Study of EMIR Band 2 (E1) optics in the 122-186GHz range

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1. Introduction

The EMIR band 2 optics and all it associated components (feed horns, optical modules, windows and filters, components of the calibration path…) were initially designed for the **129-174GHz** band (nominal band of E1 specified in 2009). The purpose of this document is to check the behavior of the EMIR band 2 optical components and of the whole optical system in the extended 122-186GHz band (operating frequency band of the SIS mixers), to check what can be the limitations (beam symmetry, cross-polarization, losses…) of the receiver performances due to the operation of optics outside it nominal design range.

2. Feed horns

2.1 Input reflection

In the 2mm band, the Vector Network Analyzer can operate in the 127-178GHz band. Different feed horns of the same model as the one used in EMIR band 2 were measured inside this band (see Figure 1) and seems to work satisfactorily. The horns behavior in the full 122-186GHz band can only be predicted with electromagnetic simulations (see Figure 2).

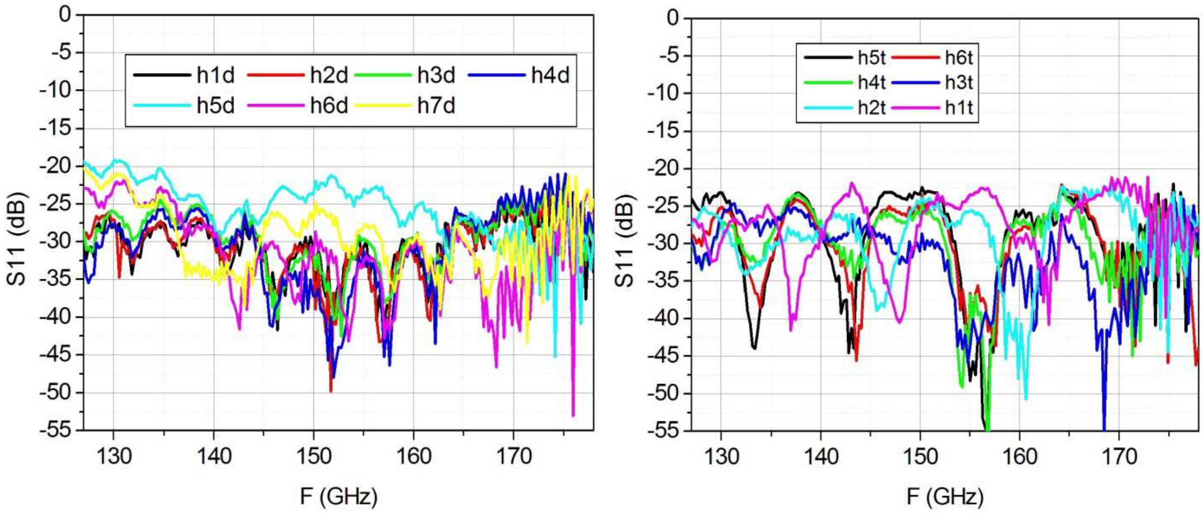

Figure 1: Feed horn measurements (left panel: straight horns; right panel: twisted horns) of PdBI band 2 / EMIR band 2 / NOEMA band 2 feed model inside the 127-178GHz band

Input reflection simulations show that the feed horns should work well down to 122GHz, but present increased reflection losses above ~ 181GHz.

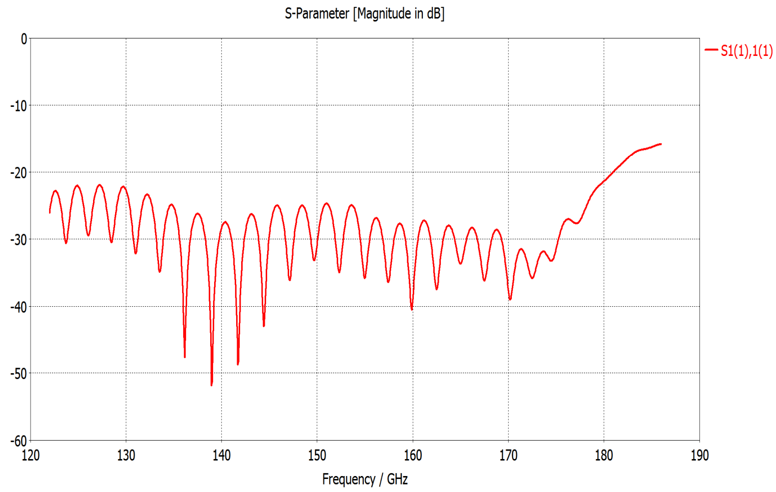

Figure 2: EMIR band 2 Straight horn simulated input reflection

2.2 Beam Symmetry

The symmetry of the beams and the side lobes levels were checked @ 122GHz, 127GHz, 150GHz, 178GHz, 183GHz and 186GHz. Figure 3 shows the 2D simulated far fields of the feed horn. The patterns are well circular at low frequencies down to 122GHz. At high frequencies the beam becomes elliptical (at the -18dB contour @ 178GHz; @ 186GHz, the beam is already elliptical at a -5dB level). Note that there is an inversion of the ellipticity of the beam (teta axis versus phi axis) between 178GHz and 183GHz.

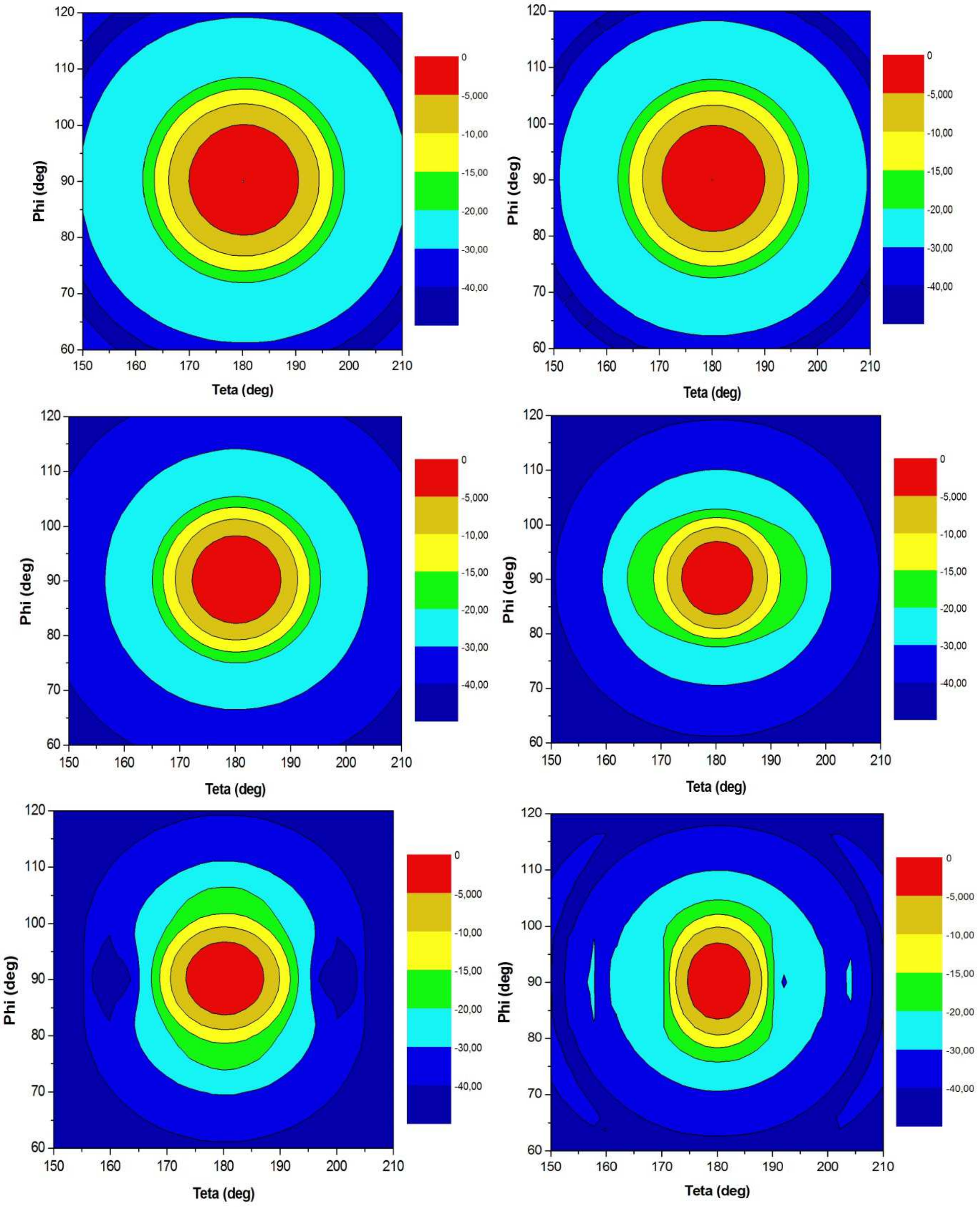

Figure 3: 2D feed horn far field power patterns. (top left: 122GHz, top right:127GHz, middle left: 150GHz, middle right: 178GHz, bottom left: 183GHz, bottom right: 186GHz)

2.3 Cross-polarization

The simulated cross-polarization levels are presented in the table below.

Frequency	Cross-polar level
122GHz	~ -33dB
127GHz	~ -36dB
150GHz	~ -52dB
179GHz	~ -26dB
183GHz	~ -21dB
186GHz	~ -20dB

For highest frequencies (183GHz, 186GHz) the simulated cross-polarization level become significant (as the measured cross-polarization level is always worse than the simulated value). It could induce an increasing of the receiver noise temperatures.

3. Optical Module

The optical module was simulated using the Integral Equation Solver of CST/ MWS.

Some 3D views of the simulated optical structures are shown on Figure 4.

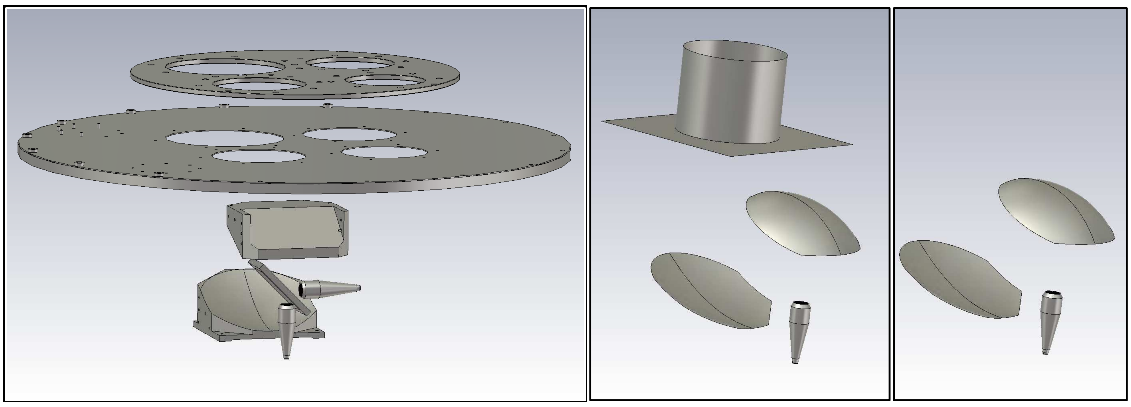

Figure 4: View of the imported and simulated structures.

Left panel: Structure imported from Solid works (only the bottom 15K cover and the top 300K cover are represented. The 77K cover was hidden). Note that the dielectric windows and filters were not imported as the insertion of dielectric materials in the IES of CST increases a lot the simulation time of the structure…

Central panel: to limit the size of the simulated structure, the cascade of the different cryostat covers was replaced by a metallic tube (of thickness equal to the distance between the bottom of the 15K cover and the top of the 300K cover) and the twisted polarization reflected by the grid was removed. Only the reflecting surfaces of the mirrors were kept for the simulation.

Right panel: To check the effects of windows and filters supports truncation at lowest frequencies, some simulations were also performed on the optical module only, without considering the cryostat environment

According to theoretical fundamental mode Gaussian optics calculations, as well as to the simulations presented in Figure 5, it seems that the beam truncation at 122GHz on the cryostat windows and filters edges is not significant.

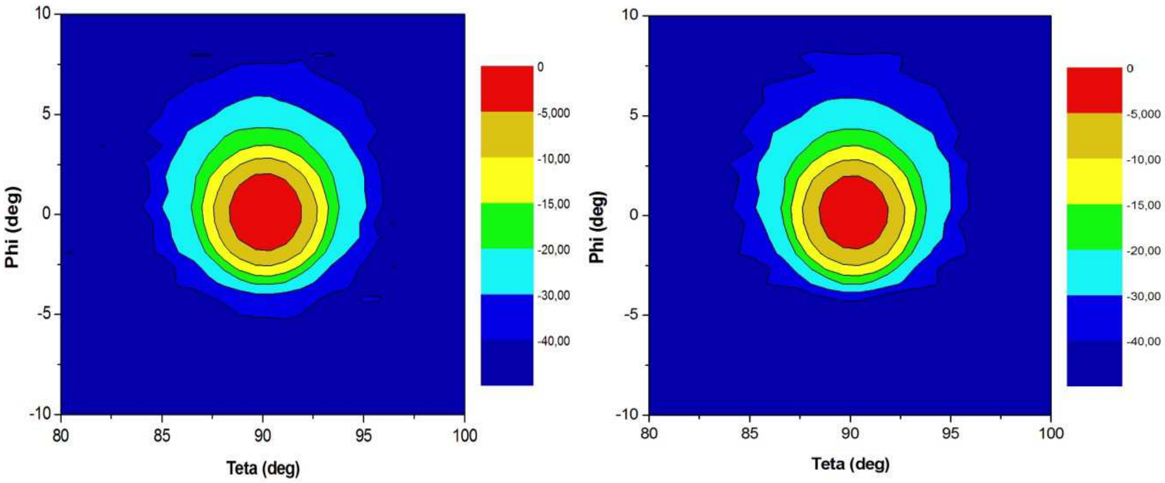

Figure 5: 2D far Fields Co-polar patterns at 122GHz considering the windows and filters truncation (left) and the optical module only (right)

Concerning the beam distortion, the ellipticity of the beams seen in the feed horn simulations at 183GHz and 186GHz seems to be less significant at the output of the optical module, for which the far field power contours seems to be almost circular at levels down to -20dB (see Figure 6)

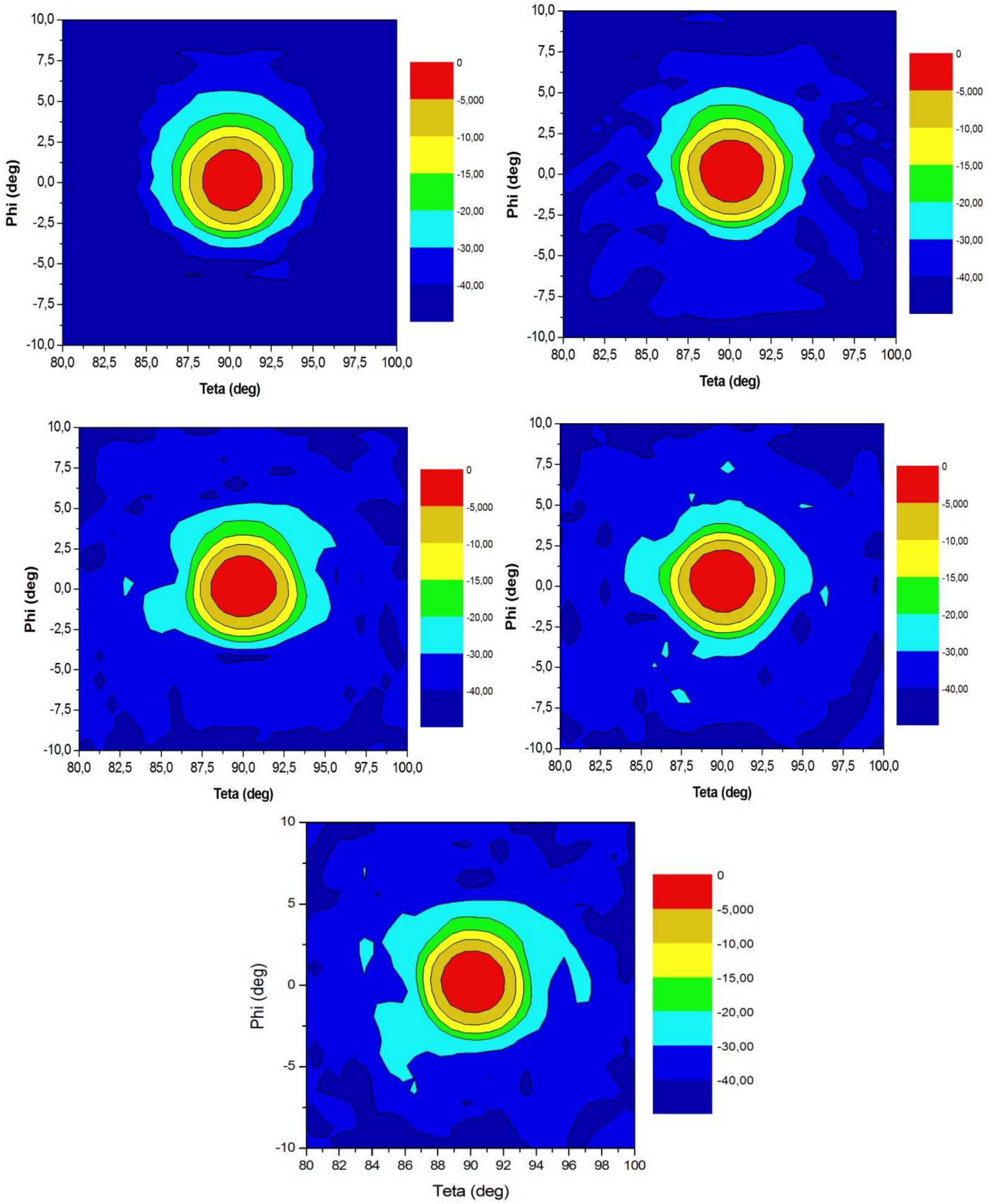

Figure 6: 2D optics far field power patterns (top left: 127GHz, top right:150GHz, middle left: 179GHz, middle right: 183GHz, bottom center: 186GHz)

4. Vacuum Windows and Infrared filters

Vacuum windows and infrared filters are pieces of dielectric (HDPE for the windows, PTFE for the IR filters) corrugated with triangular grooves cut in both faces, to limit the reflections on the dielectric surface by creating an intermediate layer with an artificial refraction index lower than the one of the dielectric.

The corrugations design is a compromise between their height and their pitch for a given corrugation angle (20 degrees of full angle for all the EMIR windows). The increasing of the corrugations height allows to improve the reflection coefficient of the windows and filters at the lower edge of the band. However, the corrugation pitch increases with the height (for a constant angle value), and above a certain limit, some unwanted transverse modes could appear in the windows/filters at the higher edge of the band. Figure 7 shows the simulated reflection and transmission of the corrugated HDPE window used in EMIR (red curves) and in future NOEMA receivers (green curves).

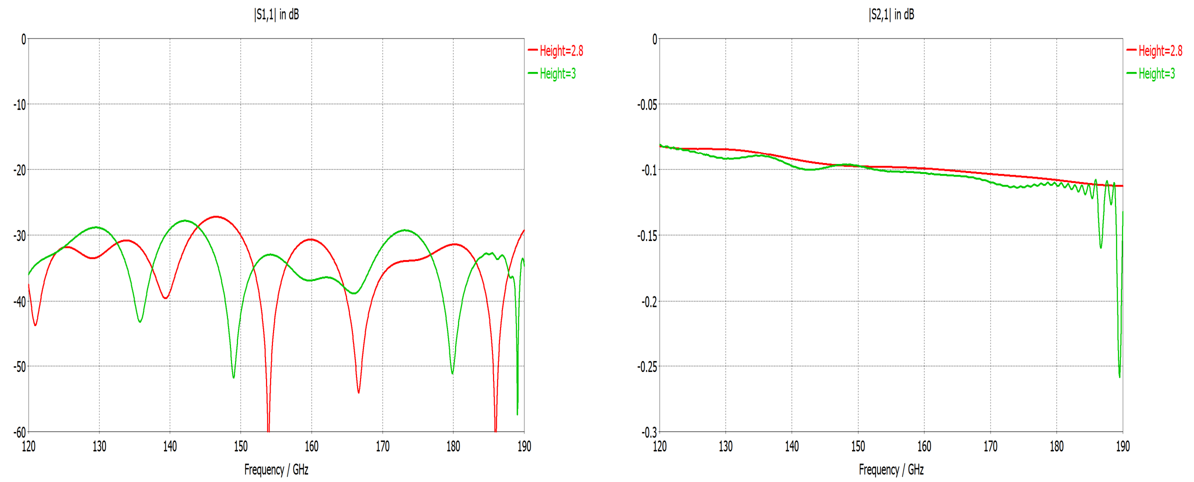

Figure 7: Reflection losses (left) and transmission losses (right) of the 2mm vacuum window developped for EMIR (in red) and NOEMA (in green) receivers

It seems that in EMIR the vacuum windows and infrared filters (both in signal path and in calibration path) can operate up to 186GHz without any disturbance from unwanted transverse spurious modes. However, note that it will not be the case for NOEMA receivers (in NOEMA design, we could see the appearance of absorption picks due to transverse modes near 186GHz…)

5. Dichroic filters

The two dichroic filters operating in band 2 were only tested in the 129-174GHz band. According to the measurements already done between 129GHz and 174GHz (see Figure 8) , we could expect that the 3mm/2mm dichroic, which reflects the 2mm band, will have increased losses at the lower and upper edges of the band. It polarization angle (shown in red on Figure 8) was chosen to minimize reflection losses at higher frequencies, so it losses at 122GHz will probably be greater than 5%. At 186GHz, the polarization angle of the dichroic would probably be at it optimum position, but even in this case, we could expect an increasing of it losses (the loss increasing is already visible between 165GHz, 168GHz, 171GHz and 174GHz even for the optimal dichroic polarization…)

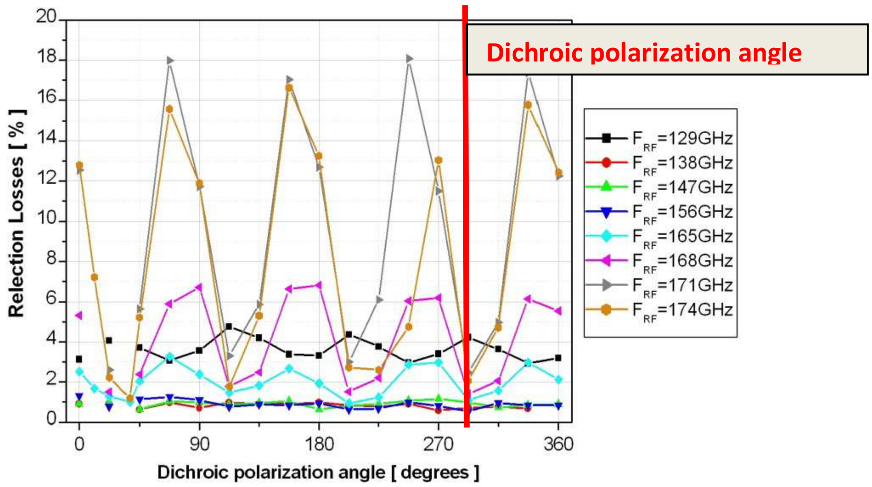

Figure 8: Reflection losses of the 3mm/2mm dichroic

Concerning the 2mm/0.8mm dichroic, which transmit the 2mm band, measurements made in the 129-174GHz show no dependence of losses versus the frequency and versus the dichroic polarization angle (see Figure 9). However, it is hard to predict it performances in the extended range without performing measurements…

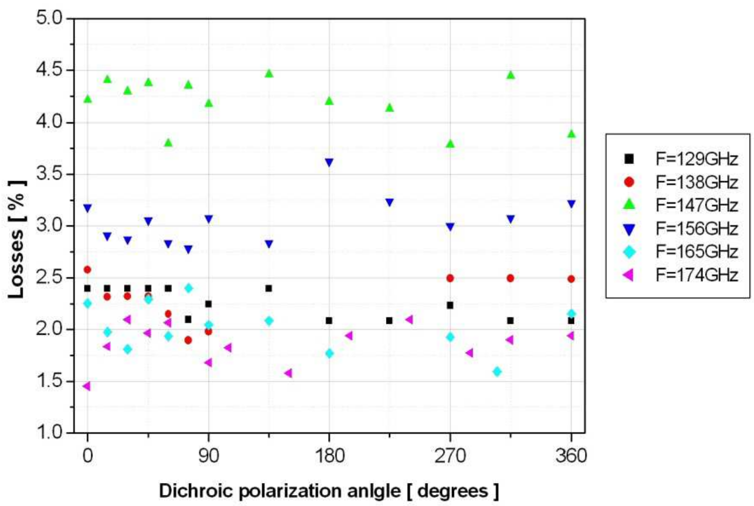

Figure 9: Transmission losses of the 2mm/0.8mm dichroic

6. Conclusion

- The non-optimized performances of the feeds (input reflection, cross-polarization level) above 180GHz probably increase the receiver noise temperature in the 180-186GHz band.
- The horns beams become elliptical near 180GHz. However, this ellipticity seems to be less significant at the output of the optical module
- At 122GHz, the truncation losses on optical components seems to be negligible.
- Windows and filters can operate in the extended band
- We expect that the 3mm/2mm dichroic losses increase at the upper and lower edges of the band.