Earth-Ionosphere Cavity Resonances Excited by Horizontal Dipoles and Magnetospheric Origin

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Abstracts

The spatial distribution of the earth-ionosphere cavity resonance excited by horizontal dipoles is calculated, and its application to the magnetospheric origin part of ELF is discussed.

1. Introduction

Earth-ionosphere cavity resonances have been generally recognized as oscillations excited by lightning flushes so far. The radiation from a vertical dipole is considered and the spatial distributions of electric or magnetic field of cavity resonances are calculated in this case. The observed power of resonances must be determined by the energy radiated at the source and the angular distance from the source. In actual case the expected power is not calculated easily because many sources with various energy spectrum are existing all over the world simultaneously.

However, statistical studies show sometimes positive facts of the idea that the most part of the observed resonance intensity is due to thunderstorms (M. Balser and C. A. Wagner, 1962)[1]. Some of the observed intensity of extremely low frequency, ELF, on the other hand, gives curious results for the idea. An alternative of the idea is that an energy coming down from magnetosphere excites those ELF. Observed intensity may consist of those two types of ELF.

An horizontal wave coming from magnetosphere may excite cavity resonance if its energy is enough to do so. The horizontal component may play an important role in the ELF wave of magnetospheric origin.

Consideration of the horizontal dipole is necessary not only for magnetospheric ELF but also for the usual cavity resonances of thunderstorm origin. Lightning flushes are not always vertical, especially in the case of cloud-to-claud discharge which is considered to be an important energy sourse of cavity resonances (E. T. Pierce, 1963)[2]. To pursue the ELF wave radiated from an individual flush, an horizontal dipole must be taken into consideration as well as vertical dipole.

In this paper the spatial distribution of the cavity resonance excited by horizontal dipoles is considered, and its application to the magnetospheric origin part is discussed.

2. Cavity resonance excited by a horizontal dipole

Suppose a horizontal dipole which radiates ELF energy at Q on the sphere of radius a. The direction of the dipole is $+x$ in the rectangular coordinate of Fig. 1. The radiation of the dipole is expressed by a Hertz vector,

$$\vec{\Pi}=\vec{u}_x\, e^{ikR}/R, \tag{1}$$

where $\vec{n}_x$ is the unit vector of x-direction and R is the distance from the dipole at Q, that is $\overline{PQ}$. The propagation constant is expressed by k. In the spherical coordinate system of Fig. 1, the Hertz vector $\vec{\Pi}$ $(\pi_r, \pi_\theta, \pi_\varphi)$ is expressed as follows,

$$\Pi_r=\Pi\sin\theta\cos\varphi,$$
$$\Pi_\theta=\Pi\cos\theta\cos\varphi,$$
$$\Pi_\varphi=-\Pi\sin\varphi,$$
$$\Pi=\sum_{n=0}^{\infty}(2n+1)\sqrt{\frac{\pi}{ka}}J_{n+1/2}(ka)\sqrt{\frac{\pi}{kr}}H^{(1)}{}_{n+1/2}(kr)P_n(\cos\theta), \tag{2}$$

omitting a constant factor.

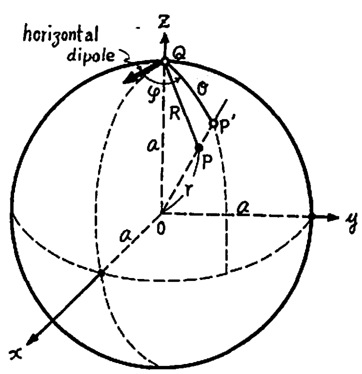

Fig. 1 A horizontal dipole at Q on the sphere of radius a.

The vertical component of magnetic field at P is given by,

$$H_r=\frac{i\omega}{r}\frac{\partial\Pi}{\partial\theta}\sin\varphi$$
$$=-\frac{i\omega}{r}\sum_{n=0}^{\infty}(2n+1)\sqrt{\frac{\pi}{ka}}J_{n+1/2}(ka)\sqrt{\frac{\pi}{kr}}H^{(1)}{}_{n+1/2}(kr)P_n{}^1(\cos\theta)\sin\varphi. \tag{3}$$

This component is given also by a transverse electric (TE) wave,

$$\vec{\Pi}_e=\vec{u}_r\sum_{n=0}^{\infty}A_n\sqrt{\gamma}H^{(1)}{}_{n+1/2}(k\gamma)P_n{}^1(\cos\theta)\sin\varphi, \tag{4}$$

where $\vec{u}_r$ is the until radial vector. But the tagential magnetic fields, H_θ (Π_e) and H_φ (Π_e), of $\vec{\Pi}_e$ are different from those of $\vec{\Pi}$. The differences of the tangential magnetic fields, H_θ $(\Pi)-H_\theta$ (Π_e) and H_φ $(\Pi)-H_\varphi$ (Π_e), are given by the transverse magnetic (TM) wave,

$$\vec{\Pi}_m=\vec{u}_r\sum_{n=0}^{\infty}B_n\sqrt{\gamma}\left\{\frac{1}{n}H^{(1)}{}_{n-1/2}(k\gamma)P^1{}_{n-1}(\cos\theta)\right.$$
$$\left.-\frac{1}{n+1}H^{(1)}{}_{n+3/2}(k\gamma)P^1{}_{n+1}(\cos\theta)\right\}\cos\varphi. \tag{5}$$

Then the initial radiation is given by the sum of the transverse electric wave $\vec{\Pi}_e$ and transverse magnetic wave $\vec{\Pi}_m$. The radiation of the tangential dipole at Q on the sphere is thus represented by the sum of two modes of spherical wave.

In order to apply the electromagnetic field to the cavity, perfect conductors of the earth and ionosphere are taken into consideration here for simplicity (Fig. 2). Coupling of the TM and TE wave is broken down. Resonance oscillations have the patterns of $P^1{}_{n-1}$ $(\cos\theta)$ $\cos\varphi$ and $P^1{}_{n+1}$ $(\cos\theta)$ $\cos\varphi$ of TM wave.

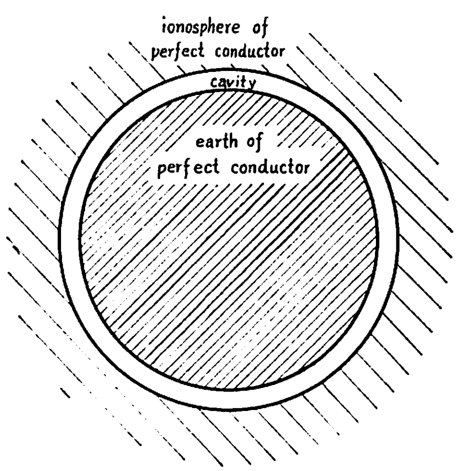

Fig. 2 The spherical cavity.

3. Application of the resonance to the ELF of the magnetospheric origin.

The observed ELF at the auroral zone is different somehow from those of middle or low latitudes (K. Yanagihara, 1963)[8]. Large bursts of ELF are often found superposed on the continuous but small excitation of resonances. The bursts are found simultaneously at the magnetically conjugate areas. Maximum occurrence of the burst is found near local midnight at Byrd station in the antarctic auroral zone. These suggest the excitation of ELF by an energy coming down along the magnetic line of force.

The idea that the burst is caused by a lightning flush may not be excluded until one-to-one correspondence is determined. However good conjugacy, large excitation and diurnal variation of the burst support strongly the other idea of magnetospheric origin. Cavity resonances of thunderstorm origin are also found in the auroral zone data. They are the continuous background noise. The noises have the typical spectrum of cavity resonances and show the UT diurnal variation corresponding to the thunderstorm activity in East Asia, Africa and South America (K. Yanagihara, 1963)[8].

Recent observations of ELF (3—30 cps) at Kakioka (36°14′ N, 140°11′ E) give the diurnal variation of intensity shown in Fig. 3. The expected diurnal curve of the cavity resonance calculated from the mean thunderstorm activity is shown also in the same figure by broken line, where the ratio of the first, second and third modes is chosen as 1 : 2 : 1 so as to fit the observed intensity ratio. Remarkable discrepancy of two curves is seen around 20h UT. High calculated values in these hours are due to the South-American activity of thunderstorm. Distribution of lightning flushes and their energy spectrum are not so clear that the expected values are tentative of course. But the contribution of South-American activity

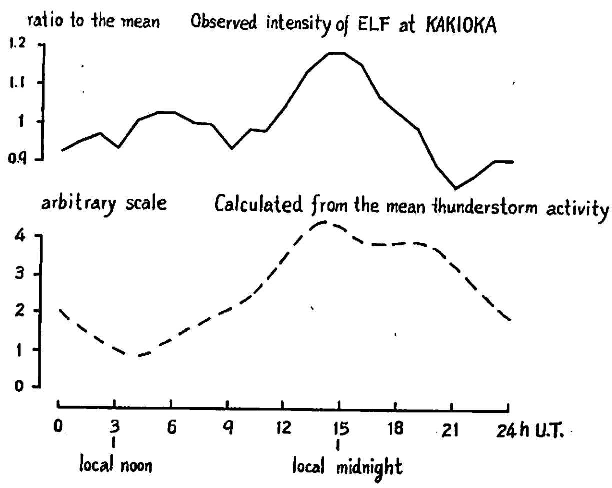

Fig. 3 The diurnal intensity variation of ELF (3—30 cps) observed at Kakioka and the calculated intensity variation due to thunderstorm activity.

cannot be neglected anyhow. Another small discrepancy is found around 4h UT which is an early afternoon hour at Kakioka.

To explain the observed data, a superposed excitation of ELF on those of the thunderstorm origin is supposed. The ratio of the contribution of thunderstorm origin part is not determined only from these data. Some probable cases are taken into consideration here. The ratios of these cases are chosen in such a way that the range of the remaining part becomes as small as possible in their diurnal variation when the calculated intensity due to thunderstorm activity is subtracted from the observed one for each hour. Bi-hourly values of the intensity of the remaining part are shown in the upper part of Fig. 4 for 3 cases.

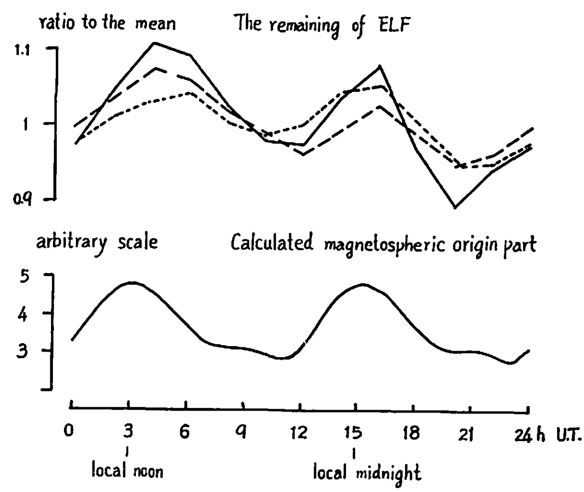

Fig. 4 The remaining part of ELF and the calculated magnetospheric origin part.

Main terms of the remaining are diurnal and semi-diurnal. The diurnal term is considered to be due to the near thunderstorm activity which causes the discrepancy around 4h UT (early afternoon) in Fig. 3. The semi-diurnal term is the part to be interpret by a magnetospheric origin.

When simultaneous horizontal dipoles at north and south conjugate areas in the auroral zone are supposed to occur at local midnight, the distribution of magnetic field of the cavity resonance can be calculated from the equation (5). The daily variation of the calculated intensity at Kakioka is shown in the lower part of Fig. 4 in an arbitrary scale, where the radiated energy ratio of the first, second and third modes is chosen as 1 : 2 : 1. This curve is to be compared with the upper curves.

The agreement of the curves thus led is a fact to support the existence of the magnetospheric origin part of ELF, though nothing is known on the detail of the origin.

References

(1) Balser, M. and C. A. Wagner (1962), Diurnal power variation of the earth-ionosphere cavity modes and their relationship to worldwide thunderstorm activity, JGR, **67**, 619-625.

(2) Pierce, E. T. (1963), Excitation of earth-ionosphere cavity resonances by lightning flushes, JGR, **68**, 4125-4127.

(3) Yanagihara, K. (1963), Geomagnetic micropulsations with periods from 0.03 to 10 seconds in the auroral zones with special reference to conjugate-point studies, JGR, **68**, 3383-3397.

水平双極子による大地電離層間空洞内共振と超高層から来る原因

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概 要

水平双極子によっておこされる大地電離層間空洞内の共振の電磁場を計算し，それを超高層から来る原因によっておこされた超低周波帯（ELF）現象に適用して観測と比較した。その結果 ELF として観測される現象には雷活動に原因するものと超高層から極光帯に入射する原因によるものとの両方のあることが推論された。