

# Spherical Beam Volume Holograms Recorded in Reflection Geometry for Diffuse Source Spectroscopy

Sundeep Jolly

A Proposal Presented to the Academic Faculty  
in Partial Fulfillment of the Requirements for the Degree of  
Bachelor of Science in Electrical Engineering with Research Option

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## **ABSTRACT**

Recent developments in volume holographic materials, methods, and techniques have allowed for the development of novel data storage, optical processing, imaging, interferometric, and spectroscopic technologies [1-4, 6, 8]. Multimodal multiplex spectroscopy (MMS) has been demonstrated to increase the optical throughput of a spectrometer as opposed to that of conventional optical spectrometers [5] and has been implemented using three-dimensional photonic crystals [5] and spherical-beam volume holograms [6-7, 9] as spectral diversity filters. While such efforts have resulted in compact and sensitive Fourier-transform holographic spectrometers [8], there still remains much room for performance improvements. Previous studies [6,7,9] have proven the utility of spherical-beam volume holograms recorded in the transmission geometry as spectral diversity filters for spectrometers; however, limited work has been done with spherical-beam volume holograms recorded in the reflection geometry. It is the major goal of the current study to gauge the potential of reflection geometry holograms recorded on photopolymer film for compact, efficient, and sensitive spectrometers as compared to that of transmission geometry holograms. For a baseline comparison, studies of the spectral operating range and resolution of holograms for the spectroscopic application recorded in both geometries will be performed. Time permitting, studies of the efficacy of reflection geometry holograms in an implementation of a compact Fourier-transform holographic spectrometer will be performed.

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# 1 Introduction and Literature Review

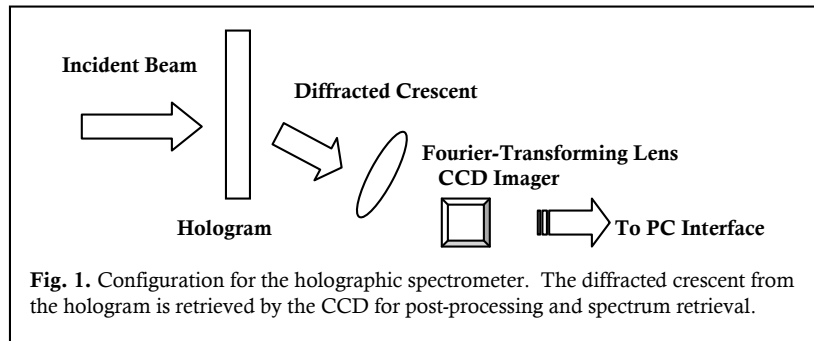
Recent developments in volume holographic materials, methods, and techniques have allowed for the development of novel data storage [1,4], optical processing [4], imaging [2,4], interferometric [4], and spectroscopic [8] technologies. Because of the demand for novel optical technologies employing holographic techniques (especially applications in data storage and integrated optical systems), there has been a recent surge of research activity in the area. It is of notice that holographic technologies are already replacing more conventional optical technologies in applications such as data storage and spectroscopy.

Highly sensitive and portable spectrometers are desirable for applications in biological and environmental sensing especially because the optical sources of interest are diffuse in nature. Conventional spectrometers generally operate by employing gratings for wavelength dispersion and demultiplexing. The intermediate signal achieved by the grating is then usually retrieved by a photodetector for data collection. Because the overlap of multiple spatial modes in some incident signals (for instance, as occurs with diffuse sources) can result in false output patterns, spatial filtering is necessary and is accomplished in conventional spectrometers by means of a slit-lens collimating setup. Although spatial filtering in such a manner can effectively increase the resolution which can be achieved with a grating-based conventional spectrometer, the slit-lens collimator blocks most of the intensity of the original light source [5].

Because of the resolution-throughput tradeoff caused by spatial filtering, conventional spectrometers are highly limited when used with diffuse, incoherent light sources, such as those often encountered in biological and environmental sensing applications. Multimodal multiplex spectroscopy (MMS) has been developed as a method of spectroscopy particularly useful when dealing with diffuse sources [5]. In MMS, an input light source is projected

onto a spectral diversity filter (SDF), which converts the input spatial-spectral signal into an output spectral diversity pattern. In this way, the SDF acts analogously to a more general wavelength dispersive element (such as a prism or holographic grating) but is readily more flexible and eliminates the resolution-efficiency tradeoff of conventional spectrometers. An MMS system would employ a Fourier-transforming lens and a charge-coupled device for processing and capturing of the intermediate signal achieved by the SDF. Post-processing of the output signal retrieved by the CCD can successfully estimate the spectrum of the input signal [5].

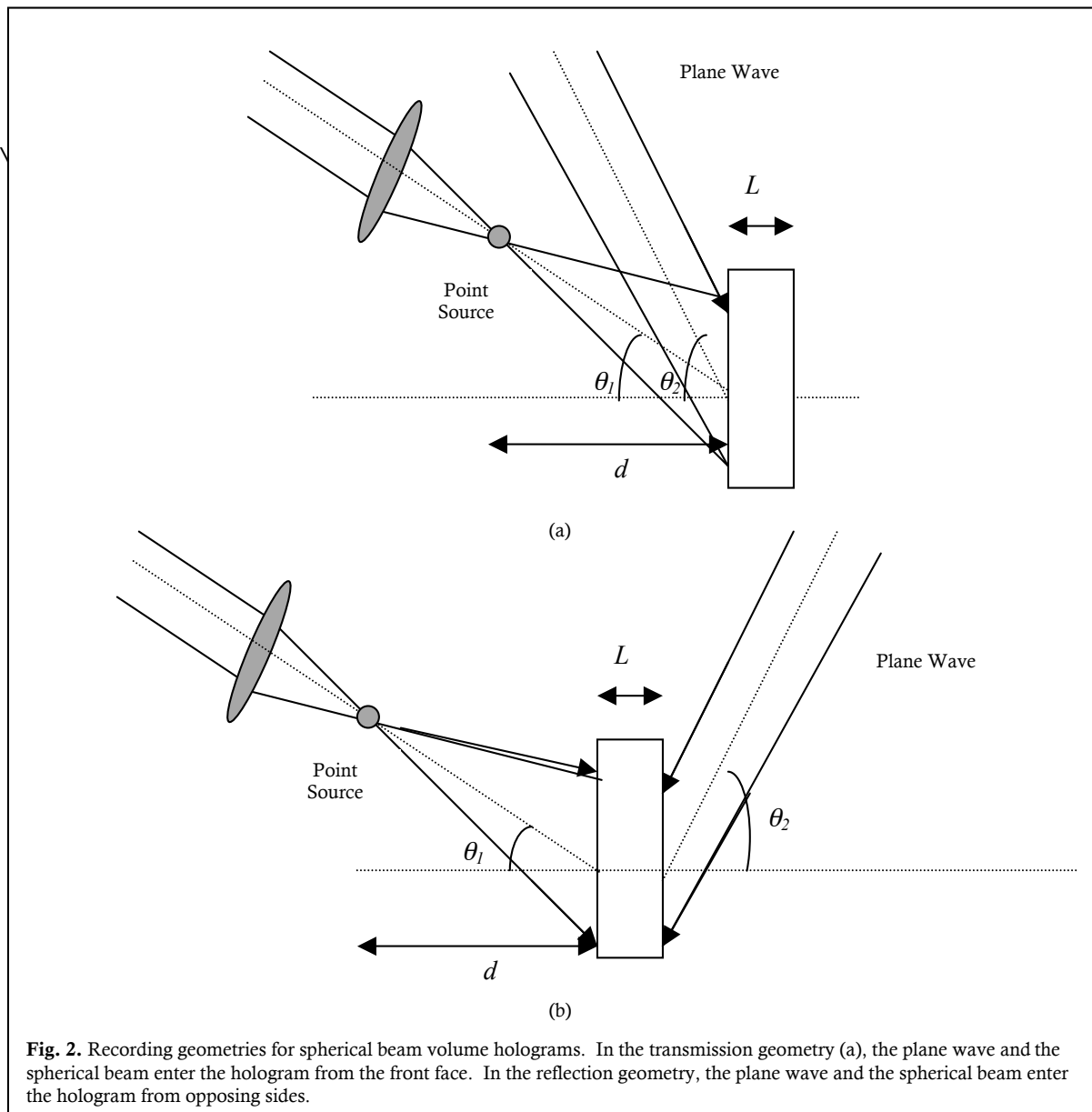
To date, SDFs have been implemented using three-dimensional photonic crystals [5] and spherical-beam volume holograms (SBVHs) [6,7]; MMS systems based on both of these two SDF implementations have been proposed, prototyped, and studied for sensitivity [5,8,9]. Recently, MMS systems for laboratory settings have entered the marketplace, demonstrating the capabilities and promise of this new technology. Of high interest, however, are compact and inexpensive spectrometers employing spherical-beam volume holograms as SDFs for their low cost and high robustness as compared to conventional optical spectrometers.



Currently, volume holographic Fourier-transform spectrometers consisting of one or more volume holograms recorded in a piece of photopolymer along with a Fourier-transforming lens and a detector array have been demonstrated [8]. A typical slitless holographic spectrometer configuration is portrayed in Fig. 1. The key operating feature of the holographic spectrometer is the retrieval of the intermediate spatial-spectral signal achieved by the holographic spectral diversity filter (i.e., the diffracted crescent) by the detector array.

## 2 Problem Statement

Optimizing the parameters that define the spectral diversity filter is essential to improving the sensitivity and resolution of holographic spectrometers. Spherical-beam volume holograms have been shown to be usable for spectral diversity filtering [6] and a compact Fourier-transform spectrometer has been demonstrated using a SBVH as the SDF [8].



**Fig. 2.** Recording geometries for spherical beam volume holograms. In the transmission geometry (a), the plane wave and the spherical beam enter the hologram from the front face. In the reflection geometry, the plane wave and the spherical beam enter the hologram from opposing sides.

Recording geometries for spherical beam volume holograms are shown in Fig. 2. The recording of a SBVH involves the interference of a plane wave (i.e., the signal beam) and a spherical beam (i.e., the reference beam) in the plane of the photopolymer being used. In the transmission geometry, the plane wave enters the photopolymer from the same direction as the spherical beam. In the reflection geometry, the plane wave and the spherical beam enter the photopolymer from opposing directions. Both recording geometries offer unique transmission and diffraction characteristics for recorded holograms.

Previous studies have determined the efficacy of SBVHs recorded in the transmission geometry as SDFs [6,9]. A preliminary study has indicated the potential of SBVHs recorded in the reflection geometry as SDFs and for implementation in compact Fourier-transform spectrometers [7]. However, while the potential of reflection geometry SBVHs for spectral diversity filtering has been asserted, studies of the performance of reflection geometry holograms in spectral diversity filtering and as the key element for a compact holographic spectrometer have not been conducted.

It is the major goal of the current study to gauge the potential of reflection geometry holograms recorded on photopolymer film for compact and highly sensitive spectrometers as compared to that of transmission geometry holograms. For a baseline comparison, studies of the spectral operating range and output holograms recorded in both geometries will be performed. Time permitting, studies of the efficacy of reflection geometry holograms in an implementation of a compact, Fourier-transform spectrometer will be performed.

## **3 Research Goals**

In order to characterize the performance of spherical beam volume holograms recorded in reflection geometry as spectral diversity filters in a holographic spectrometer, several criteria will be examined. The examination of such criteria will be accomplished through a reading setup mimicking the configuration for the holographic spectrometer given in Fig. 1.

### **3.1 Low-Target Goals**

The spectral operating range for a given spectrometer is an important parameter which defines the range of incident wavelengths for which the spectrometer is able to perform most accurately. More specifically, the spectral operating range defines the range of incident wavelengths for which the spectrometer is most sensitive and offers the best resolution and hence the best performance.

As a primary goal, the spectral operating range for holographic SDFs recorded in both the transmission geometry and the reflection geometry will be characterized. Similar recording parameters (i.e., recording time, angle between signal and reference beams, recording beam intensities) will be used to record holograms in both geometries on separate pieces of photopolymer. A monochromator will be used to provide the incident light source. By varying the incident wavelength of the incident source, the spectral operating range for the holograms can be characterized.

### **3.2 Ideal-Target Goals**

Sensitivity, resolution, and the signal-to-noise-ratio are important for characterization of the total performance of a holographic spectrometer. Measurements of sensitivity and resolution will be accomplished by using a reading setup in conjunction with a monochromator for wavelength tunability of the input source. The resolution can be



directly determined from the relationship between a change in incident wavelength and the structure of the output pattern retrieved by the CCD imager. The sensitivity can be determined by quantifying the quality of the output pattern retrieved by the CCD and relating such a quantity to the incident wavelength. The signal-to-noise-ratio can be determined by directly comparing the quality of the output pattern retrieved by the CCD to the incident light intensity on the face of the hologram and using signal-processing tools to determine the amount of noise contained within the output.

Since it is expected that the measurements for the above quantities will not be without error (for, at least, the first few measurements taken), appropriate corrections will be taken to perfect the measurement schemes for these quantities. It is expected that the development of proper measurement techniques for the quantities above will take several weeks.

### **3.3 High-Target Goals**

The application of the holographic spectrometers for diffuse source spectroscopy is of particular interest. Using a diffuser along with an incident wavelength-tunable light source (i.e., a monochromator), studies of all the parameters discussed before (spectral operating range, sensitivity, resolution, and signal-to-noise-ratio) will be performed for holograms recorded in both geometries to determine the performance of these holograms under diffuse incident source conditions.

Multiplexing in volume holograms has been shown [4] to allow for increased performance for holographic spectrometers utilizing holograms recorded in the transmission geometry. Multiplexing involves the recording of multiple holograms in a single piece of photopolymer which, in the case of the holographic spectrometers, allows for greater output resolution while retaining the same photon throughput (and therefore not damaging the efficiency of the holograms). As a high-target goal, studies to determine the ideal multiplexing scheme for holograms recorded in the reflection geometry will be performed and will allow for a comparison of the performance of multiplexed holograms recorded in reflection geometry and that of multiplexed holograms recorded in transmission geometry.

### 3.4 Project Timetable

|                |  |
|----------------|--|
| January 2007   | background reading, create recording / reading setup   |
| February 2007  | finalize recording / reading setups, record holograms, preliminary analysis of hologram characteristics (e.g., diffraction efficiency) |
| March 2007     | record holograms, analyze spectral diversity characteristics roughly, characterize spectral operating range for all holograms          |
| April 2007     | begin measurements of sensitivity, resolution, and signal-to-noise-ratio for holograms   |
| May 2007       | work on measurements of sensitivity, resolution, and signal-to-noise-ratio for holograms   |
| August 2007    | complete measurements for sensitivity, resolution, and signal-to-noise-ratio   |
| September 2007 | begin writing of final thesis, begin measurements for diffuse sources, look into multiplexing methods                                  |
| October 2007   | thesis writing, high-target goals  |
| November 2007  | thesis writing, high-target goals  |
| December 2007  | complete thesis and thesis presentation  |

Note that this timetable will be developed into a more formal Gantt Chart detailing a breakdown of tasks before work on the project begins. This timetable will be modified and update to suit the dynamic, developing needs of the project.

## 4 Implications and Future Research

It is the goal of this research to produce the parameters which will eventually lead to a viable, robust, and versatile volume holographic spectral diversity filter for inclusion as part of a commercially-viable, compact, efficient, and inexpensive MMS-based holographic spectrometer. Such spectrometers have tremendous applications when dealing with diffuse input light sources and where portability and robustness in a spectrometer is highly desirable.

The successful implementation of a spectral diversity filter using a spherical beam volume hologram recorded in the reflection geometry would invariably be followed up by studies to improve the efficacy of such an SDF by further investigation into, for instance, multiplexing methods for overcoming the resolution tradeoff that occurs when using photopolymers of varying thicknesses for better throughput.

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