# Optics 513 Final Exam

December 11, 2012

## 1 (15 Pts)

A 20 mm diameter, f/10 lens has 2 waves of third - order spherical when it is illuminated with a collimated beam of HeNe light ($\lambda$ = 633 nm).

a) What is the diameter of the geometrical image of a collimated beam at paraxial focus?

b) How many waves of defocus should be added to give the minimum geometrical spot image and what is the minimum diameter of the geometrical spot image?

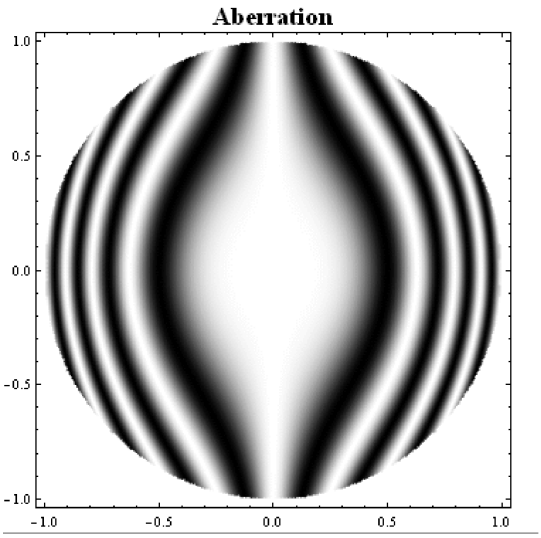
c) How many waves of defocus should be added to maximize the Strehl Ratio?

## 2) (20 Pts)

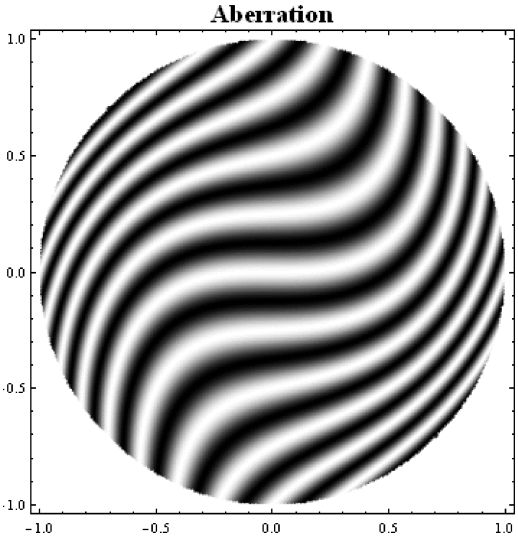
The four interferograms shown below were obtained using a two beam interferometer to test a sample at a wavelength of 500 nm. For the four interferograms the aberration is of the form $Ax\rho^2 + Bx + Cy$, where $\rho = \sqrt{x^2 + y^2}$ and $0 \le \rho \le 1$. Assume A is positive and the same for the four interferograms. Make sure that in your answer the sign is correct for B and C. State any assumptions you are making.

- Interferogram a

Assume bright fringe at left and right edges.

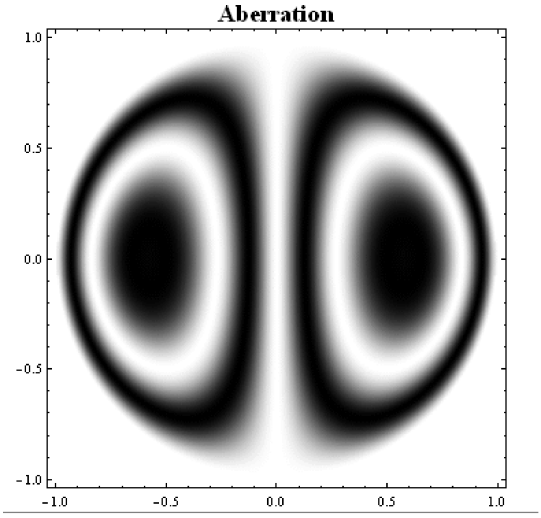


- Interferogram b



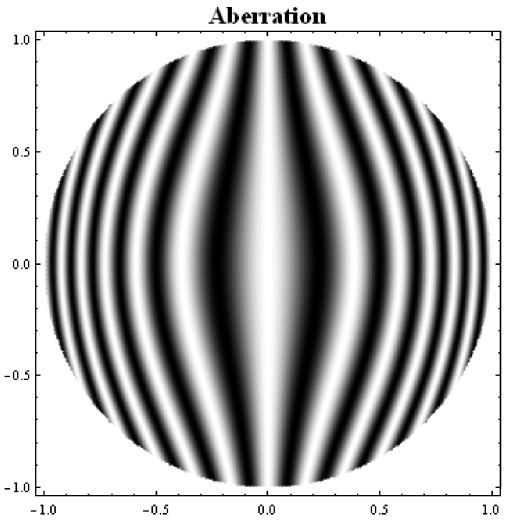

- Interferogram c

Assume bright fringe at left and right edges.



- Interferogram d

Assume bright fringe at left and right edges.




### a)

In units of microns, what is A for Interferogram a?

### b)

In units of microns, what are B and C for Interferogram b?

### c)

In units of microns, what are B and C for Interferogram c?

### d)

In units of microns, what are B and C for Interferogram d?

## 3) (10 Pts)

The Fourier Method is used for direct phase measurement interferometry for testing a mirror whose surface departs from a spherical surface by an amount $10\lambda\ \rho^4$, where $0 \le \rho \le 1$. Remember that in the Fourier method a single interferogram having a large amount of tilt is used and the irradiance falling on the detector array is Fourier transformed and filtered to obtain the wavefront. For simplicity we will assume the detector is an array of point detectors.

a) What is the minimum amount of tilt in units of fringes/radius required to perform the test in order to separate the orders if we are allowed to introduce defocus?

b) What is the minimum number of point detectors needed in the two-dimensional array used to detect the interferogram?

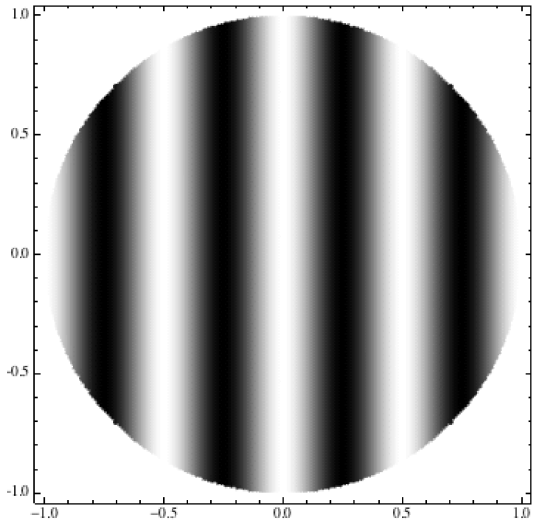
# 4) (5 Pts)

A Mirau interference objective is used in a phase-shifting interference microscope used to measure surface roughness.

Sketch the Mirau interference objective being careful to point out why it works well with a white light source. In a few words, compare the Mirau, Michelson, and Linnik interference objectives.

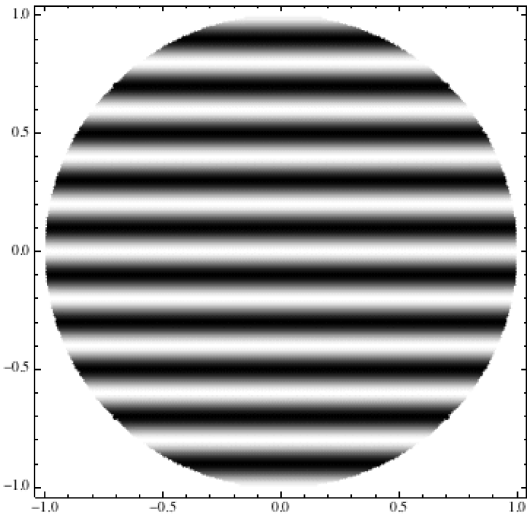
# 5) (10 Pts)

The interferogram shown below was obtained using a HeNe laser operating at a wavelength of 633 nm and a Twyman-Green interferometer to test a 10 cm diameter piece of window glass of refractive index 1.5. Note that there is a bright fringe at both the left and the right edges. Before the window glass was put into the interferometer, the interferometer was adjusted to give a single interference fringe.




a) Approximately how much wedge is in the glass?

b) Before the glass is placed in the interferometer, the interferometer is adjusted to give the interferogram shown below. Note that there is a bright fringe at both the top and the bottom. What would the interferogram look like after the window glass is placed in the interferometer? Assume the window glass has the same orientation for part a and part b.




# 6) (10 Pts)

A laser based Fizeau interferometer is used to test a corner cube.

a) Give two possible advantages of the double pass test compared to the single pass test.

b) If the double pass test is used and the corner cube has a diameter of 5 cm, how many tilt fringes will be introduced into the interferogram if the reference flat is tilted 4.5 arc-seconds. The wavelength is 633 nm. How many tilt fringes if the wavelength is 500 nm?

# 7) (10 Pts)

A scatterplate interferometer is used to test a concave spherical mirror having a 9 mm diameter and 75 mm radius of curvature.

a) The interferometer is adjusted to give a 7 bright vertical tilt fringes across the interferogram with a bright fringe at both the left and right edges of the interferogram for a wavelength of 600 nm. In units of microns, how far was the scatterplate translated from the null fringe position to obtain these 7 tilt fringes?

b) The interferometer is adjusted to give 7 bright circular defocus fringes across the interferogram with a bright fringe at both the center of the interferogram and at the edge of the interferogram for a wavelength of 600 nm. In units of microns, how far was the scatterplate translated from the null fringe position to obtain these 7 circular defocus fringes?

# 8) (10 Pts)

A computer-generated hologram is a convenient way of testing an aspheric wavefront of the form $20\,\lambda\rho^4$.

a) How much defocus should be added to reduce the amount of wavefront tilt that must be introduced in the making of the CGH to separate the + 1 order from the + 2 order? Given this amount of defocus, what wavefront tilt must be introduced to separate the + 1 and + 2 orders?

b) Let the hologram diameter be 1 cm. If a wavefront having a slope of 200 waves/radius is being tested, what is the maximum error introduced by translating the CGH sideways a distance of 10 microns from the optimum position?

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# 9) (10 Pts)

A 10 mm diameter lens having a 20 cm focal length operating at a wavelength of 500 nm is used to image a target.

a) What is the cutoff frequency of the modulation transfer function in image space for incoherent illumination if

i) the target is at infinity?

ii) the target is 40 cm from the lens?

b) A lateral shear interferometer is used to measure the MTF of the lens for a target at infinity. How much shear should be introduced to measure the MTF for a frequency of 50 lines/mm?

TABLE III
ZERNIKE RADIAL POLYNOMIALS

| $n$ | $m$ | No. | Polynomial |
|---|---|---|---|
| 0 | 0 | 0 | $1$ |
| 1 | 1 | 1 | $\rho\cos\theta'$ |
| | | 2 | $\rho\sin\theta'$ |
| | 0 | 3 | $2\rho^2 - 1$ |
| 2 | 2 | 4 | $\rho^2\cos 2\theta'$ |
| | | 5 | $\rho^2\sin 2\theta'$ |
| | 1 | 6 | $(3\rho^2 - 2)\rho\cos\theta'$ |
| | | 7 | $(3\rho^2 - 2)\rho\sin\theta'$ |
| | 0 | 8 | $6\rho^4 - 6\rho^2 + 1$ |
| 3 | 3 | 9 | $\rho^3\cos 3\theta'$ |
| | | 10 | $\rho^3\sin 3\theta'$ |
| | 2 | 11 | $(4\rho^2 - 3)\rho^2\cos 2\theta'$ |
| | | 12 | $(4\rho^2 - 3)\rho^2\sin 2\theta'$ |
| | 1 | 13 | $(10\rho^4 - 12\rho^2 + 3)\rho\cos\theta'$ |
| | | 14 | $(10\rho^4 - 12\rho^2 + 3)\rho\sin\theta'$ |
| | 0 | 15 | $20\rho^6 - 30\rho^4 + 12\rho^2 - 1$ |
| 4 | 4 | 16 | $\rho^4\cos 4\theta'$ |
| | | 17 | $\rho^4\sin 4\theta'$ |
| | 3 | 18 | $(5\rho^2 - 4)\rho^3\cos 3\theta'$ |
| | | 19 | $(5\rho^2 - 4)\rho^3\sin 3\theta'$ |
| | 2 | 20 | $(15\rho^4 - 20\rho^2 + 6)\rho^2\cos 2\theta'$ |
| | | 21 | $(15\rho^4 - 20\rho^2 + 6)\rho^2\sin 2\theta'$ |
| | 1 | 22 | $(35\rho^6 - 60\rho^4 + 30\rho^2 - 4)\rho\cos\theta'$ |
| | | 23 | $(35\rho^6 - 60\rho^4 + 30\rho^2 - 4)\rho\sin\theta'$ |
| | 0 | 24 | $70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$ |
| 5 | 5 | 25 | $\rho^5\cos 5\theta'$ |
| | | 26 | $\rho^5\sin 5\theta'$ |
| | 4 | 27 | $(6\rho^2 - 5)\rho^4\cos 4\theta'$ |
| | | 28 | $(6\rho^2 - 5)\rho^4\sin 4\theta'$ |
| | 3 | 29 | $(21\rho^4 - 30\rho^2 + 10)\rho^3\cos 3\theta'$ |
| | | 30 | $(21\rho^4 - 30\rho^2 + 10)\rho^3\sin 3\theta'$ |
| | 2 | 31 | $(56\rho^6 - 105\rho^4 + 60\rho^2 - 10)\rho^2\cos 2\theta'$ |
| | | 32 | $(56\rho^6 - 105\rho^4 + 60\rho^2 - 10)\rho^2\sin 2\theta'$ |
| | 1 | 33 | $(126\rho^8 - 280\rho^6 + 210\rho^4 - 60\rho^2 + 5)\rho\cos\theta'$ |
| | | 34 | $(126\rho^8 - 280\rho^6 + 210\rho^4 - 60\rho^2 + 5)\rho\sin\theta'$ |
| | 0 | 35 | $252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$ |
| 6 | 0 | 36 | $924\rho^{12} - 2772\rho^{10} + 3150\rho^8 - 1680\rho^6 + 420\rho^4 - 42\rho^2 + 1$ |