POWER LINE RADIATION OVER NORTHERN EUROPE OBSERVED ON THE BALLOON B_{15}-1N

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***Abstract*:** Measurements of power line radiation were carried out in northern Europe by means of balloon B_{15}-1N. The balloon was launched during the period of magnetic substorm on March 20, 1982. Relationship between the power line radiation and a magnetic substorm was investigated by the use of magnetic field intensity spectra up to 1 kHz. It revealed that the power line radiation at the fundamental frequency of 50 Hz is not enhanced, but, the harmonic frequencies at 300 Hz (6th), 450 Hz (9th) and 600 Hz (12th) are enhanced in association with the magnetic substorm.

1. Introduction

Man-made long conductor systems, such as power lines, pipe lines, or telephone lines, in the auroral zone have been sometimes interfered by geomagnetic storms inducing a large current (AKASOFU and MERRITT, 1979; LANZEROTTI, 1983). The current, so-called the Solar Induced Current (SIC) (GODDARD and BOERNER, 1978), may be induced by the Faraday's law on a loop circuit consisting of a grounded long conductor system and the earth associated with a horizontal component of geomagnetic field fluctuation (LANZEROTTI, 1983). The current on power lines is slower than 50/60 Hz so that it can induce the magnetic bias on cores of transformers of power lines and then the waveform of current and/or voltage is distorted from the non-linearity of the transformers. Electromagnetic waves are radiated by the distorted waveform of current and/or voltage. Some parts of radiated energy penetrate through the ionosphere into the magnetosphere as a power line harmonic radiation (PLHR). PLHR induces a variety of VLF emissions through the wave-particle interaction phenomenon (HELLIWELL *et al.*, 1975; LUETTE *et al.*, 1977; PARK and HELLIWELL, 1978). The above-mentioned stories have been presented by many authors as a fact, but, the physical mechanisms of any stage, especially of the waveform distortion and radiation, have not been explained practically. The relationship between the geomagnetic effect and the power line radiation is investigated under the ionosphere in this experiment.

2. Instrumentations

Figure 1 shows a block diagram of the power line radiation (PLR) receiver aboard balloon B_{15}-1N. This receiver is operated together with the VLF receiver provided by NIPR (YAMAGISHI *et al.*, 1983) so as to observe a wide range of frequency. The frequency range of the PLR receiver is from 40 Hz to 1 kHz.

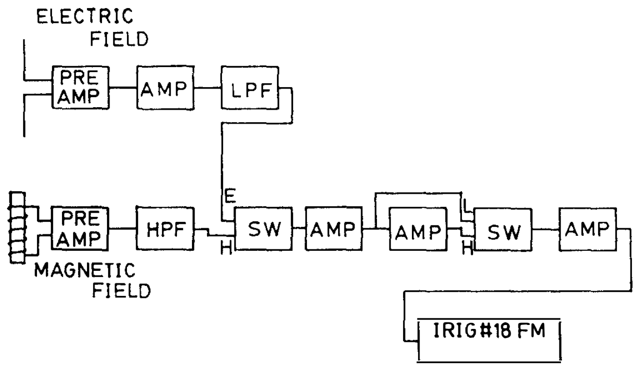

Fig. 1. A schematic block diagram of the power line radiation measurement system onboard balloon B_{15}-1N.

The receiver consists of a horizontal magnetic field sensor, a vertical electric field sensor, an analog switch for multiplexing the magnetic and the electric field signals, and a common amplifier. The output of the receiver is transmitted through the ♯18 channel of IRIG telemetry system which has the maximum frequency response of 1 kHz.

The horizontal magnetic field sensor is equipped with a loop antenna which uses a permalloy core (50 cm × 6 mm × 6 mm) wound with the copper wire (6000 turns, 0.2 mmϕ), a flat frequency response pre-amplifier, and a 40 Hz HPF which is required to reject the strong Schumann resonance part of spectrum. The vertical electric field sensor is equipped with a dipole antenna which has a copper wire of 10 m tip-to-tip, a high input impedance pre-amplifier, and a 1 kHz LPF.

The outputs from the magnetic and the electric field sensors are multiplexed sequentially. The interval of multiplexing sequence is 57 s corresponding to the rotation period of the balloon gondola to observe the whole direction in a single sequence. The multiplexed signal is separated into two amplifiers, in which the gain difference is 40 dB, to get a wide dynamic range. The data of sequentially multiplexed and gain-switched output are modulated into ♯18 channel of IRIG telemetry system and then transmitted to the tracking station at Andøya, Norway.

At the telemetry receiving station on the ground, the IRIG ♯18 telemetry signal was directly recorded on the magnetic tape to reject the interferences or confusions of 50 Hz and its harmonics from the equipments of the ground station. The recorded magnetic tapes were carefully reproduced and demodulated in Japan. The data spectral analysis and the correction of the frequency response of antennas were made by a mini-computer provided at the Sugadaira Space Radiowave Observatory, University of Electro-Communications, where the frequency of the commercial power line is 60 Hz.

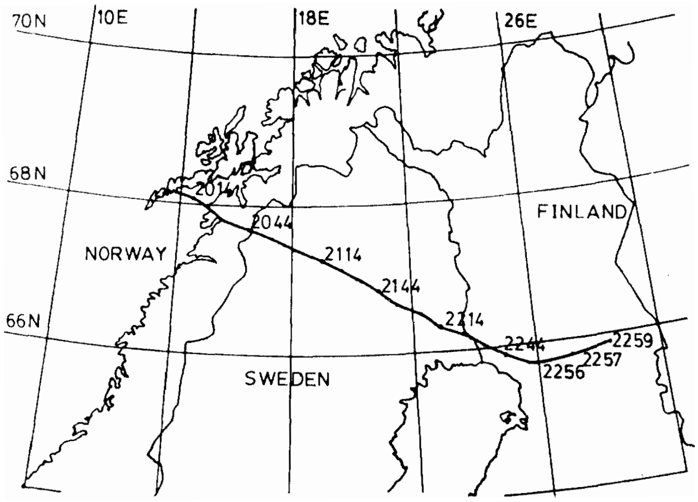

Fig. 2. The flight trajectory of balloon B_{15}-1N which was launched from Stamsund, Norway at 1909 UT on March 20, 1982.

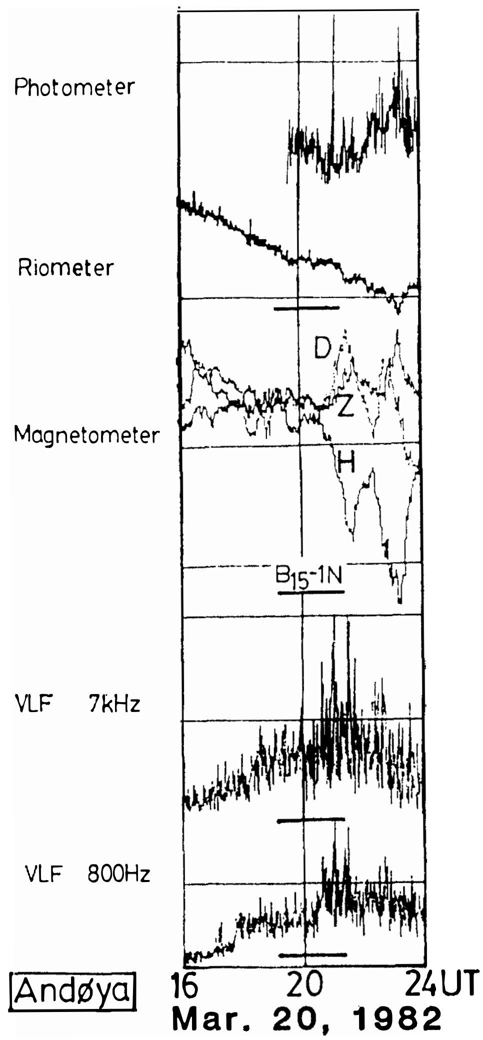

Fig. 3. The data observed at the ground station in Andφya, Norway. From the data of the magnetometer, the magnetic substorm started at 2040 UT on March 20, 1982.

3. Experiment

Balloon B_{15}-1N was launched at 1909 UT on March 20, 1982 from Stamsund, Norway (68°08′N, 13°50′E). Figure 2 shows the flight trajectory of this balloon. As shown in this figure, the balloon drifted eastward across the Swedish territory, then the payload was cut down in Finland.

Figure 3 shows the ground-based data at Andøya from 1600 to 2400 UT on March 20, 1982. In this figure, the period of the balloon flight is indicated by horizontal bars. It is noticed that the geomagnetic substorm started at 2040 UT. The auroral breakup occurred at the same time as seen in the sudden increase of the auroral intensity. Corresponding to the substorm, the intensities of VLF emissions at 800 Hz and 7 kHz increased.

Signal to noise ratio (S/N) of the telemeter channel was periodically decreased once in a rotation of the gondola for the anisotropic telemetry antenna pattern on board the balloon. The data after 2140 UT were excluded in the analysis because of the poor S/N of the telemetry signal.

4. Experimental Results

The balloon observation had been made during the geomagnetically disturbed period as seen in Fig. 3. Figure 4 illustrates the horizontal component of geomagnetic field at the period of the balloon flight as shown in Fig. 4a with the magnetic and the electric field intensities of power line radiation observed on balloon B_{15}-1N as shown in Fig. 4b and Fig. 4c, respectively. In Fig. 4b the solid lines indicate intensities of 50 Hz and its harmonics of magnetic field, and the dashed and the dotted lines indicate intensities of 60 and 180 Hz, respectively, of magnetic field. The intensities of 60 and 180 Hz are used to refer to the intensity of background noise. The electric field intensity of the same frequencies as Fig. 4b is shown in Fig. 4c. Unfortunately the gain of the electric field sensor is too low for the intensity of the signal level. Real electric field intensity does not appear in this figure, although, the upper limit of electric field intensity can be determined. Accordingly, the substorm effect on the electric field intensity cannot be examined.

In Fig. 4b the intensities of all frequencies are disturbed by the vibration of the gondola moving rapidly from the launch at 1909 till 1920 UT. The magnetic field intensity at 50 Hz has a peak at 1936 UT with the value of 1.6×10^{-4} (A/m) which is much greater than the value at 60 Hz (background noise close to 50 Hz). The intensity at 50 Hz gradually decreases with time till the end of data without any enhancement, even at the time of substorm onset at 2040 UT. The intensities of harmonic radiations at 100 and 150 Hz are less than the intensity of background noise throughout this observation. However, the enhancements of the intensities at 60, 100, 150 and 180 Hz are associated with the substorm. The enhancement except for 50 Hz may correspond to the enhancement of 800 Hz and 7 kHz as shown in Fig. 3. From these results, it is concluded in this case that geomagnetic substorm does not enhance the intensity of power line radiation at the fundamental frequency of 50 Hz.

Dynamic spectra of the magnetic field intensities in the frequency ranges of

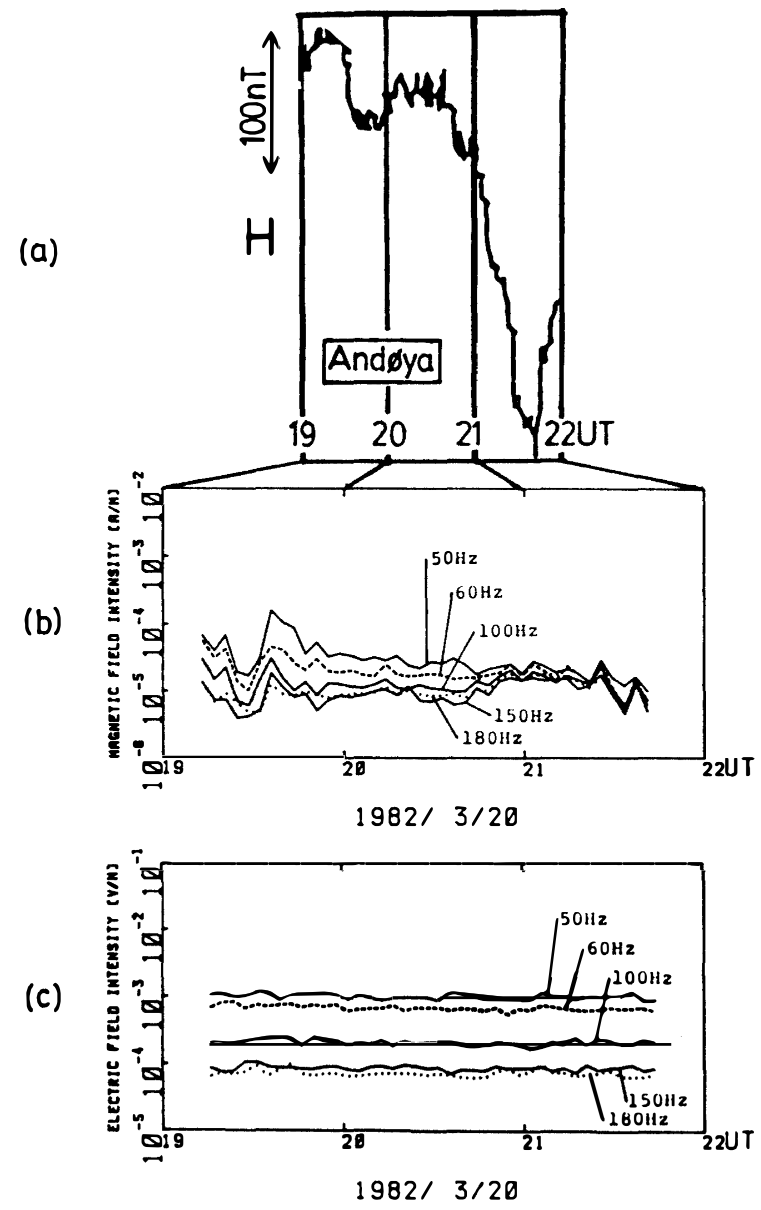

Fig. 4. *(a) The horizontal component of the magnetogram at Andϕya, Norway from 1900 to 2200 UT on March 20, 1982. (b) The magnetic field intensity at 50 Hz, and its harmonics, which are indicated by the solid lines, and of 60 and 180 Hz which are indicated by the dashed or dotted lines. The latter refers to the intensity of the background noise. (c) The electric field intensity at the same frequencies as in (b). Unfortunately the gain of the instrument is not enough so that the intensity indicated in this figure is only the upper limit of the intensity of spectrum.*

200–1000, 0–250 and 45–55 Hz are shown in Figs. 5a, 5b and 5c, respectively. The threshold level indicated in Fig. 5b is −95 dB with respect to 1 (A/m), which is 10 dB greater than that in Fig. 5a; that is, the intensity less than 200 Hz on the spectrum is much greater than the higher frequency band. Increment of the contour line is 2.5 dB in these figures. It is noticeable from Fig. 5a that the intensity of the background noise is enhanced as much as 2.5 dB around 2000 UT, and then gradually decreases

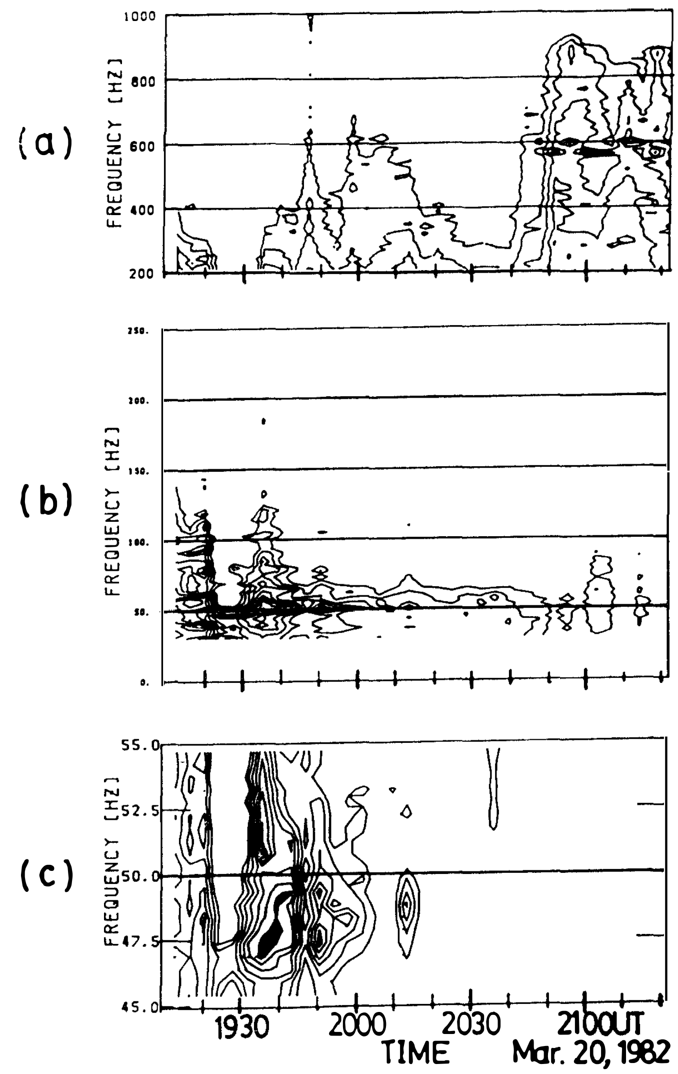

Fig. 5. Contour maps of the intensity of the magnetic field spectra observed on balloon B_{15}-1N. (a) Frequency range of 200 Hz to 1 kHz. (b) Frequency range of 0 to 250 Hz. The threshold level of indication is 10 dB greater than that of (a). (c) Magnification of the map (b) about 50 Hz which is the fundamental frequency of the power line radiation in northern Europe.

until 2040 UT. After 2040 UT the intensities are suddenly enhanced more than 7.5 dB in ten minutes. The sudden enhancement coincides with the onset of the substorm as shown in Fig. 4a. The increase of intensity corresponds to the enhancements of 800 Hz and 7 kHz on the ground as shown in Fig. 3, and also to the enhancement of 60, 100, 150 and 180 Hz as shown in Fig. 4b.

Corresponding to the peak at 50 Hz around 1935 UT in Fig. 4b, an intensity peak appears around 1935 UT in Fig. 5b. After the peak, any notable enhancements cannot appear. Furthermore, a few line-like spectral enhancements appear at 300, 450, 570 and 600 Hz with more than 2.5 dB additional enhancements during the period of 2040–2120 UT. The line-like spectral peaks except the peak at 570 Hz can be related to the power line harmonic frequencies. The peaks at 570 and 600 Hz are 5 dB greater than the background. These remarkable peaks flash alternatively. This phenomenon suggests that they may affect each other. The peak at 570 Hz may be shifted from the harmonic frequencies at 550 or 600 Hz, showing the similar phenomena observed by HELLIWELL *et al.* (1975) in the VLF range. If the two peaks are produced by the geomagnetic effect, a selective amplification mechanism at about 600 Hz and an induction mechanism of shifted frequency are required. However, we cannot exclude the possibility of electromagnetic interference from other instruments onboard balloon B_{15}-1N. The other peaks at 300 and 450 Hz can be considered as the geomagnetic effect. It is concluded that the intensity of harmonic frequencies of 150 Hz, *i.e.*, 300, 450 and 600 Hz, is enhanced by the substorm which also enhances the background noise level.

Figures 6a and 6b show magnetic field spectra obtained simultaneously on the ground at Andøya, Norway and on balloon B_{15}-1N at 2114 UT when it was flying over north Sweden. In Fig. 6a many spectral peaks of harmonic frequencies of 50 Hz can be seen up to 1 kHz, but, in Fig. 6b spectral peaks appear only at 300, 450 and

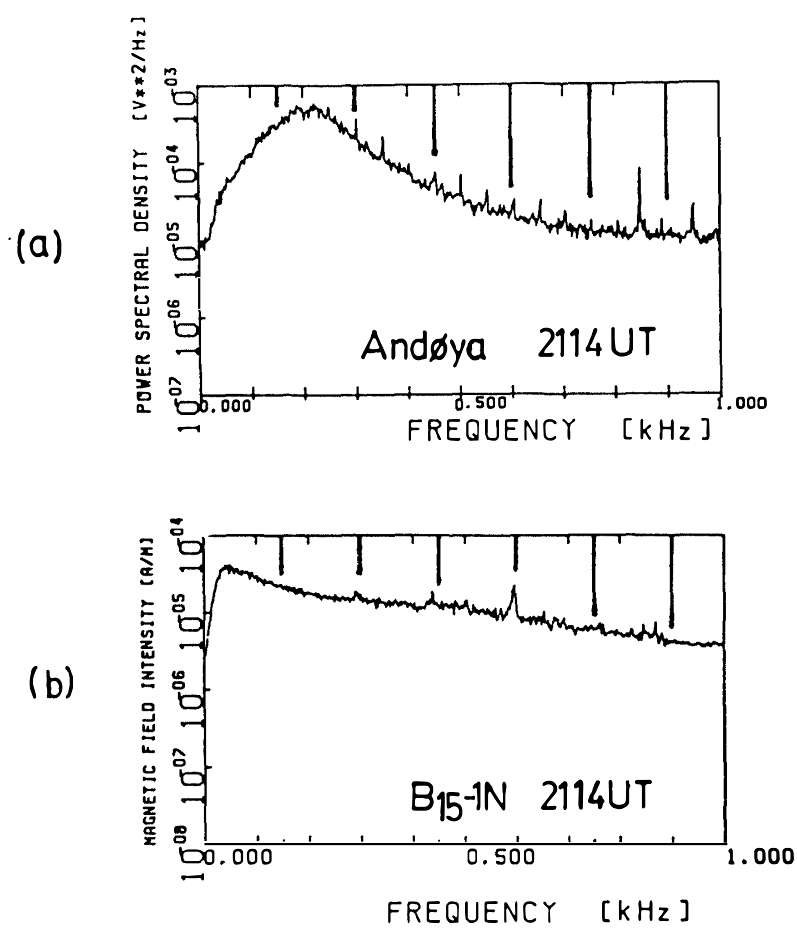

Fig. 6. Magnetic field spectra simultaneously obtained at 2114 UT on the ground station Andøya, Norway (a) and on balloon B_{15}-1N flying over north Sweden (b). Many spectral peaks of harmonic frequency of 50 Hz can be seen up to 1 kHz in the spectrum (a). They are induced from local power lines. However, spectral peaks only at 300, 450 and 600 Hz are observed on the balloon as shown in (b).

600 Hz. The harmonic spectra of 50 Hz in Fig. 6a may have been induced by the local power lines at Andøya. The three spectral peaks in Fig. 6b correspond to the peaks in Fig. 5b observed during the substorm. It is noticeable that enhancement at the three frequencies on the balloon cannot be detected on the ground as shown in Fig. 6a. The lack of enhancement at 300, 450 and 600 Hz at Andøya may be interpreted that propagating radiations are masked by the strong local power line radiations which are not disturbed so much as to produce such an enhancement.

5. Summary

Observation of the power line radiation was conducted in northern Europe in the auroral zone using balloon B_{15}-1N on March 20, 1982. During the observation, the magnetic substorm occurred at 2040 UT. Relationship between the power line radiation and the magnetic substorm is investigated by using the magnetic field spectra up to 1 kHz, observed on the balloon. The intensity of the fundamental frequency of 50 Hz gives a peak at 1935 UT and then gradually decreases till 2130 UT. The intensity peak of 50 Hz does not coincide with the substorm. Therefore, it is concluded in this observation that the power line radiation at the fundamental frequency of 50 Hz is not modulated by the geomagnetic substorm. However, the harmonic frequencies at 300, 450 and 600 Hz are enhanced in association with the substorm. These frequencies correspond to the 6th, 9th and 12th harmonics of 50 Hz. The similar results were reported by HAYASHI *et al.* (1978) in Canada where the fundamental frequency is 60 Hz. But no enhancement of the 3rd harmonic frequency appears in our observation. We cannot explain the reason why the 3rd harmonic radiation is suppressed in our case. The suppression mechanism may suggest a difference of power line radiation mechanism between northern Europe and central Canada. However, the similarity in the enhancement of harmonic radiation caused by a magnetic substorm seems to suggest power line harmonic radiations in geomagnetically disturbed conditions. On the other hand, the intensity enhancement at 570 Hz may be correlated with the intensity at 600 Hz, although we should check whether it is induced by power line harmonic radiations or only an interference of other instruments.

Acknowledgments

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