CALIBRATION ISSUES OF SPACEBORNE MICROWAVE RADIOMETER DREAM ON STSAT-2

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ABSTRACT: Dual channel Radiometer for Earth and Atmospheric Monitoring (DREAM) is the main payload on Science and Technology SATellite-2 (STSAT-2) of Korea. DREAM is two-channel microwave radiometer with linear polarization, and operating at center frequencies of 23.8 GHz and 37 GHz. An equation for DREAM calibration is derived which accounts for losses and re-radiation in the microwave components of the radiometer due to physical temperature. This paper describes the radiometric calibration equation to get antenna temperature (T_A) from the measured output data. At lower altitude, the measured deep space temperature is contaminated by middle atmosphere and earth radiation. In this paper, we presented the detail mathematical formulation to find the altitude up to which cold source brightness temperature is not affected by earth and middle atmosphere radiation. The DREAMPFM data is used to calculate the performance parameters (linearity, sensitivity, dynamic range, and etc.) of the system.

KEY WORDS: DREAM, Radiometer, STSAT-2, Calibration

1. INTRODUCTION

Dual Channel Radiometer for Earth and Atmospheric Monitoring (DREAM) is designed to be flown on Science and Technology Satellite-2 (STSAT-2). Science and Technology SATellite (STSAT) is a programme of Korea Aerospace Research Institute (KARI), for the domestic development of a low earth orbiting satellite up to mass 100 Kg. In this series, first satellite was STSAT-1, which was lunched in year 2003, for the study of a celestial observation of ultraviolet spectrum [4]. The STSAT-2 is the second satellite of STSAT program and scheduled to launch in 2007 from NARO space centre. The payloads of STSAT-2 consist of Dual-channel Radiometers for Earth and Atmosphere Monitoring (DREAM), and Satellite Laser Ranging (SLR). SLR is used to measure precise distance between STSAT-2 and a ground SLR station, for exact determination of the STSAT-2 orbit. The mission lifetime of STSAT-2 is 2 years, its perigee 300 km and apogee of 1,500 km. [2].

The DREAM instrument operates with two channels of centre frequencies of 23.8 GHz and 37 GHz. Since the STSAT-2 spacecraft is a micro-satellite, the spacecraft limits each measurement antenna aperture to about 100 mm, which corresponds to a beam-width of 10°. Because the DREAM does not have scanning mechanism, the swath width is the same as an antenna footprint which is varied from 52.5 Km to 262 Km at the height of 300 Km to 1500 Km. The DREAM will operate on 50-percent minimum duty cycle and the data size is 1 Mbytes per orbit. The bandwidth of DREAM is 600 MHz at 23.8 GHz and 1000 MHz at 37 GHz. Integration time is 200 ms for both channels. The required sensitivity is less than 0.5 K.

At one end of the switch, a "hot" reference source is observed and at the opposite end, a "cold" source is observed. The hot reference source is a microwave guide termination at the instrument ambient temperature and the cold source is provided by a horn antenna viewing deep space (~ 2.7 K). To measure physical temperature at various critical points in DREAM microwave circuitry, number of platinum resistance sensors is distributed. These temperature data are combined with the measured DREAM data and transmitted to the ground. This combined data set consisting of signal, hot calibration, and cold calibration digital voltages (counts) and instrument temperature values are used to find effective radiometric temperature (antenna temperature).

A number of sources contribute errors to the computation of the antenna temperatures. These include the noise in the signal, hot and cold source counts, and inaccuracies in the measurement of instrument temperatures and losses and inaccuracy in calibration equation itself. The mean values of hot source measurement vary slowly, but these measurements have noise; averaging in the ground processing may reduce this noise error.

Since the calibration antenna used to measure the deep space is not looking directly into deep space it looks tangential to the satellite orbit. Due to that at lower altitude (<900Km) cold source measurement is contaminated by atmosphere. So cold source measurement is used carefully in calibration process. In this paper we calculated up to which altitude cold source measurement is not contaminated by atmosphere. Another major source of noise contribution is from the receiver noise temperature of the earth looking signals, which cannot average. For protoflight model (PFM) at the 23.8 GHz and 37 GHz, the noise level, or antenna temperature resolution are less than 0.29 K, 0.35 K respectively.

Section II describes the radiometric calibration algorithms. Section III gives detail calculations for finding the altitude up to which cold source measurement is not contaminated by the atmosphere. To evaluate the performance of DREAM, the liquid nitrogen and microwave absorber as the calibration sources were used. Section IV discusses the performances and results of DREAM PFM.

2. RADIOMETRIC CALLIBRATION EQUATION

Simplified radiometer schematic is shown in figure1. The system consists of two such channels for 23.7 GHz and 37 GHz. Switch module has three inputs, and an output to the mixer. To evaluate the performance of DREAM, the liquid nitrogen is used as calibration source. A primary target is used to place in front of the signal horn for calibration of the DREAM. The temperature of this target varies from 77K to 287.29K. The T_i's in figure shows the location of the thermometers for monitoring various physical temperatures in the instrument.

It assumes that the transmission coefficients are purely ohmic and that the output temperature of a component with transmission coefficient α is given by [1]

$$T_{out} = \alpha T_{in} + (1-\alpha)T_{ph} \tag{1}$$

Where, the first term is from the loss in the component and the second term is the re-radiation from the physical temperature T_{ph} of the component.

Let in figure 1 signal with an effective temperature T_A at the signal feed horn. After passing through the, waveguide (WG) and switch, it emerges at mixer input port. Now considering transmission loss due to different components, we can write the following equations

$$T_A' = \alpha_8\alpha_7\alpha_6 T_A + \alpha_8\alpha_7(1-\alpha_6)T_6 + \alpha_8(1-\alpha_7)T_7 + (1-\alpha_8)T_8 \tag{2}$$

For cold (space) calibration ,

$$T_C' = \alpha_3\alpha_2\alpha_1 T_C + \alpha_3\alpha_2(1-\alpha_1)T_1 + \alpha_3(1-\alpha_2)T_2 + (1-\alpha_3)T_3 \tag{3}$$

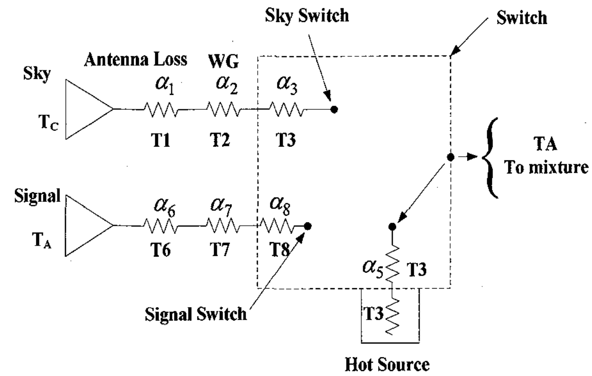


Figure1. DREAM Radiometer Schematic Diagram

Hot calibration load,

$$T_H' = \alpha_5 T_3 + (1-\alpha_5)T_3 = T_3 \tag{4}$$

The T_i (i=1 2 3 6 7 8) is physical temperature of components as shown in figure 1. For total power radiometer with square law detector the digital voltage output (C) is related to the effective temperature at input (T_{in}) by:

$$C = G T_{in} + b \tag{5}$$

Where G is gain and b is bias. Let C_A, C_C, and C_H, are digital count when T_A', T_C', T_H' are input to the mixer. Now from equation (5) we have

$$C_A = GT_A' + b \tag{6}$$

$$C_C = GT_C' + b \tag{7}$$

$$C_H = GT_H' + b \tag{8}$$

Subtracting (7) from (8) we get

$$G = (C_H - C_C)/(T_H' - T_C') \tag{9}$$

Subtracting (8) from (6) we get

$$T_A' = \frac{C_A - C_H}{G} + T_H' \tag{10}$$

Substituting (9) in (10) we get

$$T_A' = \frac{(C_A - C_H)}{(C_H - C_C)}(T_H' - T_C') + T_H' \tag{11}$$

Solving equation (2) for T_A, we have

$$T_A = \frac{T_A' - \alpha_8\alpha_7(1-\alpha_6)T_6 - \alpha_8(1-\alpha_7)T_7 - (1-\alpha_8)T_8}{\alpha_8\alpha_7\alpha_6} \tag{12}$$

Substituting T_A' from (11), T_C' from (3) and $T_H' = T_3$ into (12), we get estimated value of T_A as follows

$$\hat{T}_A = \left(\frac{C_A - C_H}{C_H - C_C}\right)\frac{\alpha_3 T_3 - \alpha_3\alpha_2\alpha_1 T_C - (1-\alpha_1)\alpha_2\alpha_3 T_1 - \alpha_3(1-\alpha_2)T_2}{\alpha_8\alpha_7\alpha_6} + \frac{T_3 - \alpha_8\alpha_7(1-\alpha_6)T_6 - \alpha_8(1-\alpha_7)T_7 - (1-\alpha_8)T_8}{\alpha_8\alpha_7\alpha_6} \tag{13}$$

From (13) it is clear that estimated antenna temperature $\hat{T}_A$ is the function of signal count (C_A), calibration counts C_H , and C_C , various instrument temperature, and transmission coefficient. In an ideal case there were no losses in the instrument, i.e. all the α's were unity, and instrument gain were linear equation (12) would reduce to

$$\hat{T}_A = T_3 + \left(\frac{C_A - C_H}{C_H - C_C}\right)(T_3 - T_C) \quad (14)$$

3. CONTAMINATION OF COLD SOURCE MEASUREMENT

The error in the cold reference measurement is serious problem in DREAM. Since DREEAM calibration antenna is in 90° of measurement antenna, so at lower altitude measurement of deep space temperature is contaminated by middle atmosphere and earth radiation. Here we are presenting necessary calculations for checking that earth/middle atmosphere is fall in the main beam of the calibration antenna or not.

In figure 2, R is the earth radius (6380 Km at pole, 6,360 Km at equator), h is altitude of STSAT-2 (300 Km ~ 1500 Km), α is half of –3dB beam width of calibration antenna (10°). Earth fall in the sight of calibration antenna main beam if $\alpha > (90^o - \theta)$. From right angle triangle ADC

$$\sin(\theta) = CD / AC$$
$$= R/(R+h) \quad (15)$$

Calculated value at lowest and highest altitude is presented in table1. From table 1 it is clear that condition $\alpha > (90^o - \theta)$ is not true in any case. Thus earth never fall in line of sight of main beam of the calibration antenna.

Table 1.

Altitude (h) (In Km)	$90^o - \theta$	$\alpha > (90^o - \theta)$
300	17.2345°	FALSE
1500	35.9388°	FALSE

For making decision about main beam intersect with middle layer of earth atmosphere or not, it is required to know the minimum distance (KL) of main beam from earth surface. From right angle triangle AKC

$$\sin(90^o - \alpha) = KC / AC$$
$$\cos(\alpha) = KC/(AB + BC)$$
$$KC = (h+R)\cos(\alpha) \quad (16)$$

Minimum distance of main beam from earth surface

$$KL = KC - LC$$
$$= (h+R)\cos(\alpha) - R \quad (17)$$

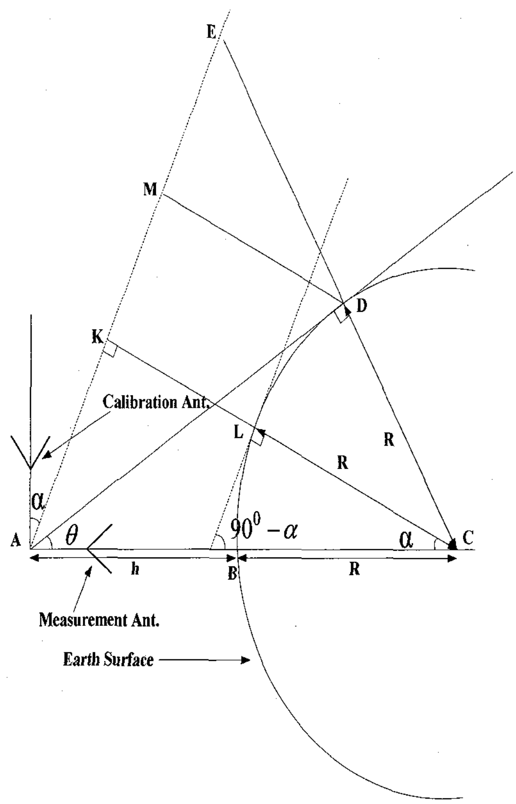


Figure2. DREAM Radiometer Schematic Diagram

Minimum distance (*KL*) of main beam from the earth for altitude 300 km (perigee) and 1500 (apogee) for $\alpha = 10^o$ is as in table 2.

Table 2.

Altitude (h) (In Km)	*KL* (In Km)
300	198.5158
1500	1380.3

As information provided by NASA [5], middle atmosphere of earth is up to 85 km and after that thermosphere layer starts. From table 2, it is clear that middle atmosphere never fall in the line of sight of -3 dB beam width of calibration antenna. But DREAM calibration antenna –3dB beam efficiency is nearly 88%. Thus side lobe contribution is very significant in cold source measurement. At lower altitude side lobes look the earth and its atmosphere, hence cold source measurement is heavily contaminated. Figure 3 shows that the variation of minimum distance *KL* from with altitude for different half beam width α. Using measured data of calibration antennas, we find that for half beam width 26.5°, beam efficiency is 99.7%, and it is safe from earth/atmospheric radiation up to altitude 900 Km. And estimated radiometric brightness temperature of deep space is 3.21 K, which close to radiometric brightness temperature 2.7 K.

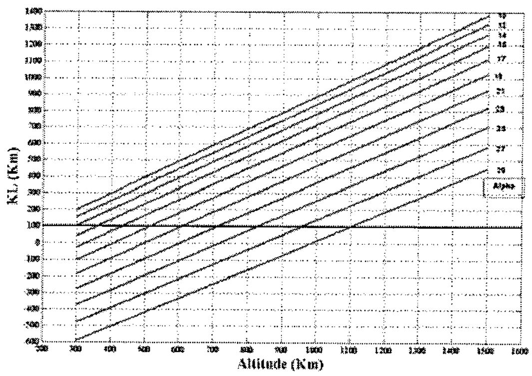
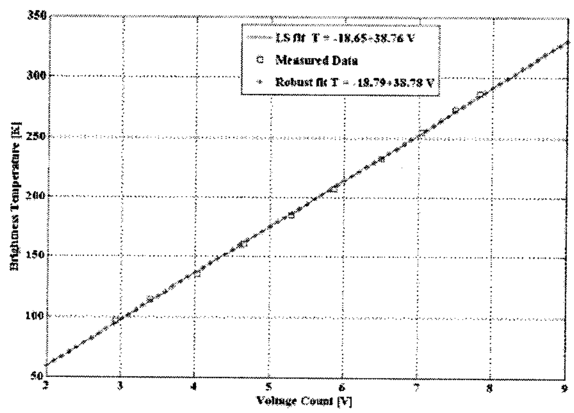
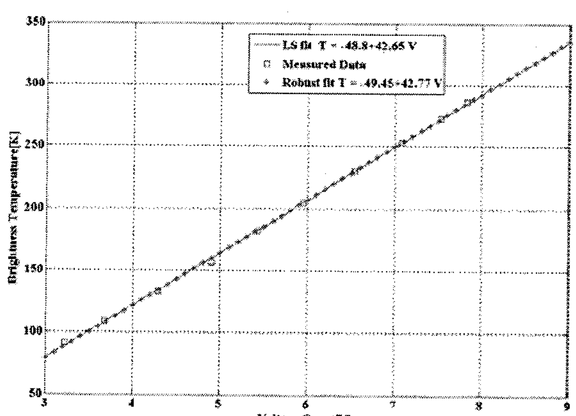


Figure 3. Altitude vs. Minimum Distance (KL) of Main Beam from Earth Surface



(a)



(b)

Figure 4. DREAM performance results. (a) 23.8 GHz receiver, (b) 37 GHz receiver.

4. DREAM PFM PERFORMNCE RESULT

Figure 4 shows the variation of DREAM receiver output with different input. For calibration, sensitivity, and linearity measurement, liquid nitrogen was used as the stable and well known input of the radiometer [3]. The temperature of liquid nitrogen is 77 K. An integration and sampling time was 200 ms. The sensitivity and linearity measurement were performed simultaneously. The linearity is the property whereby the output of radiometer is proportional to the input. For linearity measurement, we need measurement at different temperature. A variable attenuator was inserted between the antenna and receiver for the various temperature inputs. For sensitivity measurement, the long time measurement is performed at the stable input. The measurement was performed at 10 different temperature inputs for 2 minutes. Our specification is 0.5K. The experimented sensitivity was less than 0.44 K at 23.8 GHz and less than 0.38 K at 37 GHz. Linearity calculated using the linear regression method, and it is greater than 0.99.

5. CONCLUSION

This paper presents the calibration issues and system performance of DREAM. In this paper we derived the calibration equation of DREAM considering different losses. We also discussed the effect of earth and atmospheric effect on deep space brightness temperature measurement. We find out that up to what altitude the deep space measurement is not contaminated by earth and atmosphere. To evaluate the system performance of DREAM, the radiometric calibration was performed. From the data analysis, the sensitivities are 0.34 K at 23.8 GHz and 0.38 K at 37 GHz, respectively. The linearity of two channels is larger than 0.99 and the dynamic range is 3 K to 300 K in both channels. This performance results show that the DREAM PFM satisfies the system requirements and specifications.

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