Scilab Textbook Companion for Fiber Optics and Optoelectronics by R. P. Khare[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 2

Ray propagation in optical fibers

Scilab code Exa 2.1 NA angles and pulse broadning

```
//Example 2.1 // NA ,angles and pulse broadning
clc;
clear;
close;
format('v',9 )
disp("part (a)")
n1=1.5;//core refrative index
n2=1.48;//claddin refractive index
a=100/2;//radius in micro meter
na=1;//air refrative index
NA=sqrt(n1^2-n2^2);//numerical aperture
disp(NA,"numerical aperture is")
disp("part (b)")
am=(asind(NA));//
tm=asind(NA/n1);//
tc=asind(n2/n1);//
disp(am,"angle in degree is ( m)")
disp(tm,"angle in degree is (Om)")
disp(tc,"angle in degree is( c)")
```

```
disp("part (c)")
c=3*10^8;//speed of light in m/s
dtl=((n1/n2)*(n1-n2)/c);//pulse broadning per unit
    length
disp(dtl,"pulse broadning per unit length in sm^-1")
```

Scilab code Exa 2.2 number of reflections

```
//Example 2.2 // minimum and maximum number of
    reflections
clc;
clear;
close;
format('v',5)
n1=1.5;//core refrative index
n2=1.48;//claddin refractive index
a=100/2;//radius in micro meter
na=1;//air refrative index
NA=sqrt(n1^2-n2^2);//numerical aperture
am=(asind(NA));//
tm=asind(NA/n1);//
tc=asind(n2/n1);//
L=((a*10^-6)/(tand(tm)));//length in meter
x=(1/(2*L));//maximum number of reflections per
    meter
disp("all other rays will suffer reflections between
     these two extremes of "+string(0)+" and "+string
    (x)+" m^-1")
//answer is wrong in the textbook
```

Scilab code Exa 2.3 pulse broadning

```
//Example 2.3 // pulse broadning
```

```
clc;
clear;
close;
format('v',6)
h=0.85;//WAVELENGTH IN MICRO METER
y=0.035;//spectral width
c=0.021;//constant
cl=3;//speed of light in m/s
dtl=(y/cl)*c;//
disp(dtl*10^4,"pulse broadning  in ns km^-1")
```

Scilab code Exa 2.4 pulse broadning

```
//Example 2.4 // pulse broadning
clc;
clear;
close;
format('v',6)
disp("part (a)")
h=850;//WAVELENGTH IN NANO METER
l=80;//fiber length in Km
dh=30;//in Nano Meter
m1=105.5;//material dispersion for h=850nm in ps/nm-
    Km
m2=2.8;//material dispersion for h=1300nm in ps/nm-
    Km
t=m1*l*dh*10^-3;//material dispersion in ns when h
    =850nm
disp(t,"material dispersion in ns when h=850nm")
disp("part (b)")
h=1300;//WAVELENGTH IN NANO METER
l=80;//fiber length in Km
dh=30;//in Nano Meter
m1=105.5;//material dispersion for h=850nm in ps/nm-
    Km
```

```
m2=2.8;//material dispersion for h=1300nm in ps/nm-
    Km
t=m2*l*dh*10^-3;//material dispersion in ns when h
    =850nm
disp(t,"material dispersion in ns when h=1300nm")
```

Scilab code Exa 2.5 pulse broadning

```
//Example 2.5; pulse broadning
clc;
clear;
close;
format('v',6)
disp("part (a)")
h=850;//WAVELENGTH IN NANO METER
l=80;//fiber length in Km
dh=2;//in Nano Meter
m1=105.5;//material dispersion for h=850nm in ps/nm-
    Km
m2=2.8;//material dispersion for h=1300nm in ps/nm-
    Km
t=m1*l*dh*10^-3;//material dispersion in ns when h
    =850nm
disp(t,"material dispersion in ns when h=850nm")
disp("part (b)")
h=1300;//WAVELENGTH IN NANO METER
l=80;//fiber length in Km
dh=2;//in Nano Meter
m1=105.5;//material dispersion for h=850nm in ps/nm-
    Km
m2=2.8;//material dispersion for h=1300nm in ps/nm-
    Km
t=m2*l*dh*10^-3;//material dispersion in ns when h
    =850nm
disp(t,"material dispersion in ns when h=1300nm")
```

Chapter 3

Wave propagation in planar waveguides

Scilab code Exa 3.1 range of propagation constants and maximum number of modes

```
//Example 3.1 // range of propagation constants and
   maximum no. of modes
clc;
clear;
close;
format('v',9)
n1=1.5;//core refractive index
n2=1.49;//cladding refrative index
t=9.83;//thickness of guided layer in micro meter
h=0.85;//wavelength in  m
b1=((2*%pi*n1)/(h*10^-6));//phase propagation
   constant in m^-1
b2=((2*%pi*n2)/(h*10^-6));//phase propagation
   constant in m^-1
m=((4*t)/h)*(sqrt(n1^2-n2^2));//number of modes
disp("range of propagation constant is "+string(b1)+
   " to "+string(b2)+" in m^-1")
disp(round(m/2),"number of modes are")
```

Scilab code Exa 3.2 thickness

```
//Example 3.2 // thickness
clc;
clear;
close;
format('v',6)
n1=3.6;//core refractive index
n2=3.56;//cladding refrative index
h=0.85;//wavelength in m
a=((h/(2*sqrt(n1^2-n2^2))));//thickness in m
disp("thicknes of the slab should not be greater
    than "+string(a)+" m")
```

Scilab code Exa 3.3 number of TE modes and propagation parameters

```
//Example 3.3 // no. of modes
clc;
clear;
close;
format('v',10)
disp("part (a)")
n1=1.5;//core refractive index
n2=1.48;//cladding refrative index
t=10.11;//thickness of guided layer in micro meter
h=1.55;//wavelength in m
b1=((2*%pi*n1)/(h*10^-6));//phase propagation
    constant in m^-1
b2=((2*%pi*n2)/(h*10^-6));//phase propagation
    constant in m^-1
m=((2*%pi*t)/h)*(sqrt(n1^2-n2^2));//number of modes
```

```
disp(round(m/2),"number of modes are")
disp("part (b)")
n1=1.5;//core refractive index
n2=1.48;//cladding refrative index
t1=10.11;//thickness of guided layer in micro meter
t=t1/2;
h=1.55;//wavelength in  m
b1=((2*%pi*n1)/(h*10^-6));//phase propagation constant in m^-1
b2=((2*%pi*n2)/(h*10^-6));//phase propagation constant in m^-1
mo=((((2*%pi*t1)/h)*(sqrt(n1^2-n2^2)))/2;//number of modes
uma0=1.30644;// for m=0 from the curve
uma1=2.59574;// for m=1 from the curve
uma2=3.83747;// for m=2 from the curve
uma3=4.9063;// for m=3 from the curve
wma0=4.8263;// for m=0 from the curve
wma1=4.27342;// for m=1 from the curve
wma2=3.20529;// for m=2 from the curve
wma3=0.963466;// for m=3 from the curve
um0=uma0/(t*10^-6);//in m^-1
um1=uma1/(t*10^-6);//in m^-1
um2=uma2/(t*10^-6);//in m^-1
um3=uma3/(t*10^-6);//in m^-1
wm0=wma0/(t*10^-6);//in m^-1
wm1=wma1/(t*10^-6);//in m^-1
wm2=wma2/(t*10^-6);//in m^-1
wm3=wma3/(t*10^-6);//in m^-1
bm0=((wm0*t*10^-6)/mo)^2;//for m=0
bm1=((wm1*t*10^-6)/mo)^2;//for m=1
bm2=((wm2*t*10^-6)/mo)^2;//for m=2
bm3=((wm3*t*10^-6)/mo)^2;//for m=3
m0=sqrt((bm0*(b1^2-b2^2))+b2^2);//for m=0 in m^-1
m1=sqrt((bm1*(b1^2-b2^2))+b2^2);//for m=1 in m^-1
m2=sqrt((bm2*(b1^2-b2^2))+b2^2);//for m=2 in m^-1
m3=sqrt((bm3*(b1^2-b2^2))+b2^2);//for m=3 in m^-1
params = [" " "m" "um[m^-1]" "wm[m^-1]" "bm"  ];
```

```
m = ["0" "1" "2" "3"]';
um = ["um0" "um1" "um2" "um3"]';
wm  = string([22.41 11.77 33.41 4.24]');
bm = string([26 19 22 17]');
params = ["m" "um[m^-1]" "wm[m^-1]" "bm" " m [m^-1]"];
city=string([0 1 2 3]');
towns = string([um0 um1 um2 um3]');
country = string([wm0 wm1 wm2 wm3]');
 pop  = string([bm0 bm1 bm2 bm3]');
 temp = string([m0 m1 m2 m3]');
 table = [params; [ city towns country pop temp ]]
 disp(table ,"constants are :")
```

Scilab code Exa 3.4 G factor

```
//Example 3.4 //G factor
clc;
clear;
close;
format('v',10)
d=0.793;//in micro meter
v=%pi/2;//point of intersection
ua=0.934;//
wa=1.262;//
Y=(wa*(1+(sind(ua))*(cosd(ua))/ua));//
G=(1+((cosd(ua))^2)/Y)^(-1);//
disp(G,"G factor is")
//answer is wrong in the textbook
```

Chapter 4

Wave propagation in cylindrical waveguides

Scilab code Exa 4.1 normalised frequency propagation constants and phase velocity

```
//Example 4.1;//normalised frequency,propagation
   constants and phase velocity
clc;
clear;
close;
format('v',5)
disp("part (a)")
n1=1.46;//core refrative index
di=7.2;//core diameter
n=1.46;//core refrative index
d=1;//relative differnce
h=1.55 ;// in micro meter
v=((2*%pi*(di*10^-6)/2)*n*sqrt(2*(d/100)))/(h*10^-6)
   ;//normalised frequency parameter
disp(v,"normalised frequency parameter is")
disp("part (b)")
format('e',11)
b1=(2*%pi*n1)/(h*10^-6);// in m^-1
```

```
n2=n1-(d/100);//cladding refrative index
b2=(2*%pi*n2)/(h*10^-6);// in m^-1
bo1=0.82;//
b11=0.18;//
B01=(b2^2+(bo1*(b1^2-b2^2)))^(1/2);//
B11=(b2^2+(b11*(b1^2-b2^2)))^(1/2);//
disp("propogation constants are Bo1 "+string(B01)+" and B11 "+string(B11)+" ")
//propogation constants are calculated wrong in the text bOOK
disp("part (c)")
format('e',9)
c=3*10^8;// in ms^-1
vp1=(2*%pi*c)/(h*10^-6*B01);//IN MS^-1
vp2=(2*%pi*c)/(h*10^-6*B11);//IN MS^-1
disp("phase velocity are (Vp)01 "+string(vp1)+" ms^-1 and (Vp)11 "+string(vp2)+" ms^-1 ")
```

Scilab code Exa 4.2 frational power propagation

```
//Example 4.2;//frational power
clc;
clear;
close;
format('v',4)
p01=0.11;//from the graph
p11=0.347;//from the graph
disp(p01*100,"power for LP01 mode is (%) ")
disp(p11*100,"power for LP11 mode is (%)" )
```

Scilab code Exa 4.3 normalised frequency parameters and number of modes

```
// Example 4.3:Number of the modes
```

```
clc;
clear;
close;
format('v',6)
h= 0.85;// Wavelenght in micrometers
a= 50;// Core radius in micrometers
NA=0.17;//
v1=(2*%pi*a*NA)/h;
m2= round((v1^2)/2);
disp(m2,"Number of modes")
```

Scilab code Exa 4.4 diameter

```
// Example 4.4:core diameter
clc;
clear;
close;
format('v',4)
d=0.02;//difference
n1=1.5;//core refrative index
m=1000;// number of modes
h= 1.3;// Wavelenght in micrometers
a=((h/(%pi*n1))*(m/d)^(1/2));//core diamter in micro
    meter
disp(a,"core diameter in micro meter")
```

Scilab code Exa 4.5 wavelength and diameter

```
// Example 4.5:core diameter
clc;
clear;
close;
format('v',5)
```

```
d=0.02;//difference
a1=75;//in micro meter
n1=1.45;//core refrative index
m=700;// number of modes
v=sqrt(4*m);//
h=((2*%pi*(a1/2)*n1*sqrt(2*(d/100)))/v);//in micro
    meter
vc=2.405*sqrt(2);//for single mode fiber
a=((vc*h)/(%pi*n1*sqrt(2*(d/100))));//core diamter
    in micro meter
disp(a,"maximum core diameter in micro meter")
```

Chapter 5

Single mode fibers

Scilab code Exa 5.1 w and wp

```
// Example 5.1:w and wp
clc;
clear;
close;
format('v',7)
n=1.46;//core refractive index
d=0.003;//differnce in core-cladding refrative index
a=4;//core radius in micro meter
h1=1.30;// inmicro meter
h2=1.55;//in micro meter
v1=((2*%pi*(a*10^-6))*n*sqrt(2*(d)))/(h1*10^-6);//
    normalised frequency parameter
v2=((2*%pi*(a*10^-6))*n*sqrt(2*(d)))/(h2*10^-6);//
    normalised frequency parameter
w1=(a*10^-6)*(0.65+((1.619)/(v1)^(3/2))+(2.879/(v1)
    ^6));//in meter
wp1=w1-(a*10^-6)*(0.016+((1.567)/(v1)^7));//in micro
     meter
w2=(a*10^-6)*(0.65+((1.619)/(v2)^(3/2))+(2.879/(v2)
    ^6));//in meter
wp2=w2-(a*10^-6)*(0.016+((1.567)/(v2)^7));//in micro
```

```
meter
disp(" w is "+string(w1*10^6)+" and wp is "+string(
    wp1*10^6)+" in micro meter when wavelength is
    1.30 micro meter")
disp(" w is "+string(w2*10^6)+" and wp is "+string(
    wp2*10^6)+" in micro meter when wavelength is
    1.55 micro meter")
```

Scilab code Exa 5.2 difference between propogation constant and modal birefringence

```
// Example 5.2;// difference between propogation
    constant and modal birefringence
clc;
clear;
close;
format('v',6)
disp("part (a)")
bl=10;//beat length in cm
h=1;//in micro meter
db=((2*%pi)/(bl*10^-2));//in m^-1
disp(db,"difference between propogation constant in
    m^-1")
disp("part (b)")
format('v',8)
mb=db*((h*10^-6)/(2*%pi));//modal birefringence
disp(mb,"modal birefringence is")
//answer is approximately equal to the answer in the
    book
```

Scilab code Exa 5.3 waveguide dispersion parameter

```
// Example 5.3:waveguide dispersion factor
```

```
clc;
clear;
close;
format('v',6)
n=1.45;//core refractive index
d=0.003;//differnce in core-cladding refrative index
n2=1.45*(1-d);//cladding refractive index
d1=8.2;//core diameter in micro meter
a=d1/2;//core radius in micro meter
h1=1.30;// inmicro meter
h2=1.55;//in micro meter
v1=(2*%pi*a*n*sqrt(2*d))/h1;//normalised frequency
    parameter
v2=((2*%pi*(a))*n*sqrt(2*(d)))/(h2);//normalised
    frequency parameter
v1dv=0.080+0.549*(2.834-v1)^2;//
v2dv=0.080+0.549*(2.834-v2)^2;//
c=3*10^8;// in m/s
dw1=-((n2*d*v1dv)/(c*h1))*10^12;//waveguide
    dispersion factor in ps nm^-1 km^-1
dw2=-((n2*d*v2dv)/(c*h2))*10^12;//waveguide
    dispersion factor in ps nm^-1 km^-1
disp(" waveguide dispersion factor is "+string(dw1)+
    " in ps nm^-1 km^-1 at wavelength 1.3 micro
    meter")
disp(" waveguide dispersion factor is "+string(dw2)+
    " in ps nm^-1 km^-1 at wavelength 1.55 micro
    meter")
```

Scilab code Exa 5.4 diameter of core and total dispersion

```
// Example 5.4:diameter of the core
clc;
clear;
close;
```

```
format('v',4)
c=3*10^8;//in m/s
dm=6;//material dispersion in ps nm^-1 km^-1
h=1.55;//in micro meter
n1=1.45;//core refrative index
d=0.005;//differnce
n2=n1*(1-d);//cladding refrative index
x=((-dm/(((-n2*d)/(c*h))*10^12))-0.080)/0.549;//
v=-(sqrt(x)-2.834);//
d=((v*h)/(%pi*n1*sqrt(2*d)));//diameter in micro meter
disp(d,"diameter of the core in micro meter")
```

Scilab code Exa 5.5 splice loss

```
// Example 5.5:splice loss
clc;
clear;
close;
format('v',5)
h1=1.30;//in micro meter
wp1=4.6155;//in micro meter
h2=1.55;//in micro meter
wp2=5.355;//in micro meter
sl1=4.34*(1/wp1)^2;//splice loss in dB
sl2=4.34*(1/wp2)^2;//splice loss in dB
disp(sl1,"splice loss in dB when wavelength is 1.30 micro meter")
disp(sl2,"splice loss in dB when wavelength is 1.55 micro meter")
```

Chapter 6

Optical fiber cables and connections

Scilab code Exa 6.1 refrative index

```
// Example 6.1:refractive index
clc;
clear;
close;
format('v',5)
l=0.47;//in db
nf=10^((l/-10));//
x=poly(0,"x");
p=1+-2.22*x+x^2;//
y=roots(p);//
disp(y(1,1),"refractive index is")
```

Scilab code Exa 6.2 loss

```
// Example 6.2:loss
clc;
```

```
clear;
close;
disp("part (a)")
format('v',5)
dya=0.1;//
n1=1.50;//refrative index
na=1;//
k1=n1/n1;//
k2=1;//
nf=((16*(n1)^2)/((n1+1)^4));//
nlat=(2/(3.14))*(acos(dya/2)-(dya/2)*(1-(dya/2)^2)
    ^(1/2));//
nt=nf*nlat;//
lt=(-10*log10(nt));//in dB
disp(lt,"insertion loss at the joint in dB is")
disp("part (b)")
format('v',6)
dya=0.1;//
n1=1.50;//refrative index
na=1;//
k1=n1/n1;//
k2=1;//
nf=((16*(n1)^2)/((n1+1)^4));//
nlat=(2/(%pi))*(acos(dya/2)-(dya/2)*(1-(dya/2)^2)
    ^(1/2));//
nt=k2*nlat;//
lt=(-10*log10(nt));//in dB
disp(lt,"insertion loss at the joint in dB is")
```

Scilab code Exa 6.3 insertion loss at joint

```
// Example 6.3:loss
clc;
clear;
close;
```

```
format('v',5)
d=100;//micro meter
dx=0;//
dy=3;//in micro mete
dth=3;//in degree
dthr=dth*(%pi/180);//
dya=0.02;//
n1=1.48;//refrative index
na=1;//
k1=n1/n1;//
k2=1;//
nf=((16*(n1)^2)/((n1+1)^4));//
nlat=(2/(%pi))*(acos(dy/100)-(dy/100)*(1-(dy/100)^2)
    ^(1/2));//
NA=n1*(sqrt(2*dya));//
nang=((1-(na*dthr)/(%pi*NA)));//
nt=nf*nlat*nang;//
lt=(-10*log10(nt));//in dB
disp(lt,"total loss in dB is")
```

Scilab code Exa 6.4 insertion loss at joint

```
// Example 6.4:loss
clc;
clear;
close;
format('v',8)
d1=80;//micro meter
na1=0.25;//
alpha1=2;//
d2=60;//in micro meter
na2=0.21;//
alpha2=1.9;//
ncd=(d2/d1)^2;//
nna=(na2/na1)^2;//
```

```
nalpha=((1+(2/alpha1))/(1+((2/alpha2))));//
nt=ncd*nna*nalpha;//
lt=(-10*log10(nt));//in dB
disp(lt,"total loss in dB is")
```

Scilab code Exa 6.5 insertion loss at joint in the forward and backward direction

```
// Example 6.5:loss
clc;
clear;
close;
format('v',5)
d1=60;//micro meter
na1=0.25;//
alpha1=2.1;//
d2=50;//in micro meter
na2=0.20;//
alpha2=1.9;//
ncd=(d2/d1)^2;//
nna=(na2/na1)^2;//
nalpha1=1;//
nalpha=((1+(2/alpha1))/(1+((2/alpha2))));//
ncd1=1;//
nna1=1;//
nt=ncd*nna*nalpha1;//
ltf=(-10*log10(nt));//in dB
nt1=ncd1*nna1*nalpha;//
ltb=(-10*log10(nt1));//in dB
disp(ltf,"total loss forward direction in dB is")
format('v',6)
disp(ltb,"total loss backward direction in dB is")
```

Chapter 7

Optoelectronic Sources

Scilab code Exa 7.1 intrinsic carrier density

```
//Example 7.1: Intrinsic carrier
clc;
clear;
close;
//given data :
format('v',9)
m=9.11*10^-31;// in kg
k=1.38*10^-23;// in JK^-1
h=6.626*10^-34;// in Js
ev=1.6*10^-19;// in J
T=300;// in K
me=0.07*m;// in kg
mh=0.56*m;// in kg
Eg=1.43*ev;// in J
ni=2*((2*%pi*k*T)/h^2)^(3/2)*(me*mh)^(3/4)*exp(-Eg
    /(2*k*T));
disp(ni,"Intrinsic carrier concentration ,ni(m^-3) =
    ")
```

Scilab code Exa 7.2 diffusion potential

```
//Example 7.2: Diffusion potential
clc;
clear;
close;
format('v',6)
//given data :
Na=5*10^23;// in m^-3
Nd=5*10^21;// in m^-3
T=300;// in K
e=1.6*10^-19;// in J
k=1.38*10^-23;// in JK^-1
V=(k*T)/e;
ni=2.2*10^12;// in m^-3
Vd=V*log((Na*Nd)/ni^2);
disp(Vd,"Diffusion potential,Vd(V) = ")
```

Scilab code Exa 7.3 injection efficiency

```
//Example 7.3: Injection efficiency
clc;
clear;
close;
format('v',7)
//given data :
Na=10^23;// in m^-3
Nd=10^21;// in m^-3
T=300;// in K
e=1.6*10^-19;// in J
k=1.38*10^-23;// in JK^-1
mue=0.85;// in m^2V^-1s^-1
muh=0.04;// in m^2V^-1s^-1
De=(mue*k*T)/e;// in m^2s^-1
Dh=(muh*k*T)/e;// in m^2s^-1
```

```
Le=1;
Lh=Le;
eta_inj=1/(1+((De/Dh)*(Lh/Le)*(Nd/Na)));
disp(eta_inj,"Injection efficiency ,eta_inj = ")
```

Scilab code Exa 7.4 internal and quantum efficiency

```
//Example 7.4: Internal and quantum efficiency
clc;
clear;
close;
//given data :
format('v',4)
disp("part (a)")
tau_rr=1;
tau_nr=tau_rr;
eta_int=1/(1+(tau_rr/tau_nr));
disp(eta_int,"Internal quantum efficiency = ")
disp("part (b)")
format('v',7)
ns=3.7;
na=1.5;
as=0;
eta_ext=eta_int*(1-as)*((2*na^3)/(ns*(ns+na)^2));
disp(eta_ext,"External quantum efficiency = ")
```

Scilab code Exa 7.5 number of longitudinal modes

```
//Example 7.5: The number of longitudinal modes
    excited
clc;
clear;
close;
```

```
format('e',10)
//given data :
lamda=632.8*10^-9;// in m
n=1;
L=20*10^-2;// in m
del_lamda=((lamda)^2/(2*n*L))*10^9;
disp(del_lamda,"The number of longitudinal modes
    excited ,(nm) = ")
```

Scilab code Exa 7.6 The reduction and Differential quantum efficiency

```
//Example 7.6: The reduction and Differential
    quantum efficiency
clc;
clear;
close;
//given data :
format('v',5)
disp("part (a)")
alfa_eff=1.5;// in mm^-1
gama=0.8;
L=0.5;// in mm
R1=0.35;
R2=R1;
R2a=1.0;
g_th1=(1/gama)*(alfa_eff+(1/(2*L))*log(1/(R1*R2)));
g_th2=(1/gama)*(alfa_eff+(1/(2*L))*log(1/(R1*R2a)));
del_gth=g_th1-g_th2;
disp(del_gth,"The reduction in threshold gain ,(mm
    ^-1) = ")
disp("part (b)")
eta_D=(gama*(g_th2-alfa_eff))/(g_th2);
disp(eta_D," Differential quantum efficiency =  ")
```

Scilab code Exa 7.7 Internal and external power efficiency

```
//Example 7.7: Internal and external power
    efficiency
clc;
clear;
close;
//given data :
disp("part (a)")
as=0;//
ns=3.7;// assuming that the example 7.4
eta_int=0.50;// internal efficiency
V=1.5;// in V
I=120*10^-3;// in A
IBYe=120*10^-3;//
Eph=1.43;// in eV
eta_int=0.50;// internal efficiency
fi_int=eta_int*IBYe*Eph;
t_power=I*V;
P_int=fi_int/t_power;
disp(P_int,"The internal power efficiency = ")
disp("part (b)")
format('v',6)
eta_ext=eta_int*(1-as)*2/(ns*(ns+1)^2);
fi_ext=eta_ext*IBYe*Eph;
t_power=I*V;
P_ext=fi_ext/t_power;
disp(P_ext,"The external power efficiency = ")
disp("part (c)")
format('e',9)
V=1.5;// in V
I=120*10^-3;// in A
IBYe=120*10^-3;//
Eph=1.43;// in eV
```

```
n1=1.5;
n2=1.48;
na=n1;
eta_ext=0.0337;
eta_T=eta_ext*((n1^2-n2^2)/na^2);
fi_T=eta_T*IBYe*Eph;
t_power=I*V;
sfpc=fi_T/t_power;
O_loss=-10*log10(sfpc);
disp(sfpc,"The overall source fiber power coupling
   efficiency = ")
format('v',5)
disp(O_loss,"The optical loss ,(dB) = ")
```

Chapter 8

Optoelectronic Detectors

Scilab code Exa 8.1 wavelength and optical power and

```
//Example 8.1: The photon energy and optical power
clc;
clear;
close;
//given data :
format('v',5)
disp("part (a)")
h=6.626*10^-34;// in Js
c=3*10^8;// in ms^-1
E=1.52*10^-19;// in J
lamda=((h*c)/E)*10^6;
disp(lamda,"The photon energy,(micro-m) = ")
disp("part (b)")
e=1.6*10^-19;// in J
Ip=3*10^6;// in A
E=1.52*10^-19;// in J
eta=70/100;
R=(eta*e)/E;
P_in=(Ip/R)*10^-6;
disp(P_in,"The optical power,(micro W)")
```

Scilab code Exa 8.2 quantum efficiency maximum possible band gap energy and photocurrent

```
//Example 8.2: The quantum efficiency ,Maximum
   possible band gap energy and mean output
clc;
clear;
close;
//given data :
disp("part (a)")
format('v',5)
e=1;// electron
p=2;// photon
eta=(e/p)*100;
disp(eta,"The quantum efficiency ,eta(%) = ")
disp("part (b)")
h=6.626*10^-34;//in Js
c=3*10^8;// in m s^-1
lamda_c=0.85*10^-6;// in m
Eg=((h*c)/lamda_c)/1.6*10^19;
disp(Eg,"Maximum possible band gap energy ,Eg(eV) = "
   )
disp("part (c)")
e=1;// electron
p=2;// photon
eta=(e/p);
e=1.6*10^-19;// in J
h=6.626*10^-34;//in Js
c=3*10^8;// in m s^-1
lamda_c=0.85*10^-6;// in m
Eg=((h*c)/lamda_c);
P_in=10*10^-6;// in W
Ip=((eta*e*P_in)/Eg)*10^6;
disp(Ip,"The mean output ,Ip(micro A) = ")
```

Scilab code Exa 8.3 quantum efficiency and responsivity

```
//Example 8.3: The quantum efficiency and The
   responsivity of the diode
clc;
clear;
close;
//given data :
format('v',5)
disp("part (a)")
e=2*10^10;// in s^-1
p=5*10^10;// in s^-1
eta=e/p;
disp(eta,"The quantum efficiency  = ")
disp("part (b)")
e=2*10^10;// in s^-1
p=5*10^10;// in s^-1
eta=e/p;
e=1.6*10^-19;// in J
h=6.626*10^-34;//in Js
c=3*10^8;// in m s^-1
lamda=0.90*10^-6;// in m
R=(eta*e*lamda)/(h*c);
disp(R,"The responsivity of the diode,R(AW^-1) = ")
```

Scilab code Exa 8.4 multiplication factor

```
//Example 8.4: The multiplication
clc;
clear;
close;
format('v',5)
```

```
//given data :
eta=40/100;//
e=1.6*10^-19;// in J
h=6.626*10^-34;//in Js
c=3*10^8;// in m s^-1
lamda=1.3*10^-6;// in m
P_in=0.3*10^-6;// in W
I=6*10^-6;// in A
M=(I*h*c)/(P_in*eta*e*lamda);
disp(M,"The multiplication factor ,M = ")
```

Scilab code Exa 8.5 incident rate of photon

```
//Example 8.5: Photon rate
clc;
clear;
close;
//given data :
format('v',9)
e=1.6*10^-19;// in J
M=800;
eta=90/100;// quantum efficiency
I=2*10^-9;// in A
P_rate=I/(e*eta*M);
disp(P_rate,"Photon incident rate(s^-1) = ")
```

Scilab code Exa 8.6 gain and photocurrent

```
//Example 8.6: Gain and The output photocurrent
clc;
clear;
close;
//given data :
```

```
format('v',6)
disp("part (a)")
tf=6*10^-12;// in s
del_f=450*10^6;// in Hz
G=1/(2*%pi*tf*del_f);
disp(G,"the gain = ")
disp("part (b)")
format('e',10)
tf=6*10^-12;// in s
del_f=450*10^6;// in Hz
G=1/(2*%pi*tf*del_f);
eta=75/100;
P_in=5*10^-6;// in W
e=1.6*10^-19;// in J
lamda=1.3*10^-6;
h=6.626*10^-34;//in Js
c=3*10^8;// in m s^-1
I=(G*eta*P_in*e*lamda)/(h*c);
disp(I,"The output photo-current ,I(A)")
```

Scilab code Exa 8.7 rms value of shot noise current dark current and thermal noise current and singnal to noise ratio

```
//Example 8.7: rms value of shot noise ,dark noise
   and thermal noise current and S/N ratio
clc;
clear;
close;
format('v',6)
disp("part (a)")
n=0.7;//efficiency
e=1.6*10^-19;//charge
h=1.3;//in micro meter
hc=6.626*10^-34;//plack constant
c=3*10^8;//m/s
```

```
pin=500;//nW
Ip=((n*e*h*10^-6*pin*10^-9)/(hc*c));//in amperes
df=25;//Mhz
f1=1;//
is2=(2*e*Ip*df*10^6*f1);//
is=sqrt(is2);//in amperes
Id=5*10^-9;//amperes
id2=(2*e*Id*df*10^6);//
id=sqrt(id2);//in amperes
k=1.38*10^-23;//
t=300;//in kelvin
rl=1000;//ohms
it2=((4*k*t*df*10^6)/rl);//
it=sqrt(it2);//in amperes
disp(is*10^9,"rms value of shot noise current is,(nA)=")
disp(id*10^9,"rms value of dark current is,(nA)=")
disp(it*10^9,"rms value of thermal noise current is,(nA)=")
format('v',4)
disp("part (b)")
n=0.7;//efficiency
e=1.6*10^-19;//charge
h=1.3;//in micro meter
hc=6.626*10^-34;//plack constant
c=3*10^8;//m/s
pin=500;//nW
Ip=((n*e*h*10^-6*pin*10^-9)/(hc*c));//in amperes
df=25;//Mhz
f1=1;//
is2=(2*e*Ip*df*10^6*f1);//
is=sqrt(is2);//in amperes
Id=5*10^-9;//amperes
id2=(2*e*Id*df*10^6);//
id=sqrt(id2);//in amperes
k=1.38*10^-23;//
t=300;//in kelvin
rl=1000;//ohms
```

```
it2=((4*k*t*df*10^6)/rl);//
it=sqrt(it2);//in amperes
itt2=is2+id2+it2;//in A^2
ip2=Ip^2;//
sn=ip2/itt2;//
disp(sn,"S/N ratio is")
//S/N ratio is calculated wrong in the textbook
```

Chapter 9

Optoelectronic Modulators

Scilab code Exa 9.1 thickness

```
//Example 9.1: The thickness
clc;
clear;
close;
format('v',7)
//given data :
lamda=589.3*10^-9;// in m
ne=1.553;
no=1.544;
x=(lamda/(4*(ne-no)))*10^3;
disp(x,"The thickness of the a quarter wave plate,x(
   mm) = ")
```

Scilab code Exa 9.2 thickness

```
//Example 9.2: The thickness
clc;
clear;
```

```
close;
//given data :
format('v',7)
lamda=589.3*10^-9;// in m
ne=1.486;
no=1.658;
x=(lamda/(2*(no-ne)))*10^3;
disp(x,"The thickness of the a quarter wave plate,x(
    mm) = ")
```

Scilab code Exa 9.3 change in refrative index and vpi

```
//Example 9.3:change in refractive index ,net phase
    shiftand Vpi
clc;
clear;
close;
format('v',6)
v=5;//kV
l=1;//cm
ez=(v*10^3)/(l*10^-2);//in V/m
no=1.51;//
r63=10.5*10^-12;//m/V
dn=((1/2)*no^3*r63*ez);//
h=550;//nm
dfi=((2*%pi*dn*l*10^-2)/(h*10^-9));//
fi=2*dfi;//
vpi=((h*10^-9)/(2*no^3*r63))*10^-3;//kV
disp(dfi,"change in refrative index is")
disp(fi,"net phase shift is")
format('v',4)
disp(vpi,"Vpi in kV is")
//refractive index and phase shift is in the form of
    pi in the textbook
```

Scilab code Exa 9.4 phase difference additional phase difference and Vpi

```
//Example 9.4:phase difference,additional phase
    difference and Vpi
clc;
clear;
close;
format('v',7)
disp("part (a)")
h=550;//nm
l=3;//cm
no=1.51;//
ne=1.47;//
dfi=((2*%pi*l*10^-2*(no-ne))/(h*10^-9));//
disp(dfi,"phase differnce is")
//phase difference is in the form of pi in the
    textbook
disp("part (b)")
no=1.51;//
r63=26.4*10^-12;//m/V
V=200;//
d=0.25;//cm
dfi=((%pi*r63*no^3*(V)*(l*10^-2))/(h*10^-9*d*10^-2))
    ;//
disp(dfi,"additional phase differnce is")
//additional phase difference is in the form of pi
    in the textbook
disp("part (c)")
r63=26.4*10^-12;//m/V
format('v',5)
V=200;//
d=0.25;//cm
dfi=((%pi*r63*no^3*(V)*(l*10^-2))/(h*10^-9*d*10^-2))
    ;//
```

```
vpi=((h*10^-9)/(no^3*r63))*(d/l);//V
disp(vpi,"Vpi in V is")
```

Scilab code Exa 9.5 angle and relative intensity

```
//Example 9.5: angle and relative intensity
clc;
clear;
close;
//given data :
disp("part (a)")
format('v',5)
m=1;
l=633*10^-9;// in m
f=5*10^6;// in Hz
v=1500;//in m/s
n=1.33;// for water
A=v/f;
theta=asind((l/(n*A)));
disp(theta,"angle (degree) =  ")
disp("part (b)")
format('v',6)
del_n=10^-5;
L=1*10^-2;// in m
lamda=633*10^-9;// in m
eta=(%pi^2*del_n^2*L^2)/lamda^2;
disp(eta,"The relative intensity = ")
```

Chapter 10

Optical amplifiers

Scilab code Exa 10.1 refractive index and spectral bandwidth

```
//Example 10.1;refractive index and bandwidth
clc;
clear;
close;
//given data :
format('v',5)
lamda=1.55*10^-6;// in m
del_lamda=1*10^-9;// in m
L=320*10^-6;// in m
n=(lamda)^2/(2*del_lamda*L);
Gs=10^(5/10);// 5 dB is equivalent to 3.16
R1=30/100;
R2=R1;
c=3*10^8;// in m/s
del_v=(c/(%pi*n*L))*asin((1-(Gs*sqrt(R1*R2)))/(sqrt
    (4*Gs*sqrt(R1*R2))));
disp(n,"refrative index is")
format('v',6)
disp(del_v*10^-9,"spectral bandwidth in GHz is")
//bandwidth is calculated wrong in the textbook
```

Scilab code Exa 10.2 small signal gain and maximum possible achievable gain

```
//Example 10.2;small-signal gain of EDFA and maximum pssible achievable gain
clc;
clear;
close;
ts=0.80;//
sa=4.6444*10^-25;//in m^2
n12=6*10^24;//m^-3
se=4.644*10^-25;//m^2
n21=0.70;//
l=7;//in meter
x=((sa*n12*l*(((se/sa)+1)*n21-1)));//
G=ts*exp(x);//
Gdb=10*log10(G);//
Gmax=exp(se*n12*l);//
Gmaxdb=10*log10(Gmax);//
disp(Gdb,"small signal gain of EDFA in dB is")
disp(Gmaxdb,"maximum possible achievable gain in dB is")
```

Scilab code Exa 10.3 output signal power and overall gain

```
//Example 10.3;output signal power and overall gain
clc;
clear;
close;
format('v',6)
disp("part (a)")
psin=1*10^-6;//in watts
```

```
ppin=1;//in watts
gr=5*10^-14;//mW^-1
ap1=60*10^-12;//m^2
l=2000;//meter
asdb=0.15;//dB/km
as=3.39*10^-5;//m^-1
apdb=0.20;//db/km
ap=4.50*10^-5;//m^-1
z=(1-exp(-ap*l))/ap;//
y=(gr/ap1);//
y1=z*y;//
y2=y1-(as*l);//
psl=psin*exp(y2);//
disp(psl*10^6,"output signal power for forward pumping in micro Watt is")
format('v',5)
disp("part (b)")
y1=z*y;//
y2=y1-(as*l);//
psl=psin*exp(y2);//
gfra=psl/(psin);//
Gdb=10*log10(gfra);//
disp(Gdb,"overall gain in dB is")
```

Chapter 11

Wavelength division multiplexing

Scilab code Exa 11.1 interaction length

```
//Example 11.1:interaction length
clc;
clear;
close;
format('v',6)
po=1;//assume
p1=po/2;//
p2=p1;//
kl=asin(sqrt(p1));//in degree
disp(kl,"interaction length is")
//answer is in the form of pi in the textbook
```

Scilab code Exa 11.2 position of the output ports

```
//Example 11.2:position
clc;
```

```
clear;
close;
a=8.2;//in micro meter
n1=1.45;//
n2=1.446;//
h1=1.31;//in micro meter
h2=1.55;///in micro meter
v1=((2*%pi*a*sqrt(n1^2-n2^2))/h1);//
v2=((2*%pi*a*sqrt(n1^2-n2^2))/h2);//
db=2.439;//
del=5.5096*10^-3;//
k1=1.0483;//mm^-1;//
k2=1.2839///m^-1
l1=((%pi)/(4*k1));//in mm
l2=((%pi)/(4*k2));//in mm
disp("output port positioned at "+string(l2)+" mm
    with respect to the input port will gather
    signals at h1=1310nm")
disp("output port positioned at "+string(l1)+" mm
    with respect to the input port will gather
    signals at h1=1550nm")
```

Scilab code Exa 11.4 order

```
//Example 11.4: ARRAYED GUIDE
clc;
clear;
close;
//given data :
c=3*10^8;
lamda_c=1.55*10^-6;// in m
vc=c/lamda_c;
n=16;// number of channel
f=100*10^9;// in Hz
delV_FSR=n*f;
```

```
m=round(vc/delV_FSR);
disp(m,"required order of the arrayed waveguide, = "
   )
```

Chapter 12

Fiber optic communication system

Scilab code Exa 12.1 maximum possible link length and total rise time

```
//Example 12.1: link length and reise time
clc;
clear;
close;
af=2.5;//dB/km
ac=0.5;//dB/splice
nc=1;//
lc=1;//dB
ncc=2;//
plx=-10;//dBm
prx=-42;//dBm
Ms=6;//dB
L=((plx-prx-Ms-(lc*ncc))/(af+ac));//
TTX=12;//NS
TRX=11;//NS
NS1=3;//NS/KM
NS2=1;//NS/KM
tmat=(NS1*L);//ns
tint=(NS2*L);//ns
```

```
tsys=sqrt((TTX^2+tmat^2+tint^2+TRX^2));//ns
disp(L,"maximum possible link length in km is")
disp(round(tsys),"total rise time of the system in
    ns is")
```

Scilab code Exa 12.2 link length and bandwidth

```
//Example 12.2: link length and bandwidth
clc;
clear;
close;
format('v',4)
disp("part (a)")
af=3;//dB/km
ac=0.5;//dB/splice
nc=1;//
lc=1;//dB
ncc=1.5;//
plx=0;//dBm
prx=-25;//dBm
Ms=7;//dB
L=((plx-prx-Ms-(lc*ncc))/(af+ac));//
TTX=12;//NS
TRX=11;//NS
NS1=3;//NS/KM
NS2=1;//NS/KM
tmat=(NS1*L);//ns
tint=(NS2*L);//ns
tsys=sqrt((TTX^2+tmat^2+tint^2+TRX^2));//ns
disp(L,"maximum possible link length in km is")
format('v',3)
disp("part (b)")
af=3;//dB/km
ac=0.5;//dB/splice
nc=1;//
```

```
lc=1; //dB
ncc=1.5; //
plx=-0; //dBm
prx=-25; //dBm
Ms=7; //dB
L=((plx-prx-Ms-(lc*ncc))/(af+ac)); //
TTX=1; //NS
TRX=5; //NS
NS1=9; //NS/KM
NS2=2; //NS/KM
tf=((NS1*L)^2+(NS2*L)^2); //
tsys=sqrt((TTX^2+tf+TRX^2)); //ns
df=0.35/(tsys*10^-3); //
disp(round(df),"system bandwidth in MHz iz")
```

Scilab code Exa 12.3 number of subscribers

```
//Example 12.3;no. of subscribers
clc;
clear;
close;
pt=1; //mW
pn=-40; //dBm
pn1=10^(pn/10); //
c=0.05; //
d=0.11; //
x=((pn1)/(pt*c)); //
y=((log10(x))/(log10((1-d)*(1-c)))); //
n=y+1; //
disp(round(n),"no. of subscribers are")
```

Scilab code Exa 12.4 total power

```
//Example 12.4: Total power
clc;
clear;
close;
//given data :
L_eff=20;// in km
del_lamdaC=125;// in nm
gR=6*10^-14;// m/W
A_eff=55*10^-12;// in m^2;
del_lamdaS=0.8;// in nm
N=32;// number of channels
F=0.1;//  constant
P_tot=(4*F*del_lamdaC*A_eff)/(gR*del_lamdaS*L_eff*(N
    -1));
disp(P_tot,"Total power, P_tot(mW) = ")
```

Scilab code Exa 12.5 SBS threshold power

```
//Example 12.5: SBS threshold power
clc;
clear;
close;
//given data :
gb=4*10^-11;// in m/W
A_eff=55*10^-12;// in m^2
L_eff=20;// in km
lamda_p=1.55;// micro-m
n=1.46;// constant
Va=5960;// for the silica fiber in m-s^-1
Vb=(2*n*Va)/lamda_p;
del_v=100*10^6;// in Hz
del_Vb=20*10^6;// in Hz
b1=1;
b2=2;
P_th=((21*b1*A_eff)/(gb*L_eff))*(1+(del_v/del_Vb))
```

```
P_th1=((21*b2*A_eff)/(gb*L_eff))*(1+(del_v/del_Vb))
disp(P_th,"SBS threshold power for the worst case in
    mW")
disp(P_th1,"SBS threshold power for the best
    possible case in mW")
```

Chapter 13

Fiber optic sensors

Scilab code Exa 13.1 plot the graph

```
//Example 13.1: plot
clc;
clear;
close;
lod=[0;20;40;60;80;100;160];//in micro meter
slong=[1.0;0.95;0.92;0.89;0.86;0.83;0.80];//
lad=[0;10;20;30;40;50;60;70;80;90;100];//in micro meter
slat=[0;0.1;0.2;0.3;0.4;0.5;0.6;0.7;0.8;0.9;1.0];//
add=[0;1;2;3;4;5;6;7;8;9;10];//
sang=[0;0.5;0.6;0.7;0.8;0.9;1.0;1.1;.12];//
t=0:20:200;
s1=1.0:-0.03:0.7;//
subplot(131)
plot(t,s1);//
xtitle("Variation of Slong as a function of   x (with  y =0 and   =0) ")
xlabel("Longitudinal displacement   x (micro meter)")
ylabel("Slong (normalised)")
t1=0:10:100;
```

```
s2=1:-0.1:0;//
subplot(132)
plot(t1,s2);//
xtitle("Variation of Slat as a function of    y (with   x =0 and     =0) ")
xlabel("Lateral displacement    y (micro meter)")
ylabel("Slat (normalised)")
t2=0:1:10;
s3=1.0:-0.03:0.7;//
subplot(133)
plot(t2,s3);//
xtitle("Variation of Sang as a function of        (with   x =0 and  y =0) ")
xlabel("Angular displacement       (deg)")
ylabel("Sang (normalised)")
```

Scilab code Exa 13.2 phase change per unit length

```
//Example 13.2: phase change
clc;
clear;
close;
format('v',6)
//given data :
n=1.45;// index of core
a=10^-5;// in C^-1
b=5.1*10^-7;// in C^-1
lamda=.633*10^-6;// in m
// formula:- (1/L)*(del_fi/del_T)=((2*PI)/lamda)[(n/L)*(del_L/del_T)+(del_n/del_T)]
//let we assume a=del_n/del_T, b=(1/L)*(del_L/del_T), c=(1/L)*(del_fi/del_T)
c=((2*%pi)/lamda)*((n*b)+a);
disp(c,"phase change,(rad/m C) = ")
```

Scilab code Exa 13.3 phase shift

```
//Example 13.3: phase shift
clc;
clear;
close;
//given data :
format('e',9)
L=500;// in m
D=0.1;//in m
ohm=7.3*10^-5;// in rad s^-1
lamda=0.85*10^-6;// in m
c=3*10^8;// in m/s
del_fi=(2*%pi*L*D*ohm)/(c*lamda);
disp(del_fi,"phase shift, del_fi(rad) = ")
```

Chapter 14

Laser based systems

Scilab code Exa 14.1 energy and threshold electrical energy

```
//Example 14.1: energy and threshold electrical energy
clc;
clear;
close;
format('v',4)
disp("part (a)")
no=1.9*10^19;//cm^-3;//
hc=6.6*10^-34;//
v=5.45*10^14;//Hz
av=2;//
nv=1;//
n2=no/2;//
eng=((n2*hc*v)/(av*nv));// J cm^-2
disp(eng,"energy in J cm^-2 is")
format('v',5)
disp("part (b)")
oe=0.50;//
mr=0.15;//
lr=0.20;//
teng=eng/(oe*mr*lr);//
```

```
disp(teng,"threshold energy in J cm^-2 is")
//electrical energy is calculated wrong in the
   textbook
```

Scilab code Exa 14.3 maximum power emerging

```
//Example 14.3: output power
clc;
clear;
close;
h=0.6943*10^-6;//
lm=10;//in cm
r1=1.0;//
r2=0.8;//
t1=0.98;//
as=1;//cm^2;//
Ls=2;//cm
gth=((1/(2*lm))*log((1/(r1*r2*(t1)^8))))+(as*Ls)/lm;
   //
sg=1.5*10^-20;//
ndth=gth/sg;//cm^-3;//
nth=ndth*as*lm;//atoms
ni=5*nth;//atoms
ng=1.78;//
ns=2.7;//
lair=2;//
c=3*10^10;//
trt=((2*ng*lm)/c)+((2*ns*Ls)/c)+((2*lair)/c);//
   seconds
npmax=((ni-nth)/2)-(nth/2)*log(ni/nth);//photons
L=14;//cm
at=((as*Ls)/L)+((1/(2*L))*log(1/(r1*t1^8)));//
aext=((1/(2*L))*log(1/r2));//
tp=((trt)/(1-(r1*r2*t1^8*exp(-2*as*Ls))));//seconds
hc=6.6*10^-34;//
```

```
pmax=((aext/at)*hc*c*npmax)/(h*tp);//in watts
disp(pmax*10^-6,"maximum power in MW is")
//answer is wrong in the textbook
```

Scilab code Exa 14.4 pulse width and spatial length

```
//Example 14.4: pulse width and spatial length
clc;
clear;
close;
format('v',5)
disp("part (a)")
//given data :
del_v=1.5*10^9;// in Hz
tau_p=1/del_v;
C=3*10^8;// constant
disp(tau_p*10^9,"pulse width,del_v(ns) = ")
Lp=C*tau_p;
disp(Lp*10^2,"spatial length,Lp(cm) = ")
//spatial length is calculated wrong in the textbook
format('v',5)
disp("part (b)")
del_v=6*10^10;// in Hz
tau_p=1/del_v;
C=3*10^8;// constant
disp(tau_p*10^12,"pulse width,del_v(ps) = ")
Lp=C*tau_p*10^3;
disp(Lp,"spatial length,Lp(mm) = ")
```

Scilab code Exa 14.5 time difference

```
//Example 14.5: time difference
clc;
```

```
clear;
close;
format('v',5)
n=1.33;//
x=2;//
l=50;//m
c=3*10^8;//m/s
dt=((n*x*l)/c);//s
disp(dt*10^6,"time difference is,(micro-seconds)=")
```