FACE-IT

Field-Aligned Current Experiment
In
The Ionosphere and Thermosphere

Revision 2.54

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(J.E. Rasmussen, 1999)

(J.E. Rasmussen, 1999)

2. Executive Summary

The satellite FACE-IT will focus on observations of the field-aligned currents in the ionosphere with a new set of instruments. This mission will bring important insight into the physics of the high latitudinal ionosphere and contribute to our understanding of the role of field-aligned currents in the ionosphere-magnetosphere system with particular emphasis on scale sizes, structures and intensities, which are not yet clearly understood.

From a circular polar orbit the observations will give unprecedented knowledge on these phenomena, their physics and relation to the magnetosphere processes and solar wind.

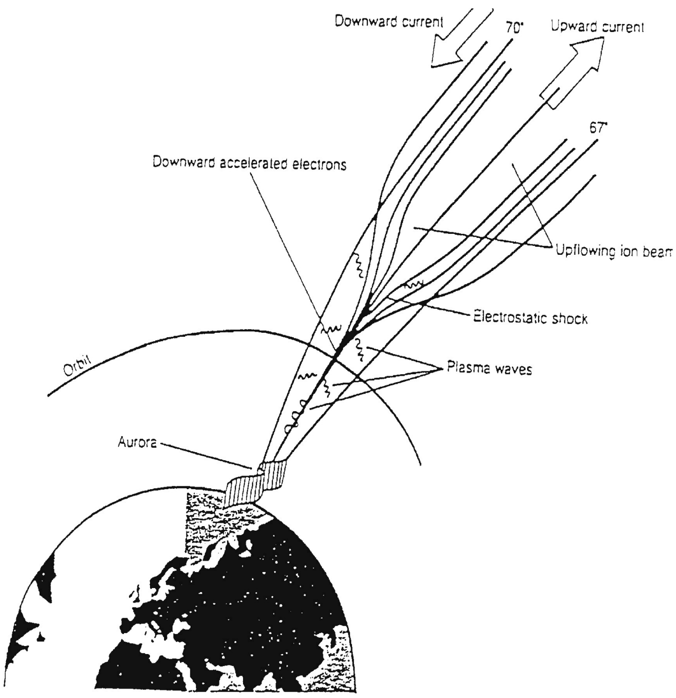

Figure 2-1 Auroral currents and associates phenomena, which FACE-IT will be observing.

The mission tries to answer some important questions related to magnetic measurements of currents in the ionosphere and the physics of the ionosphere/magnetosphere system.

- What is a typical distribution of the intensity of field-aligned currents versus their spatial scale ?
- How can different spatial and temporal variations in the observed time series be distinguished ?
- What is the relation between density gradients, wave electrical fields and the intensity of field-aligned currents ?
- What determines occurrence and location of extremely thin and strong current structures embedded in larger scale Birkeland current regions ?
- How well does magnetometer current estimates match the measurements of the new direct field-aligned current instrument ?
- Are hydromagnetic Alfvén waves related to mostly the thermal electron population (with energies below 100 eV) ?

Other science objectives for FACE-IT are:

- The electrodynamics of auroras and the large-scale physics of the cusp and auroral region.
- The physical processes of ion heating and ion outflows in the upper ionosphere at high latitudes
- Monitoring of the sources of cross-polar cap potential drops
- $\mathbf{E}\times\mathbf{B}$ correlations and associated current scale sizes
- Global mapping of $\mathbf{E}$ and $\mathbf{j}_{||}$ and their relations to phenomena in the solar wind
- Sub-auroral and equatorial electron density and electric field structures
- ΔN_e variation in patches and bubbles and their relation to plasma currents
- Waves and pulsations (up to 1 kHz) and their role in ionosphere current systems

The satellite builds on the developments in the ØRSTED project and re-uses several of the elements from this mission. Figure 2-2 shows a conceptual view of the satellite and the glass fiber coils of the Faraday Current Meter instrument.

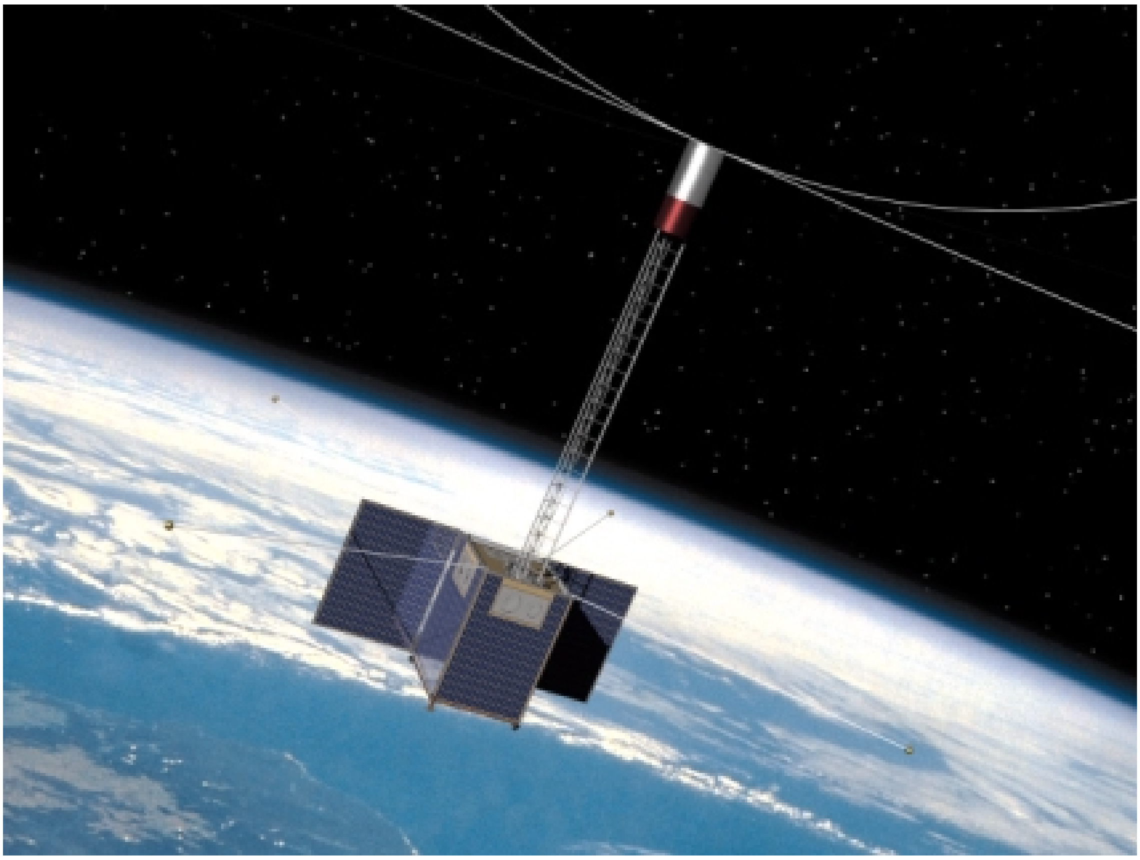

Figure 2-2 Artist view of the FACE-IT satellite (J.E. Rasmussen, 1999).

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3. Introduction

The main and novel objective of the FACE-IT mission is to make detailed studies of the field-aligned current structures of the ionosphere. This will be performed by applying new and state-of-the-art instrumentation with an unprecedented accuracy and approach. The new concepts and methods behind the FACE-IT measurements will undoubtedly lead to a drastic enhancement in our knowledge of the physical processes in the ionosphere/magnetosphere system.

The research outlined for FACE-IT will be an important step in our understanding of upper atmosphere physics and the relations between this region of the Earth, the magnetosphere and the solar wind. The mission will also be able to determine, for the first time, the small-scale structures of field-aligned currents and the coupling of electromagnetic waves and parallel electric fields in the magnetosphere related to the ionospheric current system.

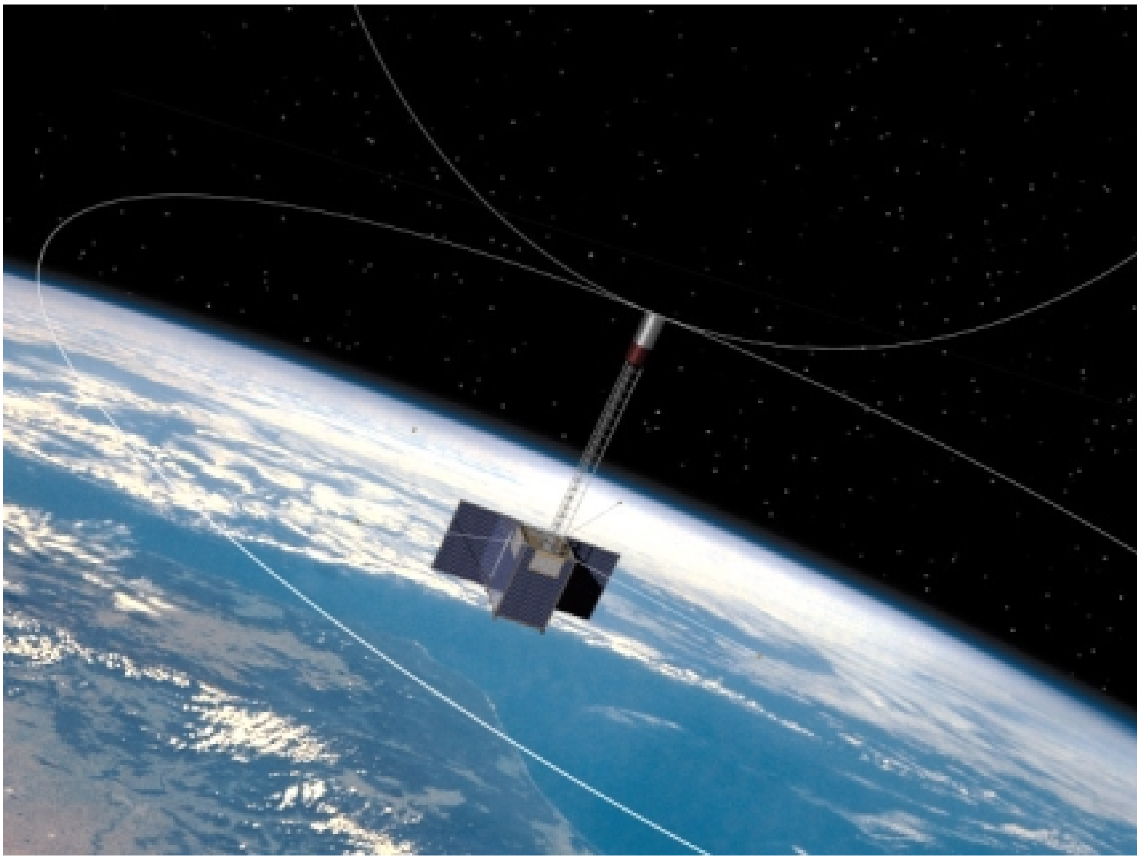


Figure 3-1 The FACE-IT satellite (J.E. Rasmussen, 1999).

The satellite is in concept and structure a further development of the ØRSTED satellite. Re-use of several of the ØRSTED elements is enhancing the system maturity of the mission.

The main instrumentation is new and a breakthrough in the way field-aligned current measurements are done. The <u>F</u>araday <u>C</u>urrent <u>M</u>eter (FCM), monitoring the phase shift of laser light in a coiled long glass fiber, gives the most precise measurements of the field-aligned currents. Together with the state-of-the-art DC and AC Magnetometer (DAM) both instruments will reveal the physics of the field-aligned current structures in high latitude phenomena as auroras. The additional electric field and electron density observations will shed light on many physical relations that still puzzle physicists studying the processes of ionized gasses in space.

The size of the FACE-IT satellite is 60×60×80 cm, weighting around 75 kg. The polar orbit will be circular, with an altitude of 800 km, aiming at a launch towards the end of 2003 or in the beginning of year 2004. The scientific objectives of the mission are believed to be fulfilled in 12 months, which is the expected lifetime of the mission.

The following chapters give a description of the scientific justification, mission characteristics and technical concept. Next to this comes a clarification of the potential and maturity of FACE-IT through a detailed presentation of the mission elements and estimated costs. Finally follows chapters laying out the implementation and time plans, together with a description of the Danish scientific and industrial consortium being able to carry the mission through to its successful completion.

4. Scientific Justification for the FACE-IT Mission

4.1 Science Objectives and Basic Payload Concept

4.1.1 Science Objectives

The encounter of the solar wind and the Earth's magnetosphere results in a range of current systems at the surface and inside the magnetosphere. Figure 4-1 shows a sketch of the magnetosphere and some of the global current systems produced by the interaction processes. The magnetopause, ring and tail currents at the boundaries of the magnetosphere together with the plasma sheet and mantle currents are the main sources for the field-aligned current connection to the ionosphere (Akasofu, 1980; Potemra, 1984).

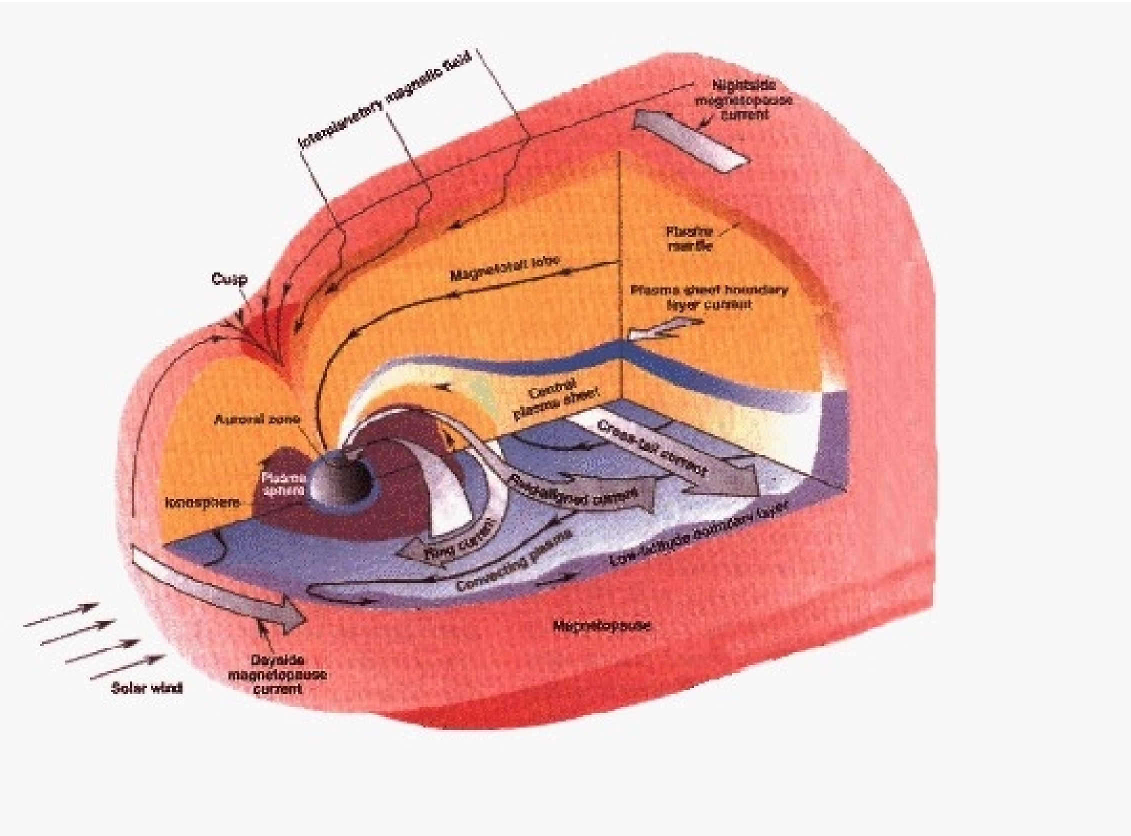


Figure 4-1 The magnetosphere and the current systems, fields and plasma regions. The field-aligned currents carry the energy and information between the regions.

The field-aligned currents carry the major energy input to the ionosphere from the magnetosphere and the solar wind, as confirmed by many observations and model simulations (Arnoldy, 1974; Potemra, 1979; Akasofu, 1980). The magnetospheric plasma flow is considered to be driven by the solar wind-magnetosphere dynamo from which an estimate of the total dissipated energy can be made (Akasofu et al., 1981). The total energy dissipation in the ionosphere, which is observed in bursts of 20-30 min., amounts to 10^{11} watts during disturbed conditions. Assuming an even distribution over both hemispheres of the auroral regions leads to average field-aligned current densities in the range of 0.1 - 2.0 μA/m^2 (Iijima and Potemra, 1976, 1978; Akasofu et al., 1981). Figure 4-2 shows the field-aligned currents, also named Birkeland currents, across the auroral oval as calculated from satellite magnetometer data.

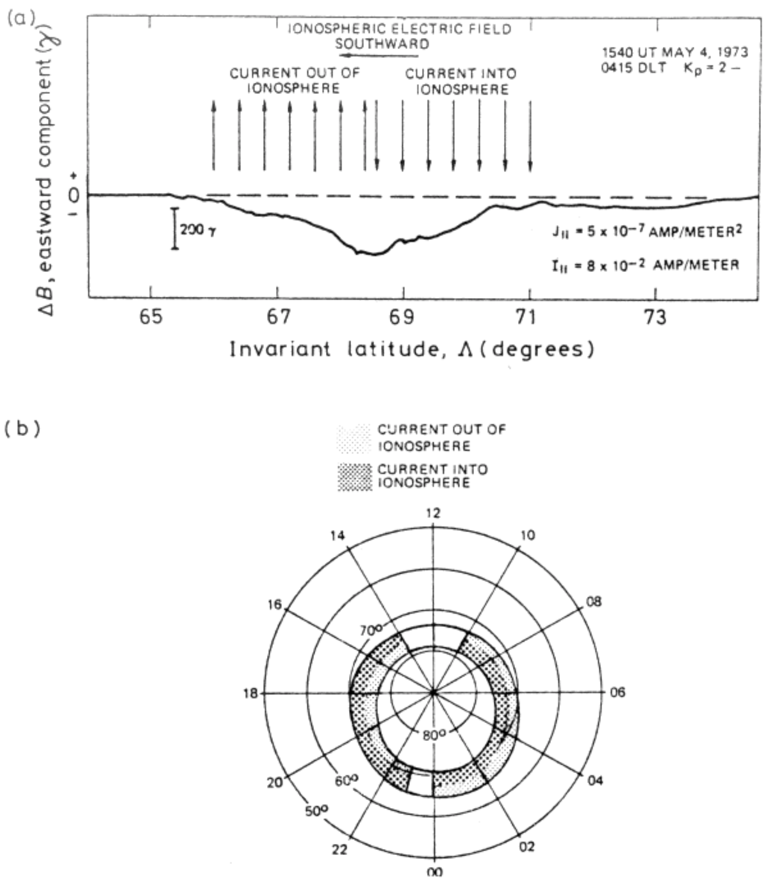


Figure 4-2 Birkeland currents in the region 1 and 2 currents of the auroral oval. The upper panel (*a*) gives the satellite-borne magnetometer measurements (Zmuda and Armstrong, 1974). The lower panel (*b*) shows the statistical distribution of Birkeland currents (Iijima and Potemra, 1978).

The deduced equivalent currents from ground magnetometer data are not able to resolve the spatial-temporal structure of the event. Thus direct observations of the magnitude and structures of these current systems will be a major breakthrough in the understanding of the interaction processes taking place between the solar wind and the upper ionized part of the atmosphere, dominated by the Earth magnetic field. Electrical currents in space are presently detected by observing their integrated magnetic characteristics or by counting the net amount of charge carriers flowing in any given direction. Both methods suffer from serious drawbacks. The interpretation of existing magnetic measurements is geometry-dependent and becomes less sensitive for small-scale current structures, dominating a range of ionospheric and magnetospheric processes. Charged particles detectors miss the particle populations with energies above and below the instrument's measurement range. Furthermore, they also require a good spatial coverage of all pitch angles for extended integration times to form the total particle distributions of the species observed.

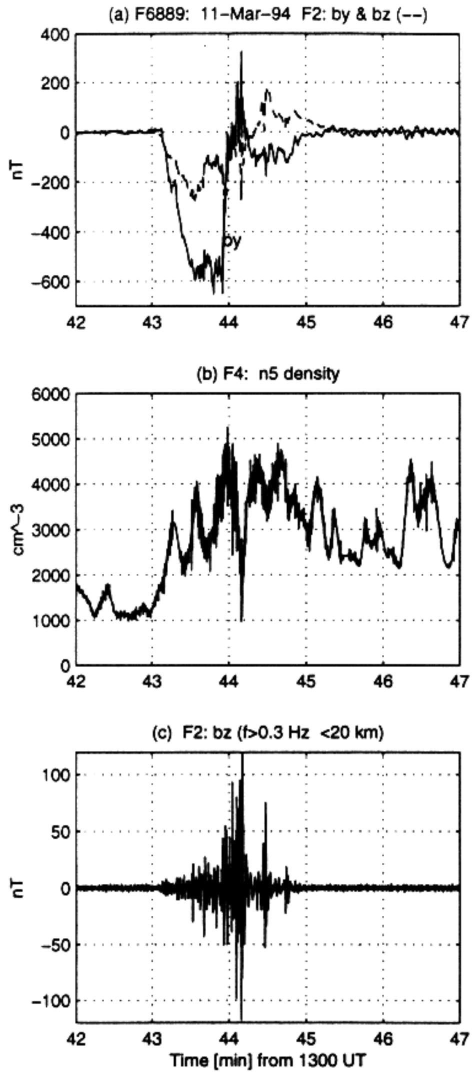


Figure 4-3 Magnetic perturbations and plasma density measurements from the FREJA satellite. The upper panel shows the two magnetic perturbations components of the magnetic field. The middle panel reveals the plasma density from the Langmuir probe. While the lower panel give the filtered magnetic field variations (Stasiewicz and Potemra, 1998).

The main scientific objective of this mission is to perform observations of the ionosphere/magnetosphere field-aligned current system with an unprecedented accuracy to reveal the small-scale spatial structure and magnitude of these currents during different geophysical conditions. It has recently been shown (Stasiewicz and Potemra, 1998), that the current contribution from these small-scale structures is substantial (> 500 $\mu A/m^2$), and much higher than previously reported. So this mission tries to answer some of the important questions related to magnetic measurements of currents in the ionosphere. They are:

- What is a typical distribution of the intensity of field-aligned currents versus their spatial scale ?
- How can different spatial and temporal variations in the observed time series be distinguished ?

- What is the relation between density gradients, wave electrical fields and the intensity of field-aligned currents ?
- What determines occurrence and location of extremely thin and strong current structures embedded in larger scale Birkeland current regions ?
- How well does magnetometer current estimates match the measurements of the new direct field-aligned current instrument ?
- Are hydromagnetic Alfvén waves related to mostly the thermal electron population (with energies below 100 eV) ?
- What is the contribution from particles in different energy ranges to the field-aligned currents in the upward and downward current structures ?

The above science objectives and questions can be fulfilled by the instrumentation suggested for the FACE-IT mission. Especially information on the field-aligned current scale sizes and temporal variations can be addressed by including the new Faraday Current Meter (FCM) and the AC/DC electric field sensors (EMP). Figure 4-4 depicts the sensitivity increase of FCM, monitoring shorter scale field-aligned current structures, compared to vector magnetometers.

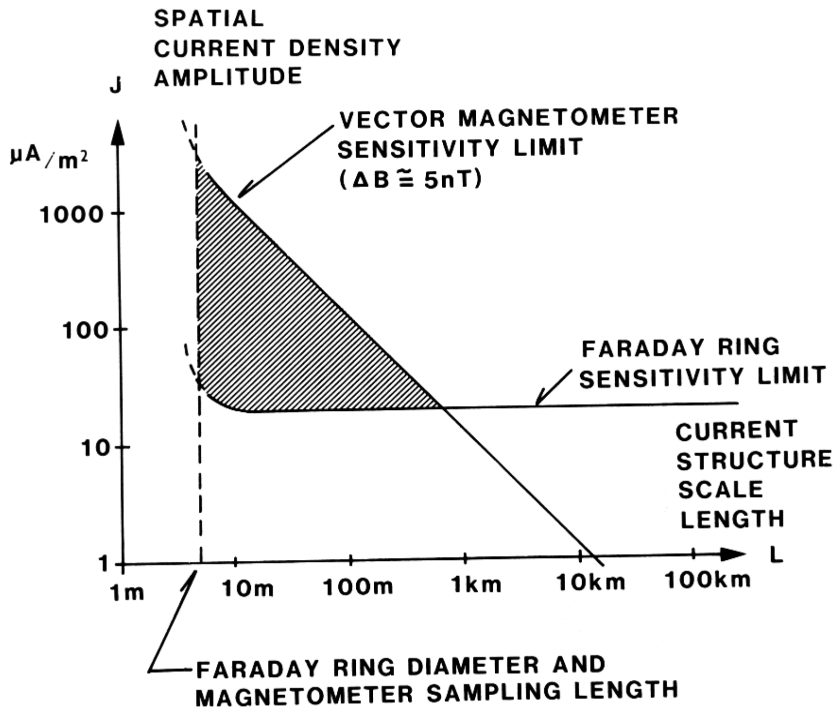


Figure 4-4 Qualitative estimate of the sensitivity limits of the FCM instruments and the vector magnetometer. The current density for the vector magnetometer is assumed to be plane sheets varying in amplitude with wavelengths perpendicular to the planes. The hatched area describes the region of small scale FAC structures accessible by the FCM instrument alone (Primdahl et al., 1986).

If the FCM instrument should fail or degrade some of the above questions can still be addressed by combining, 1) the DC and AC observations from the electrical field sensors and magnetometers, together with 2) the GPS measurements of electron density variations total electron content (TEC) and scintillations. Other backup science objectives are:

- The electrodynamics of auroras and the large-scale physics of the cusp and auroral region.
- The physical processes of ion heating and ion outflows in the upper ionosphere at high latitudes
- Monitoring of the sources of cross-polar cap potential drops
- $\mathbf{E}\times\mathbf{B}$ correlations and associated current scale sizes
- Global mapping of $\mathbf{E}$ and $\mathbf{j}_{||}$ and their relations to phenomena in the solar wind
- Sub-auroral and equatorial electron density and electric field structures
- ΔN_e variation in patches and bubbles and their relation to plasma currents
- Waves and pulsations (up to 1 kHz) and their role in ionospheric current systems

4.1.2 Mission Payload

The main science instrument on the field-aligned current mission is the new instrument called the 'Faraday Current Meter' (FCM), which is particularly well suited for measurements of small-scale space plasma currents, without the inherent uncertainties of the existing methods. The sensor consists of a circular loop of optical fiber guiding a polarized beam of laser light. The change in polarization direction of the laser light is a direct measure of the circular magnetic field along the closed fiber, attributed to the current flowing through the plane of the loop.

The FCM will be complemented by a DC and AC vector magnetometer (DAM) to monitor the large-scale variations of the field-aligned currents. Electric field sensors (EMP) monitoring DC fields and waves will assist in the interpretation of the resistivity, mobility and diffusion characteristics of the plasma, together with the GPS instrument's monitoring of the changes in the total electron content of the medium.

The payload concept for the mission can be summarized to consist of:

Main scientific instruments
- 1 FCM instrument consisting of 2 perpendicular 10 m loops
- 1 DAM vector magnetometer
- 1 EMP electric field sensor
- 1 GPS instrument

The main specifications of the FCM instrument are:

Coil size diameter:	10 m
Fiber length:	4.2 km
Laser wavelength:	1.55 μm
Mass:	1 kg
Optics, mass	1.0 kg
Electronics, mass	2.0 kg
Power:	5 W
Sensitivity:	< 10 $\mu A/m^2$
Data sampling rate:	1 - 10 kHz

The primary attitude determination will be performed based on data from sun sensors, magnetometer and GPS instrument. This information will be used by three magnetic coils to active control the attitude of the satellite. The GPS receiver will continuously determine the attitude of the spacecraft by combining GPS signal phases from three antennas. The output, based on GPS alone, gives knowledge about the three dimensional orientation to within ±2° (with an attitude rate change of <1°/sec). The sun sensors at the corners of the satellite provide better than 10°-attitude information. Thus the total attitude control subsystem will maintain the platform stability and pointing accuracy to better than one degree. An attitude accuracy of 0.2° will be obtained in the post-processing analysis applying the magnetometer data.

4.2 Science Case

4.2.1 The Role of Field-Aligned Currents (FAC)

Electric currents flowing in the plasma surrounding the Earth constitute the decisive part of the energy transport and conversion processes taking place between the Sun, the magnetosphere and the Earth's ionized upper atmosphere.

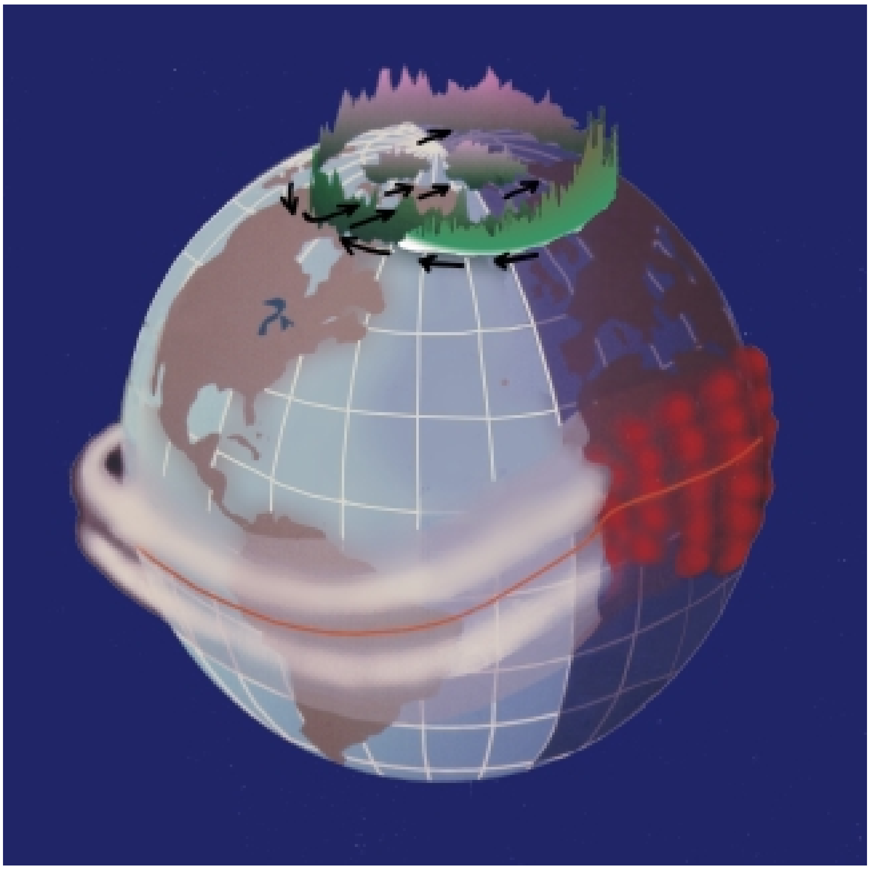


Figure 4-5 The active ionosphere regions of the Earth are the equatorial region and the high latitude auroral region.

Some of the more prominent consequences of this energy exchange are the spectacular northern and southern auroral displays, the magnetic storms regularly perturbing the Earth's otherwise quiet magnetic field, and the occasional abnormally large absorption of electromagnetic waves in the polar regions.

The solar wind drives the magnetosphere dynamo, which leads to the system of field-aligned currents (FAC) connecting the energy dissipation in the ionosphere with the plasma flows in the magnetosphere. At high latitudes FAC feed the mainly Hall current electrojets, revealing from ground observations of the interaction processes between the magnetosphere and the solar wind. The current patterns in the bottom of the ionosphere are very sensitive to the magnetosphere conditions. During magnetic storm conditions large changes in the FAC distribution of the polar cap and the auroral regions lead to a range of processes, which still are not well understood and established due to the limitations in the existing satellite observations.

The science objectives of FACE-IT covers also a range of issues related to the conditions at high latitudes in the auroral and polar regions. Below is outlined some of the reasons for these objectives.

Global high latitude currents. The bulk flow of the quiet time field-aligned currents is carried by charged particles of energies less than 1 keV. Estimates of the average large scale FAC in the high latitude region 1 are in the range of 1-30 $\mu A/m^2$. While region 2 FAC have been estimated to be up to 80 $\mu A/m^2$ (Kivelson and Russell, 1995). The latitudinal widths of the FAC filaments are reported to be less than 10 km (Stasiewicz et al., 1998). These phenomena can be studied with FACE-IT for nighttime auroral events during disturbed conditions and cusp currents and electron density enhancements related to flux-transfer events and changes in the IMF.

Figure 4-6 Auroral arcs and small scale FAC structures.

Auroral FAC. To study the processes taking place in auroras, it is important to be able to observe the structures of the FAC and their magnitude, to determine other auroral phenomena as the plasma waves, electric fields, electron and ion beams, emerging during these events. The thin sheet FAC in auroras has latitudinal widths sometimes less than 1 km with peak current densities along the direction of the magnetic field of up to 100-300 $\mu A/m^2$ (Stasiewicz and Potemra, 1998).

The 0.1-10 keV parts of the particle population carry the FAC, often in pairs of upward and downward flowing currents. Thus it is important to establish an alternative method of measuring FAC in order to resolve the large variability and the small-scale structure in FAC. Additionally, a more direct method of FAC observations will lead to a spatial and temporal resolution needed to verify the predicted structures of simulation studies.

Global ionospheric conductivity distribution. Many large-scale interpretations of the physics of the ionosphere rely on models of the spatial and temporal conductivity. Tomographic representations of the mission's observations can describe the conductivity distribution and thereby complement the derivations of other observations with less a priori knowledge of the ionospheric structures.

Space weather and magnetic storms. We are becoming increasingly dependent on technologies that are affected by the space environment and the physical phenomena dominating the space around our planet. Observations from this mission are suited to address forecasting goals by, direct measurement of electron density, currents and electric fields for assimilation into physical models designed for space weather predictions. Because of the dynamical coupling in the thermosphere-ionosphere, a physical model that assimilates these data will provide solutions to other physical parameters related to composition and winds of the species of the medium.

4.2.2 FAC Observations and Simulations

Rocket and satellite measurements have estimated the average FAC density to 0.1-20 $\mu A/m^2$ (Potemra, 1979; Akasofu, 1980; Primdahl et al., 1984). Due to instrumental limitations in the particle and magnetic field observations made by rockets and satellites, it has only been possible to infer the average magnitude of FAC over a certain spatial distance. On the other hand, small- scale structures within the main pattern of field-aligned currents have been reported (Hardy, 1979; Burke, 1981; Burke et al., 1983; Bankov et al., 1986; Lühr et al., 1994). For thin sheets the peak FAC density has been observed to be up to 135 $\mu A/m^2$ (Burke et al., 1983).

Measurements of ionized particle energies (E_p) less than 20 keV conclude that the bulk of FAC-flow is carried by charged particles of energies less than 1 keV (Arnoldy, 1974; Iijima and Potemra, 1976; Potemra, 1979). While results from the FAST satellite show a good agreement between field-aligned current estimates and that of keV-particles. For high FAC densities a hot population of the particles (1 keV $< E_p <$ 10 keV) may carry up to 50% of the total current density (Burke et al., 1983). Newer observations indicate, that only 20% of the total current are carried by the higher energies in the particle population (Stasiewicz and Potemra, 1998).

The estimated extent of the small-scale FAC sheets gives widths less than 10 km. They are often observed in pairs of upward and downward flowing currents within the larger structures of field-aligned current sheets (Burke et al., 1983; Primdahl et al., 1984; Bankov et al., 1986).

Satellite experiments have been able to measure the global characteristics of FAC. The largest FAC are measured at high auroral latitudes where the perpendicular currents in the ionosphere are the largest (Zanetti et al., 1983). FAC connected to the auroral regions have been divided into region 1 and 2 currents, flowing in opposite directions. Figure 4-7 shows schematically the closure current system of FAC, Hall and Pedersen currents in the auroral regions.

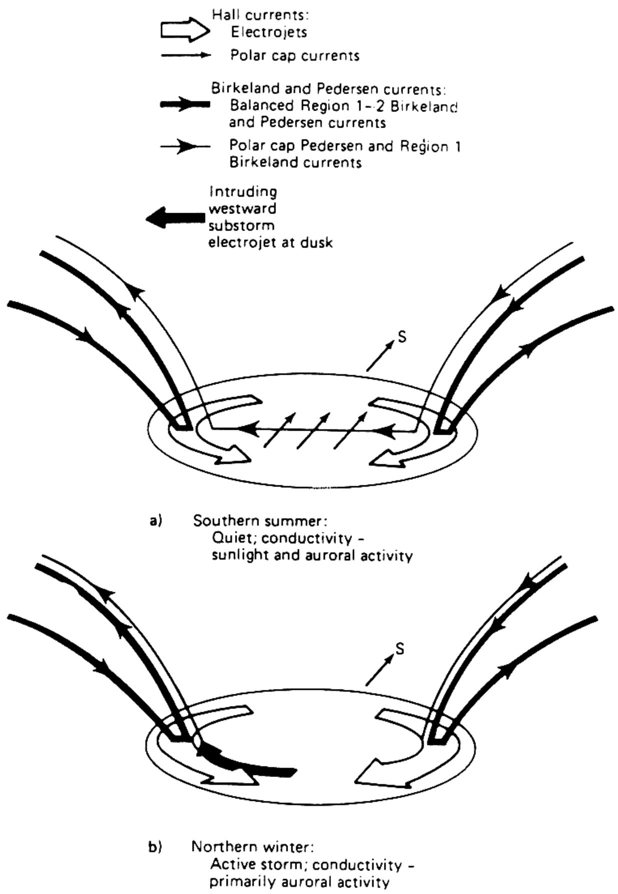


Figure 4-7 Presentations of the three-dimensional ionosphere current systems at high latitudes during quiet and active geomagnetic periods for two seasons.

Region 2 currents are mostly driven by the partial ring currents, which encircle the Earth at a distance of several Earth radii (see Figure 4-1). These FAC are observed at the equatorward side of the auroral ovals. Region 1 FAC are closely related to the electric potential drop across the magnetosphere, set-up by the solar wind-magnetosphere interaction (Vasyliunas, 1972; Potemra, 1979; Kamide et al., 1982; Stern, 1983). The whole system of currents around the Earth is more complicated than the above described, as also indicated in Figure 4-1. During substorms even the distant tail currents of the magnetosphere contribute to auroral and polar cap FAC.

Average measurements of region 1 FAC densities give magnitudes of the order of 1 $\mu A/m^2$ over a global latitudinal range of about 3 degrees (Kamide, 1982; Stern, 1983). While regions 2 currents have been found to have intensities equal to around 75% of the magnitudes measured typically for the region 1 currents.

Numerous model calculations of the current system in the ionosphere and magnetosphere have been performed (Vasyliunas, 1972; Spiro et al., 1981; Akasofu et al, 1980). The simulations have shown greater spatial detail in FAC than observed by satellite measurements. This discrepancy is strongly linked to the common detection method of FAC in space. Here the transverse disturbance in the magnetic field is measured in situ and associated with an average field aligned current. While in the model simulations FAC flow wherever there is a transverse pressure gradient in the direction of the gradient or curvature drift of the particle population (Vasyliunas, 1972). These simulations show that the ionosphere-magnetosphere coupling can produce FAC up to 80 $\mu A/m^2$ (Lyons, 1980).

Thus it is important to find an alternative method of measuring FAC, in order to resolve the large variability and the small-scale structure and intensity of FAC predicted in model simulations.

4.3 Relevance

4.3.1 Science Interest

All the scientists that are familiar with FACE-IT and the mission science objectives have shown great interest in the measurements and potential outcome for space physics. This can also be deduced in a preliminary fashion from the Letters of Recommendation. Thus it is clear that FACE-IT will get a very large international scientific attention with a high scientific yield.

The Danish institutes involved in FACE-IT cover research groups, which are involved in the usage of ØRSTED data and/or doing research in the physics of ionized gasses, ionosphere/magnetosphere physics and optical systems. Additionally come groups, institutions and researchers dealing with a range of other science aspects of the mission not described here.

The institutions primarily involved in the FACE-IT mission are:

Danish Meteorological Institute
Danish Space Research Institute
Technical University of Denmark
Risø National Laboratory

The international scientific support and participation have up to now been centered on a small group of scientists that either are contributing to the satellite instrumentation or have been devoted to the science objectives of FACE-IT. Thus the space science community expected to take part in FACE-IT has not yet involved. But we expect to have a similar large international group behind FACE-IT, as is the case for the ØRSTED mission.

4.3.2 Need and Usefulness

FACE-IT offers a unique opportunity to combine two mutually supportive instruments to meet the requirements for understanding the physics of FAC. The mission is necessary if temporal and spatial phenomena of FAC have to be addressed in a modern and thorough manner. Additionally, FACE-IT will observe the dynamical features of the ionosphere current system, which has not been done before with this type of new techniques.

4.3.3 Uniqueness and Complementarity

FACE-IT is unique in flying a new set of instruments to monitor the conditions of the ionosphere current systems. At the same the satellite will include new ways of doing in-orbit determinations that will result in improved data products.

The mission will also address the measurements in ways that use new analysis methods for combining the observations of electric currents, fields, electron densities and waves. This may very well result in new discoveries and conclusions regarding the ionosphere/magnetosphere current system and the relations to phenomena in the solar wind.

FACE-IT will be an important complement to the ESA CLUSTER-II. At the same the mission will be an important source of information for the global ground-station net, monitoring the conditions of the ionosphere.

4.3.4 Timeliness

The timing of FACE-IT is perfect if Denmark wants to possess an important international position in upper atmosphere research. FACE-IT will be an important complement to the ESA CLUSTER-II mission and all the ground-stations set up to support this mission. Thus a launch of the mission towards the end of the CLUSTER-II operational phase will result in a large international public and scientific awareness of FACE-IT, as has been the case for ØRSTED.

The plans in Scandinavia and USA (through NASA and NSF), preparing for electrodynamics missions for ionosphere/magnetosphere research, underlines the importance of the mission. FACE-IT will be the first satellite to address the physics of field-aligned currents with the suggested new set of instruments.

FACE-IT is natural successor to ØRSTED. The objectives of the two missions overlap nicely. Thus it is conceivable, that FACE-IT will extend the results of ØRSTED within the external field research. Additionally, FACE-IT will be able to exploit the acquired scientific knowledge of ØRSTED and become an important data source for this growing community of researchers and students at many universities and research institutions.

4.3.5 Relations to Other Missions and Research Programs

The FACE-IT mission is devoted to studies of the ionosphere/magnetosphere processes and relations. Earlier satellites studying similar objectives are, FAST, FREJA, ASTRID-2 and ØRSTED. Many of the findings and observations made in these missions will be enhanced by FACE-IT.

FACE-IT is also strongly related to the ESA CLUSTER-II mission focusing on the magnetosphere processes and the interaction mechanisms at the boundary of the magnetosphere. FACE-IT will be an important contribution to the extension of CLUSTER-II when flown towards the end of this mission. This can be seen by the interest expressed by ESA for the FACE-IT mission. Even if FACE-It will fly right after the completion of CLUSTER-II it will be a very valuable contribution to the understanding of the role of FAC during similar conditions as observed by CLUSTER-II.

FACE-IT fills the gap after the CLUSTER-II mission in European research activities related to the upper ionized atmosphere. This is why several European national institutions have expressed great interests in participating in the FACE-IT mission.

4.3.6 Education and Public Outreach

The FACE-IT mission has a great potential for providing university students at under-graduate and graduate levels in-depth knowledge in the processes of ionosphere physics and space research. At the moment 5 under-graduates, 2 graduates and 2 Ph.D.-students are already involved in aspects of the mission. When approved we foresee even more students participating in the instrument developments, performance verification, data analysis algorithm development and validation, simulation studies and data analysis.

The lesson-learned from the ØRSTED mission is that strong public interest arises when including a comprehensive plan for public outreach to schools and media. Thus it is our intention to pursue a similar public awareness of space research from the FACE-IT mission through www-information, talks, newspaper articles, and direct interactions and involvement of students in the project.

5. General Mission Characteristics

5.1 Scientific and Technical Requirements

5.1.1 FAC Monitoring Applying the FCM Instrument

In almost all satellite passes through regions magnetically connected to the auroral zone, magnetic fluctuations transverse to the Earth's main field are observed. The first observations of these transverse magnetic perturbations were made in the early sixties, and they were originally interpreted as hydromagnetic waves. However later observations have interpreted the transverse perturbations in terms of relatively thin current sheets flowing along the Earth's magnetic field. This interpretation of field-aligned currents (FAC) initiated a vast observational search for Birkeland currents (Kamide, 1982).

All interpretations tried to address the uncertainty, which follows by the fact, that vector magnetometer measurements along a single trajectory are insufficient to determine the curl (or divergence) of $\boldsymbol{B_o}$, and thus leave the equations open to an infinity of solutions. Making well-founded assumptions about the FAC current geometry, often leading to one-dimensional solutions, circumvent the problem. However, when the geometry is less clearly understood, which is frequently the case for filamentary fine scale structures, then the local magnetic measurements cannot be uniquely interpreted in terms of definite current densities. Thus a comparison between the derived currents and streaming particles becomes less meaningful.

Apart from the geometry issue the vector magnetometer is less sensitive to small-scale currents. Considering for the sake of the argument an infinite sheet current of density $\boldsymbol{J}$ and thickness Δx. The strength of the sheet current becomes,

$$J = \mu_0 \frac{\Delta B}{\Delta x}$$

which is inversely proportional to the scale size Δx. Thus the observations of fine-scale FAC structures with the vector magnetometer presents two problems. 1), the micro-current geometry is unknown and probably complex, and 2), the vector magnetometer sensitivity for small-scale structures is poor, being inversely proportional to the dimensions of the current filaments.

The FCM instrument removes these limitations by direct measurements of the plasma current. The basic concept of the observational method for the FCM instrument is the very general relation between magnetism and the electromagnetic relations of light, which was first determined by Faraday in 1845. The FCM is functioning on the fact, that the polarization characteristics of light, propagation along a glass fiber, coiled up in a ring, depends on the current running through the ring.

$$\alpha = V \int_S \vec{j} \cdot \hat{n} \, da$$

Here, $\vec{j}$ represents the current density, α the polarization change in the light caused by the plasma currents, and V a constant of the fiber coil material. The unit vector $\hat{n}$ is perpendicular to the surface S defined by the fiber coil. The above equation is also based on the direct relation of currents and magnetic fields, stated in the Maxwell equation,

$$\vec{j} = \nabla \times \vec{H} - \frac{\partial \vec{D}}{\partial t}$$

To assess the accuracy of the FCM instrument a range of computer simulations were performed applying plasma fluid assumptions. The sensitivity of both the FCM and the vector magnetometer was addressed to verify the qualitative results of Figure 4-4.

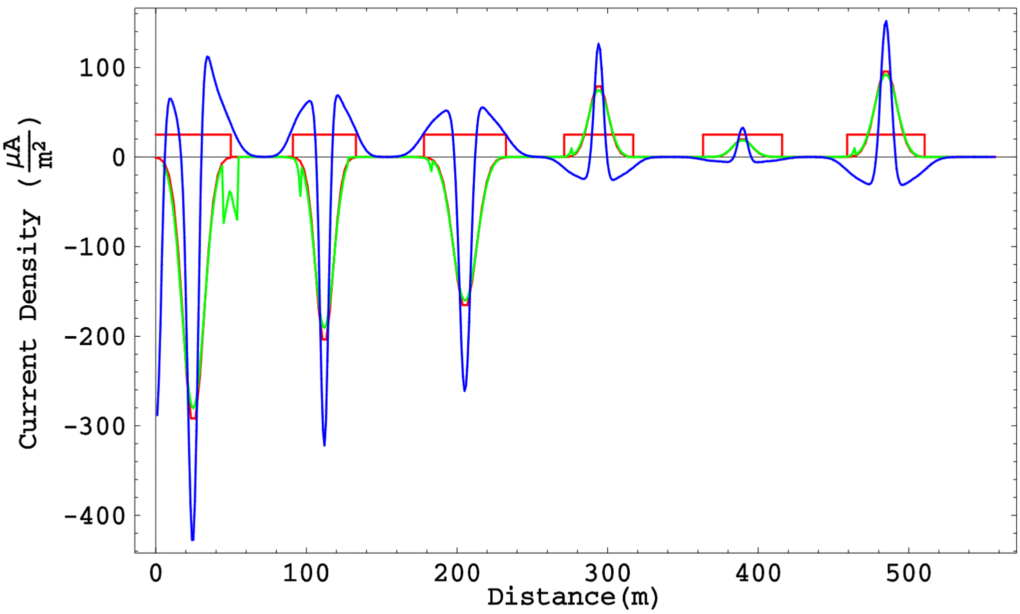


Figure 5-1 Calculated current densities from the FCM and DAM responses to small-scale FAC structures. In the simulation the spacecraft flies directly through the structures. The red curve shows the modeled FAC intensities. While the red squares depict the FAC scale sizes and structure. The blue curve gives the estimates by the vector magnetometer (DAM), and the green curve represents the FCM response. The FCM sampling rate was set to 7.0 kHz, and the diameter of the fiber loop was 10m.

For horizontal FAC scale sizes larger than 100 m the FCM measurements result in relative uncertainties less than 3%, with a minimum average resolution that is better than 10 $\mu A/m^2$. For worst case conditions with scale sizes less than 100 m (shown in the following figures) the absolute maximum error amounts to 18 $\mu A/m^2$, which relatively equals 6%. The simulated FAC structures were less than 55 m in horizontal extent over a distance of 500 m.

The errors of the vector magnetometer became at time more than 55%. In the first FAC structure, given in Figure 5-1, the absolute error of the vector magnetometer is 125 $\mu A/m^2$.

Figure 5-1 shows the response of the FCM instrument and vector magnetometer (DAM) during a flight through very small FAC filaments. The results represent the worst case conditions.

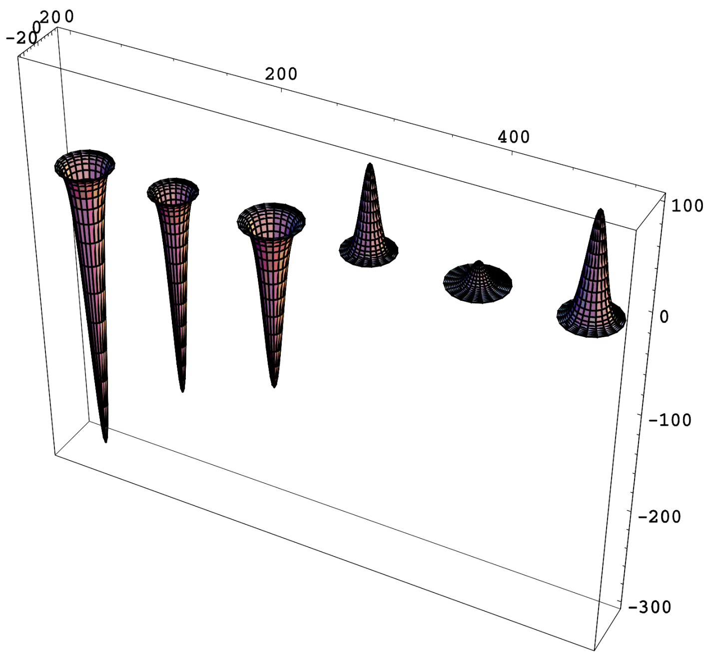


Figure 5-2 Model of the FAC structures and the current intensity distribution for the FCM response given above. The horizontal extent of the FAC structures varies from 40 m to 55 m over a total distance of 500 m.

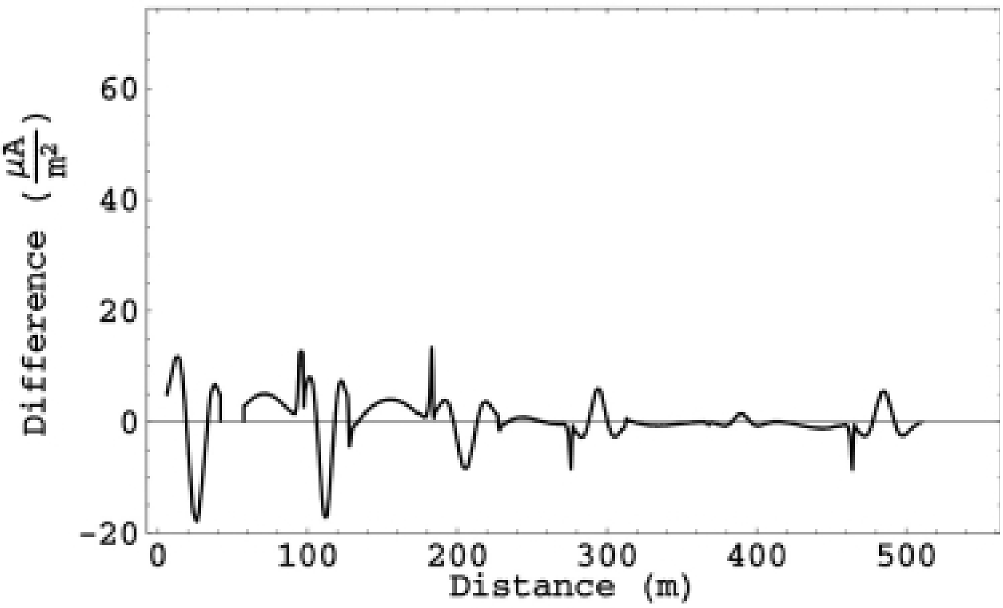


Figure 5-3 Current differences between the response of the FCM instrument and the actual simulated currents for small FAC filaments.

Figure 5-2 gives the FAC distributions along the trajectory of the satellite. The horizontal extent of the FAC structures varies from 40 m to 55 m over a total distance of 500 m.

Having not so sharp FAC current distributions, as in the presented simulation, lead to improved FCM estimates of the currents. Thus the current differences in Figure 5-3 represent the upper envelope of the instrument uncertainties. At the same time it sets the limit of the physical possible conditions in ionospheric plasma applying fluid assumptions.

5.2 Mission Specific Characteristics

5.2.1 Mission Duration

The nominal lifetime of the mission is 12 months in order to reach the scientific objectives.
Based on experience from FREJA, ØRSTED and ASTRID-2 the Commissioning Phase required needs only to be 2 months.
The designed in-orbit lifetime of all satellite elements has to match 36 months.

5.2.2 Orbital Specifications

The orbit of the FACE-IT satellite is envisioned to be polar with a high inclination (> 80°). To be able to monitor all high latitude daytime phenomena, a slowly precessing orbit is necessary, covering local times from 9:00 hours to 18:00 hours within the mission lifetime. Thus an initial sun-synchronous orbit could be possible, depending on the chosen launch opportunity.

The suggested altitude range of the circular orbit range from 700 km to 800 km.

5.2.3 Mission Timing

If the FACE-IT satellite can be launched during the lifetime of the CLUSTER-II mission and its possible extension period, it could contribute significantly to this mission. For CLUSTER-II it would be scientifically very valuable to be able to get information on the FAC structures of the ionosphere, when at the same time having ground measurements from radars, magnetometer chains and other ionospheric measurement facilities.

FACE-IT would pioneer this area of research. Other missions, suggested to NASA and a few European national programs covering similar topics, are just about to be included in their strategic plans. ESA has also had preliminary discussions on FACE-IT and how this mission could fit into the SMART program of the ESA Space Science Programme.

5.3 Data Products

Summary of key products from the main instruments is given in the table below. The data products have been grouped in lower level data (level 0-1) and processed/derived data (level 2-3).

Instrument	Data Level: 0 - 1	Data Level: 2 - 3
FCM	Beam splitter polarization components Laser and signal amplitude data Frequency shift data Noise data Sampling rate Housekeeping data	Polarization angles FAC density FAC spectral data
DAM	Fluxgate sensors output data (6) Signal spectrum data Sampling frequency Housekeeping data	AC/DC magnetic field vector data Attitude and sensor orientation data Magnetic field spectra
EMP	Electric potential differences (4 probes) E-field spectral data Sampling rate Current & voltage sweep data Health & housekeeping data	AC/DC electric fields E-field wave spectra Plasma density Plasma temperature
GPS	Pseudo-range measurements Carrier phase measurements (L1 and L2) Time Differential clock corrections Earth orientation data GPS positions and velocities GPS ephemeris data GPS orbital parameters GPS health data FACE-IT position and velocity data FACE-IT ephemeris data FACE-IT orbital parameters Predicted FACE-IT positions and velocities FACE-IT occultation sounding data	Residual phase observations TEC and d(TEC)/dt observations N_e scintillations Bending angle profiles TEC profiles Electron density profiles Refractivity profiles Error profile estimates Stratosphere/Troposphere temperature and pressure Global TEC field maps Global electron density distributions

5.4 Observational Requirements

Instrument	Observable	Accuracy/uncertainty/range		
FCM	FAC intensity FAC wave spectrum	< 10 μA/m² 1 Hz	0.1 μA/m² 0.5 Hz	0.1 - 1000 μA/m² 0.1 Hz - 10 kHz
DAM	DC magnetic field AC magnetic field B-field spectrum	0.1 nT 0.01 nT	0.06 nT 0.01 nT	± 65536 nT ± 5 nT 0.01 - 10 Hz 0.1 - 4 kHz
EMP	Electric field	0.2 mV/m	0.05 mV/m	± 5 V/m
GPS	Refractivity TEC Electron density Scintillations N_e spectrum	0.2 N units 3 TECU 10^{10} m^{-3} 0.1 radian	0.1% 3 TECU 10^{10} m^{-3} 0.01 radian	0.5 - 450 N units 3 - 1000 TECU 10^{10} - 10^{13} m^{-3} 0.1 - 20 radians 0.1 Hz - 1 kHz

6. Technical Concept

6.1 Instruments

6.1.1 FCM

When linearly polarized light passes through an optically transmissive medium, in which there exists a magnetic field parallel to the direction of propagation, the direction of polarization will be rotated. The effect occurs for all electromagnetic waves propagating in materials. But the magnitude of the rotation is very dependent on the state and composition of the medium. The phenomenon is known as the Faraday magneto-optic effect.

The design of the Faraday Current Meter (FCM) is shown in Figure 6-1. To achieve a highly polarized light source a laser is used together with polarizing beam splitters before the laser light enters the monomode fiber (Primdahl et al., 1986). Multimode fibers can not be used since the optical electric field is distributed among many modes with different spatial structure and individual propagation delays.

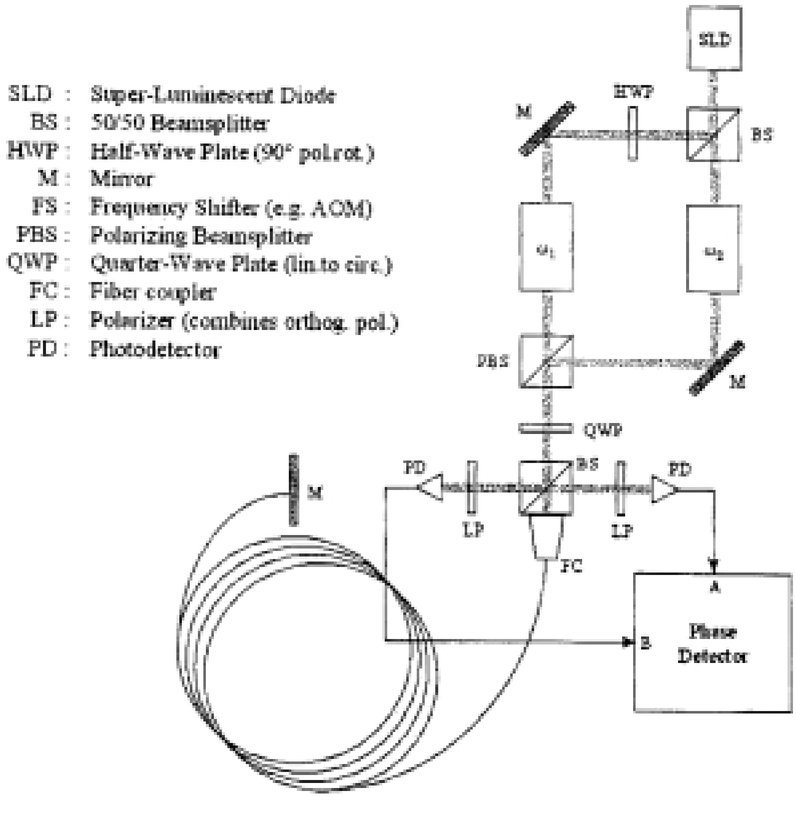


Figure 6-1 Outline of the FCM and the optical elements in the transmission and receiving system.

A longitudinal magnetic field ***H*** causes the polarization plane of the laser beam to rotate perpendicular to the direction of the wave number vector. The change in the polarization angle α becomes

$$\alpha = V \int_L \vec{H} \cdot d\vec{l}$$

where V is the Verdet constant for the fiber. The integration is performed along the entire fiber length *L*. Only the magnetic component parallel to the propagation path in the fiber will contribute to the rotation of the polarization plane of the wave. Applying Maxwell's equations, assuming no temporal electric field variations during the observation, lead to the basic relation expressing the Faraday rotation as function of the current intensity flowing perpendicular through the surface *S*.

$$\alpha = V \int_S \vec{j} \cdot \hat{n}\, da$$

$\hat{n}$ represents a unit vector perpendicular to surface *S*.

The main specifications of the FCM instrument are:

Coil size diameter:	10 m
Fiber length:	4.2 km
Laser wavelength:	1.55 μm
Mass:	1 kg
Optics, mass	1.0 kg
Electronics, mass	2.0 kg
Power:	5 W
Sensitivity:	< 10 $\mu A/m^2$
Data sampling rate:	1 - 10 kHz

A parallel development and cooperation will be established with the University of New Hampshire, USA (K. Lynch, private communication, 1999). The Danish development of the FCM instrument will take place by a consortium (lead by DMI) consisting of DMI and the companies Lucent Technologies, CRIMP and TERMA Industries.

6.1.2 DAM

The magnetometer experiment consists of a DC and an AC Magnetometer (DAM) using a common 3-axis fluxgate sensor (F. Primdahl, private communication, 1999). The steady magnetic field vector can be determined from DC level up to 10 Hz. While the AC magnetometer can measure the magnetic field components from the DC cutoff-frequency to 5 kHz.

DAM will be a further development of the instrument delivered to the ØRSTED, ASTRID-2, SAC-C and CHAMP mission. Below follows the specifications of DAM.

DC magnetometer

Power:	2.5 W
Sampling rate:	100 Hz
Range:	± 65636 nT

Resolution: 0.125 nT
Telemetry rate: 0.15 kbits/s
Noise level: < 0.06 nT
Offset stability: < ± 0.4 nT
Mass: 0.2 kg
Electronics, mass: 2.3 kg

AC magnetometer
Power: 2 W
3 dB passband: 0.1 - 4.0 kHz
Sampling rate: 8 kHz
Range: ± 5 nT
Resolution: 10 bits
Telemetry rate: < 50 kbits/s
Noise level: 0.06 nT
Electronics, mass: 0.65 kg

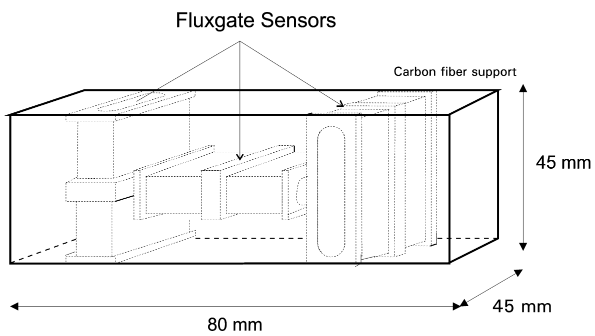


Figure 6-2 Sketch of the 3-axis fluxgate sensor of DAM.

6.1.3 EMP

The Electromagnetic field package (EMP) performs simultaneous sampling of the potential of four electric field probes (Marklund et al., 1994, 1997; Blomberg et al., 1997). In addition, since the electric probes are sampled individually, the spacecraft potential is continuously monitored giving information about the plasma density. Apart from the passively monitored electric fields, the probes may be actively swept in current or voltage to produce a current-voltage characteristic, from which information about the plasma density may be derived.

The main specifications of EMP are:

Power: 5 W
Sampling rate: 0.02 - 2 kHz
Range: ± 5 V/m
Resolution: 0.2 mV/m

Mass:	0.3 kg
Electronics, mass:	2 kg

6.1.4 GPS

The GPS instrument delivers two types of data for FACE-IT. The *navigation solution data* give the position and time of the satellite, which also aids the attitude control of the spacecraft. The *science data*, consisting of the ionosphere total electron content (TEC), electron density and fluctuations, refractivity, and spectral electron density information, are measured applying occultation techniques (Høeg et al., 1995). The method comprises of an observational scanning of the ionized gas when GPS satellite sets behind the Earth in the reference frame of FACE-IT (Figure 6-3).

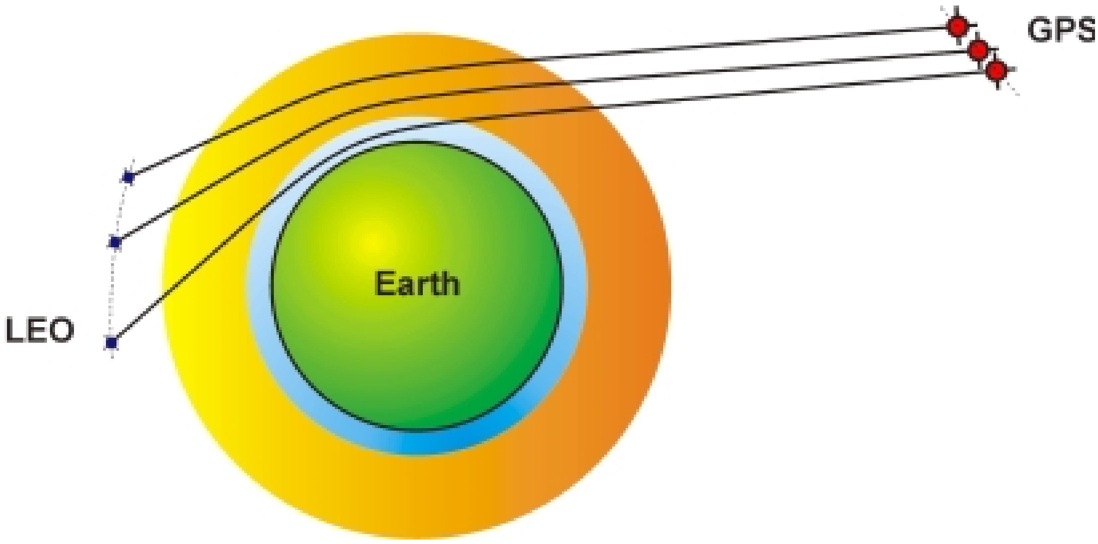


Figure 6-3 Schematic presentation of GPS limb soundings of the ionosphere electron density and fluctuations.

The reconstruction of the measurements result in information on the electron density of the ionosphere, which together with the collision terms determine the conductivity of the plasma. The next Figure shows global results of GPS limb soundings for the equatorial ionosphere (Høeg et al., 1998). The tomographical distribution of the F-region electron density have been obtained by combining measurements and ionosphere models in a similar fashion as done for the atmosphere, when applying numerical weather prediction models.

Two companies (Saab Ericsson Space (SES) and LABEN) and one institute (Jet Propulsion Laboratory (JPL)) can deliver the high-precision GPS receiver. The decision, which to choose, will be taken as part of the Phase A study and based on GPS receiver performance, price and technical maturity.

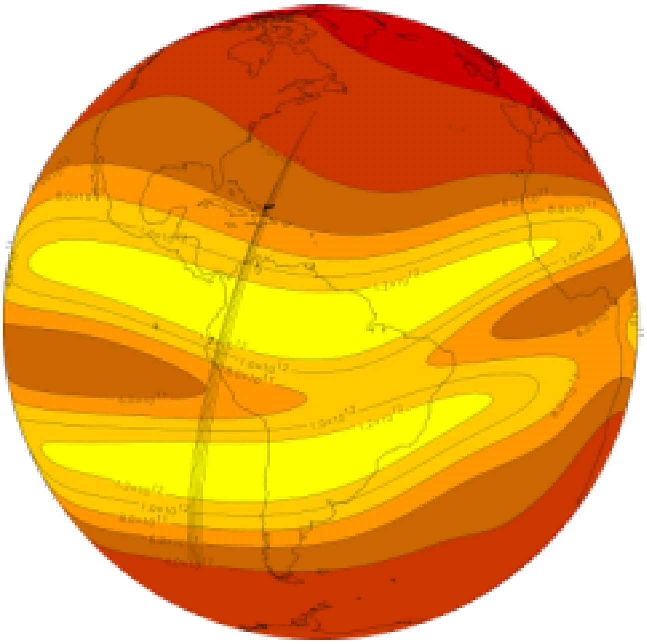


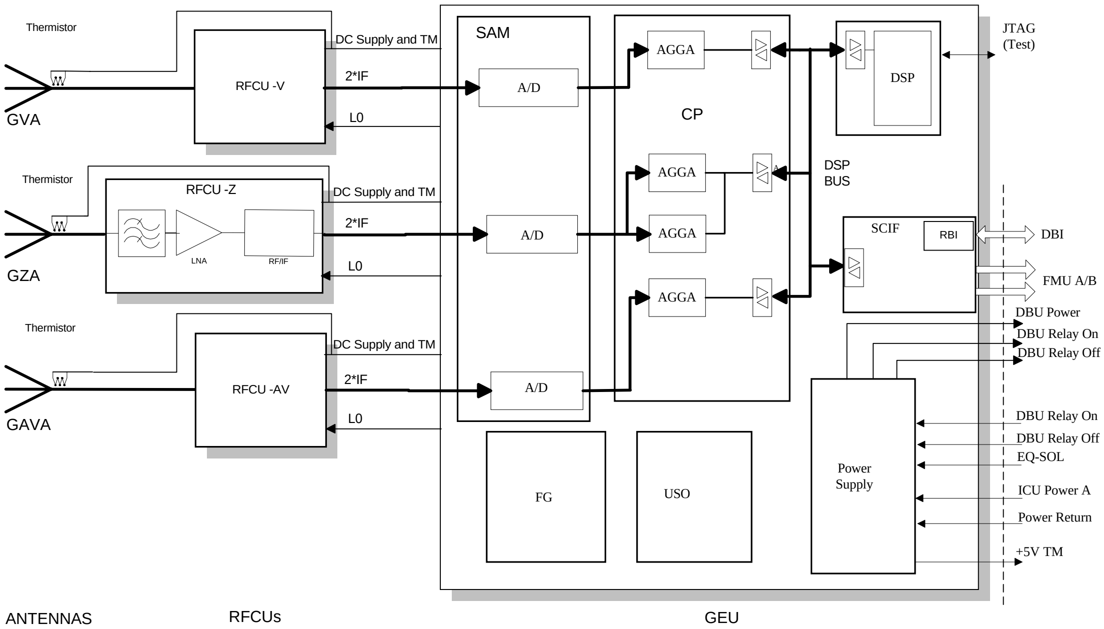
Figure 6-4 GPS occultation measurements of the equatorial ionosphere. The shown trajectories in the equatorial ionosphere are the ray paths of the GPS signals in the ionosphere.

The baseline architecture of the GPS receiver is schematically presented below. The instrument architecture described is identical to the currently developed receiver for the ESA/EUMETSAT METOP mission. This receiver (named GRAS) will fly on all future ESA Earth Observation missions. The JPL (TurboRogue) and LABEN (LAGRANGE) receivers have a similar structure and functionality as given below. Thus only the SES receiver (GRAS) is presented here.

The instrument has three receiving antennas. Two of these are used for the occultation measurements (GVA and GAVA) and one (the GZA) is used for navigation. Each antenna is connected to a dedicated nearby RFCU. Each RFCU contains pre-selection filters, low noise amplifiers, RF/IF down conversion and power supply regulator. The main function is to pre-amplify the signal to assure a good signal to noise ratio, while maintaining high distortion performance. Each one of the three RFCUs is connected, via harness, to the GEU in which signal processing, measurement and instrument control functions are implemented.

The Velocity Antennas, (GVA) and (GAVA) are directional antennas with mechanical bore sights in the velocity plane of the satellite. They are phased array antennas with an electrically tilted beam, so that the peak gain is pointing towards either the limb of the Earth or the ionosphere.

The Zenith Antenna (GZA) is a zenith pointed wide beam antenna for real-time navigation and POD. It is a planar antenna realized in the same technology as the other antennas. All the antennas are broadband performing so as to receive both GPS and GLONASS L1 and L2 signals. The antennas are right-hand circular-polarized.



GRAS Velocity Antenna (GVA)
GRAS Zenith Antenna (GZA)
Sampler (SAM)
Digital Signal Processor (DSP)
Frequency Generator (FG)
Power Supply (PS)
GRAS Anti-Velocity Antenna (GAVA)
RF Conditioning Unit (RFCU)
Channel Processor (CP)
Spacecraft interface (SCIF)
Ultra Stable Oscillator (USO)
Advanced GPS/GLONASS ASIC (AGGA)

Figure 6-5 Baseline concept of a high-precision GPS receiver.

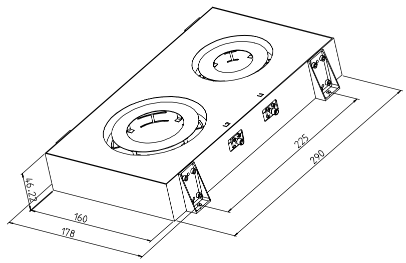


Figure 6-6 Baseline phased array antenna element for the GPS receiver.

6.2 System Concept

6.2.1 Spacecraft

FACE-IT will in its stowed configuration comply with the Ariane 5 ASAP constraints. The spatial dimensions are set to 60×60×80 cm, with an estimated weight of 75 kg. The satellite re-uses many of the elements of ØRSTED in concept and design. The mast for the FCM and DAM is thought to be a two-meter replica of the boom on ØRSTED

6.2.2 Platform

The platform is conceived as a modified ØRSTED platform. The carrying elements consist of four sides of the body, top and bottom, in a light sandwich structure, together with the canister for the main boom. The latter is suggested to be a 2.0-meter version of the ØRSTED main boom. This boom will carry the FCM and DAM instruments.

The four booms for the Langmuir probes of the EMP instrument will be glass fiber rods with the communication wires imbedded into the rods. The length of each rod is 2.0 meter. These boom and the EMP will reside on the top of the body of FACE-IT when launched, curled around the canister of the main boom.

The telemetry rate based on an analysis of the data streams is not particularly demanding. The S-band downlink data rate is suggested to be capable of 256 kbits/s. While the uplink should match 48 kbits/s.

6.2.3 Pointing Accuracy and Attitude Control

The primary attitude determination will be performed based on data from sun sensors, magnetometer and GPS instrument. This information will be used by three magnetic coils to active control the attitude of the satellite. The GPS receiver will continuously determine the attitude of the spacecraft by combining GPS signal phases from three antennas. The output, based on GPS alone, gives knowledge about the three dimensional orientation to within ±2° (with an attitude rate change of <1°/sec). The sun sensors at the corners of the satellite provide better than 10°-attitude information. Thus the total attitude control subsystem will maintain the platform stability and pointing accuracy to better than one degree.

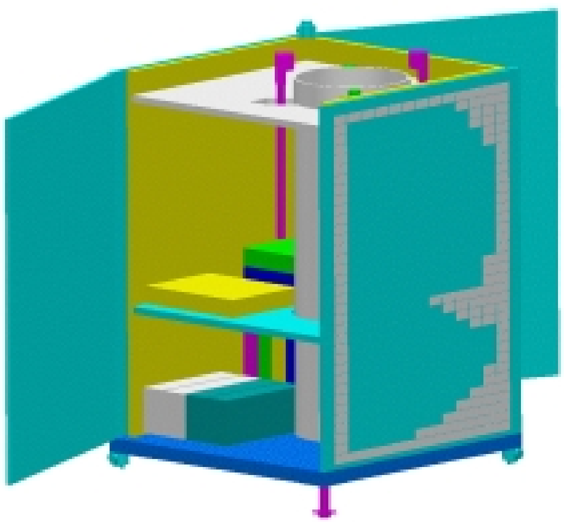


Figure 6-7 The FACE-IT satellite body. View of the interior.

6.2.4 Configuration and power

Power component	Size	Comments
FCM	5.0 W	
DAM	4.0 W	
EMP	5.0 W	
GPS	10.0 W	
Total for the main payload	**24.0 W**	
Platform	33.0 W	
Total for the satellite	**57.0 W**	

Battery charging	10-120 W	Seasonal variations
Required solar panel output	60-210 W	TBD
Number of panels	8	4 on the satellite body, 4/(8) on the deployable wings
Solar panel efficiency (EOL)	0.12	GaAs
Required panel area	3.0 m^2	TBD
Battery	10 Ah	35 min eclipse, 25% depth of discharge

6.2.5 Subsystems

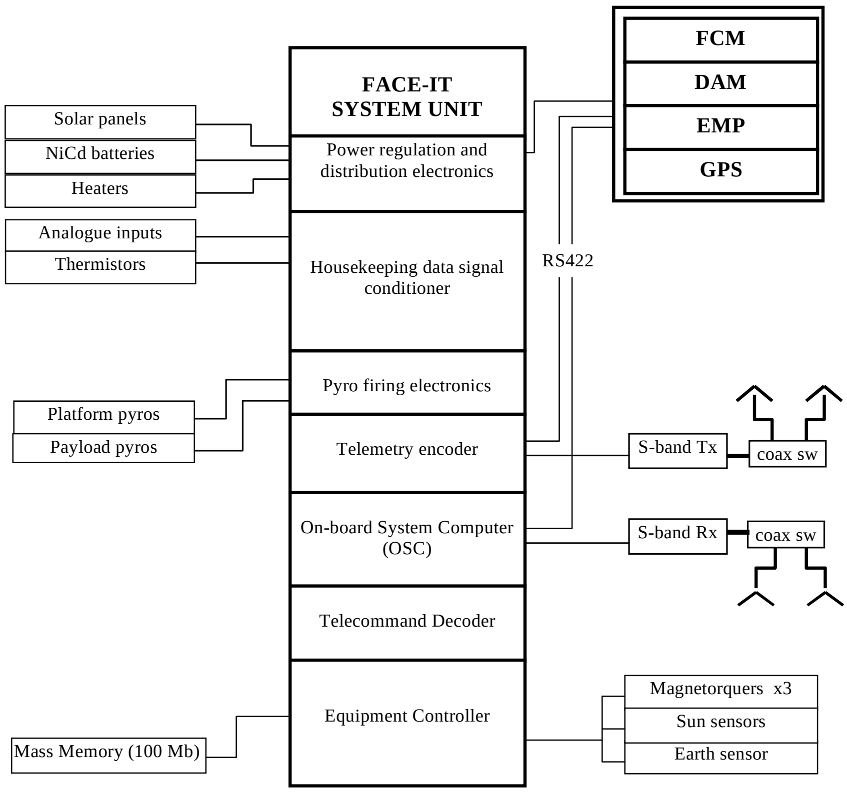


Figure 6-8 Configuration outline of the FACE-IT subsystems.

The platform uses a *System Unit* (SU) concept. This means that essentially all platform electronics are located inside a few boxes, which interface directly with external equipment units. The chosen data bus format for all equipment complies with the RS422 data bus.

The functions of the FACE-IT System Unit (FSU) are shown in the Figure 6-8. Modifications are required with respect to the ØRSTED System Unit. The grounding system uses a Single Point Ground (SPG) concept whereby currents are prevented from flowing in the structure. Separate grounds are required for power and signal returns. Units violating this requirement are typically the radio units. These are therefore located either on the FSU chassis or in immediate adjacency to the SPG. All external electrical units have dedicated DC/DC converters.

Budgets and development status of the various subsystems is as shown in the table below.

Item	Status	Comment	Mass (kg)	Power (W)
Power s/s	Basic available version with some modifications		5	
Structure	To be developed	Honeycomb structure	22	
Canister	Basic available		6	
Solar panels and substrates	Developed, need new adaptation	New materials will be tested	2	
Mechanisms	Available		3	
Harness & thermal	To be developed	Standard manufacturing practices	4	3
Booms boom motor	Booms for EMP to be developed. Main boom are developed, need new adaptation	ØRSTED design	3	5
System units	New version		7	12
ACS Earth sensor Sun sensor Magnetorquers	Available	Modified ØRSTED design	3	3
Com. System, S-band	Available		2	10
Misc., balancing			1	
Mass Margin			2	
Total			60	33
Payload			15	24
Total			75	57

6.2.6 Ground Segment

The FACE-IT ground segment is outlined in the figure below for two of the instruments. The data flow structure serves as a master for the ground segment of all science instruments of the FACE-IT mission.

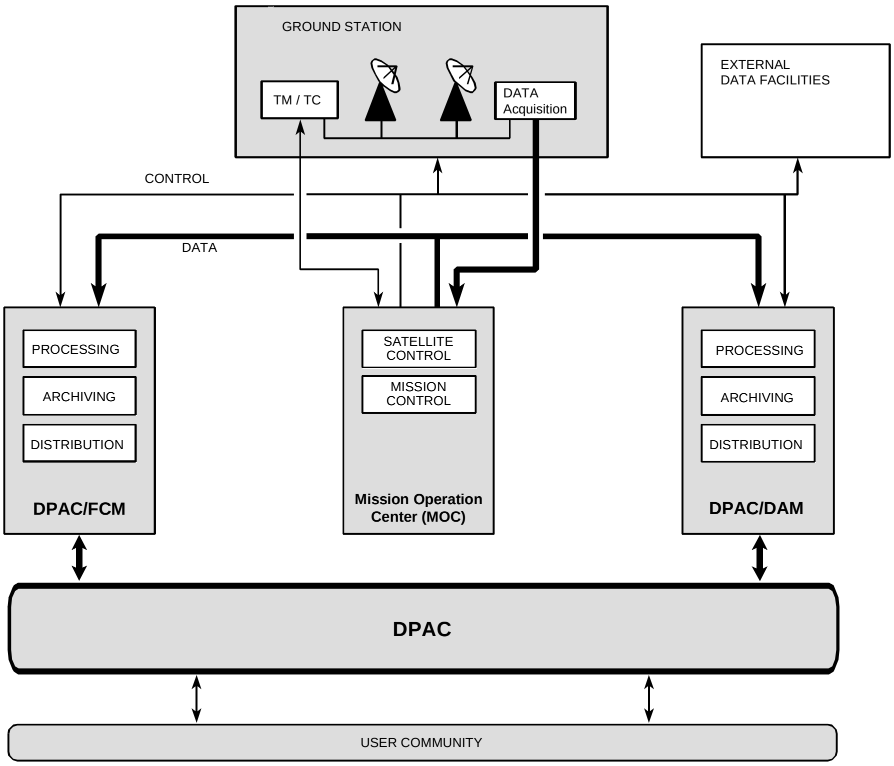


Figure 6-9 Data flow for the FACE-IT ground segment.

6.2.7 Launchers

The suggested orbital plane requires nominally only a piggyback launch. Thus an ASAP opportunity launch on an Ariane 5 rocket seems to be the most cost-effective solution for FACE-IT.

High inclination orbit piggyback launches are rather scarce. But towards the end of 2003 and around the middle of 2004 ArianeSpace has offered to reserve an ASAP launch for FACE-IT (see attached letter from ArianeSpace). The first launch mentioned is as co-passenger to the EPS/METOP-1 mission, which is an ESA/EUMETSAT mission.

METOP-1 has presently a scheduled launch in June 2003. But it is now rather certain that the launch will slip 6 - 12 months and be at the earliest in January 2004.

The least expensive dedicated launch opportunity for FACE-IT is the START launch vehicle, which can lift 420 kg into a 700-km polar orbit. Other low cost possibilities are

COSMOS and ROCKOT. The table gives the offered the launch prices for a FACE-IT mission on these vehicles in the timeframe covering year 2003 and 2004.

Launch vehicle	Payload mass (kg)	Polar orbit (km)	Price (MDKK)
START	400/420	800/700	58
COSMOS	800	1000	78
ROCKOT	1200	800	98
Ariane 5 ASAP	100	800 - 2000	7

Due to the high scientific profile of the FACE-IT mission CNES (France) has indicated, that they will considered to cover the launch expenses as part of the negotiations for a strengthened French involvement in the mission. Ongoing discussions with ESA could lead to a similar conclusion with ESA covering the above given launch costs.

6.2.8 Operations

The entire FACE-IT system will require various levels of monitoring and control consisting of the following elements.

Operation of the instruments will be monitored at the Data Processing and Analysis Center (DPAC). This entity will also plan observation schedules and routines. Daily operation will be automated and anomalies in instrument performance will be flagged to the principal investigator. After appropriate analysis the DPAC will request the Mission Operation Center (MOC) to initiate specific commands to change the operational mode or to correct the performance of the instrument.

Spacecraft operations will be handled at the MOC. The Center will monitor the satellite performance and execute the various planned commands. Daily operations will also be automated and anomalous behavior will reported to the MOC staff, who will then interact with the satellite to correct the reported anomalous behavior.

Mission control operations will normally consist of automated monitoring of the satellite where anomalies in the satellite configuration or ground system performance will be reported to the appropriate staff. Satellite constellation orbit and configuration keeping maneuvers will be performed at regular intervals or upon demand. Changes in instrument operations or observation schedules will be executed when requested through the DPACs.

Commissioning operations will comprise of satellite commissioning including:

- Damping phase, to reduce the high angular rates of the satellite induced by the separation from the launcher
- Unfolding phase, where the booms are deployed
- Acquisition phase, to bring the satellite to the nominal attitude condition
- Nominal phase, to keep the satellite in nominal attitude conditions

Data processing, archiving and distribution at the DPACs will be done automatically for the standard data sets.

6.3 Technological Complexity

6.3.1 Feasibility

The proposed mission is highly feasible. Not only is the scientific relevance well established, but also the technical approach is based on elements which all have a very sound technical basis.

Acquisition of the scientific data will be made with observation techniques and instruments for which the underlying principles have already worked out, and for which preliminary experimental evidence have already been obtained in experiments done on European and American satellites.

Processing of data will be handled through the use of algorithms that are already developed, so that the scientific data will be useable from the very beginning of the operation of the satellites.

The technical implementation of the space and ground segment is not particularly complex, and none of the various subsystems will be required to go beyond the present state-of-the-art in order to fulfil the scientific requirements for the mission.

6.3.2 Subsystem maturity

The various constituents of the system are based on previous developments as illustrated in the description below.

The FCM will be the main instrument currently under development.

The spacecraft is derived from the ØRSTED platform. The subsystems are based on concepts and design from the ØRSTED, FREJA, ASTRID-2 and CHAMP spacecraft.

The ground segment is implemented based on the known control center facilities for ØRSTED and ASTRID-2.

6.3.3 Reuse of Elements

A considerable reuse of components, design and technology is foreseen. A more detailed review of the heritage of the various system elements is presented in next section.

6.4 Heritage Aspects

The present section provides an overview of the way in which each of the mission elements derives its design or implementation from previous developments.

Mission element	Design Heritage	Implementation Heritage
FCM	New state-of-the-art development	
DAM	Detector and electronics: ØRSTED, SAC-C, ASTRID-2, CHAMP	ØRSTED, SAC-C, ASTRID-2, CHAMP
EMP	ASTRID-2	FREJA, ASTRID-2
GPS	ØRSTED, CHAMP, METOP	METOP, NPOESS
Space craft	ØRSTED	ØRSTED
Structure	ØRSTED development	ØRSTED
Power S/S	ØRSTED development	ØRSTED
System Unit	ØRSTED development	ØRSTED
On-Board Software	ØRSTED development	ESA standards
Communication S/S		Commercially available
ACS S/S	ØRSTED	ØRSTED ACS
AIV/AIT facilities AIT procedures	ESA, ASTRID-2, ODIN, ØRSTED ESTEC Test Facility	SCOS 2000 with EGSE extensions
Mission Control Center	ASTRID-2, ODIN, ØRSTED	SCOS 2000 at ESOC Flight Dynamics facilities at ESOC
Ground Stations	ASTRID-2, ODIN, ØRSTED	Commercially available
DPACs	Developments for existing small satellites and ESA EOPP Specifications for NPOESS	Current processing of GPS/MET, ØRSTED, FREJA, ASTRID-2, NPOESS and METOP data

6.5 Product Assurance

The FACE-IT mission product assurance is covered in the chapters dealing with the project management and responsibilities.

To provide product assurance functions, which are compliant with the requirements and mission objectives, a Product Assurance and Requirements Document will be prepared based on existing standards. This document together with the other documents related to this topic must comply with the overall mission objectives, goals and plans.

7. Mission Elements and Costs

7.1 Overview of Total Costs

The current budget costs for FACE-IT are summarized in the table below (1999 economical conditions).

Most numbers originate from the offers put forward by Instrument Consortia, Companies and estimates of the expenses in the ØRSTED and ASTRID-2 missions. The novel and state-of-the-art concept of FACE-IT makes it necessary to devote extra resources to the science definition studies. But this budget fact stresses the importance of the project.

Mission Element		Total Costs (MDKK)	Assumed DSSP Funding	Assumed Other Funding
Science preparation	Scientific definition studies	4.0	4.0	0.0
	Algorithm developments	6.0	6.0	0.0
System engineering and assembly integration and test		7.0	3.0	4.0
Space segment	Instruments	25.0	20.0	5.0
	Platform	35.0	10.0	25.0
	Launcher	7.0	0.0	7.0
Ground segment facilities	Command and acquisition stations	8.0	3.0	5.0
	Mission Operations Center	7.0	4.0	3.0
	Processing and archiving	7.0	7.0	0.0
Mission control and data exploitation	Mission Control	2.0	2.0	0.0
	Data utilization	1.0	1.0	0.0
Total		**109.0**	**60.0**	**49.0**

7.2 National Funding from the Small Satellite Program

It is assumed that for the period 2000 - 2003 that the Danish Small Satellite Program, as stated in the Proposal Guidelines and Requirements Document (1999), will make available to the mission 15 MDKK per year. Additional to this basic amount come industrial funding, ESA and maybe US contributions. It has not been possible to identify these funding in great detail because of the state of the mission. But it seems conceivable that other assumed funding will be found due to the great scientific potential of the FACE-IT mission.

7.3 Other Funding

For the moment, and on this level of commitment, other national funding together with contribution from other nations and international organizations have not been possible to identify and secure. Thus this item will be one of the first activities towards the end of 1999 after the down select. It will also be addressed in the first quarters of the of the project, since it is one of the major risks in the program.

8. Project Management

The project management approach will be based on the structure outlined for the ESA PLANCK Mission (ESA Document No. ESA/SPC(97)27, 1997).

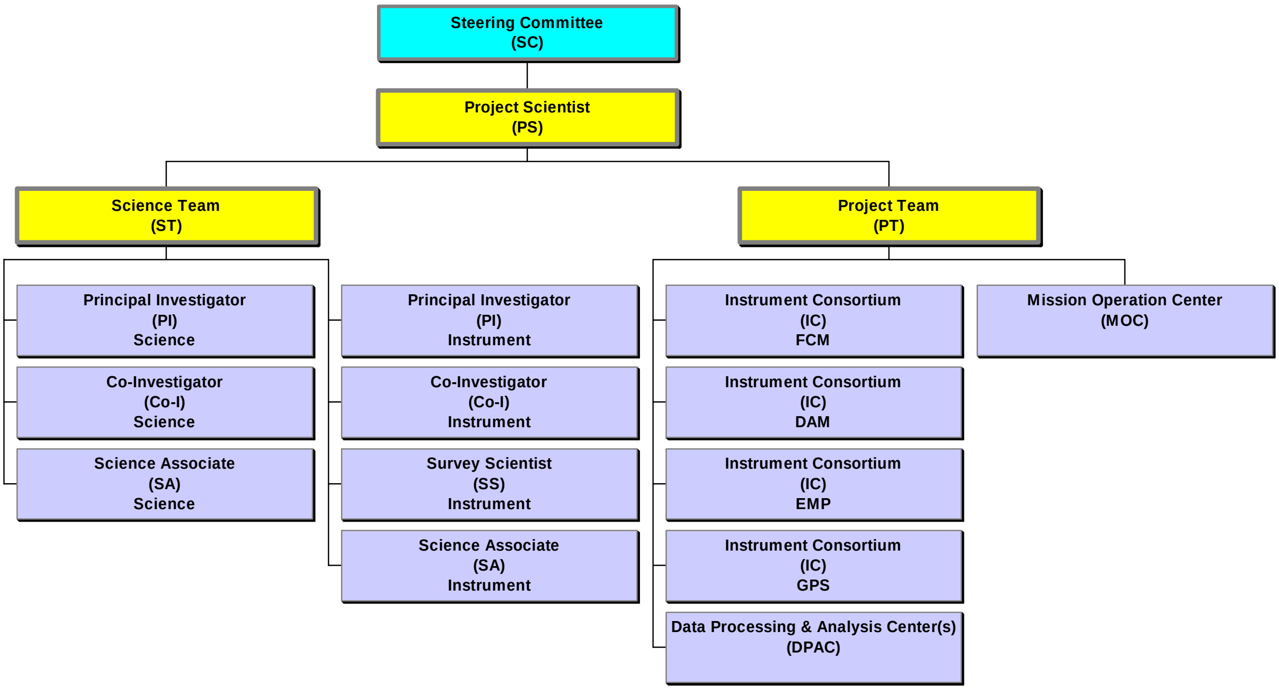


Figure 8-1 Organization diagram for the FACE-IT project.

The main management layers for FACE-IT consist of:

- ***Steering Committee*** (SC)
- ***Project Scientist*** (PS)

- ***Science Team*** (ST)
    - Project Scientist (PS)
    - Principal Investigators (PI)
    - Survey Scientist (SS)
    - Co-Investigators (Co-I)
- Science Associates (SA)

- ***Project Team*** (PT)
  - Instrument Consortia (IC)
  - Mission Operation Center (MOC)
  - Data Processing & Analysis Center (DPAC)

The two teams (ST + PT) below PS in the organizational structure will address the science issues and the developments of all satellite mission elements. ST will be responsible for science objectives and their fulfillment together with the science algorithms and data formats. PT will take care of the developments, integration and testing.

The next sections describe the project management elements in further detail and the responsibilities of each level of the FACE-IT organization.

8.1 Project Management Structure

The *science operations* will be supported by four main entities:

- A Mission Operation Center (MOC)
- A Science Team (ST)
- Instrument Consortia (IC)
- Data Processing & Analysis Centers (DPACs)

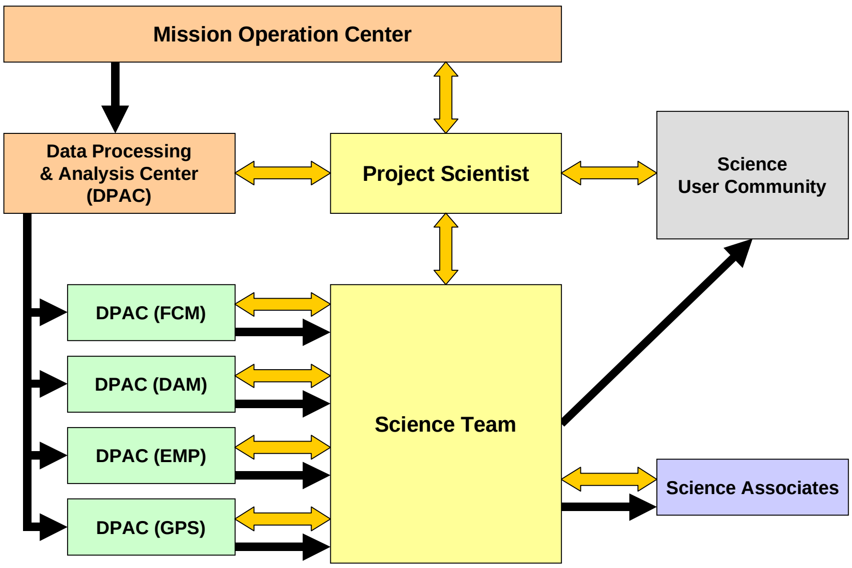


Figure 8-2 The data and information flow in the FACE-IT project. The single arrows indicate the data flow. While the double-arrows show the information flow.

The *data flow* in the operational phase of this structure will be from the satellite to the MOC, which distributes data to DPAC/DPACs and ST (see Figure 6-9 and Figure 8-2).

If found most effective, parts of the DPAC of the ICs may be centralized into a unified DPAC.

The *information flow* in the commissioning and operational phase consists of the following information routes, depicted in Figure 8-2.

- ♦ MOC ⇔ PS
- ♦ PS ⇔ ST + DPAC
- ♦ PS ⇔ User Community
- ♦ ST ⇔ IC-DPACs + SA

Below follows some of the tasks and responsibilities for each level of the FACE-IT project. The interfaces, command and decision structures are also been outlined here. Further details and plans will be part of the mission documents for the FACE-IT project.

8.1.1 Steering Committee

The prime task for The Steering Committee (SC) is to seek in an effective manner the successful realization of the FACE-IT mission and its objectives.

The decisions of SC will be executed via the Project Scientist (PS), the Science Team (ST) and the Project Team (PT). The Terms of Reference of SC and other entities of the FACE-IT project will be a prime agenda item on the first meeting of SC.

PS will perform the daily decision. While major decisions and recommendations await approval of SC, unless otherwise decided by SC. PS formulate recommendations for decision at SC, based on own evaluations and inputs from ST and PT.

SC will have the overall responsibility for the mission and the availability of funds for a successful completion of the mission. All formal decisions, major agreements and seeking of funds will be the responsibility of SC.

8.1.2 Project Scientist

The Project Scientist (PS) will act as the interface between the Science Team (ST), the Project Team (PT) and the Steering Committee (SC). Due to the limited size of the project PS will also be equivalent in some functions to a Mission Scientist.

PS will also interface with the Instrument Consortia (IC) for scientific matters. PS will be the interface to the Project Manager of PT until completion of the satellite in-orbit commissioning and thereafter with the Mission Operations Manager at the Mission Operation Center (MOC).

During all phases of the project, PS will coordinate all scientific issues with ST and PT. In particular, PS will advise on technical matters when they affect the scientific performance. During the development and operational phases, PS will monitor the state of implementation and readiness of the instrument operations and data processing infrastructure. After the completion of the in-orbit operations PS will coordinate the creation of the scientific products, their archiving and distribution to the scientific user community. PS will assume responsibility for management of the FACE-IT project at a suitable time after launch, according to the guidelines set out in the Phase A recommendations for the project management.

The Project Scientist will act as the Chairman of ST and as such coordinate the activities here. PS will oversee the preparations and execution of all scientific operations.

The Project Scientist (PS) is a permanent member of SC.

8.1.3 Science Team

The Science Team (ST) is composed of scientists (Principal Investigator and Survey Scientist) representing each Instrument Consortium (IC), associated Co-Investigators (Co-I) to each IC, Scientific Principal Investigators and Co-Investigators not directly attached to any specific Instrument Consortium, and Science Associates (SA). Thus the following group forms ST.

- The Project Scientist
- One Principal Investigator and one Survey Scientist for each Instrument Consortium
- One Scientific Principal Investigator (equivalent to the Principal Investigator of the Instrument Consortia, and therefore named PI) responsible for a specific group of objectives of the mission
- A number of Co-Investigators and Science Associates

In general, the members of ST will be expected to monitor and advise on all aspects of FACE-IT, which affect its scientific performance. In particular, they will participate in major project reviews, and perform specific tasks as needed during the development and the operational phase.

Ad-hoc experts will be invited to attend ST meetings as the need arises. The specific number and expertise of these experts will vary during the development of the mission to reflect the current needs. ST will mainly rely on the technical support of the ICs for the fulfillment of its functions. However, if deemed necessary, PS may request external scientific consultant(s) to conduct an independent review of any of the activities, which normally fall under the responsibility of ST and/or the ICs.

ST will be formed after selection of the mission. ST will remain in place until the scientific products are delivered to the community.

8.1.4 Project Team

The FACE-IT mission will maintain a Project Team (PT), directed by a Project Manager, until completion of the satellite in-orbit-commissioning phase. The Project Manager and the Project Team will have the daily responsibility for the mission. The overall responsibility retains with the Project Scientist and Steering Committee.

The main responsibilities of PT are:

- The procurement of the spacecraft and instruments
- The instrument integration into the spacecraft bus
- System testing and execution of calibration and validation plans
- Spacecraft launch and operations
- Acquisition and transmission of data to the DPACs/DPAC

The procurement approach will rely on PT delegating tasks to industrial contractors. PT will, via the Project Manager, control the process of definition of mission requirements and payload interfaces and the preferred spacecraft design.

PT will be responsible for the procurement of the spacecraft and instrument integration into the experiment module and its integration onto the spacecraft bus, system testing and execution of calibration plans, spacecraft launch and operations, and acquisition and transmission of the data to the DPACs. PT will monitor and control the work of the spacecraft industrial contractors and determine suitable satellite launch dates. During the development phases of the mission, PT will also monitor the development of the instruments, and ensure their timely readiness by monitoring the adherence of development plans to the agreed schedules. PT will decide on the technical specifications, monitor and control all interface specifications for the instruments, the spacecraft, and the information exchange specifications among all parties involved. The final decision resides with PS and SC.

8.1.5 Instrument Consortia

Four Instrument Consortia (IC) will be selected. Each IC will be expected to satisfy the following conditions.

- Each IC will be led by a single Principal Investigator (PI), who will act as interface to the Project Team and as member of the Science Team.
- Each IC will include a Survey Scientist (equal to a senior scientist), who will provide scientific guidance to IC and ST, and in particular oversee the development and operation of the data processing structure proposed by IC. The Survey Scientist (SS) is expected to be an active member of IC, and to have a significant involvement in the scientific exploitation of the data. However, SS should preferable be institutionally independent from the PI. SS will be a full member of ST and participate actively in its work.
- Each IC will be committed to carry out the following tasks:
    - Development, delivery and operation of an instrument (EM and FM).
    - Daily and longer term processing of the payload data.
    - Reduction, distribution, and archiving of the scientific data.
    - Scientific exploitation of the data.
- Each IC will contain a well-specified and identified management layer consisting at least of an experienced Technical Manager (responsible for instrument techni-

cal development) and a Data Processing Manager (responsible for development and operation of the data processing activities and facilities).

- Each IC will provide a central location where the data will be delivered from the MOC. Data reduction activities may be carried out at this location or in a more distributed fashion.
- Each IC is encouraged to involve additional associates, who could contribute actively to specific scientific and technical aspects of the mission throughout its development, operational, and exploitation phases.

Dedicated teams from within the IC will process the data from the instruments in parallel during all phases of the mission. IC will ultimately be responsible for the creation, delivery, archival, and distribution of the scientific products of the mission. If concluded from the recommendations of Phase A, all DPAC activities may be centralized in one single DPAC, giving only limited responsibility to the DPAC of each IC. This will need approval of PS and SC.

It is essential from technical, programmatic and cost viewpoints that a representative example of the flight instrument is developed, tested, and calibrated early on in the program. This will be vital for the demonstration of the scientific performance of the instrument, the flight worthiness from an engineering viewpoint and the ability to provide a valid scientific return for the lifetime of the mission.

8.1.6 Mission Operation Centers

The satellite will be controlled from the Mission Operations Center (MOC), via one or two ground-stations. The MOC will be designed, developed, and operated by the FACE-IT project.

In addition to the usual tasks of preparing for and carrying out spacecraft operations and mission analysis, the MOC will be responsible for supporting PS on all aspects concerning spacecraft operations. MOC will also maintain a database containing the raw payload data (for a period of no less than 10 years) and the spacecraft plans based on the Operations Plan. MOC will execute the PS requests for satellite commands and uplinking them.

The processing of Data Level 0 and 1A products (daily stripping of the payload data and housekeeping from the telemetry stream, ordering and correcting data stream chronology, flagging of data gaps and out-of-limit observational errors, and making all the data available to each DPAC) will be performed by MOC. Additionally, MOC will on a continuos basis alert the PS of all significant anomalies and/or deviations from the expected behavior of the spacecraft, and executing predetermined procedures to safeguard the spacecraft and payload.

8.1.7 Data Processing & Analysis Centers

The Data Processing and Analysis Center (DPAC) support all instrument operational phases. It provides the necessary hardware, software, information and manpower to the FACE-IT project. In particular, the PIs must support DPAC pre-launch instrument operations (e.g. instrument calibration analysis and simulation, and orbit operational phase functionality). In the operational phase DPAC shall inform the project (PS and ST) about the occurrence of transients and/or anomalous events in the data stream.

If concluded from the recommendations of Phase A, all DPAC activities may be centralized in one single DPAC. Such a strategy will result in only limited responsibility for the DPAC of each IC for some of the mentioned issues. The decision will require the approval of PS and SC.

DPAC must ensure, that all data processing and analysis devices including storage devices/media and output devices that are required for the full functionality are available within the scheduled times. This functionality must be at a level appropriate for the mission objectives and for the lifetime of the mission.

DPAC must make certain that the development, testing and documentation of all DPAC specific software (e.g. data access layer, user interfaces, simulation, database management, archiving etc.) are in accord with defined procedures and schedules. DPAC must execute the archiving phase and ensure that all created software is maintained and updated. Additionally, DPAC must provide the scientific user community with data and archives in agreement with procedures and schedules defined by PS and SC.

8.2 Distribution of Responsibilities

Once the FACE-IT mission are selected the detailed plan will reveal the project responsibility matrix for the science consortium as well as the industrial consortium.

The leader of the Project Team will be chosen from industry or from the staff working for the Danish Small Satellite Program at DSRI.

8.2.1 Science Team Responsibilities

- Acting as a focus for the interest of the scientific community in the FACE-IT mission.
- Maximizing the scientific return within the given boundary conditions, while at the same time insuring that the development of the mission remains compatible with the main scientific objectives.
- Reviewing the scientific goals and objectives at regular intervals in the light of recent results.
- Considering the technical requirements of the spacecraft in view of the mission objectives.
- Advising on scientific aspects of the development of the instruments.
- Formulating and optimizing the Observations Program and calibration/validation strategies, both from scientific and operational viewpoints.
- Defining and constructing an Observations Plan, which will be implemented by DPAC and MOC.

- Recommending updates or changes to the Observations Plan during the operational phase. Requesting and assuring their implementation by MOC.
- Defining data rights and publication policy following the established guidelines.
- Making efficient efforts to promote public awareness and appreciation of the FACE-IT mission.
- Supporting PS and SC in its public relations efforts.
- Preparing for and overseeing the analysis of the data.
- Creating and delivering the final scientific data products to the community.
- Oversee the organization of the data archiving

8.2.2 Project Team Responsibilities

- Daily responsibility for the mission.
- The procurement of the spacecraft and instruments.
- The instrument integration into the spacecraft bus.
- System testing and execution of calibration and validation plans.
- Spacecraft launch and operations.
- Acquisition and transmission of data to the DPACs/DPAC.
- Control the process of definition of mission requirements and payload interfaces and the spacecraft design.
- Spacecraft and instrument integration into the experiment module and its integration onto the spacecraft bus.
- System testing and execution of calibration plans.
- Spacecraft launch, operations, acquisition and transmission of the data to DPACs/DPAC.
- Monitor and control the work of the spacecraft industrial contractors.
- Monitor the development of the instruments.
- Ensure instruments timely readiness by monitoring the adherence of development plans to the agreed schedules.
- Advise on the technical specifications.
- Monitor and control all interface specifications for the instruments, the spacecraft, and the information exchange specifications in accordance with the mission objectives.

8.2.3 Instrument Consortium Responsibilities

- Elect a single Principal Investigator.
- Elect a Survey Scientist.
- Specify and identify a management layer consisting at least of a Technical Manager and a Data Processing Manager.
- Development, delivery and operation of an instrument (EM and FM models).
- Create, deliver, archive, and distribute the IC scientific mission products.
- Daily and longer term processing of IC payload data.
- Reduction, distribution, and archiving of the IC scientific data.
- Scientific exploitation of the data.

- Identify and provide a central location, where mission data will be delivered to from the MOC.
- Involve additional associates, who contribute to specific scientific and technical aspects of the mission.

8.2.4 Responsibilities of Principal Investigators

In general the Principal Investigator (PI) (supported by the Survey Scientist (SS) and the Technical and Data Processing Managers) is responsible for ensuring that the complete instrument and data processing programmed are implemented and executed within the constraints of the approved FACE-IT project. Therefore the PI will have an important role in the realization of the project.

The PI responsibilities shall include, but are not necessarily limited to, the following items.

Management
Take full responsibility for the instrument and data processing programmed at all times.
Retain full authority within the IC over all aspects related to procurement and execution of the program. In this context the PI shall be able to make commitments and make decisions on behalf of all other participants in the IC. The Technical and Data Processing Managers shall similarly be able to make commitments and decisions in their respective areas of responsibility.
Establish an efficient and effective managerial scheme, which will be used for all aspects of the instrument and data processing program.
Define the role and responsibilities of each Co-Investigator (Co-I)
Identify key team members responsible for science management, technical management, technical interfacing, data processing management, and operational management.
Plan and organize the IC efforts, and assign tasks to other members of the IC.
Provide the formal managerial interface of the instrument to PS, ST, PT and support PS management requirements (e.g. status reports, progress reviews, program reviews, change procedures, product assurance etc.).
Ensure that adequate funding is available at the required times for all aspects of the instrument and its support for the DPAC of the IC, and possibly also the DPAC.

Scientific
Attend meetings of ST, and to take a full and active part in the work of the ST.
Support groups in IC and in the FACE-IT project as appropriate.
Report on the development of the instrument and data processing.
Ensure adequate calibration analysis of all parts of the instrument both on ground and also in orbit.
Support the PS and ST in the definition of the science operations.
Participate in the definition of the observing plan.
Exploit to full depth the scientific results of the mission.
Support public relations activities related to FACE-IT. Provide material for release to the press. Participate in FACE-IT media events on request from the PS, in accordance with the Public Relations Plan.

Instrument Hardware

Define the functional requirements of the instrument and ground support equipment.

Ensure the development, construction, testing, delivery and integration of the instrument. This shall be in accordance with the standards, technical and programmatic requirements outlined for the instrument and subsequently reflected in the approved Experiment Document.

Ensure that the design and construction of the instrumentation reflect properly the environmental and interface constraints under which the instrumentation must operate.

Ensure adequate test and calibration of all parts of the instrument both on ground and also in orbit, to certify the objectives and measurement specification for the instrument.

Ensure that all required hardware for the data processing activities is available within the scheduled times.

Ensure that all procured hardware is compliant with the mission requirements, through participation in technical working groups and control boards as requested.

Ensure that the hardware allows system level performance compatibility to be maintained. Provide overall documentation during the project as defined in the Experiment Document.

Instrument Software

Ensure the development, testing and documentation of all instrument specific software (e.g. necessary for the control, monitoring, testing, simulation, operation, and data reduction/ analysis etc.) in accord with procedures and schedules as defined in the Experiment Document.

Ensure the delivery of such instrument specific software and its documentation including user manuals in accord with procedures and schedules as defined in the Experiment Document.

Support the instrument specific software integration and operation activities, in particular during payload commissioning phases.

Ensure the development, testing, documentation and delivery of on-board software, and software required during instrument system level tests in the real-time or off-line mode including auxiliary software as defined in the Experiment Document.

Ensure the development, testing, and documentation of software required both for daily and long-term data processing activities at the DPAC.

Maintain and update all software for the duration of the mission.

Assist in the definition of the functional requirements of the OSC computer and its main and peripheral units (processing units, terminals, data storage devices and media, output devices, data bus etc.).

Provide overall requested documentation during the project.

8.2.5 Responsibilities of Data Processing & Analysis Centers

- Support all instrument operational phases by providing the necessary hardware, software, information (technical data), manpower and expertise training.
- Ensure that all data processing and analysis devices including storage devices/media and output devices that are required for the full functionality are available within the scheduled times.
- Ensure that the functionality of DPAC is appropriate to the objectives and lifetime of the mission, and reflects properly the interface constraints under which to operate.

- Ensure the development, testing and documentation of DPAC specific software (e.g. data access layer, user interfaces, simulation, database management, archiving etc.) are in accord with procedures and schedules as defined.
- Ensure that all software (including instrument specific software provided by IC) is tested and integrated into the DPAC data analysis system.
- Ensure full operation of all software tasks.
- Execute the archiving phase.
- Ensure that all created software is maintained and updated.
- Provide the user community with the scientific data and archive in accord with procedures and schedules defined by the FACE-IT project.
- Provide IC on their request with off-line raw data to allow study and analysis of instrument performance.
- Support mission operations, including resolution of anomalies, malfunctions of instruments, required adjustments and calibrations.
- Recognize during all operational phases the occurrence of transients and/or anomalous events based on developed monitoring software, and inform PS and ST about these events.

8.2.6 Responsibilities of Mission Operation Center

The satellite will be controlled from the Mission Operations Center (MOC), via one or two ground-stations. The MOC will be designed, developed, and operated by the FACE-IT project.

In addition to the usual tasks of preparing for and carrying out spacecraft operations and mission analysis, the MOC will be responsible for:

Supporting the PS on all aspects concerning spacecraft operations
Maintaining a database containing the long term spacecraft plan, on the basis of PS inputs, based on the Operations Plan
Converting PS and ST requests into spacecraft commands and uplinking them
Processing of data level products 0 and 1A (daily stripping of the payload data and housekeeping from the telemetry stream, ordering and correcting data stream chronology, data gaps and out-of-limit observational errors, and making all the data available to each DPAC)
Daily conversion of spacecraft housekeeping, uplink of a corrected series of maneuvers valid for the next 3 days, and provision of the timing and pointing information to the DPACs
Checking the health and performance of the payload, by ensuring that payload housekeeping data remains within predetermined limits
Alerting the PS of all significant anomalies and/or deviations from the expected behavior of the spacecraft, and executing predetermined procedures to safeguard the spacecraft and payload
Archiving the raw payload data for a period of no less than 10 years

9. Implementation

9.1 Planning and Schedules

The project plan for the realization of the FACE-IT mission starts in January 2000, and runs for four years until the end of 2003. The detailed work breakdown structure is based on a standard phased approach.

9.1.1 Work Breakdown Structure

The implementation of the FACE-IT mission will follow the standard phased approach.

9.1.2 Phase A

Start time: 1st January, 2000
Duration: 12 months

Phase A is the feasibility study for the FACE-IT mission. Several critical items about the FCM instruments will be addressed in phase. The phase will also include a thorough review of the mission concept and the planned design of the various mission elements. It is conceived that the phase will last one year, starting from January 2000.

The organizational structure will be established in this phase, as well as the Instrument Consortia chosen for the main instruments. The involvement of the industrial partners of FACE-IT in the elements of the project will be determined in the early stage of Phase A. Industrial responsibilities and tasks will be distributed according to company interests and expertise.

The FCM instrument development will commence right after the Mid-Term Review for the Phase A (MTR-A).

9.1.3 Phase B

Start time: 1st January, 2001
Duration: 6 months

In this phase detailed mission and system design considerations will take place.

The result should lead to an architectural design review at the end of the phase. This phase will be organized in two steps with a review at mid-term. The first step will aim at harmonizing the mission element concepts and requirements. The second step will aim at defining and harmonizing the architecture of the various elements.

Below is given an outline of the activities foreseen. Step 1 covers activities in Phase A and B. While Step 2 relates to the C and D phases.

ITEM	Step 1	Step 2
Mission Analysis		
Science objectives		Definition of science preparation activities Definition of algorithms and simulations
Orbit selection	Trade-offs with respect to: - Coverage - Inclination - Altitude	Orbit confirmation
User requirements	Requirements harmonization	Definition of products Availability definitions
System Level Design		
Launcher	Trade-offs between available launchers	Launcher selection Initiate negotiations
Operations	Automation trade-offs	Definition of operations concepts
AIV/AIT	Strategy trade-offs	AIV/AIT strategy definition
FCM		
Electronics	Trade-offs with respect to: -power -weight -reliability	Design confirmation
Fiber, laser and receiving polarization unit	Trade-offs with respect to: - size - weight - accuracy	Design confirmation
On board accommodation and deployment		Definition of - weight and power - control I/F - on board memory - data protocol
DAM		
Optical Unit	Trade-offs with respect to: - power - weight	Design Confirmation
Electronic Unit	Trade-offs with respect to: - power - weight - reliability	Design Confirmation
On board accommodation		Definition of - weight and power - control I/F - on board memory - data protocol
Satellite Design		
Platform	Trade-offs with respect to: - design	Platform definition

ITEM	Step 1	Step 2
	- instrument accommodation - subsystem accommodation	
Subsystems	Trade-offs on subsystems with respect to: - power - weight - reliability	Design selection for - structure - power - system unit - ACS - communication - software - EGSE
Ground Segment		
Ground Stations	Trade-offs with respect to: - geographical location - down link options - dedicated stations versus ESA network	Definition of - location - antenna - installation - on-site electronics - communication I/F's
Control Center	Trade-offs with respect to options for basic system	Definition of satellite control with respect to:: - monitor and control - flight dynamics - simulation Definition of mission control with respect to: - constellation monitoring - system efficiency - constellation maintenance
Data Processing Analysis Centers (DPAC)	Trade-offs with respect to: DPAC implementation options	Definition of architecture for DPAC instrumentation Definition concept for instrument control
Communications	Communication link trade-offs	Definition of communication concept and architecture
Operations		
Instruments		Operations concept definition
Satellites		Operations concept definition
Mission		Operations concept definition
Ground Station		Operations concept definition
Commissioning		Operations concept definition
Management		
Management practices	Phase A/B practices, reporting etc.	Phase C/D management scheme definition
Project standards	Phase A/B standard	Implementation standards definition
Risk management	Identification of major risks	Definition of risk management plan
Team definition	Phase A/B team build-up	Definition of implementation team
Contract relations		Definition of contractual set up for the implementation phase

9.1.4 Phase C

Start time: 1st July, 2001
Duration: 18 months

Phase C covers the detailed equipment design and the engineering model (EM) assemblies and tests.

9.1.5 Phase D

Start time: 1st January, 2003
Duration: 12 months

This phase will focus on the Pre-Flight and Flight Models (PFM/FM) of the instruments, their assembly and tests. At the end of phase D the actual launch campaign starts.

The operational activities of Phase D include pre-launch activities, covering for example instrument software design and development, instrument calibrations, total spacecraft testing and integration. The pre-launch phase covers 12 months.

9.1.6 Phase E

Start time: 1st January, 2004
Duration: 26 months

The main activities of this phase of the mission consist of the spacecraft commissioning phase (2 months) and the operational phase (24 months). The operational phase includes a nominal operational phase (12 months) and a post-mission phase (12 months). The breakdown are as follows:

- Launch preparations and campaign [from two months before launch until launch].
- The launch.
- Commission phase [from launch until launch plus two months].
- Operational phase [from launch plus two months until launch plus 14 months nominal].
- Post-mission phase [from the completion of the mission until end of mission plus one year].

9.1.7 Implementation Schedules

Detailed time plan and element relations covering instrument development, spacecraft development, AIV/AIT activities and ground segment implementation are addressed in implementation schedules.

The general ideas behind the development plans are based on the project management philosophy of a V-structured life cycle development, consisting of two major process branches (design and implementation). The different phases in such a management scheme are given in the below figure.

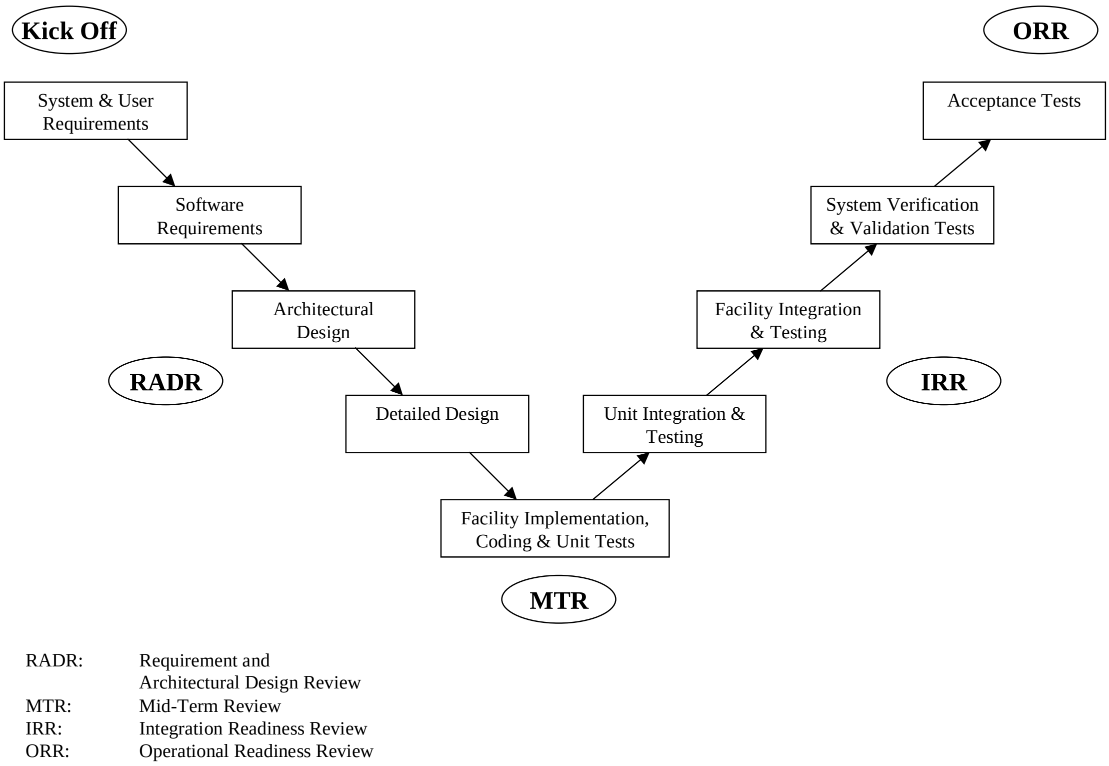


Figure 9-1 Life cycle development phases and related milestones in the management scheme for the FACE-IT mission.

The following Gantt chart shows the general time plan for developments, implementation, integration and testing of instruments, spacecraft and ground segment.

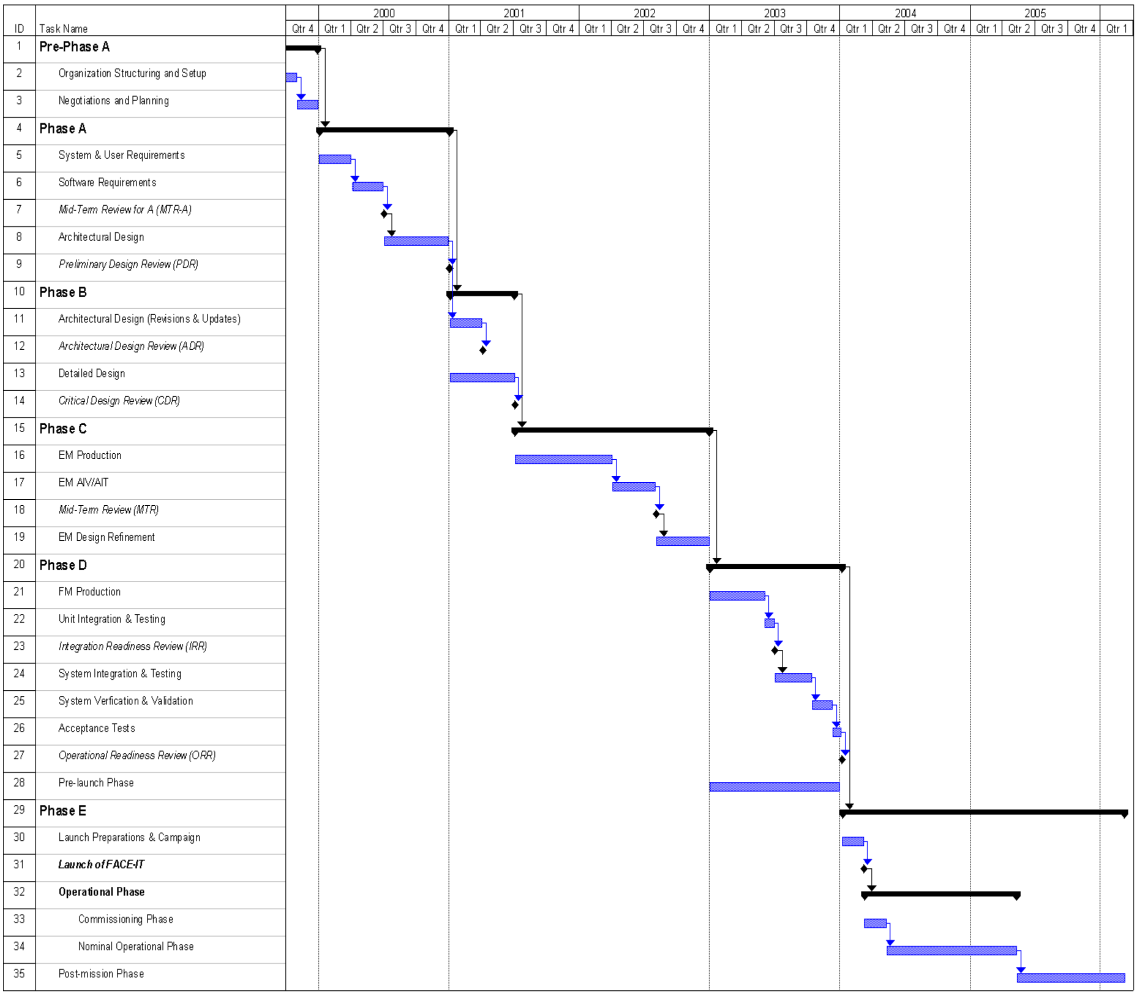


Figure 9-2 Time plans for the FACE-IT mission.

9.2 Data Dependencies / Agreements

The data dependencies will be dealt with as part of the Phase A activities for the FACE-IT mission.

Agreement issues will depend on the industrial consortia and the level of chosen international involvement. These will be presented at the Mid-Term Review (MTR-A) of the Phase A study.

9.3 Critical Issues

Apart from major risks given below the FACE-IT mission should not impose large risks for a successful completion of the satellite mission. The critical issues is:

- Necessary budgeted funding available in time for all phases of the project.
- Development of the FCM instrument.
- The completion of the Phase A and the conclusions from this phase.

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11. Letters of Support

Letters of Support for the proposed FACE-IT mission have been obtained from the following institutions and authorities. The letters have been forwarded under a separate cover.

- Danish Space Research Institute, Denmark
- ESA Solar System Working Group (SSWG), France
- ArianeSpace, France
- CNES, France
- Finnish Meteorological Institute, Finland
- Swedish Institute of Space Physics, Sweden
- Royal Institute of Technology, Sweden
- University of Texas, USA
- University of New Hampshire, USA
- University of Oslo, Norway
- Imperial College, UK

12. Appendices

12.1 Science Team

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12.2 Candidate Consortium

12.2.1 Participating Science Institutions

Danish Meteorological Institute
Danish Space Research Institute
Technical University of Denmark
Risø National Laboratory
Swedish Institute of Space Physics, Sweden
Royal Institute of Technology, Sweden
University of Texas, USA
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12.2.2 Companies and Institutions

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TICRA, Copenhagen
ALCATEL, Ballerup
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12.3 DMI

General Background

DMI is the Danish national center for operational meteorology, climate change monitoring and research of the atmosphere, covering the neutral processes in the lower troposphere/stratosphere region to the ionized physical phenomena in the ionosphere and magnetosphere.

The main objectives of DMI are environmental survey and prediction in a general sense, i.e. surveillance, forecasting, and exploration of the whole atmosphere and the sea surface for the area including Denmark and Greenland. These activities cover data collection, data processing and distribution, product extraction and delivery, research and development in the fields of meteorology, climatology, hydrology, geomagnetism, upper atmosphere physics, space physics, and solar-terrestrial physics relations.

The Research and Development Department of DMI has about 90 employees, which is organized in five divisions (Atmosphere Ionosphere Research Division, Solar-Terrestrial Physics Division, Meteorological and Oceanographic Research Division, Division for the Middle Atmosphere and Climate Research Division). The DMI key persons for this project come from the first division of the Research and Development Department.

Extensive cooperation and coordination is taking place through various international organizations and programs. DMI represents in this context Denmark in the international organizations:

WMO	World Meteorological Organization
ECMWF	The European Center for Medium Range Weather Forecasts
ESA	European Space Agency
EUMETSAT	The European Organization for the Exploitation of Meteorological Satellites
IPCC	The Intergovernmental Panel on Climate Change (IPCC), established by WMO and UNEP (United Nations Environment Program)

Use of operational satellite data has become a more and more vital part of the routine work of modern weather prediction services, and DMI has gradually developed skill and facilities, which made the institute today to the only fully operational satellite data center in Denmark.

Space Experience

ØRSTED
DMI is in charge of the research program for the Danish satellite ØRSTED, which was launched in February 1999. The satellite will among other tasks perform GPS radio occultations to retrieve temperature profiles of the troposphere and stratosphere (space based GPS Meteorology) as well as electron density profiles of the ionosphere. The physical processes of the ionosphere and neutral atmosphere will be studied based on ØRSTED observations.

METOP/EPS

The same observational technique as proposed here is included in the ESA mission METOP/EPS in the EUMETSAT and ESA Earth Observation Programme. DMI is involved as scientific advisor and holds several contracts with ESA in the fields of GRAS atmosphere profiling. The studies addresses among other things, the influence of the ionosphere fluctuations on the accuracy of the temperature profiles, the usefulness of advanced Fresnel transforms and backward propagation techniques for GRAS data retrieval, the improvements in using tomographic presentations of the occultation data from low Earth orbiting satellites, and possible climate change fingerprints in the GRAS observations.

GPSOS/NPOESS

DMI performs together with Saab Ericsson Space, Austrian Aerospace, TERMA, and U. of Leeds the Risk Reduction Phase for the GPS Occultation Sensor (GPSOS) selected to fly on the US NPOESS (National Polar-orbiting Operational Environmental Satellite System) series of polar orbiting satellites for weather monitoring. The missions are lead by the Integrated Programme Office (IPO), encompassing the institutions NOAA, NASA and the U.S. Air Force.

Requirements, setup by IPO for the GPSOS instrument, are defined by an end-to-end evaluation of the level 2 data products. Thus the whole observational chain from measurements to the high-level user data products and total error budgets are assessed. The tasks encompass scientific studies as well as development activities. The latter cover, algorithm developments for the generation of the basic sounding products (bending angles, ionosphere electron density profiles, scintillations, and troposphere profile products (temperature, pressure and humidity)), error budget analysis related to the retrieval theory and noise term estimates (thermal, multipath, correction procedures for the experimental geometry, transmitter and receiver clocks, data retrieval statistical optimization methods, and ionosphere corrections).

CLIMAP

The EU project CLIMAP is a pilot project studying the requirements for operational use of atmosphere profiling data in numerical weather forecasting and climate monitoring. In a pre-operational setup, applying observations from the satellites GPS/MET, ØRSTED, SUNSAT and SAC-C, the project will validate and assess the impact of the measurements for weather forecasting and climate monitoring together with the strategies required to effectively enhance the usefulness of the data. DMI is responsible for the data retrieval procedures and data assimilation’s into weather prediction models.

FACE-IT

The mission FACE-IT (Field-Aligned Current Experiment in the Ionosphere and Thermosphere) is one of the four missions in Phase A to follow the Danish satellite ØRSTED as the next national satellite mission. The main objective is to study the field-aligned currents in the ionosphere applying vector magnetometers and the new instrument named the ‘Faraday Current Meter’ (FCM), which directly measures the spatial fine structure field-aligned currents and their mapping to the magnetosphere. The observations from FCM and the magnetometers onboard FACE-IT will be used to develop a more detailed understanding of the interaction between the solar wind and the energy transfer processes to the magnetosphere-ionosphere system.

ACE

The ACE (Atmosphere Climate Experiment) mission is proposed in response to ESA's call for Explorer Opportunity Missions. The concept involves systematic gathering of data over a five-year period of precise profiles up through the atmosphere of temperature, humidity and ozone content globally. The data are used in conjunction with climate models and climate prediction techniques to improve the understanding of the driving forces behind climate change and variability. Six small satellites flying in two polar orbits with an altitude of 700 – 800 km will be equipped with two types of profiling instruments. The GRAS receiver will provide accurate temperature and humidity profiles using GPS occultation measurements and will be flown on all six satellites. The COALA instrument for ozone profiling using stellar occultation measurements will be installed on two satellites – one in each orbit.

Further details on all DMI space activities and areas of research can be assessed at our World Wide Web site: http://www.dmi.dk/

Qualifications of Key Person

Per Høeg. M.Sc. in Geophysics, 1981, and Ph.D. in Physics, 1987, both from the University of Copenhagen. His scientific employments cover, Research Scientist at the Danish Space Research Institute (DSRI) in the periods, 1981-1982 and 1985-1986. Visiting Research Scientist at the Max-Planck Institut für Aeronomie (MPI), Germany, 1982-1985. Visiting Research Fellow at Phillips Laboratory (PL), Boston, USA, 1987. Research Scientist at the Danish Meteorological Institute (DMI), 1986-1989. Senior Research Scientist since 1989 at the Research Department of DMI. Head of the Atmosphere Ionosphere Research Division at DMI, since 1998. In 1994, External Associate Professor (in Space Physics) at the Niels Bohr Institute (NBI), University of Copenhagen.

Presently employed at DMI as Senior Research Scientist and Head of the Atmosphere Ionosphere Research Division. External Associate Professor at NBI, University of Copenhagen.

Member of the Swedish National Science Foundation (Group 3 for Physics and Astronomy), since 1996. Since 1993, member of three of ESA's Scientific Advisory Groups (SAGs), related to the advanced usage of GPS/GLONASS occultation observations for determining the state of the neutral atmosphere and the ionosphere. Since 1994, the Danish Delegate to ESA's Program Board for Earth Observations (PB-EO). In 1996 appointed Scientific Advisor to the ESA/EUMETSAT Science Advisory Group for GRAS observations on the METOP/EPS satellites. Since 1990, the Danish representative in the international URSI Commission G for Ionosphere Research and Radio Propagation, and in 1996, the President for the Danish URSI Committee. He is the Danish Scientific Primary Investigator for the GPS observations on the ØRSTED, SUNSAT and the SAC-C satellites.

CURRICULUM VITAE

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1994-1998	Head, Remote Sensing Group, Solar-Terrestrial Physics Division, DMI
1989-1998	Senior Research Scientist, Solar-Terrestrial Physics Division, DMI
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1996-	Member, ESA/EUMETSAT GRAS Science Advisory Group (GRAS SAG)
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1996-	President, Danish National URSI Committee
1996-	Member, Board of the Danish Society for Physics, Section for Atom and Plasma Physics
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