THE DISPLACEMENT CURRENT BETWEEN THE PLATES OF A CAPACITOR AND ELECTROMAGNETIC WAVES

Toshio Hyodo

Presenting Author: Toshio Hyodo (hyodot@post.kek.jp)
Slow Positron Facility, Institute of Materials Structure Science, KEK, Tsukuba, 305-0801, Japan

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A long-standing controversy concerning the sources of the magnetic field in and around a parallel-plate capacitor is examined (Hyodo, 2022). It is sometimes stated, as a prelude to an explanation of how electromagnetic waves are generated, that the magnetic field, $\boldsymbol{B}$, in and around a capacitor is created by the varying electric field, or the displacement current density, $\varepsilon_0 \partial \boldsymbol{E}/\partial t$, between the plates. However, Planck (1922) had shown a hundred years ago that a changing electric field described by a scalar potential (conservative electric field due to electric charge) does not create a magnetic field. The electric field between the capacitor plates is a result of the charge on the plates, so change in that field, whether with a constant charging current or an alternating current, cannot be a source of the magnetic field.

In the early 1960s, King and French (French, 2000), while developing a student experiment to verify the displacement current between capacitor-plates by measuring the magnetic field there, noticed the proof by Planck (1922) and realized that their attempt had no theoretical basis. His work was introduced in a paper by French and Tessman (1963), and a detailed account was given by Purcell (1963) in his Berkeley Physics Course “Electricity and Magnetism”. For some reason, however, the idea that $\varepsilon_0 \partial \boldsymbol{E}/\partial t$ between the capacitor plates is the source of the magnetic field persists today, a hundred years later.

Here, possible factors that have prevented the correct understanding from taking root are elucidated, and the considerations that would help the correct understanding are provided as: (1) There are two types of electric fields, conservative and electromagnetically induced. The electric field made by the charge on the capacitor plates is the former and that of the electromagnetic waves is the latter. Paying attention to this, one would not mistakenly think that the displacement current between the plates is the source of magnetic field and associate it to electromagnetic waves. (2) The integral form of the Ampere-Maxwell law, often used to calculate the magnetic field, is not a law of causality. One should be careful not to take it as such from its loose apparent similarity to the Bio-Savart law. (3) While one may arbitrarily choose a surface for the surface integration to calculate magnetic field using the Ampere-Maxwell law, the source of the magnetic field is not, of course, determined by that choice. (4) The direct evidence that the magnetic field between the capacitor plates actually results only from the linear current in the leads and the radial current in the plates has recently been provided by using the Biot-Savart law analytically with some approximation by Bartlett (1990) and numerically by Milsom (2020), which was previously only explained in principle (French & Tessman, 1963; Purcell, 1963). The above discussion only concerns the displacement current density of the conservative field. The *induced electric field* around a rapidly changing current is relevant to electromagnetic waves.

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