

# EVALUATION OF VARIANT AND INVARIANT CROSS-TRACK ASYMMETRY IN THE NOAA-14 MICROWAVE SOUNDING UNIT BY A PLANNED MANEUVER AND AN UNPLANNED SPACECRAFT TUMBLE

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## Abstract

The Microwave Sounding Unit has been flown on NOAA spacecraft since 1979. It has been used by a number of teams to attempt to determine decadal trends of atmospheric temperature, often with conflicting results. While a great deal of innovation has gone into refined post-launch calibration, considerable uncertainty remains, especially regarding asymmetry of the radiances. A pitch maneuver was performed on the NOAA-14 spacecraft in which the satellite remained in an inertial drift for one orbit. This permitted all of the instruments to view the flat cosmic background while in normal scanning mode, and thus identify and quantify cross-track asymmetries. Approximately seven weeks after the maneuver was executed, the NOAA-14 spacecraft suffered a hydrazine thruster failure. A locked valve apparently failed, releasing to space hydrazine which had remained in the line from early orbit operations, sending the spacecraft in a tumble. MSU data were collected during the tumble until the instruments were turned off to conserve power. The spacecraft was recovered and resumed normal station-keeping. These two events represent a unique opportunity to examine time variable cross-track asymmetry in the MSU. This paper will describe the events of the maneuver and tumble, and present an analysis of the cross-track asymmetry and its variability.

## INTRODUCTION

The Microwave Sounding Unit (MSU) (Homan and Soltis, 1977) was first launched on the Television-InfraRed Observational Satellite - N (TIROS-N) in October 1978. It has subsequently flown on a series of NOAA polar orbiting spacecraft up to and including NOAA-14, and has provided a continuous record of observations for almost twenty-eight years. A number of atmospheric temperature time series analyses have been derived from these observations, notably those of Christy et al. (2000), Fu et al., (2006), Mears et al., (2003), and Vinnikov and Grody (2003). Considering the ongoing debate on the cause and extent of global warming, it is imperative that the MSU be characterized to the maximum possible extent. For example, Christy et al. (2000) use differences between the inner and outer scan positions to account for stratospheric emission when computing their  $T_{2LT}$  product. A scan asymmetry would affect this product. This paper describes a pitch over maneuver (POM) that recently was performed on NOAA-14 in order to evaluate any earth scene cross-track asymmetry caused by antenna side lobes, and to validate the space calibration view. For reference, Figure 1 displays the NOAA-14 spacecraft and the location of the MSU with respect to the other instruments and satellite components. Table 1 gives the basic characteristics of the MSU.

## HISTORY

Pitch maneuvers have been performed on NOAA spacecraft before. They were conducted on NOAA 2 and 3 to characterize the Improved Temperature Profile Radiometer, on NOAA 10 to characterize the Earth Radiation Budget, and most notably on NOAA 6 to examine the MSU for asymmetry. Unfortunately the original data from the NOAA 6 maneuver have been lost.

## METHODOLOGY

The term "pitch maneuver" is a misnomer since during normal orbital operations, POES spacecraft pitch forward  $360^\circ$  each orbit so that the instruments on the nadir side continuously face the earth (Figure 2). For the POM, this pitch motion is stopped, and the spacecraft maintains inertial pointing in

the pitch direction. As the spacecraft orbits the earth, the horizon sets and all of the nominal earth viewing scenes now view deep space. At the other side of the orbit, the horizon rises from the other side, and the instruments re-acquire the earth view. After exactly one orbit, the normal pitch motion is resumed.

A long sequence of commands must be sent to the spacecraft to accomplish the POM. For example, since the spacecraft is in an inertial drift, the solar array must stop rotating in order for the panels to maintain sun orientation. The earth sensor array is disabled in order to put the spacecraft into the inertial drift. Thrusters are enabled in case the spacecraft tumbles and recovery is required to assist magnetic torque recovery or to dump momentum. Normal spacecraft redundancy actions are overridden. Thruster firings did occur at the end of the maneuver as the spacecraft recovered and returned to a nominal mode.

## RESULTS OF PITCH MANEUVER

One hundred thirty-nine scans were selected while the instrument was viewing deep space, on 10 August 2006, from 16h28m35s to 17h27m53s UTC. Viewing of deep space was determined when all eleven nominal earth scene views registered to within a few counts of the space calibration view. Since the instrument counts vary with instrument temperature, the calibration space view was subtracted from the nominal earth scene counts for each scan. The mean difference of counts was converted to antenna temperature differences by multiplying by the nominal slope of 0.12K/count, and are shown as a function of scan position in Figure 3. Channels 1 and 3 are vertically polarized and channels 2 and 4 are horizontally polarized at nadir. For reference, the scan diagram for the MSU is shown in Figure 4. Note that position 1 is in the direction of the spacecraft, position 6 is at nadir, and position 11 views away from the spacecraft and is closest to the space calibration view.

The corresponding values of the standard deviation of the difference show essentially random changes of about 0.01K from one scan position to the next. For brevity, these figures will not be presented in this letter.

Three points are worth noting:

The first point to note is that the nominal earth scene viewing space records different brightness temperatures than the space calibration view. This difference is greatest in channel 1 at nadir position 6 of about 0.5 K. The vertically polarized channels register colder than the space look, and the horizontally polarized channels register warmer than the space look. As shown in figure 4, the space look is  $85.263^\circ$  from nadir. The nominal half power (3dB) antenna beamwidth is  $7.5^\circ$ , which means that the edge of the nominal field of view is  $89.013^\circ$  from nadir. As can be seen in Figure 1, the MSU sits on top of its electronics enclosure, which itself is enclosed by a thermal blanket with a reflective surface. We hypothesize that a side lobe is viewing the thermal blanket while the instrument is in its space look. Note that the nominal channel polarization is at nadir, and the polarization vector rotates through the scan. This means that when viewing space, the nominal vertical polarization channels would be horizontal, and the nominal horizontal polarization channels would be vertical. Since the nominal vertical channels are colder and the nominal horizontal channels are warmer than the space look, this suggests radiation is scattered off the thermal blanket in such a way as to be horizontally polarized.

The second point is that there is a marked asymmetry in the nominal earth scene, and the characteristics of the asymmetry differ for the different polarizations. The vertically polarized channels display maximum difference from the space look near the nominal nadir position. The horizontally polarized channels on NOAA-14 tend to have a maximum in the lower scan positions, and a minimum in the higher scan positions. This suggests that the side lobes are sensing the spacecraft components and instruments in a manner that is polarization sensitive.

The third point is that position 1 reads higher values than position 2. It is clear that the instrument side lobes are sensing something on the spacecraft in scan position 1, perhaps the Earth Radiation Budget Experiment dummy payload which appears to be in line with the MSU scan.

## SPACECRAFT TUMBLE

On 28 September 2006, a thruster on NOAA-14 released hydrazine gas, causing the spacecraft to tumble. Approximately two orbits of instrument data were collected by the onboard recorders until the instruments were turned off in order to manage power. Over the next few days the spacecraft was returned to normal operations and the instrument data were recovered. This anomaly provided a unique opportunity to evaluate whether the asymmetry found in the pitch maneuver changed during the ensuing seven weeks.

The MSU data were carefully screened to exclude any earth influence in the individual scene and calibration views. The average of each scene and space calibration views were then differenced in the same manner as for the pitch maneuver. The results are presented in Figure 5.

Two points are noticed in comparing Figure 5 to Figure 3:

First, channel 2 difference from space look is sensing about 0.15 K counts colder during the tumble than during the pitch. The other channels either have no change, or the difference from space look is positive (warmer).

Second, the absolute average of all scene positions is warmer during the tumble than during the pitch.

Since channels 2 and 4 have the same polarization, it is unknown why the change in their behavior is so different between the pitch and the tumble.

## SUMMARY

The National Oceanographic and Atmospheric Administration has successfully performed a POM on NOAA-14. The test showed that earth scene viewing space reads different values than the space calibration view does, that there is an asymmetry in the observations, and that scan position 1 is warmer than scan position 2. Data gleaned from a spacecraft tumble seven weeks later reveal that most channels' earth scene sense warmer than the space look, but that channel 2 senses colder.

## ACKNOWLEDGEMENTS

The views expressed in this publication are those of the author and do not necessarily represent an official position or policy of NOAA, the Department of Commerce, or the United States Government.

## REFERENCES

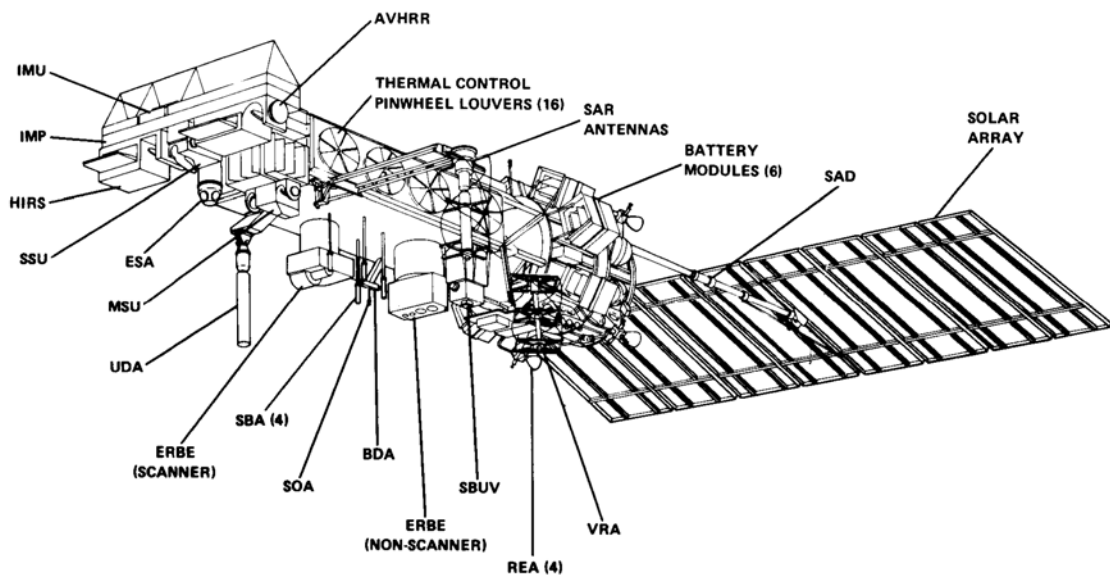
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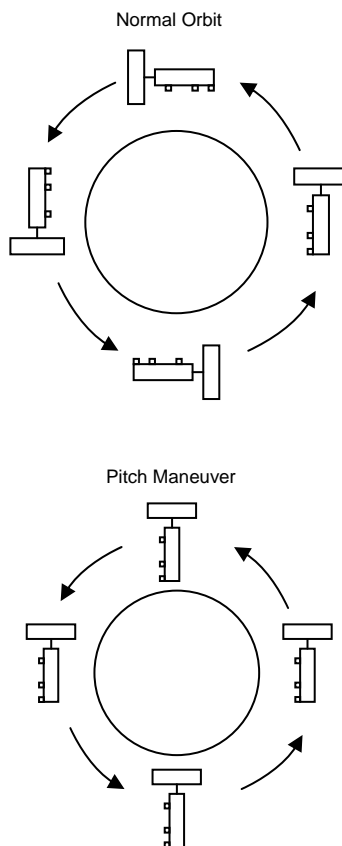
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**Figure 1:** NOAA-14 spacecraft with locations of instruments and major components. The Earth Radiation Budget Experiment (ERBE) instruments are dummies on NOAA-14. From the viewpoint of the reader, the MSU reflector for channels 1 and 2 is on the right side of the instrument, and the reflector for channels 3 and 4 is on the left side of the instrument.



**Figure 2:** Schematic of spacecraft attitude in normal orbit, and during the pitch maneuver.

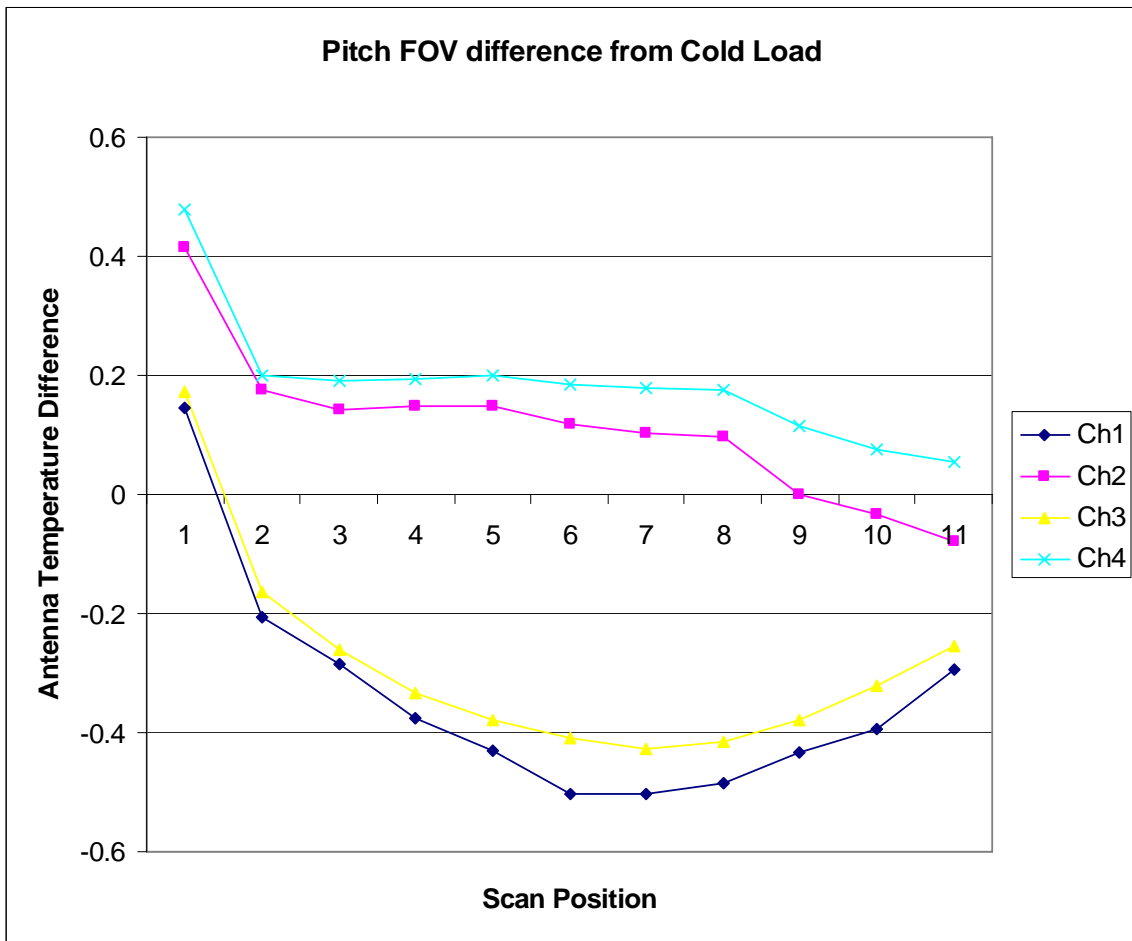


Figure 3. Mean antenna temperature difference of nominal earth scene view minus space calibration view, averaged over 139 scans viewing space, as a function of scan position. Channels 1 and 3 are vertically polarized, and channels 2 and 4 are horizontally polarized.

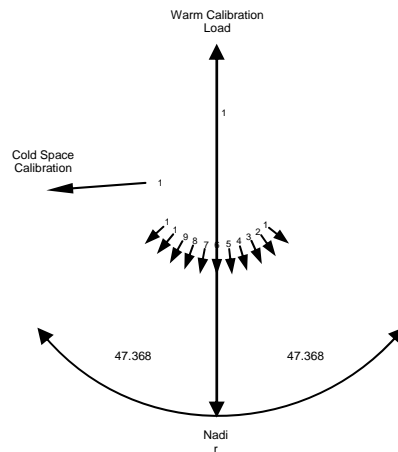


Figure 4. Schematic of MSU scan pattern. Positions 1 through 11 are earth scenes, with position 1 viewing in the direction of the spacecraft, and position 11 viewing away from the spacecraft. Position 6 is nadir. Position 12 is the cold space calibration view, and position 13 is the internal warm calibration target view. The velocity vector is out of the page.

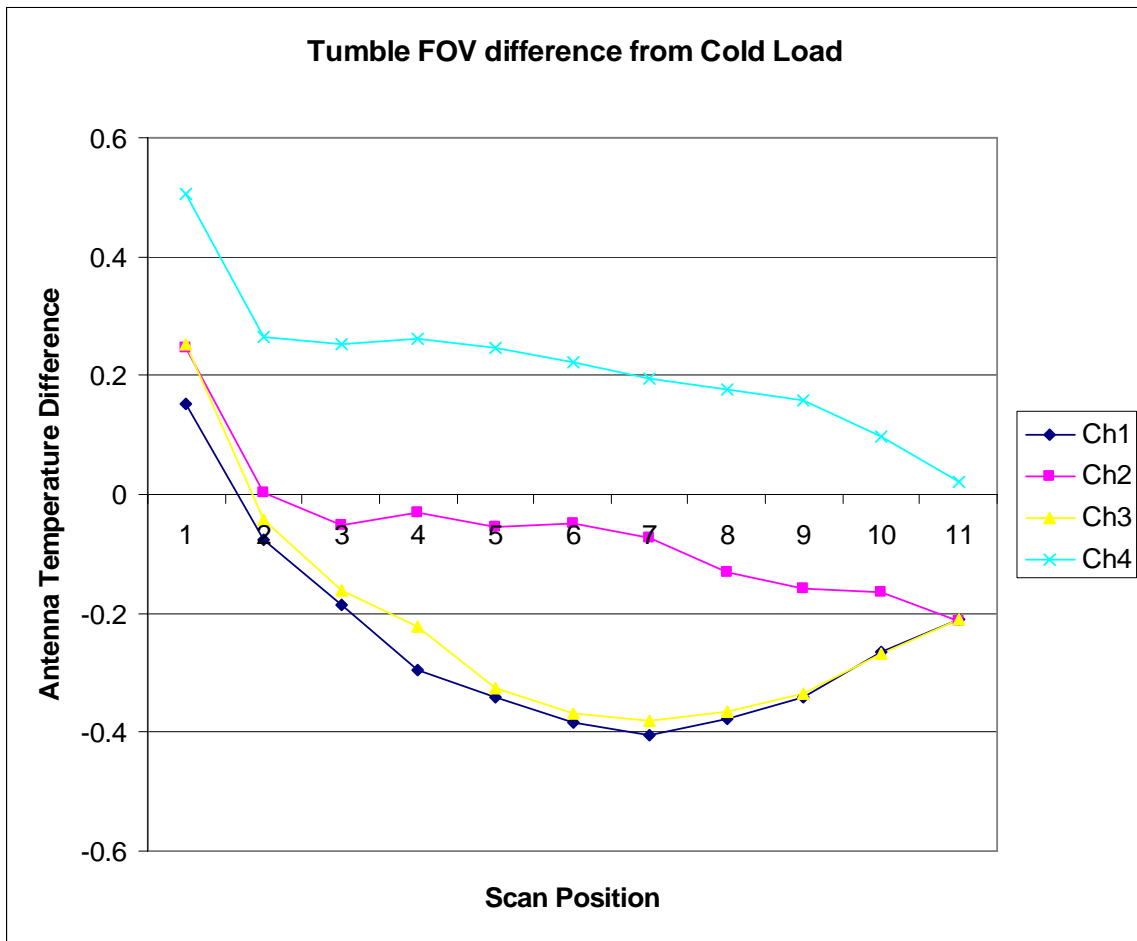


Figure 5: Same as Figure 3 but for tumble event.

Table 1. MSU Instrument Specifications				
Characteristic	Channel			
	1	2	3	4
Frequency (GHz)	50.30	53.74	54.96	57.95
RF bandwidth (MHz)	220	220	220	220
Resolution at nadir (km)	105	105	105	105
Number of earth views	11	11	11	11
Scan width from nadir	$\pm 47.4^\circ$	$\pm 47.4^\circ$	$\pm 47.4^\circ$	$\pm 47.4^\circ$
Antenna beamwidth	$7.5^\circ$	$7.5^\circ$	$7.5^\circ$	$7.5^\circ$
Antenna beam efficiency	>90%	>90%	>90%	>90%
Polarization at Nadir	V	H	V	H
Integration time (seconds)	1.84	1.84	1.84	1.84