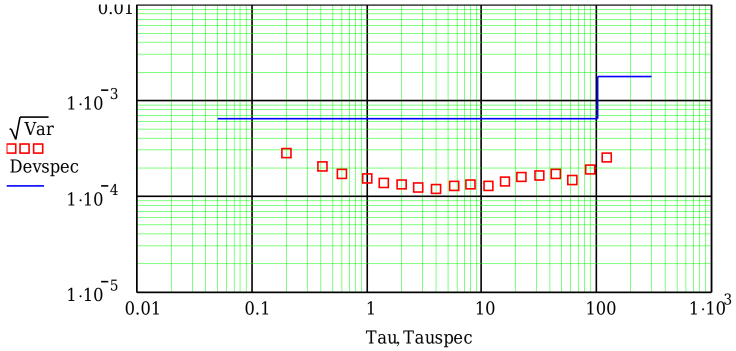


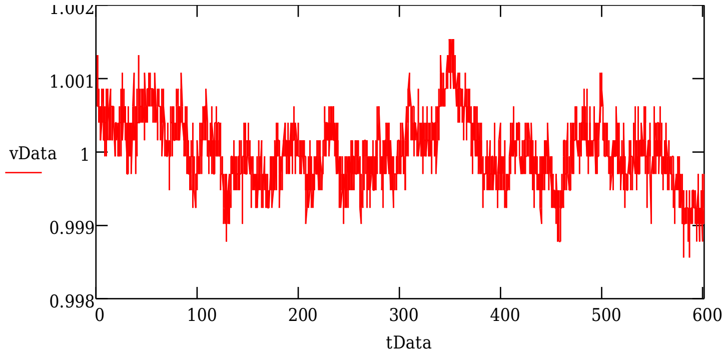
2.6.5 Band 4.(E3) 300 GHz LO USB.

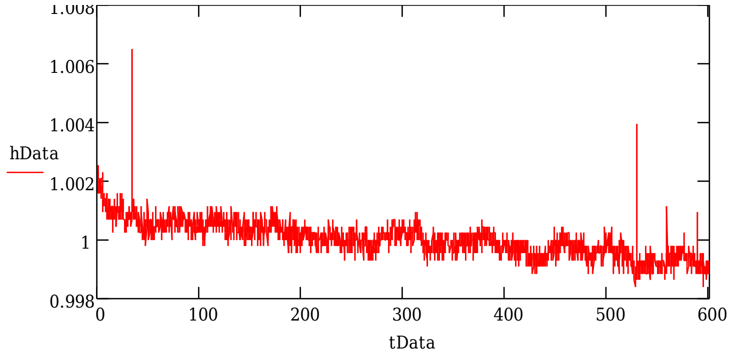
V polarization

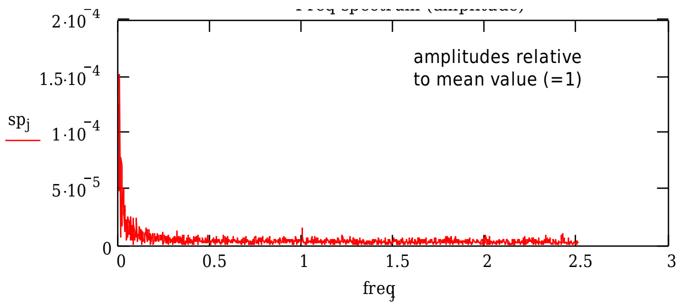
H polarization

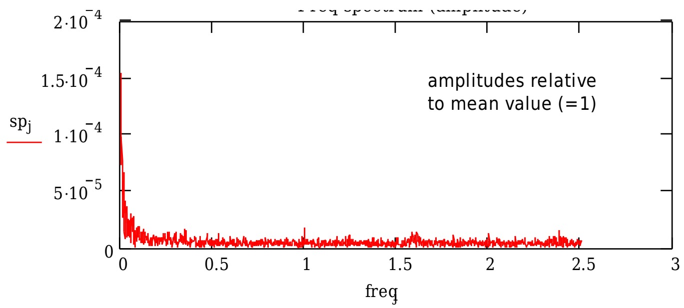








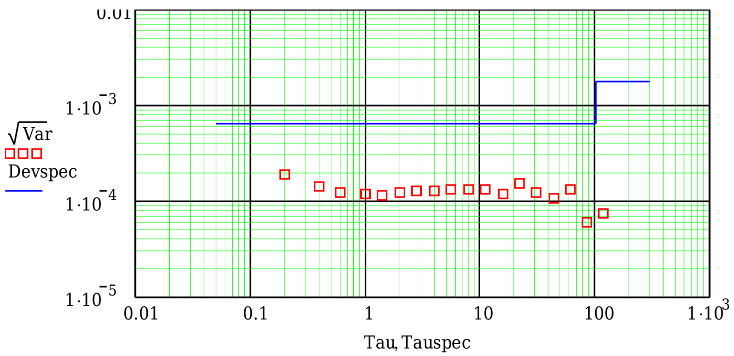




2.6.6 Band 4.(E3) 300 GHz LO LSB.

V polarization

H polarization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1·10^-3
1·10^-4
1·10^-5
√Var
Devspec
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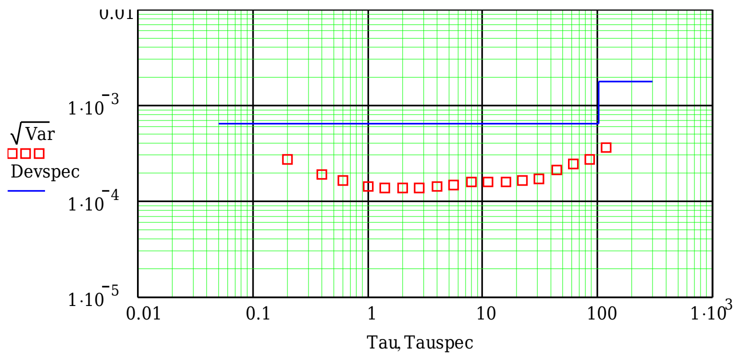
0.1
1
10
100
1·10^3
Tau, Tauspec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√Var
Devspec
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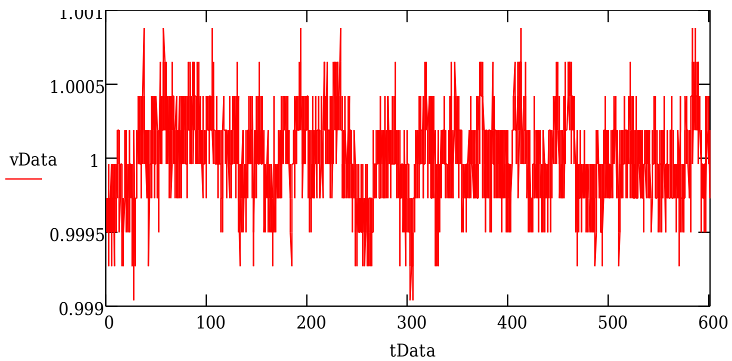
1
10
100
1·10^3
Tau, Tauspec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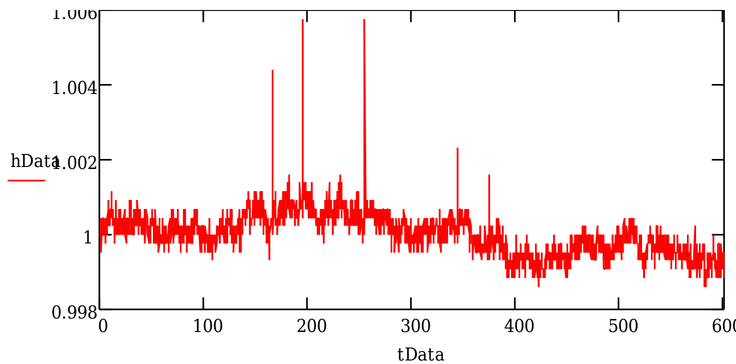
300
400
500
600
tData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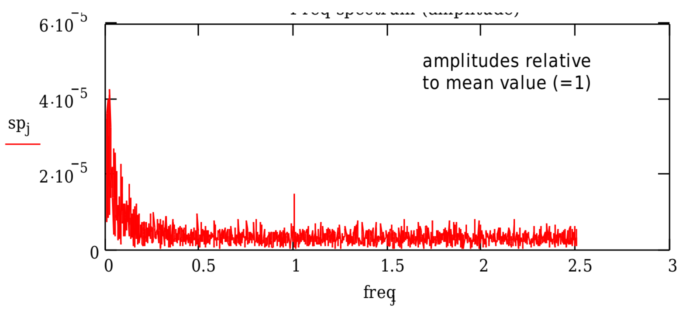
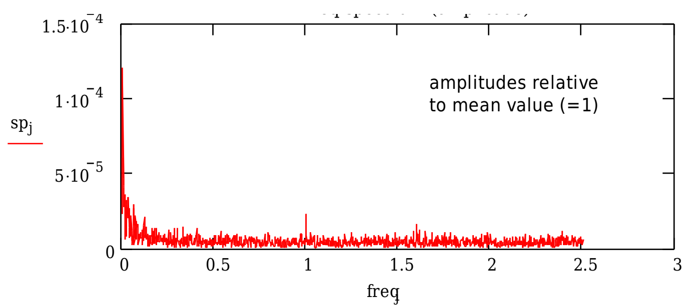
1.004
hData
1.002
1
0.998
0
100
200
300
400
500
600
tData


6·10^-5
4·10^-5
sp_j
2·10^-5
0
amplitudes relative
to mean value (=1)
0
0.5
1
1.5
2
2.5
3
freq_j


1.5·10^-4
1·10^-4
sp_j
5·10^-5
0
amplitudes relative
to mean value (=1)
0
0.5
1
1.5
2
2.5
3
freq_j

2.8 Linearity

The linearity of the system was measured by making a known change in the power level at the receiver input and tracing the changes at different parts on the IF chain. For the input power step a standard hot/cold load measurement was used. The overall gain was changed using the variable attenuators on the IF amplifier cards. The attenuation at 12 dBs is close to the standard and is taken as the reference for the rest of measurements. The values on the following tables represent the difference (in dB) of the measured Y factor at three different points in the IF chain: The receiver output, the IF amplifier/equalizer output and the continuum readout on the control desk. The power on the first two cases was measured with an HP power meter while for the third case the reading on the continuum level indicator was used.
The linearity at the receiver output is excellent and no sign of compression or noise limited performance can be seen. For the minimum attenuation range (3 dB) the gain on the IF amplifier shows already signs of compression but this is not a surprise in view of the extreme (+14 dBm) output power delivered in this range while the receiver is looking to an ambient load.

<u>Receiver output</u>

Attenuation	Δ(dB) IF 1	Δ(dB) IF 2	Δ(dB) IF 3	Δ(dB) IF 4
3			0.06	0.06
6	0.02	0.03	0.02	0.03
9	0.01	0.01	0.01	0.01
12	0.00	0.00	0.00	0.00
15	0.01	0.01	0.00	0.01

<u>IF amplifier/equalizer output</u>

Attenuation	Δ(dB) IF 1	Δ(dB) IF 2	Δ(dB) IF 3	Δ(dB) IF 4
3	-0.13	0.01	-	-
6	-0.05	0.01	-	-
9	0.00	0.01	-	-
12	0.00	0.00	-	-

<u>Continuum level meter on control desk</u>

Attenuation	Δ(dB) IF 1	Δ(dB) IF 2	Δ(dB) IF 3	Δ(dB) IF 4
3	-0.55	-0.53	-0.65	-0.70
6	-0.33	-0.37	-0.33	-0.47

9	-0.21	-0.30	-0.26	-0.36
12	0.00	0.00	0.00	0.00

2.9 Ripples on calibration loads

The (preliminary) results shown on Fig 11 seem to indicate a potential ~5% p-p calibration gain ripple for E0 arising from an ambient load mismatch. The ripple is much lower on the E2 band. The measurements were taken using the sky as reference but a good load at liquid nitrogen temperature would be preferable. More tests will be needed on different bands and with a better reference load.

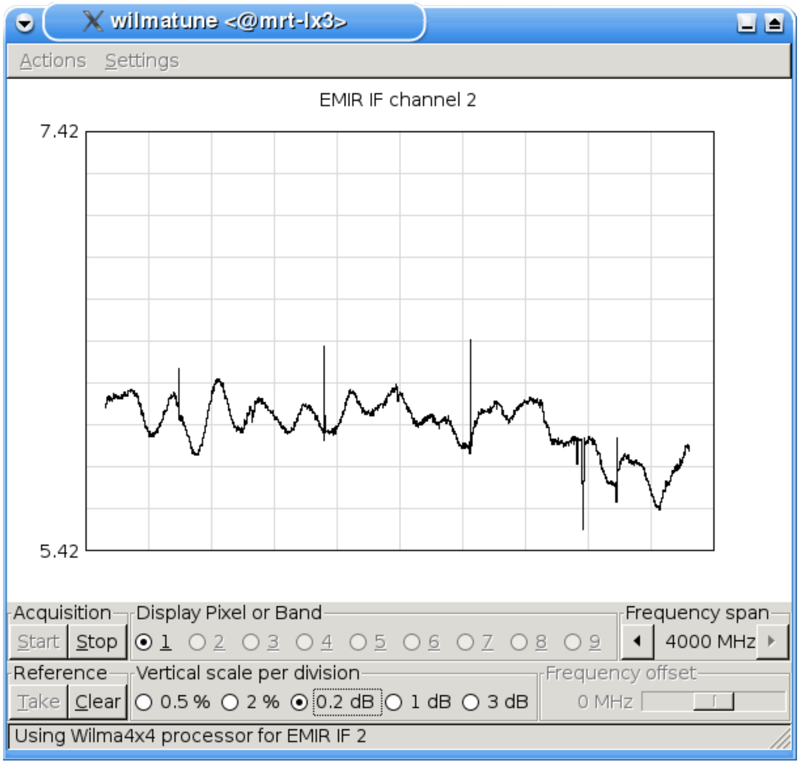


Figure 10. Ripple on ambient load for E0.

3. <u>Appendix. External optics parameters</u>

The three external mirrors (named M5 to M7 following the standard naming convention) are all flat. M5 is made in honeycomb material while the smaller M6 and M7 mirrors are machined from a solid aluminium block. Flatness of new

mirrors was measured after machining (surface accuracy < 15 um rms). The smaller mirrors have an adjustable mounting piece so the two perpendicular angles can be easily aligned; both are attached to the receiver cabin wall. Like in the old optical scheme, the bigger M5 mirror is removable so the mount includes a hinge mechanism activated by a pneumatic actuator.
The sizes and positions of the mirrors are:

- Distance M4 to M5: 860 mm
- Distance M5 to M6: 460 mm
- Distance M6 to M7: 850 mm
- Distance M7 to dichroics plane: 320 mm
- M5 size: 650 x 460 x 50 mm
- M6 size: 395 x 375 x 40 mm
- M7 size: 265 x 190 x 30 mm

The mirrors are designed for a 5 waist diameter at 3mm wavelength and include the 130 mm separation between the two receiver beams.

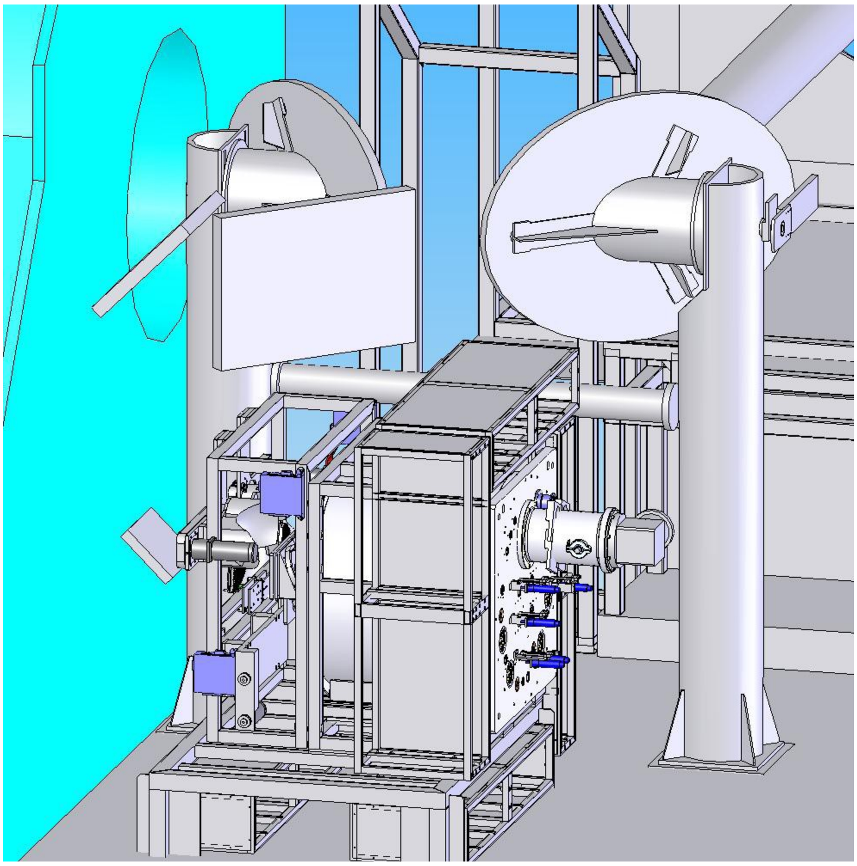


Figure 11. 3D drawing of EMIR in receiver cabin. The external mirrors are clearly visible.