## Scilab Textbook Companion for Fiber Optic Communications: Fundamentals and Applications by S. Kumar and M. J. Deen<sup>1</sup>

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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.

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### Chapter 1

### **Electromagnetics and Optics**

Scilab code Exa 1.6 To find refractive index of of the glass

```
1 // Example 1.6
2 // To find refractive index of of the glass
3 // Page no.25
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 phi=0.7297;
                                           // Critical
      angle for glass-air interface
10 n2=1;
                                           // Refractive
     index of air
11 n1=n2/sin(phi);
                                           // Refractive
     index of glass
12
13 // Displaying the result in command window
14 printf('\n Refractive index of the glass = \%0.1 f',n1
      );
```

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Refractive index of the glass = 1.5

Scilab 5.4.1 Console

Figure 1.1: To find refractive index of the glass

Scilab code Exa 1.7 To calculate the speed of light The wavelenght in medium The wavenumber in medium

```
1 / Example no 1.7
2 //To calculate a) the speed of light b) The
      wavelenght in medium c) The wavenumber in medium
3
  //Page no. 25
4
5 clc;
6 clear all;
7
  //a) The speed of light
8
                                             //Speed of
  c=3*10^8;
9
     light in free space (m/s)
10 n=1.45;
                                             //Given
      refractive index of dielectric medium
                                            //Speed of
11 v = (c/n);
      light in medium (in m/s)
```

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Scilah 5.4.1 Console



Figure 1.2: To calculate the speed of light The wavelenght in medium The wavenumber in medium

```
12
13 // Displaying the result in command window
14 printf('\n Speed of light in medium = \%0.3 f X 10<sup>8</sup> m
      /s',v*10^-8);
15
16 / b) The wavelenght in medium
17 f=190*10^12;
                                               //Given
      operating frequency of laser
   lambdam=(v/f);
                                                //Wavelenght
18
      in medium
19
  //Displaying the result in command window
20
21 printf('\n Wavelenght of laser in medium = \%0.4 f
      micrometer',lambdam*10^(6));
22
23 / (c) The wavenumber in medium
24 k=(2*\%pi)/lambdam;
                                              //Wavenumber
      in medium
25
26 //Displaying the result in command window
27 printf('\n Wavenumber in medium = \%0.2 \text{ f X } 10^{\circ}6 \text{ m}^{\circ}-1'
      ,k*10^-6)
```





Figure 1.3: To calculate magnitude of the wave vector of the refracted wave x component and z component of the wave vector

Scilab code Exa 1.8 To calculate magnitude of the wave vector of the refracted wave x component and z component of the wave vector

```
1 // Example no. 1.8
2 // To calculate a) magnitude of the wave vector of
the refracted wave b)x-component and z-component
of the wave vector
3 // Page no.26
4
5 clc;
6 clear;
7
8 //Given data
9 n1=1;
    // Refractive index of air
10 n2=1.45;
```

```
// Refractive index of slap
11 theta1=%pi/3;
      // Angle of incidence
  lambdam=1.0889*10<sup>(-6)</sup>;
12
      // Wavelength in medium
13 theta2=asin(sin(theta1)/n2);
      // Angle of refraction
14
  // a)To calculate magnitude of the wave vector of
15
      the refracted wave
16 k=((2*%pi)/lambdam);
      // Wavenumber
17
18 // Displaying the result in command window
19 printf('\n Magnitude of the wave vector of the
      refracted wave is same as wave number = \%0.2 \text{ f X}
      10^{6} \text{ m}^{-1}, k*10^(-6));
20
21
  // b)To calculate x-component and z-component of the
       wave vector
  kx=k*sin(theta2);
22
      // x-component of the wave vector
  kz=k*cos(theta2);
23
      // z-component of the wave vector
24
25 // Displaying the result in command window
26 printf('\n z-component of the wave vector = \%0.2 f X
      10^{6} \text{ m}^{-1}, kz * 10^ (-6));
  printf('\n x-component of the wave vector = \%0.2 f X
27
      10^{6} \text{ m}^{-1}, kx * 10^(-6));
28 // The answer is varrying due to round-off error
```

Scilab code Exa 1.9 To find length of the medium

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th of the medium = 500 m

Figure 1.4: To find length of the medium

```
1 //To find length of the medium
2 //Example no 1.9
3 //Page no. 30
4
5 clc;
6 clear all;
7 bandwidth = 100 * 10^9;
                                                      11
      Bandwidth of optical signal
8 w=2*%pi*bandwidth;
                                                      //
      Bandwidth of optical signal in rad/s
9 T=3.14*10^{(-12)};
                                                      //
      Delay between minimum and maximum frequency
      component
10 beta2=10*(10^(-12))^2/10^3;
                                    //Group velocity
      dispersion parameter in s<sup>2</sup>/km
11 L=T/(beta2*w);
                                                      11
      Length of the medium
12
13 // Displaying the result in command window
14 printf('\n Length of the medium = \%0.0 \text{ fm',L};
```

### Chapter 2

## **Optical Fiber Transmission**

Scilab code Exa 2.1 To find The numerical aperture The acceptanca angle The relative index defference

```
1 // Example no. 2.1
2 // To find a) The numerical aperture b) The acceptanca
       angle c) The relative index defference
  // Page no. 38
3
4
5 \, \text{clc};
6 clear;
7
8 // Given data
                                                 //
9 n1=1.47;
      Refractive index of core
10 n2=1.45;
                                                 //
      Refractive index of cladding
11
12 // a) The numerical aperture
                                                11
13 NA=(n1^2-n2^2)(1/2);
      Numerical aperture
14
```

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The numerical aperture = 0.2417 The acceptanca angle = 0.2441 Radian The relative index defference = 0.0136 -->

Figure 2.1: To find The numerical aperture The acceptance angle The relative index defference

```
15 // Displaying the result in command window
16 printf('\n The numerical aperture = \%0.4 \text{ f}', NA);
17
18 // b)The acceptanca angle
                                              // The
19
  imax=asin(NA);
      acceptanca angle
20
  // Displaying the result in command window
21
  printf('\n The acceptanca angle = %0.4 f Radian', imax
22
      );
23
24 // c)The relative index defference
25 delta=(n1-n2)/n1;
                                             // Relative
      index defference
26
27 // Displaying the result in command window
28 printf('\n The relative index defference = \%0.4 f',
      delta);
```



Figure 2.2: To find maximum bit rate distance product

Scilab code Exa 2.2 To find maximum bit rate distance product

```
1 // Example no. 2.2
2 // To find maximum bit-rate distance product
3 // Page no. 41
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 n1=1.46;
                                                          11
      Refractive index of core
10 delta=0.01;
                                                       11
      Relative difference of refractive index
11 L=1*10<sup>3</sup>;
                                                         //
      Fiber length
12 c=3*10^(8);
```

```
Speed of ligth in km/sec
13
14 n2=n1*(1-delta);
                                              //
      Refractive index of cladding
15 deltaT=(n1^2*L*delta)/(c*n2);
                                // Delay in sec
16 BL=(((c*n2)/(n1^2*delta))/10^3)*10^-6;
                      // maximum bit-rate distance
      product in Mb/s.km
17 deltaT=((n1^2*L*delta)/(c*n2))*10^9;
                        // Delay in ns
18
19 // Displaying the result in command window
20 printf('\n Refractive index of cladding = \%0.4 f',n2)
21 printf('\n Delay = \%0.0 f ns', deltaT);
22 printf('\n Approximate delay = \%0.0 f ns',deltaT+1);
23 printf('\n Maximum bit-rate distance product = \%0.1 f
      Mb/(s.km)', BL);
```

//

Scilab code Exa 2.3 To compare deltaT for step index fiber with parabolic index fiber

```
1 // Example no.2.3
2 // To compare deltaT for step index fiber with
      parabolic-index fiber
3 // Page no. 43
4
5 clc;
6 clear;
7
```

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Pulse width for step index fiber = 67.59 ns Pulse width for parabolic index fiber = 0.1667 ns Thus, the intermodal dispersion can be significantly reduced by using parabolic-index fiber -->

Figure 2.3: To compare deltaT for step index fiber with parabolic index fiber

```
8 // Given data
9 n1 = 1.47;
     // Refractive index of core
10 n2=1.45;
     // Refractive index of cladding
11 L=1*10^3;
     // Length of medium in meter
12 c=3*10^8;
     // speed of ligth in (m/s)
13 delta=(n1-n2)/n1;
14
15 // The deltaT for step index fiber
16 deltaTSIF=((n1^2*L*delta)/(c*n2))*10^9;
     //Pulse width for step index fiber
17
18
  // deltaT for parabolic-index fiber
19 deltaTPIF=((n1^2*delta^2*L)/(8*c))*10^9;
                                                       11
       Pulse width for parabolic-index fiber
20
21 // Displaying the result in command window
22 printf('\n Pulse width for step index fiber = \%0.2 f
     ns',deltaTSIF);
23 printf('\n Pulse width for parabolic index fiber =
```

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ransmitted power = 10.79 dBm eccived power = 0.3162 mW

Scilab 5.4.1 Console

Figure 2.4: To convert transmitted power into dBm To convert received power into mW

```
%0.4f ns',deltaTPIF);
24
25 // The answer of pulse width for parabolic index
fiber is wrong in book
26
27 disp('Thus, the intermodal dispersion can be
significantly reduced by using parabolic-index
fiber');
```

Scilab code Exa 2.4 To convert transmitted power into dBm To convert received power into mW

```
1 // Example 2.4
2 // a)To convert transmitted power into dBm b)To
        convert received power into mW
3 // Page no. 61
4 
5 clc;
```

```
6 clear;
7
8 // Given data
                                               11
9 Ptr=0.012;
      Transmitted power in watt
10 PrdBm = -5;
                                               // Received
       power in dBm
11
12 // a)To convert transmitted power into dBm
13 PtrdBm=10*log10(Ptr/(10^-3));
                                               //
      Transmitted power in dBm
14
15 // Displaying the result in command window
16 printf('\n Transmitted power = \%0.2 f dBm', PtrdBm);
17
18 // b)To convert received power into mW
19 PrmW = 10^{(-5/10)};
                                              // Received
      power in mW
20
21 // Displaying the result in command window
22 printf('\n Received power = \%0.4 \text{ f mW'}, PrmW);
```

Scilab code Exa 2.7 To find the core radius of step index fiber

```
1 // Example no.2.7
2 // To find the core radius of step-index fiber
3 // Page no.69
4 
5 clc;
6 clear;
7 
8 // Given data
9 n1=1.45;
```



Figure 2.5: To find the core radius of step index fiber

```
// Refractive index of core
10 delta=0.005;
11 n2=n1*(1-delta);
      // Refractive index of cladding
12 lambdac=1.1;
      // Cutoff wavelength in meter
13 lambda=1.55;
      // Operating wavelength in micrometer
14 a=((2.4048*lambdac*10<sup>-6</sup>)/(2*%pi*(n1<sup>2</sup>-n2<sup>2</sup>)<sup>(1/2</sup>)))
      /10^-6;
                    // Core radius
15
16 //Displaying the result in command window
17 printf('\n The core radius of step-index fiber = \%0
      .3f micrometer',a);
18 printf('\n Operating wavelength = \%0.2 f micrometer',
      lambda);
19 printf('\n Cutoff wavelength = \%0.1 f micrometer',
      lambdac);
20
```



otal loss in fiber = 16 dB utput power of fiber = -13 dBm utput power of fiber = 0.05 mW





21 disp('Since operating wavelength is greater than cutoff wavelength, it is single moded at this wavelength.')

Scilab code Exa 2.8 To find the total loss and output power in mW and dBm in fiber

```
1 // Example no 2.8
2 // To find the total loss and output power in mW and
dBm in fiber
3 // Page no. 72
4
5 clc;
6 clear;
7 
8 // Given data
9 losscoe=0.046; //
Loss coefficient in km^-1
```

```
//
10 L=80;
      Length of fiber in km
11 PindBm=3;
                                                       //
      Input power in dBm
12
  // To find total loss of fiber
13
14 loss=round(4.343*losscoe*L);
                                                       11
      Total loss in fiber
15
16 // Displaying the result in command window
17 printf('\n Total loss in fiber = \%0.0 \text{ f dB', loss});
18
19 // To find output power
20 PoutdBm=PindBm-loss;
                                                       //
      Output power in dBm
21
22 PoutmW=10^(PoutdBm/10);
                                                       //
      Output power in mW
23
24 //Displaying the result in command window
25 printf('\n Output power of fiber = \%0.0 \text{ f dBm'},
      PoutdBm);
26 printf('\n Output power of fiber = \%0.2 f mW', PoutmW)
      ;
```

Scilab code Exa 2.10 To design single mode fiber such that absolute accumulated dispersion

```
3 // Page no. 77
```



We choose center of band (lambda\_0) for large maximum allovable dispersion slope Dispersion slope = 0.917 ps/nm^2/km

Figure 2.7: To design single mode fiber such that absolute accumulated dispersion

```
4
5 \, \text{clc};
6 clear;
7
8
  // Given data
  lambda1=1530;
                                                   // Left
9
      edge of wavelength range in nm
10 lambda2=1560;
                                                   // Rigth
      edge of wavelength range in nm
  lambda0=1545;
                                                   // Center
11
       of the band in nm
                                                  // Fiber
12 L=80;
      length in km
13
14 disp('We choose center of band (lambda_0) for large
      maximum allowable dispersion slope.');
15
  Dlambda2=1100/L;
16
                                                 11
      Dispersion at rigth edge of band in ps/nm/km
17 S=Dlambda2/(lambda2-lambda0);
                                                 //
      Dispersion slope in ps/nm<sup>2</sup>/km
18
```





Figure 2.8: To find length of DCF power at the output of DCF gain of amplifier

```
19 // Displaying the result in command window
20 printf('\n Dispersion slope = %0.3 f ps/nm^2/km',S);
```

Scilab code Exa 2.11 To find length of DCF power at the output of DCF gain of amplifier

```
1 // Example no.2.11
2 // To find a)length of DCF b)power at the output of
DCF c)gain of amplifier
3 // Page no.80
4
5 clc;
6 clear;
7
8 // Given data
9 LTF=80;
// Length of transmission fiber
```

```
10 beta2TF=-21;
                                                      11
      Dispersion of transmission fiber in ps^2/km
11 beta2DCF=130;
                                                     //
      Dispersion of DCF in ps^2/km
12 Pin=2*10^{(-3)};
                                                    //
      Input power of transmission fiber in W
13 DCFloss=0.5;
                                                      //
      Losses of DCF in dB/km
14 TFloss=0.2;
                                                       //
       Losses of TF in dB/km
15 spliceloss=0.5;
                                                   11
      Splice loss in dB
16
17 // a)To find length of DCF
18 LDCF=(-beta2TF*LTF)/beta2DCF;
                                   // Length of DCF in
     km
19
20 // Displaying the result in command window
21 printf('\n Length of DCF = \%0.1 f km', LDCF);
22
23 // b)To find power at the output of DCF
24 PindBm=10*log10(Pin/10^(-3));
                                  // Input power of
      transmission fiber in dBm
25 Totalloss=TFloss*LTF+DCFloss*LDCF+spliceloss;
                 // Total loss in fiber in dB
26 PoutdBm=PindBm-Totalloss;
                                      // Output power of
      DCF in dBm
27
28 // Displaying the result in command window
```

#### File Edit Control Applications ?

delay between the shortest and longest path = 91.95 ns

Scilab 5.4.1 Cons

```
Figure 2.9: To find the delay between the shortest and longest path
```

Scilab code Exa 2.12 To find the delay between the shortest and longest path

```
5 \, \text{clc};
6 clear;
7
8 // Given data
                                                       11
9 NA = 0.2;
      Numerical aperture
10 L=2*10^{3};
                                                       //
      Fiber length in meters
11 n1=1.45;
                                                       //
      Core refractive index
12 delta=(NA)^2/(2*n1^2);
                                                       //
      Relative index difference
13 n2=n1;
                                                       11
      since difference between core index and cladding
      index is smaller
14 c=3*10^8;
                                                       11
      Speed of ligth in m/s
15
16 // The delay between the shortest and longest path.
17 deltaT=((n1^2*L*delta)/(c*n2));
                                                      the delay between the shortest and longest path.
18
19 // Displaying the result in command window
20 printf('\n The delay between the shortest and
      longest path = \%0.2 \,\text{f} ns',deltaT*10^9);
```

#### Scilab code Exa 2.13 To calculate the propagation constant

```
1 // Example no. 2.13
2 // To calculate the propagation constant
3 // Page no. 82
4
5 clc;
```



Figure 2.10: To calculate the propagation constant

```
6 clear;
7
8 // Given data
9 lambda0=1550*10^-9;
                                                  11
      wavelength in meter
10 beta0=6*10^6;
                                                        //
       propagation constant in rad/m
11 lambda1=1551*10^{-9};
                                                  11
      wavelength in meter
12 beta1=0.5*10<sup>-8</sup>;
                                                     11
      inverse group velocity in sec/meter
13 beta2=-10*10^-24;
                                                    second-order dispersion coefficient in sec^2/km
14 c=3*10^8;
     // Speed of ligth in m/s
15 omega0=(2*\%pi*c)/lambda0;
                                           // Radial
```

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The lower limit on the transmitter power in dBm = -1.5 The lower limit on the transmitter power in mW = 0.7079

Figure 2.11: To calculate the lower limit on the transmitter power in dBm and mW units

```
frequency at lambda0
16 omega1=(2*%pi*c)/lambda1;
                                            // Radial
      frequency at lambda1
  omega=omega1-omega0;
17
18
  // The propagation constant at 1551nm wavelength
19
20 betaomega1=(beta0+beta1*omega+beta2*omega^2/2);
             // Propagation constant at 1551nm
      wavelength
21
22 // Displaying the result in command window
23 printf('\n The propagation constant at 1551nm
      wavelength = \%0.4 \text{ f X} 10^{6} \text{ rad/s'}, betaomegal
      *10^-6);
```

Scilab code Exa 2.14 To calculate the lower limit on the transmitter power in dBm and mW units

```
1 // Example No. 2.14
2 // To calculate the lower limit on the transmitter
      power in dBm and mW units.
3 // Page No. 83
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 1=80;
                                                          //
       Length of fiber in km
10 F1 = -0.2 * 1;
                                                          11
       Fiber loss in dB
11 F2 = -0.5;
                                                          //
       Filter loss in dB
12 G=15;
                                                          //
       Amplifier gain in dB
13 Pout = -3;
                                                          //
       Minimum power required at the receiver in dBm
14
15 // Lower limit on the transmitter power
16 Pin=Pout-F1-F2-G;
                                                          //
       Lower limit on the transmitter power in dBm
17 PinmW=10<sup>(0.1*Pin)</sup>;
                                                          //
       Lower limit on the transmitter power in mW
18
19 // Displaying the result in command window
20 printf('\n The lower limit on the transmitter power
      in dBm = \%0.1 \, f', Pin);
21 printf('\n The lower limit on the transmitter power
      in mW = \%0.4 \text{ f}', PinmW);
```
#### File Edit Control Applications ?

The lower limit on the transmitter power in dBm = -1.5 The lower limit on the transmitter power in mW = 0.7079

Figure 2.12: To find the length of DCF so that the pulse width at the output of the DCF is twice the pulse width at the input of the TF

Scilab code Exa 2.16 To find the length of DCF so that the pulse width at the output of the DCF is twice the pulse width at the input of the TF

```
1 // Example No. 2.16
2 // To find the length of DCF so that the pulse width
       (FWHM) at the output of the DCF is twice the
      pulse width at the input of the TF
3
  // Page No. 84
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 beta2TF=-21*(10^(-12))^2;
                                             // Dispersion
      coefficient of transmission fiber in s<sup>2</sup>/km
10 beta2DCF=130*(10^(-12))^2;
                                            // Dispersion
      coefficient of dispersion compensating fiber in s
      ^2/\mathrm{km}
11 LTF=80;
```

```
// Length of transmission fiber in km
12 TFWHM=12.5*10<sup>(-12)</sup>;
                                             // Full-width
       at half-maximum
13 TO = TFWHM / 1.665;
                                                   // Half-
      width
14
15 // The length of required DCF
16 LDCF1=(sqrt(3)*T0^2-beta2TF*LTF)/beta2DCF;
                      // Length of dispersion
      compensating fiber in km
17 LDCF2=(-sqrt(3)*T0^2-beta2TF*LTF)/beta2DCF;
                     // Length of dispersion
      compensating fiber in km
18
19 // Displaying the result in command window
20 printf('\n The length of DCF so that the pulse width
       (FWHM) at the output of the DCF is twice the
      pulse width at the input of the TF = \%0.2 \text{ f km}',
      LDCF1);
21 printf(' or = \%0.2 \text{ f km}', LDCF2);
```

Scilab code Exa 2.17 To find the accumulated dispersion of the DCF so that the net accumulated dispersion

```
1 // Example No. 2.17
2 // To find the accumulated dispersion of the DCF so
that the net accumulated dispersion does not
exceed 1100 ps/nm
3 // Page no. 85
4
5 clc;
```

#### 

The accumulated dispersion of the DCF should be less than -3380  $\ensuremath{\text{ps/nm}}$  .

Figure 2.13: To find the accumulated dispersion of the DCF so that the net accumulated dispersion

```
6 clear;
7
8 // Given data
9 \quad lambda0 = 1490;
     // Zero dispersion wavelength in nm
10 lambda=1560;
     // Upper limit of wavelength range in nm
11 Sc=0.08;
     // Dispersion slope of transmission fiber \rm ps/nm2/
     km
12 LTF=800;
     // Length of transmission fiber in km
13 DTF=Sc*(lambda-lambda0);
                                                 //
      Dispersion at 1560 nm in ps/nm/km
14
15 // The accumulated dispersion of the DCF
16 DLDCF = 1100 - DTF * LTF;
```

//
The accumulated dispersion of the DCF in ps/nm
17
18 // Displaying the result in command window
19 printf('\n The accumulated dispersion of the DCF
should be less than %0.0 f ps/nm',DLDCF);

## Chapter 3

### Lasers

Scilab code Exa 3.1 To calculate the Einstein A and B coefficients

```
1 // Example No. 3.1
2 // To calculate the Einstein A and B coefficients
3 // Page no.99
4
5 clc;
6 clear;
\overline{7}
8 // Given data
9 tsp=2*10^-9;
     // Spontaneous lifetime associated with 2 1
      transition in seconds
10
11 deltaE=2.4*10^(-19);
     // The energy difference between the levels
12 h=1.054*10^{(-34)};
     // The distance between two levels
```

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Scilah 5.4.1 Console

Einstein coefficient A = 5 X 10^8 s^(-1) Einstein coefficient B = 7.75 X 10^21 m^3/J.s^2

Figure 3.1: To calculate the Einstein A and B coefficients

```
13 omega=deltaE/h;
      // Frequency in rad/sec
14 v=1.25*10^8;
      // The velocity of light in the medium in m/s
15
16 // The Einstein A and B coefficients
17 A = (1/tsp) * 10^{-8};
      // Einstein coefficient A
18 B=(((1/tsp)*%pi^2*v^3)/(h*omega^3))*10^-21;
                                  // Einstein coefficient
      В
19
  // Displaying the result in command window
20
21 printf('\n Einstein coefficient A = \%0.0 f \times 10^8 s
      (-1) ',A);
22 printf('\n Einstein coefficient B = \%0.2 f \times 10^{21} m
      ^3/J.s^2',B);
23
  // The answers are varrying due to round off error
24
```



The wavelength of light emitted = 1.55 micrometer The ratio of promenous emission rate to a timulated emission rate = 1.65 X 10°13 The ratio of simulated emission rate to absorption rate = 6.06 X 10°-14 The population density of the excited level = 6.06 X 10°5 cm°(-3)  $\rightarrow$ 

Figure 3.2: To calculate the wavelength of light emitted the ratio of spontaneous emission rate to stimulated emission rate the ratio of stimulated emission rate to absorption rate and the population density of the excited level

Scilab code Exa 3.2 To calculate the wavelength of light emitted the ratio of spontaneous emission rate to stimulated emission rate the ratio of stimulated emission rate to absorption rate and the population density of the excited level

```
1 // Example no. 3.2
2 // To calculate (a) the wavelength of light emitted,
        (b) the ratio of spontaneous emission rate to
        stimulated emission rate, (c) the ratio of
        stimulated emission rate to absorption rate, and
        (d) the population density of the excited level.
3 // Page no. 100
4
5 clc;
6 clear;
```

8 // Given data 9 deltaE=1.26\*10<sup>-19</sup>; // The energy difference between two levels 10  $h=1.054*10^{(-34)}$ ; // The distance between two levels 11 c=3\*10^8; // The speed of ligth in m/s 12  $kB=1.38*10^{(-23)}$ ; // The Boltzmann s constant J/K 13 T=300; // The absolute temperature in Kelvin 14  $N1 = 10^{19}$ ; // The population density in the ground state in  $\operatorname{cm}(-3)$ 1516 // (a)The wavelength of light emitted 17 h=2\*%pi\*h; // The distance between two levels in J.s 18 f=deltaE/h; // The frequency in Hz 19 lambda=(c/f)\*10^6; // The wavelength of ligth emitted in micrometer 2021 // Displaying the result in command window 22 printf('\n The wavelength of ligth emitted = %0.2 f micrometer ',lambda);

23

7

24 // The calculation of this answer is wrong in the

book

```
25
26 // (b)The ratio of spontaneous emission rate to
      stimulated emission rate
27 RspRst=(exp(deltaE/(kB*T))-1);
                                               // The
      ratio of spontaneous emission rate to stimulated
      emission rate
28
29 // Displaying the result in command window
30 printf('\n The ratio of spontaneous emission rate to
       stimulated emission rate = %0.2 f X 10<sup>13</sup>, RspRst
      *10^-13);
31
32
  // The calculation of this answer is wrong in the
      book
33
34 // (c)The ratio of stimulated emission rate to
      absorption rate
35 RstRab=(exp(-deltaE/(kB*T)));
                                                    // The
       ratio of stimulated emission rate to absorption
      rate
36
37 // Displaying the result in command window
38 printf('\n The ratio of stimulated emission rate to
      absorption rate = \%0.2 \text{ f X } 10^{-14}', RstRab*10^14);
39
40
  // The calculation of this answer is wrong in the
      book
41
42 // (d)The population density of the excited level
43 N2=(N1*exp(-deltaE/(kB*T)));
                                                     ||
      The population density of the excited level in cm
      (-3)
44
45 // Displaying the result in command window
```

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Scilab 5.4.1 Console

The longitudinal mode spacing = 85.71 GHz The minimum gain required for laser oscillation per cm =  $35.59 \text{ cm}^{-1}$ 

Figure 3.3: To calculate the longitudinal mode spacing and the minimum gain required for laser oscillation

```
46 printf('\n The population density of the excited
        level = %0.2 f X 10^5 cm^(-3)',N2*10^-5);
47
48 // The calculation of this answer is wrong in the
        book
```

Scilab code Exa 3.3 To calculate the longitudinal mode spacing and the minimum gain required for laser oscillation

```
1 // Example No. 3.3
2 // To calculate the longitudinal mode spacing and
    the minimum gain required for laser oscillation
3 // Page no. 106
4
5 clc;
6 clear;
7
8 // Given data
```

 $9 c = 3 * 10^8;$ // The speed of ligth in air 10  $L=500*10^{(-6)};$ // The distance between mirrors 11 n=3.5; // The refractive index 12 inlossdB=50; // The internal loss in dB/cm 13 R1=0.3; // The reflectivity of ligth wave which is reflected at A 14 R2=0.3; // The reflectivity of ligth wave which is reflected at B 1516 // The longitudinal mode spacing 17 deltaf=(c/(2\*n\*L))\*10<sup>-9</sup>; // The longitudinal mode spacing 18 L=0.05; // The distance between mirrors in cm 19 amir=(1/(2\*L))\*log(1/(R1\*R2)); // The loss due to mirrors per cm 20 aint=log(10^(inlossdB/10)); // The coefficient of internal loss due to scattering 2122 // The minimum gain required 23 g=aint+amir; //

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The energy density = 2.13 J/m^3

Scilab 5.4.1 Console

Figure 3.4: To calculate the energy density

```
The minimum gain required for laser oscillation

24

25 // Displaying the result in command window

26 printf('\n The longitudinal mode spacing = %0.2f GHz

',deltaf);

27 printf('\n The minimum gain required for laser

oscillation per cm = %0.2f cm^-1',g);
```

Scilab code Exa 3.4 To calculate the energy density

```
1 // Example no. 3.4
2 // To calculate the energy density.
3 // Page no. 107
4
5 clc;
6 clear;
7
8 // Given data
```

# Scille S43 Console Fei Edit Control Applications ? Control Applications ? Control S43 Console Scille S43 Console

a x

The frequency of the electromagnetic wave emitted by stimulated emission = 24 GHz

Figure 3.5: To calculate the frequency of the electromagnetic wave emitted by stimulated emission

9	P=20*10^(-3);	
	The mean power in W	
10	A=100*10^(-12);	
	The area perpendicular to the direction of li	${ m ght}$
	propagation in m <sup>2</sup>	
11	n=3.2;	
	Refractive index of gain medium	
12	c=3*10^8;	
	Speed of ligth in m/s	
13	I = P / A;	
	The optical intensity in $W/m^2$	
14		
15	// The energy density	
16	u=(n*I)/c;	
	The energy density in $J/m^3$	
17		
18	// Displaying the result in command window	
19	printf('\n The energy density = $\%0.2 \text{ f J/m^3}$ ',u);	

Scilab code Exa 3.5 To calculate the frequency of the electromagnetic wave emitted by stimulated emission

```
1 // Example no.3.5
2 // To calculate the frequency of the electromagnetic
       wave emitted by stimulated emission.
3
  // Page no.110
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 E=10^{(-4)};
                                                  // The
      energy difference between two levels in eV
10 E=10^{(-4)}*1.602*10^{(-19)};
                                                  // The
      energy difference between two levels in J
                                                 // The
11 h=1.054*10^{(-34)};
      distance between two levels
12
13 // The frequency of the electromagnetic wave emitted
       by stimulated emission.
                                                  // The
14 f=(E/(2*%pi*h))*10^-9;
      frequency of the electromagnetic wave emitted by
      stimulated emission in GHz
15
16 // Displaying the result in command window
17 printf('\n The frequency of the electromagnetic wave
       emitted by stimulated emission = \%0.0 \text{ f GHz}', \text{f};
```

Scilab code Exa 3.6 To calculate the band gap energy

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```
The band-gap energy = 1.93 X 10^-19 J
```

Figure 3.6: To calculate the band gap energy

```
1 // Example 3.6
2 // To calculate the band-gap energy.
3 // Page no.123
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 m = 9.109 * 10^{(-31)};
                                                       // The
       electron rest mass in kg
10 meff1=0.07*m;
                                                       // The
       effective mass of an electron in the conduction
      band
11 meff2=0.5*m;
                                                       // The
       effective mass of an electron in the valence
      band
12 mr=(meff1*meff2)/(meff1+meff2);
                                                       // The
       reduced mass
13 hkl=7.84*10<sup>(-26)</sup>;
                                                       // The
       electron momentum in kg.m/s
14 lambda=0.8*10<sup>(-6)</sup>;
                                                       // The
       wavelength of electromagnetic wave in m
15 h=1.054*10^{(-34)};
                                                       // The
```

# Solub 5.4.1 Console Image: Solub 5.4.1 Console File Edit: Control Applications ? Image: Solub 6.4.1 Console Image: Solub 6.4.1 Console

The photon lifetime = 2.14 ps The threshold current = 57.7 mA The current required to generate a mean photon density of 8.5  $\times$  10°21 m^-3 = 344.53 mA

Figure 3.7: To calculate the photon lifetime the threshold current and the current required to generate a mean photon density

```
distance between two levels
                                                       11
16 c = 3 * 10^8;
      Speed of ligth in m/s
17 hw=(h*2*\%pi*c)/lambda;
                                                      // The
      poton energy in J
18
19
   // The band-gap energy.
   Eg=hw-(hkl^{2}/(2*mr));
                                                     // The
20
      band-gap energy in J
21
22
   // Displaying the result in command window
  printf('\n The band-gap energy = \%0.2 f X 10^{-19} J',
23
      Eg*10<sup>19</sup>;
```

Scilab code Exa 3.7 To calculate the photon lifetime the threshold current and the current required to generate a mean photon density

1 // Example no.3.7

2 // To calculate (a) the photon lifetime, (b) the threshold current, and (c) the current required  $10^{2}1$ to generate a mean photon density of 8.5 m 33 // Page no.130 4  $5 \, \text{clc};$ 6 clear; 7 8 // Given data  $9 w = 3 * 10^{(-6)};$ // The active area width in meter 10  $d=0.3*10^{(-6)};$ // The active area thickness in meter 11 L=500\*10<sup>(-6)</sup>; // The length 12  $Te=1*10^{(-9)};$ 11 Electron lifetime 13 Neth=0.8\*10<sup>(24)</sup>; 11 Threshold electron density 14 aint=46\*10^2; 11 Internal cavity loss in  $m^{-1}$ 15 n=3.5; // Refrective index of the medium 16 R1=0.65; 11 The reflectivity of ligth wave which is reflected at A 17 R2=0.65; 11 The reflectivity of ligth wave which is

```
reflected at B
18
19 // (a)The photon lifetime
20 amir=(1/(2*L))*log(1/(R1*R2));
                                 // The loss due to
      mirrors per m
21 c=3*10^8;
                                                        //
      Speed of ligth in m/s
22 v=c/n;
      // Speed of ligth in medium (m/s)
23 Tp=1/(v*(aint+amir));
                                          // The photon
      lifetime in sec
24
25 // Displaying the result in command window
26 printf('\n The photon lifetime = \%0.2 f ps', Tp*10^12)
27
28 // (b)The threshold current
29 V = w * d * L;
                                                        //
      The active volume in m<sup>3</sup>
30 q=1.602*10^{(-19)};
                                              //The
      electron charge in C
31 Te=10^{-9};
                                                       11
      The electron lifetime in sec
32 Ith=(Neth*q*V)/Te;
                                            //The
      threshold current in mA
33
34 // Displaying the result in command window
35 printf('\n The threshold current = \%0.1 f mA', Ith
      *10^3);
```

```
36
```

```
37 // The answer calculated in book is wrong
38
39 // (c)The current required to generate a mean photon
       density of 8.5 10<sup>21</sup> m 3
40 Nph=8.5*10^21;
                                                   //Mean
      photon density
41 Tph=Tp;
                                                          //
      The photon lifetime in sec
42 I = (Ith + (Nph * q * V) / Tph);
                                         //The current
      required to generate a mean photon density of 8.5
           10<sup>21</sup> m 3
43
44 // Displaying the result in command window
45 printf('\n The current required to generate a mean
      photon density of 8.5 10^21 \text{ m}^{-3} = \%0.2 \text{ f mA}^{\prime}, I
      *10^3)
46
47 // The answer calculated in book is wrong
```

Scilab code Exa 3.8 To find the wavelength of the light emitted

```
1 // Example no.3.8
2 // To find the wavelength of the light emitted
3 // Page no.133
4
5 clc;
6 clear;
7 
8 // Given data
9 RspRst=2*10^14;
```

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Scilab 5.4.1 Console

```
The wavelength of the light emitted = 1.44 micrometer
```

Figure 3.8: To find the wavelength of the light emitted

```
// The
      ratio of spontaneous emission rate to stimulated
      emission rate
10 T=30;
      // Temperature in degree celcius
11 kB=1.38*10<sup>(-23)</sup>;
                                                  // The
      Boltzmann s constant J/K
12 h=1.054*10^{(-34)};
                                                  // The
      distance between two levels
13 c=3*10^8;
      //\ {\rm Speed} of ligth in air
14
15 T=T+273;
      // Temperature in Kelvin
16 w=(\log(RspRst)*kB*T)/h;
                                           // Frequency in
       Rad
17
```

#### File Edit Control Applications ?

Scilab 5.4.1 Console

The frequency separation between modes = 142.9 GHz The wavelength separation between modes = 0.8 nanomete: -->|

Figure 3.9: To calculate the frequency separation between modes the wavelength separation between modes

Scilab code Exa 3.9 To calculate the frequency separation between modes the wavelength separation between modes

```
1 // Example no.3.9
2 // To calculate a) the frequency separation between
    modes (b) the wavelength separation between modes
3 // Page no.133
4
5 clc;
```

```
6 clear;
7
8 // Given data
9 lambda=1.3*10^{-6};
                                                   //
      Laser diode operating wavelength
10 L = 300 * 10^{-6};
     // Cavity length
11 n=3.5;
     // Refractive index of active region
12 c=3*10^8;
     // Speed of ligth in air (m/s)
13
14 // a)The frequency separation between modes
15 deltaf=c/(2*n*L);
                                                  // The
      frequency separation between modes in GHz
16
17 // Displaying the result in command window
18 printf('\n The frequency separation between modes =
      %0.1 f GHz', deltaf *10^-9);
19
20 // (b) The wavelength separation between modes
21 deltalambda=(lambda^2*deltaf)/c;
                                 // The wavelength
      separation between modes
22
23 // Displaying the result in command window
24 printf('\n The wavelength separation between modes =
      %0.1f nanometer', deltalambda*10^9);
25
26 // The wrong unit is givan in book
```

# © Sela 543 Console File Edit: Control Applications ? Control (Applications ?) Control (Applications ?)

Figure 3.10: To calculate the effective mass of the electron in the valence band

Scilab code Exa 3.10 To calculate the effective mass of the electron in the valence band

```
11 hk1=9*10^-26;
                                                  // The
      crystal momentum in Kg.m/s
12 h=1.054*10^{(-34)};
                                              // The
      distance between two levels
13 f=3.94*10^{14};
                                                  // Light
       wave of frequency
14 m=9.109*10^{(-31)};
                                              // The
      electron rest mass in kg
15
16 mr=(hk1)^2/(2*(h*2*%pi*f-Eg));
                                // The reduced mass in kg
17 meff1=0.07*m;
                                                  // The
      effective mass of an electron in the conduction
      band
18
19 // The effective mass of the electron in the valence
       band.
20 meff2=(mr*meff1)/(meff1-mr);
                                                      ||
      The effective mass of the electron in the valence
       band.
21
22 // Displaying the result in command window
23 printf('\n The effective mass of the electron in the
       valence band = \%0.2 \text{ f X } 10^{-31} \text{ kg', meff2*10^31};
24 // The answer is varrying due to round-off error
```

Scilab code Exa 3.11 To calculate the optical gain coefficient required to balance the cavity loss and the threshold electron density Ne

#### File Edit Control Applications ?

Scilab 5.4.1 Console

The optical gain coefficient = 4.28 X 10^3 m^-1 The threshold electron density = 5.72 X 10^23 m^-3

Figure 3.11: To calculate the optical gain coefficient required to balance the cavity loss and the threshold electron density Ne

```
1 // Example no.3.11
2 // To calculate (a) the optical gain coefficient
                                                          g
       required to balance the cavity loss and (b) the
      threshold electron density Ne
3 // Page no.135
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 L=320*10<sup>-6</sup>;
      // Cavity length
10 R1=0.35;
      // The reflectivity of ligth wave which is
      reflected at A
11 R2=0.35;
      // The reflectivity of ligth wave which is
      reflected at B
12 aint=10^3;
```

```
// Internal cavity loss in m^{-1}
13 c=3*10^8;
     // Speed of ligth in air
14 Go=1.73*10^{-12};
                                                        11
      Gain coefficient in m^3/s
15 Neo=3.47 \times 10^{23};
                                                        11
      The value of the carrier density at which the
      gain coefficient becomes zero in m^{-3}
16 n=3.3;
     // Refractive index of medium
17
18 // (a) the optical gain coefficient g required to
      balance the cavity loss
19 amir=(1/(2*L))*log(1/(R1*R2));
                                         // The loss due
      to mirrors per m
20 acav=amir+aint;
     // The total cavity loss coefficient
21 gammag=acav;
      // The optical gain coefficient in m^{-1}
22
23 // Displaying the result in command window
24 printf('\n The optical gain coefficient = \%0.2 f X
      10^{3} \text{ m}^{-1}', gammag * 10^ - 3);
25
26 //(b) the threshold electron density Ne
27 v=c/n;
      // Velocity of ligth in medium
28 Tph=1/(v*acav);
```

// The photon lifetime in sec 29 Neth=Neo+1/(Go\*Tph); threshold electron density Ne

// The

threshold electron density Ne

31 // Displaying the result in command window
32 printf('\n The threshold electron density = %0.2 f X

 $10^{23} {
m m}^{-3}$ ', Neth \*10^ -23);

30

## Chapter 4

# Optical Modulators and Modulation Schemes

Scilab code Exa 4.2 To calculate the voltage required to introduce a phase shift

```
1 // Example no.4.2
2 // To calculate the voltage required to introduce a
      phase shift of pi/2.
3 // Page no.152
4
5 clc;
6 clear;
7
8 // Given data
9 \quad lambda0 = 1530 * 10^{-9};
                                            // An electro-
      optic modulator operating wavelength
10 d=10*10^{-6};
                                                     11
      Thickness
11 L=5*10<sup>-2</sup>;
```

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```
The voltage required to introduce a phase shift of pi/2 = 0.48 V
-->
```

Figure 4.1: To calculate the voltage required to introduce a phase shift

```
11
      Length
12 n0=2.2;
                                                      11
      Refractive index
13 r33=30*10<sup>-12</sup>;
                                               // Pockel
      coefficient in m/V
14 deltaphi=%pi/2;
                                              // Phase
      shift
15 V=(deltaphi*lambda0*d)/(%pi*L*n0^3*r33);
                   // The voltage required to introduce
      a phase shift of pi/2
16
17 //Displaying the result in command window
18 printf('\n The voltage required to introduce a phase
       shift of pi/2 = \%0.2 f V', V;
```

## Chapter 5

## **Optical Receivers**

Scilab code Exa 5.1 To calculate the photon incidence rate the photon absorption rate and the quantum efficiency

```
1 // Example no.5.1
2 // To calculate (a) the photon incidence rate, (b)
      the photon absorption rate, and, (c) the quantum
      efficiency.
  // Page no.196
3
4
5 \, \text{clc};
6 clear all;
7 // Given data
8 lambda=550*10^(-9);
                                                      The
                                                    11
      wavelength of electromagnetic wave in m
9 c = 3 * 10^8;
                                                    // Speed
       of ligth in air
10 h=6.626*10^{(-34)};
                                                    11
      Planck's constant
                                                    11
11 alpha=10^4;
      absorption coefficient
                                                    // width
12 W = 3 * 10^{-4};
```

# 

The photon incidence rate = 2.77 X 10^9 photon/s The photon absorption rate = 2.63 X 10^9 photon/s The quantum efficiency = 0.855  $-\!\!\!>$ 

Figure 5.1: To calculate the photon incidence rate the photon absorption rate and the quantum efficiency

	of the active region		
13	Pi=1*10^-9;	//	
	optical power		
14	eta=0.9;	// the	
	fraction of photocarriers that contribute	e to the	
	photocurrent		
15	Rp=0;	// the	
	power transmission coefficient at the		
	air semiconductor interface		
16			
17	// (a) the photon incidence rate		
18	Eph=(h*c)/lambda;	// The	
	energy of a photon		
19	Rincident=Pi/Eph;	// The	
	photon incidence rate		
20			
21	// Display result on command window		
22	printf('\n The photon incidence rate = $\%0.2$	f X $10^9$	
	$\mathrm{photon}/\mathrm{s}$ ',Rincident*10^-9);		
23			
24	// (b) the photon absorption rate		
25	Rabs=(Rincident*(1- <mark>exp</mark> (-alpha*W)));	// The	

#### File Edit Control Applications ?

Scilab 5.4.1 Console

The responsivity = 0.8 A/W The cutoff wavelength = 0.845 micrometer -->

Figure 5.2: To calculate the responsivity R and the cutoff wavelength

Scilab code Exa $5.2\,$  To calculate the responsivity R and the cutoff wavelength

```
1 // Example no.5.2
2 // To calculate (a) the responsivity R and (b) the
    cutoff wavelength
```

```
3 // Page no.198
4
5 \, \text{clc};
6 clear;
\overline{7}
8 // Given data
                                                         11
9 \text{ neta=0.9};
      The quantum efficiency
10 Eg=1.42;
                                                         //
      The band-gap energy in eV
11 lambda=1.1;
                                                         //
      The operating (free-space) wavelength in
      micrometer
12
13 // (a) The responsivity
                                                         11
14 R=(neta*lambda)/1.24;
      The responsivity in A/W
15
16 // Display result on command window
17 printf('\n The responsivity = \%0.1 f A/W', R)
      //Wrong answer in book
18
19 // (b) The cutoff wavelength
                                                       //The
20 lambdac=1.2/Eg;
       cutoff wavelength in micrometer
21
22 // Display result on command window
23 printf('\n The cutoff wavelength = \%0.3 f micrometer'
      ,lambdac)
                                                       11
      Wrong answer in book
```



Scilab 5.4.1 Console



Figure 5.3: To find quantum efficiency at different wavelength and same responsivity

Scilab code Exa 5.3 To find quantum efficiency at different wavelength and same responsivity

```
1 // Example no.5.3
2 // To find quantum efficiency at different
     wavelength and same responsivity
3
  // Page no.199
4
5 clc;
6 clear;
7
8 // Given data
9 lambda1=0.7;
                                                // The
     radiation wavelength in micrometer
10 R=0.4;
                                                      11
     The responsivity in A/W
11
  lambda2=0.5;
                                                // The
     reduced wavelength in micrometer
12 neta1=(R*1.24)/lambda1;
```

#### File Edit Control Applications ?

Scilab 5.4.1 Console

Refractive index of antireflection coating = 1.5 Thickness of antireflection coating = 90 nm -->

Figure 5.4: To determine the refractive index and thickness of the antireflection coating

Scilab code Exa 5.4 To determine the refractive index and thickness of the antireflection coating

```
1 // Example no.5.4
2 // To determine the refractive index and thickness
        of the antireflection coating
```

```
3 // Page no.199
4
5 clc;
6 clear;
\overline{7}
8 // Given data
  lambda=680*10^-9;
9
      // Wavelength of red ligth in meter
10 nair=1;
     // Refractive index of air
11 nsilicon=3.6;
     // Refractive index of silicon
12 nAR=sqrt(nair*nsilicon);
      // Refractive index of antireflection coating
13 tAR=lambda/(4*nAR);
      // Thickness of antireflection coating
14
15 // Display result on command window
16 printf('\n Refractive index of antireflection
      coating = \%0.1 \, \text{f} ',nAR)
17 printf('\n Thickness of antireflection coating = \%0
      .0 f nm',tAR*10^9)
```

Scilab code Exa 5.5 To calculate the inaccuracy with which resonator should be fabricated

```
1 // Example 5.5
2 // To calculate the inaccuracy with which resonator
should be fabricated
3 // Page no.216
4 
5 clc;
6 clear;
```
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Scilab 5.4.1 Console



Figure 5.5: To calculate the inaccuracy with which resonator should be fabricated

```
7
8 // Given data
9 R1 = 0.9;
                                                     //
      Reflectivity at point A
10 integer=4;
11 n=3.5;
                                                     //
      Reflection index of silicon
12 F=%pi/(1-sqrt(R1));
                                                     11
     The finesse of the resonator and also called as
      the ratio of the free spectral range
13 lambda0=850;
                                                     //
     Wavelength in nanometer
14 L=integer*lambda0/(2*n);
                                                     //
      Resonator length in nanometer
15
16 // The inaccuracy with which resonator should be
      fabricated
17 deltaL=L*0.5/F;
18
19 // Display result on command window
20 printf('\n Resonator length = \%0.0 f nm',L)
21 printf('\n The inaccuracy in length with which
```



peak current at LO power 10dBm = 1.1330 mA peak current after ignoring the d.c. term = 1.204 mA peak current at LO power -10dBm = 0.1133 mA peak current after ignoring the d.c. term = 0.1846 mA

Figure 5.6: To find the peak current

resonator should be fabricated =  $\%0.0 \,\text{f} \,\text{nm'}, \text{deltaL}$  )

### Scilab code Exa 5.6 To find the peak current

```
1 // Example no.5.6
2 // To find the peak current if (a) LO power = 10 dBm
     , (b) LO power = 10 dBm for the single-branch
     receiver
  // Page no.229
3
4
5 clc;
6 clear;
7
  // Given data
8
9 L=100;
                                                      11
     Length of fiber
                                                      11
10 loss=0.2*L;
     Total fiber loss
```

```
11 PtdBm=12;
                                                        11
      The peak power of the signal at the transmitter
12 R=0.9;
                                                        //
      Responsivity in A/W
13 PrdBm=PtdBm-loss;
                                                        //
      The power at the receiver
14
15 // (a) the peak current LO power = 10 dBm
16 PLO1dBm=10;
     // Power at local oscillator in dBm
17 PL01=10<sup>(0.1*PL01dBm)</sup>;
     // Power at local oscillator in mW
18 Pr=10<sup>(0.1*PrdBm)</sup>;
      // Power at receiver in mW
19 Id1=R*sqrt(Pr*PL01);
      // The peak current at LO power = 10dBm
20 I1=R*Pr/2+R*sqrt(Pr*PL01);
      // The peak current after ignoring the d.c. term
21
22 // Display result on command window
23 printf('\n The peak current at LO power 10dBm = \%0.4
      f mA', Id1)
24 printf('\n The peak current after ignoring the d.c.
      term = \%0.3 \, \text{f} \, \text{mA',I1}
25
26 // (b) the peak current LO power = -10 dBm
27 PLO2dBm = -10;
                                                         //
       Power at local oscillator in dBm
  PLO2=10^{(0.1*PLO2dBm)};
                                                          | |
28
       Power at local oscillator in mW
29
  Id2=R*sqrt(Pr*PL02);
                                                         //
       The peak current at LO power = -10dBm
30 I2=R*Pr/2+R*sqrt(Pr*PL02);
                                                         //
       The peak current after ignoring the d.c. term
31
32 // Display result on command window
33 printf('\n The peak current at LO power -10dBm = \%0
      .4 f mA', Id2)
```



The peak current for LO power 10 dBm = 2.2661 mA The peak current for LO power -10 dBm = 0.2266 mA A single-branch receiver would have a significant amount of cross-talk. In contrast, for a balanced receiver, intermodulation cross-talk is canceled out due to the balanced detection. -->

Figure 5.7: To find the peak current

34 printf('\n The peak current after ignoring the d.c. term = %0.4 f mA', I2)

### Scilab code Exa 5.7 To find the peak current

```
1 // Example no.5.7
2 // To find the peak current if (a) LO power = 10 dBm
      , (b) LO power = 10 dBm for the balanced
      receiver
  // Page no.234
3
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 L=100;
                                                         11
       Length of fiber
                                                         11
10 loss=0.2*L;
       Total fiber loss
```

```
11 PtdBm=12;
                                                          11
       The peak power of the signal at the transmitter
12 R=0.9;
                                                          //
       Responsivity in A/W
13 PrdBm=PtdBm-loss;
                                                          //
       The power at the receiver
14
15 // (a) the peak current LO power = 10 dBm
16 PLO1dBm=10;
                                                          //
       Power at local oscillator in dBm
17 PL01=10<sup>(0.1*PL01dBm)</sup>;
                                                          //
       Power at local oscillator in mW
18
  Pr=10^{(0.1*PrdBm)};
                                                          //
       Power at receiver in mW
  Id1=2*R*sqrt(Pr*PL01);
                                                          //
19
       The peak current LO power = 10 \text{ dBm}
20
21 // Display result on command window
22 printf('\n The peak current for LO power 10 dBm = \%0
      .4 f mA', Id1)
23
24 // (b) the peak current LO power = -10 dBm
25 PLO2dBm = -10;
                                                          //
       Power at local oscillator in dBm
26 PLO2=10<sup>(0.1*PLO2dBm)</sup>;
                                                          //
       Power at local oscillator in mW
27
  Id2=2*R*sqrt(Pr*PLO2);
                                                          //
       The peak current LO power = -10 \text{ dBm}
28
29 // Display result on command window
30 printf ('\n The peak current for LO power -10 \text{ dBm} =
      %0.4 f mA', Id2)
31
32
  // comment on the intermodulation cross-talk in a
      single-branch receiver and the balanced receiver
33 printf('\n A single-branch receiver would have a
      significant amount of cross-talk. In contrast,
      for a balanced receiver, intermodulation cross-
```

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Scilab 5.4.1 Console

The in-phase component of the current = -0.8012 mA The quadrature component of the current = -0.8012 mA

Figure 5.8: To find the in phase and quadrature components of the current of a balanced IQ receiver

talk is canceled out  $\n$  due to the balanced detection.')

Scilab code Exa 5.8 To find the in phase and quadrature components of the current of a balanced IQ receiver

```
1 // Example no.5.8
2 // To find the in-phase and quadrature components of
the current of a balanced IQ receiver.
3 // Page no.238
4
5 clc;
6 clear;
7 
8 // Given data
9 PLO=10; //
Local oscillator power in mW from Example 5.7a
```

# Scilab 5.4.1 Console File Edit Control Applications ? Image: Scilab S

In-phase component of phtcourrent corresponding to x-polarization = 0.4006 mÅ mÅ Gaadrature component of phtcourrent corresponding to x-polarization = -0.4006 mÅ Gaadrature component of phtcourrent corresponding to y-polarization = 0.4006 mÅ  $-\sim$ 

Figure 5.9: To find the in phase and quadrature components of the current of a polarization modulated QPSK signal

) († X

10	Pr=0.1585;	11
	Power at receiver in mW	
11	R=0.9;	//
	Responsivity in A/W	
12	st=complex((-1/sqrt(2)),(1/sqrt(2)));	//
	The QPSK transmitted signal	
13	<pre>Ii=R*sqrt(Pr*PL0)*real(st);</pre>	//
	The in-phase component of the current in mA	
14	Iq=-R* <mark>sqrt</mark> (Pr*PLO)*imag(st);	//
	The quadrature component of the current in ma	4
15		
16	// Display result on command window	
17	<pre>printf('\n The in-phase component of the curren</pre>	t =
	%0.4 f mA', Ii)	
18	printf('\n The quadrature component of the curr	ent =
	%0.4 f mA',Iq)	

Scilab code Exa 5.9 To find the in phase and quadrature components of the current of a polarization modulated QPSK signal

```
1 // Example 5.9
2 // To find the in-phase and quadrature components of
      the current of a polarization modulated (PM)
     QPSK signal
3 // Page no. 241
4
5 \, \text{clc};
6 clear;
7
8 // Given data
9 theta1=%pi/4;
10 Sx=expm(%i*theta1);
     // Signal data in x-polarization
11 theta2=(5*%pi)/4;
12 Sy=expm(%i*theta2);
     // Signal data in y-polarization
13 PLO=10;
     // Local oscillator power in mW from Example 5.8
14 Pr=0.1585;
      // Power at receiver in mW from Example 5.8
15 R=0.9;
     // Reflectivity
16
17
  // The complex photocurrent corresponding to x-
      polarization
18 Ix= (R*sqrt(Pr*PLO))*Sx/2;
                                                // The
     complex photocurrent corresponding to x-
      polarization
19 Iix=real(Ix);
```

```
// In-phase component of phtocurrent
      corresponding to x-polarization
20 Iqx = -imag(Ix);
      // Quadrature component of phtocurrent
      corresponding to x-polarization
21
22
  // The complex photocurrent corresponding to y-
      polarization
23 Iy= (R*sqrt(Pr*PL0))*Sy/2;
                                                 // The
      complex photocurrent corresponding to y-
      polarization
24 Iiy=real(Iy);
      // In-phase component of phtocurrent
      corresponding to y-polarization
25 Iqy=-imag(Iy);
      // Quadrature component of phtocurrent
      corresponding to y-polarization
26
27 // Display result on command window
28 printf('\n In-phase component of phtocurrent
      corresponding to x-polarization = \%0.4 \text{ f mA', Iix};
29 printf('\n Quadrature component of phtocurrent
      corresponding to x-polarization = \%0.4 \text{ f mA'}, \text{Iqx});
30 printf('\n In-phase component of phtocurrent
      corresponding to y-polarization = \%0.4 \text{ f mA', Iiy};
31 printf('\n Quadrature component of phtocurrent
      corresponding to y-polarization = \%0.4 \text{ f mA', Iqy};
```

# Chapter 6 **Optical Amplifiers**

Scilab code Exa 6.1 Calculation of the gain

```
1 // Example 6.1
2 // Calculation of the gain
3 // Page no 249
4
5 clc;
6 clear;
7 close;
8
9 //Given data
10
11 n=1.5;
                               // Wavelength
12 lambda=1550*10^{-9};
13 c=3*10^8;
14 p=5.73*10^-17;
15 h=6.63*10^-34
16
17
18 // Gain
19 f=c/lambda;
```

- // Refractive ondex of air
- // Velocity of light
- // Power spectral density
- // Planck constant



Figure 6.1: Calculation of the gain



Figure 6.2: Calculation of the variance of the signal ASE beat noise

```
20
21 G=(p/(2*n*h*f))+1;
22
23 //Displaying results in the command window
24 printf("\n Gain G = %0.0 f ",G);
```

Scilab code Exa6.2 Calculation of the variance of the signal ASE beat noise

1 // Example 6.2

```
2 // Calculation of the variance of the signal ASE
      beat noise
3 // Page no 255
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10
                                    // PSD of an amplifier
11 a=1.3*10^-16;
                                  // Cut off frequency
12 f=7*10^9;
                                   // Input power
13 Pi=10*10^{-6};
                                  // Responsivity
14 R=0.8;
                                  // Gain of an amplifier
15 G=20;
16
17 // The variance of the signal ASE beat noise
18 G=10^{(G/10)};
19 P=G*Pi;
20
21 r=4*R^2*P*a*f;
22 r=r*10^9;
23
24
25
26
27 //Displaying results in the command window
28 printf("\n The variance of the signal ASE beat
      noise current is = \%0.2 \,\text{f x} \, 10^{-9} \,\text{A}^{2}",r);
29
30
31 // The answers vary due to round off error
```



Figure 6.3: Calculation of the the variance of the signal ASE beat noise current the variance of the ASE ASE beat noise current and the total variance

Scilab code Exa 6.3 Calculation of the the variance of the signal ASE beat noise current the variance of the ASE ASE beat noise current and the total variance

```
1 // Example 6.3
 2 // Calculation of the (a) the variance of the
         signal ASE beat noise current, (b) the variance
          of the ASE ASE beat noise current, and (c) the
          total variance.
 3 // Page no 257
 4
 5 \, \text{clc};
 6 clear;
 7 close;
 8
 9 //Given data
10
11 G=30; // Gain
12
13 nsp=5;
14 R=0.8;
15 f1=16*10^9;
16 fe=9*10^9;
17 / Pi1 = -60;

      17
      // ***

      18
      c=3*10^8;
      // Verocrey of

      19
      h=6.63*10^-34
      // Planck constant

      20
      lambda=1530*10^-9;
      // Wavelegth

      21
      Pi1=-27;
      // Input power

                                    // Velocity of light
22 Pi2 = -60;
23 f0=16*10^9;
24
25
26 //(a) The variance of the signal ASE beat noise
        current for Pin=-27dBm
27 Po=G+Pi1;
28 Po=10^{(Po/10)};
29 Po=Po*10^{-3};
30 \quad G=10^{(G/10)};
```

```
31 f=c/lambda;
32 r=nsp*h*f*(G-1);
33 B=8*10^9;
34 / B = \min(f/2, fe);
35 r0=4*R^2*Po*r*B;
36 / r0 = r0 * 10^{12};
37
38 //(b) The variance of the ASE ASE beat noise
      current
39
40 r1=R^2*r^2*((2*f0)-fe)*fe;
41
42 // r1=r1*10^{11};
43 // (c) The total variance.
44
45 rt=r0+r1;
46
47 // Displaying results in the command window
48 printf("\n (a) The variance of the signal ASE beat
       noise current for Pin=-27dBm");
49
50 printf("\n The variance of the signal ASE beat
      noise current = \%0.2 \,\text{f} \times 10^{-8} \,\text{A}^2", r0*10^8);
51 printf("\n The variance of the ASE ASE beat noise
      current = \%0.2 \,\text{f} \times 10^{-11} \,\text{A}^{2}, r1*10^11);
52
53 printf("\n The total variance = \%0.3 f x 10^{-8} A<sup>2</sup>",
      rt*10^8);
54 // The answers vary due to round off error
55
56
57 //Given data
58
                 // Gain
59 G=30;
60 nsp=5;
61 R=0.8;
                  11
62 f1 = 16 * 10^9;
63 fe=9*10^9;
```

```
64 //Pi1=-60;
65 c=3*10^8; // Velocity of light
66 h=6.63*10^-34 // Planck constant
67 lambda=1530*10<sup>-9</sup>; // Wavelegth
68 Pi1 = -27;
                         // Input power
69 Pi2 = -60;
70 f0=16*10^9;
71
72 //(b) The variance of the signal ASE beat noise
      current for Pin=-60dBm
73 Po2=G+Pi2;
74 Po=10^{(Po2/10)};
75 Po = Po * 10^{-3};
76 G=10^{(G/10)};
77 f=c/lambda;
78 r=nsp*h*f*(G-1);
79 B = 8 * 10^9;
80 //B=min(f/2,fe);
81 r0=4*R^2*Po*r*B;
82 //r0=r0*10^{12};
83
84 //(b) The variance of the ASE ASE beat noise
      current
85
86 r1=R^2*r^2*((2*f0)-fe)*fe;
87
88 // r1=r1*10^{11};
89 // (c) The total variance.
90
91 rt=r0+r1;
92
93 // Displaying results in the command window
94 printf("n n (b) The variance of the signal ASE
      beat noise current for Pin=-60dBm");
95
96 printf("\n The variance of the signal ASE beat
      noise current = \%0.2 \text{ f} \times 10^{-11} \text{ A}^{2}, r0*10^11);
97 printf("\n The variance of the ASE ASE beat noise
```



Figure 6.4: Calculation of the amplifier gain

current = %0.2f x 10^-11 A^2",r1\*10^11); 98 99 printf("\n The total variance = %0.2f x 10^-11 A^2 " ,rt\*10^11);

### Scilab code Exa 6.4 Calculation of the amplifier gain

```
1 // Example 6.4
2 // Calculation of the amplifier gain
3 // Page no 262
```

```
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10
                                // Signal output of
11 Po=0;
       amplifier
12 // f = 7 * 10^9;
                                // Cut off frequency
13 B=7.5*10^9;
                                 // Bandwidth
                                // Responsivity
// Velocity of light
14 R=0.9;
15 c = 3 * 10^8;
                                // Operating frequency
16 lambda=1550*10<sup>-9</sup>;
                                // Noise figure
17 fn=4.5;
                                // Beat noise current
18 Ro=0.066*10^{-3};
19 h=6.626*10^{-34};
                                // Planck constant
20
21 // The amplifier gain
22 P=10<sup>(Po/10)</sup>*10<sup>-3</sup>;
23 r=Ro<sup>2</sup>/(4*R<sup>2</sup>*B*P);
24 fn=10^(fn/10);
25 f = c/lambda;
26 G=(1/fn)*(((2*r)/(h*f))+1);
27
28
29
30
31 // Displaying results in the command window
32 printf("\n The amplifier gain = \%0.0 \text{ f} ",G);
33
34
35 // The answers vary due to round off error
```



Figure 6.5: Calculation of the OSNR in a given bandwidth

Scilab code Exa 6.5 Calculation of the OSNR in a given bandwidth

```
1 // Example 6.5
 2 // Calculation of the OSNR in a bandwidth of 12.49
       GHz.
 3 // Page no 263
 4
 5 \, \text{clc};
 6 clear;
 7 close;
 8
 9 //Given data
10
                                // Gain
11 G=25;
12 c=3*10^8;
                               // Velocity of light

      13
      h=6.63*10^-34
      // Planck constant

      14
      lambda=1545*10^-9;
      // Wavelegth

15 Pi = -22;
                               // Input power
16 fn=6;
17 B=12.49*10^9;
18
19 // The OSNR in a bandwidth of 12.49 GHz
20 Po=G+Pi;
21 Po=10^{(Po/10)};
22 Po=Po*10^{-3};
23 fn=10^(fn/10);
24 \quad G=10^{(G/10)};
25 f=c/lambda;
26 r = (G * fn - 1) * (h * f / 2);
27 O=Po/(2*r*B);
28 \quad 0 = 10 * \log 10(0);
29
30 // Displaying results in the command window
31 printf("\n The OSNR in a bandwidth of 12.49 \text{ GHz} = \%0
       .2f dB",0);
32
33
34
```



Figure 6.6: Calculation of the single pass gain and 3 db bandwidth

35 // The answers vary due to round off error

Scilab code Exa $6.6\,$  Calculation of the single pass gain and 3 db bandwidth

```
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10
11 c1=3*10^8;
                               // Velocity of light
                              // Cut off frequency
12 f=7*10^9;
                              // Input power
13 L=500*10^{-6};
                              // Peak gain
14 Gp=15;
15 n=3.2;
16 Gs = 2.52;
17 R=0.32;
18 a=0.1024;
19 b = -0.6546;
20 c=1;
21
22 // The single-pass gain
23
24 x1 = (-1*b+ sqrt ((b^2) - 4*a*c)) / (2*a); // 1 s t
      r o o t
25 x2 =( -1*b- sqrt ((b ^2) -4*a*c)) /(2* a); // 2nd r
      o o t
26
27 // The 3-dB bandwidth
28 \quad G=10^{(Gp/10)};
29 x=(1-(R*x2))/(2*sqrt(R*x2));
30 f=(c1/(%pi*L*n))*asin(x);
31 // f = f * 10^{-9};
32
33 // Displaying results in the command window
34
35 printf ( 'Single pass gain Gs = \%0.2 f or', x1);
36 printf ( ' \n Single pass gain Gs = \%0.2 f ', x2);
37 printf("\n The the 3-dB bandwidth = \%0.2 f GHz ",f
      *10^-9);
38
39
```



Figure 6.7: Calculation of the saturation power and the bias current I

40 // The answers vary due to round off error

Scilab code Exa 6.7 Calculation of the saturation power and the bias current I  $\,$ 

```
1 // Example 6.6
2 // Calculation of (a) the saturation power and (b)
the bias current I
3 // Page no 273
4
```

```
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10
                               // Velocity of light
11 c=3*10^8;
12 lambda=1530*10^-9;
                              // Wavelength
                              // Overlap factor
13 t=0.3
                              // Gain cross section
14 r=7.3*10^{-20};
15 r0 = 1 * 10^{-9};
                             // Carrier lifetime
16 q=1.609*10^{-19};
17 v = 7.5 * 10^{-16};
                            // Active volume
                            // Planck constant
18 h=6.63*10^{-34}
                           // Effective area
19 A = 5 * 10^{-6};
                           // Small signal gain
20 g = 4.82 \times 10^{3};
      coeffifient
21 N=3.5*10^{23};
                            11
22
23 // (a) the saturation power and
24
25
26 f=c/lambda;
27 Ps=(h*f*A)/(t*r*r0);
28 Ps = Ps * 10^{-3};
29
30 // (b) the bias current I
31
32 I = (g/(r*r0) + N/r0) * q*v;
33 I = I * 10^3;
34 // Displaying results in the command window
35 printf("\n The saturation power Psat = \%0.3 f mW", Ps
      );
36
37 printf("\n The bias current I = \%0.3 \text{ f mA}",I);
38
39
40 // The answers vary due to round off error
```



Figure 6.8: Calculation of the variance of the signal ASE beat noise current

Scilab code Exa6.9 Calculation of the variance of the signal ASE beat noise current

```
1 // Example 6.9
2 // Calculation of the variance of the signal ASE
            beat noise current.
3 // Page no 290
4 
5 clc;
```

```
6 clear;
7 close;
8
9 //Given data
10
11 si=30;
                            // Electrical SNRs at the
      amplifier input
                           // Electrical SNRs at the
12 so=25;
      amplifier output
                           // Signal power at output
13 p=0;
                          // Signal power at input
14 r = -126;
                          // Planck constant
15 R=0.9;
                         // Frequency
16 f = 195 * 10^{12};
17 b=20*10^9;
                         // Bandwidth
18
19 // The variance of the signal ASE beat noise
      current
20 p1=10<sup>(p/10)</sup>*10<sup>-3</sup>;
21 rn=10<sup>(r/10)</sup>*10<sup>-3</sup>;
22 r1=rn*b;
23 r0=2*R^2*p1*r1;
24
25
26 //Displaying results in the command window
27 printf("\n The variance of the signal ASE beat
      noise current = %0.2 f x 10<sup>-9</sup> A<sup>2</sup> W/Hz",r0*10<sup>9</sup>)
      ;
28
29
30 // The value of noise power given in example as -126
       but for calculation it is taken as -128 in book.
       Therefore answer is varying.
```



Figure 6.9: Calculation of the ASE power spectral density per polarization

Scilab code Exa 6.12 Calculation of the ASE power spectral density per polarization

```
1 // Example 6.12
2 // Calculation of the ASE power spectral density per
       polarization.
  // Page no 296
3
4
5 clc;
6 clear;
7 close;
8
9 //Given data
10
                           // Electrical SNRs at the
11 si=30;
      amplifier input
                          // Electrical SNRs at the
12 so=25;
      amplifier output
                          // Signal power at output
13 po=2;
14 pi=-13;
                         // Signal power at input
                         // Planck constant
15 h=6.626*10^{-34};
16 f=195*10^12;
17
18 // The ASE power spectral density per polarization
19 fn=si-so;
20 fn=10^(fn/10);
21 G=po-pi;
22 G=10^{(G/10)};
23 r=(h*f*(G*fn-1))/2;
24 r=r*10^18;
25
26 //Displaying results in the command window
27 printf("\n The ASE power spectral density per
      polarization = \%0.3 \,\text{f} \times 10^{-18} \,\text{W/Hz}",r);
```



Figure 6.10: Calculation of the geometric mean of the facet reflectivity  ${\bf R}$ 

Scilab code Exa 6.13 Calculation of the geometric mean of the facet reflectivity  ${\rm R}$ 

```
1 // Example 6.13
2 // Calculation of the geometric mean of the facet
      reflectivity R
3 // Page no 296
4
5 clc;
6 clear;
7 close;
8
9 //Given data
10 Gm = 20;
11 G1=5;
12
13 // The geometric mean of the facet reflectivity R
14 Gmax=10^{(Gm/10)};
                                         // Peak Gain
                                         // Single pass
15 Gs = 10^{(G1/10)};
      gain
16 R=(sqrt(Gs)-10)/(sqrt(Gs)-Gs*10);
17
18
19
20
21 // Displaying results in the command window
22 printf("\n The geometric mean of the facet
      reflectivity R = \%0.3 f ",R);
```



Figure 6.11: Calculation of the upper bound on the single pass gain

Scilab code Exa 6.14 Calculation of the upper bound on the single pass gain

```
1 // Example 6.13
2 // Calculation of the upper bound on the single-pass
       gain
3 // Page no 297
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10
                               // Refractive index
11 n=3.5;
                               // Velocity of light
12 c1=3*10^8;
13 L=200*10^{-6};
                              // Amplifier length
14 a=0.09;
15 b = -(1.2*0.1805^{2}+0.6);
16 c=1;
17
18 // The geometric mean of the facet reflectivity R
19 f=c1/(2*n*L);
20
21 x1 = (-1*b+ sqrt ((b^2) - 4*a*c)) / (2*a); // 1 s t
     r o o t
22 x2 = (-1*b- sqrt ((b^2) - 4*a*c)) / (2*a); // 2nd r
      o o t
23
24
25
26 //Displaying results in the command window
27 printf("\n The geometric mean of the facet
      reflectivity R = \%0.2 f GHz ", f*10^-9);
28 printf("\n The upper bound on the single-pass gain
      Gs = \%0.2 f \text{ or } ", x1);
29 printf("\n The upper bound on the single-pass gain
     Gs = \%0.2 f ", x2);
```

32 // The answers vary due to round off error

## Chapter 7

## **Transmission System Design**

Scilab code Exa 7.1 Computation of the lower limit on the transmitter power

```
1 // Example 7.1
 2 // Computation of the lower limit on the
        transmitter power
 3 //
 4 // Page no. 305
 5
 6 \quad clc;
 7 clear;
 8 close;
 9
10 //Given data
11 q=1.6*10<sup>-19</sup>;
12 R=1;
13 B = 7 * 10^9;
13 B=7*10<sup>-9</sup>;

14 c=3*10<sup>8</sup>; // Velocity of light

15 h=6.62*10<sup>-34</sup>; // Planck constant
16 Q = 6;
17 k=1.38*10<sup>-23</sup>; // Boltzman constant
```



Figure 7.1: Computation of the lower limit on the transmitter power
```
18 T=298;
19 Rl=50;
20 alpha=0.046; // Fiber loss coefficient
                    // Length
21 L=130;
22
23
24 // The lower limit on the transmitter power
25 a=2*q*R*B;
26 b = (4 * k * T * B) / R1;
27 p=(2*sqrt(b)/R*Q)+((a*Q^2)/R^2);
28 Pi=p*exp(alpha*L);
29
30 //Displaying the result in command window
31 printf("\n The lower limit on the transmitter power
      = %0.2 f mW', Pi*10^3);
32 printf("\n The lower limit on the transmitter peak
      power is 7.23 \text{mW}. If the transmitter peak power <
      7.23 \text{mW}, \text{ Q} < 6.");
33
34 // The answer vary due to round off error
```

Scilab code Exa 7.2 To calculate exact and approximate Q factor if the signal is OOK and PSK

```
1 // Example no. 7.2
2 // To calculate exact and approximate Q-factor if
    the signal is (a)OOK, (b) PSK
3 // Page no. 311
4
5 clc;
6 clear;
7
8 // Given data
```



Figure 7.2: To calculate exact and approximate Q factor if the signal is OOK and PSK

 $9 \quad lambda=1.55*10^{(-6)};$ Wavelength of given signal 10 meanPin=1; // Mean fiber launch power in dBm 11 alpha=0.2; // fiber loss in dB/km 12 1=240; // fiber length in km 13 neta=0.7; // quantum efficiency 14 T = 290;// Tempearture in K 15 RL=100; // Length resistance in 16 PLOdBm = 10;// Power at local oscillator in dBm 17 Be =  $7.5 \times 10^9$ ; // Efficient bandwidth of filter in Hz 18 c=3\*10^8; // Speed of ligth in air in m/s 19 loss=alpha\*l; // Total fiber loss  $20 q=1.602*10^{(-19)};$ // Charge of electron 21  $h=6.626*10^{(-34)};$ 

11

// Planck constant 22  $kB=1.38*10^{(-23)}$ ; // Bolzman constant 2324 f=c/lambda; // mean frequency 25 R=(neta\*q)/(h\*f);// Responsivity 2627 / For OOK28 Pin=10\*log10(2)+meanPin; // peak power in dBm 29 P1rdBm=Pin-loss; // received peak power in dBm  $30 P1r = (10^{(P1rdBm/10)}) * 10^{(-3)};$ // received peak power in W 31  $PLO = (10^{(PLOdBm/10)}) * 10^{(-3)};$ // Power at local oscillator in W 32 I1=2\*R\*sqrt(P1r\*PL0); // mean of bit 1 33 sigma1=2\*q\*Be\*R\*(P1r+PLO)+(4\*kB\*T\*Be)/RL; // Square of variance of bit 1  $34 \quad I0=0;$ // mean of bit 0 35 sigma0=sigma1; // Square of variance of bit 036 Q1=(I1-I0)/(2\*sqrt(sigma1));

```
// Exact Q-
      factor
37 Q2=sqrt((neta*P1r)/(2*h*f*Be));
                                           // Approximate
      Q-factor
38
39 // Displaying the result in command window
40 printf('\n Exact Q-factor if the signal is OOK = \%0
      .1f',Q1);
41 printf('\n Approximate Q-factor if the signal is OOK
      = %0.1 f', Q2);
42
43 // For PSK
44 P1rdBm=meanPin-loss;
                                                       11
      received peak power in dBm
45 P1r=(10^(P1rdBm/10))*10^(-3);
                                             // received
      peak power in W
46 I1=2*R*sqrt(P1r*PL0);
                                                     11
     mean of bit 1
47 sigma1=2*q*Be*R*(P1r+PLO)+(4*kB*T*Be)/RL;
                                // Square of variance of
       bit 1
48 \quad IO = -I1;
     // mean of bit 0
49 sigma0=sigma1;
     // Square of variance of bit 0
50 Q1=I1/sqrt(sigma1);
                                                        //
       Exact Q-factor
51 Q2=sqrt((2*neta*P1r)/(h*f*Be));
                                           // Approximate
      Q-factor
```

52

	Scilab 5.4.1 Console
File Edit Control Applications ?	
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Scilab 5.4.1 Console	2 F X
Distance = 10 Km	
>	

Figure 7.3: Calculation of the distance

- 53 // Displaying the result in command window
- 54 printf('\n Exact Q-factor if the signal is PSK = %0.2f',Q1);
- 55 printf('\n Approximate Q-factor if the signal is PSK = %0.2 f',Q2);

#### Scilab code Exa 7.3 Calculation of the distance

```
1 // Example 7.3
2 // Calculation of the distance.
```

```
3 // Page no 315
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10 B1=2.5*10^9;
                                         // Mean optical
      power
                                        // Split loss
11 B2=10*10^9;
12 L1 = 160 * 10^{3};
                                           // Total system
      margin
13
14
15
16 // Distance
17 L2=((B1/B2)^2*L1);
18 L2=L2*10^{-3};
19
20
21
22 // Displaying results in the command window
23 printf("\n Distance = \%0.0 f Km ",L2);
24
25
26 // The answers vary due to round off error
```

Scilab code Exa 7.4 Computation of OSNR in a reference bandwidth and Q factor

```
1 // Example 7.4
2 // Computation of (a) OSNR in a reference bandwidth of 0.1 nm, (b) Q-factor.
```



Figure 7.4: Computation of OSNR in a reference bandwidth and Q factor  $% \mathcal{A}$ 

3 // Page no. 321 4  $5 \, \text{clc};$ 6 clear; 7 close; 8 9 // Given data 1011 f=10\*10^9; 12 n=1.5; //Refractive index 13  $h=6.63*10^{-34};$ 11 Planck constant 14  $c=3*10^8;$ // Velocity of light 15 lambda=1.55 $*10^{-6}$ ; // 16  $q=1.6*10^{-19}$ ; // Electron charge 17  $d=0.1*10^{-9};$ 11 Reference bandwidth 18 alpha=0.0461; 11 Fiber loss coefficient 19 L=80; // Spacing 20 Pi = -3;// Mean fiber launch power 21 N=80; // Identical amplifers

22 fe= $7*10^9$ ; 11 Electrical filter bandwidth 232425 // Signal calculation 26 df=-((c\*d)/lambda^2); //Reference frequency 27 G=exp(alpha\*L); 28 G1=10\*log10(G);29 N1 = 10 \* log 10(N); $30 \, \text{Fn} = 2 * n;$ //Noise figure 31 Fn=10\*log10(Fn);32 $33 \quad O=Pi-N1-G1-Fn+58;$ //OSNR  $34 \text{ Pi1}=2*10^{(-(3/10))};$ // Peak power in mW 35 f=c/lambda; 36 Q=sqrt((Pi1\*10^-3)/(4\*N\*n\*h\*f\*(G-1)\*fe)); //Q-factor 37 38 // Displaying the result in command window 39 printf("\n OSNR is = %0.2 f dB",0); 40 printf(" $\n$  Q-factor is = %0.2 f",Q); 4142 // The answer vary due to round off error

Scilab code Exa 7.5 Computation of the transmission distance



Figure 7.5: Computation of the transmission distance

```
1 // Example 2.1
2 // Computation of the transmission distance
3 //
4 // Page no. 325
5
6 \, \text{clc};
7 clear;
8 close;
9
10 //Given data
11
12 fl=0.2
                              // Fiber loss
13 L=100;
                              // Amplifeir spacing
14 n=1.4;
                              // Planck constant
15 h=6.63*10^{-34};
                              // Velocity of light
16 c=3*10^8;
17 lambda=1.55*10<sup>-6</sup>;
18
19 q=1.6*10^{-19};
                             // Electron charge
20 R=0.9;
21 \quad d=0.1*10^{-9};
22 alpha=0.0461;
                            // Spacing
23 L=100;
24 Pi = -3;
                            // Mean fiber launch power
                            // Identical amplifers
25 / N = 80;
26 fe=7*10^9;
                            // Electrical filter
      bandwidth
27 q=6;
28 B=5*10^9;
29
30
31 // The transmission distance
32 l=fl*L;
33 \quad G=10^{(1/10)};
34 f=c/lambda;
35 / / r = N * n * h * f * (G-1);
36 Pi=10^{(-(2/10))};
37 N=Pi/(q^2*n*h*f*(G-1)*B);
```

S	Scilab 5.4.1 Console
File Edit Control Applications ?	
😰 🕒   👗 🕞 🗓   🏷   📇   📟   🛠   🍩 🔞	
Scilab 5.4.1 Console	2 A X
Q factor= 8.017	
>	

Figure 7.6: Computation of the Q factor  $% \mathcal{A}$ 

```
38 Td=N*L;
39 Td=Td*10^-3;
40
41 //Displaying the result in command window
42 printf("\n The transmission distance is = %0.0 f km",
        Td);
```

Scilab code Exa $7.6\,$  Computation of the Q factor

1 // Example 7.6

```
2 // Computation of the Q-factor.
3 //
4 // Page no. 327
5
6 \, \text{clc};
7 clear;
8 close;
9
10 //Given data
                          // Fiber loss coefficient
11 alpha=0.18;
                         // Fiber length
12 L=190;
                         // Gain of preamplifier
13 G=20;
14 lambda=1.55*10<sup>-6</sup>; // Operating wavelength
                      // Planck constant
15 h=6.63*10^{-34};
16 n=1.409;
17 G1=10^{(G/10)};
18 f0 = 20 * 10^9;
19 R=1.1;
20 q=1.6*10^{-19};
21 fe=7.5*10^9;
22 Pi=1;
                        // Input power
23 c=3*10^8;
                        // Velocity of light
24 k=1.38*10^{-23};
25 T=298;
26 R1 = 200;
27
28 // The Q factor
29 l=alpha*L;
30 \text{ Po=Pi-l+G};
31 Po=10^(Po/10) *10^-3;
32 f=c/lambda;
33 r=h*f*(G1-1)*n;
34 fn=2*n;
35 fn=10<sup>(fn/10)</sup>;
36 I1=R*Po+2*r*f0;
37 IO=2*R*r*f0;
38 o1=(2*q*I1*fe)+((4*k*T*fe)/R1)+(2*R^2*r*(2*Po*fe+r
      *(2*f0-fe)*fe));
```



Figure 7.7: Computation of the optimum amplifier configuration

Scilab code Exa 7.7 Computation of the optimum amplifier configuration

```
1 // Example 7.7
2 // Computation of the optimum amplifier
      configuration
3 //
4 // Page no. 329
5
6 \, \text{clc};
7 clear;
8 close;
9
10 //Given data
11
                     // Amplifier gain 1
12 G1=8;
13 G2=16;
                     // Amplifier gain 2
                     // Noise figure of amplifier 1
14 fn1=7;
15 fn2=5.5;
                     // Noise figure of amplifier 2
16 H = 7;
                     // Insertion loss of the DCF
                    // Identical amplifers
17 / N = 80;
18 fe=7 \times 10^9;
                     // Electrical filter bandwidth
19 // q=6;
20
21
22 // The optimum amplifier configuration
23
24 fn1=10^(fn1/10);
25 fn2=10^(fn2/10);
26 \quad G2=10^{(G2/10)};
27 H=10^{(H/10)};
28 Fna=fn2+(fn1/(G2*H));
29 Fna=10*log10(Fna);
30 \quad G = G2 + G1 + H;
31 Fnb=fn1+(fn2/(G1*H));
32
33 Fnb=10*log10(Fnb);
34
```



Figure 7.8: Computation of the length of the DCF and the gain G2 and the Q factor

```
38
```

39 // The answer vary due to round off error

Scilab code Exa 7.9 Computation of the length of the DCF and the gain G2 and the Q factor

```
1 // Example 7.9
2 // Computation of the (a) the length of the DCF (b)
       the gain G2 and (c) the Q-factor.
3
  4 // Page no. 331
5
6 \, \text{clc};
7 clear;
8 close;
9
10 //Given data
11 b = -21 * 10^{-27};
12 L=100*10^{3};
13 Lt=100;
14 1=0.18;
                           // Loss
                           // Dispersion coefficients of
15 \ 11=0.5;
      the TF
16 G1=16;
                           // Amplifier gain
                            // Mean transmitter output
17 p = -2;
      power
18 fe=7*10^9;
                           // Velocity of light
19 c=3*10^8;
                          // Planck constant
20 h=6.62*10^{-34};
                          // Noise figure of amplifier 1
21 fn1=5.5;
                          // Noise figure of amplifier 2
22 fn2=7.5;
23 \quad lambda=1.55*10^{-6};
                         // Dispersion coefficients of
24 \text{ bd} = 145 * 10^{-27};
      the DCF
25
26 // (a) The length of the DCF
27 st=b*L;
```

```
28 \text{ sd} = -0.9 \text{ st};
29 Ld=sd/bd;
30 \ Ld = Ld * 10^{-3};
31 // (b) Gain G2
32 Ht=l*Lt;
33 Hd=l1*Ld;
34 \quad G2 = Ht + Hd - G1;
35
36 // (c) Q factor
37 \text{ Ge} = \text{G1} + \text{G2} + - \text{Hd};
38 \text{ Ge} = 10^{(Ge/10)};
39 fn1=10<sup>(fn1/10)</sup>;
40 fn2=10<sup>(fn2/10)</sup>;
41 G1=10^{(G1/10)};
42 Hd=10^{(-Hd/10)};
43 Fe=fn1+(fn2/(G1*Hd))-(1/G1);
44 f=c/lambda;
45 r=70*h*f*((Ge*Fe)-1)/2);
46 Pi=2*10<sup>(p/10)</sup>*10<sup>-3</sup>;
47 Q=sqrt(Pi/(4*r*fe));
48
49
50 //Displaying the result in command window
51 printf("\n The length of the DCF = \%0.2 \text{ f km}",Ld);
52 printf("\n Gain G2 = \%0.2 f dB", G2);
53 printf("\n Q factor = \%0.1 f",Q);
54
55 // The answer vary due to round off error
```

### Chapter 8

## **Performance Analysis**

Scilab code Exa 8.2 Computation of error probability if the receiver is a balanced homodyne or a balanced heterodyne

```
1 // Example 8.1
2 // Computation of error probability if the receiver
       is (a) a balanced homodyne or (b) a balanced
      heterodyne
3 // Page no. 354
4
5 \, \text{clc};
6 clear;
7 close;
8
9 // Given data
10 Po=5;
                            // Lunch peak power
                            // Fiber loss
11 fl=50;
                            // Preamplifier Gain
12 G=30;
13 f = 10 * 10^9;
14 n=1.5;
15 h=6.63*10^{-34};
                            // Planck constant
                            // Velocity of light
16 c = 3 * 10^8;
```



Figure 8.1: Computation of error probability if the receiver is a balanced homodyne or a balanced heterodyne

```
17 lambda=1550*10<sup>-9</sup>;
18 q=1.6*10<sup>-19</sup>;
                            // Electron charge
19 R=0.9;
20
21 // Signal calculation
22 Pr=Po-fl+G;
23 Pr=10^(Pr/10)*10^-3;
24
25 \text{ Tb}=1/(f);
26 E=Pr*Tb;
27 f1=c/lambda;
28 G = 10^{(G/10)};
29 r=n*h*f1*(G-1);
30 / rs = q * I;
31 N=r+(q/(2*R));
32 Nh=r/2+(q/(2*R));
33
34 // Error probability
35 // (a) For a balanced homodyne receiver with PSK
      signal
36 Ps=1/2*erfc(sqrt(E/N));
37 E1 = E/2;
38 // If the signal is OOK
39 Pso=1/2*erfc(sqrt(E1/(2*N)));
40
41 //(b) For a balanced heterodyne receiver with PSK
      signal
42 Pb=1/2*erfc(sqrt(E/(2*Nh)));
43 //E1=E/2;
44 // If the signal is OOK
45 Pbo=1/2*erfc(sqrt(E1/(4*Nh)));
46
47 //Displaying the result in command window
48 printf("\n For a balanced homodyne receiver with PSK
       signal = \%0.2 f X 10^{-9} ", Ps*10^9);
49
50 printf("\n For a balanced homodyne receiver with PSK
       signal If the signal is OOK, = \%0.2 \text{ f X } 10^{-3},
```



Figure 8.2: Calculation of the maximum transmission distance

```
Pso*10^3);
51 printf("\n For a balanced heterodyne receiver with
        PSK signal = %0.3 f X 10^-9", Pb*10^9);
52 printf("\n For a balanced heterodyne receiver with
        PSK signal If the signal is OOK,= %0.2 f X 10^-3",
        Pbo*10^3);
53
54 // The answer vary due to round off error
```

Scilab code Exa 8.3 Calculation of the maximum transmission distance

```
1 // Example 8.3
2 // Calculation of the maximum transmission distance.
3 // Page no 394
4
5 clc;
6 clear;
7 close;
8
```

```
9 //Given data
10 p=3;
                                               // Peak power
                                              // Bit rate
11 tb=40*10^9;
                                              // Velocity of
12 c=3*10^8;
      light
13 lambda=1550*10^{-9};
                                             // Operating
      frequency
14 1=0.2;
                                             // Loss
                                             // Distance
15 d=80;
                                            // Gain
16 G=16
                                            // Planck
17 h=6.626*10^{-34}
      constant
18 n=1;
19 pb=10<sup>-5</sup>;
                                            // Error
      probability
  11 = 80 \times 10^{3};
20
                                            // N spans
21
22
23 // The maximum transmission distance
24
25 p=p+10*log10(1/2);
26 p = 10^{(p/10)} * 10^{-3};
27 t=1/(tb);
28 E=p*t;
29 f=c/lambda;
30 fl=l*d;
31 \quad G=10^{(G/10)};
32 r=n*h*f*(G-1); // Calculation is wrong in book.
33 //pb = 1/2 * (exp(-(E/r)));
34 \text{ N} = -(E/(\log(2*pb)*r));
35
36 L=N*11;
37
38 // Displaying results in the command window
39 printf("\n The maximum transmission distance = \%0.2 f
       km",L*10^-3);
40
41 // In the book PSD per amplifier calcualation is
```



Figure 8.3: o find the mean number of signal photons required in a shot noise limited coherent communication system

wrong, therefore final answer is wrong.

Scilab code Exa 8.6 o find the mean number of signal photons required in a shot noise limited coherent communication system

```
1 // Example 8.6
2 // To find the mean number of signal photons
required in a shot noise-limited coherent
communication system based on OOK for the
```

```
following cases: (i) balanced homodyne receiver;
      (ii) balanced heterodyne receiver (a) a balanced
      homodyne or (b) a balanced heterodyne
3 // Page no. 384
4
5 \, \text{clc};
6 clear;
7 close;
8
9 // Given data
10 Pb=1*10^{-9};
     //Error probability
                                                       11
11 neta=1;
     quantum efficiency
12
13 //a) for balanced homodyne receiver
14 Ns=(erfinv(1-(2*neta*Pb)))^2;
15
16 //(b) for balanced heterodyne receiver
17 Ns1=(erfinv(1-(2*neta*Pb))*sqrt(2))^2;
18
19 //Displaying the result in command window
20 printf("\n For a balanced homodyne receiver with PSK
       signal = \%0.0 f ",Ns);
21 printf("\n For a balanced heterodyne receiver with
     PSK signal = \%0.0 \text{ f} ",Ns1);
```

## Chapter 9

# Channel Multiplexing Techniques

Scilab code Exa 9.1 Calculation of the channel spacing and the signal bandwidth in a channel and other total bandwidth of the WDM signal and the total data rate

```
1 // Example 9.1
2 // Calculation of the (a) the channel spacing, (b)
      the signal bandwidth in a channel and other total
       bandwidth of the WDM signal, and (c) the total
      data rate.
3 // Page no 392
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10 Bs = 10 * 10^{12};
                                 // Symbol rate
                                // Spectral efficiency
11 n=6;
                                // Symbol rate
12 Fs = 10 * 10^{12};
```



Figure 9.1: Calculation of the channel spacing and the signal bandwidth in a channel and cther total bandwidth of the WDM signal and the total data rate

```
// No of channels
13 N=12;
14
15
16
17 // (a) Channel spacing
18 B=Bs*log2(64);
19 f=B/n;
20
21 // (b) Total bandwidth of the WDM signal
22 T1 = (N-1) * f + (2 * Fs) / 2;
23 T1 = T1 * 10^{-12};
24 // (c) Total data rate
25 T2=N*B;
26 T2 = T2 * 10^{-12};
27
28 // Displaying results in the command window
29 printf("\n Channel spacing = \%0.0 f GHz ",f*10^-12);
30
31 printf("\n Total bandwidth of the WDM signal = \%0.0 f
       GHz ", T1);
32 printf("\n Total data rate = \%0.0 \text{ f Gb/s}",T2);
```

Scilab code Exa 9.2 Calculation of the total power at the fiber output

```
1 // Example 9.2
2 // Calculation of the total power at the fiber
output.
3 // Page no 393
4
5 clc;
6 clear;
7 close;
8
```



Figure 9.2: Calculation of the total power at the fiber output

```
9 //Given data
10
                         // Power per channel
11 p=0;
                         // Fiber loss
12 fl=0.2;
13 f=50;
                         // Wavelength
14
15
16 // The total power at the fiber output.
17 pc=10<sup>(0.1*p)</sup>;
18 tp=pc*11;
19 tp1=10*log10(tp);
20 tfl=fl*f;
21 to=tp1-tf1;
22
23
24
25
26 // Displaying results in the command window
27 printf("\n The total power at the fiber output = \%0
      .3f dBm ",to);
```

Scilab code Exa 9.3 Calculation of The lengths of the adjacent waveguides and phase shift phi1 and phi2

```
1 // Example 9.3
2 // Calculation of a) The lengths of the adjacent
waveguides and b) phase shift phil and phi2.
3 // Page no 400
4 5 clc;
6 clear;
7 close;
8
```



Figure 9.3: Calculation of The lengths of the adjacent waveguides and phase shift phi1 and phi2  $\,$ 

```
9 //Given data
10
                              // Power per channel
11 p=0;
                               // Fiber loss
12 fl=0.2;
13 m1=100;
                              // Wavelength
14 m2=110;
15 \quad lambda1 = 1550 * 10^{-9};
16 lambda2=1550.8*10<sup>-9</sup>;
17 c=3*10^8;
                             // Velocity of light
18 b0=5.87*10^{6};
19 b1=4.86*10^{-9};
20
21 // a) The lengths of the adjacent waveguides
22 l1=(2*%pi*m1)/b0;
23 12=(2*%pi*m2)/b0;
24
25
26 / / b) Phase shift phi1 and phi2.
27 dfdl=-(c/lambda1^2);
28 dbdl=2*%pi*b1*dfdl;
29 phi1=2*%pi*m1+(lambda2-lambda1)*l1*dbdl;
30 phi2=2*\%pi*m2+(lambda2-lambda1)*l2*dbdl;
31
32 //Displaying results in the command window
33 printf("\n The lengths of the adjacent waveguides =
      %0.2f micrometer ",l1*10^6);
34 printf("\n The lengths of the adjacent waveguides =
       %0.2f micrometer",12*10^6);
35 printf("\n Phase shift phi1 = \%0.2 \text{ f x } 10^2 \text{ rad}",
      phi1*10^-2);
36 printf("\n Phase shift phi2 = \%0.2 f x 10<sup>2</sup> rad",
      phi2*10^-2);
37
38 // The answers vary due to round off error
```



Figure 9.4: Calculation of the maximum reach up to which the carrier orthogonality is preserved

Scilab code Exa 9.4 Calculation of the maximum reach up to which the carrier orthogonality is preserved

```
1 // Example 9.4
2 // Calculation of the maximum reach up to which the
      carrier orthogonality is preserved.
  // Page no 408
3
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10 b=22*10^{-27};
                                    // Power launched in
      port 1
11 T=1.28*10^{-9};
                                    // Guard interval
12 N=128;
                                    // Subcarriers
13 f=78.125*10<sup>6</sup>;
                                    // Frequency spacing
      between subcarriers
14
15 // Bit rate of communication system
16 I=T/(b*2*%pi*N*f);
17 I = I * 10^{-3};
18
19
20
21 //Displaying results in the command window
22 printf("\n The maximum reach up to which the carrier
       orthogonality is preserved = \%0.0 \,\mathrm{f} \,\mathrm{km} ",I);
23
24 // The answers vary due to round off error
```



Figure 9.5: Calculation of the maximum reach up to which the carrier orthogonality is preserved
Scilab code Exa 9.5 Calculation of the maximum reach up to which the carrier orthogonality is preserved

```
1 // Example 9.5
2 // Calculation of the maximum reach up to which the
      carrier orthogonality is preserved.
3 // Page no 410
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
                          // Delay
10 d=30*10^{-12};
11 b=0.5*10<sup>-8</sup>;
12
13 // The maximum reach up to which the carrier
      orthogonality is preserved
14 L=d/b;
15 L=L*10^3;
16
17
18
19 //Displaying results in the command window
20 printf("\n The maximum reach up to which the carrier
       orthogonality is preserved = \%0.3 \,\text{f} mm ",L);
21
22 // The answers vary due to round off error
```

Scilab code Exa 9.6 Calculation of the ODTM to multiplex data



Figure 9.6: Calculation of the ODTM to multiplex data

```
1 // Example 9.6
2 // Calculation of the ODTM to multiplex data.
3 // Page no 411
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10 f1 = 10 * 10^9;
11 f2=40*10^9;
12
13
14 // The ODTM to multiplex data
15 b1=1/(f1);
16 b2=1/(f2);
17 b1=b1*10^12;
18 b2=b2*10^12;
19
20 //Displaying results in the command window
21 printf("\n Bit interval for 10 Gb/s signal is = %0
      .0f ps ",b1);
22 printf("\n Bit interval for 40 Gb/s signal is = %0.0
      f ps ",b2);
23
24 // The answers vary due to round off error
```

Scilab code Exa 9.7 Calculation of the the total data rate and the spectral efficiency

```
1 // Example 9.7
2 // Calculation of the (a) the total data rate and (b
        ) the spectral efficiency.
```



Figure 9.7: Calculation of the the total data rate and the spectral efficiency

```
3 // Page no 413
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10 M=16;
                        // No of polarization
11 np=2;
                        // No of channels
12 nc=24;
13 bs = 28 * 10^9;
                      // Symbol rate per polarization
14
15 // (a) The total data rate
16 B = bs * log2(M);
17 T=B*np*nc;
18
19
20 // (b) The spectral efficiency
21 N=bs*nc;
22 s=T/N;
23
24 //Displaying results in the command window
25 printf("\n The total data rate = \%0.3 \text{ f Tb/s}",T
      *10^-12);
26
27 printf("\n The spectral efficiency = \%0.1 \text{ f b/s/Hz}",
      s);
```

Scilab code Exa 9.8 Calculation of the number of subcarriers required to transmit information

1 // Example 9.8
2 // Calculation of the number of subcarriers required



Figure 9.8: Calculation of the number of subcarriers required to transmit information  $% \left( {{{\left[ {{{\left[ {{\left[ {{\left[ {{{\left[ {{{c}}} \right]}} \right]_{i}} \right]_{i}}} \right]_{i}}}} \right]_{i}}} \right)$ 

```
to transmit information.
3 // Page no 413
4
5 clc;
6 clear;
7 close;
8
9 //Given data
10 M = 4;
                       // No of polarization
11 np=2;
                      // No of channels
12 nc=24;
                      // Symbol rate per polarization
13 bs=10*10^9;
                     // Transmission distance
14 d=5000*10^3;
15 b=22*10^{-27};
16 ts = 49.3 \times 10^{-9};
17
18 // The total data rate
19 B = bs * log2(M);
20 T=d*b*%pi*bs;
21 //L=T/(b*2*\%pi*N*bs);
22 N = (bs * ts) / 2;
23
24
  //Displaying results in the command window
25
  printf("\n The number of subcarriers required to
26
      transmit information = \%0.0 \text{ f} ",N);
27
  // The answers vary due to round off error
28
```

Scilab code Exa 9.9 Calculation of the signal power subcarrier polarization at the fiber output and the data rate and the spectral efficiency

1 // Example 9.9



Figure 9.9: Calculation of the signal power subcarrier polarization at the fiber output and the data rate and the spectral efficiency

```
2 // Calculation of the (a) the signal power/
      subcarrier/polarization at the fiber output, (b)
      the data rate and (c) the spectral efficiency
3 // Page no 414
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
                        // Fiber loss
10 fl=0.19;
                        // Fiber length
11 fg=70;
12 nc=24;
                       // No of channels
13 ip=2;
14 bs=10*10^9;
                       // Symbol rate per polarization
                       // Symbol period
15 ts= 12.8*10<sup>-9</sup>;
                       // No of subcarriers
16 n=64;
                       // Launch power to the fiber
17 np=2;
18
19
  // (a) The signal power/subcarrier/polarization at
20
      the fiber output
```

```
21 T=fl*fg;
22 p=ip-T;
23 p1=10<sup>(p/10)</sup>;
24 s=p1/(np*n);
25 // s=s*10^{4};
26
27 // (b) The data rate
28 \text{ bs}=1/\text{ts};
29 B=\log 2(n) * bs;
30 bt=B*2*n;
31
32 // (c) the spectral efficiency
33 Tb=n*bs;
34 se=bt/Tb;
35
36
37
38
39 //Displaying results in the command window
40 printf("\n The signal power/subcarrier/polarization
       at the fiber output = \%0.3 \,\text{f} \times 10^{-4} \,\text{mW}", s*10^4);
41
42 printf("\n The data rate = \%0.0 \text{ f Gb/s}", bt*10^-9);
43
44 printf("\n The spectral efficiency = \%0.0 \text{ f b/s/Hz}",
      se);
45
  // The answers vary due to round off error
46
```

## Chapter 10

## Nonlinear Effects in Fibers

Scilab code Exa 10.1 Calculation of the non linear coefficient

```
1 // Example 10.1
2 // Calculation of the non linear coeffifient.
3 // Page no 429
4
5 \text{ clc};
6 clear;
7 close;
8
9 //Given data
                                           // Kerr
10 n2=2.5*10^{-20};
      coefficient
                                          // Wavelength
11 lambda=1550*10^{-9};
12 A = 80 * 10^{-12};
                                          // Effective area
13
14
15
16 // Non linear coeffifient
17 g=(n2*2*%pi)/(lambda*A);
18 g=g*10^3;
```



Figure 10.1: Calculation of the non linear coeffifient



Figure 10.2: Calculation of the lower limit on the effective area of the fiber

```
19
20
21 //Displaying results in the command window
22 printf("\n Nonlinear coefficient = %0.3 f W^-lm^-l ",
    g);
```

Scilab code Exa 10.2 Calculation of the lower limit on the effective area of the fiber

1 // Example 10.2

```
2 // Calculation of the lower limit on the effective
      area of the fiber.
3 // Page no 431
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
10
11 c=3*10^8;
                              // Velocity of light
                             // Total length
12 tl=1000*10^3;
                             // Amplifier spacing
13 as=100*10^3;
14 alpha=0.046*10^-3;
                           // Loss coefficient
15 L=100*10^3;
16 n2=2.5*10^{-20};
                            // Kerr coefficient
                            // Peak power at the fiber
17 p=0;
      input
                            // Operating frequency
18 lambda=1550*10^-9;
19
20 // The peak power required to form a soliton
21 Le=(1-exp(-alpha*L))/alpha;
22 n=tl/as;
23 p=10^{(p/10)};
24 r=0.5/(Le*p);
25 A=(2*%pi*n2)/(lambda*r);
26 \quad A = A * 10^{12};
27
28 // Displaying results in the command window
29 printf("\n The lower limit on the effective area of
      the fiber = \%0.2 f micrometer 2^{\circ}, A*10^-2);
30 printf("\n The effective area should be greater than
       43.62 m2 to have the peak nonlinear phase
      shift less than or equal to 0.5 rad.");
31
32
33 // The answers vary due to round off error
```



Figure 10.3: Calculation of the peak power required to form a soliton

Scilab code Exa10.3 Calculation of the peak power required to form a soliton

```
1 // Example 10.3
2 // Calculation of the peak power required to form a
      soliton
3 // Page no 435
4
5 clc;
```

```
6 clear;
7 close;
8
9 //Given data
10
11 b=-21*10^-27; // FWHM of a fundamental soliton
12 Tf=50*10^-12; // Fiber dispersion coefficient
                        // Nonlinear coefficient
13 r=1.1*10^{-3};
14
15 // The peak power required to form a soliton
16 Th=asech(sqrt(0.5));
17 f=2*Th;
18 TO=Tf/f;
19 n=(sqrt(-b))/T0;
20 P = (n^2) / r;
21 //P=P * 10^{2};
22
23
24 // Displaying results in the command window
25 printf("\n The peak power required to form a soliton
       = %0.1 f mW", P*10^2);
26
27 // Answer is wrong in book
```

Scilab code Exa 10.4 Calculation of the peak power required to form a soliton

```
1 // Example 10.4
2 // Calculation of the peak power required to form a
        soliton
3 // Page no 444
4
5 clc;
```



Figure 10.4: Calculation of the peak power required to form a soliton

```
6 clear;
7 close;
8
9 // Given data
10
11 c=3*10^8;
                                 // Velocity of light
12 S=0.06*10^3;
                               // Dispersion slope
13 D=17*10^{-6};
                               // Dispersion coefficient
14 lambda=1550*10^-9;
                              // Signal Wavelength
                              // Signal Wavelength
15 \ lc=1550*10^{-9};
16 lp=1549.6*10<sup>-9</sup>;
                              // Pump wavelength
17 \ 1=50*10^3;
                               // Length
18 r=2*%pi*10^10;
19 alpha=0.046*10<sup>-3</sup>; // Loss coefficient
20
21 // The peak power required to form a soliton
22 b3=S*(lambda<sup>2</sup>/(2*%pi*c))+D*(lambda<sup>3</sup>/(2*%pi<sup>2</sup>*c<sup>2</sup>))
      ;
23 b2=-(D*lambda^2)/(2*%pi*c);
24 o=2*%pi*(c/lp-c/lc);
25 d = (b2*o) + (b3*o^2)/2;
26 n=alpha<sup>2</sup>/alpha<sup>2</sup>*r*4*d<sup>2</sup>*(1+(4*(sin(r*d*l))<sup>2</sup>*%e<sup>(-</sup>
      alpha*1))/(1-%e^(-alpha*1)^2));
27 n=n*10^{-18};
28 // Displaying results in the command window
29 printf ("\n XPM efficiency = \%0.3 \text{ f } *10^{-3}", n);
30
31
32 // The answers vary due to round off error
```

Scilab code Exa 10.5 Calculate the efficiency of the non degenerate FWM tone if beta2 equal to negative 4 and beta2 equal to 0



The efficiency of the non-degenerate FWM tone at  $-2\Delta f$  (beta2 = 0ps^2/km) = 1

Figure 10.5: Calculate the efficiency of the non degenerate FWM tone if beta2 equal to negative 4 and beta2 equal to 0

```
1 // Example 10.5
2 // Calculate the efficiency of the non-degenerate
      FWM tone at 2 f if (a) beta 2 = 4 \text{ ps} 2/\text{km}, (
      b) beta 2 = 0 \text{ ps}^2/\text{km}.
   // Page no 453
3
4
5 \, \text{clc};
6 clear;
7 close;
8
9 //Given data
                                                           11
10 f = 50 * 10^9;
      The bandwidth
11 alpha= 0.046*10<sup>-3</sup>;
                                                           //
      The fiber loss coefficient
12 L=40*10^3;
                                                           //
      The fiber length
13
14 Leff=(1-exp(-(alpha*L)))/alpha;
                                                          //
      Effective fiber length
15
16 // (a) Calculate the efficiency of the non-
```

```
degenerate FWM tone at 2 f beta 2 = 4 \text{ ps}^2/
      km
17 bet21 = -4 * 10^{(-12)};
18 j = -1;
19 k=0;
20 \ l=1;
21 n=j+k-1;
22
23 bet1=bet21*10^(-12)/10^(3)*(2*%pi*f)^2*n;
24
25 //The efficiency of the non-degenerate FWM tone
26 neta1=(alpha^2+4*\exp(-alpha*L*10^3)*(sind(bet1*(L
      *10^3)/2))/Leff^2)/(alpha^2+bet1^2);
27
28 //Displaying results in the command window
29 printf("\n The efficiency of the non-degenerate FWM
      tone at
               2 f (beta2 = 4 p s 2/km) = 0.1 f X
      10^{(-3)} ",neta1*10^3);
30
31 // (b) Calculate the efficiency of the non-
      degenerate FWM tone at 2 \text{ f} \text{ beta} 2 = 0 \text{ ps}^2/\text{km}
32 bet22=0*10<sup>(-12)</sup>;
33 j = -1;
34 k=0;
35 \ 1=1;
36 n = j + k - 1;
37
38 bet2=bet22*10<sup>(-12)</sup>/10<sup>(3)</sup>*(2*%pi*f)<sup>2</sup>*n;
39
40 //The efficiency of the non-degenerate FWM tone
41 neta2=(alpha^2+4*\exp(-alpha*L*10^3)*(sind(bet2*(L
      *10^3)/2))/Leff^2)/(alpha^2+bet2^2);
42
43 //Displaying results in the command window
44 printf("\n\n The efficiency of the non-degenerate
      FWM tone at 2 f (beta2 = 0 \text{ ps}^2/\text{km}) = \%0.0 \text{ f} ",
      neta2);
```



Figure 10.6: To find the nonlinear phase shift at the center of the pulse and Compare the exact results with those obtained using first and second order perturbation theory

Scilab code Exa 10.6 To find the nonlinear phase shift at the center of the pulse and Compare the exact results with those obtained using first and second order perturbation theory

```
1 // Example 10.6
2 // to find the nonlinear phase shift at the center
of the pulse. Compare the exact results with
those obtained using first and second-order
perturbation theory
3 // Page no 469
4 
5 clc;
6 clear;
7 close;
8 
9 //Given data
```

```
10 P=6*10^{(-3)};
                                                       //
      The peak power of rectangular pulse
11 L=40*10^3;
                                                       //
      Fiber of length
12 Floss=0.2;
                                                       11
      The fiber loss (dB/Km)
13 gamm = 1.1 * 10^{(-3)};
14
15 alpha=Floss/4.343;
                                                       //
      Attenuation coefficient
16 Zeff=(1-exp(-alpha*10^(-3)*L))/alpha*10^3;
17
18 // The nonlinear phase shift at the center of the
      pulse
                                                       11
19 phi=gamm*P*Zeff;
      Nonlinear phase shift
20
21 //Displaying results in the command window
22 printf("\n The nonlinear phase shift at the center
      of the pulse = \%0.4 \, \text{f} rad ", phi);
23
24
25 // Results using first order
26 B01=sqrt(1+gamm^2*P^2*(Zeff)^2);
                                                       //
      Amplitude shift
27
  thet1=atan(gamm*P*Zeff);
                                                       11
      Non-linear phase shift
28
29 //Displaying results in the command window
30 printf("\n\n Amplitude shift using first order = \%0
      .3 f ",B01);
31 printf("\n Non-linear shift using first order = \%0.5
      f rad",thet1);
32
33 // Results using second order
34 x=1-((gamm)^2/2*P^2*Zeff^2);
35 y=gamm*P*Zeff;
36 thet2=atan(y/x);
                                                       //
```



Figure 10.7: Calculation of the variance of linear phase noise and nonlinear phase noise at the receiver

```
Nonlinear phase shift
37 B02=x/cos(thet2); //
Amplitude shift
38
39 //Displaying results in the command window
40 printf("\n\n Amplitude shift using second order = %0
.5f ",B02); // Answer is varying due
to round-off error
41 printf("\n Non-linear shift using second order = %0
.5f rad",thet2); // Answer is varying due
to round-off error
```

Scilab code Exa 10.7 Calculation of the variance of linear phase noise and nonlinear phase noise at the receiver

```
1 // Example 10.7
2 // Calculation of the variance of (a) linear phase
noise, (b) nonlinear phase noise at the receiver
```

```
3 // Page no 477
4
5 clc;
6 clear;
7 close;
8
9 //Given data
10
                                  // Loss coeffient
11 alpha=0.0461;
                                 // No of amplifiers
12 na=20;
13 L=80;
                                 // Amplifier spacing
14 tb=25 * 10^{-12};
                                 // Pulse width
                                 // Peak power
15 P=2*10^{-3};
16 c = 3 * 10^8;
                                 // Velocity of light
17 lambda=1550*10<sup>-9</sup>;
18 n=1.5;
                                 // Spontaneous emission
      factor
19 h=6.626*10^{-34};
                                 // Planck constant
20 \text{ r0}=1.1*10^{-3};
                                 // Nonlinear coefficient
21
22 // a) linear phase noise at the receiver
23 G=exp(alpha*L);
24 f=c/lambda;
25 R=h*f*(G-1)*n;
26 E=P*tb;
27 rl=(na*R)/(2*E);
28 rl=rl*10^3;
29
30 // (b) nonlinear phase noise at the receiver
31 Le=(1-exp(-alpha*L))/alpha;
32 rnl=((na-1)*na*(2*na-1)*R*E*r0^2*Le^2)/(3*tb^2);
33 rnl=rnl*10^9;
34
35 t=rl+rnl;
36
37 //Displaying results in the command window
38 printf("\n The linear phase noise at the receiver =
      %0.2f rad^2 ",rl);
```



Figure 10.8: Calculation of the Stokes signal power at the fiber output

- 39 printf("\n The nonlinear phase noise at the receiver  $= \%0.2 \text{ f rad}^2$ ",rnl);
- 40 printf("\n The total variance =  $\%0.2 \text{ f X } 10^{-3} \text{ rad}^2$ ",t);

Scilab code Exa $10.8\,$  Calculation of the Stokes signal power at the fiber output

1 // Example 10.8

```
2 // Calculation of the Stokes signal power at the
      fiber output
3 // Page no 480
4
5 clc;
6 clear;
7 close;
8
9 //Given data
                                   // Input power pump
10 p1=20;
                                   // Input Stokes s
11 ps = -10;
      signal power
12 alpha=0.08;
13 L=2;
                                 // Length of fiber
14 alpha1=0.046;
15 A = 40 * 10^{-12};
                                 // Effective area of
      fiber
16 g=1*10^{-13};
                                 // Raman coefficient of
      the fiber
17
18 // The Stokes signal power at the fiber output
19 p1=10<sup>(p1/10)</sup>;
20 ps=10<sup>(ps/10)</sup>;
21 Le=(1-exp(-alpha*L))/alpha;
22 s=(g*p1*Le)/A;
23 d=alpha1*L;
24 pd=ps*%e^(-d+s);
25
26
27
28 // Displaying results in the command window
29 printf("\n The Stokes signal power at the fiber
      output = \%0.15 f \text{ mW} ",pd);
```

## Chapter 11 Digital Signal Processing

Scilab code Exa 11.1 Calculation of the minimum number of taps needed to compensate for the fiber dispersion

```
1 // Example 11.1
2 // Calculation of the minimum number of taps needed
      to compensate for the fiber dispersion
  // Page no 509
3
4
5 \, \text{clc};
6 clear;
7 close;
8
9 // Given data
10 b=22*10^{-27};
                                   // Power launched in
      port 1
                                   // Power launched in
11 1=800*10^3;
      port 2
12 T=50*10^{-12};
                                  // Power launched in
      port 3
13
14
```



Figure 11.1: Calculation of the minimum number of taps needed to compensate for the fiber dispersion

```
15 // Bit rate of communication system
16 k=ceil((%pi*b*l)/T^2);
17 n=(2*k)+1;
18
19
20 // Displaying results in the command window
21 printf("\n The number of the taps = %0.3 f ",n);
22
23 // The answers vary due to round off error
```