A 54/118 GHZ DUAL-FREQUENCY FEED FOR EARTH OBSERVATION APPLICATIONS

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ABSTRACT

A dual 54/118 GHz channel capability has been studied in preparation of the EUMETSAT MetOp-SG microwave radiometers needs. EADS Astrium has been selected by ESA to carry out the Multi-Frequency Feeds for Earth Observation Applications Study. The main objective of this activity was to design and test a defocused dual-frequency horn, operating at frequencies 49-55 GHz and 109-128 GHz, to be combined with an offset reflector. To derive the required precipitation products from the measurements, both frequency bands (54 and 118 GHz) have to be optimised for a footprint overlap of at least 90% and for high beam efficiency (> 95%).
The Dual-Frequency Feed (DFF) includes a single dual-frequency horn and the diplexer for 54/118 GHz channels separation. IEEA, responsible for the horn design, has optimised a corrugated horn giving the required beam shapes at both 54 and 118 GHz. On the diplexer side, EADS Astrium has implemented an original design with waveguide integrated FSS (Frequency Selective Surface).
The design, manufacturing and test of the DFF prototype are presented in this document.
For final performance assessment, the antenna radiation patterns at reflector level are also derived with DFF measured performance as input.

1. INTRODUCTION

The channel 54 GHz is generally used to restore, amongst other things, the vertical profile of temperature of a column of atmosphere. So refining weather forecasting and improving our comprehension of the atmospheric phenomena, it appears very interesting to be directed towards the channel 118 GHz, which allows measurements with a higher degree of accuracy and more compact instruments.
The technical innovation is in the experimental development of a dual-frequency antenna 54/118 GHz which results from the combination of a radiating horn functioning in two very distant frequency bands (49-55 and 109-128 GHz) and of a low loss diplexer with good isolation which uses the FSS technology. This solution of filtering is classically used in free space for quasi-optics systems but not inserted in a waveguide as in this application.
The DFF principle is shown in Fig. 1.

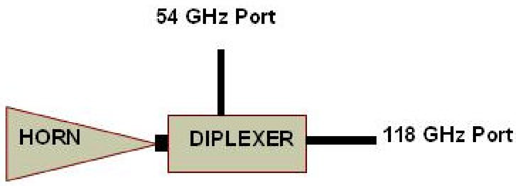


Figure 1. Dual-Frequency Feed (DFF) principle

The design, manufacturing and test activities performed on the DFF assembly are presented. For final performance assessment, the antenna radiation patterns at reflector level are derived using the measured data's at feed level.

2. THE 54/118 GHz HORN

The choice of the type of horn was very quickly directed towards a corrugated horn thanks precisely to its multi-frequency and broad band properties. The internal profile was optimized by IEEA in order to obtain for the two frequency bands a reflexion coefficient lower than -28 dB as well as radiation patterns matched to the requirements of the antenna secondary performance i.e. including the reflectors. In particular, one of the essential requirements was to achieve a footprint overlap of the traces at -3dB better than 90% for the two centre frequencies 52.5 and 118.75 GHz.

The horn design is based on a single depth corrugation profile. More details on the horn design can be found in [1]. The return loss and cross-polarisation performance are shown in Fig.2. The dual-frequency band behaviour of the horn appears clearly. Fig.3 provides the radiation patterns at 52.5 and 118.75 GHz.

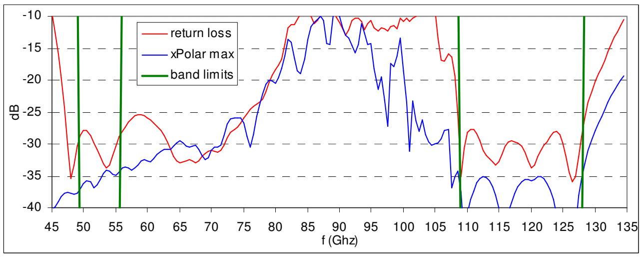


Figure 2. Return loss and cross-polarisation of the horn computed from 45 GHz to 135 GHz

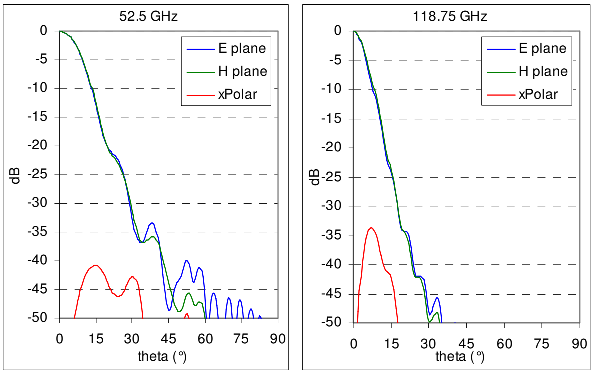


Figure 3. Far field radiation patterns of the horn at centre frequencies

3. THE DIPLEXER

The diplexer shall separate the input frequencies from the horn into two bands at two different ports with minimum losses: one around 54 GHz (band 1) and one around 118 GHz (band 2).

A new diplexer concept

Commonly, diplexer design uses a combination of filters or cavities in waveguides. To take advantage from the low loss capabilities of FSS usually used in quasi-optics front-ends, an innovative diplexer design using FFS inserted within waveguide has been developed.
To minimize insertion loss, the high frequency port is longitudinal and the low frequency port is orthogonal to the horn axis as shown in Fig. 4. The frequency filtering is performed by FSS at low frequency band and by the waveguide natural filtering at high frequency band. The FSS are fused silicate substrates with photo-etched golden rings.
To design the diplexer, individual channel filters are first optimized separately, secondly combined using T-junction and then tapers and transitions are synthesized to fit the standard waveguide access.
The diplexer is analysed and optimized employing the electromagnetic software package µWave Wizard. This design tool using the well-known Mode-Matching technique is particularly suitable for the simulation and optimization of the diplexer by offering fast processing speed and high accuracy. The higher modes generated at high frequency in the T-junction region are naturally taken into account in the analysis and the very fast computation allows optimisation with all propagating modes.

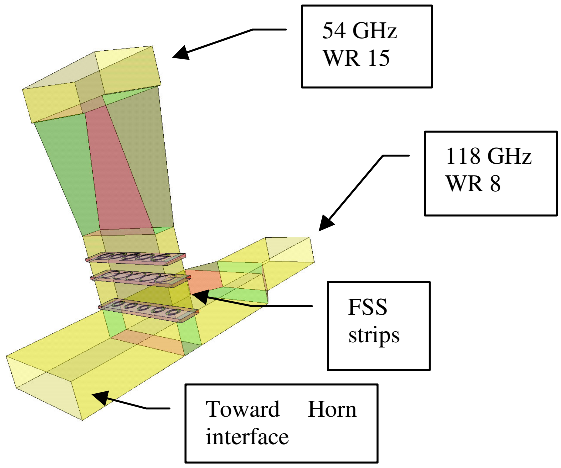


Figure 4. Diplexer junction

4. FULL DFF SIMULATION

The interaction between the horn and the diplexer has been checked. The horn and the diplexer with its transition have been implemented in a single model using µWave Wizard.
The S11 at low frequency degrades rapidly because of the proximity of the cutoff frequency of the common WG of the diplexer (42.83 GHz). A compromise between the S11 value at the lower edge of band 1 (49.75 GHz) and the S11 lobes level inside the band 1 has been carried out. This optimisation has been performed by playing with the rings dimensions of the FSS strips, the distances between FSS strips and the lengths of waveguide sections and tapers within the diplexer.
The Fig. 6 & Fig.7 are showing the DFF performance of the nominal design (Fig. 5).

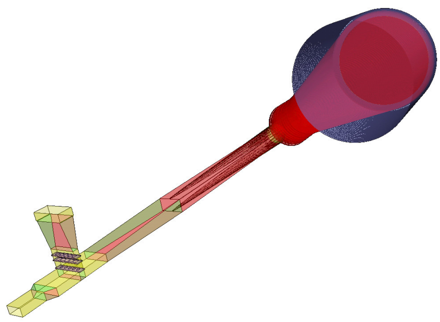


Figure 5. Full DFF model in µWave Wizard

The radiation patterns of the full DFF have been compared with the ones of the horn alone and there are no significant differences. The behaviour of the horn is not changed when connected to the diplexer.

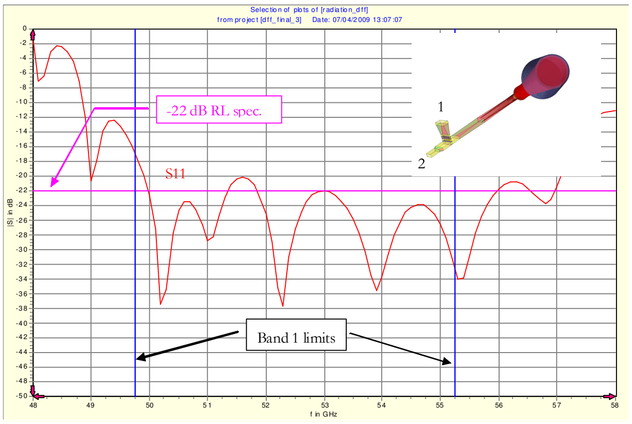


Figure 6. DFF S-parameters 49.75 – 55.25 GHz

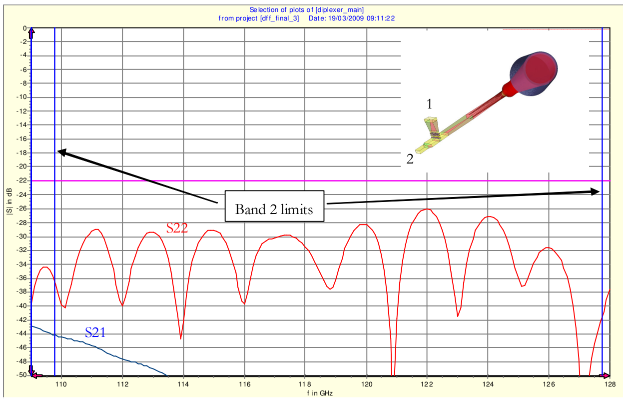


Figure 7. DFF S-parameters 109.75 – 127.75 GHz

5. THE DFF PROTOTYPE

The horn is made out of aluminium alloy by traditional machining. The parts of the diplexer are golded aluminium. The FSS strips material is fused silicate with metallic rings photo-etched on the strips.

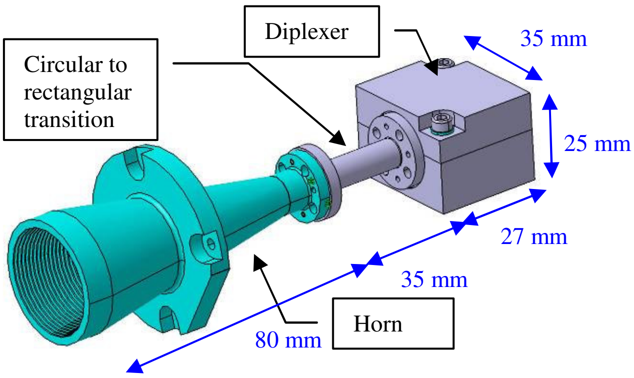


Figure 8. DFF Engineering Model

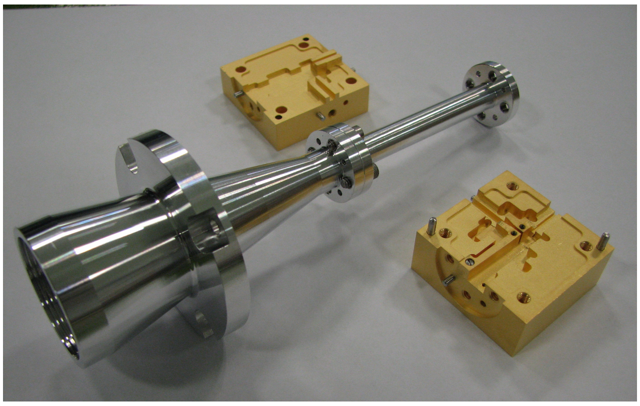


Figure 9. Picture of the horn with the transition and the two half-blocks of the diplexer

6. MEASUREMENT RESULTS

Once the horn and diplexer have been tested individually, the DFF EM has been assembled and tested. Radiation patterns, return loss and isolation have been measured at the DFF standard ports (WR15 & WR8).

The plots shown in the Fig.10 & Fig.11 combine the measured and simulated radiation patterns for the main and cross polarisation in the 0°,45°,90° and 135° planes.

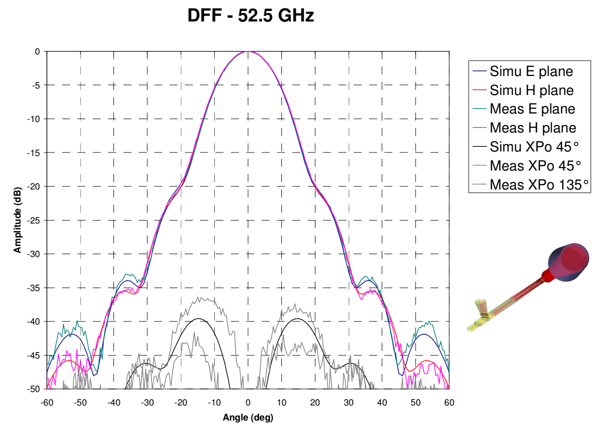


Figure 10. DFF pattern measured/simulated – 52.5 GHz

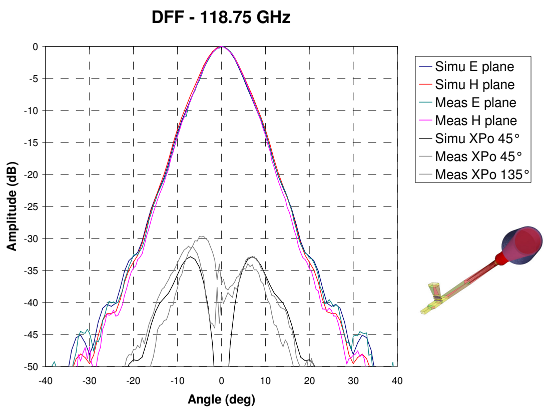


Figure 11. DFF pattern measured/simulated – 118.75 GHz

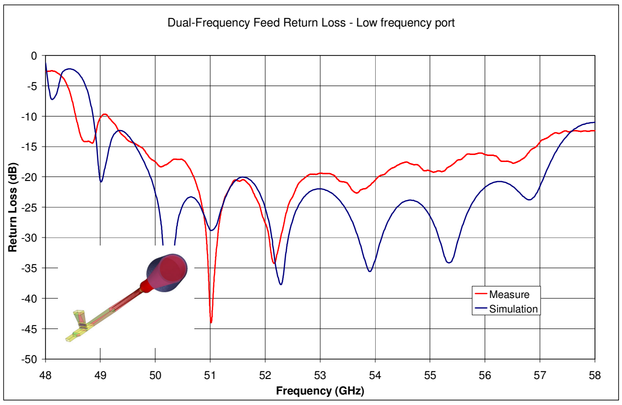


Figure 12. DFF return loss measured/simulated – LF band

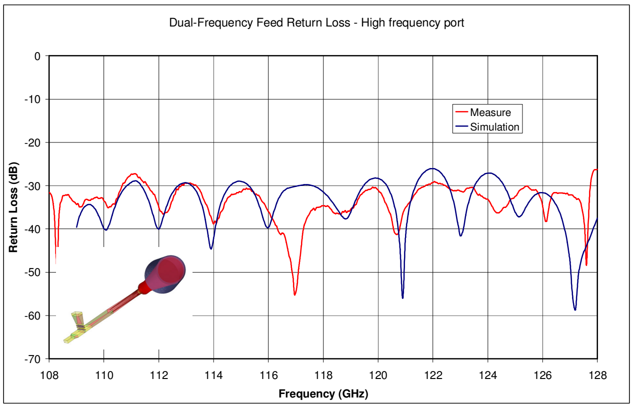


Figure 13. DFF return loss measured/simulated – HF band

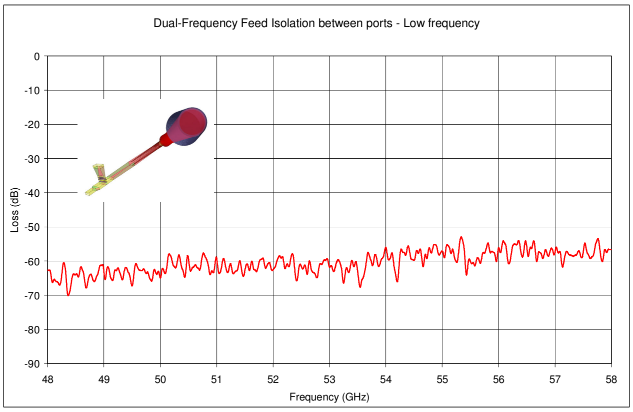


Figure 14. DFF isolation measured/simulated – LF band

The test results are very close to the simulations for the return loss and isolation. The insertion loss of the diplexer alone (Fig. 16 & Fig.17) is a little bit higher than predicted but not very far. The numerous mechanical interfaces, the mounting accuracy and the surface roughness can explain these differences.

The measurement accuracy in HF is not as good as in LF. There is some ripple which is "classical" for such measurements with the MVNA from ABmm.

The diplexer performance presented in this section is sensitive to the strength put on the four mounting screws. The RF discontinuities between the numerous pieces of the diplexer contribute to the difference observed between simulations and measurements.

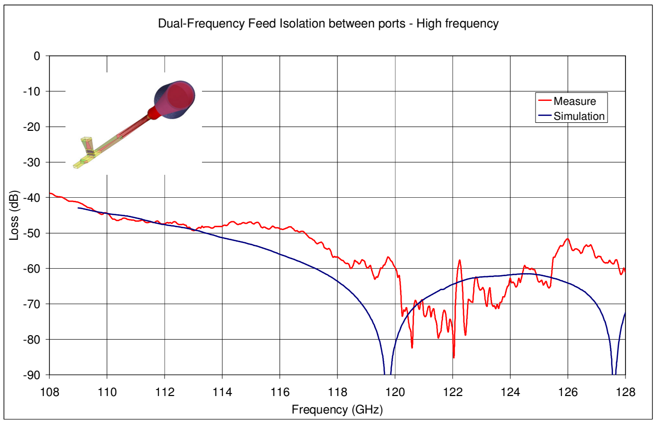


Figure 15. DFF isolation measured/simulated – HF band

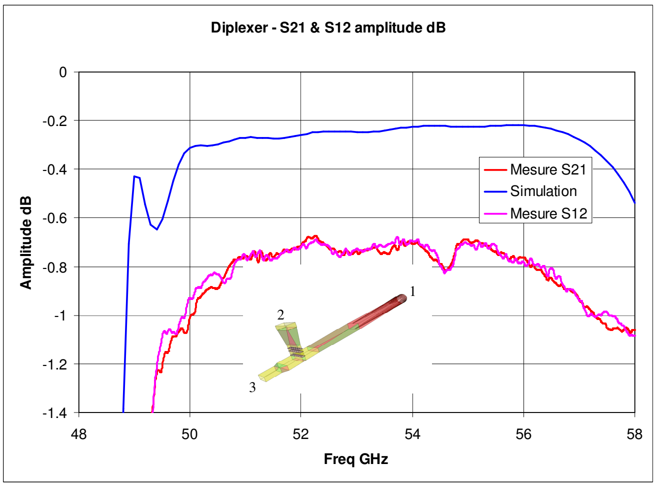


Figure 16. Diplexer insertion loss measured/simulated – LF band

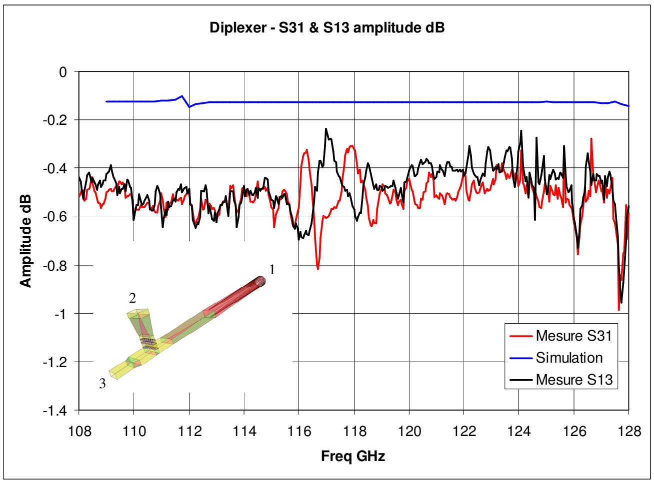
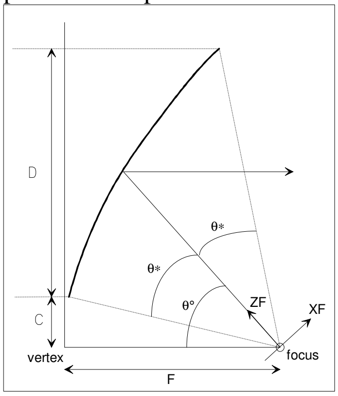


Figure 17. Diplexer insertion loss measured/simulated – HF band

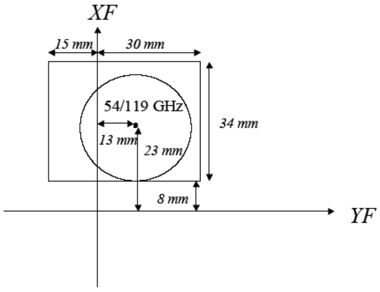
7. ANTENNA LEVEL PERFORMANCE

The antenna level radiation patterns were computed with GRASP using DFF level measured radiation patterns as input.



Offset parabolic reflector

Projected diameter 1200mm
Focal length 1100mm
Clearance 400mm
Offset angle 46.3°
Half angle of view 25.7°



Feed location within focal plane
Figure 18. Antenna geometry

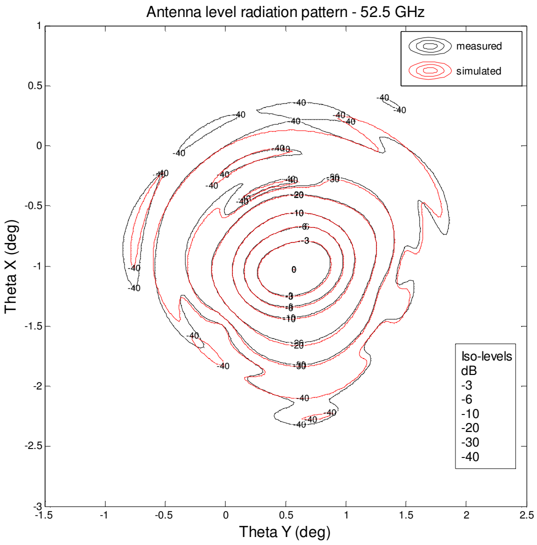


Figure 19. Antenna contour plot – 52.5 GHz – measured/simulated

Fig. 19 & Fig. 20 are showing the "measured" and simulated contour plots at antenna level; "measured" means simulated (GRASP) with measured feed radiation pattern as input. Fig. 21 shows the 52.5 & 118.75 GHz patterns superimposed. This plot demonstrates the overlap performance i.e. the ability of the feed to provide identical and collocated footprints at both frequencies. A detail of the overlap performance which is defined at -3dB level contour is shown in Fig. 22. The achieved result is 84.4 % for a 90 % requirement.

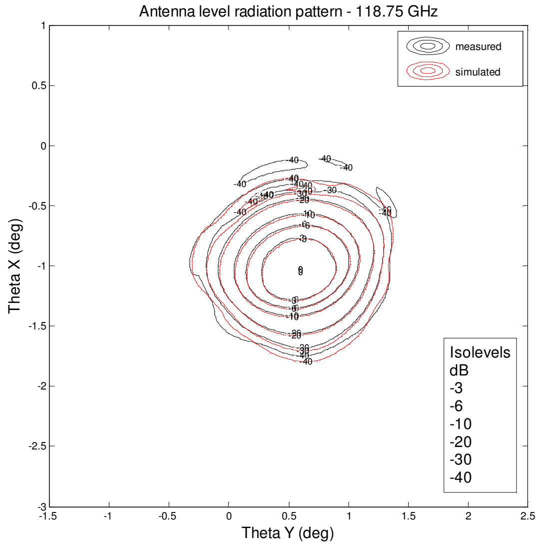


Figure 20. Antenna contour plot – 118.75 GHz – measured/simulated

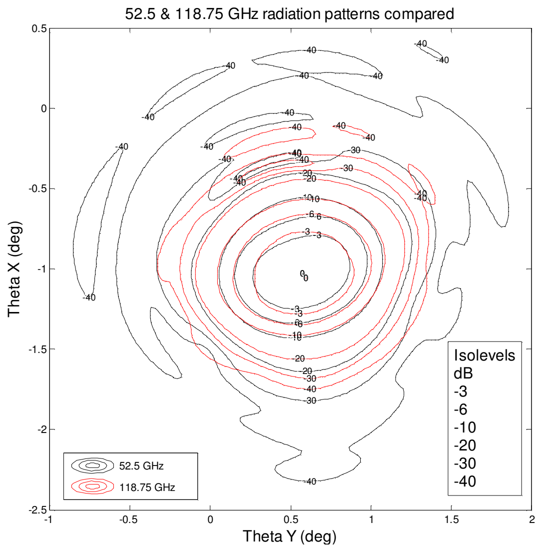


Figure 21. Antenna level contour plot – 52.5 & 118.75 GHz superimposed

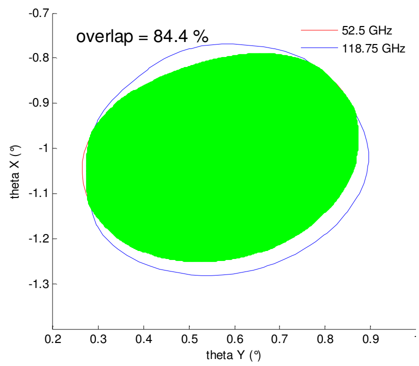


Figure 22. Overlap performance - 52.5 & 118.75 GHz - 3dB contour patterns

Channel	**52.5 GHz**					**118.75 GHz**					**SPEC**	**Compliance status**
Frequency GHz	50	51	**52,5**	54	55	110,25	114,55	**118,75**	122,95	127,25		
FHPBW deg												
min	0.44	0.44	**0.43**	0.43	0.43	0.46	0.53	**0.51**	0.47	0.43	< 0,58°	**C marginal at 114.55 GHz**
mean	0.51	0.51	**0.51**	0.52	0.52	0.54	0.59	**0.56**	0.55	0.50		
max	0.59	0.60	**0.61**	0.62	0.64	0.64	0.67	**0.61**	0.64	0.57		
FHPBW circular shape %	15.1	15.3	**17.6**	18.6	19.8	16.2	11.6	**9.1**	15.4	14.7	< 20%	**C**
FHPBW overlap %	**84.4**										> 90 %	**marginal**
Beam efficiency % computed	97.12	97.43	**97.60**	97.82	97.97	99.71	99.86	**99.78**	99.80	99.56	> 95 %	**C**
Polarisation purity computed %	0.11	0.13	**0.22**	0.20	0.22	0.14	0.31	**0.38**	0.39	0.34		
computed dB	-29.6	-28.9	**-26.6**	-27.0	-26.6	-28.5	-25.1	**-24.2**	-24.1	-24.7	< -25 dB	**C marginal at 118.75, 122.95, 127.25 GHz**
Spill-over %	1.30	1.11	**1.04**	0.96	0.93	0.11	0.09	**0.12**	0.06	0.08		

Figure 23. Dual-Frequency Feed Antenna level performance summary

Figure 23 provide the computed antenna performance: beam efficiency, FHPBW, footprint overlap, cross-polarisation and spillover on main reflector. The remaining slight non conformances are marginal.

8. CONCLUSION

A 54/118 GHz dual-frequency feed has been developed in Astrium within the framework of a R&T ESA study intended for passive radiometry application.

On horn side, a single-depth corrugated horn has been designed manufactured and tested. The required performance at antenna level is achieved in frequency bands 50-55 GHz & 110-128 GHz.

On diplexer side, the innovative concept includes three FSS strips within waveguide for filtering purpose. The full equipment, including the horn and the diplexer, has been simulated with µWave Wisard then manufactured and tested. The performance results, S-parameters and radiation patterns are suitable to the usage in a microwave radiometer for future Space application.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

1. JP. Adam, Y. Beniguel, A. Berthon, L. Costes, M. van der Vorst, “52/119 GHz Corrugated Horn Design for Earth Observation Applications”, proceedings of EuCAP 2009.