Scilab Textbook Companion for Optical Fiber Communication by A. Kalavar[1]

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Book Description

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Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

Contents

List of Scilab Codes

Chapter 1

Introduction to Optical Fiber Communication

Scilab code Exa 1.10.1 Computing maximum capacity of channel

```
// Example 1.10.1  page 1.19

clc;
clear;

Bandwidth = 2d6;      //Bandwidth of channel
Signal_to_Noise_ratio = 1;              //Signal to
   Noise ratio of channel

Capacity = Bandwidth * log2(1 +
   Signal_to_Noise_ratio); //computing capacity
Capacity=Capacity/10^6;

printf("Maximum capacity of channel is %d Mb/sec.",
   Capacity);
```

Scilab code Exa 1.13.1 Determine duration of shortest and widest optical pulse

```
// Example 1.13.1  page 1.30

clc;
clear;

Bit_rate = 2d9;       // bit rate of channel
// Given sequence is 010111101110

Shortest_duration = 1 * (1/Bit_rate);      // shortest duration is '1'
Widest_duration = 4 * (1/Bit_rate);      //widest duration is '1111'

Shortest_duration=Shortest_duration*10^9;        // Converting into nano seconds
Widest_duration=Widest_duration*10^9;        // Converting into nano seconds

printf("\nShortest duration is %.1f nano second.",Shortest_duration);
printf("\nWidest duration is %d nano second.",Widest_duration);
```

Chapter 2

Optical Fibers

Scilab code Exa 4.q Find briefrengence

```
// Question 4  page 2.75

clc;
clear;

L_BL=8d-2;    //beat length

Br=2*3.14/L_BL;      //computing modal briefringence
printf("\nModal briefringence is %.1f per meter.",Br
   );
```

Scilab code Exa 5.q Determine modal briefringence

```
// Question 5  page 2.76

clc;
clear;

```

```
L_BL=0.6d-3;    //beat length
lamda=1.4d-6;    //wavelength
L_BL1=70;
Bh=lamda/L_BL;      //computing high briefringence
Bl=lamda/L_BL1;      //computing low briefringence

printf("\nHigh briefringence is %.2e.\nLow briefringence is %.1e.",Bh,Bl);
```

Scilab code Exa 2.3.1 Estimate numerical aperture and critical angle

```
// Example 2.3.1  page 2.10

clc;
clear;

delta = 1/100;       // Relative refractive difference index
n1=1.46;          // Core refractive index (assumption)

NA= n1*sqrt(2*delta);        //computing numerical aperture
theta = 1 - delta;
Critical_angle = asind(theta);  //computing critical angle

printf("\nNumerical aperture is %.2f.\nCritical angle is %.1f degree.",NA,Critical_angle);
```

Scilab code Exa 2.3.2 Estimate numerical aperture

```
// Example 2.3.2  page 2.10
```

```

clc;
clear;

delta = 1/100;       // Relative refractive difference index
n1=1.47;         // Core refractive index

NA= n1*sqrt(2*delta);        //computing numerical aperture

printf("\nNumerical aperture is %.1f.",NA)
```

Scilab code Exa 2.4.1 Determine critical angle numerical aperture and acceptance a

```
// Example 2.4.1  page 2.11

clc;
clear;

n1=1.49;         //core refractive index
n2=1.45;         //cladding refractive index

phi = asind(n2/n1);      //computing critical angle
NA = sqrt(n1^2 - n2^2); //computing numericla aperture
theta= asind(NA);        //computing acceptance angle

printf("\nCritical angle is %.2f degrees.\nNumerical aperture is %.3f.\nAcceptance angle is %.2f degree.",phi,NA,theta);

//answer in the book for Numerical aperture is 0.343, deviation of 0.003
//answer in the book for Acceptance angle is 20.24,
```

```
    deviation of 0.18
```

Scilab code Exa 2.4.2 Determine numerical aperture

```
// Example 2.4.2  page 2.12

clc;
clear;

delta = 1/100;      // Relative refractive
    difference index
n1=1.47;        // Core refractive index

NA= n1*sqrt(2*delta);       //computing numerical
    aperture
printf("\nNumerical aperture is %.1f.",NA)
```

Scilab code Exa 2.4.3 Find numerical aperture and acceptance angle

```
// Example 2.4.3  page 2.12

clc;
clear;

delta = 1.2/100;      // Relative refractive
    difference index
n1=1.45;        // Core refractive index

NA= n1*sqrt(2*delta);       //computing numerical
    aperture
Acceptance_angle = asind(NA);   //computing
    acceptance angle
```

```
si = %pi * NA^2;        //computing solid acceptance angle

printf("\nNumerical aperture is %.3f.\nAcceptance angle is %.2f degree.\nSolid acceptance angle is %.3f radians.",NA,Acceptance_angle,si);

//answer in the book for Numerical aperture is 0.224, deviation of 0.001
//answer in the book for solid acceptance angle is 0.157, deviation of 0.002
```

Scilab code Exa 2.4.4 Find acceptance angle

```
// Example 2.4.4  page 2.13

clc;
clear;

NA = 0.45;       // Numerical Aperture

Acceptance_angle = asind(NA);    //computing acceptance angle.
printf("\nAcceptance angle is %.1f degree.",Acceptance_angle);
```

Scilab code Exa 2.4.5 Compute numerical aperture and full cone angle

```
// Example 2.4.5  page 2.13

clc;
clear;

```

```
diameter = 1;         //Diameter in centimeter
Focal_length = 10;        //Focal length in centimeter

radius=diameter/2;  //computing radius
Acceptance_angle = atand(radius/Focal_length);  //computing acceptance angle
Conical_full_angle = 2*Acceptance_angle;        //computing conical angle
Solid_acceptance_angle = %pi*Acceptance_angle^2;   //computing solid acceptance angle
NA = sqrt(Solid_acceptance_angle/%pi);      //computing Numerical aperture

printf("\nNumerical aperture is %.2f.\nConical full angle is %.2f degree.",NA,Conical_full_angle);
```

Scilab code Exa 2.5.1 Find acceptance angle

```
// Example 2.5.1  page 2.17

clc;
clear;

NA = 0.45        //Numerical aperture
betaB = 45        // Skew ray change direction by 90 degree at each reflection

Meridional_theta = asind(NA);   //computing acceptacne angle for meridoinal ray
Skew_theta = asind(NA/cosd(betaB));  //computing acceptacne angle for skew ray

printf("\nAcceptacne angle for Meridoinal ray is %.2f degree.\nAcceptance angle for Skew ray %.1f degree.",Meridional_theta,Skew_theta);
```

Scilab code Exa 2.7.1 Find normalized frequency and number of guided modes

```
// Example 2.7.1  page 2.23

clc;
clear;

core_diameter=78d-6;        //core diameter
delta=1.4/100;       //relative index difference
lamda=0.8d-6;        //operating wavelength
n1=1.47;      //core refractive index

a=core_diameter/2;      //computing core radius
v= 2*3.14*a*n1*sqrt(2*delta)/lamda;      //computing
    normalized frequency
M=(v)^2/2;      //computing guided modes

printf("\nNormalized Frequency is %.3f.\nTotal
   number of guided modes are %.1f",v,M);
printf("\nNOTE - Calculation error, answer in the
   book for normalized frequency is given as 75.156
   which should be 75.306.");

//answer in the book for normalized frequency is
   given as 75.156(incorrect) and for Guided modes
   is 5648.5(incorrect)
```

Scilab code Exa 2.7.2 Find wavelength

```
// Example 2.7.2  page 2.24

```

```
clc;
clear;

n1=1.47      //refractive index of core
a=4.3d-6;        //radius of core
delta=0.2/100        //relative index difference

lamda= 2*3.14*a*n1*sqrt(2*delta)/2.405;      //computing wavelength
lamda=lamda*10^9;
printf("Wavelength of fiber is %d nm.",lamda);
printf("\n\nNote:Calculation error, answer given in the book (1230nm) is incorrect.");

//answer in the book is given as 1230nm which is incorrect.
```

Scilab code Exa 2.7.3 `Find core radius NA and acceptance angle`

```
// Example 2.7.3  page 2.24

clc;
clear;

n1=1.482;        //refractive index of core
n2=1.474;        //refractive index of cladding
lamda=820d-9;        //Wavelength

NA=sqrt(n1^2 - n2^2);        //computing Numerical aperture
theta= asind(NA);          //computing acceptance angle
solid_angle=%pi*(NA)^2;      //computing solid angle
a=2.405*lamda/(2*3.14*NA);        //computing core radius
```

```
a=a*10^6;

printf("\nNumerical aperture is %.3f.\nAcceptance
    angle is %.1f degrees.\nSolid angle is %.3f
    radians.\nCore radius is %.2f micrometer.",NA,
    theta,solid_angle,a);

//answer in the book for Numerical aperture is
    0.155, deviation of 0.001.
//answer in the book for acceptance angle is 8.9,
    deviation of 0.1.
//answer in the book for solid acceptance angle is
    0.075, deviation of 0.001.
//answer in the book for core radius is 2.02
    micrometer, deviation of 0.02 micrometer.
```

Scilab code Exa 2.7.4 Estimate number of guided modes

```
// Example 2.7.4  page 2.25

clc;
clear;

NA=0.16     //Numerical aperture
n1=1.45     //core refractive index
d=60d-6     //core diameter
lamda=0.82d-6      //wavelength

a=d/2;      //core radius
v=2*3.14*a*NA/lamda;      //computing normalized
    frequency
v=round(v);
M=v^2/2;        //computing guided modes
M=floor(M);

```

```
printf("if normalized frequency is taken as %d, then
    %d guided modes.",v,M);
```

Scilab code Exa 2.7.5 Determine normalized frequency and number of guided modes

```
// Example 2.7.5  page 2.26

clc;
clear;

n1=1.48;      //core refractive index
n2=1.46;      //cladding refractive index
a=25d-6;      //core radius
lamda0=850d-9;
lamda1=1320d-9;
lamda2=1550d-9;

NA=sqrt(n1^2-n2^2);      //computing numerical
    aperture
v0=2*%pi*a*NA/lamda0;    //computing normalized
    frequency
M0=v0^2/2;       //computing guided modes
M0=floor(M0);
v1=2*%pi*a*NA/lamda1;
M1=v1^2/2;
M1=floor(M1);
v2=2*%pi*a*NA/lamda2;
M2=v2^2/2;
M2=floor(M2);
lamda0=lamda0*10^9;
lamda1=lamda1*10^9;
lamda2=lamda2*10^9;
printf("\nfor %d nm, normalized frequency = %.2f,
    Guided modes = %d.",lamda0,v0,M0);
printf("\nfor %d nm, normalized frequency = %.2f,
```

```
Guided modes = %d.",lamda1,v1,M1);
printf("\nfor %d nm, normalized frequency = %.2f, Guided modes = %d.",lamda2,v2,M2);

//answers in the book (sligt deviations in each)
//for 850 nm, normalized frequency = 45, Guided modes = 1012
//for 1320 nm, normalized frequency = 28.91, Guided modes = 419
//for 1550 nm, normalized frequency = 24.67, Guided modes = 304
```

Scilab code Exa 2.7.6 Estimate diameter of core

```
// Example 2.7.6  page 2.27

clc;
clear;

delta=1/100;        //relative refractive index
n1=1.3;      //core refractive index
lamda=1100d-9;      //wavelength

a=(2.4*lamda)/(2*3.14*n1*sqrt(2*delta));        //computing radius of core
d=2*a;      //computing diameter of core
a=a*10^6;
d=d*10^6;
printf("\nCore radius is %.1f micrometer\nCore diameter is %.1f micrometer",a,d);
printf("\nNOTE - In the book they have asked diameter of core. However, they have calculated only radius.");
```

Scilab code Exa 2.7.7 Calculate NA and maximum angle of entrance

```
// Example 2.7.7  page 2.27

clc;
clear;

n1=1.48;     //refractive index of core
n2=1.46;     //refractive index of cladding

NA=sqrt(n1^2-n2^2);      //computing Numerical aperture
theta=asind(NA);         //computing acceptance angle

printf("\nNumerical aperture is %.3f.\nAcceptance angle is %.2f degrees.",NA,theta);

//answer in the book for Numerical aperture is 0.244, deviation of 0.002.
//answer in the book for Acceptance angle is 14.12, deviation of 0.09.
```

Scilab code Exa 2.7.8 Calculate normalized frequency and number of guided modes

```
// Example 2.7.8  page 2.28

clc;
clear;

core_diameter=80d-6;          //core diameter
delta=1.5/100;        //relative index difference
lamda=0.85d-6;        //operating wavelength
```

```
n1=1.48;      //core refractive index

a=core_diameter/2;       //computing core radius
v= 2*%pi*a*n1*sqrt(2*delta)/lamda;       //computing normalized frequency
M=(v)^2/2;       //computing guided modes
printf("\nNormalized Frequency is %.1f.\nTotal number of guided modes are %.d.",v,M);

//answer in the book for Guided modes is 2873, deviation of 1.
```

Scilab code Exa 2.7.9 Estimate diameter of the core

```
// Example 2.7.9  page 2.28

clc;
clear;

delta=1/100;     //relative refractive index
n1=1.5;      //refractive index of core
M=1100;      //Guided modes
lamda=1.3d-6;        //wavelength

v=sqrt(2*M);     //computing normalized frequecy
a=(v*lamda)/(2*3.14*n1*sqrt(2*delta));         //computing radius of core
d=a*2;
a=a*10^6;
d=d*10^6;

printf("\nNormalize frequency is %.1f.\nCore radius is %.2f micrometer.\nCore diameter is %.1f micrometer.",v,a,d);
printf("\nCalculation error in the book while
```

```
calculating radius and diameter.");

//calculation error in the book.
//answers in the book -
//Core radius is 46.18 micrometer.(incorrect)
//Core diameter is 92.3 micrometer.(incorrect)
```

Scilab code Exa 2.7.10 Determine normalized frequency and number of guided modes

```
// Example 2.7.10  page 2.29

clc;
clear;

n1=1.48;          //refractive index of core
n2=1.46;          //refractive index of cladding
lamda1=1320d-9;          //Wavelength
lamda2=1550d-9;          //Wavelength
a=25d-6;           //radius of core

NA=sqrt(n1^2 - n2^2);          //computing Numerical aperture
v1=2*%pi*a*NA/lamda1;          //computing normalized frequency
v1=round(v1);
M1=v1^2/2;          //computing number of guided modes
M1=round(M1);
v2=2*%pi*a*NA/lamda2;
M2=v2^2/2;
M2=round(M2);
lamda1=lamda1*10^9;
lamda2=lamda2*10^9;

printf("\nfor %d nm, normalized frequency = %d, Guided modes = %d.",lamda1,v1,M1);
```

```
printf("\nfor %d nm, normalized frequency = %.2f,
    Guided modes = %d.",lamda2,v2,M2);

//answer in the book,
//for 1550 nm, normalized frequency = 24.69(
    deviation of 0.08), Guided modes = 305(deviation
    of 3)
```

Scilab code Exa 2.7.11 Compute NA and number of guided modes

```
// Example 2.7.11  page 2.29

clc;
clear all;

n1=1.5;          //refractive index of core
n2=1.38;         //refractive index of cladding
lamda=1300d-9;          //Wavelength
a=25d-6;         //core radius

NA=sqrt(n1^2 - n2^2);         //computing Numerical
    aperture
theta= asind(NA);          //computing acceptance
    angle
solid_angle=%pi*(NA)^2;       //computing solid angle
v= 2*%pi*a*NA/lamda;       //computing normalized
    frequency
M=(v)^2/2;        //computing guided modes
M=round(M);
printf("\nNumerical aperture is %.2f.\nNormalized
    frequency is %.2f.\nAcceptance angle is %.2f
    degrees.\nSolid angle is %.3f radians.\nTotal
    number of modes are %d.",NA,v,theta,solid_angle,M
    );
printf("\n\n NOTE - Calculation error in the book.\n
```

```
    (2.25 -1.9)^0.5=0.59; they have taken 0.35");


//Calculation error in the book.(2.25 -1.9)^0.5=0.59;
     they have taken 0.35
//answers in the book,
//Numerical aperture is 0.35.(incorrect)
//Normalized frequency is 42.26.(incorrect)
//Acceptance angle is 20.48 degrees.(incorrect)
//Solid angle is 0.384 radians.(incorrect)
```

Scilab code Exa 2.7.12 Compute core radius and acceptance angle

```
// Example 2.7.12  page 2.30

clc;
clear;

n1=1.48;        //refractive index of core
n2=1.478;       //refractive index of cladding
lamda=820d-9;         //Wavelength

NA=sqrt(n1^2 - n2^2);       //computing Numerical
    aperture
theta= asind(NA);          //computing acceptance
    angle
solid_angle=%pi*(NA)^2;     //computing solid angle

printf("\nNumerical aperture is %.3f.\nAcceptance
    angle is %.2f degrees.\nSolid angle is %.4f
    radians.",NA,theta,solid_angle);
```

Scilab code Exa 2.7.13 Estimate range of wavelength for single mode transmission

```

// Example 2.7.13  page 2.31

clc;
clear;

n1=1.447;        //refractive index of core
n2=1.442;        //refractive index of cladding
lamda=1.3d-6;        //Wavelength
a=3.6d-6;        //core radius

NA=sqrt(n1^2 - n2^2);        //computing Numerical aperture
v= 2*%pi*a*NA/lamda;        //computing normalized frequency

printf("As normalized frequency is %.2f which is less than 2.405, this fiber will permit single mode transmission",v);

lamda_cut_off=v*lamda/2.405
lamda_cut_off=lamda_cut_off*10^9
printf("\n\nSingle mode operation will occur above this cut off wavelength of %.2f nm",lamda_cut_off);
printf("\n\n NOTE - Calculation error in the book.\n(1.447^2 - 1.442^2)^0.5=0.121; they have taken 0.141\nHence calculations after that are incorrect in the book");

//Calculation error in the book.(1.447^2 - 1.442^2)^0.5=0.121; they have taken 0.141.Hence calculations after that are incorrect in the book.
//They have taken radius as 2.6d-6, whereas in question it is given 3.6d-6.
//answers in the book
//Normalized frequency is 1.77.(incorrect)
```

```
//cut off wavelength 956nm.(incorrect)
```

Scilab code Exa 2.7.14 Estimate number of guided modes

```
// Example 2.7.14  page 2.34

clc;
clear;

NA=0.2;      //Numericla aperture
d=50d-6;          //Diameter of core
lamda=1d-6;       //Wavelength

a=d/2;       //computing radius
v=2*3.14*a*NA/lamda;     //computing normalized frequency
Mg=v^2/4;         //computing mode volume for parabollic profile
Mg=round(Mg);
printf("\nNormalized Frequency is %.1f.\nTotal number of guided modes are %.d.",v,Mg);

//answer in the book for guided modes is 247, deviation of 1.
```

Scilab code Exa 2.7.15 Determine core diameter

```
// Example 2.7.15  page 2.34

clc;
clear;

delta=0.015;          //relative refractive index
```

```
n1=1.48;      //core refractive index
lamda=0.85d-6;      //wavelength

a=(2.4*lamda)/(2*3.14*n1*sqrt(2*delta));         //
    computing radius of core
d=2*a;      //computing diameter of core
a=a*10^7;
a=round(a);
a=a/10
d=d*10^6;
printf("\nCore radius is %.1f micrometer.\nCore
    diameter is %.1f micrometer.",a,2*a);

printf("\n\nWhen delta is reduced by 10 percent-");
delta=0.0015;
a=(2.4*lamda)/(2*3.14*n1*sqrt(2*delta));         //
    computing radius of core
d=2*a;      //computing diameter of core
a=a*10^7;
a=round(a);
a=a/10
d=d*10^6;
printf("\nCore radius is %.1f micrometer.\nCore
    diameter is %.1f micrometer.",a,2*a);
```

Scilab code Exa 2.7.16 Find number of guided modes

```
// Example 2.7.16  page 2.35

clc;
clear;

NA=0.25;      //Numericla aperture
d=45d-6;         //Diameter of core
lamda=1.5d-6;       //Wavelength
```

```
a=d/2;        //computing radius
v=2*3.14*a*NA/lamda;     //computing normalized frequency
Mg=v^2/4;         //computing mode volume for parabollic profile
Mg=round(Mg);
printf("\nNormalized Frequency is %.1f.\nTotal number of guided modes are %.d.",v,Mg);

//answer in the book for normalized frequency is 23.55, deviation 0.05
```

Scilab code Exa 2.7.17 `Estimate number of guided modes`

```
// Example 2.7.17  page 2.35

clc;
clear;

NA=0.25;       //Numericla aperture
d=45d-6;          //Diameter of core
lamda=1.2d-6;        //Wavelength

a=d/2;        //computing radius
v=2*3.14*a*NA/lamda;     //computing normalized frequency
Mg=v^2/4;         //computing mode volume for parabollic profile
Mg=round(Mg);
printf("\nNormalized Frequency is %.1f.\nTotal number of guided modes are %.d.",v,Mg);
printf("\n\nNOTE - In the question NA is given 0.22. However while solving it is taken as 0.25");

```

```
// answer in the book for number of guided modes is
   given as 216, deviation of 1.

printf("\nHence solving for NA = 0.22 also,");
printf("\n\nWhen NA=0.22");

NA=0.22;      //Numericla aperture
d=45d-6;         //Diameter of core
lamda=1.2d-6;       //Wavelength

a=d/2;       //computing radius
v=2*3.14*a*NA/lamda;     //computing normalized
   frequency
Mg=v^2/4;        //computing mode volume for
   parabollic profile
Mg=round(Mg);
printf("\nNormalized Frequency is %.1f.\nTotal
   number of guided modes are %.d.",v,Mg);
```

Scilab code Exa 2.7.18 Compute cutoff parameter and number of modes

```
// Example 2.7.18  page 2.36

clc;
clear;

n1=1.54;         //refractive index of core
n2=1.5;      //refractive index of cladding
a=25d-6;         //Radius of core
lamda=1.3d-6;       //Wavelength

NA=sqrt(n1^2-n2^2);
v=2*3.14*a*NA/lamda;     //computing normalized
   frequency
v=round(v);
```

```
Mg=v^2/4;        //computing mode volume for
   parabollic profile
Mg=round(Mg);
lamda_cut_off=v*lamda/2.405;     //computing cut off
   wavelength
lamda_cut_off=lamda_cut_off*10^6;
printf("\nNormalized Frequency is %.d.\nTotal number
    of guided modes are %.d.\nCut off wavelength is
   %.1f micrometer.",v,Mg,lamda_cut_off);
```

Scilab code Exa 2.10.1 Determine cutoff wavelength

```
// Example 2.10.1  page 2.39

clc;
clear;

a=4.5d-6;         //core diameter
delta=0.25/100;       //relative index difference
lamda=0.85d-6;        //operating wavelength
n1=1.46;      //core refractive index

v= 2*%pi*a*n1*sqrt(2*delta)/lamda;       //computing
   normalized frequency
lamda_cut_off=v*lamda/2.405;         //computing cut
   off wavelength
lamda_cut_off=lamda_cut_off*10^9;
printf("\nCut off wavelength is %.d nanometer.",
   lamda_cut_off);

printf("\n\nWhen delta is 1.25 percent-");
delta=1.25/100;
v= 2*%pi*a*n1*sqrt(2*delta)/lamda;       //computing
   normalized frequency
lamda_cut_off=v*lamda/2.405;         //computing cut
```

```
    off wavelength
lamda_cut_off=lamda_cut_off*10^7;
lamda_cut_off=round(lamda_cut_off);
lamda_cut_off=lamda_cut_off*100;
printf("\nCut off wavelength is %.d nanometer.",lamda_cut_off);

//answer in the book for cut off wavelength in the book is given as 1214nm, deviation of 1nm.
```

Scilab code Exa 2.10.2 Calculate cutoff number and number of modes

```
// Example 2.10.2  page 2.40

clc;
clear;

a=50d-6;          //core radius
lamda=1500d-9;        //operating wavelength
n1=2.53;      //core refractive index
n2=1.5;      //cladding refractive index

delta=(n1-n2)/n1;        //computing delta
v= 2*3.14*a*n1*sqrt(2*delta)/lamda;      //computing normalized frequency
M=(v)^2/2;       //computing guided modes
printf("\nNormalized Frequency is %.1f\nTotal number of guided modes are %.d",v,M);
printf("\nNOTE - Calculation error in book. \nNormalized frequency is 477, it is calculated as 47.66");

//Calculation error in book. Normalized frequency is 477, it is calculated as 47.66, hence answers after that are erroneous.
```

```
//answers  in the book
//normalized frequency = 48.(incorrect)
//guided modes = 1152.(incorrect)
```

Scilab code Exa 2.10.3 Compute number of modes

```
// Example 2.10.3  page 2.41

clc;
clear;

core_diameter=8d-6;          //core diameter
delta=0.92/100;        //relative index difference
lamda=1550d-9;         //operating wavelength
n1=1.45;      //core refractive index

a=core_diameter/2;       //computing core radius
v= 2*%pi*a*n1*sqrt(2*delta)/lamda;       //computing
    normalized frequency
M=(v)^2/2;       //computing guided modes
printf("\nNormalized Frequency is %.1f.\nTotal
    number of guided modes are %.d.",v,M);
```

Scilab code Exa 2.10.4 Calculate delay difference

```
// Example 2.10.4  page 2.41

clc;
clear;

delta=1/100;       //relative index difference
n1=1.5;      //core refractive index
c=3d8;
```

```
L=6;

n2=sqrt(n1^2-2*delta*n1^2);        //computing refractive index of cladding
delta_T=L*n1^2*delta/(c*n2);      //computing pulse broadning
delta_T=delta_T*10^11;
delta_T=round(delta_T);
printf("\nDelay difference between slowest and fastest mode is %d ns/km.",delta_T);
printf("\nThis means that a pulse broadnes by %d ns after travel time a distance of %d km.",delta_T,L);
```

Scilab code Exa 2.13.1 `Find modal briefringence`

```
// Example 2.13.1  page 2.54

clc;
clear;

L_BL=8d-2;    //beat length

Br=2*3.14/L_BL;       //computing modal briefringence
printf("\nModal briefringence is %.1f per meter.",Br);
```

Scilab code Exa 2.13.2 `Find output power`

```
// Example 2.13.2  page 2.57

clc;
clear;
```

```

Pin=500d-6;      //input power
L=200;      //length of fiber
loss=2;     //loss associated with fiber

Pin_dbm=10 * log10 (Pin/(10^-3));    //computing
   input power in dBm
Pin_dbm=round(Pin_dbm);
Pout_dbm=Pin_dbm-L*loss;        //computing output
   power level
Pout= 10^(Pout_dbm/10);
printf("Output power is %.2e mW.",Pout);
```

Scilab code Exa 2.16.1 Calculate NA and maximum acceptance angle

```
// Example 2.16.1  page 2.67

clc;
clear;

n1=1.48;        //core refractive index
n2=1.46;        //cladding refractive index

phi = asind(n2/n1);     //computing critical angle
NA = sqrt(n1^2 - n2^2); //computing numericla
   aperture
theta= asind(NA);       //computing acceptance angle
printf("\nCritical angle is %.2f degrees.\nNumerical
    aperture is %.3f.\nAcceptance angle is %.2f
   degree.",phi,NA,theta);

//answers in the book
//Critical angle is 80.56 degrees, deviation of
   0.01.
//Numerical aperture is 0.244, deviation of 0.002.
```

```
//Acceptance angle is 14.17 degree, deviation of
    0.14.
```

Chapter 4

Signal Degradation in Fibers

Scilab code Exa 4.3.1 Find signal attenuation and InputOutput ratio

```


// Example 4.3.1  page 4.4

clc;
clear;

L=10;        //fiber length in km
Pin=150d-6;      //input power
Pout=5d-6;       //output power
len=20;        //length of optical link
interval=1;      //splices after interval of 1 km
l=1.2;       //loss due to 1 splice

attenuation=10*log10(Pin/Pout);
alpha=attenuation/L;
attenuation_loss=alpha*20;
splices_loss=(len-interval)*l;
total_loss=attenuation_loss+splices_loss;
power_ratio=10^(total_loss/10);

```

```
printf("\nSignal attenuation is %.2f dBs.\nSignal
    attenuation is %.3f dB/Km.\nTotal loss in 20 Km
    fiber is %.2f dbs.\nTotal attenuation is %.2f dBs
    .\ninput/output ratio is %e.",attenuation,alpha,
    attenuation_loss,total_loss,power_ratio);
printf("\nAs signal attenuation is approximately
    equal to 10^5, we can say that line is very lossy
    .");
```

Scilab code Exa 4.4.1 Find output power

```
// Example 4.4.1  page 4.8

clc;
clear;

L=30;        //fiber length
Pin=200d-6;      //input power
alpha=0.8;       //signal attenuation per km

Pout=Pin/(10^(alpha*L/10));      //computing output
    power
Pout=Pout*10^6;
printf("\nOutput power is %.3f microwatt.",Pout);
printf("\nNOTE - calculation error in the book.\
    nThey have taken 0.8*30=2.4 which actually is 24.
    ");

//calculation error in the book.They have taken
    0.8*30=2.4 which actually is 24.
//answer in the book is 115.14 microwatt.(incorrect)
```

Scilab code Exa 4.6.1 Find attenuation due to Rayleigh scattering

```
// Example 4.6.1  page 4.12

clc;
clear;

beta_c=8d-11;        //isothermal compressibility
n=1.46;      //refractive index
P=0.286;     //photoelastic constat
k=1.38d-23; //Boltzmnn constant
T=1500;      //temperature
L=1000;      //length
lamda=1000d-9;  //wavelength

gamma_r = 8*(3.14^3)*(P^2)*(n^8)*beta_c*k*T/(3*(
    lamda^4));      //computing coefficient
attenuation=%e^(-gamma_r*L);        //computing
    attenuation
printf("\nAttenuation due to Rayleigh scattering is
    %.3f.",attenuation);
```

Scilab code Exa 4.6.2 Determine attenuation due to Rayleigh scattering

```
// Example 4.6.2  page 4.13

clc;
clear;

beta_c=7d-11;        //isothermal compressibility
n=1.46;      //refractive index
P=0.29;     //photoelastic constat
k=1.38d-23; //Boltzmnn constant
T=1400;      //temperature
L=1000;      //length
lamda=0.7d-6;  //wavelength

```

```
gamma_r = 8*(3.14^3)*(P^2)*(n^8)*beta_c*k*T/(3*(lamda^4));        //computing coefficient
attenuation=%e^(-gamma_r*L);          //computing attenuation
gamma_r=gamma_r*1000;
printf("\nRaleigh Scattering corfficient is %.3f * 10^-3 per meter\n",gamma_r);
printf("\nNOTE - in quetion they have asked for attenuation but in solution they have not calcualted\n");
printf("\nAttenuation due to Rayleigh scattering is %.3f",attenuation);

//answer for Raleigh Scattering corfficient in the book is given as 0.804d-3, deviation of 0.003d-3
```

Scilab code Exa 4.8.1 Compare SRS and SBS threshold powers

```
// Example 4.8.1  page 4.17

clc;
clear;

d=5;      //core diameter
alpha=0.4;   //attenuation
B=0.5;     //Bandwidth
lamda=1.4;    //wavelength
PB=4.4d-3*d^2*lamda^2*alpha*B;       //computing threshold power for SBS
PR=5.9d-2*d^2*lamda*alpha;       //computing threshold power for SRS
PB=PB*10^3;
PR=PR*10^3;
printf("\nThreshold power for SBS is %.1f mW.\nThreshold power for SRS is %.3f mW.",PB,PR);
```

```
printf("\nNOTE - Calculation error in the book while calculating threshold for SBS.\nAlso, while calculating SRS, formula is taken incorrectly, Bandwidth is multiplied in second step, which is not in the formula.");

//Calculation error in the book while calculating threshold for SBS. Also, while calculating SRS, formula is taken incorrectly,Bandwidth is multiplied in second step, which is not in the formula
//answers in the book
//PB=30.8mW
//PR=0.413mW
```

Scilab code Exa 4.9.1 `Find critical radius of curvature`

```
// Example 4.9.1  page 4.19

clc;
clear;

n1=1.5;      //refractive index of core
delta=0.03/100;     //relative refractive index
lamda=0.82d-6;      //wavelength

n2=sqrt(n1^2-2*delta*n1^2);      //computing cladding refractive index
Rc=(3*n1^2*lamda)/(4*3.14*(n1^2-n2^2)^1.5);      //computing critical radius
Rc=Rc*10^3;
printf("\nCritical radius is %.1f micrometer.",Rc);

//answer in the book is 9 micrometer, deviation of 0.1 micrometer.
```

Scilab code Exa 4.9.2 Find critical radius for both single mode and multi mode fib

```
// Example 4.9.2  page 4.20

clc;
clear;

n1=1.45;      //refractive index of core
delta=3/100;      //relative refractive index
lamda=1.5d-6;       //wavelength
a=5d-6;      //core radius

n2=sqrt(n1^2-2*delta*n1^2);       //computing cladding refractive index
Rc=(3*n1^2*lamda)/(4*3.14*(n1^2-n2^2)^0.5);      //computing critical radius for single mode
Rc=Rc*10^6;
printf("\nCritical radius is %.2f micrometer",Rc);

lamda_cut_off= 2*3.14*a*n1*sqrt(2*delta)/2.405;

RcSM= (20*lamda/(n1-n2)^1.5)*(2.748-0.996*lamda/lamda_cut_off)^-3;      //computing critical radius for single mode
RcSM=RcSM*10^6;
printf("\nCritical radius for single mode fiber is %.2f micrometer.",RcSM);
printf("\nNOTE - Calculation error in the book.\n(2.748-0.996*lamda/lamda_cut_off)^-3; in this term raised to -3 is not taken in the book.");

//Calculation error in the book.(2.748-0.996*lamda/lamda_cut_off)^-3; in this term raised to -3 is not taken in the book.
```

```
//answer in the book is 7.23mm.(incorrect)
```

Scilab code Exa 4.14.1 `Compute material dispersion`

```
// Example 4.14.1  page 4.31

clc;
clear;

lamda=1550d-9;
lamda0=1.3d-6;
s0=0.095;

Dt=lamda*s0/4*(1-(lamda0/lamda)^4);      //computing material dispersion
Dt=Dt*10^9;
printf("\nMaterial dispersion at 1550 nm is %.1f ps/nm/km",Dt);
printf("\n\nNOTE - Slight deviation in the answer because of printig mistake\nIn problem they have given lamda0 as 1300 nanometer \nbut while solving they have taken it as 1330 nanometer");

//answer in the book 15.6 ps/nm/km, deviaton due to printing mistake.
```

Scilab code Exa 4.15.1 `Find maximum possible bandwidth pulse dispersion and bandwi`

```
// Example 4.15.1  page 4.35

clc;
clear;

```

```
tau=0.1d-6;      //pulse broadning
dist=20d3;       //distance

Bopt=1/(2*tau);      //computing optical bandwidth
Bopt=Bopt*10^-6;
dispertion=tau/dist;         //computing dispersion
dispertion=dispertion*10^12;
BLP=Bopt*dist;       //computing Bandwidth length product
BLP=BLP*10^-3;
printf("\noptical bandwidth is %d MHz.\nDispersion per unit length is %d ns/km.\nBandwidth length product is %d MHz.km.",Bopt,dispertion,BLP);
```

Scilab code Exa 4.15.2 Calculate overall signal attenuation

```
// Example 4.15.2  page 4.36

clc;
clear;

L=10;        //fiber length in km
Pin=100d-6;      //input power
Pout=5d-6;       //output power
len=12;        //length of optical link
interval=1;      //splices after interval of 1 km
l=0.5;       //loss due to 1 splice

attenuation=-10*log10(Pin/Pout);         //computing attenuation
alpha=attenuation/L;
signal_attenuation=-alpha*L;         //computing signal attenuation
splices_loss=(len-interval)*l;         //computing splices loss
```

```
attenuation_loss=-len*alpha                //computing
    attenuation loss
total_attenuation=attenuation_loss+splices_loss;
         //computing total attenuation

printf("\nSignal attenuation is %.1f dB/Km.\nOverall
     attenuation is %d dB for 10 km.\nTotal
    attenuation is %.1f dBs for 12km.",alpha,
    signal_attenuation,total_attenuation);
```

Scilab code Exa 4.15.3 `Calculate bandwidth dispersion and bandwidth length product`

```
// Example 4.15.3  page 4.37

clc;
clear;

tau=0.1d-6;      //pulse broadning
dist=12d3;       //distance

Bopt=1/(2*tau);      //computing optical bandwidth
Bopt=Bopt*10^-6;
dispertion=tau/dist;          //computing dispersion
dispertion=dispertion*10^12;
BLP=Bopt*dist;        //computing Bandwidth length
    product
BLP=BLP*10^-3;
printf("\noptical bandwidth is %d MHz.\nDispersion
    per unit length is %.1f ns/km.\nBandwidth length
    product is %d MHz.km",Bopt,dispertion,BLP);
```

Scilab code Exa 4.15.4 `Determine maximum bit rate`

```
// Example 4.15.4  page 4.38

clc;
clear;

tau01=10;     //pulse broadning ns/mm
L1=0.1;     //length in kilometer
tau02=20;    //pulse broadning ns/m
L2=1;    //length in kilometer
tau03=2000;  //pulse broadning ns/m
L3=2;       //length in kilometer

tau1=10d-9/1d-6;
tau1=tau1*L1;
Bopt1=1/(2*tau1);     //computing optical bandwidth
tau2=20d-9/1d-3;
tau2=tau2*L2;
Bopt2=1/(2*tau2);     //computing optical bandwidth
Bopt2=Bopt2*10^-3;
tau3=2000d-9/1d-3;
tau3=tau3*L3;
Bopt3=1/(2*tau3);     //computing optical bandwidth


printf("\nWhen tau is %d ns/mm, over length %.1f km, optical bandwidth for RZ is %d MHz and for NRZ is %d MHz.",tau01,L1,Bopt1,Bopt1/2 );
printf("\nWhen tau is %d ns/m, over length %d km, optical bandwidth for RZ is %.1f KHz and for NRZ is %.1f KHz.",tau02,L2,Bopt2,Bopt2/2 );
printf("\nWhen tau is %d ns/m, over length %d km, optical bandwidth for RZ is %d Mz and for NRZ is %.1f Hz.",tau03,L3,Bopt3,Bopt3/2 );

printf("\n NOTE - printing errors in the book.\nIn first two cases tau is not multiplied by 2");

//Calculation error because, In first two cases tau
```

```
   is not multiplied by 2
//answers-
//When tau is 10 ns/mm, over length 0.1 km, optical
   bandwidth for RZ is 1000 MHz and for NRZ is 500
   MHz.
//When tau is 20 ns/m, over length 1 km, optical
   bandwidth for RZ is 50 KHz and for NRZ is 25 KHz.
```

Scilab code Exa 4.15.5 Calculate maximum possible bandwidth and dispersion

```
// Example 4.15.5  page 4.39

clc;
clear;

tau=0.1d-6;      //pulse broadning
dist=15d3;       //distance

Bopt=1/(2*tau);      //computing optical bandwidth
Bopt=Bopt*10^-6;
dispertion=tau/dist;         //computing dispersion
dispertion=dispertion*10^12;
printf("\noptical bandwidth is %d MHz.\nDispersion
   per unit length is %.2f ns/km.",Bopt,dispertion);
```

Scilab code Exa 4.15.6 Compute delay difference rms pulse broadening and maximum b

```
// Example 4.15.6  page 4.39

clc;
clear;

L=5;          //length of optical link
```

```
n1=1.5        //refractive index
c=3d8;        //speed of light
delta=1/100;          //relative refractive index

delTS=L*n1*delta/c;      //computing delay difference
delTS=delTS*10^12;
sigmaS=L*n1*delta/(2*sqrt(3)*c);     //computing rms pulse broadning
sigmaS=sigmaS*10^12;
B=1/(2*delTS);         //computing maximum bit rate
B=B*10^3;
B_acc=0.2/(sigmaS);      //computing accurate bit rate
B_acc=B_acc*10^3;
BLP=B_acc*L;       //computing Bandwidth length product

printf("\nDelay difference is %d ns.\nRMS pulse broadning is %.2f ns.\nBit rate is %.1f Mbit/s.\nAccurate bit rate is %.2f Mbits/s.\nBandwidth length product is %.2f MHz.km.",delTS,sigmaS,B,B_acc,BLP);

//answer in the book for RMS pulse broadning is 72.25 ns, deviation of 0.08ns.
//answer in the book for Bandwidth length product is  13.85 MHz.km, deviation of 0.01MHz.km.
```

Scilab code Exa 4.15.7 Estimate rms pulse broadening and bandwidth length product

```
// Example 4.15.7  page 4.40

clc;
clear;

```

```
NA=0.3;         //numerical aperture
n1=1.45;        //refractive index
M=250;          //material dispertion parameter in ps/nm
   /km
L=1;            //length
BW=50;          //Bandwidth in nm
c=3d8;          //speed of light

sigmaLamda=BW*L;
sigmaM=sigmaLamda*L*M*10^-12;
sigmaS=10^3*L*(NA)^2/(4*sqrt(3)*n1*c);
sigmaT=sqrt(sigmaM^2+sigmaS^2);      //computing
   total RMS pulse broadning
BLP=0.2/sigmaT;      //computing bandwidth length
   product
sigmaT=sigmaT*10^9;
sigmaM=sigmaM*10^9;
sigmaS=sigmaS*10^9;
BLP=BLP/10^6;
printf("\nTotal RMS pulse broadning is %.1f ns/km.\
   nBandwidth length product is %.1f MHz.km",sigmaT,
   BLP);
```

Scilab code Exa 4.15.8 Estimate Bandwidth dispersion and bandwidth length product

```
// Example 4.15.8  page 4.41

clc;
clear;

tau=0.1d-6;       //pulse broadning
dist=10d3;        //distance

Bopt=1/(2*tau);      //computing optical bandwidth
Bopt=Bopt*10^-6;
```

```
dispertion=tau/dist;          //computing dispersion
dispertion=dispertion*10^12;
BLP=Bopt*dist;       //computing Bandwidth length product
BLP=BLP*10^-3;
printf("\noptical bandwidth is %d MHz.\nDispersion per unit length is %.1f ns/km.\nBandwidth length product is %d MHz.km.",Bopt,dispertion,BLP);
```

Scilab code Exa 4.15.9 Estimate rms pulse broadening

```
// Example 4.15.9  page 4.41

clc;
clear;

RSW=0.0012;      //relative spectral width
lamda=0.85d-6;   //wavelength
L=1;          //distance in km (assumed)
M=100;        //material dispersion parameter in ps/nm/km (assumed)

sigma_lamda=RSW*lamda;
sigmaM=sigma_lamda*L*M*10^6;     //computing rms pulse broadning.
printf("\nRMS pulse broadning is %.3f ns/km.",sigmaM);
```

Scilab code Exa 4.15.10 Estimate bandwidth pulse broadening and bandwidth length p

```
// Example 4.15.10  page 4.42

clc;
```

```
clear;

tau=0.1d-6;     //pulse broadning
dist=18d3;      //distance

Bopt=1/(2*tau);     //computing optical bandwidth
Bopt=Bopt*10^-6;
dispertion=tau/dist;        //computing dispersion
dispertion=dispertion*10^12;
BLP=Bopt*dist;      //computing Bandwidth length
    product
BLP=BLP*10^-3;
printf("\noptical bandwidth is %d MHz.\nDispersion
    per unit length is %.1f ns/km.\nBandwidth length
    product is %d MHz.km",Bopt,dispertion,BLP);
printf("\nNOTE - printing mistake in the book at
    dispersion per unit length.\nThey have printed ps
    /km; it should be ns/km");

//printing mistake in the book at dispersion per
    unit length.They have printed ps/km; it should be
     ns/km.
//answer in the book 5.55 ps/km (incorrect)
```

Scilab code Exa 4.16.1 Estimate rms pulse broadening

```
// Example 4.16.1  page 4.43

clc;
clear;

RSW=0.0012;     //relative spectral width
lamda=0.90d-6;  //wavelength
L=1;        //distance in km (assumed)
P=0.025;    //material dispersion parameter
```

```
c=3d5;       //speed of light in km/s

M=10^3*P/(c*lamda);      //computing material dispersion
sigma_lamda=RSW*lamda;
sigmaM=sigma_lamda*L*M*10^7;        //computing RMS pulse broadning
sigmaB=25*L*M*10^-3;

printf("\nMaterial dispersion parameter is %.2f ps/nm/km.\nRMS pulsr broadning when sigma_lamda is 25 is %.1f ns/km.\nRMS pulse broadning is %.1f ns/km.",M,sigmaB,sigmaM);

//answer in the book for RMS pulse broadning is 0.99 ns/km, deviation of 0.01ns/km.
```

Scilab code Exa 4.18.1 Find delay difference and rms pulse broadening

```
// Example 4.18.1  page 4.45

clc;
clear;

L=10;        //length of optical link
n1=1.49      //refractive index
c=3d8;       //speed of light
delta=1/100;         //relative refractive index

delTS=L*n1*delta/c;      //computing delay difference
delTS=delTS*10^12;
sigmaS=L*n1*delta/(2*sqrt(3)*c);     //computing rms pulse broadning
sigmaS=sigmaS*10^12;
B=1/(2*delTS);         //computing maximum bit rate
```

```
B=B*10^3;
B_acc=0.2/(sigmaS);      //computing accurate bit
   rate
B_acc=B_acc*10^3;
BLP=B_acc*L;      //computing Bandwidth length
   product

printf("\nDelay difference is %d ns.\nRMS pulse
   broadning is %.1f ns.\nBit rate is %.1f Mbit/s.\
   nAccurate bit rate is %.3f Mbits/s.\nBandwidth
   length product is %.1f MHz.km",delTS,sigmaS,B,
   B_acc,BLP);

//answer for maximum bit rate is given as 1.008 Mb/s
   , deviation of 0.008 Mb/s.
```

Chapter 5

Fiber Optic Splices Connectors and Couplers

Scilab code Exa 5.2.1 Calculate loss due to Fresnel reflection

```
// Example 5.2.1  page 5.2

clc;
clear;

n1=1.47;        //refractive index of fiber
n=1;        //refractive index of air

r=((n1-n)/(n1+n))^2;    //computing fraction of
    light reflected
loss=-10*log10(1-r);    //loss
total_loss=2*loss;
printf("r = %.3f, which means %.1f percent of the
    transimitted light is reflected at one interface"
    ,r,r*100);
printf("\nTotal loss is %.3f dB",total_loss);

//answer in the book for total loss of fiber is
    0.318 dB, deviation of 0.002
```

Scilab code Exa 5.2.2 `Estimate insertion loss due to lateral misalingment`

```
// Example 5.2.2  page 5.4

clc;
clear;

n1=1.47;        //refractive index of fiber
n=1;        //refractive index of air
d=40d-6;    //core diameter
y=4d-6;     //lateral dispalcement

a=d/2;      //computing core radius
eta_lateral = (16*(n1/n)^2)/(%pi*(1+(n1/n))^4)*(2*
    acos(y/(2*a))-(y/a)*(1-(y/(2*a))^2)^0.5);     //
    computing eta_lateral with air gap
loss=-10*log10(eta_lateral);        //computing loss
     when air gap is present
eta_lateral1=(2*acos(y/(2*a))-(y/a)*(1-(y/(2*a))^2)
    ^0.5)/%pi;      //computing eta_lateral without
    air gap
loss1=-10*log10(eta_lateral1);      //computing loss
     when air gap is not present

printf("\nloss with air gap is %.2f dB.\nloss with
    no air gap is %.2f dB.\n Thus we can say that
    loss reduces considerably if there is no air gap.
    ",loss,loss1);

//answer in the book for loss with air gap is 0.91dB
    , deviation of 0.01dB.
```

Scilab code Exa 5.2.3 Estimate angular misalignment insertion loss

```
// Example 5.2.3  page 5.5

clc;
clear;

n1=1.48;          //refractive index of fiber
n=1;          //refractive index of air
theta=10;    //angle in degree
NA1=0.3;
NA2=0.6
eta_angular1= (16*(n1/n)^2)/((1+(n1/n))^4)*(1-((n*
    theta*%pi/180)/(%pi*NA1)));    //computing eta
    angular
eta_angular2= (16*(n1/n)^2)/((1+(n1/n))^4)*(1-((n*
    theta*%pi/180)/(%pi*NA2)));    //computing eta
    angular
loss1=-10*log10(eta_angular1);       //computing loss
loss2=-10*log10(eta_angular2);       //computing loss
printf("\nLoss when NA is %.1f is %.2f dB.\nLoss
    when NA is %.1f is %.2f dB.",NA1,loss1,NA2,loss2)
    ;
printf("\nThus we can say that insertion loss is
    considerably reduced with higher NA.");
```

Scilab code Exa 5.2.4 Loss due to Fresnel reflection

```
// Example 5.2.4  page 5.7

clc;
clear;

n1=1.5;          //refractive index of fiber
n=1;          //refractive index of air
```

```

r=((n1-n)/(n1+n))^2;     //computing fraction of
    light reflected
loss=-10*log10(1-r);     //loss
total_loss=2*loss;
printf("r = %.2f, which means %.1f percent of the
    transimitted light is reflected at one interface"
    ,r,r*100);
printf("\nTotal loss is %.2f dB",total_loss);

//answer in the book for total loss of fiber is 0.36
     dB, deviation of 0.01
```

Scilab code Exa 5.2.5 Estimate insertion loss due to lateral misalignment

```
// Example 5.2.5  page 5.7

clc;
clear;

n1=1.5;          //refractive index of fiber
n=1;         //refractive index of air
d=50d-6;     //core diameter
y=5d-6;      //lateral dispalcement

a=d/2;       //computing core radius
eta_lateral = (16*(n1/n)^2)/(%pi*(1+(n1/n))^4)*(2*
    acos(y/(2*a))-(y/a)*(1-(y/(2*a))^2)^0.5);      //
    computing eta_lateral with air gap
loss=-10*log10(eta_lateral);        //computing loss
     when air gap is present
eta_lateral1=(2*acos(y/(2*a))-(y/a)*(1-(y/(2*a))^2)
    ^0.5)/%pi;        //computing eta_lateral without
    air gap
loss1=-10*log10(eta_lateral1);      //computing loss
```

```
 when air gap is not present

printf("\nloss with air gap is %.2f dB.\nloss with no air gap is %.2f dB.",loss,loss1);

//answer in the book for loss with air gap is 0.95dB, deviation of 0.01dB.
```

Scilab code Exa 5.2.6 Total insertion loss

```
// Example 5.2.6  page 5.8

clc;
clear;

n1=1.47;         //refractive index of fiber
n=1;          //refractive index of air
theta=3;    //angle in degree
d=80d-6;      //core diameter
y=2d-6;       //lateral dispalcement
delta=2/100;      //relative refractive index

a=d/2;        //computing core radius
eta_lateral = (16*(n1/n)^2)/(%pi*(1+(n1/n))^4)*(2*acos(y/(2*a))-(y/a)*(1-(y/(2*a))^2)^0.5);      //computing eta lateral
loss_lateral=-10*log10(eta_lateral);     //computing loss due to lateral misalignment
eta_angular= (16*(n1/n)^2)/((1+(n1/n))^4)*(1-((n*theta*%pi/180)/(%pi*n1*(sqrt(2*delta)))));      //computing eta angular
loss_angular=-10*log10(eta_angular);    //computing loss due to angular misalignment
total_loss=loss_lateral+loss_angular;    //computing total loss due to misalignment
```

```
printf("\nloss due to lateral misalignment is %.2f dB.\nloss due to angular misalignment is %.2f dB.\nTotal loss is %.2f dB",loss_lateral,loss_angular,total_loss);

//answer in the book for loss due to lateral misalignment is 0.48 dB, deviation of 0.02.
//answer in the book for total loss due is 1.05 dB, deviation of 0.02.
```

Scilab code Exa 5.4.1 Find insertion loss

```
// Example 5.4.1  page 5.17

clc;
clear;

d=1d-6;      //lateral displacement
W=4.95d-6;   //MFD

Lsm_lat= -10*log10(%e^(-(d/W)^2));       //computing loss
printf("\nInsertion loss is %.2f dB.",Lsm_lat);
```

Scilab code Exa 5.4.2 Find angular misalignment loss

```
// Example 5.4.2  page 5.18

clc;
clear;

lamda=1.3d-6;    //wavelength
theta=1;         //angle in degree
```

```
n2=1.465;        //cladding refractive index
W=4.95d-6;       //MFD

Lsm_ang= -10*log10(%e^(-(%pi*n2*W*(theta*%pi/180)/lamda)^2));       //computing loss
printf("\nInsertion loss is %.2f dB.",Lsm_ang);
```

Scilab code Exa 5.6.1 Determine excess loss insertion loss cross talk and split ra

```
// Example 5.6.1  page 5.30

clc;
clear;

p1=50d-6;
p2=0.003d-6;
p3=25d-6;
p4=26.5d-6

EL=10*log10(p1/(p3+p4));          //computing excess loss
IL13=10*log10(p1/p3);      //computing insertion loss
IL14=10*log10(p1/p4);      //computing insertion loss
ct=10*log10(p2/p1);      //computing cross talk
sr=(p3/(p3+p4))*100;     //computing split ratio

printf("\nExcess loss is %.2f dB.\nInsertion loss from port 1 to port 3 is %.2f dB.\nInsertion loss from port 1 to port 4 is %.2f dB.\ncross talk is %.2f dB.\nSplit ratio is %.2f percent",EL,IL13,IL14,ct,sr  );
printf("\nNOTE - calculation error in the book.\nMinus sign is not printed in the answer of excess loss.\nP1 is taken 25 instead of 50 while calculating cross talk.");
```

```
//calculation error in the book.Minus sign is not printed in the answer of excess loss.P1 is taken 25 instead of 50 while calculating cross talk.
//answers in the book with slight deviations
//Excess loss is 0.12 dB.(printing error)
//Insertion loss from port 1 to port 4 is 2.75 dB.
//cross talk is −39.2 dB. (calculation error)
```

Scilab code Exa 5.6.2 Find total loss and average insertion loss

```
// Example 5.6.2  page 5.32

clc;
clear;

N=16;        //Number of ports
Pin=1d-3;    //input power
Pout=12d-6;  //output power

split_loss=10*log10(N);      //computing split loss
excess_loss=10*log10(Pin/(Pout*N));      //computing excess loss
total_loss=split_loss+excess_loss;       //computing total loss
insertion_loss= 10*log10(Pin/Pout);      //computing insertion loss

printf("\nTotal loss is %.2f dB.\nInsertion loss is %.2f dB.",total_loss,insertion_loss);

//answer in the book for Total loss is 19.14, deviation of 0.06dB.
//answer in the book for insertion loss is 19.20, deviation of 0.01dB.
```

Chapter 6

Optical Sources

Scilab code Exa 6.3.1 Find operating wavelength

```
// Example 6.3.1  page 6.7

clc;
clear;

x=0.07;
Eg=1.424+1.266*x+0.266*x^2;
lamda=1.24/Eg;      //computing wavelength
printf("\nWavlength is %.3f micrometer.",lamda);
```

Scilab code Exa 6.3.2 Find out number of longitudinal modes and frequency separati

```
// Example 6.3.2  page 6.12

clc;
clear;

n=1.7;      //refractive index
```

```
L=5d-2;      //distance between mirror
c=3d8;       //speed of light
lamda=0.45d-6;  //wavelength

k=2*n*L/lamda;       //computing number of modes
delf=c/(2*n*L);      //computing mode separation
delf=delf*10^-9;

printf("\nNumber of modes are %.2e.\nFrequency
   separation is %.2f GHz.",k,delf);
```

Scilab code Exa 6.14.1 Single longitudinal mode

```
// Example 6.14.1  page 6.42

clc;
clear;

// This is example does not consist of any numerical
    computation

printf("\nQuestion - What do you understand by
   single longitudinal mode laser or SLM? ")
printf("\nAnswer - \nIn laser operation optical gain
    alone is not sufficient for laser operation but
   a minimum amount of gain is also necessary.\nThis
    gain can be achieved when laser is pumped above
   threshold level.\nIn simplest laser structure we
   have p-n junction.Active layer is sandwitched
   between p and n type layers of higher bandgap
   material. Such broad area semiconductor laser
   need high threshold current and light confinement
    becomes difficult.\nGain guided semiconductor
   laser limit the current injection over a narrow
   stripe thus overcome the problem of light
```

```
confinement.They are also called stripe geometry
lasers.\nIn index guided laser an in index step
is introduced to form waveguide.\nIn buried
heterostructure laser the active region in buried
 by layers of lower refractive indices.\nWhen
width and thickness of the active layer is
controlled, light can be made to emerge in a
single spatial mode, but the problem arises when
such lasers oscillate in many longitudinal modes
in Fabry Perot cavity.\nThe spectral width
obtained is about 2-4 nm which can be tolerated
for 1.3 micrometer operation, but for systems
operating near 1.55 micrometer at higher bit
rates such multimode lasers can not be used. At
such times laser which emit light in a single
longitudnal mode are required to give higher bit
rates than 1 Gb/s. They are called Single
Longitudinal Mode (SLM) lasers.");
```

Scilab code Exa 6.21.1 `Determine total recombination lifetime and internally gener`

```
// Example 6.21.1  page 6.59

clc;
clear;

tr=50;        //radiative recombination lifetime
tnr=85;       //non-radiative recombination lifetime
h=6.624d-34;  //plank's constant
c=3d8;        //speed of light
q=1.6d-19;    //charge of electron
i=35d-3;      //current
lamda=0.85d-6;      //wavelength

t=tr*tnr/(tr+tnr);          //computing total
```

```
    recombination time
eta=t/tr;                    //computing internal quantum efficiency
Pint=eta*h*c*i/(q*lamda);    //computing internally generated power
Pint=Pint*10^3

printf("\nTotal recombinaiton time is %.2f ns.\nInternal quantum efficiency is %.3f.\nInternally generated power is %.1f mW.",t,eta,Pint);

//answer in the book for Internal quantum efficiency is 0.629, deviation of 0.001.
//answer in the book for Internally generated power is 32.16 mW, deviation of 0.04 mW.
```

Scilab code Exa 6.21.2 Determine total recombination life time internal quantum ef

```
// Example 6.21.2  page 6.59

clc;
clear;

tr=30;       //radiative recombination lifetime
tnr=100;      //non-radiative recombination lifetime
h=6.624d-34;   //plank's constant
c=3d8;       //speed of light
q=1.6d-19;   //charge of electron
i=40d-3;     //current
lamda=1310d-9;      //wavelength

t=tr*tnr/(tr+tnr);           //computing total recombination time
eta=t/tr;                    //computing internal quantum efficiency
```

```
Pint=eta*h*c*i/(q*lamda);    //computing internally generated power
Pint=Pint*10^3

printf("\nTotal recombinaiton time is %.2f ns.\nInternal quantum efficiency is %.3f.\nInternally generated power is %.2f mW.",t,eta,Pint);

//answer in the book for Total recombinaiton time is 23.07 ns, deviation of 0.01ns.
```

Scilab code Exa 6.21.3 Determine total recombination lifetime and internally gener

```
// Example 6.21.3  page 6.60

clc;
clear;

tr=50;        //radiative recombination lifetime
tnr=110;      //non-radiative recombination lifetime
h=6.624d-34;  //plank's constant
c=3d8;        //speed of light
q=1.6d-19;    //charge of electron
i=40d-3;      //current
lamda=0.87d-6;        //wavelength

t=tr*tnr/(tr+tnr);            //computing total recombination time
eta=t/tr;                     //computing internal quantum efficiency
Pint=eta*h*c*i/(q*lamda);    //computing internally generated power
Pint=Pint*10^3

printf("\nTotal recombinaiton time is %.2f ns.\
```

```
nInternal quantum efficiency is %.4f.\nInternally generated power is %.2f mW.",t,eta,Pint);

//answers in the book with slight deviaitons
//Total recombinaiton time is 34.37 ns, deviation of 0.01ns.
//Internal quantum efficiency is 0.6874, deviaiton of 0.0001.
//Internally generated power is 39.24 mW, deviation of 0.02mW.
```

Scilab code Exa 6.22.1 Determine optical power

```
// Example 6.22.1  page 6.68

clc;
clear;

f1=10d6;    //frequency
f2=100d6
t=4d-9;
Pdc=280d-6;     //optincal output power

w1=2*%pi*f1;    //computing omega
Pout1=Pdc*10^6/(sqrt(1+(w1*t)^2));      //computing output power

w2=2*%pi*f2;    //computing omega
Pout2=Pdc*10^6/(sqrt(1+(w2*t)^2));      //computing output power

printf("Ouput power at 10 MHz is %.2f microwatt.\nOuput power at 100 MHz is %.2f microwatt.\nConclusion when device is drive at higher frequency the optical power reduces.\nNOTE -
```

```
    calculation error. In the book square term in the
     denominater is not taken.",Pout1,Pout2);

BWopt = sqrt(3)/(2*%pi*t);
BWelec = BWopt/sqrt(2);
BWopt=BWopt*10^-6;
BWelec=BWelec*10^-6;

printf("\n3 dB optical power is %.2f MHz.\n3 dB
    electrical power is %.2f MHz.",BWopt,BWelec);


//calculation error. In the book square term in the
    denominater is not taken.
//answers in the book -
//Ouput power at 10 MHz is 228.7 microwatt.(
    incorrect)
//Ouput power at 100 MHz is 175 microwatt.(incorrect
    )
//3 dB optical power is 68.8 MHz, deviation of 0.12
//3 dB electrical power is 48.79 MHz, deviation of
    0.06
```

Scilab code Exa 6.22.2 To calculate emitted optical power as percent of internal o

```
// Example 6.22.2  page 6.69

clc;
clear;

n1=3.5;   //refractive index
n=1;      //refractive index of air
F=0.69; //transmission factor

eta = 100*(n1*(n1+1)^2)^-1;      //computing eta
```

```
printf("\neta external is %.1f percent i.e. small
    fraction of intrnally generated opticalpower is
    emitted from the device.",eta);
printf("\n\n OR we can also arrive at solution,\n");

r= 100*F*n^2/(4*n1^2);      //computing ratio of
    Popt/Pint

printf("\n Popt/Pint is %.1f percent",r);

printf("\nNOTE - printing mistake at final answer.\
    nThey have printed 40 percent it should be 1.4
    percent");
```

Scilab code Exa 6.22.3 Find operating lifetime

```
// Example 6.22.3  page 6.73

clc;
clear;

beta0=1.85d7;
T=293;       //temperature
k=1.38d-23; //Boltzman constant
Ea=0.9*1.6d-19;
theta=0.65; //thershold

betar=beta0*%e^(-Ea/(k*T));
t=-log(theta)/betar;

printf("\nDegradation rate is %.2e per hour.\
    nOperating lifetime is %.1e hour.",betar,t);

//answer in the book for Degradation rate is 6.4e-09
```

```
    per hour, deviation of 0.08e-9
//answer in the book for Operating lifetime is 6.7e
    +07 hour, deviaiton of 0.1e1
```

Chapter 7

Source to Fiber Power Launching and Photodetectors

Scilab code Exa 7.2.1 Find Fresnel reflection and power loss

```
// Example 7.2.1  page 7.11

clc;
clear;

n1=3.4;    //refractive index of optical source
n=1.46;    //refractive index of silica fiber

r=((n1-n)/(n1+n))^2;    //computing Frensel
    reflection
L=-10*log10(1-r);     //computing loss

printf("\nFrensel reflection is %.3f.\nPower loss is
    %.2f dB.",r,L);
```

Scilab code Exa 7.2.2 Compute optical power coupled

```
// Example 7.2.2  page 7.11

clc;
clear;

r=35d-6;         //radius
R=150;        //Lambertian emission pattern
NA=0.2;       //Numerical aperture
Pled= %pi^2*r^2*R*NA^2;
Pled=Pled*10^7;
printf("\nOptical power for larger core of 35
   micrometer is %.3f mW.",Pled);
r1=25d-6;
Pled1=(r1/r)^2*Pled;
printf("\nOptical power for smaller core of 25
   micrometer is %.2f mW.",Pled1);
```

Scilab code Exa 7.2.3 Calculate coupled power

```
// Example 7.2.3  page 7.12

clc;
clear;

r=25d-6;         //radius
R=39;        //Lambertian emission pattern
NA=0.25;      //numerical aperture
a=35d-6;      //area
Pc1= %pi^2*a^2*R*NA^2;  //computing coupled power
   when r<a
Pc1=Pc1*10^7;
Pc= %pi^2*r^2*R*NA^2;   //computing coupled power
   when r>a
Pc=Pc*10^7;

```

```
printf("\nOptical power when r>a is %.2f mW.\
   nOptical power when r<a is %.3f mW.",Pc,Pc1);
```

Scilab code Exa 7.2.4 Estimate external power efficiency

```
// Example 7.2.4  page 7.12

clc;
clear;

n1=3.6;  //refractive index
n=1;     //refractive index of air
F=0.68; //transmission factor
Pin=30/100; //percent power supplied

eta =(n1*(n1+1)^2)^-1;     //computing eta
P=Pin*eta;      //computing optical power emitted
eta=eta*100;
P=P*1000;
Pt=P*Pin;       //computing internal power

printf("\neta external is %.1f percent.\nOptical
   power emitted is %.1f mW.\nInternal power is %.2f
    mW.",eta,P,Pt);
printf("\nNote - Printing error in the book they
   have printed 1.5 instead of 1.3 as the answer of
   eta.");

//Printing error in the book they have printed 1.5
   instead of 1.3 as the answer of eta
```

Scilab code Exa 7.5.1 Estimate upper wavelength cutoff

```
// Example 7.5.1  page 7.24

clc;
clear;

h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
e=1.6d-19;  //charge of electron
q=1.43;     //Bandgap energy

lamda=h*c/(q*e)*10^9;    //computing wavelength
printf("\nWavelength is %d nm",lamda);
printf("\nThis proves that photodiode will not
   operate for photon of wavelength greater than %d
   nm.",lamda);

//answer in the book 868nm; deviation of 1nm
```

Scilab code Exa 7.5.2 Find photocurrent

```
// Example 7.5.2  page 7.24

clc;
clear;

R=0.6;      //responsivity
Pin=15;     //optical power in microwatt

Ip=R*Pin;       //computing photocurrent
printf("\nPhotocurrent generated is %d microAmpere."
   ,Ip);
```

Scilab code Exa 7.5.3 Find cut off wavelength

```
// Example 7.5.3  page 7.24

clc;
clear;

lamda1=1300d-9;
lamda2=1600d-9;
h=6.625d-34;    //plank's constant
c=3d8;      //speed of light
q=1.6d-19;  //charge of electron
eta=90/100; //quantum efficiency
E=0.73;     //energy gap in eV
R1=eta*q*lamda1/(h*c);
R2=eta*q*lamda2/(h*c);
lamdac=1.24/E;

printf("\nResponsivity at 1300nm is %.2f A/W.\
   nResponsivity at 1600nm is %.2f A/W.\nCut-off
   wavelength is %.1f micrometer.",R1,R2,lamdac);

//R1 is calculated as 0.92 in the book, deviation of
    0.02.
```

Scilab code Exa 7.5.4 Determine quantum efficiency and responsivity

```
// Example 7.5.4  page 7.25

clc;
clear;

lamda=0.8d-6;
h=6.625d-34;    //plank's constant
c=3d8;      //speed of light
q=1.6d-19;  //charge of electron
ne=1.8d11;  //electrons collected
```

```
np=4d11;    //photons incident

eta=ne/np;      //computing quantum efficiency
R=eta*q*lamda/(h*c);    //computing responsivity

printf("\nResponsivity of photodiode at 0.8 micrometer is %.3f A/W.",R);

//answer in the book is 0.289. deviation of 0.001 A/W
```

Scilab code Exa 7.5.5 `Find wavelength and incident power`

```

// Example 7.5.5  page 7.25

clc;
clear;

h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
eta=70/100; //quantum efficiency
I=3d-6;     //photocurrent
E=1.8d-19;  //energy of photns
q=1.6d-19;  //charge of electron

lamda=h*c/E;   //computing wavelength
R=eta*q*lamda/(h*c);    //computing responsivity
Popt=I/R;       //computing optical power
lamda=lamda*10^6;
Popt=Popt*10^6;

printf("\nWavelength is %.2f micrometer.\nResponsivity is %.3f A/W.\nIncident optical power required is %.3f microWatt.",lamda,R,Popt);
```

```
//answer of Popt in the book is calculated as 4.823,
    deviation of 0.002
```

Scilab code Exa 7.5.6 `Determine wavelength`

```
// Example 7.5.6  page 7.26

clc;
clear;

h=6.626d-34;    //plank's constant
c=3d8;       //speed of light
q=1.6d-19;   //charge of electron
E=1.35;       //energy gap in eV

lamda=h*c/(q*E);   //computing wavelength
lamda=lamda*10^6;

printf("\nThe InP photodetector will stop operation
   above %.2f micrometer.",lamda);
printf("\nNOTE - calculation error in the book");

//calculation error in the book
//answer in the book 1.47 micrometer.(incorrect)
```

Scilab code Exa 7.5.7 `Calculate wavelength and incident optical power`

```

// Example 7.5.7  page 7.27

clc;
clear;
```

```
h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
eta=65/100; //quantum efficiency
I=2.5d-6;     //photocurrent
E=1.5d-19;  //energy of photns
q=1.6d-19;  //charge of electron

lamda=h*c/E;   //computing wavelength
R=eta*q*lamda/(h*c);    //computing responsivity
Popt=I/R;        //computing optical power
lamda=lamda*10^6;
Popt=Popt*10^6;

printf("\nWavelength is %.3f micrometer.\
   nResponsivity is %.3f A/W.\nIncident optical
   power required is %.1f microWatt.",lamda,R,Popt);

//answer of R(responsivity) in the book is
   calculated as 0.694 A/W, deviation of 0.001.
```

Scilab code Exa 7.5.8 Find quantum efficiency

```
// Example 7.5.8  page 7.27

clc;
clear;

ne=3.9d6;  //electrons collected
np=6d6;    //photons incident

eta=100*ne/np;  //computing efficiency
printf("\nQuantum efficiency is %d percent.",eta);
```

Scilab code Exa 7.8.1 Determine drift time and junction temperature

```
// Example 7.8.1  page 7.39

clc;
clear;

w=25d-6;     //width
v=1d5;       //velocity
r=40d-6;     //radius
eps=12.5d-13;

t=w/v;       //computing drift time
c=eps*3.14*(r)^2/w;      //computing junction
   capacitance
c=c*10^16;
printf("\nDrift time %.1e sec.\nJunction capacitance
    %.1f pf.",t,c);
printf("\nCalculation error in the book at the
   answer of drift time.");

//calculation error in drift time answer in the book
    is 25*10^-10. it should be 2.5*10^-10.
```

Scilab code Exa 7.8.2 Find maximum response time

```
// Example 7.8.2  page 7.39

clc;
clear;

w=20d-6;     //width
```

```
v=4d4;        //velocity

t=w/v;        //computing drift time
BW=(2*%pi*t)^-1;           //computing bandwidth
rt=1/BW;      //computing response time
rt=rt*10^9;

printf("\nMaximum response time is %.1f ns.",rt);
printf("\nNOTE - Calculation error in the book.");

//Calculation error in the book, answer given is 6.2
   ns
```

Scilab code Exa 7.9.1 `Calculate noise equivalent power and specific directivity`

```
// Example 7.9.1  page 7.45

clc;
clear;

lamda=1.4d-6;
h=6.626d-34;     //plank's constant
c=3d8;        //speed of light
q=1.6d-19;    //charge of electron
eta=65/100;   //quantum efficiency
I=10d-9;      //current

NEP= h*c*sqrt(2*q*I)/(eta*q*lamda);
D=NEP^-1;

printf("\nNoise equivalent power is %.3e W.\
   nSpecific directivity is %.2e.",NEP,D);

//answers in the book for NEP is 7.683*10^-14,
   deviation of 0.04*10^-14.
```

```
//answers in the book for D is 13.01 *10^12, deviation of 0.11*10^12.
```

Scilab code Exa 7.9.2 Find mean square quantum noise current and mean square dark

```
// Example 7.9.2  page 7.46

clc;
clear;

lamda=1300d-9;
h=6.626d-34;     //plank's constant
c=3d8;        //speed of light
q=1.6d-19;  //charge of electron
eta=90/100; //quantum efficiency
P0=300d-9;  //optical power
Id=4;     //dark current
B=20d6;       //bandwidth
K=1.39d-23; //Boltzman constant
T=298;        //temperature
R=1000;       //load resister
Ip= 10^9*eta*P0*q*lamda/(h*c);
Its=10^9*(2*q*B*(Ip+Id));
Its=sqrt(Its);
printf("\nrms shot noise current is %.2f nA.",Its);

It= 4*K*T*B/R;
It=sqrt(It);
printf("\nThermal noise is %.2e A.",It);

//answer given in book for shot noise is 1.34nA, deviation of 0.01nA.
//answer given in book for Thermal noise it is 1.81*10^-8 A, deviation of 0.01*10^-8.
```

Scilab code Exa 7.10.1 Find multiplication factor

```
// Example 7.10.1  page 7.53

clc;
clear;

lamda=0.85d-6;
h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
q=1.6d-19;  //charge of electron
eta=75/100; //quantum efficiency
P0=0.6d-6;  //incident optical power
Im=15d2;   //avalanche gain

R= eta*q*lamda/(h*c);   //computing responsivity
Ip=10^8*P0*R;       //computing photocurrent
Ip=floor(Ip);
M=Im/Ip;        //computing multiplication factor
printf("\nMultiplication factor is %d.",M);
```

Scilab code Exa 7.10.2 Find avalanche gain

```
// Example 7.10.3  page 7.54

clc;
clear;

lamda=900d-9;
h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
q=1.6d-19;  //charge of electron
```

```
eta=65/100; //quantum efficiency
P0=0.5d-6;  //incident optical power
Im=10d2;    //avalanche gain

R= eta*q*lamda/(h*c);    //computing responsivity
Ip=10^8*P0*R;        //computing photocurrent
M=Im/Ip;          //computing multiplication factor
printf("\nMultiplication factor is %d.",M);

//answer in the book is 41.7 deviation 0.3.
```

Scilab code Exa 7.10.3 Find multiplication factor

```
// Example 7.10.3  page 7.54

clc;
clear;

lamda=900d-9;
h=6.626d-34;     //plank's constant
c=3d8;       //speed of light
q=1.6d-19;   //charge of electron
eta=65/100; //quantum efficiency
P0=0.5d-6;  //incident optical power
Im=10d2;    //avalanche gain

R= eta*q*lamda/(h*c);    //computong responsivity
Ip=10^8*P0*R;        //computing photocurrent
Ip=floor(Ip);
M=Im/Ip;          //computing multiplication factor
printf("\nMultiplication factor is %d.",M);
```

Scilab code Exa 7.10.4 Find wavelength incident optical power and responsivity

```
// Example 7.10.4  page 7.54

clc;
clear;

h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
q=1.602d-19;  //charge of electron
eta=70/100; //quantum efficiency
P0=0.5d-6;  //incident optical power
Ip=4d-6;   //avalanche gain
E=1.5d-19;

lamda=h*c/(E);   //computing wavelength
R= eta*q*lamda/(h*c);   //computing responsivity
P0=Ip/R;    //computing optical power

lamda=lamda*10^6;
P0=P0*10^6;
printf("\nWavelength is %.3f micrometer.\
   nResponsivity is %.4f A/W.\nOptical power is %.2f
    microWatt.",lamda,R,P0);

//answer of optical power in the book is 5.53
   microWatt, deviation of 0.17 microWatt.
```

Scilab code Exa 7.10.5 `Find multiplication factor`

```
// Example 7.10.5  page 7.55

clc;
clear;

lamda=900d-9;
h=6.626d-34;    //plank's constant
```

```
c=3d8;       //speed of light
q=1.6d-19;   //charge of electron
eta=65/100;  //quantum efficiency
P0=0.5d-6;   //incident optical power
Im=10d2;    //avalanche gain

R= eta*q*lamda/(h*c);    //computing responsivity
Ip=10^8*P0*R;        //computing photocurrent
Ip=floor(Ip);
M=Im/Ip;         //computing multiplication factor
printf("\nMultiplication factor is %d.",M);

//answer in the book is 42.55 deviation 0.45
```

Scilab code Exa 7.10.6 Calculate quantum efficiency and output photocurrent

```
// Example 7.10.6  page 7.55

clc;
clear;

h=6.626d-34;     //plank's constant
c=3d8;       //speed of light
q=1.602d-19;   //charge of electron
P0=0.5d-6;   //incident optical power(assumption)
lamda=1.5d-6;    //wavelength
M=20;        //Multiplication factor
R=0.6;       //Responsivity

eta=(R*h*c)/(q*lamda);   //computing quantum efficiency
Ip=P0*R;         //computing photocurrent
I=M*Ip*10^6;     //computing output current

printf("\nQuantum efficiency is %.3f micrometer.\
```

```
    nOutput current %d microAmpere.",eta,I);

//answer of quantum efficiency in the book is given
    as 0.495, deviation of 0.001.
```

Chapter 8

Optical Receiver Operation

Scilab code Exa 7.q Determine maximum response time

```
// Question 7  page 8.55

clc;
clear;

w=25d-6;      //width
v=3d4;        //velocity

t=w/v;        //computing drift time
BW=(2*%pi*t)^-1;          //computing bandwidth
rt=1/BW;      //response time
rt=rt*10^9;

printf("\nMaximum response time is %.2f ns.",rt);

//Answer in the book is given as 5.24ns deviation of
    0.01ns
```

Scilab code Exa 8.3.1 Find quantum efficiency and minimum incident power

```
// Example 8.3.1  page 8.9

clc;
clear;

P=10^-9;     //probability of error
eta=1;       //ideal detector
h=6.626d-34  //plank's constant
c=3d8;      //speed of light
lamda=1d-6; //wavelength
B=10^7;      //bit rate

Mn= - log(P);
printf("\n The quantum imit at the receiver to
    maintain bit error rate 10^-9 is (%.1f*h*f)/eta."
    ,Mn);
f=c/lamda
Popt= 0.5*Mn*h*f*B/eta;      //computing optical
    power
Popt_dB = 10 * log10(Popt) + 30;     //optical power
    in dbm
Popt=Popt*10^12;

printf("\nMinimum incident optical power is %.1f W
    or %.1f dBm.",Popt,Popt_dB);
```

Scilab code Exa 8.3.2 Calculate incident optical power

```
// Example 8.3.2  page 8.11

clc;
clear;

SN_dB=60;     //signal to noise ratio
h=6.626d-34  //plank's constant
```

```
c=3d8;      //speed of light
lamda=1.3d-6; //wavelength
eta=1;
B=6.5d6;      //Bandwidth

SN=10^(SN_dB/10);
f=c/lamda
Popt= 2*SN*h*f*B/eta;      //computing optical power
Popt_dB = 10 * log10(Popt) + 30;     //optical power in dbm
Popt=Popt*10^6;
printf("\nIncident power required to get an SNR of 60 dB at the receiver is %.4f microWatt or %.3f dBm",Popt,Popt_dB);
printf("\nNOTE − Calculation error in the book.\nThey have take SN as 10^5 while calculating, which has lead to an error in final answer");

//Calculation error in the book.They have take SN as 10^5 while calculating, which has lead to an error in final answer
//answer in the book 198.1nW and −37.71 dBm
```

Scilab code Exa 8.10.1 Find signal to noise ratio

```
// Example 8.10.1  page 8.25

clc;
clear;

//erfc 4.24 is given to be 2d−9

SN=(2*sqrt(2)*4.24)^2;  //computing optical SNR
SN=round(SN);
SN1=sqrt(SN);       //computing electrical SNR
```

```
printf("\nOptical SNR is %d.\nElectrical SNR is %d."
    ,SN,SN1);
```

Scilab code Exa 8.11.1 Find photon energy

```
// Example 8.11.1  page 8.26

clc;
clear;

P=1d-9;     //probability of error
eta=1;
N= -log(P);
N1=round(N);
printf("Thus %.1f or %d photons are required for
    maintaining 10^-9 BER.\nAssuming eta=1;\nE=%.1f*
    hv.",N,N1,N);
```

Scilab code Exa 8.17.1 Calculate shot noise and thermal noise

```
// Example 8.17.1  page 8.46

clc;
clear;

lamda=0.85d-6;
h=6.626d-34;    //plank's constant
c=3d8;      //speed of light
q=1.6d-19;  //charge of electron
eta=65/100; //quantum efficiency
P0=300d-9;  //optical power
Id=3.5;     //dark current
B=6.5d6;      //bandwidth
```

```
K=1.39d-23; //Boltzman constant
T=293;        //temperature
R=5d3;      //load resister
Ip= 10^9*eta*P0*q*lamda/(h*c);
Its=10^9*(2*q*B*(Ip+Id));
Its=sqrt(Its);
printf("\nrms shot noise current is %.2f nA.",Its);

It= 4*K*T*B/R;
It=sqrt(It);
It=It*10^9;
printf("\nThermal noise is %.2f nA.",It);

//answer given in book for Thermal noise it is 4.58
   nA, deviation is 0.02nA.
```

Scilab code Exa 8.17.2 Find signal to noise ratio

```
// Example 8.17.2  page 8.47

clc;
clear;

lamda=0.85d-6;
h=6.626d-34;     //plank's constant
c=3d8;        //speed of light
q=1.6d-19;  //charge of electron
eta=65/100; //quantum efficiency
P0=300d-9;  //optical power
Id=3.5;     //dark current
B=6.5d6;      //bandwidth
K=1.39d-23; //Boltzman constant
T=293;        //temperature
R=5d3;      //load resister
F_dB=3;      //noise figure
```

```
F=10^(F_dB/10);
Ip=10^9*eta*P0*q*lamda/(h*c);
Its=10^9*(2*q*B*(Ip+Id));
It1= 4*K*T*B*F/R;

SN= Ip^2/(Its+It1);
SN_dB=10*log10(SN);
SN=SN/10^4;

printf("\nSNR is %.2f*10^4 or %.2f dB.",SN,SN_dB);

//answer given in the book is 6.16*10^4 (deviation
   of 0.9) and 47.8dB (deviation of 0.16dB)
```

Scilab code Exa 8.18.1 Calculate maximum load resistance

```
// Example 8.18.1  page 8.48

clc;
clear;

Cd=7d-12;
B=9d6;
Ca=7d-12;

R=(2*3.14*Cd*B)^-1;
B1=(2*3.14*R*(Cd+Ca))^-1;
R=R/1000;
B1=B1/10^6;
printf("\nThus for 9MHz bandwidth maximum load
   resistance is %.2f Kohm\nNow if we consider input
    capacitance of following amplifier Ca then
   Bandwidth is %.2fMHz\nMaximum post detection
   bandwidth is half.",R,B1);

```

```
//answer for resistance in the book is 4.51Kohm,
    deviation of 0.01Kohm, while for bandwidth it is
    4.51 MHz, deviation of 0.01MHz
```

Chapter 9

Link Designs and Optical Amplifiers

Scilab code Exa 9.4.1 Find safty margin

```
// Example 9.4.1  page 9.11

clc;
clear;

output=13;      //laser output
sensitivity=-31;    //APD sensitivity
coupling_loss=0.5;
L=80;   //length in km
sl=0.1; //loss correspond to one splice in dB
fl=0.35;    //fiber loss in dB/km
noise=1.5;

allowed_loss=output-sensitivity;
splices_loss=(L-1)*sl;
fiber_loss=L*fl;
margin=allowed_loss-(splices_loss+fiber_loss+
   coupling_loss+noise);

```

```
printf("\nFinal margin is %.1f dB.",margin);
```

Scilab code Exa 9.4.2 Determine safety margin

```
// Example 9.4.2  page 9.12

clc;
clear;

output=3;        //laser output
sensitivity=-54;     //APD sensitivity
coupling_loss=17.5;
L=6;    //length in km
sl=1.1; //loss correspond to one splice in dB
n=3;     //number of splices
fl=5;     //fiber loss in dB/km
connector_loss=0.8;

allowed_loss=output-sensitivity;
splices_loss=n*sl;
fiber_loss=L*fl;
margin=allowed_loss-(splices_loss+fiber_loss+
    coupling_loss+connector_loss);

printf("\nFinal margin is %.1f dB.",margin);
```

Scilab code Exa 9.4.3 Determine safety margin

```
// Example 9.4.3  page 9.13

clc;
clear;

```

```
output=-10;        //laser output
sensitivity=-41;     //APD sensitivity
L=7;    //length in km
sl=0.5; //loss correspond to one splice in dB
fl=2.6;     //fiber loss in dB/km
connector_loss=1.5;
saftey_margin=6;

allowed_loss=output-sensitivity;
splices_loss=(L-1)*sl;
fiber_loss=L*fl;
margin=allowed_loss-(splices_loss+fiber_loss+
   connector_loss+saftey_margin);

printf("\nFinal margin is %.1f dB.",margin);
```

Scilab code Exa 9.4.4 Determine safety margin and link length

```
// Example 9.4.4  page 9.14

clc;
clear;

output=-10;        //laser output
sensitivity=-25;     //APD sensitivity
L=2;    //length in km
sl=0.7; //loss correspond to one splice in dB
fl=3.5;     //fiber loss in dB/km
connector_loss=1.6;
saftey_margin=4;

allowed_loss=output-sensitivity;
splices_loss=L*sl;
fiber_loss=L*fl;
margin=allowed_loss-(splices_loss+fiber_loss+
```

```
    connector_loss+saftey_margin);

printf("\nFinal margin is %.1f dB.",margin);

printf("\n\nIf laser launches a optical power of 0
    dBm then,\n");

output=0;       //laser output
sensitivity=-25;     //APD sensitivity
saftey_margin=7;
allowed_loss=output-sensitivity;
length_fiber= (allowed_loss-(splices_loss+
    connector_loss+saftey_margin))/fl;
increase=length_fiber-L;
printf("\nIncrease in the fiber length is %.2f km.",
    increase);

//answer in the book is 2.28, deviation of 0.01
```

Scilab code Exa 9.4.5 Determine link length

```
// Example 9.4.5  page 9.16

clc;
clear;

output=22;       //laser output
sensitivity=-35;     //APD sensitivity
sl=0.05; //loss correspond to one splice in dB
fl=0.4;     //fiber loss in dB/km
connector_loss=2;
saftey_margin=6;
penalties=1.5
allowed_loss=output-sensitivity;
Length = (allowed_loss-(connector_loss+penalties+
```

```
    saftey_margin))/(sl+fl);
Length=floor(Length);
printf("\nLink length is %d km.",Length);
```

Scilab code Exa 9.6.1 Find maximum bit rate

```
// Example 9.6.1  page 9.19

clc;
clear;

L=10;
ts=10;
tD=8;
tmod=L*6;
tt=L*2;

Tsys=1.1*sqrt(ts^2+tmod^2+tt^2+tD^2);
Bt=0.7/Tsys;
Bt=Bt*10^3;
printf("Maximum bit rate for link using NRZ data
    format is %.2f Mbits/sec.",Bt);
printf("\nNOTE - calculation error in the book");

//calculation error in the book
//answer given in the book is 10.3mbits/sec.(
    incorrect)
```

Scilab code Exa 9.6.2 Estimate maximum bit rate

```
// Example 9.6.2  page 9.20

clc;
```

```
clear;

L=8;
ts=8;
tD=6;
tmod=L*1;
tt=L*5;

Tsys=sqrt(ts^2+tmod^2+tt^2+tD^2);
Bt=0.7/Tsys;
Bt=Bt*10^3;
printf("\nMaximum bit rate for link using NRZ data
   format is %.2f Mbits/sec.\nMaximum bit rate for
   link using RZ data format is %.2f Mbits/sec.",Bt,
   Bt/2);
```

Scilab code Exa 9.6.3 Determine whether or not combination of component gives an ac

```
// Example 9.6.3  page 9.21

clc;
clear;

L=5;
ts=10;
tD=3;
tmod=L*2;
tt=L*9;

Tsys=sqrt(ts^2+tmod^2+tt^2+tD^2);
Bt=0.7/Tsys;
Bt=Bt*10^3;
printf("\nMaximum bit rate for link using NRZ data
   format is %.1f Mbits/sec.",Bt);
printf("\nThis is equivalent to a 3 dB optical
```

```
bandwidth of %.1f MHz, hence the desired required
bandwidth 6 MHz which will be supported",Bt/2);
```

Scilab code Exa 9.16.1 Find amplifier gain and minimum pump power required

```
// Example 9.16.1  page 9.53

clc;
clear;

Pin=2;
Pout=27;

gain_db= Pout-Pin;
gain= 10^(Pout/10)/10^(Pin/10);
min_pow = 10^(Pout/10) - 10^(Pin/10);

printf("\nGain in dB is %d dB.\nGain is %.2f.\
   nMinimum pump power is %.1f mW.",gain_db,gain,
   min_pow);

//answer in the book for gain is 317, deviation of
   0.77 and for minimum pump power it is 499.4,
   deviation of 0.2
```

Scilab code Exa 9.20.1 Maximum input and output power

```
// Example 9.20.1  page 9.65

clc;
clear;

gain_db=25;
```

```
lamdaP=980d-9;
lamdaS=1550d-9;
Pp=40d-3;

gain=10^(gain_db/10);        //computing gain
Pin=(lamdaP/lamdaS)*Pp/(gain-1);     //computing maximum input power
Pout=Pin+(lamdaP/lamdaS)*Pp;         //computing maximum output power
Pout_db=10*log10(Pout/10^-3);        //computing maximum output power in dB
Pin=Pin*10^6;
printf("\nGain is %.2f.\nMaximum input power is %.2f microWatt.\nMaximum  output power is %.2f dbm.",gain,Pin,Pout_db);
printf("\n\nNOTE - calculation error in max input power instead of G-1, G-100 is taken.");

//answer in the book for Max output power is 14.03 dBm, deviation of 0.01
//calculation error in max input power instead of G-1, G-100 is taken, answer given is 116 microWatt
```

Chapter 10

Fiber Measurements

Scilab code Exa 10.5.1 Calculate 3 dB pulse broadening and bandwidth length produc

```
// Example 10.5.1  page 10.24

clc;
clear;

To=12.6;     //width of output pulse
Ti=0.3;      //width of input pulse
l=1.2;       //length of measurement

Pulse_dispersion = sqrt(To^2 - Ti^2);   //computing pulse dispersion
PDKM=Pulse_dispersion/l;        //computing pulse dispersion per Kilometer
BW=0.44/PDKM;       //computing optical bandwidth
BW=BW*1000;
printf("\nPulse broadning is %.1f ns/km.\nOptical bandwidth is %.1f MHz.Km.",PDKM,BW);
```

Scilab code Exa 10.6.1 Determine attenuation and estimate accuracy

```
// Example 10.6.1  page 10.28

clc;
clear;

V2=12;
V1=2.5;
L2=3;
L1=0.004;

alpha_dB = 10* log10(V2/V1)/(L2-L1);
un = 0.2/(L2-L1);

printf("\nAttenuation is %.2f dB/km\nUncertainity
   +/- %.3f dB.",alpha_dB,un);

//answer for attenuation in the book is 2.26
   deviation of 0.01 and for uncertaininty is 0.066
   deviation of 0.001
```