# RADIO WAVE EMITTED BY AN EXTENSIVE AIR SHOWERS IN 10KHZ TO 1MHZ REGION

Jun Nishimura
The Institute of Space and Astronautical Science
Komaba, Meguro, Tokyo, Japan

ABSTRACT

An importance of radio wave in a frequency range less than 1MHz has been discussed by Suga at the time of the Bangalore Conference. In this paper, an estimate of radio intensities at 10KHz, 100KHz and 1MHz has been made on the basis of the Kahn-Lerche theory. An emphasis is made that negative charge excess in a shower gives main contribution for low frequency radio emission, in spite of the importance of the contribution of transverse current in the geomagnetic field in higher frequency range. An estimate is also made for radio intensity produced when the shower hits the ground. Contribution of this process seems to be important at large distance say beyond 1km from the shower axis.

## 1. INTRODUCTION

The radio wave emitted from extensive air showers has been studied since 1965 in the frequncy range of 30 to 60MHz. However, since lateral spread of the radio wave intensity was found to be steep, such studies have not been considered to be promising to detect low frequency large showers.
In a low frequncy range around 1MHz, only a few studies have been reported. Moscow and Yakutsk group (V.B.Atrashkevich et al: 1973) reported that strong radio wave of 1.9MHz with 1 to 25 micro V./M.MHz were observed for showers of $6x10^6 < Ne < 1.7x10^8$ at distances from 600m to 1300m.

Suga proposed possible detection and importance of radio wave at frequency range less than 1MHz (K.Suga: 1983). He discussed contribution of charge excess in an extensive air shower for emission of the radio wave in this range, and also discussed possible emission process when this excess charge hits the ground. Similar treatement to estimate the contributions of these processes have also been performed recently by Sakata.( T.Sakata: 1985).

Since these results seem to be promising to detect low frequency large showers, we examined the contribution on the basis of Kahn-Lerche treatement, in which we can estimate radio intensity more easily, such as to include effect of emission angle of the radio wave from shower axis. The comparison is made for the degree of the each contribution by excess charge, dipole and transverse current, and shows

excess charge gives the most important contribution between these processes in frequncy range less than 1MHz.
Radio wave emission when the excess charge hit the ground is also treated by using the formulae of the transition radiation. Contribution for the radio intensity by this process is much larger than other processes below 1MHz. We estimate a few times of 100 micro V/M.MHz or more at 1km from the shower axis for a shower of $10^{20}$ eV.

## 2. RADIO WAVE EMISSION IN A LOW FREQUENCY RANGE.

The radio wave emission from an extensive air shower has been treated by Kahn and Lerche on the basis of the Maxwell equation.(F.D.Kahn and I.Lerche:1965). They discussed the contributions from three process, i.e. charge excess, dipole and transverse current in the geomagnetic field.
They obtained a fourier transformed field strength due to each process as, in the notation of their paper:

a) Charge excess

$$E(k) = -ie\Delta/2\cdot(k\alpha)Jo(k\alpha a)Ho^{(1)\prime}(k\alpha r) \quad (1)$$

b) Dipole

$$E(k) = -iM/2\cdot(k\alpha)^2 Jo(k\alpha a)(Ho^{(1)\prime}(k\alpha r)/k\alpha r + Ho^{(1)}(k\alpha r)) \quad (2)$$

c) Current

$$E(k) = -J/2\cdot kJo(k\alpha a)Ho^{(1)}(k\alpha r). \quad (3)$$

Here $\Delta$, M and J are the excess charge, dipole moment and current in an extensive air shower. k, $\alpha$, a, and r are the wave number, Cerenkov angle, radius of shower disk and the distance of the observation point from the shower axis.

If the number of the shower particles changes with altitude as exp(-Lx), where L and x are the absorption coefficient and depth of the atmosphere measured in unit of length, another process for emission of radio wave arises.
$k\alpha$ in eq.(1) should be replaced, in this case, as

$$((k\alpha)^2 + 2ikL + L^2)^{1/2}. \quad (4)$$

The relative importance of each term in eq(4) depends on the radio concerned. Since L is of the order of 1/1km= $10^{-5}$/cm, $\alpha$ =.024 and k= $2\times10^{-4}$/cm at 1MHz, contribution of $k\alpha$ in eq.(4) becomes small in these frequency range. Thus the radio emission is mainly due to the charge acceleration rather than the Cerenkov process as illustarted in Fig.1. The effect of change of number of shower particles with altitude becomes predominant in the low frequncy radio waves.

Due to this situation, degree of the contribution of charge excess becomes important compared with that of other process in the low frequency range as seen from formulae (1),(2) and (3). The emission angle $\alpha$ is also changed to about $(L/K)^{1/2}$, giving a large angle spread compared with Cerenkov angle.This results wide lateral spread of radio pulse, and gives us a possibility to detect large extensive air showers efficiently. The relative importance of each process for intensities at various frequencies are shown in Table 1.

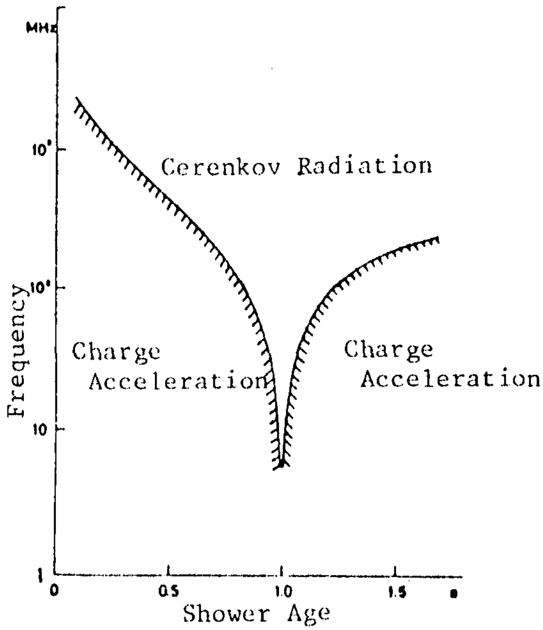


Fig.1. Relative importance of Cerekov emission and charge acceleration.

Table 1

Relative contribution of each process ( $L = 10^{-5}$ / cm )

| Freq.(MHz) | Excess charge | Dipole | Current |
|---|---|---|---|
| 100 | 1 | 0.57 | 2.2 |
| 1.0 | 1 | 0.053 | 0.24 |
| 0.1 | 1 | 0.0169 | 0.074 |

Here we refer to the values of $\Delta$ , M and J in the paper ( M. Fujii and J. Nishimura: 1968 ). This clearly indicates the importance of the charge excess in the low frequncy range, and we can estimate the radio intensity by only taking this process.

3. RADIO PULSE WHEN SHOWER PARTICLES HIT THE GROUND

When shower particles hit the ground, radio pulse is emitted by excess charge in the shower. This is just the same process known as the transition radiation. Since the shower disk hits the ground with a time duration of 0.1 to 1 micro sec. depending on the inclination of the shower axis. Only the radio wave of frequency less than 1 to 10MHz are emitted coherently. The radio pulse intensity is

$$W(f,\theta)dfd\Omega = e^2/\pi c \cdot |\cos\theta| dfd\Omega \quad , \qquad (5)$$

where f is the frequency of the radio wave, and $\theta$ is the zenith angle of the shower axis. If N charged particles are involved, e in the eq.(5) should be replaced by Ne.

## 4. NUMERICAL RESULTS AND DISCUSSIONS

Referring to the formula in section 2, 3, numerical evaluations are made and shown in Fig 2, 3. Here we assume number of shower particles changes with altitude as :

$$N = No.\exp(-x^2/2(\sigma c)^2),$$

where $\sigma$ is around 5 micro sec. for a vertical incident shower. The calculated radio intensity is 100 to 1000 micro V/m.MHz for a shower of $10^{20}$ eV and is similar to those orders of magnitude obtained by Suga and Sakata.

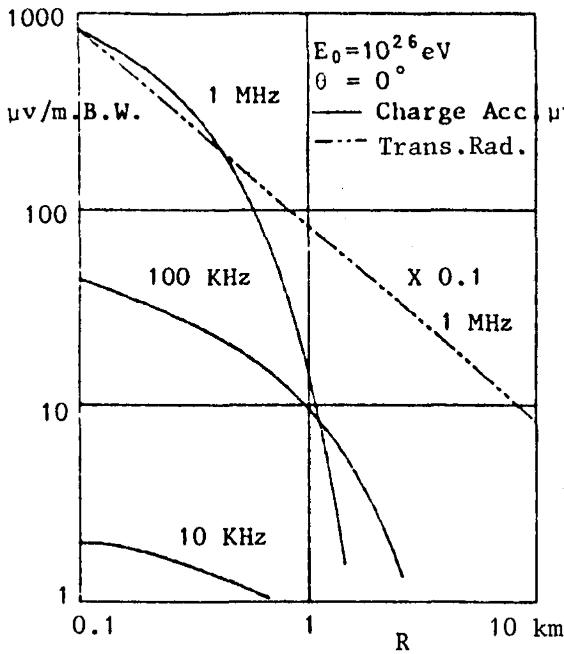


Fig.2. Radio intensity per band width of each Frequency. Vertical incident Shower.

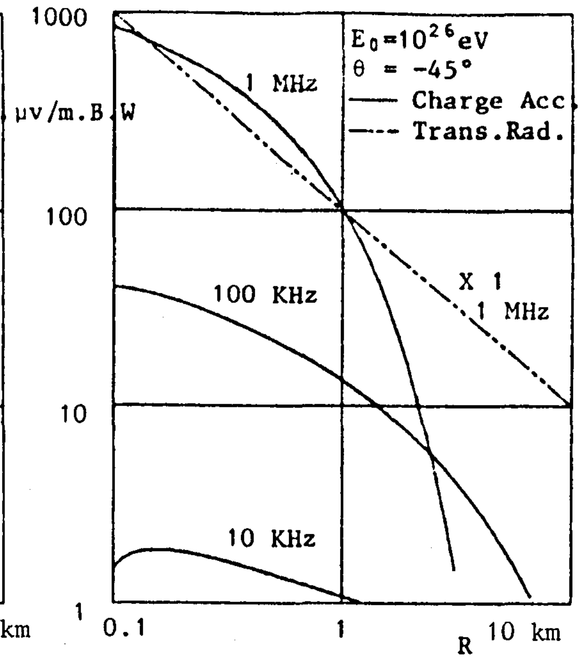


Fig.3. Radio intensity of shower with Zenith angle of -45 degrees.

The transition radiation emitted by charge excess in shower gives the most predominant contribution at a distance beyond 1km. Since the intensity of transition radiation is known to be changed as $(\sqrt{\varepsilon}-1/\sqrt{\varepsilon}+1)$, where $\varepsilon$ is a dielectric constant of the ground, which indicate that radio intensity is affected by condition of the ground. Other processes to emit the radio wave are proposed by Suga and Sakata. Contribution of those processes will be discussed at the time of the conference.

### References

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