MICROWAVE BLACKBODY CALIBRATION OF THE TIROS N MICROWAVE SOUNDER UNIT*

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ABSTRACT

The calibration procedure of the TIROS N Microwave Sounder Unit (MSU), a radiometer with data channels at 50.3 GHz, 53.74 GHz, 54.96 GHz and 57.95 GHz for measuring atmospheric temperature profiles, is discussed and the antenna brightness temperature algorithm is developed.

The calibration of the second flight model of the TIROS N Microwave Sounder Unit radiometer has been completed using a microwave blackbody temperature reference with Brewster angle absorbers. The final antenna brightness temperature algorithm, which is dependent on the modulating switch temperature T_I, has been developed in quadratic form as

$$T_B(T_I) = C_0(T_I) + C_1(T_I)\left[\frac{V - V_{S/C}}{V_C - V_{S/C}}\right] + C_2(T_I)\left[\frac{V - V_{S/C}}{V_C - V_{S/C}}\right]^2 ,$$

where

T_B ≡ antenna brightness temperature

V ≡ radiometric output voltage

$V_{S/C}$ ≡ radiometric output voltage when viewing an onboard spacecraft target

V_C ≡ radiometric output voltage when viewing cold space

$C_0(T_I) \equiv T_{S/C} + C_0'(T_I)$, the spacecraft target temperature plus an experimentally determined coefficient

$C_1(T_I) \equiv (T_C - T_{S/C}) + C_1'(T_I)$, the difference between the cold space temperature and the spacecraft target temperature plus an experimentally determined coefficient

$C_2(T_I)$ ≡ an experimentally determined coefficient.

The general algorithm plot is shown in Figure 1.

The TIROS N MSU is a self-calibrating microwave radiometer which periodically looks at an onboard spacecraft target of known temperature and cold space, whose cosmic background temperature is of the order of 2.7°K. Eleven scanned data positions map the earth atmosphere, generating temperature profiles of the atmosphere by measuring the millimeter wave emissions of the oxygen resonance lines. Since the accuracy of the brightness temperature measurement is important, a technique has been developed to calibrate the instrument while it is undergoing thermal-vacuum temperature-cycling acceptance tests.

A sketch of the microwave blackbody calibration test equipment is shown in Figure 2, where one blackbody wedge at 100°K simulates cold space and another variable-temperature blackbody wedge, referred to as the earth target, is used to provide calibrated input temperature. Provisions to alter the instrument temperature have also been included by attaching heat exchanging plates to the instrument bay. The instrument and earth target temperature profiles are outlined in Figure 3 over a portion of the thermal cycling tests by using the variable instrument and earth target temperatures. The antenna brightness temperature algorithm is developed on a "black box" basis, and the instrument performance is characterized for all expected operating temperatures.

Although under normal operating conditions the scan cycle is completed in 25 seconds, the calibration procedure developed requires that the rotating antenna reflectors be sequentially positioned for a few minutes to look at the earth target, the cold space target and the onboard spacecraft target. Many frames of data, each frame containing 13 measurements, are obtained during a short period of time so that high measurement accuracies are achieved. A sample data block is shown in Figure 4. The data are then reduced using the standard linear radiometer relationship and compared with actual blackbody temperature values from platinum resistance sensors imbedded in the earth target. Corrections are also made for modulating switch temperature (defined as instrument temperature) deviations from nominal instrument temperature values on which the algorithm coefficients are based. A sample of the reduced data is shown in Figure 5. Gain fluctuations are removed by normalizing the radiometric voltage outputs, using the term $[(V - V_{S/C})/(V_C - V_{S/C})]$ as the running variable. The quadratic coefficients for each channel at each instrument temperature are then tabulated, as shown in Figure 6. The coefficients shown in Figure 6 were demonstrated not to vary significantly with instrument temperature, with deviations between the actual and predicted temperature values being approximately 0.5°C. Therefore, a regression using all measurements over all instrument temperatures was made, and the final mean absolute deviation was calculated to be less than 0.3°C.

The final algorithm coefficients for TIROS N MSU Flight Model 2 are:

	C_0'	C_1'	C_2
Channel 1	-0.719	-3.337	4.240
Channel 2	-0.373	-3.654	3.681
Channel 3	-0.404	-1.592	4.412
Channel 4	-0.470	-1.618	4.262

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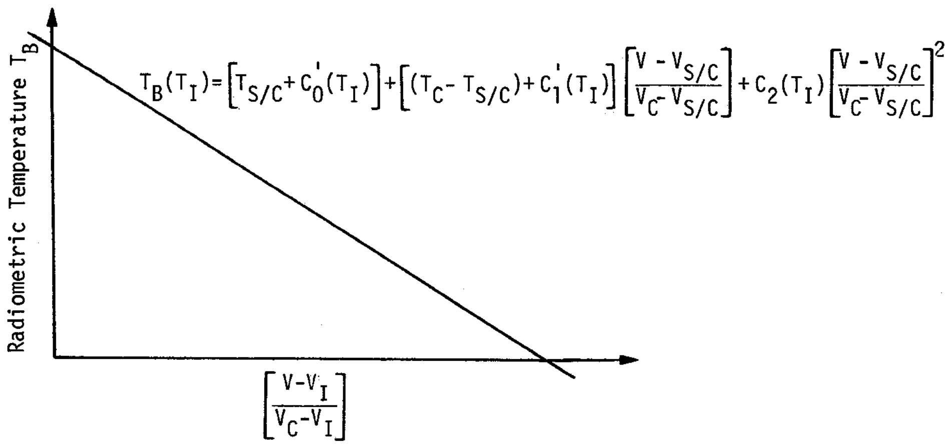

Figure 1. Antenna Brightness Temperature Algorithm

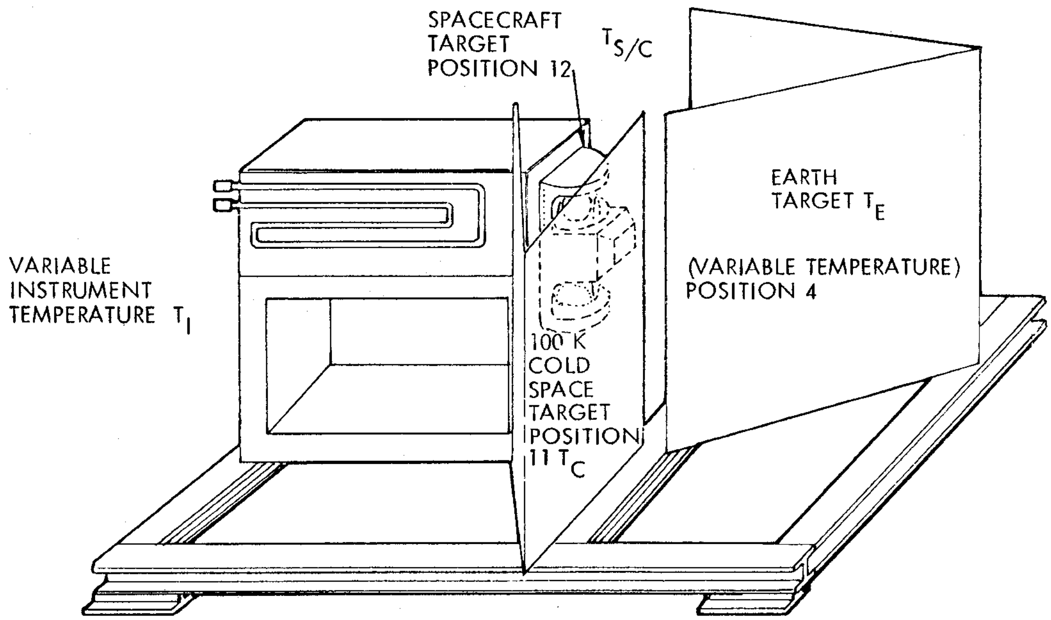

Figure 2. Sketch of TIROS N MSU Thermal-Vacuum Calibration Equipment

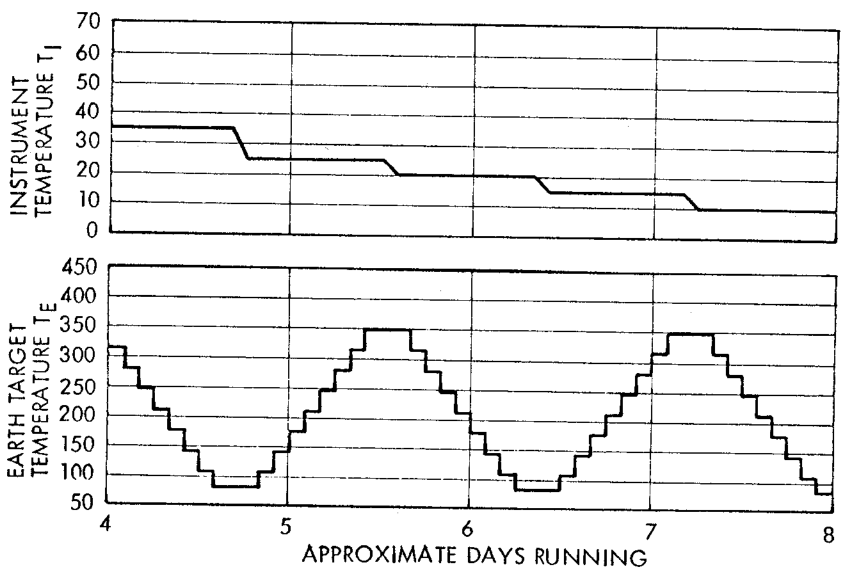

Figure 3. TIROS N MSU Thermal-Vacuum Temperature Profile

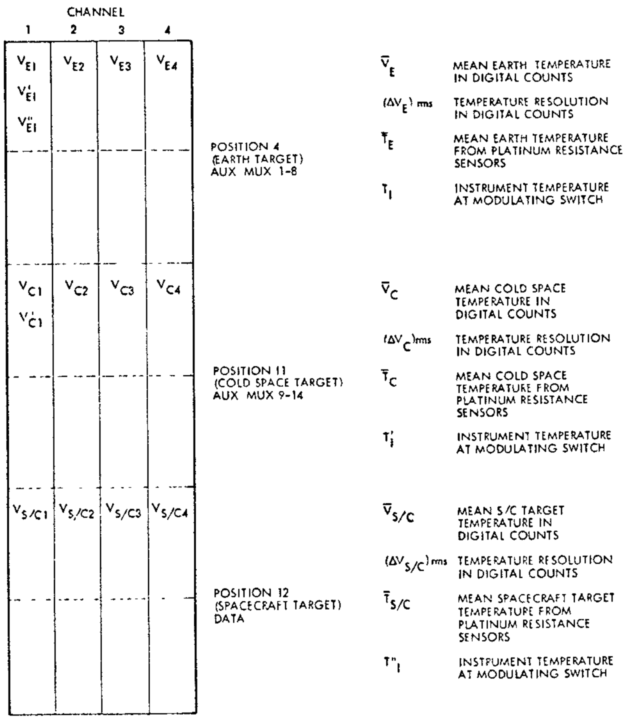

Figure 4. TIROS N MSU Calibration

TIROS N MICROWAVE SOUNDER UNIT, FLIGHT MODEL NO. 2
CHANNEL 1, MODULATING SWITCH TEMPERATURE $T_I = 20^\circ C$

$C_0' = -1.023$
$C_1' = -3.802$
$C_2 = 4.975$

$\left[\frac{V - V_{S/C}}{V_C - V_{S/C}}\right]$	$T_{ESTIMATED}$	T_{ACTUAL}	$\Delta = T_{EST} - T_{ACT}$
-0.307	76.321	76.495	0.174
-0.305	76.346	76.295	-0.051
-0.306	76.369	76.244	-0.125
-0.125	40.997	40.973	-0.024
-0.127	41.201	41.057	-0.134
-0.127	41.026	41.048	0.020
0.038	6.490	6.546	0.057
0.036	6.580	6.575	-0.005
0.036	6.565	6.643	0.079
0.035	6.557	6.600	0.043
0.204	-28.501	29.581	-0.080
0.202	-28.485	-28.507	-0.022
0.201	-28.636	-28.489	0.147
0.754	-132.229	-132.105	0.124
-0.748	-131.783	-132.215	-0.432
0.750	-132.043	-132.184	-0.142
0.755	-132.473	-132.172	0.301
0.959	-166.326	-166.325	0.000
0.966	-167.529	-166.900	0.629
0.954	-155.657	-165.991	-0.334
0.956	-165.837	-166.050	-0.224

Figure 5. Format of Calibration Data Regression

$$T_{PRED} = \left[T_{S/C} + C_o'(T_I)\right] + \left[(T_C - T_{S/C}) + C_1'(T_I)\right]\left[\frac{V - V_{S/C}}{V_C - V_{S/C}}\right] + C_2(T_I)\left[\frac{V - V_{S/C}}{V_C - V_{S/C}}\right]^2$$

TIROS N MICROWAVE SOUNDER UNIT FLIGHT MODEL NO. 1							
MODULATING SWITCH TEMPERATURE		10°C	15°C	20°C	25°C	35°C	40°C
CHANNEL 1	C'_0	-0.2700512952	0.3516772016	-0.3026763866	0.4683565591	-0.01076452422	0.2628611299
50.3 GHz	C'_1	-4.002022993	-3.422808964	-3.064835373	-4.097940568	-3.857772087	-4.225893887
	C_2	-0.1606654841	3.346078241	3.369396418	1.015294734	2.473809289	3.675109428
CHANNEL 2	C'_0	-0.2605357486	0.0476652179	-0.4691663316	0.1297065660	-0.2485842272	-0.1422998159
53.74 GHz	C'_1	-3.815729313	-3.094300428	-2.786857119	-3.766494639	-3.688845196	-3.700704061
	C_2	-0.8212297848	3.209650652	3.181765499	1.099284532	2.626108666	3.477483424
CHANNEL 3	C'_0	-0.2874849125	0.2058591576	-0.3397646754	0.3805874346	-0.1872462332	0.1077348332
54.96 GHz	C'_1	-1.853490776	-1.148052005	-0.9681886807	-1.758477544	-1.545505188	-2.107501162
	C_2	0.5368652628	3.297525050	3.479303697	1.403272934	3.272152549	4.256213624
CHANNEL 4	C'_0	-0.5261829619	-0.09252855851	-0.5974941759	-0.02233141517	-0.5808496187	-0.1916176184
57.95 GHz	C_1	-1.943238315	-1.494850895	-1.457607314	-2.063817352	-2.405788438	-2.163475981
	C_2	0.5279252266	3.658878709	3.98794653	2.077012072	4.854791911	3.585285224

Figure 6. Quadratic Coefficients Tabulation Format