Unified Electromagnetic Theory of Matter and Light

Section B — **Structure of Light**

Part B1 - **Physical Structure of the Electromagnetic Wave**

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Abstract

This paper introduces a conceptual three-dimensional model of an electromagnetic wave as a continuous, periodically evolving physical structure. The model considers an approximately annular organization of the electric and magnetic fields and examines their transformation through an intermediate electromagnetic configuration associated with Maxwell's displacement current.

The electric field E, magnetic field B, and displacement current J_D are treated as coupled aspects of one evolving electromagnetic structure. The intermediate configuration is proposed to maintain continuity between successive phases of the wave and to participate in the redistribution of electromagnetic energy along the direction of propagation.

The model considers radial energy transport governed by the phase relationship between the longitudinal electric field E_z and the circumferential magnetic field. It proposes a characteristic longitudinal-field value E_{z0} at which the period-averaged Poynting vector is axial: configurations below or above this reference value are contract or expand, respectively.

The present paper does not attempt to complete the quantitative development of this structure. Its principal purpose is to establish the geometrical, energetic, and dynamical framework of the electromagnetic-wave model.

Part B2 develops energy-dependent transverse size, coherent merging, radius growth, and energy changes during propagation. Part B3 investigates local interaction with bound electrons and the photoelectric effect, offering quantitative tests of the proposed field configuration.

Part B1 therefore serves as the conceptual foundation for the later structural and interaction-based development of the model. Its remaining fundamental open problem is the construction of a complete three-dimensional electromagnetic field solution that reproduces the proposed geometry, energy transport, and transverse stability within the full Maxwell and momentum-balance framework.

1. Introduction

Part A1 describes electromagnetic tori, in which the electric and magnetic fields oscillate with a phase shift of $\pi/2$. In Part B1, attention turns to electromagnetic waves, where the electric and magnetic fields oscillate synchronously and propagate as a continuous structure.

Electromagnetic waves are conventionally described by Maxwell's equations, which

determine the relationships between electric and magnetic fields and their propagation through space. The familiar sinusoidal representation describes the variation of these fields with position and time. It does not, however, by itself specify the complete three-dimensional organization of a spatially localized electromagnetic wave.

The present paper investigates the possibility that an electromagnetic wave possesses a continuous internal structure characterized by a transverse distribution of electric and magnetic fields. The proposed model considers an approximately annular field configuration whose internal geometry evolves periodically during propagation. Its longitudinal periodicity is determined by the wavelength λ, while its transverse organization is described by characteristic geometrical dimensions.

The electromagnetic wave is treated as one continuous structure rather than as a sequence of independent electromagnetic objects. Successive half-wavelength regions represent different phases of the same evolving electromagnetic process. This distinction is important because electromagnetic energy and transverse organization must remain continuous as the field configuration changes during propagation.

A central role in the proposed description is assigned to Maxwell's displacement current,

$$J_D = \varepsilon_0 \frac{\partial E}{\partial t}.$$

For a sinusoidally varying electric field, the displacement current is shifted by one quarter of a period relative to the electric field. The model examines whether this relationship can support a periodic transformation between the approximately annular field configuration and an intermediate electromagnetic configuration associated with displacement current and its accompanying magnetic field.

The intermediate configuration is proposed to maintain electromagnetic continuity between successive phases of the wave. Its contribution is not treated as an additional form of energy independent of the electric and magnetic fields. Rather, it represents a complementary electromagnetic configuration through which energy may be redistributed while the complete electromagnetic energy remains conserved.

The transverse dimensions are hypothesized to be regulated by the phase relation between E_z and B. The model introduces E_{z0} as a proposed common reference field level corresponding to vanishing average radial Poynting flux; the assumed departures Ez < Ez0 and Ez > Ez0 are associated with contraction and expansion, respectively.

At the proposed equilibrium Ez = Ez0, the Poynting vector is directed, on average, along the propagation axis. Different wave energies may then correspond to different transverse radii without requiring proportional growth of the characteristic transverse electric and magnetic amplitudes.

The present paper is intended primarily as the conceptual foundation of this electromagnetic-wave model. It develops the proposed three-dimensional geometry, electromagnetic continuity, periodic transformation through the displacement-current configuration, energy redistribution, and the basic idea of transverse regulation.

Part B2 examines energy-dependent transverse size, coherent merging, growth of the characteristic transverse radius, redistribution of energy, and changes in wave energy and geometry.

Part B3 then examines the local interaction of the electromagnetic wave with bound electrons. In particular, it applies the model to the photoelectric effect and uses the electron-ejection process to constrain characteristic field amplitudes, local interaction dimensions, and the relationship between total wave energy and locally transferred energy.

The purpose of Part B1 is therefore not to determine all characteristic parameters independently. Its role is to establish the physical picture within which the later quantitative and interaction-based developments can be formulated.

The proposed interpretation does not modify Maxwell's equations. Rather, it investigates whether a continuous, spatially organized electromagnetic wave can be described through their coupled field dynamics together with the proposed transverse structural mechanism. Some questions introduced here are developed in Parts V and VI, while a more fundamental problem remains open: the construction of a complete three-dimensional electromagnetic field solution that reproduces the proposed geometry, energy transport, and transverse stability within the full Maxwell and electromagnetic momentum-balance framework.

2. Three-Dimensional Structure of the Electromagnetic Wave

Maxwell's equations describe the spatial and temporal relationships between electric and magnetic fields. They determine how electromagnetic disturbances propagate, but they do not prescribe a unique transverse geometry for every possible field configuration. The present model therefore investigates whether an electromagnetic wave can possess a continuous, approximately annular internal structure.

The proposed structure is characterized by three geometrical quantities: the wavelength λ which determines the longitudinal periodicity; the characteristic transverse radius R; and the radial thickness a, which describes the region of concentrated electromagnetic energy.

These quantities represent different properties of the wave. In particular, the model does not assume that the transverse radius is proportional to the wavelength.

2.1. Annular Organization of the Electric and Magnetic Fields

The proposed electromagnetic wave contains a continuous region of concentrated electric and magnetic fields surrounding its propagation axis.

The electric field is predominantly radial, while the magnetic field follows a closed circumferential configuration. The radial and longitudinal components of the electric field and the circumferential magnetic field can be expressed as

$$\vec{E} = E_r\overrightarrow{e_r} + E_z\overrightarrow{e_z}$$

$$\vec{B} = B_\varphi\overrightarrow{e_\varphi}$$

Their spatial distributions are coupled through Maxwell's equations and evolve continuously during propagation.

The absence of magnetic monopoles requires

$$\nabla \cdot \vec{B} = 0$$

This condition is compatible with the proposed circumferential magnetic-field configuration.

The predominantly radial organization of the electric field, however, requires additional consideration. In the absence of electric charges, Gauss's law does not permit an arbitrary divergence of the electric field. In a linear vacuum, the corresponding condition in cylindrical coordinates is

$$\frac{1}{r}\frac{\partial(rE_r)}{\partial r} + \frac{\partial E_z}{\partial z} = 0$$

A longitudinal electric-field component is therefore required to compensate for the radial divergence of the proposed electric-field distribution.

The present model introduces a proposed characteristic amplitude Ez0 for the longitudinal electric field. It is hypothesized that the phase correlation between E_z and B changes sign as the selected field measure crosses Ez0, providing inward, axial, or outward average radial energy transport.

The longitudinal electric field follows from the field geometry and Maxwell constraints. Its relative phase with the magnetic field is the quantity that controls the average radial energy flow; the assumed reference value Ez0 specifies a proposed equilibrium within this model.

The significance of this longitudinal component extends beyond the divergence condition. Together with the circumferential magnetic field, it determines the radial component of the Poynting vector and thus participates in the transverse redistribution of electromagnetic energy.

The electric and magnetic fields need not have identical radial distributions. Their different positions, widths, and gradients influence the longitudinal field. The additional hypothesis is that a characteristic field condition Ez = Ez0 is accompanied by zero in-phase correlation between Ez and B.

The resulting inward or outward redistribution of electromagnetic energy, together with the return displacement-current distribution, is proposed to establish a relatively sharp electromagnetic transition between the wave and its surroundings.

This transition is not a material boundary. It represents a possible self-organized electromagnetic boundary whose guiding function is analogous to that of a conventional waveguide.

The following sections present this proposed regulating condition. Its physical origin, the claimed universality of Ez0, and a complete three-dimensional field solution remain open.

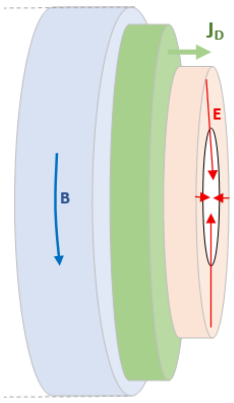


Figure 1. Schematic representation of the proposed transverse electromagnetic structure. The predominantly radial electric field is surrounded by a circumferential magnetic field. The intermediate configuration associated with displacement current is indicated schematically. The longitudinal electric-field component, required by the complete electromagnetic field geometry, is not explicitly shown. The boundaries represent characteristic field regions rather than material surfaces.

2.2. Longitudinal and Transverse Dimensions

The wave propagates along its longitudinal axis, denoted by z.

Its periodicity is characterized by the wavelength λ. Within this continuous structure, successive regions of length λ/2 correspond to successive electromagnetic half-periods.

The characteristic transverse radius R describes the position of the concentrated annular field region. Its radial thickness is denoted by a.

The two transverse parameters should not be confused:

- R specifies the characteristic distance of the annular structure from the propagation axis.

- a describes the radial width over which its electromagnetic energy is concentrated.

Because electromagnetic fields have continuous spatial distributions, neither parameter represents a rigid material boundary.

For a relatively narrow annular region, an approximate effective volume over one full wavelength may be written as

$$V_{\text{eff}} \approx 2\pi \text{Ra}\lambda$$

This geometrical expression provides a useful estimate but does not replace integration over the actual electromagnetic energy-density profile.

The longitudinal and transverse scales are therefore treated as distinct characteristics of the proposed wave structure. The wavelength determines the spatial period of oscillation, while the transverse dimensions describe the organization of electromagnetic energy around the propagation axis.

2.3. Continuous Structure Along the Propagation Axis

The proposed electromagnetic wave is not regarded as a succession of independent toroidal objects.

Instead, its internal configuration changes continuously along the direction of propagation. Successive half-wavelength regions represent different phases of one connected electromagnetic process.

This distinction is particularly important at transitions between adjacent half-periods.

A reduction in the electric or magnetic contribution associated with one geometrical configuration does not necessarily imply a disappearance of the complete electromagnetic structure. The model proposes that energy is periodically redistributed into an intermediate configuration associated with displacement current.

Consequently, the transverse organization of the wave need not be reconstructed independently at the beginning of each half-period.

The proposed intermediate configuration and its role in maintaining energy continuity are examined in Sections 4–6.

2.4. Electromagnetic Energy Transport

The direction and magnitude of electromagnetic energy transport are described by the Poynting vector:

$$\vec{S} = \vec{E} \times \vec{H}$$

For the proposed electromagnetic structure, retaining the conventional magnetic constitutive relationship, this expression becomes

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$$

As introduced in Section 2.1, the electric field contains both radial and longitudinal components, while the magnetic field is predominantly circumferential.

$$\vec{E} = E_r\overrightarrow{e_r} + E_z\overrightarrow{e_z}$$

$$\vec{B} = B_\varphi\overrightarrow{e_\varphi}$$

The corresponding Poynting vector contains two components:

$$\vec{S} = S_r\overrightarrow{e_r} + S_z\overrightarrow{e_z}$$

The longitudinal component is determined by the radial electric field:

$$S_z = \frac{E_r B_\varphi}{\mu_0}$$

The radial component is determined by the longitudinal electric field:

$$S_r = -\frac{E_z B_\varphi}{\mu_0}$$

Their ratio determines the instantaneous inclination of electromagnetic energy transport relative to the propagation axis:

$$\frac{S_r}{S_z} = -\frac{E_z}{E_r}$$

If the longitudinal component of the Poynting vector is positive, the inclination angle is given by

$$\tan \alpha = -\frac{E_z}{E_r}$$

Consequently, even a relatively small longitudinal electric-field component can significantly influence the direction of electromagnetic energy transport.

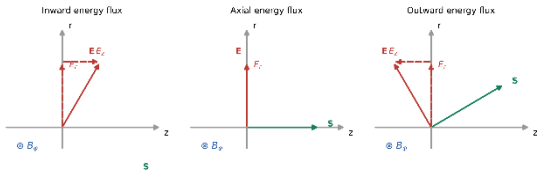


Figure 2. Geometrical relationship between the electric field and the Poynting vector. The longitudinal electric-field component modifies the direction of electromagnetic energy transport, producing an inward, axial, or outward radial orientation.

The longitudinal component is constrained by the electromagnetic field geometry. Its phase relative to the magnetic field, rather than its amplitude alone, determines the direction of the average radial energy transport.

2.5. Phase Relationship and Average Energy Transport

The instantaneous radial component of the Poynting vector does not necessarily determine the long-term transverse evolution of the electromagnetic wave. For this purpose, the energy flux averaged over an oscillation period must be considered.

For an illustrative harmonic field configuration, let

$$B_\varphi = B_a \cos \theta$$

$$E_r = A \cos \theta$$

The longitudinal electric field can be separated into two phase components:

$$E_z = H \sin \theta + G \cos \theta$$

The component H is in quadrature with the magnetic field, while the component G is in phase or antiphase with it, depending on its sign.

Averaging the Poynting vector over one complete period gives

$$\langle S_z \rangle = \frac{AB_a}{2\mu_0}$$

$$\langle S_r \rangle = -\frac{GB_a}{2\mu_0}$$

The inclination of the average electromagnetic energy flux is consequently determined by

$$\tan \bar{\alpha} = -\frac{G}{A}$$

The quadrature component H produces periodic radial energy redistribution but does not contribute to the average radial energy flux in this harmonic representation.

The in-phase component G, however, determines whether electromagnetic energy is preferentially transported toward or away from the propagation axis.

2.6. Radial Regulation of the Electromagnetic Wave

The proposed equilibrium condition is defined by a characteristic longitudinal electric-field measure Ez0. The model hypothesizes that crossing this value changes the sign of the in-phase component of Ez relative to B and therefore the direction of average radial energy transport.

Three characteristic configurations are distinguished as working hypotheses.

For Ez < Ez0, the in-phase field correlation is producing a small inward average radial Poynting flux and a tendency toward transverse contraction.

For Ez = Ez0, the in-phase correlation is assumed to vanish. Average radial energy flow is then zero, although the quadrature component of Ez may remain nonzero.

For Ez > Ez0, the in-phase correlation is hypothesized to reverse sign, yielding outward average radial energy flow and a tendency toward transverse expansion.

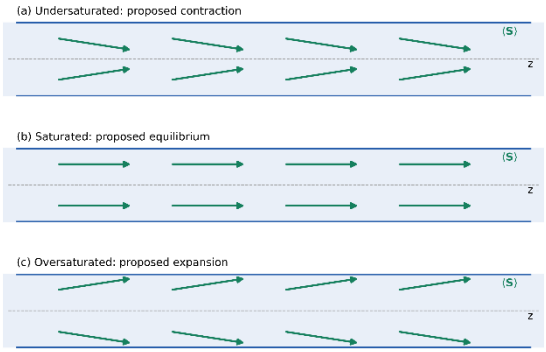


***Figure 3**. Proposed orientation of the average Poynting vector in the three hypothesized states Ez < Ez0, Ez = Ez0, and Ez > Ez0. The inward, axial, and outward directions illustrate the assumed transverse feedback around the reference state.*

In combination with the return displacement-current distribution, this mechanism is proposed to contribute to the formation of a relatively sharp electromagnetic transition between the wave and its surroundings.

The following chapter develops the consequences of this mechanism for the transverse equilibrium and energy-dependent radius of the electromagnetic wave.

2.7. Electromagnetic Energy and Field Geometry

The electromagnetic energy density in vacuum is given by

$$u_{\mathrm{EM}} = \frac{\varepsilon_0 E^2}{2} + \frac{B^2}{2\mu_0}$$

The total energy within a selected region of the electromagnetic wave is obtained by integrating this density over the corresponding volume.

For a spatially localized field configuration, the result depends on both the field amplitudes and their three-dimensional distributions.

Consequently, two waves with comparable characteristic electric and magnetic amplitudes may contain different amounts of energy if their transverse dimensions differ.

Different energies may correspond to different transverse radii if the proposed equilibrium preserves approximately comparable characteristic field magnitudes. This does not follow from the energy integral alone.

However, the existence of such a family of dynamically stable configurations is not established by the energy equation alone.

It requires a mechanism capable of maintaining the corresponding transverse field organization.

2.8. Geometrical Interpretation and Its Limits

The annular representation offers a possible three-dimensional interpretation of the internal organization of an electromagnetic wave. It provides a geometrical framework for examining energy transport, displacement-current dynamics, and the possible regulation of transverse dimensions.

It does not, however, follow uniquely from Maxwell's equations.

A complete physical description must establish electric and magnetic field distributions that satisfy the full Maxwell equations, conserve electromagnetic energy and momentum, and reproduce the proposed continuous propagation.

The present chapter therefore defines the geometrical framework of the model. The following chapter examines the hypothetical mechanism through which the transverse structure might become dynamically regulated. [1], [2], [7]

3. Dynamic Equilibrium and Transverse Geometry

The proposed electromagnetic wave possesses a continuous transverse field structure characterized by a radius R and an effective radial width a. Its transverse dimensions are hypothesized to be dynamically regulated by the direction of electromagnetic energy transport.

The proposed regulation is based on the longitudinal-field reference Ez0 and the corresponding assumed sign change of the in-phase Ez–B correlation. The associated radial Poynting flux is hypothesized to provide a restoring tendency.

The mechanism is complemented by a return displacement-current distribution, which contributes to the radial limitation of the magnetic field.

Together, these processes provide the conceptual basis for a self-organized electromagnetic structure capable of adjusting its transverse dimensions to its energy content.

3.1. Radial Organization and the Longitudinal-Field Reference

The radial electric field and the circumferential magnetic field occupy different but mutually coupled regions surrounding the propagation axis.

The radial component of the electric field vanishes at the propagation axis due to cylindrical symmetry. Its magnitude increases with radial distance, reaches a characteristic maximum, and subsequently decreases toward the outer electromagnetic boundary.

The model does not require a strict saturation limit of the radial electric field. Instead, it introduces the hypothesis that a characteristic measure of the longitudinal field reaches Ez0 when its in-phase correlation with the magnetic field vanishes.

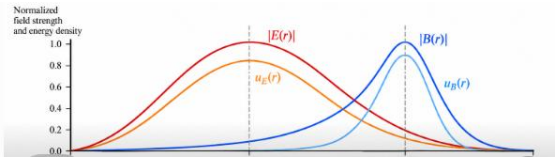


Figure 4. Conceptual radial distributions of the electric and magnetic fields. Their differing widths and gradients influence the longitudinal component Ez; a proposed phase relationship defines the equilibrium reference Ez0. The profiles are schematic.

The longitudinal electric field is constrained by the divergence condition and by the actual coupled field geometry. The proposed Ez0 reference concerns its phase correlation with B, what is in correlation with nonlinear contribution to Gauss's law.

The magnetic field reaches its characteristic maximum farther from the propagation axis. Its radial distribution is coupled to the electric field and to the associated displacement-current distribution.

As established in Section 2.4, the longitudinal electric-field component determines the radial component of the Poynting vector:

$$S_r = -\frac{E_z B_\varphi}{\mu_0}$$

The longitudinal energy flux is determined by

$$S_z = \frac{E_r B_\varphi}{\mu_0}$$

The instantaneous direction of electromagnetic energy transport is consequently given by

$$\frac{S_r}{S_z} = -\frac{E_z}{E_r}$$

Depending on the magnitude and phase of the longitudinal electric-field component, electromagnetic energy may be transported preferentially toward or away from the propagation axis.

The present model hypothesizes that the radial organization of the complete coupled fields

determines how the Ez–B correlation changes as the transverse geometry changes.

In the outer region, the return displacement current contributes to the radial limitation of the magnetic field. The combined action of these mechanisms is proposed to establish a relatively sharp electromagnetic transition between the wave and its surroundings.

3.2. Contraction when E_z < E_z0

Consider a wave whose characteristic longitudinal-field measure is below the proposed equilibrium reference Ez0.

The contraction hypothesis is expressed by the condition:

$$\boldsymbol{E_z < E_z0}$$

For this state, the model hypothesizes a small inward component of the average Poynting vector:

$$\langle S_r \rangle < 0$$

Electromagnetic energy is therefore preferentially transported toward the inner region of the wave while continuing to propagate predominantly along the longitudinal axis.

If the total energy remains approximately constant, the reduction of the transverse dimensions increases the electromagnetic energy density and the characteristic field amplitudes.

For geometrically similar field configurations, the total energy contained within one wavelength may be approximated by

W_\lambda\approx C\varepsilon_0E_0^2R^2\lambda

where C is a dimensionless coefficient describing the transverse and longitudinal field distributions.

This approximation assumes comparable transverse profiles and a nearly constant relative radial width. It is a geometrical energy relation and does not establish the existence of the proposed equilibrium.

At constant energy and wavelength, it gives

$$E_0 R \approx \text{constant}$$

The proposed inward energy redistribution may move the configuration toward Ez = Ez0, if the required phase-feedback law exists.

3.3. The E_z0 Reference and Radial Equilibrium

The proposed equilibrium is defined by the characteristic longitudinal-field measure Ez0.

At Ez = Ez0, the model assumes that the part of Ez correlated in phase with the circumferential magnetic field is zero.

This condition makes the period-averaged radial Poynting component vanish. A nonzero quadrature component of Ez remains compatible with equilibrium.

The equilibrium reference is denoted by

Ez = Ez0

A quantitative model must specify how changing the longitudinal-field measure modifies the in-phase correlation G between Ez and B.

At the proposed equilibrium the defining transport condition is:

$$\langle S_r \rangle = 0$$

while longitudinal energy transport remains present:

$$\langle S_z \rangle > 0$$

The average Poynting vector is then predominantly axial; this is a statement about average flux, not the absence of instantaneous radial exchange.

The longitudinal electric field itself does not necessarily disappear. As explained in Section 2.4, its quadrature component may remain present and participate in periodic internal

energy redistribution without producing a net radial energy flux.

The proposed state is dynamically organized and permits internal periodic redistribution of electromagnetic energy.

The universality and numerical value of Ez0, and any associated common transverse amplitudes, remain hypothetical and require quantitative derivation and independent tests.

3.4. Expansion when Ez > Ez0

Suppose that a wave receives additional energy while its transverse geometry is initially unchanged, raising the proposed characteristic longitudinal-field measure above Ez0.

The model hypothesizes that the in-phase Ez–B correlation then changes sign and produces outward average radial energy transport. This is not a consequence of amplitude growth alone.

The ensuing redistribution may increase the effective radius, lower the characteristic field concentration, and return the wave toward the reference condition Ez = Ez0.

The average Poynting vector is then hypothesized to acquire an outward radial component:

$$\langle S_r \rangle > 0$$

Electromagnetic energy is preferentially transported toward larger radii.

This redistribution provides a possible mechanism for increasing the transverse dimensions of the electromagnetic wave without requiring a proportional increase in its characteristic field amplitudes.

As the effective radius increases, the additional energy is distributed over a wider region; the proposed restoring trend ends when the equilibrium condition is recovered.

The three conceptual states may therefore be summarized by the table below.

Field condition	Average radial energy transport	Proposed geometrical response
E_z < E_z0	Inward	Contraction
E_z = E_z0	Zero	Constant radius
E_z > E_z0	Outward	Expansion

Table 1*. Three hypothesized transverse states relative to Ez0.*

The reference Ez0 denotes a proposed longitudinal-field threshold for the sign change of the in-phase Ez–B correlation, not a universal maximum allowed by Maxwell's equations.

The three-state correspondence is the central working hypothesis of the transverse regulation model; it is not yet deduced from an independent field equation.

3.5. Energy-Dependent Equilibrium Radius

The proposed Ez0 condition does not prescribe one universal transverse radius.

If the characteristic field profiles at equilibrium remain comparable, waves carrying different energies may accommodate them by adopting different transverse dimensions.

For geometrically comparable equilibrium configurations the approximate energy relation becomes

$$W_\lambda \approx C\varepsilon_0 E_s^2 R^2$$

Consequently,

$$R \approx \sqrt{\frac{W_\lambda}{C\varepsilon_0 E_s^2 \lambda}}$$

At a fixed wavelength and for comparable field profiles, the equilibrium radius therefore scales approximately with the square root of the energy:

$$R \propto \sqrt{W_\lambda}$$

Additional energy may therefore correspond to a larger equilibrium radius while the characteristic transverse field amplitudes remain similar.

This relationship distinguishes the proposed model from a description in which electromagnetic waves possess either a universal transverse radius or field amplitudes directly proportional to their total energies.

3.6. Stability Against Small Perturbations

Consider a proposed equilibrium wave of energy W and radius R0 with Ez = Ez0.

If the radius increases at nearly constant energy, the proposed characteristic Ez falls below E_z0; the hypothesized in-phase field correlation then gives inward radial energy transport.

The proposed mechanism produces an inward radial component of the average Poynting vector, tending to restore the original transverse dimensions.

Conversely, a decrease in the radius is hypothesized to raise Ez above Ez0 and yield outward average radial energy transport.

The required restoring relationship may be expressed schematically as

$$\frac{\langle S_r \rangle}{\langle S_z \rangle} \approx -\chi \frac{R - R_0}{R_0}$$

Here χ is a positive response coefficient in a schematic restoration law. Its value and physical origin cannot be inferred solely from the definition of Ez0.

This expression describes a negative-feedback mechanism in which deviations from the equilibrium radius produce oppositely directed radial energy transport.

A distinction must nevertheless be made between the direction of electromagnetic energy transport and the complete electromagnetic momentum balance.

The Poynting vector determines the redistribution of electromagnetic energy. A complete demonstration of transverse stability additionally requires that the corresponding electromagnetic momentum and stress distributions support the proposed restoring response.

The expression above therefore defines the required stabilizing behavior rather than an independently derived constitutive relationship.

3.7. Electromagnetic Boundary and Self-Guiding Mechanism

The proposed transverse confinement of the electromagnetic wave involves two complementary mechanisms.

The first is associated with the radial orientation of electromagnetic energy transport. The longitudinal electric-field component influences the direction of the Poynting vector and may thereby contribute to maintaining the concentration of electromagnetic energy within the wave.

The second mechanism is associated with the radial distribution of the longitudinal displacement current.

For an approximately axisymmetric configuration, the circumferential magnetic field is related to the enclosed longitudinal displacement current by the Ampère–Maxwell equation:

$$B_\varphi(r) = \frac{\mu_0}{r} \int_0^r J_{p,z}(r') r' dr'$$

The model proposes that the longitudinal displacement current contains an inner contribution and an oppositely directed return contribution distributed over the peripheral region of the electromagnetic wave.

If these contributions compensate each other, the total enclosed displacement current approaches zero:

$$I_{p,\text{total}} = 2\pi \int_0^b J_{p,z}(r) r dr \approx 0$$

where b denotes the outer radial limit of the concentrated electromagnetic structure.

Under the assumed field geometry, the circumferential magnetic field consequently approaches zero at this boundary:

$$B_\varphi(b) \approx 0$$

The combined action of radial energy redistribution and the return displacement-current distribution is proposed to establish a relatively sharp electromagnetic transition between the wave and its surroundings.

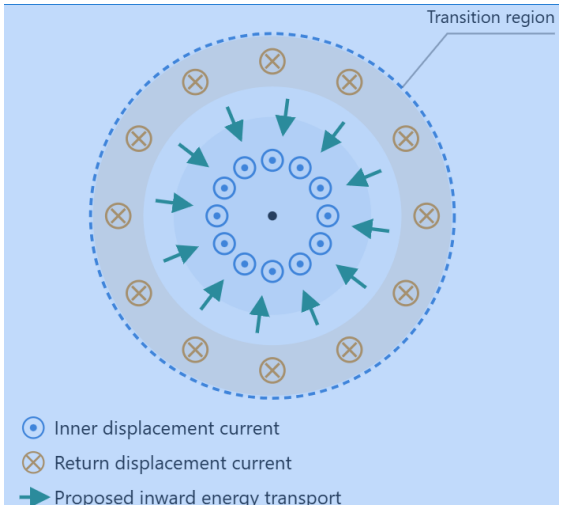


Figure 5. Conceptual transverse organization of the inner and return displacement currents. Their magnetic contributions compensate at the outer boundary, while the proposed radial energy-transport mechanism contributes to the transverse concentration of the electromagnetic field.

This electromagnetic boundary may be compared with the guiding boundary of a conventional waveguide.

In an open homogeneous region, ideal Bessel-type electromagnetic field distributions may extend far beyond their central field region. In conventional waveguides, appropriate boundary conditions restrict the transverse field distribution and permit guided electromagnetic modes with finite transverse energy.

The model proposes that the Ez0 phase-feedback mechanism and the return displacement-current distribution may provide effective guiding conditions without a material wall.

The boundary is therefore interpreted as a self-organized electromagnetic transition rather than a mechanically rigid surface.

The displacement-current closure alone does not establish the confinement of the complete electromagnetic field. The existence and persistence of the proposed boundary must ultimately be demonstrated through the coupled field equations and electromagnetic momentum balance.

3.8. Radial Electromagnetic Confinement and Displacement-Current Compensation

The proposed electromagnetic-wave structure contains an inner longitudinal displacement-current region and an oppositely directed peripheral return-current region. Their mutual compensation may produce a cylindrical surface across which no radial electromagnetic energy is transported.

A mathematical example of this mechanism can be obtained from an axisymmetric solution of Maxwell's equations. Consider the circumferential magnetic field

$$B_\varphi(r, z, t) = B_0 J_1(qr) \cos(\beta z - \omega t),$$

where J_1 is the Bessel function of the first kind and $\beta^2 + q^2 = \omega^2/c^2$.

Let b denote the cylindrical radius defined by the first positive zero of J_1:

$$qb = 3.831706.$$

The magnetic field then satisfies

$$B_\varphi(b, z, t) = 0$$

at every longitudinal position and at every instant.

The corresponding longitudinal displacement-current density is

$$J_{d,z} = \frac{qB_0}{\mu_0} J_0(qr)\cos(\beta z - \omega t).$$

Because J_0 changes sign within the selected radius, the inner and peripheral regions carry oppositely directed displacement currents. Their integrated contributions satisfy

$$I_d(b) = 2\pi \int_0^b J_{d,z}(r)\,, r, dr = 0.$$

The radial component of the Poynting vector is

$$S_r = -\frac{E_z B_\varphi}{\mu_0}.$$

Consequently,

$$S_r(b, z, t) = 0.$$

This demonstrates an exact, time-independent condition of zero radial electromagnetic energy flux through the selected cylindrical surface. The cancellation is maintained throughout the electromagnetic oscillation and is consistent with Maxwell's equations.

The mathematical solution therefore provides a possible description of the proposed inner-current and return-current organization.

The physical mechanism responsible for selecting and maintaining such a surface within a self-organized electromagnetic wave remains a subject for further investigation.

3.9. Dynamic Equilibrium as a Working Hypothesis

The proposed transverse configuration combines radial energy redistribution around Ez0 with the inner and return displacement-current distributions.

When Ez < Ez0, an inward average radial energy flux is hypothesized to raise the characteristic field concentration.

At Ez = Ez0, the in-phase Ez–B correlation is assumed to vanish, allowing predominantly longitudinal average energy transport.

When Ez > Ez0, an outward average radial flux is hypothesized to increase the effective radius until the proposed reference state is approached.

The return displacement-current distribution complements this process by contributing to the radial limitation of the magnetic field.

The resulting geometry may possess a characteristic boundary and an energy-dependent equilibrium radius, provided that a self-consistent field and momentum solution supports the required response.

The geometrical relationship between the electric and magnetic fields, the Poynting vector, and displacement current follows from Maxwell's equations. The proposed Ez0 threshold and restoring feedback are additional, and require additional checks.

The objective is to establish a conceptual framework for transverse self-organization, not to claim a complete dynamical field solution.

The following chapters examine the complementary role of displacement current in the periodic transformation of the electromagnetic structure and the continuity of its energy during propagation. [1], [2], [7]

4. Displacement Current and the Intermediate Field Configuration

The preceding chapters introduced a continuous electromagnetic wave with an approximately annular transverse structure. The proposed wave undergoes periodic changes in its electric and magnetic field distributions while maintaining longitudinal propagation.

A central question is how the electromagnetic structure evolves between successive phases of the oscillation, particularly when the electric and magnetic contributions associated with the annular configuration become weak.

The present model assigns an important role to Maxwell's displacement current. It investigates whether the associated electromagnetic field configuration can represent an intermediate phase of the same continuous electromagnetic process.

Displacement current is also associated with the proposed transverse organization of the electromagnetic wave. Its inner and return contributions may participate in establishing the electromagnetic boundary introduced in Section 3.7.

4.1. Displacement Current in Maxwell's Equations

In classical linear vacuum, the displacement-current density is defined by

$$\overrightarrow{J_p} = \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

In a more general electromagnetic description, it is expressed as

$$\overrightarrow{J_p} = \frac{\partial \vec{D}}{\partial t}$$

In the absence of conduction current, the Ampère–Maxwell equation becomes

$$\nabla \times \vec{B} = \mu_0 \overrightarrow{J_p}$$

where the conventional magnetic constitutive relationship is retained.

The present model treats any additional amplitude-selection rule, including a common Ez0, as a structural hypothesis rather than a modification of the classical definition of displacement current.

For the vacuum relation Jd = ε0 ∂E/∂t, the quarter-period shift follows directly for sinusoidal E. A distinct nonlinear constitutive response is not assumed in Part B1.

The longitudinal component of the displacement-current density is given by

$$J_{p,z} = \frac{\partial D_z}{\partial t}$$

Its spatial distribution is directly associated with the longitudinal electric-field component introduced in Section 2.1.

Displacement current is therefore connected not only to the temporal evolution of the electromagnetic wave but also to its three-dimensional field organization.

4.2. Quarter-Period Phase Relationship

Consider a sinusoidally varying electric-field component at a fixed position:

$$E(t) = E_0 \cos(\omega t)$$

For a linear electromagnetic response, the corresponding displacement-current density is

$$J_p(t) = -\varepsilon_0 \omega E_0 \sin(\omega t)$$

The displacement current is therefore shifted by one quarter of a period relative to the corresponding electric-field component.

When the electric field reaches its maximum, its instantaneous rate of change vanishes and the corresponding displacement current is zero.

One quarter of a period later, the electric-field component passes through zero while the magnitude of its displacement current reaches a maximum.

The same relationship applies during successive phases, with the signs changing according to the direction of field variation.

The quarter-period relationship nevertheless provides a useful conceptual starting point for understanding the periodic transformation of the electromagnetic structure.

A maximum in displacement current does not, by itself, demonstrate that the electromagnetic energy has been transferred into a distinct spatial configuration. That interpretation

requires the additional geometrical hypothesis developed below.

4.3. The Intermediate Electromagnetic Configuration

The model proposes that the electromagnetic wave alternates between an approximately annular field configuration and an intermediate configuration associated with displacement current.

In the annular phase, the electric and magnetic fields possess the transverse organization described in Section 2.

As this configuration evolves, the displacement-current distribution becomes increasingly important.

The model considers the possibility that it forms an approximately axial distribution over a finite transverse region.

Through the Ampère–Maxwell relationship, such a distribution is associated with a circulating magnetic field.

The intermediate configuration is therefore not represented by displacement current alone. It includes the complete electric and magnetic fields associated with this phase of the electromagnetic process.

Its spatial organization may differ from that of the annular configuration.

The proposed transformation may be represented schematically as

$$(E, B) \rightarrow J_{p\text{-associated configuration}} \rightarrow (-E, -B)$$

This sequence describes a periodic transformation of one continuous electromagnetic wave rather than the creation and destruction of separate electromagnetic objects.

The precise three-dimensional field profiles required for this transformation remain to be determined.

4.4. Inner and Return Displacement Currents

For an approximately axisymmetric electromagnetic structure, the longitudinal displacement-current distribution is related to the circumferential magnetic field through the Ampère–Maxwell equation.

For a circular contour of radius r surrounding the propagation axis,

$$2\pi r B_\varphi(r) = \mu_0 I_p(r)$$

where the enclosed longitudinal displacement current is

$$I_p(r) = 2\pi \int_0^r J_{p,z}(r') r' dr'$$

Consequently,

$$B_\varphi(r) = \frac{\mu_0}{r} \int_0^r J_{p,z}(r') r' dr'$$

The radial distribution of the magnetic field is therefore determined by the cumulative longitudinal displacement current enclosed within the selected radius.

The proposed model distinguishes two spatially connected contributions:

- an inner longitudinal displacement current;
- an oppositely directed return displacement current distributed over the peripheral region.

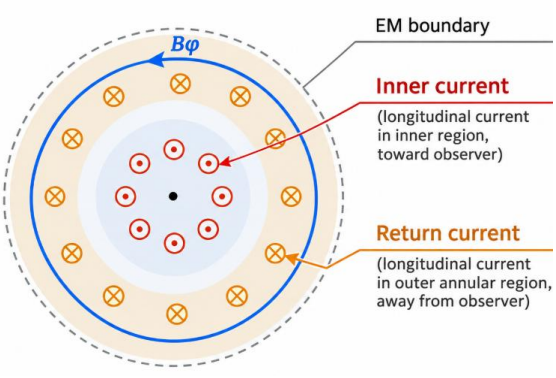


Figure 6. Transverse representation of the inner and return displacement-current distributions at a selected phase of the electromagnetic wave. The circumferential

magnetic field is determined by the enclosed longitudinal displacement current.

If the inner and return contributions compensate each other, the total enclosed displacement current approaches zero at the outer boundary b:

$$2\pi \int_0^b J_{p,z}(r) r dr \approx 0$$

The circumferential magnetic field consequently approaches zero at this boundary:

$$B_\varphi(b) \approx 0$$

The return displacement current thus provides a possible mechanism for terminating the radial distribution of the circumferential magnetic field without introducing a conducting material surface.

Together with the proposed phase-guided radial transport, magnetic-field closure may contribute to a narrow electromagnetic transition.

The resulting configuration is conceptually analogous to a guided electromagnetic mode, although its boundary is proposed to arise from the electromagnetic field itself rather than from a material waveguide.

The cancellation of the enclosed displacement current establishes a condition for magnetic closure. It does not independently demonstrate the confinement of all electric-field components or the stability of the complete electromagnetic structure.

4.5. Continuity Between Successive Half-Wavelength Regions

The electromagnetic wave is treated as a continuous structure with longitudinal periodicity determined by its wavelength.

Successive half-wavelength regions correspond to successive phases of the electromagnetic oscillation.

At the transition between neighboring regions, the annular field contribution may become weak while the intermediate configuration associated with displacement current becomes prominent.

The model proposes that this intermediate configuration provides electromagnetic continuity across the transition.

Consequently, the characteristic transverse organization of the wave need not disappear and be reconstructed independently at every half-wavelength boundary.

Instead, its internal field configuration evolves continuously from one phase into the next.

This provides a possible physical interpretation of how a structured electromagnetic wave maintains its longitudinal continuity while undergoing periodic changes in its transverse electromagnetic geometry.

The intermediate configuration may also connect neighboring regions that initially contain different amounts of electromagnetic energy.

The role of this connection in longitudinal energy redistribution is examined in Section 8.

4.6. Displacement Current and Energy Transport

Displacement current is central to the proposed intermediate configuration, but it must be distinguished from electromagnetic energy flux.

The energy flux is determined by the Poynting vector:

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

Thus, the displacement-current density is not itself an energy flux. Its units and physical definition differ from those of the Poynting vector.

Nevertheless, the longitudinal displacement current and the radial Poynting-vector

component are related through the longitudinal electric field:

$$J_{p,z} = \frac{\partial D_z}{\partial t}$$

$$S_r = -\frac{E_z B_\varphi}{\mu_0}$$

The longitudinal electric-field component therefore participates in two complementary processes.

Its temporal variation contributes to the displacement-current distribution, while its magnitude and phase relative to the magnetic field determine the radial component of electromagnetic energy transport.

The displacement current consequently participates in the spatial organization of the magnetic field, while the Poynting vector describes the redistribution of electromagnetic energy.

The model assigns displacement current a structural and dynamical role in this process without treating it as an independent energy carrier.

The complementary energy associated with the intermediate configuration will be denoted by W_J and examined in the following chapter.

This quantity represents energy assigned to the intermediate electromagnetic configuration, not an independent energy density proportional simply to the square of displacement current.

4.7. The Intermediate Configuration as a Working Hypothesis

The proposed electromagnetic model assigns three complementary functions to the field configuration associated with displacement current.

First, it may participate in maintaining electromagnetic continuity as the annular field configuration periodically changes.

Second, the inner and return displacement-current distributions provide a conceptual mechanism for limiting the radial extent of the circumferential magnetic field.

Third, the intermediate configuration may provide a continuous electromagnetic connection through which neighboring half-wavelength regions exchange energy and adjust their transverse dimensions.

These processes are coupled through the longitudinal electric-field component and the corresponding electromagnetic energy transport.

The model consequently interprets displacement current as an important element of both longitudinal continuity and transverse electromagnetic organization.

The basic relationships between electromagnetic fields and displacement current follow from Maxwell's equations. The proposed three-dimensional organization, proposed phase-feedback response, and self-guiding mechanism represent additional structural hypotheses whose complete quantitative description remains open.

The following chapter examines the corresponding energy balance and defines the complementary energy associated with the proposed intermediate configuration. [1], [2]

5. Periodic Energy Exchange

The preceding chapter introduced the hypothesis that electromagnetic-wave propagation involves a periodic transformation between an approximately annular field configuration and an intermediate configuration associated with Maxwell's displacement current.

If these configurations represent successive phases of one continuous electromagnetic process, their transformation must preserve the total electromagnetic energy, except for energy exchanged with neighboring regions.

The present chapter develops an idealized energy description of this process, taking into account the proposed Ez0 phase-feedback response.

The complementary energy associated with the intermediate configuration is introduced as part of the complete energy balance rather than as an independent addition to the electromagnetic energy.

5.1. Electromagnetic Energy Density

In classical linear vacuum, electromagnetic energy is stored in the electric and magnetic fields. Its energy density is given by

$$u_{EM} = \frac{\varepsilon_0 E^2}{2} + \frac{B^2}{2\mu_0}$$

Here, the electric-field magnitude includes both radial and longitudinal components:

$$E^2 = E_r^2 + E_z^2$$

For the electromagnetic geometry introduced in Section 2, the classical energy density therefore becomes

$$u_{EM} = \frac{\varepsilon_0}{2}(E_r^2 + E_z^2) + \frac{B_\varphi^2}{2\mu_0}$$

The proposed Ez0 phase-feedback response may require a more general energy-density expression.

If the proposed phase-feedback response is represented by a local, lossless constitutive relationship, the electric energy density can be expressed as

$$u_r = \int_0^{D_r} E_r(D')dD'$$

provided that the integral is independent of the integration path.

The total energy density then becomes

$$u = u_D + \frac{B^2}{2\mu_0}$$

This formulation permits a longitudinal-field response while retaining electromagnetic energy conservation.

The energy of the coupled electromagnetic field must be evaluated consistently. The conventional quadratic electric and magnetic energy density is retained as the reference in Part B1.

5.2. Energy of the Annular Configuration

The approximately annular configuration is characterized by the predominantly radial electric field and the circumferential magnetic field introduced in Section 2.

Their assigned energy contributions are denoted by W_E and W_B.

In the conventional quadratic approximation, these contributions may be represented by

$$W_E = \int_V \frac{\varepsilon_0 E_r^2}{2} dV$$

$$W_B = \int_V \frac{B_\varphi^2}{2\mu_0} dV$$

These expressions describe the energy assigned to the annular configuration within the selected volume.

During the electromagnetic oscillation, the internal field configuration evolves continuously. The energy associated with the annular configuration may consequently decrease while the complementary contribution associated with the intermediate configuration increases.

A reduction in the annular energy contribution does not imply a disappearance of electromagnetic energy.

The proposed Ez0 phase-feedback response may additionally influence the distribution of energy among the field components and their spatial configurations.

5.3. Complementary Energy Associated with Displacement Current

The intermediate configuration is associated with Maxwell's displacement current and the corresponding electric and magnetic fields.

Its complementary energy contribution is denoted by W_J.

The complete energy balance of the proposed structure may be expressed as

$$W = W_E + W_B + W_J$$

Consequently,

$$W_J = W - W_E - W_B$$

The subscript J identifies the connection with the displacement-current configuration. It does not imply that displacement current possesses an independent fundamental energy density proportional to its squared magnitude.

The complementary contribution represents the energy not assigned to the annular electric and magnetic configurations.

It may include energy associated with the longitudinal electric field, the modified magnetic-field distribution, and the proposed phase-feedback response within the intermediate configuration, provided that these contributions have not already been included in W_E or W_B.

The decomposition must therefore avoid counting the same electromagnetic energy twice.

5.4. Complementary Temporal Dependence

Consider an idealized periodic transformation in which the energy assigned to the annular configuration varies according to

$$W_E + W_B = W_0 \cos^2(\omega t)$$

The complementary energy associated with the intermediate configuration is then represented by

$$W_J = W_0 \sin^2(\omega t)$$

Their sum remains constant:

$$W_E + W_B + W_J = W_0$$

This representation expresses the central energetic hypothesis of the proposed electromagnetic-wave model.

When the annular contribution decreases, the intermediate contribution increases. When the intermediate contribution decreases, the annular contribution increases correspondingly.

Annular energy $W_E + W_B$

Intermediate energy W_J

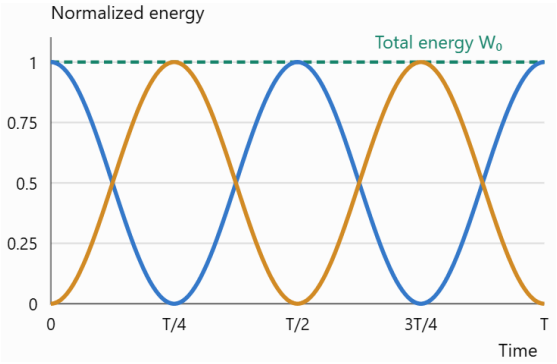


***Figure 7**. Idealized periodic redistribution of energy between the annular and intermediate electromagnetic configurations. The sum of the two contributions remains constant.*

The sinusoidal-squared dependence represents an idealized energy model. The coupled field response may modify the actual temporal dependence without violating the requirement of total energy conservation.

5.5. Energy Exchange During One Half-Period

The proposed transformation can be followed through successive phases of the electromagnetic oscillation.

Phase	Annular energy	Intermediate energy
Initial maximum	W_o	0
One eighth of a period	$W_o/2$	$W_o/2$

One quarter of a period	0	W_o
One half of a period	W_o	0

***Table 2**. Illustrative energy exchange between field configurations.*

At the beginning of the idealized cycle, the annular contribution is maximal.

As the field configuration evolves, the complementary contribution associated with displacement current becomes increasingly prominent.

After one quarter of a period, the intermediate contribution reaches its maximum in the idealized representation, while the annular contribution reaches its minimum.

The transformation subsequently reverses.

The quantities in the table represent the proposed energy allocation within the idealized model. They do not establish that the individual physical field components must vanish or reach their maxima simultaneously throughout the complete electromagnetic structure.

5.6. Displacement Current and the Rate of Energy Exchange

For a sinusoidally varying electric-field component in the linear approximation, displacement current is shifted by one quarter of a period relative to the field itself.

The corresponding idealized rate of change of the annular energy contribution is

$$\frac{d(W_E + W_B)}{dt} = -\omega W_0 \sin(2\omega t)$$

The complementary energy changes at the opposite rate:

$$\frac{dW_J}{dt} = \omega W_0 \sin(2\omega t)$$

Consequently,

$$\frac{dW_E}{dt} + \frac{dW_B}{dt} + \frac{dW_J}{dt} = 0$$

The maximum energy-exchange rate occurs when the two complementary energy contributions are equal.

The displacement current is associated with the evolving electromagnetic configuration, while the actual redistribution of electromagnetic energy is described by the Poynting vector.

In particular, the longitudinal electric-field component connects these two aspects of the electromagnetic process through

$$J_{p,z} = \frac{\partial D_z}{\partial t}$$

and

$$S_r = -\frac{E_z B_\varphi}{\mu_0}$$

The magnitude of the displacement current alone does not determine the rate of electromagnetic energy transfer.

5.7. Conservation of Energy and Longitudinal Transport

A propagating electromagnetic wave continuously transports energy through space.

Energy may enter or leave a selected region through its longitudinal and radial boundaries.

For a local, lossless constitutive description, electromagnetic energy conservation can be expressed as

$$\frac{\partial u}{\partial t} + \nabla \cdot \vec{S} = 0$$

where u represents the complete electromagnetic energy density, including the contribution associated with the proposed phase-feedback response.

The Poynting vector is given by

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

The total energy of a selected region remains constant only when the net energy flux through its boundary vanishes.

The proposed model therefore distinguishes three related processes:

- periodic transformation between the annular and intermediate configurations;
- longitudinal energy transport between neighboring half-wavelength regions;
- radial redistribution of energy associated with the proposed regulation of the transverse radius.

All three processes must satisfy the same electromagnetic energy-conservation requirement.

5.8. Energy Continuity in the Proposed Wave Structure

The complementary energy description provides a possible interpretation of how the electromagnetic wave maintains continuity during periodic changes in its internal field configuration.

As the annular energy contribution decreases, the intermediate configuration becomes more prominent.

The total electromagnetic energy need not disappear when the annular contribution approaches its minimum. Likewise, the transverse organization of the wave need not be reconstructed independently at the beginning of each half-period.

The proposed Ez0 phase-feedback response and the associated longitudinal electric-field component may participate in maintaining this continuous electromagnetic organization.

The return displacement current complements this process by contributing to the radial limitation of the circumferential magnetic field.

The precise distribution of energy between the proposed configurations remains to be established through a complete electromagnetic field solution.

The following chapter examines the continuity of electromagnetic energy during propagation, with particular attention to longitudinal transport and the preservation of the transverse structure. [1], [2]

6. Energy Continuity During Propagation

The preceding chapter introduced a complementary energy description of the proposed electromagnetic wave.

During its periodic evolution, the energy assigned to the annular configuration decreases as the contribution associated with the intermediate configuration increases, and vice versa.

Electromagnetic propagation, however, requires more than periodic redistribution of energy within a selected region. Energy must also be transported continuously along the propagation axis while the transverse structure remains dynamically organized.

The present chapter examines the relationship between these processes.

6.1. Energy Conservation in a Propagating Wave

Electromagnetic energy conservation is described by Poynting's theorem:

$$\frac{\partial u}{\partial t} + \nabla \cdot \vec{S} = 0$$

For the proposed axisymmetric electromagnetic structure, this conservation equation takes the form

$$\frac{\partial u}{\partial t} + \frac{1}{r}\frac{\partial (rS_r)}{\partial r} + \frac{\partial S_z}{\partial z} = 0$$

Here, S_z describes longitudinal energy transport, while S_r describes radial energy redistribution.

This equation connects the longitudinal and transverse changes in electromagnetic energy density.

A local increase in energy density may result from longitudinal inflow, radial inflow, or both. Conversely, a local decrease must be accompanied by an appropriate energy outflow.

The proposed longitudinal-field response may modify the internal energy distribution and the orientation of the Poynting vector.

However, it must not introduce an unaccounted source or loss of electromagnetic energy.

6.2. Periodic Transformation During Propagation

The electromagnetic wave is assumed to propagate along the z-axis while its internal field configuration changes periodically.

Its longitudinal periodicity is characterized by the wavelength λ, while its temporal periodicity is determined by the frequency f.

The conventional vacuum propagation relationship is

$$c = \lambda f$$

The present conceptual model retains this relationship as its reference description. The complete coupled field solution must establish whether and under what conditions the proposed internal field dynamics preserve it.

Successive regions of length

$$L = \frac{\lambda}{2}$$

represent successive half-periods of the electromagnetic oscillation.

Within the proposed interpretation, each region undergoes a transformation between an approximately annular configuration and an intermediate configuration associated with displacement current.

Electromagnetic energy is redistributed between these configurations while continuing to propagate along the wave.

The electromagnetic wave is therefore treated as one continuous field structure rather than as a sequence of independently reconstructed objects.

6.3. The Intermediate Configuration at Half-Wavelength Transitions

Consider the transition between two successive half-wavelength regions.

In the idealized periodic description introduced in Section 5, the energy associated with the annular configuration may approach its minimum at this transition.

The complementary energy associated with the intermediate configuration then approaches its maximum.

The corresponding energy balance is

$$W = W_E + W_B + W_J$$

The intermediate configuration is associated with the longitudinal electric field, the displacement-current distribution, and the corresponding magnetic-field organization.

Its role is not to introduce a separate carrier of energy independent of electromagnetism.

Rather, it represents a complementary organization of the same electromagnetic field.

The proposed intermediate configuration may therefore provide a continuous electromagnetic connection between neighboring half-wavelength regions.

6.4. Longitudinal Energy Transport Through the Intermediate Configuration

The actual longitudinal energy flux remains determined by the Poynting vector:

$$S_z = \frac{E_r B_\varphi}{\mu_0}$$

The longitudinal power transported through a transverse cross-section of radius b is

$$P_z = 2\pi \int_0^b S_z(r) r dr$$

During the periodic transformation of the electromagnetic structure, the electric and magnetic field distributions may change.

The corresponding longitudinal energy flux may therefore also vary locally.

The model hypothesizes that the intermediate configuration provides a continuous electromagnetic connection through which energy can be exchanged between neighboring half-wavelength regions.

The displacement current participates in the formation of the associated electromagnetic fields but is not itself identified with the energy flux.

A complete quantitative description requires the field components and their phase relationships throughout the intermediate configuration.

6.5. Energy of a Selected Half-Wavelength Region

Let W_n denote the electromagnetic energy associated with a selected half-wavelength region.

Its energy may change when the longitudinal power entering the region differs from the power leaving it or when radial energy exchange occurs.

For a fixed control volume, the complete energy balance may be expressed as

$$\frac{dW_n}{dt} = P_{in} - P_{out} - P_r$$

where P_{in} and P_{out} represent the incoming and outgoing longitudinal power, while P_r represents the net outward radial power across the selected boundary.

If radial energy exchange with the surroundings is negligible, the expression simplifies to

$$\frac{dW_n}{dt} = P_{in} - P_{out}$$

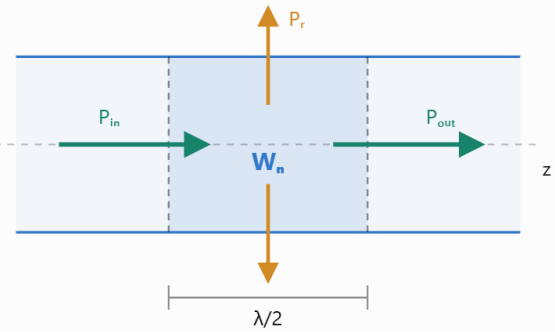


***Figure 8**. Energy balance of a selected half-wavelength control volume. Longitudinal energy transport and radial energy exchange jointly determine changes in the energy contained within the region.*

In a steady periodic state, the average incoming and outgoing powers are equal if there is no net radial energy exchange.

Consequently, the average energy contained within the selected region remains constant.

If neighboring regions initially possess different energy densities, their longitudinal energy exchange may modify their electromagnetic field amplitudes and transverse dimensions.

This process is examined in Section 8.

6.6. Continuity of the Transverse Structure

Energy continuity is accompanied by a separate question concerning the transverse organization of the electromagnetic wave.

The proposed model assumes that the annular and intermediate configurations are successive phases of one connected electromagnetic structure.

As the annular contribution decreases, the intermediate configuration may retain the transverse organization of the electromagnetic field through its own spatial distribution.

The characteristic radius need not therefore be selected independently at every half-wavelength transition.

The proposed transverse continuity involves two complementary mechanisms.

The longitudinal electric-field component influences the radial orientation of the Poynting vector and thereby the redistribution of electromagnetic energy.

At the same time, the return displacement-current distribution contributes to the radial limitation of the circumferential magnetic field.

The combined action of these mechanisms is proposed to maintain the electromagnetic boundary throughout the periodic transformation of the wave.

At equilibrium, the average radial energy exchange with the surroundings is expected to approach zero.

6.7. Independence of Longitudinal and Transverse Scales

The longitudinal and transverse dimensions of the electromagnetic wave describe different aspects of its organization.

The wavelength λ determines the longitudinal spatial periodicity, while the characteristic transverse radius R describes the radial concentration of electromagnetic energy.

The model does not assume a universal proportionality between these quantities:

$$R/\propto \lambda$$

Electromagnetic waves with the same wavelength may therefore possess different transverse dimensions if their energy contents differ.

Conversely, waves with different wavelengths may possess comparable transverse dimensions.

The precise relationship between energy, wavelength, and transverse geometry remains a separate quantitative problem.

6.8. Energy Continuity as a Structural Principle

The proposed model combines three complementary aspects of electromagnetic continuity.

The first is the periodic redistribution of energy between the annular and intermediate electromagnetic configurations.

The second is longitudinal energy transport between successive half-wavelength regions.

The third is radial energy redistribution associated with the proposed Ez0 condition and the Ez–B phase relationship.

These processes are connected within one continuously evolving electromagnetic field.

The displacement-current distribution participates in the formation and radial limitation of the circumferential magnetic field, while the Poynting vector describes the actual redistribution of electromagnetic energy.

The proposed electromagnetic boundary may therefore persist during the periodic transformation of the internal field configuration.

The present description establishes the conceptual relationship between energy conservation, longitudinal continuity, and transverse self-organization.

The following chapter considers the conditional relation between energy-dependent transverse geometry and the proposed Ez0 reference. [1], [2]

7. Longitudinal-Field Equilibrium and Energy-Dependent Geometry

The preceding chapters proposed a radial regulation mechanism based on the longitudinal-field reference Ez0, the in-phase Ez–B correlation, and the return displacement-current distribution.

This chapter examines the consequences of that working hypothesis for characteristic field magnitudes and the energy-dependent radius.

The field value Ez0 labels the proposed axial-average-flow state. It does not mean that the longitudinal electric field must vanish, or that the radial electric field has a strict upper saturation amplitude.

7.1. Transverse Geometry and Electromagnetic Energy

The proposed electromagnetic wave possesses an approximately annular region of concentrated electromagnetic energy.

Its characteristic transverse geometry is described by the radius R and the effective radial width a.

The complete electromagnetic energy includes the contributions associated with the annular and intermediate field configurations:

$$W = W_E + W_B + W_J$$

For a geometrically similar family of electromagnetic waves, the energy contained within one wavelength may be approximated by

$$W_\lambda = C\varepsilon_0 E_0^2 R^2$$

where C is a dimensionless coefficient representing the complete electromagnetic energy distribution within the selected approximation.

The expression assumes comparable relative field profiles and a nearly constant ratio between the effective radial width and the characteristic radius.

The coefficient C may depend on field profiles and phase organization. Its dependence must be determined without assuming a particular nonlinear energy density.

7.2. Geometrical Asymmetry when Ez < Ez0

The radial electric field and circumferential magnetic field possess different spatial distributions within the proposed electromagnetic structure.

Their characteristic radial positions, widths, and gradients need not be identical.

The divergence condition and the coupled radial field geometry constrain the longitudinal electric-field component.

As demonstrated in Section 2.4, the average radial energy flux depends on the correlation between this longitudinal component and the magnetic field:

$$\langle S_r \rangle = -\frac{\langle E_z B_\varphi \rangle}{\mu_0}$$

For Ez < Ez0, the model hypothesizes an inward radial orientation of the average energy flux:

$$\langle S_r \rangle < 0$$

The dominant energy transport remains longitudinal, while the radial component contributes to the concentration of electromagnetic energy toward the propagation axis.

This expresses the proposed tendency of a broad wave to approach Ez = Ez0.

7.3. Increase of Field Amplitude During Contraction

Consider a wave with Ez < Ez0 whose radius decreases while energy and wavelength remain approximately constant.

Under the geometrical approximation introduced in Section 7.1, the characteristic electric-field amplitude increases as the transverse radius decreases:

$$E_0 R \approx \text{constant}$$

The characteristic electric-field amplitude is therefore approximately inversely proportional to the transverse radius:

$$E_0 \propto \frac{1}{R}$$

If the corresponding electric and magnetic amplitudes remain approximately related by

$$E_0 \approx cB_0$$

the characteristic magnetic-field amplitude increases together with the electric-field amplitude.

The inward redistribution of electromagnetic energy may therefore increase the characteristic field amplitudes without requiring additional energy to enter the wave.

The changing field geometry is hypothesized to adjust the in-phase longitudinal component until the reference condition Ez = Ez0 is reached.

The resulting equilibrium is identified with the proposed Ez0 equilibrium electromagnetic configuration.

7.4. The Proposed Ez0 Equilibrium State

The model introduces a characteristic Ez0 reference state described by the electric and magnetic field amplitudes E_o and B_o.

The proposed reference state requires a field mechanism that relates the characteristic longitudinal amplitude to the phase correlation between Ez and B.

In this state, the average radial component of the Poynting vector approaches zero:

$$\langle S_r \rangle = 0$$

while longitudinal energy transport remains present:

$$\langle S_z \rangle > 0$$

The longitudinal electric-field component may nevertheless remain nonzero.

Its quadrature component can participate in periodic internal energy redistribution and in the formation of the longitudinal displacement current without producing a net radial energy flux.

7.5. Response to Ez > Ez0 and Transverse Expansion

Consider a proposed equilibrium electromagnetic wave that receives additional energy while its transverse dimensions initially remain unchanged.

The additional energy modifies the electromagnetic field distribution and may shift the longitudinal-field measure above Ez0.

The model proposes that this modification changes the magnitude and phase of the longitudinal electric-field component, producing an outward radial orientation of the average Poynting vector:

$$\langle S_r \rangle > 0$$

Electromagnetic energy is consequently transported preferentially toward larger radial distances.

The resulting transverse expansion distributes the additional energy over a larger region and allows the electromagnetic structure to approach its equilibrium configuration again.

The proposed mechanism thus allows an electromagnetic wave to accommodate additional energy primarily through an increase in its transverse dimensions.

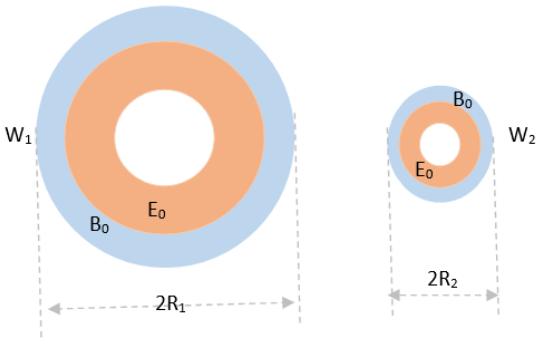


Figure 9. Schematic comparison of two electromagnetic-wave regions carrying different energies. The proposed Ez0 equilibrium may correspond to similar characteristic field amplitudes and different transverse radii; this has not been independently derived.

7.6. Energy-Dependent Equilibrium Radius

An important consequence of the proposed Ez0 regulation mechanism is that a common

characteristic field amplitude does not require a common transverse radius.

For a proposed equilibrium electromagnetic wave, the approximate energy-radius relationship is

$$W_\lambda = C\varepsilon_0 E_0^2 R^2$$

The corresponding equilibrium radius is

$$R = \sqrt{\frac{W_\lambda}{C\varepsilon_0 E_0^2 \lambda}}$$

At a fixed wavelength and for geometrically similar field profiles, the transverse radius scales with the square root of the energy:

$$R \propto \sqrt{W_\lambda}$$

For two proposed equilibrium electromagnetic-wave regions at the same wavelength, the relationship between their radii becomes

$$\frac{R_2}{R_1} = \sqrt{\frac{W_2}{W_1}}$$

The resulting geometrical relationship may be illustrated by the following normalized values:

Relative energy W/W_1	**Relative radius R/R_1**	Relative characteristic amplitude E/E_0
1	1	1
2	1.414	1
4	2	1
9	3	1
16	4	1
100	10	1

Table 3. *Energy and transverse radius in an approximate equilibrium family.*

A wave containing one hundred times more energy may therefore possess a ten times larger transverse radius while maintaining approximately the same characteristic field amplitudes, under the stated geometrical assumptions.

This relationship is conditional on the effective geometrical coefficient remaining approximately constant.

7.7. The Ez0 Reference and Characteristic Amplitudes

The distinction between electromagnetic energy and field amplitude can be expressed through the differential form of the approximate energy-radius relationship.

At a fixed wavelength and for a constant geometrical coefficient,

$$\frac{dW}{W} = 2\frac{dE_0}{E_0} + 2\frac{dR}{R}$$

If the electromagnetic wave remains in its E_z0 reference state, its characteristic electric-field amplitude remains approximately constant:

$$dE_0 = 0$$

The energy change is consequently related to the change in transverse radius by

$$\frac{dW}{W} = 2\frac{dR}{R}$$

or

$$\frac{dR}{R} = \frac{1}{2}\frac{dW}{W}$$

The proposed Ez0 regulation mechanism therefore does not impose an upper limit on the total energy of the electromagnetic wave.

Instead, additional energy may be accommodated through an increase in the transverse dimensions.

The phase correlation of the longitudinal electric field with B is hypothesized to regulate radial transport, while transverse size adjusts to the energy carried by the structure.

7.8. Stability of the equilibrium configuration

The proposed at Ez0 equilibrium electromagnetic configuration must respond consistently to small departures from its equilibrium radius.

Consider an electromagnetic wave with fixed energy W and equilibrium radius R_0.

If its transverse radius increases slightly, its characteristic field amplitudes decrease. The proposed Ez0 regulation then produces an inward radial energy flux, tending to restore the equilibrium radius.

Conversely, if the transverse radius decreases, the increased concentration of electromagnetic energy is hypothesized to produce an outward radial energy flux.

The required restoring relationship was introduced in Section 3.6:

$$\frac{\langle S_r \rangle}{\langle S_z \rangle} = -\chi \frac{R - R_0}{R_0}$$

where χ is a positive dimensionless coefficient representing the proposed restoring response.

The required orientation of electromagnetic energy transport is illustrated schematically below.

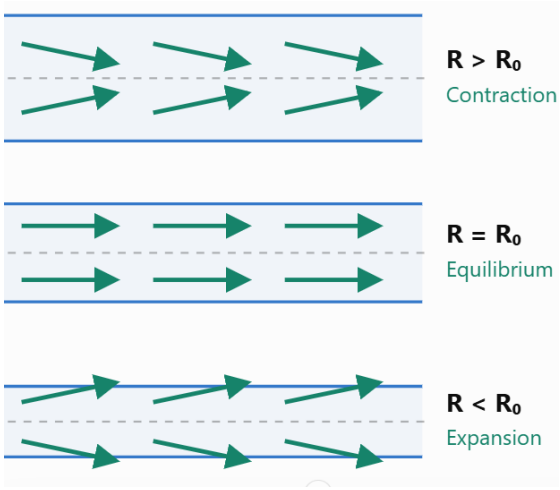


***Figure 10**. Required restoring orientation of the average Poynting vector for small departures from the equilibrium radius of an electromagnetic wave with constant energy.*

The return displacement-current distribution complements this mechanism by contributing to the radial limitation of the circumferential magnetic field.

Together, these processes are proposed to maintain a relatively sharp electromagnetic boundary.

Complete stability must be verified through a consistent electromagnetic momentum balance. The proposed restoring relationship defines required behavior rather than a derived law.

7.9. Longitudinal Energy Redistribution and Transverse Adjustment

Successive half-wavelength regions of the same electromagnetic wave may temporarily contain different amounts of energy.

If these regions possess approximately the same characteristic field amplitudes, their corresponding equilibrium radii may differ.

An exchange of energy between neighboring regions modifies their electromagnetic energy concentrations.

The region that loses energy becomes with Ez below Ez0 relative to its previous transverse geometry and is hypothesized to contract.

The region that receives additional energy becomes with Ez above Ez0 and is hypothesized to expand.

Both regions may consequently approach new equilibrium configurations corresponding to their redistributed energies.

The intermediate electromagnetic configuration associated with displacement current is proposed to provide a continuous connection between neighboring half-wavelength regions.

Through the combined action of longitudinal energy redistribution and transverse regulation, differences between neighboring regions may gradually decrease.

The detailed mechanism of this coupling is examined in the following chapter.

7.10. Scope of the Ez0 Reference Hypothesis

The proposed Ez0 reference is interpreted as an equilibrium condition of the coupled electromagnetic structure; the mechanism selecting this value has not been established.

The longitudinal electric-field component, influenced by both the divergence condition and the proposed phase-feedback response, provides a mechanism through which the radial orientation of the Poynting vector may be regulated.

The return displacement-current distribution complements this mechanism by contributing to the radial limitation of the magnetic field.

The resulting electromagnetic structure is hypothesized to accommodate different amounts of energy while maintaining approximately the same characteristic characteristic field amplitudes.

Its transverse radius is therefore interpreted as an energy-dependent geometrical parameter rather than a universal dimension of electromagnetic radiation.

The proposed mechanism establishes a conceptual relationship between longitudinal-field organization, electromagnetic energy transport, and transverse geometry.

The complete coupled field solution, the numerical determination of the proposed Ez0 equilibrium amplitudes, and the quantitative confirmation of transverse stability remain subjects of further investigation.

The following chapter examines how longitudinal energy redistribution between neighboring regions may contribute to maintaining the structural coherence of the propagating electromagnetic wave. [1], [3], [5]

8. Longitudinal Energy Redistribution and Structural Coherence

The preceding chapters introduced a continuous electromagnetic wave whose transverse structure is proposed to be regulated through the proposed Ez0 phase-feedback response, radial energy redistribution, and the return displacement-current distribution.

Different amounts of electromagnetic energy may correspond to different equilibrium radii while the characteristic characteristic field amplitudes remain approximately constant.

A further question arises when successive half-wavelength regions contain different amounts of energy.

The proposed model treats these regions as successive phases of one continuous electromagnetic structure rather than as independent electromagnetic objects.

Their common intermediate configuration, associated with displacement current, is proposed to establish a connection through which electromagnetic energy may be redistributed.

This chapter examines how longitudinal energy redistribution and transverse regulation may jointly contribute to the structural coherence of the electromagnetic wave.

8.1. Successive Half-Wavelength Regions

Consider two neighboring half-wavelength regions of the same electromagnetic wave.

Their longitudinal dimensions are determined by the common wavelength, while their transverse dimensions may differ according to their energy contents.

Let their energies be W_1 and W_2, and their characteristic transverse radii be R_1 and R_2.

If both regions are initially in Ez0 equilibrium and possess geometrically similar field profiles,

the approximate energy relation introduced in Section 7 gives

$$\frac{W_1}{W_2} \approx \frac{R_1^2}{R_2^2}$$

Consequently, different energies may correspond to different transverse radii even when the characteristic electric and magnetic field amplitudes are approximately equal.

Such differences do not imply that the neighboring regions are physically disconnected.

The model proposes that their continuous electromagnetic connection may allow energy redistribution and corresponding adjustments of their transverse dimensions.

8.2. Overlapping Fields and Longitudinal Coupling

Electromagnetic fields do not terminate abruptly at the longitudinal boundary of a geometrically defined half-wavelength region.

The field distributions associated with neighboring regions may therefore overlap, particularly within their common intermediate configuration.

In classical linear electrodynamics, overlapping electromagnetic fields can be represented by their superposition:

$$\vec{E} = \overrightarrow{E_1} + \overrightarrow{E_2}$$

$$\vec{B} = \overrightarrow{B_1} + \overrightarrow{B_2}$$

The corresponding classical electric energy density contains an additional term arising from the overlap:

$$u_E = \frac{\varepsilon_0}{2}\left(E_1^2 + E_2^2 + 2\overrightarrow{E_1} \cdot \overrightarrow{E_2}\right)$$

An analogous expression applies to the magnetic energy density.

These expressions illustrate how the electromagnetic energy distribution depends on the relative orientations and phases of overlapping field contributions.

However, the present model additionally introduces a proposed Ez0 phase-feedback response within the inner region of the electromagnetic wave.

Consequently, the complete field configuration cannot generally be obtained through the independent linear superposition of two coupled field solutions.

The spatial organization of the shared configuration must instead be determined by the coupled electromagnetic equations and the proposed phase-feedback response.

Coupling between neighboring electromagnetic regions may influence the longitudinal electric field, displacement-current distribution, and Poynting vector.

The model therefore identifies the common intermediate configuration as a possible physical basis for energy redistribution between neighboring half-wavelength regions.

8.3. Shared Intermediate Configuration

The intermediate electromagnetic configuration becomes especially important near transitions between successive half-wavelength regions.

As described in Sections 4–6, the annular energy contribution may approach its minimum while the complementary contribution associated with displacement current becomes prominent.

The model proposes that both neighboring regions participate in the formation of a shared intermediate electromagnetic configuration.

This configuration includes the longitudinal electric field, the displacement-current distribution, and the corresponding magnetic field.

If the neighboring regions possess different transverse radii, their contributions to the shared configuration may also possess different radial distributions.

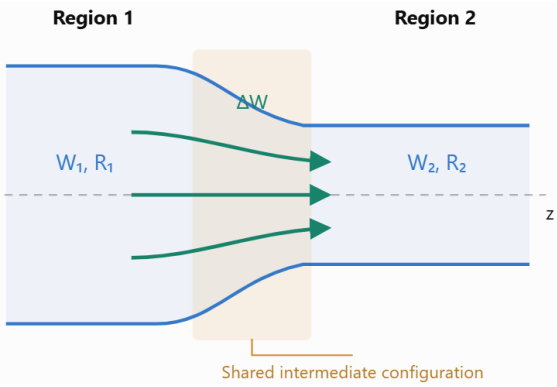


***Figure 11**. Conceptual representation of two neighboring half-wavelength regions with different energies and transverse radii. Their shared intermediate electromagnetic configuration provides a possible connection for longitudinal energy redistribution.*

The resulting intermediate configuration may develop a transverse geometry that differs from either neighboring configuration considered separately.

Its characteristic radius is not assumed to be predetermined. It depends on the coupled field distributions, their relative phases, and their energy contents.

The proposed Ez0 phase-feedback response may additionally contribute to this adjustment.

8.4. Longitudinal Energy Redistribution

Let the first half-wavelength region initially contain more electromagnetic energy than the second:

$$W_1 > W_2$$

The model proposes that their electromagnetic coupling may allow part of the energy associated with the first region to be transferred to the second.

Denoting the transferred energy by ΔW, the resulting energies become

$$W_1' = W_1 - \Delta W$$

$$W_2' = W_2 + \Delta W$$

If there is no net energy exchange with other regions or the surroundings, the combined energy remains constant:

$$W_1' + W_2' = W_1 + W_2$$

This relationship expresses energy conservation during the proposed internal redistribution.

The actual transferred energy must be determined from the electromagnetic energy flux through the common transition region.

For a fixed transverse control surface, it can be expressed as

$$\Delta W = \int_{t_1}^{t_2} \int_A S_z dA\, dt$$

where the flux represents the net longitudinal transfer across the selected surface over the considered time interval.

If the control surface moves with the electromagnetic wave, the energy flux must additionally account for the motion of the boundary.

Energy conservation establishes the relationship between the energy lost by one region and the energy gained by the other. It does not independently determine the direction or magnitude of the transfer.

The proposed tendency toward energy equalization remains a hypothesis concerning the coupled electromagnetic field dynamics.

8.5. Response of the Neighboring Regions

Suppose that both neighboring regions are initially in Ez0 equilibrium.

The transfer of energy modifies their energy contents before their transverse dimensions have fully adjusted.

The region losing energy becomes with Ez below Ez0 relative to its original geometry.

According to the proposed regulation mechanism, the average Poynting vector acquires an inward radial component:

$$\langle S_{r,1} \rangle < 0$$

The first region therefore tends to contract.

Conversely, the region receiving additional energy becomes with Ez above Ez0 relative to its original geometry. The average Poynting vector is proposed to acquire an outward radial component:

$$\langle S_{r,2} \rangle > 0$$

The second region consequently tends to expand.

After their geometrical adjustment, both regions may approach their characteristic characteristic field amplitudes while possessing modified equilibrium radii.

For geometrically similar equilibrium configurations,

$$R_1' = R_1 \sqrt{\frac{W_1 - \Delta W}{W_1}}$$

$$R_2' = R_2 \sqrt{\frac{W_2 + \Delta W}{W_2}}$$

Longitudinal energy redistribution and transverse geometrical adjustment are therefore interpreted as coupled processes.

8.6. Common Transverse Geometry

If the energies of two neighboring at Ez0 equilibrium regions become equal, their equilibrium radii also become equal under the same geometrical assumptions.

For an idealized isolated pair, complete energy equalization would give

$$W_1' = W_2' = \frac{W_1 + W_2}{2}$$

The transferred energy is then

$$\Delta W = \frac{W_1 - W_2}{2}$$

Using the approximate quadratic relationship between energy and transverse radius, the resulting common radius becomes

$$R_c = \sqrt{\frac{R_1^2 + R_2^2}{2}}$$

This result illustrates how the proposed combination of longitudinal energy redistribution and transverse longitudinal-field equilibrium may lead to a common transverse geometry.

For example, consider two neighboring at Ez0 equilibrium regions with the following relative energies and radii:

Configuration	Region 1	Region 2
Initial relative energy	4	1
Initial relative radius	2	1
Final relative energy	2.5	2.5
Final relative radius	1.581	1.581

Table 4. *Comparison of neighboring electromagnetic regions.*

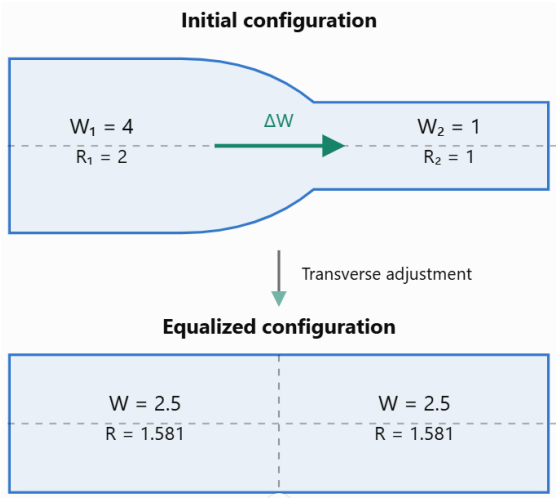


Figure 12*. Idealized energy redistribution between two neighboring regions initially at the proposed Ez0 equilibrium. The region losing energy contracts, while the region gaining energy expands. This schematic response requires verification.*

The example represents a possible final configuration rather than a calculation of the

temporal evolution of the electromagnetic fields.

The actual rate of equalization and the possibility of repeated or oscillatory energy exchange remain to be established.

8.7. Energy Transport and the Poynting Vector

The proposed shared intermediate configuration must be consistent with electromagnetic energy conservation.

For the field geometry introduced in Section 2, the Poynting vector possesses both longitudinal and radial components:

$$S_z = \frac{E_r B_\varphi}{\mu_0}$$

$$S_r = -\frac{E_z B_\varphi}{\mu_0}$$

These components describe two complementary aspects of electromagnetic energy redistribution.

The longitudinal component governs the transfer of energy along the electromagnetic wave.

The radial component governs the redistribution of energy within its transverse structure.

When neighboring half-wavelength regions possess different energies and transverse dimensions, the coupled organization of their common intermediate configuration may modify both components.

The longitudinal redistribution of energy consequently changes the conditions under which the individual regions approach their equilibrium configurations.

The resulting changes in the longitudinal electric-field component may then modify the radial orientation of the Poynting vector.

This establishes a conceptual connection between longitudinal energy transport and transverse geometrical adjustment.

The direction of the additional longitudinal energy transfer cannot be inferred solely from the difference between the scalar energies of the neighboring regions. It must follow from their coupled vector fields and phase relationships.

8.8. Coherence of the Continuous Electromagnetic Wave

The longitudinal coupling of neighboring half-wavelength regions is proposed to contribute to the structural coherence of the complete electromagnetic wave.

In this context, structural coherence refers to the preservation of a connected electromagnetic structure with consistent longitudinal periodicity and mutually coordinated transverse dimensions.

The model does not require every half-wavelength region to contain exactly the same amount of electromagnetic energy at every instant.

Temporary differences may arise through interactions with other electromagnetic waves, matter, or external fields.

The proposed shared intermediate configuration provides a continuous electromagnetic connection through which these differences may influence neighboring regions.

Longitudinal energy redistribution may reduce differences in their energy contents, while transverse regulation may reduce differences in their characteristic radii.

The return displacement-current distribution complements this process by contributing to the radial limitation of the circumferential magnetic field.

The electromagnetic wave is therefore interpreted as a continuous and internally coupled structure rather than as a sequence of independent toroidal objects.

This structural interpretation does not replace the conventional definition of optical coherence in terms of phase correlations. It describes an additional geometrical aspect of the proposed electromagnetic-wave model.

8.9. Energy Redistribution and Quantization

The proposed longitudinal energy redistribution should not be confused with energy quantization.

The model permits electromagnetic energy to be redistributed continuously between neighboring half-wavelength regions while preserving the total energy.

The transferred amount is not assumed to represent a universal energy quantum.

Likewise, a characteristic longitudinal reference Ez0 does not independently determine a discrete set of allowed electromagnetic energies.

Different energies may correspond to different transverse radii within the approximate geometrical description.

The present chapter therefore concerns the internal coupling and structural coherence of an electromagnetic wave.

Its interaction with matter and the energy transferred during the photoelectric effect are examined separately in Part B3.

8.10. Scope of the Proposed Coupling Mechanism

The present model proposes that neighboring half-wavelength regions remain connected through their shared electromagnetic field configuration.

The intermediate configuration associated with displacement current may allow longitudinal energy redistribution between regions containing different amounts of energy.

The resulting deviations from Ez = Ez0 are hypothesized to change the in-phase correlation of Ez with B and therefore the radial Poynting flux.

The present work does not derive the feedback law that would produce this phase response.

The combined action of longitudinal energy redistribution, radial energy transport, and return displacement-current closure may contribute to the continuity and structural coherence of the electromagnetic wave.

The chapter develops this coupling as a structural hypothesis without postulating a specific nonlinear constitutive law.

The precise field profiles, the direction and rate of energy equalization, and the stability of the resulting configuration remain subjects of further investigation.

The next chapter distinguishes the demonstrated linear electromagnetic relations from the proposed Ez0 equilibrium hypothesis. [1], [3], [5]

9. Maxwell Linearity and the Proposed Ez0 Reference

The model defines a possible transverse equilibrium by a characteristic longitudinal electric-field value Ez0 and an assumed vanishing in-phase Ez–B correlation.

The hypothesis concerns the existence of a physical selection and feedback mechanism for a particular field amplitude, not a change to the established expression for the Poynting vector.

Maxwell's linear vacuum equations are invariant under a common rescaling of E and B. Accordingly, they cannot select a universal nonzero Ez0 by themselves.

Part B1 therefore treats Ez0 as an still unverified reference condition. A dynamical law linking this reference to the relative phase of Ez and B is required before radial stability can be claimed.

9.1. Linearity and the Amplitude-Selection Problem

In classical vacuum electrodynamics, Maxwell's equations are linear in the electric and magnetic fields.

If a pair of electromagnetic fields represents a solution, their uniformly scaled counterparts

$$\overrightarrow{E'} = \alpha\vec{E}$$

$$\overrightarrow{B'} = \alpha\vec{B}$$

also satisfy the same source-free Maxwell equations, where α is an arbitrary constant.

The spatial and temporal organization of the fields remains unchanged.

The linear vacuum field equations leave the overall amplitude undetermined and do not imply the proposed universal longitudinal-field reference.

This also holds for spatially complex configurations with a longitudinal electric field and return displacement current.

Local cancellation of field components is ordinary linear superposition; it cannot supply an amplitude-selecting feedback law.

Consequently, Ez0 and the claimed change of average radial-flow direction must be experimentally or theoretically established beyond field geometry alone.

This is the principal outstanding dynamical requirement of the proposed model.

The next chapter discusses termination and growth of a finite coherent chain.

10. Coherent Chain Termination and Growth by Reflection

A finite coherent electromagnetic structure cannot terminate through an abrupt discontinuity of the electromagnetic field. Near the end of the coherent chain, the last half-waves progressively lose the structural support provided by neighbouring half-waves. Their transverse radius therefore decreases smoothly toward zero.

In the interior of a stable coherent chain,

$$R_1 \approx R_2 \approx \cdots \approx R_N \approx R_0$$

where R_0 represents the preferred transverse radius of the stable electromagnetic structure.

Near the end of the chain, however, the number of neighbouring half-waves decreases. The last half-waves therefore cannot maintain the same structural balance as those in the interior. Their transverse radii decrease progressively,

$$R_{N-2} < R_0$$

$$R_{N-1} < R_{N-2}$$

$$R_N \to 0$$

The end of the coherent electromagnetic wave is therefore not represented by an abrupt termination. It is a smooth spatial transition in which the transverse electromagnetic structure gradually contracts,

$$R(z) \to 0$$

This terminal region becomes particularly important during reflection.

When the leading part of a finite electromagnetic wave reaches a mirror, it is reflected while the following part of the same wave is still approaching the mirror. For a nearly normal reflection, the incident and reflected parts temporarily occupy the same spatial region and propagate in opposite directions.

Where the electric fields are locally in phase, the total electric-field amplitude can approach

$$E_{\mathrm{tot}} = E_{\mathrm{in}} + E_{\mathrm{ref}} \approx 2E_0$$

The local electromagnetic energy distribution is therefore temporarily modified. Within the present model, an excess of energy in one half-wave disturbs the equilibrium with neighbouring half-waves.

For an undisturbed coherent chain,

$$W_1 \approx W_2 \approx \cdots \approx W_N \approx W_0$$

where W_0 is the characteristic energy associated with an equilibrium half-wave.

During reflection, one local region may temporarily acquire

$$W_i = W_0 + \Delta W$$

while neighbouring regions remain closer to

$$W_{i-1} \approx W_{i+1} \approx W_0$$

This local imbalance creates a tendency for electromagnetic energy to redistribute toward neighbouring parts of the coherent chain. The redistribution need not occur only toward the rear of the wave. It may propagate in both longitudinal directions,

$$W_i \rightarrow W_{i-1}, W_i, W_{i+1}$$

until a smoother local energy distribution is restored.

Within the present model, this redistribution is associated with a corresponding redistribution of the transverse radius. A half-wave carrying excess energy tends temporarily toward a larger radius,

$$\Delta W_i > 0 \Rightarrow \Delta R_i > 0$$

while subsequent energy transfer reduces the local excess and distributes the structural deformation along the coherent chain.

The terminal region responds differently from the interior. Because the last half-waves already possess reduced transverse radii, an additional energy flux reaching the end does not encounter an abrupt boundary. Instead, it strengthens the weakened terminal half-waves.

Thus,

$$R_N \rightarrow R_N + \Delta R_N$$

and field structure can extend into the region beyond the previous effective end of the chain.

The coherent chain therefore grows not by creating an isolated new wave from zero, but by strengthening the smoothly decaying terminal region. The effective end of the electromagnetic structure is displaced outward,

$$L_{\mathrm{coh}} \rightarrow L_{\mathrm{coh}} + \Delta L$$

The newly strengthened terminal region then becomes part of the fully developed coherent structure.

This mechanism can be represented schematically as

$$\begin{aligned} &\text{reflection} \rightarrow \text{self-overlap} \\ &\rightarrow \text{local energy excess} \\ &\rightarrow \text{longitudinal redistribution} \\ &\rightarrow \text{terminal strengthening} \rightarrow L_{\mathrm{coh}} \end{aligned}$$

The process is continuous. No discontinuous creation of a new electromagnetic half-wave is required. The electromagnetic fields evolve smoothly, while the terminal profile of the coherent structure is displaced.

Reflection therefore provides a natural mechanism by which the longitudinal extent of a coherent electromagnetic structure may increase.

For a finite incident wave, the process occurs repeatedly. Successive half-waves reach the mirror and participate in the overlap between the incident and reflected fields. Each interaction produces a new local redistribution of electromagnetic energy. Reflection can therefore generate a sequence of redistribution events rather than a single isolated event.

This sequence may be represented as

$$\Delta W_1, \Delta W_2, \Delta W_3, \ldots, \Delta W_N$$

and may be interpreted as a burst of longitudinal energy-redistribution processes travelling through the coherent structure.

As these events reach the terminal region, they may progressively strengthen the previously

weakened end of the chain and increase its coherent length.

The total electromagnetic energy must nevertheless remain conserved in an ideal reflection. If the same total energy becomes distributed over a longer coherent structure,

$$W_{\mathrm{tot}} = \mathrm{const}$$

while

$$L_{\mathrm{coh}}$$

the average energy per unit longitudinal length must decrease,

$$\frac{W_{\mathrm{tot}}}{L_{\mathrm{coh}}}$$

Within the geometric model developed in this work, this provides a possible mechanism for a simultaneous reduction of the equilibrium transverse radius,

$$L_{\mathrm{coh}} \uparrow \Rightarrow R_0$$

Thus reflection may produce two complementary structural changes:

$$L_{\mathrm{coh}}$$

and

$$R_0$$

The electromagnetic structure becomes longitudinally longer and transversely narrower.

10.1 Redistribution of Energy and Elongation of the Coherent Wave Structure

Reflection produces a temporary increase in the local electric-field amplitude, creating an energy imbalance within the coherent electromagnetic wave structure.

In the proposed model, this imbalance initiates longitudinal energy redistribution between electromagnetically connected half-wavelength regions. As the excess energy propagates along the coherent structure, its transverse radius gradually decreases, approaching a more uniform and narrower configuration.

When the redistributed energy reaches the terminal region of the coherent structure, it can contribute to its longitudinal extension. The result is a transformation from a shorter and wider coherent structure into a longer and narrower one.

Assuming conservation of total energy, approximately constant characteristic electromagnetic energy density, and geometrically similar transverse field profiles, the initial and final configurations satisfy

$$(R_1^2 L_1 = R_2^2 L_2)$$

where R represents the characteristic transverse radius and L the coherent length.

The proposed mechanism therefore distinguishes between transverse redistribution of electromagnetic energy and longitudinal extension of the coherent structure. The detailed dynamics of this transformation remain to be established through the complete electromagnetic energy and momentum balances.

Under this assumption, reflection does not merely reverse the direction of propagation. It can also act as a mechanism for redistribution of electromagnetic energy within the coherent structure and for extension of its longitudinal coherence. [3], [4], [5], [6]

11. Quantitative Parameters and Experimental Verification

The preceding chapters developed a geometrical and dynamical interpretation of electromagnetic-wave propagation. The model proposes a continuous transverse field structure, periodic transformation through an intermediate configuration associated with displacement current, and a possible proposed Ez0 regulation mechanism regulating the characteristic field amplitudes.

These mechanisms provide a framework for describing the proposed electromagnetic wave. However, a quantitative theory must also determine its characteristic dimensions and field magnitudes.

The present chapter identifies the principal parameters of the model and outlines how their values may be constrained through subsequent theoretical and experimental investigation.

11.1. Characteristic Parameters of the Electromagnetic Wave

The proposed electromagnetic-wave structure is characterized by its longitudinal wavelength, transverse geometry, and electric and magnetic field amplitudes.

The longitudinal wavelength is related to frequency through the conventional vacuum propagation relation:

$$c = \lambda f$$

The characteristic transverse geometry is described by the radius R and effective radial thickness a.

The model introduces a proposed characteristic longitudinal-field reference Ez0, associated with vanishing average radial energy flow, and representative transverse amplitudes E0 and B0.

These quantities describe different properties of the electromagnetic wave. The wavelength determines its longitudinal periodicity, while R and a characterize the spatial distribution of electromagnetic energy around the propagation axis.

The model does not assume that R is universally proportional to the wavelength.

The equilibrium radius is hypothesized to depend on the wave energy, provided the proposed phase-feedback response exists.

Consequently, determining the characteristic amplitudes does not automatically determine the transverse dimensions.

A complete quantitative description must establish the relationship between these parameters through the actual three-dimensional electromagnetic field distributions.

11.2. Reference Field Amplitudes

The numerical value and any universality of Ez0 have not been derived from Maxwell's equations.

A complete field model must still demonstrate the assumed response and long-term transverse localization.

Nevertheless, the subsequent analysis of electromagnetic-wave interaction with a bound electron requires representative field magnitudes.

A provisional reference value for the characteristic electric-field amplitude is

$$E_0 \approx 1.5 \times 10^9 \ \mathrm{V/m}$$

For corresponding propagating field components satisfying the approximate relation between their amplitudes, the associated magnetic-field amplitude is

$$B_0 \approx 5 \ \mathrm{T}$$

These values are introduced as working parameters for the subsequent investigation.

These values are working inputs rather than universal amplitudes established by the proposed Ez0 mechanism.

Their significance depends on whether they can consistently account for independent observations without separate adjustment for each experimental case.

11.3. Energy and Transverse Dimensions

Within the approximate geometrical description of Section 7, the energy of a wave near the proposed Ez0 reference depends on its effective transverse radius.

For geometrically similar field profiles at a fixed wavelength, this relationship is represented by

$$W = C\lambda\varepsilon_0 E_0^2 R^2$$

Here, C incorporates the effective spatial distribution of electromagnetic energy, including the contribution assigned to the intermediate configuration associated with displacement current.

The expression provides a possible relationship between energy and transverse geometry. It does not independently establish the numerical value of R because the total energy and the complete geometrical coefficient must also be determined.

Furthermore, the relation assumes that the relative field profiles remain approximately similar as the transverse dimensions change.

A more complete electromagnetic field description may require a geometry-dependent coefficient.

The quantitative determination of the transverse radius remains separate from the hypothesized universal value of Ez0.

11.4. Connection to the Interaction with an Electron

The interaction between an electromagnetic wave and a bound electron provides a possible route for investigating the model's characteristic parameters.

An electron responds to the local electric and magnetic fields and to their temporal and spatial variation.

Consequently, the outcome of an interaction may depend not only on the total electromagnetic energy but also on the field amplitudes, transverse geometry, relative orientation, and available interaction time.

The displacement-current amplitude introduces an additional frequency-dependent quantity:

$$J_{D,0} = \varepsilon_0 \omega E_0$$

If the characteristic transverse electric-field amplitude is approximately constant across frequencies, the corresponding displacement-current amplitude scales with frequency; this is conditional, not a consequence of Ez0 alone.

This provides a possible connection between the temporal dynamics of the proposed electromagnetic structure and its interaction with matter.

The model therefore suggests that the characteristic field amplitudes and dimensions may be constrained by studying the response of a bound electron to the evolving electromagnetic fields.

However, the existence of such a connection does not by itself establish the photoelectric threshold or the experimentally observed photon-energy relation. These require a quantitative interaction model.

11.5. Quantitative Investigation in Part B2

Part B3 will extend the present model to the interaction between an electromagnetic wave and a bound electron.

Its objective will be to investigate whether the proposed field configuration can account for the characteristic behavior of the photoelectric effect.

Particular attention will be given to determining or constraining the transverse radius R, effective radial thickness a, and characteristic longitudinal interaction length.

The latter must be distinguished from the wavelength itself. Although the longitudinal electromagnetic periodicity is determined by lambda, the spatial interval over which an electron interacts coherently with the field may depend on the interaction geometry and dynamics.

The subsequent analysis will also examine whether a common set of characteristic field amplitudes can describe interactions at different frequencies and for different bound-electron states.

The representative values introduced in Section 11.2 provide an initial basis for this investigation.

Their consistency must ultimately be evaluated against experimental observations.

Matching one threshold is insufficient to test the Ez0 feedback hypothesis; independent wavelengths and interaction geometries must be described with the same parameters.

11.6. Experimental Significance and Further Development

The principal quantitative challenge of the present model is to establish the proposed electromagnetic structure without introducing independently adjustable parameters for every experimental situation.

A successful description would need to determine the characteristic field amplitudes, transverse geometry, and energy redistribution from a consistent electromagnetic framework.

The present paper does not complete that task.

Instead, it identifies the structural hypotheses and the parameters whose values must be established.

The proposed interaction with a bound electron provides one possible route for testing these assumptions, while a complete three-dimensional field solution remains necessary to determine the underlying proposed Ez0 regulation mechanism.

Part B3 therefore represents the next stage of the investigation: moving from the proposed structure and propagation of the electromagnetic wave toward quantitative constraints obtained from its interaction with matter.

The following chapter summarizes the remaining theoretical questions and the principal requirements for developing the model into a complete electromagnetic description. [1], [2], [3], [4], [5], [6], [7]

12. Discussion and Open Problems

The present paper develops a conceptual physical picture of an electromagnetic wave as a continuous, periodically evolving three-dimensional field structure. Its principal elements are an approximately annular organization of the electric and magnetic fields, an intermediate electromagnetic configuration associated with Maxwell's displacement current, continuous redistribution of electromagnetic energy, and a possible dynamical regulation of the transverse geometry.

The purpose of Part B1 is not to complete every quantitative aspect of this model. Rather, it establishes the geometrical and dynamical framework from which the subsequent developments follow.

Several questions introduced here are therefore not left unresolved within the complete series. Part B2 develops the structural evolution of the electromagnetic wave, including longitudinal-field equilibrium, energy-dependent transverse dimensions, coherent merging, growth of the characteristic transverse radius R_0, and changes of wave energy during propagation. Part B3 examines the local interaction with bound electrons and uses the photoelectric effect to constrain characteristic field amplitudes and interaction dimensions.

The remaining open problems are more fundamental. They concern whether the proposed physical picture can ultimately be derived from a complete electromagnetic field solution.

12.1. Complete Three-Dimensional Field Solution

The principal theoretical problem is the construction of explicit three-dimensional electric and magnetic fields that reproduce the proposed wave structure.

Such fields must satisfy the complete Maxwell equations, including the divergence conditions, Faraday's law, and the Ampère-Maxwell equation. They must also reproduce longitudinal propagation while remaining consistent with local conservation of electromagnetic energy and momentum.

The annular and intermediate configurations introduced in this paper are presently geometrical and dynamical descriptions. A complete solution must determine their actual vector fields, radial profiles, longitudinal dependence, and temporal evolution.

The decisive question is therefore whether the proposed continuously evolving structure can exist as a self-consistent electromagnetic field configuration without requiring an external confining mechanism.

12.2. Intermediate Electromagnetic Configuration

The quarter-period relationship between a sinusoidally varying electric field and displacement current follows directly from Maxwell's equations. The interpretation of this relationship as a periodic transformation through a distinct intermediate spatial configuration is an additional structural hypothesis.

The model proposes that this configuration provides continuity between successive phases of the electromagnetic wave and participates in redistribution of electromagnetic energy.

In particular, the complementary energy assigned to the intermediate configuration must ultimately be represented entirely through the complete electromagnetic fields. It must not constitute an additional independent form of energy.

A quantitative solution must therefore demonstrate how the intermediate configuration participates simultaneously in field evolution, energy conservation, and longitudinal energy transport.

12.3. Electromagnetic Momentum and Radial Stability

The proposed transverse regulation is based on the possibility that small differences between the spatial distributions of the electric and magnetic fields influence radial electromagnetic energy and momentum transport.

Within the proposed three-state model, $E_z < E_{z0}$ corresponds to inward radial energy transport, $E_z = E_{z0}$ to zero average radial flux, and $E_z > E_{z0}$ to outward transport.

The direction of the corresponding radial Poynting-vector component provides an indication of energy redistribution, but energy flow alone does not establish the mechanical stability of the electromagnetic structure.

A complete treatment must therefore evaluate the electromagnetic momentum balance, including the Maxwell stress tensor.

12.4. Magnetic Closure and Periodic Transformation

The absence of magnetic monopoles is compatible with closed magnetic-field configurations, but it does not uniquely determine the annular geometry proposed in this model.

A complete field solution must establish whether the required magnetic organization can remain continuous while the electromagnetic wave passes through its successive phases.

The transformation between the annular and intermediate configurations must preserve both field continuity and electromagnetic energy and momentum.

The possible role of phase closure and magnetic geometry in constraining the internal structure therefore remains an important theoretical problem.

12.5. Parameters Developed in Part B2

Part B1 proposes that waves carrying different energies may have different transverse sizes while approaching a common longitudinal-field reference Ez0.

The detailed evolution of this transverse structure is developed further in Part B2.

In particular, Part B2 examines the relationship

$$R_0 = R_0(W),$$

the increase of transverse size with wave energy,

$$\frac{dR_0}{dW} > 0,$$

the coherent merging of electromagnetic waves, and the growth or reduction of W and R_0 during propagation.

The quantitative form of the function $R_0(W)$ remains subject to further refinement, but the question of structural evolution is therefore treated as a continuation of the present conceptual framework rather than as an unresolved problem confined to Part B1.

12.6. Parameters Constrained in Part B3

Part B1 introduces a proposed Ez0 reference and characteristic transverse amplitudes without deriving their numerical values.

Part B3 approaches this problem from the opposite direction. Instead of deriving the amplitudes entirely from the free electromagnetic wave, it examines their consequences during interaction with a bound electron.

The photoelectric effect provides constraints on the characteristic field amplitudes, local interaction dimensions, and the amount of energy transferred during an electron-ejection event.

This establishes an important distinction between two complementary tasks:

$$\text{field dynamics} \rightarrow E_0, B_0$$

and

$$\text{interaction with matter} \rightarrow \text{constraints on } E_0, B_0.$$

Agreement between these two routes would provide a substantially stronger test of the model than either approach alone.

12.7. Experimental Verification

The proposed model should ultimately be tested through observations that distinguish its structural predictions from a description based only on conventional wave parameters.

Part B2 identifies possible tests associated with transverse coherence, coherent merging, structural growth, and the characteristic transverse radius R_0.

Part B3 provides a separate experimental route through interaction with bound electrons and the photoelectric effect.

These later investigations do not remove the need for a complete field solution. They provide independent empirical constraints that such a solution must satisfy.

The strongest development of the model would therefore combine three requirements:

$$\text{Maxwell-consistent field structure},$$
$$"\{stable\ transverse\ dynamics\},$$

and

$$\text{agreement with interaction experiments.}$$

The purpose of Part B1 is to establish the common physical framework within which these requirements can be investigated. [1]–[7]

13. Conclusions

This paper introduces a conceptual three-dimensional interpretation of an electromagnetic wave as a continuous, periodically evolving physical structure.

The proposed electromagnetic wave is not treated as a succession of independent objects.

Successive half-wavelength regions represent different phases of one connected electromagnetic process whose internal field organization changes continuously during propagation.

The model considers an approximately annular transverse organization of the electric and magnetic fields and assigns an important role to Maxwell's displacement current. The quarter-period relationship between a varying electric field and displacement current provides the temporal basis for a proposed intermediate electromagnetic configuration connecting successive phases of the wave.

This intermediate configuration is not interpreted as an additional independent form of energy. It represents a complementary organization of the electromagnetic field through which continuity and energy redistribution may be maintained.

The model proposes that transverse geometry may be regulated by the Ez–B phase relationship. A common longitudinal reference Ez0 is hypothesized to mark the state where average radial energy transport vanishes; the states below and above it are associated with contraction and expansion.

At the proposed Ez0 reference, waves of different energies may possess different transverse radii while maintaining comparable transverse field amplitudes. This requires a feedback law not yet derived from Maxwell's linear equations.

Part B1 establishes this geometrical and dynamical foundation.

Part B2 examines coherent merging, energy-dependent size, radius growth, and changes in energy and geometry during propagation, extending the proposed equilibrium framework.

Part B3 then examines the local interaction of these structures with bound electrons. The photoelectric effect provides a route for constraining the characteristic field amplitudes and local interaction geometry and for distinguishing the total energy of an electromagnetic wave from the energy transferred in an individual electron-ejection event.

The three parts therefore address successive levels of the same model:

Part B1: physical structure of the EM wave

Part B2: evolution and growth of the EM − wave structure

Part B3: *local interaction of the EM wave with matter*

The principal unresolved theoretical requirement is now more sharply defined. A complete three-dimensional electromagnetic field solution must reproduce the proposed geometry, periodic transformation, energy transport, and transverse stability while satisfying Maxwell's equations and the full electromagnetic momentum balance.

Part B1 therefore serves not as the final quantitative description of the electromagnetic wave, but as the conceptual foundation on which the subsequent structural and interaction-based analysis is built.

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