GSFC-DE-200-038-2

PERFORMANCE ANALYSIS OF THE SCAN PLATFORM CONTROL ELECTRONICS

MAY 4, 1978

REVISED SEPTEMBER 10, 1979

R. A. Hoffman
Code 696
Goddard Space Flight Center
Greenbelt, MD 20771

Table of Contents

I. SYSTEM DESCRIPTION

A. Purpose

The purpose of the scan platform control system is to provide the control signals to the scan platform drive electronics, which operates the motor to rotate the scan platform to align a fiducial direction on the scan platform with the direction of the earth's magnetic field (as projected onto the spacecraft X-Y plane), or to align the fiducial direction to a commanded offset to this field direction.

B. Requirements

The system provides two logic level control signals to the scan platform drive electronics, a drive-no drive signal, and a clockwise-counter clockwise signal. These signals are generated from processing the output signal from the control system magnetometer in a manner defined by a minor mode command. These control signals cause the scan platform fiducial line to be aligned to the local magnetic field, as projected onto the spacecraft X-Y plane, to the accuracy of processing, in the following manner, depending upon the status of ground commands:

i) The fiducial line always parallel to the field.
ii) The fiducial line always antiparallel to the field.
iii) The fiducial line at an offset angle to either of the above directions, with the angle determined by a commanded value and the strength of the local field.

C. Coordinate Systems

i) Spacecraft system:

+X axis in direction of spacecraft velocity.

+Y axis radially outward from the earth when spacecraft is "right-side-up" (when orbit plane is oriented such that spacecraft is moving from dawn to dusk hemisphere over north pole) and inward when "up-side-down" or inverted.

+Z axis normal to orbit plane in a right-handed system.

ii) Scan platform - The fiducial line is parallel to the 0^{o} detectors in the X-Y plane.

iii) Scan platform shaft encoder - 0^{o} when fiducial line is aligned with the +X axis of the spacecraft. The rotation angle, ϕ, is positive clockwise, i.e., rotation from +X toward -Y.

iv) Control magnetometer - rotates with the scan platform; axis is normal to fiducial line; + output when component of the magnetic field is in -Y direction when $\phi = 0^{o}$.

D. Brief Description

The scan platform control system is composed of three subsystems:

i) Control magnetometer

Single axis, $\pm 64,000\gamma$ range. Sensor is mounted on the magnetometer mast; electronics in mounted within LAPI instrument.

ii) Magnetometer mast, along +Z axis of the spacecraft, mounted on the scan platform.

iii) Control system electronics, mounted in the central electronics box of LAPI, which processes the signal from the control magnetometer and provides the control signals for the scan platform drive electronics.

The magnetometer is used as a nulling device. The output of the magnetometer is digitized in the control system electronics, and compared to a digital word which is controlled by a minor mode command. This word provides for zero level of the magnetometer, and can be adjusted for magnetometer drift, spacecraft contamination fields, or as an offset angle to a true null. The + or - output of this comparison, together with ground command bits, which define the mode of operation selected from I-B above, defines the logic signals to rotate the scan platform to proper alignment.

II. PARAMETER ANALYSIS

A. Magnetic field strength for dipole field at the earth's surface:

$$B = B(\text{equator})\ (1 + 3 \sin^2 \lambda)^{1/2}$$

with B(equator) = 32,000 gammas.

B. Dip angle or inclination

$$\tan \phi(\text{dip}) = 2 \tan \lambda(\text{magnetic latitude})$$

C. Rate of change of ϕ

$$\frac{d\phi}{dt} = \frac{d\phi}{d\lambda}\frac{d\lambda}{dt} = \frac{360^\circ}{100\text{min}} \quad \frac{2}{(1+4\tan^2\lambda)\ \cos^2\lambda} = \frac{7.2^\circ/\text{min}}{(1+4\tan^2\lambda)\cos^2\lambda}$$

The above three quantities are plotted in Figure II-1.

D. Digitization accuracy

Magnetometer full scale = $\pm$64,000 gammas

6 bits (5 bits + sign) - 2000 gammas
7 bits (6 bits + sign) - 1000 gammas
8 bits (7 bits + sign) - 500 gammas
9 bits (8 bits + sign) - 250 gammas

E. Angular uncertainty due to digitization

$$\sin \alpha = \frac{\text{digitization accuracy}}{\text{total field}}$$

Maximum total field: 64,000 gammas
Minimum total field: 27,000 gammas

Digitization	Uncertainty in: Maximum field	Minimum field
6 bits	1.80°	4.24°
7 bits	0.90°	2.12°
8 bits	0.45°	1.06°
9 bits	0.23°	0.53°

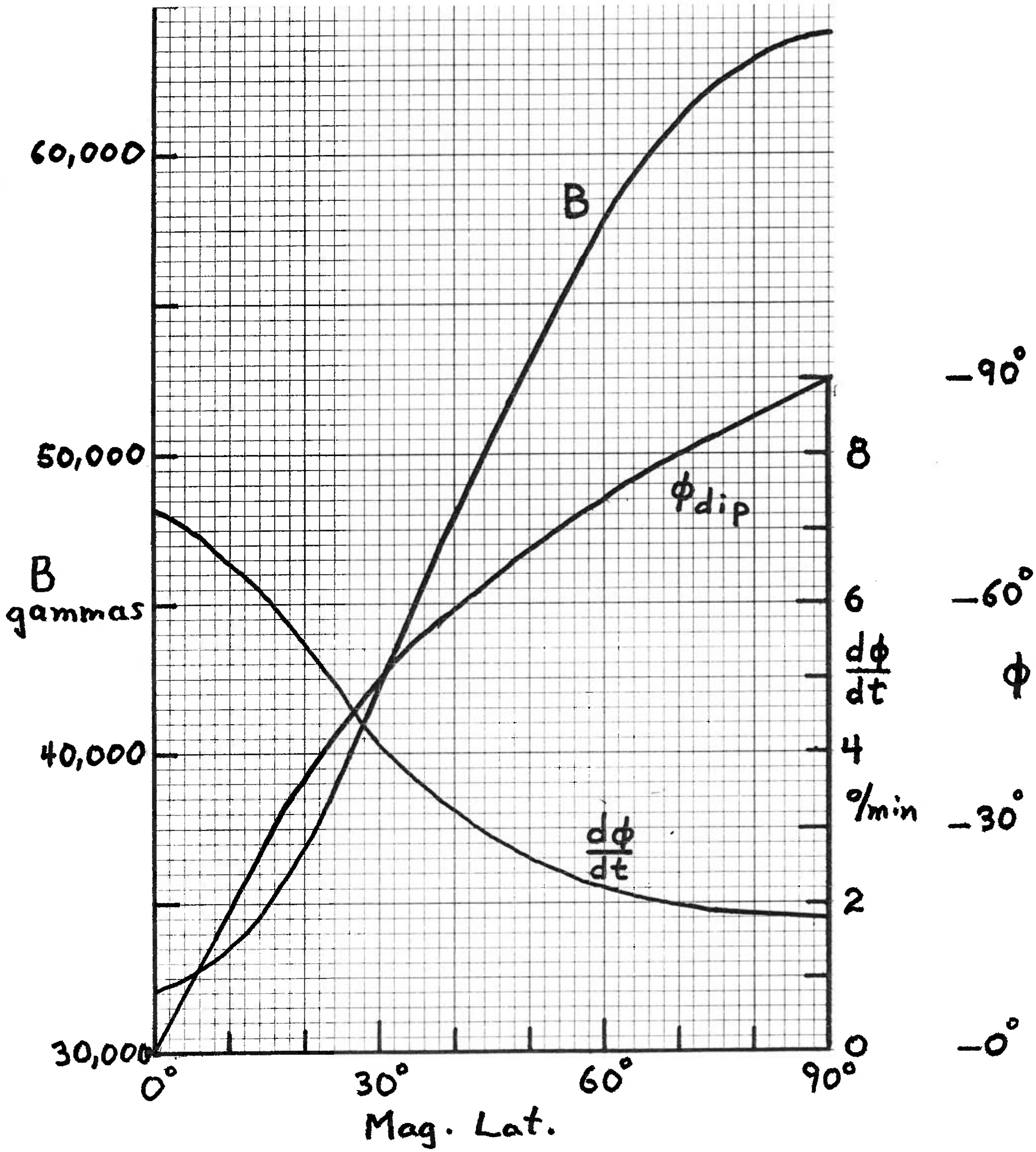

60,000
50,000
40,000
30,000
B
gammas
B
ϕ_{dip}
$\frac{d\phi}{dt}$
$\frac{d\phi}{dt}$
°/min
8
6
4
2
0
−90°
−60°
−30°
−0°
ϕ
0°
30°
60°
90°
Mag. Lat.

FIGURE II-1

III. BASIC OPERATION

A. Shaft Encoder vs. Latitude

See Figures III-1.

Logic Table for Nulling

Case	Magnetometer Output	Rotational Direction
1. Fiducial line anti-parallel to field. S/C rightside up.	+ -	ccw or $-\phi$ cw or $+\phi$
2. Fiducial line parallel to field. S/C rightside up.	+ -	cw or $+\phi$ ccw or $-\phi$
3. Fiducial line anti-parallel to field. S/C upside down.	+ -	ccw or $-\phi$ cw or $+\phi$
4. Fiducial line parallel to field. S/C upside down.	+ -	cw or $+\phi$ ccw or $-\phi$

Note that case pairs (1,3) and (2,4) are identical.

B. Acquisition Situations

This analysis assumes that at power-on the scan platform is at an arbitrary angle. It determines whether pre-set logic will initially orient the platform correctly. The cases considered in III-A and their corresponding logic are utilized. Cases 1-4 are straight forward and present no problem. Logic is commanded irrespective of spacecraft location and initial shaft encoder angle.

IV. NULL ANALYSIS

Principle: the null cone must be sufficiently large that the magnetometer will sense when the fiducial line passes into it, and after the drive signal to the scan platform is removed, the fiducial line must not move into the opposite drive direction region. Four factors must be considered:

1. Magnetometer noise equivalent angle.
2. Rotation angle of scan platform between successive digitizations of the magnetometer signal.
3. Magnetometer mast oscillation angle and bearing play.
4. Overshoot of platform after drive signal is removed.

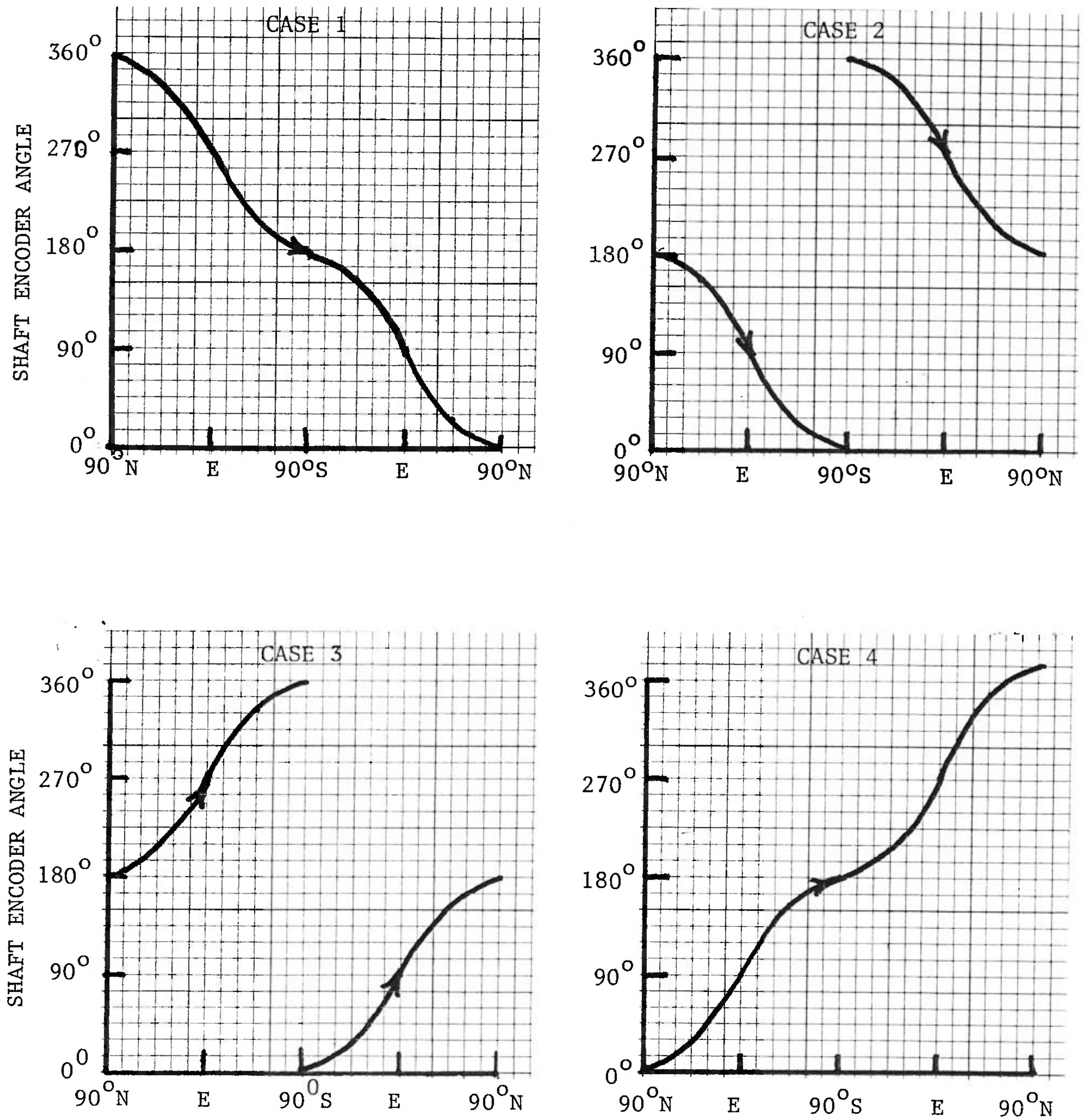

CASE 1
CASE 2
CASE 3
CASE 4
SHAFT ENCODER ANGLE
360°
270°
180°
90°
0°
90°N
E
90°S
E
90°N

FIGURE III-1

A. Magnetometer Noise

The magnetometer noise can be specified as <3mV. The equivalent angle is

$$\tan \mu = \frac{3mV}{\text{total field signal}}$$

For the maximum field of 64,000 gammas, the signal is equivalent to 2,500 mV; for the minimum field of 27,000 gammas, the signal is equivalent to 1,023 mV. Thus

	B gammas	μ
Max field:	64,000	0.07°
Min field:	27,000	0.16°

B. Scan Platform Angle of Rotation

The magnetometer signal will be converted from analog to digital 16 times/sec., synchronized to the minor frame. Should a null cone edge to stop driving come just after a digitization occurred, the scan platform would move for 1/16 sec before the Drive Enable could be turned off. The maximum angle of rotation for 1/16 sec appears in Run 41 of the RCA document "Simulation of the DE-B Scan Platform Control System", Note No. 4.15.2-041, at about 0.95 sec. after the Drive Enable is turned on, or at about 0.9° of platform rotation. This angle is 0.15°, or about two-thirds faster than the average rate of rotation.

C. Magnetometer Mast Oscillation Angle and Bearing Play

At the nominal rotation rate of 90°/min., the sum of these angles is measured to be 0.28°.

D. Overshoot

Overshoot is the angle through which the scan platform rotates after the drive signal to the scan platform motor is turned off. This angle is inversely proportional to the friction of the motor and resolver (angle encoder) bearings. Using the value of 50 in-oz-sec^2 for the inertia, 10 in-oz for the minimum specified friction, and 0.04 radians/sec for the maximum angular velocity (see B above) the overshoot is

$$\Theta_{max} = 1/2 \frac{\omega^2}{\ddot{\theta}} = 1/2 \frac{\omega^2}{(f/I)} = 1/2 \frac{(0.04)^2}{(10/50)} = 4 \times 10^{-3} \text{rad} = 0.24^{\circ}$$

E. Requirements

The first two factors determine the size of the null cone required for sensing the need to turn the drive signal off. This angle lies between 0.22° and 0.31° for the maximum and minimum field conditions.

The factors C and D determine the extent the platform can be additionally allowed to move without passing into the region where the drive signal for the opposite direction of drive would be turned on. It is 0.52°.

The application of these uncertainties for determining null cone sizes is given in Section V.

V. DE SCAN PLATFORM ELECTRONICS LOGIC

A. General

The basic mode of operation of the Scan Platform Control Electronics requires that the magnetometer output "H" be compared to a commanded bias "B", and the platform shall be driven until they (H and B) are equal within the resolution required (null cone). The comparisons for turning the drive motor on (setting motor command bit D=1) or turning it off (D=0) can be of 6,7,8 or 9 bits, depending upon the commanded configuration, and may be of different resolution.

This method of driving can be slightly modified to allow driving of the platform until H is no longer equal to B. For example if H is greater than B the platform will be driven through the region where H is equal to B and into the region where H is less than B. At this point the Drive will be shut off and the platform will drift back through the H=B region until H is greater than B when the entire cycle will begin again. This mode of operation is designed to reduce the total number of motor drive operations and will only slightly reduce the pointing accuracy of the platform.

B. Command Bits

The Scan Platform Minor Mode Command is used to control the scan platform modes of operation. (See Table 1) The principal bit is the PAP bit which defines the operating mode to be parallel (PAP=1) or anti-parallel (PAP=0). The following definitions apply:

MNEMONIC	BIT #	DEFINITION
PAP	16	If desired operation is Parallel then PAP=1, if anti-parallel then PAP=0.
DRN	~~13~~ 14	If DRN=1 then platform driving will be normal. (Drive into the null cone, H=B, and then stop driving). If the platform is pointing on either side of the null cone it will be driven back into the null cone. If DRN=0 then the alternate drive method of driving into the null cone, through it and out the other side will be incorporated. This method will cause driving in one direction only.
DRR	~~14~~ 15	This bit is used to determine which direction the platform will drive only if DRN=0. If DRR=0 then the platform will drive if H is greater than B (HGTB) through H equal B and out the other side of the null cone where H is less than B. Note the the proper drive direction is determined by the PAP command bit. At this point the drive output, D, will return to 0 and driving will cease. If DRR=1 then the platform will drive if H is less than B (HLTB) through H equals B and out the other side of the null cone where H is greater than B. At this point driving will cease (D=0).
B1-B9	1-9	B1 through B9 are the bias bits "B" that are used for comparison with the "H" magnetometer output. B1 is the MSB and B9 the LSB.

DR1 DR2	10 11	DR1 and DR2 are used together to determine the null cone size for turning the drive motor on (D=1). The logic table is as follows:

DR1	DR2	RESOLUTION
0	0	6 bits
0	1	7 bits
1	0	8 bits
1	1	9 bits

SDR1 SDR2	12 13	SDR1 and SDR2 are used together to determine the null cone size for turning the drive motor OFF (D=0). The logic table is as follows:

SDR1	SDR2	RESOLUTION
0	0	6 bits
0	1	7 bits
1	0	8 bits
1	1	9 bits

TABLE 1

OPERATIONAL TRUTH TABLE

CASE NUMBER	BIT 16 (PAP)	HGTB	DRIVE DIRECTION (DD)	
1	0	1	CCW	DD=0
	0	0	CW	DD=1
2	1	1	CW	DD=1
	1	0	CCW	DD=0
3	0	1	CCW	DD=0
	0	0	CW	DD=1
4	1	1	CW	DD=1
	1	0	CCW	DD=0

Note that Cases 1 and 3 are identical as are Cases 2 and 4. Thus for all operations it only requires the command bit PAP to choose between the four case numbers. The other command bits also need to be configured to support the basic modes of operation as defined above.

C. Normal Operation

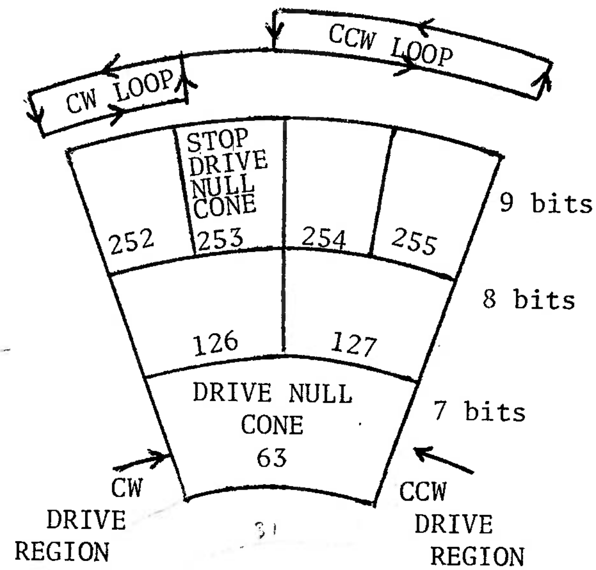
Normal operation of the Scan Platform is defined as follows:

Set DRN=1
DRR=don't care
B1-B9=TBS (Example 253: 011111101)
DR1=0 }
DR2=1 } 7 bits (011111=63)
SDR1=1 }
SDR1=0 } 9 bits (011111101=253)
PAP=1 or 0 depending on desired parallel or anti-parallel operation.

Note that the SDR resolution must always be equal to or greater than the DR resolution.

The resultant operation is to drive when the 7 bit DR comparison (H) with the first 7 bits of B1-B9 (B) does not agree, and to stop driving when the 9 bit SDR comparison (H) with B1-B9 (B) agrees. Driving will occur in either direction, depending upon whether the 7 bit H is greater than or less than B. B will have to be determined from prelaunch test data and analysis of flight data.

The hysteresis loops appear as follows:



The actual angular sizes of the null cones depend upon the magnetic field strength at the instantaneous location of the spacecraft. The range is as follows:

DR1-2 or SDR1-2	Maximum Field	Minimum Field
6	1.80°	4.24°
7	0.90°	2.12°
8	0.45°	1.06°
9	0.23°	0.53°

The maximum field region appears over the poles, the minimum at the equator.

Referring back to Section 4-E, Requirements, and the above figure, it is necessary that the H=B condition be sensed when a 9 bit comparison is made at 253. Since the sum of factors A and B, magnetometer noise and scan platform angle of rotation, is 0.22° for the maximum field region and 0.31° for the minimum, the 9 bit null cone size appears adequate (though marginal for maximum fields) for the SDR comparison. However, after power has been removed from the motor factors C and D (mast oscillation and bearing play plus overshoot) may carry the magnetometer another 0.52^{o} beyond the angle resulting from factors A and B. This is permissible so long as the angle does not go beyond the 7 bit null cone (defined by the DR bits). Thus we have the requirement that the sum of the four factors cannot be larger than twice the null cone defined by the SDR bits (angle defined by 252 + 253 in the example). Thus, in this case a 9 bit SDR comparison for the maximum field region is inadequate, since

$$2 \times 0.23^{o} = 0.46^{o} < 0.22^{o} + 0.52^{o} = 0.74^{o}$$

instead of the requirement of greater than. Thus an 8 bit SDR is required.

D. Alternate Operation

Alternate operation of the Scan Platform is defined as follows:

Set DRN=0
DRR=1 or 0 depending on desired drive mode (see definition)
B1-B9=TBS
DR1=0, DR2=1 } 7 bits
SDR1=0, SDR2=1 } 7 bits
PAP=1 or 0 depending on desired parallel or anti-parallel operation.

The resultant operation is to drive into the through the 7 bit null cone and then stop driving. Driving will occur in one direction only. The choice of direction with the DRR bit will be made based on hemisphere and case number. The size of the null cone will be determined by the DR and SDR command bits. B will have to be determined from prelaunch test data.

E. Other Operations

Reconfiguration of B1-B9 may be used to arbitrarily choose any desired pitch angle for the scan platform fiducial line after suitable calibration of the magnetometer performance.