3rd Year Electrical Engineering (ECE)

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Faculty of Engineering

Ain-Shams University

Electromagnetic Waves
(ECE331s)

Project Report

Section: 2

Group: 7

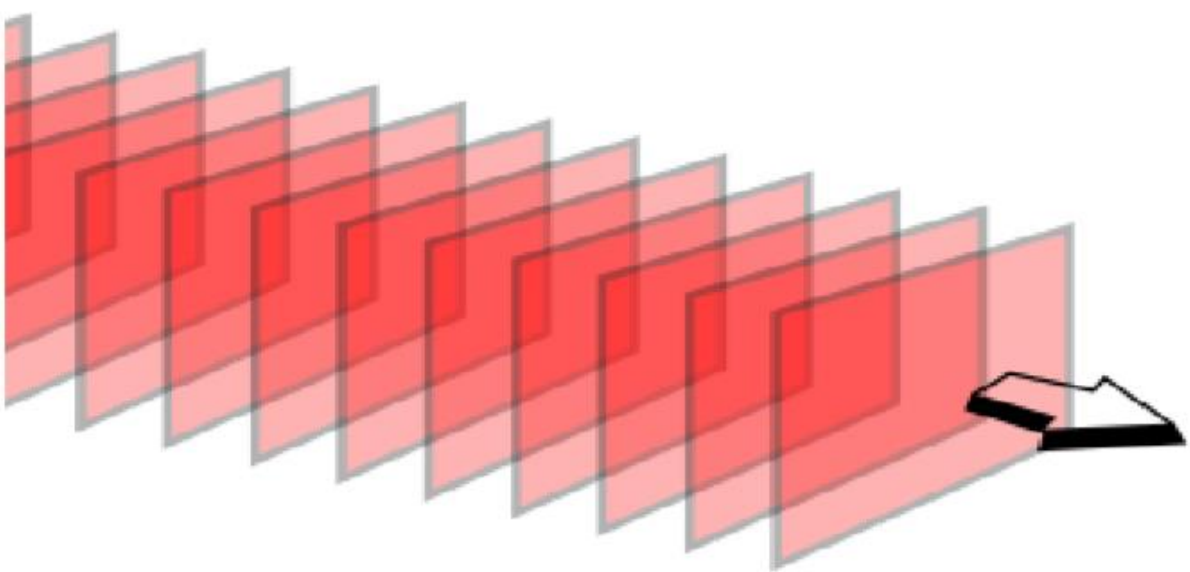
Name	ID
Youssef Ihab Mohamed	**2101044**
Abdallah Mohamed Abdelhameed	**2100523**
Zyad Yasser Mohamed	**2100828**

➢ Introduction:

This report focuses on the simulation and analysis of Gaussian beam propagation using MATLAB. A Gaussian beam, characterized by its field intensity following a Gaussian distribution. Understanding its propagation dynamics is crucial for various applications, including optical communication and laser systems.

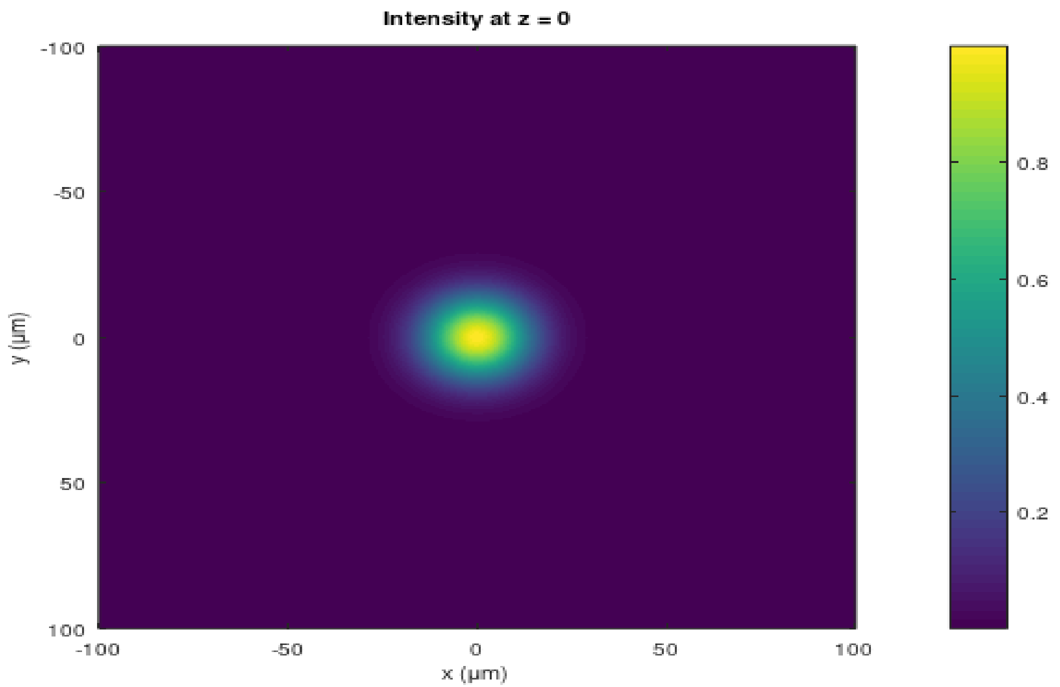
➢ Objective:

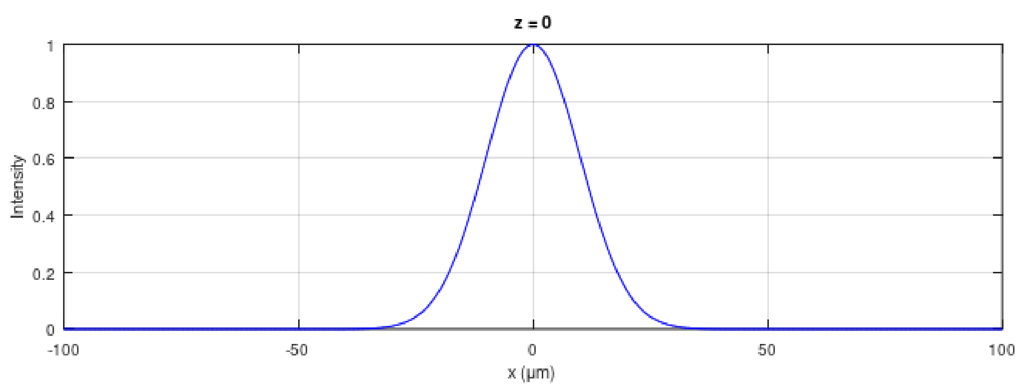
The objective is to validate theoretical predictions through numerical simulations, ensuring that the reflected beam intensities match those of the incident beam at corresponding distances. This report details the simulation approach, MATLAB code, intensity distribution figures, and a comprehensive analysis of the results, providing insights into Gaussian beam propagation and reflection phenomena



➢ MATLAB Code Results:

1)Intensity at $Z = 0$ (Incident Beam):

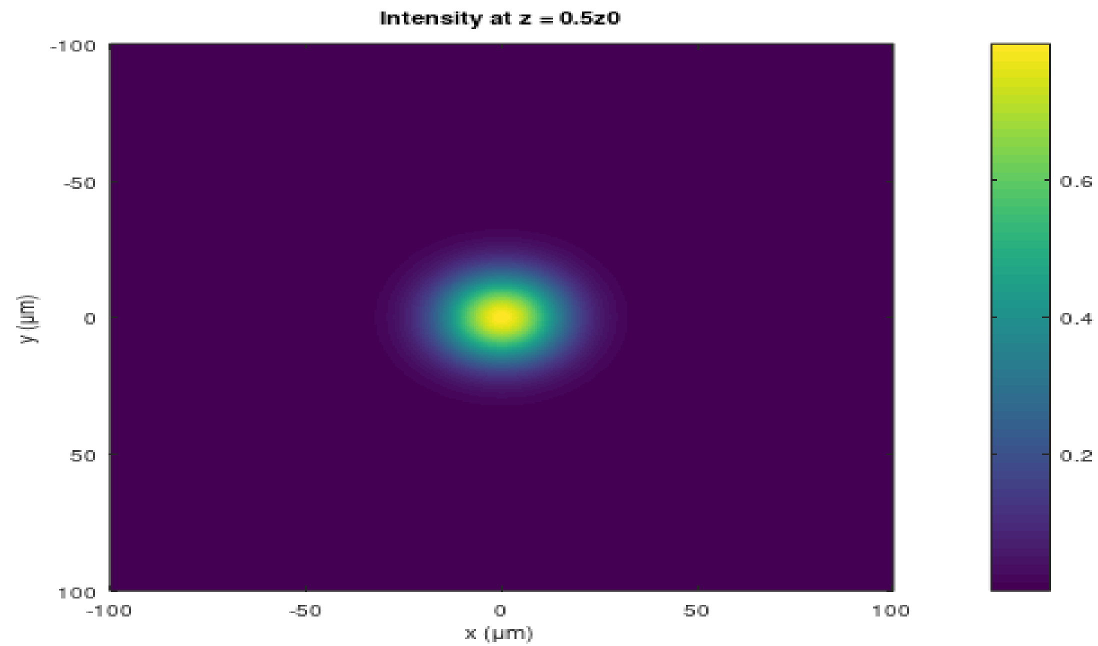


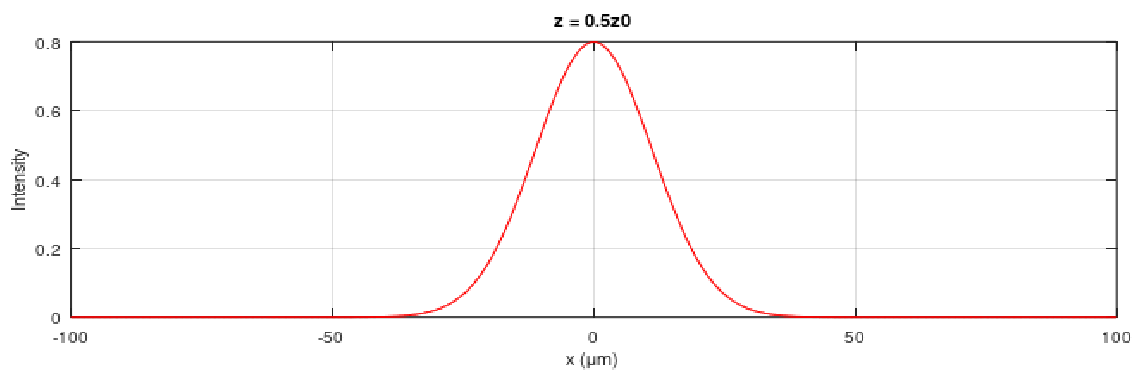


➢ Comment:

As expected, Intensity at $Z = 0$ is the highest intensity $(I(r) = 1)$ with the smallest beam area.

2)Intensity at $Z = 0.5\ Z_o$ (Incident Beam):

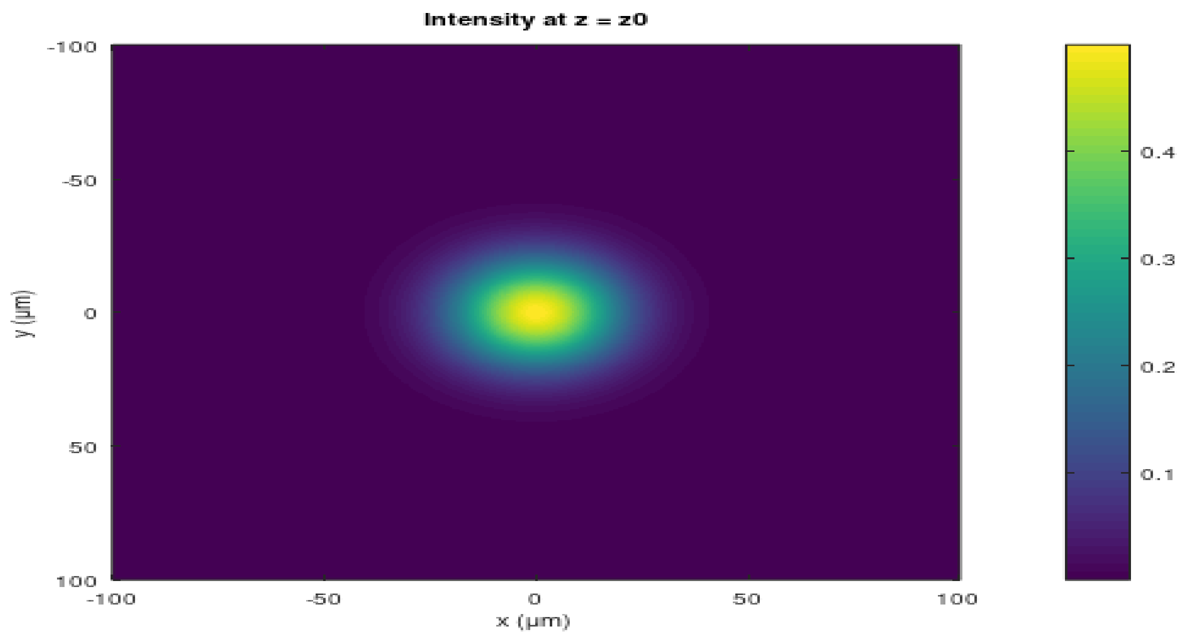


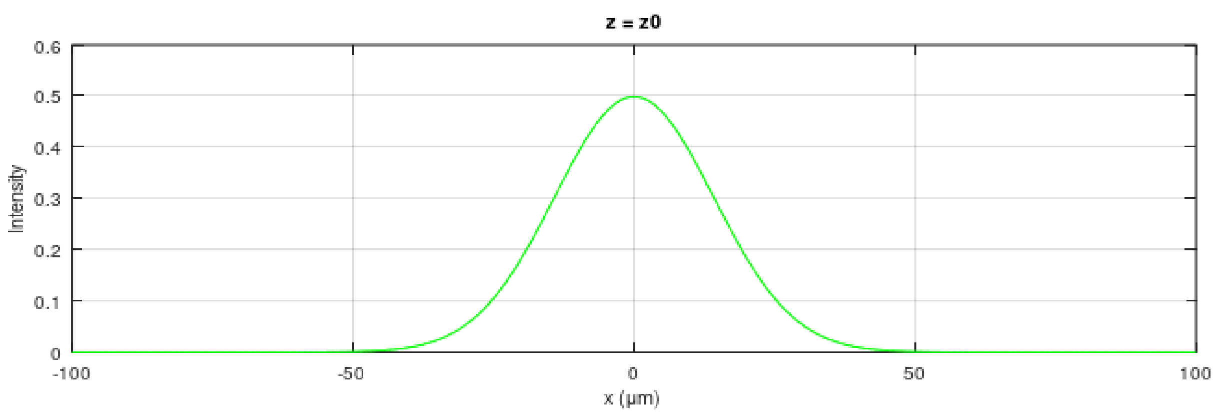


➢ <u>Comment:</u>

As expected, Intensity at $Z = 0.5\ Z_o$ is less than that at $Z = 0$ due to propagation attenuation (field decays) according to gaussian beam intensity equation ($I(r) = 0.8$) with larger beam area than that at $Z = 0$ due to increasing the radial distance ρ.

3)Intensity at $Z = Z_o$ (Incident Beam):

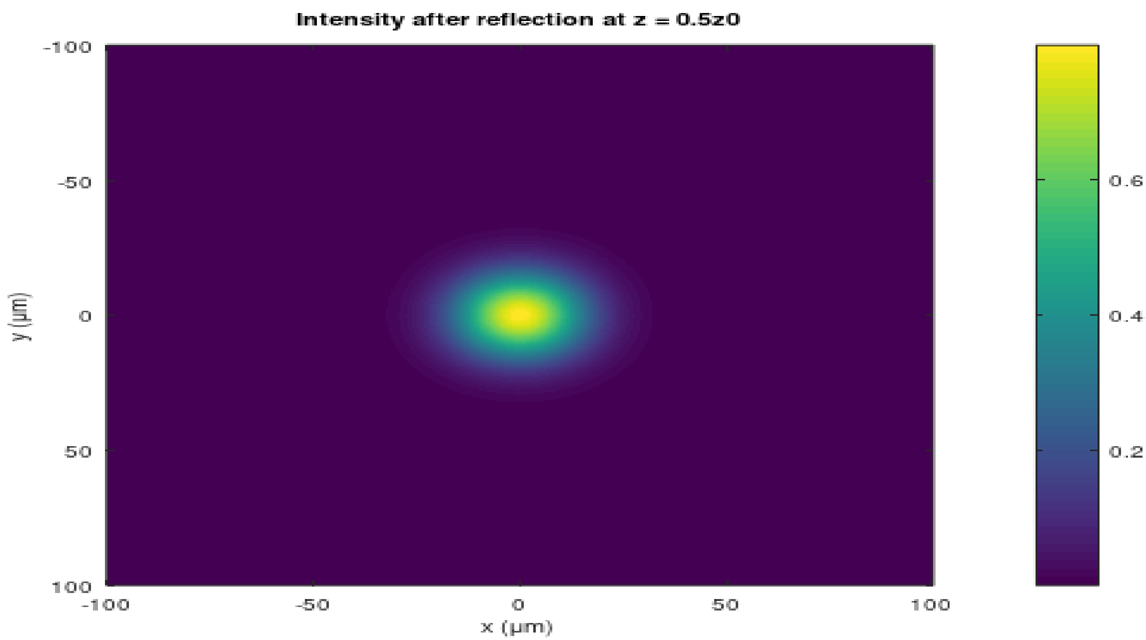


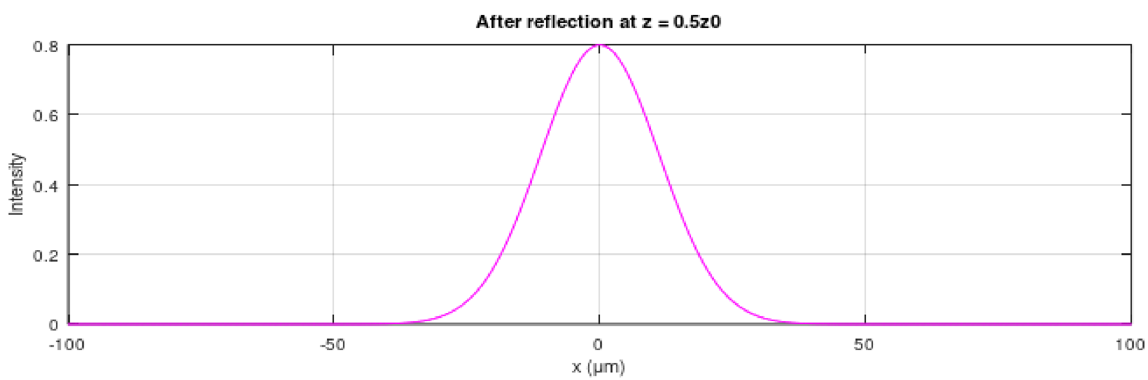


➢ <u>Comment:</u>

As expected, Intensity at $Z = Z_o$ is less than that at $Z = 0.5\ Z_o$ due to propagation attenuation (field decays) according to gaussian beam intensity equation ($I(r) = 0.5$) with larger beam area than that at $Z = 0$ due to increasing the radial distance ρ.

4)Intensity at $Z = 0.5\ Z_o$ (Reflected Beam):

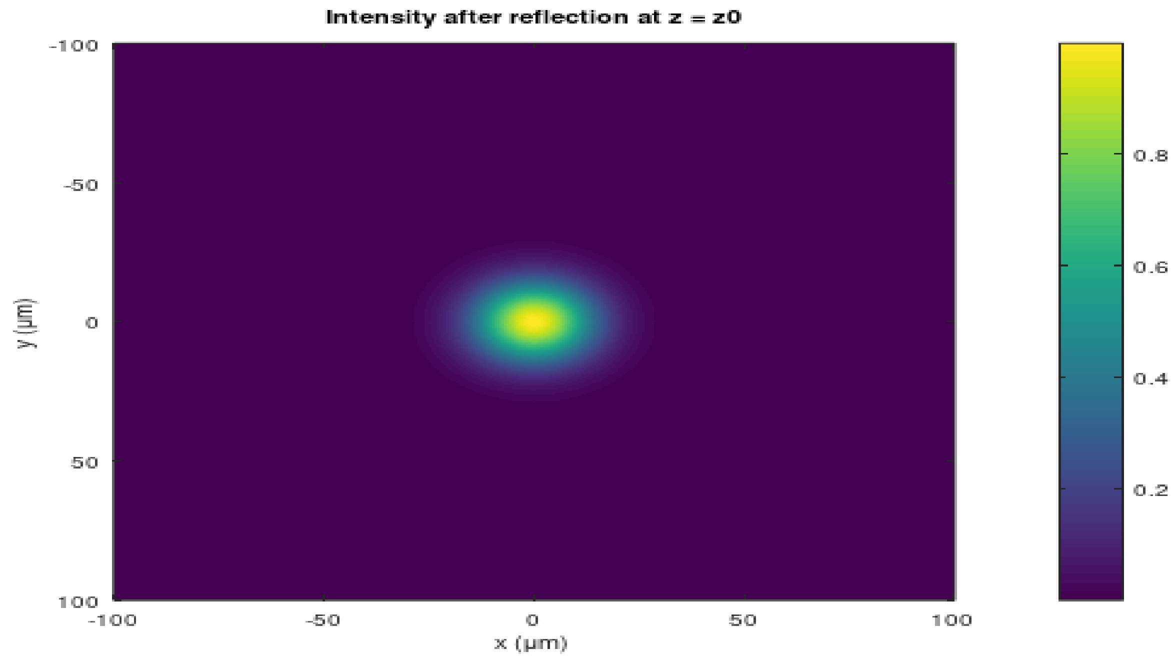


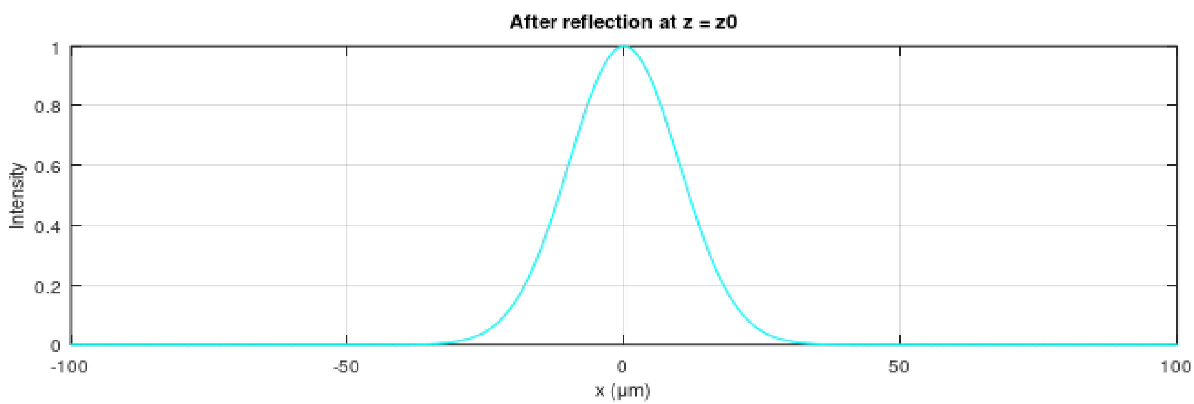


- <u>Comment:</u>

As expected, Intensity at $Z = \ 0.5\ Z_o$ of the reflected beam equals that of the incident beam according to gaussian beam intensity equation and mirror equation ($I(r) = 0.8$) with also the same area for both incident and reflected beams.

5)Intensity at $Z = Z_o$ (Reflected Beam):

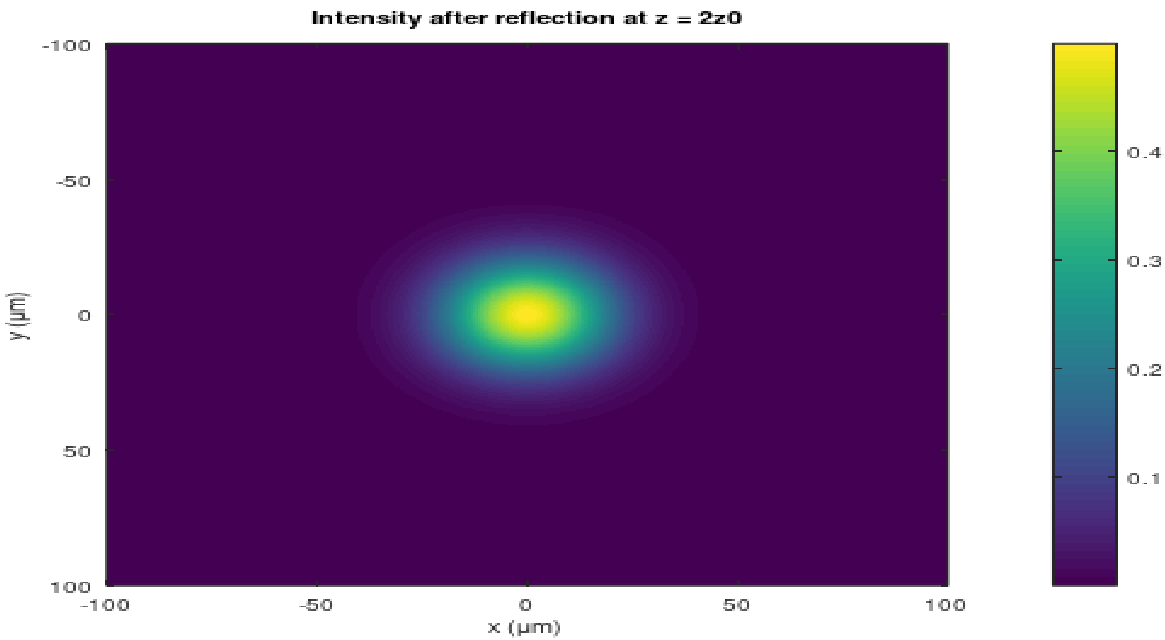


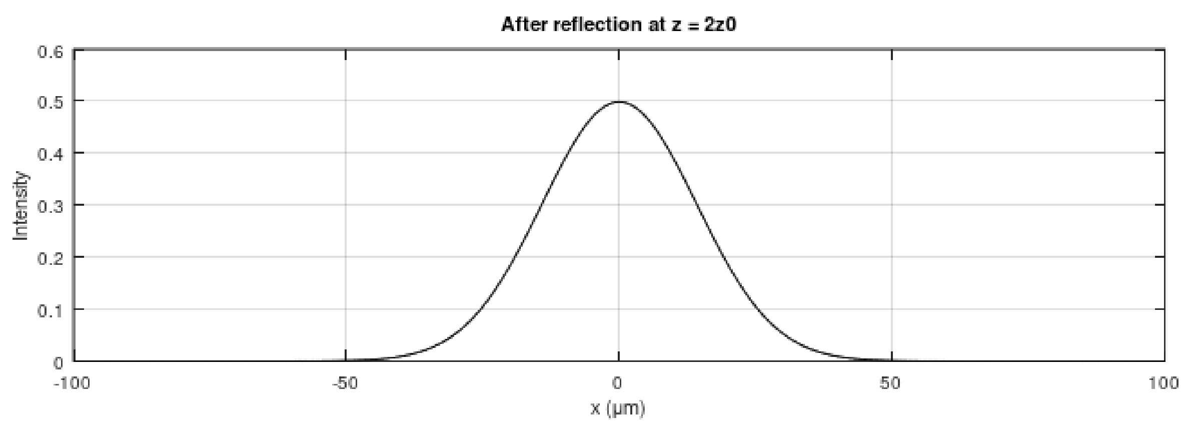


➢ <u>Comment:</u>

As expected, Intensity at $Z = \ Z_o$ of the reflected beam equals that of the incident beam according to gaussian beam intensity equation and mirror equation ($I(r) = 1$) with also the same area for both incident and reflected beams.

6)Intensity at $Z = 2\,Z_o$ (Reflected Beam):

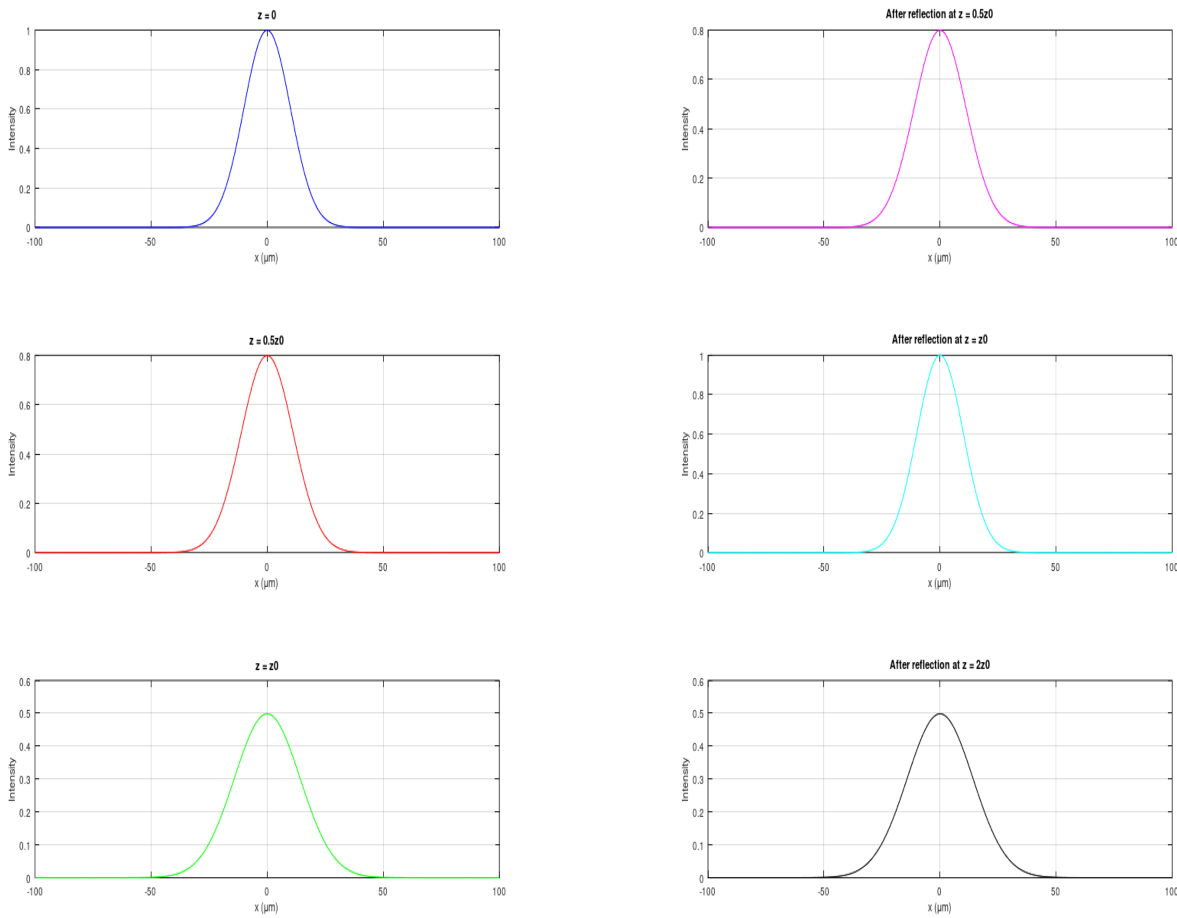




➢ <u>Comment:</u>

As expected, Intensity at $Z = \ 2\,Z_o$ of the reflected beam equals that of the incident beam according to gaussian beam intensity equation and mirror equation ($I(r) = 0.5$) with also the same area for both incident and reflected beams.

➢ Resulting Intensity plots:



➢ Conclusion:

The incident Gaussian beam, characterized by a Gaussian field distribution, exhibits a spatial variation where the field intensity decreases with increasing radial distance ρ. Upon reflection, the intensities of the reflected beam correspond closely to those of the incident beam at equivalent propagation distances.

➢ Full Project Code:

```
% Parameters
lambda = 3.2e-6;             % Wavelength in meters
w0 = 20e-6;                  % Beam waist in meters
k = 2 * pi / lambda;         % Wave number
z0 = pi * w0^2 / lambda;     % Rayleigh range

% Spatial domain
x = linspace(-5*w0, 5*w0, 1024);

y = x;
[X, Y] = meshgrid(x, y);
rho = sqrt(X.^2 + Y.^2);

% Initial Gaussian beam at z=0
U0 = exp(-rho.^2 / w0^2);

% Fourier Transform propagation
dk = 2 * pi / (x(end) - x(1));
kx = linspace(-dk*length(x)/2, dk*length(x)/2 - dk, length(x));
ky = kx;
[KX, KY] = meshgrid(kx, ky);
kz_squared = k^2 - KX.^2 - KY.^2;
kz = sqrt(max(0, kz_squared));         % Avoid imaginary kz

% Propagate beam to 0.5z0 and z0
Uz_0_5 = ifft2(ifftshift(fftshift(fft2(U0)) .* exp(-1j * kz * (0.5 * z0))));
Uz_1 = ifft2(ifftshift(fftshift(fft2(U0)) .* exp(-1j * kz * z0)));

% Reflect from mirror
mirror = exp(-1j * k * (X.^2 + Y.^2) / (-2 * z0));
U_mirror = Uz_1 .* mirror;

% Propagate after reflection
Uz_ref_0_5 = ifft2(ifftshift(fftshift(fft2(U_mirror)) .* exp(-1j * kz * (0.5 *
z0))));
Uz_ref_1 = ifft2(ifftshift(fftshift(fft2(U_mirror)) .* exp(-1j * kz * z0)));
Uz_ref_2 = ifft2(ifftshift(fftshift(fft2(U_mirror)) .* exp(-1j * kz * (2 * z0))));

% Plot intensity at z = 0
figure;
imagesc(x * 1e6, y * 1e6, abs(U0).^2);
```

```
title('Intensity at z = 0');
xlabel('x (\mum)');
ylabel('y (\mum)');
colorbar;

% Plot intensity at z = 0.5z0
figure;
imagesc(x * 1e6, y * 1e6, abs(Uz_0_5).^2);
title('Intensity at z = 0.5z0');
xlabel('x (\mum)');
ylabel('y (\mum)');
colorbar;

% Plot intensity at z = z0
figure;
imagesc(x * 1e6, y * 1e6, abs(Uz_1).^2);
title('Intensity at z = z0');
xlabel('x (\mum)');
ylabel('y (\mum)');
colorbar;

% Plot intensity after reflection at z = 0.5z0
figure;
imagesc(x * 1e6, y * 1e6, abs(Uz_ref_0_5).^2);
title('Intensity after reflection at z = 0.5z0');
xlabel('x (\mum)');
ylabel('y (\mum)');
colorbar;

% Plot intensity after reflection at z = z0
figure;
imagesc(x * 1e6, y * 1e6, abs(Uz_ref_1).^2);
title('Intensity after reflection at z = z0');
xlabel('x (\mum)');
ylabel('y (\mum)');
colorbar;

% Plot intensity after reflection at z = 2z0
figure;
imagesc(x * 1e6, y * 1e6, abs(Uz_ref_2).^2);
title('Intensity after reflection at z = 2z0');
xlabel('x (\mum)');
ylabel('y (\mum)');
```

```
colorbar;

figure;

% Plot intensity at z = 0
subplot(3, 2, 1);
plot(x * 1e6, abs(U0(round(end/2), :)).^2, 'b');
title('z = 0');
xlabel('x (\mum)');
ylabel('Intensity');
grid on;

% Plot intensity at z = 0.5z0
subplot(3, 2, 3);
plot(x * 1e6, abs(Uz_0_5(round(end/2), :)).^2, 'r');
title('z = 0.5z0');
xlabel('x (\mum)');
ylabel('Intensity');
grid on;

% Plot intensity at z = z0
subplot(3, 2, 5);
plot(x * 1e6, abs(Uz_1(round(end/2), :)).^2, 'g');
title('z = z0');
xlabel('x (\mum)');
ylabel('Intensity');
grid on;

% Plot intensity after reflection at z = 0.5z0
subplot(3, 2, 2);
plot(x * 1e6, abs(Uz_ref_0_5(round(end/2), :)).^2, 'm');
title('After reflection at z = 0.5z0');
xlabel('x (\mum)');
ylabel('Intensity');
grid on;

% Plot intensity after reflection at z = z0
subplot(3, 2, 4);
plot(x * 1e6, abs(Uz_ref_1(round(end/2), :)).^2, 'c');
title('After reflection at z = z0');
xlabel('x (\mum)');
ylabel('Intensity');
grid on;
```

```
% Plot intensity after reflection at z = 2z0
subplot(3, 2, 6);
plot(x * 1e6, abs(Uz_ref_2(round(end/2), :)).^2, 'k');
title('After reflection at z = 2z0');
xlabel('x (\mum)');
ylabel('Intensity');
grid on;
```