Main Design Parameters and Imaging/Radiometric Performances of the METOP Second Generation Conically Scanning Radiometers

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Abstract—**In the context of MetOp Second Generation (MetOp-SG) phase A/B1 study, Thales Alenia Space is responsible of Microwave Imager (MWI) and Ice Cloud Imager (ICI) instruments. MWI and ICI are conically scanning microwave radiometers, together covering frequency range from 18.7 GHz up to 664 GHz. The on-going study covers all elements of the space segment and instrument architecture and deals with the analysis of the space system requirements and the definition of candidate implementation concepts in order to satisfy the user's needs and requirements. MWI and ICI will fly on a spacecraft in a near circular sun-synchronous, near polar orbit. In order to acquire measurements on a wide swath the instrument will rotates continuously about an axis parallel to the local spacecraft vertical with an active portion of the scan of ~±65 deg centred on the foreword direction of the spacecraft. The Earth scene view is a nearly constant incidence angle of about 53 deg. Challenging Imaging and radiometric requirements are applicable to MWI and ICI instruments and a trade-off has been performed in order to identify and size main system parameters.**

In the paper a description of the trade-off that was performed will be presented and the results achieved will be described.

Index Terms— Remote sensing, Microwave Radiometer, Microwave Imager

I. INTRODUCTION

Challenging imaging and radiometric requirements are required for MWI (Microwave Imager) and ICI (Ice Cloud Imager) instruments and, in the context of the MetOp-SG Phase A/B1 study, a trade-off has been performed in order to identify and size main system parameters, namely:

- Scan rate
- Integration time of each channel
- Sensitivity performances
- Calibration timeline
- Image Quality

The scan rate will determine the Along-Track overlap and the maximum available integration time. This trade-off will be then driven by the requirements on Along-Track overlap and on sensitivity performances (NEΔT).

Within the instrument sizing activities, image quality aspects related to the mitigation of aliasing errors had to be taken in consideration. An image quality model was developed for this purpose and will be used to analyze the effects of aliasing and blurring effects by mean of an Aliasing Index (AI), which represents the percentage of antenna temperature rms which appears as aliasing error in case of image interpolation processing is done on-ground. This error mainly arises in dependence of the spatial sampling adopted in the original image.

The AI and the radiometric performances were compared to find the best compromise that allows to achieve optimum design and compliance to the requirements.

II. MISSION REQUIREMENTS

The METOP SG mission poses tight requirements to the MWI and ICI radiometers in terms of:

- Number of channels
- Sensitivity requirements
- Footprint size
- Radiometric accuracy
- Inter-pixel accuracy
- Inter-channel accuracy
- Orbital stability

The MWI covers frequency range from 18,7 GHz to 183 GHz with 28 channels in total. Channels up to 100 GHz are measured in V and H polarisation and channels above 100 GHz in V polarisation only. The ICI covers frequency range from 183 GHz to 664 Ghz with 13 channels in total. 243 GHz and 664 GHz channels are measured in V and H polarisation and other channels in V polarisation only. The details of the MWI and ICI instrument requirements are provided in Table I and II.

In addition to radiometric requirements, there are also image quality requirements. As a minimum requirement, all channels must provide at least contiguous footprints between consecutive scan lines. As a goal requirement, 30% overlap between two consecutive scan lines is preferable

TABLE I. MWI BASELINE CHANNELS & REQUIREMENTS

Channel	Centre Frequency [GHz]	BW [MHz]	NeDT [K]		FP [km]	Polarisation
			G	R	(lessthan)	
MWI-5	18,7	200	0.5	0.6	50	V, H
MWI-6	23,8	400	0.45	0.6	50	V, H
MWI-7	31,4	200	0.5	0.6	30	V, H
MWI-8	50,3	400	0.5	1	30	V, H
MWI-9	52,6	400	0.5	1	30	V, H
MWI-10	53,2	400	0.5	1	30	V, H
MWI-11	53,8	400	0.5	1	30	V, H
MWI-12	89	4000	0.8	1	10	V, H
MWI-13	100,49	4000	0,8	1	10	V, H
MWI-14	118.7503±4.0	2x1000	0,7	1,2	10	V
MWI-15	118.7503±2.1	2x400	0,7	1,2	10	V
MWI-16	118.7503±1.4	2x400	0,7	1,2	10	V
MWI-17	118.7503±1.2	2x400	0,7	1,2	10	V
MWI-18	166,9	1425	0.7	1	10	V
MWI-19	183.31±8.4	2x3000	0.6	0.8	10	V
MWI-20	183.31±6.1	2x1500	0.75	1	10	V
MWI-21	183.31±4.9	2x1500	0.75	1	10	V
MWI-22	183.31±3.4	2x1500	0.75	1	10	V
MWI-23	183.31±2.0	2x1500	1	1.2	10	V

TABLE II. ICI CHANNELS & REQUIREMENTS

Channel	Frequency [GHz]	BW [MHz]	NeDT [K]		FP [km]	Polarisation	
			G	R	(lessthan)	G	R
MWI-19	183.31±8.4	2x3000	0,4	0,5	15	45	V
MWI-22	183.31±3,4	2x1500	0,5	0,6	15	45	V
MWI-23	183.31±2.0	2x1500	0,6	0,7	15	45	V
MWI-24	243,2±2.5	2x3000	0,5	0,6	15	45	V,H
MWI-25	325,15±9,5	2x3000	0,7	0,8	15	45	V
MWI-26	325,15±3,5	2x2400	0,8	1	15	45	V
MWI-27	325,15±1,5	2x1600	1	1,1	15	45	V
MWI-29	448±7,2	2x3000	1	1,2	15	45	V
MWI-30	448±3,0	2x2000	1	1,4	15	45	V
MWI-31	448±1,4	2x1200	1,3	1,9	15	45	V
MWI-32	664±4,2	2x5000	1	1,5	15	45	V,H

III. SCAN RATE VS INTEGRATION TIME

The most critical channels, that have influence on the trade-off between scan rate and integration time, are the ones that have least margins in terms of sensitivity (NEΔT) and the ones that have the smallest effective footprint.

In order to identify the most critical channels in terms of sensitivity, we used the noise figures estimated for the complete receiver chain (from the antenna to the output of the receivers). This represents the worst case for what concerns Noise Figures.

Then sensitivity was computed for all channels, starting from faster scan rates to the slower ones, until all the channels were at least compliant to the mandatory sensitivity requirement. The channel that was indetified as being the last one in achieving compliance is the most critical channel and is therefore also the channel that determines the maximum scan rate that the instrument can have. Afterwards we analyzed the slowest possible scan rate, where all channel achieve goal NEΔT requirements.

Between these two mentioned limits a trade-off between sensitivity and image quality expressed as an Aliasing Index was done. Aliasing Index represents the percentage of antenna temperature rms which appears as aliasing error on resampled images. This AI depends on the spatial sampling of radiometer footprints.

In the trade-off, aliasing and sensitivity plots were compared to find the “best” compromise as suggested in [2]. A specific tool was developed to implement that approach.

The upper limit for the scan rate is in principle achievable by the scan mechanism, with the drawback of an increase on number of revolutions over the instrument lifetime, which increases risks. To reduce the risks on the scan mechanism, the slowest scan rate should be selected. On the other hand, this will ensure only marginal compliance to the footprint overlap requirement, for that reason a 10% of margin is added for the choice of the scan rate.

To improve sensitivity performance, one can average more than one Hot and/or Cold calibration samples over more than one calibration cycle. To identify the channel that requires most effort to achieve the mandatory sensitivity requirement and the one that requires most effort to achieve goal sensitivity requirement, we started investigation considering only one Hot and one Cold calibration samples over only one calibration cycle. Then we have increased progressively the number of calibration samples and of averaged calibration cycles in order to establish the best compromise between sensitivity improvement and number of averaged samples. An upper limit for the averaging is set by the stability of the radionmeter.

The results will depend on the number of calibration samples and calibration cycles that are averaged to assess the contribution of calibration to the sensitivity. The final numbers of averaged calibration samples will depend on many parameters like accuracy performance, thermal design and mechanical design aspects that is not possible to establish at this stage of the study.

IV. SYSTEM PARAMETERS DEFINITION

The definition of the scan rate and of the integration time was made analysing the most critical channels in a parametric way considering normalized Along-Track (AT) and Cross-Track (XT) sampling coefficient.

For the Along track coefficient the value AT=1 corresponds to adjacent footprints in consecutive scan lines and AT=0.7 corresponds to 30% of footprint overlap between consecutive scan lines. For the Cross Track coefficient the value XT=1 corresponds to an integration time that coincides with the dwell time (0% oversampling) while XT=0.5 corresponds to an oversampling of 50% with respect to the dwell time; this two values are considered as upper and lower limits for the integration time.

The analysis was performed by identifying on the Aliasing Index plot (see Fig. 1 and Fig 2) the image sampling range which allows compliance to mandatory and/or goal sensitivity requirements [1] (see Fig. 3 and Fig 4). This full compliance domain is depicted in Fig. 5 (the AT and XT axis limits are extended to 1.5 to ease the explanation). The domain not guaranteeing compliance to sensitivity and AT overlap requirements is depicted with a blue background.

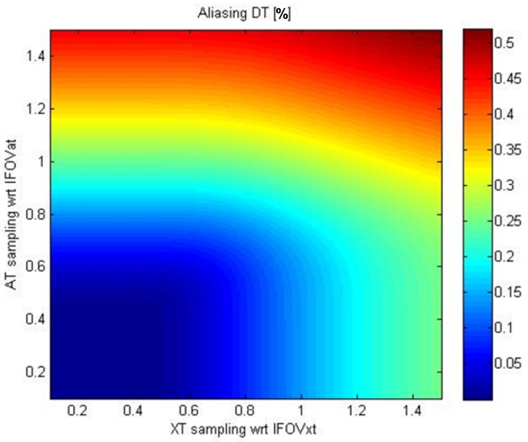

Figure 1. Total Percentage Aliasing Effect, including blurring effect.

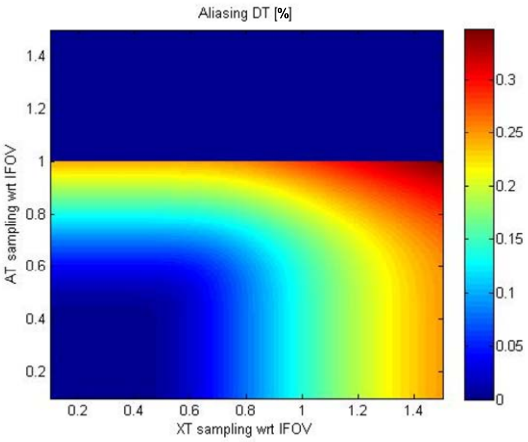

Figure 2. Aliasing effect limited for values of AT less than or equal to 1.

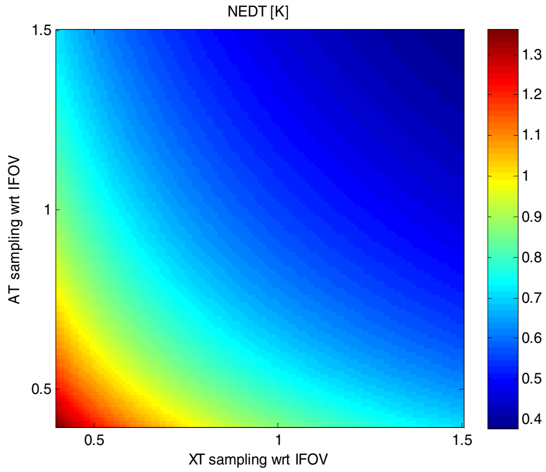

Figure 3. Sensitivity Distribution NEDT with respect to AT and XT overlap

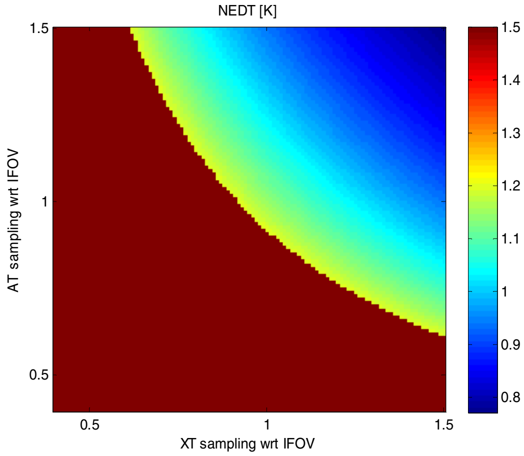

Figure 4. Identification of acceptable AT and XT Overlap Factors for Sensitivity Distribution NEDT.

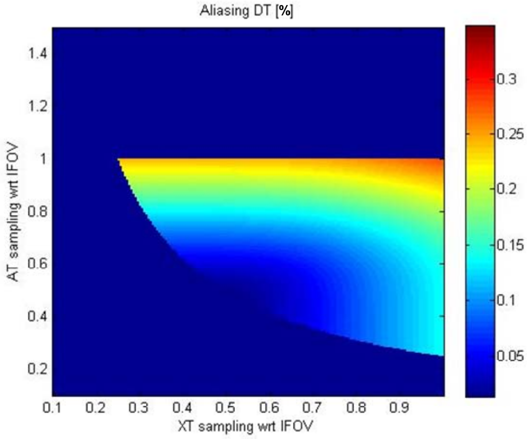

Figure 5. Identification of acceptable AT and XT Overlap Factors (area compliant with R or G) for Aliasing DT.

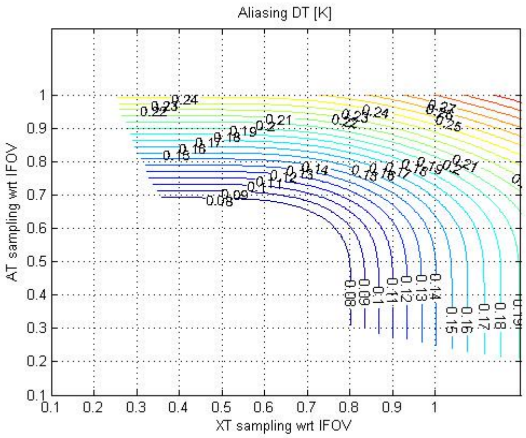

Figure 6. Identification of Aliasing Indexes Relevant to acceptable couple of AT and XT overlaps

From Fig. 6 it is possible to analyse the interdependency between the desired Aliasing Index and NeDT (which, in turn, is function of the XT overlap).

Selecting the couple Aliasing Index/XT overlap one can identify the correspondent AT overlap and then determine the relevant scan rate on a plot of AT overlap vs scan rate (see Fig. 7).

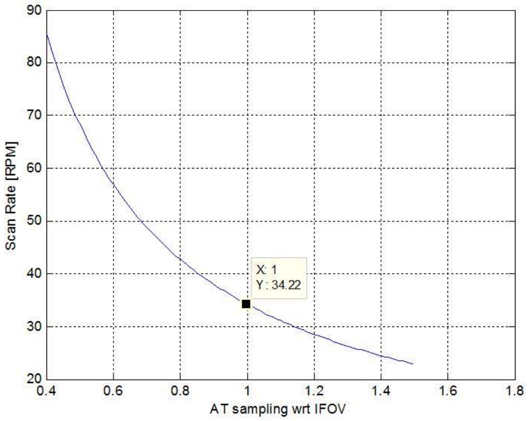

Figure 7. Scan rate corresponding to the minimum aliasing index.

V. CONCLUSIONS

A procedure was illustrated to find the “best” trade-off between scan rate and integration time and a tool was developed to support the system analyses.

It was found that the scan rate of MWI is limited by the minimum scan rate to avoid gaps with the smallest footprint (lower limit) and by the maximum scan rate to achieve the Goal NeDT requirement (upper limit). This means that the scan rate is somewhere between these two limits, depending on additional requirements on image performances not yet established.

The identified maximum scan rate is in principle achievable by the scan mechanism, with the drawback of an increase on risk that is not possible to quantify at that stage. Therefore at the moment it is not possible to fix the scan rate on the basis of a technical constraint only.

One possible solution to overcome scan rate limitation is to enlarge the smallest footprint to the maximum allowed limit, however this would reduce the scan rate only marginally.

Fixing to 0.2 the maximum AI (aliasing error equal to the 20% of the antenna temperature rms) the required scan rate still remains rather high.

In order to reduce techonological risks, it has been therefore decided to size the scan rate as the lowest possible with an additional 10% margin. This yields, considering a integration time equal to the dwell time, to an aliasing index value of 23.9 % for the smaller footprint, which is considered sufficient for the image quality and, at the same time, allows compliance with applicable requirements. However a better Aliasing Index can be reached accepting an integration time smaller than the dwell time to ensure only a marginal compliance to the sensitivity requirement. The best that can be achieved in this case for the smaller footprint is ~21.7%.

REFERENCES

[1] MetOp-Second Generation [MetOp-SG] Space Segment Space System Requirements Document [SSRD] MOS-RS-ESA-SYS-0001.

[2] Aliasing Error on Conical Scanning Radiometers, MOS-TN-ESA-MWI-0037, 21/01/2011.