HIRS/3 - CURRENT PERFORMANCE AND POSSIBLE IMPROVEMENTS

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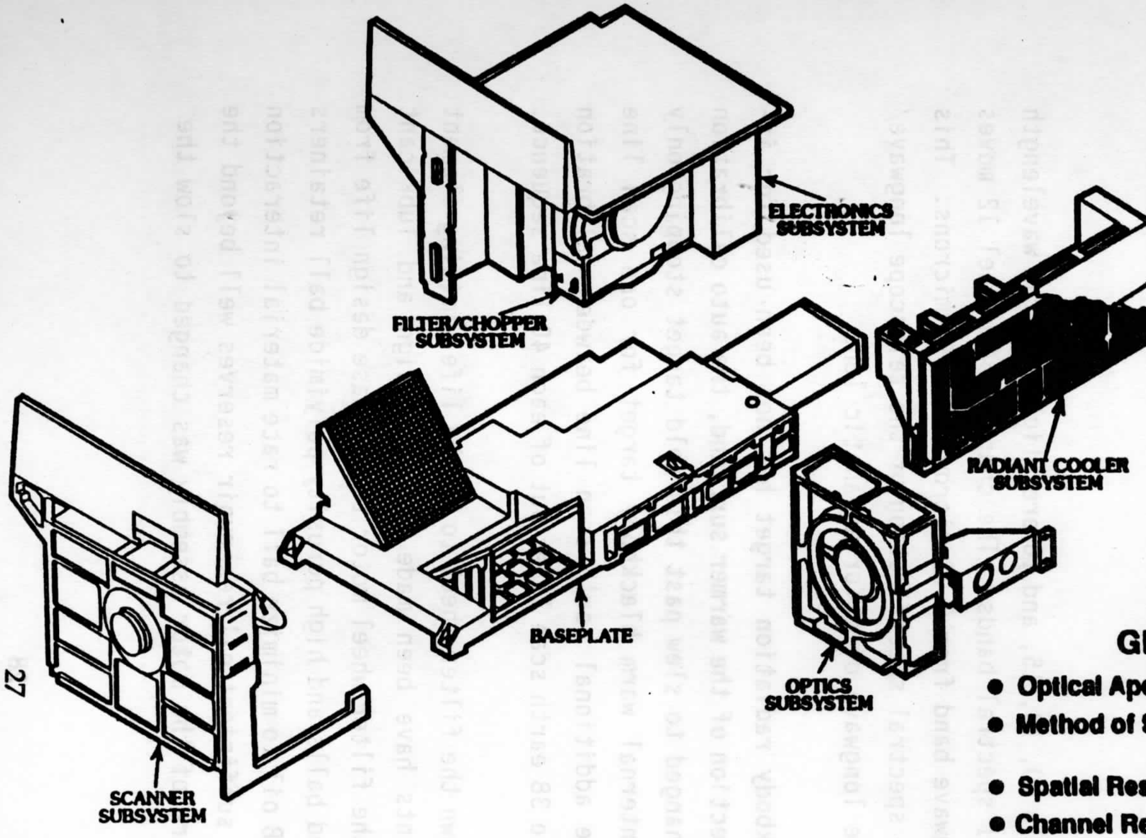
1. INTRODUCTION

The HIRS/3, High Resolution Infrared Sounder, is the latest version of the multispectral infrared sounding instrument first flown on TIROS-N in October 1978. Since then, an unbroken series of eight instruments has provided operational sounding data. The HIRS/2 was used through NOAA-10/G and 12/D. The improved HIRS/2I is flying on NOAA-11/H and another is scheduled to fly on NOAA-12/I in June 1993. The HIRS/3 instruments are being developed for the NOAA-K, L, and M satellites projected for launch between 1996 and 1999, two additional TIROS-ATN satellites to follow the K, L, M series and possibly the EUMETSAT METOPS-1 satellite. This paper will describe design changes in the HIRS/3, compared to the HIRS/2I, summarize the preliminary radiometric performance measurements of HIRS/3, flight model H301, and describe some possible improvements to HIRS/3. Finally, the radiometric performance achievable by improving the HIRS/3 design will be specified.

2. HIRS DESCRIPTION

The HIRS is a crosstrack, discrete stepping, linescan instrument that measures radiance in 20 spectral channels between .69 and 14.95 microns. The measured radiances permit the calculation of temperature and water vapor content from the earth's surface to about 40 km, with particular emphasis on the troposphere. The instantaneous field of view (IFOV) of HIRS/2I is 1.4 degrees, or 20 km at nadir. The scan mirror steps 49.5 degrees either side of nadir in 1.8 degree increments with a total of 56 steps per scan line. The scan mirror dwells at each scan step for a period of 100 milliseconds, less the step and settle time, and retraces in 800 milliseconds, taking a total time of 6.4 seconds per scan line. Spectral separation is provided by a rotating filter wheel with two rings of narrow band filters. Calibration of the 19 infrared channels is provided by viewing an on-board warm blackbody target and cold space. Figure 1 is an exploded view of the instrument showing the modular design of its subsystems and listing its general characteristics.



GENERAL CHARACTERISTICS

- **Optical Aperture:** 5.9 inches (15.0 cm)
- **Method of Scan:** Cross tracking stepping ±49.5° in 1.8° increments at 10 steps per second
- **Spatial Resolution:** 1.4°, 20 km at nadir
- **Channel Registration:** Channels within a band (LW, SW) coregistered to window channels within ± 1 percent of spatial resolution
- **Detector Cooling:** IR detectors cooled and regulated to 100K
- **Calibration:** Stable Blackbody (288K) and Space
- **Design Life:** 3-5 years
- **Size :** 16 x 18 x 27 inches (41 x 46 x 69 cm)
- **Weight Total:** 74 pounds (34kg)
- **Power:** 24 watts Avg (+25w for outgassing)

FIG. 1 HIGH RESOLUTION INFRARED RADIATION SOUNDER (HIRS/3)

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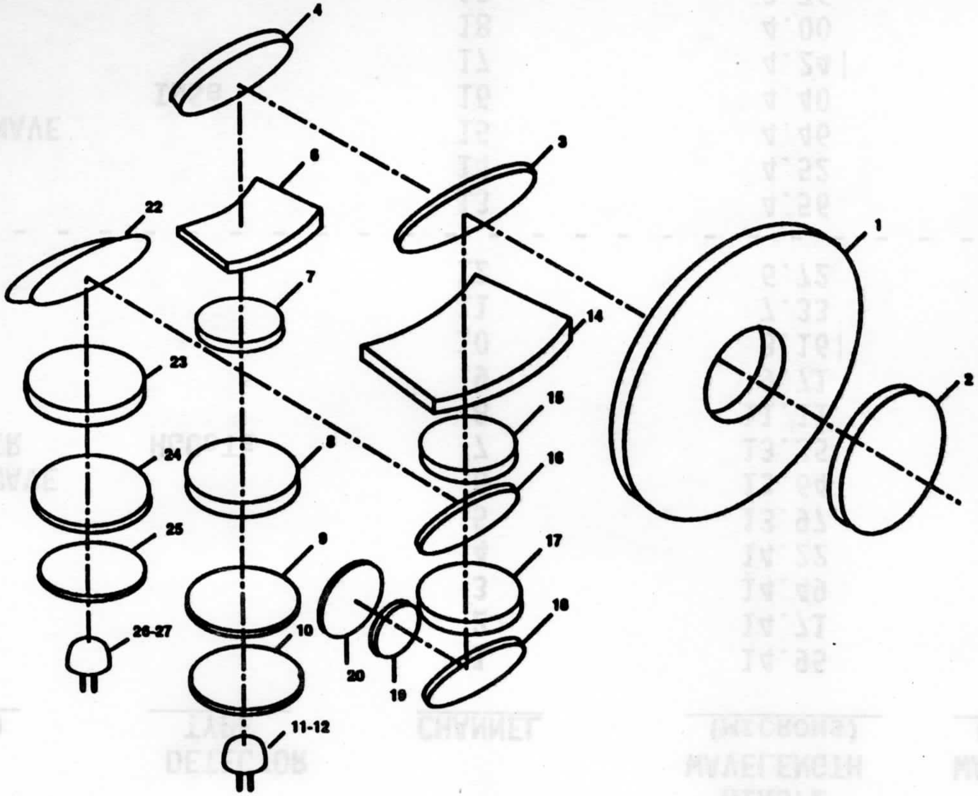
3. HIRS DESIGN CHANGES FOR HIRS/3

The basic external configuration of the HIRS/3 remains the same as the HIRS/2I. Optically, the HIRS/3 elements are identical with HIRS/2I as shown in Figure 2, except that the telescope primary and secondary mirrors, elements 1 and 2, are Zerodur® in place of Cervit® and the visible beamsplitter, element 16, has an indium tin oxide instead of a gold coating to reflect the shortwave IR and pass the visible radiation. Internally, however, several significant design changes are being made to improve HIRS/3 performance and reliability. The spectral properties of two longwave and three shortwave infrared channels were changed to enhance the HIRS capability when used with the AMSU. Table 1 lists all twenty channels' central wavelengths with changes between HIRS/2 and /2I and between HIRS/2I and /3 highlighted.

The spectral changes in channels 10, 13, 15, and 16 are slight central wavelength adjustments within the HIRS/2I spectral bands. The change to channel 12 moves the lower boundary of the longwave band from 6.72 microns to 6.52 microns. This change required changes in the spectral specification of the telescope longwave/ shortwave beamsplitter and the longwave detector aplanatic lens.

Since the internal cold blackbody radiation target has not been used for in-flight calibration due to reflection of the warmer surround, the auto calibration sequence of HIRS/3 has been changed to slew past this cold target stopping only at the space view and the internal warm blackbody target for one scan line interval each. This adds one additional earth scan line between calibration intervals bringing the total to 38 earth scan lines out of each 40 line sequence.

Because flight history has shown the filter wheel to be the life limiting element of the instrument, improvements have been made in the design and lubricant retention of the bearings in the filter wheel motor to increase design life from two to three years. TIC-coated balls and high porosity polyimide ball retainers are used with the Krytox® 143AB oil to minimize ball to race material interaction and to assure availability of sufficient oil reservoir reserves well beyond the design lifetime. The structure of the motor assembly was changed to slow the



1. PRIMARY MIRROR
2. SECONDARY MIRROR
3. INFRARED BEAMSPLITTER
4. FOLDING MIRROR, LW
5. FIELD STOP, LW
6. LW FILTERS
7. LW LENS #1
8. LW LENS #2
9. VACUUM WINDOW,LW
10. COOLER WINDOW,LW
11. APALANT LENS,LW
12. DETECTOR, LW
13. FIELD STOP,SW
14. SW FILTERS
15. SW LENS #1
16. VISIBLE BEAMSPLITTER
17. VISIBLE LENS #1
18. FOLDING MIRROR VISIBLE
19. VISIBLE LENS #2
20. DETECTOR WINDOW,VISIBLE
21. DETECTOR VISIBLE
22. FOLDING MIRROR
23. SW LENS #2
24. VACUUM WINDOW,SW
25. SW LENS #2 COOLER WINDOW
26. APLANAT LENS, SW
27. DETECTOR, SW

FIG. 2 OPTICAL SCHEMATIC HIRS/3

TABLE 1. SPECTRAL CHANNEL CHANGES BETWEEN HIRS/2, HIRS/2I AND HIRS/3

BAND	DETECTOR TYPE	CHANNEL	HIRS/2 WAVELENGTH (MICRONS)	HIRS/2I WAVELENGTH (MICRONS)	HIRS/3 WAVELENGTH (MICRONS)
LONGWAVE IR	HgCdTe	1	14.95	14.95	14.95
		2	14.71	14.71	14.71
		3	14.49	14.49	14.49
		4	14.22	14.22	14.22
		5	13.97	13.97	13.97
		6	13.64	13.64	13.64
		7	13.35	13.35	13.35
		8	11.11	11.11	11.11
		9	9.71	9.71	9.71
		10	8.16	12.55	12.47
		11	7.33	7.33	7.33
		12	6.72	6.72	6.52
SHORTWAVE IR	InSb	13	4.56	4.56	4.57
		14	4.52	4.52	4.52
		15	4.46	4.46	4.47
		16	4.40	4.40	4.45
		17	4.24	4.13	4.13
		18	4.00	4.00	4.00
		19	3.76	3.76	3.76
VISIBLE	Silicon	20	0.69	0.69	0.69

outgassing lubricant loss to space by at least an order of magnitude from the HIRS/2I design.

With the enhanced radiant cooler margin capacity demonstrated in the HIRS/2I non-microphonic design, the operating temperature of the cooled IR detectors was lowered by five Kelvins to 100K in flight model H301 with further temperature reductions being considered for flight models H302 and 303. The resulting increase in LW detector performance (20-25%) along with a mechanical change in the filter wheel subsystem to eliminate wheel wobble with its resultant fixed background modulation has resulted in radiometric performance of H301 which exceeds the NEDN goal specifications, giving it the possibility of being the best overall performing HIRS to date. These changes do not impact the radiometric performance of the shortwave channels as significantly since these channels are not detector noise limited. Table 2 lists the preliminary measurements of the radiometric performance of H301, and compares its performance to the performance of the average of the HIRS/2I instruments and to flight model 2I which has the best radiometric performance of any HIRS/2 or HIRS/2I instrument. The missing data for channels 4 and 8 is due to non-spec filters being installed at that time.

The data in Table 2 illustrates that the HIRS/3 design provides radiometric performance equal or slightly better than the most sensitive of the HIRS/2I instruments and has performance margin over the NEDN goals ranging from 1.27 to 7.50.

The FOV ground footprint of H301 is retained at the nominal 20 km size of HIRS/2I. The probability of having a 17 km LW footprint in H302 exists due to a slightly reduced acceptance angle of recent MCT LW detector units. The SW FOV will be sized to match the LW with a custom-sized telescope field stop. With the large margin in NEDN performance demonstrated in H301, the consideration of intentionally reducing the FOV footprint size even further is within the realm of possibility. This change and others to further enhance the capabilities of HIRS performance are discussed in the following sections.

TABLE 2. RADIOMETRIC PERFORMANCE (NEDN) OF HIRS/3 FM H301 COMPARED WITH HIRS/2I AVERAGE AND FM-2I

CHANNEL	NEDN SPEC	NEDN GOAL	HIRS/2I AVG	HIRS/2I FM-2I	HIRS/3 H301 RECENT T/V	MARGIN OVER GOALS
1	3.00	0.75	1.09	0.65	0.59	1.27
2	0.67	0.25	0.27	0.15	0.14	1.79
3	0.50	0.25	0.19	0.12	0.13	1.92
4	0.31	0.20	0.09	0.06	--	--
5	0.21	0.20	0.08	0.05	0.06	3.33
6	0.24	0.20	0.08	0.06	0.06	3.33
7	0.20	0.20	0.05	0.03	0.04	5.00
8	0.10	0.10	0.02	0.03	--	--
9	0.15	0.15	0.03	0.02	0.02	7.50
10	0.15	0.10	0.06	0.04	0.04	2.50
11	0.20	0.20	0.04	0.03	0.03	6.67
12*	0.20	0.07	0.05	0.03	0.04	1.75
13	0.006	0.002	0.0012	0.0009	0.0009	2.22
14	0.003	0.002	0.0012	0.0011	0.0006	3.33
15	0.004	0.002	0.0011	0.0009	0.0006	3.33
16	0.004	0.002	0.0008	0.0007	0.0005	4.00
17	0.002	0.002	0.0010	0.0009	0.0006	3.33
18	0.002	0.002	0.0006	0.0004	0.0004	5.00
19	0.001	0.001	0.0002	0.0002	0.0002	5.00
20	0.10% A	--	--	0.009%	(0.006%)	

*CH 12 IS 6.5μ FOR H301, 6.7μ FOR HIRS/2I

NEDN IN mW/m^2 ST CM^{-1}

4. IMPROVEMENTS TO HIRS/3

Because the NEDN goals are in the order of the atmospheric noise limit, further improvements in sensitivity can be traded for a smaller IFOV, which increases the probability of finding a clear atmospheric column. Our specific objective is to reduce the nadir IFOV by an additional factor of 2, from 20 km to 10 km, while maintaining NEDN's comparable to those of the H301. Such an IFOV reduction, in turn, reduces the detector area by a factor of 4, and, as shown by the equation in Figure 3, increases the NEDN by a factor of 2. To maintain the NEDN levels of the H301, we therefore need to identify improvements that reduce the NEDN (increase sensitivity) by a factor of 2.

In the shortwave band, these improvements consist of (a) a reduction in non-detector noise and (b) an optimization of the channel integration times. Past and present HIRS sounders are sensitivity limited in the shortwave band by non-detector noise, principally pickup and microphonics that result from the long leads between the preamplifier and the high impedance detector (InSb). These noise sources are greatly attenuated when a cooled preamp front end is added to the detector. Based on the improvements seen when this modification was made in the AVHRR imager, this change will provide an improvement of at least 3:1. Optimization of the channel integration times provides uniform sensitivity margins across the band; it consists of transferring integration time from the spectrally wider channels (18, 19) to the spectrally narrower channels (13-15, 17).

In the longwave band, the baseline requirement is to maintain the low level of background modulation noise obtained in HIRS/3, H301. This noise is produced when there is relative motion between the large, non-uniform HgCdTe detector and the non-uniform background in the ambient instrument. Large reductions in background modulation noise were achieved in the transition from the HIRS/2 to the HIRS/2I by increasing the resonant frequencies of the radiant cooler, which eliminated its susceptibility to low level disturbances from the instrument mounting platform, including those introduced by other instruments. Further reductions, to below the detector noise level, were made in the HIRS/3 by means

- o **HIRS RADIOMETRIC PERFORMANCE CAN BE EXPRESSED AS:**

$$NE\Delta N_\nu = \frac{16\ \alpha\ f_n^2}{\sqrt{2}\ \pi^2\ \Delta\nu\ T_\nu\ D_\nu^*\ t_\nu^{1/2}\ A_d^{1/2}}$$

- o **IMPROVED DESIGN:**
  - **MAINTAINS VALUES OF f_n, SPECTRAL BANDWIDTH $\Delta\nu$ AND OPTICS TRANSMISSION T_ν**
  - **REDUCES DETECTOR AREA, A_D, BY A FACTOR OF 4 (REDUCED IFOV)**
  - **REALLOCATES INTEGRATION TIME, t_ν, AMONG CHANNELS**
  - **REDUCES NOISE DEGRADATION FACTOR, α**
  - **INCREASES DETECTOR D^***

FIG. 3 HIRS/3 DESIGN CHANGES OFFERING IMPROVED RADIOMETRIC PERFORMANCE IN LONGWAVE CHANNELS

of changes to the filter wheel subassembly (described in the previous section), which reduced the relative motion between the filter wheel and the detector.

With the conditions in place for low background modulation, the sensitivity in the longwave band can be improved over that of the H301 by (a) reducing the noise degradation factor (ratio of total noise to detector noise), (b) reducing the detector temperature, and (c) optimizing the channel integration times. The detector noise voltage is proportional to $A_d^{-1/2}$, where A_d is the detector area. As a consequence, reducing the linear IFOV by a factor of 2, which reduced A_d by a factor of 4, increases the detector noise voltage by a factor of 2 and reduces the degradation factor.

The D* of the HIRS/3 detectors increases with a reduction in temperature at a rate that varies from 2.3%/K to 4.4%/K, depending on the wavelength. The detector control temperature can be reduced by 6K, to 94K, by a reduction in the detector bias power. The detector responsivity (VW^{-1}) is directly proportional to the product $\phi_b^{1/2}m$, where ϕ_b is the bias power and m is the number of rectangular elements (connected in series) into which the detector is divided. In the current HIRS design, m = 2. This can easily be increased to m = 4 because of the large size of the detector (2.2 mm square). This allows us to obtain the same responsivity at one-fourth the bias power, a reduction from 18 mW to 4.5 mW. Such a reduction is sufficient to reduce the control temperature by 6K, to 94K, and still maintain a temperature margin of 5K under worst case conditions. In the longwave, channel 1 is not included in the integration time optimization because its integration time is already very long. Among the remaining channels (2-12), channel integration time is transferred from the middle to the end channels (2, 3, 11), to compensate for the natural fall-off in optical transmittance and detector D*.

When the above improvements are combined with a 2:1 reduction in the IFOV, we obtain the performance shown in Table 3, which shows that we can meet our objectives of a 10 km IFOV and NEDN's below the goal levels.

TABLE 3. RADIOMETRIC PERFORMANCE ACHIEVABLE IN HIRS/3 WITH DESIGN IMPROVEMENTS

CHANNEL	NEDN SPEC	NEDN GOAL	SN H301 MEASURED	IMPROVED DESIGN w 10 KM IFOV	MARGIN OVER GOALS
1	3.00	0.75	0.59	.425	1.8
2	0.67	0.25	0.14	.100	2.5
3	0.50	0.25	0.13	.094	2.7
4	0.31	0.20	0.09*	.065*	3.1
5	0.21	0.20	0.06	.043	4.7
6	0.24	0.20	0.06	.044	4.5
7	0.20	0.20	0.04	.029	7.6
8	0.10	0.10	0.02*	.013*	7.7
9	0.15	0.15	0.02	.013	11.5
10	0.15	0.10	0.04	.031	3.2
11	0.20	0.20	0.03	.024	8.3
12	0.20	0.07	0.04	.032	2.2
13	0.006	0.002	0.0009	.001	2.0
14	0.003	0.002	0.0006	.0007	3.0
15	0.004	0.002	0.0006	.0007	3.0
16	0.004	0.002	0.0005	.0006	3.5
17	0.002	0.002	0.0006	.0007	3.0
18	0.002	0.002	0.0004	.0007	3.0
19	0.001	0.001	0.0002	.0007	3.0
20	0.10% A	--	(0.006%)	.0003	3.0

* EST

Possible additional improvements to the HIRS/3 sounder are (a) an improved in-orbit calibration target and (b) an increase in the number of soundings per step. The properties of an improved in-orbit target are listed in Table 4, where they are compared with those of the HIRS/3. With the nadir IFOV reduced to 10 km, the next logical step is to go to multiple IFOVs, which increases the data density and further increases the probability of finding clear atmospheric columns.

Conceptually at least, this is a straightforward modification. Both the field stops and the detectors are changed from single to multiple elements. In addition, the telescope can accommodate four, 10 km IFOVs in place of one, 20 km IFOV. However, the relay optics would have to be redesigned. On the other hand, the 94K control temperature can be retained by further dividing the large detector from m = 4 to m = 8, which maintains both the detector responsivity and the total detector bias power.

TABLE 4. POSSIBLE IMPROVEMENT IN HIRS/3 IN-ORBIT INFRARED CALIBRATION TARGET

	HIRS/2I & HIRS/3	IMPROVED DESIGN
EMISSIVITY	0.990	≥ .997; LARGER, DEEPER CAVITIES, THINNER PAINT
SENSOR ACCURACY	0.10K	≤ 0.05K; 4-WIRE CONNECTION
UNIFORMITY (GRADIENT)	0.02 - 0.34K	<0.1K; HIGHER CONDUCTANCE BASE, GREATER VIEW OF INTERNAL INSTRUMENT
STABILITY THERMAL	≤ 0.085K/MIN	≤ 0.05K/MIN; GREATER CAPACITY, OUT OF HEAT FLOW PATHS

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