ON-ORBIT ANTENNA REFLECTOR LOSS MEASUREMENTS FOR ADVANCED TECHNOLOGY MICROWAVE SOUNDER (ATMS) CALIBRATION

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ABSTRACT

The Advanced Technology Microwave Sounder (ATMS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite is a total power radiometer and scans across the track within a range of ±52.77° from nadir. It has 22 channels and measures the microwave radiation at either quasi-vertical or quasi–horizontal polarization from the Earth's atmosphere. From the ATMS pitch-over deep space scan observations, it is found that the antenna reflector losses play an important role in calibration and dominates the scan angle dependent features in the ATMS antenna temperatures. Since the losses are small, they are difficult to measure by traditional means. However, they can be assessed directly from pitch over observations by using deep space radiation measured at different scan angle. This paper describes a physical model developed for the correction of reflector emissivity, which incorporates the angular dependent terms derived from the pitch-over maneuver data. Based on the pitch-maneuver data, the expected V/H polarization emissivity value is in the range of 0.002 to 0.0065. Considering the facts that ATMS is heritage of historical NOAA series microwave sounding instruments like MSU and AMSU, on which the reflector emissivity correction model can also be used to improve TDR/SDR data quality.

Index Terms— Suomi NPP, ATMS, Antenna Emissivity, Pitch-over Maneuver

1. INTRODUCTION

The Advanced Technology Microwave Sounder (ATMS) onboard the Suomi NPP satellite profiles atmospheric temperature and moisture in all-weather conditions, and supports continuing advances in numerical weather prediction (NWP) for improved short- to medium-range weather forecast skills. On February 20, 2012, the Suomi NPP satellite made its pitch-over maneuver. The spacecraft is pitched completely off the Earth to enable ATMS to acquire full scans of deep space. Further study of the pitch maneuver data showed a systematic scan-dependent radiometric bias, which is a sine-squared function of scan angle for the Quasi-Vertical (QV) channels (channels 1, 2, 16), and a cosine-squared function of scan angle for the Quasi-Horizontal (QH) channels (channels 3-15, 17-22) [4]. The antenna temperature along a scan-line for a quasi-vertical polarization curves up (i.e., a smiling feature), and that for a quasi-horizontal curves down (i.e., a frown feature). A theoretical model is then established to explain the scan-angle dependent feature of ATMS measurement bias, with model parameters derived from the pitch-over maneuver data. In Weng and Yang's model, the Quasi-V and Quasi-H polarized near-field radiation term were expressed as function of scan

$$S_a^{Qv} = \beta_0 + \beta_1 \sin^2\theta \quad (1a)$$
$$S_a^{QH} = \beta_0 + \beta_1 \cos^2\theta \quad (1b)$$

Where θ is scan angle, β_0 and β_1 are model parameters determined from pitch maneuver data. The scan angle dependence features of model-simulated antenna temperature for both quasi-vertical and quasi-horizontal polarization are consistent with maneuver measurements. The observed and model-simulated antenna temperatures have either a minimum or a maximum at nadir. Previous study on F16-SSMIS instrument indicated that thermal radiation from antenna reflector can be a major cause of calibration bias [2][3]. For spaceborne microwave sounding instruments, the antenna reflector is required to be designed as lossless with reflectivity larger than 0.999. But study on

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SSMIS calibration shows that, the degradation of SIOx coating of reflector surface may result in reduced reflectivity and consequently significant emissivity [6]. The reflection coefficient for a specimen of the reflector material can be measured with a network analyzer. However, if the reflection coefficient is close to one, which it will be for a decent reflector, it turns out to be difficult if not impossible to achieve the necessary measurement accuracy by this method [5].

In this paper, a physical based reflector emissivity correction model is developed from pitch maneuver observations, the model is then applied in TDR calibration.

2. POLARIZED REFLECTOR EMISSIVITY MODEL

ATMS has two receiving antennas, with one receiving antenna serving for channels 1-15 with frequencies below 60 GHz and a separate receiving antenna for channels 16-22 with frequencies above 60 GHz. The antennas consist of plane reflectors mounted on a scan axis at a 45° tilt angle so that radiation is reflected from a direction perpendicular to the scan axis into a direction along the scan axis (i.e., a 90° reflection). With the scan axis oriented in the along-track direction, this results in a cross-track scan pattern. The reflected radiation is focused by a stationary parabolic reflector onto a dichroic plate, and then either reflected to or passed through to a feedhorn. Each aperture/reflector serves two frequency bands for a total of four bands. When the reflector scans to an angle θ relative to the feed horn orientation, the received brightness temperature is a combination of the vertical and horizontal components. The following equations give the resulting signals expressed in full Stokes vector [1]:

$$R_Q = \begin{bmatrix} R_{Qv} \\ R_{Qh} \\ R_{Q3} \\ R_{Q4} \end{bmatrix} = \begin{bmatrix} cos^2\theta & sin^2\theta & \frac{1}{2}sin2\theta & 0 \\ sin^2\theta & cos^2\theta & -\frac{1}{2}sin2\theta & 0 \\ -sin2\theta & sin2\theta & cos2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times (S_R + S_T) \tag{2}$$

In equation(2), S_R is the cold space radiation reflected by antenna reflector and S_T is thermal radiation from reflector itself. It can be shown that

$$S_R = \begin{bmatrix} S_{RH} \\ S_{RV} \\ S_{R3} \\ S_{R4} \end{bmatrix} = R_c \frac{1-sin2\theta_r}{(1+\sin 2\theta_r)^2} \begin{bmatrix} 1+sin2\theta_r \\ 1-sin2\theta_r \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} r_h R_c \\ r_h^2 R_c \\ 0 \\ 0 \end{bmatrix} \tag{3a}$$

and

$$S_T = \begin{bmatrix} S_{TH} \\ S_{TV} \\ S_{T3} \\ S_{T4} \end{bmatrix} = R_{rfl} \frac{2sin2\theta_r}{(1+\sin 2\theta_r)^2} \begin{bmatrix} 1+sin2\theta_r \\ 2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} (1-r_h)R_{rfl} \\ (1-r_h^2)R_{rfl} \\ 0 \\ 0 \end{bmatrix} \tag{3b}$$

Taken in the plate and environment reference frames (scan plane as incident plane), substitute S_R and S_T in equation (3) into equation (2) leads to the vector expression of radiation leave off reflector surface:

$$R_Q = \begin{bmatrix} R_{Qv} \\ R_{Qh} \\ R_{Q3} \\ R_{Q4} \end{bmatrix} = \begin{bmatrix} R_{rfl} + r_h(R_s - R_{rfl}) + [(R_s - R_{rfl})(r_h^2 - r_h)]sin^2\theta \\ R_{rfl} + r_h(R_s - R_{rfl}) + [(R_s - R_{rfl})(r_h^2 - r_h)]cos^2\theta \\ 0 \\ 0 \end{bmatrix} \tag{4}$$

In equation above, $R_s = R_c$ when reflector face to cold space, and $R_s = R_w$ when it face to warm load. Equation (4) provides a physical model for simulating pitch over observations obtained through a polarized antenna reflector. It can be seen that when a polarized reflector is used to scan the scene, even the scene is uniform and unpolarized, the output signals will become linear polarized, and can be expressed as a function of reflector emissivity, reflector physical temperature, scene temperature, and scan angle. Figure 1 shows the simulated radiation in brightness temperature under different reflector temperature and reflectivity conditions. For Quasi-V channels, it is a square of the sinusoidal curve and for Quasi-H channels it follows a cosine curve. It can be seen that the impact of reflector thermal radiation can become significant when the scene radiation equals cosmic background, which is the case for cold space view in ATMS scan cycle. For example, if the reflector reflectivity is only 0.994, then the cold target brightness temperature being used in calibration is not 2.73K deep space brightness temperature anymore, the thermal emission of reflector with a magnitude as large as 4.5K should be considered.

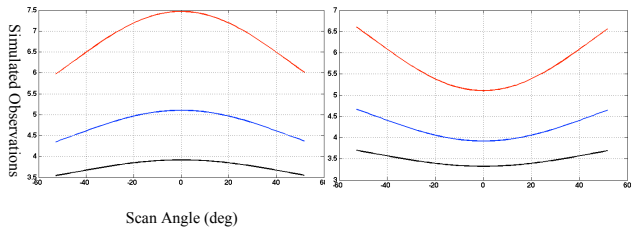

Figure.1 Simulated cold space observations from antenna reflection for quasi-H (left) and quasi-V channels (right). Scene temperature is sent to 2.73K, reflector physical temperature is set to 300K. red, blue and black line is corresponding to antenna reflectivity equals to 0.992,0.996 and 0.998 respectively.

3. RESULTS AND CONCLUSIONS

By applying the two-point calibration equation, the antenna emissivity for ATMS quasi- vertical channels can be solved as:

$$\varepsilon_h = \frac{\delta(R_w - R_c)}{\delta[(R_w - R_{rfl})sin^2\theta_w - (R_c - R_{rfl})sin^2\theta_c] - (R_c - R_{rfl})(sin^2\theta_s - sin^2\theta_c)}$$

For quasi-horizontal channels it is:

$$\varepsilon_h = \frac{\delta(R_w - R_c)}{\delta[(R_w - R_{rfl})cos^2\theta_w - (R_c - R_{rfl})cos^2\theta_c] - (R_c - R_{rfl})(cos^2\theta_s - cos^2\theta_c)}$$

The ATMS reflector emissivity spectrum then can be determined from pitch maneuver datasets, as shown in

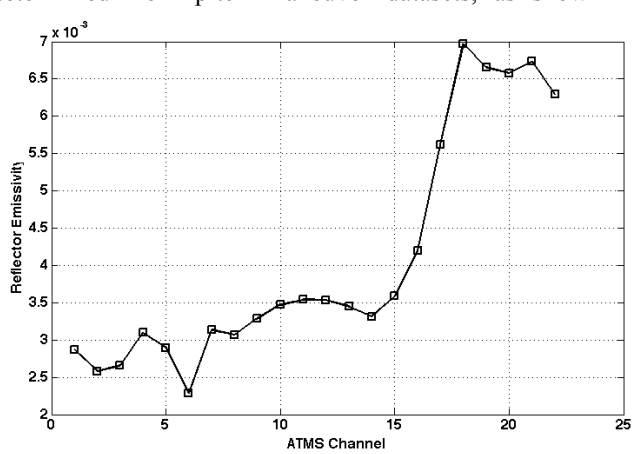

Figure 2. The retrieved emissivity is increase with frequency.

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