Measuring the Geometry of Coherent Electromagnetic Structures

Franc Rozman & UI

Abstract

Measurements of optical coherence are traditionally interpreted as determining the statistical phase correlation of electromagnetic fields. Longitudinal coherence is measured by introducing an optical-path difference between two interfering beams, whereas transverse coherence is determined by the visibility of interference in the double-slit experiment. Although these measurements are fundamental to wave optics, they are generally not interpreted as revealing the geometry of the propagating electromagnetic field.

This paper proposes an alternative interpretation within the framework of the toroidal electromagnetic model. If electromagnetic waves consist of dynamically coupled toroidal field structures, the measured coherence length may represent the ***longitudinal dimension*** *of a coherent electromagnetic chain, while the maximum slit separation supporting stable interference may represent its* ***transverse dimension****. The two complementary experiments would therefore determine the principal geometrical dimensions of the same coherent electromagnetic structure.*

The proposed interpretation does not modify Maxwell's equations or the experimental procedures used in conventional coherence measurements. It changes only the physical interpretation of the measured quantities. Several experimental tests are proposed, including systematic investigations of the dependence of the coherent structure on spectral bandwidth, optical intensity, propagation conditions, and multiple scattering.

The model is formulated as a falsifiable working hypothesis. If future experiments demonstrate that longitudinal and transverse coherence are fully described by conventional statistical theory under all conditions, the proposed interpretation would receive no experimental support. Conversely, if reproducible geometrical relationships are found that cannot be explained solely by statistical coherence, interference experiments may provide direct information about the internal geometry of coherent electromagnetic structures.

1. Introduction

The coherence of light is one of the fundamental concepts of wave optics. It determines whether electromagnetic waves arriving along different paths can produce stable interference. Measurements of coherence have therefore played a central role in optical physics for more than a century.

Two complementary types of coherence are commonly distinguished. **Temporal coherence** is investigated by introducing a difference in optical path length between two beams. The visibility of the interference pattern decreases when the optical-path difference exceeds the coherence length. **Spatial coherence** is investigated by allowing light to pass through two laterally separated apertures. As the separation between the apertures increases, the visibility of the interference fringes gradually decreases.

In conventional electromagnetic theory, these two measurements characterize statistical correlations of the electromagnetic field. The coherence length is interpreted as the longitudinal distance over which the field remains phase correlated, while spatial coherence describes the correlation of the field at different transverse positions. These concepts have proven highly successful in describing interference phenomena and are routinely used in optical metrology.

The present work considers a different physical interpretation. In a preceding study, electromagnetic waves were described as localized toroidal field structures capable of forming coherent sequences through weak electromagnetic coupling. Within that framework, coherence is regarded not merely as a statistical property of the field but as a manifestation of a physically connected electromagnetic structure extending through space.

If such coherent electromagnetic structures exist, conventional interference experiments may contain more geometrical information than is usually assumed. The measurement of coherence length could then represent the **longitudinal extent** of a coherent electromagnetic structure, while the double-slit experiment could determine its **transverse extent**. The familiar concepts of temporal and spatial coherence would therefore acquire a direct geometrical interpretation.

The purpose of this paper is not to question the experimental validity of classical coherence theory. The observed interference phenomena remain exactly the same. Instead, we ask whether those same experiments can also be interpreted as measurements of the geometry of coherent electromagnetic structures. This possibility leads to several experimentally testable predictions and suggests new ways of investigating the physical organization of propagating electromagnetic waves.

2. Longitudinal Coherence Measured by Optical-Path Difference

The longitudinal coherence of light is commonly investigated by introducing a controlled difference in optical path length between two portions of the same light beam. One of the simplest realizations of this principle is obtained using a transparent plane-parallel plate. Part of the incident light is reflected from the front surface of the plate, while another part propagates through the material, is reflected from the rear surface, and returns to interfere with the first beam. Similar measurements are routinely performed with Michelson, Fabry–Pérot, and other interferometric arrangements.

When the optical-path difference is small, the two beams remain phase correlated and produce a clear interference pattern. As the path difference is gradually increased, the visibility of the interference fringes decreases. Beyond a certain optical-path difference, stable interference is no longer observed. This experimentally determined distance is known as the **longitudinal coherence length** of the light.

The measured coherence length depends on the spectral purity of the source. Highly monochromatic light, such as that produced by a stable laser, exhibits a much greater coherence length than broadband white light. The experimental procedure, however, is always the same: the maximum optical-path difference supporting stable interference is determined.

Within conventional wave optics, this measurement is interpreted as the longitudinal distance over which the electromagnetic field preserves a sufficiently stable phase correlation. The coherence length is therefore regarded as a statistical property of the electromagnetic field.

The present work considers an alternative interpretation based on the toroidal electromagnetic model. If an electromagnetic wave consists of a sequence of mutually coupled toroidal field structures, the measured coherence length may represent the **physical longitudinal extent of a coherent electromagnetic chain**. In this picture, the disappearance of interference indicates not only the loss of statistical phase correlation but also the end of the dynamically connected toroidal structure.

The experiment itself remains completely unchanged. Only its physical interpretation is different. The measured optical-path difference at which interference disappears is interpreted as the longitudinal dimension of a coherent electromagnetic structure rather than solely as a statistical correlation length.

This interpretation naturally suggests a complementary question. If the optical-path-difference experiment determines the longitudinal dimension of a coherent electromagnetic chain, can the double-slit experiment determine its transverse dimension? The following section examines this possibility.

3. Transverse Coherence Measured by the Double Slit

The double-slit experiment is one of the best known demonstrations of optical interference. When coherent light illuminates two closely spaced slits, each slit acts as a secondary source of electromagnetic waves. The two emerging wavefronts interfere and produce a characteristic pattern of bright and dark fringes on a distant observation screen.

The visibility of the interference pattern depends on the degree of transverse coherence of the incident light. If the separation between the two slits is gradually increased, the visibility of the interference fringes decreases. Beyond a certain separation, stable interference is no longer observed. In conventional optics, this behavior is interpreted as a reduction of the spatial correlation of the electromagnetic field across the two slits.

The experimental procedure is conceptually analogous to the measurement of longitudinal coherence. In the longitudinal experiment, interference disappears when the optical-path difference becomes too large. In the double-slit experiment, interference disappears when the lateral separation between the two slits exceeds the transverse coherence of the incident light.

The present work proposes an alternative geometrical interpretation of this measurement. If an electromagnetic wave consists of a coherent chain of mutually coupled toroidal field structures, the double-slit experiment may determine the **transverse dimension of that coherent chain**.

Within this interpretation, interference is possible only while both slits are illuminated by the same coherent electromagnetic structure.

As the slit separation increases, the probability that a single coherent structure simultaneously reaches both slits decreases. When the slit separation exceeds the transverse extent of the coherent chain, stable interference is no longer expected.

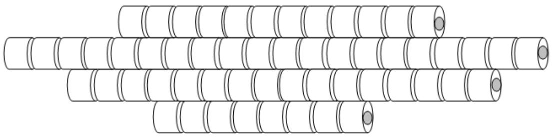

Figure 1. *Schematic representation of a coherent electromagnetic chain composed of mutually coupled toroidal field structures. Each toroidal unit is assumed to represent a localized electromagnetic building block, while neighboring toroids remain phase-locked through weak electromagnetic coupling, forming a single dynamically connected structure. Within the proposed interpretation, the longitudinal dimension of the chain may be determined by optical-path-difference measurements, whereas its transverse dimension may be determined by double-slit interference experiments. The drawing is illustrative and is not intended to represent the actual scale or spacing of the toroidal units*

The experimental observations remain unchanged. Only the interpretation of the measured quantity differs. Instead of regarding the loss of interference solely as a reduction of statistical spatial coherence, the proposed model interprets it as the geometrical limit of a coherent electromagnetic structure extending across both slits.

This interpretation provides a natural complement to the longitudinal coherence measurement. The optical-path-difference experiment characterizes the longitudinal extent of the coherent structure, whereas the double-slit experiment characterizes its transverse extent. Together, the two experiments may therefore determine the principal dimensions of a coherent electromagnetic structure propagating through space.

Within the proposed toroidal model, these two dimensions define the geometry of a coherent electromagnetic chain. The longitudinal dimension is determined by the maximum optical-path difference supporting interference, while the transverse dimension is determined by the maximum slit separation for which a stable interference pattern can still be observed.

4. Interpretation within the Toroidal Model

The preceding sections considered two well-established interference experiments. One determines the maximum optical-path difference for which stable interference is observed, while the other determines the maximum lateral separation between two slits that still produces a visible interference pattern. In conventional optics, these experiments measure longitudinal and transverse coherence, respectively.

The toroidal electromagnetic model proposes that these two measurements may also have a direct geometrical interpretation. Instead of describing only statistical phase correlations, they may determine the physical dimensions of a coherent electromagnetic structure propagating through space.

In the proposed model, an individual electromagnetic wave is represented by a localized toroidal field structure. Neighboring toroidal structures may become electromagnetically coupled through the overlap of their peripheral fields, forming a coherent chain. The chain is therefore regarded as a single dynamically connected electromagnetic object rather than as a collection of independent waves.

Two independent geometrical dimensions characterize such a coherent chain. The first is its **longitudinal extent**, determined experimentally by the largest optical-path difference for which interference remains observable. The second is its **transverse extent**, determined by the greatest separation between two slits that can still be illuminated by the same coherent electromagnetic chain.

Together, these two measurements define the effective geometry of the coherent structure. The longitudinal measurement characterizes its extension along the direction of propagation, whereas the double-slit experiment characterizes its extension perpendicular to the propagation direction. In this interpretation, the two experiments become complementary measurements of the same physical object.

The proposed model therefore distinguishes between two different levels of electromagnetic organization. The elementary building block is the localized toroidal field structure introduced in the preceding work. Coherent light, however, is not assumed to consist of isolated toroidal structures. Instead, many neighboring toroids become phase-locked through weak electromagnetic coupling, producing an extended coherent chain. Interference experiments are then interpreted as measurements of the dimensions of this larger coherent entity rather than of an individual toroidal structure.

This interpretation also provides a possible explanation for the remarkable stability of interference phenomena. Instead of requiring phase correlations to be maintained independently by a large number of separate electromagnetic structures, coherence becomes an intrinsic property of a dynamically connected electromagnetic chain. The observed interference pattern is then a consequence of the geometrical continuity of this chain across the experimental arrangement.

The present interpretation does not modify Maxwell's equations or the observed interference phenomena. It introduces only an additional hypothesis concerning the physical organization of coherent electromagnetic fields. Whether this geometrical interpretation provides experimentally distinguishable predictions is considered in the following section.

5. Predictions Different from Conventional Coherence Theory

The proposed geometrical interpretation is meaningful only if it leads to experimentally testable consequences. If all observable phenomena remain identical to those predicted by conventional coherence theory, the toroidal interpretation would represent only an alternative description of the same experiments. The principal question is therefore whether the coherent electromagnetic chain possesses measurable properties that are not explicitly predicted by the conventional statistical interpretation.

The first prediction concerns the interpretation of longitudinal coherence measurements. Conventional optics regards the coherence length as a statistical property determined by the spectral characteristics of the light source. Within the toroidal model, the same measurement is interpreted as the physical longitudinal dimension of a coherent electromagnetic chain. Although both interpretations describe the same experiment, the latter assigns a direct geometrical meaning to the measured quantity.

A more significant difference appears in the interpretation of transverse coherence. Conventional coherence theory describes the visibility of the double-slit interference pattern as a consequence of the spatial correlation of the electromagnetic field. The toroidal model proposes that the same experiment measures the transverse dimension of a coherent electromagnetic chain. Stable interference is expected only while both slits are simultaneously reached by the same coherent structure.

This interpretation suggests a direct experimental test. A series of double-slit experiments may be performed using a highly monochromatic, spatially filtered laser beam while systematically increasing the separation between the slits. If the interference visibility decreases solely according to the established theory of spatial coherence, the conventional interpretation is sufficient. If, however, a reproducible limiting slit separation is observed that cannot be explained by the spatial coherence of the source, beam geometry, detector resolution, or other known experimental factors, this would indicate the existence of an additional geometrical property of the propagating electromagnetic field.

A second prediction follows from the combination of the two complementary interference experiments discussed in this paper. If the longitudinal coherence experiment determines the length of the coherent electromagnetic chain and the double-slit experiment determines its transverse width, then together they provide two independent geometrical dimensions of the same propagating structure. Such a geometrical interpretation is absent from the conventional theory, where longitudinal and transverse coherence are treated as statistical correlation functions without attributing them to a localized physical object.

The proposed interpretation therefore does not seek to replace conventional coherence theory but to extend its physical meaning. The decisive question is whether future experiments can determine whether coherence is solely a statistical property of electromagnetic fields or whether it also reflects the geometry of dynamically connected electromagnetic structures

6. Proposed Experiments

6.1 Longitudinal and Transverse Measurements

The proposed interpretation can be tested using established optical methods without introducing new measurement principles. The same prepared light source should be used for two complementary experiments.

The first experiment determines the longitudinal dimension of the coherent electromagnetic structure by introducing an increasing optical-path difference between two interfering beams using a Michelson interferometer, a Fabry–Pérot interferometer, or another suitable interferometric arrangement. The visibility of the interference fringes is recorded as a function of the optical-path difference until interference disappears.

The second experiment determines the transverse dimension using a series of double slits with progressively increasing slit separation. The beam diameter, wavelength, and optical alignment remain unchanged while the visibility of the interference fringes is measured for each slit separation.

Instead of defining coherence by a single threshold value, both experiments should determine the complete visibility functions

$$V_L(\Delta l)$$

and

$$V_T(d),$$

which describe the gradual evolution of interference as a function of longitudinal and transverse separation.

Together, these measurements provide the effective longitudinal dimension

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

and transverse dimension

$$W_{\mathrm{coh}}$$

of the proposed coherent electromagnetic chain.

6.2 Dependence on Physical Conditions

The measurements should be repeated under different physical conditions in order to investigate whether the dimensions of the coherent structure remain constant or vary systematically.

The principal variables include:

- spectral bandwidth,
- optical intensity,
- propagation distance,
- repeated scattering,
- and different types of light sources.

Conventional coherence theory predicts a well-defined dependence on spectral bandwidth, while the toroidal interpretation additionally allows the possibility that the dimensions of the coherent structure depend on the physical organization of the electromagnetic field.

In particular, the model predicts that repeated scattering may reduce the effective dimensions of the coherent electromagnetic chain even when the selected spectral bandwidth remains unchanged. Likewise, if electromagnetic coupling depends on the local energy density, variations of optical intensity may influence the dimensions of the coherent structure.

6.3 Experimental Controls

Any reduction of interference visibility must first be shown not to originate from conventional experimental limitations. Particular attention should therefore be paid to detector resolution, beam diameter, slit geometry, wavefront quality, polarization, mechanical stability, and atmospheric fluctuations.

Measurements should preferably be repeated using different light sources, including single-mode lasers, multimode lasers, and spectrally filtered thermal light, in order to distinguish source-dependent effects from possible intrinsic properties of coherent electromagnetic structures

7. Discussion

The present work does not propose new interference experiments or modify the well-established principles of wave optics. All experiments discussed in this paper are standard optical techniques that have been used for many decades to characterize the coherence of light. The novelty lies exclusively in the physical interpretation of the measured quantities.

In conventional optics, longitudinal and transverse coherence are regarded as statistical properties of the electromagnetic field. The present model suggests that these same measurements may also describe the geometry of a coherent electromagnetic structure composed of mutually coupled toroidal field units. Under this interpretation, coherence is not viewed solely as a statistical correlation but also as a manifestation of a physically connected electromagnetic object.

One of the attractive features of this interpretation is that it unifies two seemingly independent measurements. The optical-path-difference experiment determines the longitudinal dimension of the coherent structure, while the double-slit experiment determines its transverse dimension. Together, these complementary measurements may provide a geometrical description of coherent light.

The proposed model also raises new experimental questions that are not usually considered in conventional coherence measurements. If coherent electromagnetic chains exist, their dimensions may depend not only on the spectral purity of the light but also on the physical conditions under which the light propagates. In particular, repeated scattering, beam intensity, and other processes that may influence the electromagnetic coupling between neighboring toroidal structures could modify the dimensions of the coherent chain. These possibilities remain hypothetical and require dedicated experimental investigation.

An important characteristic of the proposed interpretation is its falsifiability. The model does not rely on qualitative analogies but leads to quantitative experimental questions. If longitudinal and transverse coherence measurements are found to be completely explained by conventional coherence theory under all tested conditions, without revealing any additional geometrical relationships, the proposed interpretation would receive no experimental support. Conversely, if reproducible geometrical limits or systematic relationships are observed that cannot be attributed to known coherence effects, they would motivate further investigation of the physical organization of propagating electromagnetic fields.

The proposed interpretation should therefore be regarded as a working hypothesis rather than a completed theory. Its value depends entirely on experimental verification. The experiments suggested in this paper are intended not to replace conventional coherence theory but to determine whether the familiar concepts of longitudinal and transverse coherence also possess a direct geometrical meaning.

Finally, the proposed interpretation may have implications extending beyond interference phenomena. If coherent electromagnetic structures possess measurable dimensions, similar concepts could become relevant in diffraction, resonant optical cavities, nonlinear optics, and possibly in the interaction between electromagnetic radiation and matter. Whether such connections exist remains an open question for future research.

The present paper should therefore be regarded as a natural continuation of the toroidal electromagnetic model. The preceding work proposed a possible physical structure of the electromagnetic wave, whereas the present work investigates whether the dimensions of such a structure can be determined experimentally using established interference techniques. If confirmed, these experiments would provide the first direct geometrical characterization of coherent electromagnetic structures.

8. Conclusions

This paper has presented an alternative interpretation of two well-established optical coherence experiments. The experiments themselves remain entirely unchanged. The proposed modification concerns only the physical interpretation of the measured quantities.

In conventional wave optics, longitudinal and transverse coherence are regarded as statistical properties of the electromagnetic field. Within the toroidal electromagnetic model, the same measurements may instead represent the geometrical dimensions of a coherent electromagnetic structure composed of mutually coupled toroidal field units.

According to this interpretation, measurements based on optical-path differences determine the **longitudinal extent** of the coherent electromagnetic chain, while double-slit experiments determine its **transverse extent**. Together, these complementary experiments may therefore provide a direct geometrical characterization of coherent light.

The proposed interpretation leads naturally to a number of experimentally testable predictions. In particular, it suggests investigating possible relationships between the dimensions of the coherent electromagnetic chain and such quantities as spectral bandwidth, light intensity, propagation conditions, and repeated scattering. These experiments employ conventional optical techniques and therefore require no fundamentally new measurement principles.

The hypothesis presented here should be regarded as a working physical model rather than an established description of electromagnetic coherence. Its validity depends entirely on experimental verification. If future measurements reveal no deviations from the predictions of conventional coherence theory, the proposed geometrical interpretation would receive no experimental support. Conversely, if reproducible geometrical relationships are found that cannot be explained solely by statistical coherence, they would indicate that coherent electromagnetic fields possess an internal physical organization extending beyond the conventional statistical description.

The principal contribution of this work is therefore not a new interference experiment, but a new question: **Do coherence measurements characterize only statistical phase correlations, or do they also reveal the geometry of coherent electromagnetic structures?** The answer to this question can be obtained experimentally and may contribute to a deeper physical understanding of the organization of propagating electromagnetic waves.

If coherence measurements are ultimately shown to determine not only statistical correlations but also the geometry of coherent electromagnetic structures, interference experiments may become one of the most direct experimental tools for investigating the internal organization of propagating electromagnetic waves.