Semester S1 – Module 3

Module Fundamentals of coherent photonics

TUTORIAL

SPATIAL OPTICS_2

FREE-SPACE PROPAGATION AND GAUSSIAN BEAMS

Exercise 1: Free space propagation of a Gaussian beam

Let us consider a Gaussian beam with a waist of width $2w_0$ (full width at e^{-1} maximum), propagating along the Oz-axis.

1. Show that at the distance α from the waist (Rayleigh (or Fresnel) length), the beam radius is $\sqrt{2}w_0$.
2. Make the numerical calculus for λ= 1µm, w_0 = 0.01mm ; 1mm ; 10mm ; 1m ; 1m.
3. The Gaussian beam is emitted by a He-Ne laser (λ= 633nm). The diameter of its waist is $2w_0$ = 1mm.
   a. Calculate the beam divergence.
   b. Calculate the beam diameter, the radius of curvature at the distance z = 10m from the waist.

Exercise 2: Some characteristics of an Earth-Moon telemetry experiment

Laser range finding consists of sending a short and powerful light pulse and then measuring the back-and-forth time on a scattering object. The measurement of the Earth-Moon distance is possible thanks to a reflector R previously placed on the lunar ground. This problem is aimed at determining the spatial characteristics of the beam sent to the moon. The laser emits a pulse with a rectangular time profile of duration Δt = 2 ns, an energy of 1 Joule and an average wavelength λ_0= 1060nm. The diameter $2w_0$ of the waist of the Gaussian beam is equal to 10mm. The distance Earth - Moon is L = 3.8 10^5 km.

1. Determine the diameter of the beam on the moon.

2. On the moon, the beam is reflected by a reflector R which will be considered as a single circular plane mirror with a radius r_0 = 0.4 m. The power transmission coefficient of the atmosphere is τ = 0.75. Determine the power collected by the plane mirror. Conclusion?
3. Propose a device at the laser output to increase the power collected by the reflector.

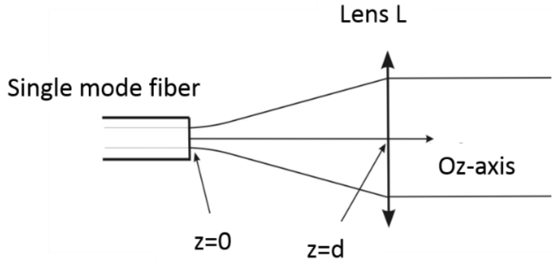
Exercise 3: Coupling of laser light into an optical fiber

We want to couple a Gaussian beam into a single mode fiber by use of a microlens. The laser beam with an wavelength λ_0 = 1.55µm has a diameter of 2 mm. The diameter of the fiber core is 8 µm and its numerical aperture is 0.13.

1. Calculate the Rayleigh length of the Gaussian beam.
2. A microlens is placed approximately 10 cm from the waist.
   a. What can be said about the diameter and wavefront of the beam incident on the lens?
   b. In which plane of the lens should the end of the fiber be placed? Justify the answer.
3. It is assumed that the coupling is optimal when the diameter of the beam (full width at e^{-1} maximum) in the plane of the fiber end is equal to the diameter of the fiber core.
   a. Deduce the value of the divergence of the incident beam on the fiber.
   b. Is it compatible with the numerical aperture of the fiber? Why?
   c. Calculate the corresponding value of the focal length of the lens.

Exercise 4: Collimation of a Gaussian beam

Light propagating inside a single mode fiber diverges at the end of the optical guide. We will quantify this divergence and choose the appropriate lens location to collimate the beam.



Geometry of the beam at the fiber exit; action of the lens L.

We will take as the origin of the Oz-axis the output plane of the optical fiber. The transverse coordinates will be described by the variables x and y. The radiation emitted by the single mode fiber has a Gaussian profile. In the plane z=0, the phase profile is flat and the beam has a diameter equal to $2w_0$ (full width at e^{-1} maximum).

1. The average wavelength used is λ_0 =1.3µm. The radius of the beam w_0 has the value w_0 = 4 µm. Deduce the numerical value of the Rayleigh length α and then the angle of divergence θ of the optical field at long distance.
2. For z >> α, write a simplified expression of the optical field E according to , in particular, α, θ, x, y, z, λ_0.
3. The collimation lens has a focal length f = 300mm. Write the expression of the E_L the field after the lens knowing that it is located in z = d >> α
4. What distance d must be chosen for E_L to have a plane wave structure. Show that the analytical expression of the field is very much simplified when the distance d has been correctly chosen.
5. From this, deduce numerically w_L the radius of the collimated beam after the lens. Then give the corresponding Rayleigh length α_L.

Reminder 1: propagation of Gaussian beams.

A Gaussian beam propagating along the z axis has the following formula:

$$E(x,y,z) = \frac{E_0.e^{\frac{-(x^2+y^2)}{w^2}}.e^{\frac{-j\pi(x^2+y^2)}{R\lambda}}.e^{-jkz}.e^{j\mathrm{arctg}(\frac{z}{\alpha})}}{\sqrt{1+\frac{z^2}{\alpha^2}}}$$

Reminder 2: action of a lens on a beam.

A lens of focal length f acts on a field as a parabolic phase term. Thus for a lens with an optical axis Oz, E' the field after the lens is deduced from the field E before the lens by the formula:

$$E' = E.e^{j.\frac{\pi(x^2+y^2)}{\lambda.f}}$$
