The EMMA instrument on the Astrid-2 micro-satellite


Stockholm, January 2003

1 Alfvén Laboratory, Royal Institute of Technology, Stockholm, Sweden  
2 Institute of Automation, Technical University of Denmark, Lyngby, Denmark  
3 Danish Space Research Institute, Copenhagen, Denmark  
4 Also at University of Texas at Dallas, Richardson, TX, U.S.A.  
5 Now at University of Colorado, Boulder, CO, U.S.A.  
6 Also at University of Southampton, United Kingdom.  
7 TERMA Electronics AS, Lystrup, Denmark  
8 Now at Ericsson Telebit A/S, Viby J, Denmark
Abstract. The EMMA instrument on Astrid-2 is designed to provide simultaneous sampling of two electric and three magnetic field components up to about 1 kHz. The spin plane components of the electric field are measured by two pairs of opposing probes extended by wire booms with a separation distance of 6.7 m. The probes have titanium nitride (TiN) surfaces, which has proved to be a material with excellent properties for providing good electrical contact between probe and plasma. The wire booms are of a new design where the booms in the stowed position are wound around the exterior of the spacecraft body. The boom system was flown for the first time on this mission and worked flawlessly. The magnetic field is measured by a tri-axial fluxgate sensor located at the tip of a rigid, hinged boom extended along the spacecraft spin axis and facing away from the sun. The new advanced-design fluxgate magnetometer uses digital signal processors for detection and feedback, thereby reducing the analogue circuitry to a minimum.

In addition to measuring the electric field by current biasing the electric probes, they may also be used to estimate plasma density and temperature by means of sweeping the bias to obtain a current-voltage characteristic. From this, information about the coupling between the probe and the plasma may be derived as well. Sampling is done at 16, 256, or 2048 samples per second. EMMA is equipped with 12 MB memory for storage of data from times without ground station contact and also for use with the highest sampling rate where the data throughput exceeds the capacity of the telemetry link.

The EMMA instrument worked very well during its seven months of operation. A wealth of scientific data was collected and significant progress on its interpretation has already been made, as evidenced by several already published papers. The instrument characteristics as well as a brief review of the science accomplished and planned are presented.
Introduction

Astrid-2 is a Swedish micro-satellite launched 10 December 1998 into an 83-deg inclination circular orbit at 1000 km altitude. It remained operational until 24 July 1999. The orbital plane regresses 360 deg relative to the Sun in approximately 7 months, so during the lifetime of the spacecraft the orbit covered all local times. The mission has dual primary objectives. First, it is an orbiting instrument platform for studying auroral electrodynamics. Second, it is a technology demonstration of the feasibility of using micro-satellites for innovative space plasma physics research. To facilitate the inclusion of adequate instrumentation on a space and mass constrained micro-satellite, significant new instrument development was necessary. Holback et al. [2001] describe the Langmuir probe instrument (LINDA – Langmuir INterferometry and Density instrument for Astrid-2) and Norberg et al. [2001] describe the particle detectors (MEDUSA – Miniaturised Electrostatic DUal-top-hat Spherical Analyser) and UV imagers (PIA – Photometers for Imaging the Aurora). Overviews of the Astrid-2 mission are given by Blomberg et al. [1999] and Marklund et al. [1997; 2001a]. Here we describe the electric and magnetic field instrument EMMA (Electric and Magnetic Monitor of the Aurora) and briefly review some results obtained as well as the potential for future research.

Scientific Objectives and Results

The EMMA instrument together with the other instruments on-board Astrid-2 allow for a number of scientific topics to be addressed. Below is a list of examples of topics, studied or planned for future study.

Sources of the Cross-Polar Potential Drop. The cross-polar potential drop arises from the solar wind’s interaction with Earth’s magnetic field. EMMA has provided new valuable data that may deepen our understanding of the interaction mechanisms [e.g., Eriksson et al., 2001].

Electric Fields and Currents in the Nightside Convection Throat. Enhanced electrojet activity is often associated with an auroral bulge in the nightside ionosphere. Astrid-2 data have demonstrated that current continuity across the bulge region is not necessarily maintained by polarisation electric fields, as in the Cowling channel model, but rather by local field-aligned currents flowing in both direction [Marklund et al., 2001b]

Transpolar Aurorae. The high-inclination orbit of Astrid-2 puts it in an ideal position for studying transpolar auroral arcs. A thorough investigation, combining Astrid-2 data with Polar UVI and DMSP data is underway. Initial results on the configuration of plasma flows and field-aligned currents in transpolar arcs are presented by Blomberg and Cumnock [2002].

Global Mapping of $E$, $j_{\phi}$. To understand the fundamental relationship between the ionospheric electric field and the field-aligned currents on a global scale, statistical surveys based on data from the same platform are needed [e.g., Blomberg et al., 1992]. Such pictures
are normally not found in the literature. EMMA data were recently used to ascertain the Weimer 2K ionospheric electric field model [Eriksson et al., 2002].

*Global Mapping of B.* With its precision magnetometer, Astrid-2 has been used as a complement to the Danish Ørsted satellite, whose primary objective is to map the geomagnetic field.

*Waves and Pulsations up to 1 kHz.* With a maximum sampling rate of the field instruments of 2048 s\(^{-1}\) wave frequencies up to the local proton gyro frequency are covered. Thus, a multitude of pure wave as well as wave-particle interaction phenomena may be studied. Ivchenko et al. [2001] discuss initial results in a recent paper.

*Cusp Topology and Dynamics.* Astrid-2 passes through the cusp regularly whenever the orbital plane has a noon-midnight orientation. Using the particle and field instruments on-board will allow detailed studies of the low-altitude signatures of the polar cusp. Initial results were presented by Keith et al. [2001].

*Ion Clouds and Ion Injection.* Høymork et al. [2001] studied dense ion clouds in the inner magnetosphere and discussed their possible relation to substorm ion injection. Further study of the particle characteristics and the plasma flows associated with these events will shed light on the ion injection mechanisms.

*Spacecraft-plasma Interaction.* Any spacecraft disturbs the surrounding plasma to an extent that depends on the spacecraft design and how it is operated as well as on the properties of the plasma it traverses. The spacecraft charges electrically which creates an electrostatic barrier around it. Since the spacecraft moves at 7 km/s it leaves a wake behind it. Understanding these effects more thoroughly is important to a complete understanding of the instrument performance. Initial results on the interaction of Astrid-2 with the plasma environment based on EMMA and LINDA data were presented by Ivchenko et al. [2001].

*Electrodynamics of Aurora and Black Aurora.* A discovery by the Freja spacecraft [Marklund et al., 1994; 1997] illustrates the complexity of field-aligned acceleration processes. An anti-symmetry exists between the electric field structures in the upward field-aligned current region associated with auroral particles and those in the downward current region. Freja demonstrated the existence of upward acceleration of electrons in these regions, leading to the formation of ionospheric density cavities and associated strong transverse electric fields. The upward acceleration region is typically found at lower altitudes than the auroral acceleration regions, and EMMA can contribute significant new observational data to shed additional light on the processes operating.

*Sub-auroral and Equatorial Electric Field Structures.* Strong poleward directed electric fields are commonly observed at sub-auroral latitudes in the pre-midnight sector. They are believed to be associated with closure of field-aligned currents through the mid-latitude trough,
an ionospheric region of depleted plasma density and, thus, low conductivity. An overview of the subject is found in Karlsson et al. [1998]. Recent work based on Astrid-2 data is reported on by Figueiredo [2001] and by Figueiredo et al. [2002].

*Physics of Transverse Ion Heating.* Transverse ion heating is thought to be an important mechanism for ion outflow from the upper atmosphere. The heating often takes place at fairly low altitude, and so, Astrid-2 is in a good position to measure *in situ* the fields, waves, and particle properties associated with the heating process.

*E-B Correlation and its Scale Size Dependence.* Electric and magnetic fields associated with static structures in the ionosphere are often correlated. The electric field maps, at least partially, upwards along the geomagnetic field, and the field-aligned current produces a transverse magnetic disturbance field. Assuming complete mapping of the electric field the height-integrated ionospheric conductivity may be inferred from the ratio of the magnetic to the electric field. At least for large scale sizes the electric field normally maps well between different altitudes. Studying the degree of correlation for smaller scale sizes may yield additional information about the ionosphere-magnetosphere interaction processes.

![EMMA sensor locations](image.png)

*Fig. 1. EMMA sensor locations.*
Instrument design

EMMA is designed to measure two components of the electric field and three components of the magnetic field simultaneously with high bit resolution and variable time resolution, see Table 1. The sensor locations are shown in Figure 1. The instrument box contains eight printed circuit boards (PCB's), holding the electronics for the electric sensors, for the fluxgate sensors, for sampling and digitizing of all electric and magnetic sensor signals, for the boom motor control, as well as for the LINDA instrument [Holback et al., 2001], see Table 2.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Range</th>
<th>Resolution</th>
<th>Bits</th>
<th>Sample rate (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (2 components)</td>
<td>± 5 V/m</td>
<td>0.03 mV/m</td>
<td>16</td>
<td>16, 256, 2048</td>
</tr>
<tr>
<td>B (3 components)</td>
<td>± 62 µT</td>
<td>0.12 nT</td>
<td>20</td>
<td>16, 256, 2048</td>
</tr>
</tbody>
</table>

Table 1. Summary of measured quantities.

Fig. 2. Block diagram of EMMA and LINDA.
EMMA also has a 12 MB data memory for temporary storage of data either when outside of
ground-station contact or when sampling at a data rate exceeding the capacity of the telemetry
link. A block diagram of EMMA and LINDA, residing in the same instrument box, is shown in
Figure 2.

<table>
<thead>
<tr>
<th>Subunit</th>
<th>PCB’s</th>
<th>Dimensions (mm × mm × mm)</th>
<th>Volume (dm³)</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E field</td>
<td>2</td>
<td>177 × 134 × 30</td>
<td>0.7</td>
<td>0.33</td>
<td>1.5</td>
</tr>
<tr>
<td>B field</td>
<td>2</td>
<td>177 × 134 × 32</td>
<td>0.7</td>
<td>0.34</td>
<td>1.6</td>
</tr>
<tr>
<td>Density</td>
<td>2</td>
<td>177 × 134 × 26</td>
<td>0.6</td>
<td>0.27</td>
<td>1.5</td>
</tr>
<tr>
<td>ESU</td>
<td>1</td>
<td>177 × 134 × 18</td>
<td>0.4</td>
<td>0.21</td>
<td>1.0</td>
</tr>
<tr>
<td>DC/DC</td>
<td>1</td>
<td>177 × 134 × 23</td>
<td>0.5</td>
<td>0.15</td>
<td>1.6</td>
</tr>
<tr>
<td>Box</td>
<td></td>
<td>193 × 140 × 144</td>
<td></td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>8</td>
<td></td>
<td>2.71</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Characteristics of the subunits of EMMA and LINDA residing in the instrument box.
The DC/DC converter efficiency is 78%. ESU is the EMMA System Unit.

Fig. 3. EMMA wire boom mechanisms
Four spherical sensors located in the spin plane and extended away from the spacecraft using wire booms measure two components of the electric field (see Figure 1). The deployment system for the wire booms is of a new design where the wire in the stowed configuration is wound around the perimeter of the spacecraft body. Each wire runs through a small loop, which is attached to a belt driven by a stepper motor. During boom deployment the stepper motor moves the belt up to 2 mm per second. As the belt moves the wires are unwound from the spacecraft body. In the deployed configuration the centre of each probe is located 3.35 m from the centre of the spacecraft. The deployment mechanism is illustrated in Figure 3.

The total mass of the boom system including the deployment mechanisms is less than 2 kg, compared to about 14 kg for four conventional mechanisms. For Astrid-2, the booms were fairly short, but there are no fundamental reasons why the new design could not allow considerably longer boom lengths with only a slight increase in mass. In addition, there are variations of the design that may prove even more viable for longer booms. Thus, even though long low-mass wire booms were not flight tested before the Astrid-2 launch, the successful in-flight performance proved that a significant reduction of the mass of future boom systems is attainable without compromising reliability. Figure 4 shows the boom system in the stowed position. A more detailed description of the low-mass wire boom system is found elsewhere [Hellman, 1996].

The sensors each have a mass of 100 grammes, a diameter of 35 mm, and a Titanium Nitride (TiN) surface. TiN has proved to have excellent surface properties providing clean electrical contact between the probe and the surrounding plasma. This is evidenced, for example, by an almost complete lack of hysteresis in the current-voltage characteristic of the probes. TiN is used also for the LINDA probes as well as on the Cassini mission and is likely, due to its superior properties compared to more traditional coatings such as DAG-213 or vitreous carbon, to become a new standard for probe surface material in space. Figure 4 (right) shows one of the four EMMA probes.

Fig. 4. The Astrid-2 satellite in the clean room two months prior to launch.
Before sampling, the probe signals are amplified by pre-amplifiers located inside the spacecraft body. Ideally, pre-amplifiers should be mounted as close to the sensor as possible. Often the pre-amplifiers are mounted inside the spherical sensors but with the relatively short boom length on Astrid-2 this is not necessary, resulting in a reduction of complexity without loss of instrument performance. The signals also pass through low-pass filters designed to suppress aliasing from the sampled signals. The filtering is the same for all (electric and magnetic) sensor signals. The signals from the four electric field probes are sampled individually as voltages with respect to the satellite body, and are telemetred individually to the ground. This allows for computational reconstruction of the satellite potential with full time resolution, which helps with identifying rapid fluctuations in the plasma density, as well as time intervals where one or more of the probes are saturated because of spacecraft charging.

Each of the four probes can be fed with individually set bias currents, in order to optimize the quiescent point on the current-voltage characteristic, or equivalently, to minimize the contact impedance between probe and plasma to make the measurement as insensitive as possible to variations in the ambient plasma density or temperature. Low contact impedance provides for as clean as possible a measurement of the probe potential with respect to the plasma. The bias current can be selected either in the range ± 40 nA in 20 pA increments or in the range ± 450 nA in 220 pA increments. In addition, the bias currents of one or more probes may be stepped through an adjustable sequence of values (known as a current sweep) at an adjustable rate in order to register the current-voltage characteristics of the probe with respect to the plasma. This is useful for gaining information needed both for optimizing the choice of bias current and for determining plasma and probe properties such as density, temperature and photoemission characteristics.

The fluxgate sensors are located at the end of a 0.9 m long rigid boom extending axially from the platform on the side facing away from the Sun. The three sensors are nominally orthogonal to each other and the sensor unit is co-located with the ASC camera head to optimize the attitude determination of the sensor axes. The fluxgate measurements are based on a principle first described by Piil-Henriksen et al. [1996] and the sensor design is developed from the one used in the Ørsted mission [Brauer et al., 2000]. The raw fluxgate sensor signals are digitally sampled and then three DSP’s (Digital Signal Processors) are used to perform the field extraction and the generation of the feedback currents for the sensors, driven by three digital-to-analogue converters (DAC). The excitation frequency is 8 kHz and the excitation circuit uses parametric amplification to reduce power consumption.

The algorithms executed by the DSP’s form the core of the magnetometer. The main routines are: field extraction, integration, feedback generation, and filtering of the data for the telemetry. The field-extraction algorithm corresponds to the analogue input filter, the phase detector and the integrator in a classical instrument. The magnetometer is contained on two PCB’s, see Table 2. The sensor is box-shaped 45.4 by 53.4 by 33.0 mm^{3} with a mass of 150 grammes. The 5 mm diameter sensor cable is a highly flexible and ultra-low temperature type with a mass per
length of 30 g/m. A more thorough description of the magnetometer is given by Pedersen et al. [1999].

The ASC was an add-on experiment in an attempt to get an early flight test of the Ørsted core instruments. It did send samples of good star sky pictures, and it provided attitude information for some short periods, but it could not provide continuous attitude information as hoped. Because of the challenges involved in adapting the Ørsted (three-axis stabilized) ASC to the spinning Astrid-2 platform it was realized already pre-flight that ASC attitudes might not be available during the whole mission, and so an alternative method for attitude determination was developed at Ålborg University, Denmark [Bak, 1999], in part based on the Ørsted attitude control. The method uses magnetometer data only to build a dynamical model of the spacecraft spin and orientation in space. The method has proved to work well, routinely providing attitudes at the 0.1° accuracy level.

Magnetometer calibrations were performed on instrument level at the “Magnetsrode” test facility of the Institute of Geophysics and Meteorology, Technical University of Braunschweig, Germany, in the laboratory at DTU and at the Danish Meteorological Institute’s Magnetic Observatory at Brorfeld, Denmark [Brauer et al., 2000]. The final satellite-level magnetic calibration was performed at the Swedish Geological Survey’s Magnetic Observatory at Lovö near Stockholm, Sweden. The operating and near-flight configured satellite was exposed to the monitored Earth’s field in about 60 different directions, and a scalar calibration was performed. Taking a local field gradient into account and compensating for the DAC non-linearities, the overall standard deviation of the individual data points was 1.3 $\mu$T. This includes all the perturbations from the satellite and the remaining non-linearities in the sensor and the DAC’s. At the 16 Hz filtered output the instrument’s band noise was below 50 $\mu$T [Pedersen et al., 1999].

The Swedish Space Corporation and all the instrument providers successfully complied with the magnetic cleanliness requests put up by the magnetometer teams and the project. Tests at Lovö confirmed the very low magnetic perturbations from the satellite by sequentially power cycling the subsystems. The maximum perturbation came from the transmitter, and it proved to be 4 nT at the boom-deployed magnetometer sensor [Merayo et al., 1998].

The ASC (Advanced Stellar Compass) camera was operating during the magnetometer calibration, and whenever the star sky was within the camera field of view the boresight direction and the rotation about the boresight was determined in celestial coordinates. Twelve simultaneous observations of the magnetic vector field and the camera attitude in Right Ascension, Declination and Rotation allowed the determination of the rotation matrix between the magnetometer sensor unit and the ASC camera. The intercalibration resulted in an angular pointing accuracy of 6 arc sec between the magnetometer sensor unit and the local magnetic field [Merayo, 1999; Merayo et al., 2001].
The controlling unit of EMMA is the ESU (EMMA System Unit), which comprises a microprocessor running the flight software as well as system RAM and ROM, bus controllers, a telemetry interface, a clock generator for timing synchronization, and supporting circuitry. The ESU is responsible for responding to ground commands (real-time or time-tagged commands arriving at pre-determined times from the Astrid-2 system unit), for performing the sensor sampling, and for formatting and storing the data in on board data memory.

The flight software resides both in a ROM and in an EEPROM. The ROM contains the default software whereas the copy in EEPROM is patchable by ground commands, thus providing both the possibility to make in-flight modifications to the software and to revert to the default version in case the EEPROM one becomes corrupted, by radiation damage, operator mistakes, or any other reason. The LINDA flight software is incorporated as a module in the EMMA software and is executed by the same processor.

The data memory consists of 12 MB of RAM for temporary storage of the measured samples and is needed for data recording when the satellite is not in contact with either of the ground stations or when the highest sampling rate is used. The memory is operated as a FIFO which makes it a transparent telemetry queue which grows, shrinks, or idles depending on sampling rate and on whether the telemetry stream is switched on or not. Part of the memory is used to hold LINDA data. Depending on the operational mode of LINDA some fraction of the memory may be allocated as a buffer for LINDA data compression. Also stored in memory are data from the attitude sensors as well as selected housekeeping (hk) and status data from EMMA, LINDA, and the ASU (Astrid-2 System Unit).

A typical memory allocation is 8 MB for storing EMMA data, 2 MB for storing LINDA data, and a 2 MB temporary data area for LINDA data used for on-board processing and data compression. Assuming 8 MB for EMMA and that the hk data rate has been set low, approximate numbers for the time periods for which data can be held in memory are given in Table 3.

<table>
<thead>
<tr>
<th>Sampling rate</th>
<th>16 s(^{-1})</th>
<th>256 s(^{-1})</th>
<th>2048 s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory capacity</td>
<td>8 h</td>
<td>30 mins</td>
<td>4 mins</td>
</tr>
</tbody>
</table>

Table 3. Summary of typical EMMA data memory capacity.

**Operational modes**

EMMA can be operated in a variety of different modes. In electric field mode (high-impedance mode), the sensors are biased with a known current (which may be zero, also known as keeping the sensor floating) and their electric potential with respect to the spacecraft body is measured. By taking the difference in potential between opposing probes and dividing by their
separation distance the component of the electric field along the line-of-sight between the sensors is obtained. The potentials with respect to the satellite body of the four electric sensors are sampled in synchronism with the three orthogonal flux-gate sensors at either 16, 256, or 2048 samples per second. All four potentials are telemetred to ground which makes possible some interferometry as well as estimation of the satellite potential by taking the average of the potentials of two or more probes.

Another mode, mainly used for diagnostics since it overlaps with the purpose of the LINDA instrument, is one where one of the four probes is operated in density mode, biased with a fixed voltage and the current running to it being measured. This is also known as low-impedance mode. Since this is an auxiliary mode the existing ADC (analogue-to-digital converter) normally used for housekeeping data is used for the current sampling rather than adding extra hardware, and thus, no housekeeping data sampling is performed when the instrument is running one probe in density mode.

Current sweeps may be performed in a highly flexible way. Sweeping is done by stepping either the current or the voltage through a sequence of known values while measuring the other quantity. The result of a sweep is a current-voltage characteristic for the probe-plasma coupling, which may provide information on plasma density, plasma temperature, photoelectron temperature (if the sensor is sunlit), etc. Parameter tables may be uploaded which govern the current level stepping, and both the duration of the sweeps and their repetition frequency are individually adjustable. The sweeping may rotate between the probes or the same probe may be swept at each instance. Since the probe-plasma coupling is capacitive there is a minimum duration per current level for the measurement to make sense. Also, it is desirable that a sweep can be completed within a fraction of a satellite spin. Sweeping is normally not performed at the lowest sampling rate (16 s\(^{-1}\)).

The rate of telemetring housekeeping data can be adjusted in binary steps from \(\frac{1}{4}\) s and upward. Normally the hk data rate is selected so that the amount of hk telemetred is some reasonably low fraction of the amount of science data.

**Telemetry**

The Astrid-2 telemetry is packetized. Thus, there are normally no empty slots in the telemetry stream whatever the mode of operation of the instrument. EMMA and LINDA are allocated 12 out of every 16 packets in the ASU (Astrid-2 System Unit) telemetry. The data rate from satellite to ground is 131,072 bits/s and the modulation is Viterbi encoded BPSK (bipolar phase shift keying).

Each packet contains 250 bytes of data. The most basic telemetry packet type is the one containing the electric and magnetic field samples, 15 samples of each quantity per packet, and associated timing and status information. There are also packet types for star imager data and
command acknowledge, for sun sensor data, for housekeeping data, as well as a few special packet types for dumping instrument status information. In addition, the ESU handles a few different packet types for LINDA data.

The EMMA data memory normally acts as a FIFO in the sense that whenever EMMA is instructed to send a packet to the telemetry stream the oldest unsent packet in the data memory is sent. The exception to this is the command acknowledge packet, which is sent to ground immediately upon completion of command execution.

The time needed to dump the data memory to the ground is roughly 14 minutes, assuming 10 MB’s worth of stored data and neglecting possible new data stored in memory while dumping. This is close to the length of a long ground station passage.

**Data examples**

![Graph of Electric field data from the wire boom deployment 7 January 1999.](image)

Fig. 5. Electric field data from the wire boom deployment 7 January 1999.
Figure 5 shows electric field data during the wire boom deployment. The four panels show the potential of each of the four electric probes with respect to the spacecraft body. The sine modulation is due to the spin of the spacecraft. The increasing envelope of the signals is evidence of the booms being deployed. The spacecraft was in a region where the largest contribution to the measured electric field was the field induced by the motion of the spacecraft. The sine modulation slowly increases its wave period. This is because of the spacecraft spin slowing down as a result of the increased moment of inertia as the booms deploy.

![Graph showing electric field data](image)

Fig. 6. Magnetic field data from the deployment of the axial boom 11 January 1999.
Figure 6 shows magnetic field data during the deployment of the axial boom in sensor coordinates. The axial boom deploys at 0914:01 at which time the signals B1 and B3 change place. The boom swung 90 degrees around the B2 axis as it deployed which caused B1 to become the nearly axial component instead of B3 in the stowed position.

**Fig. 7.** Electric field data from a northern hemisphere polar pass showing the normal two-cell convection pattern with a dawn-to-dusk directed polar cap electric field.
Figure 7 shows despun electric field data from a polar pass. E1msp and E2msp are both spin plane components. E1msp is along the projection of the magnetic field onto the plane and E2 is perpendicular to B, positive in the duskward direction. The electric field induced by the spacecraft motion has been subtracted so the plotted components refer to an inertial frame of reference. E1msp is seen to be small which is to be expected at 1000 km altitude. E2msp shows auroral electric fields on either side of the polar cap and a duskward electric across the polar cap, consistent with a normal auroral oval and a two-cell convection pattern.

Figure 8 shows the duskward electric field (E2msp) and the sunward residual (IGRF subtracted) magnetic field (B3msp) for a polar pass through a transpolar auroral arc. Gradients in the sunward magnetic field indicate field-aligned current sheets. The region 1 and region 2 current systems are clearly seen as well as a current system associated with the transpolar arc. Co-located with the arc, and connected to the local current system, we also see sunward plasma convection. For more details see Blomberg and Cumnock [2002].

Summary

EMMA is the electric and magnetic field instrument for the Astrid-2 micro-satellite. It measures two components of the electric field and three components of the magnetic field at sampling rates up to 2048 s⁻¹. Novel technology was developed in order to fit the instrument into the tight
micro-satellite envelope. Most notably a new wire boom system was flown significantly reducing the mass compared to conventional systems and the magnetometer was a highly digitalized flux-gate instrument.

EMMA as well as other instruments on Astrid-2 have already provided material for several studies of the processes associated with the aurora, as evidenced by a number of papers that have already appeared in the literature as well as several studies underway.

In conclusion, Astrid-2 and EMMA have demonstrated the feasibility of double-probe electric field measurements on micro-satellites. In addition, lessons on how to make future micro-satellite missions even more successful have been learned. Ample data for further study exist.

References


Fig. 1. EMMA sensor locations.

Fig. 4. The Astrid-2 satellite in the clean room two months prior to launch.
The EMMA instrument on the Astrid-2 micro-satellite

L. G. Blomberg, G. T. Marklund, P. -A. Lindqvist, F. Primdahl, P. Brauer,
L. Bylander, J. A. Cumnock, S. Eriksson, N. Ivchenko, T. Karlsson,
A. Kullen, J. M. G. Merayo, E. B. Pedersen, J. R. Petersen

Abstract. The EMMA instrument on Astrid-2 is designed to provide simultaneous sampling of
two electric and three magnetic field components up to about 1 kHz. The spin plane
components of the electric field are measured by two pairs of opposing probes extended by
wire booms with a separation distance of 6.7 m. The probes have titanium nitride (TiN)
surfaces, which has proved to be a material with excellent properties for providing good
electrical contact between probe and plasma. The wire booms are of a new design where the
booms in the stowed position are wound around the exterior of the spacecraft body. The boom
system was flown for the first time on this mission and worked flawlessly. The magnetic field is
measured by a tri-axial fluxgate sensor located at the tip of a rigid, hinged boom extended along
the spacecraft spin axis and facing away from the sun. The new advanced-design fluxgate
magnetometer uses digital signal processors for detection and feedback, thereby reducing the
analogue circuitry to a minimum.

In addition to measuring the electric field by current biasing the electric probes, they may also be
used to estimate plasma density and temperature by means of sweeping the bias to obtain a
current-voltage characteristic. From this, information about the coupling between the probe and
the plasma may be derived as well. Sampling is done at 16, 256, or 2048 samples per second.
EMMA is equipped with 12 MB memory for storage of data from times without ground station
contact and also for use with the highest sampling rate where the data throughput exceeds the
capacity of the telemetry link.

The EMMA instrument worked very well during its seven months of operation. A wealth of
scientific data was collected and significant progress on its interpretation has already been made,
as evidenced by several already published papers. The instrument characteristics as well as a
brief review of the science accomplished and planned are presented.

19 pages
8 figures
Keywords: EMMA, Astrid-2 satellite, micro-satellite, ionosphere, magnetosphere