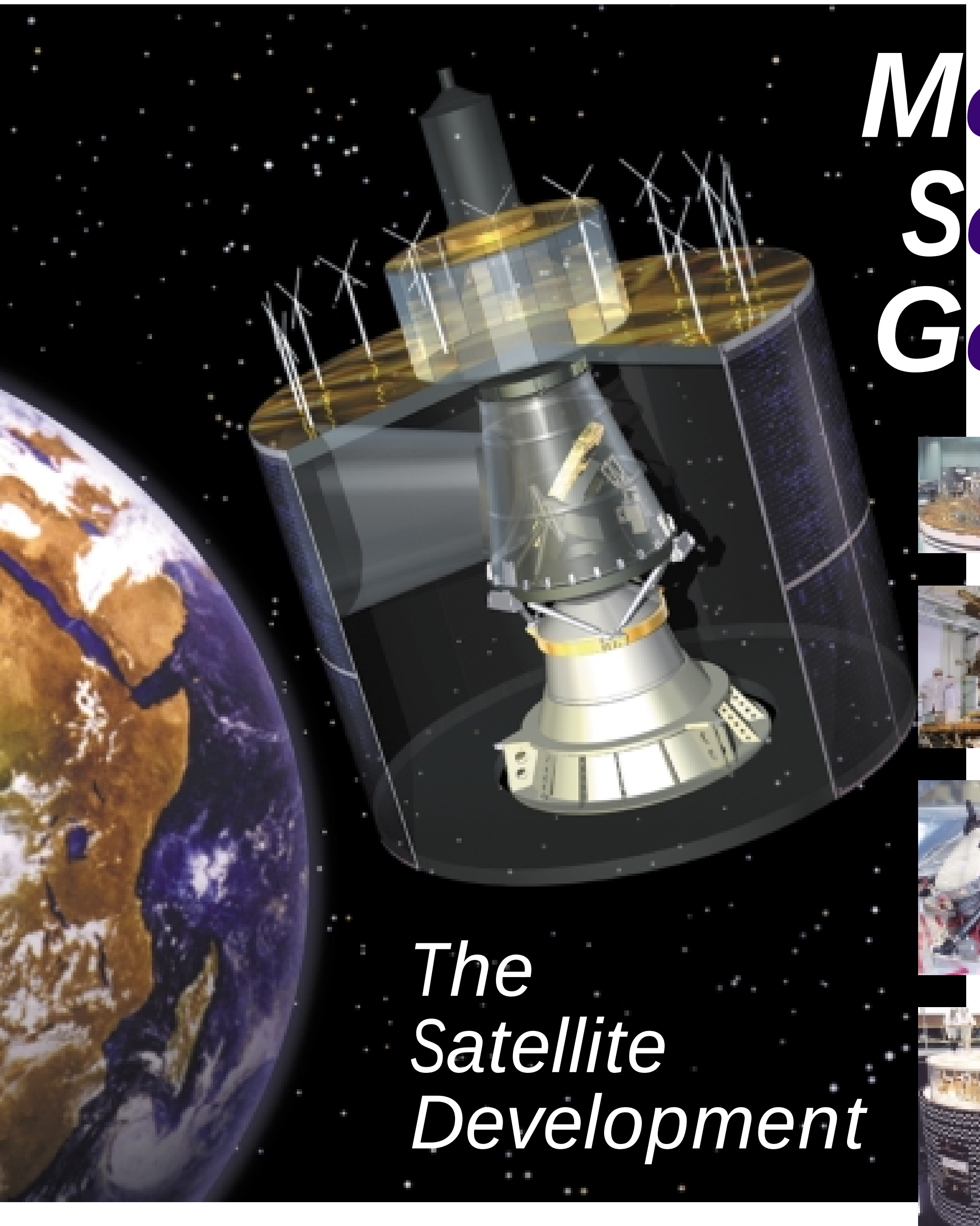
BR-153

November 1999

Meteosat Second Generation



The Satellite Development

European Space Agency
Agence spatiale européenne

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Foreword

Now, in November 1999, MSG-1, the Meteosat Second Generation development flight model, is about one year away from its scheduled launch. Its flight-readiness review is planned to take place in August 2000, with launch on an Ariane vehicle scheduled for the end of October 2000, from Kourou, French Guiana.

We in the Project look forward to these events with confidence, secure in the knowledge that the flight-model spacecraft will deliver excellent performance, based on a development plan that includes:

- *the mechanical and thermal tests already successfully performed on a Structural and Thermal Model spacecraft*
- *the electrical performance tests, some of which are still ongoing, on an Electrical Model spacecraft, and*
- *last but not least, subsystem tests performed on Flight Model hardware and software that prove that the performance margins identified on earlier models are also available on the Flight Model.*

At this point, integration of the second of the three-spacecraft series has also begun, in time for its scheduled launch in 2002.

This Brochure provides a comprehensive overview of the history of the MSG programme, the mission objectives, which are tailored to meet the ever evolving and ever more demanding needs of operational meteorology and climatology, and the design and development of the MSG spacecraft, the systems and subsystems of which incorporate many technical advances, and of their state-of-the-art payloads.

G. Dieterle
MSG Project Manager


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1 Introduction

1.1 Programme Outline

The primary objective of MSG is to ensure continuity of atmospheric observation from the geostationary orbit at 0.0 degrees longitude and inclination, as part of a worldwide, operational meteorological satellite system consisting of four polar-orbiting and five geostationary satellites (the World Weather Watch programme of the World Meteorological Organisation).

The Meteosat Second Generation (MSG) satellites benefit from several major improvements with respect to the first generation in terms of performance:
- *12 imaging channels instead of 3*
- *an image every 15 minutes instead of every 30 minutes*
- *improved spatial resolution, and*
- *extra services such as a Search and Rescue Mission and an experimental Radiation Budget measurement instrument, along with much improved communications services.*

The MSG development programme is now about 1 year away from the first scheduled satellite launch. A satellite thermal and mechanical model was successfully tested already in 1998, an engineering model is currently undergoing final testing to demonstrate the electro-optical performance and, in parallel, the first flight unit (MSG-1) is being integrated and tested for an Ariane launch from Europe's Guiana Space Centre in October 2000. Two more spacecraft, MSG-2 and MSG-3, which are identical to MSG-1, are also being manufactured to be ready in 2002 for launch and 2003 for storage.

MSG Facts and Figures

Purpose	– To make an image of the Earth and its atmosphere every 15 minutes in 12 spectral bands (2 visible, 1 high-resolution visible, 7 infrared, 2 water vapour)	
	– Dissemination of the image data and other meteorological information to data user stations	
Technical Features	– Spin-stabilised spacecraft	
	– Mass (at launch)	about 2 ton
	– Diameter	3.2 m
	– Height	3.7 m
	– Lifetime	7 yr
	– Orbit	geostationary
	– Orbit location	in the equatorial plane and above 0° longitude
	– Launch vehicle	compatible with Ariane-4 and Ariane-5
	– Launch date	October 2000 (MSG-1)
	– Payload	• Spinning Enhanced & Visible InfraRed Imager (SEVIRI) • Geostationary Earth Radiation Budget (GERB) Instrument • Search & Rescue (S & R) Transponder • Mission Communication Package (MCP)

The MSG programme is a co-operative venture with Eumetsat, the European Organisation for the Exploitation of Meteorological Satellites, based in Darmstadt, Germany. For the first MSG satellite, Eumetsat is contributing about 30% of the development cost of the ESA programme and is financing 100% of the two additional flight units, MSG-2 and MSG-3. In addition to having overall system responsibility with respect to end-user requirements (i.e. operational meteorology from geostationary orbit), Eumetsat is also developing the ground segment and procuring the three launchers, and will operate the system nominally from 2001 until 2012.

The MSG programme is based on the heritage of the first-generation Meteosats, which have now been operated for about 22 years with 7 consecutive satellites in orbit. This allows the technological risk to be kept to a minimum. Moreover, costs are also being kept to a minimum thanks to the low-cost spinning-satellite design principle used and due to the economy of scale of a three-satellite procurement in combination with contracting rules with industry such as firm fixed pricing and incentives based on meeting schedule and on in-orbit performance.

MSG is an ESA Optional Programme, which was started in 1994 and is funded by thirteen of the Agency's Member States: Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom.

1.2 History of the MSG Satellite Concept

The concept of the Meteosat Second Generation (MSG) satellites has been developed through a series of workshops organised by ESA with the European meteorological community, which started in Avignon, France, in June 1984.

This first MSG workshop identified the major future requirements for space meteorology in Europe as follows:
- geostationary satellites providing high-frequency observations
- an imaging mission with higher resolution and more frequent observations than the first-generation Meteosats
- an all-weather atmospheric-sounding mission.

Based on the Avignon workshop, three expert reports on imagery, infra-red and millimetre-wave sounding and on data circulation were commissioned by ESA.

The reports on imagery and sounding were presented to a second workshop with the European meteorological community in Ravenna, Italy, in November 1986. That workshop confirmed the basic requirements of the Avignon workshop and provided some updates and refinements.

The data circulation report was reviewed at a workshop in Santiago de Compostela, Spain, in May 1987. This workshop recommended two important changes concerning the Data Circulation Mission (DCM) of the first-generation Meteosat *satellites: the processed image data must be available within 5 minutes of acquisition, as required for nowcasting applications, and the current analogue WEFAX service to secondary user stations must be replaced by a digital format.*

In 1986, a new European intergovernmental organisation called Eumetsat was set up in Europe to 'establish, maintain, and operate a European system of operational, meteorological satellites'. Since then, ESA has been collaborating with Eumetsat on the definition of the MSG satellites.

In 1987, ESA initiated several instrument concept studies, covering:

- *a visible and infra-red imager (VIRI)*
- *an infra-red sounder (IRS)*
- *a microwave sounder (MWS)*
- *the data-circulation mission (DCM)*
- *the proposed scientific instruments.*

Parallel studies of an 8-channel VIRI and of the infra-red sounder were performed by industry, and they demonstrated the basic feasibility of these instruments. The microwave sounder was studied via parallel contracts, which revealed major problems with respect to, for example, mass, diameter and sensitivity.

In the same year, ESA also provided parallel contracts to study possible satellite configurations for MSG. As a result, a spin-stabilised satellite configuration was excluded due to the presence of the microwave sounder. Dual-spin configurations were considered but rejected as the MWS and IRS instruments require very stable pointing of the platform, whilst the IRS instrument requires a very stable rotation of the drum, and these two requirements cannot be satisfied simultaneously. Accordingly, the only viable configurations for the multi-instrument satellites were three-axis-stabilised configurations.

These results were presented at a workshop with Eumetsat and the meteorological community in Bath (UK) in May 1988. As a conclusion of this workshop, the overall mission philosophy was again endorsed, while some mass-driving requirements were reconsidered and eventually revised.

However, a few months later further doubts were raised about the usefulness of the sounding mission, as proposed in Bath, and about the relationship between the sounding mission of MSG in a geostationary orbit and sounding missions from polar-orbiting satellites. As a consequence, the mission requirements were again reconsidered, and further mission studies were called for.

The essential point of the reconsideration of the mission requirements was that some sounding capability had to be retained. It was proposed to achieve this by adding 5 additional narrow-band channels to the imager VIRI that had been defined in Avignon and in Bath, in order to obtain a pseudo-sounding capability. Consequently, the corresponding instrument was then named the 'Enhanced VIRI', or EVIRI. Thus, further mission-feasibility studies were requested by Eumetsat and initiated by ESA.

On the basis of the results of these deliberations and a recommendation by

ESA, the Eumetsat Council determined in June 1990 that:

- MSG should be a spin-stabilised satellite

- the spin-stabilised satellite should have a capability for air mass analysis as the essential part of the former sounding mission and a high-resolution visible channel.

Following this decision, and the new requirement that the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) should also be capable of providing data for air mass analysis, ESA conducted an assessment study of the feasibility of accommodating the extra channels into SEVIRI. Originally, EVIRI had 8 channels, and the new SEVIRI requirements called for 14 channels (1 high-resolution visible, 3 in the VNIR, and 10 in the IR).

The assessment study concluded that the imager could be expanded to accommodate 12 channels in total (1 high-resolution visible, 3 in the VNIR, and 8 in the IR). The requirement for 10 cooled IR channels was essentially not feasible, given the cost and schedule constraints.

Finally, with Eumetsat endorsement, ESA initiated the development of a spin-stabilised, geostationary satellite with a 12-channel imager, called the 'Meteosat Second Generation' satellite.

1.3 Mission Objectives

As the successor of the Meteosat first-generation programme, MSG is designed to support nowcasting, very short and short range forecasting, numerical weather forecasting and climate applications over Europe and Africa, with the following mission objectives:

- multi-spectral imaging of the cloud systems, the Earth's surface and radiance emitted by the atmosphere, with improved radiometric, spectral, spatial and temporal resolution compared to the first generation of Meteosats

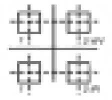
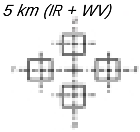
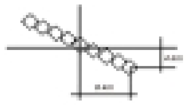
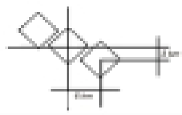
- extraction of meteorological and geophysical fields from the satellite image data for the support of general meteorological, climatological and environmental activities

- data collection from Data Collection Platforms (DCPs)

- dissemination of the satellite image data and meteorological information upon processing to the meteorological user community in a timely manner for the support of nowcasting and very-short-range forecasting

- support to secondary payloads of a scientific or pre-operational nature which are not directly relevant to the MSG programme (i.e. GERB and GEOSAR)

- support to the primary mission (e.g. archiving of data generated by the MSG system).

	MOP	MSG
Imaging format		
Imaging cycle	30 min	15 min
Channels	Wavelength	
Visible	0.5 - 0.9	HRV VIS 0.6 VIS 0.8 IR 1.6
Water vapour	WV 6.4	WV 6.2 WV 7.3
IR window	IR 11.5	IR 3.9 IR 8.7 IR 10.8 IR 12.0
Pseudo Sounding		IR 9.7 IR 13.4
Sampling Distance	2.25 km (Visible) 4.5 km (IR + WV)	1 km (HRV) 3 km (others)
Pixel Size	2.25 km (Visible)  5 km (IR + WV) 	1.4 km (HRV)  4.8 km (others) 
Number of detectors	4	42
Telescope diameter	400 mm	500 mm
Scan principle	Scanning telescope	Scan mirror

DATA CIRCULATION MISSION

Transmission raw data rate	0.333 Mb/s	3.2 Mb/s
Disseminated image	0.166 Mb/s	1 Mb/s
Transmission burst mode	2.65 Mb/s	Search & Rescue package

The mission evolution from First- to Second-Generation Meteosat

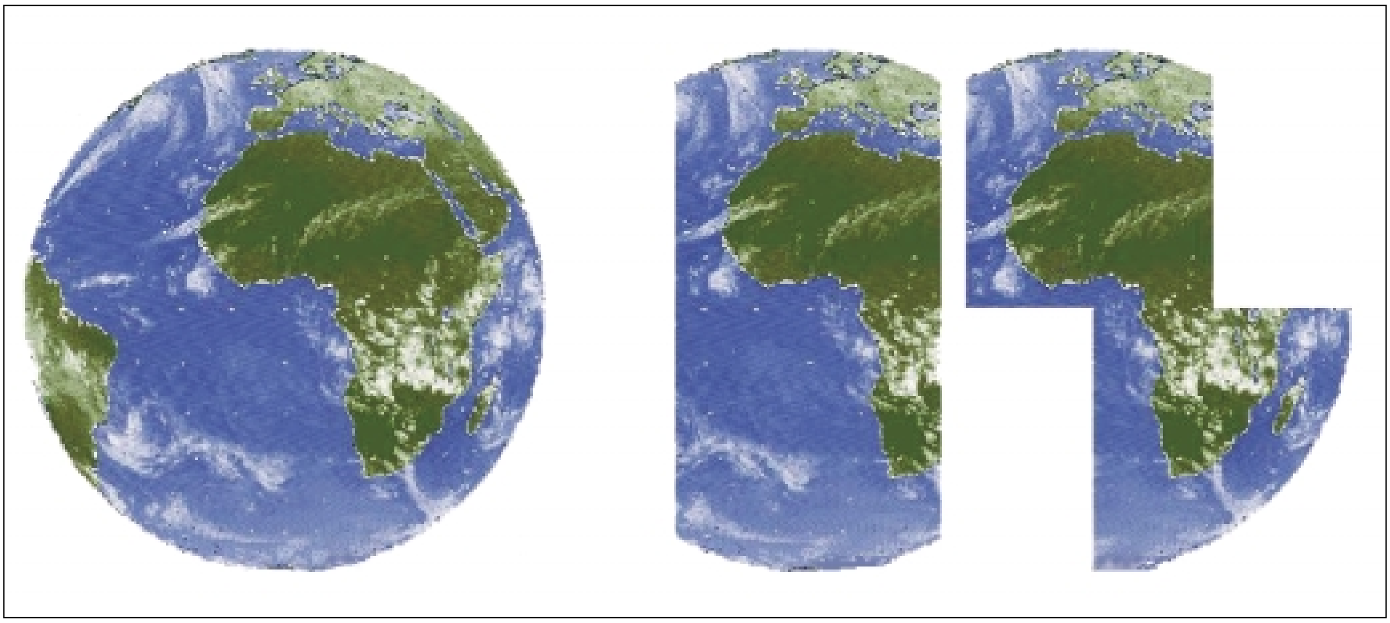
The mission objectives were subsequently refined by Eumetsat, taking into account further evolutions in the needs of operational meteorology, and resulted in:

- *the provision of basic multi-spectral imagery, in order to monitor cloud systems and surface-pattern development in support of nowcasting and short-term forecasting over Europe and Africa*
- *the derivation of atmospheric motion vectors in support of numerical weather prediction on a global scale, and on a regional scale over Europe*
- *the provision of high-resolution imagery to monitor significant weather evolution on a local scale (e.g. convection, fog, snow cover)*
- *the air-mass analysis in order to monitor atmospheric instability processes in the lower troposphere by deriving vertical temperature and humidity gradients*
- *the measurement of land and sea-surface temperatures and their diurnal variations for use in numerical models and in nowcasting.*

Imaging Mission

To support the imaging mission objectives, a single imaging radiometer concept known as the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) has been selected. This concept allows the simultaneous operation of all the radiometer channels with the same sampling distance. Thus, it provides improved image accuracy and products like atmospheric motion vectors or surface temperature and also new types of information on atmospheric stability to the users. Moreover, as the channels selected for MSG are similar to those of the AVHRR instrument currently flown in polar orbits, the efficiency of the global system will be increased owing to the synergy of polar and geostationary data.

The imaging mission corresponds to a continuous image-taking of the Earth in the 12 spectral channels with a baseline repeat cycle of 15 minutes. The calibration of the infra-red cold-channel radiometric drift may be performed every 15 minutes, owing to the presence of an internal calibration unit involving a simple and robust flip-flop mechanism and a black body. The imager



Earth imaging frames: full image area, HRV channel normal mode and alternative mode

provides data from the full image area in all channels except for the high-resolution visible channel, where the scan mode may be varied via telecommand from the normal mode to an alternative mode.

The six channels VIS 0.6, VIS 0.8, IR 1.6, IR 3.9, IR 10.8 and IR 12.0 correspond to the six AVHRR-3 channels on-board the NOAA satellites, while the channels HRV, WV 6.2, IR 10.8 and IR 12.0 correspond to the Meteosat first-generation VIS, WV and IR channels. The following channel pairs are referred to as split-channel pairs, since they provide similar radiometric information and may therefore be used interchangeably: VIS 0.6 & VIS 0.8, IR 1.6 & IR 3.9, WV 6.2 & WV 7.3, and IR 10.8 & IR 12.0.

The HRV channel will provide high-resolution images in the visible spectrum, which can be used to support nowcasting and very short-range forecasting applications.

The two channels in the visible spectrum, VIS 0.6 and VIS 0.8, will provide cloud and land-surface imagery during daytime. The chosen wavelengths allow the discrimination of different cloud types from the Earth's surface, as well as the discrimination between vegetated and non-vegetated surfaces. These two channels also support the determination of the atmospheric aerosol content.

The IR 1.6 channel can be used to distinguish low-level clouds from snow surfaces and supports the IR 3.9 and IR 8.7 channels in the discrimination between ice and water clouds. Together with the VIS 0.6 and VIS 0.8 channels, the IR 1.6 channel

The spectral characteristics of the SEVIRI channels

Channel	*Absorption Band Channel Type*	*Nom. Centre Wavelength (µm)*	*Spectral Bandwidth (µm)*
HRV	Visible High Resolution	nom. 0.75	0.6 to 0.9
VIS 0.6	VNIR Core Imager	0.635	0.56 to 0.71
VIS 0.8	VNIR Core Imager	0.81	0.74 to 0.88
IR 1.6	VNIR Core Imager	1.64	1.50 to 1.78
IR 3.9	IR / Window Core Imager	3.92	3.48 to 4.36
WV 6.2	Water Vapour Core Imager	6.25	5.35 to 7.15
WV 7.3	Water Vapour Pseudo-Sounding	7.35	6.85 to 7.85
IR 8.7	IR / Window Core Imager	8.70	8.30 to 9.10
IR 9.7	IR / Ozone Pseudo-Sounding	9.66	9.38 to 9.94
IR 10.8	IR / Window Core Imager	10.80	9.80 to 11.80
IR 12.0	IR / Window Core Imager	12.00	11.00 to 13.00
IR 13.4	IR / Carbon Diox. Pseudo-Sounding	13.40	12.40 to 14.40

may also support the determination of aerosol optical depth and soil moisture.

The IR 3.9 channel can be utilised to detect fog and low-level clouds at night and to discriminate between water clouds and ice surfaces during daytime. Furthermore, the IR 3.9 channel may support the IR 10.8 and IR 12.0 channels in the determination of surface temperatures by estimating the tropospheric water-vapour absorption.

The two channels in the water-vapour absorption band, WV 6.2 and WV 7.3, will provide the water-vapour distribution at two distinct layers in the troposphere. These two channels can also be used to derive atmospheric motion vectors in cloud-free areas and will support the IR 10.8 and IR 12.0 channel in the height assignment of semi-transparent clouds.

The IR 8.7 channel may also be utilised for cloud detection and can support the IR 1.6 and IR 3.9 channels in the discrimination between ice clouds and Earth surfaces. Moreover, the IR 8.7 channel may also be applied together with the IR 10.8 and IR 12.0 channel to determine the cloud phase.

The SEVIRI channel, which covers the very strong fundamental vibration band of ozone at 9.66 µm, denoted as IR 9.7, will be utilised to determine the total ozone content of the atmosphere and may also be applied to monitor the altitude of the tropopause.

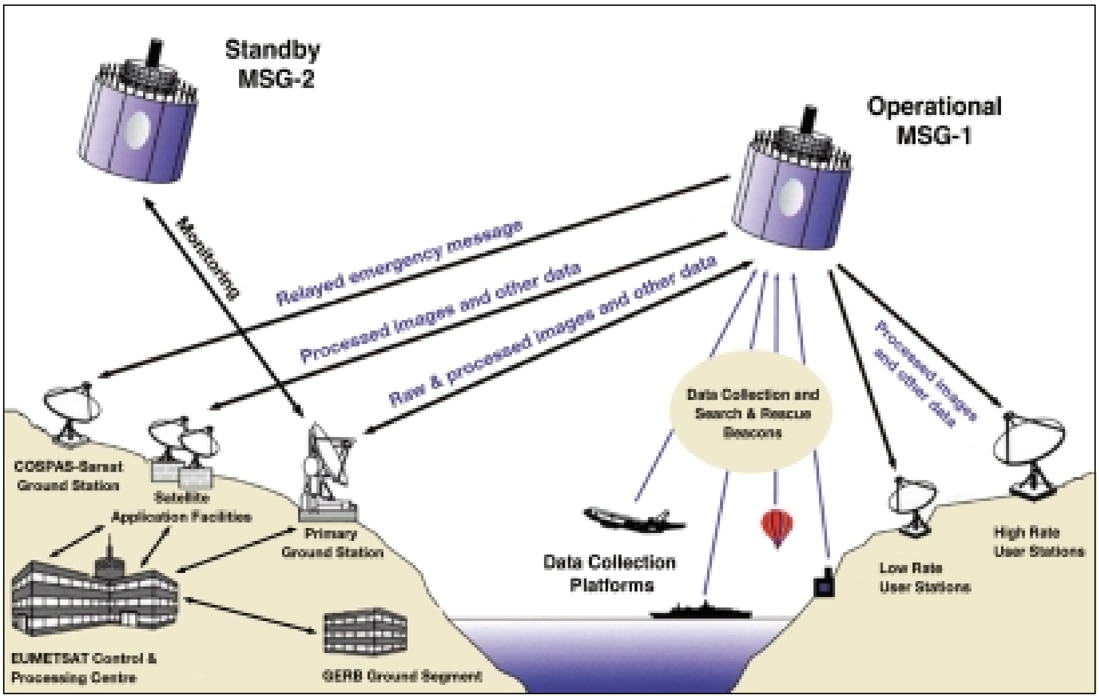
The two channels in the atmospheric window, IR 10.8 and IR 12.0, will mainly be used together with the IR 3.9 channel in order to determine surface temperatures.

The IR 13.4 channel covers one wing of the fundamental vibration band of carbon dioxide at 15 µm and will therefore mainly be utilised for atmospheric temperature sounding in support of air-mass instability estimation.

Product Extraction Mission

The product extraction mission will provide Level 2.0 meteorological, geophysical and oceanographical products from SEVIRI Level 1.5 imagery. It will continue the product extraction mission of the current Meteosat system, and provide additional new products. MSG meteorological products will be delivered to the meteorological user community in near-real-time via the Global Telecommunication System (GTS) or via the satellite's High-Rate Image Transmission (HRIT) and Low-Rate Image Transmission (LRIT) schemes.

MSG mission overview



Data Collection and Relay Mission

The data collection and relay mission will collect and relay environmental data from automated data-collection platforms via the satellite. The mission will be a follow-on to the current Meteosat Data Collection Mission, with some modifications as follows:

- Increased number of international Data Collection Platform (DCP) channels
- Increased number of regional channels
- Data Collection Platform (DCP) retransmission in near-real-time via the LRIT link
- Some of the regional channels will operate at a higher transmission rate.

Dissemination Mission

The dissemination mission will provide digital image data and meteorological products through two distinct transmission channels:

- High-Rate Information Transmission (HRIT) transmits the full volume of processed image data in compressed form
- Low-Rate Information Transmission (LRIT) transmits a reduced set of processed image data and other meteorological data.

Both transmission schemes will use the same radio frequencies as the current Meteosat system, but coding, modulation scheme, data rate and data formats will be different. Different levels of access to the high- and low-rate information transmission data will be provided to different groups of users through encryption.

The Meteorological Data Distribution mission of the current Meteosat system will be integrated into the HRIT and LRIT missions of MSG.

Geostationary Earth Radiation Budget (GERB) experiment

The GERB payload is a scanning radiometer with two broadband channels, one covering the solar spectrum, the other covering the infrared spectrum. Data will be calibrated on board in order to support the retrieval of radiative fluxes of reflected solar radiation and emitted thermal radiation at the top of the atmosphere with an accuracy of 1%.

Geostationary Search and Rescue (GEOSAR) relay

The satellite will carry a small communications payload to relay distress signals from 406 MHz beacons to a central reception station in Europe, which will pass the signals on for the quick organisation of rescue activities. The geostationary relay allows a continuous monitoring of the Earth's disc and immediate alerting.

2 PROGRAMMATICS

2.1 Organisation

The MSG system is developed and implemented under a co-operative effort by Eumetsat and ESA, with responsibilities shared as follows:

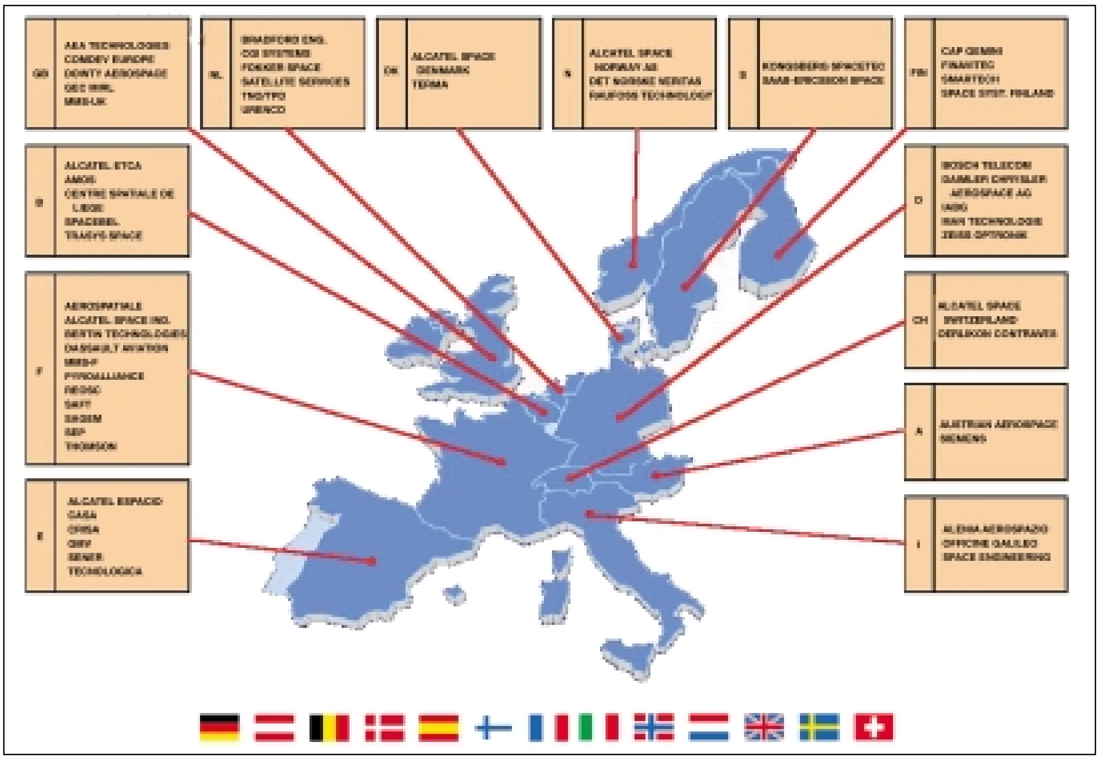
ESA:

- develops the MSG-1 prototype
- acts, on behalf of Eumetsat, as procurement agent for:
  - MSG-2/3 satellites
  - interchangeable flight-spare equipment
  - Image Quality Ground Support Equipment (IQGSE)
  - the 'Enhanced Suitcase'.

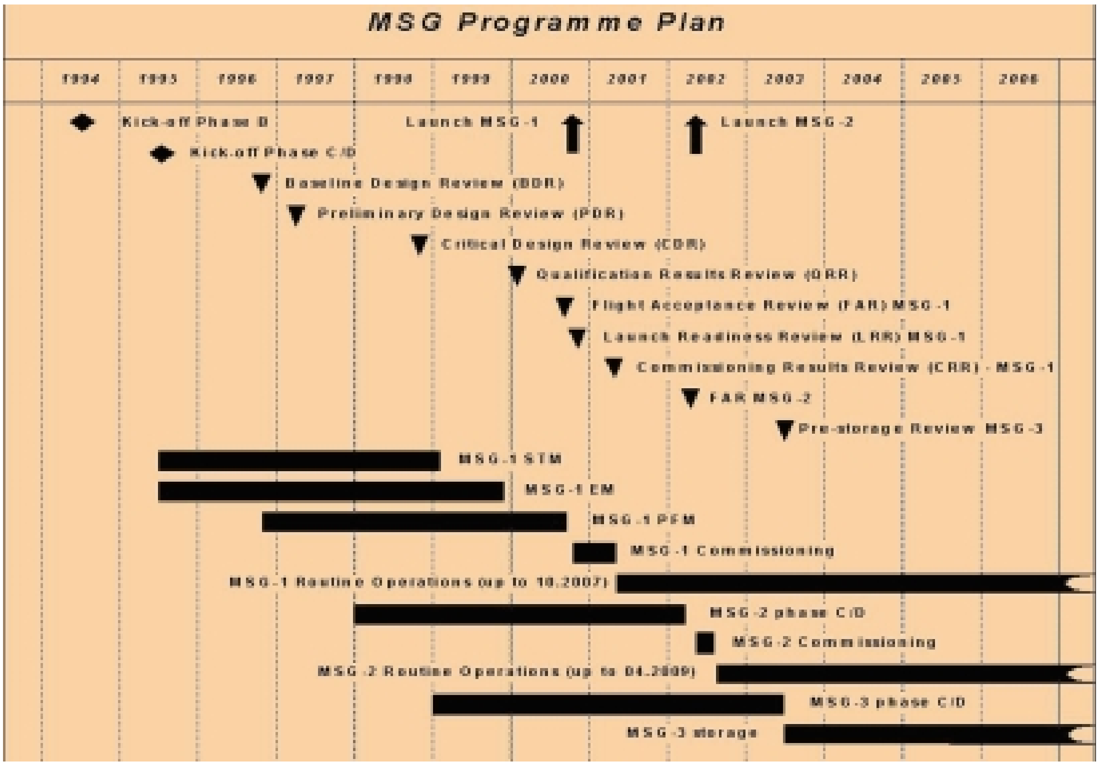
For the development and follow-up of the production of the satellites, ESA has established the MSG Project team at its European Space Research and Technology Centre (ESTEC) in Noordwijk (NL). This team is part of the ESA Directorate of Application Programmes, within the Earth Observation Development Programmes Department.

Eumetsat:

- contributes one third of MSG-1 funding, and funds procurement of MSG-2/3
- finalises and maintains the End User Requirements for the MSG mission
- procures all launchers and the services for post-launch early operations



The MSG industrial consortium



- *develops the ground segment*
- *ensures consistency between the system segments (space, ground, launcher services segments)*
- *operates the system (over at least 12 years).*

A project team in Eumetsat acts as the system architect and integrator. The development and integration of the overall ground segment is carried out by the Eumetsat team, with the development of the individual ground facilities subcontracted to industrial companies across Europe. Once integrated and fully tested, the MSG system will be routinely operated by the Eumetsat operations team.

Industrial Consortium

For the development, manufacturing, integration and testing of the MSG satellites, ESA placed a contract with a European industrial consortium, led by the French company Alcatel Space Industries (Cannes). The work has been subdivided over 105 contracts, which were negotiated with 56 different companies.

The UK National Environmental Research Council (NERC), acting through the Rutherford Appleton Laboratory (RAL), is responsible for the provision of the scientific payload. The GERB instrument is developed, based on funding from the United Kingdom, Belgium and Italy, as an 'Announcement of Flight Opportunity' instrument. This optical instrument, monitoring the Earth's radiation, will make use of a small free volume and available resources on the spacecraft platform.

Launcher

Arianespace is providing the launch vehicle and all associated launch services. The launch will be performed nominally by an Ariane-5 vehicle, as part of a dual or triple launch. Compatibility with Ariane-4 (as part of a dual launch inside Spelda-10) is retained as a back-up.

2.2 Overall Schedule

The Phase-B activities were started in February 1994, during which detailed plans and requirements were established, necessary for precise definition of the main development, qualification and manufacturing activities. Phase-C/D started in July 1995 and will last until the Flight Acceptance Review in August 2000. It will cover the detailed design, development, qualification and manufacture of the satellite.

3 SATELLITE DEVELOPMENT

3.1 Design & Development of the MSG Satellite

Heritage

In order to limit MSG development cost and risks, existing hardware/design heritage from the Meteosat first generation and other satellite programmes has been used to the maximum possible extent. This approach could be implemented successfully for several units within the classical support subsystems.

Within the Electrical Power Subsystem (EPS), the Power Distribution Unit (PDU) is based on the Cluster/Soho design, and the solar-array cell implementation was also taken over from Cluster. The batteries are based on standard cells from SAFT (F). The Data Handling Subsystem is based on a standard design from Saab-Ericsson Space (S). In the Attitude and Orbit Control Subsystem (AOCS), all sensors (ESU, SSU and ACU) are off-the-shelf items, with only the control electronics having to be specially developed. Most of the Unified Propulsion Subsystem (UPS) elements are off-the-shelf items, and only the tanks and Gauging Sensor Unit (GSU) are new developments. Nearly all of the Mission Communication Package (MCP) units are based on the design heritage of the Meteosat first generation. The Search and Rescue Transponder is a new development, and the S-band Telemetry/Telecommand Transponder is a standard Alenia (I) design.

The scientific payload (GERB) and the main imaging instrument (SEVIRI) are completely new developments.

Model Philosophy

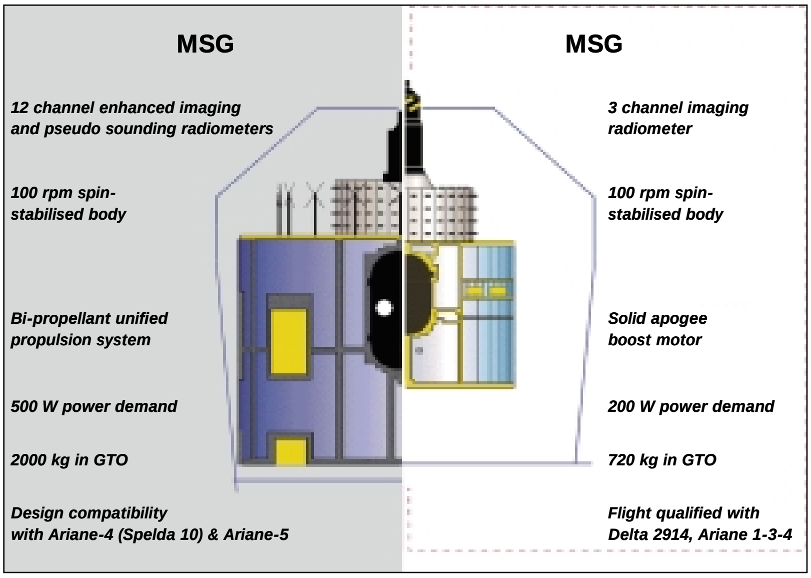
For all support and MCP units, a model concept including a Structural and Thermal Model (STM), an Engineering Model (EM), a Qualification Model (QM) and Flight Models (FM1, 2 and 3) has been implemented. For SEVIRI, the EM/QM and FM1 models are replaced by an Engineering Qualification and a Proto-Flight Model (EQM and PFM).

The STM units were manufactured exclusively for the use in the satellite STM, but their number was limited, as flight hardware was used as far as possible, e.g. solar panels, primary and secondary structures, tanks. The EM units were used to validate the design and to perform a pre-qualification, consisting of mechanical, thermal and electromagnetic compatibility tests. The EM units are manufactured with standard components. The QM units, equipped with High-Rel parts, served to perform the standard qualification. For all flight-model units, only acceptance tests will be performed.

The concept of pre-qualification of the EM units provided a lot of flexibility in the QM/FM manufacturing schedule later in the programme. It made it possible in many cases to advance the FM unit manufacturing and the qualification units were then completed after FM delivery.

Rolling-Spare Philosophy

Since MSG is a multi-satellite programme, a rolling-spare philosophy has been adopted; for example, the QMs act as spares for FM-1. They will, however, be normally used on FM-2, with FM-2 units becoming available as spares for FM-2, after which



An MSG/MOP comparison

these units will be used on FM-3, while the FM-3 units will remain as the ultimate spares.

Satellite Design

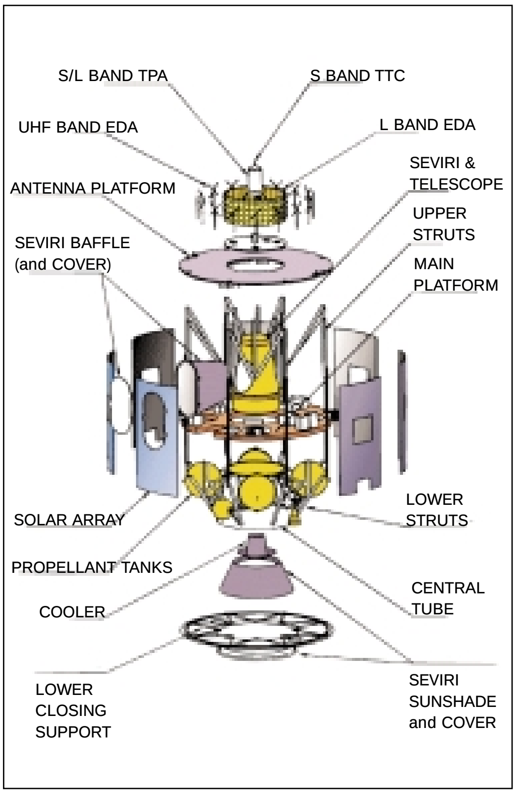
The MSG concept is based on the same design principles as the Meteosat first-generation satellite and is also spin-stabilised at 100 rpm. A cylindrical-shaped solar drum, 3.2 m in diameter, includes in the centre the radiometer (SEVIRI), and on top the antenna farm. The total height of the satellite, including the antenna assembly, is 3.74 m.

The satellite itself is built in a modular way and is composed of the following elements:

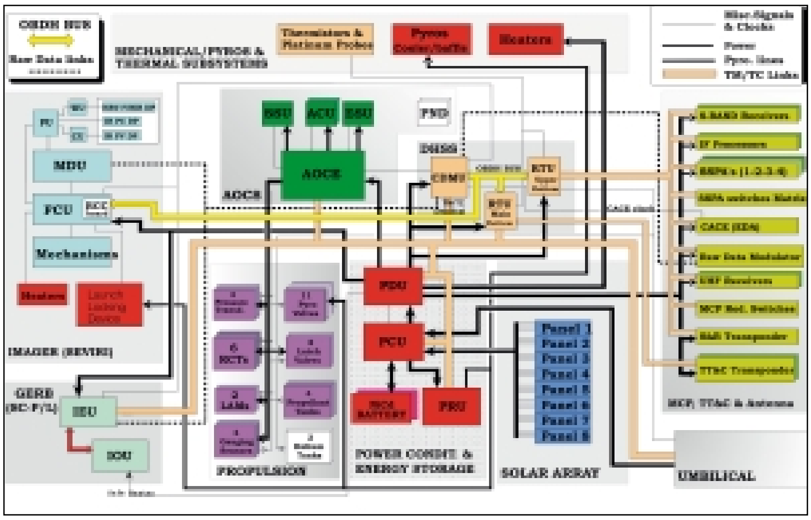
- *The Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument, located in the central compartment of the satellite, ensures the generation of image data; formatting of image data is completed at satellite level before transmission to the ground.*
- *The Mission Communication Package (MCP), including antennas and transponders, is in the upper compartment. It ensures the transmission of image data to the ground and the relay of other mission data.*
- *The GERB (Geostationary Earth Radiation Budget) instrument.*
- *The Geostationary Search and Rescue (GEOSAR) payload, which is made of a transponder with the capacity for relaying distress signals.*
- *The satellite support subsystems.*

The MSG satellite support subsystems consist of:

- *the Data Handling Subsystem (DHSS) and the associated Data Handling Software (DHSW), which splits into the Application Software (ASW) and the Basic Software (BSW)*
- *the Electrical Power Subsystem (EPS)*
- *the Attitude and Orbit Control Subsystem (AOCS)*
- *the Unified Propulsion Subsystem (UPS)*
- *the Telemetry, Tracking and Command Subsystem (TT & C)*
- *the Thermal Control Subsystem (TCS)*
- *the Structure Subsystem and the Mechanisms and Pyrotechnic Devices.*



Exploded view of the MSG satellite



The electrical/ functional architecture of the satellite

For its initial boost into geostationary orbit as well as for station-keeping, the satellite uses a bi-propellant system. This includes small thrusters, which are also used for attitude control. The MSG solar array, built from eight curved panels, is wrapped around the satellite body.

The support subsystems, Data Handling (DHSS), Power (EPS), Attitude and Orbit Control (AOCS) and the S-band transponders are located on top of the main platform, together with the Geostationary Earth Radiation Budget (GERB) experiment. The Unified Propulsion Subsystem (UPS) is located on the bottom side of the main platform.

The antenna platform houses all elements of the Mission Communication Package (MCP), i.e. electronic units and antenna.

The Meteorological Payload consists of the radiometer (SEVIRI) as the main instrument and a scientific experiment, GERB.

The Mission Communication Package (MCP) includes: the raw data links, image dissemination link, Search and Rescue transponder and the telemetry/ telecommand transponders.

The Electrical Power Subsystem (EPS) generates, stores, conditions and distributes the power for all subsystems, including thermal control and pyrotechnic functions. The following units are part of the EPS: Solar Array, Batteries, Power Conditioning Unit (PCU), Power Distribution Unit (PDU) and the Pyrotechnic Release Unit (PRU).

The Data Handling Subsystem (DHSS), consisting of the Central Data Management Unit (CDMU) and two Remote Terminal Units (RTUs), serves the internal data exchange via an Onboard Data Handling (OBDH) bus. SEVIRI is directly connected to the OBDH bus, whereas all other subsystems are controlled and monitored via the RTUs.

The Attitude and Orbit Control Subsystem (AOCS) comprises a Control Electronics Unit (AOCE), the Sun and Earth Sensors (SSU, ESU), an Accelerometer Package (ACU) and the Passive Nutation Dampers (PNDs). The AOCS directly commands the Unified Propulsion Subsystem (UPS).

The UPS is a bipropellant system including the Liquid Apogee boost Motors (LAMs), the Reaction Control Thrusters (RCTs), the propellant- and pressurant tanks and all necessary valves, filters, pressure regulator, pressure transducers and the Gauging Sensor Units (GSUs).

MSG's mechanical subsystem includes the primary structure, the secondary structure (LAM support, solar-array fixation) and the SEVIRI cooler and baffle cover (which will be ejected prior to reaching the final geostationary orbit).

3.2 AIT Programme

The AIT programme is based on a three-model philosophy, namely:

- *a Structural and Thermal Model (STM)*
- *an Engineering Model (EM)*
- *Flight Models (FM).*

Electrical integration and testing, which are performed on EM and FMs, are done as much as possible at subsystem level. At satellite level, these subsystems are assembled with a guiding principle of the necessary minimum of testing.

The STM

The main purpose for building an STM is to qualify the mechanical structure of the satellite, and to validate its thermal behaviour. This model serves also for mechanical interface verification and to establish mechanical procedures. The mechanical tests on the STM were successfully completed in spring 1999. It was subsequently dismantled to recover the flight elements from it.

The EM

The main purpose of the EM is to verify all of the satellite's electrical interfaces, and to demonstrate that the satellite can meet the required performance goals. A second important task is to establish and validate test procedures and databases, together with the relevant EGSE. All satellite EM tests were performed in Alcatel's facilities in Cannes (F).

The FM

The FM undergoes a series of tests to demonstrate that it is flight worthy, and that it fulfils the performance requirements. These tests are the same, or similar to tests performed on the STM and EM and will be performed at Alcatel in Cannes.

The Main Test Programme

– *The Thermal-Balance Test* was performed in the Large Solar Simulator at ESTEC (NL)

Overview of the major tests at satellite level

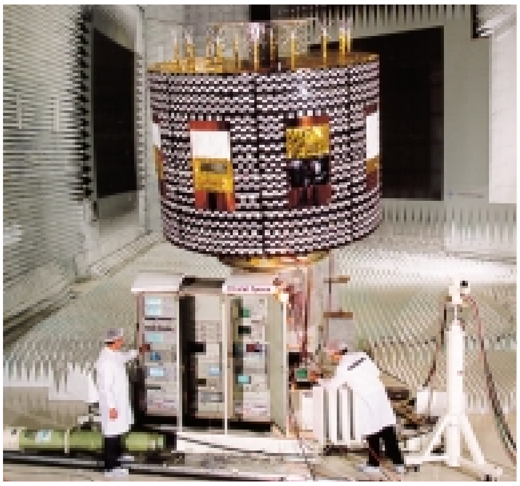
	STM	EM	FM
• Thermal Balance / Thermal Vacuum Test	√		√
• Vibration (Sine)	√		√
• Acoustic Noise	√		√
• Mass Properties Determination, incl. Balancing	√		√
• Spin	√	√	√
• Cover Release	√		
• Separation and Shock	√		
• Integration Test		√	√
• Integrated System Test (IST 1)		√	√
• Antenna Tests in CATR		√	√
• EMC Test		√	√
• SEVIRI Reference Test Ambient		√	√
• IST 2			√

In a vacuum environment (1x10^{-5} bar), various thermal cases were simulated and the temperature response of the satellite was compared with the predictions of the mathematical thermal model. This test was performed in spring 1998 with good results.

– *Mechanical Tests:* Their purpose is to verify that the resonance frequencies of the satellite are as required by the launcher authority, and to demonstrate that the mechanical construction of the satellite is strong enough to withstand all of the mechanical forces that it will experience throughout its lifetime.
– *Integration Test:* Its purpose is to establish correct functioning of a subsystem, and to verify its interfaces with other subsystems.
– *Integrated System Test:* The IST verifies that the entire satellite functions correctly, and that the performance requirements can be achieved.
– *Antenna Tests in CATR:* The tests performed on the Compact Antenna Test Range (CATR) are designed to demonstrate the performance and functioning of the antenna subsystem on the satellite.
– *EMC Test:* This is the classical test to demonstrate electromagnetic compatibility of the satellite with its expected environment, with at least 6 dB design margin. Also included is a test to demonstrate non-sensitivity with respect to electrostatic discharge.
– *Spin Test:* This test is performed with the satellite mounted on a spin table, rotating at its nominal operational speed of 100 rpm. This test validates all operations that depend on the spinning motion of the satellite, such as correct de-spinning of the L-band and UHF-band antennas, and the east-west scanning of the SEVIRI instrument.

Thermal-balance testing in progress in the Large Space Simulator at ESTEC in Noordwijk (NL)

– *SEVIRI Reference Test Ambient:* This test verifies SEVIRI's performance under ambient conditions. As such, it forms part of the IST, but because of the complex set-up with a dedicated optical system it is designated as a separate test.
– *SEVIRI Optical Vacuum Test:* This test demonstrates the performance of the SEVIRI infrared channels, with the detectors operating at temperatures of 85 to 95 K. To achieve this, the satellite is placed in a vacuum chamber, together with the same optical system that was used for the reference test.



EMC test in progress in the CATR

General Test Approach

Basically, the same set of tests is performed before and after the mechanical tests, to make sure that the mechanical forces experienced have no negative influence on the performance, with the exception of the spin test and the optical vacuum test.

For subsequent FMs, the test programme is slightly more relaxed. The sine-vibration and thermal-balance tests are removed, because they are essentially design verification tests that are no longer required at that stage of the programme.

To support the Assembly, Integration and Test (AIT) Programme, a suite of Ground Support Equipment (GSE) is needed. It consists of Mechanical GSE, Electrical GSE and Optical GSE.

Mechanical GSE (MGSE)

All items of a mainly mechanical nature belong in this group, but range from the satellite transport container (ca. 4 m x 4 m x 5 m), over various types of dollies (structures on which the satellite is mounted), via lifting devices, to simple masts on which to mount test antennas.

Electrical GSE (EGSE)

This group of seven computer systems contains all equipment needed to operate, control and monitor the satellite.They are:

1. *Overall Check-Out Equipment (OCOE)*
2. *TM/TC Special Check-Out Equipment (SCOE)*
3. *EPS SCOE*
4. *AOCS SCOE*
5. *RF SCOE*
6. *Image SCOE*
7. *Launch SCOE.*

Working closely together, their tasks range from supplying electrical power, to verifying the performance of the payload instruments. Each one has its own control computer, which in turn receives instructions from a central controller. Operation of the central computer is determined by the AIT engineers through direct manual input, or execution of pre-programmed sequences of commands.

Optical GSE (OGSE)

The OGSE comprises all equipment that is needed to provide input signals to the satellite's optical sensors and instruments.

3.3 Product Assurance

A 'quality product' can be defined as one that meets the customers' requirements – particularly in terms of performance, reliability, durability and usability. In order *to ensure that the MSG satellite is such a 'quality product' meeting the customer's agreed requirements, a set of proven activities, to be carried out during design inception up to launch, are brought together and detailed in a Product Assurance (PA) Plan. This ensures that quality is built-in right from the start of the project.*

The primary elements addressed in the PA Plan are:
- *Design/Qualification Reviews*
- *Reliability and Safety*
- *Critical Items Control*
- *Parts, Materials and Processes*
- *Software Quality Assurance*
- *Audits*
- *Production Control*
- *Configuration & Documentation Control*
- *Cleanliness and Contamination Control.*

Design/Qualification Reviews

Each design review is a formal comprehensive audit of the MSG design, and is intended to optimise the design approach and achieve the required qualification and performances.

The following satellite-level reviews are foreseen:
- *Preliminary Design Review (PDR)*
- *Critical Design Review (CDR)*
- *Qualification Results Review (QRR)*
- *Flight-Acceptance Review (FAR)*
- *Launch-Readiness Review (LRR)*
- *Commissioning-Results Review (CRR).*

The PDR is a technical review of the then current maturity of the design. It also includes a PA status review.

The CDR will freeze the detailed design, manufacturing processes and procedures in order to define the FM hardware baseline.

A QRR is held to consider the collective evidence from tests, inspections, reviews and analyses to prove that requirements have been met with the margin specified.

The FAR is held at the end of the FM test programme and will establish the flightworthiness of the satellite. The FAR also gives consent to ship to the launch site.

The LRR is held at the launch site, six days prior to launch, to verify whether the whole system, including the satellite, the ground stations, the LEOP and the launcher are ready for launch.

The CRR will establish the whole system after start-up and verify that all satellite systems are working in orbit according to their design specifications and releases routine operations

Reliability and Safety

The Reliability and Safety Plan addresses all areas that would compromise the life of the mission, or affect the staff and the environment prior to launch.

Critical Items Control

A Critical Items List (CIL) is produced by the Prime Contractor and all Subcontractors having design responsibility. The list includes all activities and precautions taken to minimise and control the risks relating to these items

Parts, Materials and Processes

All parts, materials and processes used in building the MSG satellite must be qualified for use in a space environment and meet ESA requirements.

Software Quality Assurance

The quality of the mission software is also of vital importance as any problem here could seriously affect the satellite's operation.

Audits

The Prime Contractor is required to conduct audits of his own (internal audits) and of his subcontractors' and suppliers' (external audits) facilities, equipment, personnel procedures, services and operations in order to verify compliance with the PA requirements.

Production Control

Extensive controls are in place during the production of the various satellite models. These controls provide a fully documented overview of all areas, including assembly and test and have built-in traceability. Typical controls are:

– *Mandatory Inspection Points (MIPs): These take place at critical points during manufacture.*
– *Test Readiness Review (TRR): These take place prior to formal acceptance testing of the related item.*
– *Test Review/Delivery Review Board (TRB/DRB): These Boards review test results and manufacturing data and decide on suitability for delivery to the next stage of integration.*
– *Material Review Boards (MRBs): These Boards are held when a major non-conformance has been found against the relevant requirements.*

Configuration & Documentation Control

– *Configuration Control: Documentation for the MSG project is kept under formal change control.*
– *Non-Conformance Reports (NCRs): Closure of major NCRs is essential before proceeding to the next level/integration/test.*
– *Data Packs: In order to formally complete a DRB, a full Acceptance Data Pack (ADP) must be approved by PA at the appropriate levels. This provides full traceability right back to component level, and is invaluable in tracking down possible causes of problems that may occur in the later stages of build/test.*

Cleanliness and Contamination

Cleanliness is one of the driving elements for the satellite's imaging-mission performance. SEVIRI is a contamination-sensitive optical and cryogenically cooled instrument. It has units that are built to different classes of cleanliness and this presents a difficult technical situation during environmental test phases.

A contamination-budget assessment has been generated to predict the performance degradation due to contamination that may arise as a consequence of the on-ground activities.

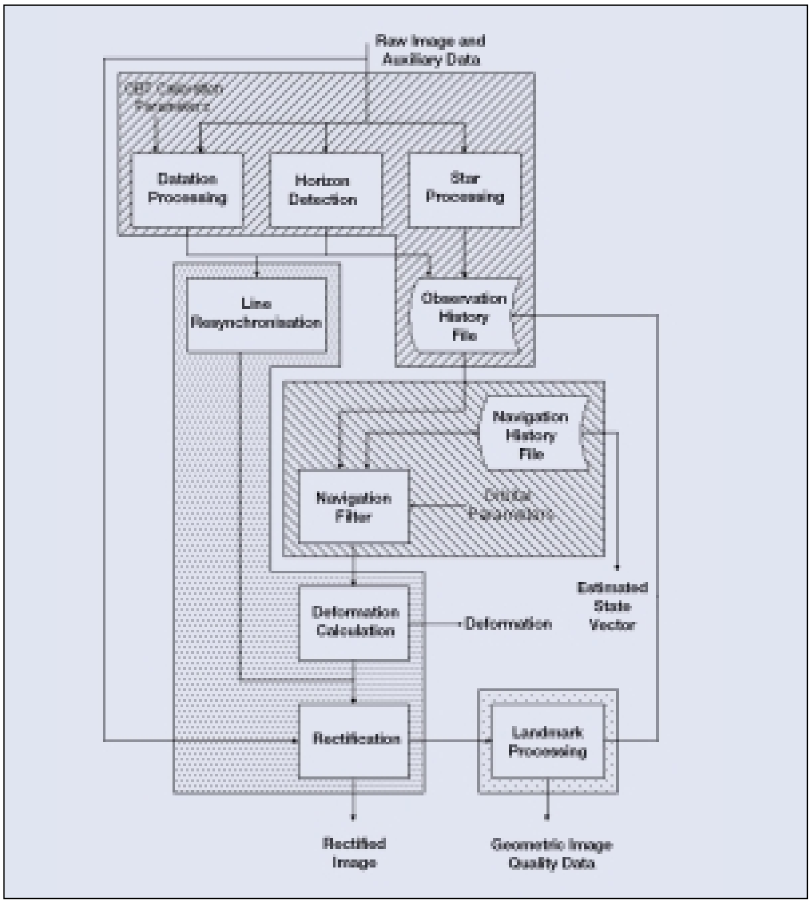
3.4 Image-Quality Ground Support Equipment (IQGSE)

The Image-Quality Ground Support Equipment (IQGSE) for the Meteosat Second Generation (MSG) satellites is a computer *system for the processing and quality measurement of MSG images. The IQGSE software is coded in the C language with an X/Motif man/machine interface operating on a UNIX-based workstation.*

The IQGSE will be used for two different purposes: firstly to qualify on-ground the geometric image-quality performance of the MSG satellite system, and secondly to verify in flight the geometric image-quality performance of the MSG satellite system during the commissioning phase and other periods of the satellite's seven-year design lifetime.

The IQGSE architecture consists of five software modules. Its backbone is the Image Rectification Software (IRS), which computes and applies a high-accuracy geometric correction to the raw MSG images received from the ground segment. Concurrently with the image-rectification process, the IRS automatically measures absolute and relative landmark displacements for a given set of predefined landmarks. The IRS output comprises the rectified MSG image and the corresponding geometric image-quality file that contains the landmark processing results. The Landmark Catalogue Builder Tool (LCBT), the Image Quality Measurement Tool (IQMT) and the Performance Analysis Tool (PAT) support the IRS. The LCBT builds and maintains the landmark catalogue using the World Vector Shoreline database. The IQMT measures automatically or interactively the absolute and relative landmark displacements, while the PAT computes the image-quality figures of merit from the geometric image-quality file. Finally, there is the MSG Image and Data Simulator (MIDAS) in order to validate the Image Rectification Software before the launch of the first MSG satellite.

The Image Rectification Software (IRS) Module comprises four main functions: the pre-processing, the navigation filter, the image rectification, and the landmark processing function. The pre-processing function converts the on-board time to Universal Time (UT) and determines the satellite spin period and the line start delays. Furthermore, it calculates the Sun-to-Earth centre angle by extracting the Earth-to-space and space-to-Earth transitions, and performs the star detection. The navigation filter function determines a parameter state vector describing, for example, the satellite spin-axis attitude, the satellite orbit, the satellite rigid-body wobble, and the detector alignments within the focal plane. Eventually, the image rectification function performs the line-start jitter compensation and the image re-sampling. Simultaneously with the real-time rectification, the landmark processing function measures the rectified image quality on up to 1000 landmarks.



The Image Rectification Software (IRS) concept

MSG Prime
Alcatel Space Industries

Direct Subcontractors

Primary Structure	- Oerlikon Contraves
Secondary Structure	- Fokker Space
SEVIRI-Baffle	- Casa
Mechanisms & Pyro's	- Sener
Pyro's	- Dassault Aviation
M&P Test Facilities	- IABG
Data Handling Subsystem	- Saab-Ericsson Sp.
RTU TE	- Austrian Aerospace
Thermal Control	- Casa
Thermal Hardware	- Austrian Aerospace
Harness	- Casa
CPP Agent	- Tecnologica
CPP Agent	- Bosch Telecom
MGSE	- Austrian Aerospace
OCOE	- Terma
OCOE Eng. Support	- Satellite Services
OCOE Supplies	- CGI Systems
RF SCOE	- Siemens
SIFA / Launch SCOE	- Siemens
Image SCOE	- Alcatel Espacio
ASW Support	- Space Syst. Finland
PA Support	- Det Norske Veritas
System Eng. Support	- Casa
SEVIRI-Baffle	- Sener
ETE OGSE (Feas.)	- Spacebel
ASW Eng. Support	- Cap Gemini
Support to SGSE	- Trasys Space
Software Validation	- GMV
Various GSE Elements	- AMOS
AIT Eng. Support	- Finavitec
S/W Dependability Study	- Finavitec
Eng. Support to ISV	- GMV
OCOE Guarantee	- CGI Systems
OCOE Guarantee	- Satellite Services

AOCS / EPS / UPS
Daimler-Chrysler

ESA/SSU	- Officine Galileo
PND	- Urenco
Solar Array Panels	- Fokker Space
Battery Cells	- SAFT
PDU	- Alcatel Space DK
LCL-Hybrids	- Alcatel Space N
PDU EGSE	- Alcatel ETCA
PRU & Pyro Testers	- Austrian Aerospace
PCU-Hybrids	- Alcatel ETCA
Simulators	- Alcatel ETCA
Gauging Sensor Unit	- Bradford Eng.
Pressurant Tanks	- MAN Technologie
Pressure Regulator	- Aerospatiale
Check Valves	- Raufoss Technology
Helium Filter	- SEP
Propellant Filter	- Dowty Aerospace
Pyro Valve	- Pyroalliance
Pressure Transducer	- SEP

SEVIRI
MMS- F

Structure	- Daimler-Chrysler
Scan Assembly	- Daimler-Chrysler
Scan Mirror	- Zeiss Optronik
Drive Unit	- Alcatel Space Ind.
Drive Unit Eng. Support	- Sener
Drive Unit Testers	- Sener
Telescope Optics	- Zeiss Optronik
TSA AIT Support	- Daimler-Chrysler
FPOB / F&D / Aplanats	- Reosc
FPOB Eng. Support	- Spacebel
FPOB Facilities	- CSL
Passive Cooler Assembly	- Fokker Space
Cooler	- Bertin Technologies
PCA Cold Wiring	- Sagem
Coating	- Reosc
MLI	- Austrian Aerospace
Calibration Unit	- Sener
Radiometer / Source	- AEA Technologies
Refocussing Mechanism	- TNO/TPD
HRV/VNIR Detectors	- Thomson
IR Detectors	- GEC MIRL
Main Detection Unit	- Alcatel Space CH
ASIC Design	- Smartech
MDU TE	- Kongsberg Spacetec
Functional Control Unit	- Crisa
Preamplifier Unit - BB	- MMS-UK
Harness	- Casa
MGSE	- Austrian Aerospace
EGSE	- Finavitec
OGSE	- Spacebel
OGSE Mirror	- Zeiss Optronik
Preamplifier Unit	- Comdev
SEVIRI Testing	- CSL
AIT Support	- Crisa
Thermal H/W	- Austrian Aerospace
OGSE	- AMOS
AIT Support	- Spacebel Informatique

MCP
Alenia Aerospazio

Engineering Support	- Space Engineering
Raw Data Modulator	- Alcatel Espacio
IF Processor & S/R Tx	- Alcatel Space N
MCP Units	- Bosch Telecom
TTC Antenna & UHF Rx	- Saab-Ericsson Sp.
SAW Filters	- Alcatel Space N
DC/DC Converters	- Alcatel Space DK

4 PAYLOAD

4.1 The Spinning Enhanced Visible and Infra-Red Imager (SEVIRI)

The SEVIRI instrument is the primary payload of the MSG spacecraft.

The SEVIRI Instrument Characteristics

Spectral range:
- *0.4 – 1.6 µm*
  (4 visible/near infra-red channels)
- *3.9 – 13.4 µm*
  (8 infra-red channels)

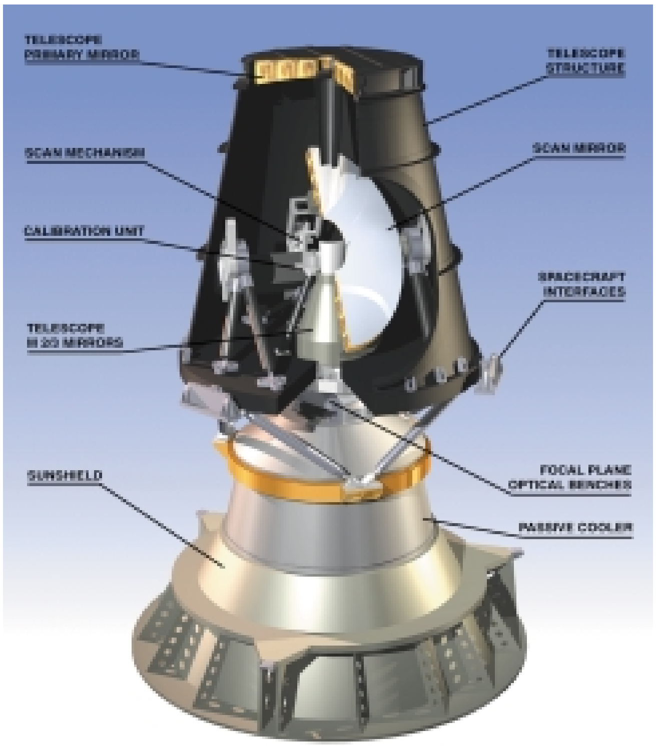
Resolution from 36 000 km altitude:
- *1 km in high resolution for visible channels*
- *3 km in infra-red and visible channels*
  Focal plane cooled to 85/95 K

Earth scanning achieved by a combination of satellite spin (east-west) and mirror scanning (south-north).
- *One image every 15 minutes*
- *245 000 full images over 7-year nominal lifetime*

Instrument mass: 260 kg
Dimensions:
- *2.43 m height*
- *1m diameter (without Sun shield)*
- *Power consumption: 150 W*
- *Data rate: 3.26 Mbit/s*

SEVIRI Operating Principle

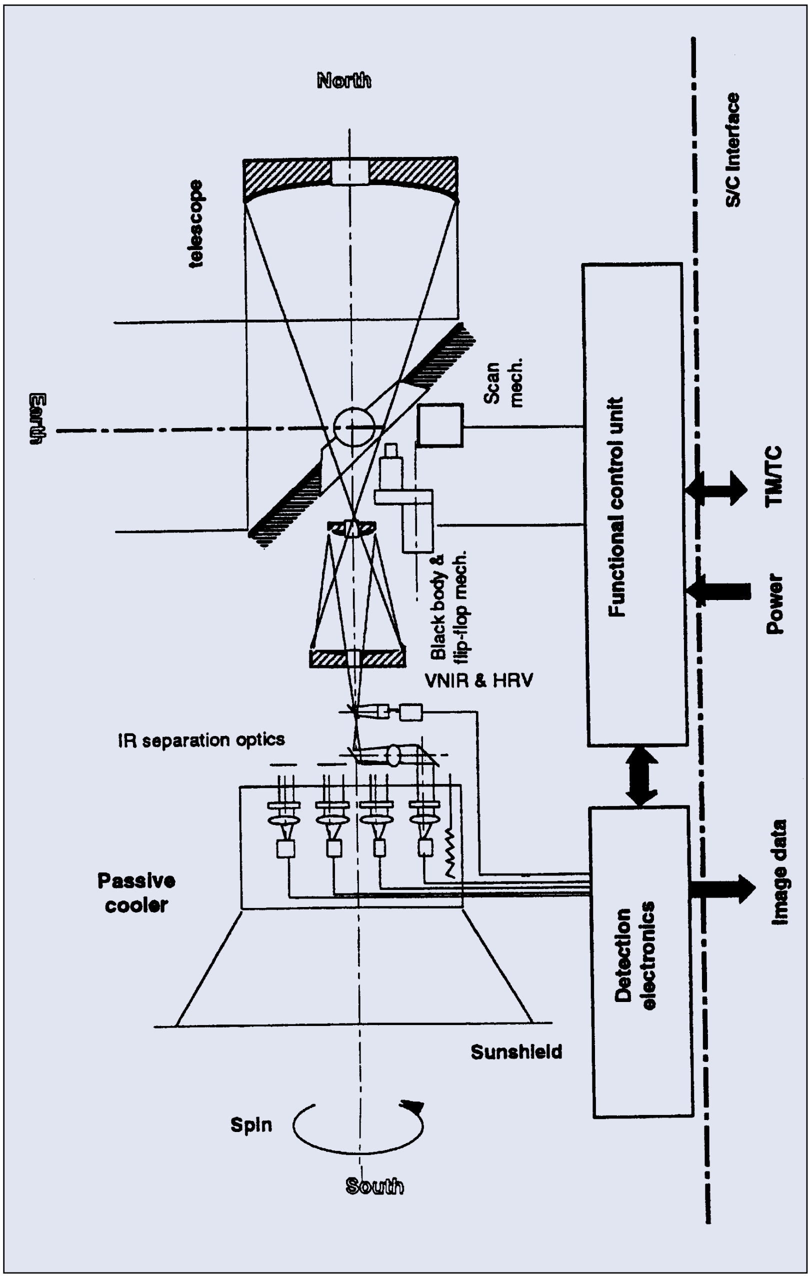
The SEVIRI instrument's functional architecture is based on four main assemblies:
- *the Telescope and Scan Assembly (TSA), including the Calibration Unit and the Refocusing Mechanism*
- *the Focal Plane & Cooler Assembly (FPCA)*
- *the Functional Control Unit (FCU)*



The main SEVIRI instrument unit

- *the Detection Electronics (DE) including the Main Detection Unit (MDU), the Preamplifier Unit (PU) and the Detectors.*

The instrument's operating principle can be summarised as follows:
- *The scan mirror is used to move the instrument Line-Of-Sight (LOS) in the south-north direction.*
- *The target radiance is collected by the telescope and focused towards the detectors.*
- *Channel separation is performed at telescope focal-plane level.*
- *A flip-flop type mechanism is periodically actuated to place the calibration reference source into the instrument field of view.*



Functional schematic and operating principle of SEVIRI

- Imaging data are directly transferred from the MDU to the onboard data-handling subsystem.
- SEVIRI function, control and telemetry/telecommand interfaces with the satellite are ensured by the FCU.

The Bi-dimensional Earth Scan

The basic purpose of the instrument is to take images of the Earth at regular intervals during a 15-minute image repeat cycle (involving a 12 min 30 sec Earth imaging phase and an up to 2 min 30 sec calibration and retrace phase).

Earth imaging is obtained by a bi-dimensional Earth scan, combining the satellite spin and the scan mirror rotation:

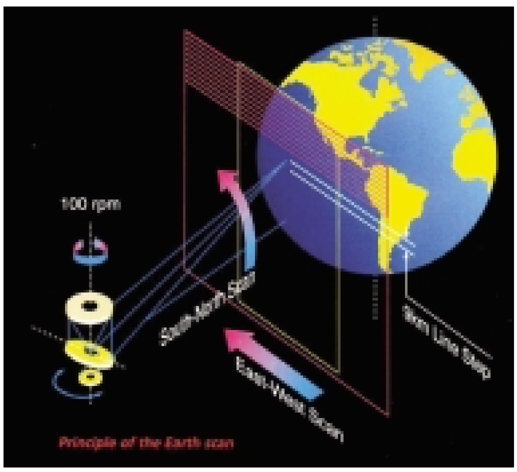
- *The rapid scan (line scan) is performed from east to west thanks to the satellite's rotation around its spin axis. The latter is perpendicular to the orbital plane and is nominally oriented along the south-north direction.*

- *The slow scan is performed from south to north by means of a scanning mechanism, which rotates the scan mirror in 125.8 µrad steps. A total scanning range of ±5.5 deg (corresponding to 1527 scan lines) is used to cover the 22 deg Earth-imaging extended range in the south-north direction, and 1249 scan lines cover the whole Earth in the baseline repeat cycle.*

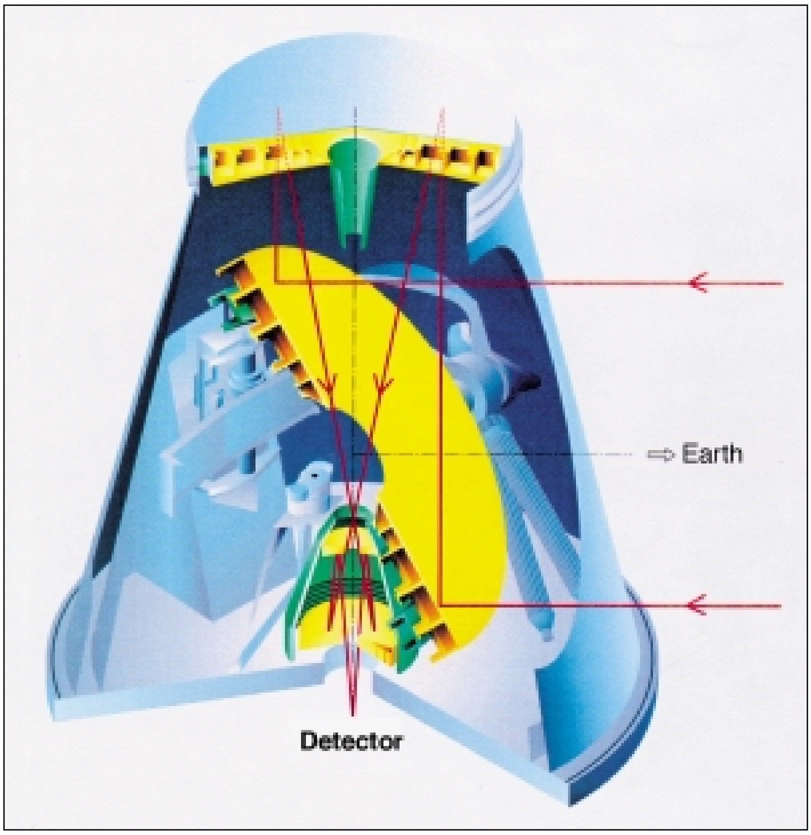
The Telescope and Scan Assembly

The Telescope and Scan Assembly includes the telescope optics, the telescope structure and the mechanism assemblies.

The telescope's basic optical layout is based on a three-mirror concept:



The Earth-imaging principle



The mirror concept for SEVIRI

- M1: large Primary Mirror, concave aspherical, with 510 mm optical useful diameter
- M2: Secondary Mirror, concave aspherical, of 200 mm diameter
- M3: Tertiary Mirror, convex aspherical, of 60 mm diameter.

The required focal length (5367 mm) is obtained by successive magnification of the two mirrors M2 and M3. The total length of the telescope structure is 1.3 m.
The Scan Mirror is located in front of the Primary Mirror, close to its focal plane, with a tilt of 45° relative to the optical path. The mirror has an elliptical shape (410 mm semi-major axis and 260mm semi-minor axis) and an elliptical central hole, which allows the optical beam to pass through after its reflection towards the primary mirror M1.

All mirrors are of lightweight construction and manufactured from Zerodur.

The telescope structure relies on the use of a central stiff base plate, which interfaces with the spacecraft via three isostatic mounts. The base plate is manufactured from a 70 mm aluminum honeycomb sandwich, including 4 mm-thick CFRP face sheets on each side. Each functional component is attached to the base plate through a dedicated support structure:

- *a stiff CFRP cone, providing the aperture to the spacecraft baffle and supporting the primary mirror M1*
- *the Scan Assembly Support Structure, consisting of a stiff CFRP U-shaped frame and 8 CFRP struts, providing the support for the moveable scan mirror and its associated mechanisms*
- *dedicated isostatic mounts to hold the Refocusing Mechanism (REM) located in the centre hole of the base plate. The M2/M3 mirror support structure interfaces with the REM top*
- *a tripod carrying the Calibration Mechanism*
- *a titanium strut arrangement (6 struts mounted at the lower side of the base plate) to keep the Focal Plane and Cooler Assembly in position.*

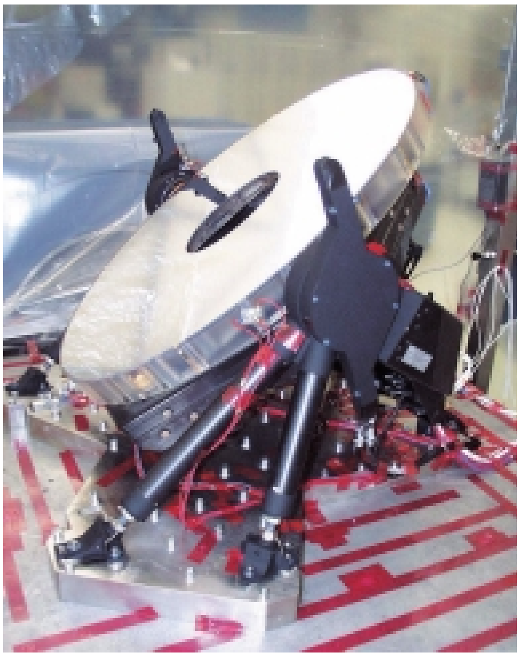
The main instrument electronics (MDU, FCU and PU electronic boxes) are located on the MSG main base plate. The SEVIRI Sun shield is directly mounted to the MSG spacecraft structural cone.

The mechanical design of SEVIRI includes three mechanism assemblies: the Scan Assembly, the Calibration Unit and the Refocusing Mechanism.

The Scan Assembly *includes the Zerodur scan mirror, a scan support structure mainly manufactured from CFRP, and the scan assembly mechanisms, which are primarily composed of:*

- *a linear spindle drive utilising a stepper motor with redundant windings*

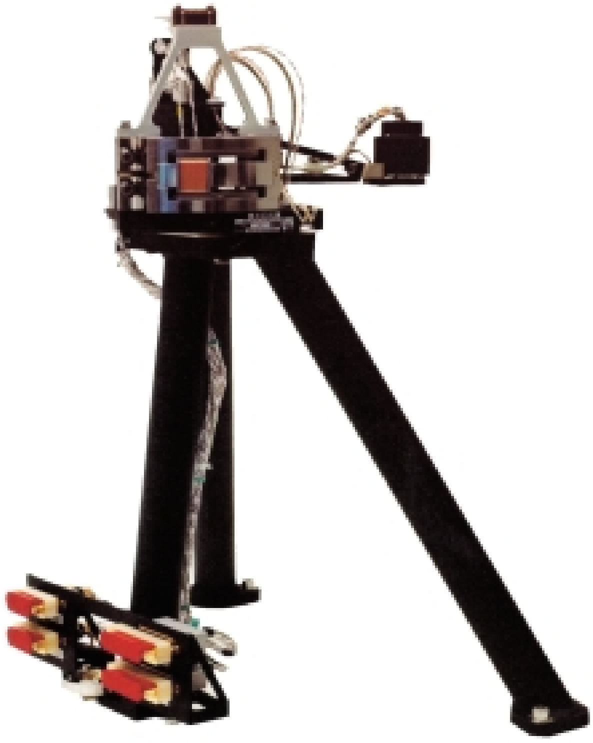
The Scan Assembly mounted on a shaker table for test purposes



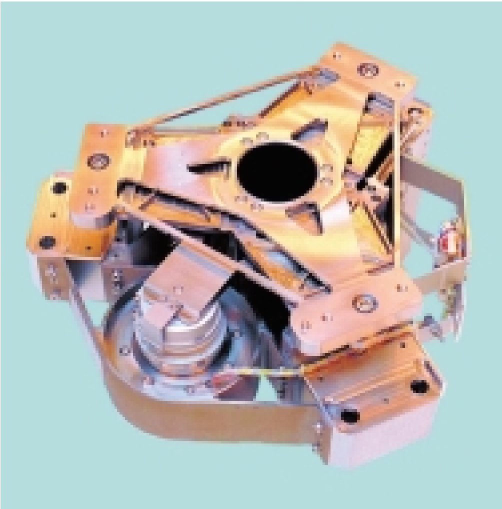
- a kinematic link system which transfers the longitudinal movements of the linear spindle drive into rotations at scan mirror level
- a set of angular contact ball bearings (dry-lubricated) allowing for small oscillatory rotations of the scan mirror
- a set of springs attached to the mirror rotation axis to allow for spin load compensation in-orbit
- a dedicated Launch Locking Device (LLD) to clamp the scan mechanism during launch.

The main purpose of the *Calibration Unit* (CALU) is to allow the calibration of the infra-red channels of the radiometer, by inserting a Black Body Calibration Reference Source (CRS) into the optical beam at the M1 focal point. The CALU represents a flip-flop type of mechanism based on a DC voice coil motor. To limit the shock loads when reaching the rest positions, dedicated shock absorbers are used.

The *Refocusing Mechanism* (REM) allows for in-orbit focus adjustments (in 1.4 micron steps over a 2 mm range) by moving the M2/M3 mirror assembly along the instrument's south-north axis. The REM features a stepper motor, a transmission gearbox and a roller screw providing the translation. The mechanical linear guide is provided by the elastic deformation of a six-bladed arrangement.



The Calibration Unit assembly



The Focal Plane and Cooler Assembly

The *Passive Cooler Assembly* (PCA) is a two-stage passive cooling device, composed of the Radiator Assembly (RA) and the Sun-shield Assembly (SA), which provide the infra-red detectors with a cryogenic environment (basically 85 K in summer and 95 K in winter).

The Sun shield is used to avoid direct solar fluxes on the first- and second-stage radiator of the RA. Thanks to the design of the internal cone (elliptically shaped), the secondary flux on the second-stage radiator is already minimised.

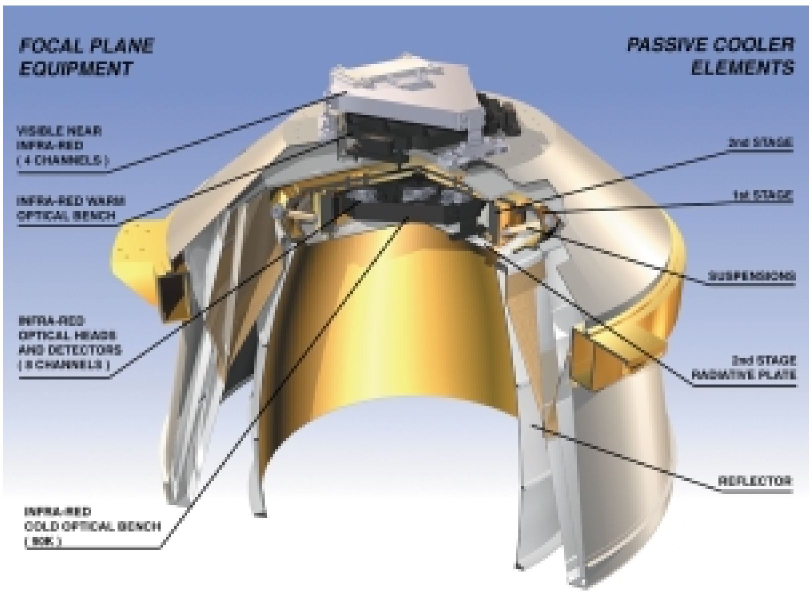
The PCA heat radiation towards cold deep-space is in the range 10 mW to 10 W. One of the RA's most critical subsystems is the Detection Cold Wiring (DCW), which provides the electrical connection between the detectors located in the cold part (CIRO) and the warm part of the instrument (RA housing). The DCW needed to be optimised in order to comply with the electrical requirements whilst minimizing the thermal impact due to conductive losses (thermal gradient of about 200 K between cold and warm parts of the RA). Structurally, the CIRO is thermally de-coupled from the warm part by a set of low-conductive suspensions (12 GFRP struts) and a dedicated GFRP cone.

The PCA is equipped with heaters, in order to allow for periodic decontamination of the instrument (operations to remove frozen contaminants from the cold surfaces).

The *Focal Plane Assembly's* Optical Benches (FPOBs) are designed to accommodate the 12 channels of SEVIRI. The Benches consist

The Refocusing Mechanism

The Radiator Assembly with Optical Benches



The Radiator Assembly during integration

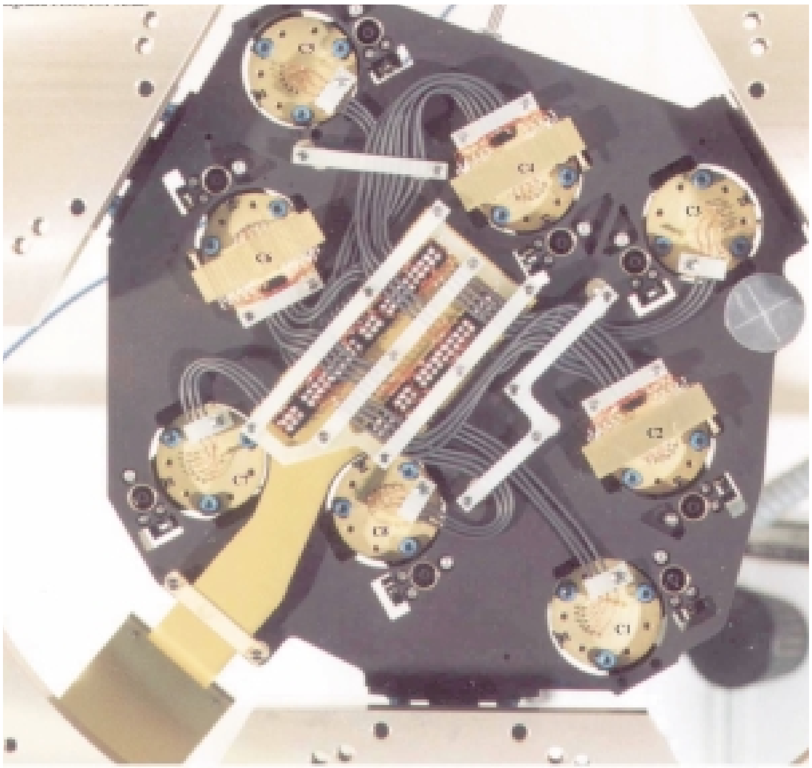
of two main assemblies: the VNIR and HRV Optical Bench (VHRO) for the 4 visible channels, and the Warm/Cold IR Optical Bench (WIRO/CIRO) for the 8 infra-red channels. The CIRO will be thermally regulated at 85 and 95 K depending on the solstices and on the cooler capabilities during MSG's lifetime, whilst the VHRO is regulated at 20ºC.

The FPOBs support the detectors and perform the appropriate imaging after the in-field beam separation at the telescope focal-plane level. Thus, most of the SEVIRI spectral, geometric and radiometric performances rely directly on the FPOB's design and performance.

The Functional Control Unit *(FCU) provides the SEVIRI command, control and interfaces with the MSG spacecraft's on-board data handling subsystem. The FCU has three major sections:*

- *the core section including the functional mode and sequence management*
- *the mechanism section (electronics driving the mechanisms)*
- *the heater and telemetry section dedicated to thermal power management as well as telemetry conditioning and management;*

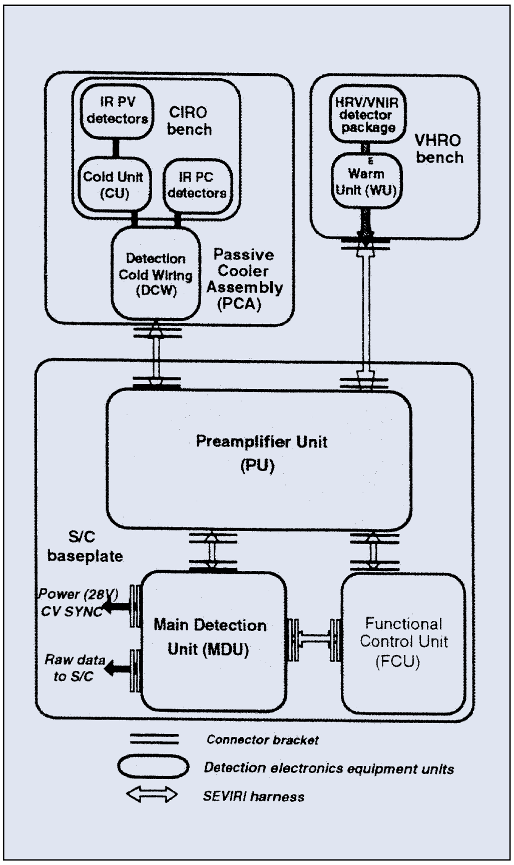
The thermal control of the instrument is also managed by the FCU.



The *Detection Electronics* (DE) consist of the detectors, the Pre-amplifier Unit (PU) and the Main Detection Unit (MDU).

The 12 SEVIRI channels have 8 Infra-Red (IR) detectors and 1 High Resolution detector in the Visible (HRV), 2 Visible and 1 Near IR (NIR). The IR detectors are all in mercury-cadmium telluride, whereas the visible detectors are in silicon and the NIR detector is in indium-gallium arsenide. The detectors are shaped and sized to satisfy both the radiometric and imaging performance requirements of the SEVIRI instrument.

CIRO equipped with cold channels and wiring



The signal acquired by each detector of the 42 chains is first amplified by the Pre-amplifier Unit (PU). The PU uses a general design with a modular approach common to all photovoltaic and photoconductive amplifiers. This subsystem consists of three assemblies:

- The Cold Unit (CU) containing the front-end parts of the IRPV chains. This trans-impedance amplifier common to all PV chains is implemented for impedance matching and for low-noise amplification.
- The Warm Unit (WU) is devoted to the front-end parts of HRV/VNIR pre-amplifiers.
- The PU main box contains the remaining electronics dedicated to shaping the analogue signal to the specified values, and includes telemetry/telecommand interfaces.

The *Main Detection Unit* (MDU) contains the signal-processing electronics, including signal conditioning, anti-aliasing filtering, sampling and conversion of analogue

The hardware elements of the detection chain signals into digital signals. The sampling delays are adjustable via telecommand, for all 42 chains of SEVIRI. The actual quantification is made inside the MDU by a 12-bit ADC, for an effective 10-bit resolution at the electronics output, after digital dynamic-offset and fine-gain corrections. Auxiliary data coming from the telemetries, which are needed for radiometry and image processing, are added to the detection data for image processing on the ground.

A star-sensing function is implemented in the MDU. It is activated whenever the star-sensing windows are telecommanded. No processing at SEVIRI level (filtering or dynamic offset correction) is applied to the star-sensing function. This raw data is sent to the spacecraft in the same way as any other auxiliary data.

SEVIRI Performance Verification

The on-board calibration process for the IR channels of the Imaging Radiometer consists of three steps:

- measuring the cold deep-space radiance for the determination of the instrument self emission

Major SEVIRI engineering-model radiometric and imaging performances: comparison of specifications and test results*

	Specifications	Test Results	Margins
Radiometric Noise	Specified per channel	Compliant at BOL test	Large margins
Sampling Distance	S/N 1 km for HRV, 3 km for the other channels.	All channels compliant under worst case conditions	N/A
Registration Errors	Specified between channels in both E/W and S/N directions	Compliant	Large margins
MTF and Image Quality	Specified per channel with templates	See examples	Sufficient margins
Radiance Response	Specified per channel	Compliant	Large margins
Spectral Response and Stability	Specified per channel	Compliant	As specified within the template
Scan Motion	Specified for S/N scanning / pointing	Stable and Compliant	Large margins
On-Board Calibration	Specified to 0.6K accuracy at EOL	Compliant	Large margins

*BOL = Beginning Of Life; EOL = End Of Life; MTF = Modulation Transfer Function (image-quality indicator); S/N and E/W = South/North (scan mirror line by line movement) and East/West (satellite revolution).

SEVIRI EM channel registration

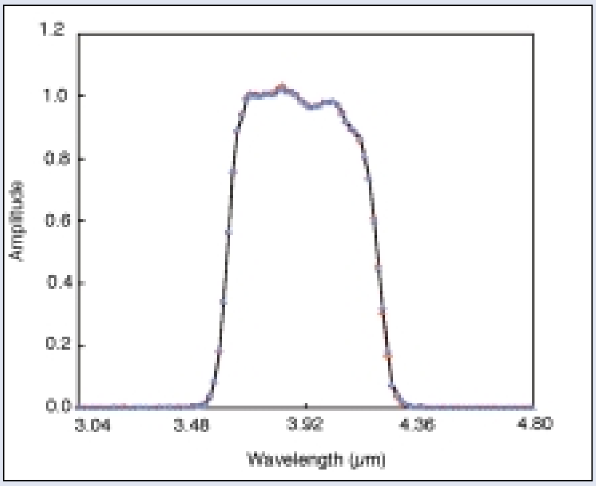
Units in Km SSP	*E/W on HRV/VNIR (static)*	*S/N on HRV/VNIR channels*	*E/W on IR channels (static)*	*S/N on IR channels*	*E/W on IR, HRV/VNIR (static)*	*S/N on IR HRV/VNIR*
TP1	*0.049*	*0.083*	-	-	-	-
TP2	*0.042*	*0.105*	-	-	-	-
TP3	*0.049*	*0.099*	*2.559*	*0.395*	*1.484*	*53.829*
TP4	*0.027*	*0.097*	*2.438*	*0.383*	*1.494*	*53.506*
TP5	*0.071*	*0.094*	*2.464*	*0.403*	*1.487*	*53.565*
TP6	*0.057*	*0.096*	*2.456*	*0.409*	*1.493*	-
TP7	*0.948*	*0.096*	-	-	-	-
TP8	*0.047*	*0.102*	-	-	-	-

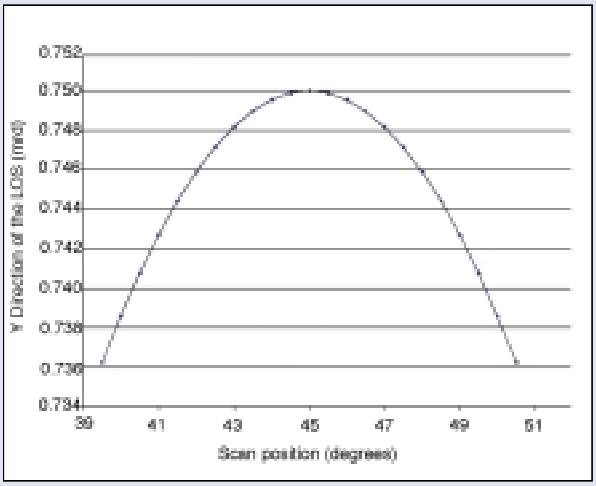
** Column 1 describes the Test Phases (TP); Columns 2 to 5 show the resulting registration error between Test Phases for both Visible and Infrared Channels. Column 6 and 7 describe registration between Visible and Infrared Channels. This shows a stable SEVIRI instrument when submitted to various thermal environments. Note: TP3 covers the SEVIRI Cold Operational (COP) phase at 85K, TP4 the SEVIRI Cold Operational phase (COP) at 95K, TP5 the SEVIRI Hot Operational (HOP) phase and TP6 the SEVIRI PCA Hot case.*

SEVIRI EM noise budget at Beginning of Life (BOL)

Channel (µm)	*HRV*	*VNIR 0.6*	*VNIR 0.8*	*NIR 1.6*	*IR 3.9*	*IR 6.2*	*IR 7.3*	*IR 8.7*	*IR 9.7*	*IR 10.8*	*IR 12.0*	*IR 13.4*
Specification (K)	*1.07*	*0.53*	*0.49*	*0.25*	*0.35*	*0.75*	*0.75*	*0.28*	*1.50*	*0.25*	*0.37*	*1.80*
Prediction (K)	*0.47*	*0.13*	*0.14*	*0.07*	*0.14*	*0.28*	*0.14*	*0.11*	*0.36*	*0.12*	*0.17*	*0.47*
Measured (K)	*0.43*	*0.16*	*0.14*	*0.07*	*0.11*	*0.19*	-	*0.07*	*0.21*	*0.07*	*0.11*	*0.23*

** For the end-of-life assessment, about 30% to 50% margin has to be considered, depending on channels*





Left: Example of Spectral Response of SEVIRI IR 3.9 Channel (EM)
Right: Scan Mirror Line of Sight (LOS) Evolution during Nominal Full Imaging (EM)

SEVIRI engineering-model integration at satellite level

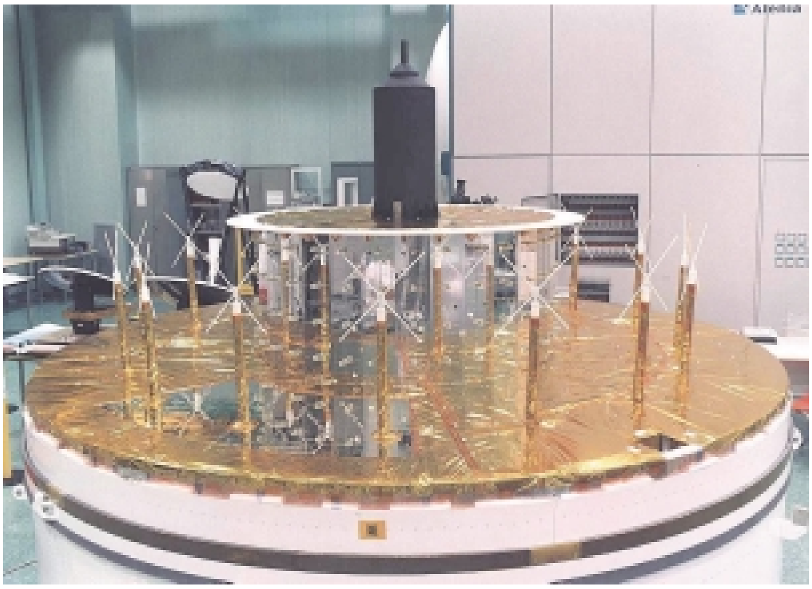
- *measuring the radiance coming from the on-board black body (at temperature T_0) resulting in an output (in counts) as measured by SEVIRI; the black-body true radiance is determined through the knowledge of the thermal and optical properties of the instrument*

- *measuring the on-board black body at temperature $T_0+\Delta T$ with $\Delta T \sim 20$ K; this last measurement is performed to help in correcting the impact of the elements that are not in the beam path of the black body, namely the scan mirror and the M1 mirror and its baffle.*

The VNIR channel calibration is based on a vicarious calibration consisting of measuring some known landmarks on Earth.

SEVIRI Development Status

The SEVIRI Engineering Model has successfully passed all instrument-level testing and has demonstrated that the design meets the specification. In the meantime, the SEVIRI EM has been integrated into the EM satellite, where environmental testing has started.
The SEVIRI Proto-Flight Model (PFM) has completed instrument-level testing with the same success and has been shipped to Alcatel (F) for integration into the satellite.



4.2 The Mission Communication Package (MCP)

MCP Antenna Subsystem

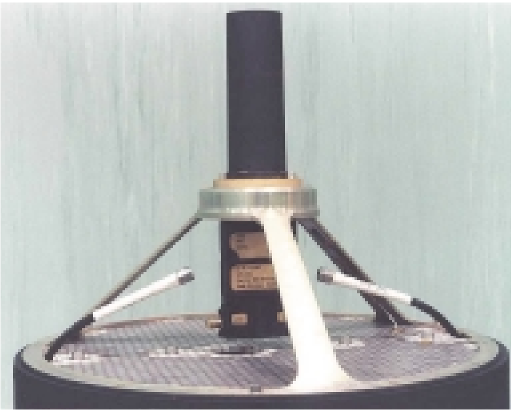
The MSG telecommunications system has a number of tasks, each of which requires a particular antenna:

- Reception of telecommands and transmission of housekeeping data. The TT&C S-band transponder is used for this task and is connected to a dedicated telemetry and telecommand antenna (TT&C antenna)
- Transmission of the measured radiometer (SEVIRI) data, coming from the data-handling subsystem, to the primary ground station. The electronically despun antenna (EDA) is used for this task in L-band.
- Reception of pre-processed images with associated data. A toroidal pattern antenna (TPA) operating in S-band is used for this task.
- Transmission to users, using the L-band EDA antenna for low-resolution and high-resolution data.
- Receiving data from Data Collection Platforms (DCPs). The electronically switched circular array antenna uses the UHF-EDA at 402 MHz.
- Transmission of the DCP data, using the L-band EDA antenna.
- Receiving emergency (Search & Rescue) messages using the UHF-EDA at 406 MHz.
- Transmission of Search & Rescue messages, using the L-band EDA antenna.

The Mission Communication Package (MCP) antenna (FM1) at Alenia Aerospazio (I), with the TT&C antenna on top, and the S- and L-band Toroidal Pattern Antenna (TPA) inside the black cylindrical radome. The L-band Electronically Despun Antenna (EDA) can be seen in the middle, and the UHF-EDA in front of it

The *TT&C antenna* operating in S-band, is a low-gain wide-coverage antenna whose design had been optimised for MSG taking into account the much larger spacecraft body compared to the previous Meteosat satellite series. The new design makes use of four spiral conductors printed on a cylinder and fed in quadrature as the radiating elements. In the base of this antenna, various hybrids have been integrated to provide the required phase shifts for the spirals and another to provide the hot-redundant connection for the two TT&C transponders (both receiver sections are permanently on).

The coverage of this antenna from the spinning satellite is from $\theta = 0°$ (satellite spin axis) to $\theta = 120°$ for all azimuth angles in right-hand circular polarisation.



The TT & C antenna

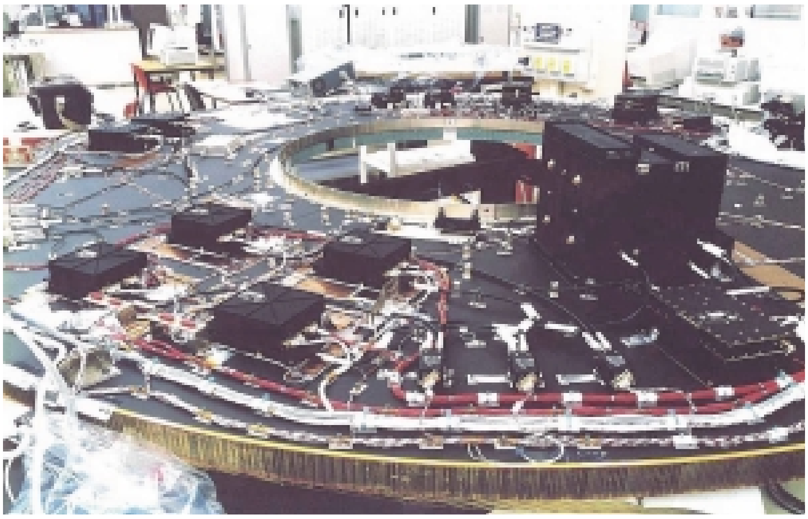
The Toroidal L and S-band antennas are narrow-band, reduced-height, slotted waveguide antennas, which provide toroidal patterns in the plane perpendicular to the spin axis. They are mounted side-by-side inside a black-painted radome. The low-gain L-band TPA functions as back up for the high-gain, L-band electronically despun antenna in transmit mode. The S-band TPA acts as a receive-only antenna for the pre-processed high- and low-resolution data uplinked from the primary ground station.

The L-band Electronically Despun Antenna (EDA) is used in transmit mode only to send the raw image data to the primary ground station and the processed data, received via the S-band, to the secondary users. As the satellite rotates at 100 rpm and the high-gain antenna beam needs to be aimed at the ground continuously, an electronic means of despinning this beam in the opposite direction to the satellite's rotation is implemented. This antenna is composed of 32 columns of 4 dipoles each, and is mounted in a cylindrical way close to the top of the satellite.

The transmit beam is built up from four or five active columns, which are fed by an array of: one 4-Way Power Divider (4WPD), 4 Variable Power Dividers (VPDs), and 8 Single-Pole Four-Way PIN diode switches (SP4T). The VPD allows the RF transmit signal to be split into two output signals of constant phase, but with seven programmable output-level ratios between the two outputs. The 8 outputs from the VPDs are fed via 8 electronic switches (SP4Ts) to the feed boards of the 32 antenna columns. By switching the right amount of power to the right column and being synchronised with the satellite spin rate, an antenna beam is created which appears to be stationary with respect to the ground. A high-gain (~ 12 dB) antenna beam is thus available, easing the ground-station requirements for the secondary user community.

The UHF-band EDA Antenna: To receive the meteorological data from the Data Collection Platforms (DCPs) operating in the UHF band and the newly implemented Search & Rescue mission on MSG, an electronically switched UHF array of 16 crossed dipoles was selected. These dipoles are positioned in front of the L-band EDA, which at a distance of 3/4 λ acts as a reflector for the UHF array. A simplified beam-forming network is employed, whereby the outputs of the dipoles are connected to the inputs of four 4-way electronic switches, which in turn are connected to the inputs of a 4-way power combiner. Of the 16 dipoles, four are used to form the beam whereby the next dipole is selected every 22.5° synchronised with the satellite's spin rate.

To control and supply all of the complex timed switching for the various active elements of the antenna subsystem, a dedicated equipment item known as the Common Antenna Control Electronics (CACE) is used. This equipment receives synchronisation signals from the data-handling subsystem and generates the correctly timed drive signals for the SP4Ts and VPDs in the antenna subsystem. Apart from the normal despun mode, this equipment also allows the antenna to be



The MCP subsystem for the FM1 satellite being integrated and tested at Alenia Aerospazio (I)

put into a fixed-beam mode, which permits the antenna beam pattern to be measured on the ground or in orbit.

MCP Transponder Subsystem

On board the satellite, the MCP Transponder Subsystem's tasks are the reception, amplification and transmission of the following channels:

- Raw Data channel: down-linking to the Primary Ground Station (PGS) of the SEVIRI (and GERB when applicable) raw data stream, plus auxiliary/ancillary information received from the Data Handling Subsystem.
- HRIT channel: high-data-rate dissemination to the user community (High-Rate User Stations, or HRUSs) of processed meteorological data and images received from the PGS.
- LRIT channel: low-data-rate dissemination to the user community (Low-Rate User Stations, or LRUSs) of processed meteorological data and images received from the PGS.
- DCP channel: relay of messages from the Data Collection Platforms to the PGS for further distribution.
- Search & Rescue channel: relay of distress signals from emergency beacons on the visible Earth's disc to dedicated ground stations (COSPAS/SARSAT network).

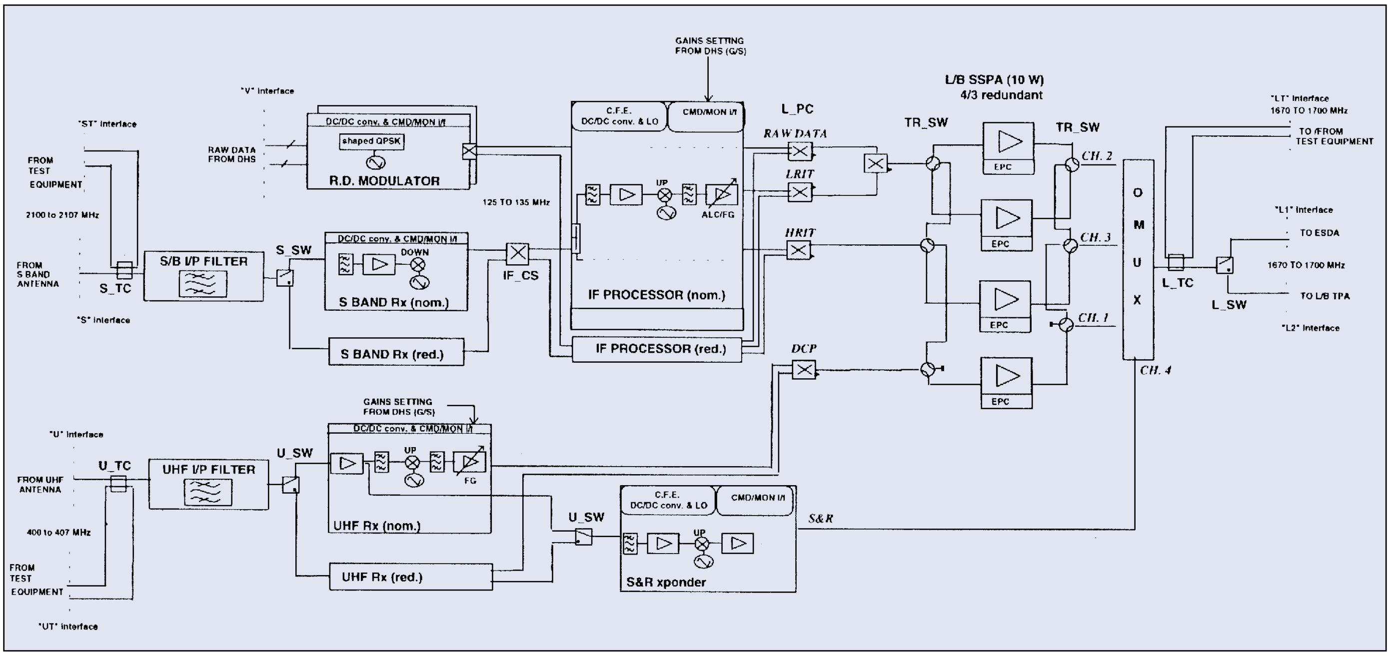
The raw data signal coming from the Data Handling Subsystem is fed into the Raw Data Modulator (internally redundant) equipment, which performs the QPSK modulation before entering the Intermediate Frequency Processor (IFP). The IFP also receives the HRIT and LRIT signals coming from the S-band antenna via the S-band filter and the S-band receiver (two in cold redundancy) which contain the necessary low-noise amplification and frequency down-conversion. The IFP equipment, which operates in cold redundancy, filters and up-converts the three signals separately and amplifies them to a selected output level or with a certain fixed received-signal (RD, HRIT and LRIT) gain set by ground command. The output signals of the IFP drive the Solid-State Power Amplifiers (SSPAs) directly to their chosen operating points.

The multi-carrier DCP channel, which can be composed of up to 460 individual carriers, enters the transponder together with the Search and Rescue signal via the UHF filter and feeds the two UHF receivers (configured in cold redundancy). They perform the low-noise amplification and frequency up-conversion to the corresponding down-link frequency in L-band. The DCP signal is then forwarded to the SSPA matrix for further amplification.

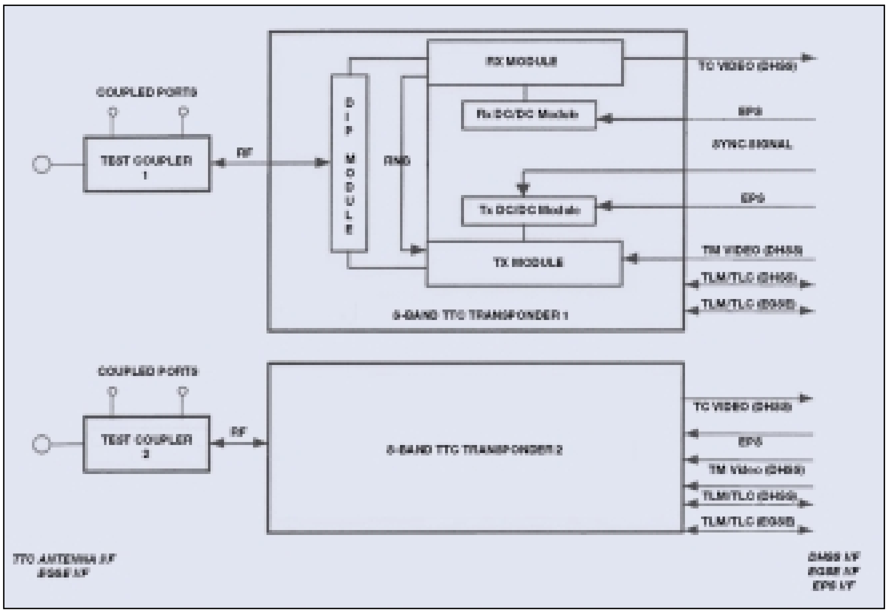
The SSPA matrix is composed of four SSPAs (output power about 10 W per amplifier) in a 4/3 redundancy scheme. One SSPA is allocated to the HRIT channel, one is used by the RD and LRIT channels simultaneously, one is dedicated to the DCP channel, and

MCP communication-link characteristics and associated frequencies

	Raw Data	**HRIT**	**LRIT**	**DCP**	**S&R**
Up-link frequency (MHz)	*Not applicable*	*2015.65*	*2101.5*	*402.06*	*406.05*
Down-link frequency (MHz)	*1686.83*	*1695.15*	*1691.0*	*1675.281*	*1544.5*
Useful signal bandwidth (MHz)	*5.4*	*1.96*	*0.66*	*0.75*	*0.06*
Bit rate	*7.5 Mbps*	*2.3 Mbps*	*290 kbps*	*100 bps*	*400 bps*
Modulation	*QPSK*	*QPSK*	*BPSK*	*PM*	*PM*



The MCP block diagram



TT&C transponder block diagram

An MSG TT&C transponder

The main performance parameters of the TTC transponders

Receiver		
• Up-link frequency	2068.6521 MHz	MSG-1
	2067.7321 MHz	MSG-2
	2069.5729 MHz	MSG-3
• Carrier acquisition range	–128 dBm to –50 dBm	
• Telecommand operation range	–110 dBm to –50 dBm	
• Telecommand modulation scheme	PM of subcarrier on up-link carrier	
• Telecommand subcarrier	8 kHz	
• Bit rate	1000 bps	
• Noise figure	3 dB	
Transmitter		
• Down-link frequency (two modes of operation, coherent or non-coherent w.r.t. the up-link frequency)	2246.5 MHz	MSG-1
	2245.5 MHz	MSG-2
	2247.5 MHz	MSG-3
• Output power	3 W	
• Telemetry modulation scheme	PM of subcarrier on down-link carrier	
• Telemetry subcarrier	65.536 kHz	
• Bit rate	8192 bps	
Ranging Channel		
• RNG tone capability	100 – 300 kHz	
• RNG channel video bandwidth	650 kHz	
Power Consumption		
• 2 Rx ON, 2 Tx OFF	12.4 W	
• 2 Rx ON, 1 Tx ON	32.4 W	
Subsystem Mass	7900 g	

the remaining redundant SSPA can be used by any of the other channels in case of failure.

The Search and Rescue signal is pre-amplified by the UHF receiver and then further filtered, frequency up-converted and power-amplified in the S&R Transponder. The objective is to provide support to the international COSPAS-Sarsat humanitarian-oriented Search and Rescue Organisation.

After power amplification, all of the channels (RD+LRIT, HRIT, DCP and S&R) are filtered and combined in the output multiplexer (OMUX), before being fed to the Antenna Subsystem.

TT&C Subsystem

The Telemetry, Tracking and Command (TTC) Subsystem consists of two S-band transponders and performs the following functions:

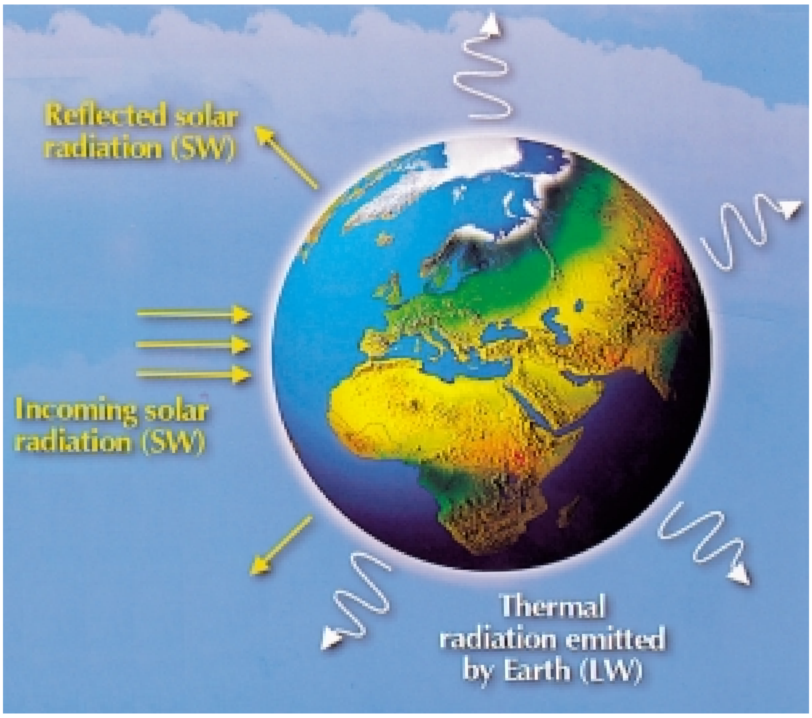
- *Reception and demodulation of the up-link command and ranging subcarriers of the S-band signal transmitted by the ground control station.*
- *Delivery of the telecommand video signal to the on-board Data Handling Subsystem.*
- *Modulation of the down-link carrier by the received and demodulated ranging signal and the telemetry signals received from the on-board Data Handling Subsystem.*
- *Power amplification and delivery of the S-band down-link carrier to the Antenna Subsystem.*
- *The down-link carrier can be generated coherently or non-coherently with respect to the up-link carrier received from the ground station.*

The TTC Subsystem is composed of two identical transponders, each consisting of several modules packaged in a single unit. The receiver and transmitter of each transponder are electrically independent, except for the necessary interconnections to perform the ranging operations. The receivers of the transponders are always 'on' at any time during the satellite's lifetime, while the transmitters are operated in cold redundancy.

4.3 The Geostationary Earth Radiation Budget Experiment (GERB)

MSG satellite resources allow for the accommodation of an Announcement of Opportunity instrument. The ensuing flight opportunity has been taken up by a European consortium (led by the UK Natural Environmental Research Council acting through the Rutherford Appleton Laboratory), which has developed and manufactured a new optical instrument, the GERB. With a three-mirror telescope and all supporting functions, GERB will measure the components of the Earth's Radiation Budget (ERB), which is the balance between the incoming radiation from the Sun and the outgoing reflected and scattered solar radiation plus the thermal-infrared emission to space.

Observations from space have a central role in understanding the Earth's Radiation Budget since they are quasi-global. GERB will measure energies leaving the Earth over the geographical region seen by MSG, thereby exploiting the excellent temporal sampling possible from geostationary orbit. These observations are the first of their kind and will make an important contribution to the enhancement of the climate simulation models (diurnal cycle), with strong practical relevance to global climate change, food production and natural-disaster prediction.



Components of the Earth's Radiation Budget

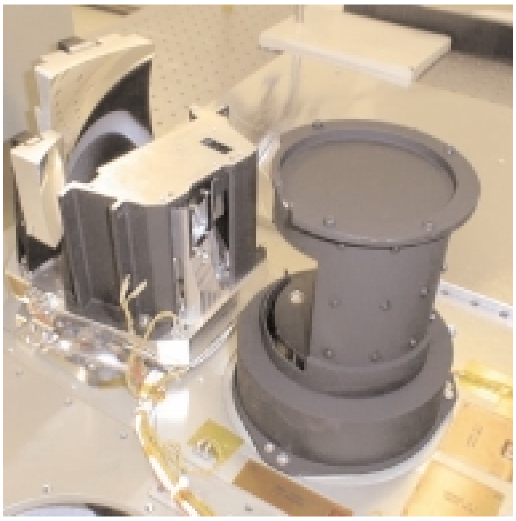
GERB consists of two units:
The *Instrument Optical Unit* (IOU) which is very compact (56 x 35 x 33 cm^3), and includes essentially:

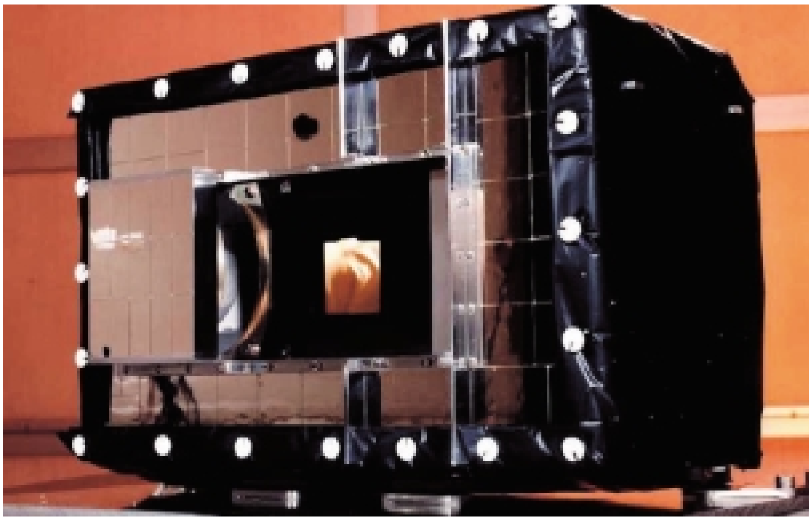
- the telescope (three-mirror anastigmatic system)
- the de-scanning mirror for staring at appropriate targets
- the detector (a linear blackened thermoelectric array of 256 elements) with its signal-amplification and processing circuitry (including ASICs and a DSP)
- the quartz filter mechanism used to switch the measurement into alternate wavebands (total and shortwave)
- the calibration devices (black body and solar diffuser)
- the passive thermal design.

The *Instrument Electronic Unit* (22 x 27 x 25 cm^3), which on one side conditions power and signals from MSG to further distribute them to the optical unit, and on the other collects and formats data generated by the IOU before transmitting it

The Instrument Optical Unit (bottom left)

The GERB flight model (below)





Performance characteristics of the GERB instrument

Wavebands	Total Shortwave (SW) Longwave (LW)	0.32 – 30µm 0.32 – 4µm 4 – 30µm
Radiometry	SW	LW
Absolute Accuracy	<1%	<0.5%
Signal/Noise	1250	400
Dynamic Range	0 – 380 $W.m^{-2}ster^{-1}$	0 - 90 $W.m^{-2}ster^{-1}$
Spatial Sampling	45 x 40 km (NS x EW) at nadir	
Temporal Sampling	15 min SW and LW fluxes	
Cycle Time	Full Earth disc, both channels in 5 mn	
Co-Registration	Spatial : 3 km w.r.t. SEVIRI at satellite subpoint Temporal : within 15 mn of SEVIRI at each pixel	
Instrument Mass	25 kg	
Power	35 W	

to MSG (owing to its microprocessor, GERB has a high level of autonomy).

The radiometric performance is obtained after adequate calibration:
- On the ground, the instrument has been subjected to an extensive characterisation programme under vacuum.
- On board, a solar-illuminated integrating sphere and a black-body device with known characteristics are implemented in the optical unit.

The scan mirror, which rotates counter to the satellite's spin direction, allows the telescope to point successively at the black body, the Earth, and the integrating sphere within each MSG period. Therefore – considering deep-space views also – a highly accurate correction of each GERB Earth pixel measurement can be performed on the ground.

4.4 The Search and Rescue (S&R) Mission

In addition to serving the primary meteorological missions, MSG is also equipped with a transponder for the Geostationary Search and Rescue service of the COSPAS-Sarsat organisation.

The basic S&R concept involves:
- Distress radio beacons (ELTs for aviation use, EPIRBs for maritime use, and PLBs for personal use), which transmit signals during distress situations.
- Instruments on board satellites in geostationary and low Earth orbits, which detect or relay the signals transmitted by distress radio beacons.
- Ground receiving stations, referred to as Local User Terminals, which receive and process the satellite down-link signal to generate distress alerts.
- Mission Control Centres, which receive alerts and forward them to Rescue Coordination Centres or Search and Rescue Points of Contact.

The geostationary S&R system component consists of 406 MHz repeaters carried on board various geostationary satellites including MSG, and the associated ground facilities which process the satellite signal.

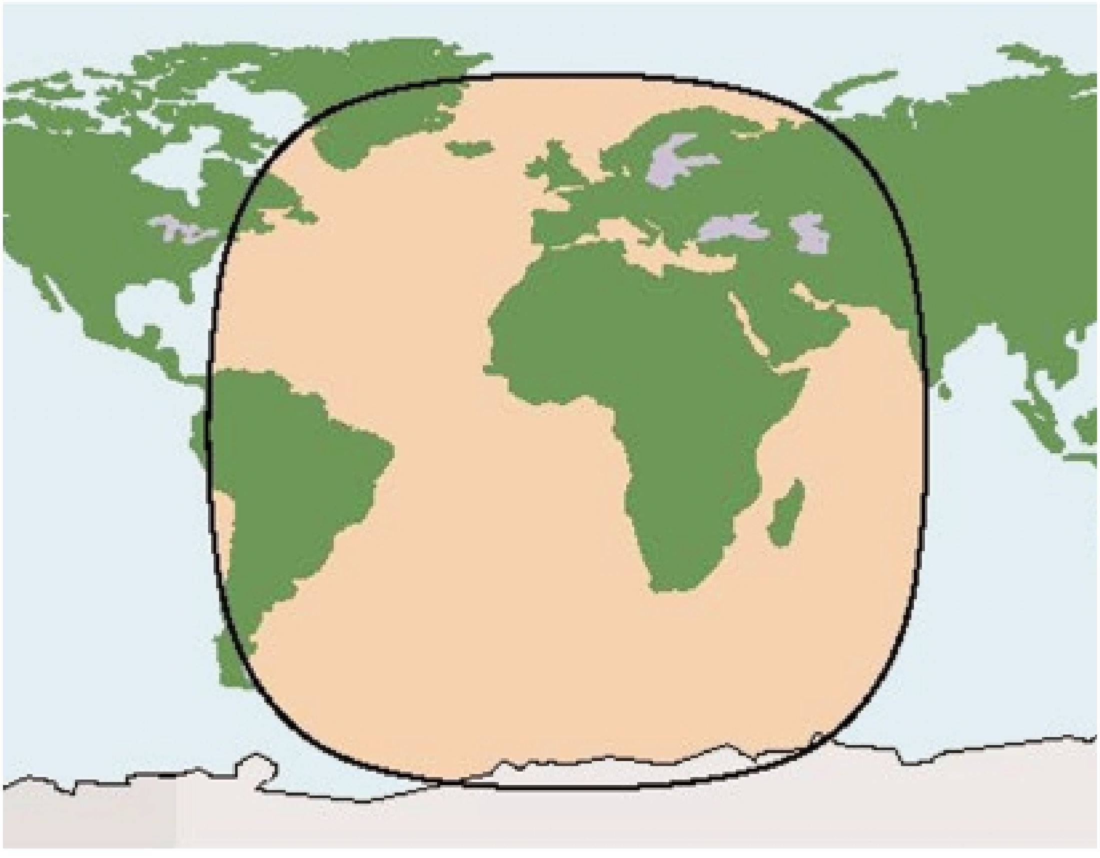
The MSG S&R frequency plan is based on the 406.05 MHz up-link from the emergency beacons to the satellite, and a down-link to the ground station in the S&R frequency band centred at 1544.5MHz. The received beacon signals are directly translated to the L-band down-link, with main filtering of the band performed in the

S&R transponder block using a SAW filter operating in the up-link frequency band.

The COSPAS-Sarsat S&R frequencies are not very different from those of the Meteosat data links, and with just a little extra development effort the S&R requirements have been accommodated on MSG. Nonetheless, since S&R is not part of the meteorological objectives of the MSG programme, it was agreed to implement this payload subject to some constraints, namely:

- *no interference with the meteorological missions*
- *switch-off in the event of a power shortage*
- *minimum mass and cost.*

These constraints have been fulfilled by making the S&R transponder non-redundant. Both the UHF receive antenna and the L-band transmit antenna provide coverage of the full Earth as seen from longitude 0.0°. The geographical area covered complements the existing Cospas-Sarsat geostationary coverage very well.



The geographical area covered by MSG for Search and Rescue

5 SATELLITE SUBSYSTEMS

5.1 The Structure

The MSG satellite is spin-stabilised. The body is a cylindrical-shaped drum, 3.218 m in diameter. The total height of the satellite, including the antenna assembly, is 3.742 m. The outer skin is dedicated to the fixed solar array. The internal configuration is built around the SEVIRI instrument, including a double-stage passive cooler accommodated on the lower part of the spacecraft.

The MSG satellite structure consists of two main parts: the Primary Structure (191.6 kg) providing support for payload and most subsystems, and the Secondary Structure (27.5 kg) providing support for UPS (Unified Propulsion System) and EPS (Electronic Power Subsystem) equipment. The SEVIRI baffle (15.5 kg) is a light structure that protects the instrument's field of view from spurious radiation or pollution. On the ground and during launch, a cover protects the cooler from pollution.

Primary Structure

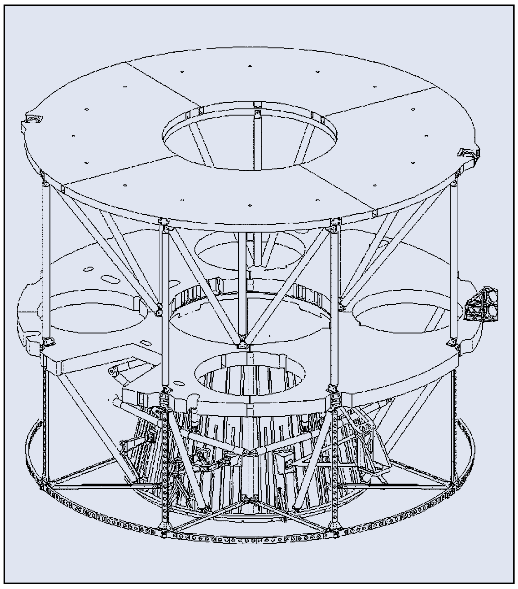
The main elements of the Primary Structure are:

- *the Service Module Structure providing support for payloads and for the main part of support subsystems equipment*
- *the Antenna Platform to accommodate the MCP subsystem equipment.*

The Service Module Structure consists of :

- *The Conical Central Tube, based on a stringer-stiffened shell design and equipped with three rigid interface rings for attachment with:*
  - *launcher adapter and lower struts at the lower ring*
  - *main platform at the upper interface ring*
  - *propellant-tank supports at the upper and intermediate rings.*

  The Central Tube provides fixation for part of the propulsion subsystems pipe-work, and additional interfaces for the fixation of the thermal lower closing support and umbilical connectors, as well as support for the launcher-separation actuators.
- *The Main Platform, fixed on the Central Tube, manufactured in sandwich form with aluminium skins, provides interfaces for the SEVIRI instrument and accommodates part of the propulsion subsystem units on its lower face.*
- *A set of lower struts fixed on the Central Tube support the main platform edges. Two additional struts support the main platform, below the two heavy batteries.*
- *A set of upper struts connect the Service Module to the Antenna Platform.*



MSG Structure: Antenna Platform, Main Platform, SEVIRI Sunshade, Lower Support Closing Ring and Upper & Lower Struts

The *Antenna Platform* is manufactured in sandwich form with aluminium skins, providing interfaces for the accommodation of both MCP transponders on its lower face, and Antenna Assembly on its upper face.

Secondary Structure and Baffle

The function here is to provide intermediate supports for Unified Propulsion System (UPS) and Electrical Power System (EPS) equipment:

UPS Secondary Structure

- Two LAM supports, each constituted by three pairs of struts providing the LAM for iso-static and rigid mounting, alignment accuracy and stability
- Two helium-tank supports, each constituted by one tripod and one bipod, providing the helium tanks with iso-static and rigid mounting.
- Two E/W (east/west) and two N/S (north/south) thruster supports, constituted by structural brackets for rigid mounting, with vertical adjustment capabilities (E/W thrusters).
- The E/W and the N/S thruster supports are fixed, respectively, to the Main Platform and to the Antenna Platform.

EPS Secondary Structure

- SAP (Solar Array Panel) supports, constituted for each of the eight SA panels by a set of 6 brackets providing the SA panels with rigid and iso-static mounting, to allow their thermo-elastic dilation. Of the six brackets used for each SAP, two are fixed to the Antenna Platform and two to the Lower Closing Support.
- A Lower Closing Support (based on a light, profiled structure) provides fixation to the Thermal Lower Closing Support, which sustains the LAM Thermal Closing, the valves, and also the lower SAP supports.

SEVIRI Baffle

The SEVIRI Baffle is a light structure, protecting the instrument's field of view from spurious radiation or pollution, and is constituted by a main body with three structural frames. The main body's form fits the shape of the SEVIRI optical beam, and consists of:

- A metallic envelope, which is an assembly of two curved thin shells and two lateral iso-grid plates for rigidity purposes.
- Two optical vanes fixed at the end of the metallic envelope.
- A thermal-control interface flange.

The thermo-optical and optical performances are ensured by the optical vanes and black-paint coating inside the main body. The three frames stiffen the SEVIRI entry baffle, and ensure its interface with the main platform cover and mechanism.

Materials

Primary Structure Materials

- Aluminium alloy for most of the structural parts and machined parts (rings, struts brackets) or sheets for the Central Tube skins or platform skins.
- Carbon-Fibre Reinforced Plastic (CFRP) for struts of propellant tank supports.
- Titanium for the most loaded brackets of the propellant-tank support struts.
- Other materials for structural part assembly (titanium bolts for strut fittings) or bonding (adhesive).

Secondary Structure Materials
- *Aluminium alloy for most of the structural parts.*
- *Other materials for structural part assembly (titanium bolts for strut fittings) or bonding (adhesive).*

5.2 The Unified Propulsion System (UPS)

The first-generation Meteosat was equipped with two independent propulsion systems. A solid-propellant apogee boost motor, MAGE-1, and a small hydrazine propulsion system served for orbit, attitude, spin and nutation control. The MSG UPS combines the two propulsive tasks in one common tankage and feed system, and it will be a world first for a UPS to operate at under 100 rpm. The incorporation of a Propellant Gauging Sensor Unit (GSU) is an innovative element, allowing the user to have an accurate knowledge of the propellant remaining during the last three years of the mission.

The significantly larger mass of MSG, weighing in at about 2000 kg compared to the 720 kg of the first-generation satellite, has led to the implementation of a pressure-regulated bi-propellant propulsion system operating with Mono-Methyl Hydrazine (MMH) as the fuel and nitrogen tetroxide (MON-1) as the oxidiser. This not only provides the higher total impulse required for the MSG mission, but also leads to an improvement in the specific impulse: a 7 % increase comparing the LAM with the previous solid ABM, and a 15% increase when comparing the bi-propellant Reaction Control Thrusters (RCTs) with the hydrazine monopropellant thrusters used previously.

The main requirements for the UPS are to inject the satellite into geostationary orbit after its release from the Ariane launcher. This will consume about 83% of the total loaded propellant of 976 kg contained in four spherical tanks of 750 mm diameter. Besides the spin-rate control and the attitude manoeuvres, most of the propellant will be consumed by inclination control (11% of total propellant mass) and east/west manoeuvres (4%) throughout the seven years of nominal operation.

The UPS is comprised of the following key equipment:

- *two 400 N LAMs*
- *six 10 N RCTs*
- *eleven fill and drain valves*
- *four propellant tanks*
- *two latch valves*
- *two pressurant tanks*
- *three pressure transducers*
- *four gauging sensors.*

The design of the UPS, the choice of equipment, the manufacturing tools and procedures are based on the experience acquired during the Spacebus projects. Nevertheless, a significant analytical design, test and assembly preparation effort was required, to adapt the well-known integration approach to the totally different MSG configuration.

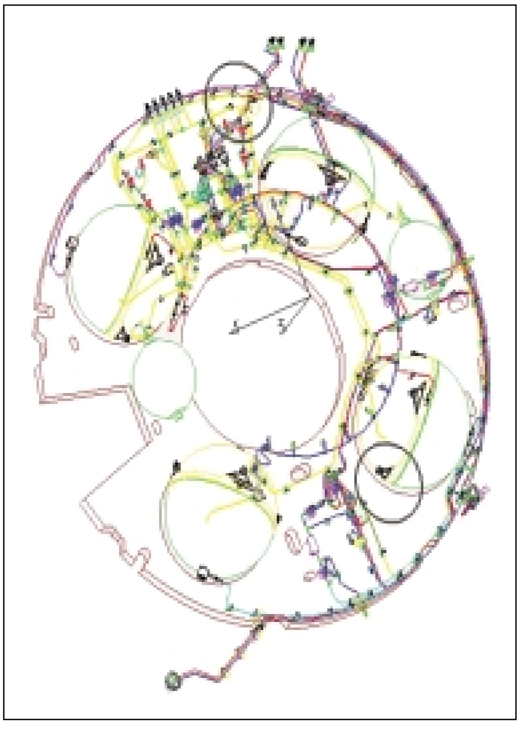
Most of the equipment is of European origin, with only the latching valves, the RCT flow-control valves and the propellant filter cartridges being procured from the USA. The UPS has a mass of 94 kg and is operated by the Attitude and Orbit Control

Electronics (AOCE). A specially built UPS unit tester allows self-standing checkout and operation of the UPS at equipment and satellite level via a skin connector.

Subsystem Design

The main design driver for the UPS is the spin environment and the payload cooler accommodation in the central cone of the Primary Structure. This configuration necessitated the placement of two LAMs at a radius of 1200 mm from the spin axis.

It was decided to accommodate the UPS on the lower face of the main platform, which was not occupied by any other equipment. The three main subassemblies, the Pressurant Control Panel (PCP) and the two Propellant Isolation Assemblies (PIAs) for oxidiser and fuel are located between the propellant-tank cutouts. The four propellant tanks, the two pressurant tanks and the two LAMs are mounted via struts and brackets to the central cone. The fact that the axial thrusters (N/S thrusters) are located on the antenna platform required a staggered integration sequence, which led to the provision of screw joints on pipes leading from the main platform to the antenna platform. The position of the radial thrusters (E/W thrusters) has been chosen such that the diagonal use of one upper and one lower thruster will always have the satellite centre of gravity between them throughout the mission.

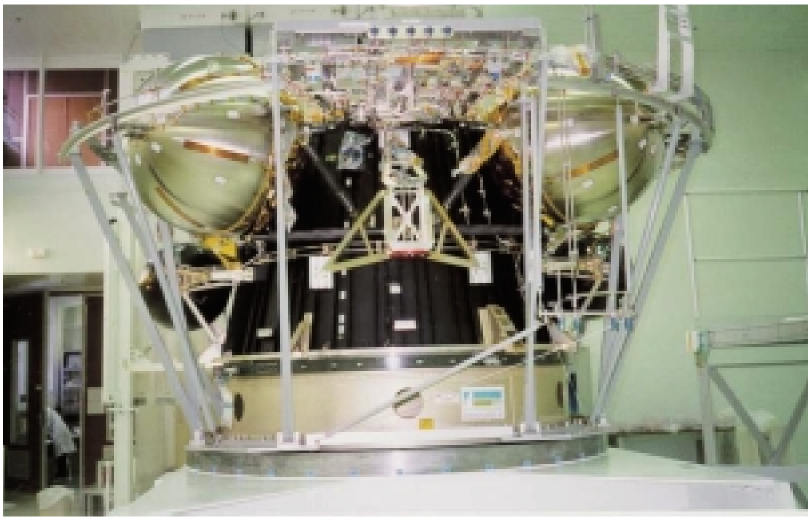


The UPS layout on the underside of the Main Platform

The routing of the 90 m of quarter-inch titanium tubes needed careful consideration regarding the launch and spin environment, to avoid tanks being filled-up or depleted unsymmetrically or propellant being trapped in pressurant lines during initial spin-up.

Two carbon-fibre-wrapped helium tanks (max. operating pressure 275 bar, volume 35 l) supply – via pyrotechnic valves, a pressure regulator and check valves – the four propellant tanks (max. operating pressure 22 bar, volume 219 l). The propellant tanks supply the six RCTs arranged in two redundant branches via two latching valves and the two LAMs via four pyro valves. Minimum fracture safety factors were used to optimise tank mass.

For fill and drain purposes, the propellant tank valves are located on the Lower Closing Support structure, thereby allowing for optimum draining.



The first UPS flight model (FM1) on its transport and integration jig

Due to the non-availability of a European two-stage regulator, it was decided to operate the RCTs for the initial spin-up and attitude manoeuvres in a pre-blow-down mode from the propellant tanks (12 – 8 bar), prior to pressurisation to 18.5 bar for the apogee manoeuvres. This will avoid any leakage-related critical pressure increases. After station acquisition, the LAMs and the pressurisation part will be isolated by firing the normally open (NO) pyro valves.

In order to allow maximum propellant utilisation, a high gauging-accuracy requirement was specified, leading to the design and development of a very precise capacitive propellant Gauging Sensor Unit (GSU), which is built into the propellant tanks. The qualification testing has shown that an accuracy of ± 0.05% of total tank volume can be achieved for the last three years of mission. Such a performance has never previously been achieved on a satellite propulsion system and is 30 times better than with existing techniques. It is important in so far as it allows accurate planning for the final de-orbiting manoeuvre.

5.3 The Attitude and Orbit Control System (AOCS)

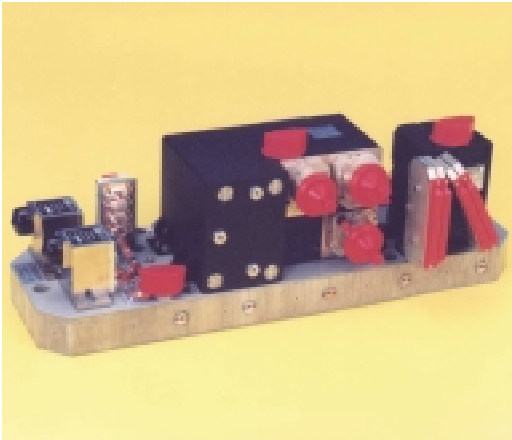
Like the first-generation Meteosats, MSG is equipped with a similarly designed subsystem whereby the attitude, nutation, spin rate and reference pulse are generated by specific Sun, Earth and acceleration sensors. Many of the off-the-shelf equipment items have required changes and additional performance testing. The main processing unit of the Attitude and Orbit Control Electronics (AOCE) and the Passive Nutation Damper (PND) are MSG-specific developments.

The changes introduced within the AOCS include:
- *synchronisation pulse generation in eclipse*
- *stable satellite, inertia ratio > 1*
- *multi-burn apogee manoeuvres*
- *active nutation damping using a micro-controller*
- *interface with data-handling software*
- *Passive Nutation Damper tuned for geostationary orbit (GEO).*

The first change means that the AOCS has to provide for a satellite synchronisation pulse in eclipse, while the second means that the Active Nutation Damping (AND) in Geostationary Transfer Orbit (GTO) is primarily required in case a liquid apogee boost motor fails. This is less critical than on the first-generation spacecraft, where the non-stable configuration (solid apogee boost motor and satellite) needed continuous surveillance and active nutation control until separation of the boost motor. It was decided to limit the utilisation of the

Left: The Attitude and Orbit Control Electronics (AOCE) unit

Right: The Attitude Sensor Assembly (ASA) unit: left to right, 2 ACUs, connector bracket and ASA alignment mirror, ESU (3 telescopes), and SSU (meridian and skew slit)



AND to GTO and to fine-tune the PNDs for the GEO inertia ratios, to achieve optimum performance.

The AOCS configuration with the AOCE and the Attitude Sensor Assembly (ASA) consists of the following equipment:

1 x	*AOCE, internally redundant*
1 x	*Sun Sensor Unit (SSU), internally redundant*
1 x	*Earth Sensor Unit (ESU), 3 channels*
2 x	*Accelerometer Units (ACUs)*
1 x	*Attitude Sensor Bracket (ASB), equipped with connector bracket, harness, alignment mirror and bonding straps*
2 x	*Passive Nutation Dampers (PNDs).*

Two sets of System Checkout Equipment (SCOE), derived from the subsystem electrical ground-support equipment, were provided for satellite and launch-activity support. Except for the AOCE and PND, the other equipment had previously been used on scientific and telecommunication satellites. The ACU was used on the first-generation Meteosats.

The total mass of the AOCS is 16 kg and its power consumption (mode-dependent) varies between 8 and 14.5 W, with a maximum peak during UPS Liquid Apogee Motor commanding of 70 W for 100 ms.

Subsystem Design

The major tasks to be fulfilled by the AOCS are:

- *Attitude Measurement*
  - *Sun aspect angle*
  - *Earth aspect angle*
  - *Nutation angle and frequency (GTO).*
- *Satellite Synchronisation Pulse Generation*
  - *SSP 1, Sun Synchronisation Pulse*
  - *SSP 2, Earth Synchronisation Pulse*
  - *Spin rate.*

– *Nutation Damping*
  • *Active nutation damping, axial RCTs in closed loop (GTO)*
  • *Passive nutation damping, PNDs (GEO).*

– *Operational interface with the UPS*
  • *Monitoring of UPS sensors*
  • *RCT, LAM and Latching Valve command generation and control*
  • *Monitoring of command duration and number of pulses generated.*

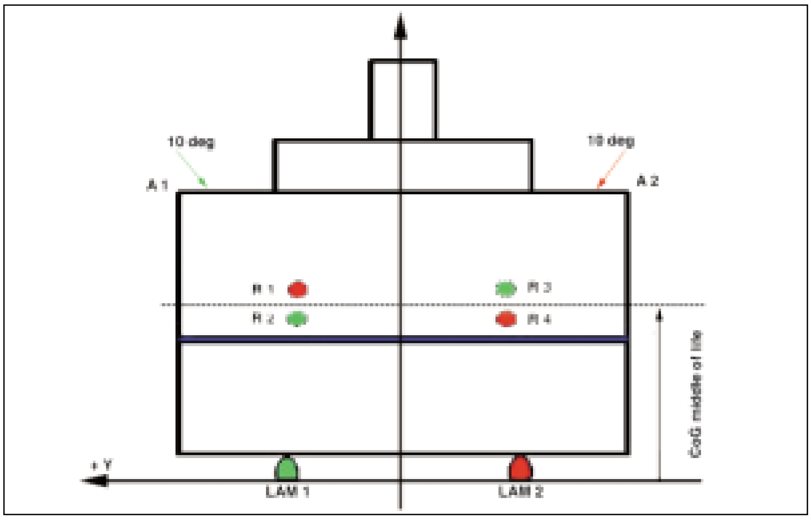
Besides servicing these main tasks, the AOCS interfaces with the Data Handling and the Electrical Power Systems. Integrated in one box, AOCE-B is cold-redundant to AOCE-A. Significant cross-strapping is provided between all sensors and actuators within the AOCE. The temperature monitoring of the RCTs and LAMs and the coils of the latching valves have their own redundancies.

For fast failure identification, it was decided to equip the combustion chambers of RCTs and LAMs with thermocouples. As a thermocouple always needs the reference temperature at its junction to the normal harness, the thermocouple wires have been routed to the AOCE, where this transition is performed within the connectors. Thermistors installed inside the AOCE close to these connectors measure the required reference temperature. The thermocouple output is then transformed into a standard analogue output. The AOCE also provides monitoring of secondary voltages, current and converter temperatures for housekeeping purposes.

As the spinning of the MSG satellite provides a self-stabilised attitude, it was decided that most of the manoeuvres (except AND) should be open-loop and ground-controlled, with two ground stations available during GTO. This minimises the on-board monitoring and reconfiguration effort. In order to further protect the satellite against propulsion-induced effects (leakage and spurious firing), the latching valves will be closed after manoeuvres. Action blocks in the monitoring and recovery function (Data Handling Subsystem software) are therefore limited to reacting to spin-rate anomalies, synchronisation loss and invalid sensor pulses.

The UPS provides for two redundant branches, which are cross-strapped to both AOCEs. Three RCTs can provide all necessary control torques. For east/west manoeuvres, the diagonal radial thrusters are used (e.g. R1 and R3) in pulse mode.

The AOCS/UPS actuator arrangement: green indicates the nominal thruster branch, and red the redundant branch



Main AOCS requirements and performance

Function	Requirement	Result	Remark
		Synchronisation Pulse	
Sun, SSPI	< 0.05 deg	< 0.046 deg	outside the central region of the Sun Aspect Angle
	< 200 ns, jitter	< 136 ns	under common mode noise and AOCE jitter
Eclipse, SSP2	< 0.18 deg	< 0.175	with 1 rpm spin rate variation into eclipse, excluding Earth radiance error
		Active and Passive Nutation Damping (AND & PND)	
AND in GTO	5 to 0.15 deg in < 10 min	$5.2 < \tau < 10$ min	at 55 rpm and inertia radio $1.2 < \lambda < 1.35$
PND in GEO	0.01 deg to 2 arcs in < 5 min	$\tau < 4$ min	50% margin for $\lambda = 1.1$ at 40˚C and $\lambda = 1.25$ at 5˚C
		Spin-Rate Measurement	
GTO, 5-100 rpm	< 1 rpm, 5-30 rpm	< 0.001 rpm	no nutation, no eclipse
	< 0.1 rpm, 30-100 rpm	< 0.002 rpm	no nutation, no eclipse
GEO, 99-101 rpm	< 0.01 rpm	< 0.0002 rpm	no nutation, no eclipse
	< 0.1 rpm, 30-100 rpm	< 0.05 rpm	no nutation, no eclipse
		Spin-Axis-Orientation Measurement	
GTO	< 0.03 deg	< 0.273 deg	all ESUs, using on ground ESU calibration mode, no nutation, no wobble
GEO	< 0.1 deg	< 0.05 deg	no nutation, incl. wobble error
		Nutation Determination	
GTO	< 0.01 deg resolution	0.001-0.0023 deg	for 0.01-5 deg at 55 rpm
GEO	< 0.003 deg	< 0.0023 deg	for 0.003-0.12 deg at 100 rpm

5.4 The Electrical Power System (EPS)

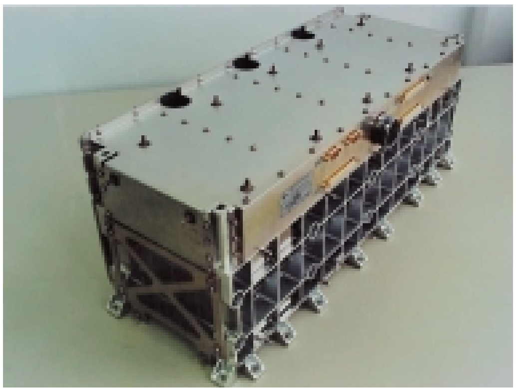
The electrical power system is formed from five separate elements: a solar-array photovoltaic energy source; two nickel-cadmium storage batteries; a Power Control Unit (PCU); a Power Distribution Unit (PDU); and a Pyrotechnic Release Unit (PRU). In sunlight, the power is generated by solar cells. Peak power loads, which exceed the solar array's capabilities, are supplied from the batteries through battery-discharge regulators. During eclipse operations, all power is supplied by the batteries. At the end of each eclipse period, the batteries are recharged from the solar array. The solar array and batteries are designed and sized for a 10-year mission lifetime, including reliability and failure-tolerance requirements.

Subsystem Design

Solar Array

The solar array is the satellite's primary source of power. It consists of eight curved solar-array panels mounted around the body of the spacecraft. Seven panels are identical and interchangeable standard solar panels, and one is a special panel with a large cut-out window serving as the SEVIRI instrument-viewing aperture. A total of 7854 high-efficiency silicon solar cells are attached to the eight panels. Each 60 mm x 32 mm cell is covered by a cerium-doped cover glass, which has an indium-tin oxide coating to make it conductive and thereby prevent surface charging.

Sixty-six cells are interconnected in series to obtain a string output of 30 V via a single series blocking diode. There are one



One of MSG's two nickel-cadmium batteries

hundred and nineteen solar-cell strings around the circumference of the spacecraft and these are connected in parallel. About one third of these solar cells view the Sun at any moment during the satellite's spin cycle. The solar array will provides a power output of more than 600 W for up to 10 years in geostationary orbit. The complete solar array weighs 76 kg.

Batteries
Secondary power, for peak loads and eclipse operations, is provided from two 29 Ah nickel-cadmium batteries. Each battery has 16 series-connected cells, provides an average of 20 V, and has an energy capacity of 580 Wh. Passive thermal control via a radiator plate for cooling plus active thermistor-controlled heaters will maintain the batteries within their operational limits throughout the mission.

As the batteries are mounted close to the spacecraft's outer circumference, they experience a force of 18 g due to its 100-rpm spin rate. This force was found to have a detrimental effect on the capacity of the battery cells. Extensive investigations and tests established that capacity loss is minimised if the smallest dimension of the cell is orientated in the direction of the acceleration force.

Each battery weighs 27.5 kg, giving a total battery mass of 55 kg.

The Power Control Unit (PCU)
The PCU provides centralised management of the 27 V power bus. It converts the energy from the solar array and the batteries into a regulated bus voltage. The unit contains a six-section shunt solar-array regulator, four battery-charge regulators and six battery-discharge regulators. Included in this equipment are the spacecraft power-bus and battery-cell management and protection functions, telemetry and telecommand housekeeping functions, and ground-support umbilical interfaces.

The PCU has been designed with a high level of autonomy, redundancy and modularity to protect against failures or any failure-propagation modes. Reliability and failure tolerance is necessary due to the intrinsically singular nature of the bus voltage supply and the limited energy resources available from the solar array and batteries. The PCU weighs 23.5 kg.

The Power Distribution Unit (PDU)
The PDU is the interface equipment between the power subsystem and the other spacecraft subsystems and payloads. It distributes the power to all spacecraft loads through 42 current-limiting switches. These switches protect the power bus from overcurrent failures in any of the spacecraft

The Power Distribution Unit (PDU) (left)

The Pyrotechnic Release Unit (PRU) (right)

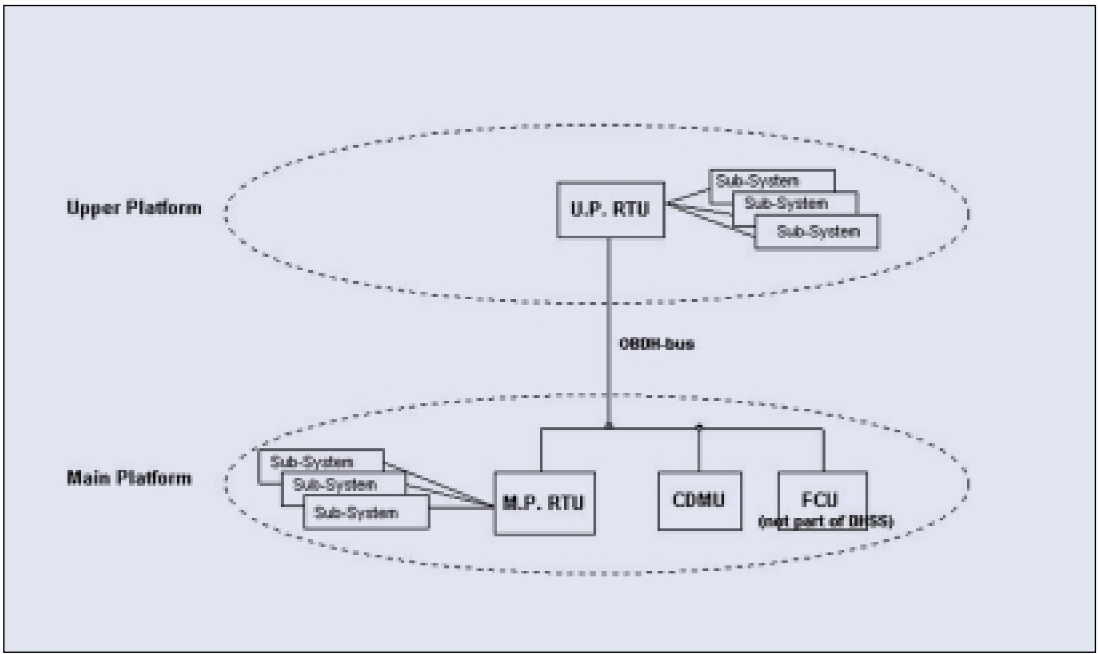
equipment. It also ensures that other equipment does not experience power-supply disruption during failure recovery. In addition, there are 54 simple transistor switches in the PDU for thermal-control heater on/off switching. Main and redundant auxiliary converters supply the telemetry circuitry, which monitors the power to the users. Bus and battery cell undervoltage protection by the shedding of non-essential loads is also incorporated. Additionally, power-up 'on-switching' and a time-limited 'on-retriggering' of essential spacecraft equipment loads, in order to restore DC power for a limited number of 'on-retry' attempts, is included. The PDU weighs 9.7 kg.

The Pyrotechnic Release Unit (PRU)
The PRU conditions and safely distributes the energy to ignite either singly, or a maximum of three simultaneously, of the 32 pyrotechnic initiators used within the satellite. The PRU is powered directly from the two spacecraft batteries and supplies a pulse current of 5 A amplitude and 25 ms duration. On-ground and launcher safety requirements have imposed a minimum of three levels of protection-inhibits between the power source and the initiators to ensure that inadvertent firing of these safety-critical devices cannot occur. This requirement is fulfilled by series relays and current limiters placed between the batteries and the initiators. The PRU weighs 5 kg.

5.5 Data Handling & Onboard Software

Data Handling Subsystem (DHSS)
The MSG Data Handling Subsystem (DHSS) consists of three physical units: the Central Data Management Unit (CDMU), and the two Remote Terminal Units (RTUs). The three units are interconnected via the serial standard OBDH data bus. One RTU is located on the spacecraft's main platform and monitors the equipment mounted there. The other is located on the upper platform and monitors the MCP subsystem. The two RTUs are identical except for their OBDH bus terminal addresses, which can be set by external address plugs.

Also connected to the OBDH bus is the



Architecture of the Data-Handling Subsystem (DHSS)

FCU of the SEVIRI subsystem. The FCU incorporates a dedicated OBDH interface, the Remote Terminal Interface (RTI).

The CDMU is master on the OBDH bus, and controls all traffic on the bus. Commands and acquisitions are thus sent out from the CDMU to the different subsystems of the satellite via the RTUs, or via the SEVIRI FCU.

The CDMU is also equipped with a programmable Central Reconfiguration Module (CRM), which can reconfigure the DHSS (including the CDMU) upon reception of several different alarm signals. Most of these alarms are generated by the CDMU itself (e.g. on detection of a non-correctable memory error or a memory-protection violation), but there is also one external

Characteristics of the Data-Handling Subsystem (DHSS)

	CDMU	RTU UP	RTU MP
Dimensions:			
Length	340 mm	250 mm	250 mm
Width (depth)	234 mm	234 mm	234 mm
Height	287.5 mm	203 mm	203 mm
Mass	11.3 kg	7.3 kg	7.3 kg
Mean Power (typical value)	19 W	7.7 W	7.7 W
Peak Power (worst case, over 1 ms)	34.5 W	19.7 W	19.7 W
Reliability	0.990	0.997	0.997
Subsystem reliability (with CRM)	0.975		

system alarm relating to the satellite 'safe mode'.

The DHSS provides the following basic functions:

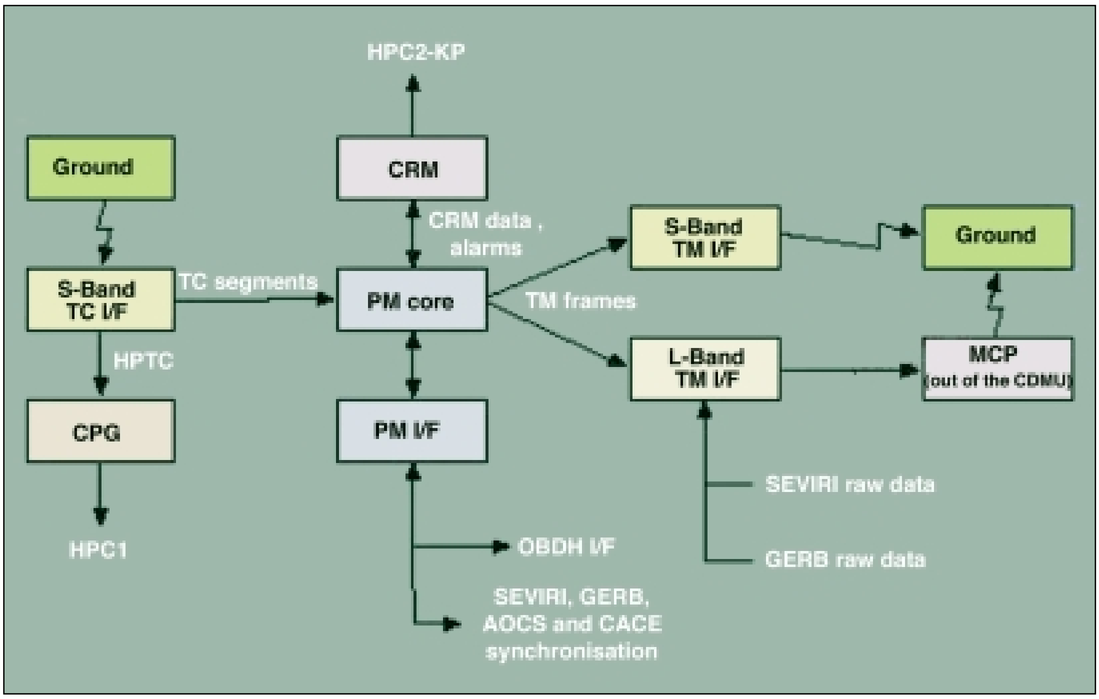
- Decodes and distribute telecommands through a hot-redundant telecommand (TC) chain using TC packets formatted according to the ESA Packet Telecommand Standard. All TCs, except high-priority TCs (handled by TC decoder hardware), are forwarded directly to the onboard software.
- Acquires and encodes telemetry data (S-band) at a rate of 8192 bps, including coding, formatted according to the ESA Packet Telemetry Standard.
- Acquires and encodes payload data (L-band) at a speed of 2 x 3.75 Mbps, including coding. Three Virtual Channels are used: on VC0 and VC1, packet headers are generated by Basic Software (BSW), while on VC7, all telemetry packets are generated by Application Software (ASW), except for idle packets.
- Provides an On-Board Time (OBT) function using a high-precision TCX oscillator.
- Distributes a set of dedicated clocks including: AOCE clock, CACE clock, MCP clock, and Payload (SEVIRI/GERB) Master Clocks.
- Controls the reading out of raw data from the payload (SEVIRI and GERB) using CTS/RTS hand-shaking signals.
- Provides a processing capability for ASW control functions.
- Provides command and monitoring capabilities for other subsystems through RTU input/output channels.

Onboard Software

All spacecraft command and control, all autonomous functions like onboard failure handling and thermal control, as well as all telemetry acquisition and reporting and all but the most basic telecommanding is centralised in the MSG onboard software.

The fast rotation of the satellite imposes special requirements on the exact synchronisation of the payload data acquisition, which directly influences the quality of the image. The overall mission requirement of 24 h autonomy in orbit requires a relatively comprehensive onboard failure detection, isolation and recovery (FDIR) setup. These functions, together with a telemetry and telecommand implementation, which fully complies with the ESA Packet Telemetry/Telecommand Standards, and the higher-level, application-oriented requirements defined in the ESA Packet Utilisation Standard, are among the most demanding and drive the software design to a large extent.

Since several of these tasks are asynchronous in nature, use of a conventional scheduler-based operating system, which activates tasks periodically in a fixed sequence, is not possible. Instead, the software is based on a pre-emptive multitasking kernel, which supports asynchronous task activation. Abandoning the relative simplicity of a scheduler-based system comes at the expense of increased software complexity and the need for special software verification and testing efforts, which led in turn to an extended and comprehensive software verification and validation programme.



The onboard hardware/software context

The software is split into two major blocks, reflecting the difference between a lower-level hardware-oriented operating-system kernel, the Basic Software (BSW), and higher-level application-oriented functions, which together form the Application Software (ASW). The complete onboard software suite runs on a 31750 microprocessor in the Central Data Management Unit (CDMU). The software was written in ADA, with only very limited use of Assembler code for time-critical procedures.

The onboard software is stored in 56 kW of ROM and copied into 96 kW of RAM upon initialisation. The memory margins are 11% and 20%, respectively.

esa

Memory map of MSG's onboard software