INSAT-2E: Launch and early orbit phase operations

S. Rangarajan and M. Annadurai

Indigenously built satellite INSAT-2E was launched on 2 April 1999 from Kourou, French Guiana. The satellite has been declared operational after going through the planned sequence of operations and detailed in-orbit tests. The planning aspects and the operational experience of the launch and early orbit phase operations are discussed in this article.

INSAT-2E is the last of the second generation INSAT series of satellites built by ISRO for continuation and enhancement of services in the areas of telecommunication, TV broadcasting and meteorology. The satellite is located in the geostationary orbit (GSO) over the longitude of 83° east. Extensive mission planning and analysis as well as establishment and evaluation of the required ground segment elements resulted in a smooth and successful operationalization of INSAT-2E.

Mission planning

INSAT-2E was launched on a dedicated flight of Ariane 42P launch vehicle. Being the lone payload for this launch, it was possible to optimize the geostationary transfer orbit (GTO), the initial orbit into which the satellite would be placed by the launcher. In particular, the perigee of the transfer orbit was chosen to be 250 km instead of the nominal 200 km and the inclination of GTO to be 4° instead of the nominal 7°. These choices resulted in correspondingly less propellant expenditure from the satellite to achieve the final GSO.

Yet another improvement in this mission was in the choice of the launch window – the allowed time slot for launch. The launch window is generally constrained by the requirements imposed by the satellite's systems, primarily the power and thermal control systems. In case of multiple passengers on the same launch, the launch window is determined as the intersection of the individual requirements. In the earlier INSAT launches by Ariane launch vehicle, the opening of the launch window was constrained by the requirements of the co-passenger. For the launch of INSAT-2E, on the other hand, one could advance the lift off time by almost half-an-hour, thereby considerably improving the geometry for calibrating the on-board gyros required for attitude control during major manoeuvers.

Until GSO is realized, the satellite has a large relative motion with respect to the earth, hence necessitating a network of earth stations spread over the globe to establish a near-continuous link with the satellite. INSAT series of satellites are controlled from the INSAT master control facility (MCF) at Hassan, wherein a large number of earth stations, capable of tracking the satellite, are also located. Besides Hassan, the earth stations used for the launch and early orbit phase (LEOP) operations of INSAT-2E are Perth (Australia), Fucino (Italy) and Lake Cowichan (Canada). Of these, the station at Lake Cowichan is being used for the first time for INSAT missions. The communication with the individual stations was established with INTELSAT facility at Washington to which MCF, Hassan was linked by reliable digital communication lines. These links ensure data transmission to and fro in real time so that the satellite mission analysts located in Hassan would be transparent wherefrom the satellite telemetry is being received or the satellite is being commanded.

The most important activities during LEOP are:

- Transferring from the elliptical GTO to the final GSO by firing appropriately the liquid apogee motor (LAM) carried on the satellite.
- To open out the appendages like the antennas, solar array, and the sail/boom which are kept stowed during the launch phase.
- Establishing normal on-orbit earth pointing mode.
- Payload turn-on, testing and commissioning.

The final desired orbit is a circular one lying in the equatorial plane; in other words, the orbital inclination as well as eccentricity in the GSO are zero. The orbit delivered by the launch vehicle is so chosen to have a common point with the final orbit. Choosing the apogee of the GTO to be at geosynchronous height and also ensuring that the apogee occurs over the equator are essential. This enables one to simultaneously correct for the inclination as well as to raise the perigee. The

S. Rangarajan is at the INSAT Master Control Facilities, Hassan 573 201, India; and in SatCom Programmes, ISRO HQ, Bangalore 560 094, India; M. Annadurai is in the INSAT-2E Mission Programme, ISRO Satellite Centre, Bangalore 560 017, India.

difference vector between the desired velocity in the GSO and the current velocity of GTO at the manoeuver point is referred to as *delta-velocity*. This being a vector, its orientation is achieved by properly orienting the spacecraft and the magnitude is achieved by firing the motor for a calculated duration.

INSAT uses a unified bi-propellant system for initial orbit raising as well as for on-orbit operations. The use of LAM allows station acquisition with multiple burns through motor restart. The main advantages of the multi-burn strategy are:

- The engine can be calibrated during the first burn making the subsequent burns more accurate.
- Subsequent burns can compensate for the errors in previous burns.
- Since the arc, over which each burn is made, is smaller, the burn efficiency is greater.

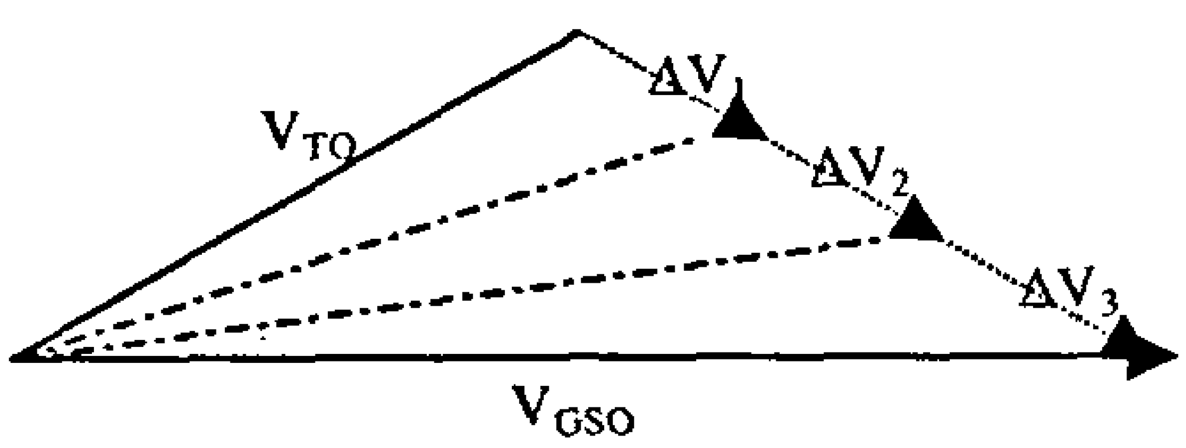


Figure 1.

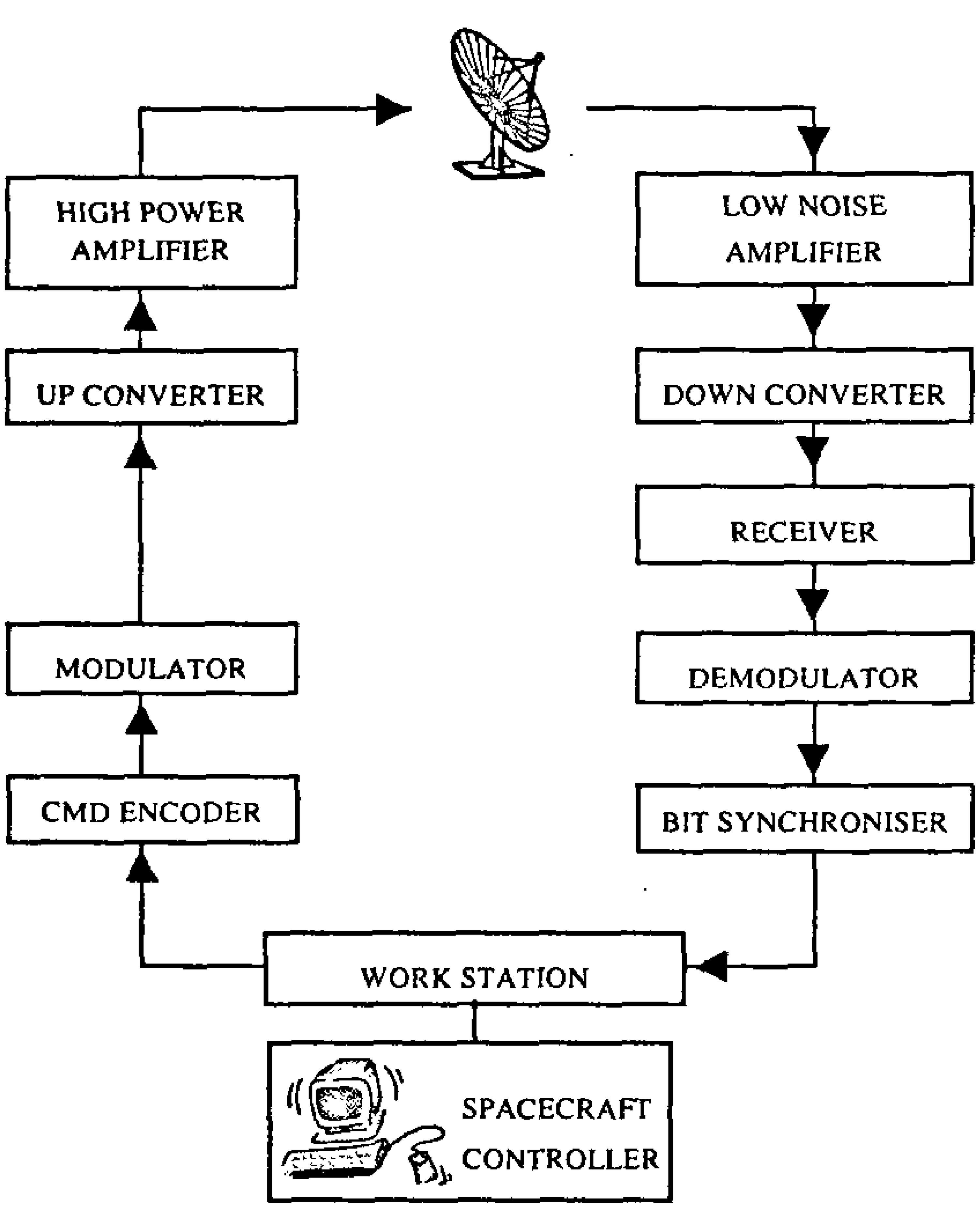


Figure 2.

The burn sizes and coast phases are so adjusted that the final burn occurs close to the desired on-station longitude namely, 83° east. Typically, two or more revolutions are allowed between consecutive burns for the purpose of orbit tracking and manoeuver planning. Based on all the above considerations, four burns of LAM were executed for INSAT-2E.

Mission control ground segment

The ground segment for the mission control consists of earth stations, baseband systems for telemetry, tracking and command (TT & C), data acquisition, processing and archival systems. Figure 2 illustrates a typical chain encompassing the above elements.

To support the mission a number of modules of software in the areas of flight dynamics and spacecraft health monitoring and control, are developed. These complex modules are extensively tested by specialist groups and evaluated in an integrated environment. These run in distributed client–server architecture under UNIX operating system. The software extensively supports GUI in the form of real-time display of telemetry parameters, trend analysis packages for deriving performance trends, and pre-formatted display pages.

Pre-launch activities

Extensive simulations of the INSAT-2E mission were planned and conducted to validate and verify the various mission elements – hardware, software, and procedures. The network stations as well as the launch site were included in the simulations. These simulations not only help in the checkout of the interfaces, but also facilitate the mission operations personnel to familiarize themselves with the mission environment and operations. The mission personnel stationed at the network stations exercised various commanding modes and also the flight voice procedures. The tools used for the simulation exercises were the following:

- Software simulator
- On-orbit data of INSAT-2A, 2B, 2C and 2D
- INSAT-2E data received from the launch pad.

A full dress rehearsal was conducted for a duration of 27 h starting at 0400 UT of 30 March 1999 with the participation of the teams at MCF, network stations and the launch pad.

On the day of the launch, six-and-a-half-hours prior to the opening of the launch window, the spacecraft was turned on and the sub-system personnel routed the data to MCF for health analysis. Following this, as many as 257 commands were sent as part of the initialization procedure to place the satellite in its launch configuration. Dry tuned gyros (DTG) were turned on and after their temperatures stabilized, the drift rate was estimated by ground software at MCF and the corresponding drift compensation commands were sent to the satellite. Six minutes prior to the lift-off, the satellite power was switched to the internal battery. The launch vehicle count-down sequence proceeded smoothly and the launch vehicle lifted off at 2203 UT on 2 April 1999.

Transfer orbit operations

The various operations carried out in the first three transfer orbits till LAM firing are the following:

- Monitoring the spacecraft health
- Thermal and battery management
- Gyro calibration
- Rehearsal of LAM orientation
- Ranging at regular intervals and orbit determination.

Table 1. Details of LAM firing

Date	Burn duration (sec)	Delta velocity (m/sec)	Post-manoeuver Perigee ht (km)	Post-manoeuver Inclination (deg.)	Post-manoeuver Period (h)
4 Apr	933	166	1979	3.3	11.15
6 Apr	3605	744	14572	0.9	15.55
8 Apr	1971	503	32244	0.11	22.50
10 Apr	219	60	35276	0.11	23.82

Seven minutes after the injection of INSAT-2E into GTO, the signal was acquired at MCF at 2232 UT on 2 April. The spacecraft health parameters were found to be nominal with the south face of the spacecraft and since this face has the folded solar panels, there was adequate power generation for the operations. Soon after, test commands were issued from MCF to establish the health of the command system. The geometry at injection was such that the earth viewing face of the satellite is towards the earth, at the same time generating enough solar power. With this geometry it is possible to calibrate the on-board DTGs using the earth sensor and sun sensor data as absolute reference. Once such a calibration is done, DTG can be used as an inertial sensor for LAM orientation and firing, even in the absence of an absolute sensor.

The first firing of LAM was planned in the third apogee. Earth acquisition, DTG calibration, and re-orientation for LAM attitude preceded this. During LAM, it is necessary to regulate the pressure of both the oxidizer (N_2O_4) and the fuel (mono-methyl hydrazine). For this purpose, pressurant gas (helium) is carried in a separate tank. A fall in pressure in this tank is an important indication of the consumption of propellants for the LAM. The first firing of LAM was commenced at 0021 UT of 4 April for about 16 min. This was followed by three more firings of LAM on 8th, 11th and 13th apogees, as shown in Table 1.

In all, LAM was fired for a total duration of about two hours. Right through the engine delivered the rated thrust

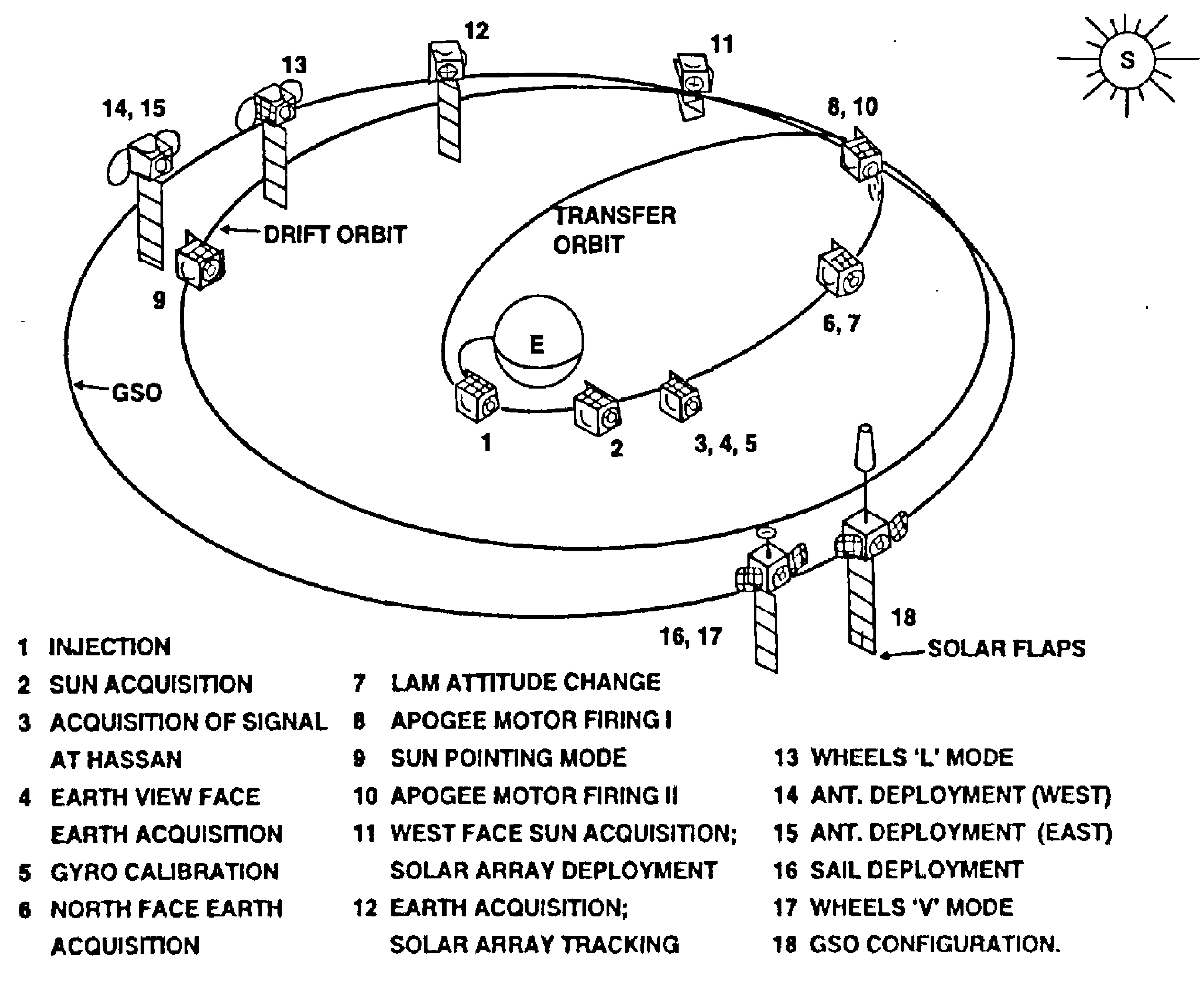


Figure 3.

of 440 N at a specific impulse of better than the rated 313 s.

At the end of the fourth burn, the satellite was over 74.3° east longitude, drifting at the rate of 1.75° per revolution. For arresting this drift and positioning the satellite over the required longitude, station acquisition manoeuvers were carried out using thrusters rated at 22 N. These thrusters are also used for on-orbit attitude and orbit control.

Deployments

The configuration of the satellite at injection is a cuboid measuring 1.93 m × 1.77 m × 2.7 m. After completing all the LAM firings, the satellite is brought into on-orbit configuration with the solar array in the south face fully deployed, with antennas deployed on the east and west faces and the boom/sail assembly opened out on the north face. In this configuration, the satellite measures 25.78 m from north to south.

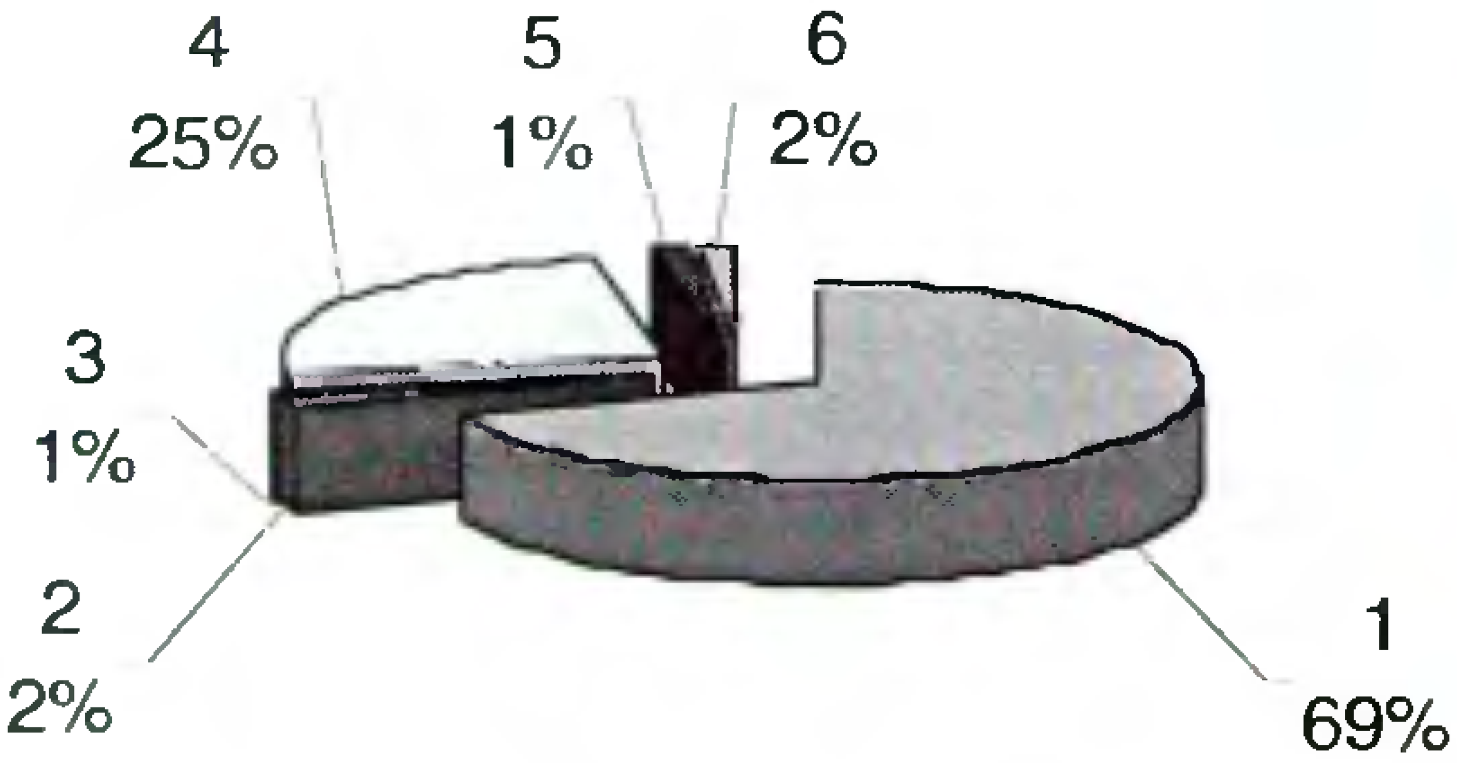
On 11 April 1999, the solar array deployment was commanded at 0445 UT after ensuring the required temperature condition at the hinges. The array consists of four panels, each measuring 2.7 m × 1.95 m and capable of generating in excess of 2800 W at normal incidence. On the same day, the reflectors in the east and west faces were opened out by ground command. These reflectors provide the required footprint for the communication payload.

Table 2. Propellant budget for INSAT-2E

Total lift-off mass of the spacecraft	2549.50 kg
(–) Spacecraft dry mass	1147.82 kg (1401.68 kg)
(–) Pressurant	3.75 kg
Total propellant on the spacecraft	1397.93 kg

No.	Activity	Mass consumption (kg)
1	LAM operations	964.69
2	Attitude hold prior to drift orbit	31.60
3	Station acquisition	12.52
4	Station keeping: N–S	335.24
5	Station keeping: E–W	13.08
6	On-orbit attitude maintenance	18.98
7	Contingencies	21.82
		1397.93

Propellant consumption for various activities



In the normal on-orbit phase, the satellite orientation is maintained in three-axis stabilized mode with the earth-viewing face locked on to the earth. The stability for this orientation is provided by two fly-wheels running at a nominal speed of 4800 rpm, providing a large angular momentum about the pitch axis (north–south axis). These wheels are equally canted about the pitch axis in the pitch-yaw plane. This arrangement (V-mode) provides the capability of absorbing disturbances about the pitch axis as well as in roll/yaw. As and when the angular momentum stored in the wheels exceeds the set thresholds, the thrusters (of 22 N rating) are fired for short durations to bring back the wheel speeds within the operating range.

During the early hours of 12 April 1999, a series of attitude manoeuvers were carried out to achieve the required earth-pointing mode. Soon after, the wheels were run up to the nominal speed and the control was changed over to the wheels.

The last of the deployment operations was that of the boom/sail assembly kept stowed in the north face of the satellite. After releasing the hold-down mechanism by ground command, the sail/boom was deployed in a controlled fashion by operating a motor. This sail provides counter-balancing of the torque produced by the impinging solar radiation on the sun tracking solar panels in the south face.

Payload turn on

A series of five trim manoeuvers were performed to position the spacecraft at the intended orbital slot of 83°

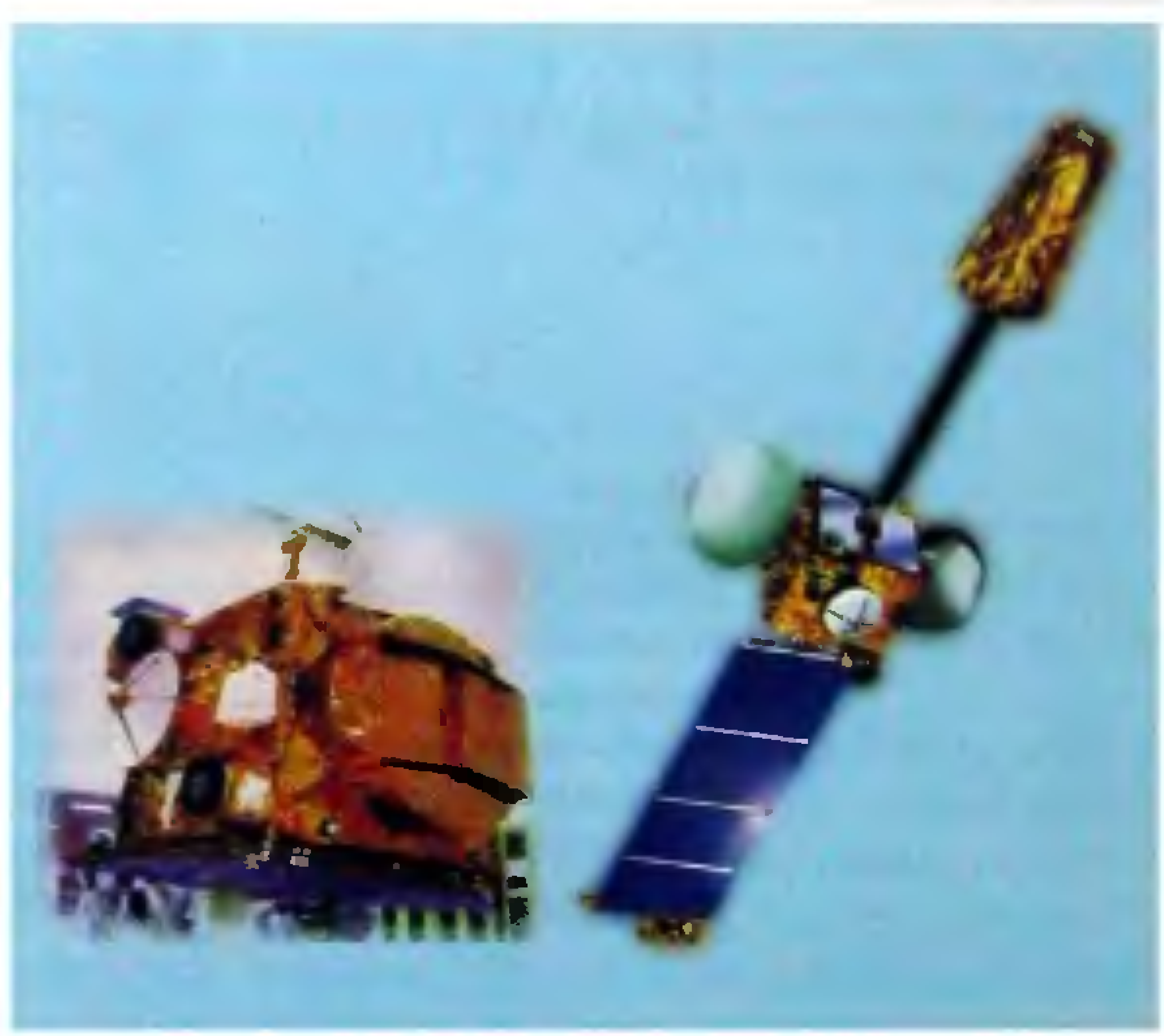


Figure 4. ***a***, Launch configuration and ***b***, on-orbit configuration.

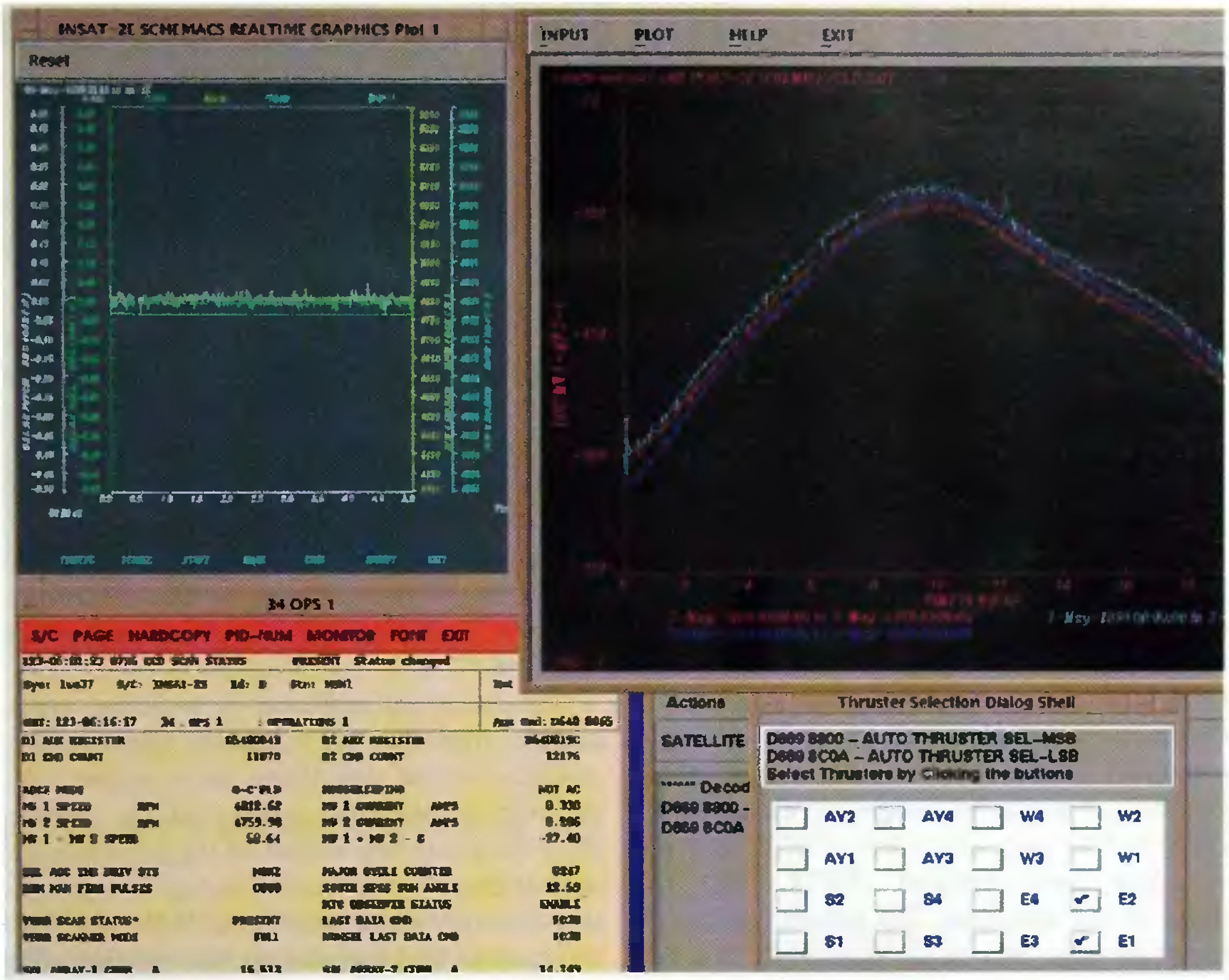


Figure 5. Real time graphics display.

east longitude. On 15 April 1999, the travelling wave tube amplifiers (TWTA), which form the core of the communication transponders were turned on. Two days later, signals were uplinked to the transponders and the in-orbit characterization was carried out for the next ten days. Parallelly, the meteorological payload consisting of the very high resolution radiometer (VHRR) in visible, thermal infrared and water vapour channels, as well as the CCD-based camera operating in visible, near-infrared and shortwave infrared were turned on and characterized.

Mission life

The mission life of a satellite is dictated by several factors including the available propellant for maintenance of the orbit and orientation, and the reliability of the various subsystems. In the case of INSAT-2E, at the end of the station acquisition manoeuvers approximately 400 kg of propellant remains, which will ensure an in-orbit mission life of about 13 years. The overall propellant budget for INSAT-2E is depicted in Table 2 and the pie chart.

It may be seen that most of the remaining propellant is identified for maintenance of orbital inclination to within 0.1° and the longitude of the satellite at 83° east.

At the end of the in-orbit payload tests, the satellite is declared to have entered the normal phase. The operations in the normal phase are typically, commanding for meteorological imaging, thermal management by operating heaters at appropriate times, battery management during eclipse seasons, and periodic station-keeping operations for cancelling out the effects of orbital perturbations. The sattellite has been declared operational in April 1999 and keeping good health.

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