Light Propagation Analysis in Holographic Data Storage 
Using a Refractive Parameter

Satoshi Tagami, Daisuke Barada, Toyohiko Yatagai

1 Graduate School of Engineering, Utsunomiya University
2 Center for Optical Research and Education (CORE), Utsunomiya University

E-mail: mt176223@cc.utsunomiya-u.ac.jp

1 Introduction

In order to analyze the noise generated from a holographic data storage, light propagation analysis in the volume hologram is required. The volume hologram consists of refractive index distribution. Conventional light propagation analysis methods in a medium with refractive index distribution are based on numerical analysis such as RCWA and FDTD. However, the calculation volume is limited to a small volume in the numerical methods. In this study, an analytical function based method is proposed.

2 Proposed method

When the change in electric susceptibility is linear to light intensity, it is expressed by

\[ \frac{\chi(r)}{j W} \frac{W_S(r)}{W_R(r)} \] (1)

where \( W_S \), \( W_R \) are signal and reference waves. Here, a refractive parameter \( \alpha \) is introduced and \( \chi(r, \alpha) = \alpha H(r) \), (2)

where \( H \) is a volume hologram function. The wave equation satisfied in the volume hologram is expressed by

\[ \nabla^2 W(r, \alpha) + (1 + \chi(r, \alpha)) W(r, \alpha) = 0 \] (3)

where \( W \) is a solution and can be expanded by

\[ W(r, \alpha) = \sum_{m=0}^{\infty} \frac{1}{m!} \frac{\partial^m W(r, 0)}{\partial \alpha^m} \alpha^m. \] (4)

In the case of \( \alpha = 0 \), eq.(3) is rewritten as

\[ \nabla^2 W(r, 0) + (1 + \chi_0) W(r, \alpha) = 0. \] (5)

This equation is a Helmholtz equation so that plane wave solution is obtained. The plane wave solution is used as an incident beam to the volume hologram. When eq.(3) is differentiated by \( \alpha \) and in the case of \( \alpha = 0 \),

\[ \nabla^2 \frac{\partial W(r, 0)}{\partial \alpha} + (1 + \chi_0) \frac{\partial W(r, 0)}{\partial \alpha} = -H(r) W(r, 0), \] (6)

is obtained. This equation is inhomogeneous Helmholtz equation so that the solution can be written by Green’s function method as follows:

\[ \frac{\partial W(r, 0)}{\partial \alpha} = \int_V \exp \left( \frac{ik\sqrt{1 + \chi_0}|r - r'|}{4\pi|r - r'|} \right) \frac{H(r') W(r', 0)}{d^3 r'}. \] (7)

Similarly, \( m \)th derivatives are expressed by

\[ \nabla^2 \frac{\partial^m W(r, 0)}{\partial \alpha^m} + (1 + \chi_0) \frac{\partial^m W(r, 0)}{\partial \alpha^m} = -H(r) \frac{\partial^{m-1} W(r, 0)}{\partial \alpha^{m-1}}. \] (8)

Thus, \( m \)th derivative can be sequentially obtained by \( m - 1 \)th derivative and the solution expressed by eq.(4) is obtained.

This work has been partially supported by the Japan Science and Technology Agency (JST) under the Strategic Promotion of Innovation Research and Development Program.