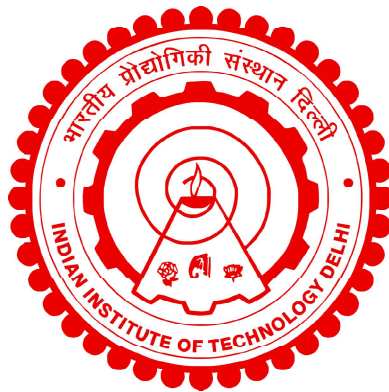


INVESTIGATIONS ON LONGITUDINAL SPATIAL COHERENCE OF ELECTROMAGNETIC OPTICAL FIELDS

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INDIAN INSTITUTE OF TECHNOLOGY DELHI

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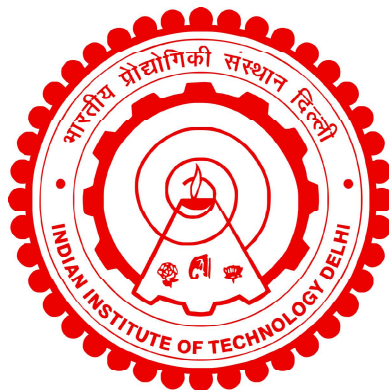
GAYTRI ARYA

Department of Physics

Submitted

in partial fulfillment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY
DELHI**

MAY 2024

Dedicated to My Parents and Teachers

Certificate

This is to certify that the thesis entitled “ **Investigations on Longitudinal Spatial Coherence of Electromagnetic Optical Fields** ”, submitted by **Gaytri Arya** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** in Physics, is a record of the original, bonafide research work carried out by her under my supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

Prof. Bhaskar Kanseri
Thesis Supervisor
Department of Physics,
Indian Institute of Technology Delhi.

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Abstract

This thesis examines the longitudinal spatial coherence (LSC) for electromagnetic (EM) fields, including higher-order correlations. The investigation of the vectorial aspect of the EM field for LSC begins with two-point quantities called electromagnetic degree of coherence (EMDOC) and degree of cross-polarization (DOCP). Theoretical and experimental results for monochromatic fields infer the role of LSC in the intensity modulations. The generalized EM interference law is derived, which delineates the role of LSC on the modulations in Stokes parameters for the interference of the fields from two extended sources. We analyze the degree of polarization (DOP) using Stokes parameters for various amplitude and polarization distributions on the source plane. Our experimental findings on DOP align with the theoretical predictions. Further, longitudinal coherence consists of temporal coherence and LSC, employed to manipulate the Stokes scintillations. By utilizing the angular diversity principle of LSC, the variation of Stokes scintillations resulting from temporal coherence can be adjusted within a smaller range of longitudinal shifts. The theoretical and experimental analysis of the Hong-Ou-Mandel (HOM) interference between two LSC beams shows a significant increase in the second-order correlation with an increase in the difference of angular widths. An interesting aspect of utilizing LSC beams in the HOM setup is the dependence of second-order correlations on the individual angular width of an LSC beam in one arm of the interferometer. The theoretical foundation of LSC beams assumed the field to be spatially incoherent, but the physical realization of the sources tends to be partial spatial coherence. Therefore, the LSC is investigated for partially coherent sources. The influence of transverse spatial coherence of the source and the propagation of the fields resulted in the degradation of LSC. This demands optimized parameters for efficient imaging systems based on LSC. The study of LSC in different directions made in the thesis is expected to contribute to understanding LSC and its efficient implementation in a wide variety of areas, such as optical coherence tomography (OCT), holography, ghost imaging etc.

सार

यह थीसिस उच्च-क्रम सहसंबंधों सहित विद्युत चुम्बकीय (ईएम) क्षेत्रों के लिए अनुदैर्घ्य स्थानिक सुसंगतता (एलएससी) की जांच करती है। एलएससी के लिए ईएम क्षेत्र के सदिश पहलू की जांच दो-बिंदु मात्राओं से शुरू होती है जिन्हें विद्युत चुम्बकीय सुसंगतता की डिग्री (ईएमडीओसी) और क्रॉस-ध्रुवीकरण की डिग्री (डीओसीपी) कहा जाता है। मोनोक्रोमैटिक क्षेत्रों के लिए सैद्धांतिक और प्रयोगात्मक परिणाम तीव्रता मॉड्यूलेशन में एलएससी की भूमिका का अनुमान लगाते हैं। सामान्यीकृत ईएम हस्तक्षेप कानून व्युत्पन्न किया गया है, जो दो विस्तारित स्रोतों से क्षेत्रों के हस्तक्षेप के लिए स्टोक्स मापदंडों में मॉड्यूलेशन पर एलएससी की भूमिका को चित्रित करता है। हम स्रोत तल पर विभिन्न आयाम और ध्रुवीकरण वितरण के लिए स्टोक्स मापदंडों का उपयोग करके ध्रुवीकरण की डिग्री (डीओपी) का विश्लेषण करते हैं। डीओपी पर हमारे प्रायोगिक निष्कर्ष सैद्धांतिक भविष्यवाणियों के अनुरूप हैं। इसके अलावा, अनुदैर्घ्य सुसंगतता में अस्थायी सुसंगतता और एलएससी शामिल होते हैं, जो स्टोक्स सिंटिलेशन में हेरफेर करने के लिए नियोजित होते हैं। एलएससी के कोणीय विविधता सिद्धांत का उपयोग करके, अस्थायी सुसंगतता से उत्पन्न स्टोक्स सिंटिलेशन की भिन्नता को अनुदैर्घ्य बदलावों की एक छोटी श्रृंखला के भीतर समायोजित किया जा सकता है। दो एलएससी बीमों के बीच हांग-ओ-मंडेल (एचओएम) हस्तक्षेप का सैद्धांतिक और प्रायोगिक विश्लेषण कोणीय चौड़ाई के अंतर में वृद्धि के साथ दूसरे क्रम के सहसंबंध में महत्वपूर्ण वृद्धि दर्शाता है। एचओएम सेटअप में एलएससी बीम के उपयोग का एक दिलचस्प पहलू इंटरफेरोमीटर की एक भुजा में एलएससी बीम की व्यक्तिगत कोणीय चौड़ाई पर दूसरे क्रम के सहसंबंधों की निर्भरता है। एलएससी बीम की सैद्धांतिक नींव ने क्षेत्र को स्थानिक रूप से असंगत माना है, लेकिन स्रोतों की भौतिक प्राप्ति आंशिक रूप से स्थानिक सुसंगतता की ओर जाती है। इसलिए, आंशिक रूप से सुसंगत स्रोतों के लिए एलएससी की जांच की जाती है। स्रोत की अनुप्रस्थ स्थानिक सुसंगतता और क्षेत्रों के प्रसार के प्रभाव के परिणामस्वरूप एलएससी का क्षरण हुआ। यह एलएससी पर आधारित कुशल इमेजिंग सिस्टम के लिए अनुकूलित मापदंडों की मांग करता है। थीसिस में किए गए विभिन्न दिशाओं में एलएससी के अध्ययन से एलएससी को समझने और ऑप्टिकल सुसंगतता टोमोग्राफी (ओसीटी), होलोग्राफी, भूत इमेजिंग इत्यादि जैसे विभिन्न क्षेत्रों में इसके कुशल कार्यान्वयन में योगदान की उम्मीद है।

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Abbreviations

BCP	B eam C oherence P olarization
BS	B eam S plitter
CCD	C harged- C oupled D evice
CP	C ircularly P olarized
DOC	D egree O f C oherence
DOCP	D egree O f C ross P olarization
DOP	D egree O f P olarization
EF	E lectric F ield
EM	E lectro- M agnetic
EMDOC	E lectro- M agnetic D egree O f C oherence
EP	E lliptically P olarized
FF-OCT	F ull- F ield O ptical C oherence T omography
FWHM	F ull- W idth H alf M axima
GAF	G aussian A mplitude F ilter
GSM	G aussian S chell M odel
GSP	G eneralized S tokes P arameter
HBT	H anbury B rown and T wiss
HOM	H ong- O u- M andel
HWP	H alf W ave P late
LP	L inearly P olarized
LSC	L ongitudinal S patial C oherence
MCF	M utual C oherence F unction
MO	M icroscope O bjective
NA	N umerical A perture
OCT	O ptical C oherence T omography
QWP	Q uarter W ave P late

RGGD	R otating G round G lass D iffuser
SDC	S patial D egree of C oherence
SOP	S tate O f P olarization
TSC	T ransverse S patial C oherence
VCZ	v an C ittert Z ernike

Symbols

ω	Angular frequency
θ	Angular width
α	Angle subtended by an arbitrary point source
Γ_{ij}	Beam coherence polarization matrix element
$P(\mathbf{r}_1, r_2, \tau)$	Degree of cross-polarization
$S_n(\mathbf{r}_1, \mathbf{r}_2, \tau)$	Generalized Stokes parameters
$I(r)$	Intensity
$\rho_{\parallel}$	Longitudinal spatial coherence length
Δz	Longitudinal shift
Ψ	Mutual coherence function
γ_{ϵ}	Normalized electromagnetic degree of coherence in space-time
γ	Normalized complex degree of coherence
α_n	Normalized generalized Stokes parameters
$g^{(2)}$	Normalized second-order correlation
$J(\mathbf{r}, t)$	Polarization matrix
c	Speed of light in vacuum
$S_n(\mathbf{r}, t)$	Stokes parameters
k	Wave-vector in free space
l_c	Temporal coherence length
τ	Time difference
σ_g	Transverse spatial coherence length
λ	Wavelength
V_n	Visibility of n^{th} Stokes parameter