P.3

MICROSPACECRAFT AND EARTH OBSERVATION: ELECTRICAL FIELD (ELF) MEASUREMENT PROJECT

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INTRODUCTION

Past attempts to map the Earth's electrical field have been severely limited by the lack of simultaneous global measurements. Previous measurements have been made by sounding rocket- and satellite-borne sensors, but these measurements have covered only singular points in the field. These satellite observations are augmented by ground-radar (incoherent scatter) plasma-drift measurements; however, only six ground-based installations are producing such local electrical-field maps. The expansion of this ground-based radar network to meet a global objective is politically and financially impossible. Global electrical-field maps constructed by forcing mathematically formulated models to fit this limited set of data points are not only inaccurate, but the degree of inaccuracy is impossible to evaluate(1). Therefore, we see a need for an inexpensive, extensive, long-lasting global electrical-field measurement system (ELF).

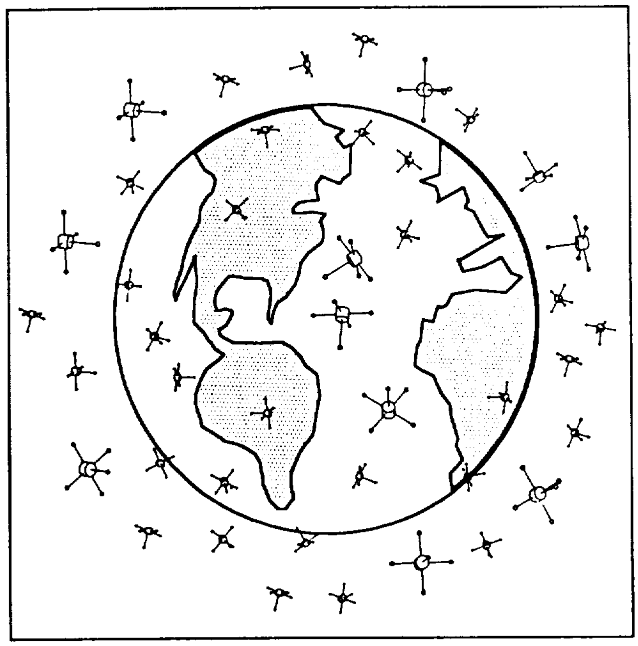

Fig. 1. Artist's conception of the ELF constellation surrounding the Earth.

DESIGN CONSIDERATIONS

The primary performance driver for this mission is the need to measure the attitude of each spacecraft very accurately. In addition, it is necessary to know the electrical charge generated by the satellite as it crosses the magnetic field lines ($E = V \times B$). This value must be factored out of the measurements. It will not be necessary to control the attitude of the satellite precisely, but the attitude will have to be known to within $\pm 1°$ to achieve the desired accuracy. Also, the payload sensing booms must rotate in order to balance photoelectric effects and aid in the measurement of the $V \times B$ bias.

In order to achieve the desired global coverage, a constellation of about 50 satellites in at least 18 different orbits will be used as shown by the artist's conception in Fig. 1. To reduce the cost of each satellite, off-the-shelf, proven technology will be used wherever possible. We set a limit of 25 kg and $500,000 per satellite. We expect the program cost, including the deployment of the entire constellation, to be less than $100 million. The minimum projected mission life is five years.

Design Evolution

Several designs were considered for the ELF satellite: (1) gravity gradient satellite; (2) dual spinner satellite; and (3) simple spinner satellite.

Gravity gradient satellite. The first design considered was a gravity gradient satellite. This is a satellite in which, because of its mass distribution, one face of the satellite constantly points at the Earth. Because this is a very stable configuration, there is no need for an active attitude control system. This design was discarded due to the electrical-field sensor requirement that it must spin.

Dual spinner satellite. Second, a dual spinner satellite such as those used for communication purposes was considered. This was in order to satisfy the sensor requirement of spinning as well as to have a face of the satellite constantly Earth-pointing for ease of communication. We abandoned this design due to the unnecessary complications caused by having to interface between the rapidly spinning and slowly spinning platforms of the satellite.

Simple spinner satellite. Last, a simple spinner satellite was considered. With this design, the complexities of interfacing between two platforms spinning at different rates do not exist, yet the sensor requirements are still satisfied. The rest of this document describes this final design configuration.

Electrical-Field Sensing System

The electrical-field sensing system will consist of three orthogonal sets of insulated booms with conductive spheres attached to the ends, as shown by Fig. 2. The electrical potential across each pair of conductive spheres will be

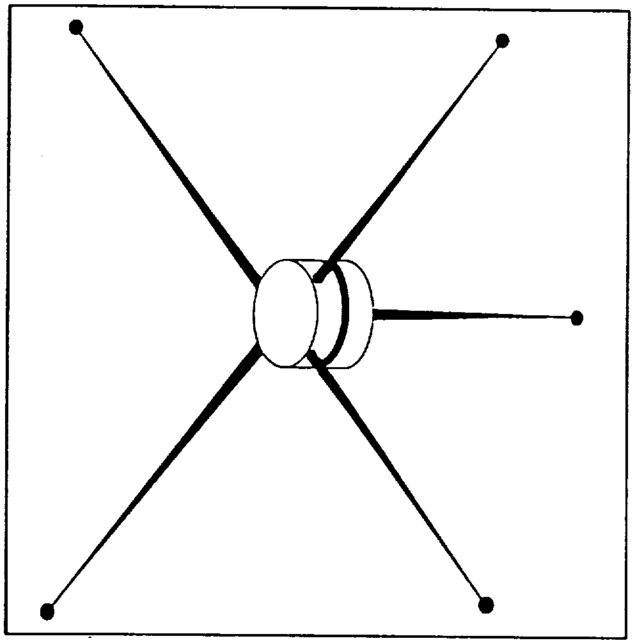

Fig. 2. Close-up exterior view of an ELF satellite.

measured to get the three-dimensional electrical-field measurement at a point. The boom system must be rotating in order to mitigate the photoelectric charge build-up caused by exposure to the sun. To achieve the desired accuracy, the spheres must be separated by at least 1 m and be rotating at no more than 10 rad per sec. Since the rotation causes a sinusoidal variation in the output, potential readings must be taken at least every 0.1 sec to get the desired resolution.

Mission Description

The most dynamic electrical-field activity around the Earth occurs near the poles in the 50° to 70° latitude regions. It is in this region that phenomena such as the aurora are observed most frequently. Little activity of interest occurs in the equatorial regions. Therefore, the ELF satellites will be placed in orbits with inclinations between 45° and 90°. This placement gives good coverage of the poles as well as some coverage of the equatorial regions.

The ELF satellites will be placed at altitudes between 500 and 1000 km. In this range, the Earth's electrical field does not change dramatically with a change in altitude. Also, 500 km is high enough to give the lowest satellite a minimum mission life of 5 years before the orbit decays, and 1000 km is low enough to escape the radiation from the Van Allen belts.

ELF Constellation Deployment

Two deployment scenarios are being considered. The first considers using Orbital Sciences Corporation's Pegasus as a dedicated launch vehicle. The second option looks at piggyback opportunities on McDonnell Douglas's Delta II launch vehicle.

If the Pegasus is used, six satellites will be launched at a time. When the proper orbit is reached, one of the six satellites will be ejected from the Pegasus upper stage. The rest of the cluster will remain attached to the stage. This concept is shown in Fig. 3. The stage will then be maneuvered to a slightly different altitude (about 75 km higher) or a slightly different inclination (about 2.5° difference) where another ELF satellite will be ejected. This sequence will be repeated until all six satellites have been ejected. Launching the satellites in clusters like this reduces the required number of launches. By slightly changing either the altitude or inclination of each satellite in the cluster, the satellites will be dispersed even further by orbital perturbations caused by the Earth's oblateness. This will result in the required global coverage.

The Delta II has the room for four ELF satellites to piggyback on it. The major problem with using this launch vehicle is that the satellites will go to wherever the primary payload dictates. Few polar launches are planned for the 1990s; most launches will be to inclinations below about 35°. Therefore, some sort of onboard propulsion for each ELF satellite will be required to get it into the proper type of orbit and altitude. However, there does not appear to be enough room for such a propulsion system. A possible alternative might be to use a tether deployment system. The details and requirements for this type of launch are still being investigated.

Upon insertion into orbit, a radio signal will be sent to the satellites to activate them. A programmed routine on board the spacecraft will cause the sensor booms to deploy and the attitude control jets to fire, spinning the satellite.

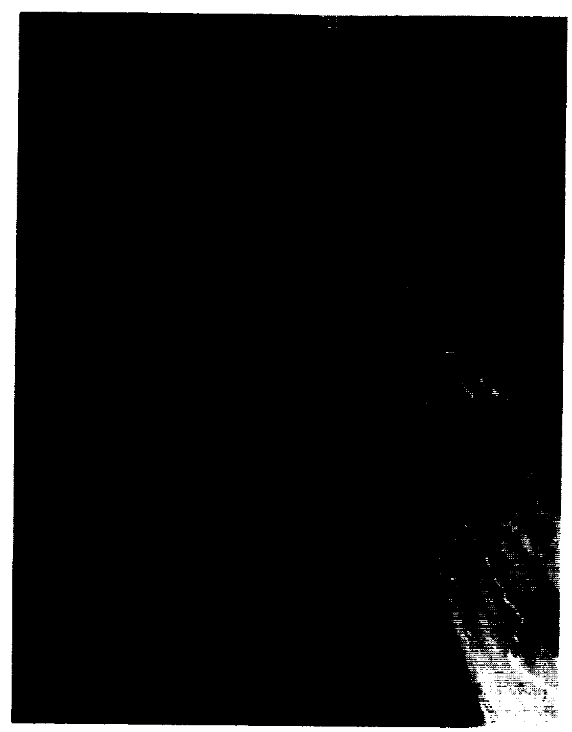

Fig. 3. Artist's conception of an ELF satellite being ejected from the Pegasus's upper stage.

Attitude Control and Determination System

The satellite is modeled as a spinning oblate platform that spins at 10 rpm. The orientation or attitude of each satellite will not be controlled, but the spin rate will be controlled to 10 ± 2 rpm. An onboard cold gas propellant system will be used to spin up the satellite initially, as well as make any necessary spin rate adjustments.

Two 2-axis magnetometers, two sun sensors, and one horizon-crossing sensor are used to determine the attitude of each ELF satellite. By using different combinations of these five sensors, the attitude of the satellite can be determined at all times during the orbit. Some of the data will be redundant, but this redundancy can be used to enhance the accuracy of the readings. These readings will lie within the ±1° error margin for attitude knowledge.

Data Processing System

The data processing system is sized to store up to 24-hours' worth of data. These data include the electrical-field potential as well as the attitude readings. This system will also handle housekeeping functions on board the satellite.

Communication System

Because the attitude of each ELF satellite will not be controlled and each satellite can maintain a different orientation, a virtually omnidirectional antenna is needed on board for communication. A stripline wraparound antenna meets this requirement. Frequencies in the S-band will be used for receiving instructions and transmitting the collected data to a ground station. Data will be transmitted twice per day to one ground station. The ground station will use a 4.3-m parabolic dish with tracking capabilities. The actual location of this ground station is yet to be determined. Each satellite will take a maximum of 82 sec to transmit the stored data. It is expected that each satellite will pass within range of the ground station at least twice per day.

Power System

Each satellite's power will come from solar cells wrapped around the exterior of the spacecraft. Since the satellites will not generally be placed in sun-synchronous orbits, they will have to function in the dark as well. Therefore, the solar cells will be backed up with batteries. The minimum power generation will be 12.77 W, which will be sufficient to cover the power requirements of all systems.

ELF Satellite Structure and Configuration

The cylindrical primary structure is 45 cm in diameter and 35 cm high. It will be composed of 0.16- to 0.32-cm-thick aluminum 6061-T6. The primary support plate will be made of 1.25-cm-thick aluminum honeycomb. Most subsystem components will be mounted on this plate as shown by Fig. 4. Individual component covers will provide radiation shielding as required.

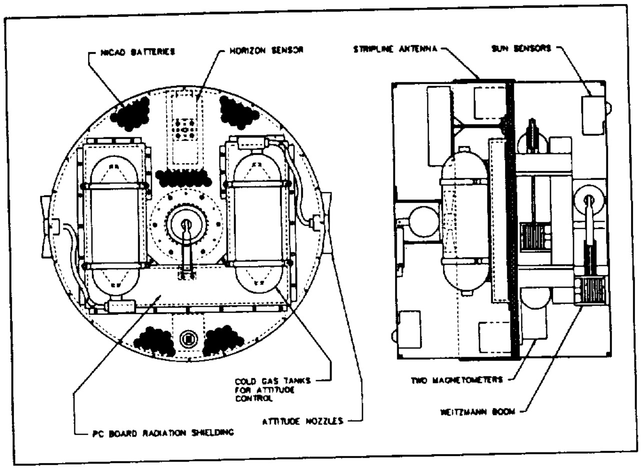

Fig. 4. Internal layout of the subsystem components.

Thermal Control System

The extreme temperatures were determined for the ELF satellites by considering the worst cases of the hottest and coldest orbits. The hottest orbit is one in which one flat face of the satellite constantly faces the sun. If an ELF satellite winds up with this orientation, all onboard components will stay within their temperature ranges. The coldest orbit considered was one in which the flat faces of the satellite never see the sun. The temperature ranges for this case went below the component limits. In order to compensate for this, three 1-W heaters will be used to keep the components within their required operating temperature. These heaters are equipped with their own temperature regulating switches.

Conclusions

Each satellite has a mass of 19.1 kg and will cost less than $250,000 for the actual hardware. Including deployment costs, the program will cost about $70 million for 8 Pegasus launches and 48 satellites. Labor costs have not yet been computed.

We expect to be able to deploy about 50 satellites. Because we are deploying a constellation of 50 satellites there is inherent redundancy in this system. The most catastrophic event that could happen is to have the launch vehicle explode. But even this will not affect the system drastically since at the most six satellites will be lost. We expect to lose not more than 10% of the satellites to launch vehicle malfunction, ELF subsystem failure, or space debris impact.

REFERENCES

1. Sojka, J. J., 2-DEF A Two Dimensional Electric Field Mission, Center for Atmospheric and Space Sciences, Utah State University, Logan, Utah, CASS Report #89-5-2, November 1989.