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A simple capacitor model for radio emission associated with earthquakes*

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In this brief report we propose a simple model based on the properties of an electric capacitor under short-circuit conditions as a possible mechanism of radio emissions associated with earthquakes. This model can be considered as complementary to other models concerning the same problem.

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1. Introduction

Nowadays, there exists a great amount of information on the natural electromagnetic emission from ultralow frequency up to radio frequencies possibly associated with the preparation mechanism of earthquakes.[1,2] Many theoretical models have been proposed as an explanation of this phenomenon.[1–4] Cracking in rocks, rupture of adhesive bonds, displacement of crack sides and dislocation motions are all known to cause broadband electromagnetic emission.[4] Among the several proposed models, Warwick *et al*[2] used the concept of electric capacitor. They took the sides of a fracture in a rock acting as the plates of a condenser for building a radiative model to explain a radio event occurring six days prior to the great Chilean earthquake of May 22, 1960. In this brief report we also use the capacitor concept to propose a possible mechanism of radio emission associated with fault zones.

In Ref.[2] Warwick *et al* proposed that the radio emission detected on four widely separated receivers in the northern hemisphere was a consequence of stress-induced piezoelectric fields when microscopic rock fractures occurred prior to the Chilean earthquake on May 22, 1960. Without underestimating this last proposal, we present in this brief report another possible contribution to the radiation emission produced by an earthquake. The idea is as simple as this: a seismic fault zone may be associated with a large capacitor where the plates are the two sides of the fault and the separation between them consist of dielectric sediment padding. As Bernard[5] remarked, a difference of potential exists in the rupture zone (electrokinetics effects are not despised but are not considered in our model). Due to the stress mechanical situation, motion of the inhomogeneous sediments between the plates may occur, resulting in a short circuit between them. At this moment a RLC circuit appears since a capacitor presents an inductance behaviour when currents depending on time are considered[6,7] and a radiation is emitted from the walls between the plates.

Indeed, if we consider a circular parallel-plate capacitor of radius a and plate separation $d \ll a$, being the z-component the axis of the capacitor, ϕ and ρ the other cylindrical coordinates and neglecting the effects of the fringing fields, the Maxwell equations can be combined to obtain a wave equation for both electric and magnetic fields. For low frequencies ($\lambda \gg d$), the field will be independent of the ϕ and z coordinates and we arrive at

$$\frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial E}{\partial\rho}\right) - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = 0, \tag{1}$$

and

$$\frac{\partial}{\partial\rho}\left(\frac{1}{\rho}\frac{\partial(\rho B)}{\partial\rho}\right) - \frac{1}{c^2}\frac{\partial^2 B}{\partial t^2} = 0, \tag{2}$$

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where the electric field is $\boldsymbol{E} = E\hat{\boldsymbol{k}}$ and the magnetic field is represented by $\boldsymbol{B} = B\hat{\boldsymbol{e}}_\phi$.

The solutions of Eqs.(1) and (2) are given by

$$\boldsymbol{E} = E_0 J_0(k\rho)\mathrm{e}^{\mathrm{i}kct}\hat{\boldsymbol{k}}, \tag{3}$$

and

$$\boldsymbol{B} = B_0 J_1(k\rho)\mathrm{e}^{\mathrm{i}kct}\hat{\boldsymbol{e}}_\phi, \tag{4}$$

respectively.

It is interesting to notice that the equivalent LC circuit presents a resonant frequency[7] at

$$w_{\mathrm{Res}} = kc = \frac{1}{\sqrt{LC}} \approx \frac{x_{01}c}{a}, \tag{5}$$

where x_{01} is the first root of the Bessel function $J_0(x)$, k is magnitude of the wave vector and c is the light speed.

On the other hand, we know that $J_0(kr)$ may be represented by a Fourier–Bessel series in terms of $J_0\left(\frac{x_{0n}}{a}\rho\right)$ and $N_0\left(\frac{y_{0n}}{a}\rho\right)$, x_{0n} and y_{0n} being the nth roots of $J_0(x)$ and $N_0(x)$ respectively.

If we have a difference of potential between the plates and suddenly a short circuit appears, due to the resistance R of the circuit, the electric energy will be dissipated at a time close to $\tau = \frac{R}{2L}$, with $L \approx \frac{d}{2c^2}$. But not all of the energy will be consumed by the resistance since the electric and magnetic fields will cross the wall of the capacitor.[8] Radiation will be emitted by the capacitor with principal frequencies of the order of the first root of the Bessel functions times c/a. Since the first roots are between one and ten, the typical radiated frequencies will approximately be

$$\omega_t \approx \frac{c}{a}. \tag{6}$$

On the other hand, the power emitted by the capacitor can be estimated by using the Poynting vector and integrating over the wall of the capacitor, then we have

$$P \approx \frac{cV^2}{d}a,$$

in Gaussian units.

We are taking an ideal circular capacitor, but if we choose another configuration, the result will be very similar and we can generalize that a charged capacitor subject to a short circuit will radiate frequencies of the order of

$$\nu \approx \frac{c}{\sqrt{A}}, \tag{7}$$

where A represents the area of the capacitor's plates, and the power emitted will be around

$$P \approx c\frac{V^2}{d}\sqrt{A} \tag{8}$$

during a time close to $R/2L$. It has to be noticed that part of this energy will be consumed by the considered resistance, but we are just approximating the order of magnitude.

If we associate the charged capacitor with a fault zone in a gross first approximation and due to the stress situation, a short circuit appears, and we will obtain radiation. For fault zones from 1 to $10^4\mathrm{km}^2$, from Eq.(7) we will have frequencies in the interval $(10^5, 10^3)$Hz, which are very close to radio frequencies. Considering a difference of potential of 1V[5] and a separation $d \approx$1m, by using Eq.(8) the power for A=1km^2 and $A = 10^4\mathrm{km}^2$ respectively, is of the order of P=10 to P=10^3W.

These frequencies are of the order of magnitude claimed to be present in the Chilean earthquake of 1962[2] and the power is sufficient for being detected in the northern hemisphere. The whole fault zone could not present a capacitor behaviour but only a certain part of it, so the effective area would be lower, giving place to higher frequencies. Nevertheless, to obtain visible radiation the area would have to be of the order of $10^{-8}\mathrm{cm}^2$, probably corresponding to a tip effect.

In summary, in this brief report we have proposed an oversimplified model for suggesting that a short circuit effect between the plates of a capacitor could be taken into account as a phenomenon which possibly contributes in the radio emission associated with earthquakes.

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