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EXCITATION OF CYCLOTRON SPIKES IN THE IONOSPHERIC PLASMA

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EXCITATION OF CYCLOTRON SPIKES IN THE IONOSPHERIC PLASMA

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Reprinted from
CANADIAN JOURNAL OF PHYSICS
43, 291 (1965)

EXCITATION OF CYCLOTRON SPIKES IN THE IONOSPHERIC PLASMA

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Received November 4, 1964

ABSTRACT

The occurrence of resonances in the ionosphere at frequencies which are harmonics of the gyrofrequency have been detected by the topside-sounder satellite, Alouette I. It has been observed that the occurrence of cyclotron spikes on ionograms is a function of the angle between the antenna and the earth's magnetic field. The number of cyclotron spikes observed is a maximum when the appropriate antenna is parallel to the earth's magnetic field.

INTRODUCTION

The occurrence of resonances in the ionosphere at the harmonics of the gyrofrequency has been detected by the topside-sounder satellite, Alouette I (Lockwood 1963). Since the spin rate of the satellite is different than the sounding cycle of the topside sounder, the orientation of the satellite varies from one ionogram to the next. Thus, cyclotron spikes occur on ionograms with the sounding antenna at various angles to the earth's magnetic field. It is observed that the number of cyclotron spikes occurring on an ionogram is a maximum when the sounding antenna is parallel to the earth's magnetic field.

METHOD OF ANALYSIS

The relative location of the antennas and the magnetometer in Alouette I, as well as the direction of rotation of the satellite, is shown in Fig. 1. The celestial coordinates of the spin vector and the angular position of the satellite relative to the magnetic field vector are obtained from the magnetometer

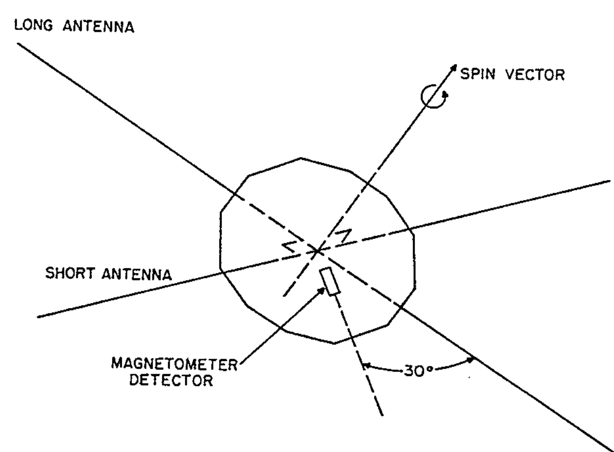

FIG. 1. The relative locations of the antennas and the magnetometer in Alouette I.

data. When the spin vector is parallel to the magnetic field, the antennas are perpendicular to the magnetic field for the complete rotation of the satellite. However, when the spin vector is perpendicular to the magnetic field, the angle between each antenna and the magnetic field changes from 0° to 90° and back to 0° twice per rotation. By choosing occasions for which the satellite orientation satisfied the second of these two conditions, one can observe conveniently the occurrence of cyclotron spikes in ionograms as a function of the angle between the antennas and the earth's magnetic field. The most accurate angular reference is the time at which the magnetic field detected by the magnetometer is zero, the magnetometer axis being perpendicular to the magnetic field at that instant. An example of the magnetometer output is shown in Fig. 2. At the time the observation was made the spin period was about 54 seconds.

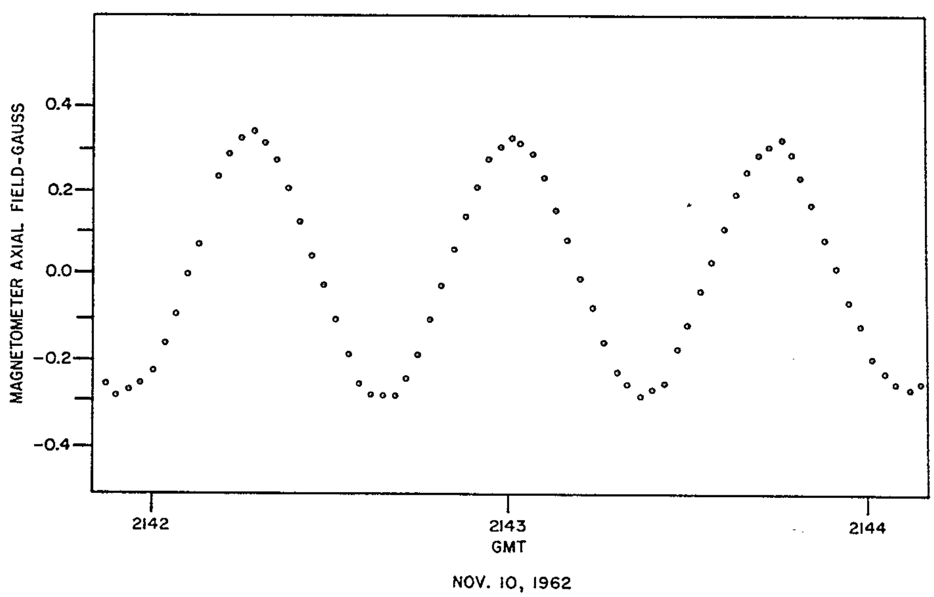

FIG. 2. An example of the output of the magnetometer in Alouette I.

An inspection of Fig. 1 indicates that the long antenna crosses a maximum of the magnetic field at a rotation of 60° after the magnetometer measures zero field. Also, since the antenna system is symmetric with respect to the spin vector, the second half-rotation is a repetition of the first-half rotation. Thus, in Figs. 4 and 5, the abscissa which represents the angular position of the antenna has a range of 180°.

The antenna system contains a passive electrical crossover network located between the transmitter–receiver system and the two orthogonal antennas. Below the crossover frequency of about 4.7 Mc/s the long antenna system is most efficient, with the short antenna effectively isolated from the transmitter–receiver system. Above about 4.7 Mc/s the short antenna system is

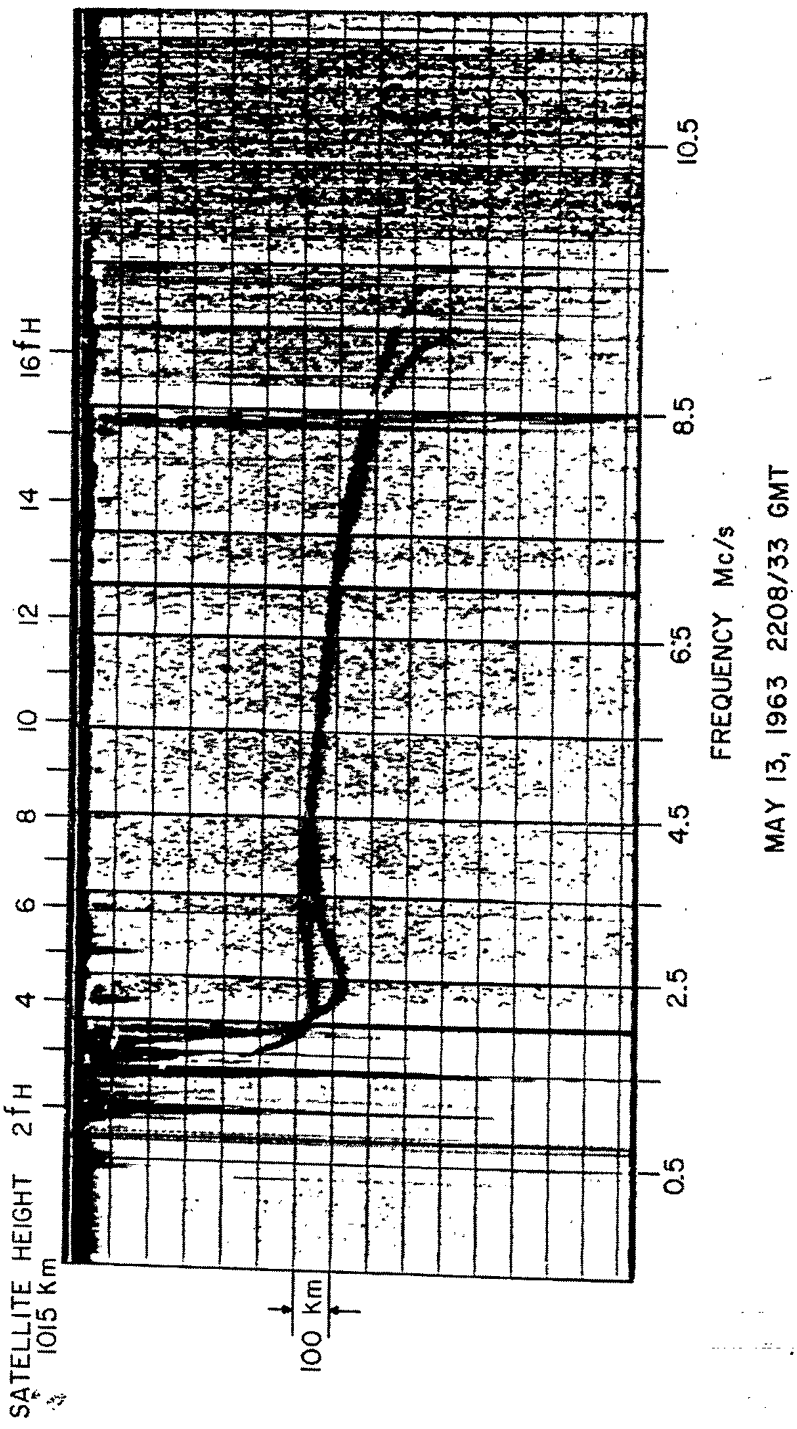

FIG. 3. An ionogram with 16 cyclotron spikes, 80° W. longitude, 1° S. latitude.

most efficient, with the long antenna isolated from the transmitter–receiver system (30 dB at 6 Mc/s).

DISCUSSION OF OBSERVATIONS

The observation of cyclotron spikes is hampered by the following condition. The receiver is desensitized above the critical frequency of the F layer by ground transmitters owing to the AGC response of the receiver, and cyclotron spikes are rarely observed above the critical frequency of the F layer. This condition restricts the observation of high-harmonic cyclotron spikes to the hours near noon when the critical frequency of the F layer is highest.

Near the equator, where the critical frequency may be higher than 10 Mc/s and the gyrofrequency is the smallest, the highest-harmonic cyclotron spikes are observed. Figure 3 shows an ionogram containing cyclotron spikes up to the 16th harmonic. A sequence of 18 ionograms, containing the one shown in Fig. 3, was analyzed to determine the angle between each antenna and the earth's magnetic field when the cyclotron spikes were observed. For the sequence of ionograms the spin vector of the satellite was perpendicular to the magnetic field so that the angle between each antenna and the earth's magnetic field changed from 0° to 90° and back to 0° twice per rotation. The result is shown in Fig. 4. Cyclotron spikes below the 8th harmonic are detected by the receiver system using the long antenna. Those above the 8th harmonic are detected with the use of the short antenna. The adjectives "low-harmonic" and "high-harmonic" will be used to refer to cyclotron spikes detected by the long and short antennas respectively. The sloping dashed line illustrates the

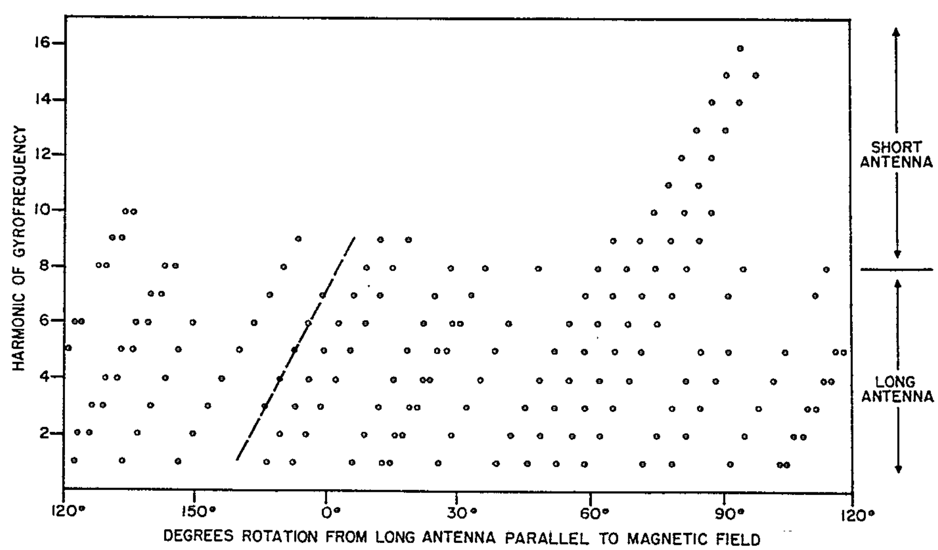

FIG. 4. The occurrence of cyclotron spikes as a function of the angle between the long antenna and the earth's magnetic field: equatorial latitudes.

cyclotron spikes which occur on a single ionogram. The figure shows that the high-harmonic cyclotron spikes detected with the short antenna occur when the short antenna is parallel to the earth's magnetic field. Not shown is the fact that the amplitude of the low-harmonic cyclotron spikes, detected by the long antenna, is decreased when the long antenna is perpendicular to the magnetic field (at 90° in Fig. 4).

Figure 5 shows the result of a similar analysis for a mid-latitude sequence of ionograms in which the same effect is observed. Since the gyrofrequency is larger, the antenna crossover occurs at the fifth harmonic of the gyrofrequency.

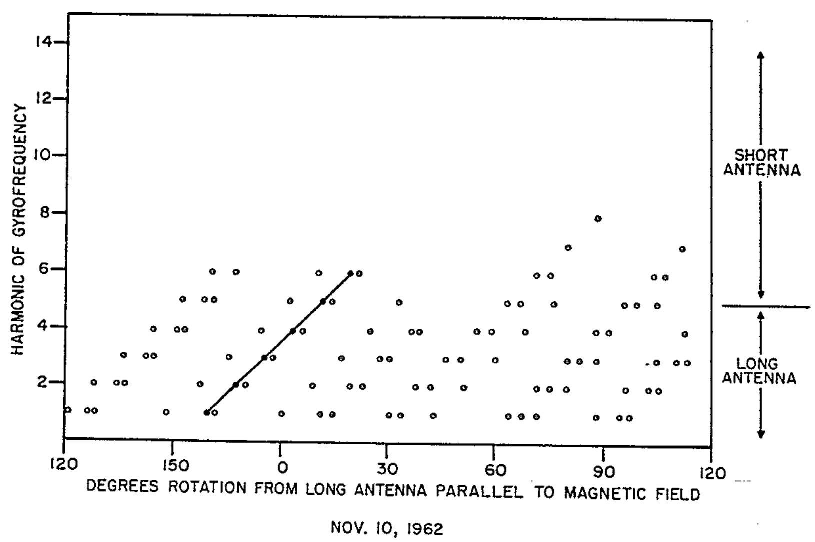

FIG. 5. The occurrence of cyclotron spikes as a function of the angle between the long antenna and the earth's magnetic field: mid-latitudes.

Again, the high-harmonic cyclotron spikes are observed when the short antenna is parallel to the earth's magnetic field.

Table I summarizes some occasions in which high-harmonic cyclotron spikes

TABLE I

Cyclotron spikes

Date	Time (G.M.T.)	Long.	Lat.	Dip angle
			Equatorial	
Feb. 23/63	1931	66° W.	4° S.	18°
Feb. 24/63	2011	76° W.	4° N.	31°
May 13/63	2208	80° W.	1° S.	20°
Aug. 30/63	1845	64° W.	1° S.	23°
			Mid-latitude	
Nov. 10/62	2143	66° W.	27° N.	61°
Dec. 26/62	1507	71° W.	43° N.	73°
Mar. 19/63	2225	145° W.	49° N.	67°
July 15/63	1939	84° W.	44° N.	75°

were observed. The observations were made over diverse geographical locations for which the range in dip angle was 18–75°. In all cases the number of cyclotron spikes on an ionogram was a maximum when the short antenna was parallel to the earth's magnetic field.

A sequence of equatorial ionograms was analyzed in which the spin vector was almost parallel to the earth's magnetic field (±10°), and both antennas were continuously perpendicular (approximately) to the magnetic field. Not only were no high-harmonic cyclotron spikes observed (Fig. 6), but the average number of low-harmonic cyclotron spikes decreased from the usual average of about eight (Fig. 4) to an average of about five (Fig. 6). The abscissa in Fig. 6 gives relative angular position only, since both antennas were continuously perpendicular to the magnetic field. Figures 4 and 6 show an apparent discrepancy in the behavior of the low-harmonic and high-harmonic cyclotron

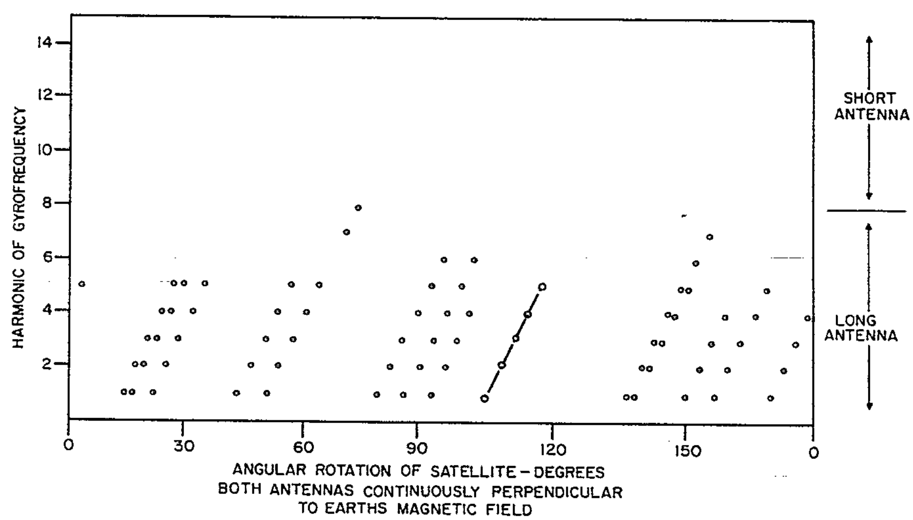

FIG. 6. The occurrence of cyclotron spikes on ionograms when both antennas are continuously perpendicular to the earth's magnetic field.

spikes. A strong angular dependence for the cyclotron resonance is observed for the high-harmonic cyclotron spikes, while no angular dependence is observed for the low-harmonic cyclotron spikes. A decrease in the average number of low-harmonic cyclotron spikes occurs (Fig. 6) when both antennas are simultaneously perpendicular to the magnetic field.

The difference in the orientation of the satellite for Figs. 4 and 6 is as follows. For Fig. 4, each of the two antennas is alternately parallel and perpendicular to the magnetic field. Thus, at all times, either one or the other antenna has a major projection parallel to the magnetic field. This projection must be considered since it is known that below 4.7 Mc/s the two antennas are not completely decoupled from each other electrically, because of the crossover network. On the other hand, for Fig. 6, both antennas are continuously perpendicular to the earth's magnetic field and have no projection parallel to the magnetic field. Thus, the lack of angular dependence for the low-harmonic cyclotron spikes in Fig. 4 is due to the lack of complete isolation between the two antennas. Sufficient energy is radiated and detected by the combination of antennas to produce the eight low-harmonic cyclotron spikes and mask the angular dependence of the cyclotron resonance. However, when both antennas are approximately perpendicular to the magnetic field, the decrease in the average number of low-harmonic cyclotron spikes (Fig. 6) reflects the angular dependence of the cyclotron resonance at low harmonics of the gyrofrequency.

SUMMARY

The observation of cyclotron spikes is restricted by several conditions. Since the receiver is desensitized by ground interference above the critical frequency of the F layer, cyclotron spikes are rarely seen above the critical frequency. This condition restricts the observation of the higher-harmonic cyclotron spikes to the daytime, when the critical frequency of the F layer is highest. Also, for the high-harmonic cyclotron spikes to be observed, the sounding at a particular harmonic of the gyrofrequency must occur when the appropriate antenna is parallel to the earth's magnetic field. Above about 5 Mc/s, cyclotron spikes are observed if the sounding at the appropriate frequency occurs when the short antenna is parallel to the earth's magnetic field. The observation of cyclotron spikes above about 5 Mc/s is particularly sensitive to the angle between the short antenna and the magnetic field, and is limited to a range of about ±15°. For cyclotron spikes below 5 Mc/s, little angular dependence is observed as the long antenna sweeps through the range of 0–90° aspect angle, because of the electrical behavior of the two antennas at these frequencies. However, a definite decrease in the average number of cyclotron spikes is observed when both antennas are continuously perpendicular to the earth's magnetic field.

ACKNOWLEDGMENTS

The author is indebted to the National Research Council of Canada for providing the celestial coordinates of the Alouette I spin vector.

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