Scilab Textbook Companion for Optical Fiber Communication by G. Keiser[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

List of Figures

Chapter 1

Overview of Optical Fiber Communication

Scilab code Exa 1.1 Program to calculate time period and phase shift

```
//clear//
//Caption:Program to calculate time period and phase
    shift
//Example1.1
//Page 8
clear;
clc;
close;
f1 = 10^5; //f1 = 100KHz
f2 = 10^9; //f2 = 1GHz
T1 = 1/f1;
T2 = 1/f2;
phi = (1/4)*360;
phi_rad = phi/57.3;
disp(T1,'Time period of sine wave with frequency =
   100 KHZ')
disp(T2,'Time period of sine wave with frequency = 1
   GHZ')
disp(phi,'phase shift in degrees');
```

```
disp(phi_rad,'phase shift in radians');
//Result
//Time period of sine wave with frequency = 100 KHZ
//     0.00001
//Time period of sine wave with frequency = 1GHZ
//    1.000D-09
//phase shift in degrees
//    90.
//phase shift in radians
//    1.5706806
```

Scilab code Exa 1.2 Program to calculate bandwidth from its spectrum

```
//clear//
//Caption:program to calculate bandwidth from its
   spectrum
//Example1.2
//page10
clear;
clc;
close;
fLow = 10^4; //fLOW = 10KHZ lowest frequency
fHigh = 10^5; //FHigh = Highest frequency
B = fHigh - fLow;
disp(B,'Bandwidth in Hz = ')
//Result
//Bandwidth in Hz =    90000.
```

Scilab code Exa 1.4 Shannon Channel Capacity formula

```
//clear//
//Caption:Shannon Channel Capacity formula
//Example1.4
```

```
//page 12
clear;
clc;
close;
B = 10^6; //Bandwidth of noisy channel 10MHZ
S_N = 1; //signal-to-noise ration is 1
C = B*log2(1+S_N);
disp(C,'The maximum capacity for this channel in bits/sec C =')
//Result
//The maximum capacity for this channel in bits/sec C = 1000000.
```

Scilab code Exa 1.5 Capacity of a channel using shannon's formula

```
//clear//
//Caption:Capacity of a channel using shannon's formula
//Example1.5
//page 12
clear;
clc;
close;
fLow = 3*(10^6); //low frequency = 3MHz
fHigh = 4*(10^6); //hihg frequency = 4MHz
S_N_dB = 20; //signal-to-noise ratio 20 dB
S_N = 10^(S_N_dB/10);
B = fHigh - fLow;
C = B*log2(1+S_N);
disp(B,'Bandwidth in Hz B = ')
disp(C,'Capacity of a channel in bits/secs C =')
disp(S_N,'signal to noise ratio S/N = ')
//Result
// Bandwidth in Hz B =      1000000.
// Capacity of a channel in bits/secs C =
```

```
    6658211.5
// signal to noise ratio S/N =      100.
```

Scilab code Exa 1.6 Program to calculate attenuation

```
//clear//
//Caption:Program to calculate attenuation (or) loss
    os power
//Example 1.6
//page 14
clear;
clc;
close;
P1 =1; //one watt
P2 = P1/2; //reduced by half value
Atten_dB = 10*log10(P2/P1);
disp(Atten_dB,'Attenuation in dB = ');
power_lost = 10^(Atten_dB/10)
disp(power_lost,'The amount of power lost = ');
//Result
//Attenuation in dB =      - 3.0103
//The amount of power lost =      0.5
```

Scilab code Exa 1.7 Power gain calculation

```
//clear//
//Caption: Power gain calculation for a signal
    travelling from
//one point to another point
//Example 1.7
//page 14
clear;
clc;
```

```
close;
Loss_line1 = -9; //-9 dB
Amp_gain2 = 14; //14 dB
Loss_line3 = -3; //-3 dB
dB_at_line4 = Loss_line1+Amp_gain2+Loss_line3;
disp(dB_at_line4,'The amount of power gained by a
    signal travelling from point1 to point4 in dB = '
    )
//Result
//The amount of power gained by a signal travelling
    from point1 to point4 in dB =     2.
```

Chapter 2

Optical Fiber: Structure, Wave guiding and Fabrication

Scilab code Exa 2.1 `Critical Angle of incidence`

```
//clear//
//Caption:Critical Angle of incidence
//Example 2.1
//page 37
clear;
close;
clc;
n1 = 1.48;
n2 = 1.00;
phic = asin(n2/n1);
disp(phic*57.3,'Total Interflection reflection angle
   :critical angle of incidence in degrees')
//Result
//Total Interflection reflection angle:critical
   angle of incidence 42.509773
```

Scilab code Exa 2.2 Finding Critical angle, numerical aperture, acceptance angle

```
//clear//
//Caption: Finding Critical angle, numerical
   aperture, acceptance angle
//Example 2.2
//page 45
clear;
close;
clc;
n1 = 1.48; //core refractive index
n2 = 1.46; //cladding index
phic = asin(n2/n1)*57.3;
NA = sqrt(n1^2 - n2^2);
phi0 = asin(NA)*57.3;
disp(phic,'Critical anlge')
disp(NA,'numerical aperture')
disp(phi0,'acceptance angel in air')
//Result
//Critical anlge
//      80.575927
//numerical aperture
//     0.2424871
//acceptance angel in air
//   14.034412
```

Scilab code Exa 2.3 Calculate NORMALIZED FREQUENCY 'V' and Numerical Aperture

```
//clear//
//Caption:Program  to Calculate NORMALIZED FREQUENCY
    'V' and Numerical Aperture
//Example2.3
//Page 58
clear;
close;
```

```
clc;
a = 25e-06;
Lambda =1300e-09;
V = 26.6;
Numerical_Aperture = V*Lambda/(2*%pi*a)
disp(Numerical_Aperture,"Numerical Aperture is");
disp(M = (V^2)/2,'Total number of modes M entering
   the fiber is:')
//Result
// Numerical Aperture is:    0.2201431
// Total number of modes M entering the fiber is:
   353.78
```

Scilab code Exa 2.4 Power flow in the core and cladding of step-index fiber

```
//clear//
//Caption:Power flow in the core and cladding of
   step-index fiber
//Example 2.4
//page 62
clear;
close;
clc;
V = [22,39];
M =V^2/2;
Pcladd_P = (4/3)*(M.^(-0.5));
Pcore_P = 1- Pcladd_P;
disp(M,'Total number of modes')
disp(Pcladd_P*100,'Percentage of power propagates in
    the cladding')
//Result
// Total number of modes
//     242.    760.5
// Percentage of power propagates in the cladding
//     8.5709913    4.8349182
```

Scilab code Exa 2.5 Program to calculate Fiber Birefringence BETA_f

```
//clear//
//Caption: Program to calculate Fiber Birefringence
   BETA_f
//Example2.5
//page 65
clear;
close;
clc;
Lambda = input('Enter the wavelength of Optical
   Signal');
Lp = input('Beat Length');
BETA_f_FORMULA1 = 2*%pi/Lp;
disp(BETA_f_FORMULA1,"The fiber birefriengence using
    formula 1");
BETA_f_FORMULA2 = Lambda/Lp;
disp(BETA_f_FORMULA2,"The fiber birefriengence using
    formula 2");
//Result
//Enter the wavelength of Optical Signal 1300e-09
//Beat Length 8e-02
//The fiber birefriengence using formula 1
   78.539816
//The fiber birefriengence using formula 2
   0.0000162
```

Chapter 3

Signal degradation in Optical Fibers

Scilab code Exa 3.1 Program to Find Attenuation in dB/km

```
//clear//
//Caption:Program to Find Attenuation in dB/km
//Example3.1
//page 91
clear;
clc;
z = [1 2]; //diatances are in kilometer
alpha_in_dB_per_km = 3;
r = (alpha_in_dB_per_km*z)/10;
P0_Pz = (10^r);
for i = 1:length(P0_Pz)
  Pz_P0(i) = 1-(1/P0_Pz(i)) ;
end
disp(Pz_P0*100,'Optical signal power decreased by in
    percentage')
//RESULT
//Optical signal power decreased by in percentage
//    49.881277
//    74.881136
```

Scilab code Exa 3.2 Calculate input and output power

```
//clear//
//Caption: To Calculate input and output power in
   dBm
//Example3.2
//page 91
clear;
close;
clc;
Pin = 200e-06; //power launched into the fiber
alpha = 0.4; //attenuation in dB per KM
z = 30;  //optical fiber length 30 KM
Pin_dBm = 10*log10(Pin/1e-03);
Pout_dBm = 10*log10(Pin/1e-03)-alpha*z;
Pout = 10^(Pout_dBm/10)
disp(Pin_dBm,'Pin_dBm')
disp(Pout_dBm,'Pout_dBm')
disp(Pout*1e-03,'Output power in watts')
//Result
//Pin_dBm =   - 6.9897
//Pout_dBm =      - 18.9897
//Output power in watts  =  0.0000126
```

Scilab code Exa 3.3 Rayleigh scattering loss

```
//clear//
//Caption:Rayleigh scattering loss
//Example3.3
//page97
clear;
```

```
close;
clc;
alpha_0 = 1.64; //attenuation at Lambda_0 in dB/KM
Lambda_0 = 850e-09;// wavelength 850 nanometer
Lambda = 1310e-09; //wavelength 1350 nanometer
alpha_Lambda = alpha_0*((Lambda_0/Lambda)^4);
disp(alpha_Lambda,'Rayleigh scattering loss alpha(
    Lambda) = ')
//Result
//Rayleigh scattering loss alpha(Lambda) = 0.2906929
```

Scilab code Exa 3.4 calculate percent in decrease of number of modes

```
//clear//
//Caption:Program to calculate percent in decrease
    of number of modes
//Example 3.4
//page 99
clear;
clc;
alpha = 2; //graded index profile
n2 = 1.5; //cladding
Lamda = 1.3e-06; //wavelength
R = 0.01; //bend radius of curvature
a = 25e-06;// core radius
delta = 0.01; //core-cladding index profile
k = 4.83e06; //propagation constant
disp(k,'k = ')
part1 = (2*a/R)+floor((3/(2*n2*k*R))^(2/3));
part2 = (alpha+2)/(2*alpha*delta);
Neff_Ninf = 1-part1*part2;
disp('number of modes decreased by')
disp('Percent  in graded-index fiber',Neff_Ninf*100)
//RESULTS
//number of modes decreased by 50 Percent  in graded
```

```
-index fiber
```

Scilab code Exa 3.5 Calculation of pulse broadening

```
//clear//
//Caption: Calculation of pulse broadening
//Example3.5
//page 103
clear;
clc;
close;
C = 3e08; //free space velocity in metre/sec
n1 = 1.48;//core refractive index
n2 = 1.465;//cladding refractive index
delta = 0.01; //index difference
L = 10^3;//fiber length 10KM
deltaT = (L*(n1^2)/(C*n2))*delta;
disp((deltaT/L)*10^12,'pulse broadening in ns/KM')
//Result
//pulse broadening in ns/KM = 49.838453
```

Scilab code Exa 3.6 Calculation of bandwidth distance

```
//clear//
//Caption:Calculation of bandwidth distance
//Example3.6
//page 104
clear;
clc;
close;
n1 = 1.48;//core refractive index
n2 = 1.465;//claddinig refractive index
delta = 0.01;//index difference
```

```
C =3*(10^8); //free space velcotiy
BL = (n2/(n1^2))*(C/delta);
disp(BL,'Bandwidth distance in bPS-M')
disp(BL/10^9,'Bandwidth distance in MbPS-KM')
//Result
//Bandwidth distance in bPS-M
//      2.006D+10
//Bandwidth distance in MbPS-KM
//      20.064828
```

Scilab code Exa 3.7 Find out the Material Dispersion

```
//clear//
//Caption:Program to Find out the Material Dispersion
//Example3.7
//page107
clear;
clc;
Lamda = 800e-09;//Wavelength in meter
sigma_Lamda_LED = 40e-09;//spectral width in meters
pulse_spread = 4.4e-12;//pulse spread in sec/meter
mat_dispersion = pulse_spread/sigma_Lamda_LED
disp(mat_dispersion,'material dispersion in seconds/square meter')
//Result
//material dispersion in seconds/square meter 0.00011
```

Scilab code Exa 3.8 Find out Waveguide Dispersion

```
//clear//
//Caption:Program to Find out Waveguide Dispersion
```

```
//Example3.8
//page110
clear;
clc;
n2 = 1.48; //index of cladding
delta = 0.002; //index difference
Lamda = 1320e-09; //Wavelength in meters
V_dVb_dV = 0.26; //The value in square brackets for
    v = 2.4
C =3e08;//Enter the velocity of light in free space
Dwg_Lamda = -(((n2*delta)/C)*(1/Lamda))*V_dVb_dV
disp(Dwg_Lamda*1e06,'The waveguide dispersion in ps/
    nm.km');
//RESULTS
//The waveguide dispersion in ps/nm.km   = -
    1.9434343
```

Chapter 4

Optical Sources

Scilab code Exa 4.1 Program to find intrinsic carrier concentration

```
//clear//
//Caption: Program to find intrinsic carrier
    concentration
//Example4.1
//page136
clear;
close;
clc;
m = 9.11e-31; //Electron rest mass in kg
me = 0.068*m; //Effective electron mass kg
mh = 0.56*m; //Effective hole mass in kg
Eg = 1.42*1.60218e-19;//band-gap energy in volts
kB = 1.38054e-23;//Boltzma's constant
T = 300; //room temperature in kelvin
h = 6.6256e-34;//Planck's constant
K = 2*((2*%pi*kB*T/(h^2))^1.5)*((me*mh)^0.75);//
    characteristic constant of material
ni = K*%e^(-Eg/(2*kB*T));
disp(ni,'intrinsic carrier concentration in cubic
    meter')
//Result
```

```
//intrinsic carrier concentration in cube meter
   2.551D+12
```

Scilab code Exa 4.3 Energy gap and Wavelength of GaAlAs

```
//clear//
//Caption: Finding Enegy gap and Wavelength
//Example4.3
//page146
clear;
close;
clc;
x =0.07;// compositional parameter of GaAlAs
Eg = 1.424+1.266*x+0.266*x^2;
Lamda = 1.240/Eg;
disp(Eg,'Band Energy gap in ev')
disp(Lamda,'Wavelength in micro meters')
//Result
// Band Energy gap in ev       1.5139234
// Wavelength in micro meters 0.8190639
```

Scilab code Exa 4.4 Compositional parameter of InGaAsP

```
//clear//
//Caption: Finding Enegy gap and Wavelength
//Example4.4
//page146
clear;
close;
clc;
y =0.57;// compositional parameter of InGaAsP
Eg = 1.35-0.72*y+0.12*(y^2);
Lamda = 1.240/Eg;
```

```
disp(Eg,'Band Energy gap in ev')
disp(Lamda,'Wavelength in micro meters')
//Result
// Band Energy gap in ev   0.978588
// Wavelength in micro meters 1.2671318
```

Scilab code Exa 4.5 `find out the Internal Quantum Efficiency and Internal Power le`

```
//clear//
//Caption :To find out the Internal Quantum Efficiency and Internal Power level of LED source
//Example4.5
//page149
clear;
clc;
tuo_r = 30e-09;//radiative recombination in seconds
tuo_nr =100e-09;//non-radiative recombination in seconds
Etta_internal = 1/(1+(tuo_r/tuo_nr));//internal quantum efficiency
h = 6.6256e-34; //Plank's constant
C = 3e08; //velocity in m/sec
q = 1.602e-19; //electron charge in coulombs
I = 40e-03;//drive current in Amps
Lamda = 1310e-09;// peak wavelength of InGaAsP LED
Pinternal = (Etta_internal*((h*C)/q))*(I/Lamda);//internal power level
disp(Pinternal,'THE INTERNAL POWER GENRATED WITH IN LED SOURCE IN WATTS IS');
disp(Etta_internal,'The internal Quantum efficiency for the given radiative and non-radiative recombination time is');
disp(Etta_internal*100,'Internal Quantum Efficiency in Percentage');
//RESULT
```

```
//THE INTERNAL POWER GENRATED WITH IN LED SOURCE IN
   WATTS IS
//0.0291427
//The internal Quantum efficiency for the given
   radiative and non-radiative recombination time is
    0.7692308
//Internal Quantum Efficiency in Percentage
// 76.923077
```

Scilab code Exa 4.6 `External Quantum Efficiency in percentage`

```
//clear//
//Caption: External Quantum Efficiency in percentage
//Example 4.6
//page151
clear;
close;
clc;
n = 3.5; //refractive index of an LED
Etta_External = 1/(n*(n+1)^2);
disp(Etta_External*100,'External Efficiency in
   percentage')
//Result
//External Efficiency in percentage    1.4109347
```

Scilab code Exa 4.7 `Program to find Lasing Threshold gain`

```
//clear//
//Caption:Program to find Lasing Threshold gain
//Example4.7
//page156
clear;
clc;
```

```
L = 500e-06; //Laser diode length in meters
R1 = 0.32//reflection coefficient value of one end;
R2 = 0.32//reflection coefficient value of another end;
alpha_bar =10/1e-02; //absorption coefficient;
alpha_end = (1/(2*L))*log(1/(R1*R2));//mirror loss in the lasing cavity
alpha_threshold = alpha_bar+alpha_end;//total loss
disp(alpha_threshold,"The Threshold Gain per metre")
alpha_threshold_cm = alpha_threshold/100
disp(alpha_threshold_cm ,"The Threshold Gain per centimetre");
//Result
//The Threshold Gain per metre 3278.8686
//The Threshold Gain per centimetre 32.788686
```

Scilab code Exa 4.8 Program TO Calculate Frequency Spacing \& Wavelength Spacing

```
//clear//
//Caption:Program TO Calculate Frequency Spacing & Wavelength Spacing
//Example4.8
//page160
clear;
clc;
Lamda = 850e-9 //Emission wavelength of LASER diode
n = 3.7 //refractive index of LASER diode
L = 500e-6//length of LASER diode
C = 3e08 //velocity of Light in free space
delta_frequency = C/((2*L)*n);
delta_Lamda = (Lamda^2)/((2*L)*n);
Half_power = 2e-09; //half power point 3 nanometer
sigma = sqrt(-(Half_power^2)/(2*log(0.5)));
disp(delta_frequency,'Enter the frequency spacing in Hertz');
```

```
disp(delta_Lamda,'Enter the waelength spacing in metres');
disp(sigma,'spectral width of the gain');
//RESULT
//Enter the frequency spacing in Hertz
//    8.108D+10
//Enter the waelength spacing in metres
//   1.953D-10
//spectral width of the gain
//      1.699D-09
```

Scilab code Exa 4.9 `number of half-wavelengths and wavelength spacing`

```
//clear//
//Caption:Calcualtion of number of half-wavelengths and wavelength spacing between lasing modes
//Example4.9
//page161
clear;
clc;
close;
Lambda = 900e-09;// wavelength of ligth emitted by laser dioda
L = 300e-06;// length of laser chip
n = 4.3; //refractive index of the laser material
m = 2*L*n/Lambda;//number of half-wavelengths
delta_Lambda = (Lambda^2)/(2*L*n);//wavelength spacing
disp(m,'number of half-wavelengths spanning the region between mirror surfaces')
disp(delta_Lambda,'spacing between lasing modes is')
//Result
//number of half-wavelengths spanning the region between mirror surfaces    2866.6667
//spacing between lasing modes is    3.140D-10
```

Chapter 5

Power Launching and Coupling

Scilab code Exa 5.1 Calculation of Lateral power distribution coefficient

```
//clear//
//Caption: Calculation of Lateral power distribution
    coefficient
//Example5.1
//page192
clear;
clc;
close;
phi = 0; //lateral coordinate
Half_power = 10; //half power beam width
teta = Half_power/2;
teta_rad = teta/57.3;
L = log(0.5)/log(cos(teta_rad));
disp(L,'Lateral power distribution coefficient L=')
//Result
//Lateral power distribution coefficient L =
   181.83303
```

Scilab code Exa 5.2 Calculate Optical Power Emitted

```
//clear//
//Caption:Program to  Calcualte Optical Power
    Emitted from the Light source and Optical power
    coupled to step-index fiber
//Example5.2
//page194
clear;
close;
clc;
rs = 35e-06;//the source radius in meter
a = 25e-06; //the  core radii of step-index fiber
    meter
NA = 0.20; //the numerical aperture value
Bo = 150e04;// radiance in W/square meter.sr
Ps = ((%pi^2)*(rs^2))*Bo;//power emitted by the
    source
if (rs <=a) then
  PLED_step = Ps*(NA^2);
elseif (rs>a) then
  PLED_step = (((a/rs)^2)*Ps)*(NA^2);
end
disp(Ps,'Optical power emitted by LED light source
    Ps =')
disp(PLED_step,'Optical Power coupled into step
    index fiber in Watts PLED_step =');
//RESULT
//Optical power emitted by LED light source Ps =
    0.0181354
//Optical Power coupled into step index fiber in
    Watts PLED_step =   0.0003701
```

Scilab code Exa 5.3 Fresnel reflection, power coupled and power loss

```
//clear//
//Caption:Fresnel reflection , power coupled and
```

```
    power loss
//Example5.3
//page194
clear;
clc;
close;
n1 =3.6;//refractive index of optical source
n = 1.48; //refractive index of silica fiber
R = ((n1-n)/(n1+n))^2;
L = -10*log10(1-R);
disp(L,'Power loss in dB L =')
//Result
//Power loss in dB L = 0.8310322
```

Scilab code Exa 5.4 Power coupled between two graded index fibers

```
//clear//
//Caption:Power coupled between two graded index
    fibers
//Example5.4
//page205
clear;
clc;
close;
a =1e-06; //core radii in meters
d = 0.3*a;//axial offset
PT_P = (2/%pi)*(acos(d/(2*a))-(1-(d/(2*a))^2)^0.5*(d
    /(6*a))*(5-0.5*(d/a)^2));
PT_P_dB = 10*log10(PT_P)
disp(PT_P_dB,'Optical power coupled from first fiber
     into second fiber in dB is=')
//Result
//Optical power coupled from first fiber into second
     fiber in dB is =  - 1.2597813
```

Scilab code Exa 5.5 Loss between single mode fibers due to Lateral misalignmen

```
//clear//
//Caption:Loss between  single mode fibers due to
   Lateral misalignment
//Example5.5
//page 211
clear;
clc;
close;
V = 2.405; //normalized frequency
n1 =1.47; //core refractive index
n2 = 1.465; //cladding refractive index
a = (9/2)*10^-06; //core radii in meters
d = 1e-06; //lateral offset in meters
W = a*(0.65+1.619*V^(-1.5)+2.879*V^-6);
Lsm = -10*log10(exp(-(d/W)^2));
disp(W,'mode-field diameter in meters W =');
disp(Lsm,'Loss between single mode optical fibers
   due to lateral offset Lsm =')
//Result
//mode-field diameterin meters W =  0.0000049
//Loss between single mode optical fibers due to
   lateral offset Lsm = 0.1775797
```

Scilab code Exa 5.6 Loss between single mode fibers due to angular misalignment

```
//clear//
//Caption:Loss between single mode fibers due to
   angular misalignment
//Example5.6
//page212
```

```
clear;
clc;
close;
clear;
clc;
close;
V = 2.405; //normalized frequency
n1 =1.47; //core refractive index
n2 = 1.465; //cladding refractive index
a = (9/2)*10^-06; //core radii in meters
d = 1e-06; //lateral offset in meters
W = a*(0.65+1.619*V^(-1.5)+2.879*V^-6);//mode-field diameter
teta = 1; //in degrees
teta = 1/57.3; //in radaians
Lambda = 1300e-09;//wavelength in meters
Lsm_ang = -10*log10(exp(-(%pi*n2*W*teta/Lambda)^2));
disp(Lsm_ang,'Loss between single mode fibers due to angular misalignment Lsm_ang =')
//Result
//Loss between single mode fibers due to angular misalignment Lsm_ang = 0.4054658
```

Chapter 6

Photodetectors

Scilab code Exa 6.1 Cut-off wavelength of photodiode

```
//clear//
//Caption:Cut-off wavelength of photodiode
//Example6.1
//page224
clear;
clc;
close;
h = 6.625*(10^-34); //planks constant
C = 3*(10^8); //free space velocity
Eg = 1.43*1.6*(10^-19);//joules
LambdaC = h*C/Eg;
disp(LambdaC,'Cut-off Wavelength of photodiode in
    meters =')
//Result
//Cut-off Wavelength of photodiode in meters=
    0.0000009
```

Scilab code Exa 6.2 Calculation of Quantum efficiency

```
//clear//
//Caption: Calculation of Quantum efficiency
//Example6.2
//page 226
clear;
clc;
close;
Ip_q = 5.4*(10^6);//electron-hole pairs generated
Pin_hv = 6*(10^6);//number of incident photons
etta = Ip_q/Pin_hv;
disp(etta,'Quantum efficiency =')
disp(etta*100,'Quantum efficiency in percentage =')
//Result
//Quantum efficiency = 0.9
//Quantum efficiency in percentage = 90.
```

Scilab code Exa 6.3 Calculation of photocurrent

```
//clear//
//Caption:Calculation of photocurrent
//Example6.3
//page226
clear;
clc;
close;
R = 0.65; //Responsivity of photodiode
Pin = 10*(10^-6); //Optical power level in watts
Ip = R*Pin;
disp(Ip*10^6,'The amount of photocurrent generated
   in uA =')
//Result
//The amount of photocurrent generated in uA = 6.5
```

Scilab code Exa 6.4 Calculation of Responsivity of photodiode

```
//clear//
//Caption:Calculation of Responsivity of photodiode
//Example6.4
//page227
clear;
clc;
close;
Lambda = 1300e-09; //wavelength in meters
C = 3*(10^8); //free space velocity
v =C/Lambda; //frequency in Hz
q = 1.6*(10^-19);//Change in coulombs
etta = 0.9; //quantum efficiency 90%
h = 6.625*10^-34; //planks constant
R = (etta*q)/(h*v); //Responsivity
disp(R,'Responsivity of photodiode at 1330nm in A/W
    R = ')
Eg = 0.73; //energy gap in electron volts
LambdaC = 1.24/Eg; //cut-off wavelength in meters
disp(LambdaC,'cut-off wavelength in meters = ')
//Result
//Responsivity of photodiode at 1330nm in A/W R =
    0.9418868
//cut-off wavelength in meters = 1.6986301
```

Scilab code Exa 6.5 primary photocurrent and multiplication factor

```
//clear//
//Caption:To find primary photocurrent and
    multiplication factor
//Example6.5
//page230
clear;
clc;
```

```
close;
etta = 0.65; //quantum efficiency of silicon
   qavalanche photodiode
C = 3*(10^8); //free space velocity in m/s
Lambda = 900e-09;//wavelength in meters
q = 1.6*(10^-19);//charge in coulombs
h = 6.625*(10^-34);//planks constant
v = C/Lambda; //frequnecy in Hz
Pin = 0.5*10^-06;//optical power
Ip = ((etta*q)/(h*v))*Pin;
Im = 10*(10^-06); //multiplied photocurrent
M = Im/Ip; //multiplication factor
disp(Ip*10^6,'Primary photocurrent in uAmps Ip=')
disp(ceil(M),'Primary photocurrent is multiplied by
   a factor of M =')
//Result
//Primary photocurrent in uAmps Ip =    0.2354717
//Primary photocurrent is multiplied by a factor of
   M =   43.
```

Scilab code Exa 6.6 Mean-square shot noise current, Mean-square dark current and M

```
//clear//
//Caption:Mean-square shot noise current, Mean-
   square dark current and Mean-Square thermal noise
    current
//Example6.6
//page 234
clear;
clc;
close;
Lambda = 1330e-09; //wavelength in meters
ID = 4e-09;//photodiode current
etta = 0.90;//quantum eficiency
RL = 1000; //Load resistance 1000 ohms
```

```
Pin = 300e-09; //incident optical power is 300 nano watts
Be = 20*(10^6); //receiver bandwidth
q = 1.6*(10^-19); //charge in coulombs
h = 6.625*10^-34;//planks constant
v= (3*10^8)/Lambda; //frequency in Hz
Ip = (etta*q*Pin)/(h*v);//primary photocurrent
Ishot = 2*q*Ip*Be; //shot-noise current
Ishot = sqrt(Ishot);
IDB = 2*q*ID*Be; //dark current
IDB = sqrt(IDB);
T = 283; //room temperature in kelvin
KB = 1.38*10^-23; //boltzmann's constant
RL = 1000; //load resistance
IT = (4*KB*T)*Be/RL;//Thermal noise current
IT = sqrt(IT);
disp(Ip*10^6,'primary photocurrent in uA IP =')
disp(Ishot*10^9,'mean-square shot noise current for a pin photodiode in nA Ishot =')
disp(IDB*10^9,'mean-square dark current in nA IDB=')
disp(IT*10^9,'mean-square thermal noise current for the receiver in nA IT =')
//Result
//primary photocurrent in uA IP = 0.2890868
//mean-square shot noise current for a pin photodiode in nA Ishot = 1.3602042
//mean-square dark current in nA IDB = 0.16
//mean-square thermal noise current for the receiver in nA IT = 17.675746
```

Scilab code Exa 6.7 circuit bandwidth of a photodiode

```
//clear//
//Caption:circuit bandwidth of a photodiode
//Example6.7
```

```
//page 239
clear;
clc;
close;
CP = 3*10^-12;//photodiode capacitance is 3 pico farad
CA = 4*10^-12;//amplifier capcitance is 4 pico farad
CT = CP+CA; //total capacitance
RT1 = 1000; //photodiode load resistance
BC1 = 1/(2*%pi*RT1*CT); //circuit bandwidth
RT2 = 50; //photodiode load resistance
BC2 = 1/(2*%pi*RT2*CT);//circuit bandwidth
disp(BC1,'Circuit bandwidth for 1kilo Ohm photodiode resistance BC1 =')
disp(BC2,'Circuit bandwidth for 50 ohm photodiode resistance BC2 =')
//Result
//Circuit bandwidth for 1kilo Ohm photodiode resistance BC1 = 22736420.
//Circuit bandwidth for 50 ohm photodiode resistance BC2 =  4.547D+08
```

Chapter 7

Optical Receiver Operation

Scilab code Exa 7.1 To find optimum decision threshold

```
//clear//
//Caption: To find optimum decision threshold
//Example7.1
//Page 258
clear;
clc;
close;
bon = 1;
boff =0;
sigma_on = 1;
sigma_off = 1;
Q = (bon-boff)/(sigma_on+sigma_off)
Vth = bon-Q*sigma_on
disp(Q,'Q parameter value =')
disp(Vth,'optimum decision threshold Vth =')
//Result
//Q parameter value = 0.5
//optimum decision threshold Vth = 0.5
```

Scilab code Exa 7.2 find out signal-to-noise ratio and probability

```
//clear//
//Caption: To find out signal-to-noise ratio and
    probability of error for given 'Q'
//Example7.2
//Page 258
clear;
clc;
close;
Q = 6;
Pe = (1/2)*(1-erf(Q/sqrt(2)));
S_N_dB = 10*log10(2*Q);
disp(Pe,'Probability of error Pe(Q) =')
disp(S_N_dB,'Signal-to-noise ratio in dB S/N =')
//Result
//Probability of error Pe(Q) = 9.866D-10
//Signal-to-noise ratio in dB S/N = 10.791812
```

Scilab code Exa 7.3 Plotting Bit-Error-Rate versus Q factor

```
//clear//
//Caption:Plotting Bit-Error-Rate versus Q factor
//Example7.3
//page 259
clear;
clc;
close;
Q = 0:0.01:8;
Pe = (1/2)*(1-erf(Q./sqrt(2)));
a =gca();
a.data_bounds =[0,1e-16;8,0.5];
plot(Q,Pe,'r')
```

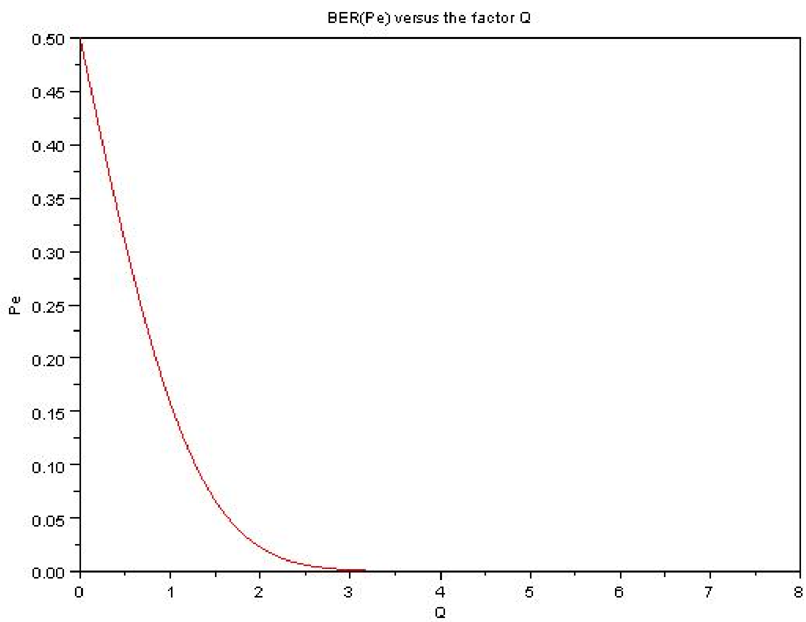

Figure 7.1: Plotting Bit-Error-Rate versus Q factor

```
xlabel('Q')
ylabel('Pe')
title('BER(Pe) versus the factor Q')
disp(Pe(1),'Probability of error at Q =0')
disp(Pe(101),'Probability of error at Q =1')
disp(Pe(201),'Probability of error at Q =2')
disp(Pe(301),'Probability of error at Q =3')
disp(Pe(401),'Probability of error at Q =4')
disp(Pe(501),'Probability of error at Q =5')
disp(Pe(601),'Probability of error at Q =6')
disp(Pe(701),'Probability of error at Q =7')
disp(Pe(801),'Probability of error at Q =8')
//Result
//Probability of error at Q =0
//     0.5
//Probability of error at Q =1
//     0.1586553
//Probability of error at Q =2
//     0.0227501
//Probability of error at Q =3
//     0.0013499
//Probability of error at Q =4
//     0.0000317
//Probability of error at Q =5
//     0.0000003
//Probability of error at Q =6
//     9.866D-10
//Probability of error at Q =7
//     1.280D-12
//Probability of error at Q =8
//     6.106D-16
```

Scilab code Exa 7.4 `find the energy of the photon incident on photodiode`

```
//clear//
```

```
//Caption: To find the energy of the photon incident
    on photodiode
//and Minimum incident optical power
//Example7.4
//page 262
clear;
clc;
close;
h =  6.626e-34; //planks constant J/s
C = 3e08; //free space velocity in m/s
B = 10e06; //data rate 10 Mb/sec
tuo = 2/B; //1/tuo = half the data rate B
Lambda = 850e-09; //operating wavelength in nm
E = 20.7*h*C/Lambda;
Pi  = E/tuo;
disp(E,'Energy of the incident photon E =')
disp(Pi,'minimum incident optical power Pi =')
disp(10*log10(Pi*1000),'minimum incident optical
   power in dBm =')
//Result
// Energy of the incident photon E =  4.841D-18
// minimum incident optical power Pi = 2.420D-11
// minimum incident optical power in dBm =  -
   76.161059
```

Chapter 8

B Digital Links

Scilab code Exa 8.1 Program to calculate the Total Optical Power loss

```
//clear//
//Caption:Program to calculate the Total Optical
   Power loss
//Example8.1
//page 287
clear;
clc;
close;
system_margin = 6; //in dB
alpha = 3.5; //attenuation in dB/Km
L =6; // Length of transmission path in Km
lc = 1; //connector loss in dB
PT = 2*lc+alpha*L+system_margin;
disp(PT,'The total optical power loss in dB PT =')
//Result
//The total optical power loss in dB PT =  29.
```

Scilab code Exa 8.2 Program to calculate the system margin

```
//clear//
//Caption:Program to calculate the system margin
//Example8.2
//page 288
clear;
clc;
close;
Ps = 3; //laser output in dBm
APD_sen = -32; //APD sensitivity in dBm
Allowed_Loss = Ps-APD_sen;//in dB
lsc = 1; //source connector loss in dB
ljc = 2*4; //two (jumper+connector loss) in dB
alpha = 0.3;//attenuation in dB/Km
L = 60; //cable length in Km
cable_att = alpha*60;//cable attenuation in dB
lrc = 1; //receiver connector loss in dB
system_margin = Allowed_Loss-lsc-ljc-cable_att-lrc;
disp(system_margin,'The  Final Margin in dB =')
//Result
//'The  Final Margin in dB =  7.
```

Scilab code Exa 8.3 Program to calculate link rise time

```
//clear//
//Caption: Program to calculate link rise time
//Example8.3
//page 291
clear;
clc;
close;
t_tx = 15e-09; //transmitter rise time
t_mat = 21e-09; //material dispersion related rise
    time
t_mod = 3.9e-09; //rise time resulting from modal
    dispersion
```

```
t_rx =14e-09; //receiver rise time
tsys = sqrt(t_tx^2+t_mat^2+t_mod^2+t_rx^2)
disp(tsys*1e09,'link rise time in nano seconds tsys
   =')
//Result
//link rise time in nano seconds tsys = 29.617731
```

Scilab code Exa 8.4 Program to calculate link rise time with GVD rise time

```
//clear//
//Caption:Program to calculate link rise time
//Example8.4
//page292
clear;
clc;
close;
t_tx = 25e-12; //transmission rise time in sec
t_GVD = 12e-12; //GVD rise time in sec
t_rx = 0.14e-09; //receiver rise time in sec
tsys = sqrt(t_tx^2+t_GVD^2+t_rx^2)
disp(tsys*1e09,'link rise time in nano seconds tsys
   =')
//Result
//link rise time in nano seconds tsys = 0.1427200
```

Scilab code Exa 8.5 Calculation of Number of bits affected by a burst error

```
//clear//
//Caption:Calculation of Number of bits affected by
   a burst error
//Example8.5
//page 306
clear;
```

```
clc;
close;
bit_error_dur = 1e-03; //bit-corrupting burst noise
   duration in msec
B = 10e03; //data rate 10kb/sec
N = B*bit_error_dur;
disp(N,'Number of bits affected by a burst error N='
   )
//Result
// Number of bits affected by a burst error N = 10.
```

Scilab code Exa 8.6 Program to find coefficients of generator polynomial

```
//clear//
//Caption: Program to find coefficients of generator
    polynomial
//Example8.6
//page 308
clear;
clc;
close;
x = poly(0,'x');
G = x^7+0+x^5+0+0+x^2+x+1;
C = coeff(G);
disp(C($:-1:1),'Coefficients of generator polynomial
    C =')
//Result
// Coefficients of generator polynomial C = 1.    0.
        1.    0.    0.    1.    1.    1.
```

Scilab code Exa 8.7 Program to find CRC(Cyclic Redundancy Check)

```
//clear//
```

```
//Caption: Program to find CRC(Cyclic Redundancy
   Check)
//Example8.7
//page 308
clear;
clc;
close;
x = poly(0,'x');
m = [1,1,1,1,0];
G = x^7+x^6+x^5+x^4+0+0+0+0;
D = x^3+0+x+1;
[R,Q]  = pdiv(G,D)
R = coeff(R);
Q = coeff(Q);
R = abs(modulo(R,2));
Q = abs(modulo(Q,2));
disp(R,'Remainder R =')
disp(Q,'Quotient Q =')
disp([m R],'CRC for the given information CRC =')
//Result
//Remainder R =
//      1.     0.     1.
//Quotient Q =
//      1.     1.     0.     1.     1.
//CRC for the given information CRC =
//      1.     1.     1.     1.     0.     1.     0.     1.
```

Scilab code Exa 8.8 Program to percentage of burst error detected by CRC

```
//clear//
//Caption: Program to percentage of burst error
   detected by CRC
//Example8.8
//page 309
clear;
```

```
clc;
close;
N =32;
Ped = 1-(1/(2^N));
disp(Ped*100,'Percent of burst error detected by CRC
    for a length of 32 Ped=')
//Result
//Percent of burst error detected by CRC for a
   length of 32 Ped=100.
```

Scilab code Exa 8.9 Percent overhead to the inforamtion stream

```
//clear//
//Caption: Percent overhead to the inforamtion
   stream Using Reed-Solomon code for error
   correction
//Example8.9
//page 309
clear;
clc;
close;
S =8; //Reed-Solomon code with 1 byte
n = (2^S-1); // length of coded sequence
k = 239; //length of message sequence
r = n-k;
disp(r,'number of redundant bytes r =')
disp((r/k)*100,'Percent overhead =')
//Result
//number of redundant bytes r = 16.
//   Percent overhead =       6.6945607
```

Chapter 9

Analog Links

Scilab code Exa 9.1 `Relative Intensity Noise (RIN)`

```
//clear//
//Caption:Program to find Relative Intensity Noise (
    RIN)
//Example9.1
//page 320
clear;
clc;
close;
IB_Ith = [1.3,1.4,1.5,1.6];//ratio between bias
    current and threshold current
f = 100e06; //frequency = 100MHz
RIN = ((IB_Ith-1)^-3)/f;
RIN_dB = 20*log10(RIN);
disp(RIN_dB,'Relative Intensity Noise(RIN) in dB/Hz
    RIN_dB =')
//Result
//Relative Intensity Noise(RIN) in dB/Hz RIN_dB =
//   - 128.62728  - 136.1236  - 141.9382  -
    146.68908
```

Scilab code Exa 9.2 Find limiting conditions for pin-photodiode

```
//clear//
//Caption: Program to Find limiting conditions for
   pin−photodiode
//Example9.3
//page 323
clear;
clc;
close;
T =300;//room temperature in kelvin
kB = 1.38054e-23; //Boltzmann's constant in Joules/k
m =0.25; //modualtion index
RIN_dB = -143; //Relative intensity in dB/Hz
RIN = 10^(RIN_dB/10);
Pc = (10^(0/10))*1e-3; //power coupled to optical
   fiber in dBm
R = 0.6; //Responsivity A/w
Be = 10e06; //bandwidth 10MHz
ID = 10e-09; //dark current 10nA
Req = 750; //equivalent resistance 750 ohm
Ft = 10^(3/10); //in 3 dB
M = 1; //Multiplication factor for pin photodiode
R = 0.6; //responsivity in A/m
q = 1.602e-19; //charge in coulombs
p = 0:-1:-20;
P = (10^(p/10))*1e-3;
C_N_1 = 0.5*((m*R*P)^2)/(4*kB*T*Be*Ft/Req);
C_N_3 = 0.5*m^2/(RIN*Be);
C_N_2 = 0.5*m^2*R*P/(2*q*Be);
figure
plot(p,10*log10(C_N_1),'r')
xlabel('Received Optical Power(dBm)')
ylabel('Carrier−to−noise ratio(dB)')
```

```
title('Carrier-to-noise ratio 1 (Preamplifier receiver noise)')
figure
plot(p,10*log10(C_N_2),'m')
xlabel('Received Optical Power(dBm)')
ylabel('Carrier-to-noise ratio(dB)')
title('Carrier-to-noise ratio 2 (Quantum noise)')
figure
plot(p,10*log10(C_N_3)*ones(1,length(p)))
xlabel('Received Optical Power(dBm)')
ylabel('Carrier-to-noise ratio(dB)')
title('Carrier-to-noise ratio 3 (Reflection noise)')
```

Chapter 10

WDM Concepts and Components

Scilab code Exa 10.1 Finding the center wavelength

```
//clear//
//Caption: Finding the center wavelength
//Example10.1
//page 343
clear;
clc;
close;
delta_v = 14e12; //optical bandwidth
Lambda = 1520; //spectral band
C = 3e08; //free space velocity
delta_Lambda = (Lambda^2)*delta_v/C;
disp(delta_Lambda*1e-09,'spectral band in nano meter
   ')
//Result
//spectral band in nano meter = 107.81867
```

Scilab code Exa 10.2 Finding mean frequency spacing

```
//clear//
//Caption: Finding mean frequency spacing
//Example10.2
//page 343
clear;
clc;
close;
C = 3e08; //free space velocity
delta_Lambda = 0.8e-09; //spectral band in meter
Lambda = 1550e-09;//wavelength in meter
delta_v = C*delta_Lambda/Lambda^2;
disp(ceil(delta_v*1e-09),'Mean Frequency spacing in
   GHz =')
//Result
// Mean Frequency spacing in GHz = 100.
```

Scilab code Exa 10.3 find coupling ratio, Excess loss, Insertion loss, Return loss

```
//clear//
//Caption:Program to find coupling ratio, Excess
   loss, Insertion loss, Return loss of 2x2 Fiber
   coupler
//Example10.3
//page 348
clear;
clc;
close;
P0 = 200e-06; //input optical power level in watts
P1 = 90e-06; //output power at port 1
P2 = 85e-06; //output power at port 2
P3 = 6.3e-09; //output power at port 3
Coupling_ratio = (P2/(P1+P2))*100;
Excess_loss = 10*log10(P0/(P1+P2));
```

```
Insertion_loss_0_1 = 10*log10(P0/P1);
Insertion_loss_0_2 = 10*log10(P0/P2);
Return_loss = 10*log10(P3/P0);
disp(Coupling_ratio,'Coupling ratio')
disp(Excess_loss,'Excess loss in dB')
disp(Insertion_loss_0_1,'Insertion loss(port 0 to
   port 1) in dB')
disp(Insertion_loss_0_2,'Insertion loss(port 0 to
   port 2) in dB')
disp(Return_loss,'Retunr loss in dB')
//Result
// Coupling ratio
//    48.571429
// Excess loss in dB
//    0.5799195
// Insertion loss(port 0 to port 1) in dB
//    3.4678749
// Insertion loss(port 0 to port 2) in dB
//    3.7161107
// Retunr loss in dB
//  - 45.016894
```

Scilab code Exa 10.5 Finding output powers at output port of 2x2 coupler

```
//clear//
//Caption:Finding output powers at output port of 2
   x2 coupler
//Example10.5
//page 350
clear;
clc;
close;
S = sqrt(1/2)*[1,%i;%i,1];//scattering matrix
Ein = [1;0];
Eout = S*Ein;
```

```
Pout1 = Eout(1)*conj(Eout(1));
Pout2 = Eout(2)*conj(Eout(2));
disp(Pout1,'Output power at port 1 Pout1 =')
disp(Pout2,'Output power at port 2 Pout2 =')
//Result
//Output power at port 1 Pout1 =  0.5
//Output power at port 2 Pout2 =  0.5
```

Scilab code Exa 10.6 `Program to find waveguide length`

```
//clear//
//Caption:Program to find waveguide length
//Example10.6
//page 353
clear;
clc;
close;
k = 0.6/1e-03; //coupling coefficient per milli meter
m =1; //mode=1
L = %pi*(m+1)/(2*k);
disp(L*1e03,'Coupling Length in mm L =')
//Result
//Coupling Length in mm L =  5.2359878
```

Scilab code Exa 10.7 `Program to find Excess loss, Splitting loss and total loss`

```
//clear//
//Caption: Program to find Excess loss, Splitting loss and total loss
//Example10.7
//page 355
clear;
```

```
clc;
close;
Power_Lost = 5/100;
FT = 1-Power_Lost; //power coupled
N = 32;
Excess_Loss = -10*log10(FT^log2(N));
Splitting_Loss = -10*log10(1/N);
Total_Loss = Excess_Loss+Splitting_Loss;
disp(Excess_Loss,'Excess Loss in dB')
disp(Splitting_Loss,'Splitting Loss in dB')
disp(Total_Loss,'Total Loss experienced in Star
   Couplers in dB')
//Result
// Excess Loss
//     1.1138197
// Splitting Loss
//     15.0515
// Total Loss experienced in Star Couplers
//    16.16532
```

Scilab code Exa 10.8 Program to Waveguide Length difference

```
//clear//
//Caption:Program to Waveguide Length difference
//Example10.8
//Page 357
clear;
close;
clc;
delta_Lambda = 0.08e-09; //wavelength spacing in
   nano meters
Lambda = 1550e-09; //wavelength in meters
neff = 1.5; //effective refractive index in the
   waveguide
C =3e08; //free space velocity
```

```
delta_v1 = 10e09; //frequency spacing 1
delta_v2 = 130e09; //frequency spacing 2
delta_L1 = C/(2*neff*delta_v1);
delta_L2 = C/(2*neff*delta_v2);
disp(delta_L1*1e03,'waveguide length difference in milli meters')
disp(delta_L2*1e03,'waveguide length difference in milli meters')
//Result
//waveguide length difference in milli meters
//      10.
//waveguide length difference in milli meters
//     0.7692308
```

Scilab code Exa 10.9 `Fiber Bragg Grating: Peak Reflectivity, Coupling coefficient,`

```
//clear//
//Caption:Fiber Bragg Grating: Peak Reflectivity, Coupling coefficient, full-bandwidth
//Example10.9.a
clear;
close;
clc;
kL = [1,2,3];
Rmax = tanh(kL)^2;
//Example10.9.b
L =0.5e-02;
Lambda_Bragg = 1530e-09;
neff = 1.48;
delta_n = 2.5e-04;
etta = 82/100;
k = %pi*delta_n*etta/Lambda_Bragg;
delta_Lambda = (Lambda_Bragg^2)*(((k*L)^2+%pi^2)^0.5)/(%pi*neff*L);
disp(k/100,'Coupling coefficient per cm k =')
```

```
disp(delta_Lambda*1e09,'full bandwidth in nm =')
disp('-----------------------------------------------')
disp('kL              Rmax(%)')
disp('-----------------------------------------------')
disp(kL,'kL')
disp(Rmax*100,'Rmax')
disp('-----------------------------------------------')
//Result
// Coupling coefficient per cm k =  4.2093235
// full bandwidth in nm =       0.3807652
// -----------------------------------------------
//  kL              Rmax(%)
// -----------------------------------------------
//  kL
//
//    1.              2.             3.
//  Rmax
//   58.002566    92.934918    99.013396
// -----------------------------------------------
```

Scilab code Exa 10.10 `Phased-Array-Based-Devices:Channel spacing interms of wavele`

```
//clear//
//Caption:Phased-Array-Based-Devices:Channel spacing interms of wavelength and path-length difference
//Example10.10
//page 372
clear;
clc;
close;
Lambda_c = 1550e-09; //central design wavelength
nc = 1.45; //refractive index of grating array waveguide
ns = 1.45; //refractive index of teh star coupler
ng = 1.47; //group index of grating array waveguide
```

```
x = 5e-06 ; //center-to-center spacing between the input waveguides
d = 5e-06 ; //center-to-center spacing between the output waveguides
m =1;
Lf = 10e-03;//distance between transmitter and object
delta_L = m*Lambda_c/nc;
delta_Lambda = (x/Lf)*(ns*d/m)*(nc/ng);
disp(delta_L*1e06,'Waveguide length difference in um =')
disp(delta_Lambda*1e09,'Channel spacing interms of wavelength in nm=')
//Result
//Waveguide length difference in um =  1.0689655
// Channel spacing interms of wavelength in nm = 3.5756803
```

Scilab code Exa 10.11 `Phased-Array-Based Devices:Length difference between adjacen`

```
//clear//
//Caption:Phased-Array-Based Devices:Length difference between adjacent array waveguides
//Example10.11
//page 373
clear;
close;
clc;
nc = 1.45; //effective refractive index
Lambda_C = 1550.5e-09; //center wavelength
delta_Lambda = 32.2e-09; //free spectral range
C = 3e08; //free space velocity in m/s
delta_L = Lambda_C^2/(nc*delta_Lambda);
disp(delta_L*1e06,'length difference between adjacent array waveguides in um =')
```

```
//Result
//length difference between adjacent array waveguides in um =51.489618
```

Scilab code Exa 10.12 Maximum number of channels

```
//clear//
//Caption:Maximum number of channels that can be placed in the tuning range
//Example10.12
//page 383
clear;
clc;
close;
Lambda = 1550e-09; //DBR laser operating wavelength
delta_neff = 0.0065; //maximum index change
delta_Lambda_tune = Lambda*delta_neff; //tuning range in meters
delta_Lambda_signal = 0.02e-09; //source spectral width in meters
delta_Lambda_channel = 10*delta_Lambda_signal;
N = delta_Lambda_tune/delta_Lambda_channel;
disp(N,'The number channels that can operate in this tuning range is N=')
//Result
//The number channels that can operate in this tuning range is N = 50.375
```

Chapter 11

Optical Amplifiers

Scilab code Exa 11.1 Program to calculate Photon density

```
//clear//
//Caption:Program to calculate Photon density
//Example11.1
//page 397
clear;
clc;
close;
Vg = 2e08; //group velocity in m/s
h = 6.625e-34; //planks constant
C = 3e08; //free space velocity in m/s
Lamda = 1550e-09;//operating wavelength
V = C/Lamda; //frequency in Hz
w = 5e-06; //width of optical amplifier in meters
d = 0.5e-06; //thickness of optical amplifier in
    meters
Ps = 1e-06; //optical signal of power
Nph = Ps/(Vg*h*V*w*d);
disp(Nph,'The photon density in photons/cubic meter
    is Nph = ')
//Result
//The photon density in photons/cubic meter is Nph =
```

```
1.560D+16
```

Scilab code Exa 11.2 `Pumping rate and zero-signal gain`

```
//clear//
//Caption:Pumping rate and zero-signal gain
//Example11.2(a) and (b)
//page 397
clear;
clc;
close;
I = 100e-03; //bias current in Amps
w = 3e-06; //active area width in meters
L = 500e-06; //amplifier lenght in meters
d = 0.3e-06; //active area thickness in meters
q = 1.602e-19; //charge in coulombs
Rp = I/(q*d*w*L);
disp(Rp,'The pumping rate in electrons/s.cubicmeter is Rp =')
Tuo = 0.3; //the confinement factor
a = 2e-20; //gain coefficient in square meter
J = I/(w*L); //bias current density in Amp/squre meter
nth = 1e24; //threshold density per cubic meter
Tuor = 1e-09; //Time constant in seconds
g0 = Tuo*a*Tuor*((J/(q*d))-(nth/Tuor))
disp(g0/100,'The zero-signal gain per cm is g0 = ')
//Result
// The pumping rate in electrons/s.cubicmeter is Rp = 1.387D+33
// The zero-signal gain per cm is g0 = 23.229297
```

Scilab code Exa 11.3 `Maximum input power and maxmimum output power`

```
//clear//
//Caption: Maximum input power and maxmimum output
    power
//Example 11.3
//page 404
clear;
clc;
close;
Lambda_p = 980e-09; //pump wavelength
Lambda_s = 1550e-09; //signal wavelength
Pp_in = 30e-03; //input pump power in watts
G = 10^(20/10); //gain
Ps_in = (Lambda_p/Lambda_s)*Pp_in/(G-1)
disp(Ps_in*1e06,'The maximum input power in uW is
    Ps_in =')
Ps_out = Ps_in+(Lambda_p/Lambda_s)*Pp_in;
disp(Ps_out*1e03,'The maximum output power in mW is
    Ps_out =')
disp(10*log10(Ps_out*1e03),'The maximum output power
    in dBm is Ps_out =')
//Result
//The maximum input power in uW is Ps_in = 191.59335
//The maximum output power in mW is Ps_out =
    19.159335
//The maximum output power in dBm is Ps_out =
    12.823804
```

Scilab code Exa 11.6 Optical Signal-to-noise ratio (OSNR)

```
//clear//
//Caption: Optical Signal-to-noise ratio (OSNR)
//Example11.6
//page 412
clear;
close;
```

```
clc;
Q = 6; //Q factor of 6
OSNR = (1/2)*Q*(Q+sqrt(2));
disp(10*log10(OSNR),'Optical Signal-to-noise ratio in dB OSNR =')
//Result
//Optical Signal-to-noise ratio in dB OSNR = 13.471863
```

Scilab code Exa 11.7 Program to find CRC(Cyclic Redundancy Check)

```
//clear//
//Caption: Program to find CRC(Cyclic Redundancy Check)
//Example8.7
//page 308
clear;
clc;
close;
x = poly(0,'x');
m = [1,1,1,1,0];
G = x^7+x^6+x^5+x^4+0+0+0+0;
D = x^3+0+x+1;
[R,Q]  = pdiv(G,D)
R = coeff(R);
Q = coeff(Q);
R = abs(modulo(R,2));
Q = abs(modulo(Q,2));
disp(R,'Remainder R =')
disp(Q,'Quotient Q =')
disp([m R],'CRC for the given information CRC =')
//Result
//Remainder R =
//      1.      0.      1.
//Quotient Q =
```

```
//       1.      1.      0.      1.      1.
//CRC for the given information CRC =
//       1.      1.      1.      1.      0.      1.      0.      1.
```

Scilab code Exa 11.8 `OSNR for different ASE noise level`

```
//clear//
//Caption: OSNR for different ASE noise level
//Example11.8
//page 413
clear;
clc;
close;
P_ASE1 = -22; //ASE level in dBm
P_ASE2 = -16; //ASE level in dBm
Pout = 6; //amplified signal level in dBm
OSNR1 = Pout - P_ASE1; //Optical SNR in dBm
OSNR2 = Pout - P_ASE2; //Optical SNR in dBm
disp(OSNR1,'Optical SNR in dBm OSNR =')
disp(OSNR2,'Optical SNR in dBm OSNR =')
//Result
//Optical SNR in dBm OSNR =   28.
//Optical SNR in dBm OSNR =   22.
```

Scilab code Exa 11.9 `Noise penalty factor`

```
//clear//
//Caption: Noise penalty factor
//Example11.9
//page 414
clear;
clc;
close;
```

```
G =[10^(30/10),10^(20/10)]; //Amplifier Gain
for i = 1:length(G)
  Fpath(i) = (1/G(i))*((G(i)-1)/log(G(i)))^2;
  disp(10*log10(Fpath(i)),'Noise penalty factor in
     dB Fpath =');
  disp(G(i),'for a gain of G =');
end
//Result
// Noise penalty factor in dB Fpath = 13.204571
// for a gain of G = 1000.
// Noise penalty factor in dB Fpath = 6.6477902
// for a gain of G =  100.
```

Scilab code Exa 11.10 Upper bound on input optical signal power

```
//clear//
//Caption: Upper bound on input optical signal power
//Example11.10
//page 415
clear;
clc;
close;
etta = 0.65; //Quantum efficiency
nsp = 2; // population inversion between two levels
R =50; //load resistance inohms
Lambda = 1550e-09; //operating wavelength in meters
T = 300; //room temperature in kelvins
kB = 1.38054e-23; //boltzmann's constant
h = 6.6256e-34; //plank's constant
C = 3e08; //free space velocity in m/s
V = C/Lambda; //frequency in Hz
q = 1.602e-19; //charge in columbs
Ps_in = kB*T*h*V/(R*nsp*(etta^2)*(q^2));
disp(Ps_in*1e06,'Upper bound on input optical signal
     power in micro watts Ps_in=')
```

```
//Result
//Upper bound on input optical signal power in micro
    watts Ps_in =  489.81635
```

Chapter 12

Non-Linear Effects

Scilab code Exa 12.1 Effective length of fiber

```
//clear//
//Caption:Effective length of fiber
//Example12.1
//page 432
clear;
clc;
close;
L = 75;//amplifier spcaing in kilometer
alpha = 4.61e-02; //fiber attenuation per Km
Leff = (1-exp(-alpha*L))/alpha;
disp(Leff,'Effective length of fiber in kilo meters
    Leff =')
//Result
//Effective length of fiber in kilo meters Leff =
    21.008494
```

Scilab code Exa 12.2 Stimulated Brillouin Scattering(SBS)

```
//clear//
//Caption: Calculation of Stimulated Brillouin
   Scattering(SBS) threshold power
//Example12.2
//page 433
clear;
clc;
close;
delta_VB = 20e06; //Brillouin linewidth in Hz
Aeff = 55e-12; //effective cross-sectional area of
   the propagating wave in square meter
Leff = 20e03; //effective length
b = 2;//polarization factor
gB = 4e-11;//Brillous gain coefficient m/W
delta_Vsource = 40e06; //optical source linewidth in
    Hz
Pth = 21*(Aeff*b/(gB*Leff))*(1+(delta_Vsource/
   delta_VB));
disp(Pth*1e03,'SBS threshold power in milli watts
   Pth=')
//Result
//SBS threshold power in milli watts Pth=  8.6625
```

Scilab code Exa 12.3 Four-wave mixing-calculation of power generated

```
//clear//
//Caption: Four-wave mixing-calculation of power
   generated due to the
//interaction of signals at different frequencies
//Example12.3
//page 438
clear;
clc;
close;
chi1111 = 6e-15;//Third order nonlinear
```

```
    suceptibility cubicmeter/W.s
D =3; //degenerating factor
Leff = 22e03;//effective length in meters
Aeff = 6.4e-11;//effective cross-sectional area of
    the fiber in square meter
etta = 0.05;//quantum efficiency
Lambda = 1540e-09; //Wavelength in single mode
    fibers in meter
C = 3e08; //free space velocity in m/sec
alpha =0.0461; //atttenuation per Km
L =75; //fiber link length in Km
P = 1e-03; //each channel input power of 1 milli
    watts
n = 1.48; //refractive index
k = ((32*(%pi^3)*chi1111)/((n^2)*Lambda*C))*(Leff/
    Aeff); //nonlinear interaction constant
P112 = etta*(D^2)*(k^2)*(P^3)*exp(-alpha*L);
disp(P112*1e03,'Power generated due to interaction
    of signals at different freq. in milli watts P112
    =')
//Result
// Power generated due to interaction of signals at
    different freq. in milli watts P112= // 5.798D-08
```

Scilab code Exa 12.4 Full-width Half-Maximum(FWHM) soliton pulse normalized time

```
//clear//
//Caption:Full-width Half-Maximum(FWHM) soliton
    pulse normalized time
//Example12.4
//page 446
clear;
clc;
close;
Ts = [15e-12,50e-12]; //FWHM soliton pulse width
```

```
To = Ts/1.7627;
disp(To*1e12,'Normalized time for FWHM soliton pulse
    in pico seconds To =')
//Result
//Normalized time for FWHM soliton pulse in pico
   seconds To = [8.5096727  28.365576]
```

Scilab code Exa 12.5 `normalized distance parameter`

```
//clear//
//Caption:Calculation of normalized distance
   parameter for dispersion shifted fiber
//Example12.5
//page 446
clear;
clc;
close;
Ts = 20e-12; //FWHM soliton pulse width in seconds
D = 0.5e-06; //dispersion of the fiber ps/(nm.km)
Lambda = 1550e-9;//wavelength in meter
C = 3e08;//free space velocity in m/s
Ldisp = 0.322*2*%pi*C*(Ts^2)/((Lambda^2)*D);
disp(Ldisp/1000,'dispersion length in Km Ldisp =')
//Result
//dispersion length in Km Ldisp =  202.10804
```

Scilab code Exa 12.6 `Program to calculate soliton peak power`

```
//clear//
//Caption: Program to calculate soliton peak power
//Example12.6
//page 447
clear;
```

```
clc;
close;
Lambda = 1550e-9; //wavelength in meters
n2 = 2.6e-20; //power in square meter/w
Aeff =  50e-12; //effective area in square meter
Ldisp = 202e03; //dispersion length in meters
Ppeak = (Aeff/(2*%pi*n2))*(Lambda/Ldisp);
disp(Ppeak*1e03,'Soliton peak power in milli watts Ppeak =')
//Result
//Soliton peak power in milli watts Ppeak = 2.3485354
```

Scilab code Exa 12.7 `FWHM soliton pulse width and fraction of bit slot`

```
//clear//
//Caption:FWHM soliton pulse width and fraction of bit slot occupied by a soliton
//Example12.7
//page 448
clear;
clc;
close;
//Example12.7.a
Ldisp = 100e03; //disperison length in meter
omega = 4682; //oscillation period
LI = omega*Ldisp;
disp(LI,'interaction distance in meter LI=')
//Example12.7.b
D = 0.5e-06; //disperison of fiber in ps/nm.km
C = 3e08;//free space velocity
S0 = 8;//normalized separation of neighnoring solitons
B = 10e09; //data rate 10 Gb/sec
Lambda = 1550e-9; //wavelength in meters
```

```
Beta2 = (Lambda/(2*%pi));
LT = (C*exp(S0))/(16*D*B^2*(Beta2^2)*(S0^2));
disp(LT*1e03,'Total transmission distance in Km LT = ')
//Example12.7.c
Ts = 0.881/(S0*B);
disp(Ts*1e12,'FWHM soliton pulse width in pico seconds Ts =')
//Example12.7.d
Ts_TB = 0.881/S0;
disp(Ts_TB*100,'Fraction of the bit slot occupied by a soliton in percentage Ts_TB=')
//Result
//interaction distance in meter LI = 4.682D+08
//Total transmission distance in Km LT = 2.870D+11
//FWHM soliton pulse width in pico seconds Ts = 11.0125
//Fraction of the bit slot occupied by a soliton in percentage Ts_TB = 11.0125
```

Chapter 13

Optical Networks

Scilab code Exa 13.1 Calculation of power budget for optical link

```
//clear//
//Caption: Calculation of power budget for optical
   link
//Example13.1
//page 464
clear;
clc;
close;
N = [5,10,50]; //number stations
alpha = 0.4;//attenuation in dB/Km
L_tap = 10;// coupling loss in dB
L_thru = 0.9;// coupler throughput in dB
Li = 0.5;//Intrinsic coupler loss in dB
Lc = 1.0; // coupler-to-fiber loss in dB
L = 0.5; //link length in Km
fiber_Loss = alpha*L; //fiber loss in dB
Pbudget = N*(alpha*L+2*Lc+Li+L_thru)-alpha*L-2*
   L_thru+2*L_tap;
disp(fiber_Loss,'fiber loss in dB for L =500 m')
disp(Pbudget,'power budget in dB for optical link
   when N = 5,10 and 50 stations respectively =')
```

```
//Result
//fiber loss in dB for L =500 m
//      0.2
//power budget in dB for optical link when N = 5,10
   and 50 stations respectively =
//     36.     54.     198.
```

Scilab code Exa 13.2 Calculation of Number stations for given loss

```
//clear//
//Caption: Calculation of Number stations for given
   loss
//Example13.2
//page 465
clear;
clc;
close;
alpha = 0.4; //attenuation in dB/Km
L_tap = 10; // coupling loss in dB
L_thru = 0.9; // coupler throughput in dB
Li = 0.5; //Intrinsic coupler loss in dB
Lc = 1.0; // coupler-to-fiber loss in dB
L = 0.5;  //link length in Km
Pbudget_LED = 38; // power loss between source and
   receiver in dB for LED source
Pbudget_LASER = 51;//power loss between source and
   receiver in dB for LASER source
N_LED = (Pbudget_LED+alpha*L-2*L_thru-2*L_tap)/(
   alpha*L+2*Lc+Li+L_thru)
N_LASER = (Pbudget_LASER+alpha*L-2*L_thru-2*L_tap)/(
   alpha*L+2*Lc+Li+L_thru)
disp(ceil(N_LED),'Number of stations allowed for
   given loss of 38 dB with LED source')
disp(floor(N_LASER),'Number of stations allowed for
   given loss of 51 dB with LASER source')
```

```
//Result
//Number of stations allowed for given loss of 38 dB with LED source
//      5.
//Number of stations allowed for given loss of 51 dB with LASER source
//     8.
```

Scilab code Exa 13.3 Calculation of worst case Dynamic Range

```
//clear//
//Caption: Calculation of worst case Dynamic Range
//Example13.3
//page 465
clear;
clc;
close;
N = [5,10] ;//number of stations
alpha = 0.4;//attenuation in dB/Km
L = 0.5; //link length in Km
Lc = 1.0; // coupler-to-fiber loss in dB
L_thru = 0.9;// coupler throughput in dB
Li = 0.5;//Intrinsic coupler loss in dB
DR = (N-2)*(alpha*L+2*Lc+Li+L_thru);
disp(DR,'worst-case dyanmic range in dB for N =5 and 10 respectively DR =')
//Result
//worst-case dyanmic range in dB for N =5 and 10 respectively DR =
//      10.8     28.8
```

Scilab code Exa 13.4 Calculation of power margin between transmitter and receiver

```
//clear//
//Caption: Calculation of power margin between
   transmitter and receiver for Star architectures
//Example13.4
//page 466
clear;
close;
clc;
N = [10,50]; //number of stations
alpha = 0.4; //attenuation in dB/Km
L = 0.5 ;//distance in Km
Lexcess = [0.75,1.25]; //excess loss in dB for N =10
    and 50
Lc = 1.0; //connector loss in dB
Ps_Pr(1) = Lexcess(1)+alpha*2*L+2*Lc+10*log10(N(1));
Ps_Pr(2) = Lexcess(2)+alpha*2*L+2*Lc+10*log10(N(2));
disp(Ps_Pr(1),'The power margin in dB between the
   transmitter and receiver for N=10 is Ps-Pr =')
disp(Ps_Pr(2),'The power margin in dB between the
   transmitter and receiver for N=50 is Ps-Pr =')
//Result
//The power margin in dB between the transmitter and
    receiver for N=10 is Ps-Pr = 13.15
//The power margin in dB between the transmitter and
    receiver for N=50 is Ps-Pr = 20.6397
```

Scilab code Exa 13.5 Determination of maximum length of multimode fiber link

```
//clear//
//Caption:Determination of maximum length of
   multimode fiber link
//Example13.5
//page 477
clear;
clc;
```

```
close;
L_OM2 = 40; //length of OM2 fiber
L_OM3 = 100; //length of OM3 fiber
BW_OM2 = 500e06;//bandwidth of OM2 fiber
BW_OM3 = 2000e06; //bandwidth of OM3 fiber
Lmax = L_OM2*(BW_OM3/BW_OM2)+L_OM3;
disp(Lmax,'The maximum link length in meter is Lmax
    =')
//Result
//The maximum link length in meter is Lmax = 260.
```

Chapter 14

Performance Measurement and Monitoring

Scilab code Exa 14.10 `Performance Measurement and Monitoring`

```
//clear//
//Caption:Performance Measurement and Monitoring
//Figure:14.10 Plotting pulse shape of gaussian
    distribution
//and determining 3-dB optical and electrical
    bandwidth
clear;
close;
clc;
sigma = 1;
t = -3*sigma:0.01:3*sigma;
p = (1/(sigma*sqrt(2*%pi)))*exp(-t^2./(2*sigma^2));
fdB_optical = 0.187/sigma;
fdB_electrical = 0.133/sigma;
disp(fdB_optical,'fdB_optical')
disp(fdB_electrical,'fdB_electrical')
plot(t,p,'r')
xlabel('Time t')
ylabel('Relative pulse amplitude P(t)')
```

```
title('Figure:14.10 Definitions of pulse-shape
   parameters')
xgrid(1)
//Result
//fdB_optical    = 0.187
//fdB_electrical = 0.133
```