Scilab Textbook Companion for Fiber Optic Communications Technology by D. K. Mynbaev And L. L. Scheiner[1]

Created by
Dr. Lochan Jolly
optical communication
Electrical Engineering
Mumbai/TCET
College Teacher
None
Cross-Checked by
None

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Book Description

Title: Fiber Optic Communications Technology

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 2

Physics of Light A brief Overview

Scilab code Exa 2.2.1 `light velocity`

```

//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 2.2.1
//OS=Windows 10
////Scilab version Scilab 6.0.0-beta-2(64 bit)
clc;
clear;

//given
c=3E8;//velocity of light in m/sec
n=1.5;//refractive idex of glass

v=(c/n);//light velocity in glass in m/s
mprintf("Light velocity in glass=%.1fx10^8 m/s",v/1
   e8);
```

Scilab code Exa 2.2.2 `angle of reflection and refraction`

```

//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 2.2.2
//OS=Windows 10
//Scilab version Scilab 6.0.0-beta-2(64 bit)
clc;
clear;

//given
n1=1;//refractive index 1
theta1=30;//angle of incidence in degrees
n2=1.5;//refractive index 2

u=sind(theta1);
theta2=asind(u/n2);//angle of refraction in degrees
    case1

theta3=theta1//From figure 2.4(a) given theta3=
    theta1=30 degrees//angle of relection
v=n2*sind(theta1);
theta4=asind(v/n1)//angle of refraction in degrees
    case 2
mprintf("\n Angle of reflection=%.1f degrees",theta3
    );
mprintf("\n Angle of refraction case 1=%.1f degrees
    ",theta2);
mprintf("\n Angle of refraction case2=%.1f degrees "
    ,theta4);
```

Scilab code Exa 2.2.3 critical incident angle

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 2.2.3
//OS=Windows 10
////Scilab version Scilab 6.0.0-beta-2(64 bit)
clc;
clear;

//given
n1=1.6;//refractive index in glass rod
n2=1;//refractive index of air
thetha2=90;//angle of refraction in degrees

v=n2/n1;
thethac=asind(v);//critical incident angle in
   degrees
mprintf("the critical incident angle=%.2f degrees",
   thethac);
```

Scilab code Exa 2.3.1 Energy of single Photon

```

//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 2.3.1
```

```
//OS=Windows 10
////Scilab version Scilab 6.0.0-beta-2(64 bit)
clc;
clear;

//given
lambda=650E-9;//wavelength in meter
h=6.6E-34;//Planck's constant in SI units
c=3E8;//velocity of light in m/s

Ep=(h*c/lambda);//energy of single photon in V
E=1e-3;///total energy in joules
N=(E/Ep);//number of photos
mprintf("\n Number of photons=%.1f x10^15 ",N/1e15);//division by 1e15 to convert the unit to x10^15
```

Scilab code Exa 2.3.2 color of radiation

```

//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 2.3.2
//OS=Windows 10
////Scilab version Scilab 6.0.0-beta-2(64 bit)
clc;
clear;

//given
Ep=2.5*1.602*1e-19;//energy in V
c=3E8;//velocity of light in m/s
h=6.6261E-34;//Planck's constant in SI units

lambda=(c*h/Ep);//lambda in meter
```

```
mprintf("Wavelength is=%.1f nm. \nIt will emit green
    colour.",lambda*1e9);//Multiplication by 1e9 to
    convert the unit from m to nm
//the answer vary due to rounding
```

Chapter 3

Optical Fiber Basics

Scilab code Exa 3.1.1 Critical angle

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 3.1.1
//windows 7
//Scilab version -6.0.0
clc;
clear all;
//given

//case 1
n1=1.48;//refractive index of the core
n2=1.46;//refractive index of the cladding

//case 2
n3=1.495;//refractive index of the core
n4=1.402;//refractive index of the cladding

//case 1
b=n2/n1;
thetac=asind(b);
mprintf("\n the critical incident angle for case 1
```

```
is=%.2f degrees",thetac);

//case 2
g=n4/n3;
mprintf("\n\nthe ratio=%.2f",g);
thetac2=asind(g);
mprintf("\n the critical incident angle for case 2 is=%.2f degrees",thetac2);
```

Scilab code Exa 3.1.2 `Critical angle`

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 7
//Scilab version- 6.0.0
//Example 3.1.2
clc;
clear all;
//given

//case 1
n1=1.48;//Refractive index of the core for silica fiber
n2=1.46;//Refractive index of the cladding for silica fiber

//case 2
n3=1.495;//Refractive index of the core for plastic optical fiber
n4=1.402;//Refractive index of the cladding for plastic optical fiber

//case 1
```

```
alphac=asind(sqrt(1-(n2/n1)^2));
mprintf("\n The Critical propogation angle for case 1 = %.2f deg",alphac);

//case 2
alphac2=asind(sqrt(1-(n4/n3)^2));
mprintf("\n The Critical propogation angle for case 2 = %.2f deg",alphac2);
```

Scilab code Exa 3.1.3 acceptance angle

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 3.1.3
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

//case 1
n1=1.48;//refractive index of the core
n2=1.46;//refractive index of the cladding

alphac=asin(sqrt(1-(n2/n1)^2));
mprintf("\n The Critical propogation angle for case 1 = %.2f deg",alphac);
b=sin(alphac);
thetaa=asind(n1*b);//by snell's law

a=2*thetaa;//acceptance angle of the fiber
mprintf("\nThe acceptance angle for case 1 is = %.2f deg",a);
```

```

//case 2
n3=1.495;//refractive index of the core
n4=1.402;//refractive index of the cladding

alphac2=asin(sqrt(1-(n4/n3)^2));
mprintf("\n The Critical propogation angle for case 1 = %.2f deg",alphac2);
b2=sin(alphac2);
thetaa2=asind(n3*b2);//by snell's law

a2=2*thetaa2;//acceptance angle of the fiber
mprintf("\nThe acceptance angle for case 2 is = %.2f deg",a2);
```

Scilab code Exa 3.1.4 Numerical aperture

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 3.1.4
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

//case 1
n1=1.48;//refractive index of the core
n2=1.46;//refractive index of the cladding

//case 2
n3=1.48;//refractive of the index of core
n4=1.402;//refractive index of the cladding
```

```

//case 1
b=n1*n1;
c=n2*n2;
v=b-c;
NA=sqrt(v);//numerical aperture for case 1
mprintf("\n numerical aperture for case 1=%.2f",NA);

//case 2
e=n3*n3;
r=n4*n4;
t=e-r;
NA1=sqrt(t);//numerical aperture for case 2
mprintf("\n numerical aperture for case 2=%.2f",NA1);
//
```

Scilab code Exa 3.2.1 `Light Power`

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 7
//Scilab version- 6.0.0
//Example 3.2.1
clc;
clear all;
//given

A=0.5;//attenuation in dB/Km
Pin=1E-3;//input power in milli watts
L=15;//length in kilometers

a=[(-A*L)/10];
```

```
b=10^(a);
Pout=(Pin*b)*1E3;
mprintf("ouput power is=%.2f mW",Pout);
```

Scilab code Exa 3.2.2 Maximum Transmission Distance

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 7
//Scilab version- 6.0.0
//Example 3.2.2
clc;
clear all;
//given

A=0.5;//Attenuation in dB/km
Pin=1E-3; //Power launched in mW
Pout=50E-6; //Receiver sensitivity in uW
e=Pin/Pout;
s=10/A;
d=log10(e);
lmax=s*d;//maximum transistion distance

mprintf("Maximum transistion distance = %.2f km",
    lmax);
```

Scilab code Exa 3.3.1 Number of modes

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 3.3.1
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given
d=62.5E-6;//core diameter in SI units
NA=0.275;//numerical aperture
lambda=1300E-9;//operating wavelength lambda in m

x=3.14*d*NA;

V=x/lambda;

N=(V^2)/4;

mprintf("Number of modes for graded index fiber = %
    .2f",N);
```

Scilab code Exa 3.3.2 distance covered by light pulse

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 3.3.2
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given
```

```
L=5;//fiber length in km
NA=0.275;//numerical aperture
c=3E5;//speed of light in km
n1=1.48;//refractive index

p=2*c*n1;

e=NA*NA;

d=L*e;

deltatsi=(d/p)*1E9;//answer is changed due round-off
Q=(deltatsi/L)

mprintf("\n light pulse spreading= %.2f sec",
    deltatsi);
mprintf("\n ratio of deltatsi per length is=%.2f sec
    /Km",Q);
```

Scilab code Exa 3.3.3 maximum bit rate

```

//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 3.3.3
//windows 7
//Scilab version -6.0.0
clc;
clear;
//given
L=5;//fiber length in km
NA=0.275;//numerical aperture
c=3E5;//speed of light in km
n1=1.48;//refractive index

```

```
p=2*c*n1;

e=NA*NA;

d=L*e;

deltatsi=(d/p)*1E9;//pulse spreading in ns //answer vary due round-off
deltatsi_by_L=(deltatsi/L)//pulse spreading per unit length in ns/Km//answer vary due round-off
Maximum_bit_rate=1e3/deltatsi_by_L//maximum bit rate in Mbits/s//multiplication by 1e3 to conver unit from Gbits/s to Mbits per sec
mprintf("\n maximum bit rate = %.1f  Mbits/s", Maximum_bit_rate);//answer vary due to rounding
```

Scilab code Exa 3.3.4 Maximum bit rate

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 7
//Scilab version- 6.0.0
//Example 3.3.4
clc;
clear all;
//given
N1=1.487;//refractive index
delta=1.71;
L=5E3;//length of the graded index fiber
c=3E8;//velocity of light in m/s

b=delta*delta;
e=L*N1*b;
```

```
w=8*c;
deltatg1=(e/w)*1E5;//pulse spreading due to modal dispersion
Q=(deltatg1/L)*1E3;//maximum bit rate

mprintf("\n pulse spreading due to modal dispersion=%.2f sec",deltatg1);
mprintf("\n maximum bit rate=%.2f sec/Km",Q);
```

Scilab code Exa 3.3.5 Chromatic dispersion

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 7
//Scilab version- 6.0.0
//Example 3.3.5
clc;
clear all;
//given

S0=0.097;//zero dispersion slope in ps/(nm^2.km)
lambda0=1343E-9; //zero dispersion wavelength in m
lambda=1300E-9;//operating wavelength in m

b=lambda0*lambda0*lambda0*lambda0;
c=lambda*lambda*lambda;
x=b/c;
e=lambda-x;
g=S0/4;
Dlambda=g*e*1E9;
Q=(Dlambda/(50E-9));

mprintf("\n the ratio of the dlamda to the length is
```

```
=%.2f ns/Km",Q);
mprintf("\n chromatic dispersion parameter =%.2f sec/m",Dlambda);
```

Scilab code Exa 3.4.1 bit rate

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 7
//Scilab version- 6.0.0
//Example 3.4.1
clc;
clear all;
//given

NA=0.275;//numerical aperture
N1=1.487;//refractive in dex
c=3E8;//speed of light in m/s
L=1E3;//length of the link
a=N1*N1*N1;
b=8*c*a;
d=NA*NA*NA*NA;
g=L*d;
BRg1=(b/g);
mprintf("the bits restricted by modal dispersion is=%.2f bit/s",BRg1);
```

Chapter 4

Optical Fibers A Deeper Look

Scilab code Exa 4.4.1 Power in cladding

```
//Fiber−optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 4.4.1
//windows 7
//Scilab version −6.0.0
clc;
clear all;
//given

d=62.5E-6;//core diameter in SI units
D=125E-6;//cladding diameter in SI units
NA=0.275;//numerical aperture
lambda=1300E-9;//operating wavelength lambda in m

x=3.14*d*NA;
V=x/lambda;
PcladbyPtotal=2*sqrt(2)/(3*V)
mprintf("\nPower carried by fiber cladding = %.3f",
    PcladbyPtotal);
```

Scilab code Exa 4.6.1 pulse spreading

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 4.6.1
//windows 8
//Scilab version -6.0.0
clc;
clear all;
//given

lambda=850;// wavelength in nm
L=100E12;//Length of fiber in nm
deltalambda=70;//spectral width wavelength in nm
S0=0.097;//zero dispersion slope in ps/nm^2.km
lambda0=1343;//assumed zero dispersion wavelength in
     nm

y=lambda0/lambda;
x=1-(y*y*y*y);

Dlambda=-(S0*x*lambda)/4;

deltatgmat=(Dlambda*deltalambda)/1000;

mprintf("Pulse spreading by material dispersion = %
    .2f ns/km",deltatgmat);

deltatmat=deltatgmat*100;

mprintf("\nPulse spreading over entire fiber = %.2f
    s",deltatmat);
```

Chapter 5

Single Mode Fibers Basics

Scilab code Exa 5.1.1 Numerical Aperture

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 5.1.1
//windows 8
//Scilab version -6.0.0
clc;
clear all;
//given

n1=1.4675;//Refractive index of the core for silica
    fiber
n2=1.4622;//Refractive index of the cladding for
    silica fiber

x=n1*n1;
y=n2*n2;

NA=sqrt(x-y);

mprintf("Numerical aperture of singlemode fiber =%.2
    f",NA);
```

Scilab code Exa 5.2.1 Limitation in Transmission Length

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 5.2.1
clc;
clear all;
//given

A=0.2;//Attenuation in dB/km
Pin=0.029E-3; //Power launched in mW
Pout=0.001E-3; //Receiver sensitivity in mW
e=Pin/Pout;
s=10/A;
d=log10(e);
l=s*d;//maximum transistion distance

mprintf("Maximum transistion distance = %.2f km",l);
```

Scilab code Exa 5.3.1 pulse spreading

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
```

```
//Example 5.3.1
clc;
clear all;
//given
lambda=1310;//operating wavelength in nm
deltalambda=1;//wavelength in nm
L=1;//length of fiber in km

Dmatlambda=2;//material dispersion in ps/nm.km from
    graph
deltatmat=Dmatlambda*deltalambda*L;

mprintf("pulse spread caused by material dispersion=
   %.2f ps",deltatmat);
```

Scilab code Exa 5.3.2 pulse spread

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 5.3.2
clc;
clear all;
//given
lambda=1550;//operating wavelength in nm
deltalambda=1;//wavelength in nm
L=1;//length of fiber in km
Dmatlambda=20;//material dispersion in ps/nm.km
Dwglambda=5;//waveguide dispersion in ps/nm.km

deltatmat=Dmatlambda*deltalambda*L;
deltatwg=Dwglambda*deltalambda*L;
```

```
mprintf("pulse spread caused by material dispersion=%.2f ps",deltatmat);
mprintf("\npulse spread caused by waveguide dispersion=%.2f ps",deltatwg);
```

Scilab code Exa 5.3.3 chromatic dispersion

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 5.3.3
clc;
clear all;
//given

lambda=1550;//operating wavelength in nm
L=1;//Length of fiber in km
deltalambda=1;//spectral width wavelength in nm
Dlambda=15;//given chromatic dispersion parameter in ps/nm.km

deltatchrom=Dlambda*deltalambda;
mprintf("\nchromatic dispersion in single mode fibre = %.2f ps",deltatchrom);
```

Scilab code Exa 5.3.4 pulse spread

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 5.3.4
clc;
clear all;
//given

Dpmd=0.5;//polarization mode dispersion coefficient
    in ps/sqrt(km)
L=100;//fibre length in km
deltatpmd=Dpmd*sqrt(L);

mprintf("Pulse spread caused by PMD for single  mode
    fiber= %.2f ps",deltatpmd);
```

Scilab code Exa 5.3.5 BRchrom

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 5.3.5
clc;
clear all;
//given

L=100;//given assumed fiber optic length in km
deltalambda=1;//spectral width wavelength in nm
Dlambda=2;//given chromatic dispersion parameter in
    ps/nm.km

```

```
e=4*Dlambda*deltalambda*L;
BRchrom = 1000/e;
mprintf("Maximum bit rate limited by chromatic
    dispersion= %.2f Gbps",BRchrom);
```

Scilab code Exa 5.3.6 bit rate limited by PMD

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 5.3.6
clc;
clear all;
//given

Dpmd=0.5;//polarization mode dispersion coefficient
    in ps/sqrt(km)

L=100;//for assumed fibre length in km
deltatpmd=Dpmd*sqrt(L);
mprintf("Pulse spread caused by PMD for single  mode
    fiber= %.2f ps",deltatpmd);

a=4*deltatpmd;
BRpmd=1000/a;
mprintf("\nBit Rate of %.2f Gbps is limited by PMD."
    ,BRpmd);
```

Chapter 6

Single Mode Fibers A Deeper Look

Scilab code Exa 6.2.1 power leakage

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 6.2.1
//windows 8
//Scilab version -6.0.0
clc;
clear all;
//given

a1=12.45E-6;//radius of the cladding for silica
    fiber
a=4.15E-6;//radius of the core for silica fiber
w0=5.15E-6;//in m
lambda=1600E-9;//wavelength in m
x=exp(-2*(a1^2/w0^2));
y=1-x;
Ploss=-10*log10(y);

mprintf("Possible power leakage %.2f micro-dB",Ploss
```

```
*1000000);
```

Scilab code Exa 6.3.1 DCF

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 6.3.1
//windows 8
//Scilab version -6.0.0
clc;
clear all;
//given

L=100E12;//Length of the single-mode fiber link in
    nm

lambda0=1310;//average of zero-dispersion wavelength
     in nm
lambda=1550;//operating wavelength in nm
S0=0.092;//zero dispersion slope in ps/nm^2

y=lambda0/lambda;
z=1-y^4;
Dlambda=(S0/4)*lambda*z;

deltalambda=1;//light source's spectral width in nm

deltat=Dlambda*deltalambda*L;

mprintf("Pulse spread caused by chromatic dispersion
     = %.2f ps",deltat*1E-12);

x=6.66;//here, x= L/Ldcf assumed to be 6.66
```

```
Ddcf=-Dlambda*x;
mprintf("\nWe need DCF of %.2f ps/nm.km to
    compensate for dispersion in a conventional SM
    fibre.",Ddcf);
```

Chapter 8

Fiber Cable connectorization and testing

Scilab code Exa 8.1.1 Intrinsic Loss

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 8.1.1
//windows 8
//Scilab version-6.0.0
clc;
clear all;
//given

//case 1
d1=65.5E-6;//diameter of the core considering 62.5+3
    in m
d2=59.5E-6;//diameter of the core considering 62.5-3
    in m

Pcoreloss=-10*log10((d2/d1)^2);
mprintf("Intrinsic loss due to diameter mismatch = %
   .2f dB",Pcoreloss);

```

```
//case 2
NA1=0.290;//numerical aperture of fiber considering
    0.275+0.015
NA2=0.260;//numerical aperture of fiber considering
    0.275-0.015

Pna=-10*log10((NA2/NA1)^2);
mprintf("\nIntrinsic loss due to NA mismatch = %.2f
    dB",Pna);
```

Scilab code Exa 8.4.1 `Link Support Capability`

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 8.4.1
//windows 8
//Scilab version-6.0.0
clc;
clear all;
//given

L=2000;//installation length in m
lambda=850E-9;//operating wavelength in m
deltalambda=20E-9;//spectral width in m
BW=16;//maximum bit rate in M bit/s
TAUltwrise=4;//rise time of light wave equipment in
    ns


TAUsystrise=0.35/BW;//total system rise time in ns
mprintf("Total system rise time= %.2f ns",
    TAUsystrise);
```

Chapter 9

Light Sources and transmitters Basics

Scilab code Exa 9.1.1 `Power radiated by LED`

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 9.1.1
clc;
clear all;
//given

lambdap=850;//Peak wavelength in nm
n=0.01;//quantum efficency is 1%
Ep=1248/lambdap;//energy of photon in eV
I=50;//current supposed to be in mA

P=n*Ep*I;
mprintf("Power radiated by LED = %.3f mW",P);
```

Scilab code Exa 9.1.2 power coupled

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 9.1.2
clc;
clear all;
//given
Pout=100E-6;//radiated power in W

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

b=n1*n1;
c=n2*n2;
v=b-c;
NA=sqrt(v);//numerical aperture
mprintf("\n numerical aperture=%.2f",NA);

Pin=Pout*NA*NA*1000000;
mprintf("\nLight power Pin=%.2f W",Pin);
```

Chapter 10

Characteristics of laser Diodes

Scilab code Exa 10.1.1 Probability of exciting electron

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 10.1.1
//windows 7
//Scilab version -6.0.0
clc;
clear all;
//given
E=0.712;//the energy gap E=Ec-Ef in eV
Kb=1.38E-23;//Boltzman constant in J/K
T=300;//Room temperature in K
e=1.6E-19;//Electrons value in Coulomb
P=(Kb*T)/e;
Y=E/P;
fE= exp(-Y);

mprintf("the probability of excited electrons at
   conduction band at room tenmperature = %.3f ",fE
   *1E+12);
```

Scilab code Exa 10.1.2 Ratio of majority to minority charge carriers

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 10.1.2
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given
T=300;//temperature in K
kB=1.38E-23;//Boltzman constant in J/K
E=kB*T;
e=1.6E-19;//Electrons value in Coulomb
Vd=0.7;;//depletion voltage in V
P=e*Vd;
Y=P/E;
Ratio=exp(Y);
mprintf("Ratio of majority to minority charge
   carriers in an n type and a p type of silicon
   semiconductor = %.2f",Ratio);
```

Scilab code Exa 10.2.1 slope Efficiency

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 10.1.2
//windows 7
```

```
//Scilab version -6.0.0
clc;
clear all;
//given
T=300;//temperature in K
kB=1.38E-23;//Boltzman constant in J/K
E=kB*T;
e=1.6E-19;//Electrons value in Coulomb
Vd=0.7;;//depletion voltage in V
P=e*Vd;
Y=P/E;
Ratio=exp(Y);
mprintf("Ratio of majority to minority charge
    carriers in an n type and a p type of silicon
    semiconductor = %.2f",Ratio);
```

Scilab code Exa 10.2.2 `power efficiency`

```

//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 10.2.2
//windows 7
//Scilab version -6.0.0
clc;
clear ;
//given

//case 1
lambda=840;//Operating wavelength in nm
Eg=1248/lambda;//semiconductor bandgap in eV
e=1.6E-19;//Electrons value in Coulomb
V=Eg;//voltage in V
```

```
R=1;//Reflectivity
I=10E-3;//Current in A
P1=I*I*R;
P2=I*V;
P3=P1+P2;
Pout=1.25E-3;//Output power in W
ETAp=Pout/P3;
mprintf("Power Efficiency of a VCSEL diode = %.3f",
   ETAp);
ETAP=ETAp*100;
mprintf("\n Hence, Power Efficiency of a VCSEL diode
    = %.1f Percent ",ETAP);

//case 2
lambda2=1300;//Operating wavelength in nm
Eg2=1248/lambda2;//semiconductor bandgap in eV
e2=1.6E-19;//Electrons value in Coulomb
V2=Eg2;//voltage in V
R2=1.84;//Reflectivity
I2=312E-3;//Current in A
P11=I2*I2*R;
P22=I2*V2;
P33=P11+P22;
Pout1=1E-3;//Output power in W
ETAp1=Pout1/P33;
mprintf("\nPower Efficiency of a broad area laser
   diode = %.3f", ETAp1);
ETAP1=ETAp1*100;
mprintf("\n Hence, Power Efficiency of a broad area
   laser diode = %.1f Percent ",ETAP1);//the answer
   vary due to rounding
```

Scilab code Exa 10.3.1 `Io and To`

```

//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 10.3.1
//windows 7
//Scilab version-6.0.0
clc;
clear;
//given
Ith1=40//threshold current in mA at 25 degree centigrade
Ith2=66//threshold current in mA at 25 degree centigrade
T1=25;//temperature  in degree centigrade for calculation of threshold current
T2=65//temperature  in degree centigrade for calculation of threshold current
delta=2.5//threshold current change with temperature in percent per degree centigrade
Io=Ith1/(1+(delta/100)*T1);//characteristic current in mA at 0
x=log(Ith1/Io)//constant
To=T1/x//characteristic temperature degree centigrade
mprintf("Io =%0.0f mA ",Io)
mprintf("\nTo =%0.0f degree Centigrade",To)//answer vary due to rounding
```

Scilab code Exa 10.3.2 `delay time`

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 10.3.2
```

```
//windows 7
//Scilab version -6.0.0
clc;
clear all;
//given

tau=2E-9;//Carrier recombination lifetime in s
Ith=90E-3;//threshold current in A
Ip=40E-3;//amplitude of modulation current in A

Ib=80E-3;//Assumed bias current in A
Td=tau*log(Ip/(Ip+Ib-Ith));

mprintf("The delay time for broad-area laser diode =
    %.2f ns",Td*1E+9);
```

Scilab code Exa 10.3.3 `noise power`

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 10.3.3
//windows 7
//Scilab version -6.0.0
clc;
clear all;
//given
RIN=1E-16;//relative intensity in 1/Hz
P=100E-6;//power received in W
BW=100E+6;//Receiver bandwidth in Hz

Pn=sqrt(RIN*(P^2)*BW);

mprintf("The average noise power detected by
```

```
receiver = %.2f micro-w",Pn*1E+6);
```

Scilab code Exa 10.4.1 Light coupling

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 10.4.1
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

//case 1
R=0.035;//Reflectivity for the air-silica interface
NAt=0.275;//Typical Numerical Aperture in a GI
   multimode fiber
D=1;//Ratio of the diameter of the fiber core to the
    diameter of the source
X=2*(D^2);
Y=1-1/X;
ETAcgi=(NAt^2)*Y;

mprintf("The amount of light coupling in a GI
   multimode fiber is = %.3f",ETAcgi);

//case 2
NAt2=0.13;//Typical Numerical Aperture in a SI
   singlemode fiber
EATcsi=NAt2^2;
mprintf("\nThe amount of light coupling in a SI
   singlemode fiber is = %.3f",EATcsi);
```

Chapter 11

Receivers

Scilab code Exa 11.1.1 Photocurrent

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 11.1.1
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

R=0.85;//Responsivity od photodiode in A/W
P=1E-3;//Input power saturation in W

Ip=R*P;
mprintf("The photocurrent =%.2f mA",Ip*1E+3);
```

Scilab code Exa 11.1.2 Responsivity

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 10.3.3
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given
ETA=0.7;//The quantum efficiency
lambda=1664;//Operating wavelength in nm
R=(ETA/1248)*lambda;

mprintf("Responsivity of an InGaAs photodiode =%.3f A/W",R);
```

Scilab code Exa 11.1.3 `width of depletion region`

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 11.1.3
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

ETA=0.7;//The quantum efficiency
alphaabs=1E+5;//absorption coefficient
w=(log(1-ETA))/(-alphaabs);

mprintf("The width of the depletion region of an InGaAs photodiode =%.1f micro-m",w*1E+6);
```

Scilab code Exa 11.1.4 Bandwidth

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 11.1.4
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

Vsat=1E+5; //ssaturation voltage in volts

//case 1
w1=40E-6;//width of the depletion region of an Si photodiode
tautr1=w1/Vsat;
BWsi=1/(2*%pi*tautr1);
mprintf("Bandwidth of Si photodiode = %.3f Gbit/s",BWsi*1E-9);

//case 2
w2=4E-6;//width of the depletion region of an InGaAs photodiode
tautr2=w2/Vsat;
BWInGaAs=1/(2*%pi*tautr2);
mprintf("\nBandwidth of InGaAs photodiode = %.2f Gbit/s",BWInGaAs*1E-9);
```

Scilab code Exa 11.3.1 RMS and bandwidth normalized values

```
//Fiber-optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 11.3.1
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

Pin=0.1E-6;//Average input power in W
lambda=1550;//Operating wavelength in nm
R=1;//Responsivity of an MF-432 PIN photodiode
Ip=R*Pin;
e=1.6E-19;//Electrons value in Coulomb
BWpd=2.5E+9;//Bandwidth of an MF-432 PIN photodiode
   in Hz
Is=sqrt(2*e*Ip*BWpd);
Isn=Is/sqrt(BWpd);//shot noise current in A/sqrt(Hz)

Kb=1.38E-23;//Boltzman constant in J/K
T=300;//Room temperature in K
P=Kb*T;
Rl=50E+3;
x=(4*P)/Rl;
It=sqrt(x*BWpd);
Itn=sqrt(x);//thermal noise current in A/sqrt(Hz)

id=3E-9;//average dark noise current in A
Id=sqrt(2*e*id*BWpd);
Idn=Id/sqrt(BWpd);//dark noise current in A/sqrt(Hz)
```

```
Inoise=sqrt(Is^2+It^2+Id^2);
mprintf("RMS value of noise current for an MF-432
    PIN photodiode = %.1f nA", Inoise*1E+9);

Inoisen=sqrt(Isn^2+Itn^2+Idn^2);
mprintf("\nBandwidth value of noise current for an
    MF-432 PIN photodiode = %.3f pA/Hz", Inoisen*1E
    +12);
```

Scilab code Exa 11.3.2 SNR

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 11.3.2
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

Pin=0.1E-6;//Average input power in W
lambda=1550;//Operating wavelength in nm
T=300;//Room temperature in K
R=1;//Responsivity of an MF-432 PIN photodiode
X=R^2*Pin^2;
Inoise=30.2E-9;//RMS value of noise current for an
    MF-432 PIN photodiode

SNR=X/(Inoise^2);
mprintf("SNR of an MF-432 PIN photodiode = %.2f",SNR
    );
```

Scilab code Exa 11.3.3 SNR

```
//Fiber-optics communication technology, by Djafer K
    . Mynbaev and Lowell L. Scheiner
//Example 11.3.3
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

M=20;//Multiplication factor of a photodiode
Pin=0.1E-6;//Average input power in W
T=300;//Room temperature in K
BWpd=2.5E+9;//Bandwidth of a photodiode in Hz
Rl=50E+3;
R=0.9;//Responsivity of a photodiode
e=1.6E-19;//Electrons value in Coulomb

//case 1
Fssi=2.49;//excess noise factor of Si avalanche
    photodiode
SNRs=(R*Pin)/(2*e*Fssi*BWpd);
mprintf("SNR of Si avalanche photodiode = %.2f",SNRs
    );

//case 2
FsInGaAs=12.78;//excess noise factor of InGaAs
    avalanche photodiode
SNRt=(R*Pin)/(2*e*FsInGaAs*BWpd);
mprintf("\nSNR of InGaAs avalanche photodiode = %.1f
    ",SNRt);
```

Scilab code Exa 11.3.4 NEP

```
//Fiber-optics communication technology, by Djafer K. Mynbaev and Lowell L. Scheiner
//Example 11.3.4
//windows 7
//Scilab version-6.0.0
clc;
clear all;
//given

NEPnormBW1=3.3E-12;//Bandwidth normalised NEP in W/sqrt(Hz)
BW1=10E+6;//Bandwidth for case 1 in Hz

x=NEPnormBW1*sqrt(BW1);

NEPnormBW2=30E-12;//Bandwidth normalised NEP in W/sqrt(Hz)
BW2=115E+6;//Bandwidth for case 2 in Hz

y=NEPnormBW2*sqrt(BW2);

NEP=sqrt(x^2+y^2);
mprintf("Noise-Equivalent power(NEP) = %.1f nW",NEP*1E+9);

Rmax=1.1;//Maximum value of responsivity of a photodiode in A/W
Rlambda=0.9;//Responsivity of a photodiode for given wavelength 1300nm in A/W

```

```
NEPlambdaBW1=x*(Rmax/Rlambda);
mprintf("\nNoise−Equivalent power(NEP) for given
   wavelength lambda=1550nm = %.1f nW",NEPlambdaBW1
   *1E+9);

NEPlambdaBW2=y*(Rmax/Rlambda);
mprintf("\nNoise−Equivalent power(NEP) for given
   wavelength lambda=1550nm = %.1f nW",NEPlambdaBW1
   *1E+9);
```

Scilab code Exa 11.3.5 Sensitivity

```
//Fiber−optics communication technology, by Djafer K
   . Mynbaev and Lowell L. Scheiner
//Example 11.3.5
//windows 7
//Scilab version −6.0.0
clc;
clear all;
//given

BER=1E-9;//bit error rate
Kb=1.38E-23;//Boltzman constant in J/K
T=300;//Room temperature in K
P=Kb*T;
Rl=50E+3;
x=(4*P)/Rl;
It=sqrt(x*BWpd);
Q=6;
e=1.6E-19;//Electrons value in Coulomb

Pmin=(It+e*Q*BWpd)*(Q/Rl);
mprintf("The minimal optical power−photodiode
```

```
sensitivity Pmin= %.2f nW",Pmin*1E+9);
```

Chapter 12

Components of Fiber Optic Networks

Scilab code Exa 12.2.1 channel spacing

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.2.1
clc;
clear all;
//given

deltaf=100E9;//spacing in Hz
lambda=1550;//wavelength in nm
c=3E17;//speed of light in nm/s
f=c/lambda;

x=1/(f*f);
deltalambda=c*deltaf*x;

mprintf("Spacing between channels is = %.2f nm",
    deltalambda);
```

Scilab code Exa 12.3.1 Gain of Fabry Perot semiconductor optical amplifier

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.3.1
clc;
clear all;
//given

R=0.32;//Reflectance (power reflection coeeficient)

//case 1 Gs value assumed as 2
Gs=2;//assumed single-pass amplification factor

x=Gs*((1-R)^2);
y=(1-R*Gs)^2;
Gfpa=x/y;

mprintf("Gain of Fabry-Perot semiconductor optical
    amplifier = %.2f for Gs=2",Gfpa);

//case 2 Gs value assumed as 3
Gs2=3;//assumed single-pass amplification factor

x2=Gs2*((1-R)^2);
y2=(1-R*Gs2)^2;
Gfpa2=x2/y2;

mprintf("\nGain of Fabry-Perot semiconductor optical
    amplifier = %.2f for Gs=3",Gfpa2);
```

Scilab code Exa 12.3.2 Gain of Travelling wave semiconductor amplifier

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.3.2
clc;
clear all;
//given

g=106;//maximum gain coefficient in 1/cm
alpha=14;//loss coefficient of a cavity in 1/cm
tau=0.8;//confinement factor
L=500E-3;//assumed length of a typical travelling-
    wave semiconductor amplifier in cm

y=tau*g-alpha;
z=y*L;
Gs=exp(z);
mprintf("Gain of a travelling-wave semiconductor
    amplifier = %.2f.",Gs);
```

Scilab code Exa 12.3.3 Bandwidth of Fabry Perot semiconductor optical amplifier

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
```

```
//Windows 8
//Scilab version- 6.0.0
//Example 12.3.3
clc;
clear all;
//given

x=0.96;//assumed R*Gs value
L=500E-3;//assumed length of a typical travelling-
    wave semiconductor amplifier in cm
v=3.6;//refractive index of SOA medium

y=asin((1-x)/(2*sqrt(x)));
BWfpa=((v/L)*y);
mprintf("Bandwidth of Fabry-perot semiconductor
    amplifier = %.2f rad/s.",BWfpa);
```

Scilab code Exa 12.3.4 Noise figure

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.3.4
clc;
clear all;
//given

Pis=300E-6;//input-signal power in W
Pin=30E-9;//input noise power in w
B=1E-9;//Bandwidth in m
Pos=60E-3;//output signal power in W
Pon=20E-6;// output noise  power in W
```

```

SNRin=Pis/Pin;
SNRout=Pos/Pon;

Fn=SNRin/SNRout;

mprintf("Noise figure of an optical amplifier = %.2f
    .",Fn);
```

Scilab code Exa 12.3.5 ASE power

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.3.5
clc;
clear all;
//given

lambda=1300E-9;//operating wavelength in m
c=3E8;//speed of light in m
f=c/lambda;
hf=1.53E-19;//photon energy
nsp=3;
G=1000;//by converting gain into absolut no.
deltalambda=40E-9;//bandwidth of TWA in m
//BW=((f*deltalambda)/(lambda^2));
BW=1.775E12;
Pase = 2*nsp*hf*G*BW;

mprintf("ASE power generated= %.2f mW",Pase*1000);
```

Scilab code Exa 12.4.1 `Gain of EDFA`

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.4.1
clc;
clear all;
//given

//case 1
Pin=300E-6;//light input power in W
Pout=60E-3;//output power in W

Gain=Pout/Pin;
x=log10(Gain);
Gdb=10*x;

mprintf("Gain of erbium-doped fibre for case 1 = %.2f dB",Gdb);

//case 2
Pase=30E-6;//ASE power in W

Gdb2=10*log10(Gain-(Pase/Pin));
mprintf("\nGain of erbium-doped fibre for case 2 = %.2f dB",Gdb);
```

Scilab code Exa 12.4.2 connection losses

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 12.4.2
clc;
clear all;
//given

w1=10.5E-6;//MFD of transmission fibre in m
lambda=1550E-9;//operating wavelength in m
w2=5.3E-6;//assumed average MFD of Pirelli EDF-PAX-01 Fiber in m

a=w1*w2;
y=w2^2+w1^2;
z=(2*a)/y;

Ldb=-10*log10(z^2);
mprintf("Connection loss in transmission fibre = %.2f dB",Ldb);
```

Chapter 13

Passive Components Switches and Functional Modules of FiberOptic Networks

Scilab code Exa 13.1.1 coupling length

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 13.1.1
clc;
clear all;
//given

lambda1=1300E-9;//Wavelength of lambda 1 in m
lambda2=1550E-9;//Wavelength of lambda 2 in m
DELTA=0.0031;//given for SM fiber
delta=2*DELTA;//relative refractive index
a=4E-6;//assumed fiber core radius in m
u=12E-6;//distance between 2 fiber axes in m
w=u/a;

```

```
k1=411.06;//
k2=852.47;//

//since the arguement of raised sine and cosine series reaches Pi/4=0.785 hence k*L=785 gives:
Lc1=785/k1;
mprintf("For 1300nm, Coupling length= %.2f mm",Lc1);
Lc2=785/k2;
mprintf("\nFor 1550nm, Coupling length= %.2f mm",Lc2);
```

Scilab code Exa 13.2.1 Angular separation and length between transmission diffract

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 13.2.1
clc;
clear all;
//given

//case 1
lambda1=1540.56E-9;//wavelength in m
lambda2=1541.35E-9;//wavelength in m
d=5E-6;//grating pitch in m

x=lambda1/d;
theta1=asind(x);
y=lambda2/d;
theta2=asind(y);

Asep=theta2-theta1;
```

```
mprintf("Angle of separation = %.2f deg.",Asep);

//case 2

z=tand(theta2)-tand(theta1);
L=245E-6/z;

mprintf("\nLength required to separate wavelength = %.2f m",L);
```

Scilab code Exa 13.3.1 frequency and tuning time

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 13.3.1
clc;
clear all;
//given

//case 1
deltan=0.07;//Difference between refractive indexes of TE and TM modes
v=3.75E3;//velocity of sound in LiNb)3 in m/s
lambda=1540.56E-9;//optical wavelength in m
L=22E-3;//length of acousto-optic interaction

LAMDA=lambda/deltan;//wavelength for period of grating
Fsaw=v/LAMDA;
mprintf("Frequency of surface acoustic wave = %.2f Hz",Fsaw);
```

```

//case 2
Ttun=(L/v)*1E6;
mprintf("\nTuning time acousto-optic interaction = %.2f micro-s",Ttun);
```

Scilab code Exa 13.4.1 Length of Faraday rotators

```
//Fibre Optics Communication Technology, by Djafer K. Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 13.4.1
clc;
clear all;
//given


Oe=(10^3)/(4*%pi);
pfib=0.0128/Oe;//verdet's angle min/Oe-cm for silica fibre
pcry=9*60/Oe;//verdet's angle min/Oe-cm for BIG(Bi-substituted iron garnet) crystal
H=1000*Oe;//strength of magnetic field in A/m
phi=45*60;//angle in minutes

Lfib=phi/(pfib*H);
mprintf("Length of faraday rotators made from silica fibre= %.2f cm",Lfib);

Lcry=phi/(pcry*H);
mprintf("\nLength of faraday rotators made from silica fibre= %.2f mm",Lcry*10);
```

Chapter 14

An Introduction to Fiber Optic networks

Scilab code Exa 14.1.1 `time to download`

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 14.1.1
clc;
clear all;
//given
H=4.16E6;//Information carrying capacity(that is
    bandwidth) of a transmission line in bit
C=56E3;//time of transmission in bit/s

//By Hartley's law
T=H/C;

mprintf("It takes %.2f sec to download %.2f bits
    from internet to PC",T,H);
```

Scilab code Exa 14.1.2 Link Power budget

```
//Fibre Optics Communication Technology, by Djafer K
    . Mynbaev and Lovell L.scheiner
//Windows 8
//Scilab version- 6.0.0
//Example 14.1.2
clc;
clear all;
//given

lambda=1310;//operating wavelength in m
L=36;//Length of transport line in km
p=10;//linked power budget in dB
Lsm=0.6;//loss of SM fiber in db/km
Linkloss=Lsm*L;

mprintf("Link loss = %.1f dB\n Hence, we need to use
    in-line amplifier",Linkloss);
```