ASSESSING THE SIDELOBE CONTRIBUTION TO THE RADIATIVE MEASUREMENTS OF THE W-BAND CHANNEL ON ATMS

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1. INTRODUCTION

The Advanced Technology Microwave Sounder (ATMS) [1] is the next-generation satellite-borne microwave instrument for atmospheric sounding. It was designed and built for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program [2] by the Electronics Systems Division of Northrop Grumman. The ATMS is a total-power radiometer consisting of 22 channels (table 1) tuned to detect microwave energy emitted and scattered by the atmosphere and the Earth's surface.

Ch	Frequency (GHz)	Beamwidth (degrees)		Beam Efficiency (%)	
		Req't	Meas.	Req't	Meas.
1	23.8	4.68 – 5.72	5.32 – 5.51	≥ 95	96
2	31.4	4.68 – 5.72	5.23 – 5.60	≥ 95	97
3	50.3	1.98 – 2.42	2.26 – 2.31	≥ 95	97
4	51.76	1.98 – 2.42	2.30 – 2.37	≥ 95	97
5	52.8	1.98 – 2.42	2.30 – 2.32	≥ 95	97
6	53.596+/-0.115	1.98 – 2.42	2.23 – 2.31	≥ 95	97
7	54.40	1.98 – 2.42	2.20 – 2.31	≥ 95	97
8	54.94	1.98 – 2.42	2.25 – 2.29	≥ 95	97
9	55.50	1.98 – 2.42	2.28 – 2.30	≥ 95	97
10	57.290344	1.98 – 2.42	2.20 – 2.23	≥ 95	98
11	57.290344+/-0.217	1.98 – 2.42	2.20 – 2.23	≥ 95	98
12	57.290344+/-0.3222+/-0.048	1.98 – 2.42	2.20 – 2.23	≥ 95	98
13	57.290344 +/-0.3222+/-0.022	1.98 – 2.42	2.20 – 2.23	≥ 95	98
14	57.290344 +/-0.3222+/-0.010	1.98 – 2.42	2.20 – 2.23	≥ 95	98
15	57.290344 +/-0.3222+/-0.0045	1.98 – 2.42	2.20 – 2.23	≥ 95	98
16	88.2	1.98 – 2.42	2.04 – 2.26	≥ 95	96
17	165.5+/-1.55	0.99 – 1.21	1.09 – 1.19	≥ 95	95
18	183.31+/-7	0.99 – 1.21	1.07 – 1.20	≥ 95	95
19	183.310+/-4.5	0.99 – 1.21	1.07 – 1.20	≥ 95	95
20	183.310+/-3	0.99 – 1.21	1.07 – 1.20	≥ 95	95
21	183.310+/-1.8	0.99 – 1.21	1.07 – 1.20	≥ 95	95
22	183.310+/-1	0.99 – 1.21	1.07 – 1.20	≥ 95	95

Table 1. Identification and geometric parameters of the ATMS channels. [3]

The observation mode is that of a scanning cross-track instrument, with 96 Beam Positions (BP) evenly spaced in angle from the sunward to the anti-sun edge of the scan (figure 1). The proto-flight unit of ATMS has undergone an extensive characterization campaign [4]. It has been proven to meet or exceed all performance requirements. It is scheduled to be launched on the NPOESS Preparatory Project (NPP) [5] spacecraft in 2011.

Microwave radiometers have wide beamwidths and significant sidelobes. This entails the possibility that the signal of interest, which comes from a far-away scene, might become contaminated by signals from other sources. During operation of heritage radiometers, it was noticed that the brightness temperature of a uniform scene appears to change in a non-physical manner as it is observed at different angles from nadir, with this effect being most pronounced near the edges of the scan range, as the antenna sees a changing combination of scene radiation, cold space radiation and spacecraft emission while it swings through a scan. The correction for this effect was always applied 'a posteriori'; the NGAS System Performance Team is implementing a correction ' a priori' by predicting the correction from measured instrumental parameters before making the measurement.

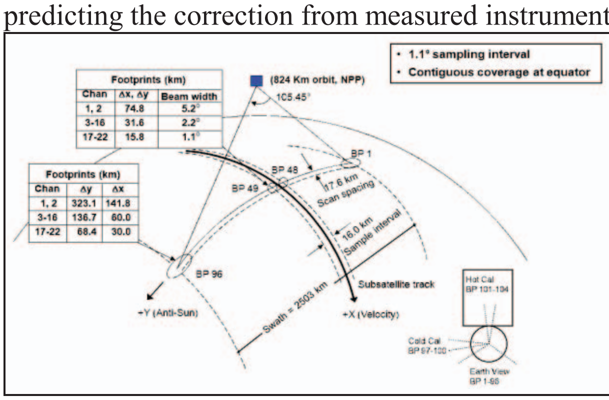

Figure 2. Scan characteristics of the ATMS mission [6]

This work produces more accurate error budgets and also allows us to quantify the amount of radiation collected in the cross-polarized state. All these quantities are needed to refine the error model for the instrument. We report on the results of the re-analysis of beam pattern data from the channels at 88.2 GHz (channel 16). The analysis for the K-band channel has been published elsewhere [7], and the other channels are being processed. Another goal is to quantify the uncertainty (if any) introduced when the measurements are conducted only along the 'principal' planes of the beam. Principal planes are defined as those lying along the in-track and cross-track directions, as defined by the orbital motion of the spacecraft.

2. PROCESSING THE DATA

During the pre-launch testing, the beam patterns were measured by taking 'cuts' through the antenna beam.. These one-dimensional profile data are smoothed , to eliminate instrumental noise. Profiles from the same azimuthal cut (and different polarizations) are then re-scaled to a common maximum of gain (figures 2a and 2b).

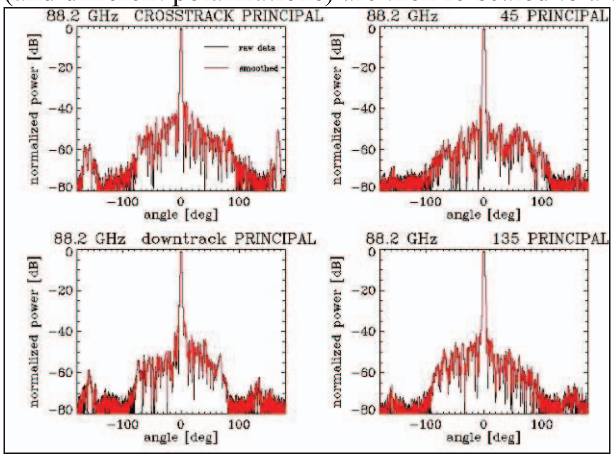

Figure 2a. Response of the antenna to radiation which is co-polarized with the antenna's own polarization state. All data normalized to the recorded maximum. Black traces = raw data; red traces = data smoothed with boxcar integrator

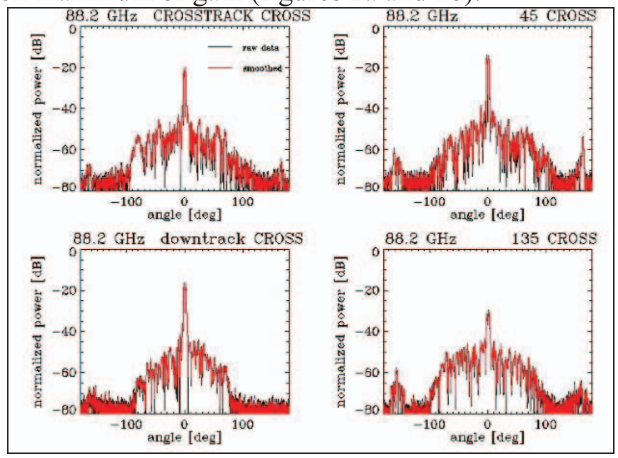

Figure 2b. Response of the antenna to radiation which is cross-polarized with the antenna's own polarization state..

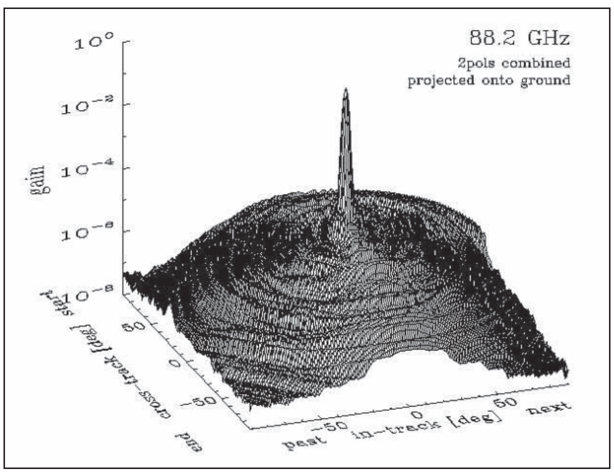

Figure 3. Response of the antenna to unpolarized signal.

The cuts are taken at BP 48 (corresponding to 0.55 deg from true nadir), BP01 and BP96 (the extreme edges of the scan range) and the nominal position of the cold space calibration view (83.4 deg from true nadir).

The one-dimensional profiles are processed into a two-dimensional array which represents the gain of the antenna beam in alt-azimuth coordinates. The gain for areas not measured directly is interpolated from the nearest available data, using a weighting function which preserves continuity of the profile and its first derivative. One such array is calculated for the co-polarized status, and another for the cross-polarized data. Co-adding the two arrays yields a map of the overall sensitivity of the radiometric channel to unpolarized radiation (figure 3).

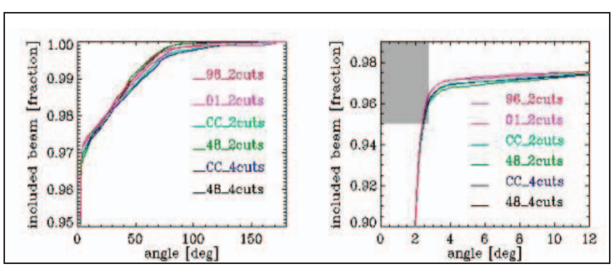

Figure 4. Beam efficiency calculated for several BPs

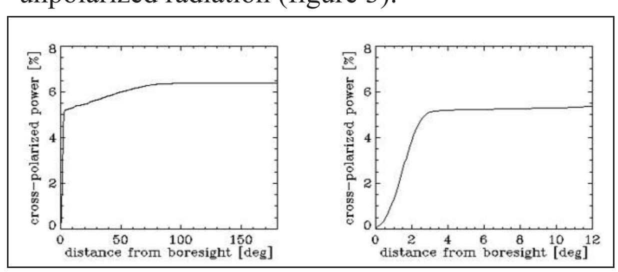

Figure 5. Fraction of radiance collected from the cross-polarized state

3. BEAM EFFICIENCY AND POLARIZATION PURITY

The beam efficiency is defined as the fraction of the total radiometric sensitivity which falls within the cone of half-opening equal to 1.25 times the nominal beamwidth of the channel. It is calculated by integrating the map of overall sensitivity as a function of angular distance from the origin, and ratioing the results with their maximum value. This process yield the curves of figure 4; in order to comply with the requirements, the instrument must hit the grey area located at the upper left corner of the parameter space. The performance of the 88.2 GHz channel determined by this work matches what had been declared by the instrument provider (96%).

The polarization purity is defined as the ratio between the integrated sensitivity of the channel to radiation in the cross-polarization and the integrated sensitivity of the channel to all polarizations. It was calculated as a function of angular distance from the antenna boresight and is shown in figure 5. The data indicate that the sensitivity to cross-polarized radiation is minimal at boresight, reaches a non-negligible plateau (5% of total signal) a few degrees away from the center of the beam, and continues to increase as we move away from the the boresight. Future work will assess how much this level of polarization purity might affect the radiometric accuracy over water scenes.

4. WHAT IS A COMPLETE DATASET ?

The database from ATMS-NPP allows us to verify whether the information gathered from measuring four 'cuts' through the beam pattern justifies the increase in testing time and cost.

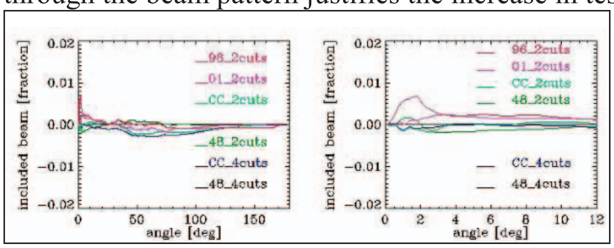

Figure 6. When only two cuts are included in the calculations, the power enclosed in the main beam is underestimated

Taking the value derived at BP48 for the 4-cuts dataset as a reference, figure 6 shows the difference in beam efficiency at the four beam positions for which data are available: BP48 (nadir) and BPCC (cold calibration) which were measured in four cuts, while BP01 and BP96 (the scan edges) which were measured in only two cuts. For ease of comparison, there are also two simulated measurements of what a 'two cuts only' approach would yield for BP48 and BPCC, obtained by disregarding the existing cuts at 45 and 135 deg. The data show a loss of information when only two cuts are measured, and as a result the enclosed beam efficiency at BP48 and BPCC appears slightly lower than it should be. As we remarked for the K-band data [7], it is impossible from these few sets to determine whether the out-of-family behavior observed at BP01 is intrinsic in the geometry of the scan, or is an artifact of the measurement. In either case, the ATMS satisfies all the applicable requirements.

5. MODELING THE SIDELOBES

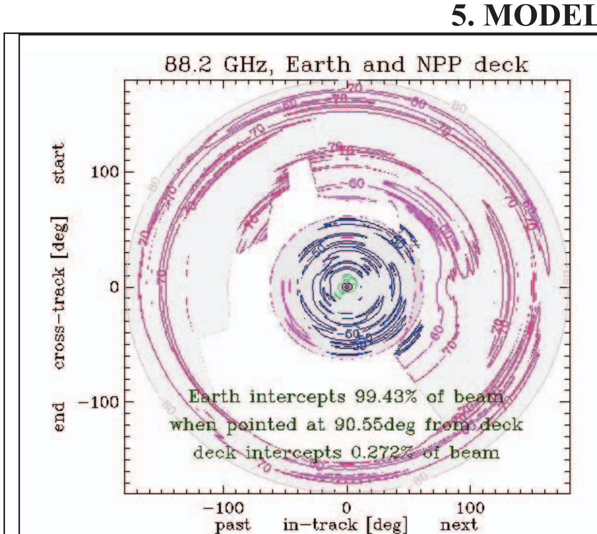

Figure 7. The gain-weighted beam projected onto the Earth and the NPP spacecraft; BP48 view; 88.2 GHz channel

The next step consists of projecting the measured beam patterns over the Earth's disc and the profile of the NPP spacecraft. The NPP 'horizon' includes the instruments and communication antenna located near ATMS. The results are shown in Figure 7 for BP48, in Azimuthal Equidistant projection. The boresight of the antenna is at the center of the picture, at coordinates (0,0). The shaded areas correspond to the Earth and to the NPP spacecraft. The fraction of beam occupied by each target is also given. The small solid angle (0.025% of the gain-weighted beam) occupied by both the Earth disc and the NPP horizon in figure 7 is attributed to the latter (which is in the foreground). Similar calculations were performed for BP1, BP96 and the cold space look. The beam fractions have been fed into a simple model of the ATMS environment. In the model, the Earth has a uniform brightness temperature of 250K, the cold space has brightness temperature of 2.7 K, and the NPP spacecraft has a uniform brightness temperature of 200K. The results are summarized in table 2.

Table 3 reports results from the same analysis for channel 1 (K-band).

BP	Earth disk	Cold space	NPP deck	Δ Tb
01	98.440%	0.811%	0.749%	-2.380 K
48	99.430%	0.298%	0.272%	-0.873 K
96	98.510%	1.200%	0.290%	-3.113 K
CC	0.342%	98.945%	0.713%	2.253 K

desired target (green)
sidelobe contribution (yellow)

Table 2. Sidelobe effects on the apparent brightness temperature ; 88.2 GHz channel

BP	Earth disk	Cold space	NPP deck	Δ Tb
01	98.820%	0.706%	0.474%	-1.983 K
48	99.690%	0.289%	0.021%	-0.725 K
96	99.070%	0.888%	0.042%	-2.217 K
CC	0.126%	99.688%	0.186%	0.679 K

desired target (green)
sidelobe contribution (yellow)

Table 3. Sidelobe effects on the apparent brightness temperature ; 23.8 GHz channel (already reported in [7]

6. CONCLUSIONS

These results show that:

- the beam efficiency is higher than reported by the instruments manufacturer
- the polarization purity of the channels is high, but could become a factor in the analysis of window-channel data over water scenes
- information is lost when the beam pattern is measured with only two 'cuts' along the principal planes
- the contamination of the brightness temperature of the Earth scene from unwanted radiation thought the sidelobes of the antenna can be estimated and included in the radiative error budget
- the contamination is significant even at nadir, and sufficiently large that, if left uncorrected, will dominate the uncertainty of the SDRs for edge-of-scan pixels,
- the contamination will be a non-negligible contributor to the calibration uncertainty.
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7. ACKNOWLEDGEMENTS

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