Indian Geostationary Meteorological satellites and Instrument on board of these satellites and Payloads of INSAT-3D satellite

Introduction:

Atmosphere observations from the vantage point of geostationary orbit with the satellite located over the region of interest provides a synoptic view of one third of the globe and enables observations throughout day and night. The meteorological instruments from geostationary platform enable observation in the electromagnetic spectrum covering visible and thermal infrared regions. Such images acquired at the regular intervals of time throughout the day enables estimation of cloud motion Vectors at various heights giving useful information about winds at different heights. Further thermal images provide valuable information about sea surface temperatures. Both visible and thermal images also provide extremely useful information about cyclones, their location and their trajectories. Realizing the enormous utility of these images India included meteorological instrument in the suite of payloads to be accommodated on the INDIAN NATIONAL SATELLITE (INSAT).

The multipurpose INSAT satellites were three-axis stabilized platforms enabling realization of compact meteorological instruments. The multipurpose INSAT programme started with the procurement of the INSAT- 1 series of satellites built as per ISRO specifications in the early eighties heralded the era of satellite based meteorological observations in INDIA

Very High Resolution Radiometer (VHRR)

Mission:	*Launch Year:*
INSAT-1A	1982
INSAT-1B	1983
INSAT-1C	1988
INSAT-1D	1990
INSAT-2A	1992
INSAT-2B	1993
INSAT-2E	1999
METSAT	2002
INSAT-3A	2003

Channel	1A to 1D	2A to 2B	2E/3A/Metsat
VIS (Km x Km)	2.75	2	2
IR (Km x Km)	11	8	8
WV (Km x Km)	-	-	8

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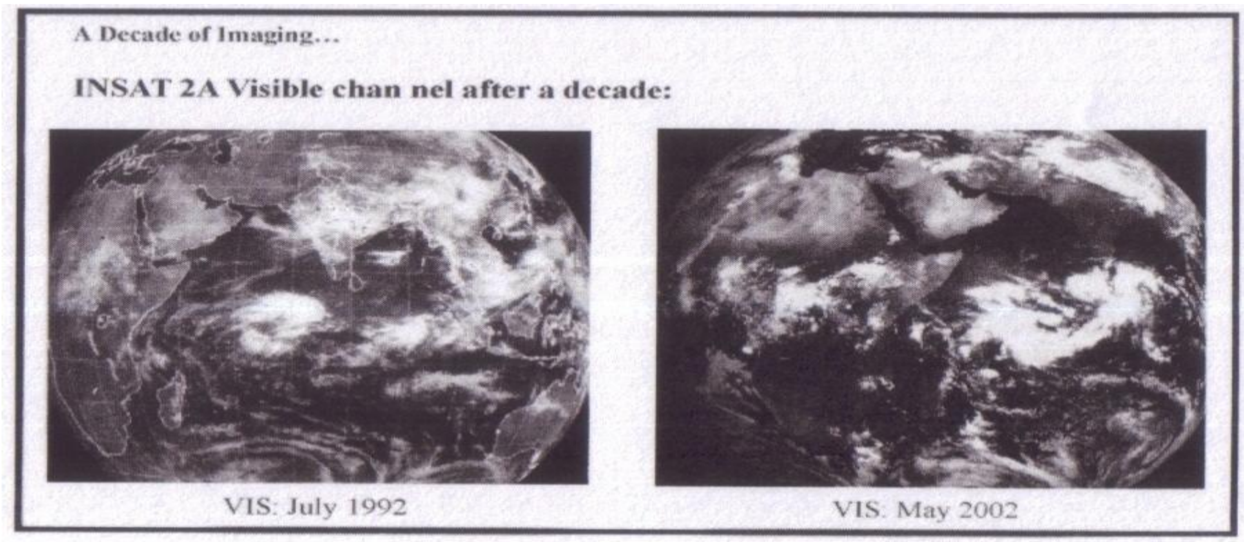
The INSAT 1 series (1A, 1B, 1C, 1D) carries a Very High Resolution Radiometer providing images in visible and thermal infra red regions with spatial foot prints of 2.75 kilometers and 11 kilometers. The instrument was capable of taking pictures in full frame mode, normal frame and sector scan modes. Full frame scanning took about 33 minutes for imaging the earth disc while the normal frame was designed to make observation of truncated disc but still covering the area of interest enabling a triplet of images to be taken at half an hour interval. This triplet was used for Cloud motion vector determination.

The sector mode was meant to be used to track cyclones by covering a smaller north south coverage and India meteorology department made use of this data between 1983-2002.

INSAT 2 series of satellites were realized indigenously and the VHRR instrument was developed at Space applications center with active involvement of LEOS, Thermal group of

ISAC and Inertial Systems Unit of VSSC. The VHRR developed was an improved version with resolutions of visible (2 kilometers) and IR (8 kilometers) channels. The first of the series INSAT 2A was launched in 1992 followed by INSAT 2B in 1993.



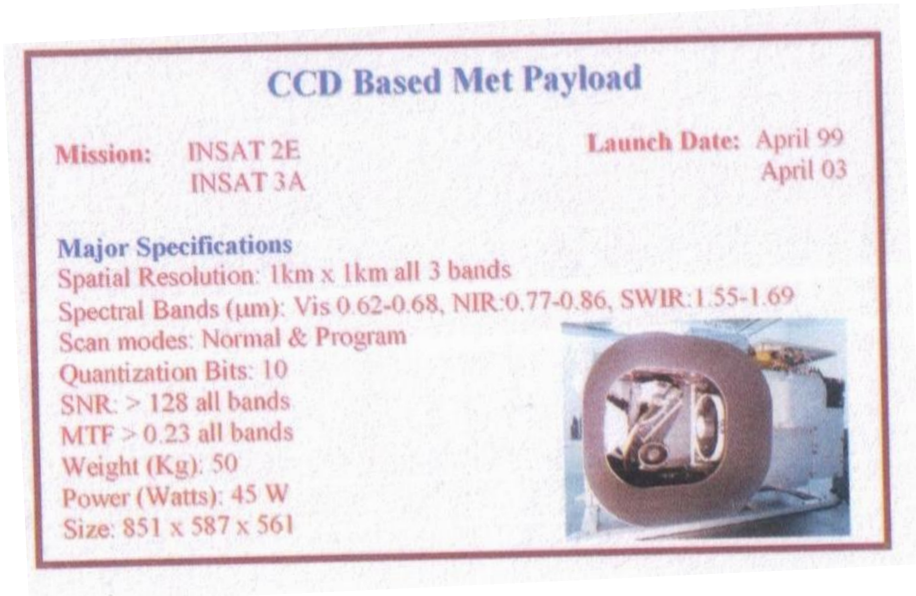
The VHRR instruments provided visible images for over a decade. However the thermal images were available only for limited periods as problems were encountered in the interconnections between IR detector and the processing chain.

The next generation VHRRs with an additional water vapour channel were developed and flown on INSAT 2E, Kalpana and INSAT 3A while INSAT 2E mechanism developed problem after about a year of its launch in 1999. VHRR instruments launched on Kalpana in 2002 and INSAT 3E in 2003 are providing regular images around the clock.

Kalpana was a unique mission as it was realized in a very short time as an exclusive meteorological satellite and flown on Polar Satellite Launch Vehicle.

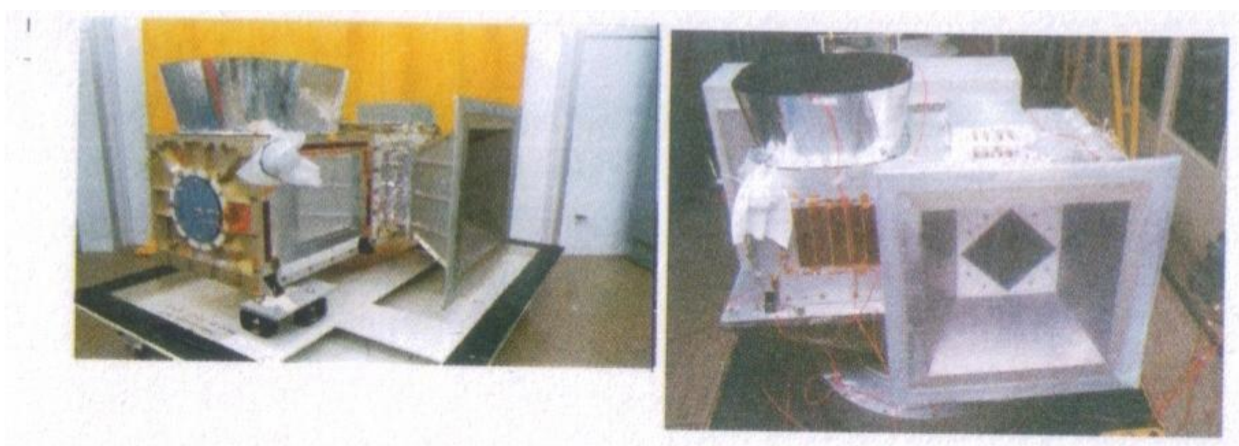
INSAT 2E and INSAT 3A carried a unique 3 channel CCD payload which provided images in visible, near infra red and short wave infra red channels at one kilometer resolution, Imaging an area of 30 kilometers by 6000-kilometer every minute while the Indian subcontinent region is covered in 24 minutes.

The atmospheric observation capabilities will be enhanced very significantly. When the 6 channel Imager and 9 channel Sounder instruments are launched onboard INSAT-3D satellite. The imager is being designed to provide one-kilometer resolution in Visible, Short wave infrared region. It will provide four-kilometer resolution in Mid infrared and the two split thermal channels. It will also provide an eight-kilometer water vapour channel. The Sounder instrument provides information in 19 narrow spectral bands enabling retrieval of moisture and temperature profiles. These instruments will be carried onboard an exclusive meteorological satellite INSAT 3D. With the availability of data from these instruments there would be a very significant spurt in geophysical parameter retrieval and their usages in various numerical models.



Indigenous Development of VHRR:

Space borne meteorological instruments are complex in nature, demands high precision and reliability. ISRO look up this challenging task in mid eighties and has demonstrated its ability to design, deploy and operate a complex meteorological payload- Very High Resolution Radiometer (VHRR)- as part of long life geostationary missions.



Development of indigenous VHRR instrument for meteorological application was taken up for INSAT-2 series of multifunction GEO spacecraft. It was the first endeavor by ISRO to develop a state-of-art Electro Optical Payload operating on a Geo-synchronous platform having imaging capabilities in the Thermal Infrared region of EM spectrum. It was developed as replacement for procured two channel VHRR instruments onboard INSAT-1 series of spacecraft, with enhanced spatial resolution with comparable weight and size. Also the third spectral channel was added during the course of development without any additional weight and size penalty. The work was initiated in mid 80's and continued till the launch of the firth flight model onboard INSAT 3A in 2003. The VHRR payload was qualified (through dedicated

Structural and Engineering- Thermal models) for design life of ten years commensurate with INSAT program requirements.

The development of VHRR was a completely indigenous effort. All the subsystem were developed in-house, with imports restricted to a few critical components only. Indigenous development of complex subsystems like-

Optical system: An eight-inch telescope with a unique dichroic filter to separate visible and infrared channels along with the associated coatings to meet the UV exposure and large thermal excursions encountered on orbit.

A passive radiant cooler: For cooling of Mercury Cadmium Infrared detectors down to about 105 degrees Kelvin.

A bi-axial scan mechanism: For sending the radiation from different parts of the earth disc to the telescope.

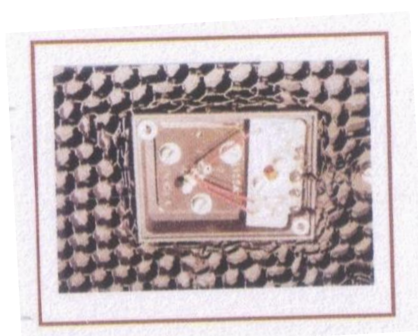
Development of VHRR required expertise in a wide range of subjects including optics design and fabrication, optical coatings, detectors and semiconductors, long-life positioning mechanisms with very high precision, low noise electronics, cryogenics, vacuum technology, heat transfer, structure design and computer engineering to name a few. In order to make best use of the expertise available across all ISRO centers in a given subject, the development activities were spread over many ISRO centers with SAC as the lead center.

Optics

VHRR was required to be operated over wide temperature range from 10˚ C to 40˚C. Criticality of this requirement was recognized early in the project while selecting configuration of optics subsystem. The optics was designed around 8" RC telescope that is relatively insensitive to temperature induced performance changes. The problem of incorporating dichroic beam splitter in the converging output beam of RC telescope was solved by a very fabricated in-house. The optics design as well as dichroic fabrication was carried out at SAC, while fabrication of both the primary and secondary mirrors of telescope was carried out at Electro-Optics Laboratories (LEOS). Special coatings required to meet the stringent demands of geostationary platforms were realized and qualified before incorporation in the instrument. The dichroic coating separating visible and infrared was a significant development.

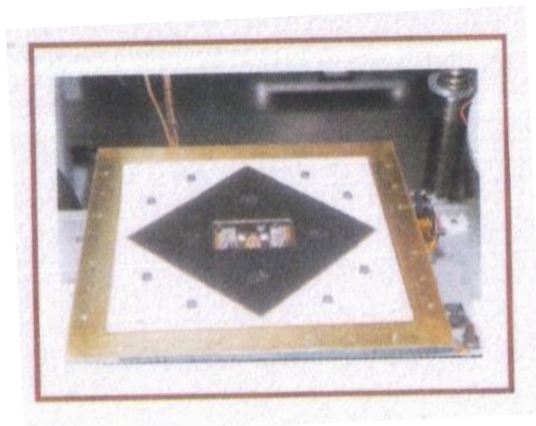
Detectors:

The visible channel of VHRR uses an array of silicon detectors in dual redundant configuration. Very critical requirement for out-of-field response was addressed and solved through an innovative mask design suggested by the design team to the vendor. Infrared channel made use of Mercury Cadmium Telluride detectors. Detectors for the IR channels need to be cooled to cryogenic temperature of about 105 kelvin in order to get required radiometric performance.



Radiant Cooler

To meet the operating temperature requirement of IR detector a three stage passive radiant cooler incorporating technologies like precision optical polishing, nickel coating and super insulating supports as well as low conductivity electrical interconnects was indigenously developed by Thermal group of ISRO Satellite Center (ISAC). Mathematical model of the cooler was also developed to predict on-orbit performance for the life of the mission. A control circuit was developed to control the temperature of the detectors to within ±0.25K. Operation of the cooler is flight proven with more than 18 years of cumulative operation onboard INSAT 2E, INSAT 3A and Kalpana-1.



Scan Mechanism

VHRR uses a Beryllium scan mirror to scan the earth image. A bi-axial scan mechanism with very high linearity and repeatability (150 uR and 5 uR respectively) was developed at ISRO Inertial Systems Unit (IISU, VSSC), using precision Inductosyn and limited angle motors, mechanical design and sophisticated servo technologies.

Camera Electronics

VHRR camera electronics was designed to function as a self-contained subsystem including power supply, signal processors, data formatter, temperature controller and housekeeping circuits; all housed in a compact package using motherboard-daughter board technology with redundancy.

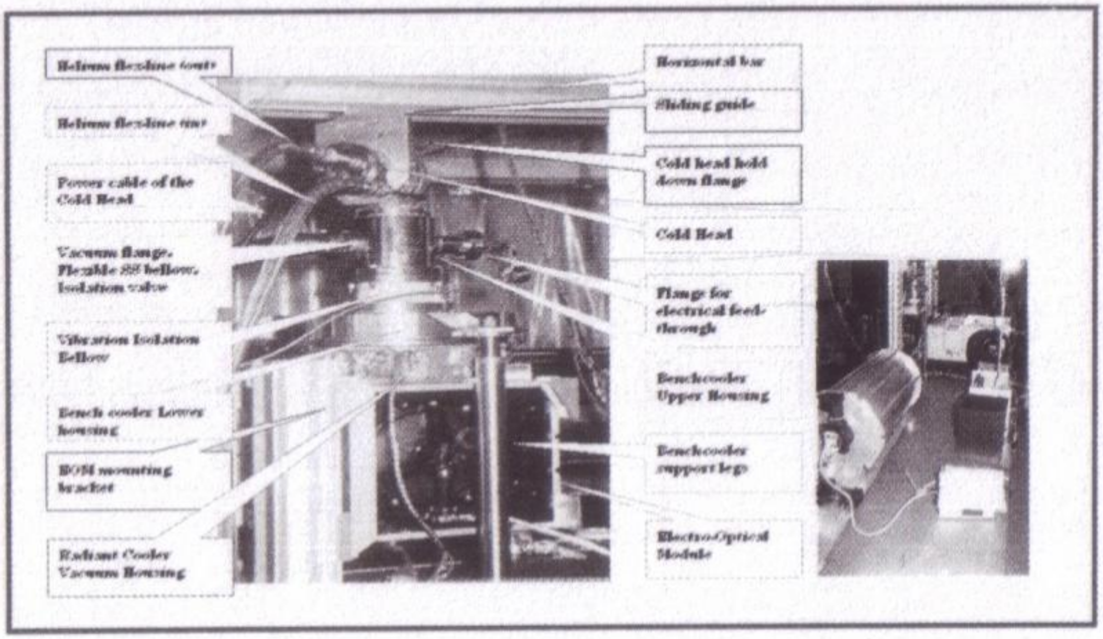
In order to meet stringent radiometric requirement with discrete detectors, a very low noise electronics subsystem was developed. Achieved electronics noise for visible and IR channels were less than 75fA/Ö (Hz) and 7nV/Ö respectively.

Mechanical Structure and Housing

High-stability, precision housings for optical subsystem were designed and realized. All the structural elements were optimized through design and test to meet the weight constraint without compromising on the structural integrity required to survive environmental loads during launch and in-orbit. All the structural elements were realized at SAC, expect for the CERP sunshade for optical view-port realized at CMSE (VSSC).

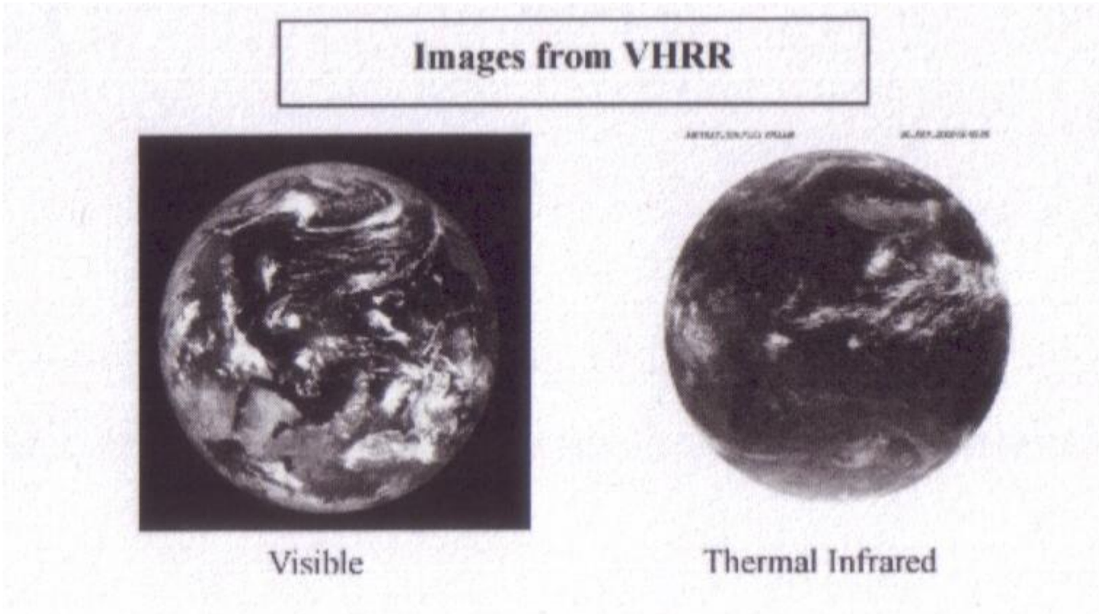
Instrument Integration and Checkout

Integrating the having diverse technology was challenging task. Special purpose checkout and ground handling subsystems were developed. The payload optimization and checkout was automated to a large extent with specialized checkout software. In order to operate and characterize IR channels in the laboratory.



Salient Features of Indigenous VHRR:

1	Spectral Channels	
	Visible (VIS)	0.55 to 0.75 mm (all missions)
	Thermal Infrared (TIR)	10.5 to 12.5 mm (all missions)
2	Spatial Resolution	
	VIS	2 km
	TIR	8 km
3	Dynamic Range/Sensitivity	
	VIS	0-100 % Albedo (SNR > 6 @ 2.5% Albedo)
	TIR	4 –340 K (NEDT< 0.25 K @ 300K)
4	Scanning Modes	
	Full Frame Mode	Full Earth Disk
	Normal Mode	Full East-West, 50° N to 40° S North-South
	Sector Scan Mode	Full East-West, 4.5° North-South (Selectable Position)
5	Image Periodicity	
	Full Frame Mode	
	Normal Mode	
	Sector Scan Mode	40 min.30 min.30 min. for 3 scans
6	Weight	60 kg
7	Power	40 W



3. Improvements and Operationalisation:

The first two indigenous instruments onboard INSAT-2A and 2B developed snags in thermal channel due to snapping of interconnection within the radiant cooler. However the visible channel performance was satisfactory based on extensive ground simulations modifications were identified for implementation.

Very High Resolution Radiometer (VHRR)

VHRR has been flown on-board the INSAT-2E, Kalpana and INSAT-3A spacecrafts. It is an enhanced version of the two-band VHRR flown on INSAT-2A/2B. This instrument is equipped with an additional WV band (5.7 to 7.1 mm) to map the atmospheric moisture patterns which provide wind velocity and moisture content in various regions of the earth disc.

The configuration of the instrument is modified from its predecessors to accommodate WV channel optics, sensor and electronic chains. A simplified block schematic of VHRR is shown in Figure 1. The following paragraphs describe in brief the configuration and operation of the instrument. The incoming radiation is reflected onto an 8-inch primary mirror of the reflective telescope by a two-axis gimbal-mounted beryllium scan mirror. A gold film dichroic beam-splitter placed in the converging beam from the secondary mirror of the telescope separates the radiant energy. The visible energy is transmitted through the dichroic while combined WV and TIR energy is reflected at right angles to the original direction. This allows the radiation from the earth to be channeled to visible and combined IR focal planes simultaneously with high optical efficiency. The detector configuration for the VIS band consists of two staggered arrays of four silicon photodiodes each; while for WV and TIR bands, the detector package contains two sets of dual mercury–cadmium–telluride (MCT) photoconductive detector elements in close proximity to band defining filters. This detector package was specifically designed such that the original design of radiant cooler for INSAT-2A/2B could be utilized with only minor modifications. The IR detectors are operated nominally at a temperature of 105 K to limit thermally generated noise. One of the detectors in each band is energized, while the other set provides the cold redundancy. Both sets are identical in function and can be switched ‘on’ and ‘off’ from the ground through radio-command.

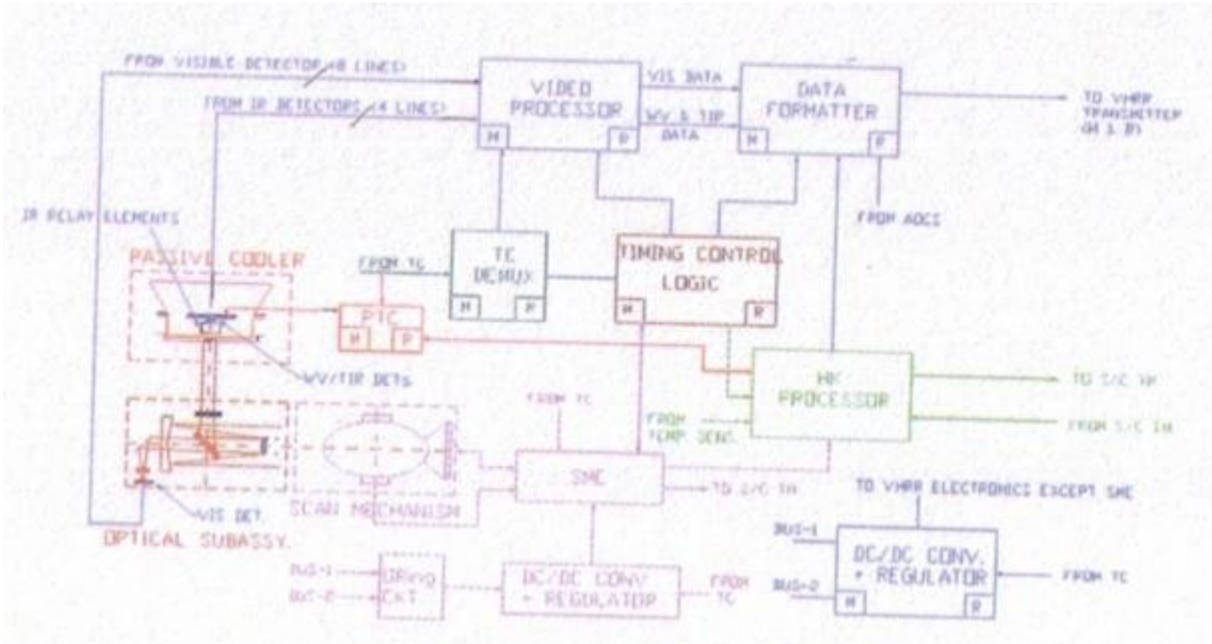


Figure-1 Block Schematic of VHRR

The two-dimensional image of the earth is generated by sweeping the instantaneous geometric field of view of the detectors by rotation of the scan mirror-gimbals in two orthogonal axes. For every sweep of the mirror, four contiguous lines of VIS band and one line each of WV and TIR bands are generated in east–west direction. At the end of the sweep, the mirror is stepped south through an angle equivalent to eight kilometers on the ground and data collection is resumed in the reverse direction for the next sweep. This improves the scanning efficiency which, in turn, enables faster coverage rate at reduced noise bandwidth of the system. Three modes of operation (Figure 2) are provided to allow trade-off between area and frequency of coverage.

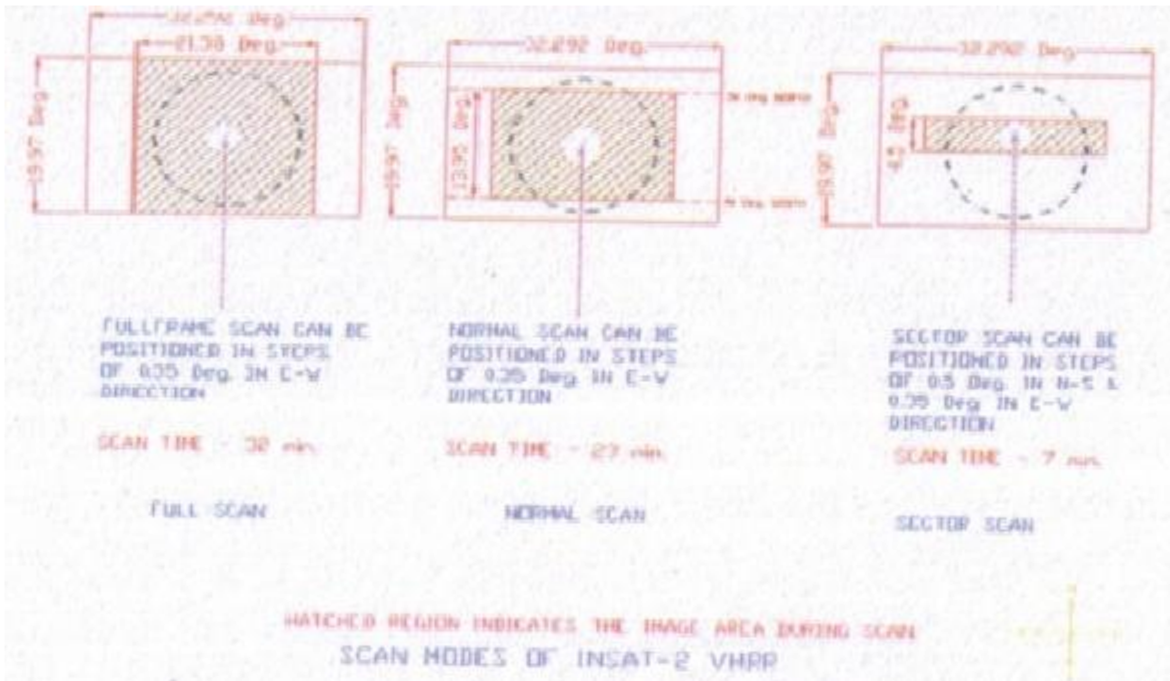


Figure-2 Scan Modes of INSAT-2 VHRR

Full frame mode scans 20 x 20 degree in about 33 min covering full earth disc and some space around. Normal frame mode coverage in east–west direction is the same as in full frame mode, while in north–south direction; scan extent is 14 degrees, covering 50 degrees N to 40 degrees S latitudes in 23 min. Sector frame mode provides 4.5 degrees coverage in north–south direction spanning approximately 2800 km (351 scan lines) in about 7.2 min. The east–west coverage remains unchanged as in full and normal frame modes. The sector can be positioned, through radio command, anywhere in full scan field in steps of 0.5 degree (312 km or 39 lines) in north–south direction. This mode is particularly suited for rapid repetitive coverage during severe weather conditions like cyclones.

Kalpana-1/ METSAT

Kalpana-1 is an exclusive meteorological geostationary satellite which was launched on 12th September, 2002 and is located at 74 degrees E, Originally named METSAT,r enamed after Kalpana Chawla who perished in the space shuttle Columbia. It carries a Very High Resolution Radiometer (VHRR) capable of imaging the Earth in the visible, thermal infrared and water vapor bands.

The VHRR payloads on kalpana-1 are as follows:

Payloads	Channel	Resolution	Data Rate	RF Frequency
VHHR (very high resolution radiometer)	visible(0.55-0.75uM)	2x2 Km	526.5 kbps	4503.5 MHz
	Infrared (10.5-12.5uM)	8x8 Km		
	water vapour (5.7-7.1uM)	8x8 Km		

Modes of Operation: There are three types of modes of operations, namely Full Frame, Normal and sector modes. The range of full frame mode is 20deg in both N-S and E-W direction and takes 33 minutes and number of lines will be 1560. The normal mode covers a range of 14deg in N-S direction and 20deg in E-W direction and takes 23 minutes and number of lines will be 1092. The sector mode is very useful for tracking the synoptic systems like cyclones etc. and covers a range of 4.5 deg in N-S direction (selectable) and 20deg in E-W direction takes 7minutes (3 scans in 23 minutes) and number of lines will be 351. Presently this satellite is providing half hourly normal scans round the clock.

Mode of Operation	Time of coverage	Coverage Area
Full frame mode	33 minutes	20x20 degrees
Normal scan mode	23 minutes	14 degrees in NS & 20 degrees in EW
Sector scan mode	7 minutes	4 degrees in NS & 20 degrees in EW

The VHRR payloads on INSAT-3A are as follows:

Payloads	Channel	Resolution	Data Rate	Frequency
VHHR (very high resolution radiometer)	visible (0.55-0.75 um)	2x2 Km	526.5 kbps	4501.5 MHz
	Infrared (10.5-12.5um) water vapour (5.7-7.1um)	8x8 Km		

Modes of Operation of INSAT-3A, VHRR:

There are three types of modes of operations, namely Full Frame, Normal and sector modes. The range of full frame mode is 20deg in both N-S and E-W direction and takes 33 minutes and number of lines will be 1560. The normal mode covers a range of 14deg in N-S direction and 20deg in E-W direction and takes 23 minutes and number of lines will be 1092. The sector mode is very useful for tracking the synoptic systems like cyclones etc. and covers a range of 4.5 deg in N-S direction (selectable) and 20deg in E-W direction takes 7minutes (3 scans in 23 minutes) and number of lines will be 351.At present INSAT-3A VHRR is being operated in Full frame mode i.e 24 no's of scan received and processed in day on hourly basis.

Mode of Operation	Time of coverage	Coverage Area
Full frame mode	33 minutes	20x20 degrees
Normal scan mode	23 minutes	14 degrees in NS & 20 degrees in EW
Sector scan mode	7 minutes	4 degrees in NS & 20 degrees in EW

The dark and cold space views at the east and west ends are used for establishing reference radiance for all the three bands. A full end-to-end calibration of WV and TIR bands is provided by swinging the mirror to view a black body cavity fitted on the inner side of north plate of the instrument. The physical temperature of the black body is accurately monitored by platinum resistance thermometers at five locations and is tele-metered through VHRR data stream. The system response for black body view is available in the video data slot.

These data sets provide calibration coefficients for WV and TIR bands. A comparison of the coefficients with ground values is made to estimate band response variation and to update the ground calibration data.

The detector outputs of all the channels of the three bands are individually amplified, band limited and digitized to 1024 grey levels by A/D converters. The digitized data of all the channels, housekeeping information, calibration data, etc. are formatted, randomized and transmitted serially in extended C band. VHRR shares solid state power amplifier (SSPA) with the CCD instrument for data transmission.

Scan Mechanism Assembly

Scan mechanism consists of two-axis gimbal-mounted beryllium mirror. This gimbal is servo-driven in two orthogonal axes by independent servo-motors to give precise movements to an elliptical beryllium scan mirror mounted in the gimbals at 45 degrees to the optical axis. The scan mirror is fabricated from a 19 mm thick beryllium block with major axis of 340 mm and minor axis of 210 mm. The back side of the mirror is scooped with square pattern to reduce weight. The minor axis of the mirror is the fast scan axis. The mirror swings ± 5 degrees (mechanical) per second about this axis to provide effective optical sweep of 20 degrees to the detector field of view to generate one scan line per second. The other axis which is orthogonal to the fast scan axis is called slow scan axis. The mirror is stepped through 224 microradian about this axis after completion of one fast scan. In the fast scan direction, data is collected for both forward and reverse sweeps of the mirror. The number of steps in the slow scan direction depends on the mode of operation of the instrument. The instrument is mounted in the spacecraft in such a way that fast scan lines are parallel to the equator while slow scan steps correspond to north to south movement.

In addition to 20 degrees stepping in north–south direction, there is a provision to rotate the mirror through 90 degrees about the slow scan axis to view a black body which is fitted on the inner face of the north panel of EO module. There is also an in-built offset capability in east–west direction to position the earth disc at the centre of the image for any position of the satellite from 70 degrees E to 100 degrees E longitudes.

Mechanical limit stops on the west and south ends provide mechanical reference for fast and slow scan axes, respectively. A precise 256 pole inductosyn angle encoder is used to provide position information in the servo loop. The system operates in null seeking mode to maximize sensitivity and linearity of the system.

Radiant Cooler

IR detectors are required to be maintained at a precisely controlled low temperature between 105 and 115 K to reduce the detector thermal noise. In addition, precise temperature control ensures that the offset measured during space look remains valid during the actual image period and that the response of the detector through a picture frame is unaltered.

A passive radiant cooler is used to cool the IR detector package below its operating temperature of 105 K. The cooler consists of three stages called patch, radiator and vacuum-housing-sunshield. The patch is the coldest stage on which the detector is mounted. It is effectively a high emittance honey-comb cavity mimicking a black body which is north oriented to radiate to deep space all the time. The patch is supported in the radiator by means of four fiberglass rods. The radiator surface is co-planar with the patch and is painted white to minimize radiator temperature. The rear surfaces of the patch and the radiator are gold-plated to reduce radiation heat load.

The radiator is attached to the vacuum housing by eight fiberglass supports. The housing supports the patch–radiator assembly as well as IR optical components such as focusing lens, vacuum window, etc. To avoid direct viewing of the sun by the patch, a pyramidal sunshield assembly made of four trapezoidal panels is attached to the vacuum housing. The sunshield surfaces facing the patch are highly polished for high specularity and low emissivity to minimize heat input to the patch. The external surfaces of the vacuum housing and sunshield are covered with silverized teflon tape to reject heat to deep space. The complete assembly is mounted on an interface plate through eight fiberglass support rods to provide thermal isolation to the cooler from the electro-optic module.

Heaters are fixed on the patch, radiator, vacuum housing and sunshield to heat up these parts to 300 K for decontamination in-orbit before the commencement of normal operation.

Patch heaters and platinum resistance thermometers mounted on the patch are used in a closed loop proportional servo to control the patch temperature at any of the eight set points from 105 to 115 K with an accuracy of better than 0.25 K. The set points are selected through ground commands to optimally use available cooling capacity.

Optics Assembly

The VHRR optics assembly consists of telescope, dichroic beam splitter, IR collimating lens, IR relay optics and visible band optical elements as shown in Figure 3.The telescope is a Richy-Chretian type with 200 mm diameter concave hyperboloid primary mirror and 55 mm diameter convex hyperboloid secondary mirror separated by 285 mm. The primary and secondary mirror-mounts as well as the barrel are made of INVAR to precisely maintain the separation of mirrors over the temperature excursions from 0 to 40°C.

The convergent light beam from the secondary mirror is intercepted by a specially designed dichroic which reflects 85% of IR energy and transmits 75% of visible energy without distortion of the wavefront. The energy paths for two beams are now separated by 90 degrees. The transmitted VIS band energy is reflected by a fold mirror onto an array of visible detectors, while the reflected IR energy is collimated before exiting the telescope. This scheme enables independent optimization of performance of TIR and WV bands inside the radiant cooler before it is mounted on the electro-optics module.

Camera Electronics

The major functions of camera electronics are: (i) to amplify, DC restore and digitize detector outputs; (ii) to control IR detector package temperature; (iii) to generate master clock and other control pulses; (iv) to format, code and randomize data. In addition, the electronics monitors and formats various housekeeping parameters and contains spacecraft interfaces.

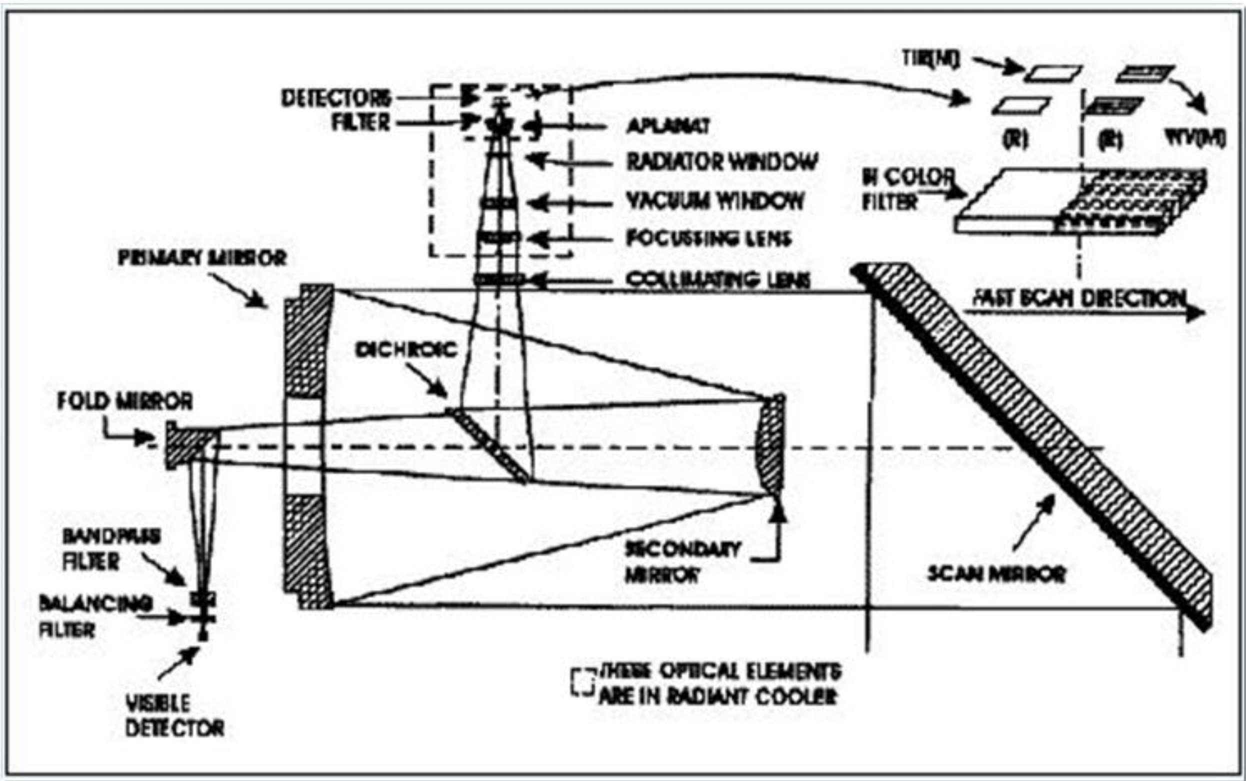


Fig. 3: Schematic of VHRR Optics Assembly

Signal Processing

The photo current from visible detectors is 1 nA full scale. This is amplified by a trans-impedance pre- amplifier having a gain of 30 x 10^6 V/A. The pre-amplifiers for WV and TIR bands have super matched bipolar transistors in the input stage to amplify very low level voltage signals (300 m V full scale) from the detectors in respective bridge configurations. All pre-amplifiers are placed in the vicinity of detectors to minimize noise pick-up in signal lines.

In order to extract useful signals from pre-amplifier outputs, large zero-signal offset has to be subtracted before further amplification. This offset is sampled when the mirror is looking towards space. The precise offset subtraction is achieved by digitization and storage of offset through a dual loop sampling. During subsequent signal amplification, this offset, converted to analogue voltage through DAC, is subtracted from pre-amplified detector output, so that full dynamic range is used for actual video signal. The amplified output is passed through noise limiting, anti-aliasing filter before being digitized. The digitized output is serialized, formatted with housekeeping information and transmitted to the ground after modulation on extended C band carrier. The total chain gain for visible channel is of the order of 7500 x 10^6 V/A and for IR channels, 35,000 V/A.

IR Detector Temperature Control

WV and TIR detectors are operated at controlled cryogenic temperature to reduce their thermal noise significantly below the minimum useful signal level. The temperature of the detectors is controlled by first cooling the detectors passively through the radiant cooler and then stabilizing the temperature using a proportional temperature controller. The temperature controller uses platinum resistance thermometer (PRT) temperature sensors as feedback elements and heaters as actuators to control the temperature at slightly above the limiting temperature achieved by the cooler. This allows the detector temperature to be maintained at the selected set points with an accuracy of 0.25 K in presence of diurnal and annual patch temperature variations due to heat load cycles.

The temperature control has provision to automatically switch-off bias to the detectors when temperature exceeds 125 K. This feature protects detectors from inadvertent operation at higher temperature.

The patch temperature control, being vital functions, has complete functional redundancy and cross-coupling between heaters and controllers.

Control logic and formatter

This is the master controller for the instrument. It generates bit rate clock at 526.5 kHz which is used by all timing and control blocks as a basic timing signal. All the video processing circuit functions are also synchronized with this clock. The formatter takes data from video processors, scans mechanism, attitude control and analog/ digital telemetry circuits and inserts them in instrument output stream along with frame synchronization code. The final output is randomized and given to the transmitter for down link.

Charge Coupled Device Payload

The CCD payload is designed to carry out earth imaging in three spectral bands. The bands are selected to have applications in meteorology as well as vegetation mapping. All the three bands provide co-registered images with a ground resolution of 1 km ´ 1 km. The payload retains the basic telescope and scan mechanism of the VHRR instrument. The separation of three bands is achieved by two dichroic beam splitters. The first dichroic reflects SWIR energy and transmits VIS/NIR energy; while second dichroic reflects NIR energy and transmits VIS energy. The VIS and NIR band detector arrays (Si, CCDs) are placed directly in the split focal plane of the telescope, whereas an auxiliary lens doublet refocuses the telescope beam to a secondary focus where the SWIR charge coupled photodiode (CCPD) array detector is placed. This optical configuration is selected to accommodate two different sizes of detector elements for identical foot prints on the ground. Ground processing is further facilitated by selecting a unidirectional scanning in fast scan direction in view of hybrid scan concept used for this payload. In this type of scanning, mechanical scanning and electronic scanning are simultaneously carried out in two orthogonal axes. This scan geometry generates a three-band image strip of 300 km wide (north–south) and 6300 km long (west–east) for each sweep of scan mirror from west to east in one minute.

Flexible programmable scan modes allow generation of images with up to 24 contiguous strips covering an area of 6300 km x 6300 km. Again, a positioning mechanism enables this image field to be positioned anywhere in a scan field of 20 degrees x 20 degrees covering full earth disc. Table 2 gives major specifications of the instrument.

CCD	Visible (0.62-0.68 um)	1x1 Km	1.28875 Mbps	4508.9 MHz
	NIR (0.77-0.86 um)			
	SWIR (1.55-1.69 um)			

Modes of Operation of INSAT-3A, CCD: There are two Modes of Operation for CCD payload. The scan coverage in East-West is 10deg in all modes whereas North-South coverage will vary depending upon the mode. The two modes are Normal and Program mode. The coverage in the normal mode will be 10 deg. Positioned by ground command within 20 deg. Field where as in the Program mode 1 to 25 lines, each covering 0.395 deg. Currently IMD is processing hourly images during day time only. At present INSAT-3A CCD is being operated in Normal frame mode at fixed time i.e. 0300, 0500, 0600, 0700, 0900&1100 GMT during day

Mode of Operation	Time of coverage	Coverage Area
Normal frame mode	25 minutes	10 X10 deg
Program mode	Programmable	Programmable

The CCD payload consists of the following major functional blocks:

Scan Mechanism Assembly

The scan mechanism consists of a gimballed scan mirror which sweeps the composite detector field of view in two orthogonal axes to generate wide-field two dimensional imagery. The fast scan sweep of the mirror generates 300 video lines over 6300 km east–west span every minute. The stepping of the mirror south by about 0.4 degrees after each west to east scan helps to generate successive image strips. Earth imaging is done only during west to east scan of the mirror, while retrace is much faster to improve scan efficiency; retrace time being only about 1.25% of active line time.

The total scan field of mirror is ± 13 degrees in east– west direction and ± 10 degrees in north–south direction, while active image field is ± 5 degrees in east–west direction and a maximum of ± 5 degrees in north–south direction. This active image field can be positioned anywhere in the total scan field to generate imagery of any part of visible earth disc.

For linear and precisely controlled motion of the mirror in two orthogonal axes, inductosyn encoders are used as angular position feedback devices and servo motors are used as actuators. The two independent servo loops are synchronized to initiate north–south stepping during fast scan retrace.

The scan mechanism also includes a linearity enhancing function such that a stored mirror image pattern of ground measured error is superimposed on the mirror drive signal, point-by-point, as the mirror scans in the fast scan direction. The ground measurements have shown that this scheme substantially improves the fast scan linearity when energized. There is a provision to disable this function through ground command if required.

Optics and Detector Assembly

The optics schematic of INSAT-2E CCD payload is shown in Figure 4. This configuration was selected after exploring different design approaches where image quality, compactness, ease of assembly/disassembly, accessibility for alignment and co-registration of detectors, spacecraft size constraints and polarization sensitivity were some of the main design considerations. The optical system simultaneously images a north–south strip of 300 km on three separate detector arrays, each having 300 equivalent pixels and individual spectral filter for band definition. The scan mirror, telescope, dichroic beam splitters, fold mirror, lens doublet and band pass filters together constitute the optical assembly. The front end of the system consisting of the scan mechanism and telescope is identical to that of VHRR payload except that the telescope performance has been upgraded to provide required image quality over larger field of view of ± 0.25 degrees at twice the spatial frequency of VHRR. The detectors used for VIS and NIR bands are 2048 element linear silicon CCD arrays. The outputs of three consecutive detector array elements are added together. Thus 900 pixels of each array are utilized to construct 300 image pixels for each band. A customized readout chronogram has been designed to read the unused pixels at a dump rate ten times faster than useful pixel readout rate. This scheme optimizes the performance requirements for signal amplifiers and A/D converters and economizes on the data transmission rate at the cost of complexity in generation of drive signals. The excellent signal to noise ratio performance obtained through the instrument has established the soundness of this readout scheme.

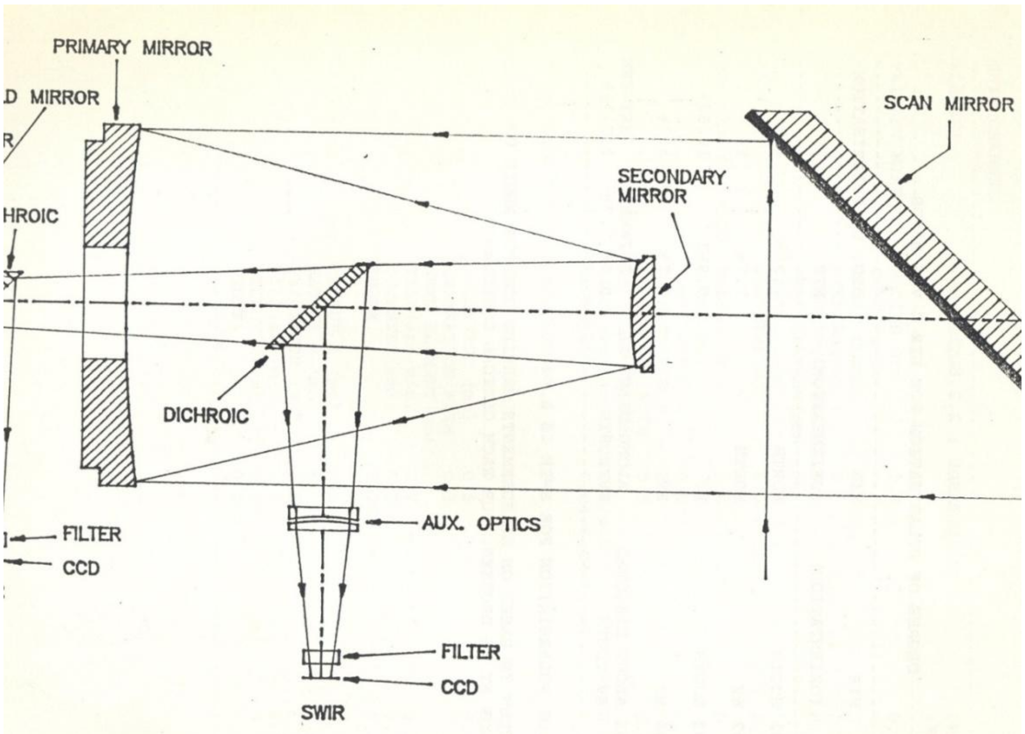


Fig.4: Optics schematic of INSAT-2E CCD Payload

The SWIR detector consists of a 300 element linear CCPD array. This is a hybrid assembly where InGaAs photodiodes are coupled to silicon CCD readout shift registers. A low noise signal extraction has been achieved by operating the detector in ‘vidicon mode’. In this mode of operation, during signal integration period, the photocurrent discharges an initial fixed charge placed on the junction capacitance of the detector element. A measured charge injected into the CCD shift register potential wells restores the initial value of charge on the junction capacitance at the end of integration period. The remaining charge is skimmed back into the potential wells of the shift registers and is extracted as ‘inverted video’ signal through shift register clocking mechanism. As the pixel sizes of VIS/NIR and SWIR CCD arrays are different, effective focal lengths are adjusted by auxiliary optics in SWIR band to give identical ground resolution of better than 1 km x 1km for all the three bands.

Camera Electronics

The camera electronics performs the following functions: (i) provides clock and bias inputs to detectors; (ii) processes and digitizes detector outputs; (iii) formats video signal along with auxiliary information; (iv) monitors instrument status through analog and digital telemetry; (v) interfaces with other spacecraft bus subsystems and (vi) controls the SWIR detector temperature through feedback loop.

Detector driver and bias circuits: All three detector arrays require various bias voltages and clock waveforms for their operation. These signals are provided by voltage regulators and clock drives placed close to the detector arrays to minimize the noise pick up and reflections due to long cable length. The following parameters were considered while designing the clock driver and bias circuits: (i) voltage levels; (ii) control of noise on sensitive lines; (iii) rise and fall time for clock levels; (iv) delay between clocks; (v) drive requirements for different waveforms.

Video processing chains: *The functions of video processing chains are to condition the output signal from detector, perform DC restoration*, extract the video information and digitize it with ten bit resolution and accuracy.

For VIS and NIR bands, video output from CCD is a three level pulse amplitude modulated (PAM) signal riding on 4 to 11 V DC level. The RMS input noise is about 1.2 mV for VIS band and 0.7 mV for NIR chain for an integration time of 8.334 milliseconds. This requires an amplifier bandwidth of 530 kHz for proper signal conditioning. The saturation signal is about 775 mv for VIS and 490 mv for NIR bands, dark signal being less than 4% of saturation signal for operating temperature range of the detectors. To guard against the possible radiation-induced increase in dark signal, a provision is made for all three bands to subtract ground command controlled offset from video signal. This helps in utilizing available dynamic range more effectively even after possible long-term radiation effects.

The design of the SWIR pre-amplifier is similar to VIS/NIR pre-amplifiers except that the bandwidth required is about 230 kHz. However, the further amplification and conditioning circuits are different as the DC restored signal needs to be subtracted from preload reference level to extract the video signal.

Control Logic and Formatter: The control logic generates waveforms required for the detector operation and for the control of video processor functions. It also generates the control pulses for multiplexing the video signal into the data formatter along with analogue and digital housekeeping information.

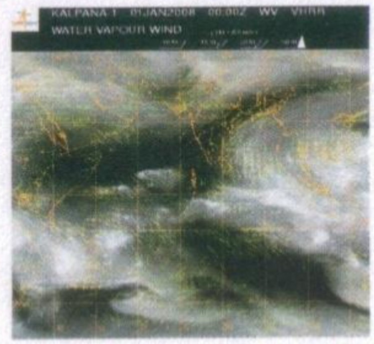
Telemetry circuit: Instrument health is monitored through analogue and digital telemetry channels, both in CCD data stream as well as in main spacecraft telemetry. Here, various voltage and current levels, scan mechanism position and drive current status, temperatures at different locations in the instrument and configuration of the instrument in various modes of operation are telemetered to ground for continuous monitoring. In addition, full spacecraft telemetry which operates at 1 kbits/sec is sandwiched into 1.3 Mbits/sec CCD data stream to provide added redundancy for spacecraft telemetry. The hardware and data rate overhead due to this addition is small enough to justify its inclusion in CCD data stream considering its usefulness.

SWIR detector temperature controller: The temperature of the SWIR detector is maintained at 15 ± 1°C to control its dark current variation. For this, the detector mount is first cooled down through passive radiation to below 15°C. A temperature controller, operating in feedback control mode, controls the temperature at selected set point (15°C or 20°C) using heaters as actuators and thermistors as feedback elements. An on-off type of controller has been used to reduce power dissipation in driver transistors in view of its adequacy for required degree of control.

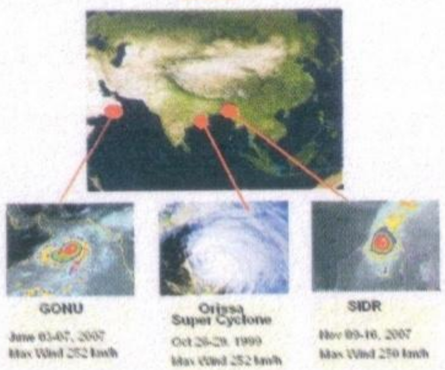
Applications

The data from all these payloads are being used for obtaining wind vectors (both Cloud motion vector and water vapour image derived atmospheric motion vectors), Quantitative precipitation estimate (QPE), Outgoing long wave radiation (OLR).

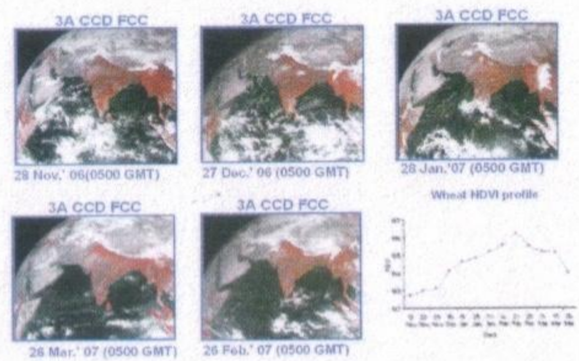
In addition the data from CCD payload is also used for vegetation index and snow cover studies. The data from VHRRs have also been used for determining Cyclones track.



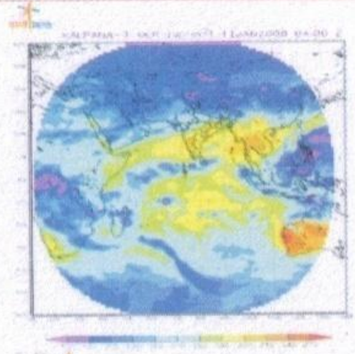
3 Super Cyclones over the Indian Ocean during the past decade

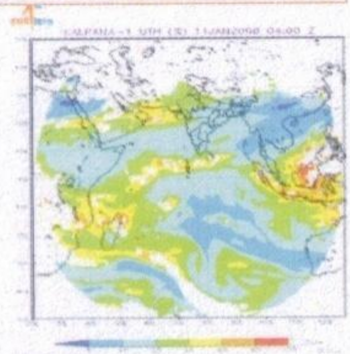


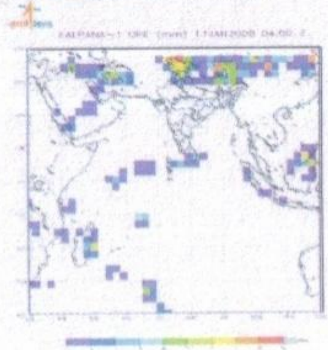
NDVI profile from INSAT 3A CCD (1km)



Operational Geophysical Parameters from KALPANA







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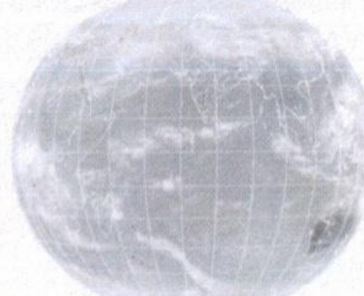
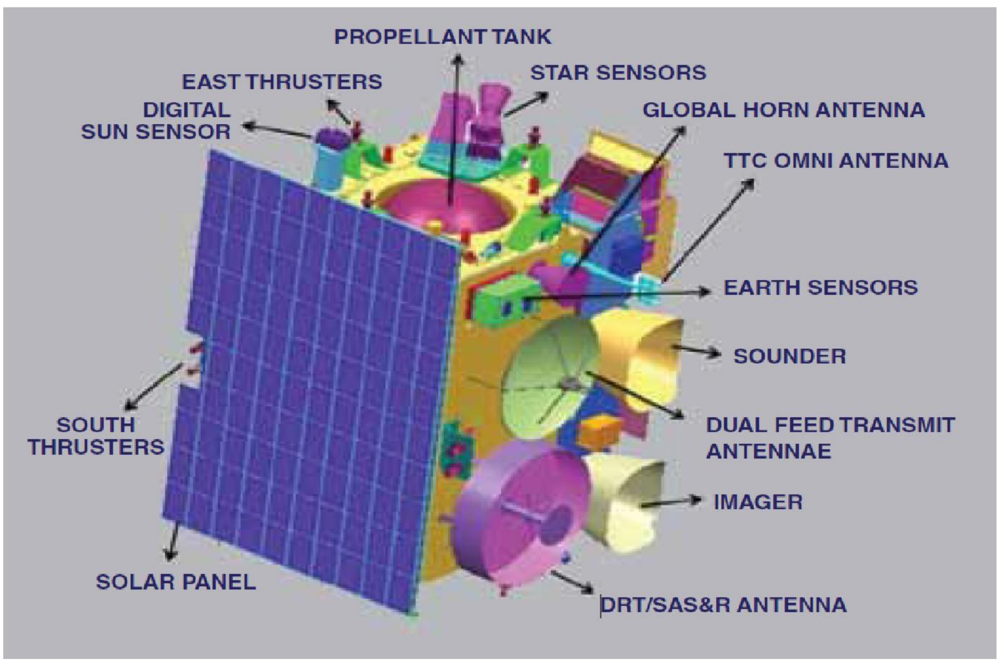


4. INSAT-D (New Capabilities)

India on 26th July 2013 successfully launched its advanced meteorological spacecraft INSAT-3D by Ariane-5 launch vehicle from the spaceport of Kourou in French Guiana and parked at 82˚E. INSAT-3D is designed for enhanced meteorological observations, monitoring of land and ocean surfaces, generating vertical profile of the atmosphere in terms of temperature and humidity for weather forecasting and disaster warning. It carries four payloads viz. 6 channel multi-spectral Imager (optical radiometer) capable of generating the images of the earth in six channels, 19 channel Sounder radiometer that measures emitted energy in 18 IR bands and reflected solar energy in one visible band., Data Relay Transponder (DRT) and Search and Rescue Transponder. Two meteorological payloads (Imaging System, Atmospheric Sounder) were activated on August 7 - 8, 2013.

Having established an operational system capable of providing the basic imagery in multiple channels from Geo Stationary platform it was necessary to improve the observational capabilities to enhance the applications. Towards this development of a dedicated meteorological satellite INSAT 3D with two instruments was initiated. An Imager instrument with more spectral channels and improved spatial resolution from 2 kilometers to one kilometer for Visible and Mid Infra red channels has been developed. This provide data from improved accuracy Sea Surface Temperature retrieval using split thermal channel and Mid Infra red channel caters to observation of clouds during night. The 3.9 µm mid infra red channel responds to both emitted terrestrial radiation, and reflected solar radiation. Since the emissivity of water droplets at 3.9 µm is less than that for longer wavelengths, it is also used to identify fog and stratiform cloudiness in this imagery and to discriminate between water and ice clouds. Use of mid infra red channel at night offers a good substitution for visible channel imagery. It is also used to track low-level fields and infer near-surface wind circulation. Atmospheric Motion Vector retrieval has been improved because of improved spatial resolution.



IMAGER

The INSAT-3D Imager is a six-channel (one visible, five infrared) imaging radiometer designed to sense radiant and solar reflected energy from sampled areas of the earth. With more number of spectral channels and improved ground resolution, INSAT-3D Imager can be considered an enhanced version of Very High Resolution Radiometer (VHRR), the five indigenous instruments flown on INSAT 2A through INSAT 3A satellites and on Kalpana-1. The Imaging System of INSAT-3D has significant improvements over that of KALPANA and INSAT-3A:

- Imaging in Middle Infrared band to provide night time pictures of low clouds and fog.
- Imaging in two Thermal Infrared bands for estimation of Sea Surface Temperature (SST) with better accuracy.
- Higher Spatial Resolution in the Visible and Thermal Infrared band

Imager Instrument Characteristics

INSAT-3D Imager generates earth image in six spectral channels. It uses a scan mirror mounted on two axes gimbal for scanning the earth disk. The ground projection at nadir varies from 1 km for Visible and SWIR channels to 8 km for a channel in Water Vapor band. Adequate radiometric resolution and dynamic range is provided for all channels to meet the application science goals.

Table 1.1: INSAT-3D Imager Channel Specification

Channels Number	Channel ID	Channel name	Spectral range (µm)	Resolution (Km)	Purpose
1.	VIS	visible	0.55 – 0.75	1.0	Clouds, Surface features
2.	SWIR	short wave infrared	1.55 – 1.70	1.0	Snow, Ice and water phase in clouds
3.	MIR	medium wave infrared	3.7 – 3.9	4.0	Clouds, Fog, Fire
4.	WV	water vapour	6.5 – 7.1	8.0	Upper-Troposphere Moisture
5.	TIR1	long wave infrared	10.3 – 11.3	4.0	Cloud top and surface temperature
6.	TIR2	split	11.5 - 12.5	4.0	Lower-Troposphere Moisture

Table-1 Key feature of the INSAT-3D imager are shown below:

Telescope aperture	310 MM
Number of channels	6
Channel separation	Beam Splitter
Channel Definition	Interference filter
Instantaneous Field of View	280 rad Vis and SWIR (1km) 1120 rad MIR, TIR-1 & TIR-2 (4km) 2240 rad WV (8km)
Sampling interval	1.75 Samples/IFOV for VIS, SWIR, MIR & TIR 1/2
Scan Step Angle	3.5 Samples/IFOV for WV Linear in E-W Direction (8 R step size) Line step 224 rad N-S
Scan rate	180/Sec – 0.2 sec turn around
Scan Linearity	28 R (peak-peak)
Frame Time	26 minutes + HK Time for Full Frame mode
Signal Quantization	10 bit/ sec
Down Link Data Rate	3.92725 Mb/sec

The salient features of INAST-3D Imager are as follows:

1. Blackbody calibration sequence is modified as compared to VHRR of earlier satellites.
2. Faster sampling of SME HK data to incorporate complete SME data in payload data format at 55 ms rate to avoid dependence on 'dwell mode TM' of spacecraft & simplify ground processing & archival.
3. Two flexible mode of operation:
    - Full frame mode scans 18 degree EW x18 degree NS covering the entire Earth disc.
    - Program mode covering 18 degree in EW direction NS coverage can be defined in terms of number of lines to be scanned.
4. High Resolution mode: in the Fast Scan direction IFOVs are over sampled by 1.75 times. For the Slow Scan new high resolution mode is planned. In this mode alternate scan lines shall be at 56 rad intervals instead of the nominal 224 rad. This will provide over sampling in slow scan direction facilitating much improved resolution for WVP, TIR-1 & TIR-2 channels.

A flexible scan pattern allows tradeoff between the coverage and the imaging periodicity. The instrument is capable of generating full disk imaging in 26 minutes. Table-1 lists salient instrument characteristics including the dynamic range and radiometric specification for different spectral channels are listed in table-2 Infrared radiometric fidelity is maintained by frequent and timed interval views of space for reference (1.1 or 2.2 second, ground command selectable). Views of the full-aperture internal blackbody at the end of an imaging operation or whenever commanded establishes a high-temperature baseline for in orbit calibration for IR channels.

Instrument Operation

The INSAT-3D Imager is capable of generating full-earth imagery of 18˚?N-S by 18˚?E-W as well as sector imagery (using program mode) that contains the edges of the earth's disk. The N/S size and position of the sector as well as the number of repeat scans of the sector is controllable through command. Sector scan selection permits continuous, monitoring of mesoscale phenomena. The field of regard (FOR) for both modes is 24˚?(E-W) X 19˚?(N-S) During non-imaging period, the scan mirror is kept at its reset position, ready to initiate scanning. The location of reset position depends on the pre-selected scan mode (full disk/program), as well as east-west (fast scan) and north-south (slow san) offsets. On receipt of scan start command from ground, mirror drive mechanism initiates scan. The scan pattern consists of west-east (fast scan) movement for 18˚ at the rate of 20˚/s (optical). At the end of this scan line, the mirror steps to south by 224 uR and initiates east west-scan again at 20˚/s. the time taken for a fast scan line including south (slow scan) stepping is 1.1s. the pattern repeats for the required number of lines. Number of lines to be scanned is programmable for program mode while that for full disk mode, it is fixed as 1402 lines. The whole sequence is repeated for selected number of times for program mode. The mirror traverses to an internal black-body view at the end of each imaging operation, or immediately on receipt of a specific command for black-body calibration any time during non-imaging period. The black-body calibration sequence-both automatic and commanded includes pre and post calibration space looks to improve calibration accuracy.

Fig 6 depicts the scanning geometry of INSAT-3D Imager for full disk and program mode in reference to FOR. **Proposed mode of operation of INSAT-3D, Imager and Sounder**:

There are three modes of operation of INSAT-3D satellite for Imager & Sounder payloads:

Mode of Operation	Time of coverage	Coverage Area
Full frame mode	26 minutes	18x18 degrees
Programmed Normal scan mode	23 minutes	14x18degrees
Programmed Sector scan mode	6 minutes	4 degrees in NS & 18 degrees in EW

During a scan, the detector outputs for all the channels are sampled at a uniform rate. The sampling rate of detector output is 5460 samples/s for MIR, WV, TIR-1 and TIR- 2 channels and 21840 samples/s for the VIS and SWIR channels.This combined with scan rate of 2°/s (optical) results in over-sampling of the detector output in fast scan direction by a factor of 1.75 for all channels except WV. The over-sampling ratio for WV channel is 3.5. Thus, each VIS and SWIR sample is 16 µrad E/W and each IR sample is 64 µrad E/W.

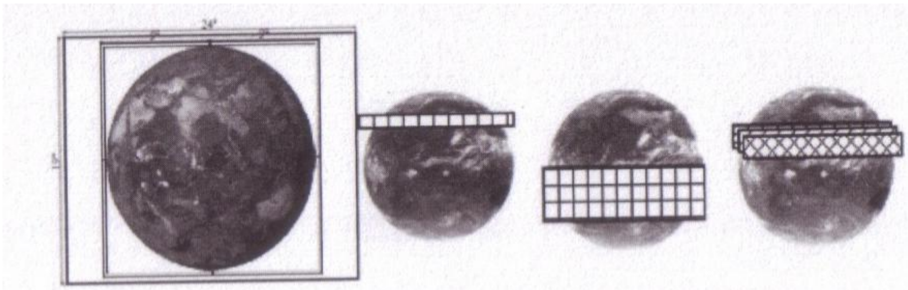


Figure 6: FOR and Placement of Full Disk and Programmable Sector

Figure 6: FOR and Placement of Full Disk and Programmable Sector

Motion of the scan mirror of the companion payload, Sounder causes a small but well-defined disturbance of spacecraft attitude. Effect of this disturbance on the pointing of the Imager scan mirror is calculated in real time by the spacecraft Attitude and Orbit Control System (AOCS) and a correction signal is sent to the Imager scan mechanism electronics. The AOCS also provides compensation signals that correct the scan mirror pointing for the expected spacecraft attitude and orbital effects. It is planned, that the expected attitude and orbital disturbance as a function of orbit position for next 24 hours will be computed on the ground and corresponding correction parameters will be uploaded to AOCS. This scheme for real-time correction of the mirror pointing errors is expected to reduce the time required to process the received imagery on the ground and to make both companion payloads independent of each-other. Provision in the design exists to disable the correction scheme through a ground command.

Table 2. Radiometric Performance of Imager Channels

Channel	Spectral width (mm)	IGFOV at Nadir (km)	S/N or NEDT (K)	Scene Condition	Dynamic Range
VIS	0.55 to 0.75	1	150:1	100% Albedo	0-100% Albedo
SWIR	1.55 to 1.70	1	150:1	100% Albedo	0-100% Albedo
MIR	3.80 to 4.00	4	1.4	300K	180-320K
WVP	6.5 to 7.10	8	1	230K	180-320K
TIR-1	10.3 to 11.3	4	0.35	300K	180-340K
TIR-2	11.5 to 12.5	4	0.35	300K	180-340K

Ttable-3. The INSAT-3D imager and sounder channel specification:

Payloads	Channel	Resolution	Data Rate	Frequency
Imager	visible (0.52-0.77 um)	1x1 Km	3.92725 Mbps	4781 MHz
	SWIR (1.55-1.70 um)	1x1 Km		
	MIR (3.8-4.0 um)	4x4 Km		
	WV (6.5-7.1 um)	8x8 Km		
	TIR-1 (10.3-11.3 um)	4x4 Km		
	TIR-2 (11.5-12.5 um)	4x4Km		
Sounder	LWIR -7 channel (14.71-12.02 um)	10x10 Km	40.00 Kbps	4798 MHz
	MWIR-5 Channel (11.03-6.51 um)			
	SWIR-6 Channel (4.57-3.74 um)			

	VIS (0.695 um)			
DRT	Up link 402.75MHz			4506.05MHz
S&SR	Up link 406.05MHz			4507 MHz

Instrument Description

The INSAT-3D Imager consists of an Electro-Optics (EO) module and a set of electronics packages including power-supply modules. A simplified block schematic of the instrument is shown in Figure 7. The EO module, containing the telescope, scan assembly, and detectors along with cooler, is mounted external to the spacecraft. The electronics packages are mounted on an internal panel of the spacecraft. The complete Payload weighs approximately 130 kg.

EO Module

The EO module consists of scan mechanism assembly, telescope, aft optics, cooler assembly with cooled detectors, detector heads for un-cooled channels, preamplifiers, and view-port sunshade. Exploded view of the EO module is depicted in Figure 8. Emitted radiation and the reflected sunlight from the scene pass through a view-port protected by a sunshade, then the precision flat scan mirror controlled by a scan mechanism assembly, deflects the radiation into a reflective telescope. The energy collected and focused by the telescope and auxiliary optics is converted to electrical signals by a set of detectors. The electrical signals are amplified by preamplifiers for onward transmission to the electronics packages for further processing. Optical performance is maintained by restricting the EO module total temperature range to 25˚-10°C, and radiometric performance is maintained by limiting the temperature change between views of cold space (rate of change of temperature).

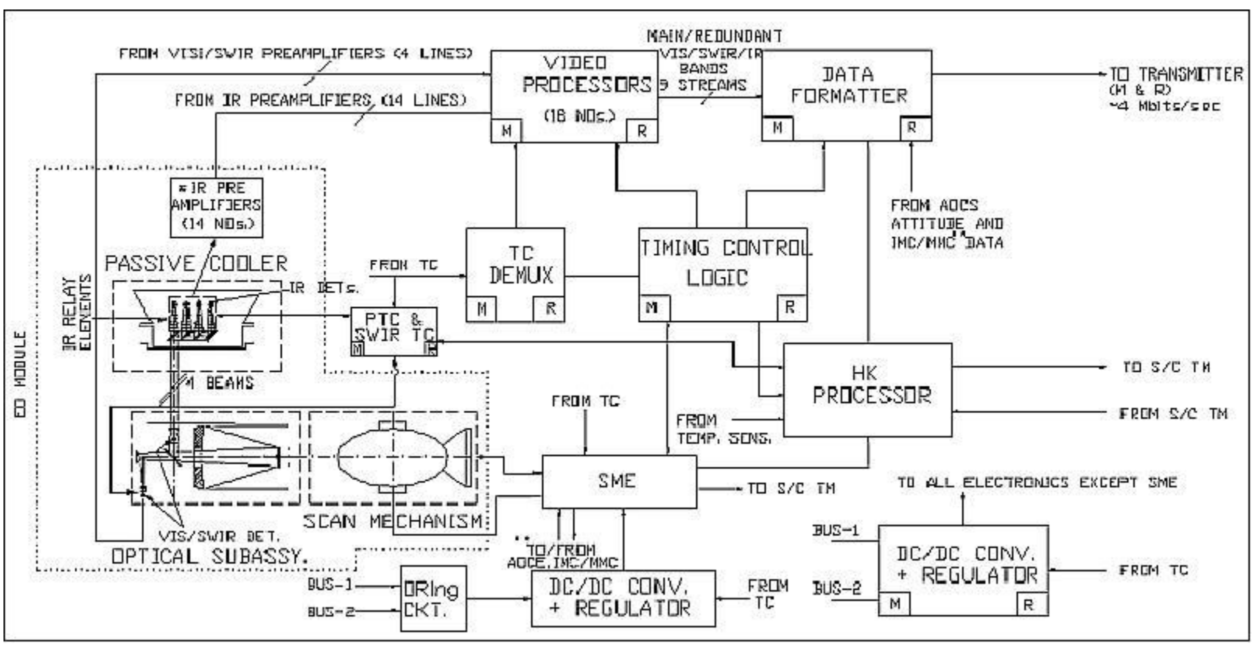
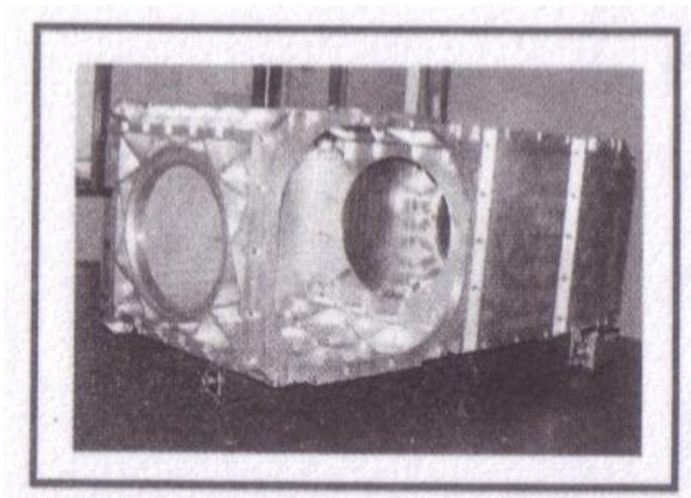


Figure 7: Block schematic of INSAT-3D Imager

The scan mirror mechanism is a two-axes gimbaled servo driven system to give the desired movement to an elliptical SiC (Silicon Carbide) mirror mounted at 45° to the optical axis. This scan mirror is driven about two orthogonal axes by independent servo loops. Each servo loop consists of an Inductosyn which works as an angle encoder and error detector. The actuators of the servo are two limited angle torquers which drive the fast-scan and slow-scan shafts.

The minor axis of the scan mirror is the fast scan axis and provides scanning in the East-West direction. The slow scan axis provides North-South stepping to the mirror. The mirror swings ±4.5°?(mechanical) in 0.9 s about the fast scan axis. This ±4.5° swing can be positioned in an overall ±6° Field of Regard (FOR), thus providing an 18°? East-West scan of the Earth in a 24° FOR. The earth subtends at an angle of 17.4°from GEO so the Earth disc and the surrounding space is always scanned. At the end of each fast scan line, the mirror steps South by a distance equivalent to 8 km on ground. In the fast scan direction, the data is collected for both forward scan and the reverse sweeps of the mirror.



A schematic diagram of INSAT-3D optics subsystem is as shown in Figure 9. A Cassegrain telescope with a 310 mm diameter primary mirror, concentrates the energy onto a 50 mm diameter secondary mirror. The surface shape of this mirror forms a long focal length beam that passes the energy to the detectors via aft optics. Dichroic beam splitters in the aft optics separate the scene radiance into the spectral bands of interest.

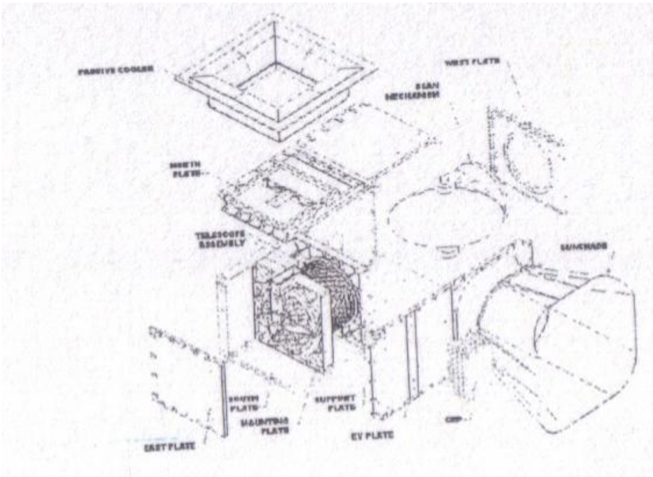
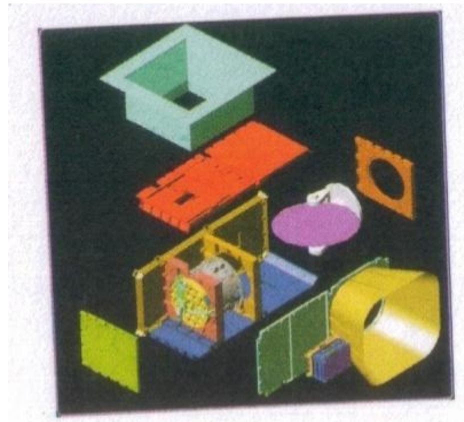
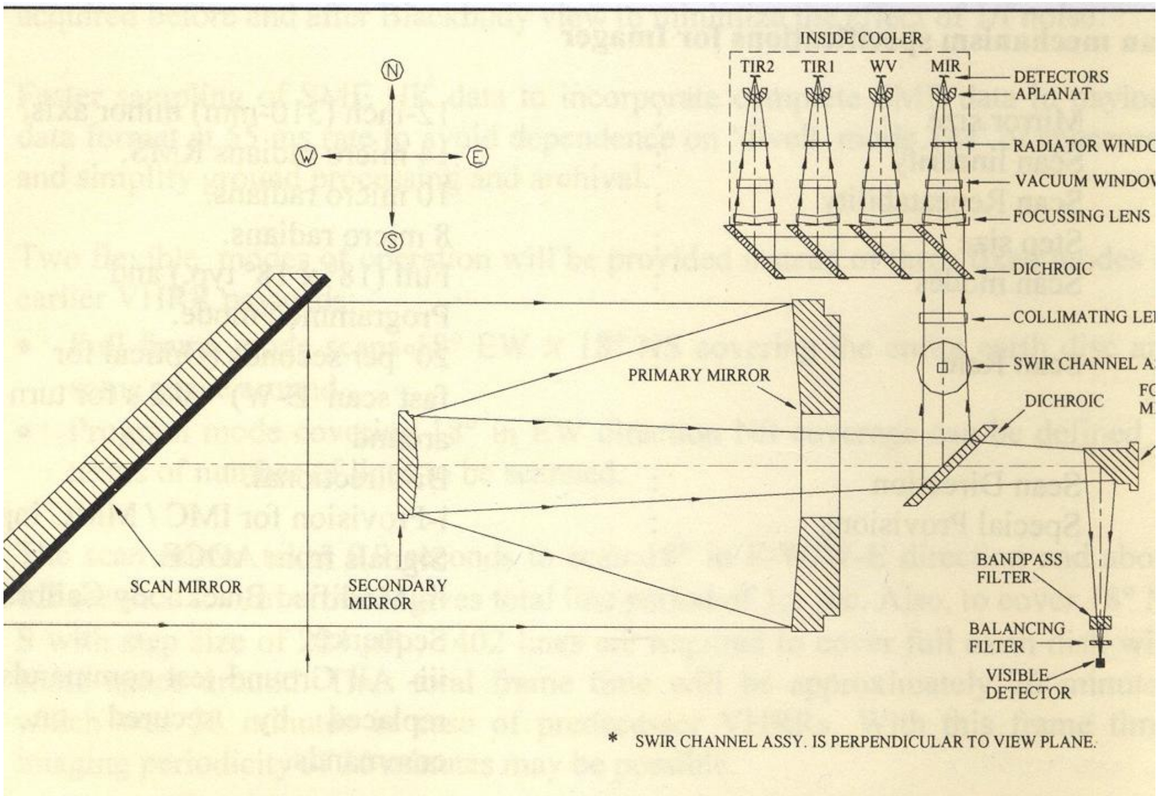


Figure 4





OPTICAL SCHEMATIC OF INSAT-3D IMAGER

There are five dichroic systems for beam separation. The first two dichroics separates the visible and SWIR channels respectively. The separated IR beam is collimated and pass through remaining dichroics. The separated four IR beams enter the passive radiant cooler through individual focus lens assembly before reaching the respective channel detectors. Field size and shape is defined by individual detector elements. A three stage, passive radiant cooler with close-loop heater control maintains the cooled IR detectors at the nominal temperature of

95 K. The radiating surfaces of the cooler are thermally isolated from the rest of the instrument and are adequately shielded from the radiation from Earth. Rotation of the spacecraft about its yaw axis is planned once every six months to avoid sun radiation and to ensure that the low temperature is maintained throughout the year. The visible and SWIR detectors are photodiodes of silicon and InGaAs (Indium Gallium Arsenide) material, respectively. They each contain sixteen elements (eight each for main and redundant arrays). Each element produces an instantaneous geometric field of view (IGFOV) that is nominally 28 microradians (μrad) on a side, which corresponds to a 1 km x 1 km pixel on the surface of the Earth at the spacecraft's nadir view. Each visible channel features a Read-Out Integrated Circuit (ROIC) incorporated in the same detector package using thick-film technology. The ROIC employs capacitive trans-impedance amplifiers followed by an eight-to-one multiplexer and output buffer. This arrangement gives very low readout noise and simplifies design of detector signal processing circuit. Two staggered arrays of eight elements of InGaAs photodiodes form the SWIR channel detector. The resistive trans impedance amplifiers mounted external to the detector package provide pre-amplification. The detector package is operated at a controlled temperature of 15°C. Each of the MIR, TIR-1 and TIR-2 channel detector packages contains four detector elements (two each main and redundant), whereas the Water Vapor channel detector package contains two detectors (one each main and redundant). The detector element of MIR channel is an InSb (Indium Antimonide) photodiode. The remaining three channels employ photo-conductive HgCdTe (Mercury Cadmium Telluride) detectors. The high-impedance MIR detector needs buffering close to the detector element. Hence, the first stage of the preamplifier is integrated in the detector package. Each detector element is square in shape, with an IGFOV of 112 μrad for MIR, TIR-1 and TIR-2, (corresponding to a square pixel 4 kilometer per side at nadir) and 224 μrad for WV channel resulting in a suborbital pixel of 8 kilometer on a side. Though physically separated in the instrument, the detector arrays are optically registered. Deviations in this optical registration due to residual physical misalignments left after assembling the payload and to the size and separation tolerances of the detector elements can be corrected on the ground by the processing software.

Electronics

The Imager electronics consist of detector signal processing including preamplifiers, control logic and data formatter, scan mechanism electronics, detector temperature controllers, auxiliary circuits for command and housekeeping telemetry and power supply. Out of these, the pre-amplifier for both the detectors and the Inductosyn of scan mechanism subsystem are housed in the EO Module, while rest of the circuits is parts of the electronics packages.

Signal processing chain for each channel is composed of a detector, preamplifier, clamp and filter circuits and analog-to-digital (A/D) converter. All signal chains are totally independent and isolated. It is possible to cross-strap redundant signal processing chain for any channel with anyone of the two redundant control logic and formatter.

As discussed in an earlier section, visible channel detector employs ROIC within the detector package readout of integrated signal. This signal is in a multiplexed form containing output from all eight detector elements. It is taken to the electronics package for A/D conversion and insertion of the data into instrument output stream.

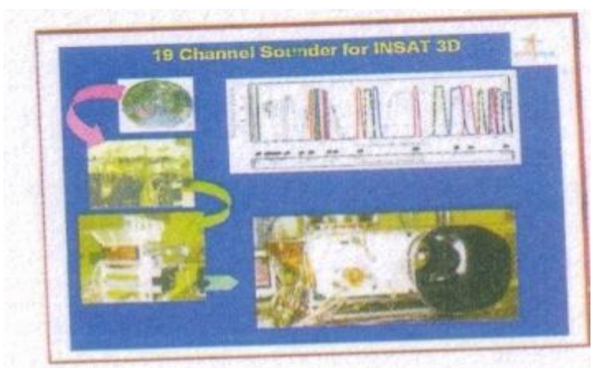
Each detector element of the SWIR channel has a separate high gain (2×10^8 V/A) trans-impedance preamplifiers. The preamplifiers are implemented in a specially developed thick film hybrid microcircuit each containing preamplifiers for four elements and placed close to the detector in the EO module. These pre-amplifiers are followed by post-amplifiers that contain electrical filtering and space clamping circuits. The digitization of the signals is also part of the space clamp circuitry. A single 12 bit A/D converter caters to all elements. Some of the dynamic range of ADC is used for space-clamping.

The IR channels have a separate amplifier/processor for each detector element though the elements in a channel share A-D converters. The MIR channel has a current sensing preamplifier for the high-impedance InSb detector, with the first stage within the detector package. Individual preamplifiers for Water Vapour, TIR-1 and TIR-2 channels are low noise voltage amplifiers mounted on the EO module. The IR information is clamped and converted to 10-bit digital form, providing a dynamic range from near 0.1% to over 100% of the response range.

Electronic calibration signals are injected after pre-amplifiers for all channels except for Inductosyn preamplifiers and utilizes limited angle torquers as actuators and 256 poles Inductosyn ?as angle encoders. The design is centered around a CMOS microprocessor and FPGA. Sub pixel level non-linearity, step size and repeatability are achieved by judicious use of digital and analog error correction circuits. The fixed pattern errors are precisely measured on ground and correction is applied through look up tables stored in Read Only Memory.

Sounder:

The INSAT-3D is a radiometer that senses specific data parameters for atmospheric vertical temperature and moisture profiles, surface and cloud top temperature, and ozone distribution by ISRO. It is the first such instrument has been developed by ISRO.INSAT-3D Sounder measures radiation in nineteen channels, eighteen narrow channels are distributed over three IR bands (seven long-wave (LW), five mid-wave (MW), six short-wave (SW)), while one is a broad visible channel. The sounding is carried out over 10 x 10 km area at a time. Its scan profile is completely programmable for trading coverage verses frequency of observations.



Like Imager, the spectral channels of INSAT 3D Sounder are very similar to those of NOAA GOES Sounder instruments.

It provide information on the vertical profiles of temperature, humidity and integrated ozone of 30x30 km. These profiles will be available for a selected region over Indian landmass every one hour and for the entire Indian Ocean Region every sixth hours.

Table-4. Key features of INSAT-3D sounder are:

Telescope Aperture	310 MM

No. of Cannels	19 (18 infrared +1 Visible)
Channel Definition	Filter wheel with interference filter
Instantaneous field of view	2800 R x 2800 R (N-S) (10km x 10km) 2800 R E-W/N-S
No. of simultaneous sounding step size	4 per channel
Frame time area	185 minutes for 6400km x 6400km sounding
Signal Quantization	12 bit/sample
Down Link Data Rate	40 Kb/sec
System power	100 watt
System weight	144 Kg

The salient features of INSAT-3D sounder design are as follows:

1. Blackbody calibration sequence is modified as compared to VHRR of earlier satellites.
2. In order to improve noise performance, facility to collect two or four samples (0.2 sec or 0.4 sec step & dwell time) of the same area also which can then be processed on ground. This will increase the sounding time proportionally.
3. A biannual rotation of yaw by 1800 has been introduced to reduce the cooler patch temperature. This is to be taken care during processing.

Instrument Characteristics

The INSAT-3D Sounder measures radiance in eighteen IR and one visible channel simultaneously over an area of area of 10 km x 40 km at nadir every 100 ms. Using a two-axes gimbaled scan mirror, this footprint can be positioned anywhere on the earth disk. A program mode of scanning allows sequential sounding of a selected area with periodic space and calibration looks. In this mode, a ‘frame' consisting of multiple ‘blocks' of the size 640 km x 640 km, can be sounded. The selected frame can be placed anywhere within a 24º (E-W) x 19º (N-S) FOR. As with Imager, Sounder provides adequate radiometric resolution for the intended science applications. Table-3 lists salient instrument characteristics. Ground resolution, radiometric specification and dynamic range for different spectral channels are listed in Table-4.

Infrared radiometric fidelity is maintained by timed interval views of the space for reference (approximately every 120 s). And the full-aperture internal blackbody (at 30 minutes interval or whenever commanded) location of the space view (east or west) is ground command selectable. The blackbody view establishes a high-temperature baseline for in orbit calibration for IR channels. Also during space views, an electrical calibration (E-cal) signal, consisting of a sixteen step staircase, is injected every time. Eventually, this staircase signal covers the full dynamic range of the video processors.

The E-cal signal helps in checking the stability of the amplifiers and of the data stream.

Table-5 Sounder Characteristics

Telescope Aperture	310 mm f
Number of channels	19 (18 Infrared + 1 Visible)
Channel Definition	Filter Wheel with interference Filters
Instantaneous Field of View	280 x 280 mR (10 x 10 km)
Sampling Interval	280 mR E-W/N-S
No. of simultaneous Sounding per Channel	4
Scan linearity	50 mR rms
Scan Repeatability	10 mR rms
Step size	FS: 140 mR (Mechanical) SS: 11:20 mRProgram
Mode: Any sector in 24° x 19° FOR by gradual stepping both in fast scan and slow scan axis.	
Step & Dwell Timing	Selectable from 100, 200, 300 & 400 ms
In-flight Calibration	Full Aperture Black body and Space view
Signal Quantisation	12 Bits/Sample
Down Link Data Rate	40K Bits/Sec

Table 6: INSAT-3D Sounder Channel Specification

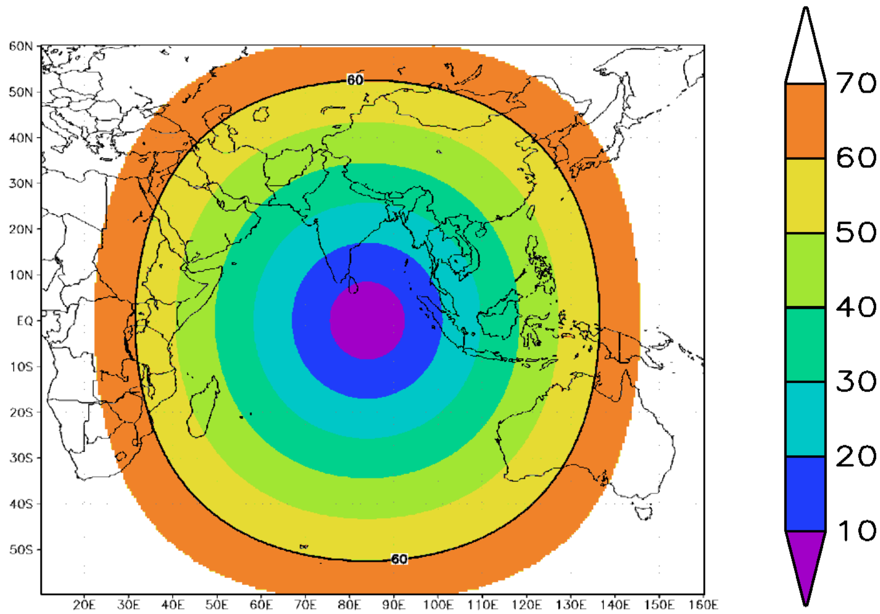
Detector	Ch. No.	Central wavelength (µm)	Wavenumber (cm^{-1})	NEΔT @300K	Principal absorbing gas	Purpose
Long wave	1	14.67	682	0.17	CO_2	Stratosphere temperature
	2	14.32	699	0.16	CO_2	Tropopause temperature
	3	14.04	712	0.15	CO_2	Upper-level temperature
	4	13.64	733	0.12	CO_2	Mid-level temperature
	5	13.32	751	0.12	CO_2	Low-level temperature
	6	12.62	793	0.07	water vapor	Total precipitable water
	7	11.99	834	0.05	water vapor	Surface temp., moisture
Mid wave	8	11.04	906	0.05	window	Surface temperature
	9	9.72	1029	0.10	ozone	Total ozone
	10	7.44	1344	0.05	water vapor	Low-level moisture
	11	7.03	1422	0.05	water vapor	Mid-level moisture
	12	6.53	1531	0.10	water vapor	Upper-level moisture
Short wave	13	4.58	2184	0.05	N_2O	Low-level temperature

	14	4.53	2209	0.05	N_2O	Mid-level temperature
	15	4.46	2241	0.05	CO_2	Upper-level temperature
	16	4.13	2420	0.05	CO_2	Boundary-level temp.
	17	3.98	2510	0.05	window	Surface temperature
	18	3.76	2658	0.05	window	Surface temp., moisture
Visible	19	0.695	14367	-	visible	Cloud

Instrument Operation

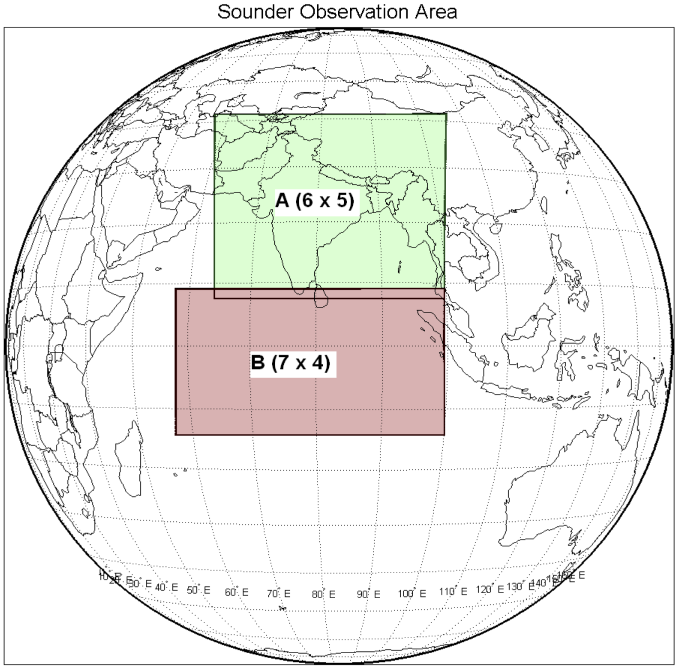
The scan mirror motion, synchronized with the filter wheel, determines the sounding operation. At a particular mirror position, the filter wheel rotates and sequentially brings all 18 IR spectral filters into the optical paths of the three bands. This activity takes around 80 ms, after which, the filter-less (blank region) of the wheel starts. During this period of about 20 ms, the scan mirror steps to the next location in East-West direction and settles before the start of occurrence of the first filter in the optical path. This time is also used for the DC restoration of the IR detector output. Thus, the total time for one filter-wheel revolution is 100 ms (600 rpm). It is possible to carry out multiple (up to four) measurements before the scan mirror steps to a new location. The VIS channel is sampled independently of the filter-wheel position.

The operation of the Sounder is controlled by ground commands in terms of configuration, gain, sounding area location and other such parameters. The sounding area is defined in terms of east –west and north –south ‘blocks'. A step in the east-west direction is 10 km and such 64 steps make a block in the east-west direction. - Similarly, each step into the north-south direction is of 40 km, and 16 steps make a block in the north-south direction. The number of blocks can be independently selected in both directions. For example, 1 block in E-W and 1 block in N-S direction will scan 640 km x 640 km on the ground at the sub satellite location. Depending upon the scan offset selection: the maximum number of blocks in each direction can be 15. The dwell time for each sounding can be selected from 100 ms to 400 ms in steps of 100 ms. The sounding is bi-directional in the East-West direction. After every 1216 filter wheel revolutions, the mirror slews into the east-west direction to a location 9º away from nadir for a space look. The direction of this slewing (East or West) is ground command selectable so as to optimize the sounding time and to avoid any sun-moon intrusion. After the commanded ‘N' steps into the E-W direction are traversed, the scan mirror steps to South by 1120 µrad and starts scanning in the reverse direction. The south stepping takes 200 ms including the stabilization time. The sounding operation described so far is periodically (every 30 minutes), interrupted for views of the internal blackbody.



Observation zenith angle INSAT-3D, Sub-satellite point at 82E)

Sounder Observation Area



6400 km x 6400 km scan takes 180 minutes
64 x 64 pixel scan takes 1.80 minutes
A: 6 x 5 = 30 Frames x 1.8 minutes = 54 min
B: 4 x 7 = 28 Frames x 1.8 minutes = 51 min

<u>Sounder Scan Schedule (6 Hour cycle):</u>

00:00-00.54Z : Region A
01:00-01.54Z : Region A
02:00-02.54Z : Region A
03:00-03.54Z : Region A
04:00-04.54Z : Region A
05:00-05.51Z: <u>Region B</u>
.........repeat above cycle

The signals from the detectors are processed and readout in synchronization with the filter wheel rotation. Thus, the data format for the Sounder, which includes the sounding data as well as other auxiliary information, repeats every 100 ms.

Instrument Description

Like the Imager, the Sounder consists of an Electro-Optics (EO) module and a set of electronics packages including power supply modules. A simplified block schematic of the instrument is shown in Figure 10. The EO module, containing the telescope, scan assembly, filter wheel and its cooler and detectors along with their cooler, is mounted external to the spacecraft.

The electronics packages that provide circuitry for the signal processing functions, scan mirror control, power supply and other auxiliary functions, are mounted on an internal panel of the spacecraft. The Sounder instrument has a total mass of 145 kg.

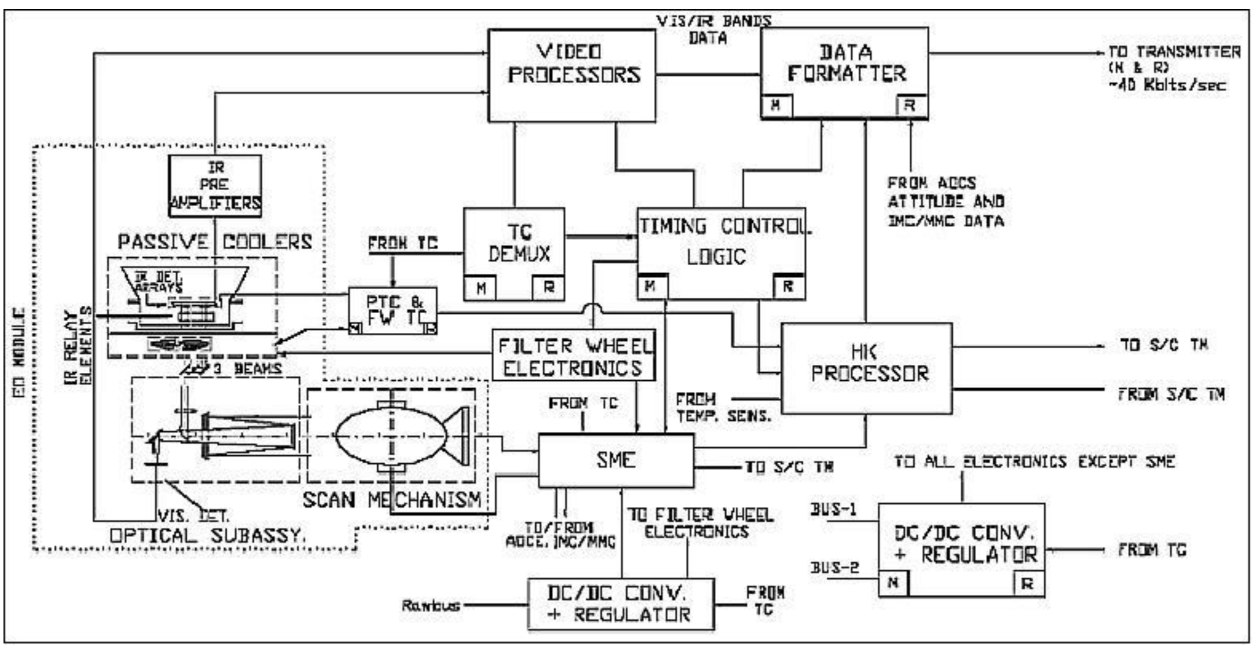
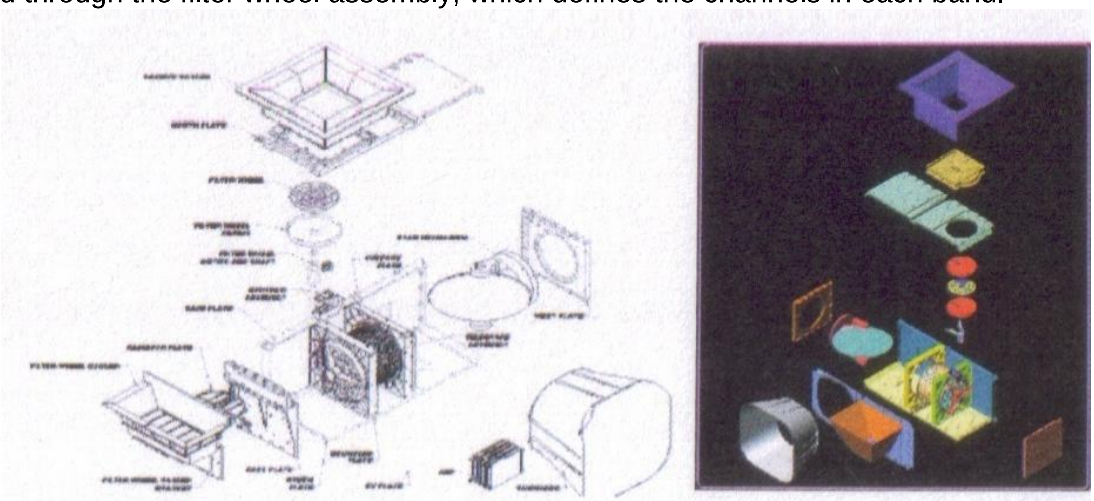


Figure 10: Block schematic of INSAT-3D IR Sounder

Optics (EO) Module

The basic structure of the EO module is similar to that of the Imager except for the filter-wheel and associated cooler. It consists of a scan mechanism assembly, telescope, aft optics, filter-wheel assembly with its cooler, a cooler assembly with the cooled detectors, the detectors for the uncooled channels, preamplifiers, and a viewport sunshade. An exploded view of Sounder EO module is shown in Figure 11.

The optical scheme for the Sounder is shown in Figure-12. The telescope for the Sounder is identical to that of the Imager. Dichroic beam splitters separate the scene radiance into various spectral ranges of interest. There are a total of three dichroic beam-splitters in the instrument. The first one, placed behind the primary mirror, separates the VIS channel from the IR channels. The VIS beam is transmitted through the dichroic and after subsequent folding, is measured by the VIS detector array. The reflected IR radiation is collimated after passing through a collimating lens. A set of two dichroic systems and a fold mirror separate the LWIR, SWIR and MWIR bands, in that order. These beams, corresponding to the three bands, are passed through the filter wheel assembly, which defines the channels in each band.



Figure

Figure 11: Exploded view of Sounder

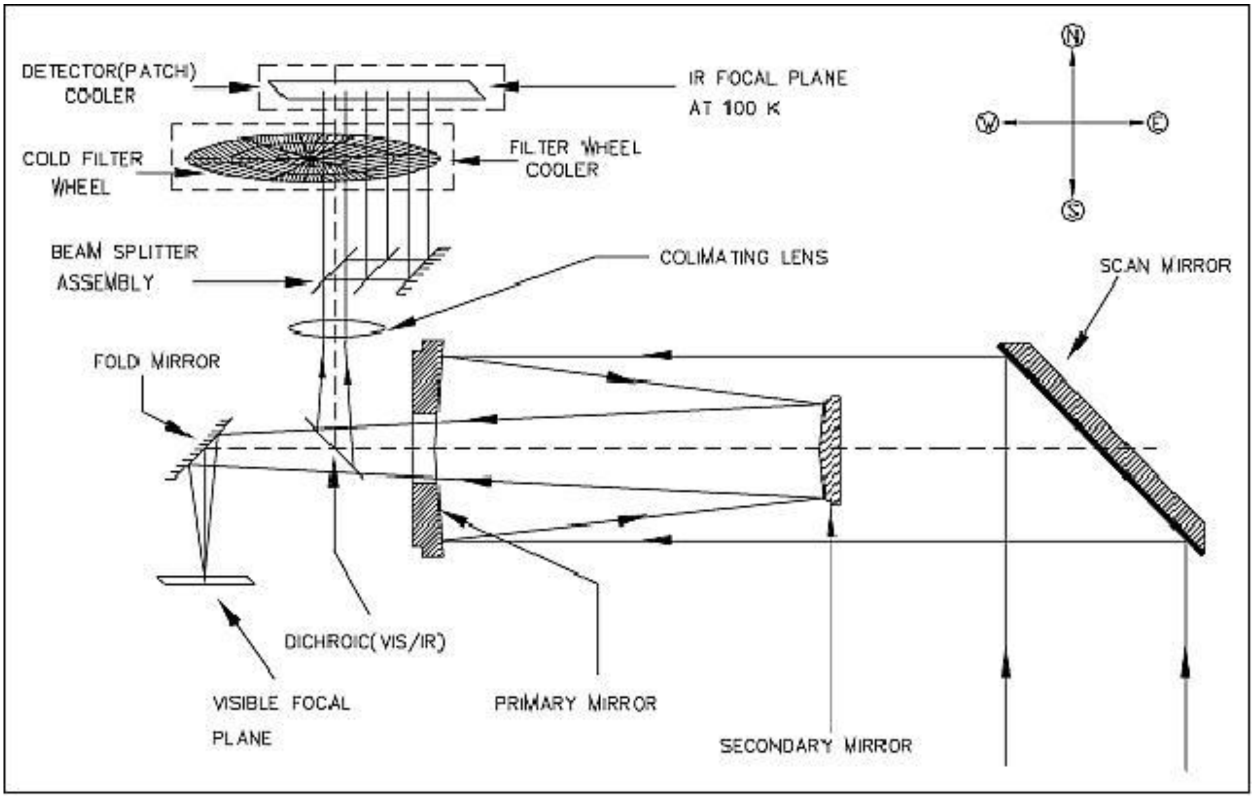


Figure 12: INSAT-3D Sounder Optics Schematic

The filter wheel has 18 filter windows distributed into three concentric rings, one each for the LWIR (7 channels), the SWIR (6 channels) and the MWIR (5 channels). The filter lengths and inter filter gaps are optimized to get the best possible performance of all channels with this size of the wheel. Nearly 20% of the wheel area is kept blank, i.e. without any filters. When this portion blocks the optical path, the scan mirror stepping takes place. Thus, the mirror is held stationary during sounding. The filter wheel rotates at a uniform speed of 600 rpm, completing one revolution in 100 ms.

The filters on the wheel function as the spectral defining elements for each of the 18 IR channels. Since the filter wheel is placed away from the detectors in the cooler, its temperature has major a effect on the radiometric stability and background radiation. To minimize these effects, the wheel is cooled to 213K using a separate cooler. The temperature of the wheel casing is controlled with a stability of ±1 K.

The 19 channels of the Sounder are acquired by use of four distinct detector head assemblies. Each detector assembly consists of an array of four detector elements arranged in N-S direction. Each detector element is of the size 10 km x 10 km on the ground (280 µrad IGFOV) at Nadir. Thus, each detector head assembly provides a footprint of 10 km x 40 km.

The detector for the VIS channel is very similar to that of the Imager, except that the element size is larger commensurate with the IGFOV, and each array contains only four detectors instead of eight for the Imager. This is the only channel with redundancy for the detector and the signal processor.

The 3 detector assemblies catering to the LWIR, MWIR and SWIR channels, sense the 18 IR channels. Each detector assembly has four detector elements. The LWIR and MWIR detectors are HgCdTe detectors operated in PC mode while for SWIR, InSb detectors are operated in PV mode. The first stage of the preamplifier is integrated within the SWIR detector package, similar to the MWIR detector package for the Imager These detectors are mounted in a passive cooler similar to the one used in the Imager and operated at a nominal temperature of 95 K with a stability of better than ±0.25 K

Electronics

Except for the signal-processing scheme for IR channels and filter-wheel drive electronics, the Sounder electronics is similar to that of Imager. Signal from each of the IR detectors is available in time-multiplexed form for various channels because of the filter wheel rotation. The time for which a scene is exposed to the detector is different for different bands but same for each channel of a band. The detector signal is integrated for the time interval during which detector is exposed to scene through a particular channel filter. Integrated signal is digitized with 12-bit resolution. A common ADC is used to digitize all for detectors of a channel. The blank portion of the filter wheel is used for DC restoration. The inter filter gaps are used for 1/f noise shaping. Each of these operations is precisely synchronized with filter wheel rotation. Each rotation of the filter wheel generates a reference pulse (FWRP) precisely located on the filter-wheel. All signal processing timings are generated with reference to this pulse. A First-In-first-Out (FIFO) memory is used to temporarily store the sampled video data. Writing to the FIFO is synchronized with FWRP, while internally generated stable timing signals, read out data to maintain constant data rate. This efficiency absorbs any short-term variations in the filter wheel speed including jitter.

Application

With the data from Imager and Sounder, it is planned to generate products covering the following

Table-7 Geophysical parameters from Imager

No.	Parameter	Input Channels/Data
1	Cloud Mask (CM)	MIR, TIR-1, TIR-2
2	Outgoing Longwave Radiation (OLR)	WV, TIR-1, TIR -2
3	Quantitative Precipitation Estimation (QPE) GPI, IMRSA and HE	TIR-1, TIR- 2
4	Sea Surface Temperature (SST)	SWIR, MIR, TIR – 1, TIR –2
5	Snow Cover	VIS, SWIR, TIR – 1, TIR –2
6	Fire	MIR , TIR -1
7	Smoke	VIS, MIR, TIR –1, TIR –2
8	Aerosol	VIS, TIR –1, TIR -2
9	Cloud Motion Wind Vector (CMV)	VIS, TIR-1, TIR –2
10	Water Vapor Wind Vector (WVWV)	WV, TIR-1,TIR –2
11	Upper Tropospheric Humidity (UTH)	WV, TIR-1, TIR –2
12	Fog	SWIR, MIR, TIR-1, TIR-2

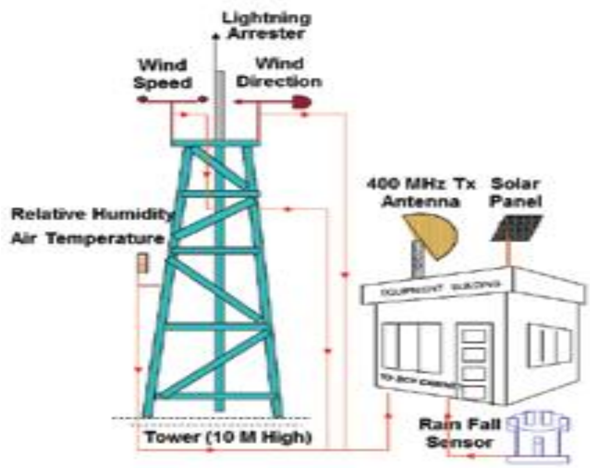
Table-8 Geophysical parameters from Sounder

No.	Parameter	Input Data
1	Temperature, Humidity and Ozone profile	Brightness temperatures for 18 Sounder Channel and grey count for channel 19
2	Geo-potential Height	Sounder retrieved temperature and humidity profiles at 40 pressure levels
3	Layer Perceptible Water	Retrieved humidity at standard pressure levels

4	Total Perceptible Water	Retrieved humidity at standard pressure levels
5	Lifted Index	Sounder retrieved temperature and humidity profiles at standard pressure levels
6	Dry Microburst Index	Sounder retrieved temperature and humidity profiles at standard pressure levels
7	Maximum Vertical Theta-E Differential	Sounder retrieved temperature and humidity profiles at standard pressure levels
8	Wind Index	Geo- potential Height and retrieved temperature and humidity profiles at standard pressure levels

Data Relay Transponder (DRT): Data Relay Transponder (DRT) on-board INSAT-3D will be used for receiving meteorological, hydrological and oceanographic data from remote, uninhabited locations over the coverage area from Data Collection Platforms (DCPs) like Automatic Weather Station (AWS), Automatic Rain Gauge (ARG) and Agro Met Stations (AMS). The data is relayed back for down linking in extended C-Band

INSAT Data Collection Platform



Elements of Data Collection Platform

For extreme weather related disasters such as cyclone, floods and drought, real time observations of the associated parameters with appropriate network density is very important. Satellite enabled Data Collection Platforms provide a unique solution for gathering meteorological data from all over the country including remote and inaccessible places. India Meteorological Department (IMD) and ISRO have established more than 1800 Data Collection Platforms.INSAT-3D provides continuity of service of DRT which is currently carried by KALPANA-1 and INSAT-3A.

nd Network (ISTRAC), Bangalore.

Satellite Aided Search and Rescue (SAS & R) Transponder: INSAT-3D is equipped with a Search and Rescue payload (operating in 406 MHz) that picks up and relays the alert signals originating from the distress beacons of maritime, aviation and land based users to the Indian Mission Control Centre (INMCC) located at ISRO Telemetry, Tracking and Command Network (ISTRAC), Bangalore. The major users of Satellite Aided Search and Rescue service in India are the Indian Coast Guard, Airports Authority of India (AAI), Directorate General of Shipping, Defence Services and fishermen. The Indian service region includes a large part of the Indian Ocean region covering India, Bangladesh, Bhutan, Maldives, Nepal, Seychelles, Sri Lanka and Tanzania for rendering distress alert services. INSAT-3D joins INSAT-3A to provide operational Search and Rescue service

Conclusion

From the vantage point of geostationary orbit observation of earth and its atmosphere has been carried out since 1983 with progressively improving capability through INSAT-1 followed by INSAT-2 series very high-resolution radiometers. INSAT-2E onwards a three-channel CCD instrument has been providing 1 kilometer images.

The next generation dedicated meteorological spacecraft with advanced instruments like 6 channel imager and 19 channel sounder has enhanced the observational capabilities over Indian Ocean region. Six-channel Imager has started to support many new applications (such as Fog detection, cyclone tracking, Thunder storm events and western disturbance) as while Sounder is providing vertical temperature and moisture profile on 24-hour basis over the Indian region.

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