

# APPLIED OPTICS AND LASERS

2021/22

Prof. José Manuel Rebordão

V3 - 7-12-2021

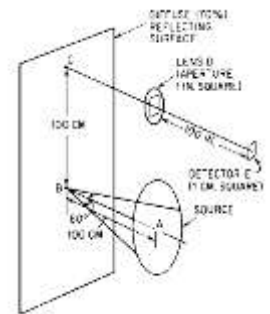
## Lab groups

### 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  $(\mu\text{m})^2$ ”. 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  $10 \text{ W}\cdot\text{sr}^{-1}\cdot\text{cm}^{-2}$  radiating uniformly toward plane **BC**. The diameter of **A** subtends  $60^\circ$  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  $1 \text{ in}^2$  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, Python, 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  $\Lambda = 0.1 \text{ mm}$  along both axis; the grating is inscribed within a  $L = 1 \text{ cm}$  square) and is illuminated by a plane wave ( $\lambda = 0.6328 \mu\text{m}$ ). Consider a Fourier lens with a focal length of  $f = 50 \text{ cm}$ . 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  $\Lambda$ ,  $L$ ,  $p$ ,  $\lambda$  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, very useful references (ask, if necessary):
  - 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  $D_1 = 8.2 \text{ m}$ ,  $D_2 = 1.1 \text{ m}$ ; telescope focal length  $f = 14.4 \text{ m}$ ;  $\lambda = 10 \mu\text{m}$ . Consider  $t = 15 \text{ mm}$  and  $\lambda = 1 \mu\text{m}$ .



- 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  $W = W_{040}p^4$ . Fix the coefficient in order to have the desired number of  $\lambda$  at the border of the pupil.
- You can find, in section 7.4.1 of Goodman (4rd edition), the corresponding analytical exercise 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=2ahUKEwjEvOj5IsDzAhWH4YUKHW71Dj0QFnoECAMQAQ&url=https%3A%2F%2Fwp.optics.arizona.edu%2Ficwyant%2Fwp-content%2Fuploads%2Fsites%2F13%2F2016%2F08%2F03-BasicAberrations\\_and\\_Optical\\_Testing.pdf&usg=AOvVaw2LwJLQQCyfIRmOxs-PT1o9](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjEvOj5IsDzAhWH4YUKHW71Dj0QFnoECAMQAQ&url=https%3A%2F%2Fwp.optics.arizona.edu%2Ficwyant%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 coronagraph** (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>).

### C – POLARIZATION & ELECTROOPTICS – select two problems

Study in Yariv, *Quantum Electronics*, the relevant parts of section 5.4 and chapter 14, as well as Saleh's *Fundamentals of Photonics* (2019 edition), chapter 6. For Mueller matrices, see [https://en.wikipedia.org/wiki/Mueller\\_calculus](https://en.wikipedia.org/wiki/Mueller_calculus)

1. Solve Saleh's Problems 6.1.10 and 6.1.11: demonstrate that you understand this implementation of an anti-glare screen.
2. Solve Saleh's Problem 21.2.2 (electrooptics).
3. Relate linear states of polarization (left and right) and linear polarization states (a state in each set being a linear combination of the states of the other set) apply a birefringence model on circular polarization modes and demonstrate that optical activity rotates the plane of polarization of a linear state, therefore similarly to a half-wave plate. You can use Jones vectors and matrices to describe polarization and transformations. See also Hecht, *Optics*, sections 8.10 and 8.13.

### D – LASERS – select 2 problems

Take as a reference Saleh (2019), chapters 15, 16 and 17. A general overview of laser physics and laser subsystems was presented in class. Study the relevant chapters in more depth in order to tackle two of the following problems:

1. Solve Saleh's Problem 15.4.6 (Resonant Absorption of a Medium in Thermal Equilibrium)
2. Elaborate, as much as you can, on Saleh's Problem 16.3.1 (Operation of an Ytterbium-doped YAG laser)
3. Solve Saleh's Problem 16.4.6 (Q-switched Ruby Laser Power)

Coming...

### E – COHERENCE