APPLIED OPTICS AND LASERS

2021/22

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V1 - 10-10-2021

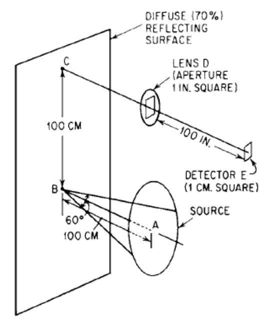
Lab groups

A – RADIOMETRY *(Use exclusively SI symbols)* – select two problems

1. Compute the un-aided human eye retina integrated irradiance of the image of Venus. Use SI units but provide also the result in "number of photons per second, per (μm)^2". Consider the phases of Venus and assess the irradiance as a function of the phase angle.

2. Compute the focal plane spectral irradiance of the image of the Sun within the spectral band 550-560 nm, imaged by an ideal lens of 1 m focal length and maximum diameter of 20 cm. Your sensor is the CCD230-42 Back Illuminated Scientific CCD Sensor, manufactured by E2V. Take note of the possibility of saturation, considering that you can play with the diameter of the stop aperture, even for the minimum exposure.

3. **A** is a circular source with a radiance of 10 W.sr^{-1}.cm^{-2} radiating uniformly toward plane **BC**. The diameter of **A** subtends 60° from point **B**. The distance **AB** is 100 cm and the distance **BC** is 100 cm.



An optical system at **D** forms an **image** of the region about point **C** at **E** *(planes through C and E are conjugated)*. Plane **BC** is a diffuse (lambertian) reflector with a reflectivity of 70%. The optical system (**D**) has a 1 in^2 aperture (1 inch = 2.54 cm) and the distance from **D** to **E** is 2.54 m *(100 inches)*. The transmission of the optical system is 80%. We wish to determine the power incident on a 1-cm square photodetector at **E**.

Determine successively: the irradiance at **B**, the irradiance at **C**, the reflected radiance at **C**, the irradiance of the detector at **E** and finally the power received by the detector.

B – FOURIER OPTICS - all

1. Implement a full numerical model (in Matlab, Phyton, C, …) of the spatial filtering experiment in lab. Consider a simple diffracting object (a cross-periodic amplitude sinusoidal grating (along the x-axis and y axis) with the same period of Λ = 0.1 mm along both axis; the grating is inscribed within a L = 1 cm square) and is illuminated by a plane wave (λ = 0.6328 μm). Consider a Fourier lens with a focal length of f = 50 cm. Sample properly the Fourier plane and check that spectrum maxima are located at the right spatial frequencies. Now, filter the 0-order, recover the object and discuss its modifications (this may be easier for a grating periodic along x, only).

   Notes:
   - Do not hardcode the values of Λ, L, p, λ and f in order to use different objects and Fourier lenses.
   - If you decide to use FFT-2D algorithms, be careful about the asymmetric position of the null frequency.
   - Very useful references:
     - Amidror I, Mastering the Discrete Fourier Transform in One, Two or Several Dimensions - Pitfalls and Artifacts (Springer, 2013)
     - Khare K, Fourier Optics and Computational Imaging (Wiley, 2015)

2. The aperture stop of a typical telescope has the shape of an annular aperture with (usually) straight struts holding the secondary mirror. Assume there are **four** perpendicular struts, aligned in x and y.

   a. Model analytically the complete pupil and compute the PSF **analytically**. Plot the main results in order to identify the effect of the spider' struts and their thickness, t, considering the following parameters (taken from ESO VLT): diameters D_1 = 8.2 m, D_2 = 1.1 m; telescope focal length f = 14.4 m; λ = 10 μm. Consider t = 15 mm and λ = 1 μm.

   b. Now, model the same pupil numerically, with a suitable sampling step (scale it down in order to cope with your computer capabilities, keeping the problem at the same wavelength) and compute the PSF numerically. Add spherical aberration, recompute the PSF and compare. Do it for several values of spherical aberration.

   Notes:

- For spherical aberration, the wavefront aberration is $W = W_{040}\rho^4$. Fix the coefficient in order to have the desired number of λ at the border of the pupil.
- You can find, in section 7.4.1 of Goodman (4rd edition), the corresponding analytical exercice for defocusing, in the framework of the generalized pupil function).
- See also: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjEvOj5lsDzAhWH4YUKHW71Dj0QFnoECAMQAQ&url=https%3A%2F%2Fwp.optics.arizona.edu%2Fjcwyant%2Fwp-content%2Fuploads%2Fsites%2F13%2F2016%2F08%2F03-BasicAberrations_and_Optical_Testing.pdf&usg=AOvVaw2LwJLQQCyfIRmOxs-PT1o9

3. Analyze in detail (and convince me that you did understand it in no more than 5 pages) **one** of the following two important applications of Fourier optics: the ***Lyot coronograph*** (for example, Goodman, 4rd ed, section 8.3.1 & Figure 8.6) *or* ***phase contrast imaging*** (Zernike, 1953 Nobel prize) (for example, Goodman or https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi3sbeBnMDzAhUJEhQKHSraBHsQFnoECAgQAQ&url=http%3A%2F%2Flight.ece.illinois.edu%2FECE460%2FPDF%2FMicroscopy.pdf&usg=AOvVaw3z8RVbBf7c8FLCkU3c4Lk9).

Coming…

C – INTERFEROMETRY

D – COHERENCE

E - LASERS

B – DEVICES AND LINEAR SYSTEMS

4. Design (to 1st order) a 170 m focal length Ritchey–Chrétien telescope, coupled to the CCD sensor CCD230-42 Back Illuminated Scientific CCD Sensor, manufactured by E2V. Estimate FOV, mirror diameters and PSF width.

5. Design a microscope of overall magnification of 200 and a field-of-view of 2 mm, using ideal lenses. Ensure that the exit pupil is 1 cm after the ocular. Compute focal lengths, axial distances and diameters of relevant apertures. The system is supposed to be used by a human with normal vision.

6. The properties of focusing and steering devices depend on the required spatial variations on the phase of the incoming wave, both in space or in time. Address the problem 5.3 of *Goodman, Introduction to Fourier Optics (3rd ed, 2005)*.

7. Diffracting structures can act like focusing devices for a wide range of spectrum domains. Analyze the behavior of the *Fresnel Zone Plate*, solving Problem 5.14 of *Goodman, Introduction to Fourier Optics (3rd ed, 2005)*.

8. Solve the problems 5.9, 5.10, 5.11 of *Goodman, Introduction to Fourier Optics (3rd ed, 2005)*.

9. Analyse the performance of the pinhole camera for different assumptions – Problem 6.7 of *Goodman, Introduction to Fourier Optics (3rd ed, 2005).*

10. The *Iterative Fourier Transform Algorithm* (IFTA), also known as *Gerchberg-Saxton* (GS) algorithm, allows to reconstruct an object from its spectrum provided some assumptions can be accepted on its boundary, positiveness, compactness or spectrum phase. It belongs to the category of "retrieval" algorithms, in case waves amplitude and phase are not simultaneously available. It is an important algorithm to compute holograms that generate user-defined images. Read section 6.6.4 of *Goodman* (a lot of information, including Matlab code, can be found on the *internet*) and show that you have implemented, adapted or played with this algorithm. For example, choose an initial and simple *bounded* image and compute its Fourier transform; discard the spectral phase and do the 'ping-pong' between the direct and reciprocal spaces. The image you selected initially should be partially retrieved… Try to understand if the algorithm is converging, using a suitable metrics. Enjoy!

C - SPATIAL ANALYSIS

11. Represent analytically the amplitude transmission function, $t(x,y)$, of a binary square array (1 cm side) of square apertures (5 μm), pitch of 10 μm in both directions (duty cycle of 50%). Compute its Fourier Transform (FT). [Use all the tools available: δ-Dirac, combs, rect, convolution]. Plot the power spectrum (square of modulus of the FT), and try to see clearly (by adjusting scales and sampling correctly) the effects of the single aperture side, the pitch and side of the envelope aperture.

12. Problem 6.1 of *Goodman, Introduction to Fourier Optics (3rd ed, 2005)* addresses part of the approach to interferometric imaging (the spatial frequency part). Solve it by computing directly the PSF, considering the system is incoherent.

13. Solve the problems 6.10 and 6.12 of Goodman, Introduction to Fourier Optics (3rd ed, 2005).

14. The aperture stop of a typical telescope has the shape of an annular aperture with (usually) straight struts holding the secondary mirror. Assume there are **four** perpendicular struts, aligned in x and y. Model analytically the complete pupil and compute the PSF analytically. Plot the main results in order to identify the effect of the spider' struts and their thickness, t, considering the following parameters (taken from ESO VLT): diameters D_1 = 8.2 m, D_2 = 1.1 m; telescope focal length f = 14.4 m; λ = 10 μm. Consider t = 15 mm.

15. Demonstrate you did understand the section *"Review of Coherent Image Formation"*, pages 461-467 of *J.D.Gaskill, Linear Systems, Fourier Transforms and Optics*. You should a) clearly explain the sequence of imaging or filtering models and also b) regenerate the *Example* (numerical application results and Figure 11.6).

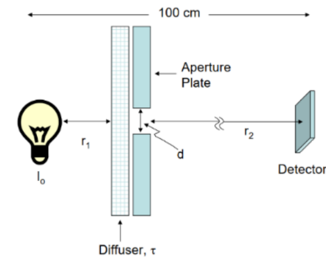
D – RADIOMETRY ***(****Use exclusively SI symbols)*

4. Compute the un-aided human eye retina integrated irradiance of the image of Venus. Use SI units but provide also the result in "number of photons per second, per (μm)^2". Try to take into account the effects of the Earth atmosphere, with suitable (and very well identified) assumptions.

5. Compute the focal plane spectral irradiance of the image of the Sun within the spectral band 550-560 nm, imaged by an ideal lens of 1 m focal length and diameter of 20 cm. Your sensor is the CCD230-42 Back Illuminated Scientific CCD Sensor, manufactured by E2V. Take note of the possibility of saturation, considering that you can play with the diameter of the stop aperture.

6. The irradiance from the Sun at the mean radius of the Earths's orbit around the Sun is E_e = 1353 W/m^2 (the *solar constant*). The Sun subtends a diameter of about 0.535 deg at the Earth. Assuming the Sun to be a circular disk, facing the Earth, what is the average radiance L_s of the Sun over the solar disk? If the Sun were a perfect black body at 6000 K, what would be the approximate solar constant?

7. A lamp with a radiant intensity of 0.1 W.sr^{-1} illuminates a lambertian diffuser 10 cm away with a 1 cm diameter aperture, located just beyond the diffuser; this secondary 1 cm diameter source then illuminates a detector 100 cm from the lamp. What is the irradiance on the detector if the transmission of the diffuser is 0.60?



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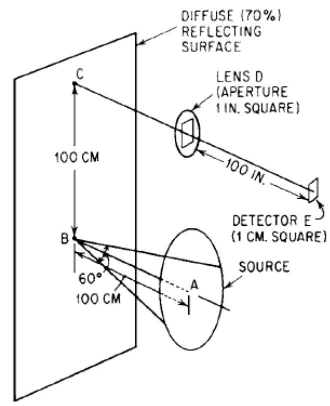

REFERENCES TO BE USED

I. Amidror, The Theory of the Moiré Phenomenon: Vol. I: Periodic Layers, (2nd ed., Springer-Verlag, 2009)
J. W. Goodman, Introduction to Fourier Optics (3rd ed., Roberts & Company, 2005)
J. D. Gaskill, Linear Systems, Fourier Transforms and Optics (Wiley, 1978)