Scilab Textbook Companion for Optical Fiber Communication System by M. K. Raina[1]

Created by
Nizam Ansari
B. Tech
Electronics Engineering
Uttarakhand Technical University, Dehradun
College Teacher
Vaseem Ahmad
Cross-Checked by
Ganesh R

May 24, 2016

---

[1] Funded by a grant from the National Mission on Education through ICT, http://spoken-tutorial.org/NMEICT-Intro. This Textbook Companion and Scilab codes written in it can be downloaded from the "Textbook Companion Project" section at the website http://scilab.in

Book Description

Title: Optical Fiber Communication System

Author: M. K. Raina

Publisher: Satya Prakashan

Edition: 3

Year: 2008

ISBN: 81-7684-442-X

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 2

Ray Theory Transmission in Optical Fiber

Scilab code Exa 2.1 Determine the critical angle and the numerical aperture and acceptance angle

```
//Ex:2_1
clc;
clear;
close;
n1=1.55;// core refractive index
n2=1.50;// cladding refractive index
x=asin(n2/n1); // Critical angle in radians
x1=x*180/(%pi);// Critical angle in degree
n_a=sqrt(n1^2-n2^2);// Numerical aperture
x_a=asin(n_a)*180/(%pi);
x_a1=ceil(x_a);// Acceptance angle in Degree
printf("Critical angle in degree= %f degree",x1);
printf("\n Numerical aperture= %f ",n_a);
printf("\n Acceptance angle in degree= %f degree",
   x_a1);
```

Scilab code Exa 2.2 Calculate the numerical aperture

```
//Ex:2.2
clc;
clear;
close;
c=3*10^8;// speed of light in m/s
v=2*10^8;// in m/s
n1=c/v;
x=75;// in degree
n2=n1*sin((x*3.14/180));
n_2=1.44;
n_a=sqrt(n1^2-n_2^2);// numerical aperture
printf("Numerical aperture = %f",n_a);
```

Scilab code Exa 2.3 Find the numerical aperture and acceptance angle

```
//Ex:2.3
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.47;// cladding refractive index
dl=(n1-n2)/n1;
n_a=n1*(sqrt(2*dl));// numerical aperture
x_a=(asin(n_a))*180/%pi;// acceptance angle in
   degree
printf("Numerical aperture = %f",n_a);
printf("\n acceptance angle in degree = %f degree",
   x_a);
```

Scilab code Exa 2.4 Determine the numerical aperture and acceptance angle and critical angle

```
//Ex:2.4
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.45;// cladding refractive index
dl=(n1-n2)/n1;
n_a=n1*(sqrt(2*dl));// numerical aperture
x_a=(asin(n_a))*180/%pi;// acceptance angle in
    degree
x_c=(asin(n2/n1))*180/3.14;// critical angle in
    degree
printf("Numerical aperture = %f",n_a);
printf("\n acceptance angle in degree = %f degree",
    x_a);
printf("\n critical angle in degree = %f degree",x_c
    );
```

Scilab code Exa 2.5 Determine the refractive indices

```
//Ex:2.5
clc;
clear;
close;
dl=0.012;
n_a=0.22;// numerical aperture
n1=n_a/(sqrt(2*dl));// core refractive ondex
n2=n1-(dl*n1);// cladding refractive index
printf("core refractive ondex = %f",n1);
printf("\n cladding refractive index = %f",n2);
```

Scilab code Exa 2.6 Calculate the refractive indices

```
//Ex:2.6
clc;
clear;
close;
dl=0.01;
n_a=0.35;// numerical aperture
n1=n_a/(sqrt(2*dl));// core refractive ondex
n2=n1-(dl*n1);// cladding refractive index
printf("core refractive ondex = %f",n1);
printf("\n cladding refractive index = %f",n2);
```

Scilab code Exa 2.7 Determine the acceptance angle and critical angle and number of modes

```
//Ex:2.7
clc;
clear;
close;
n2=1.59;// cladding refractive index
n_a=0.2;// numerical aperture
n1=sqrt(n2^2+n_a^2);// core refractive index
n_1=1.60;// core refractive index
n_o=1.33;
A=(sqrt(n_1^2-n2^2))/n_o;
x_a=(asin(A))*180/%pi;// acceptance angle in degree
x_c=(asin(n2/n1))*180/%pi;// critical angle in
   degree
y=1300*10^(-9);// in meter
a=25*10^(-6);// in meter
v=(2*%pi*a*n_a)/y;
V=floor(v);
M=V^2/2;// number of modes transmitted
printf("acceptance angle in degree = %f degree",x_a)
   ;
printf("\n critical angle in degree = %f degree",x_c
```

```
);
printf("\n number of modes transmitted = %d",M);
```

Scilab code Exa 2.8 Find the numerical aperture and max angle

```
//Ex:2.8
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.47;// cladding refractive index
dl=(n1-n2)/n1;
n_a=n1*(sqrt(2*dl));// numerical aperture
x_e=(asin(n_a))*180/%pi;// the maximum entrance angle in degree
printf("Numerical aperture = %f",n_a);
printf("\n the maximum entrance angle in degree = %f degree",x_e);
```

Scilab code Exa 2.9 Calculate the numerical aperture and acceptance angle

```
//Ex:2.9
clc;
clear;
close;
n1=1.44;// core refractive index
dl=0.02;
n_a=n1*sqrt(2*dl);
n_a=n1*(sqrt(2*dl));// numerical aperture
x_a=(asin(n_a))*180/%pi;// acceptance angle in degree
printf("Numerical aperture = %f",n_a);
```

```
printf("\n acceptance angle in degree = %f degree",x_a);
```

Scilab code Exa 2.10 Find the refractive index and critical angle and the numerical aperture

```
//Ex:2.10
clc;
clear;
close;
n1=1.50;// core refractive index
n2=(99/100)*1.50;// cladding refractive index
x_c=(asin(n2/n1))*180/%pi;// critical angle in degree
n_m=sqrt(n1^2-n2^2);// numerical aperture
printf("critical angle = %f degree",x_c);
printf("\n numerical aperture = %f",n_m);
```

Scilab code Exa 2.11 Find the numerical aperture and fractional difference

```
//Ex:2.11
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.45;// cladding refractive index
n_m=sqrt(n1^2-n2^2);// numerical aperture
dl=(n1-n2)/n1;// fractional difference
printf("numerical aperture = %f",n_m);
printf("\n fractional difference = %f",dl);
```

Scilab code Exa 2.12 Find the critical angle and acceptance angle and brewster angle and numerical aperture

```
//Ex:2.12
clc;
clear;
close;
n1=1.46;// core refractive index
n2=1.45;// cladding refractive index
x_c=(asin(n2/n1))*180/%pi;// critical angle in degree
n_m=sqrt(n1^2-n2^2);// numerical aperture
x_a=(asin(n_m))*180/%pi;// acceptance angle in degree
printf("critical angle = %f degree",x_c);
printf("\n acceptance angle = %f degree",x_a);
printf("\n numerical aperture = %f",n_m);
```

Scilab code Exa 2.13 Calculate the refractive indices

```
//Ex:2.13
clc;
clear;
close;
n_m=0.204;// numerical aperture
dl=0.01;// index difference
n1=n_m/(sqrt(2*dl));// core refractive index
n2=n1*(1-dl);// cladding refractive index
printf("core refractive index = %f",n1);
printf("\n cladding refractive index = %f",n2);
```

Scilab code Exa 2.14 calculate the critical angle and numerical aperture

```
//Ex:2.14
clc;
clear;
close;
n1=1.46;// core refractive index
dl=0.01;// index difference
n_2=n1-(n1*dl);// cladding refractive index
x_c=(asin(n_2/n1))*180/%pi;// critical angle in
    degree
n_m=sqrt(n1^2-n_2^2);// numerical aperture
printf("critical angle = %f degree",x_c);
printf("\n numerical aperture = %f",n_m);
```

Scilab code Exa 2.15 Calculate the critical angle and acceptance angle and numerical aperture and the percentage of light

```
//Ex:2.15
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.45;// cladding refractive index
x_c=(asin(n2/n1))*180/%pi;// critical angle in
    degree
n_m=sqrt(n1^2-n2^2);// numerical aperture
x_a=(asin(n_m))*180/%pi;// acceptance angle in
    degree
n_c=(n_m)^2*100;// percentage of light
printf("critical angle=%f degree",x_c);
printf("\n acceptance angle=%f degree",x_a);
```

```
printf("\n numerical aperture=%f",n_m);
printf("\n percentage of light=%f%%",n_c);
```

Scilab code Exa 2.16 Estimate the NA and the solid acceptance angle and critical angle

```
//Ex:2.16
clc;
clear;
close;
n1=1.50;// core refractive index
dl=0.01;// index difference
n_m=n1*(sqrt(2*dl));// numerical aperture
x_a=%pi*(n_m)^2;// acceptance angle in radian
n2_1=1-dl;// the ratio of n2 to n1
x_c=(asin(n2_1))*180/%pi;// critical angle in degree
printf("numerical aperture=%f",n_m);
printf("\n acceptance angle=%f radian",x_a);
printf("\n critical angle=%f degree",x_c);
```

Chapter 3

Modes And Rays

Scilab code Exa 3.1 Find the core radius

```
//Ex:3.1
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.48;// cladding refractive index
y=1.3*10^-6;
m=1000;// the no. of models
v=sqrt(2*m);
a=(v*y)/(2*%pi*(sqrt(n1^2-n2^2)))*10^6;// core
   radius in micrometer
printf("core radius=%f micrometer",a);
```

Scilab code Exa 3.2 Find the dimension of the core

```
//Ex:3.2
clc;
clear;
```

```
close;
n1=1.505;// core refractive index
n2=1.502;// cladding refractive index
n_m=sqrt(n1^2-n2^2);// numerical aperture
y=1.3*10^-6;
v=2.4;
a=(v*y)/(2*%pi*(sqrt(n1^2-n2^2)))*10^6;// core radius in micrometer
printf(”numerical aperture=%f”,n_m);
printf(”\n core radius=%f micrometer”,a);
```

Scilab code Exa 3.3 Find the propagation constant

```
//Ex:3.3
clc;
clear;
close;
n1=1.5;// core refractive index
dl=0.01;//index difference
m=0;// for the dominant mode
v=0;// for the dominant mode
y=1.3;// in micrometer
a=5;// radius in micrometer
k=(2*%pi)/y;
b=k^2*n1^2-(2*k*n1*sqrt(2*dl))/a;
B=sqrt(b);// propagation constant in rad/um
printf(”propagation constant=%f rad/um”,B);
```

Scilab code Exa 3.4 Prove that propagation constant of an optical fiber is the product of free space propagation constant and the rms value

```
//Ex:3.4
clc;
```

```
clear;
close;
b=1/2;// propagtion constant
printf("normalised propagtion constant");
printf("\n B=((b/k)^2-n2^2)/(n1^2-n2^2)");
printf("\n thus when b=1/2");
printf("\n B=k*sqrt(n2^2+b*(n1^2-n2^2))");
printf("\n B=k*sqrt((n1^2-n2^2)/2)");
printf("\n which gives its rms value");
```

Scilab code Exa 3.5 Find the number of TE modes

```
//Ex:3.5
clc;
clear;
close;
n1=3.6;// core refractive index
n2=3.3;// cladding refractive index
d=2.0;// thickness in um
y=0.8;// wavelength in um
m=(2*d*sqrt(n1^2-n2^2))/y;// total no. of models allowed
M=ceil(m);// total no. of models allowed
printf("total no. of models allowed=%d",M);
```

Scilab code Exa 3.6 Find the normalised frequency and number of guided modess

```
//Ex:3.6
clc;
clear;
close;
n1=1.48;// core refractive index
```

```
a=40*(10^-6);// core radius in meter
dl=0.015;// index difference
y=0.85*(10^-6);// wavelength in um
v=(2*%pi*a*n1*sqrt(2*dl))/y;// normalised frequency
M=v^2/2;
m=ceil(M);// the total no. of guided  modes
printf("normalised frequency=%f",v);
printf("\n the total no. of guided  modess =%d",m);
```

Scilab code Exa 3.7 Calculate the refractive index and normalised V number and total number of guided modes

```
//Ex:3.7
clc;
clear;
close;
n1=1.46;// core refractive index
dl=0.015;// index difference
a=30*(10^-6);// core radius in meter
y=0.85*(10^-6);// wavelength in um
n2=n1-(n1*dl);// cladding refractive index
v=(2*%pi*a*n1*sqrt(2*dl))/y;// normalised frequency
M=v^2/2;// the total no. of guided  modes
printf("cladding refractive index=%f",n2);
printf("\n normalised frequency=%f",v);
printf("\n the total no. of guided  modess =%d",M);
```

Scilab code Exa 3.8 Calculate the diameter of the fiber

```
//Ex:3.8
clc;
clear;
close;
```

```
n1=1.5;// core refractive index
dl=0.01;// index difference
M=1100;// the total no. of guided  modes
y=1.3*(10^-6);// wavelength in um
v=sqrt(2*M);// normalised frequency
a=(v*y)/(2*%pi*n1*sqrt(2*dl))*10^6;// core radius in meter
printf("normalised frequency=%f",v);
printf("\n the diameter of the fiber core =%f um",2*a);
```

Scilab code Exa 3.9 Determine the normalised frequency for fiber

```
//Ex:3.9
clc;
clear;
close;
n1=1.45;// core refractive index
n_m=0.16;// numerical aperture
a=30*10^-6;// core radius in micrometer
y=0.5*(10^-6);// wavelength in um
v=(2*%pi*a*n_m)/y;// normalised frequency
printf("normalised frequency=%f",v);
```

Scilab code Exa 3.10 What should be the max thickness of the guided slab

```
//Ex:3.10
clc;
clear;
close;
n1=3.6;// core refractive index
n2=3.56;// cladding refractive index
```

```
y=0.85*(10^-6);// wavelength in um
m=1;
n=0;
v_c=2.405;// for planner guide
a=(v_c*y)/(2*%pi*sqrt(n1^2-n2^2));// core radius in
    micrometer
printf("the max thickness=%f um",a*10^6);
```

Scilab code Exa 3.11 Estimate the diameter of the fiber core

```
//Ex:3.11
clc;
clear;
close;
n1=1.5;// core refractive index
y=1.3*(10^-6);// wavelength in um
M=1100;//  total no. of models
dl=0.01;// index difference
v=sqrt(2*M);
V=ceil(v);
a=(V*y)/(2*%pi*n1*sqrt(2*dl))*10^6;// core radius in
    micrometer
a1=ceil(a);// core radius in micrometer
printf("the core diameter=%d um",2*a1);
```

Scilab code Exa 3.12 Determine the max possible core diameter

```
//Ex:3.12
clc;
clear;
close;
n1=1.45;// core refractive index
dl=0.015;// index difference
```

```
y=0.85*(10^-6);// wavelength in meter
v=2.4*(1+(2/2))^(0.5);// Max normalised frequency
a=(v*y)/(2*%pi*n1*(2*dl)^(0.5));// Max core radius in m
d=2*a;// The max core diameter in meter
printf(”The max core diameter in meter=%f um”, d*10^6);
```

Scilab code Exa 3.13 Determine the normalised frequency

```
//Ex:3.13
clc;
clear;
close;
n1=1.48;// core refractive index
n2=1.46;// cladding refractive index
a=2.5;// radius in um
y=0.85;// wavelength in um
dl=(n1-n2)/n1;// index difference
v=(2*%pi*a*n1*(2*dl)^(0.5))/y;// the normaised frequency
M=(v*v)/2;// number of modes
printf(”The number of modes=%f”, M);
```

Scilab code Exa 3.14 Find the numerical aperture and solid acceptance angle and number of modes

```
//Ex:3.14
clc;
clear;
close;
a=25;// radius in um
y=1.3;// wavelength in um
```

```
v=26.6;// the normaised frequency
NA=(v*y)/(2*%pi*a);// Numerical aperture
a_c=%pi*(NA)^2;
M=(v*v)/2;
printf("The number of modes=%f", NA);
printf("\n The number of modes=%f", a_c);
printf("\n answer in textbook is wrong");
printf("\n The number of modes=%f", M);
```

Scilab code Exa 3.15 Find the cut off wavelength and min core diameter

```
//Ex:3.15
clc;
clear;
close;
n1=1.49;// core refractive index
n2=1.47;// cladding refractive index
a=2;// radius in um
dl=(n1-n2)/n1;// index difference
v_c=2.405;
y_c=(2*3.14*a*n1*(2*dl)^(0.5))/v_c;// cut off
    wavelength in um
Y=1.31;// wavelength in um
A=(v_c*Y)/(2*3.14*n1*(2*dl)^(0.5));// min core
    radius in um
printf("The cut off wavelength =%f um", y_c);
printf("\n The min core radius =%f um", A);
```

Scilab code Exa 3.16 Estimate the total number of guided modes

```
//Ex:3.16
clc;
clear;
```

```
close;
a=25;// radius in um
NA=0.3;// Numerical aperture
y=1;// wavelength in um
v=(2*%pi*a*NA)/y;// the normalised frequency
V=47.1;// the normalised frequency
M=(V*V)/4;// The mode volume
printf("The normalised frequency =%f", v);
printf("\n The mode volume =%d guided modes", M);
```

Scilab code Exa 3.17 Determine the cut off wavelength

```
//Ex:3.17
clc;
clear;
close;
n1=1.46;// core refractive index
a=4.5;// radius in um
dl=0.0025;// relative index difference
v_c=2.405;
y_c=(2*3.14*a*n1*(2*dl)^(0.5))/v_c;// cut off wavelength in um
printf("The cut off wavelength =%f um", y_c);
```

Scilab code Exa 3.18 Calculate the cut off number and number of modes

```
//Ex:3.18
clc;
clear;
close;
n1=1.5;// core refractive index
n2=1.45;// cladding refractive index
a=50;// radius in um
```

```
y=1.3;// operating wavelength in um
NA=sqrt(n1^2-n2^2);// numerical aperture
N_A=0.38;
v=(2*%pi*a*N_A)/y;// cut of numbers
M=v^2/2;// number of modes
printf("The cut of numbers =%f", v);
printf("\n The number of modes =%f", M);
```

Scilab code Exa 3.19 What will be the max allowable radius

```
//Ex:3.19
clc;
clear;
close;
n1=1.53;// core refractive index
n2=1.5;// cladding refractive index
y=1.5;// operating wavelength in um
NA=sqrt(n1^2-n2^2);// numerical aperture
a=(2.405*y)/(2*3.14*NA);// max radius in um
printf("The max core radius =%f um", a);
```

Scilab code Exa 3.20 Find V number and how many modesit will support

```
//Ex:3.20
clc;
clear;
close;
a=25;// max radius in um
y=0.8;// operating wavelength in um
NA=0.343;// numerical aperture
v=(2*%pi*a*NA)/y;// v-number
M=v^2/2;//number of modes
printf("The v-number =%f", v);
```

```
printf("\n The number of modes =%f", M);
```

Scilab code Exa 3.21 Determine the core size and cladding index

```
//Ex:3.21
clc;
clear;
close;
n1=1.5;// core refractive index
NA=0.38;// numerical aperture
v=75;// v-number
y=1.3;// operating wavelength in um
a=(v*y)/(2*%pi*NA);// core radius in um
n2=sqrt(n1^2-NA^2);// cladding refractive index
printf("The core radius =%f um", a);
printf("\n The cladding refractive index =%f", n2);
printf("\n answer in textbook is wrong");
```

Scilab code Exa 3.22 Calculate the corresponding divergence angle

```
//Ex:3.22
clc;
clear;
close;
y=1.2;// operating wavelength in um
w=5;// spot size in um
x=(2*y)/(%pi*w);// the divergence angle in degree
printf("The divergence angle =%f degree", x);
```

Scilab code Exa 3.23 Find the cut off wavelength for a step index fiber

```
//Ex:3.23
clc;
clear;
close;
n1=1.46;// core refractive index
a=4.5;// core radius in um
dl=0.0025;// relative index difference
NA=n1*(sqrt(2*dl));// numerical aperture
v=2.405;
y=(2*%pi*a*NA)/(v);// cut off wavelength in um
printf("The cut off wavelength =%f um", y);
```

Scilab code Exa 3.24 Calculate the number of modes

```
//Ex:3.24
clc;
clear;
close;
n1=1.5;// core refractive index
n2=1.47;// cladding refractive index
y1=0.87;// operating wavelength in um
y2=1.5;// operating wavelength in um
a=25;// max radius in um
NA=sqrt(n1^2-n2^2);// numerical aperture
v1=(2*%pi*a*NA)/y1;
v2=(2*%pi*a*NA)/y2;
al=2;// parabolic index profile for GRIN
M1=(al/(al+2))*(v1^2/2);// number of modes
M2=(al/(al+2))*(v2^2/2);// number of modes
printf("The number of modes at 870 nm =%f um", M1);
printf("\n The number of modes =%f um", M2);
```

Scilab code Exa 3.25 Find the core radius and NA and spot size and also find the divergence angle

```
//Ex:3.25
clc;
clear;
close;
n1=1.5;// core refractive index
n2=1.46;// cladding refractive index
v=2.4;// cut off parameter
y=0.85;// operating wavelength in um
NA=sqrt(n1^2-n2^2);// numerical aperture
a=(v*y)/(2*3.14*NA);// max radius in um
w=v*a;// spot size
x=(2*y)/(3.4*w);// divergence angle in degree
d=50;// distance in meter
w_s=(y*d)/(%pi*w);// spot size at 50 meter
printf("The numerical aperture =%f um", NA);
printf("\n The max core radius =%f um", a);
printf("\n The spot size =%f um", w);
printf("\n The divergence angle =%f degree", x);
printf("\n The spot size at 50 meter =%f m", w_s);
```

Scilab code Exa 3.26 Find the max allowable diameter

```
//Ex:3.26
clc;
clear;
close;
n1=1.53;// core refractive index
n2=1.50;// cladding  refractive index
y=1.2;// wavelength in um
v=2.405;
a=(v*y)/(2*3.14*(sqrt(n1^2-n2^2)));// core radius in
    micrometer
```

```
printf("The max diameter=%f um",2*a);
```

Scilab code Exa 3.27 Find the fractional refractive index change and the largest core size

```
//Ex:3.27
clc;
clear;
close;
n1=1.47;// core refractive index
n2=1.46;// cladding  refractive index
y=1.3;// wavelength in um
dl=(n1-n2)/n1;// fractional refractive index diff
NA=sqrt(n1^2-n2^2);
v=2.405;
a=(v*y)/(2*3.14*(sqrt(n1^2-n2^2)));// largest core radius in micrometer
n_eff=n1-(NA/(2*3.14*(a/y)));// fractional refractive index
printf("The largest core radius =%f um", a);
printf("\n The fractional refractive index=%f",n_eff);
```

Scilab code Exa 3.28 Calculate the cut off parameter and the of modes

```
//Ex:3.28
clc;
clear;
close;
n1=1.50;// core refractive index
n2=1.48;// cladding  refractive index
NA=sqrt(n1^2-n2^2);// numerical aperture
a=25;// core radius in um
```

```
y=0.85;// wavelength in um
v=(2*3.14*a*NA)/y;// cut off parameter
M=v^2/2;// number of modes
printf("The cut off parameter =%f", v);
printf("\n The number of modes =%d",M);
```

Scilab code Exa 3.29 Calculate the max value of D and also find the acceptance angle

```
//Ex:3.29
clc;
clear;
close;
n1=1.50;// core refractive index
a=25;// core radius in um
y=1.5;// wavelength in um
v=2.405;
NA=(v*y)/(2*3.14*a);// numerical aperture
D=(NA/n1)^2/(2);// max value of D
n2=n1-(D*n1);// cladding refractive index
printf("The max value of D =%f",D);
printf("\n The cladding refractive index =%f",n2);
```

Scilab code Exa 3.30 Calculate the relative refractive index difference and acceptance angle and critical angle and solid acceptance angle and NA and normalised V number and number of guided modes

```
//Ex:3.30
clc;
clear;
close;
n1=1.52;// core refractive index
n2=1.48;// cladding  refractive index
```

```
a=45;// core radius in um
y=0.85;// wavelength in um
dl=(n1-n2)/n1;// relative refractive index
x=(asin(n2/n1))*(180/3.14);// critical angle in degree
NA=sqrt(n1^2-n2^2);// numerical aperture
a_c=(asin(NA))*(180/3.14);// acceptance angle in degree
a_s=3.14*(n1^2-n2^2);// solid acceptance angle
v=(2*3.14*a*0.34)/y;// normalise v–number
M=v^2/2;// number of guided modes
a1=5;// for single mode step fiber
v1=(2*3.14*a1*0.34)/y;
M1=v1^2/2;
R=M-M1;// reduction in modes
printf(”The max value of D =%f”,dl);
printf(”\n The critical angle =%f degree”,x);
printf(”\n The acceptance angle =%f degree”,2*a_c);
printf(”\n The solid acceptance angle =%f degree”,a_s);
printf(”\n The numerical aperture =%f”,NA);
printf(”\n The normalise v–number =%f”,v);
printf(”\n The number of guided modes =%d”,M);
printf(”\n The reduction in modes =%d”,R);
```

Scilab code Exa 3.31 Find the normalised frequency and number of guided modes

```
//Ex:3.31
clc;
clear;
close;
n1=1.46;// core refractive index
a=45/2;// max radius in um
y=0.85;// operating wavelength in um
```

```
NA=0.17;// numerical aperture
v=(2*3.14*a*NA)/y;//normalised frequency
M=v^2/2;// number of modes
printf(”The normalised frequency =%f”, v);
printf(”\n The number of modes =%d”, M);
```

Chapter 4

Attenuation And Absorption in Optical Fibers

Scilab code Exa 4.1 Find the overall signal attenuation and signal attenuation per km for the fiber and overall signal attenuation for a 8 km optical link and numerical input output power ratio

```
//Ex:4.1
clc;
clear;
close;
Pi=100*10^-6;// mean optical power in watt
Po=2*10^-6;// output mean power in watt
L=6;// length in km
L1=8;// length in km
as=10*log(Pi/Po)/log(10);// signal attenuation in dB
as1=as/L;// signal attenuation per km
Li=as1*L1;// Loss incurred along 8 km
Ls=7;// Loss due to splice in dB
as2=Li+Ls;// overall signal attenuation in dB
As2=29.4;// aprox. overall signal attenuation in dB
Pio=10^(As2/10);// i/p o/p power ratio
printf("The signal attenuation =%f dB", as);
printf("\n The signal attenuation per km =%f dB/km",
```

```
    as1);
printf("\n The trgth =%f km", Li);
printf("\n The overall signal attenuation =%f dB", as2);
printf("\n The i/p o/p power ratio =%f ", Pio);
```

Scilab code Exa 4.2 Determine the max possible link length

```
//Ex:4.2
clc;
clear;
close;
Pi=1.5*10^-3;// mean optical power in watt
Po=2*10^-6;// output mean power in watt
a=0.5;// dB/km
L=(10*log(Pi/Po)/log(10))/a;// max possible link Length in km
printf("The max possible link Length =%f km", L);
```

Scilab code Exa 4.3 Determine the theoritical attenuation due to fundamental rayleigh scattering

```
//Ex:4.3
clc;
clear;
close;
n=1.46;// core refractive index
p=0.286;// photoelastic coeff
b=7*10^-11;// isothermal compressibility
k=1.381*10^-23;// boltzmann's constant
tf=1400;// fictive temperature in k
y1=0.85*10^-6;// wavelength in m
yr=((8*%pi^3)*(n^8)*(p^2)*(b*k*tf))/(3*y1^4);
```

```
e=2.718281828;
akm=e^(-yr*10^3);
at=10*log(1/akm)/log(10);// attenuation at y=0.85 um
y2=1.55*10^-6;// wavelength in m
yr1=((8*%pi^3)*(n^8)*(p^2)*(b*k*tf))/(3*y2^4);
akm1=e^(-yr1*10^3);
at1=10*log(1/akm1)/log(10);// attenuation at y=1.55 um
y3=1.30*10^-6;// wavelength in m
yr2=((8*%pi^3)*(n^8)*(p^2)*(b*k*tf))/(3*y3^4);
akm2=e^(-yr2*10^3);
at2=10*log(1/akm2)/log(10);// attenuation at y=1.30 um
printf("The Loss of an optical fiber =%f dB/km", at);
printf("\n The Loss of an optical fiber =%f dB/km", at1);
printf("\n The Loss of an optical fiber =%f dB/km", at2);
```

Scilab code Exa 4.4 calculate the threshold optical powar for SBS and SRS

```
//Ex:4.4
clc;
clear;
close;
d=6;// core diameter in m
y=1.55;// wavelength in m
a=0.5;// attenuation in dB/km
v=0.4;
Pb=4.4*10^-3*d^2*y^2*a*v;// threshold power for SBS
Pr=5.9*10^-2*d^2*y*a;// threshold power for SRS
printf("The threshold power for SBS =%d mw", Pb*10^3);
```

```
printf(”\n The threshold power for SRS =%f W’ , Pr);
```

Scilab code Exa 4.5 Estimate the critical Radius of curvatur at which large Bending Losses occur in both caces

```
//Ex:4.5
clc;
clear;
close;
n1=1.46;// core refractive index
dl=0.03;// relative refractive index difference
y=0.85*10^-6;// operating wavelength in m
a=4*10^-6;// core radous in m
n2=sqrt(n1^2-2*dl*n1^2);// cladding refractive index
Rc=(3*n1^2*y)/(4*%pi*(n1^2-n2^2)^1.5);// critical radius of curvature for multimode fiber
Dl=0.003;// relative refractive index difference
N2=sqrt(n1^2-2*Dl*n1^2);//
yc=(2*%pi*a*n1*(2*Dl)^0.5)/2.405;// cut off wavelength in m
y1=1.55*10^-6;// operating wavelength in m
Rcs=(20*y1*(2.748-0.996*(y1/yc))^-3)/(0.005)^1.5;// critical radius of curvature for a single mode fiber
printf(”The critical radius of curvature for multimode fiber =%f um”, Rc*10^6);;
printf(”\n The critical radius of curvature for a single mode fiber =%f um”, Rcs*10^3);
```

Scilab code Exa 4.6 Compute The material loss of a graded index fiber

```
//Ex:4.6
clc;
```

```
clear;
close;
x=2;// index profile
dl=0.0126;// index difference
a=(85/2)*10^-6;// core radius
R=2*10^-3;// curve of radius
n1=1.45;// core refractive index
k=6.28;
y=850*10^-9;// wavelength in m
A=(x+2)/(2*x*dl);
B=(2*a/R);
C=(3*y/(2*k*R*n1))^(2/3);
D=B+C;
E=A*D;
F=1-E;
Lm=-10*log(1-A*(B+C))/log(10);// macrobend loss in dB
printf("The macrobend loss =%f dB", Lm);
printf("\n The answer is wrong in the textbook");
```

Scilab code Exa 4.7 Calculate the Loss Of An Optical fiber

```
//Ex:4.7
clc;
clear;
close;
Pi=15;// optical power in uw
Po=7;// ouput power in uw
L=0.15;// length in km
Ls=(10*log(Pi/Po)/log(10))/L;// Loss of an optical fiber in dB
printf("The Loss of an optical fiber =%d dB", Ls);
```

Scilab code Exa 4.8 Calculate the signal attenuation per km and overall signal attenuation for 12km

```
//Ex:4.8
clc;
clear;
close;
Pi=200*10^-6;// average optical power in watt
Po=5*10^-6;// average output power in watt
L=20;// in km
L1=12;// in km
ns=5;// number of attenuation
a=0.9;// attenuation in dB
sa=10*log(Pi/Po)/log(10);// signal attenuation
sp=sa/L;// signal attenuation per km
sn=sp*L1;// signal attenuation for 12 km
sn1=ns*a;// attenuation in dB
sn2=sn+sn1;// overall signal attenuation in dB
printf("The signal attenuation per km =%f dB/km", sp
   );
printf("\n The overall signal attenuation=%f dB ",
   sn2);
```

Scilab code Exa 4.9 Find the overall signal attenuation and the signal attenuation per kilometer of the fiber and the overall attenuation for a 10km

```
//Ex:4.9
clc;
clear;
close;
Pi=100*10^-6;// average optical power in watt
Po=4*10^-6;// average output power in watt
L=6;// in km
L1=10;// in km
sa=10*log(Pi/Po)/log(10);// signal attenuation
```

```
sp=sa/L;// signal attenuation per km
sn=sp*L1;// signal attenuation for 12 km
sn1=sn+9;// overall signal attenuation in dB
printf("The signal attenuation=%f dB", sa);
printf("\n The signal attenuation per km =%f dB/km",
    sp);
printf("\n The overall signal attenuation=%d dB ",
   sn1);
```

Scilab code Exa 4.10 Find the overall loss and the overall loss in dB per km and also find the overall signal attenuation and the numerical input and output power ratio

```
//Ex:4.10
clc;
clear;
close;
Pi=20*10^-6;// average optical power in watt
Po=7.5*10^-6;// average output power in watt
sl=10*log(Pi/Po)/log(10);// signal Loss in dB
L=15;// in km
L1=30;// in km
ns=29;// number of attenuation
sp=sl/L;// signal Loss per km
sn=sp*L1;// signal attenuation for 30 km
sn1=sn+ns;// overall signal attenuation in dB
i_o=10^(sn1/20);// input output power ratio
printf("The signal Loss =%f dB", sl);
printf("\n The signal Loss per km=%f dB/km", sp);
printf("\n The overall signal attenuation=%f dB",
   sn1);
printf("\n The input output power ratio=%f", i_o);
```

Scilab code Exa 4.11 Dtermine the attenuation in db per km due to rayleigh scattering in silica

```
//Ex:4.11
clc;
clear;
close;
Tf=1400;// temperature in k
Bc=7*10^-11;// in m^2/N
n=1.38;//
P=0.29;// Photoelastic coefficient
y=0.9*10^-6;// wavelength in m
K=1.38*10^-23;// boltzman's constant
Rrs=((8*%pi^3)*(n^8)*(P^2)*(Bc*Tf*K))/(3*y^4);
Rrs1=Rrs/10^-3;// per km
e=2.718281828;// Exponential term
Lkm=e^(-Rrs1);// transmission loss facter
At=10*log(1/Lkm)/log(10);// Attenuation in dB/km
printf("The Attenuation=%f dB/km", At);
```

Scilab code Exa 4.12 Calculat the threshold optical powers of SBS and SRS

```
//Ex:4.12
clc;
clear;
close;
y=1.35;// wavelength in um
d=5;// core diamater in um
a=0.75;// attenuation in dB/km
v=0.45;// bandwidth in GHz
Pb=4.4*10^-3*(d^2)*(y^2)*(a*v);// threshold optical power for sbs
Pr=5.9*10^-2*(d^2)*(y)*(a);// threshold optical power for sbr
```

```
Pbr=Pb/Pr;// the ratio of threshold power level
printf("The ratio of threshold power level=%f %%",
   Pbr*100);
```

Scilab code Exa 4.13 Calculate the critical radius of curvature at which large bending losses occour

```
//Ex:4.13
clc;
clear;
close;
n1=1.5;// core refractive index
y=0.85*10^-6;// wavelength in m
dl=0.024;// relative refractive index difference
N2=sqrt(n1^2-2*dl*n1^2);// cladding refractive index
n2=1.46;
Rcs=(3*n1^2*y)/((4*%pi)*(n1^2-n2^2)^1.5);// critical
    radius of curvature for multimode fiber
printf("The critical radius of curvature =%f um",
   Rcs*10^6);
```

Scilab code Exa 4.14 Find the critical radius of both single mode and multimode fibers

```
//Ex:4.14
clc;
clear;
close;
n1=1.45;// core refractive index
y=1.5*10^-6;// wavelength in m
dl=0.03;// relative refractive index difference
a=5*10^-6;// core radius
n2=sqrt(n1^2-2*dl*n1^2);// cladding refractive index
```

```
yc=(2*%pi*a*n1*sqrt(2*dl))/(2.405);
Rcs=(20*y*(2.748-0.996*(y/yc))^-3)/(n1^2-n2^2)^1.5;// critical radius of curvature for single mode fiber
Rcs1=(3*n1^2*y)/((4*%pi)*(n1^2-n2^2)^1.5);// critical radius of curvature for multimode fiber
printf(”The critical radius of curvature for single mode fiber =%f um”, Rcs*10^6);
printf(”\n The answer is wrong in the textbook”);
printf(”\n The critical radius of curvature for multimode fiber =%f um”, Rcs1*10^6);
```

Scilab code Exa 4.15 Find the loss in db per km of the fiber

```
//Ex:4.15
clc;
clear;
close;
L=500/1000;// distance in km
Pio=(1/(1-0.75));
Ls=10*log(Pio)/log(10)/L;// Loss in dB/km
printf(”The Loss =%f dB/km”, Ls);
```

Scilab code Exa 4.16 Calculate the power level in mW after travelling a distance of 5 km

```
//Ex:4.16
clc;
clear;
close;
L=5;// length in km
a=0.5;// attenuaion loss in dB/km
Po=10^-3*10^(-(a*L)/10);// power level in mW
```

```
printf("The power level =%f mW", Po*10^3);
```

Scilab code Exa 4.17 Calculate the fiber loss in dB

```
//Ex:4.17
clc;
clear;
close;
L=1;// distance in km
Pio=(1/(1-0.40));
Ls=10*log(Pio)/log(10)/L;// Loss in dB/km
printf("The Loss =%f dB/km", Ls);
```

Scilab code Exa 4.18 What will be the transmission length caused by the fiber

```
//Ex:4.18
clc;
clear;
close;
Pi=1*10^-3;// input power in watt
Po=0.75*10^-3;// output power in watt
a=0.5;// in dB/km
L=(10*log(Pi/Po)/log(10))/a;// transmission length
   in km
printf("The transmission length =%f km", L);
```

Scilab code Exa 4.19 Find the macrobend loss of a single mode fiber and also calculate the mode field diameter

```
//Ex:4.19
clc;
clear;
close;
y=1300*10^-9;// wavelemgth in m
yc=1200*10^-9;// cut off wavelength in m
rc=5*10^-6;// core diameter in m
n=1.5;// refractive index
R=1.2/100;// curve of radius in m
dmf=2*rc*((0.65)+0.434*(y/yc)^1.5+0.0149*(y/yc)^6);
    // mode field diameter
K=(2*%pi)/y;
Lm=-10*log(1-(K^4)*(n^4)*((3.95*10^-6)/(8*R^2))^6)/
    log(10);// macrobend loss
printf("The mode field diameter =%f um", dmf*10^6);
printf("\n The macrobend loss =%f dB", Lm);
printf("\n The answer is wrong in the textbook");
```

Scilab code Exa 4.20 Find the loss in dB per km for a fiber

```
//Ex:4.20
clc;
clear;
close;
Pi=10*10^-3;// input power in watt
Po=8*10^-3;// output power in watt
L=0.150;// length in km
Ls=(10*log(Po/Pi)/log(10))/L;
printf("The transmission length =%f km", Ls);
```

Chapter 5

Dispersion in Optical Fibers

Scilab code Exa 5.1 Find out the max bandwidth and pulse dispersion per unit length and also find bandwidth length product

```
//Ex:5.1
clc;
clear;
close;
t=0.1*10^-6;// pulse broading in sec
d=12;// disance in km
B=1/(2*t);// max bandwidth MHz
ds=t/d;// dispersion in ns/km
bl=B*d;// bandwidth length product
printf("The max bandwidth =%d MHz", B/10^6);
printf("\n The dispersion =%f ns/km", ds*10^9);
printf("\n bandwidth length product =%d MHz km", bl
   /10^6);
```

Scilab code Exa 5.2 Find out the max bandwidth and pulse dispersion per unit length and also find bandwidth length product

```
//Ex:5.2
clc;
clear;
close;
t=0.1*10^-6;// pulse broadening in sec
d=15;// disance in km
B=1/(2*t);// max bandwidth MHz
ds=t/d;// dispersion in ns/km
bl=B*d;// bandwidth length product
printf("The max bandwidth =%d MHz", B/10^6);
printf("\n The dispersion =%f ns/km", ds*10^9);
printf("\n bandwidth length product =%d MHz km", bl
    /10^6);
```

Scilab code Exa 5.3 Calculate the Na and multipass pulse brodening and bandwidth length product

```
//Ex:5.3
clc;
clear;
close;
n1=1.465;// core refractive index
n2=1.45;// cladding refractive index
c=3*10^8;// the speed of light in m/s
NA=sqrt(n1^2-n2^2);// numerical aperture
Mp=(NA^2)/(2*n1*c);// multipath pulse broadening in
    ns/km
bl=(1/NA^2)*(2*n1*c);// bandwidth length product in
    GHz km
printf("The numerical aperture =%f", NA);
printf("\n The multipath pulse broadening =%f ns/km"
    , Mp*10^9);
printf("\n The bandwidth length product =%d GHz km",
     bl/10^9);
```

Scilab code Exa 5.4 find the material dispersion and estimate also the rms pulse broadening

```
//Ex:5.4
clc;
clear;
close;
ds=0.020;// material dispersion
c=3*10^8;// the speed of light m/s
y=1.3;// wavelength in um
M=ds/(c*y);// material dispersion parameter in ps/nm/km
w=6;// spectral width in nm
l=1;// length in km
rm=w*l*M;// rms pulse broadening in ns/km
printf("The material dispersion parameter =%f ps/nm/km", M*10^12);
printf("\n The rms pulse broadening =%f ns/km",rm*10^9);
```

Scilab code Exa 5.5 Estimate the rms pulse broadening per km of the fibers

```
//Ex:5.5
clc;
clear;
close;
wr=0.0014;// relative spectral width in nm
y=1.3*10^-6;// wavelength in m
w=wr*y;// spectral width in nm
ds=0.020;// material dispersion
c=3*10^8;// the speed of light in m/s
```

```
M=ds/(c*y);// material dispersion parameter in ps/nm/km
l=1;// length in km
rm=w*l*M;// rms pulse broadening in ns/km
printf("The rms pulse broadening =%f ns/km",rm*10^9*10^3);
```

Scilab code Exa 5.6 Find the delay difference and rms pulse broadening and max bit rateand Bandwidth length product for the fiber

```
//Ex:5.6
clc;
clear;
close;
n1=1.46;// core refractive index
dl=0.01;// relative index difference
L=10*10^3;// optical length in meter
c=3*10^8;// the speed of light in m/s
dt=(L*n1*dl)/c;// delay difference in s
dT=dt*10^9;// delay difference in ns
rm=(L*n1*dl)/(2*sqrt(3)*c);// rms pulse broadening s
rM=rm*10^9;// rms pulse broadening ns
bt=0.2/rm;// max bit rate in bit/sec
bT=bt/10^6;// max bit rate in M bits/sec
bl=bt*L;// bandwidth length product in Hz meter
bL=(bt*L)/(10^6*10^3);// bandwidth length product in MHz km
printf("The delay difference =%d ns", dT);
printf("\n The rms pulse broadening =%f ns", rM);
printf("\n The max bit rate =%f M bits/sec", bT);
printf("\n The bandwidth length product =%f MHz km", bL);
```

Scilab code Exa 5.7 Estimate the max bit rate assuming only intermodel dispersion

```
//Ex:5.7
clc;
clear;
close;
n1=1.5;// core refractive index
dl=0.01;// relative index difference
L=6*10^3;// optical length in meter
c=3*10^8;// the speed of light in m/s
rm=(L*n1*dl)/(2*sqrt(3)*c);// rms pulse broadening s
rM=rm*10^9;// rms pulse broadening ns
bt=0.2/rm;// max bit rate in bit/sec
bT=bt/10^6;// max bit rate in M bits/sec
printf("The rms pulse broadening =%f ns", rM);
printf("\n The max bit rate =%f M bits/sec", bT);
```

Scilab code Exa 5.8 Find the delay difference and rms pulse broadening and max bit rate

```
//Ex:5.8
clc;
clear;
close;
n1=1.4;// core refractive index
dl=0.012;// relative index difference
L=6*10^3;// optical length in meter
c=3*10^8;// the speed of light in m/s
dt=(L*n1*dl)/c;// delay difference in s
dT=dt*10^9;// delay difference in ns
rm=(L*n1*dl)/(2*sqrt(3)*c);// rms pulse broadening s
rM=rm*10^9;// rms pulse broadening ns
bt=0.2/rm;// max bit rate in bit/sec
bT=bt/10^6;// max bit rate in M bits/sec
```

```
printf("The delay difference =%d ns", dT);
printf("\n The rms pulse broadening =%f ns", rM);
printf("\n The max bit rate =%f M bits/sec", bT);
```

Scilab code Exa 5.9 Find the rms pulse broadening and Bandwidth length product for the fiber

```
//Ex:5.9
clc;
clear;
close;
n1=1.5;// core refractive index
c=3*10^8;// the speed of light m/s
w=6*10^-6;// rms spectral width in m
M=200;// material dispersion parameter in ps/nm/km
NA=0.25;// numerical aperture
w=50;// spectral width in nm
L=1;// length in m
rm=w*L*M;// rms pulse broadening in s/km
rM=rm/10^3;// rms pulse broadening in ns/km due to
   material dispersion
rm1=(L*1000*(NA)^2)/(4*sqrt(3)*n1*c);//rms pulse
   broadening in ns/km due to material dispersion in
    sec/m
rM1=rm1*10^9;// rms pulse broadening in ns/km due to
    intermodel dispersion in ns/km
rmt=sqrt(rM^2+rM1^2);// total rms pulse broadening
   in ns/km
bl=0.2/(rmt*10^-9);// bandwidth length product in Hz
    km
bL=bl/10^6;// bandwidth length product in MHz km
printf("The total rms pulse broadening =%f ns/km",
   rmt);
printf("\n The bandwidth length product =%f MHz km",
   bL);
```

Scilab code Exa 5.10 Determine the total first order dispersion and also find the waveguide dispersion

```
//Ex:5.10
clc;
clear;
close;
yo=1320;// zero dispersion wavelength in nm
y=1290;// dispersion wavelength in nm
so=0.092;// dispersion slop
dt=(y*so/4)*(1-(yo/y)^4);// toal first order
   dispersion at 1290 nm in ps/nm/km
yo1=1310;// zero dispersion wavelength in um
y1=1550;// dispersion wavelength in nm
so=0.092;// dispersion slop
dt1=(y1*so/4)*(1-(yo1/y1)^4);// toal first order
   dispersion at 1550 nm in ps/nm/km
DM=13.5;// profile dispersion in ps/nm/km
DP=0.4;// profile dispersion in ps/nm/km
DW=dt1-(DM+DP);// wavelength dispersion in ps/nm/km
printf("The toal first order dispersion at 1290 nm =
   %f ps/nm/km", dt);
printf("\n The toal first order dispersion at 1550
   nm =%f ps/nm/km", dt1);
printf("\n The wavelength dispersion at 1550 nm =%f
   ps/nm/km", DW);
```

Scilab code Exa 5.11 Find the model birefrigence and coherence length and also the propagation constant

```
//Ex:5.11
```

```
clc;
clear;
close;
L=6*10^-2;// beat length in m
dy=6*10^-9;// spectral width in m
y=1.3*10^-6;// operating wavelength in m
BF=y/(L);//model birefrigence in um
Lc=y^2/(BF*dy);// coherence length in m
db=2*3.14/(L);// difference beween two propagation constants
dB=(2*3.14*BF)/y;
printf(”The model birefrigence =%f um”, BF*10^6);
printf(”\n The coherence length=%f m”, Lc);
printf(”\n The difference beween two propagation constants=%f”, db);
printf(”\n The difference beween two propagation constants=%f”, dB);
```

Scilab code Exa 5.12 Find the model birefrigence and interpret the length

```
//Ex:5.12
clc;
clear;
close;
y=0.85*10^-6;// operating wavelength in m
L=0.5*10^-3;// beat length in m
BF=y/(L);//model birefrigence in um
L1=75;// beat length in m
BF1=y/(L1);//model birefrigence in um
printf(”The model birefrigenceat 0.5 nm =%f*10^-3”, BF);
printf(”\n The model birefrigence at 75 m =%f*10^-8”, BF1*10^8);
```

Scilab code Exa 5.13 Find the beat length within the fiber

```
//Ex:5.13
clc;
clear;
close;
Lc=100000;// coherence length in m
y=1.32*10^-6;// operating wavelength in m
dy=1.5*10^-9;// spectral width in m
BF=y^2/(Lc*dy);//model birefrigence in um
L=y/BF;// beat length in m
printf(”The beat length=%f m”, L);
```

Scilab code Exa 5.14 Find the rms intermodel pulse broadening

```
//Ex:5.14
clc;
clear;
close;
n1=1.46;// core refractive index
NA=0.25;// numerical aperture
c=3*10^5;// the speed of light km/s
L=7;// length in km
si=NA^2/(4*sqrt(3)*n1*c);//intermodel pulse broadening ns/km
st=si*L;//total intermodel pulse broadening
BW=0.187/st;// bandwidth in MHz
printf(”The intermodel pulse broadening =%f ns/km”, st*10^9);
printf(”\n The bandwidth =%f MHz”, BW/10^6);
```

Scilab code Exa 5.15 Compute the max dispersion

```
//Ex:5.15
clc;
clear;
close;
n1=1.46;// core refractive index
df=0.025;
L=500;// length in m
c=3*10^8;// the speed of light in m/s
dt=(n1*L*df^2)/(8*c);// max dispersion in ns/m
printf("The  max dispersion =%f ns/m", dt*10^9);
printf("\n The answer in the textbook is wrong");
```

Scilab code Exa 5.16 Calculate the amount of material dispersion

```
//Ex:5.16
clc;
clear;
close;
dy=15;// spectral width in nm
L=25;// optical length in km
ps=1.60;//pulse spreads in ns/km
pS=1.6;// pulse spreads in ns/km
d=pS/(dy*L);// material dispersion in ns/km^2/nm
printf("The  max dispersion =%f ns/km^2/nm", d);
```

Scilab code Exa 5.17 Calculate the intermodel dispersion of a step index fiber

```
//Ex:5.17
clc;
clear;
close;
n1=1.46;// core refractive index
NA=0.2;// numerical aperture
L=1.5*10^3;// length in m
c=3*10^8;// the spee of light in m/s
dt=(L*NA^2)/(2*c*n1);//intermodel dispersion in ns/
   km
printf("The intermodel dispersion =%f ns/km", dt
   *10^9);
```

Scilab code Exa 5.18 Compute the pulse broadening due to modal and combined pulse broadening and also compute the actual BLP

```
//Ex:3.18
clc;
clear;
close;
BLP=250*10^6;// bandwidth length product in Hz
tr=0.32/BLP;// intermodel pulse width broadening
md=75;// material dispersion in ps/nm.km
tm=2.25;//pulse broadening due to material
   dispersion in ns/km
tc=sqrt((tr*10^9)^2+tm^2);// combine pulse
   broadening in ns/km
Ba=0.32/tm*10^9;// actual BLP in Hz.km
Bac=Ba/10^6;// actual BLP in MHz.km
printf("The intermodel pulse width broadening =%f ns
   /km", tr*10^9);
printf("\n pulse broadening due to material
   dispersion =%f ns/km", tm);
printf("\n The combine pulse broadening =%f ns/km",
   tc);
```

```
printf("\n The actual BLP =%f MHz.km", Bac);
```

Scilab code Exa 5.19 Compute the material dispersion

```
//Ex:5.19
clc;
clear;
close;
L=40;// length in m
Ny=.75;// in ps/nm
dy=8;// spectral width in nm
t_mat=L*Ny*dy;// chromatic/material dispersion in ps
t_mat1=t_mat/1000;// chromatic/material dispersion
   in ns
printf("The chromatic/material dispersion =%f ns",
   t_mat1);
```

Scilab code Exa 5.20 Calculate the pulse width of the received signal and approximate bit rate

```
//Ex:5.20
clc;
clear;
close;
y=1.3;// operating wavelength in um
md=2.80;// material dispersion in ns
wd=0.50;// waveguide dispersion in ns
wt=0.60;// width of transmitted pulse in ns
td=sqrt(md^2+wd^2);// total dispersion in ns
dt=wt+td;// received pulse width in ns
br=1/(5*dt*10^-9);// max bit rate bit/sec
Br=br/10^6;// max bit rate in mbps
printf("The received pulse width =%f ns", dt);
```

```
printf(”\n The  max bit rate =%f mbps”, Br);
```

Scilab code Exa 5.21 Calculate the pulse width of the received signal and approximate bit rate

```
//Ex:5.21
clc;
clear;
close;
y=0.85;// operating wavelength in um
md=2.75;// material dispersion in ns
wd=0.45;// waveguide dispersion in ns
wt=0.50;// width of transmitted pulse in ns
td=sqrt(md^2+wd^2);// total dispersion in ns
dt=wt+td;// received pulse width in ns
br=1/(5*dt*10^-9);// max bit rate bit/sec
Br=br/10^6;// max bit rate in mbps
printf(”The received pulse width =%f ns”, dt);
printf(”\n The  max bit rate =%f mbps”, Br);
```

Scilab code Exa 5.22 find the total dispersion

```
//Ex:5.22
clc;
clear;
close;
n1=1.46;// core refractive index
df=0.025;
L=1500;// length in meter
c=3*10^8;// the speed of ligth in m/s
md=(n1*L*df)/(c*(1-df));// max dispersion in sec
Md=md*10^9;// max dispersion in ns
printf(”The max dispersion =%d ns”, Md);
```

Scilab code Exa 5.23 Find the intermodel dispersion

```
//Ex:5.23
clc;
clear;
close;
n1=1.5;// core refractive index
L=1000;// length in meter
NA=0.22;// numerical aperture
dl=(NA/n1)^2/2;
c=3*10^8;// the speed of ligth in m/s
dt=(L*n1*dl)/c;//intermodel dispersion in sec
dT=dt*10^9;//intermodel dispersion in ns
printf("The max dispersion =%d ns", dT);
```

Scilab code Exa 5.24 Find the total intermodal and intramodal and total dispersion

```
//Ex:5.24
clc;
clear;
close;
w=30;// line width in nm
L=1.5;// length in km
d1=6;// in ns/km
d2=85;// in ps/km/nm
d3=d2/1000;// in ns/km/nm
dt=d1*L;// intermodel dispersion in ns
dt1=w*d3*L;// intramodel dispersion in ns
dT=sqrt(dt^2+dt1^2);// total dispersion in ns
printf("The max dispersion =%d ns", dt);
```

```
printf("\n The max dispersion =%f ns", dt1);
printf("\n The max dispersion =%f ns", dT);
printf("\n answer in the textbook is wrong");
```

Scilab code Exa 5.25 Find the intermodal dispersion

```
//Ex:5.25
clc;
clear;
close;
n1=1.55;// core refractive index
n2=1.48;// cladding refractive index
l=150;//fiber length in m
c=3*10^8;//the speed of light in m/s
dl=(n1^2-n2^2)/(2*n1);
dL=0.068;
dt=(l*n1*dL)/(c);// intermodel dispersion in s
dT=dt*10^9;// intermodel dispersion in ns
printf("The intermodel dispersion =%f ns", dT);
```

Scilab code Exa 5.26 Find the intermodal dispersion per km

```
//Ex:5.29
clc;
clear;
close;
n1=1.42;// core refractive index
dl=0.02;
c=3*10^8;//the speed of light in m/s
dt=(n1*dl)/c;// intermodel disersion in sec/m
dt1=dt*1000;// intermodel disersion in sec/km
dt2=dt1*10^9;// intermodel disersion in ns/km
```

```
printf("The intermodel dispersion per km =%f ns/km",
    dt2);
```

Scilab code Exa 5.27 Find the waveguide dispersion parameter DW

```
//Exa:5.27
clc;
clear;
close;
printf("Dwg=n2*(dl/cy)*V(d^2(Vb)/dV^2)");
printf("\n Dwg=n2*(dl/cy)*V(d^2(V(1-exp(-V))))/dv^2"
   );
printf("\n =CV(Z-V)exp(-V)");
printf("\n where C=n2(dl/cy)");
printf("\n waveguide dispersion will be zero , when
   V=2");
```

Scilab code Exa 5.28 Find the pulse spreading due to material dispersion

```
//Ex:5.28
clc;
clear;
close;
y=900;// operating wavelength in nm
yo=1343;// wavelength in nm
so=0.095;// in ps/nm^2-km
L=150;// in km
dy=50;//in nm
Dy=(so*y/4)*(1-(yo/y)^4);// inps/nm-km
Dy1=Dy*(-1);// do not consider -ve sign
dt=Dy1*L*dy;// pulse spreading in ps
dt1=dt/1000;// pulse spreading in ns
printf("The pulse spreading =%f ns", dt1);
```

Scilab code Exa 5.29 Find the pulse spread due to material and waveguide dispersion

```
//Ex:5.29
clc;
clear;
close;
n1=1.48;// core refractive index
y=900;// operating wavelength in nm
yo=1343;// wavelength in nm
so=0.095;// in ps/nm^2-km
L=1.5;// in km
dy=50;//in nm
dl=0.002;
c=3*10^8;// the speed of ligth in m/s
Dm=(so*y/4)*(1-(yo/y)^4);// inps/nm-km
Dm1=Dm*(-1);// do not consider -ve sign
Vd=0.26;
Dw=((n1*dl)/(c*y*10^-9))*(Vd);
DW=Dw*10^6;// in ps/nm-km
dt=DW*L*dy;// pulse spreading in ps
dt1=dt/100;// pulse spreading in ns
printf("The pulse spreading =%f ps", dt1);
```

Scilab code Exa 5.30 calculate wo and wp for operation at wavelength is 1310 nm and 1550 nm

```
//Ex:5.30
clc;
clear;
close;
```

```
a=4.1*10^-6;// core radius in um
dl=0.0036;
y1=1.310*10^-6;// operating wavelength in um
y2=1.550*10^-6;// operating wavelength in um
n1=1.4677;// core refrative index at y=1.310
n2=1.4682;// core refrative index at y=1.550
v1=(2*3.14*a*n1*sqrt(2*dl))/y1;// normalised frequency at y=1.310
v2=(2*3.14*a*n2*sqrt(2*dl))/y2;// normalised frequency at y=1.550
wo=a*(0.65+(1.619/v1^1.5)+2.879/v1^3);
wp=wo-a*(0.016+1.567/v1^7);
wo1=a*(0.65+(1.619/v2^1.5)+2.879/v2^3);
wp1=wo-a*(0.016+1.567/v2^7);
printf(”The value of wo =%f um”, wo*10^6);
printf(”\n The value of wp =%f um”, wp*10^6);
printf(”\n The value of wo1 =%f um”, wo1*10^6);
printf(”\n The value of wp1 =%f um”, wp1*10^6);
```

Scilab code Exa 5.31 calculate the range of the propagation constant and length of the beat length

```
//Ex:5.31
clc;
clear;
close;
y=1.30*10^-6;// operating wavelength in m
dn1=10^-6;
dn2=10^-5;
db1=(dn1*2*3.14)/y;// in per m
db2=(dn2*2*3.14)/y;// in per m
Lp1=(2*3.14)/(db1);// beat length in m
Lp2=(2*3.14)/(db2);// beat length in m
printf(”The max core radius =%f um”, db1);
printf(”\n The max core radius =%f um”, db2);
```

```
printf("\n The beat length =%f m", Lp1);
printf("\n The beat length =%f cm", Lp2*100);
printf("\n Hence, range of beat length; 13cm−1.3m");
```

Scilab code Exa 5.32 Estimate the waveguide dispersionfor the given fiber

```
//Ex:5.32
clc;
clear;
close;
n1=1.48;// core refractive index
dl=0.0027;
a=4.4*10^-6;// radius in m
y=1.32*10^-6;// operating wavelength in m
n2=n1*(1-dl);
c=3*10^8;// the speed of ligth in m/s
v=(2*3.14*a*n1*sqrt(2*dl))/y;
VD=0.080+0.549*(2.834-v)^2;
DW=(-1)*(n2*dl*VD)/(c*y);// wavelength dispersion in s /um/m
Dw=DW*10^6;// wavelength dispersion in ps /nm/km
printf("The wavelength dispersion =%f ps n/m/km", Dw);
```

Scilab code Exa 5.33 What should be the radius of the core so that the total dispersion at this wavelength is zero

```
//Exa:5.33
clc;
clear;
close;
n1=1.48;// core refractive index
dl=0.01;// refractive index difference
```

```
c=3*10^8;// the speed of light in m/s
y=1.55;// wavelength in um
DM=7;// in ps/nm–km
DW=(-1)*DM;// in ps/nm–km
X=-10^12*(n1*dl)/(c*y);// in ps/nm/km
Z=(DW/X)-0.08;//
V=2.834-sqrt(Z/0.549);
a=(V*y)/(2*%pi*n1*sqrt(2*dl));// core radius in um
printf(”The core radius =%f um”, a);
```

Chapter 6

Preparation of Optical Fibers And Cables

Scilab code Exa 6.1 Compute the stain on the fiber and what will happen if this condition is maintained

```
//Ex:6.1
clc;
clear;
close;
r=125*10^-6;// cladding radius in meter
R=8*10^-2;// curve of radius in meter
s=((R+2*r)/(R+r))-1;
s_p=s*100;// percentage of strain
printf("The percentage of strain =%f %%", s_p);
printf("\n If this condition is maintained the fiber
    will maintain without any break");
```

Scilab code Exa 6.2 Find the pulling tension

```
//Ex:6.2
```

```
clc;
clear;
close;
w=40*10^-3;// cable weighing in kg/m
R=20*10^-2;// radius of curvature in meter
n=0.19;// co-efficient of friction
x=(3.14/4);// angle in rad
si=42.36;// pulling tension at the entrance in kg
X=(si/(w*R));//
Y=asinh(si/(w*R));
Z=w*R*sinh(n*x+Y);//puttling tension at the exit of an optical cable
printf("The puttling tension at the exit of an optical cable =%f kg", Z);
```

Chapter 7

Optical Fiber Connection Connectors Joints And Couplers

Scilab code Exa 7.1 Calculate the fiber loss in db

```
//Ex:7.1
clc;
clear;
close;
n1=1.46;// core refractive index
n=1;// refractive index due to air
r=((n1-n)/(n1+n))^2;
r1=0.03;// r take upto two decimal place
l_s=-10*log(1-r1)/log(10);// fiber loss in db
l_t=2*l_s;// total loss in db
printf("The fiber loss =%f db", l_s);
printf("\n there is a similar loss at the other
   interface");
printf("\n The total fiber loss =%f db", l_t);
```

Scilab code Exa 7.2 Find the insertion loss due to lateral misalignment

```
//Ex:7.2
clc;
clear;
close;
n1=1.46;// core refractive index
n=1;// refractive index due to air
a=25*10^-6;// core radius in m
y=3*10^-6;// in m
A=(y/a)*(1-(y/(2*a))^2)^0.5;
B=acos(y/(2*a));
C=n1/n;
M=(16*C^2)/(%pi*(1+C)^4);
n_lat=M*(2*B-A);// coupling efficiency for multimode step index fiber
L_lat=-10*log(n_lat)/log(10);// insertion loss for lateral misalignment
n_lat1=(1/%pi)*(2*B-A);// coupling efficiency when there is no air gap
L_lat1=-10*log(n_lat1)/log(10);// insertion loss for lateral misalignment when there is no air gap
printf(”The coupling efficiency for multimode step index fiber =%f”, n_lat);
printf(”\n The insertion loss for lateral misalignment =%f dB”, L_lat);
printf(”\n The coupling efficiency when there is no air gap =%f”, n_lat1);
printf(”\n The insertion loss for lateral misalignment when there is no air gap =%f dB”, L_lat1);
```

Scilab code Exa 7.3 Calculate the total insertion loss at the joint

```
//Ex:7.3
```

```
clc;
clear;
close;
n1=1.50;// core refractive index
n=1;// refractive index due to air
a=25*10^-6;// core radius in m
y=4*10^-6;// in m
A=(y/a)*(1-(y/(2*a))^2)^0.5;
B=acos(y/(2*a));
C=n1/n;
M=(16*C^2)/(%pi*(1+C)^4);
n_lat=M*(2*B-A);// coupling efficiency for multimode step index fiber
L_lat=-10*log(n_lat)/log(10);// insertion loss for lateral misalignment
dx=4*(3.14/180);// angular misalignment in radian
dl=0.02;// relative index difference
NA=n1*sqrt(2*dl);// numerical aperture
n_ang=1-(0.069/(3.14*NA));// coupling efficiency due to angular misalignment
L_ang=-10*log(n_ang)/log(10);// loss due to angular misalignment
Lt=L_lat+L_ang;// total insertion loss in dB
printf("The total insertion loss =%f dB", Lt);
printf("\n the answer is wrong in the textbook");
```

Scilab code Exa 7.4 Estimate the insertion loss at the joint when there is a small gap and when an index matching fluid is inserted between the fiber end

```
//Ex:7.4
clc;
clear;
close;
n1=1.46;// core refractive index
```

```
n=1;// refractive index due to air
a=1;// core radius in m
y=0.12;// lateral offset
A=(y/a)*(1-(y/(2*a))^2)^0.5;
B=acos(y/(2*a));
C=n1/n;
M=(16*C^2)/(%pi*(1+C)^4);
n_lat=M*(2*B-A);// coupling efficiency when there is a smsll air gap
L_lat=-10*log(n_lat)/log(10);// insertion loss when there is a smsll air gap
n_lat1=(1/%pi)*(2*B-A);// coupling efficiency when the joint is indexed matched
L_lat1=-10*log(n_lat1)/log(10);// insertion loss when the joint is indexed matched
printf("The insertion loss when there is a smsll air gap =%f dB", L_lat);
printf("\n The insertion loss when the joint is indexed matched =%f dB", L_lat1);
```

Scilab code Exa 7.5 Find the insertion loss of a signal in the fwd and backward directions

```
//Ex:7.5
clc;
clear;
close;
d1=60*10^-6;// core diameter of fiber 1 in m
d2=50*10^-6;// core diameter of fiber 1 in m
NA1=0.25;// numerical aerture of fiber 1
NA2=0.22;// numerical aerture of fiber 2
a1=2.0;// for fiber 1
a2=1.9;// for fiber 2
n_cd=(d2/d1)^2;
n_NA=(NA2/NA1)^2;
```

```
n_a=(1+(2/a1))/(1+(2/a2));
n_t=n_cd*n_NA*n_a;// total coupling efficiency
Lt=-10*log(n_t)/log(10);// total loss at the joint
   in dB
printf("The total coupling efficiency in the frw
   direction =%f", n_t);
printf("\n The total loss at the joint in the frw
   direction =%f dB", Lt);
printf("\n In the backward direction n_cd & n_a are
   all unity therefore there will be no loss in the
   backward direction of transmission of the signal
   ");
```

Scilab code Exa 7.6 Calculate the insertion loss at the jont in the fwd and backward direction

```
//Ex:7.6
clc;
clear;
close;
d1=80*10^-6;// core diameter of fiber 1 in m
d2=60*10^-6;// core diameter of fiber 1 in m
NA1=0.25;// numerical aerture of fiber 1
NA2=0.20;// numerical aerture of fiber 2
a1=1.9;// for fiber 1
a2=2.1;// for fiber 2
n_cd=(d2/d1)^2;
n_NA=(NA2/NA1)^2;
n_a=(1+(2/a1))/(1+(2/a2));
n_t=n_cd*n_NA*n_a;// total coupling efficiency in
   the frw direction
Lt=-10*log(n_t)/log(10);// total loss at the joint
   in the frw direction in dB
n_cd1=1;
n_NA1=1;
```

```
n_a1=(1+(2/a2))/(1+(2/a1));
n_t1=n_cd1*n_NA1*n_a1;// total coupling efficiency
   in the backward direction
Lt1=-10*log(n_t1)/log(10);// total loss at the joint
    in the backward direction in dB
printf("The total loss at the joint in the frw
   direction =%f dB", Lt);
printf("\n The total loss at the joint in the
   backward direction =%f dB", Lt1);
```

Scilab code Exa 7.7 Determine the insertion loss of the splices

```
//Ex:7.7
clc;
clear;
close;
n1=1.5;// core refractive index
n=1.47;// refractive index due to air
a=1;// core radius in m
y=0.12;// lateral offset
A=(y/a)*(1-(y/(2*a))^2)^0.5;
B=acos(y/(2*a));
C=n1/n;
M=(16*C^2)/(%pi*(1+C)^4);
n_lat=M*(2*B-A);// coupling efficiency of the splice
L_lat=-10*log(n_lat)/log(10);// insertion loss of
   the splice
printf("The insertion loss of the splice =%f dB",
   L_lat);
```

Scilab code Exa 7.8 Determine the refractive index of the fiber core

```
//Ex:7.8
```

```
clc;
clear;
close;
L_f=0.036;
n_f=10^(-0.036);
// here we get a quadratic equation in n1 and on
   solving we get
n1=(2.17+sqrt((-2.17)^2-4*1*1))/2;// refractive
   index of the fiber core
printf("The refractive index of the fiber core =%f",
    n1);
```

Scilab code Exa 7.9 Find the numerical aperture of the fiber

```
//Ex:7.9
clc;
clear;
close;
n1=1.46;// core refractive index
n=4;// refractive index due to air
x=%pi/180;
A=(16*n1^2)/((1+n1)^4);
B=n*x;
n_ang=10^(-0.06);// angular coupling efficiency
NA=B/((%pi)*(1-(n_ang/A)));// numerical aperture
printf("The numerical aperture =%f", NA);
```

Scilab code Exa 7.10 Find the insertion loss due to misalignment assuming index matching

```
//Ex:7.10
clc;
clear;
```

```
close;
y=5*10^-6;// lateral misalignment in m
a=25*10^-6;// core diameter in m
Lt=0.85*(y/a);// misalignment loss
n_c=1-Lt;// coupling efficiency
L_i=-10*log(n_c)/log(10);// insertion loss in dB
Lt1=0.75*(y/a);// misalignment loss if we have both guided and leaky modes
n_c1=1-Lt1;// coupling efficiency
L_i1=-10*log(n_c1)/log(10);// insertion loss in dB if we have both guided and leaky modes
printf(”The insertion loss =%f dB”, L_i);
printf(”\n The insertion loss,if we have both guided and leaky modes =%f dB”, L_i1);
```

Scilab code Exa 7.11 Find the insertion loss due to misalignment

```
//Ex:7.11
clc;
clear;
close;
n1=1.5;// core refractive index
n=1;// refractive index due to air
x=5*%pi/180;
C=n1/n;
A=(16*C^2)/((1+C)^4);
B=n*x;
NA=0.22;// numerical aperture
n_ang=A*(1-(B/(%pi*NA)));// angular coupling efficiency
L_ang=-10*log(n_ang)/log(10);// inserion loss when NA=0.22
NA1=0.32;// numerical aperture
n_ang1=A*(1-(B/(%pi*NA1)));// angular coupling efficiency
```

```
L_ang1=-10*log(n_ang1)/log(10);// inserion loss when
    NA=0.32
printf("The inserion loss when NA=0.22 =%f dB",
   L_ang);
printf("\n The inserion loss when NA=0.32 =%f dB",
   L_ang1);
```

Scilab code Exa 7.12 Find the insertion loss of a fiber joint

```
//Ex:7.12
clc;
clear;
close;
V=2.50;// normalised frequency
n1=1.5;// core refractive index
a=4.5*10^-6;// core radius in m
NA=0.2;// numerical aperture
y=3*10^-6;// lateral misalignment in m
w=a*((0.65+1.62*(V)^-1.5+2.88*(V)^-6)/2^0.5);//
   normalised spot size in m
T1=2.17*(y/w)^2;// Loss due to lateral offset in dB
x=(%pi/180)*w;
Ta=2.17*((x*n1*V)/(a*NA))^2;// loss due to angular
   misalignment in dB
T=T1+Ta;// total insertion loss in dB
printf("The total insertion loss =%f dB", T);
printf("\n The answer is wrong in the textbook");
```

Scilab code Exa 7.13 Find the insertion losses between the input and output ports and cross talk and split ratio for the device

```
//Ex:7.13
clc;
```

```
clear;
close;
P1=65;// optical power in uW
P2=0.005;// output power at port 2 in uW
P3=24;// output power at port 3 in uW
P4=26.5;// output power at port 4 in uW
Le=10*log(P1/(P3+P4))/log(10);// Excess loss in dB
Le1=10*log(P1/P3)/log(10);// insertion loss port 1 to 3 in dB
Le2=10*log(P1/P4)/log(10);// insertion loss port 1 to 4 in dB
ct=10*log(P2/P1)/log(10);// cross talk in dB
sr=(P3/(P3+P4))*100;// split ratio
printf("The Excess loss =%f dB", Le);
printf("\n The insertion loss port 1 to 3  =%f dB", Le1);
printf("\n The insertion loss port 1 to 4  =%f dB", Le2);
printf("\n The cross talk =%f dB", ct);
printf("\n The split ratio =%f %%", sr);
```

Scilab code Exa 7.14 Calculate the fresnel loss at each glass air boundary

```
//Ex:7.14
clc;
clear;
close;
n=1;
n1=1.48;
r=((n1-n)/(n1+n))^2;// fresnel's reflection
Ls=-10*log(1-r)/log(10);// optical loss in dB
Lt=2*Ls;// total fresnel loss
printf("The total fresnel loss =%f dB", Lt);
```

Scilab code Exa 7.15 Find the numerical aperture

```
//Ex:7.15
clc;
clear;
close;
NA1=0.32;// numerical aperture for fiber1
NA2=0.22;// numerical aperture for fiber2
Lc=20*log(NA1/NA2)/log(10);// NA mismatch coupling loss
printf("The NA mismatch coupling loss =%f dB", Lc);
```

Scilab code Exa 7.16 Find the coupling ratio and excess loss and insertion loss and cross talk

```
//Ex:7.16
clc;
clear;
close;
P0=250;// optical power in uW
P1=80;// output power at port 1 in uW
P2=70;// output power at port 2 in uW
P3=5*10^-3;// output power at port 3 in uW
cr=(P2/(P1+P2))*100;// coupling ratio
Le=10*log(P0/(P1+P2))/log(10);// Excess loss in dB
Le1=10*log(P0/P1)/log(10);// insertion loss port 0 to 1 in dB
Le2=10*log(P0/P2)/log(10);// insertion loss port 0 to 2 in dB
ct=10*log(P3/P0)/log(10);// cross talk in dB
printf("The coupling ratio =%f %%", cr);
printf("\n The Excess loss =%f dB", Le);
```

```
printf(”\n The insertion loss port 0 to 1  =%f dB”,
   Le1);
printf(”\n The insertion loss port 0 to 2 =%f dB”,
   Le2);
printf(”\n The cross talk =%f dB”, ct);
```

Scilab code Exa 7.17 What fraction of the input power goes to each port and compute the throughput loss and tap loss and directionality and the excess loss

```
//Ex:7.17
clc;
clear;
close;
P_21=4/5;// ratio of the input available at port2
P_31=1/5;// ratio of the input available at port3
Lt=-10*log(P_21)/log(10);// throughput loss
Lp=-10*log(P_31)/log(10);// tap loss
Le=-10*log(P_21+P_31)/log(10);// excess loss
printf(”The throughput loss =%f dB”, Lt);
printf(”\n The tap loss =%f dB”, Lp);
printf(”\n Directionality=−10*log(0/Pi=infinity)”);
printf(”\n The excess loss =%d dB”, Le);
```

Scilab code Exa 7.18 What fraction of the input power goes to each port and compute the throughput loss and tap loss and compute the loss due to radiation scattering in the complex

```
//Ex:7.18
clc;
clear;
close;
Le=4;// excess loss in dB
```

```
D=60;// Directionality in dB
P_41=10^-6;// the ratio of P4 to P1
P_31=0.670/5;// the ratio of P3 to P1
P_21=P_31*4;// the ratio of P2 to P1
Lt=-10*log(P_21)/log(10);// throughput loss
Lp=-10*log(P_31)/log(10);// tap loss
Ls=-10*log(0.670)/log(10);// loss due to radiation scattering in dB
printf(”The fraction of the input power goes to each of the ports =%f dB”, P_21);
printf(”\n The throughput loss =%f dB”, Lt);
printf(”\n The tap loss =%f dB”, Lp);
printf(”\n The loss due to radiation scattering =%f dB”, Ls);
```

Scilab code Exa 7.19 Determine the attenuation per km for the fiber

```
//Ex:7.19
clc;
clear;
close;
L1=1.5;// length in km
L2=2/1000;// length in km
Pi=50.1*10^-6;// optical power in W
Po=385.4*10^-6;// output power in W
a=(10/(L1-L2))*log(Po/Pi)/log(10);// attenuation per km
printf(”The attenuation per km =%f dB/km”, a);
```

Scilab code Exa 7.20 Determine the optical loss due to scattering for a fiber

```
//Ex:7.20
```

```
clc;
clear;
close;
Psc=5.31*10^-9;//
Popt=98.45*10^-6;//
L=5.99;// length in km
asc=(4.343*10^5/L)*(Psc/Popt);// scattering loss in the fiber in dB
printf("The scattering loss in the fiber =%f dB/km",asc);
```

Chapter 8

Optical Sources

Scilab code Exa 8.1 Find the total carrier recombination life time and power internally generated within the device

```
//Ex:8.1
clc;
clear;
close;
tr=40;// rediative life time in ns
tnr=60;// nonrediative life time in ns
i=35*10^-3;// drive current in amp
y=0.85*10^-6;// wavelength in m
h=6.626*10^-34;// plank constant
c=3*10^8;// the speed of light in m/s
e=1.602*10^-19;// charge
t=tr*tnr/(tr+tnr);// total carrier recombination
   lifetime ns
ni=t/tr;// internal quantam efficiency
pi=(ni*h*c*i)/(e*y);// internal power in watt
p_int=pi*10^3;// internal power in mW
printf("The total carrier recombination lifetime =%d
    ns", t);
printf("\n The internal power =%f mW", p_int);
printf("\n the answer is wrong in textbook");
```

Scilab code Exa 8.2 Find the peak emissionwavelength from the device

```
//Ex:8.2
clc;
clear;
close;
tr=30;// rediative life time in ns
tnr=50;// nonrediative life time in ns
i=40*10^-3;// drive current in amp
pi=28.4*10^-3;// internal power in watt
h=6.626*10^-34;// plank constant
c=3*10^8;// the speed of light in m/s
e=1.602*10^-19;// charge
t=tr*tnr/(tr+tnr);// total carrier recombination
   lifetime ns
ni=t/tr;// internal quantam efficiency
y=(ni*h*c*i)/(e*pi);// peak emission wavelength in m
printf("The total carrier recombination lifetime =%f
    ns", t);
printf("\n The peak emission wavelength =%f um", y
   *10^6);
```

Scilab code Exa 8.3 Find the external power efficiency of a GaAs planar LED

```
//Ex:8.3
clc;
clear;
close;
nx=3.6;// refractive index
Fn=0.68;// transmission factor
```

```
pe_pi=(Fn)/(4*nx^2);
pi_p=0.3;
nep=pe_pi*pi_p;// external power efficiency
printf("The external power efficiency =%f %%", nep
   *100);
```

Scilab code Exa 8.4 Find the coupling efficiency and the optical loss in decibels and loss relative to the internally generated optical power

```
//Ex:8.4
clc;
clear;
close;
n=3.6;// core refractive index
NA=0.15;// numerical aperture
nc=NA^2;// coupling efficiency
l_s=-10*log(nc)/log(10);// loss in db
pe_pi=0.023*0.0013;// from ex 8.3
pc=-10*log(pe_pi)/log(10);// loss in decibels
   relative to Pint
printf("The coupling efficiency =%f %%", nc*100);
printf("\n The loss =%f db", l_s);
printf("\n The loss in decibels relative to Pint=%f
   db", pc);
```

Scilab code Exa 8.5 Calculate the optical power coupled into a 200 um diameter

```
//Ex:8.5
clc;
clear;
close;
r=45*10^-6;// radius in m
```

```
NA=0.3;// numerical aperture
rd=40;// radiance
A=3.14*(r*100)^2;// area in cm^2
pe=3.14*(1-r)*A*rd*NA^2;// optical power coupled into the fiber
Pe=pe*10^4;// optical power coupled into the fiber uW
printf("The optical power coupled into the fiber =%f uW", Pe);
```

Scilab code Exa 8.6 What will be the overall efficiency when the frwd voltage across the diode is 2V

```
//Ex:8.6
clc;
clear;
close;
pc=150*10^-6;// coupling power W
p=20*10^-3*2;// optical power W
npc=pc/p;// overall efficiency
Npc=npc*100;// percentage of overall efficiency
printf("The percentage of overall efficiency =%f %%", Npc);
```

Scilab code Exa 8.7 Find the number of longitudinal modes of a ruby laser

```
//Ex:8.7
clc;
clear;
close;
n=1.5;// refractive index
L=0.05;// crystal length in m
y=0.5*10^-6;// wavelength in m
```

```
c=3*10^8;// speed of light in m/s
q=2*n*L/y;// the number of longitudinal modes
df=c/(2*n*L);// frequency separation of the modes in Hz
Df=df/10^9;// frequency separation of the modes in GHz
printf("The number of longitudinal modes =%f", q);
printf("\n The frequency separation of the modes =%f GHz", Df);
```

Scilab code Exa 8.8 Find the wavelength of optical emission from the device

```
//Ex:8.8
clc;
clear;
close;
Eg=1.43;// bandgap energy in eV
dy=0.15*10^-9;
c=3*10^8;// speed of light in m/s
y=1.24/Eg;// in um
y1=y*10^-6;// wavelength of optical emission in m
df=(c*dy)/(y1^2);// the line width in Hz
Df=df/10^9;// the line width in GHz
printf("The wavelength of optical emission  =%f um", y);
printf("\n The frequency separation of the modes =%d GHz", Df);
```

Scilab code Exa 8.9 Find the length of the optical cavity and the number of longitudinal modes emitted

```
//Ex:8.9
```

```
clc;
clear;
close;
n=3.6;// refractive index
c=3*10^8;// speed of light in m/s
y=0.85*10^-6;// wavelength in m
df=275*10^9;// frequency separation of the modes in Hz
L=c/(2*n*df);// crystal length in m
L1=L*10^6;// crystal length in um
q=2*n*L/y;// the number of longitudinal modes
printf("The crystal length =%f um", L1);
printf("\n The the number of longitudinal modes =%d", q);
printf("\n answer is wrong in textbook");
```

Scilab code Exa 8.10 Find the external power efficiency of the device

```
//Ex:8.10
clc;
clear;
close;
nt=0.20;// total efficiency
Eg=1.43;// bandgap energy in eV
V=2.2;// applied voltage in volts
nep=(nt*Eg)/V;// external power efficiency
Nep=nep*100;// percentage of external power efficiency
printf("The external power efficiency =%f %%", Nep);
```

Scilab code Exa 8.11 Calculate the divergence angle of LED

```
//Ex:8.11
```

```
clc;
clear;
close;
h=0.35*10^-3;// irradiance W/cm^2
po=0.45*10^-3;// power output in watt
d=1.5;// separation distance in cm
x=sqrt((4*po)/(3.14*d^2*h));// divergence angle in radians
X=(x*180)/3.14;// divergence angle in degree
printf("The divergence angle =%f degree ", X);
```

Scilab code Exa 8.12 Calculate the irradiance at the detector

```
//Ex:8.12
clc;
clear;
close;
ni=0.09;// normal efficiency
d=2*2.54;// separation distance in cm
x=0.2;// divergence angle in radians
vf=2.0;// forward voltage in volts
i_f=65*10^-3;// forward current in amp
pi=vf*i_f;// input power in Watt
po=ni*pi;// output power in Watt
H=4*po/(3.14*d^2*x^2);// irradiance in watt/cm^2
H1=H*1000;// irradiance in mwatt/cm^2
printf("The irradiance =%f mwatt/cm^2 ", H1);
```

Scilab code Exa 8.13 Calculate the internal quantum efficiency for an LED

```
//Ex:8.13
clc;
clear;
```

```
close;
tr=3.5;// relative life time in ms
tnr=50;// nonrelative life time in ms
ni=tnr/(tr+tnr);// internal quantam efficiency
printf("The internal quantam efficiency =%f %%", ni
   *100);
```

Scilab code Exa 8.14 Calculate the optical power complete into the fiber generated by an optical source

```
//Ex:8.14
clc;
clear;
close;
ni=0.15;// internal quantam efficiency
vf=2.0;// forward voltage in volts
i_f=15*10^-3;// forward current in amp
x=25;// acceptance angle in degree
pi=vf*i_f;// input power in Watt
po=ni*pi;// output power in Watt
NA=(sin(x*3.14/180));
nc=NA^2;// numerical aperture
pf=nc*po;// optical power coupled into optical fiber
    in w
printf("The optical power coupled into optical fiber
    =%f mW ", pf*1000);
```

Scilab code Exa 8.15 Calculate the radiative life time

```
//Ex:8.15
clc;
clear;
close;
```

```
tnr=10;// nonrediative life time in ns
n_inj=0.80;// injection efficiency
n_ex=0.60;// extraction efficiency
nt=0.025;// total efficiency
nr=nt/(n_inj*n_ex);// non rediative life time in ns
tr=((1/nr)-1)*tnr;// rediative life time in ns
printf("The rediative life time =%d ns", tr);
```

Scilab code Exa 8.16 Calculate the bandwidth of the LED with a rise time of 30 ns

```
//Ex:8.16
clc;
clear;
close;
tr=30*10^-9;// rise time in s
Bw=0.35/tr;// bandwidth in Hz
printf("The bandwidth =%f MHz", Bw/10^6);
```

Scilab code Exa 8.17 Compute the divergence angle

```
//Ex:8.17
clc;
clear;
close;
y=630*10^-9;// operating wavelength in m
w=25*10^-6;// spot size in m
x=2*y/(3.14*w);// divergence angle in radians
x1=x*180/3.14;//  divergence angle in degree
printf("The  divergence angle =%f radians", x);
printf("\n The  divergence angle =%f degree", x1);
```

Scilab code Exa 8.18 calculate the energy in electron volts associated with light source

```
//Ex:8.18
clc;
clear;
close;
y1=550*10^-3;// peak of eyes response in um
y2=10.6;// standard wavelength in um
y3=2.39;// predominant IR line of He-Ne laser in um
E1=1.24/y1;// energy in electron volts
E2=1.24/y2;// energy in electron volts
E3=1.24/y3;// energy in electron volts
printf("The  energy =%f electron volts", E1);
printf("\n The energy =%f electron volts", E2);
printf("\n The energy =%f electron volts", E3);
```

Scilab code Exa 8.19 Calculate the cut off wavelength of GaAs material

```
//Ex:8.19
clc;
clear;
close;
Eg=1.4;// energy in electron volts
y=1.24/Eg;// cut off wavelength in um
y1=y*1000;// cut off wavelength in nm
printf("The  cut off wavelength =%d nm", y1);
```

Scilab code Exa 8.20 calculate the corresponding divergence angle

```
//Ex:8.20
clc;
clear;
close;
y=1200*10^-9;// operating wavelength in m
w=5*10^-6;// spot size in m
x=2*y/(3.14*w);// divergence angle in radians
x1=x*180/3.14;//  divergence angle in degree
printf("The  divergence angle =%f radians", x);
printf("\n The  divergence angle =%f degree", x1);
```

Scilab code Exa 8.21 Calculate the max angle of acceptance and the coupling efficiency of the fiber

```
//Ex:8.21
clc;
clear;
close;
n1=1.48;// core refractive index
n2=1.46;// cladding refractive index
NA=sqrt(n1^2-n2^2);// numerical aperture
xa=(asin(NA))*(180/%pi);// acceptance angle in
   degree
nc=NA^2;// coupling efficiency
printf("The  acceptance angle =%f degree", xa);
printf("\n The coupling efficiency =%f %%", nc*100);
```

Scilab code Exa 8.22 Calculate the frequency separation of the resonant modes of a GaAs laser

```
//Ex:8.22
clc;
clear;
```

```
close;
c=3*10^8;// speed of light in m/s
n=3.66;// for GaAs
L=150*10^-6;// cavity length in m
dv=c/(2*n*L);//frequency separation in Hz
dv1=dv/10^12;// frequency separation in GHz
h=6.64*10^-34;// plank constant
q=1.6*10^-19;// charge of an electron
dE=(h*dv)/q;// energy separation eV
printf(”The frequency separation =%f GHz”, dv1);
printf(”\n The energy separation =%f meV”, dE*1000);
```

Scilab code Exa 8.23 Find the LED conversion efficiency from electrical to optical power

```
//Ex:8.23
clc;
clear;
close;
po=2*10^-3;// optical power in watts
I=100*10^-3;// current in amp
V=2;// applied voltage in volt
pe=I*V;// electrical power in watts
n=(po/pe)*100;// conversion efficiency
printf(”The conversion efficiency =%d %%”, n);
```

Scilab code Exa 8.24 Find the wavelength of optical emission and determine its live width in Hz

```
//Ex:8.24
clc;
clear;
close;
```

```
c=3*10^8;// speed of light in m/s
h=6.64*10^-34;// plank constant
Eg=1.43;// gap energy in eV
y=(1.24*10^-6)/Eg;// wavelength in m
dy=0.1*10^-9;// in m
df=(dy*c)/y^2;// width in Hz
printf(”The wavelength =%f um”, y*10^6);
printf(”\n The width =%d GHz”, df/10^9);
```

Scilab code Exa 8.25 Find the internal quantum efficiency and internal power level and also find the power emitted from the device

```
//Ex:8.25
clc;
clear;
close;
tr=25;// rediative life time in ns
tnr=90;// nonrediative life time in ns
i=3.5*10^-3;// drive current in amp
y=1.31*10^-6;// wavelength in m
h=6.625*10^-34;// plank constant
c=3*10^8;// the speed of light in m/s
e=1.6*10^-19;// charge
t=tr*tnr/(tr+tnr);// total carrier recombination lifetime ns
ni=t/tr;// internal quantam efficiency
pi=(ni*h*c*i)/(e*y);// internal power in watt
p_int=pi*10^3;// internal power in mW
P=p_int/(ni*(ni+1));// power emitted in mW
printf(”The total carrier recombination lifetime =%f ns”, t);
printf(”\n The internal quantam efficiency =%f ”, ni);
printf(”\n The internal power =%f mW”, p_int);
printf(”\n The power emitted =%f mW”, P);
```

Scilab code Exa 8.26 calculate the external power efficiency of the device

```
//Ex:8.26
clc;
clear;
close;
nt=0.18;// total efficiency
Eg=1.43;// band gape energy eV
V=2.5;// appied voltage in volt
n_ex=(nt*(Eg/V))*100;// external efficiency
printf("The external efficiency =%f %%", n_ex);
```

Scilab code Exa 8.27 Determine the length of the optical cavity and the longitudinal modes emitted

```
//Ex:8.27
clc;
clear;
close;
c=3*10^8;// speed of light in m/s
n=3.6;// for GaAs
df=278*10^9;// separation in Hz
y=0.87*10^-6;// wavelength in m
L=c/(2*n*df);// cavity length in m
l=L*10^6;// cavity length in um
L1=floor(l)*10^-6;// cavity length in m
q=(2*n*L1)/y;// number of longitudinal modes
printf("The cavity length =%d um", l);
printf("\n The number of longitudinal modes =%d", q)
    ;
```

Scilab code Exa 8.28 find the optical loss in dB

```
//Ex:8.28
clc;
clear;
close;
ac=14;// acceptance angle in degree
nc=(sin(ac*3.14/180))^2;// coupling efficiency
l_s=-10*log(nc)/log(10);// loss in decibels
printf("The coupling efficiency =%f", nc);
printf("\n The loss =%f decibels", l_s);
```

Scilab code Exa 8.29 What are the frequency and wavelength spacings

```
//Ex:8.29
clc;
clear;
close;
c=3*10^8;// speed of light in m/s
n=3.7;// for GaAs
L=500*10^-6;// cavity length in m
y=850*10^-9;//
df=c/(2*n*L);//frequency separation in Hz
df1=df/10^9;// frequency separation in GHz
dy=(y*y)/(2*L*n);// wavelength in m
dy1=dy*10^9;// wavelength in nm
printf("The frequency separation =%d GHz", df1);
printf("\n The wavelength separation =%f nm", dy1);
```

Chapter 9

Optical Detectors

Scilab code Exa 9.1 Calculate the responsivity of the device

```
//Ex:9.1
clc;
clear;
close;
e_c=550;// number of electron collected
p=800;// number of photon incident
n=e_c/p;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=1.3*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
printf("The responsivity =%f Amp/Watt", R);
```

Scilab code Exa 9.2 Calculate the efficiency of a PIN silicon photodiode

```
//Ex:9.2
clc;
```

```
clear;
close;
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.85*10^-6// wavelength in m
R=0.274;// responsivity in A/W
n=(R*h*c)/(e*y);// quantum efficiency
n1=n*100;// % of quantum efficiency
printf("The quantum efficiency =%f %%", n1);
```

Scilab code Exa 9.3 calculate the quantum efficiency and max possible band gap energy and mean output photocurrent

```
//Ex:9.3
clc;
clear;
close;
e_c=1;// number of electron collected
p=3;// number of photon incident
n=e_c/p;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.8*10^-6// wavelength in m
Eg=(h*c)/y;// band gap energy in J
R=(n*e*y)/(h*c);// responsivity in A/W
Po=10^-7;// in W
Ip=R*Po;// output photo current
printf("The quantum efficiency =%f %%", n*100);
printf("\n band gap energy =%f*10^-20 J", Eg*10^20);
printf("\n The output photo current =%f nA", Ip
   *10^9);
```

Scilab code Exa 9.4 calculate the responsivity and and received optical power and corresponding number of received photons

```
//Ex:9.4
clc;
clear;
close;
n=0.50;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.85*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Ip=10^-6;// mean photo current
Po=Ip/R;// received optical power in W
f=c/y;
re=(n*Po)/(h*f);
rp=re/n;// number of received photons
printf(”The responsivity =%f A/W”, R);
printf(”\n The received optical power =%f uW”, Po*10^6);
printf(”\n The number of received photons =%f*10^13 photons/sec”, rp/10^13);
```

Scilab code Exa 9.5 Show that a GaAs photodetector will cease to operate above 087 um

```
//Ex:9.5
clc;
clear;
close;
h=6.626*10^-34;// plank constant
```

```
c=3*10^8;// speed of light in m/s
Eg=1.43;// in eV
Eg1=Eg*1.602*10^-19;// in J
y=(h*c)/Eg1;// cut off wavelength in m
printf("The cut off wavelength =%f um", y*10^6);
```

Scilab code Exa 9.6 What will be the max response time for the device

```
//Ex:9.6
clc;
clear;
close;
vd=2.5*10^4;// carrier velocity in m/s
w=30*10^-6;// width in m
Bm=vd/(2*%pi*w);
Tm=1/Bm;// max response time in sec
Tm1=Tm*10^9;// max response time in ns
printf("The max response time =%f ns", Tm1);
```

Scilab code Exa 9.7 Find the multiplication factor under these conditions

```
//Ex:9.7
clc;
clear;
close;
n=0.65;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.85*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Po=0.35*10^-6;// in W
Ip=R*Po;// output photo current
```

```
I=9*10^-6;// output current in A
M=I/Ip;// multiplication factor
M1=ceil(M);
printf("The multiplication factor =%d", M1);
```

Scilab code Exa 9.8 Find wavelength at which photodiode operating and what will be the incident optical power

```
//Ex:9.8
clc;
clear;
close;
n=0.50;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
Eg=1.5*10^-19;// in J
y=(h*c)/Eg;// cut off wavelength in m
f=c/y;
R=(n*e)/(h*f);// responsivity in A/W
Ip=2.7*10^-6;// photo current in A
Po=Ip/R;// incident optical power in W
Po1=Po*10^6;// incident optical power in uW
printf("The cut off wavelength =%f um", y*10^6);
printf("\n The responsivity =%f A/W ", R);
printf("\n The incident optical power =%f uW", Po1);
```

Scilab code Exa 9.9 Calculate the responsivity of a detector

```
//Ex:9.9
clc;
clear;
close;
```

```
n=0.15;// quantum efficiency
e=1.6*10^-19;// charge
h=6.63*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.85*10^-6;// cut off wavelength in m
f=c/y;// frequency in Hz
R=(n*e)/(h*f);// responsivity in A/W
printf("The responsivity =%f A/W ", R);
```

Scilab code Exa 9.10 Calculate the quantum efficiency and responsivity of the detector

```
//Ex:9.10
clc;
clear;
close;
Iph=75*10^-6;// output photocurrent in A
y=0.85;// operating wavelength in um
Pi=750*10^-6;// incident optical power in uW
R=Iph/Pi;// responsivity in A/W
n=1.24*R/y;// external quantum efficiency
n1=n*100;// percentage of external quantum
   efficiency
printf("The responsivity =%f A/W ", R);
printf("\n The external quantum efficiency =%f%% ",
   n1);
```

Scilab code Exa 9.11 Calculate the transit time for silicon photodiode

```
//Ex:9.11
clc;
clear;
close;
```

```
Vs=10^5;// saturation in m/s
W=7*10^-6;// depletion layer width in m
tr=W/Vs;// transit time in sec
printf(”The transit time =%f ps”, tr*10^12);
```

Scilab code Exa 9.12 Calculate the max 3dB bandwidth for a silicon

```
//Ex:9.12
clc;
clear;
close;
Vs=3*10^4;// saturation in m/s
W=25*10^-6;// depletion layer width in m
tr=W/Vs;// transit time in sec
f=0.35/tr;// max 3 dB bandwidth Hz
f1=f/10^6;// max 3 dB bandwidth Hz
printf(”The max 3 dB bandwidth =%d MHz”, f1);
printf(”\n The answer is wrong in the textbook”);
```

Scilab code Exa 9.13 Find the transit time and junction capacitance and time constant of the photodiode

```
//Ex:9.13
clc;
clear;
close;
Vs=3*10^4;// saturation in m/s
W=25*10^-6;// depletion layer width in m
E=10.5*10^-11;// in F/m
RL=15*10^6;// load resister in ohm
A=0.25*10^-6;// area in mˆ2
tr=W/Vs;// transit time in sec
Cj=E*A/W;// junction capacitance in F
```

```
t=RL*Cj;// time constant in sec
printf("The transit time =%f ns", tr*10^9);
printf("\n The junction capacitance =%f pF", Cj
    *10^12);
printf("\n The time constant =%f us", t*10^6);
```

Scilab code Exa 9.14 calculate the cut off wavelength for silicon and germanium PIN diodes

```
//Ex:9.14
clc;
clear;
close;
Eg1=1.12;// band gap for Si in eV
Eg2=0.667;// band gap for Ge in eV
y_si=1.24/Eg1;// cut off wavelength for Si in um
y_he=1.24/Eg2;// cut off wavelength for Ge in um
printf("The cut off wavelength for Si  =%f um", y_si
    );
printf("\n The cut off wavelength for Ge =%f um",
    y_he);
```

Scilab code Exa 9.15 Calculate the responsivity and received optical power and corresponding number of received photons

```
//Ex:9.15
clc;
clear;
close;
n=0.50;// quantum efficiency
e=1.6*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
```

```
y=0.9*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Ip=10^-6;// mean photo current
Po=Ip/R;// received optical power in W
f=c/y;
re=(n*Po)/(h*f);
rp=re/n;// number of received photons
printf("The responsivity =%f A/W", R);
printf("\n The received optical power =%f uW", Po*10^6);
printf("\n The number of received photons =%f*10^13 photons/sec", rp/10^13);
```

Scilab code Exa 9.16 What will be the output photocurrent

```
//Ex:9.16
clc;
clear;
close;
R=0.40;// Responsivity in A/W
m=100*10^-6;// incident flux in W/m—m
A=2;// area in m—m
Po=m*A;// incident power in W
Ip=R*Po;// photon current in A
printf("The photon current =%d uA", Ip*10^6);
```

Scilab code Exa 9.17 Determine the operating wavelength of the device and Calculate the incident power

```
//Ex:9.17
clc;
clear;
close;
```

```
n=0.65;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
Eg=1.5*10^-19;// in J
y=(h*c)/Eg;// cut off wavelength in m
f=c/y;
R=(n*e)/(h*f);// responsivity in A/W
Ip=2.5*10^-6;// photo current in A
Po=Ip/R;// incident optical power in W
Po1=Po*10^6;// incident optical power in uW
printf("The cut off wavelength =%f um", y*10^6);
printf("\n The responsivity =%f A/W ", R);
printf("\n The incident optical power =%f uW", Po1);
```

Scilab code Exa 9.18 Determine the wavelength

```
//Ex:9.18
clc;
clear;
close;
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
Eg=1.43;// in eV
Eg1=Eg*1.602*10^-19;// in J
y=(h*c)/Eg1;// cut off wavelength in m
printf("The cut off wavelength =%f um", y*10^6);
```

Scilab code Exa 9.19 Find the optical gain and common emitter gain

```
//Ex:9.19
clc;
clear;
```

```
close;
n=0.45;// quantum efficiency
h=6.62*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=1.2*10^-6;// cut off wavelength in m
Ic=20*10^-6;// collector current in A
Po=120*10^-6;// incident optical power in W
e=1.602*10^-19;// charge
Go=(h*c*Ic)/(y*Po*e);// optical gain
h_e=Go/n;// common emitter gain
printf(”The optical gain =%f”, Go);
printf(”\n The common emitter gain =%f”, h_e);
```

Scilab code Exa 9.20 Calculate the multiplication factor of diode

```
//Ex:9.20
clc;
clear;
close;
n=0.5;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=1.3*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Po=0.4*10^-6;// in W
Ip=R*Po;// output photo current
I=8*10^-6;// output current in A
M=I/Ip;// multiplication factor
printf(”The multiplication factor =%d”, M);
```

Scilab code Exa 9.21 Calculate the multiplication factor of APD

```
//Ex:9.21
clc;
clear;
close;
n=0.85;// quantum efficiency
e=1.6*10^-19;// charge
h=6.625*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.9*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Po=0.6*10^-6;// in W
Ip=R*Po;// output photo current
I=10*10^-6;// output current in A
M=I/Ip;// multiplication factor
printf("The multiplication factor =%d", M);
```

Scilab code Exa 9.22 Calculate the quantum efficiency and wavelength of operation and responsivity and incident optical power

```
//Ex:9.22
clc;
clear;
close;
e_c=1.2*10^11;// number of electron collected
p=2*10^11;// number of photon incident
n=e_c/p;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
E=1.5*10^-19;// energy in J
y=(h*c)/E// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Ip=2.6*10^-6;// photocurrent in A
Po=Ip/R;// incident optical power in W
printf("The quantum efficiency =%d %%", n*100);
```

```
printf("\n The wavelength =%f um", y*10^6);
printf("\n The responsivity =%f Amp/Watt", R);
printf("\n The incident optical power =%f uW", Po*10^6);
```

Scilab code Exa 9.23 Calculate the multiplication factor of an APD

```
//Ex:9.23
clc;
clear;
close;
n=0.40;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=1.35*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Po=0.2*10^-6;// in W
Ip=R*Po;// output photo current
I=4.9*10^-6;// output current in A
M=I/Ip;// multiplication factor
printf("The multiplication factor =%d", M);
```

Scilab code Exa 9.24 Find the responsivity and optical power and corresponding number of received photons

```
//Ex:9.24
clc;
clear;
close;
n=0.55;// quantum efficiency
e=1.6*10^-19;// charge
h=6.626*10^-34;// plank constant
```

```
c=3*10^8;// speed of light in m/s
y=0.85*10^-6// wavelength in m
R=(n*e*y)/(h*c);// responsivity in A/W
Ip=2*10^-6;// mean photo current
Po=Ip/R;// received optical power in W
re=(n*Po*y)/(h*c);// number of received photons
printf("The responsivity =%f A/W", R);
printf("\n The received optical power =%f uW", Po*10^6);
printf("\n The number of received photons =%f*10^13 photons/sec", re/10^13);
```

Scilab code Exa 9.25 Find the wavelength of incident radiation and output photocurrent and also find the output photocurrent if the multiplication factor is 18

```
//Ex:9.25
clc;
clear;
close;
h=6.625*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
n=1;// quantum efficiency
e=1.602*10^-19;// charge
E=1.3*10^-19;// energy in J
y=(h*c)/E;// wavelength in m
M=18;// multiplication factor
rp=10^13;// no. of photon per sec
Po=rp*E;// output power in w
Ip=(n*Po*e)/E;// output photocurrent in A
I=M*Ip;// photocurrent in A
printf("The wavelength =%f um", y*10^6);
printf("\n The output power =%f uW", Po*10^6);
printf("\n The photocurrent =%f uA", I*10^6);
```

Scilab code Exa 9.26 calculate the quantum efficiency and max possible band gap energy and mean output photocurrent

```
//Ex:9.26
clc;
clear;
close;
e_c=2*10^10;// number of electron collected
p=5*10^10;// number of photon incident
n=e_c/p;// quantum efficiency
e=1.602*10^-19;// charge
h=6.626*10^-34;// plank constant
c=3*10^8;// speed of light in m/s
y=0.85*10^-6;// wavelength in m
y1=0.85;// wavelength in um
Eg=(h*c)/y;//  bandgap energy in J
Eg1=1.24/y1;// bandgap energy in terms of eV
Po=10*10^-6;// incident power in W
Ip=(n*e*Po)/Eg;// mean output photocurrent in A
printf("The quantum efficiency =%d %%", n*100);
printf("\n The bandgap energy =%f*10^-19 J", Eg
   *10^19);
printf("\n The bandgap energy =%f eV", Eg1);
printf("\n The mean output photocurrent =%f uA", Ip
   *10^6);
```

Chapter 10

Optical Fiber Systems

Scilab code Exa 10.1 Determine the voltage needed to effect a phase change of pi radians

```
//Ex:10.1
clc;
clear;
close;
r=30.8*10^-12;// electro optice coefficient in m/V
L=3*10^-2;// length in m
y=1.3*10^-6;// wavelength in m
n=2.1;
d=30*10^-6;// distance between the electrodes in m
V=(y*d)/((n)^3*r*L);// voltage required to have a pi
    radian phase change in volt
printf("The voltage required to have a pi radian
   phase change  =%f volt", V);
```

Scilab code Exa 10.2 Calculate the total channel loss

```
//Ex:10.2
```

```
clc;
clear;
close;
a_fc=4;// fider cable loss in dB/km
aj=0.7;// splice loss in db/km
L=5;// length in km
a_cr1=4;// connector losses
a_cr2=3.5;// connector losses
CL=(a_fc+aj)*L+(a_cr1+a_cr2);// total channel loss in dB
printf(”The total channel loss =%d dB”, CL);
```

Scilab code Exa 10.3 Determine the dispersion equalisation penalty and estimate penalty with and without mode coupling

```
//Ex:10.3
clc;
clear;
close;
p=0.5*10^-9;// pulse broadening in s/km
L=12;// length in km
Pt=p*sqrt(L);// with mode coupling, the total rms broadening in s
BT=20*10^6;//
DL=2*(2*Pt*BT*sqrt(2))^4;// dispersion equalization penalty in dB
Pt1=p*L;// without mode coupling, the total rms broadening in s
DL1=2*(2*Pt1*BT*sqrt(2))^4;// without mode coupling, equalization penalty in dB
DL2=2*(2*Pt1*150*10^6*sqrt(2))^4;// without mode coupling,dispersion equalization penalty with 125 Mb/s
DL3=2*(2*Pt*125*10^6*sqrt(2))^4;// with mode coupling,dispersion equalization penalty with 125
```

```
Mb/s
printf("with mode coupling, the total rms broadening =%f ns", Pt*10^9);
printf("\n The dispersion equalization penalty =%f dB", DL*10^4);
printf("\n without mode coupling, the total rms broadening =%f dB", Pt1*10^9);
printf("\n without mode coupling, equalization penalty =%f dB", DL1);
printf("\n without mode coupling,dispersion equalization penalty with 125 Mb/s =%f dB", DL2);
printf("\n with mode coupling,dispersion equalization penalty with 125 Mb/s =%f dB", DL3);
printf("\n The answer is wrong in the textbook");
```

Scilab code Exa 10.4 Find the possible link length without employing repeaters and max possible link length

```
//Ex:10.4
clc;
clear;
close;
Pi=-2.5;// mean optical power launched into the fiber in dBm
Po=-45;// mean output optical power available at the receiver in dBm
a_fc=0.35;// fider cable loss in dB/km
aj=0.1;// splice loss in db/km
a_cr=1;// connector losses
Ma=6;// safety margin in dB
L=(Pi-Po-a_cr-Ma)/(a_fc+aj);// length in km when system operating at 25 Mbps
Po1=-35;// mean output optical power available at the receiver in dBm
L1=(Pi-Po1-a_cr-Ma)/(a_fc+aj);// length in km when
```

```
system operating at 350 Mbps
printf("The length when system operating at 25 Mbps =%f km", L);
printf("\n The length when system operating at 350 Mbps =%f km", L1);
```

Scilab code Exa 10.5 Find the optical power budget for an optical link

```
//Ex:10.5
clc;
clear;
close;
Tx=-80;// transmitter output in dBm
Rx=-40;// receiver sensitivity in dBm
sm=32;// system margin in dB
L=10;// in km
fl=2*L;// fider loss in dB
cl=1;// detector coupling loss in dB
tl=0.4*8;// total splicing loss in dB
ae=5;// angle effects & future splice in dB
ta=29.2;// total attenuation in dB
Ep=2.8;// excess power margin in dB
printf("The fider loss =%f dB", fl);
printf("\n The total splicing loss =%f dB", tl);
printf("\n The fangle effects & future splice =%f dB", ae);
printf("\n The total attenuation =%f dB", ta);
printf("\n The excess power margin =%f dB", Ep);
printf("\n hence the system can operate with small excess power margin")
```

Scilab code Exa 10.6 What is the max transmission distance and if transmission is star coupler and if it is reflector star coupler

```
//Ex:10.6
clc;
clear;
close;
Lc=1;// connector loss in db
Ls=5;// star coupler insertion loss in dB
af=2;// fider loss in dB
Ps=-14;// transmitted power in dBm
Pr=-49;// receiver sensitivity in dBm
sm=6;// system margin in dB
N=16;
L=(Ps-Pr-Ls-4*Lc-(10*log(N))/log(10)-sm)/(2*af);//
    max transmission length in km when transmission
    star coupler is used
N1=32;
L1=(Ps-Pr-Ls-4*Lc-(10*log(N1))/log(10)-sm)/(2*af);//
     max transmission length in km when reflection
    star coupler is used
printf("The max transmission length when
    transmission star coupler is used =%f km", L);
printf("\n The max transmission length when
    reflection star coupler is used =%f km", L1);
```

Scilab code Exa 10.7 Find the rise time and the date rate for a system supporting NRZ and RZ coding

```
//Ex:10.7
clc;
clear;
close;
y=860*10^-9;// wavelength in m
L=5000;// length in m
X=0.024;
dy=20*10^-9;// spectral width in m
dts=6*10^-9;// silica optical link rise time in s
```

```
dtr=8*10^-9;// detector rise in s
c=3*10^8;// speed of light in m/s
dtm=-(L*dy*X)/(c*y);// material dispersion delay time in s
id=2.5*10^-12;// intermodel dispersion in s/m
dti=id*L;// intermodel dispersion delay time
dtsy=sqrt((dts^2)+(dtr^2)+(dtm^2)+(dti^2));// system rise time in s
Br_max=0.7/dtsy;// max bit rate for NRZ coding in bit/s
Br_max1=0.35/dtsy;// max bit rate for RZ coding in bit/s
printf(”The system rise time =%f ns”, dtsy*10^9);
printf(”\n The max bit rate for NRZ coding =%f Mbit/s”, Br_max/10^6);
printf(”\n The max bit rate for RZ coding =%f Mbit/s”, Br_max1/10^6);
```

Scilab code Exa 10.8 Find the modal dispersion limited transmission distance

```
//Ex:10.8
clc;
clear;
close;
Br=50*10^6;// data rate in b/s
c=3*10^8;// speed of light in m/s
n1=1.47;//
dl=0.02;//
n12=n1*dl;// the difference b/w n1 and n2
L_si=(0.35*c)/(n12*Br);// transmission distance for Si fiber
L_GI=(2.8*c*n1^2)/(2*n1*n12*Br);// transmission distance for GRIN fiber
printf(”The transmission distance for Si fiber =%f m
```

```
", L_si);
printf("\n The transmission distance for GRIN fiber =%f m", L_GI);
```

Scilab code Exa 10.9 Find the material dispersion limited transmission distance

```
//Ex:10.9
clc;
clear;
close;
Br=20*10^6;// data rate in b/s
c=3*10^8;// speed of light in m/s
y=86*10^-9;// wavelength in m
dy=30*10^-9;// spectral width in m
X=0.024;
Tb=1/Br;
Lmax=(0.35*Tb*c*y)/(dy*X);// material dispersion limited transmission distance for RZ coding in m
printf("The material dispersion limited transmission distance =%d m", Lmax);
```

Scilab code Exa 10.10 Find the material dispersion limited distance and modal dispersion and also fint out the attenuation limited distance

```
//Ex:10.10
clc;
clear;
close;
y=860*10^-9;// wavelength in m
c=3*10^8;// speed of light in m/s
n1=1.47;//
dl=0.02;//
```

```
n12=n1*dl;// the difference b/w n1 and n2
La=1/1000;// loss a in dB/m
Pr=-65;// receiver power in dB
Pt=-5;// transmitted power in dB
dy=30*10^-9;// line width in m
X=0.024;
Lmax=(0.35*c*y)/(dy*X);// material dispersion limited distance for RZ coding in m
L_GI=(1.4*c*n1)/(n12);// model dispersion limited distance for RZ coding in m
L_At=(Pt-Pr)/(La);// attenuation limited distance for RZ coding in m
printf("The material dispersion limited distance =%f*10^10*1/Br m", Lmax/10^10);
printf("\n The model dispersion limited distance =%f*10^10*1/Br m", L_GI/10^10);
printf("\n The attenuation limited distance =%d-20 log(Br) km", L_At/10^3);
```