Electrodynamics of Hertzian Dipole Generators using Impressed Fields

Michael E. Tobar(1), Ben T. McAllister(1), Raymond Y. Chiao(2), Maxim Goryachev(1)
(1) ARC Centre of Excellence for Engineered Quantum Systems and ARC Centre of Excellence for Dark Matter Particle Physics, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.
(2) School of Natural Sciences, University of California Merced, 5200 N. Lake Rd, Merced, CA 95343, USA

To understand the creation of electromagnetic energy (or a photonic degree of freedom) from an external energy source, an electromotive force must be generated, capable of separating positive and negative charges. The separation of charges (free or bound) may be modelled as a permanent polarization (in general time dependent), which has a non-zero electric vector curl, created by an external force per unit charge, sometimes referred as an impressed electric field [1]. The resulting system forms a physical dipole in the static case, or a Hertzian dipole in the time dependent case. We show that Maxwell's equations, and in particular Faraday's law are modified through the addition of the external force per unit charge via the constitutive relations, which is essential to oscillate free or bound charge in a lossless way [1]. This system is the electrical dual of the magnetic solenoid described by a magnetic vector potential and excited by an electrical current. Correspondingly, the creation of a Hertzian electric dipole, from the forceful separation of positive and negative charge, may be described by an electric flux density, which exhibits an electric vector potential and a magnetic current boundary source, within the frame work of two-potential theory without the need for the existence of the magnetic monopole. From this result we derive the Dual electric Aharanov-Bohm (DAB) Berry phase and make the conjecture that it should be equivalent to the geometric phase that is described in modern electric polarization theory, which also describes the nature of the permanent polarization of a ferroelectric [2]. This work gives a formal meaning to the electric vector potential that defines the DAB geometric phase and determines that a permanent polarization has both a scalar and vector potential component. We show that both must be considered to fully describe the nature of a physical electric dipole, which inevitably, is a generator of electricity and a creator of photons. We highlight some examples: 1) Electromagnetic generator based on Lorentz force, where the impressed force per unit charge that polarizes the conductor, comes from mechanical motion of free electrons due to the impressed velocity of the conductor relative to a stationary DC magnetic field. 2) The time dependent polarized electret, the underlying principle behind piezoelectric nano-generators. In the open circuit state, both bound and free charge electricity generators/antennas are equivalent to idealized Hertzian dipoles, with the open circuit voltage equal to the induced electromotive force (emf). Analyzing the short circuit responses, we show that the bound charge electricity generator has a capacitive source impedance. In contrast, we show for the ideal free charge AC electricity generator, the back emf from the inductance of the loop that defines the short circuit, directly cancels the source emf, so the voltage across the inductor is solely determined by the magnetic current boundary source. Thus, we determine the magnetic current boundary source best describes the output voltage of an AC generator, rather than the electric field.

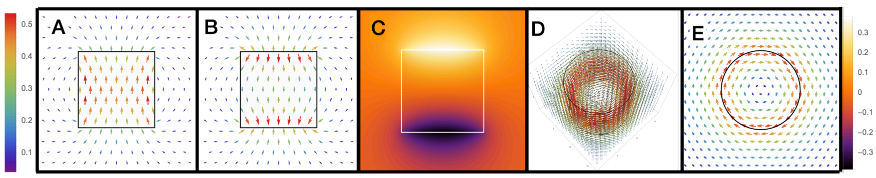

Figure 1. Field and potential plots for a cylindrical Hertzian dipole. **A)** 2D vector plot of Electric flux density in the $(r-z)$ plane. **B)** 2D vector plot of the electric field in the $(r-z)$ plane. **C)** 2D colour density plot of the electric scalar potential in the $(r-z)$ plane. **D)** 3D vector plot of the electric vector potential. **E)** 2D vector plot of the electric vector potential in the $(r-\phi)$ plane.

References

[1] ME Tobar, BT McAllister, M Goryachev, "Electrodynamics of Free- and Bound-Charge Electricity Generators Using Impressed Sources," *Phys. Rev. Applied* , **15**, 014007, 2021, 10.1103/PhysRevApplied.15.014007.

[2] ME Tobar, RY Chiao, M Goryachev, "Dual Aharanov-Bohm Berry Phase and the Electric Vector Potential due to the Generation of Electricity through Permanent Bound and Free Charge Polarization," *arXiv:2101.00945 [physics.class-ph]*, 2021, https://arxiv.org/abs/2101.00945.