APPENDIX J: INSTRUMENT SCAN PROPERTIES

Each instrument onboard the NOAA KLM and NOAA-N,N’ series of spacecraft has its own unique scanning properties. This appendix contains a table of parameters (Table J-1) for the scanning instruments on the TIROS-N through NOAA-14 series (the TIROS-N series), and a table for the instruments on NOAA KLM and NOAA-N, N’ (Table J-2). It should be noted that the AVHRR instrument scans from the anti-Sun side to the Sun side; i.e., from right to left when facing in the direction of satellite motion. All other instruments scan in the opposite direction.

The SEM and DCS/2 instruments have not been included in this appendix, because neither instrument scans. The SEM has fixed FOVs and the DCS/2 is a passive instrument acting as a transponder. Technically, the SBUV/2 instrument does not scan, but is a nadir viewing instrument. However, a brief section (J.4) is included describing how it looks at the earth through a sequence of 12 wavelength changes.

In addition, this appendix contains a section for each instrument with figures showing the scan motion.

Table J-1. Satellite Scanning Instrument Parameters for TIROS-N through NOAA-14.

Parameter	AVHRR/2	HIRS/2 & 2I [7]	SSU	MSU
IFOV (Degrees)	0.0745	HIRS/2: 1.22 HIRS/2I: 1.40	10	7.5
Full scan period (seconds)	0.1667	6.4	32	25.6
Earth View				
Total number of earth view steps	2048	56	8	11
Center to center FOV step angle (Degrees)	0.0541	1.8	10	9.4737
Max scan angle (Degrees from Nadir to the center of outer earth FOV)	55.37	49.5	35	47.3685
Total earth view time (msec)	51.2	5600[1]	32000[6]	20823
FOV integration time + dead time[8] (msec)	0.025	100	4000	1893

Integration period/FOV (msec)	0.025	Channel 1=5.1; Channels 2-12=1.8; Channels 13-20=4.5.	3600	1820
Initial offset time from TIP to start of integration period (msec) [4]	2.529	20.4	400	0
Difference between the TIP start to center of integration period of first FOV (msec)	2.5415	23.0	2200	910
Rotational rate during integration	6 cycles/sec	0	0	0
Space View				
Space view time (msec)	0.250	4800[2]	15600[6]	1820
Number of samples	10	48	4	1
Integration time/sample (msec)	0.025	Channel 1=5.1; Channels 2-12=1.8; Channels 13-20=4.5.	3600	1820
Total integration time (msec)	0.250	216	14400	1820
Internal Calibration Target (ICT) View(s)				
Internal calibration target(s) view time (msec)	0.250	Cold: 5600[3] Warm: 5600[3]	15600[6]	1820
Number of samples	10	56	4	1
Integration time/sample (msec)	0.025	4.5	3600	1820
Total integration time (msec)	0.250	256	14400	1820
Ground Resolution [5]				
IFOV diameter at nadir (km)	1.1	HIRS/2: 17.7 HIRS/2I: 20.4	147.5	109.9
IFOV at center of outer FOV (km)	6.2 x 2.3	HIRS/2: 59.5 x 30.4 HIRS/2I: 68.3 x 34.8	243.9 x 183.4	356.4 x 175.8
Half Swath Width [5]				

Nadir to center of outer FOV (km)	1460.2	HIRS/2: 1089.4 HIRS/2I: 1089.4	604.2	816.8
Nadir to far edge of outer FOV (km)	1463.3	HIRS/2: 1119.8 HIRS/2I: 1124.4	736.3	1173.2

1 The earth view steps rapidly, then holds at each position while the 20 filter segments are sampled. Multispectral data from one visible, seven shortwave, and twelve longwave are obtained.

2 The space views position is held while the 20 filter segments are sampled 48 sequential times.

3 The ICT view positions are held while the 20 filter segments are sampled 56 sequential times.

4 Time offsets from TIP first major frame time to the center of the first FOV when all instruments are at the beginning of scan (every 128 seconds).

5 All earth dimensions are based on a 833 km height above a spherical earth of radius 6371.22 km.

6 The space and ICT view sequences are performed every 256 seconds and last 32 seconds. This is followed by 7 cycles of earth view sequences (each lasting 32 seconds).

7 HIRS/2I was flown on NOAA-14 only.

8 Dead time is defined as the non-integration time needed for reflector slewing and/or transferring of data.

Table J-2. NOAA Satellite Scanning Instrument Parameters for NOAA KLM and NOAA-N, N'.

	AVHRR/3	**HIRS/3**	**HIRS/4**	**AMSU**			**MHS**
				-A1	**-A2**	**-B**	
IFOV (Degrees)	0.0745	1.40	0.69	3.3	3.3	1.1	1.1
Full scan period (seconds)	0.1667	6.4	6.4	8	8	2.67	2.67
Earth View							

Total number of earth view steps	2048	56	56	30	30	90	90
FOV Step angle (Degrees)	0.0541[6]	1.8	1.8	$3^1/_3$	$3^1/_3$	1.1	1.1111
Max scan angle (Degrees from Nadir to the center of outer earth FOV)	55.37 [6]	49.5	49.5	48.33	48.33	48.95	49.4444
Total earth view time (msec)	51.2	5600[1]	5600[1]	6075	6075	1620	1710
FOV integration time + dead time (msec)[7]	0.025	100	100	202.5	202.5	19	19
Integration period/FOV (msec)	0.025	Channel 1=5.1; Channels 2-12 = 1.8; Channels1 3-20 = 4.5.	Channel 1=5.1; Channels 2-12 = 1.8; Channels 13-20 = 4.5.	165	158	18	19
Initial offset time from TIP to start of integration period (msec) [4]	2.529	20.4	20.4	3.55	3.26	-9	-38[8]
Difference between the TIP to center of integration period of first FOV (msec)	2.5415	23.0	23	86.05	82.26	9	-28.5
Rotational rate during integration	6 cycles/sec	0	0	0	0	1 rad/ sec	1rad/ sec
Space View							
Space view time (msec)	0.250	4800[2]	4800[2]	365	365	75	76

Number of integration samples	10	48	48	2	2	4	4
Integration time (msec)	0.025	Channel 1=5.1; Channels 2-12 = 1.8; Channels 13-20 = 4.5.	Channel 1=5.1; Channels 2-12 = 1.8; Channels 13-20 = 4.5.	165	158	18	19
Total integration time (msec)	0.250	216	216	330	316	72	76
Internal Calibration Target (ICT) View							
Internal calibration target view time (msec)	0.250	5600[3]	5600[3]	365	365	75	76
Number of integration dwells	10	56	56	2	2	4	4
Integration time/dwell (m/sec)	0.025	Channel 1=5.1; Channels 2-12 = 1.8; Channels 13-20 = 4.5.	Channel 1=5.1; Channels 2-12 = 1.8; Channels 13-20 = 4.5.	165	158	18	19
Total integration time (msec)	0.250	252	252	330	316	72	76
Ground Resolution [5]							
IFOV diameter at nadir (km)	1.1	20.4	10.2	48.05	48.05	16.0	16
IFOV at center of outer FOV (km)	6.24 x 2.3	68.3 x 34.8	34.15 x 17.4	149.1 x 79.4	149.1 x 79.4	51.6 x 26.9	51.6 x 26.9
Half Swath Width [5]							

Nadir to center of outer FOV (km)	1460.2	1089.4	1089.4	1034.8	1034.8	1063.1	?
Nadir to far edge of outer FOV (km)	1463.3	1124.4	1107.325	1113.4	1113.4	1089.4	?

1 The earth view steps rapidly, then holds at each position while the 20 filter segments are sampled. Multispectral data from one visible, seven shortwave, and twelve longwave are obtained.

2 The space views position is held while the 20 filter segments are sampled 48 sequential times.

3 The ICT view position is held while the 20 filter segments are sampled 56 sequential times.

4 Time offsets from TIP first major frame time to the center of the first FOV when all instruments are at the beginning of scan (every 128 seconds).

5 All earth dimensions are based on a 833 km height above a spherical earth of radius 6371.22 km.

6 NOAA-16 has a max scan angle of 55.25 degrees with a step angle of 0.053981436 degrees.

7 Dead time is defined as the non-integration time needed for reflector slewing and/or transferring of data.

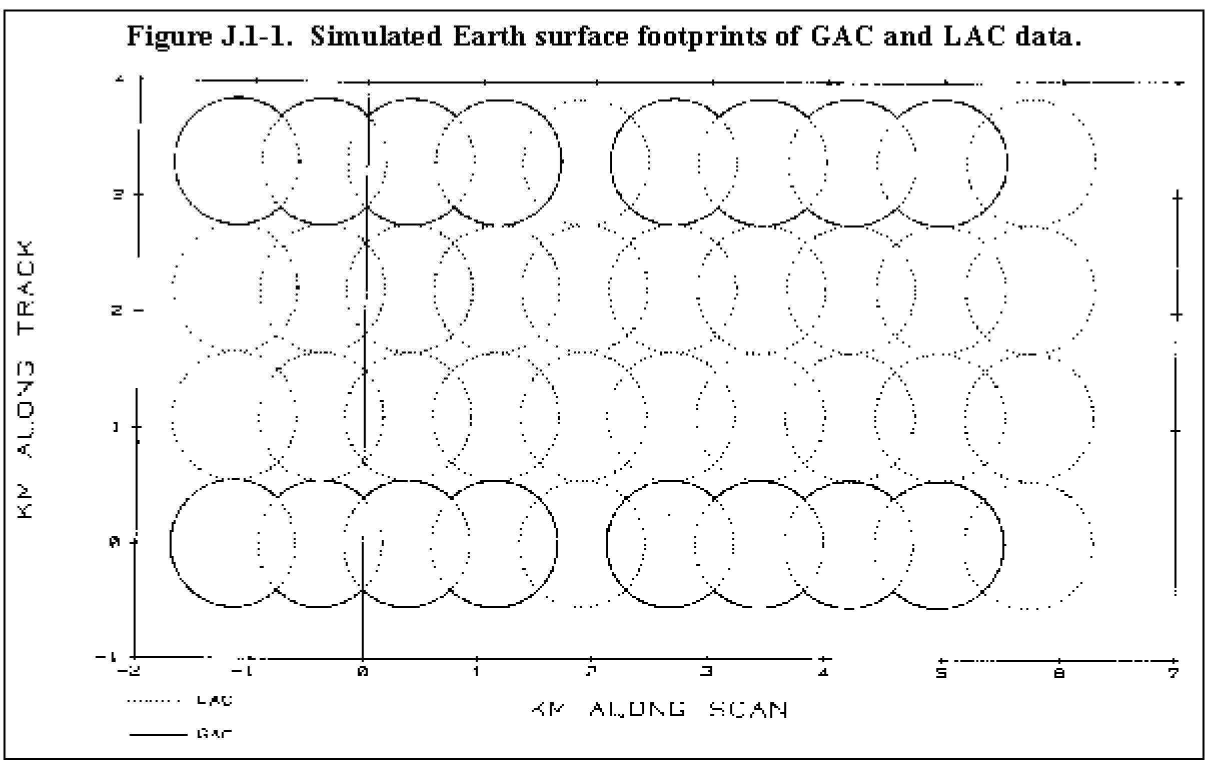
8 MHS data is delayed 2 scan periods for data handling overhead prior to the TIP time stamp.

J.1 AVHRR/3

The AVHRR/3 is an imaging system in which a small field of view (1.3 milliradians by 1.3 milliradians) is scanned across the earth from one horizon to the other by continuous 360 degree rotation of a flat scanning mirror. The orientation of the scan lines are perpendicular to the spacecraft orbit track and the speed of rotation of the scan mirror is selected so that adjacent scan lines are contiguous at the subsatellite (nadir) position. The analog data output from the sensors is digitized on board the satellite at a rate of 39,936 samples per second per channel. Each sample step corresponds to an angle of scanner rotation of 0.95 milliradians. At this sampling rate, there are 1.362 samples per IFOV. A total of 2048 samples will be obtained per channel per Earth scan, which will span an angle of $\pm$ 55.4 degrees from the nadir (subpoint view). All six spectral channels of the AVHRR/3 are registered so that they all measure energy from the same spot on the earth at the same time.

As with earlier versions of the AVHRR instrument, the GAC processing of the AVHRR/3 data makes the frame rates directly compatible by only using the data from every third AVHRR/3 scan. The data are further reduced by averaging the value of four adjacent samples and skipping one sample of each channel of AVHRR data across each scan line used. Figure J.1-1 shows the relationship of GAC and LAC data, while Figure J.1-2 shows the signal position as a function of scan angle for the AVHRR/3 instrument.

Figure J.1-1. Simulated Earth Surface Footprint of GAC and LAC Data.



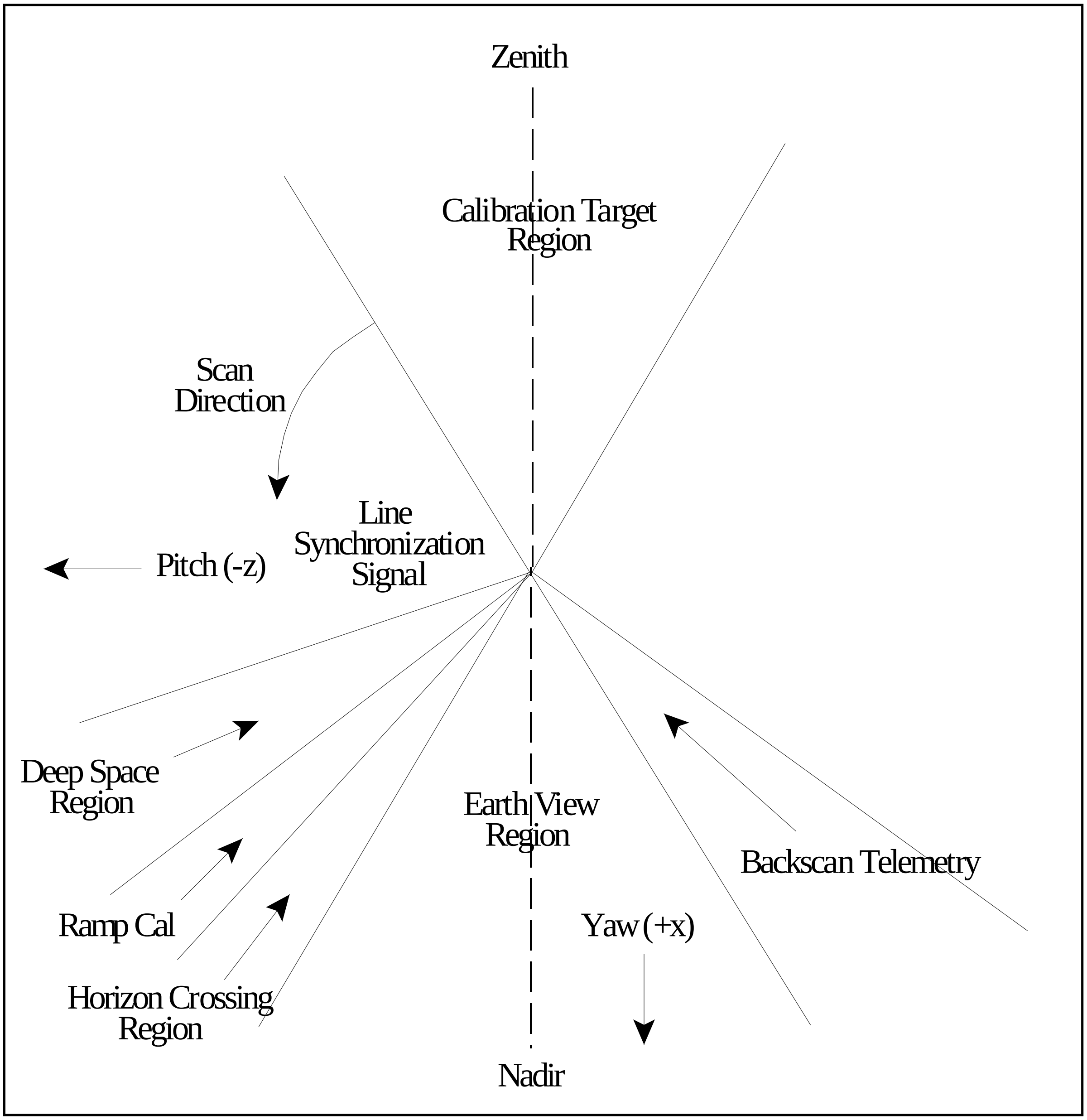


Figure J.1-2. AVHRR/3 Signal Position as a Function of Scan Angle.

J.2 HIRS/3 and HIRS/4

The High Resolution Infrared Radiation Sounder (HIRS/3 and HIRS/4) is a discrete stepping, line-scan instrument. An elliptical scan mirror provides cross-track scanning of 56 increments of 1.8 degrees. The mirror steps rapidly (<35 msec), then holds at each position while the 20 filter segments are sampled. This action takes place each 100 msec. The instantaneous HIRS/3 FOV

for each channel is approximately 1.4 degrees in the visible and shortwave IR, and 1.3 degrees in

the longwave IR band which, from an altitude of 833 kilometers, encompasses an area of 20.3 kilometers and 18.9 kilometers in diameter, respectively, at nadir on the Earth. The instantaneous HIRS/4 FOV for each channel is approximately 0.69 degrees in the visible, shortwave and longwave IR bands which, from an altitude of 833 kilometers, encompasses an area of 10.005 kilometers in diameter at nadir on the Earth.

Figure J.2-1 shows the Earth scan pattern and the angular locations of the calibration targets relative to Earth scan for the HIRS/3 and HIRS/4 instrument. Figures J.2-2 and J.2-3 show the simulated earth-surface footprints for HIRS/3 and HIRS/4; and AMSU-A for a half scan and a full scan, respectively. Note: the scan mirror step size remains at 1.8 degrees per step for HIRS/3 and HIRS/4, so Figures J.2-2 and J.2-3 indicate the correct footprint position. However, the FOV of the HIRS/4 instrument is halved, so the footprint diameter for HIRS/4 will be half that of HIRS/3.

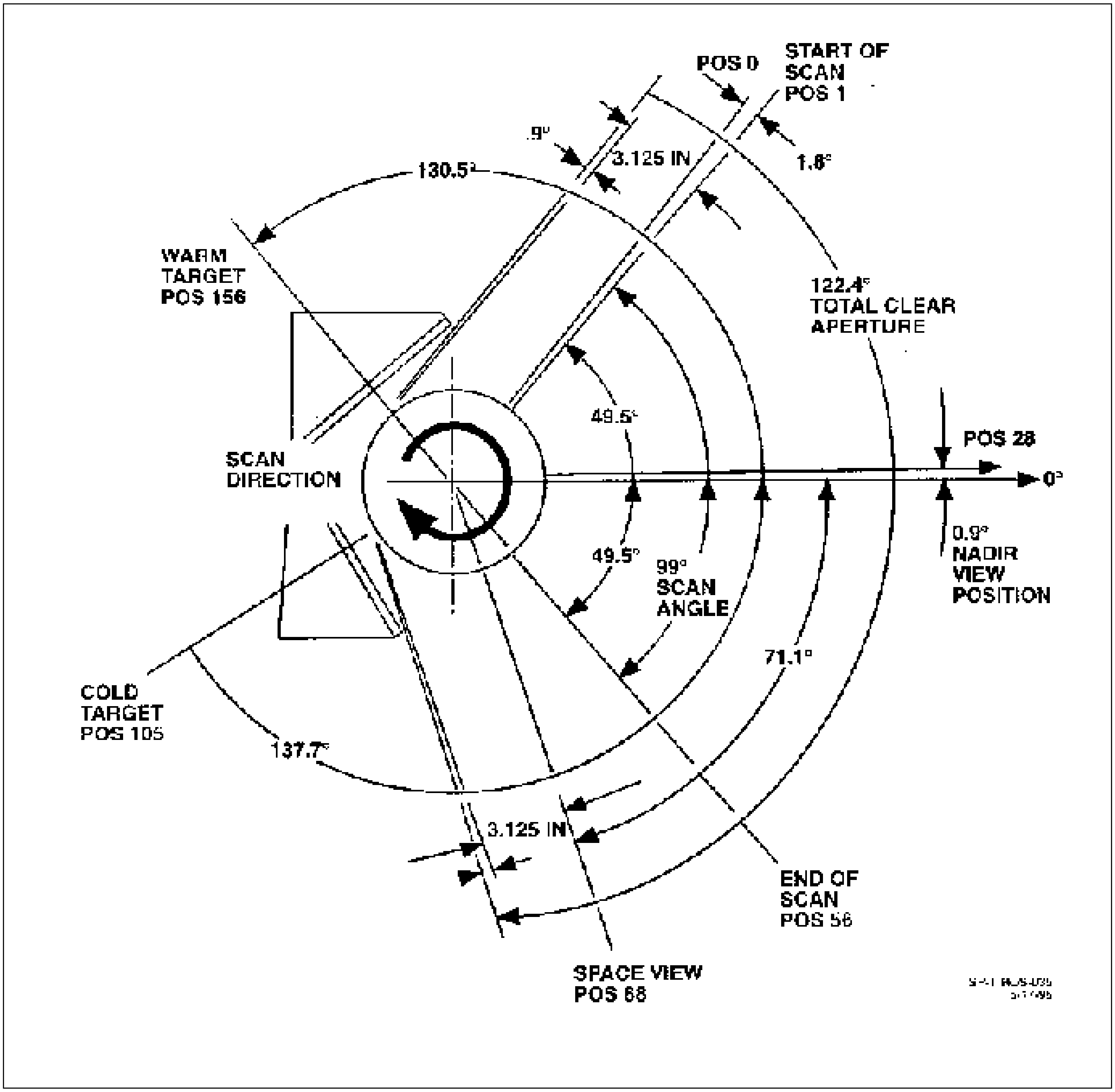


Figure J.2-1. Scan Angles for HIRS/3 and HIRS/4 Instruments

Figure J.2-2. Simulated Earth-surface footprints for HIRS/3 and AMSU-A (detail), half-scan.

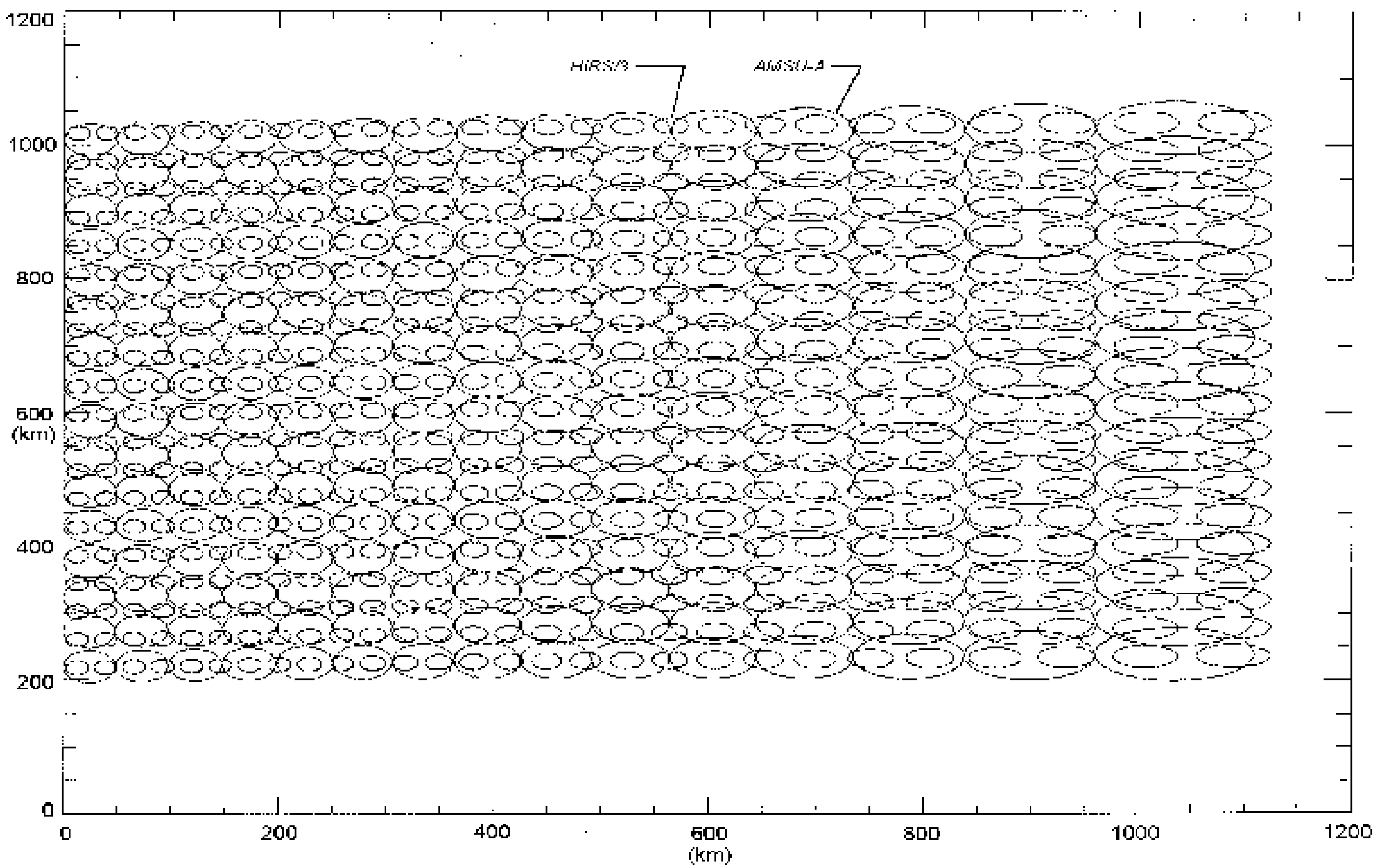


Figure J.2-2. Simulated Earth-surface Footprints for HIRS/3, HIRS/4 and AMSU-A (Detail), Half-Scan.

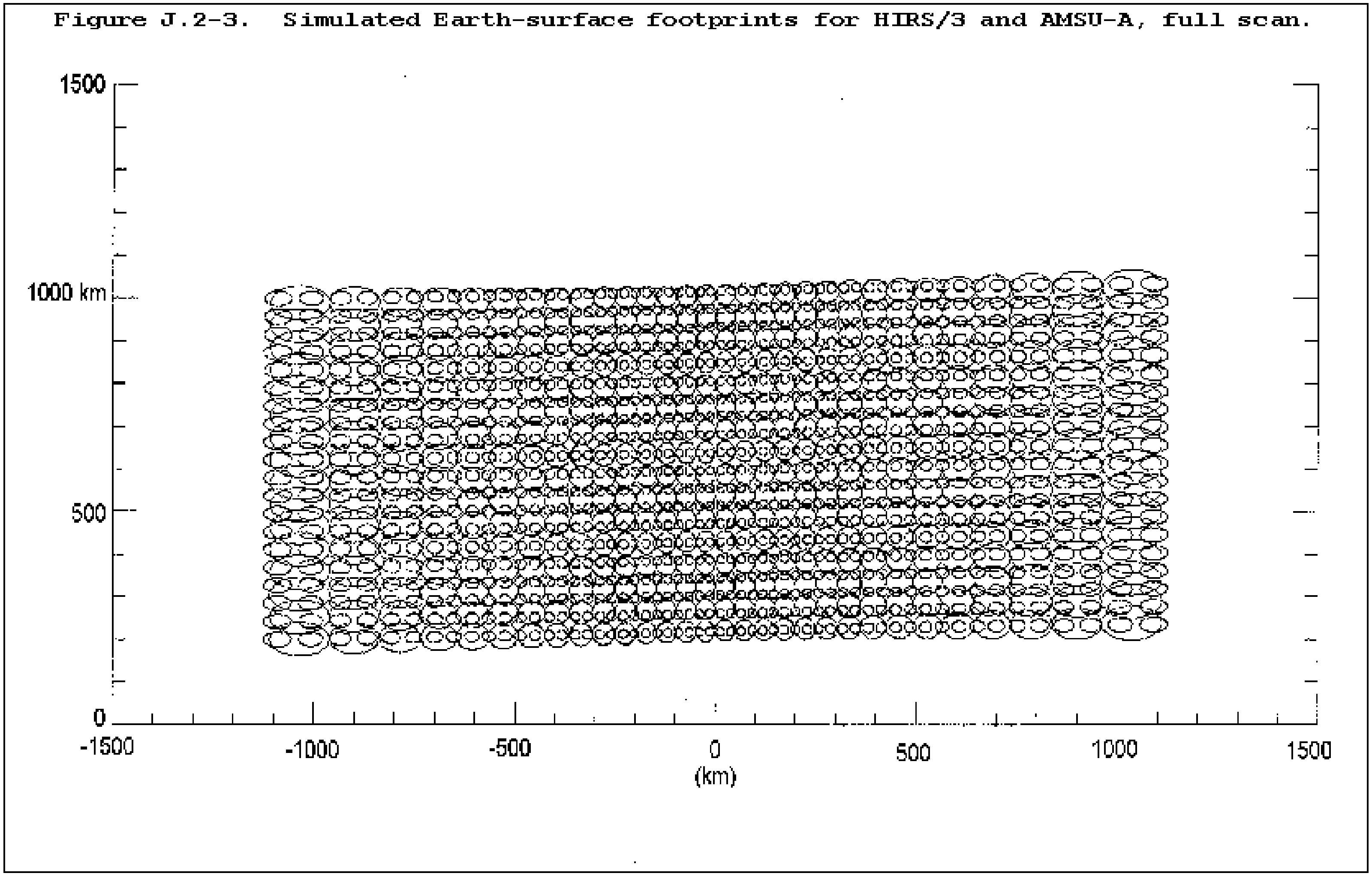


Figure J.2-3. Simulated Earth-Surface Footprints for HIRS/3, HIRS/4 and AMSU-A, Full Scan.

J.3 NOAA-KLM and NOAA-N, N' Microwave Instruments

Table J.3-1 contains a summary of scan initiation and FOV information for the microwave instruments.

Table J.3-1. Synopsis of Microwave Scan Initiation and FOV Information.

Instrument	Scan Period (seconds)	Integration Start Delay after 8 sec sync pulse (ms)	IFOV + dead time[2] (ms)	Earth Pixel integration period (ms)	IFOV (degrees)	Separation between adjacent Earth IFOVs (degrees)
AMSU-A1	8	+3.55	202.516	165	3 3/10	3 1/3
AMSU-A2	8	+3.26	202.50	158	3 3/10	3 1/3
AMSU-B	8/3	-9[1]	19	18	1 1/10	1 1/10
MHS	8/3	0[3]	19	19	1 1/10	1 1/9

Notes:

AMSU-A1 and AMSU-A2 are a step and stare instrument. AMSU-B is a continuous slew instrument.

1 On receipt of the 8 second sync pulse, the AMSU-B FOV will be at Cell 1 centered with its integration period half completed.

2 Dead time defined as the non-integration time needed for reflector slewing and/or transferring of data.

3 MHS data is delayed 2 scan periods (5 2/3 seconds) because of spacecraft and instrument data handling. Level 1b geo-locations are corrected for this data. HRPT data does not adjust for the delay.

AMSU-A is a cross-track, line-scanned instrument designed to measure scene radiances in 15 discrete frequency channels. At each channel frequency, the antenna beamwidth is a constant 3.3 degrees (at the half power point). Thirty contiguous scene resolution cells are sampled in a stepped-scan fashion (i.e., the instrument's FOV rotates to a data collection position, stops, collects data, then moves to the next collection position, stops, collects data, etc.) every eight seconds, each scan covering 50 degrees on each side of the subsatellite path. The AMSU-A

instrument starts at earth position 1, then goes sequentially to earth position 30, then to the cold calibration view position and then to the warm load view position (See Figure J.3-1). These scan patterns and geometric resolution translate to a 50 km diameter cell at nadir and a 2,343 km swath width from the 833 km nominal orbital altitude.

In the step scan, the AMSU-A antenna steps and stops at each beam position for a period equal to the sample period, plus a settle time, sufficient to insure a maximum jitter (percentage overshoot/undershoot of the antenna step). For AMSU-A1, a jitter up to +10% is allowed for any 10 ms period in the first .33 of the step period. Otherwise, the jitter will be less than or equal to $\pm$5%. For AMSU-A2, a jitter up to +10% is allowed for any 20 ms period in the first .33 of the step period. Otherwise, the jitter will be less than or equal to +/-5%. The step time for the 30 earth view beam positions will be equal.

Each channel of the AMSU-A instrument is considered to form a beam. All main beam axes of the AMSU-A will be coincidental, i.e., they will be pointing in the same direction at the same time for any given beam position. In the following paragraphs, if only one beam is discussed, it is inferred to represent any and all beams.

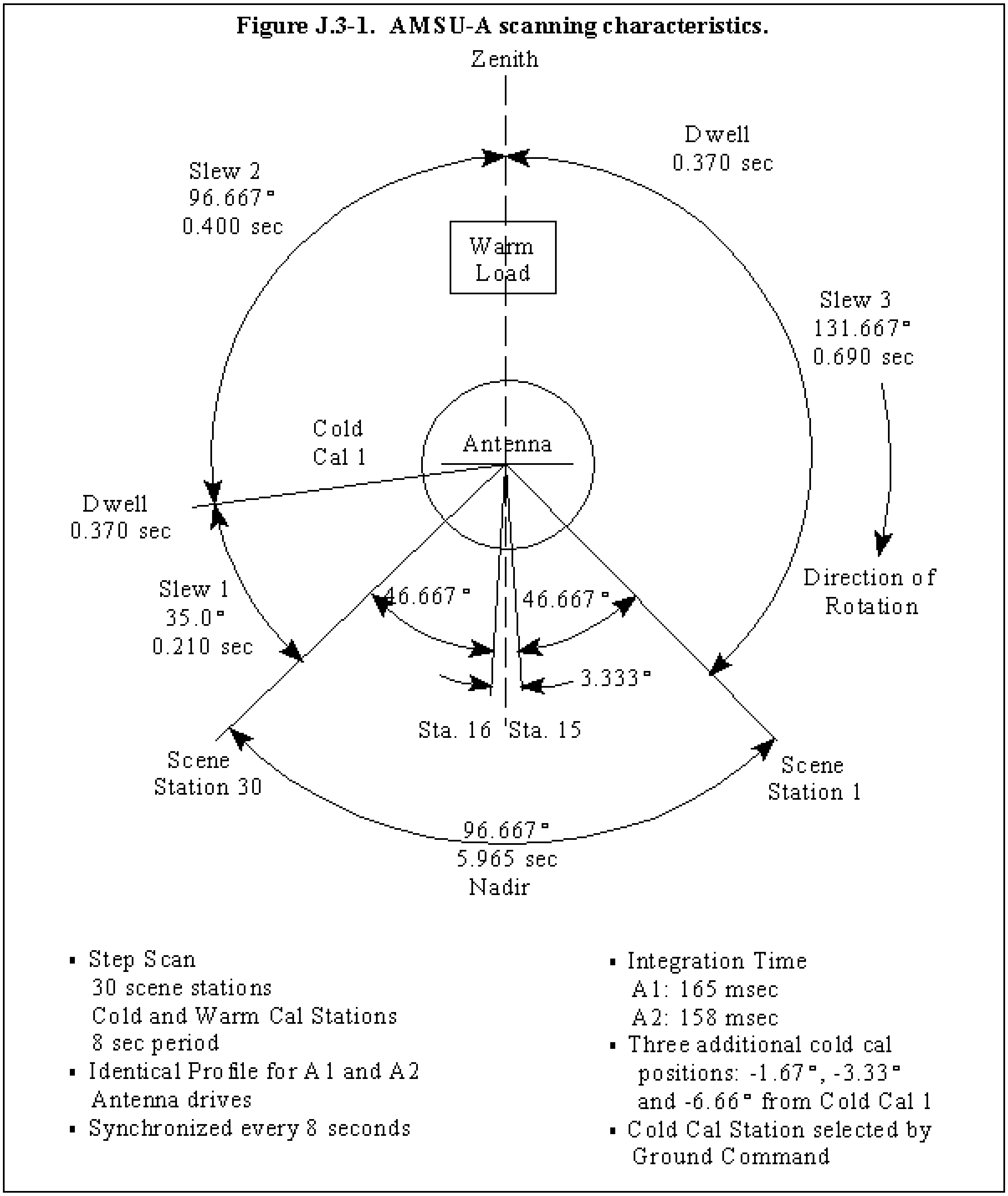
The AMSU-A beams will have cross-track scanning. All beams will scan in a plane perpendicular to the spacecraft orbital velocity vector. Note: The spacecraft velocity vector is pointing in the direction towards the reader (out of the page). The sense of the scan will be counterclockwise as one looks along the spacecraft orbital velocity direction (i.e., the antenna scans from the sun direction through nadir to the cold space direction and repeats as shown in Figure J.3-1).

The AMSU-A beams will scan the earth viewing sector a total of 96.66 degrees ($\pm$48.33 degrees from nadir) on beam centers. There will be a total of 30 beam positions (30 resolution cells on the earth surface), to be called cell numbers 1 through 30, from sun to antisun. There will be 15 cells on either side of nadir. The beam center position of each cell is separated from the adjacent cell along the scan direction by 3.33 degrees (there will be a non-cumulative step tolerance of $\pm$ 0.04 degrees).

There will be four beam positions selectable by command, to provide a cold (space look) calibration position. The primary cold calibration beam position will nominally be at 6.66 degrees from the sun X velocity plane in the nadir direction. The three alternate cold calibration positions will nominally be at 8.33, 10.00 and 13.33 degree declinations.

The location of the beam positions (earth viewing) in time with respect to the frame synchronization pulse for AMSU-A1 and AMSU-A2 are illustrated in Figures J.3-2 and J.3-3, respectively.

Figure J.3-1. AMSU-A Scanning Characteristics.



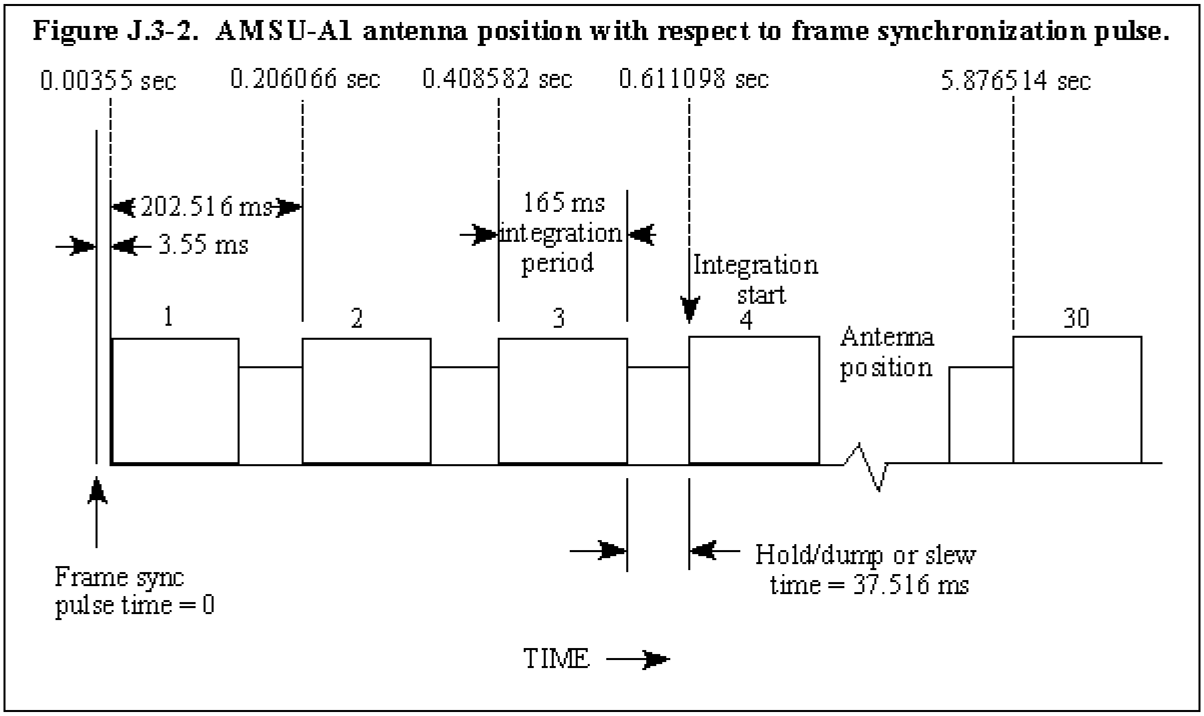


Figure J.3-2. AMSU-A1 Antenna Position with Respect to Frame Synchronization Pulse

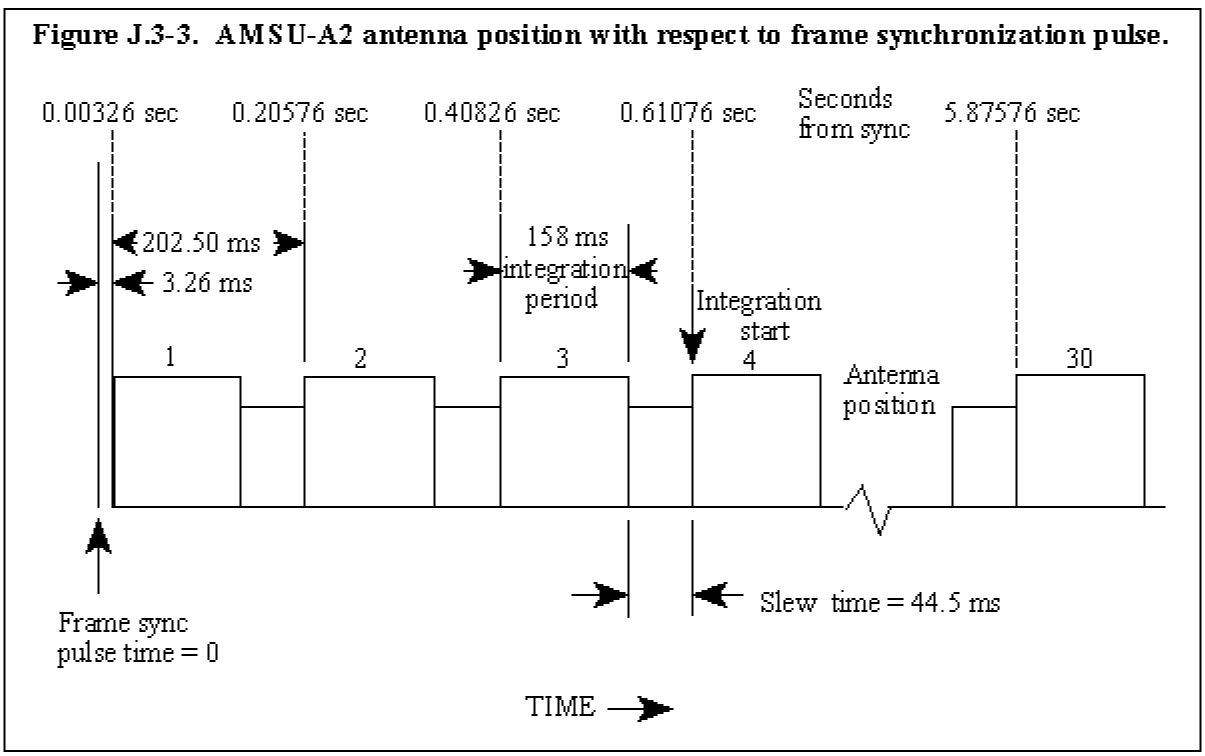


Figure J.3-3. AMSU-A2 Antenna Position with Respect to Frame Synchronization Pulse

AMSU-B is a cross-track, line scanned instrument designed to measure scene radiances in 5 channels. At each channel frequency, the antenna beamwidth is a constant 1.1 degrees (at the half power point). Ninety contiguous scene resolution cells are sampled in a continuous fashion, each scan covering 50 degrees on each side of the subsatellite path. These scan patterns and geometric resolution translate to a 16.3 km diameter cell at nadir at a nominal altitude of 850 km. Figure J.3-4 shows the size of the AMSU-B footprint over the entire Earth scan.

Figure J.3-4. AMSU-B scanning.

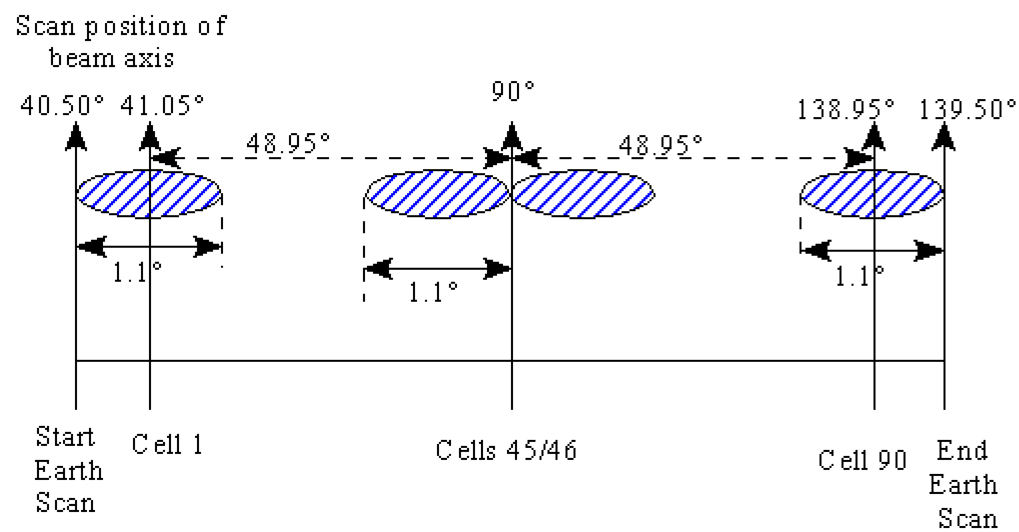


Figure J.3-4. AMSU-B Scanning.

All antenna beams for AMSU-B scan in a plane perpendicular to the instrument's baseplate, containing nadir in the x-z plane. The maximum deviation from the scan plane will be less than or equal to 0.1 degrees. The direction of scan motion is from Sun (+z) to nadir (+x) to anti-Sun side (-z). During earth scan, the cross track motion will be continuous with the angular velocity constant to within $\pm$2%. All antenna beams will scan $\pm$48.95 degrees about nadir with reference to the beam axis. The scan period will be 8/3 seconds, in order to maintain a relationship with the AMSU-A scan pattern. The scan plane and motion for the AMSU-B instrument are shown in Figure J.3-5.

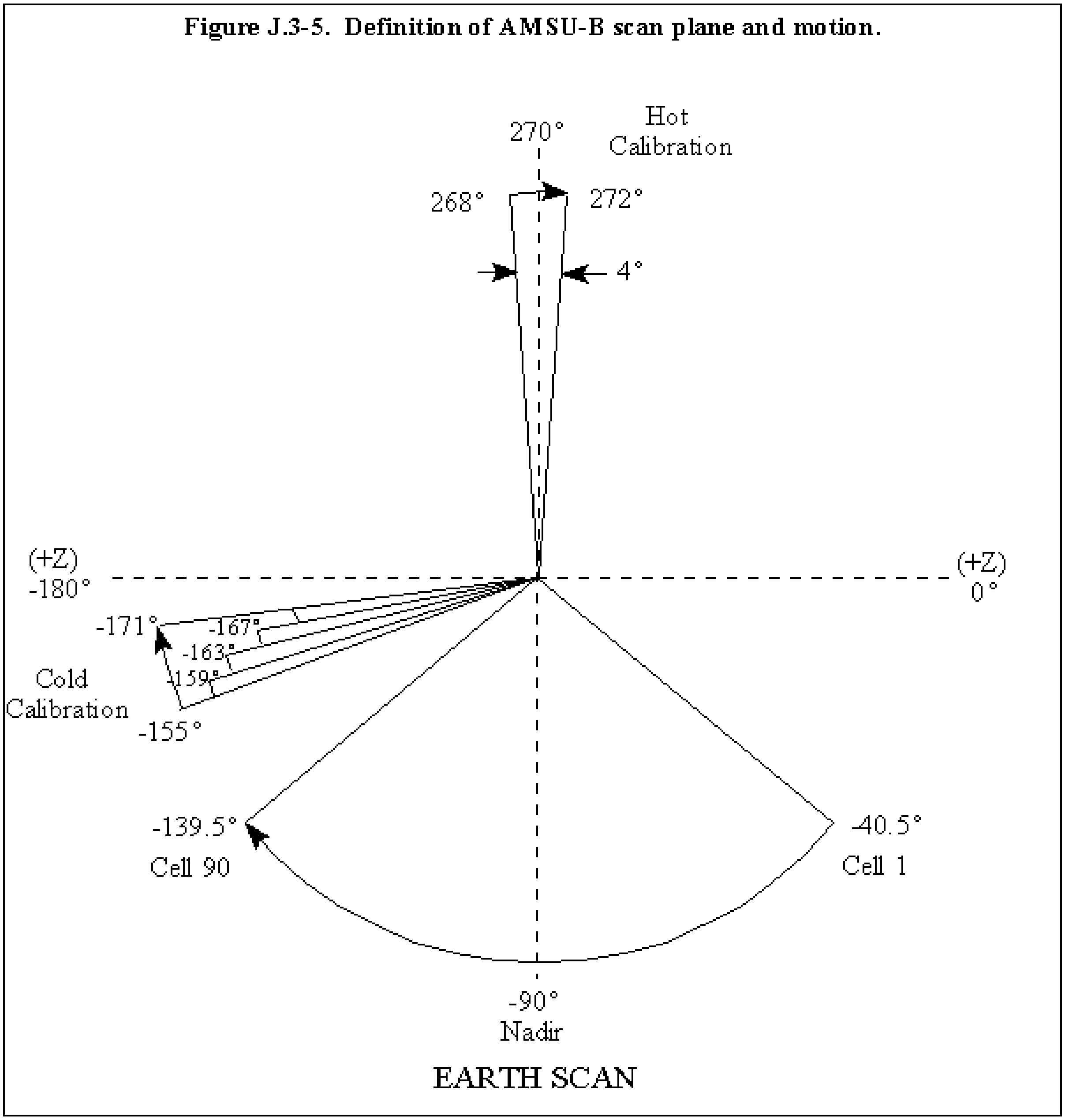


Figure J.3-5. Definition of AMSU-B Scan Plane and Motion

The Microwave Humidity Sounder (MHS) is a self-calibrating microwave radiometer, observing the Earth with a field of view of ±50 degrees across nadir, in five frequency channels of the millimeter-wave band (89-190 GHz). MHS, together with the complementary AMSU-A instruments, provides the operational microwave sounding capability for the NOAA-N, -N' meteorological satellites.

MHS is a cross-track, line-scanned instrument. Ninety contiguous scene resolution cells are sampled in a continuous scan, covering 49.44444... degrees on each side of the sub-satellite path, with an antenna beam width of 1.11111... degrees at half power point. These scan patterns and geometric resolution translate to a 17-km diameter cell at nadir from the 870 km nominal orbital altitude.

In scan mode, the MHS reflector performs the scan profile. This is a predefined position versus time profile which incorporates the Earth view and the two calibration targets, as shown in

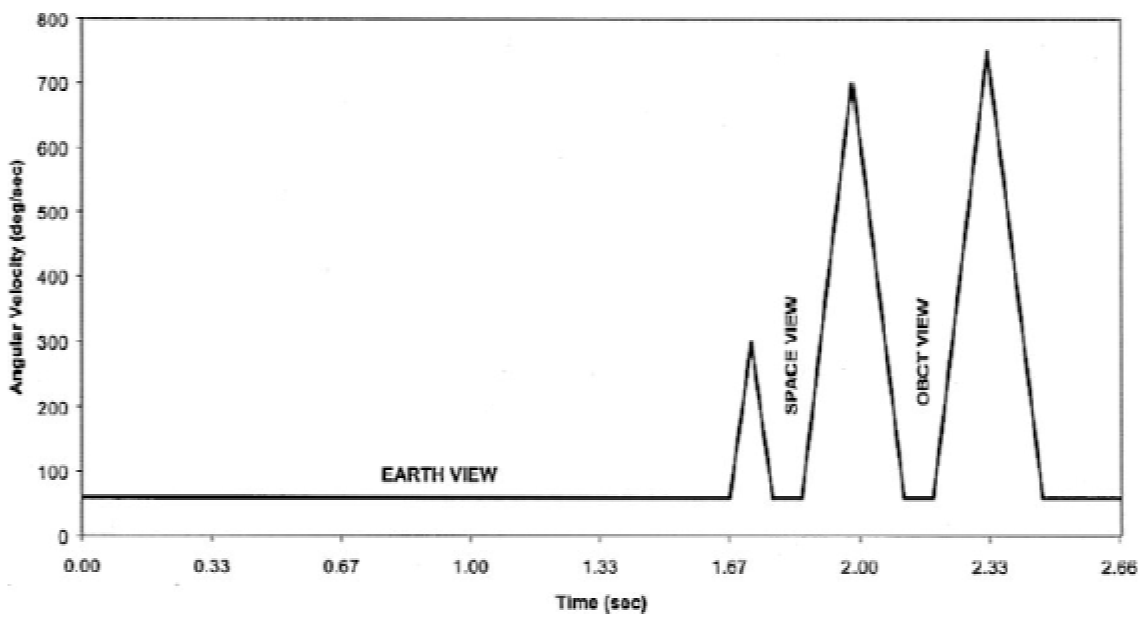


Figure J.3-6. MHS Scan Profile Velocity versus Time

Figures 3.9.2.2-1 and J.3-6. Three predefined profiles are provided: profiles 0, 1 and 2; and these are the same except for small changes in the position of the Space view.

J.4 SBUV/2

The SBUV/2 instrument is a nadir pointing nonspatial scanning instrument sensitive to radiation in the 160 to 400 nm ultraviolet spectrum. The overall radiometric resolution is approximately 1 nm in this spectral band. The SBUV instrument optical hardware and main electronics are carried in two modules. The Sensor Module (SM) contains the optical elements and detectors while the Electronics Module (ELM) houses the main electronics and power supplies.

The use of a deployable diffuser in the SM gives the instrument the versatility of selecting between solar and earth measurements. With the diffuser stowed, the instrument views the earth directly. The data from this configuration corresponds to earth radiance. With the diffuser deployed into the "Sun" position, the detector output measurements correspond to solar irradiation data. Ground and in flight calibration data are used to convert the detector data and diffuser mode data to solar irradiation or earth radiance units.

The SM houses the monochromator optical hardware (see Figure J.6-1) which uses a movable grating to select the wavelength where measurements will be made. The grating mechanism can be commanded to any one of 8,192 positions giving the monochromator approximately 0.1 nm wavelength resolution. Commands which correspond to grating positions come from a Read Only Memory (ROM). Data read from the ROM correspond to 12 discrete wavelength positions in the "Discrete" mode. In the "Sweep" mode, the ROM data is simply a grating position corresponding to the wavelength where the sweep will start.

The photo multiplier tube (PMT) in the monochromator has a very large dynamic range (greater than 120 db). This range is transmitted in 3 ranges requiring a total of .75 seconds for stepping and settling of the grating to a new position and 1.25 seconds of integrating time before transmission, when the instrument is in this "Discrete" grating mode.

In the "Sweep" mode, the grating is stepped every 50 ms and the PMT signal is integrated (while the stepping continues) for 100 ms before transmission.

The Cloud Cover Radiometer (CCR) has a fixed 379 nm filter for wavelength selection and is co-aligned to the monochromator; therefore, it views the same scene as the monochromator. The output of the CCR represents the amount of cloud cover in a scene, as the name implies, and is used to remove the effects of clouds in the monochromator data. CCR data is transmitted once per second in both Discrete and Sweep modes.

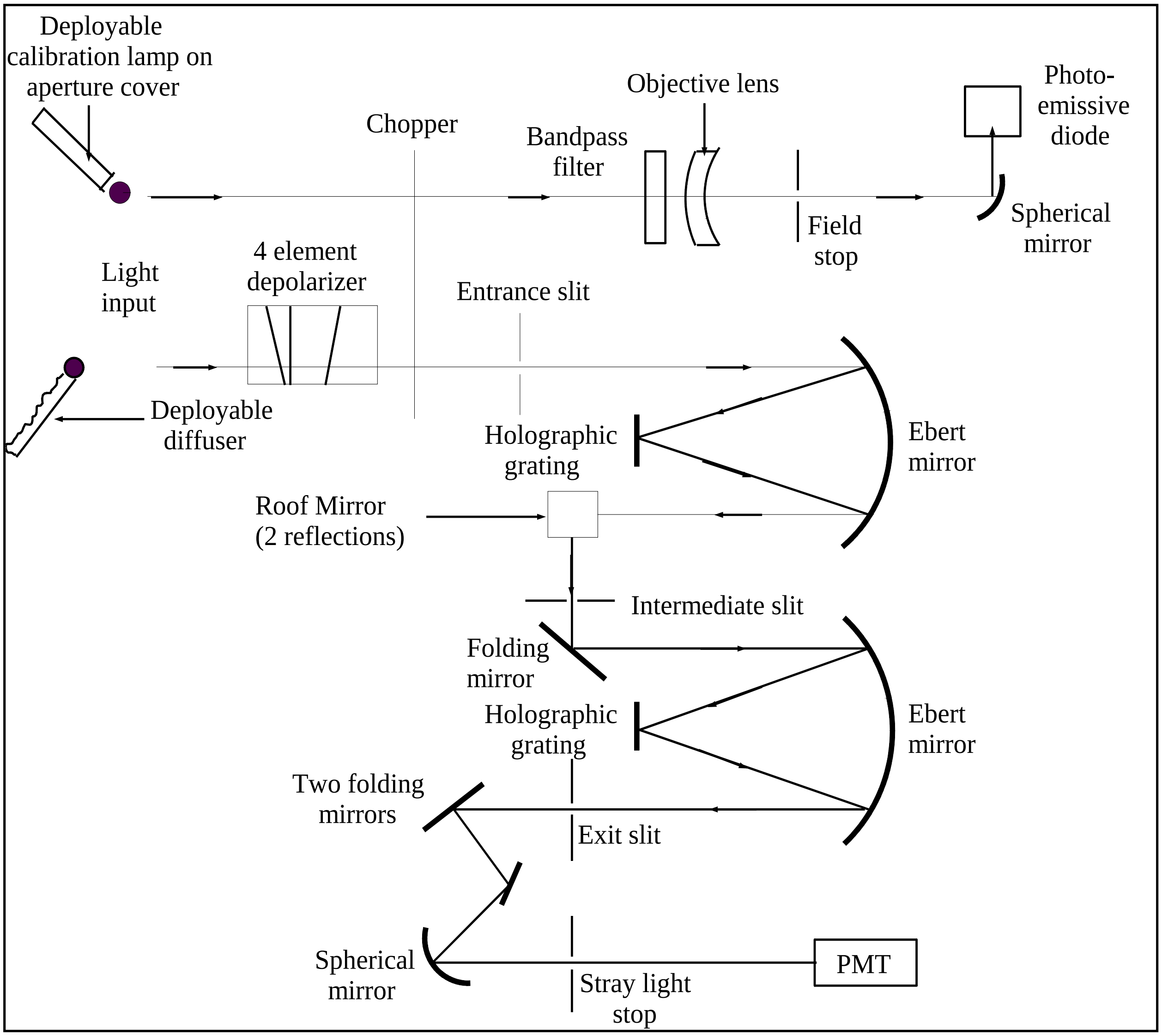


Figure J.4-1. Simplified Optical Path of SBUV/2 Instrument