SATELLITE MEASUREMENTS OF DC ELECTRIC FIELDS IN THE IONOSPHERE

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Abstract. This paper presents initial results from the dc electric field experiment on the low altitude polar orbiting Injun 5 satellite. At low latitudes, where the ionospheric plasma is expected to corotate with the earth, the only observed electric field is the $\mathbf{V} \times \mathbf{B}$ electric field due to the motion of the satellite through the ionosphere. Comparisons of the computed $\mathbf{V} \times \mathbf{B}$ field agree with the measured electric field within about ± 10 mV/m. At the plasmapause boundary small changes (~ 5 to 15 mV/m) in the dc electric field are observed which are believed to be due to magnetospheric convection phenomena at the plasmapause boundary. At high latitudes large amplitude (~ 100 mV/m) electric field irregularities and disturbances, believed to be due to ionospheric electric fields, are observed on virtually every passage over the polar regions. Long period electric field oscillations with periods on the order of 15 sec also are commonly observed at high latitudes.

1. Introduction

The importance of magnetospheric electric fields and the associated convection of plasma in the magnetosphere has been recognized for a number of years (Axford and Hines, 1961; Dungey, 1961; Piddington, 1962a, 1962b; Boström, 1966; Axford, 1969); however, only recently have techniques been developed for the measurement of magnetospheric electric fields and the study of magnetospheric convection. Of the variety of techniques from which electric fields can be directly or indirectly deduced (see Axford, 1969) probably the most extensive and sensitive measurements have been obtained from artificial Ba cloud releases (Haerendel *et al.*, 1967, 1969; Föppl *et al.*, 1968; Wescott *et al.*, 1969). Relatively few direct probe measurements of dc electric field measurements have been reported. Mozer and Bruston (1967), Fahleson *et al.* (1968), and Aggson (1969) have used the double probe technique on sounding rockets to measure ionospheric electric fields. Heppner (1968) has reported on results from the electric field experiment on the OV1 10 satellite which detected electric field disturbances with periods less than about 60 sec. This paper presents initial results from the dc electric field experiment on the low altitude (677 to 2528 km) polar orbiting Injun 5 satellite. These measurements are among the first reported satellite measurements of *dc* electric fields using the double probe technique.

2. Instrumentation

The electric field experiment on Injun 5 is of the double probe type described by Fahleson (1967), Aggson (1969), and others. The probes used consist of two conducting spheres 20.3 cm in diameter mounted on booms with a center-to-center separation of 2.85 m as shown in Figure 1.

If the two spheres have identical characteristics and if wake effects and other

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spacecraft related perturbations can be ignored, then the difference between the floating potential and the plasma potential will be the same for each sphere and the electric field in the plasma can be determined directly from the difference in the floating potential and the separation distance of the two spheres. Possible errors in the double probe technique due to differences in the contact potential of the spheres, unequal photoelectron emission, and various other effects are discussed by Fahleson (1967).

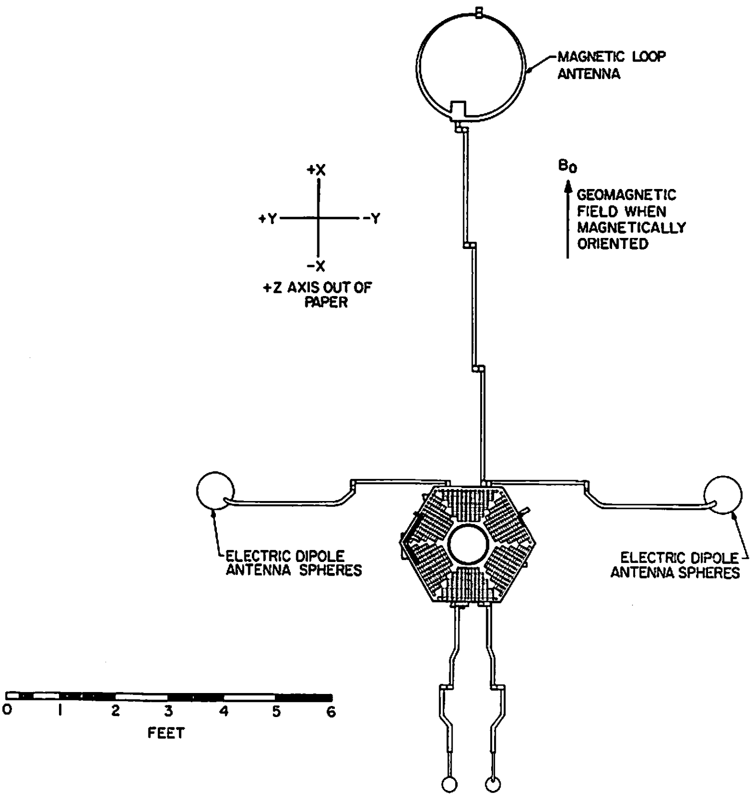

Fig. 1. Top view of Injun 5 showing the electric antenna geometry.

The Injun 5 spacecraft is magnetically oriented by a bar magnet within the spacecraft such that when properly aligned the x-axis of the spacecraft is parallel to the geomagnetic field with the positive x-axis pointing downward in the Northern Hemisphere. Typical maximum alignment errors between the x-axis and the geomagnetic field are about 10 to 15°. As shown in Figure 1, when the spacecraft is oriented magnetically, the axis through the two spheres is perpendicular to the geomagnetic field. The dc electric field experiment, therefore, is primarily sensitive to the electric field $\mathbf{E}_\perp$ perpendicular to the geomagnetic field.

The potential difference between the spheres is obtained from a high input impedance (20 MΩ) differential amplifier located in the main spacecraft electronics. The differential amplifier has a dynamic range of ±1.0 V and an RC time constant of 0.4 sec. The output from the differential amplifier is sampled by the digital data system once every 4 sec with 8 bit (256 step) accuracy. The minimum resolvable electric field strength increment is approximately 2.75 mV/m. In order to make a quantitative estimate of the error due to the finite voltmeter impedance, the ac impedance of the spheres is measured every 30 sec by differentially driving the spheres with a constant amplitude ac current source and measuring the resulting ac potential difference between the spheres. Further details of the Injun 5 dc electric field experiment are given by Gurnett *et al.* (1969).

3. Comparison with V × B

The potential difference between the spheres observed for a typical mid-latitude pass is shown in Figure 2. The systematic sinusoidal variation evident in the potential difference, with a period of about 20 min, is due to the **V**×**B** electric field arising from the satellite motion through the ionosphere. The sinusoidal modulation of the **V**×**B** potential is caused by the slow rotation of the satellite and the electric antenna axis around the geomagnetic field with a period of about 20 min. The dashed lines in Figure 2 are the potential limits of the **V**×**B** electric field as computed from the satellite orbit. The satellite velocity **V** was computed relative to a coordinate system corotating with the earth. At middle and low latitudes, where the ionospheric plasma is expected to corotate with the earth (Axford, 1967), only the **V**×**B** electric field should be observed. In order to fit the computed **V**×**B** potential limits to the observed maxima and minima of the sphere potential difference (when the electric antenna axis becomes aligned and anti-aligned respectively with **V**×**B**), it was found to be necessary to subtract a constant offset voltage of about 40 mV from the measured sphere potential difference. This offset voltage is believed to be due to differences in the surface properties of the two spheres. As can be seen from Figure 2, when this offset voltage is taken into account the maximum and minimum sphere potential differences agree very well with the limits for the **V**×**B** potential. This excellent agreement demonstrates that the double probe electric field experiment on Injun 5 can measure accurately electric fields in the ionosphere. From comparisons between the measured

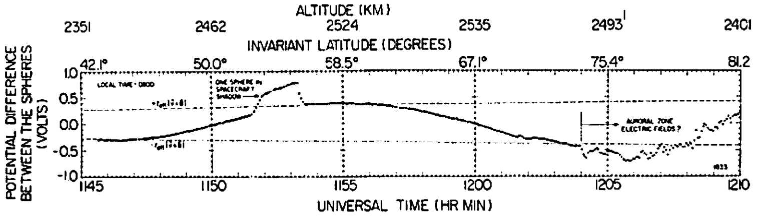

Fig. 2. DC potential difference between the spheres compared with the V × B potential limits (dotted lines).

electric field and V × **B** under various conditions, the error limits for the absolute dc electric field measurements have been estimated to be about ±10 mV/m.

The abrupt 0.3 V increase in the sphere potential difference from 1152 to 1153 UT in Figure 2 is due to the change in the photoelectron emission of one of the spheres as it passes through the shadow of the spacecraft body. Similar optical shadowing effects are commonly observed in the dc electric field data and are easily identified. Small (10 mV/m) errors due to unequal shadowing of the spheres by the booms also are observed for some orientations. No wake effects have been observed. Sheath resistances observed in orbit generally are considerably less than the input impedance of the differential amplifier so that errors due to the 'loading' of the antenna by the differential amplifier are usually negligible.

4. High Latitude Electric Field Irregularities

Starting at approximately 1204 UT and 73° INL during the pass illustrated in Figure 2, large amplitude (0.3 V) irregular perturbations from the V × **B** potential are observed. These irregular perturbations in the sphere potential difference, observed on virtually every pass over the polar regions, are believed to be due to spatial irregularities in the ionospheric electric field of the same type reported by Heppner *et al.* (1968).

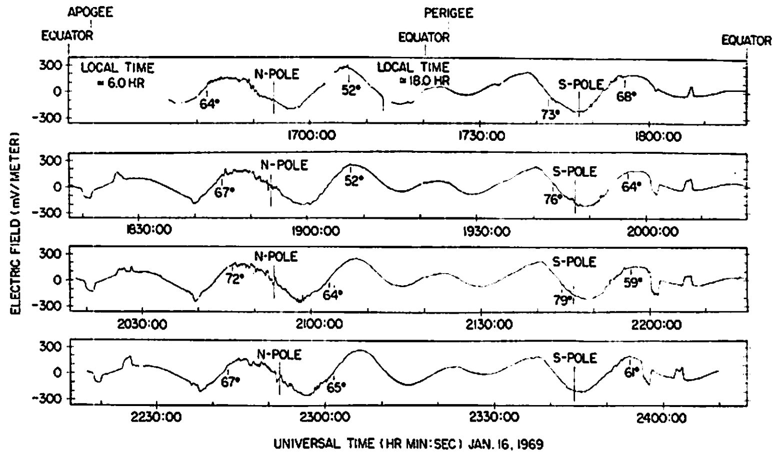

Fig. 3. DC electric field for a sequence of four consecutive orbits.

To illustrate the general character of these electric field irregularities, Figure 3 shows the dc electric field data for a sequence of four entire orbits during a period of relatively little magnetic activity ($K_p \leqslant 3$). The time scales for these orbits have been aligned to permit direct comparison of successive passes over each polar region. As can be seen electric field irregularities are evident on every pass over the polar region. The lowest latitude at which the electric field irregularities are observed is quite variable, from as low as 52° to as high as 79° INL. Generally the largest amplitudes are observed at INL > 70°. Although the general region of the irregularities is similar for successive passes over a given polar cap, the detailed electric field structure shows little similarity from one orbit to the next. Typical peak amplitudes for these electric field irregularities during a given orbit are on the order of 30 to 100 mV/m.

Preliminary investigations of electron density data obtained from the AFCRL electron density experiment on Injun 5 have shown that large amplitude (5 to 25%) irregular electron density fluctuations are observed often in the same general region that the electric field irregularities are observed. A similar correlation also has been observed with the OGO 6 satellite (Hanson, 1969; Heppner, 1969).

5. The Plasmapause Boundary

Since various current magnetospheric models picture the plasmapause boundary as being the inner boundary of magnetospheric convection (Nishida, 1966; Brice, 1967), several plasmapause crossings have been investigated to determine if any net disturbance from the V × **B** field could be detected as the satellite crossed the plasmapause boundary.

Investigation of these plasmapause crossings has shown that the electric field generally varies smoothly near the plasmapause boundary and that a small (5 to 15 mV/m) but measurable change in the dc electric field is often evident at the plasma-

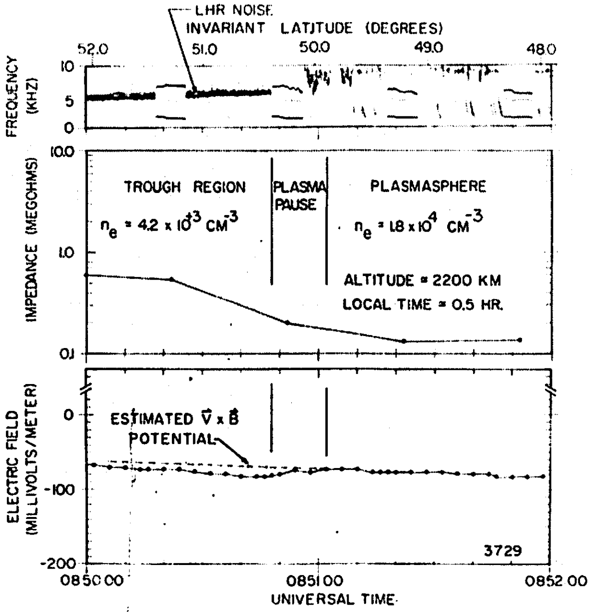

Fig. 4. DC electric field variations at a typical plasmapause crossing.

pause boundary. The electric field irregularities described in the previous section are normally encountered at latitudes somewhat higher than the plasmapause.

A typical plasmapause crossing is shown in Figure 4 at 0851:20 UT. The plasmapause location in this case was identified from the characteristic 'lower hybrid resonance (LHR) breakup' effect commonly found in the VLF electric field data at the plasmapause boundary (Carpenter *et al.*, 1968), the characteristic increase in the sheath resistance at the plasmapause boundary (Gurnett *et al.*, 1969), and the change in the electron density as measured directly by the AFCRL electron density measurement on Injun 5.

The dc electric field is seen to vary smoothly as the satellite crosses the plasmapause, with no evidence of the large amplitude electric field irregularities of the type typically found at higher latitudes. By extrapolating the **V** × **B** potential from the low latitude side of the plasmapause (dotted line in Figure 4), where we assume that there is no ionospheric electric field, a small shift in the dc electric field on the order of 15 mV/m is evident upon crossing the plasmapause boundary. Estimates of errors (Fahleson, 1967) due to unequal sunlight and ram ion shadowing of the two spheres cannot account for the observed change in the sphere potential difference. This shift in the dc electric field, therefore, is attributed to a convection electric field on the order of 15 mV/m, corresponding to a convection velocity on the order of 0.4 km/sec. The sense and magnitude of the change in the electric field component measured (the spheres were aligned approximately in the N–S direction) is consistent with a transition from corotation inside the plasmasphere to nearly noncorotation outside the plasmasphere.

6. Long Period Electric Field Oscillations

Large amplitude electric field oscillations with periods on the order of 15 to 20 sec are frequently found in the Injun 5 electric field data, particularly in the latitude range from about 70 to 80° INL. Two particularly remarkable examples of long period electric field oscillations occurred during the orbit shown in Figure 5 on the low latitude side of the discontinuities in the dc electric field evident at about 1534:00 and 1643:00 UT. The electric field data near these times are shown with an expanded scale in Figure 6. These electric field discontinuities and associated electric field oscillations are remarkable in that at the times of the electric field discontinuities the

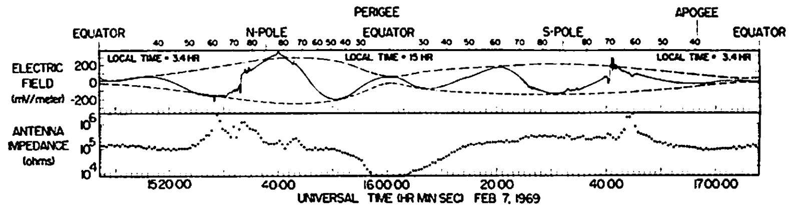

Fig. 5. Conjugate electric field discontinuities and associated electric field oscillations.

satellite was at very nearly conjugate points in the geomagnetic field. The invariant latitude at these times differed by only 3° (73° vs. 70°, respectively) and the magnetic local time differed by only 0.14 hr (3.27 hr vs. 3.41 hr, respectively). A detailed examination of these two events strongly suggest a close magnetically conjugate relationship. The N–S electric field component (which was the approximate orientation of the electric antenna axis in both cases) decreases toward higher latitudes in both hemispheres and the magnitude of the electric field discontinuity is very nearly the same in both hemispheres. The periods of the electric field oscillations observed in both hemispheres are also very nearly the same – about 17 sec. This close magnetically conjugate relationship, particularly for the electric field discontinuities, is very suggestive that the electric field and associated convection are mapped from one hemisphere to the other along the geomagnetic field line, as is often presumed for the 'frozen field' model of magnetospheric convection.

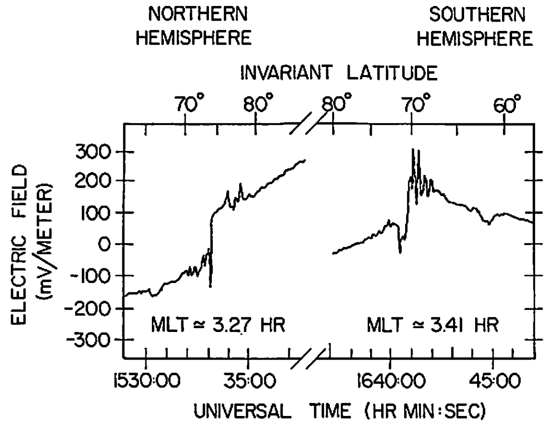

Fig. 6. Expanded illustrations of the discontinuities and electric field oscillations shown in Figure 5.

At the present time the detailed nature of these long period electric field oscillations is largely unknown. It has not yet been established whether the observed oscillations are basically a temporal variation or a long wavelength (100 km) spatial structure converted to a temporal variation by the satellite motion through the ionosphere. Since very similar fields were observed at magnetically conjugate points, it is reasonably certain that the oscillations are a magnetospheric phenomena occurring over a relatively wide range of *L* shells. If these electric field oscillations are due to hydromagnetic waves in the magnetosphere, then corresponding large amplitude magnetic field oscillations (possibly corresponding to pc 2 micropulsations) also should be observed. No comparable magnetic field oscillation could be found from ground magnetometer records investigated for the two cases illustrated in Figures 5 and 6, although in neither case was the subsatellite point closer than 1000 km to the nearest ground magnetometer.

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References

Aggson, T. L.: 1969, AGU Conference on Electric Fields in the Magnetosphere, March 10–13, Houston, Texas.

Axford, W. I.: 1967, in *Physics of Geomagnetic Phenomena* (ed. by S. Matsushita and W. H. Campbell), Academic Press, New York, p. 1243.

Axford, W. I.: 1969, *Rev. Geophys.* **7**, 421.

Axford, W. I. and Hines, C. O.: 1961, *Can. J. Phys.* **39**, 1433.

Boström, R.: 1966, in *Aurora and Airglow* (ed. by B. M. McCormac), Reinhold Publishing Corporation, New York, p. 293.

Brice, N. M.: 1967, *J. Geophys. Res.* **72**, 5193.

Carpenter, D. L., Walter, F., Barrington, R. E., and McEwen, D. J.: 1968, *J. Geophys. Res.* **73**, 2929.

Dungey, J. W.: 1961, *Phys. Rev. Letters* **6**, 47.

Fahleson, U. V.: 1967, *Space Sci. Rev.* **7**, 238.

Fahleson, U. V., Kelley, M. C., and Mozer, F. S.: 1968, University of California, preprint.

Föppl, H., Haerendel, G., Haser, L., Lüst, R., Melzner, F., Meyer, B., Neuss, H., Rabben, H., Rieger, E., Stocker, H., and Stoffregen, W.: 1968, *J. Geophys. Res.* **73**, 21.

Gurnett, D. A., Pfeiffer, G. W., Anderson, R. R., Mosier, S. R., and Cauffman, D. P.: 1969, *J. Geophys. Res.*, **74**, 4631.

Haerendel, G., Lüst, R., and Reiger, E.: 1967, *Planet. Space Sci.* **15**, 1.

Haerendel, G., Lüst, R., Rieger, E., and Völk, H.: 1969, in *Atmospheric Emissions* (ed. by B. M. McCormac and A. Omholt), Van Nostrand and Reinhold Company, p. 293.

Hanson, W. B.: 1969, private communication.

Heppner, J. P.: 1968, NASA-Goddard Space Flight Center, preprint X-612-68-331.

Heppner, J. P.: 1969, private communication.

Heppner, J. P., Aggson, T. L., and Maynard, N. C.: 1968, Symposium on the Physics of the Magnetosphere, September, Washington, D.C.

Mozer, F. X. and Bruston, P.: 1967, *J. Geophys. Res.* **72**, 1109.

Nishida, A.: 1966, *J. Geophys. Res.* **71**, 5669.

Piddington, J. H.: 1962a, *J. Geophys.* **7**, 183.

Piddington, J. H.: 1962b, *Planet. Space Sci.* **9**, 947.

Wescott, E. M., Stolarik, J. D., and Heppner, J. P.: 1969, *J. Geophys. Res.* **74**, 3469.