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OPTICAL IMAGING INSTRUMENTS FOR THE REMOTE SENSING PROGRAMME OF THE EUROPEAN SPACE AGENCY

Abstract

This paper defines the requirements of optical and infra-red multispectral imaging established for Coastal Ocean and Land Applications, and outlines the payload and technology studies in progress, together with the most likely design solutions to be adopted.

The current ESA planning envisages that a first space system will be launched in the mid-1980's with a second launch approximately two years later.

1. INTRODUCTION

The European Space Agency has been actively involved in various aspects of remote sensing for approximately ten years. At this time, the effort is concentrated into three principal areas:

- the Earthnet Programme,
- the Remote Sensing Experiments for the First SPACELAB Payload (FSLP),
- the preparation of a European Remote Sensing Satellite Programme Proposal including:
  - . system studies and instrument definition,
  - . technology activities,
  - . aircraft experiments.

This paper is concerned with the optical instrumentation aspects of the satellite programme.

2. DEVELOPMENT OF THE REQUIREMENTS

Figure 1 attempts to illustrate by means of a logic flow diagram the evolution steps leading to the identification of requirements for the optical instruments. Starting from a basic question of "what, if any, are the European needs for an Earth resources satellite(s) system?", Working Groups were established to look at seven basic themes:

. Agricultural monitoring,
. Land-use monitoring,
. Water resources management,
. Coastal and ocean surveying and monitoring,
. Polar region monitoring,
. Mineral resources and dynamic geology,
. Development aid assistance.

The output of these Working Groups was in the form of Missions Requirements Reports, one per theme, which identified three basic satellite missions grouped by requirements compatibility:

. Land applications,
. Coastal ocean monitoring,
. Global ocean monitoring.

Further refinements are in hand to attempt to satisfy the Coastal and Global Ocean Monitoring missions by a single satellite payload complement. This aim appears to have been achieved for the optical payload. Thus the present status of the programme evolution is that requirements for two optical payloads are identified:

- The Optical Imaging Instrument (OII) for the Land Applications Satellite System (LASS),

- The Ocean Colour Monitor (OCM) for the Coastal Global Ocean Monitoring Satellite System (COMSS).

3. THE OPTICAL IMAGING INSTRUMENT (OII)

3.1 Principal Requirements

Table 1 lists the current principal requirements for the OII in the more or less classical manner. The spectral channel definitions have been derived largely from "user" experience with the Landsat MSS data and various aircraft sensors. Earlier definitions included thermal infra-red requirements but a basic conflict of local time of measurement requirement between agricultural monitoring and geological studies, coupled with cost, complexity and priority considerations, led to dropping this feature.

Fundamental to the requirements are the specifications on spectral channel registration and relative calibration. The general imaging definitions are built around a push-broom camera as opposed to a mechanical scanner. Emphasis has been put on multispectral utilization, rather than imaging in the classical sense, in order to permit multi-spectral analysis on an area-sampling basis without needs for initial spectral channel to spectral channel image registration by data re-sampling.

As a second priority, there exists a requirement for a panchromatic channel of twice the basic resolution; the interpretation of "second priority" being that the optical instrument will have the inherent measurement capability, assuming it is feasible and does not degrade the multi-spectral performance, but that utilization of the capability will be on an optional basis to the multispectral mode.

3.2 Potential Design Solutions

At the time of writing, two technical solutions are being considered. One is an adaptation of the MBB MOMS (Modular Optical Multispectral Scan) which could consist of six modules, one per channel, each module being an arrangement of two parallel telescopes with detectors organised to create a single, continuous array to cover the complete swath.

The second solution is the subject of an on-going Phase A study. This solution consists of two cameras, one to provide the first four spectral bands and the panchromatic, and a second for the two reflected IR channels. A single camera solution would be very desirable but no practical optical solution has been found to provide both the total field requirement (14°) and the total spectral coverage (520 to 2,350 nm).

The visible camera is defined around an F/5.4 dioptric system of 105 mm aperture with multichroic splitting of the four spectral bands. A baseline solution for the focal plane layout consists of a staggered arrangement of either 7 CCD arrays of 1728 elements or 6 of 2048 elements. The basic optical design is also compatible with utilization of CCD/TDI devices.

For the reflected IR camera an F/2.8 telescope of 200 mm is tentatively chosen based on first assumptions of the detector performances.

3.3 Supporting Technology

In parallel with the design definition of the payload, certain critical aspects of the equipment are being investigated. Some of these items are already the subject of industrial action, others are in various stages of requirement definition. Table 2 lists the items in the OII supporting programme with brief descriptions of each task.

While most of the subjects under investigation are fairly self-evident, it is perhaps interesting to comment specifically on three of the items.

In terms of pure technology, the development of a large array of detectors for the near, reflected IR channels at 1650 nm and 2215 nm represents a particular challenge. The status to date (March 1980) is that a device of 1024 elements (25 micron square per element) has been successfully fabricated, following initial fabrication of 64 element devices for proof of technique.

The technology of the device is based on doped Pb.Te. sputtered on a silicon substrate. The next phase of this activity, following the on-going testing programme, is planned to look in detail at the read-out electronics and the general optical and thermal interfacing problems.

Two of the activities in the supporting programme are concerned with calibration, as this is certainly a fundamental problem of the push-broom type camera.

While one of the activities is aimed at the problem of generation of the calibration data, the second task is oriented towards a capability to inflight correct the data before down-transmission. This does not necessarily mean a fully automatic system, insofar as the establishment of the correction factors may involve certain ground processing, but is rather aimed at being able to provide precalibrated data directly to user stations. It is also, in the longer term, seen as a necessary capability to be achieved before on-board data processing can be eventually considered.

4. THE OCEAN COLOUR MONITOR (OCM)

4.1 Principal Requirements

The requirements for this instrument have been particularly difficult to establish. Table 3 gives the currently identified principal performance requirements following several revisions. These requirements have originated from specific studies of the problem of determination of the content and concentrations of chlorophyl and turbidity. Technically, the main problem is to measure changes in the small amount of sunlight scattered from below the sea-surface in the 400 to 500 nm region in the presence of a much stronger fluctuating signal component coming from atmospheric and sea-surface scattering. This problem generates requirements for several spectral channels dedicated to correction functions and to needs for high photometric quality. Further technical difficulties are imposed on this instrument by requirements to avoid sun-glint viewing conditions, coupled with constraints on the instrument configuration within the overall satellite and the needs to provide the necessary viewing for passive cooling of the thermal IR channel detectors.

4.2 Potential Design Solutions

Because of the difficulties experienced to derive a satisfactory requirement definition for this instrument, the first industrial design phase (Phase A) is only now being initiated. Thus an overall design concept has yet to be derived. However, certain aspects of the requirements are expected to lead almost automatically to the choice of instrument concept.

A dominating requirement in this respect is the very wide angle image (swath 80°) which strongly suggests an object-space, mechanical scanning configuration. Further, the need for high, inter-channel, relative calibration accuracy suggests that the number of detectors employed should be limited. Thus it is reasonably safe to predict that the instrument will be a mechanical across-track line scanner rather than a push-broom type camera as the OII.

The requirement to produce multispectral data of a high photometric quality will almost certainly influence the definition of the means of spectral band separation and focal-plane design in order to try to avoid need for data re-sampling before multispectral analysis. Major difficulties are expected in providing the calibration requirements and the implied calibration stability of the instrument.

4.3 Supporting Technology

As for the OII, a Supporting Technology Plan has been initiated for the OCM which is listed by subject in Table 4. It will be noted that particular emphasis is given to the scanning mechanism with two parallel tasks looking at mechanical and magnetic bearing arrangements. For these tasks, a constant-speed, continuously-rotating scan mirror arrangement is assumed.

5. FUTURE PROGRAMME ACTIVITIES

At the time of writing, the European Space Agency is preparing the follow-on programme activities for the approval of the ESA Member States. The proposal will cover competitive Phase B1 activities for system definition of the first satellite system. In parallel, the optical payload activities will continue by way of extension of the technology tasks into more detailed breadboarding activities based on the Phase A studies.

The overall programme plan calls for a launch of the first satellite in the mid-1980's with the second satellite following by two years. At this time, the COMSS satellite is favoured for the first launch.

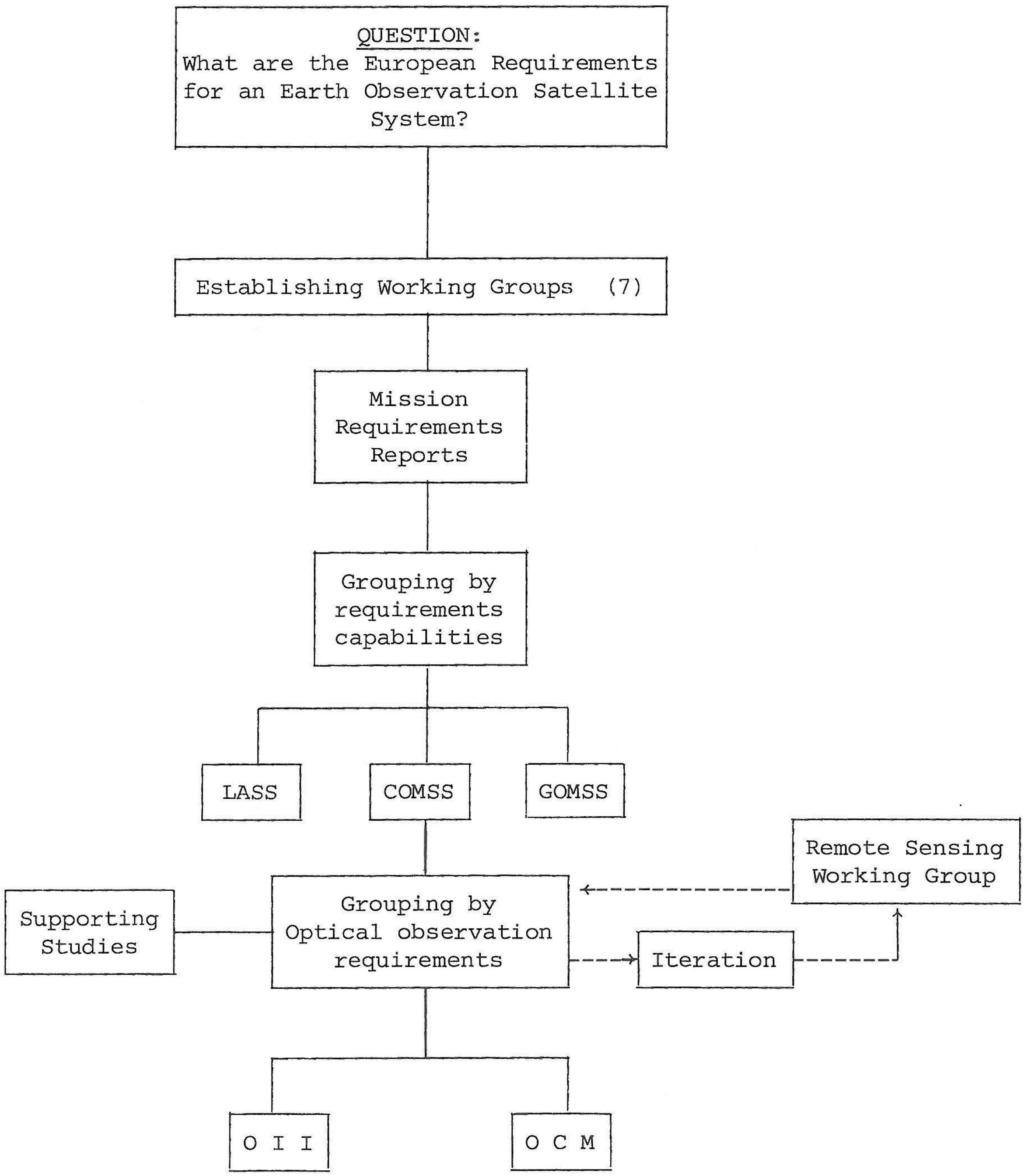

Figure 1

Derivation of the Optical Payload Requirements

Spectral Channels	1) 520 - 600 nm 2) 640 - 690 nm 3) 759 - 800 nm 4) 800 - 900 nm 5) 1550 - 1750 nm 6) 2090 - 2350 nm 7) 400 - 1000 nm (panchromatic)
Radiometric Resolution	< 0.05% mean earth signal at 60° solar zenith angle (75° for TDI)
Calibration Accuracy	1% relative and 2% absolute (target)
Spatial Resolution	< 30 meters at sub-satellite point < 15 meters in panchromatic
M.T.F.	0.5 at Nyquist frequency (target)
Imaging requirements	. Orbit altitude 681 km . Orbit repeat cycle 17 days . Inclination 98° . Max. track separation 160 km . Image swath width 167 km (broken into sub-swaths corresponding to CCD sizing) . Channel to channel registration 0.1 pixel
Residual instrument polarisation	< 1%*

* An alternative to provide a polarimeter to measure the signal polarisation is under consideration

Table 1 - Principal OII Requirements Summary

Task/Title	Description of Objectives
Telescope design and breadboarding	Demonstration, by breadboarding, of the feasibility of a wide field (14) F/5.4, 105 nm aperture, flat-field, chromatically corrected telescope
TDI evaluation	Technology evaluation of existing commercial devices
CCD development monitoring	Evaluation of potential European and Canadian sources to fulfil OII requirements
Focal plane assembly	Design and breadboarding of critical components
IR detector cooling	Design and breadboarding of passive cooler/cold focal plane of near-IR equipment
A/D converter and buffer	Design and breadboarding of high-speed (1.8 Mbits/sec), hybrid multiplexer, A/D converter and data buffer
Calibration methods study	General investigation of possible utilization of sources and standard detectors for in-flight calibration
Calibration correction study	Study of a breadboarding hardware design to perform real-time in-flight data calibration correction

Table 2 - OII Supporting Technology Tasks

Spectral Channels

Channels	Wavelength nm	3dB width nm	Principal Physical Parameters
1	415	20/30	Yellow substance absorption
2	440	20	Phytoplankton absorption
3	520	20	Phytoplankton absorption and/or turbidity
4	565	20	Turbidity
5	620	20	Turbidity
6	785	30	Atmospheric correction
7	1020	60	Atmospheric correction
8	11500	2000	Surface temperature
9	11000	1000	Atmospheric correction

Spatial Resolution

< 800 meters (channels 1-6)
<2000 meters (channel 7)
400 meters (channel 8)
800 meters (channel 9)

Radiometric Resolution

NE$\Delta\rho$ 0.1% (channels 1-7) at 60° solar zenith angle
NEΔT 0.2 K (channels 8-9) at 290 K

Calibration Accuracy

Visible
1% relative inter-channels
2% absolute (target)

IR
0.2 K (290 K) relative
0.5 K (290 K) absolute

Imaging Requirements

Orbit altitude	675 km
Orbit repeat cycle	3 days
Orbit inclination	98°
Local time over mid-Europe (descending)	11.30
Image swath	± 40°
Channel to channel registration	<1/10 pixel (VIS/VIS)
	<1 pixel (VIS/IR)

Sun-glint Avoidance

Image plane tilt by command
or additional spectral channel at 2200 nm

Polarisation (residual)

< 1% or provide polarimeter

Table 3 - Principal OCM Requirements Summary

Task/Title	Description of Objectives
Silicon diode and thick-film preamplifier study	Design and breadboard representative units for proof of concept
Thermal IR preamplifier	Design and breadboard of monolithic, multichannel preamplifier for use with CMT and/or PbTe detectors
Thermal IR detector array	Breadboard evaluation of monolithic IR detector array
Scanning mechanism bearing evaluation	Separate tasks to evaluate mechanical and magnetic bearing application to scanning-head requirements
A/D converter	Study and breadboarding of low-speed, high-linearity, 10-bit encoder
IR detector cooling	Study and breadboarding of critical items
Computer correction of image scan geometry	Evaluation of ground processing requirements to provide images in standard map projections (requirement to assist instrument configuration trade-off studies

Table 4 - OCM Supporting Technology Tasks