Received May 30, 2021, accepted June 13, 2021, date of publication June 21, 2021, date of current version June 28, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3090862

Electric Model for Electromagnetic Wave Fields

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ABSTRACT This paper presents the first theoretical framework that defines the electric infinitesimal structure model of electromagnetic waves. This model represents the electromagnetic fields by electric field components only. These components have a specific spatial arrangement that is responsible for exerting both the magnetic force and the electric force applied by the electromagnetic waves. There is no existing work that specifies this infinitesimal purely electric structure. Previous work considered electromagnetic waves to be formed by two types of fields, despite the belief that the magnetic field is an electric field in its origin. The model has been built by analyzing the changes in the flow of electric charges producing changing currents. These charges emit electric fields with disturbances spreading in the space to reflect the changes of charges position and speed inside current elements. These disturbances in the electric fields contain discontinuity points reflecting these changes. Applying Gauss's law at these discontinuity points indicates the existence of electric charges, referred to as discontinuity charges. These spreading discontinuity charges electrically interact with static charges and current elements present at the crossing points in the space. This interaction produces forces on these charges and elements that are equivalent in magnitude and direction to the observed electric force and magnetic force exerted by electromagnetic waves. The relationship between these forces has been analyzed to obtain the formulas that govern them. These formulas are found to be exactly equivalent to Maxwell's equations proving the validity of the proposed model. Moreover, this model is in alignment with the experiments of pair production phenomena, i.e., photons split to electron and positron, which indicate that photons may have embedded charges inside them. This work is important to help scientists in modeling the physical reality of photons and in better understanding the deeper physical process behind electromagnetic wave interactions.

INDEX TERMS Electromagnetic wave, photon, light, magnetism, electromagnetic fields, electromagnetism, monopoles, magnetic charge, Maxwell's equations, fundamental forces, field theory, elementary particle, quantum field theory, photon split, pair production, electron, positron, electromagnetic radiation, photon structure.

I. INTRODUCTION

The classical electromagnetic wave theory is one of the greatest achievements of humanity. It provides a framework to unite electricity, magnetism, and light phenomena, as well as, starting a revolution on the mechanical way of thinking of transporting energy through mediums [1]. The development of this revolutionary theory started when Faraday discovered the electromagnetic induction, and it was fulfilled when electromagnetic waves were successfully generated by Hertz [2].

The relationship between electricity and magnetism started when Oersted found that a current-carrying wire generates a force on a magnetized compass needle. This relationship was explored further by Ampere and others to develop the physical laws that govern the observed interactions between electricity and magnetism. Ampere showed that the interaction between two current-carrying wires depends on their lengths, current directions, and current intensities. The fundamental empirical laws of electricity and magnetism were completed when Faraday discovered the electromagnetic induction, i.e., a change in the magnetic flux linking a circuit induces a current in that circuit proportional to the change rate [3]. It was observed that the induced current is in a direction that generates a magnetic field opposes the changing magnetic flux linking the circuit. This observation is known as Lenz's law with respect to the physicist who formulated it. These empirical laws were mathematically formulated into four equations by Maxwell in 1861. These four equations linked

The associate editor coordinating the review of this manuscript and approving it for publication was Lei Zhao.

the laws that govern all the experimental observations of the electric and magnetic effects of currents and electric charges. These equations suggested that light is an electromagnetic phenomenon. They also predicted the existence of electromagnetic waves [4], [5]. The existence of these waves was confirmed by Hertz in 1888 [6]. This confirmation opened the way for many electromagnetic radiation applications to enter daily life such as telegraphy and radio communication.

The electromagnetic waves are represented by two types of fields: the electric field and the magnetic field. These fields are perpendicular to each other and responsible for exerting the electric force and the magnetic force observed in the space. This representation has been used to reflect the relationship between the electric field and the magnetic field as specified in Maxwell's equations [7]–[15]. These equations are pure mathematics and are successful in predicting the outcome of a well-designed experiments, but this does not override the need for real understanding and visualization of the deeper physical process behind electromagnetic wave interactions, which is the physicists job, hence the problem [16]. Maxwell has not specified the nature of electricity and magnetism in his equations, and he has considered them as two different interdependent phenomena. This consideration has changed when Einstein suggested that the electric field and the magnetic field are two subjects of the same phenomenon, i.e., magnetism is a form of electricity [17], [18]. Despite this change, no model has been developed to represent the electromagnetic waves using the electric field only. This can be explained in part by the lack of a valid theoretical framework explaining the magnetic force using the electric force basis, in a way that is consistent with the electromagnetic theory and facilitates the derivation of the infinitesimal laws of magnetism [19]–[24].

This problem has been recently resolved by the Electric Origin of the Magnetic Force (EOMF) theory described in [25], [26]. This theory explains the magnetic force applied on a current element in the space, referred to as the destination element, by another current element, referred to as the source element, as the net electric force applied to the destination element due to purely electric charges interaction. These electric charges are: the moving charges inside the destination element to produce the current, and the charges surrounding the destination element due to the electric field changes around it that indicate the movement of the charges inside the source element. When a charge moves, it causes changes to the electric field spreading in the space. These changes in the electric field are found to have discontinuity points to reflect the changes in positions of the moving charges inside the source element. By applying Gauss's law, electric charges are found to exist at these discontinuity points. These electric charges are referred to as discontinuity charges. A set of these charges are produced by a source element to reflect the movement of charges inside it to generate the current. These sets are referred to as the infinitesimal discontinuity units. The discontinuity charges interact with the moving charges inside a destination element. The net electric force produced on the destination element by this interaction is equivalent in magnitude and direction to the observed magnetic force on it. This explanation has been proved by deriving the infinitesimal magnetic force law and Biot-Savart law using the basis of electric forces as specified in the electromagnetic theory. The work described in [25], [26] shows how the EOMF theory is applied to magnetic fields generated by constant currents and charges moving at constant speeds, but it does not show how this theory is applied to electromagnetic waves generated by varying currents and accelerating charges. This issue is resolved in this paper.

In this contribution, the first electric model for the infinitesimal structure of electromagnetic waves is proposed. This model consists of electric field components only. These components have a specific spatial arrangement that is responsible for exerting both the magnetic force and the electric force applied by the electromagnetic waves. This model is achieved by applying the EOMF theory to current elements with accelerating/decelerating charges. The current elements are modeled to reflect the changes happening to their moving charges with respect to time. The effect of these changes on the spreading electric field from the moving charges is analyzed. The analysis shows that these changes produce infinitesimal discontinuity units with discontinuity charges that have different strengths. When these units interact with other charges and current elements, this difference in strength produces a change in the observed magnetic field and electric field. The relationship between the changes in the magnetic field and the electric field is quantified and found to be an exact equivalent to the empirical laws reported in Maxwell's wave equations. This exact equivalency to Maxwell's equations proves the validity of the proposed model.

The advantages of the proposed model over the current model lie in the ability in explaining the observed electromagnetic properties and phenomena that could not be explained using the current model, as well as, in providing a theoretical framework to resolve controversial problems such as the existence of magnetic monopoles [8], [27]–[30]. For example, it explains why the electric field and the magnetic field are perpendicular to each other, why the amount of these two fields are related to each other by the speed of light in the medium, why changes in the electric field produce a magnetic field and vice versa, and why the direction of the induced current generates a magnetic field resisting the changes in the magnetic flux, i.e., Lenz's law. Also, the proposed model specifies the electric origin of the magnetic field in electromagnetic radiation. This may help scientists in visualizing the reality of photons, which are electromagnetic energy discrete quantities, and in better understanding the deeper physical process behind their interactions. Such understanding may help scientists and engineers in making advancements to the technology and applications of electromagnetism. More details about these advantages are provided through the discussion of this paper.

This paper is organized as follows: Section (II) provides background information about Maxwell's equations that is needed to understand the terminology of this work. Section (III) reviews related works in this area. Section (IV) describes the electric model of electromagnetic waves. Section (V) discusses the results of the model. Section (VI) concludes the paper with a summary of the work and its impact on the current state of the research in this field.

II. BACKGROUND

Maxwell's equations are a set of partial differential equations that mathematically describe how electric and magnetic fields are generated by charges, currents, and changes of the fields. This set consists of four equations: Gauss's law equation (1), Gauss's law for magnetism equation (2), Faraday's law of induction equation (3), and Ampere's circuital law equation (4).

$$\nabla \cdot E = \frac{\rho}{\epsilon}. \tag{1}$$

$$\nabla \cdot B = 0. \tag{2}$$

$$\nabla \times E = -\frac{\delta B}{\delta t}. \tag{3}$$

$$\nabla \times B = \mu \boldsymbol{j} + \frac{1}{c^2}\frac{\delta E}{\delta t}. \tag{4}$$

where $\nabla\cdot$ is the divergence operation, E is the electric field, ρ is the electric charge density, ϵ is the permittivity of the medium, B is the magnetic field, $\nabla\times$ is the curl operation, δ is the partial derivative operation, t is time, $\boldsymbol{j}$ is the steady current density, μ is the permeability of the medium, and c is the speed of light in the medium. The medium is possible to be a vacuum or a material. The speed of light in a vacuum is 3×10^8 m/s, approximately. Maxwell's equations show how fluctuating electric and magnetic fields generate waves that propagate at the speed of light in a medium. These waves may have different wavelengths to produce the spectrum of light.

III. RELATED WORK

There is no existing model that represents the electromagnetic waves by electric fields only in a way that is consistent with the electromagnetic theory. This section provides descriptions for the current model for the electromagnetic waves, and the electric origin of the magnetic force theory.

The electromagnetic waves are viewed in two ways to explain its wave-particle duality, the classical view and the quantum mechanics view. In the classical view, the electromagnetic waves consist of two fields: the magnetic field and the electric field. These two fields are perpendicular to each other, and their relationship is specified in Maxwell's equations [31], [32]. The interaction between these fields and charged particles is specified in the Lorentz force equation. This view is used to explain the electromagnetic fields and their interaction with charged particles, and to capture information about the generating charges. In the quantum mechanics view, electromagnetic waves are represented by small energy units called photons [33]–[37]. These photons are electrically neutral, and they are either real or virtual. This view is used to explain the photoelectric phenomena. In both views, the electromagnetic waves do not have a charge, and are not affected by electric fields and magnetic fields.

The electric origin of magnetic force theory provides a successful explanation to the magnetic force as a purely electric one that facilitates the derivation of its law [25]. It analyzes the changes of the spreading electric field in the space due to the movement of the electric charges generating the current. These changes generate infinitesimal discontinuity charges, where each two-pair set forms a unit that reflects the movement of charges inside the current element. These units are referred to as infinitesimal units, see figure (1).

These infinitesimal units spread in the space at the speed of light. When a current element present at a crossing point in the space, these units interact with the charges of that current element, for example, see figure (2).

This interaction is purely electric and produces a net electric force on the current element. This net force is proportional to the amount of the current charges in the source element that produced the interacting infinitesimal units, and to the amount of the current charges in the destination element present at the crossing point in the space as specified in equation (5) [25].

$$\overrightarrow{dF_{12}} = \frac{1}{4\,\pi\,\epsilon}\frac{dQ_1\,dQ_2}{|\overrightarrow{r}|^2}(\overrightarrow{a_2} \times \overrightarrow{a_1} \times \overrightarrow{a_r}). \tag{5}$$

where $\overrightarrow{dF_{12}}$ is the net force applied to the destination current element located at the crossing point, denoted by 2, due to its interaction with the infinitesimal discontinuity charge units produced by the source current element, denoted by 1. dQ_1 and dQ_2 are the amounts of the electric charges generating the currents inside the source element and the destination element, respectively. $\overrightarrow{a_1}$ and $\overrightarrow{a_2}$ are the unit vectors that show the propagation directions of the currents inside the source element and the destination element, respectively. $\overrightarrow{r}$ is the distance vector pointing from the source current element toward the destination current element. $\overrightarrow{a_r}$ and $|\overrightarrow{r}|$ are the unit direction and the amplitude of the distance vector, respectively. Equation (5) is rewritten to equation (6) to be in current terms by substituting for dQ_1 and dQ_2 using their relation to currents flowing in their corresponding elements.

$$\overrightarrow{dF_{12}} = \frac{\mu}{4\pi}\frac{I_1\,I_2}{|\overrightarrow{r}|^2}\,dl\,dl\,(\overrightarrow{a_2} \times \overrightarrow{a_1} \times \overrightarrow{a_r}) \tag{6}$$

where I_1 and I_2 are the amounts of current flowing in the source current element and the destination current element, respectively. dl is the infinitesimal length of a current element. Notice that equation (6) is an exact equivalent to the infinitesimal magnetic force law. The full details of this theory with its proof are provided in [25], [26]. The work described in [25], [26] applies the EOMF theory on constant currents and charges moving at constant speeds, but it does not apply it on varying currents and accelerating/decelerating charges.

This paper describes how to apply EOMF theory on infinitesimal elements that contains accelerating/decelerating

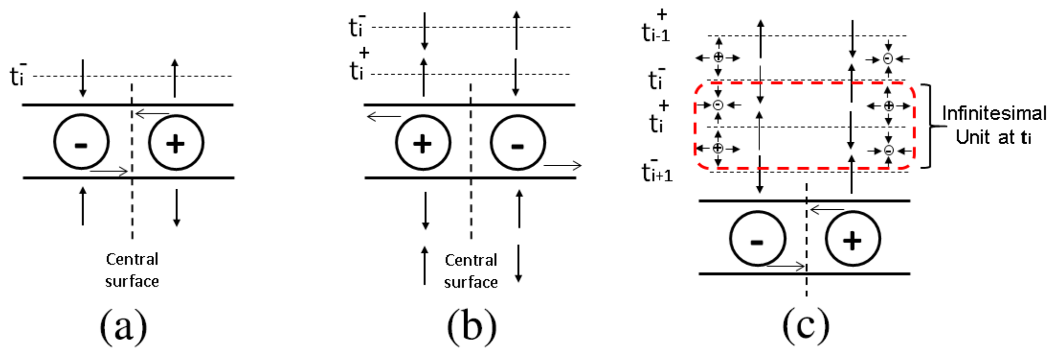

FIGURE 1. Shows the electric field spreading through the space for a current element due to the movement of positive and negative charges, as well as, the discontinuity charges, and the generated infinitesimal unit at t_i.

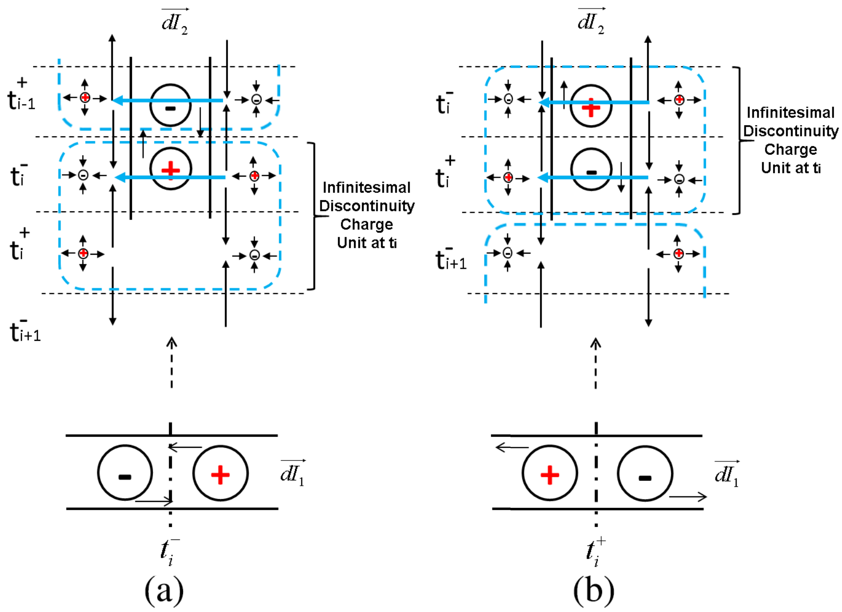

FIGURE 2. Shows an example for the interaction between an infinitesimal discontinuity charge unit and the charges of a current element present at a crossing point in the space for discontinuity charges generated at (a) t_i^-, and (b) t_i^+.

charges, i.e., varying currents. This applications provides a model for the infinitesimal structure of the produced electromagnetic waves. This model has been proved by deriving the Maxwell's equations governing electromagnetic waves.

IV. METHODOLOGY

This section describes how to build an electric model for the electromagnetic waves using the electric origin of magnetic forces theory. This theory is applied to current elements that contain accelerating or decelerating charges inside them. This application is performed by analyzing the electric field and its changes spreading in the space due to the movement of electric charges inside the current elements. In this analysis, the current elements are two types: source and destination. The source element contains moving charges that generate the electric field spreading in the space. The destination element contains moving charges that interact with the spreading electric field. The analysis is performed on currents produced by moving positive and negative charges in opposite directions at the same speed to simplify the presentation in this paper. This analysis is applicable for currents generated by moving positive charges, by moving negative charges, or by both moving positive and negative charges at different speeds.

The analysis process requires defining a 3D space, infinitesimal points and infinitesimal current elements, as well as, building models to represent charge movements, and current elements with accelerating/decelerating charges. The 3D space is defined by three orthonormal unit vectors $\overrightarrow{u_1}$, $\overrightarrow{u_2}$, and $\overrightarrow{u_3}$, such that any element in the space is decomposed into its three perpendicular components. Each component is analyzed separately along its own axis. For each axis, an infinitesimal point in the space is defined as a 3D square shape that is smaller than any non-infinitesimal one, i.e., nothing can be measured smaller than it. An infinitesimal current element consists of two touching infinitesimal points

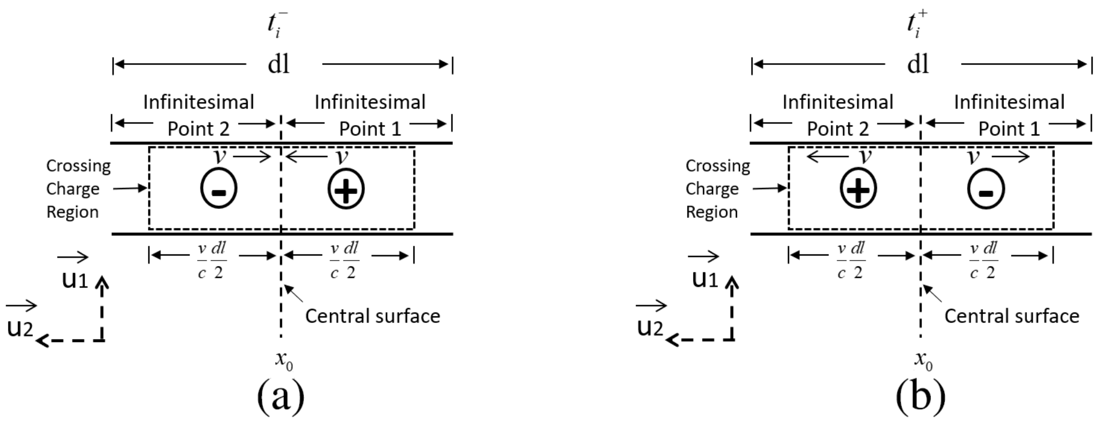

FIGURE 3. Shows how current is modeled inside an infinitesimal current element with a current propagating in the negative $\vec{u_1}$ direction at t_i. (a) Shows the positions of the current charges at t_i^- before crossing the central surface. (b) Shows the positions of the current charges at t_i^+ after crossing the central surface.

such that the touching area between them is the crossing surface for the current charges, refer to figure (3).

Notice that there is no surface inside an infinitesimal point. A current is generated in an element by having a charge crossing the surface between the two infinitesimal points during an infinitesimal time dt, such that the crossing charge is seen occupying each point for $dt/2$. The infinitesimal length for a current element is denoted by dl. The relationship between dl and dt is determined by the maximum hypothetical possible speed for a charge and the traveling speed for electric field changes in the space, which is the speed of light, c, i.e., $dl = c\,dt$. This relationship is used for two reasons: to have a unified analysis space that handles current elements generated by charges moving at any speed, and to satisfy the fact that a continuous current is continuously seen generated in the current element during dt from any point in the space [26]. The direction of a current element is defined by the direction of its flowing current.

The analysis process is described in the following three subsections: Subsection (IV-A) describes the used model to represent charge movements and current elements with accelerating/decelerating charges. Subsection (IV-B) provides the analysis for the electric field emitted by the moving current charges, as well as, its changes that produce the discontinuity charges. Finally, subsection (IV-C) describes the analysis for the interaction of the spreading discontinuity charges with static charges and current elements present at the crossing points in the space.

A. MODEL

For a current element with accelerating/decelerating charges, it is modeled as follows. In these elements, the charges exit the current element at a speed different than the speed they have entered that element with. But since current is a flow of charges, this indicates that the flow of charges entering the current element is different than the flow of charges exiting the current element. The flow of charges moving at a speed v is defined in equation (7).

$$flow = N\,q\,v\,dA \tag{7}$$

where $flow$ is the flow of charges crossing a surface, N is the number of flowing charged objects, q is the electric charge of the flowing charged objects, and dA is the cross area of the infinitesimal current element. Equation (7) indicates that the same charge flow might be generated using different combinations of speed values, numbers of charges, and charge values. So for two different combinations, they produce the same effect in the space as long as they have the same flow regardless of the values of the involved charges and speeds. Therefore the change of speed of the current charges inside the current element at t_i is modeled by a change in the number of charges existing around the crossing surface at that moment. For decelerating charges, the speed of the charges entering the current element at t_i^- is higher than the speed of the charges exiting the current element at t_i^+. This is modeled by having the number of charges existing around the surface at t_i^- larger than the number of charges around the surface at t_i^+, see figure (4). The difference in charges can be explained in part by assuming the charges that do not exit the element at t_i^+ to be stopped at the surface such that half of the charge is observed at each side of the surface, and since the same amount of positive and negative charges have stopped, the net charge of the stopped charges is zero.

For accelerating charges, a similar analysis is followed. Let the acceleration process be happening at t_i to increase the speed from $v_!$ at t_{i-1} to v_2 at t_{i+1}, where v_2 is larger than v_1. Then, the speed of the charges entering the current element at t_i^- is v_1, and it is lower than the speed of the charges exiting the current element at t_i^+, which is v_2. This is modeled by having the number of charges existing around the surface at t_i^- smaller than the number of charges around the surface at t_i^+, see figure (5). The difference in charges can be explained in part by assuming the extra charges that exit the element at t_i^+ are the ones were stopping at the surface at t_i^- and moved to exit the element at t_i^+, see figure (5).

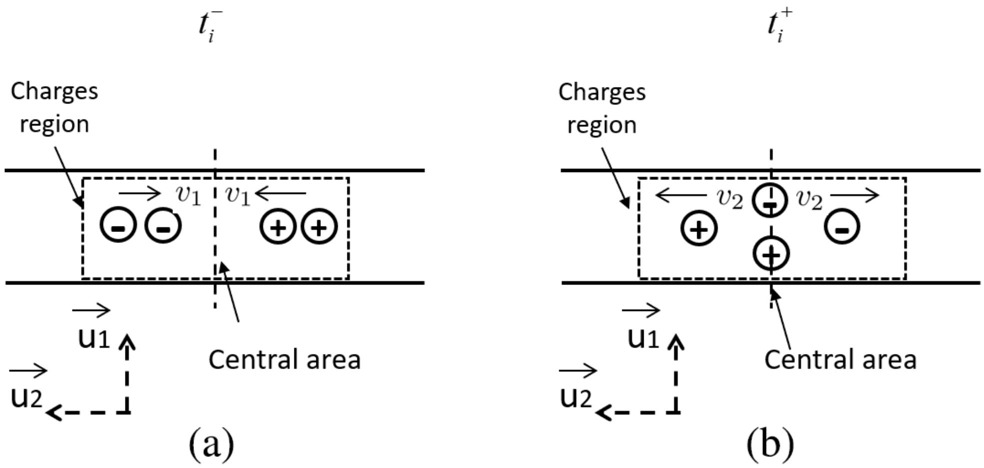

FIGURE 4. Shows the charges model for a current generated by decelerating charges. The speed of the charges entering the current element at t_i^- is higher than the speed of the charges exiting the current element at t_i^+. This is modeled by having the amount of charges existing around the surface at t_i^-, shown in (a), larger than the amount of charges around the surface at t_i^+, shown in (b).

B. EMITTED ELECTRIC ANALYSIS

The electric charges around the surface of the current element emit electric fields that are spreading through space in all directions. The analysis of the spreading electric field is performed over the two basic directions $\vec{u_1}$ and $\vec{u_2}$. The analysis along $\vec{u_3}$ is omitted because it is an exact equivalent to the analysis done for $\vec{u_1}$. This analysis is performed on a single infinitesimal current element where current charges are present at two locations only: the left side and the right side of the central infinitesimal surface of the current element. Therefore, charges are not seen when they are outside the infinitesimal current element vicinity. For charges traveling along a trajectory path, the superposition principle and the retarded time effect are used to sum the contributions from all the infinitesimal elements comprising the path on a point in the space. For a current element with a current flowing in the positive direction of $\vec{u_2}$, and the current is generated by accelerated charges, see figure (6), at t_i^-, the positive current charges generating the current during t_i are at the right side of the current element and moving toward the left side, while the negative charges are at the left side and moving toward the right side, see figure (6 a). At t_i^+, the positive current charges that crossed the surface are at the left side of the current element, while the negative charges that crossed the surface are at the right side, see figure (6 b). Notice that the number of charges at t_i^+ is larger than the number of charges at t_i^-. Then at t_{i+1}^-, the positive current charges generating the current during t_{i+1} are at the right side of the current element and moving toward the left side, while the negative charges are at the left side and moving toward the right side, see figure (6 c). The amount of charges at t_{i+1}^- is similar to the amount of charges was at t_i^+ to indicate the new speed achieved at t_i^+.

1) BASIC DIRECTION $\vec{u_1}$

For an observer at position $\boldsymbol{x}$ in the positive side of $\vec{u_1}$ that is observing the electric field emitted from the left side and the right side of the infinitesimal surface by current charges, at t_i^- moment, the positive charge at the right side emits an electric field in the positive direction of $\vec{u_1}$, and the negative charge at the left side emits an electric field in the negative direction of $\vec{u_1}$. At t_i^+ moment, the positive charge that crossed the surface is now at the left side of the current element and emits an electric field in the positive direction of $\vec{u_1}$, while the negative charge that crossed the surface is at the right side and emits an electric field in the negative direction of $\vec{u_1}$. The number of charges at t_i^+ is larger than the number of charges at t_i^-, therefore the electric field emitted at t_i^+ is stronger. These changes in the electric field spread through space at the speed of light in all directions. When this continues for a while, these changes in the electric field form a pattern spreading in the space to indicate the movement of charges and its acceleration to generate the current as shown in figure (6). This spreading pattern is assumed to be always seen the same with no change by any observer at any position in the space at any time, because otherwise, the current would have different directions at different points in the space, and this is not true.

The generated pattern of changes in the electric field, i.e., from positive to negative direction and from negative to positive direction, due to charge movements indicates a discontinuity in the electric field spreading in the space. Each discontinuity point is an infinitesimal region that is enclosed by an infinitesimal surface bounding it. Gauss law is then applied at the discontinuity points of the observed electric field emitted from the left side and the right side of the central surface of the infinitesimal current element, such that the changes in the electric field emitted from each side are independently treated from the other side. Following Gauss's law and assuming constant permittivity, ϵ, this discontinuity in the electric field indicates the existence of an electric charge [38]. This charge is called a discontinuity charge. Figure (6 c) shows discontinuity charges produced by a current element. This analysis is similar to the one performed in [25], [26], but

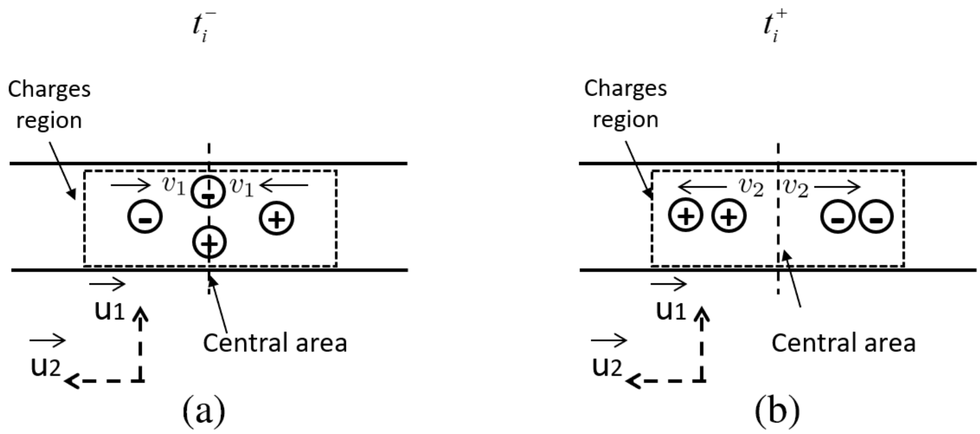

FIGURE 5. Shows the charges model for a current generated by accelerating charges. The speed of the charges entering the current element at t_i^- is smaller than the speed of the charges exiting the current element at t_i^+. This is modeled by having the amount of charges existing around the surface at t_i^-, shown in (a), smaller than the amount of charges around the surface at t_i^+, shown in (b).

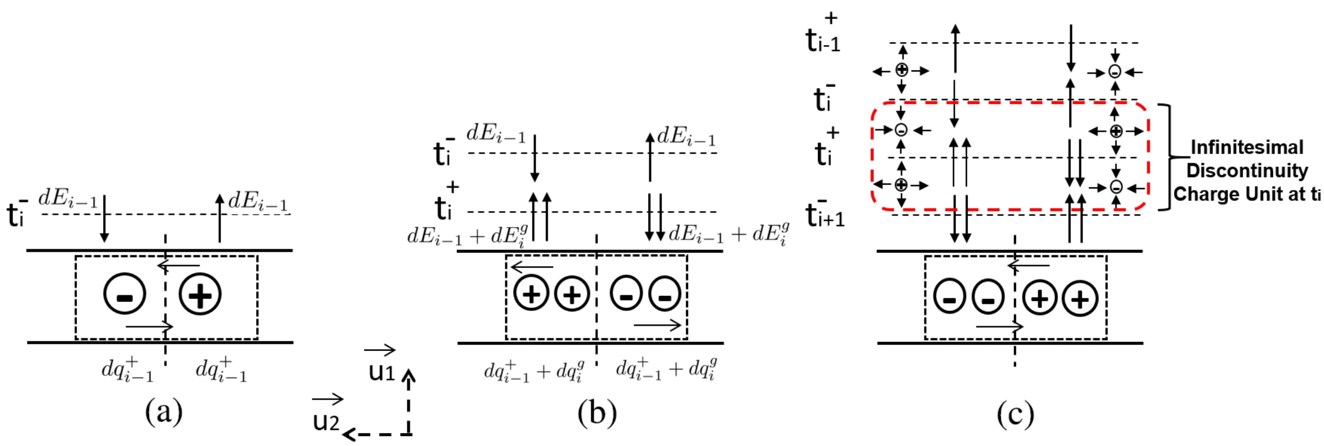

FIGURE 6. Shows the modeled distribution of charge for a current generated by accelerating charges at t_i, as well as the distribution of the electric field emitted by the current charges around the central surface of the current element. The distribution is shown for three moments (a) t_i^-, (b) t_i^+, and (c) t_{i+1}^-. The distribution of the discontinuity charges is shown in (c).

in this work the amount of charges changes during t_i to reflect the changes in the speed of the current charges.

The amplitude of the generated discontinuity charge is associated with the strength of the emitted electric fields at its discontinuity point according to Gauss's law. This indicates that, along the direction of $\vec{u_1}$, the discontinuity charges generated at t_i^+ moment have a larger amplitude than the ones generated at t_i^- moment. This is because the amount of charges around the surface at t_i^+ is larger, so the electric field emitted at t_i^+ is stronger. For detailed analysis, let the amount of the positive and negative current charges produces the current at t_{i-1}^+ is dq_{i-1}^+, and the amplitude of the produced electric field by this amount of charge is dE_{i-1}. Let the amount of the corresponding discontinuity charges produced during t_{i-1} is dq_{i-1}^{cn} and the amount of the electric field applied by the discontinuity charges at t_{i-1} is denoted by dE_{i-1}^{cn}. Considering the right side of the surface of the current element, at t_i^-, the positive charges at the right side of the surface have an amount of dq_{i-1} and emits an electric field of amplitude dE_{i-1}, see figure (6 a). This emitted electric indicates the end of the last discontinuity charge produced during t_{i-1} and indicates the start of the first discontinuity charge produced during t_i on the right side of the surface. At t_i^+, a negative charge presents on the right side of the surface with an amount of $dq_{i-1}^+ + dq_i^g$, where dq_i^g is the charge that indicates the change in the speed of the current charges due to acceleration during t_i. This negative charge appearing at the right side of the surface emits an electric field of amount $dE_{i-1} + dE_i^g$, where dE_i^g indicates the change in electric field strength emitted by current charges due to dq^g, see figure (6 b). This field indicates the end of the first discontinuity charge produced during t_i and the start of the last discontinuity charge on the right side. The amount of the first discontinuity charge produced during t_i is larger than the amount of last the discontinuity charge produced during t_{i-1}. That is because the electric fields surrounding the surface of this discontinuity point are larger, see figure (7), i.e., $d\Phi_{Ei}^- = 2\,dE_{i-1} + dE_i^g$, where $d\Phi_{Ei}^-$ is the electric flux through the closed surface enclosing the first discontinuity charge produced during t_i. According to Gauss's law, a volume charge is proportional to the net electric flux passing through the closed surface enclosing that volume, i.e., $q = \epsilon \Phi_E$, where Φ_E is the electric flux through a closed surface and q is the charge enclosed inside that surface. So the charge of the first discontinuity charge produced during t_i is denoted by $dq_i^{cn-} = dq_{i-1}^{cn} + dq_i^{cng}$, where dq_i^{cng} is the discontinuity charge change introduced to indicate the change in the emitted electric field due to the change in the charge speed during t_i. The amount of the electric field applied by this discontinuity charge on the charges interacting with it is denoted by $dE_i^{cn-} = dE_{i-1}^{cn} + dE_i^{cng}$, where dE_i^{cng} is the increase in the electric field amount due to the increase in the discontinuity charge by dq_i^{cng}. At t_{i+1}^-, a positive charge of amount $dq_{i-1}^+ + dq_i^g$ presents at the right side of the surface and emits an electric field of amount $dE_{i-1} + dE_i^g$. This indicates the end of the last discontinuity charge produced during t_i and the start of the first discontinuity charge during t_{i+1}. This last discontinuity charge is larger than the first one produced at t_i. That is because the surrounding electric field to its surface point is larger, i.e., $d\Phi_{Ei}^+ = 2\,dE_{i-1} + 2\,dE_i^g$, where $d\Phi_{Ei}^+$ is the electric flux through the closed surface enclosing the last discontinuity charge produced during t_i. Therefore, the last discontinuity charge produced during t_i is denoted $dq_i^{cn-} = dq_{i-1}^{cn} + 2\,dq_i^{cng}$. The amount of the electric field applied by this discontinuity charge on the charges interacting with it is denoted by $dE_i^{cn} = dE_{i-1}^{cn} + 2\,dE_i^{cng}$. A similar analysis is applied to the left side of the surface to find the discontinuity charges produced during t_i at the left side. The produced pairs of the discontinuity charges during t_i are presented graphically in figure (7). For the first pair, each charge has an amount of $dq_{i-1}^{cn} + dq_i^{cng}$ and surrounded by an electric field of $dE_{i-1}^{cn} + dE_i^{cng}$, while the second pair has a $dq_{i-1}^{cn} + 2\,dq_i^{cng}$and surrounded by an electric field of $dE_{i-1}^{cn} + 2\,dE_i^{cng}$. These two pairs may be viewed as a unit that is spreading on the space to reflect the change in the position and speed of the current charges. This unit can be modeled by two unit: constant unit and change unit. The constant unit represents the strength of the electric field that would be produced if the charges stopped acceleration at t_i. The strength of the electric field in this unit is similar to the one produced by the flow of charges in the previous moment at t_{i-1}^+, i.e., the last acceleration moment. The change unit represents the change in the electric field strength due to the change in the charges speed due to acceleration, therefore it is referred to as the electromagnetic wave unit, too. Figure (8) shows a graphical representation of these units.

2) BASIC DIRECTION $\overrightarrow{u_2}$

For an observer at the positive side of $\overrightarrow{u_2}$ that is observing the electric field emitted from the left side and the right side of the infinitesimal surface by current charges, the electric field spreading in the space along the positive $\overrightarrow{u_2}$ direction is shown in figure (9). At t_i^- moment, the positive charge

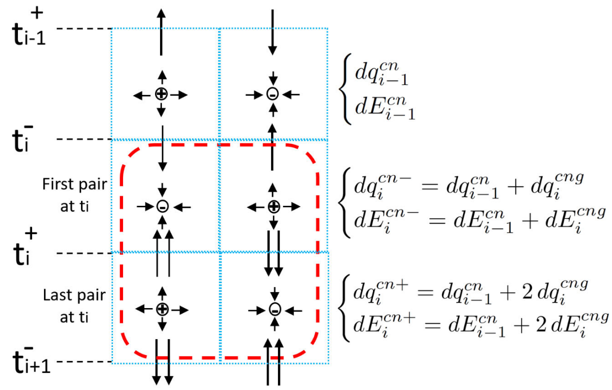

FIGURE 7. Shows the produced pairs of the discontinuity charges during t_i.

at the right side emits an electric field pointing toward the positive direction of $\overrightarrow{u_2}$, while the negative charge at the left side emits an electric field pointing toward the negative direction of $\overrightarrow{u_2}$. At t_i^+ moment, the positive charge at the left side emits an electric field pointing toward the positive direction of $\overrightarrow{u_2}$, while the negative charge at the right side emits an electric field pointing toward the negative direction of $\overrightarrow{u_2}$. The generated pattern of changes in the electric field indicates a discontinuity in the electric field spreading in the space. By applying Gauss's law, this discontinuity in the electric field indicates the existence of discontinuity charges. The discontinuity charges produced at t_i^+ are larger than the ones produced at t_i^-. This is because the amount of charges at t_i^+ is larger than the amount of charges at t_i^-. The detailed analysis for the electric field emitted and generated discontinuity charges is similar to the one performed for the case of an observer at the positive side of $\overrightarrow{u_1}$. The generated discontinuity charge from each side is shown in figures (9 a and b). Notice that the position of the last discontinuity charge generated from the left side overlaps with the position of the first discontinuity charge generated from the right side, as well as, the overlap between the first discontinuity charge generated from the left side and the last discontinuity charge generated from the right side during t_{i-1}. For simplicity the overlapped representation for these discontinuity charges is used, refer to figures (10). So, for each t_i, a source element generates two pairs of discontinuity charges. These two pairs spread in the space to indicate and encode the movement of charges inside source current elements.

C. DISCONTINUITY CHARGE INTERACTIONS

The spreading discontinuity charges interact with the static charges and current elements present at the crossing points in the space.

1) INTERACTION WITH STATIC CHARGES

For static charges, the electric charge of a static object occupying the vicinity of a current element is modeled by a point charge at the center of the current element. This point charge fully interacts with any electric field present at any point

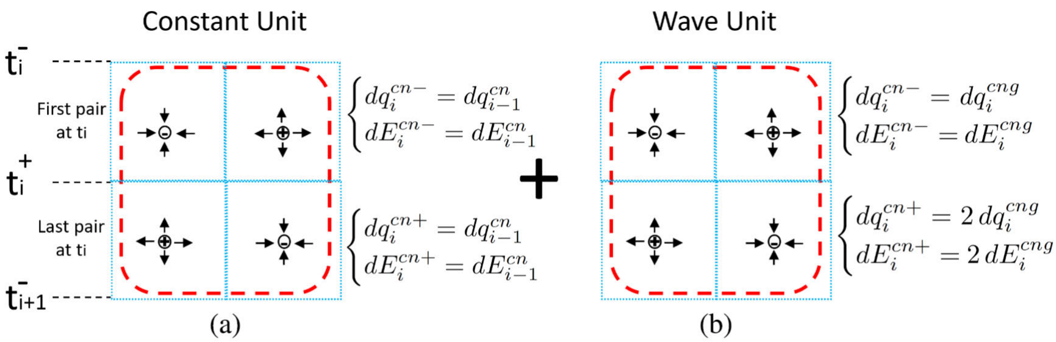

FIGURE 8. Shows a graphical representation of the constant unit, shown in (a), and the wave unit, shown in (b), for a discontinuity unit generated by accelerating charges. The summation of these two units is the total produced pairs of discontinuity charges during t_i.

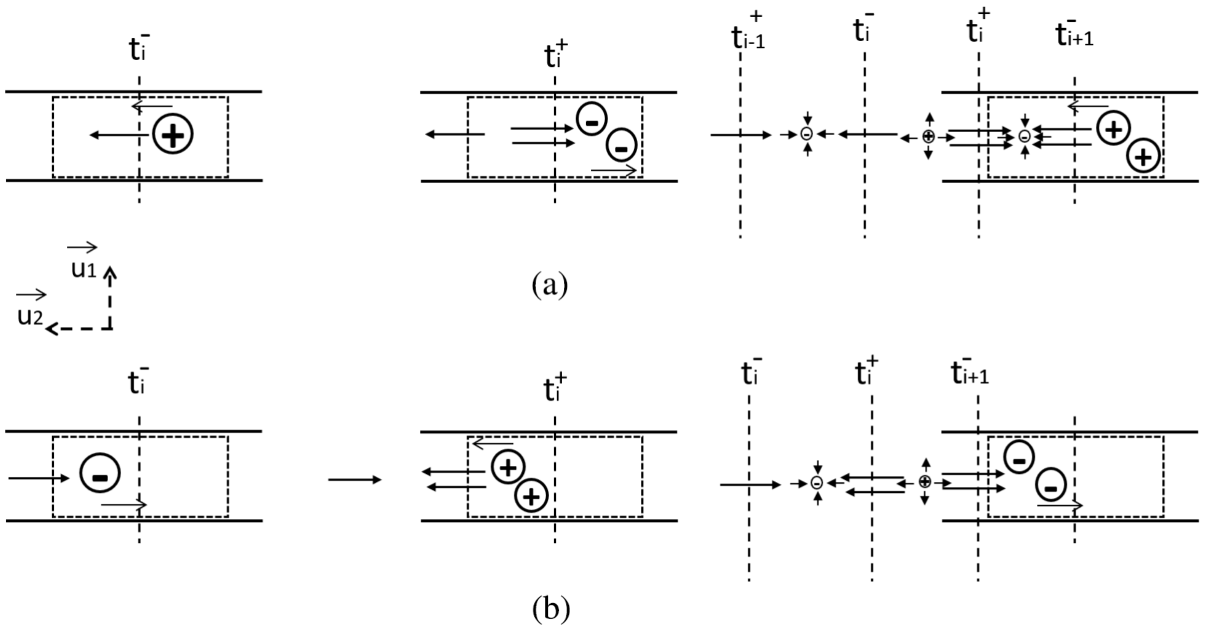

FIGURE 9. Shows the electric field and discontinuity charges spreading in the space along the positive $\overrightarrow{u_2}$ direction produced by a current element with a current flowing along the positive $\overrightarrow{u_2}$ direction during t_i. (a) shows the patterns generated from the right side of the central surface of the current element. (b) shows patterns generated from the left side of the central surface of the current element.

in the current element. This model is used to reflect the charge property of the object interacting with the discontinuity charge unit, this property is not seen partially since the object is assumed to be formed by one part. There are two basic cases: (1) a static charge lies on the plane that contains the current element and a charge with a position vector that is perpendicular to the current element direction, and (2) a static charge lies on the plane that contains the current element and a charge with a position vector that is along the current element direction. Analyzing the interaction for these two cases allows analyzing the interaction of discontinuity charges with any static charge at any position in the space by dividing its basic components along $\overrightarrow{u_1}$, $\overrightarrow{u_2}$, and $\overrightarrow{u_3}$.

a: CASE 1: PERPENDICULAR POSITION VECTOR

For the first case, let a positive static charge dq_{st} be at the center of a current element at position x in the space on $\overrightarrow{u_1}$. This charge has a distance vector $\overrightarrow{r}$ with respect to a source current element as shown in figure (11). The source current element has a current flowing in the positive direction of $\overrightarrow{u_2}$. The distance vector $\overrightarrow{r}$ is perpendicular to the source current element and its flowing current. Let the current be generated by accelerating charges. At t_i, the current element generates two pairs of discontinuity charges along $\overrightarrow{u_1}$. The first pair, generated at t_i^-, has an electric field in the positive direction of $\overrightarrow{u_2}$, which is similar to the source current. While the second pair, generated at t_i^+, has an electric field in the negative direction of $\overrightarrow{u_2}$, which is opposite to the source current. The amount of charge in the second pair is larger than the one in the first pair since the current charges are accelerating. Therefore the electric field in the second pair is stronger than the one in the first pair, and the electric field in the first pair is stronger than the ones found in the pairs generated at t_{i-1}^+, see figure (12).

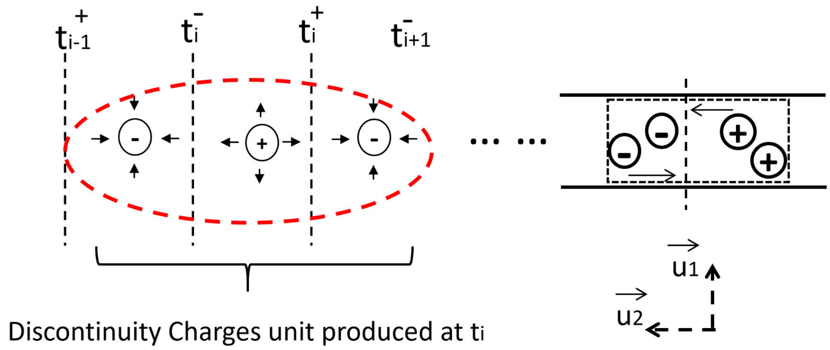

FIGURE 10. Shows the discontinuity charges unit spreading along $\overrightarrow{u_2}$ generated by a current element that has current flowing in the direction of positive $\overrightarrow{u_2}$.

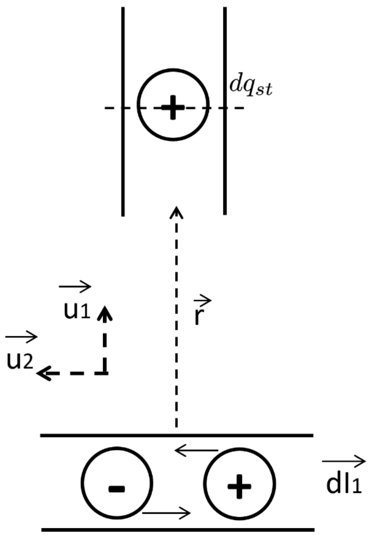

FIGURE 11. Shows the arrangement for the first case of static charge interaction with spreading discontinuity charges. A positive static charge dq_{st} is at the center of a destination current element at position x in the space on $\overrightarrow{u_1}$. This charge has a distance vector $\vec{r}$ that is perpendicular to the source current element $\overrightarrow{dl_1}$.

These pairs arrive at the position of the static charge, they convolve with it during their passing moment as follows. The electric field in the first pair interact with the static charge for $dt/2$ when it enters the vicinity of the current element, see figure (12 a). This electric field applies a force on the static charge pushing it in the positive direction of $\overrightarrow{u_2}$ defined in equation (8).

$$dF_i^{st-} = dq_{st}\,(dE_{i-1}^{cn} + 2dE_i^{cng})\,\overrightarrow{u_2} \tag{8}$$

where dF_i^{st-} is the electric force applied on the static charge due to interaction with the discontinuity charges generated at t_i^-. dq_{st} is the static charge. When the second pair enters the vicinity of the static charge element, the electric field from both pairs interact with the static charge for $dt/2$, see figure (12 b). This net electric field applies a force on the static charge pushing it in the negative direction of the of $\overrightarrow{u_2}$ since the second pair of discontinuity charges is stronger as defined in equation (9).

$$dF_i^{st-+} = dq_{st}\,(-2dE_i^{cng})\,\overrightarrow{u_2} \tag{9}$$

where dF_i^{st-+} is the electric force applied on the static charge due to interaction with the discontinuity charges generated at t_i^- and t_i^+. Then the first pair leaves the vicinity leaving the second pair by itself in the vicinity of the static charge element, see figure (12 c). The electric field of this pair applies a force on the static charge pushing it in the negative direction of $\overrightarrow{u_2}$ for $dt/2$ as defined in equation (10).

$$dF_i^{st+} = dq_{st}\,(-dE_{i-1}^{cn} - 4dE_i^{cng})\,\overrightarrow{u_2} \tag{10}$$

where dF_i^{st+} is the electric force applied on the static charge due to interaction with the discontinuity charges generated at t_i^+. Notice that the static charge stays the same and in its position during this interaction with discontinuity charges. The static charge interacts with each discontinuity charge for dt. Therefore the accumulated electric force applied on it as if these discontinuity charges applied simultaneously for dt is computed in equation (11).

$$dF_i^{st}\,dt = dF_i^{st-}\,\frac{dt}{2} + dF_i^{st-+}\,\frac{dt}{2} + dF_i^{st+}\,\frac{dt}{2} \tag{11}$$

Using equations (8, 9, and 10), equation (11) is rewritten into equation (12).

$$dF_i^{st}\,dt = -dq_{st}\,2dE_i^{cng}\,\overrightarrow{u_2}\,dt \tag{12}$$

where dF_i^{st} is the accumulated electric force applied on the static charge due to interaction with the discontinuity charges generated at t_i. Notice that the electric fields of the constant unit cancel the effect of each other because they have the same amount but in opposite directions. Equation (12) indicates that dF_i^{st} is generated by the net electric field that results from integrating the electric field existing in the wave unit along its propagation access. Therefore equation (12) is rewritten into equation (13).

$$dF_i^{st} = -dq_{st}\,dE_i^{w}\,\overrightarrow{u_2} \tag{13}$$

where dE_i^w is the strength of the net electric field that results from integrating the electric field existing in the wave unit along its propagation access. The sum of the electric fields

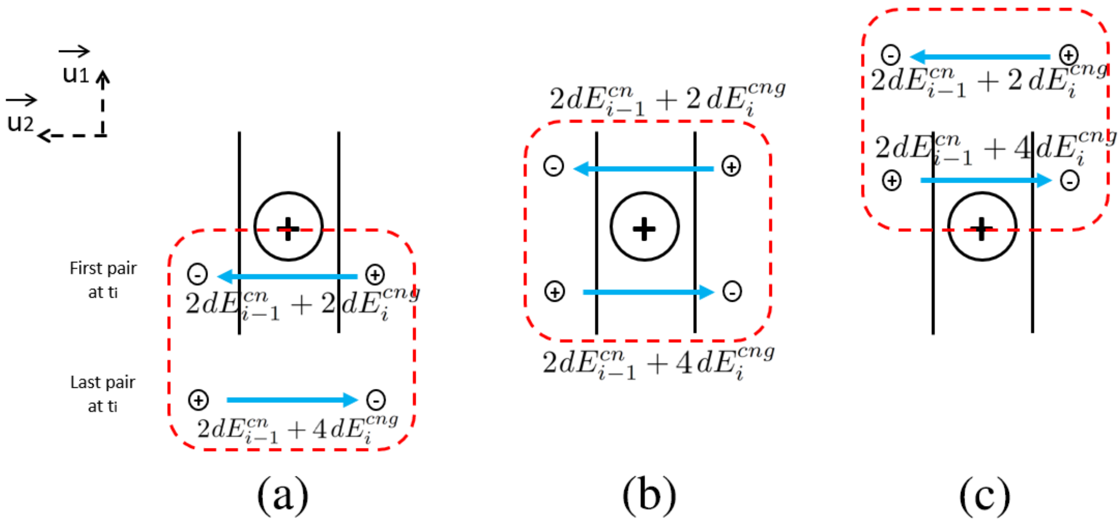

FIGURE 12. Shows the interaction of a positive static charge dq_{st} with discontinuity charges generated at t_i and spreading along the positive direction of $\overrightarrow{u_1}$. (a) The distribution of charges when the first pair is at the lower of the current element. (b) The distribution of the charges when the first pair and the last pair are at top point and lower point, respectively. (c) The distribution of charges when the last pair is at the top of the current element.

contained within the wave unit vicinity is equal to zero in all directions except to the one perpendicular to the propagation direction it is equal to $dE_i^w = 2dE_i^{cng}$.

b: CASE 2: PARALLEL POSITION VECTOR

For the second case, when the positive static charge dq_{st} is at position x in the space on $\overrightarrow{u_2}$. This charge has a distance vector $\overrightarrow{r}$ with respect to a source current element as shown in figure (13). The distance vector $\overrightarrow{r}$ is along the direction of the current element. The interaction of this charge with the passing discontinuity charges generated at t_i by the current element is modeled as follows. Each discontinuity charge during its passing exists at the two sides, i.e., left and right sides, of the static charge for $dt/2$. For example, for the case shown in figure (13), the negative discontinuity charge travels toward the positive direction of $\overrightarrow{u_2}$. During its passing by the static charge, the discontinuity charge stays at the left side for $dt/2$, see figure (14 a), so it applies an electric force on the static charge toward the negative direction of $\overrightarrow{u_2}$ as defined in equation (14).

$$dF_{Lpd-}^{st} = -dq_{st}\, dE_i^{cng}\, \overrightarrow{u_2} \tag{14}$$

where dF_{Lpd-}^{st} is the electric force applied on the static charge dq_{st} by a negative discontinuity charge on its left. In the next moment of its travel, the discontinuity charge is at the right side of the static charge and stays for $dt/2$, see figure (14 b), so it applies an electric force on the static charge toward the positive direction of $\overrightarrow{u_2}$ as defined in equation (15).

$$dF_{Rpd-}^{st} = dq_{st}\, dE_i^{cng}\, \overrightarrow{u_2} \tag{15}$$

where dF_{Lpd-}^{st} is the electric force applied on the static charge dq_{st} by a negative discontinuity charge on its right. These two applied forces have the same amount but opposing each other. So the net force applied on the static charge during the passing of this negative discontinuity charge is zero as defined in equation (16).

$$dF_{pd-}^{st}\, dt = dF_{Lpd-}^{st}\,\frac{dt}{2} + dF_{Rpd-}^{st}\,\frac{dt}{2} = 0 \tag{16}$$

where dF_{pd-}^{st} is the net force applied on the static charge during the passing time dt of a negative discontinuity charge. The same analysis is performed for a positive passing discontinuity charge. The net force applied on the static charge due to the passing of the positive discontinuity charges, referred to as dF_{pd+}^{st}, is zero, i.e., $dF_{pd+}^{st} = 0$. Similarly, the interaction of the remaining discontinuity charges in the wave unit with the static charge, see figures (14 b, c and d), applies a zero net force on the static charge.

c: ARBITRARY POSITION VECTOR

The net force applied by a wave unit on a static charge at an arbitrary position, with respect to a source current element, is found by projecting the static charge into the two orthogonal unit vectors defining the plane that contains the static charge and the source current element. The applied net force is defined in equation (17).

$$\left|dF_i^{st}\right| = dq_{st}\, dE_i^w \left|\overrightarrow{r} \times \overrightarrow{dl_s}\right| \tag{17}$$

The direction of this force depends on two factors: the direction of flowing current in the source element and changes of the charges speed if they are accelerating or decelerating. For accelerating charges the direction of the force is in the opposite direction of the current element because the discontinuity charges generated at t_i^+ are stronger than the ones generated at t_i^-. While for decelerating charges the direction of the net force is in the direction of the current, because the discontinuity charges generated at t_i^+ are weaker than the ones generated at t_i^-.

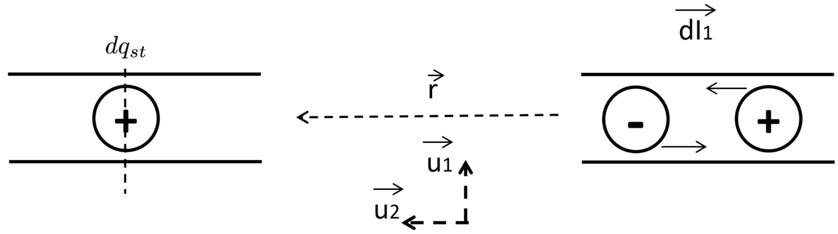

FIGURE 13. Shows the arrangement for the second case of static charge interaction with spreading discontinuity charges. A positive static charge dq_{st} is at the center of a destination current element at position x in the space on $\overrightarrow{u_2}$. This charge has a distance vector $\overrightarrow{r}$ that is along the direction of the source current element $\overrightarrow{dl_1}$ with current flowing in the positive direction of $\overrightarrow{u_2}$.

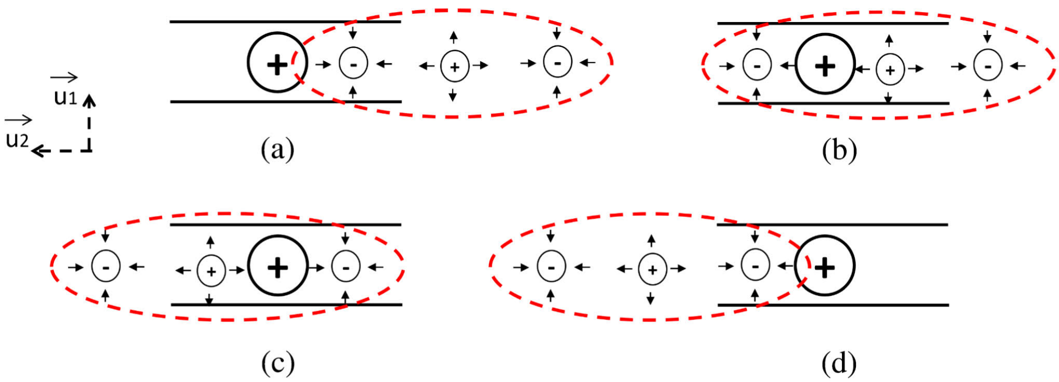

FIGURE 14. Shows the interaction of a positive static charge dq_{st} with discontinuity charges generated at t_i and spreading along the positive direction of $\overrightarrow{u_2}$. Each discontinuity charge exists at each side of the of the static charge for $dt/2$. The positions of the discontinuity charges around the static charge during their full interaction is shown in figures (a to d).

2) INTERACTION WITH CURRENT ELEMENTS

The interaction of the spreading discontinuity units with current elements present at the crossing points is analyzed for two basic cases: (1) when the destination current element has a position vector that is perpendicular to the source current element direction, and (2) when the destination current element has position vector that is along the source current element direction.

a: CASE 1: PERPENDICULAR POSITION VECTOR

For the first basic case, the interaction of the spreading discontinuity unit is analyzed for the three main components of the destination current element: (1) $\overrightarrow{u_1}$ component where the destination current direction is perpendicular to the source current element and on the same plane, (2) $\overrightarrow{u_2}$ component where the destination current direction is parallel to the source current element, and (3) $\overrightarrow{u_3}$ component where the destination current direction is perpendicular to the source current element and lies completely on the perpendicular plane, see figure (15). The analysis of these three cases covers all the possible current element situations that have position vectors perpendicular to the source current element. These destination current elements interact with both the constant unit and the wave unit. The interaction with the constant unit similar to the interaction with discontinuity charges produced by source current elements with constant currents. The interaction with the constant unit produces the observed static magnetic force on the destination current element. The details of this interaction are provided in [25], [26] and they are omitted here to avoid redundancy.

The analysis of the interaction of the destination current element with the wave unit part is performed for the three components.

i) DESTINATION ELEMENT COMPONENT ALONG $\overrightarrow{u_1}$

For $\overrightarrow{u_1}$ component, as shown in figure (16), the interaction begins when the destination current element interacts with the first pair of the discontinuity charges generated at t_i. At this moment, the current charges of the destination element enter the vicinity around its surface, and the discontinuity charges surrounding it are shown in figure (17 a). The wave discontinuity charges produced at t_i^- are at the lower point of the destination current element, while there are no wave discontinuity charges surrounding the upper point. This stays for $dt/2$. The force applied on the current element by wave discontinuity charges at t_i^-, denoted by dF_i^{w-}, is computed in equation (18).

$$dF_i^{w-} = \frac{dq_{dst}}{2}\, 2\, dE_i^{cng}\, \overrightarrow{u_2} \tag{18}$$

Then, the current charges in the destination current element switch positions around its surface, and the current element sees the source current charges exiting the vicinity around the surface of the source current element. The distribution of

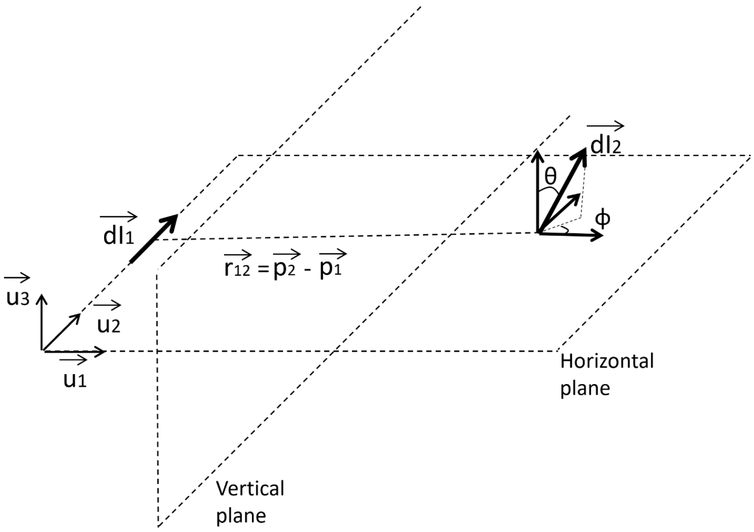

FIGURE 15. Shows the arrangement of current elements for the first basic case when the destination current element $\overrightarrow{dl_2}$ has position vector that is perpendicular to the source current element, $\overrightarrow{dl_1}$, direction.

the wave discontinuity charges surrounding the destination current element is shown in figure (17 b). The wave discontinuity charges produced at t_i^+ are at the lower point of the destination current element, while the wave discontinuity charges produced at t_i^- are at the upper point of the destination current element wave discontinuity charges surrounding the upper point. This stays for $dt/2$. The force applied on the current element by wave discontinuity charges at t_i^+, denoted by dF_i^{w+}, is computed in equation (19).

$$dF_i^{w+} = \frac{dq_{dst}}{2}\, 2\, dE_i^{cng} + \frac{dq_{dst}}{2}\, 4\, dE_i^{cng}\, \overrightarrow{u_2} \tag{19}$$

After that, new current charges enter the vicinity around the surface of the destination element to generate the current for the next moment, and the destination element starts to see new current charges entering the vicinity around the surface of the source current element to generate the current for t_{i+1} moment. The acceleration of the charges in the source element is already done at this point and they are running at the new constant speed achieved during t_i. The distribution of the wave discontinuity charges at this moment t_{i+1}^- is shown in figure (17 c). The wave discontinuity charges produced at t_i^+ are at the upper point of the destination current element, while no wave discontinuity charges surrounding the lower point. The force applied on the current element by wave discontinuity charges at t_{i+1}^-, denoted by dF_{i+1}^{w-}, is computed in equation (20).

$$dF_{i+1}^{w-} = \frac{dq_{dst}}{2}\, 4\, dE_i^{cng}\, \overrightarrow{u_2} \tag{20}$$

Notice that dF_{i+1}^{w-} contributes to the force applied on the destination current element for t_{i+1}^-. At this moment, the destination current element starts interacting with the discontinuity charges, which have been generated when the source current charges are running at the new constant speed

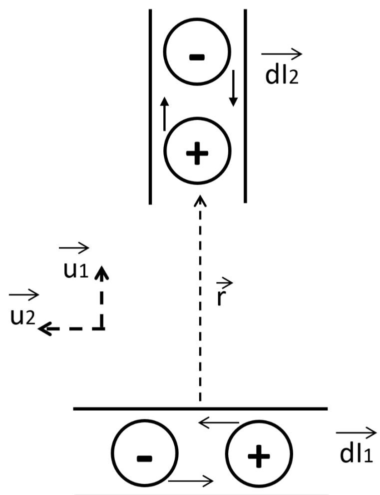

FIGURE 16. Shows the arrangement for the first case of current element interaction with spreading discontinuity charges. The destination current, $\overrightarrow{dl_2}$ is at the positive side of $\overrightarrow{u_1}$ with a flowing current on $\overrightarrow{u_1}$ direction. This charge has a distance vector $\overrightarrow{r}$ that is perpendicular to the source current element $\overrightarrow{dl_1}$ which has a current flowing on the positive direction of $\overrightarrow{u_2}$.

achieved during t_i. So despite there are no wave discontinuity charges surrounding the lower point of the destination current element, this point is surrounded by the discontinuity charges of the constant unit generated at t_{i+1}^-. So dF_{i+1}^{w-} together with the forces applied on the destination element at this moment by the constant units generated at t_i and t_{i+1} produce the new force level obtained by the wave the unit dt ago. This reflects the new speed that source current charges achieved due to the acceleration at t_i.

The change in the magnetic force introduced by the wave unit is defined in equation (21).

$$dF_i^w\, dt = dF_i^{w-}\frac{dt}{2} + dF_i^{w+}\frac{dt}{2} - 0_{i-1} \tag{21}$$

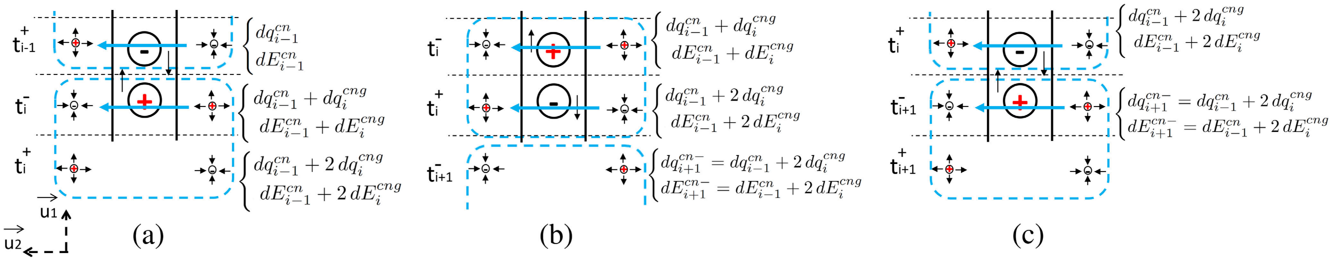

FIGURE 17. Shows the interaction between a destination current element along $\overrightarrow{u_1}$ and an infinitesimal discontinuity charge unit, includes both constant unit and wave unit, generated at t_i and spreading in the space along $\overrightarrow{u_1}$.

where dF_i^w is the additional magnetic force applied on the destination current element when it starts seeing the current in the source element at t_i. 0_{i-1} is the force applied on the destination element by the wave unit in the previous moment which is zero. By using equations (18 and 19), equation (20) is rewritten as in equation (22).

$$dF_i^w = dq_{dst}\, 2\, dE_i^{cng}\, \overrightarrow{u_2} \tag{22}$$

Since $dE_i^w = 2\, dE_i^{cng}$, equation (22) is rewritten as in equation (23).

$$dF_i^w = dq_{dst}\, dE_i^w\, \overrightarrow{u_2} \tag{23}$$

Equation (23) indicates the magnetic force contained within the vicinity of a wave unit. This vicinity has a dimension of dl and time dimension of dt since a wave unit moves at the speed of light [26]. This force is the exact equivalent to the additional magnetic force applied on the destination current element in equation (23). To represent this force in the terms of the destination current, let I_{dst} be the amount of the current flowing in the destination current element. Then dq_{dst} is expressed in terms of its current as defined in equation (24).

$$dq_{dst} = I_{dst}\, dt = I_{dst}\, \frac{dl}{c} \tag{24}$$

Using equation (24), equation (23) is rewritten as defined in equation (25).

$$dF_i^w = \frac{1}{c}\, dE_i^w\, I_{dst}\, dl\, \overrightarrow{u_2} \tag{25}$$

The magnetic force contained within the wave unit is proportional to the current flowing in the destination current element. This dependency is removed by computing the contained magnetic field in the wave unit instead of the force. This is done by removing the destination current element from equation (25) as defined in equation (26).

$$dB_i^w = -\frac{1}{c}\, dE_i^w\, \overrightarrow{u_3} \tag{26}$$

where dB_i^w is the magnetic field contained in the wave unit generated by the source unit at t_i. The direction of this magnetic field is $-\overrightarrow{u_3}$ because the relationship between the magnetic field and the destination current to produce the force is the cross product. Notice that the cross product between the direction of the contained electric field and the direction of the contained magnetic field is in the propagation direction of the wave unit, while the amplitude of the contained magnetic field is related to the amplitude of the contained electric field by $1/c$. This notice is fully consistent with the electric field and magnetic field properties of the electromagnetic wave as described in the electromagnetic theory [31], [39].

Equation (26) specifies the magnetic field contained in a wave unit, which occupies the space with a vicinity of dimension dl and time dt. The contained magnetic field introduces a change to the magnetic field that was existing dt ago at its current crossing point in the space, as well as, it introduces a change to the magnetic field existing at the next crossing point in the space, which is at dl distance from the current point. That is because the previous state that was dt ago at the current point has traveled dl distance in the space during dt. So the change in the magnetic field introduced by a wave unit with respect to time is defined in equation (27).

$$\frac{dB_i^w}{dt} = -\frac{1}{c}\, \frac{dE_i^w}{dt}\, \overrightarrow{u_3} \tag{27}$$

To find the relationship between the changes with respect to time and the changes with respect to space, equation (27) is rewritten to equation (28) by substituting $dt = dl/c$ in the right side.

$$\frac{dB_i^w}{dt} = -\frac{c}{c}\, \frac{dE_i^w}{dl}\, \overrightarrow{u_3} \tag{28}$$

Equation (28) is simplified as in equation (29).

$$\frac{dB_i^w}{dt} = -\frac{dE_i^w}{dl}\, \overrightarrow{u_3} \tag{29}$$

In equation (29), dE_i^w is the change in the electric field $\overrightarrow{u_2}$ component along the infinitesimal distance dl along $\overrightarrow{u_1}$, i.e., $dE_i^w \overrightarrow{u_2} = \overrightarrow{E}(\overrightarrow{x} + dl\overrightarrow{u_1}) - \overrightarrow{E}(\overrightarrow{x})$. The direction of the magnetic field change with respect to dt associated with this change in the electric field is along $\overrightarrow{u_3}$, i.e., $-dB_i^w \overrightarrow{u_3} = \overrightarrow{B_i}(t) - \overrightarrow{B_i}(t - dt)$. These relationships allow equation (29) to be represented using the curl mathematical operation as shown in equation (30).

$$\frac{d\overrightarrow{B}}{dt} = -\nabla \times \overrightarrow{E} \tag{30}$$

Equation (30) is the exact equivalent to Maxwell's third equation, i.e., Faraday's law of induction, in electromagnetic theory. This is the first part of the proof to show that this electric model is valid to represent electromagnetic wave fields. To complete the proof, equation (27) is rewritten to equation (31) by substituting $dt = dl/c$ in the left side.

$$\frac{dB_i^w}{dl} = -\frac{1}{c^2}\frac{dE_i^w}{dt}\overrightarrow{u_3} \tag{31}$$

In equation (31), $-dE_i^w$ is equivalent to the change in the electric field along $\overrightarrow{u_2}$ by the wave unit during dt, i.e., $-dE_i^w\overrightarrow{u_2} = \overrightarrow{E_i}(t) - \overrightarrow{E_i}(t-dt)$. While, dB_i^w is the change of the magnetic field along $\overrightarrow{u_3}$ over the infinitesimal distance dl along $\overrightarrow{u_1}$, i.e., $dB_i^w\overrightarrow{u_3} = \overrightarrow{B_i}(\overrightarrow{x} + dl\overrightarrow{u_1}) - \overrightarrow{B_i}(\overrightarrow{x})$. These relationships allow representing equation (31) using the curl mathematical operation as shown in equation (32).

$$\nabla \times \overrightarrow{B} = \frac{1}{c^2}\frac{d\overrightarrow{E}}{dt} \tag{32}$$

Equation (32) is the exact equivalent to the displacement current portion of Maxwell's fourth equation, Ampere's circuital law, in electromagnetic theory for time-varying current. By adding the other portion related to the steady movement of charges and currents, equation (32) is rewritten as in equation (33).

$$\nabla \times \overrightarrow{B} = \mu\boldsymbol{j} + \frac{1}{c^2}\frac{d\overrightarrow{E}}{dt} \tag{33}$$

where $\boldsymbol{j}$ is the steady current density. $\mu\boldsymbol{j}$ is known as the Ampere's law part, which is obtained by a lengthy mathematical operation that begins with Biot-Savart law [40]. This law is obtained by applying the electric origin of magnetic forces theory on steady moving charges and currents [25], [26]. This electric model of electromagnetic wave fields provides a theoretical framework that facilitates the derivation of Maxwell's equations for time-varying currents and fields. Obtaining these equations proves the validity of the proposed model.

ii) DESTINATION ELEMENT COMPONENT ALONG $\overrightarrow{u_2}$

The analysis of the interaction of the wave unit with a destination current element along $\overrightarrow{u_2}$ follows the same steps performed for the destination current element along $\overrightarrow{u_1}$, see figure (18). The interaction begins when the destination current element interacts with the last pair of the discontinuity charges generated at t_{i-1}. At this moment, the current charges of the destination element have switched their position around the surface to exit its vicinity, and the distribution of the wave discontinuity charges surrounding it are shown in figure (19 a). The wave discontinuity charges produced at t_i^- are at the lower side of the destination current element, while there are no wave discontinuity charges surrounding the upper side. This stays for $dt/2$. Then, new current charges enter the vicinity around the surface of the destination current element, and the distribution of the discontinuity charges around it reflects the distribution of the charges around and inside the source current element. The distribution of the wave discontinuity charges surrounding the destination current element is shown in figure (19 b). The wave discontinuity charges produced at t_i^+ are at the lower side of the destination current element, while the wave discontinuity

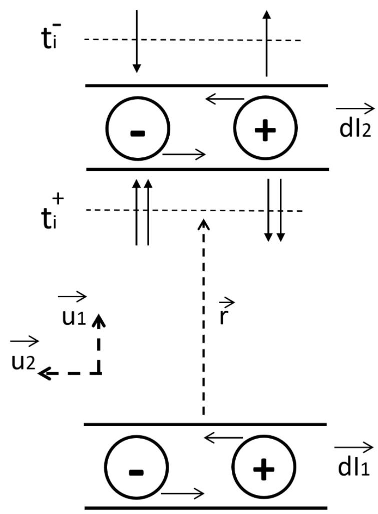

FIGURE 18. Shows the arrangement for the second case of current element interaction with spreading discontinuity charges. The destination current, $\overrightarrow{dl_2}$ is at the positive side of $\overrightarrow{u_1}$ with a flowing current on $\overrightarrow{u_2}$ direction. This charge has a distance vector $\overrightarrow{r}$ that is perpendicular to the source current element $\overrightarrow{dl_1}$ which has a current flowing on the positive direction of $\overrightarrow{u_2}$, too.

charges produced at t_i^- are at the upper side of the destination current element wave discontinuity charges surrounding the upper point. This stays for $dt/2$. Then, the charges inside the destination current element switch their positions around the surface to exit its vicinity. The distribution of the wave discontinuity charges is shown in figure (19 c). The wave discontinuity charges produced at t_i^+ are at the upper side of the destination current element, while there are no wave discontinuity charges at the lower side of the destination current element. This stays for $dt/2$. This last configuration contributes to the force applied by the constant units generated at t_i and t_{i+1} to produce the new force level obtained by the wave the unit dt ago. By computing the forces applied on the wave discontinuity charges on the destination element using the same method used for the current element along $\overrightarrow{u_1}$, the change in the magnetic field introduced by the wave unit is an exact equivalent to the one defined in equation (26). This result is fully consistent with the electromagnetic theory for this case.

iii) DESTINATION ELEMENT COMPONENT ALONG $\overrightarrow{u_3}$

The analysis of the interaction of the wave unit with a destination current element along $\overrightarrow{u_3}$, see figure (20), is done as follows. The interaction starts when the wave discontinuity charges produced at t_i^- are at the center of the destination current element, see figure (21 a). The electric field of discontinuity charges applies a force on the positive and the negative charges around the surface of the destination current element. This force is perpendicular to the movement of the charges. These charges are not permitted to leave the current element, therefore they push the current element in the direction of the forces. These forces have the same amount but in opposite direction, hence the net force applied on the current element is

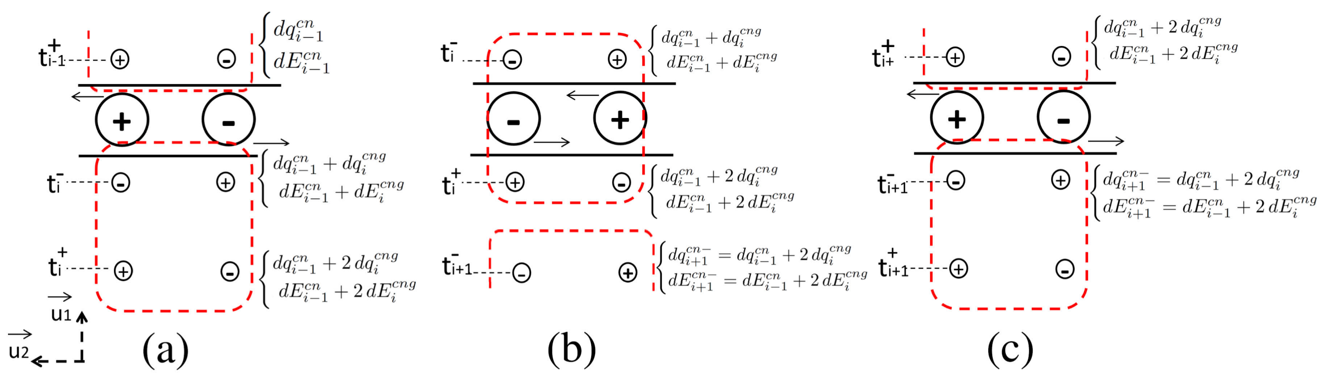

FIGURE 19. Shows the interaction between a destination current element along $\vec{u_2}$ with a current flowing in the positive direction of $\vec{u_2}$, and an infinitesimal discontinuity charge unit, includes both constant unit and wave unit, generated at t_i and spreading in the space along $\vec{u_1}$.

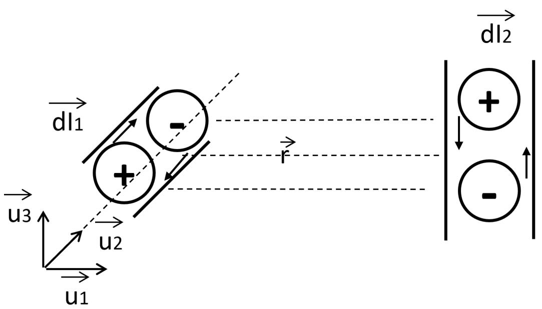

FIGURE 20. Shows the arrangement for the third case of current element interaction with spreading discontinuity charges. The destination current, $\vec{dl_2}$ is at the positive side of $\vec{u_3}$ with a flowing current on the negative $\vec{u_3}$ direction. This charge has a distance vector $\vec{r}$ that is perpendicular to the source current element $\vec{dl_1}$ which has a current flowing on the positive direction of $\vec{u_2}$.

zero. This stays for $dt/2$. Then the wave discontinuity charges produced at t_i^+ are at the center of the destination current element, see figure (21 b). The electric field of discontinuity charges applies a force on the positive and the negative charges around the surface of the destination current element. This force is perpendicular to the movement of the charges. These charges are not permitted to leave the current element, therefore they push the current element in the direction of the forces. These forces have the same amount but in opposite direction, hence the net force applied on the current element is zero. So the total force applied to this current element during dt is zero. The interaction ends when the wave discontinuity charges produced at t_{i+1} enter the vicinity of the current element and the wave discontinuity charges produced at t_i^+ are at the center of the destination element but from the other side, see figure (21 c). Following an analysis similar to the one described for figure (21 a), the net force applied on the current element is zero. This result is fully consistent with the electromagnetic field theory for this case.

b: CASE 2: PARALLEL POSITION VECTOR

For the second basic case when the destination current element has a position vector that is along the source current element direction, the interaction of the spreading discontinuity unit is analyzed for the three main components of the destination current element: (1) $\vec{u_1}$ component where the destination current direction is perpendicular to the source current element and on the same plane, (2) $\vec{u_2}$ component where the destination current direction is parallel to the source current element, and (3) $\vec{u_3}$ component where the destination current direction is perpendicular to the source current element. The analysis of these three cases covers all the possible situations for the destination element that have position vectors along the source current element direction. These destination current elements interact with both the constant unit and the wave unit. The analysis is performed using the constant unit and the wave unit combined together to simplify the discussion.

i) DESTINATION ELEMENT COMPONENT ALONG $\vec{u_1}$

The analysis of the interaction of the wave unit with a destination current element along $\vec{u_1}$, see figure (22), is done as follows. The first effect starts when the destination current element is interacting with the last pair of the discontinuity charges generated at t_{i-1}. The discontinuity charges are at the center of the destination current element, see figure (23 a). The electric field of discontinuity charges applies a force on the positive and negative charges around the surface of the destination current element. This force is perpendicular to the movement of the charges. These charges are not permitted to leave the current element, therefore they push the current element in the direction of the forces. These forces have the same amount but in opposite direction, so the net force applied on the current element is zero. This stays for $dt/2$. Then the discontinuity charges produced at t_i^- are at the center of the destination current element, see figure (23 b). The electric field of discontinuity charges applies a force on the positive and negative charges around the surface of the destination current element. This force is perpendicular to the movement of the charges. These charges are not permitted to leave the current element, therefore they push the current element in the direction of the forces. These forces have the same amount but in opposite directions, hence the net force applied on the current element is zero. So the total force applied to this current element during dt is zero. The interaction ends when

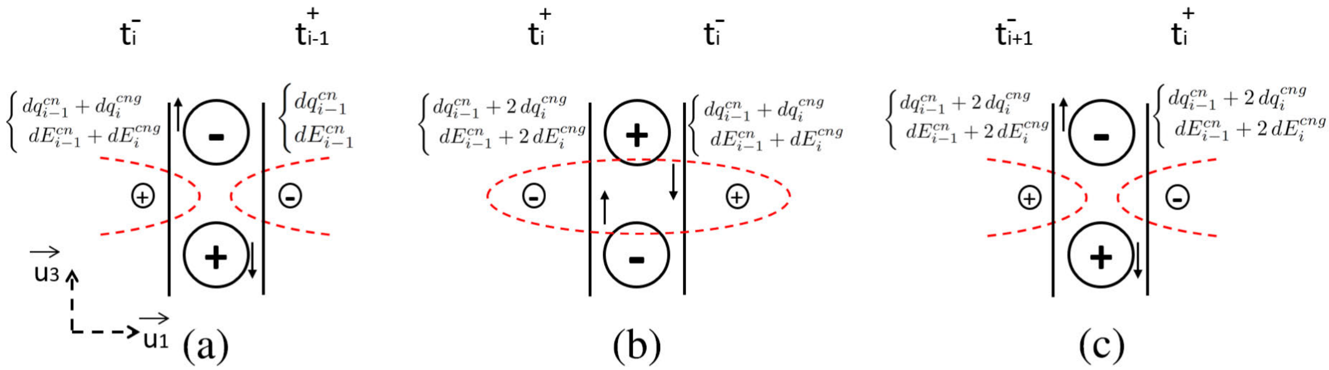

FIGURE 21. Shows the interaction between a destination current element along $\overrightarrow{u_3}$ with a current flowing in the negative direction of $\overrightarrow{u_3}$, and an infinitesimal discontinuity charge unit, includes both constant unit and wave unit, generated at t_i and spreading in the space along $\overrightarrow{u_1}$.

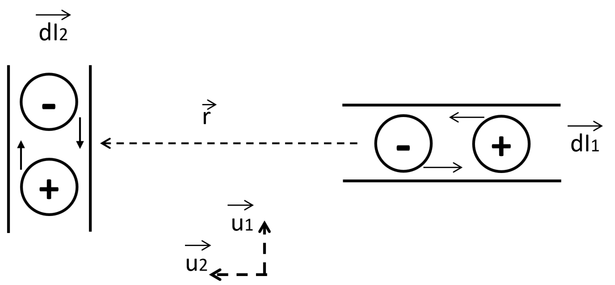

FIGURE 22. Shows the arrangement for the $\overrightarrow{u_1}$ component of the second basic case of current element interaction with spreading discontinuity charges. The destination current, $\overrightarrow{dl_2}$ is at the positive side of $\overrightarrow{u_2}$ with a flowing current on the positive $\overrightarrow{u_1}$ direction. This charge has a distance vector $\overrightarrow{r}$ that is parallel to the source current element $\overrightarrow{dl_1}$ which has a current flowing on the positive direction of $\overrightarrow{u_2}$.

the wave discontinuity charges produced at t_{i+1} enter the vicinity of the current element and the wave discontinuity charges produced at t_i^+ are at the center of the destination element but from the other side, see figure (23 c). Following an analysis similar to the one described for figure (23 a), the net force applied on the current element is zero. This result is fully consistent with the electromagnetic field theory for this case.

ii) DESTINATION ELEMENT COMPONENT ALONG $\overrightarrow{u_2}$

The analysis of the interaction of the wave unit with a destination current element along $\overrightarrow{u_2}$, see figure (24), is done as follows. The first effect starts when the destination current element is interacting with the last pair of the discontinuity charges generated at t_{i-1}. The discontinuity charges surround the charges of the destination current element, see figure (25 a). The electric field of discontinuity charges applies a force on the positive and negative charges around the surface of the destination current element. This force is along the direction of the destination current element where charges are free to move without affecting the current element. Therefore the net force applied to the current element is zero. The forces applied to the charges do not affect the movement of the charges. This can be explained in part by the fact that these forces have been encountered, i.e., canceled, by the repulsive forces between the current charges and the driving force of the current to maintain the uniform distribution of the charges, to maintain the zero net charge of the current element, and to maintain the current value. This stays for $dt/2$. Then the discontinuity charges produced at t_i^- surround the charges of the destination current element, see figure (25 b). The electric field of discontinuity charges applies a force on the positive and negative charges around the surface of the destination current element. This force is along the direction of the current element. The charges are allowed to freely move along that direction without affecting the current element. So the net force applied to the current element is zero. Then the total force applied to this current element during dt is zero. The interaction continues for two more steps when the wave discontinuity charges produced at t_{i+1} enter the vicinity of the current element and until all wave discontinuity charges produced at t_i^+ are outside the vicinity of the destination element. The analysis for the remaining two steps is similar to the one performed for the ones in figure (25 a) and figure (25 b), respectively. For example, the first step of the remaining two steps is shown in figure (25 c). This figure is similar to the one shown in figure (25 a), and the net force applied on the current element in this case is zero. This result is fully consistent with the electromagnetic field theory for this case.

iii) DESTINATION ELEMENT COMPONENT ALONG $\overrightarrow{u_3}$

The analysis of the interaction of the wave unit with a destination current element along $\overrightarrow{u_3}$ is similar to the one performed along $\overrightarrow{u_1}$. The discontinuity charges produced are at the center of the destination current element. The electric field of discontinuity charges applies a force on the positive and negative charges around the surface of the destination current element. This force is perpendicular to the movement of the charges. Therefore they push the current element in the direction of the forces. These forces have the same amount but in opposite direction, hence the net force applied on the current element is zero. So the total force applied to this current element during dt is zero. This result is fully consistent with the electromagnetic field theory for this case.

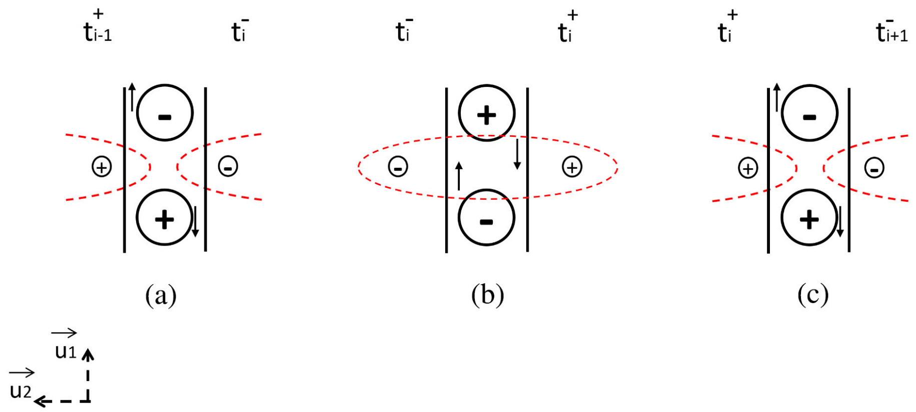

FIGURE 23. Shows the interaction between a destination current element along $\vec{u_1}$ with a current flowing in the negative direction of $\vec{u_1}$, and an infinitesimal discontinuity charge unit, includes both constant unit and wave unit, generated at t_i and spreading in the space along $\vec{u_2}$.

V. DISCUSSION

This section discusses the alignment between wave units and electromagnetic wave properties and phenomena, suggested testing for these units, the existence of magnetic monopoles, and the relationship between the proposed model and Maxwell's equations.

A. ELECTROMAGNETIC PROPERTIES AND PHENOMENA

Wave units have the same properties and effects that are observed in electromagnetic wave fields, for example, the applied forces, the relationship between the amplitudes of the fields of these forces, the relationship between the directions of these fields and the propagation direction, the neutral electric charge, electromagnetic induction, Lenz's law, and compatibility with relativity theory.

Wave units apply forces on charges and current elements that are an exact equivalent to the forces exerted by electromagnetic wave fields, which are known as magnetic field and electric field. The amplitude of the magnetic field is proportional to the amplitude of the electric field by 1/c. That is because the magnetic force is represented in terms of the currents and the magnetic field is defined by removing the term of the destination current element from the force equation, not the term of the destination charge, hence the 1/c factor. The relationship between these fields and the propagation direction of wave units is described by the cross product between $\vec{E}$ and $\vec{B}$, i.e., the propagation direction is equal to $\angle \vec{E} \times \vec{B}$, which is fully consistent with the well-known electromagnetic theory. Wave units have zero net charge enclosed in its vicinity, i.e., the sum of the discontinuity charges forming a wave unit is zero, and this is consistent with the observed property of light photons that they are electrically neutral. Also this is consistent with Maxwell's equations which admit solutions for charges moving at the speed of light if equal amounts of positive and negative charges are present [41]–[43].

Regarding electromagnetic induction, wave units are able to produce a voltage across an electrical conductor because of the none zero net electric field between the discontinuity charges forming them. This electric field makes the free electrons inside the conductor move in a direction opposite to the direction of the electric field. Therefore the charge distribution inside the conductor changes producing an electric field inside it, referred to as an induced electric field. This induced field produces a potential difference between the ends of the conductor, when these ends are connected to form a return path, a current flows inside the conductor. Electromagnetic induction is produced either by varying the magnetic field or by moving the conductor inside the steady magnetic field. A varying magnetic field is produced either by a varying current or by a steady current inside a moving current element. A varying current is produced by accelerating (decelerating) charges to increase (decrease) the flowing current. These changes in the speed of the charges produce wave units that are formed by discontinuity charges in a special arrangement. The last generated discontinuity charges have a stronger (weaker) electric field compared to the first generated discontinuity charges. This produces a net electric field and virtual magnetic field the inside wave unit vicinity as described in equations (30 and 33), respectively. These fields interact with the charges inside the conductor producing the observed induction effect.

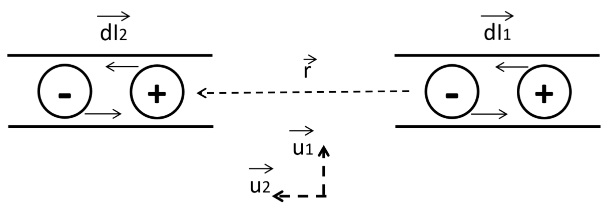

FIGURE 24. Shows the arrangement for the $\vec{u_2}$ component of the second basic case of current element interaction with spreading discontinuity charges. The destination current, $\vec{dl_2}$ is at the positive side of $\vec{u_2}$ with a flowing current on the positive direction of $\vec{u_2}$. This charge has a distance vector $\vec{r}$ that is parallel to the source current element $\vec{dl_1}$ which has a current flowing on the positive direction of $\vec{u_2}$, too.

A steady current flowing inside a moving current element is able to produce the electromagnetic induction. When a

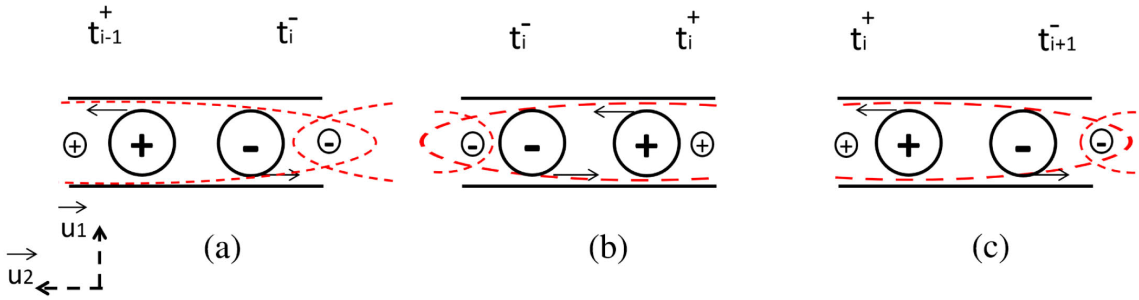

FIGURE 25. Shows the interaction between a destination current element along $\vec{u_2}$ with a current flowing in the positive direction of $\vec{u_2}$, and an infinitesimal discontinuity charge unit, includes both constant unit and wave unit, generated at t_i and spreading in the space along $\vec{u_2}$. Intersecting dashed lines show discontinuity charges that have overlap between the start and end of two consecutive moments due to the locations of current charges inside the source element as described in the analysis for figure (9).

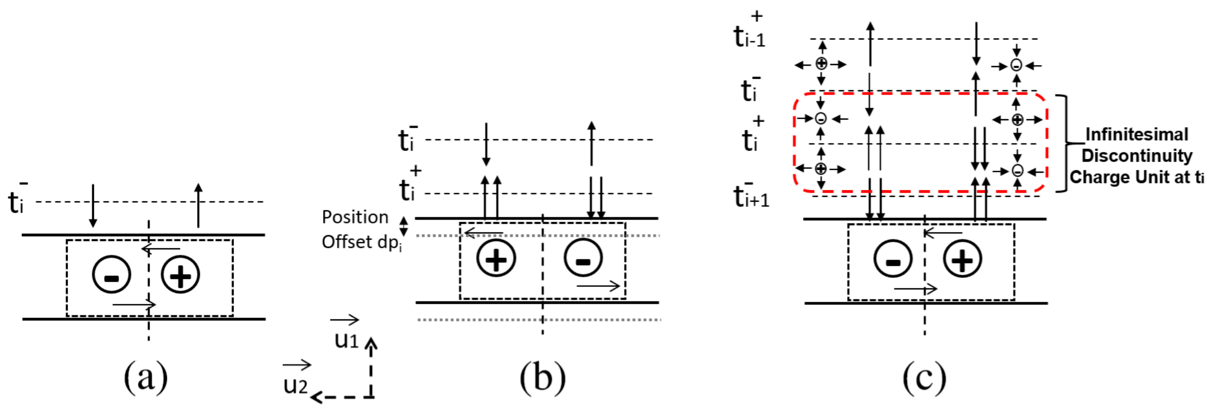

FIGURE 26. Shows the infinitesimal discontinuity charge unit and the spreading electric field generated at t_i due to the movement of a current element along $\vec{u_1}$ with current flowing on the positive direction of $\vec{u_2}$. The flowing current is steady and the current element moves a distance dp_i along the $\vec{u_1}$.

source current element is moving closer to a destination element during t_i, the source element is closer to the destination element at t_i^+ than it is at t_i^-, see figure (26). This indicates the electric field is strong at t_i^+ than it is at t_i^-. So the last generated pair has a stronger electric field than the first generated pair. While if the source element is moving away from the destination element. the source element is further to the destination element at t_i^+ than it is at t_i^-. This indicates the electric field is weaker at t_i^+ than it is at t_i^-. So the last pair has a weaker electric field than the first pair. Hence the electromagnetic induction. For the case of moving a conductor inside a steady magnetic field, the conductor is viewed as a collection of free electrons. When the conductor moves, all these electrons move in the same direction, therefore this case is considered an interaction problem between moving charges and magnetic field [26].

Regarding Lenz's law, the direction of the induced current generated in a circuit interacting with wave units depends on which pair of the discontinuity charges is stronger: the first pair or the last pair. If the first pair has a stronger electric field, the net electric field in the wave unit is in the direction of the electric field in the source element, so the induced current has the same direction of source element's current. That is because the first pair is generated when the current charges enter the vicinity around the surface of the source element. In this case, the positive charge at the starting side of the electric field in the source element while the negative charge is at the end side of the electric field. But the first pair is an image reflecting the state of the charges inside the source element, so the electric field between the discontinuity charges in this pair is similar to the one found in the source element at this state. If the last pair has a stronger electric field, the net electric field in the wave unit is opposite to the direction of the electric field in the source element, so the induced current has the opposite direction of the source element's current. That is because the last pair is generated when the current charges have switched their positions around the surface of the source element. In this case, the positive charge is at the end side of the electric field inside the source element, while the negative charge is at the start side of the field, hence the electric field is between the discontinuity charges in this pair is opposite to the one found in the source element at this state.

The first pair is stronger than the last pair when the source current is decreasing, charges are decelerating, or the source element is getting further. In this case, the magnetic field is getting weaker at the destination element, and the direction of the induced current is in the direction the source current. Hence it appears as if the conductor is generating current in a direction to strengthen the magnetic field that is getting weaker inside it. The last pair is stronger than the first pair when the source current is increasing, charges are accelerating, or the source element is getting closer. In this case, the magnetic field is getting stronger at the destination element, and the direction of the induced current is opposite to the direction of the source current. Hence it appears as if the conductor is generating current in a direction to resists the magnetic field that is getting stronger inside it. This behavior is known as Lenz's law.

Wave units are fully compatible with relativity theory. Regardless of the observation frame, accelerating/decelerating charges in that frame produce changes in the electric field spreading in the space. These changes produce wave units that contain discontinuity charges with a special spatial arrangement. This arrangement allows wave units to simultaneously exert both: an electric field, which applies a force that is independent of the velocity of the charge experiencing it, and a magnetic-like field, which applies a force that is dependent on the velocity of the charge experiencing it. Therefore, these wave units are compatible with the relativity theory and relativistic invariant as specified in [44], [45].

Wave units model that contains discontinuity charges shows how the electric force and the magnetic-like force are simultaneously applied when a change is observed in one of the fields, i.e., the electric field or the magnetic field. An observed change in either field indicates a change in the source element generating this field, either in the speed of the charges generating the current, e.g., varying current, or in the position of the current element, e.g., a magnet approaching a coil. Such a change produces wave units that exert both the electric force and the magnetic force corresponding to this change as described in section (IV). Notice that magnets contain electrical currents at the atomic level generated by the movement of the electric charges and their spinning inside the atom, mainly electrons [46], [47]. Therefore, the principles of the EOMF theory apply to magnets. So, these wave units and associated explanations are consistent with Tesla experiments [48].

Wave units spreading in the space, see figure (27), is the result of applying the electric origin of magnetic forces theory on accelerating charges and changing currents. This theory explains the existence of magnetic forces and facilitates the derivation of their empirical laws that have been obtained through experiments.

B. TESTING WAVE UNITS MODEL

Testing this model may require splitting wave units to their discontinuity charges. Notice that those wave units, which are electromagnetic radiation, form photons, which are discrete quantities of electromagnetic radiation energy. If wave units have a chance to split such that the positive discontinuity charges are separated from the negative ones, it is possible to generate charged photons or charged particles of equally positive and negative charges depending on the behavior of the discontinuity charges after separation. The latter one has been observed in experiments when photons of high energy are temporarily split into electrons and positrons when they pass near the nucleus [49]–[55]. This splitting process is referred to as pair production. Because there is no source for these charges other than the photons involved in the splitting process, this may indicate that these charges have been embedded inside the photons. Having embedded charges inside the photons is in alignment with the proposed electric model for wave units, which include discontinuity charges. The pair production process and the existence of electron and positron due to photon interactions cannot be explained using the current model for electromagnetic waves, which considers photons as electrically neutral black boxes that exert electric field and magnetic field. Therefore, the proposed model is a step forward toward modeling the physical reality of photons, and better understanding the deeper physical process behind their electromagnetic wave interactions. Designing an experiment for this test is not part of this work and it is better suited for future research.

C. ON THE EXISTENCE OF MAGNETIC MONOPOLES

The concept of magnetic charges has been introduced due to the lack of an apparent source for magnetic fields generated by electrically neutral wires with flowing currents. These magnetic charges are assumed to be the source of the magnetic fields. According to this assumption, the existence of magnetic charges indicates that magnetic field lines should have a start and an end, and these lines do not form a closed loop. This assumption opposes Maxwell's equations and Gauss law which mathematically prove that magnetic field lines form closed loops and there are no isolated magnetic charges. Therefore, efforts have been made to modify Maxwell's equations to include terms for magnetic charges. But no natural magnetic charges have ever been identified to prove their existence [56]–[58], [58]–[61]. However, this assumption has not been ignored since there is no theoretical framework that is available to deny it, and there is no apparent source for magnetic fields. This issue is going to be resolved once the source of magnetic fields is identified, and this is the goal of the EOMF theory.

Magnetic fields are found in two cases: in static fields around constant currents, and in electromagnetic waves produced by changing currents. For static fields, the EOMF theory shows that the source of the magnetic-like field around constant currents is the discontinuity charges spreading in the space to indicate the changes in the position of the moving charges generating the source currents as described in [25], [26]. The work in [26] shows that the distribution of the discontinuity charges around the source forms closed loop magnetic-like field lines with no start and end, so the divergence of the magnetic flux is always zero. While for electromagnetic waves, the EOMF theory shows that the source of the magnetic-like field is the discontinuity charges in the

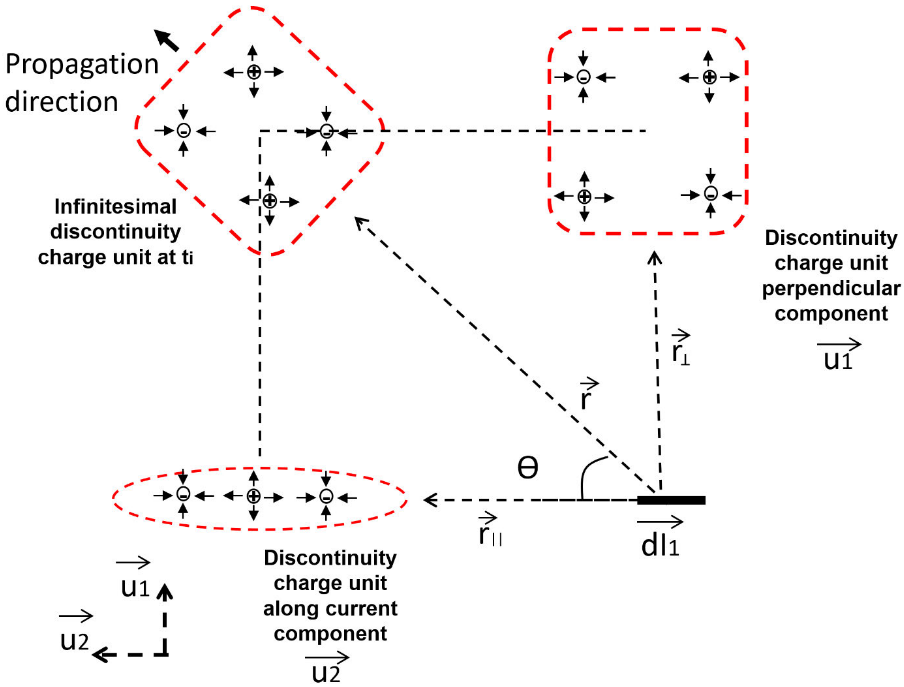

FIGURE 27. Shows spreading wave unit in one plane at arbitrary position and angle, with orthonormal components along $\vec{u_1}$ and $\vec{u_2}$.

wave units spreading in the space to indicate the changes in speed and position of the moving charges generating the source changing currents as described in this work. So the EOMF theory provides the needed theoretical framework to deny the need for magnetic charges to explain the source of magnetic fields. This may help in resolving the confusion about the existence of magnetic monopoles.

D. RELATIONSHIP WITH MAXWELL's EQUATIONS

This work and Maxwell's equations are completing each other. Maxwell's equations are a mathematical formulation of the empirical laws that govern all the experimental observations of the electric and magnetic effects of currents and electric charges. These equations do not specify the nature of the electric force and the magnetic force. Maxwell was assuming these two forces as two different interdependent phenomena, but his equations are successful in predicting the observed forces of well-designed experiments regardless of the nature of these forces. This assumption was considered because electrically neutral wires with flowing currents are able to generate magnetic fields, and the origin of magnetism was unknown.

On the other hand, this work and the Electric Origin of the Magnetic Force (EOMF) theory address the origin of the magnetic force. The EOMF theory explains the origin of the magnetic force as a consequence of purely electric interaction between the current charges and the surrounding discontinuity charges spreading in the space reflecting the changes in positions and speed of the source current charges. By quantifying the force generated by this interaction, it is found to be an exact equivalent to the magnetic force computed using Maxwell's equations and consistent with the well-known electromagnetic theory, hence the validity of this explanation and EOMF theory.

The EOMF theory has been developed using electric field concepts and laws only, such as Gauss's law and Columb's law. This development depends on two facts: (1) the fact that changes in the electric field travel at the speed of light, which has been obtained from Maxwell's equations and the experimental work of Ampere and Faraday, and (2) the fact that no energy can travel faster than the speed of light from Einstein's work. If these two facts and this theory had been available before the date of Oersted's discovery, the fundamental magnetic field properties, laws, relationship to a varying electric field, and the existence of electromagnetic waves would have been predicted on a theoretical basis as a direct consequence of the fundamental laws of electricity. All these predictions have been confirmed by the experimental work of Ampere, Biot-Savart, Faraday, Maxwell, and Hertz.

VI. CONCLUSION

This paper presented the first electric model for the electromagnetic wave fields, i.e., the electric field and the magnetic field, that is fully consistent with the electromagnetic theory. This model represents these fields by electric field components only. These components have a specific spatial arrangement that is responsible for exerting both the magnetic force and the electric force applied by the electromagnetic waves. The model has been built based on the analysis of the changes in the electric field spreading in the space due to the changes of position and speed of the charges generating the source currents. The analysis shows that these changes in the electric field contain discontinuity points to reflect the changes in positions of these charges. These discontinuity points contain electric charges as indicated by Gauss's law. These electric charges are referred to as discontinuity charges. These discontinuity charges electrically interact with the moving charges inside current elements and with static charges. This interaction produces forces on destination elements that are equivalent in magnitude and direction to the observed electric force and magnetic force exerted by electromagnetic waves. The relationship between these forces has been analyzed to obtain the formulas that describe them. These formulas are found to be exactly equivalent to the well-known Maxwell's equations.

This work lies in the intersection between physics and electrical engineering. The proposed model with the electric origin of magnetic forces theory provide the theoretical framework needed to explain electromagnetic fundamentals and its empirical laws, which could not be explained by previous theories. This theoretical framework may help scientists in resolving controversial problems that have not been solved yet, e.g., the existence of magnetic monopoles. Moreover, the proposed model is a step forward toward modeling the physical reality of photons, and better understanding the deeper physical process behind their electromagnetic wave interactions, e.g., pair production. Pair production is a direct conversion of radiant energy to matter. Better understanding this process may help scientists in controlling this conversion. Controlling this conversion between matter and energy is going to open the door for future applications that allow creating materials from energy, and transporting objects at high speed by converting them to energy, then converting that energy back to matter in a controlled environment.

Further research is required to investigate and to understand the nature of the electric force, the nature of the electric charge, and the effect of charge movements in the space. This investigation may need to be conducted in connection with other explorations to the nature of the other fundamental forces within a unified framework, e.g., string theory. Such understanding may help scientists and engineers in making advancements to the technology and applications of electromagnetism and electromagnetic materials.

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