ECE 299 Holography and Coherent Imaging

Final Exam

7 December 2009

This is a take home exam. Students must not discuss this exam with anyone except Professor Brady prior to turning it in. Any non-human resource (e.g. books, the internet, etc.) may be consulted.

Each problem accounts for 12.5 points

Please write your name here:____

1. Magnification and Gabor Holograms. A transmission electron microscope uses a 200 kV potential to produce electrons with center wavelength 2.5 picometers.

   (a) Sketch the use of this electron beam in a Gabor hologram geometry, indicating the size of the object (h), the object-recording medium range and the holographic recording aperture size.

   (b) Assuming that a Gabor hologram is recorded using the geometry of (a) and reconstructed using an optical beam of wavelength 0.6 micrometers, indicate the maximum resolution one may obtain in reconstructing the object in terms of the electron and optical wavelengths, the object size and range and the holographic recording aperture size.

   (c) Derive an expression for the maximum useful holographic aperture size in terms of the object size and range and the electron and optical wavelengths.

   (d) Assuming that the object is 50 nm in transverse extent and the object range is 5 mm, what is the maximum resolution one could obtain in optical reconstruction of the object?

2. Filtering and bandwidth for off-axis holograms. Write a paragraph comparing the relative advantages and disadvantages of holographic recording using the Gabor geometry, the Leith-Upatneiks geometry and phase shifting interferometry.

3. Resolution of holographic imaging. Consider an object illuminated by a plane wave. Light is scattered under the Born approximation. The wavelength of the illuminating wave is centered at 1.5 microns may be scanned over a 100 nm range. The hologram may be observed over a 1 cm aperture at a range of 10 cm.

   (a) Estimate the transverse and longitudinal spatial resolution one may obtain on the object when the holographic data is collected in a transmission geometry.

   (b) Estimate the transverse and longitudinal spatial resolution one may obtain on the object when the holographic data is collected in a reflection geometry.

   (c) Use sketches of the wavenormal surfaces and object Fourier space to explain the difference between (a) and (b).

4. Bragg degeneracy and wave normal surface diagrams.

(a) Use wave normal surface diagrams to explain why a red light cannot scatter off a reflection hologram recorded using blue light.

(b) What is the largest angle through which a hologram recorded at 633 nm can diffract 514 nm light?

5. Holographic pulse encoding.

Design a system to use a volume hologram to encode a temporal pulse with temporal resolution of 30 femtoseconds and length 10 picoseconds.

(a) Sketch the system geometry.
(b) Assuming that the index of refraction of the holographic recording material is 1.7, how thick must the material be?
(c) Assuming that the hologram modulates light with center wavelength 600 nm, what are the maximum and minimum wavelengths at which the hologram operates?
(d) What is the maximum spectral resolution of the hologram?

6. Computer generated holograms.

   Simulate the use of 1000 dpi black and white printer to make a Fourier transform CGH carrying the image “Go Duke.” Describe your encoding algorithm, show an image of the CGH and show the image that one would observe at a range of 10 cm when your CGH is illuminated by a plane wave of light with wavelength 633 nm.

7. Sampling and digital holograms.

   A 2048 by 2048 pixel focal plane array with 5 micron pixels is used in an off axis geometry to image an object at a range of 20 cm using 500 nm illumination. Estimate the largest size object that one can observe using this system and the resolution with which one can unambiguously reconstruct the object.

8. Reconstruction of a digital hologram.

The figure below shows simulation of a digitally recorded off axis hologram. The units are in mm. The recording wavelength is 600 nm. The figure is linked as digital data on the course web site and is on line at at www.disp.duke.edu/~dbrady/courses/holography/final/finalP8.mat

(a) Estimate the spatial carrier frequency in lp/mm.
(b) Estimate the pixel pitch in lp/mm.
(c) The hologram encodes a secret message (in text) at ranges of 7 and 10 mm. Reconstruct images of the secret messages.