

Scilab Textbook Companion for
Optical Fiber Communication
by A. Selvarajan, S. Kar and T Srinivas¹

Created by
Lochan Jolly
Optical communication
Electrical Engineering
Tcet
College Teacher
None
Cross-Checked by
Reshma

July 31, 2019

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

Book Description

Title: Optical Fiber Communication

Author: A. Selvarajan, S. Kar and T Srinivas

Publisher: McGraw-Hill, New Delhi

Edition: 1

Year: 2002

ISBN: 0070445567

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes	4
2 Light propagation in optical fiber	6
3 Fiber optic technology	22
4 Optical sources and transmitter circuits	26
5 Optical Detectors and Receivers	35
6 Integrated Optics and Photonic Circuits	44
7 Wavelength Division Multiplexing	54
8 Coherent Optical Communication	57
9 Optical Amplifiers	60
10 Photonic Switching	66
11 Fiber Optic Communication System Design	70
13 Video Transmission	76
14 Data Communication and LAN	79

List of Scilab Codes

Exa 2.1	1	6
Exa 2.2	2	7
Exa 2.3	3	9
Exa 2.4	4	13
Exa 2.6	6	13
Exa 2.8	8	15
Exa 2.9	9	18
Exa 2.10	10	19
Exa 3.1	1	22
Exa 3.2	2	22
Exa 4.1	1	26
Exa 4.2	2	28
Exa 4.3	3	30
Exa 4.4	4	32
Exa 5.1	1	35
Exa 5.2	2	37
Exa 5.3	3	38
Exa 5.4	4	40
Exa 5.5	5	41
Exa 6.1	1	44
Exa 6.2	2	47
Exa 6.3	3	47
Exa 6.4	4	50
Exa 6.5	5	50
Exa 6.6	6	52
Exa 7.1	1	54
Exa 8.1	1	57
Exa 9.1	1	60

Exa 9.2	2	62
Exa 9.3	3	63
Exa 10.1	1	66
Exa 10.2	2	66
Exa 11.1	1	70
Exa 11.2	2	72
Exa 13.1	1	76
Exa 14.1	1	79
Exa 16.1	1	82
Exa 16.2	2	84
Exa 16.3	3	85
Exa 16.4	4	86
Exa 16.5	5	88

List of Figures

2.1	1	8
2.2	2	10
2.3	3	11
2.4	4	12
2.5	6	14
2.6	8	16
2.7	9	17
2.8	10	19
3.1	1	23
3.2	2	25
4.1	1	27
4.2	2	29
4.3	3	31
4.4	4	33
5.1	1	36
5.2	2	37
5.3	3	39
5.4	4	40
5.5	5	42
6.1	1	45

6.2	2	.....	46
6.3	3	.....	48
6.4	4	.....	49
6.5	5	.....	51
6.6	6	.....	53
7.1	1	.....	55
8.1	1	.....	58
9.1	1	.....	61
9.2	2	.....	62
9.3	3	.....	64
10.1	1	.....	67
10.2	2	.....	68
11.1	1	.....	71
11.2	2	.....	73
13.1	1	.....	77
14.1	1	.....	80
16.1	1	.....	83
16.2	2	.....	84
16.3	3	.....	85
16.4	4	.....	87
16.5	5	.....	88

Chapter 2

Light propagation in optical fiber

Scilab code Exa 2.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 2.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //case-1
8 ncore=1.46//refractive index of core
9 nclad=1//refractive index of cladding
10 c=3e5//velocity of light in Km/s
11 L=1// length of path in Km
12 NA=sqrt(ncore^2-nclad^2)//Numerical aperture
13 deltat_tau_by_L=(NA^2)/(2*c*ncore) //multipath pulse
    broadening in s/Km
14 deltat_tau=deltat_tau_by_L*L//bandwidth distance product
    Hz
15 BL=(1/deltat_tau)*L//bandwidth distance product Hz
16 mprintf('Numerical aperture=%f',NA);//The answers
    vary due to round off error
```

```

17 mprintf('\nMultipath pulse broadening=%fns/Km',
    delt_tau_by_L*1e9);//The answer provided in the
    textbook is wrong//multiplication by 1e9 to
    convert s/Km to ns/Km
18 mprintf('\nBandwidth distance product=%fMHz',BL*1e
    -6);//The answer provided in the textbook is
    wrong//multiplication by 1e-6 to convert Hz to
    MHz
19 //case-2
20 ncore=1.465//refractive index of core
21 nclad=1.45//refractive index of cladding
22 NA=sqrt(ncore^2-nclad^2)//Numerical aperture
23 delt_tau_by_L=(NA^2)/(2*c*ncore) //multipath pulse
    broadening in s/m
24 BL=(1/delt_tau_by_L)*L//bandwidth distance product
    Hz
25 mprintf('\n\nNumerical aperture=%f',NA);
26 mprintf('\nMultipath pulse broadening=%fns/Km',
    delt_tau_by_L*1e9);//The answer provided in the
    textbook is wrong//multiplication by 1e9 to
    convert s/Km to ns/Km
27 mprintf('\nBandwidth distance product=%fGHz',BL*1e
    -9);//The answer provided in the textbook is
    wrong//multiplication by 1e-6 to convert Hz to
    GHz

```

Scilab code Exa 2.2 2

```

1 //Optical Fiber communication by A selvarajan
2 //example 2.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;

```

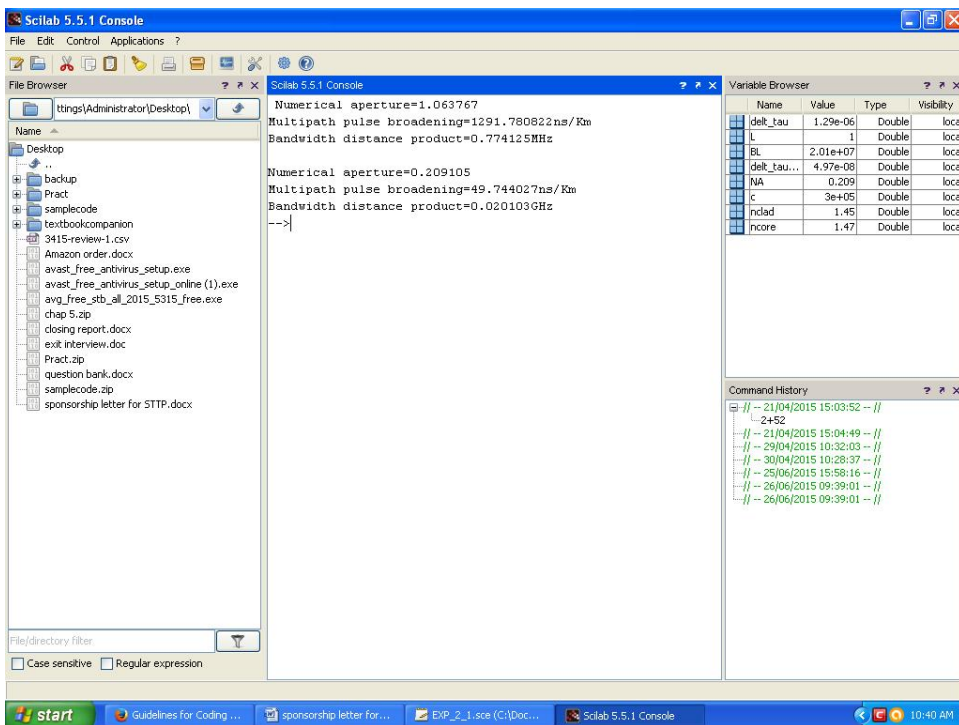


Figure 2.1: 1

```

6 clear all;
7 lamda1=0.7//wavelength in um
8 lamda2=1.3//wavelength in um
9 lamda3=2//wavelength in um
10 f_lambda1=(303.33*(lamda1^-1)-233.33)//equation for
    lambda1
11 f_lambda2=(303.33*(lamda2^-1)-233.33)//equation for
    lambda2
12 f_lambda3=(303.33*(lamda3^-1)-233.33)//equation for
    lambda3
13 mprintf("Material dispersion at Lambda 0.7um=%f",
    f_lambda1)
14 mprintf("\nMaterial dispersion at Lambda 1.3um=%f",
    f_lambda2)//The answers vary due to round off
    error
15 mprintf("\nMaterial dispersion at Lambda 2um=%f",
    f_lambda3)//The answers vary due to round off
    error
16 mprintf('\nIts is a standard silica fiber')

```

Scilab code Exa 2.3 3

```

1 //Optical Fiber communication by A selvarajan
2 //example 2.3
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 ncore=1.505//refractive index of core
9 nclad=1.502//refractive index of cladding

```

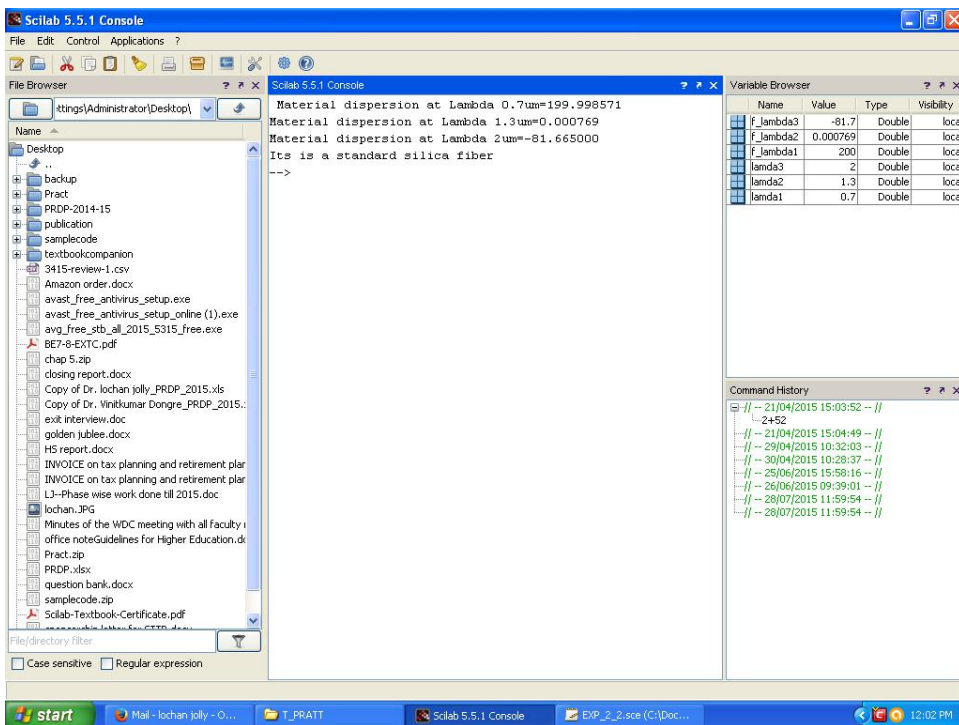


Figure 2.2: 2

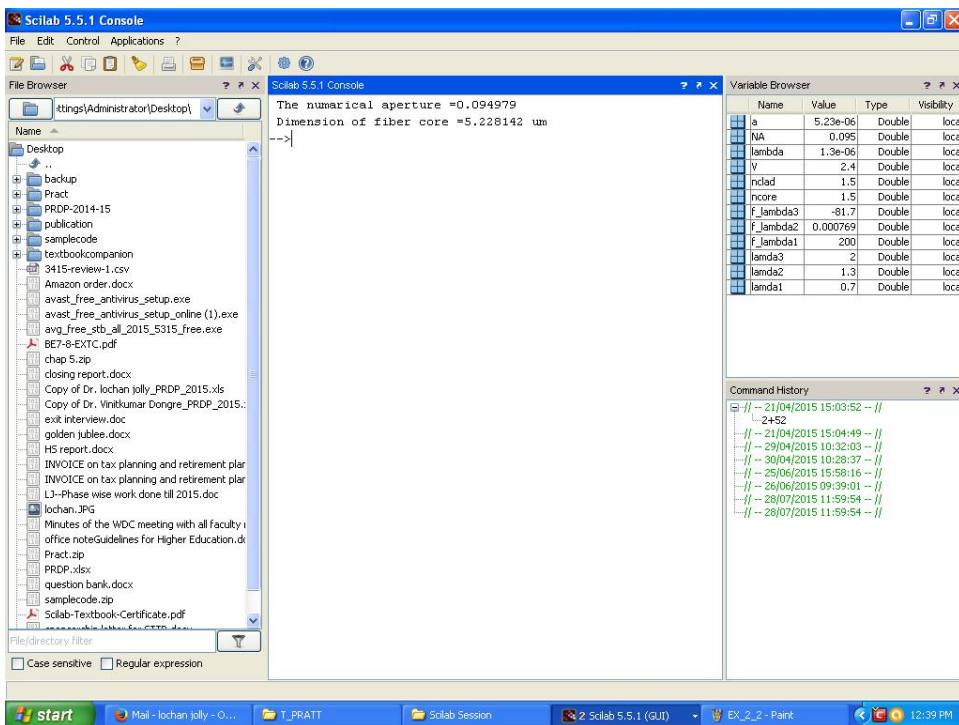


Figure 2.3: 3

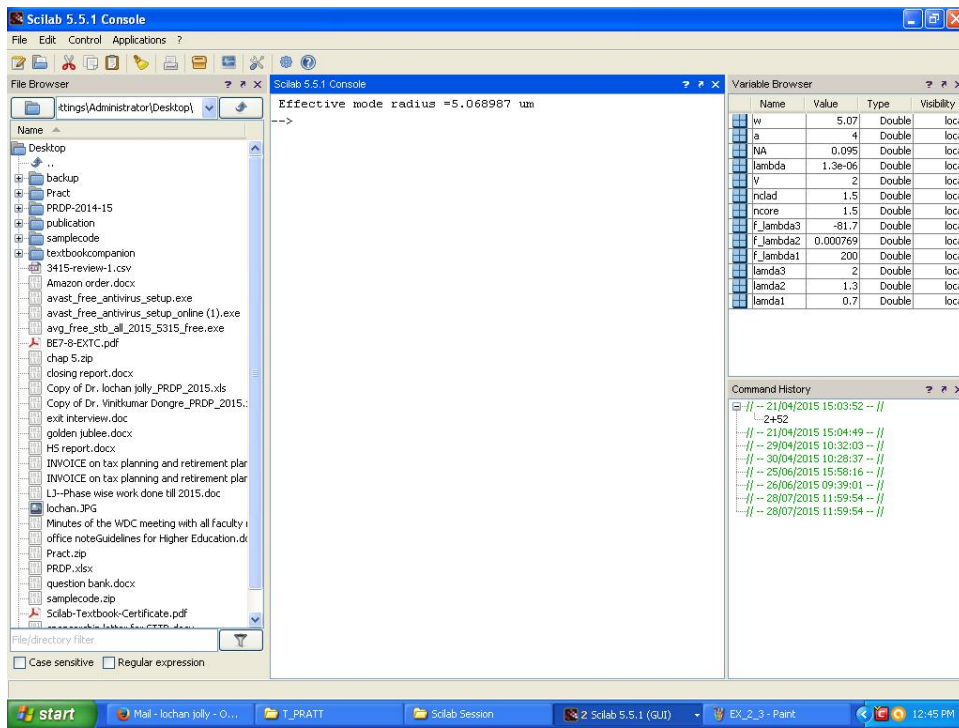


Figure 2.4: 4

```

10 V=2.4//v no. for single mode
11 lambda=1300e-9//operating wavelength in m
12 //to find
13 NA=sqrt(ncore^2-nclad^2)//numerical aperture
14 a=V*(lambda)/(2*%pi*NA)//dimension of fiber core in
    m
15 //display
16 mprintf("The numarical aperture =%f",NA);
17 mprintf("\n Dimension of fiber core =%f um",a*1e6)//
    multiplication by 1e6 to convert unit from m to
    um

```


Scilab code Exa 2.4 4

```
1 //Optical Fiber communication by A selvarajan
2 //example 2.4
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8
9 V=2//v no. for single mode
10 a=4//radius of fiber in um
11 //to find
12 w=a*(0.65+1.619*V^(-3/2)+2.87*V^-6)//effective mode
    radius in um
13 //display
14
15 mprintf(" Effective mode radius =%f um",w)
```

Scilab code Exa 2.6 6

```
1 //Optical Fiber communication by A selvarajan
2 //example 2.6
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 m=0// for dominant mode
9 v=0// for dominant mode
10 n1=1.5// refractive index of core
11 delta=0.01// core clad index difference
12 a=5// fiber radius in um
```

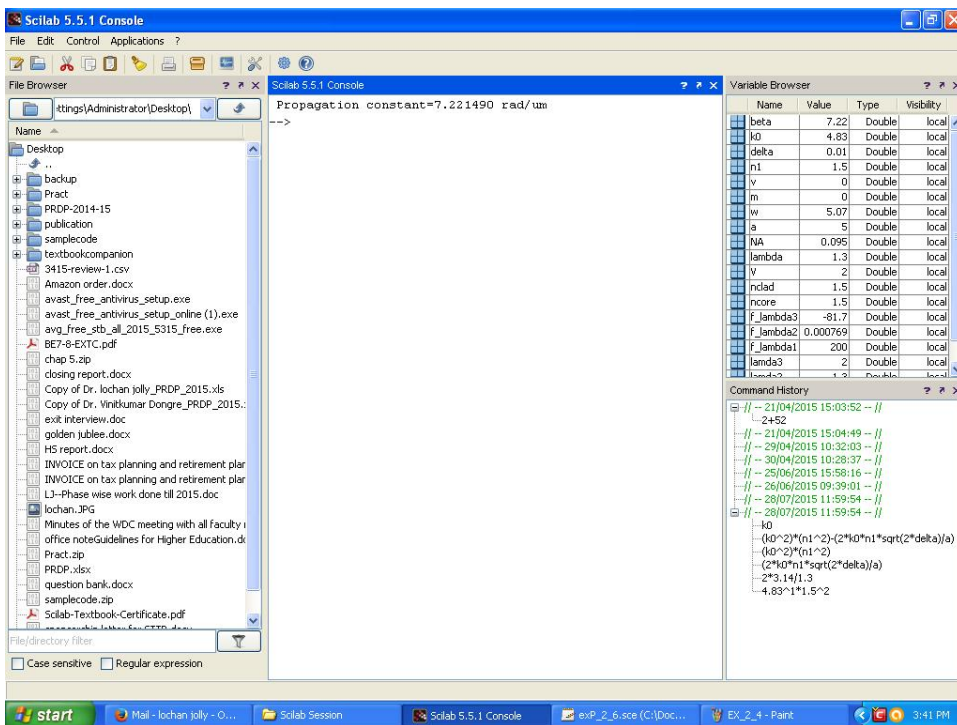


Figure 2.5: 6

```

13  lambda=1.3//wavelength of operation in um
14  // to find
15  k0=(2*%pi/lambda)//constant in /m
16  beta=sqrt((k0^2)*(n1^2)-(2*k0*n1*sqrt(2*delta)/a))//
    propagation constant in rad/um
17  mprintf('Propagation constant=%f rad/um',beta)//The
    answers vary due to round off error

```

Scilab code Exa 2.8 8

```

1  //Optical Fiber communication by A selvarajan
2  //example 2.8
3  //OS=Windows XP sp3
4  //Scilab version 5.5.1
5  clc;
6  clear all;
7  //given
8  M=1000;//modes supported
9  lambda=1.3;//operating wavelength in um
10 n1=1.5;//refractive index of core
11 n2=1.48;//refractive index of cladding
12 //to find
13 V=sqrt(2*M)// normalised frequency V no.
14 NA=sqrt(n1^2-n2^2)//numerical apperture
15 R=lambda*V/(2*%pi*NA)//radius of fiber in um
16 //display
17 mprintf("Core Radius=%fum",R)//The answer provided
    in the textbook is wrong

```

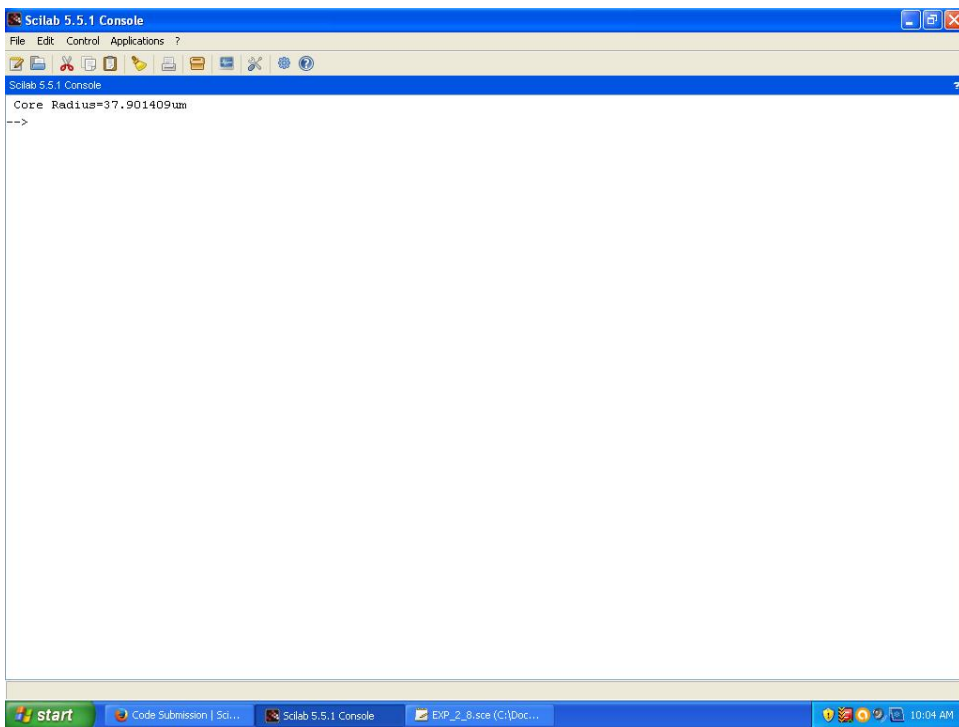


Figure 2.6: 8

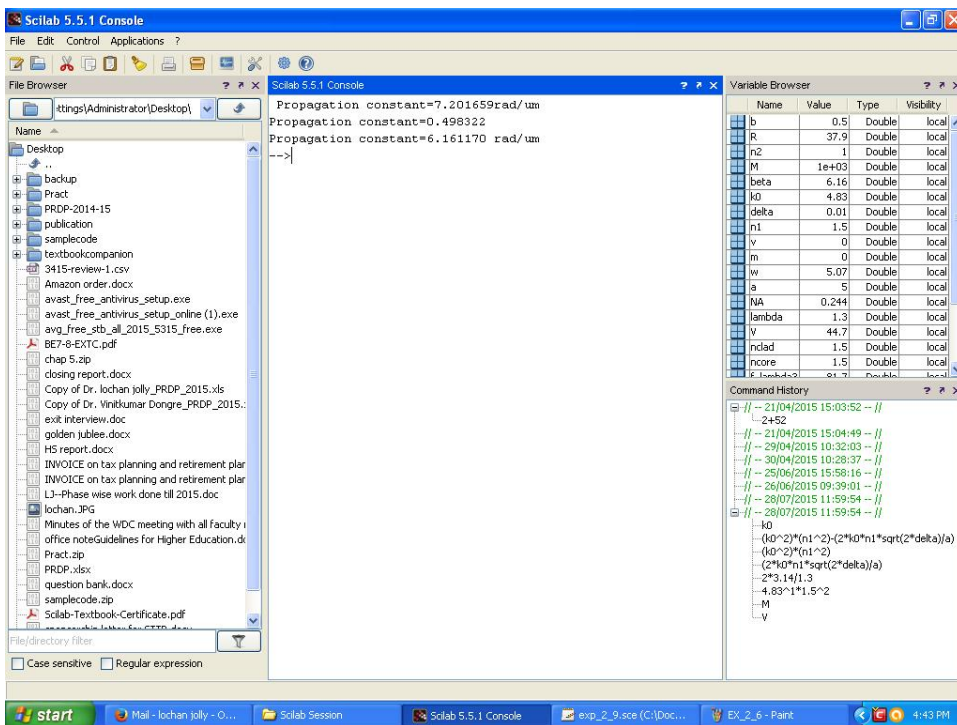


Figure 2.7: 9

Scilab code Exa 2.9 9

```
1 //Optical Fiber communication by A selvarajan
2 //example 2.9
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 lambda=1.3;//wavelength of operation in um
9 n1=1.5;// refractive index of core
10 n2=1.48;// refractive index of cladding
11 k0=2*%pi/lambda;//constant in /m
12 //case-1
13 b=0.5//normalized propagation constant
14 k0=2*%pi/lambda//constant
15 beta=k0*sqrt(n2^2+b*(n1^2-n2^2))//propagation
    constant
16 mprintf("Propagation constant=%frad/um",beta)//The
    answers vary due to round off error
17 //case-2
18 //given
19 lambda=1.3;//wavelength of operation in um
20 n1=1.5;// refractive index of core
21 n2=1.48;// refractive index of cladding
22 k0=2*%pi/lambda;//constant in /m
23 b=0.5//normalized propagation constant
24 k0=2*%pi/lambda//constant
25 b=((n1+n2)/2)^2-n2^2)/(n1^2-n2^2)//normalized
    propagation constant
26 mprintf("Propagation constant=%f ",b)//The answers
    vary due to round off error
27
28 //case-3
29 //given
30 lambda=1.3;//wavelength of operation in um
31 n1=1.5;// refractive index of core
32 n2=1.0;// refractive index of cladding
```

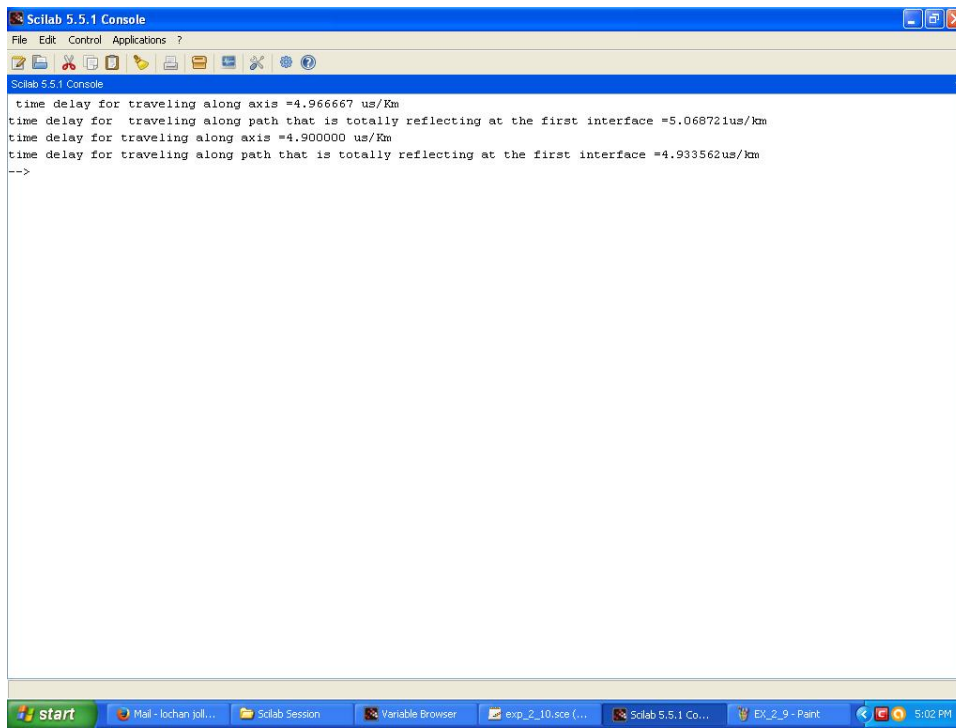


Figure 2.8: 10

```

33 k0=2*%pi/lambda;//constant in /m
34 b=0.5//normalized propagation constant
35 k0=2*%pi/lambda//constant
36 beta=k0*sqrt(n2^2+b*(n1^2-n2^2))//propagation
   constant
37 mprintf("\nPropagation constant=%f rad/um",beta)//
   The answers vary due to round off error

```

Scilab code Exa 2.10 10

```

1 //Optical Fiber communication by A selvarajan

```

```

2 //example 2.10
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 //case-1
9 n1=1.49;//refractive index of core
10 n2=1.46//refractive index of cladding
11 c=3*10^5;//speed of light in Km/s
12 t1=n1/c;//time delay for one traveling along axis in
    s/Km
13 t2=(n1^2/n2)/c//time delay for one traveling along
    path that is totally reflecting at the first
    interface in s/km
14 mprintf("time delay for traveling along axis =%f us/
    Km",t1*1e6)//multiplication by 1e6 to convert the
    unit from s/Km to us/Km
15 mprintf("\\ntime delay for traveling along path that
    is totally reflecting at the first interface =
    %fus/km",t2*1e6)//multiplication by 1e6 to
    convert the unit from s/Km to us/Km
16 //case-2
17 n1=1.47;//refractive index of core
18 n2=1.46//refractive index of cladding
19 c=3*10^5;//speed of light in Km/s
20 t1=n1/c;//time delay for one traveling along axis in
21 t2=(n1^2/n2)/c//time delay for one traveling along
    path that is totally reflecting at the first
    interface
22 mprintf("\\ntime delay for traveling along axis =%f
    us/Km",t1*1e6)//multiplication by 1e6 to convert
    the unit from s/Km to us/Km
23 mprintf("\\ntime delay for traveling along path that
    is totally reflecting at the first interface =
    %fus/km",t2*1e6)//multiplication by 1e6 to
    convert the unit from s/Km to us/Km
24

```


25 //The answer provided in the textbook is wrong it
has got wrong unit

Chapter 3

Fiber optic technology

Scilab code Exa 3.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 PL=1;//length of preform in m
9 PD=25e-3;//diameter of preform in m
10 OD=125e-6;//outer diameter of optical fiber in m
11 V=%pi*((PD/2)^2)*PL;//volume of Preform cylinder in
    m^3
12 L=V/(%pi*((OD)^2));//Length of optical fiber in m
13 mprintf("Length of optical fiber=%fKm",L/1e3);//
    division by 1e3 to convert unit from m to Km
```

Scilab code Exa 3.2 2

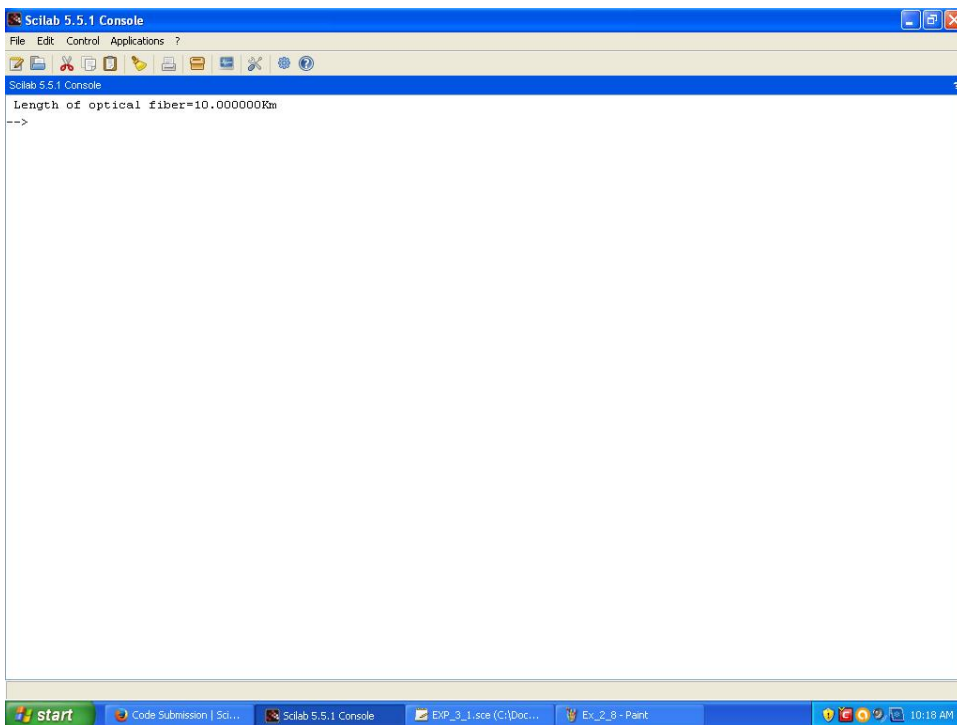


Figure 3.1: 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 3.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 NA1=0.2;//numerical apperture of fiber 1
9 NA2=0.1;//numerical apperture of fiber 2
10 D1=12;// core daimeter of fiber 1 in um
11 D2=6;// core daimeter of fiber 2 in um
12 Losses=20*log10(NA1/NA2)+20*log10(D1/D2);// total
    fiber to fiber coupling losses due to NA mismatch
    and size mismatch
13 mprintf("total losses=%fdB ",Losses);
```

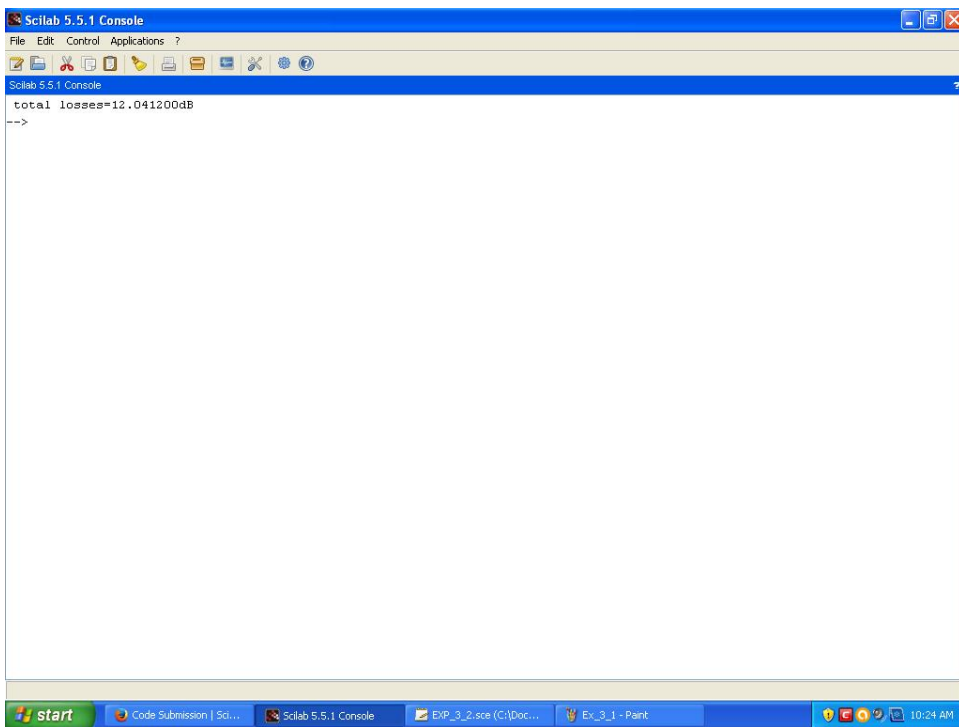


Figure 3.2: 2

Chapter 4

Optical sources and transmitter circuits

Scilab code Exa 4.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 4.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 tau_r=12*10^-9//radiative recombination time in s
9 tau_nr=35*10^-9//non-radiative recombination time in
  s
10 n1=3.5//refractive index of semiconductor
11 n2=1//refractive index of air
12 d=0.4*10^-6//active later thickness in m
13 V=8//recombination velocity
14 eta_int=1/(1+(tau_r/tau_nr))//internal quantum
  efficiency
15 tau=1/((tau_r^-1)+(tau_nr^-1)+(2*V/d))//total
```

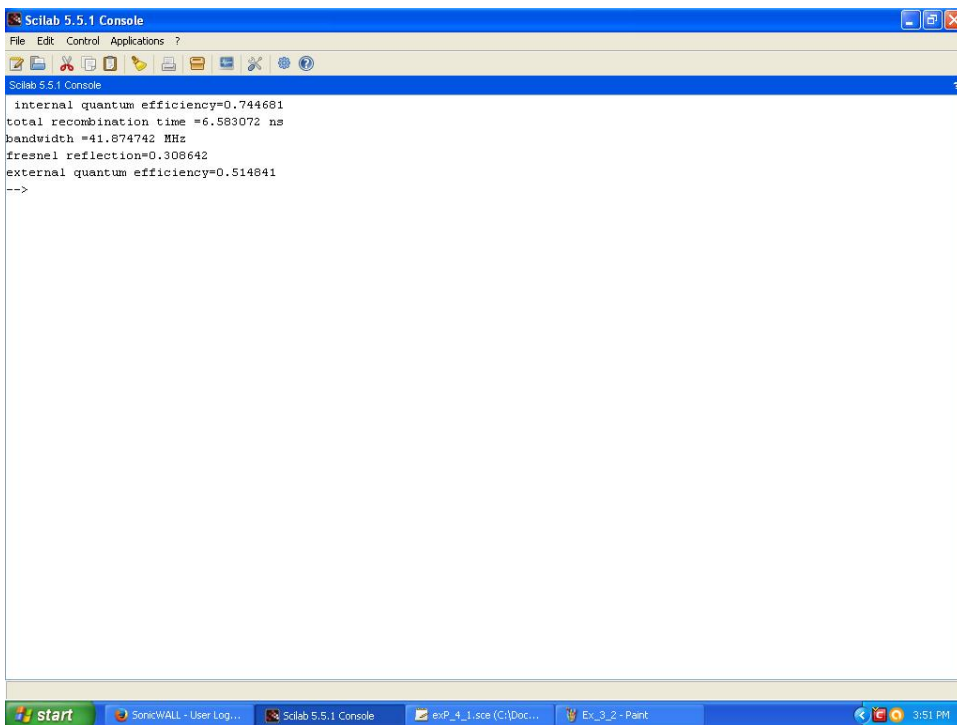


Figure 4.1: 1

```

    recombination time in s
16 f=sqrt(3)/(2*pi*tau)//bandwidth in Hz
17 F3=((n1-n2)^2/(n1+n2)^2)//fresnel reflection
18 eta_ext=eta_int*(1-F3)//external quantum efficiency
19 mprintf("internal quantum efficiency=%f",eta_int)//
    The answers vary due to round off error
20 mprintf("\ntotal recombination time =%f ns",tau*1e9)
    //multiplication by 1e9 to convert unit from s to
    ns//The answers vary due to round off error
21 mprintf("\nbandwidth =%f MHz",f*1e-6)//
    multiplication by 1e-6 to convert unit from Hz to
    MHz///The answers vary due to round off error
22 mprintf("\nfresnel reflection=%f ",F3)//The answers
    vary due to round off error
23 mprintf("\nexternal quantum efficiency=%f",eta_ext)
    //The answers vary due to round off error

```

Scilab code Exa 4.2 2

```

1 //Optical Fiber communication by A selvarajan
2 //example 4.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 lambda=1.3//wavelength of laser in um
9 w=5//active layer width in um
10 d=2//active layer thickness in um
11 n1=3.5//refractive index of core
12 n2=3.49//refractive index of cladding
13 //to find
14 k0=2*pi/lambda//propagation constant

```

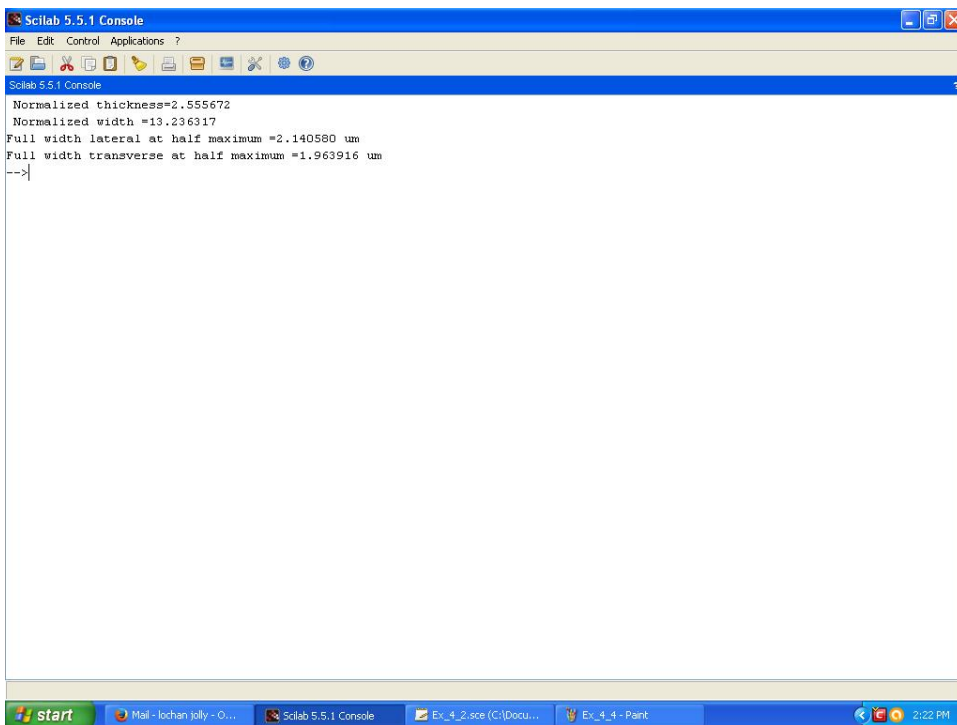



Figure 4.2: 2

```

15 row=0.3//confinement factor
16 neff=sqrt(n2^2+row)//effective refractive index
17 D=k0*d*(sqrt(n1^2-n2^2))//normalized thickness
18 W=k0*w*(sqrt(neff^2-n2^2))//normalized width// the
    answer given in textbook is wrong
19 Wlat=w*(sqrt(2*log(2)))*(0.32+2.1*(W^-1.5))//Full
    width lateral at half maximum in um/ the answer
    given in textbook is wrong
20 Wtra=d*(sqrt(2*log(2)))*(0.32+2.1*(D^-1.5))//Full
    width transverse at half maximum in um/ the
    answer given in textbook is wrong
21 mprintf("Normalized thickness=%f",D)//The answers
    vary due to round off error
22 mprintf("\n Normalized width =%f",W)//multiplication
    by 1e9 to convert unit from s to ns/// the
    answer given in textbook is wrong
23 mprintf("\nFull width lateral at half maximum =%f um
    ",Wlat)//multiplication by 1e-6 to convert unit
    from Hz to MHz//// the answer given in textbook
    is wrong
24 mprintf("\nFull width transverse at half maximum =%f
    um",Wtra)//multiplication by 1e-6 to convert
    unit from Hz to MHz//// the answer given in
    textbook is wrong

```

Scilab code Exa 4.3 3

```

1 //Optical Fiber communication by A selvarajan
2 //example 4.3
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;

```

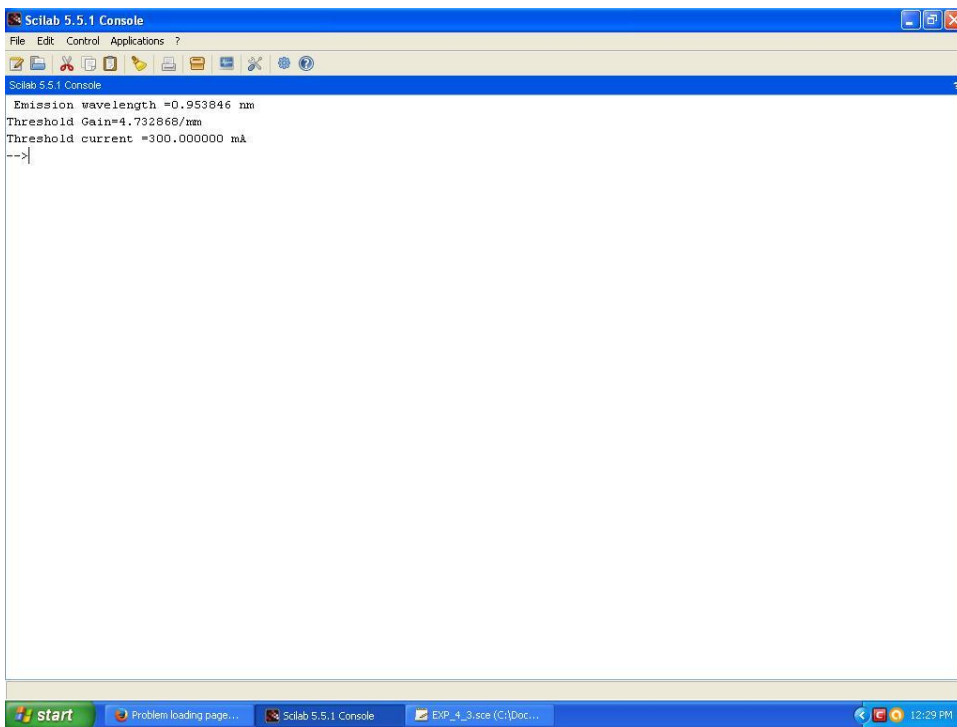


Figure 4.3: 3

```

7 //given
8 clear all;
9 Eg=1.3//band gap energy in eV
10 l=0.4//cavity length in mm
11 R1=0.5//reflectivities on ends
12 R2=0.5//reflectivities on ends
13 alpha=3//loss coefficient in /mm
14 current_density=30*10^5//current density in amp/m^2
15 area=0.2*0.5*10^-6//laser active area in m^2
16
17 lambda=1.24/Eg//emission wavelength in um
18 gth=alpha+(1/(2*l))*log(1/(R1*R2))// Threshold Gain
19 threshold_current=current_density*area//threshold
   current in A
20 mprintf(" Emission wavelength =%f nm",lambda)//
   multiplication by 1e3 to convert unit from um to
   nm
21 mprintf("\nThreshold Gain=%f/mm",gth)
22 mprintf("\nThreshold current =%f mA",
   threshold_current*1e3)//for converting unit from
   A to mA

```

Scilab code Exa 4.4 4

```

1 //Optical Fiber communication by A selvarajan
2 //example 4.4
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 clear all;
9 lamda=0.85*10^-6//wavelength of operation in m

```

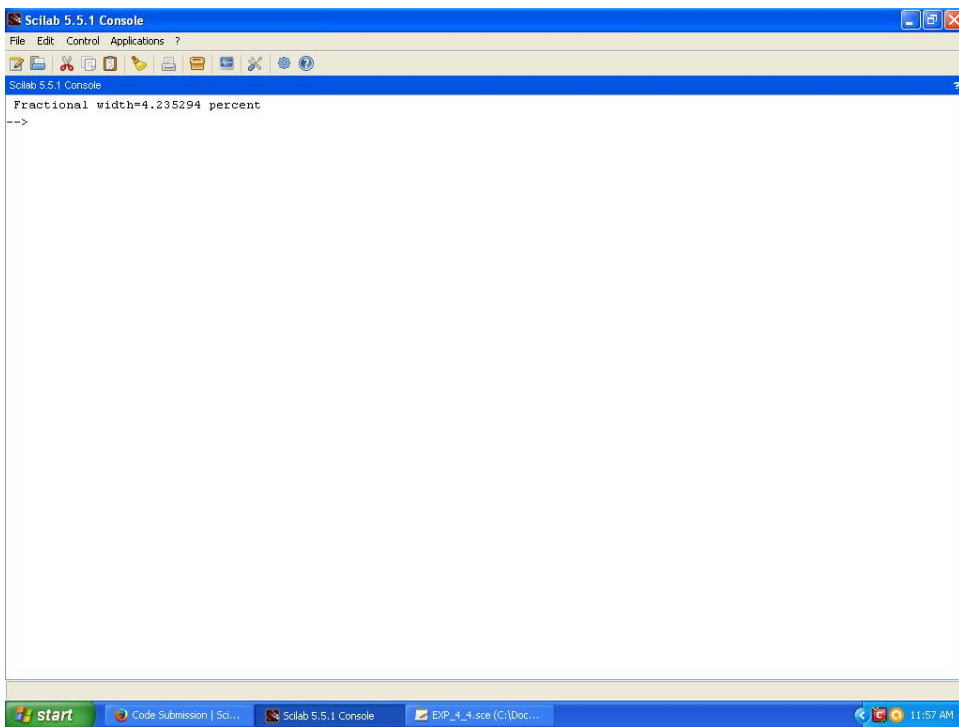


Figure 4.4: 4

```
10 delta_lamda=36*10^-9//spectral width in m
11 fractional_width=delta_lamda/lamda//fractional width
12 mprintf("Fractional width=%f percent",
    fractional_width*100)//multiplication by 100 to
    represent information in percentage
```

Chapter 5

Optical Detectors and Receivers

Scilab code Exa 5.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 5.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8
9 optical_power=10*10-6//optical power in W
10 R=0.5//Responsivity in A/W
11 Is=optical_power*R//shot noise current in A
12 Id=2*10-9//dark current in A
13 Rl=1e6//Load resistance in ohm
14 B=1e6//bandwidth in Hz
15 T=300//Temperature in K
16 K=1.38*10-20//Boltzman constant in m2 g s-2 K-1
17 q=1.609*10-19//charge of a electron in Coulombs
```

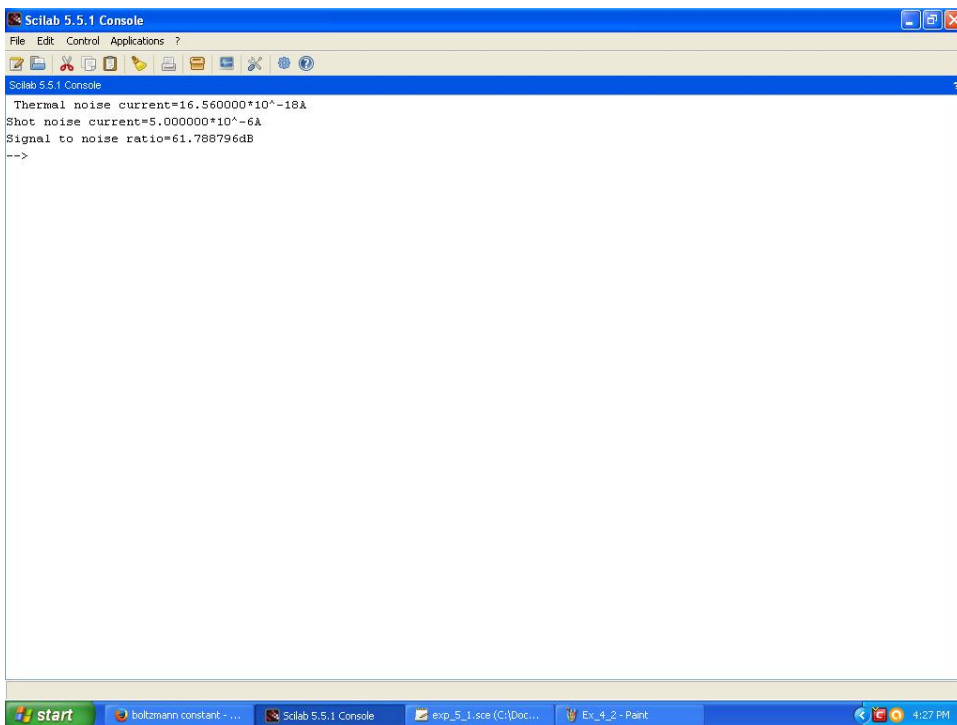


Figure 5.1: 1

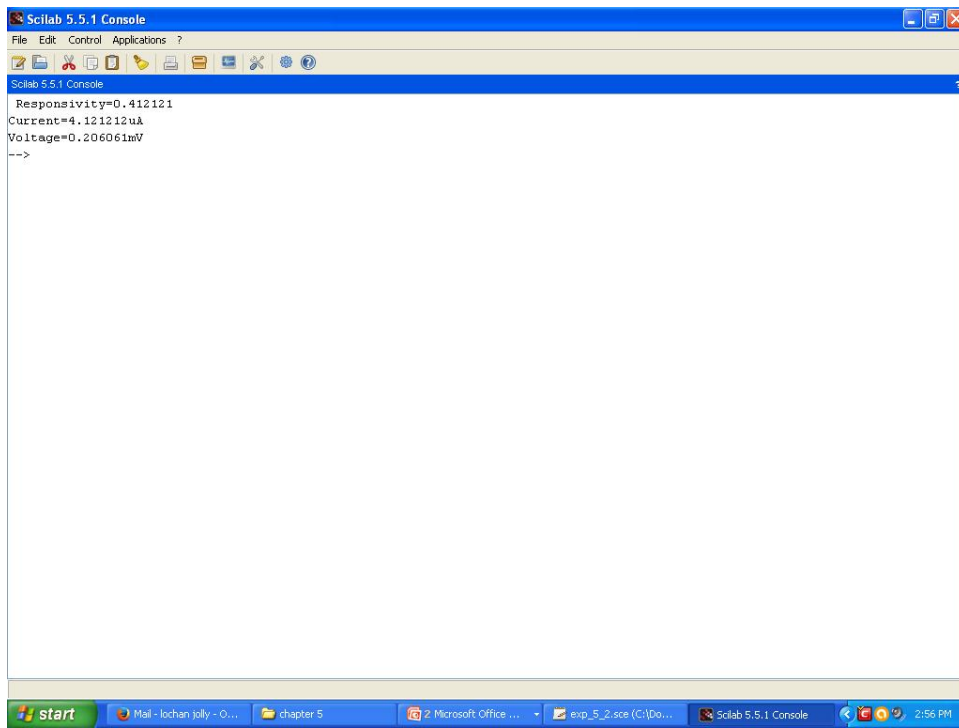


Figure 5.2: 2

```

18 Ith=4*K*T*B/R1//Mean Square Thermal noise current in
    A
19 SNR=(Is^2)/(2*q*(Is+Id)+Ith)//Signal to noise ratio
20 mprintf("Thermal noise current=%f*10^-18A",Ith
    *10^18)
21 mprintf("\nShot noise current=%f*10^-6A",Is*10^6)
22 mprintf("\nSignal to noise ratio=%fdB",10*log10(SNR)
    )//The answers vary due to round off error

```

Scilab code Exa 5.2 2

```

1 //Optical Fiber communication by A selvarajan
2 //example 5.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 eta=0.6//quantum efficiency
9 Po=10*10^-6//optical power in W
10 q=1.6*10^-19//charge of an electron in coulomb
11 lambda=0.85*10^-6//wavelength in m
12 h=6.6*10^-34//planck's constant
13 c=3*10^8//velocity of light in m/s
14 Rl=50//load Resistance in ohm
15 R=(q*eta*lambda)/(h*c)//responsivity in A/W
16 I=R*Po//current in A
17 V=Rl*I//Voltage in V
18 mprintf(" Responsivity=%f" ,R)
19 mprintf("\nCurrent=%fA" ,I*10^6)//multiplication by
    1e6 to convert unit from A to uA
20 mprintf("\nVoltage=%fV" ,V*10^3)//multiplication by
    1e6 to convert unit from V to mV

```

Scilab code Exa 5.3 3

```

1 //Optical Fiber communication by A selvarajan
2 //example 5.3
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 tau_tr=2*1e-9//transit time in sec

```

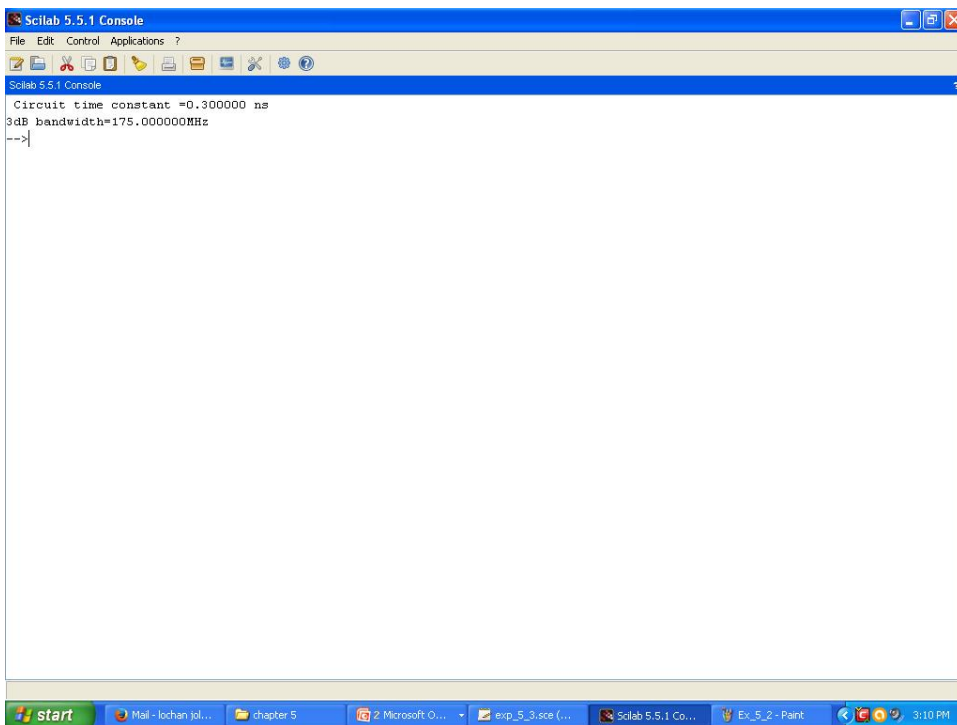


Figure 5.3: 3

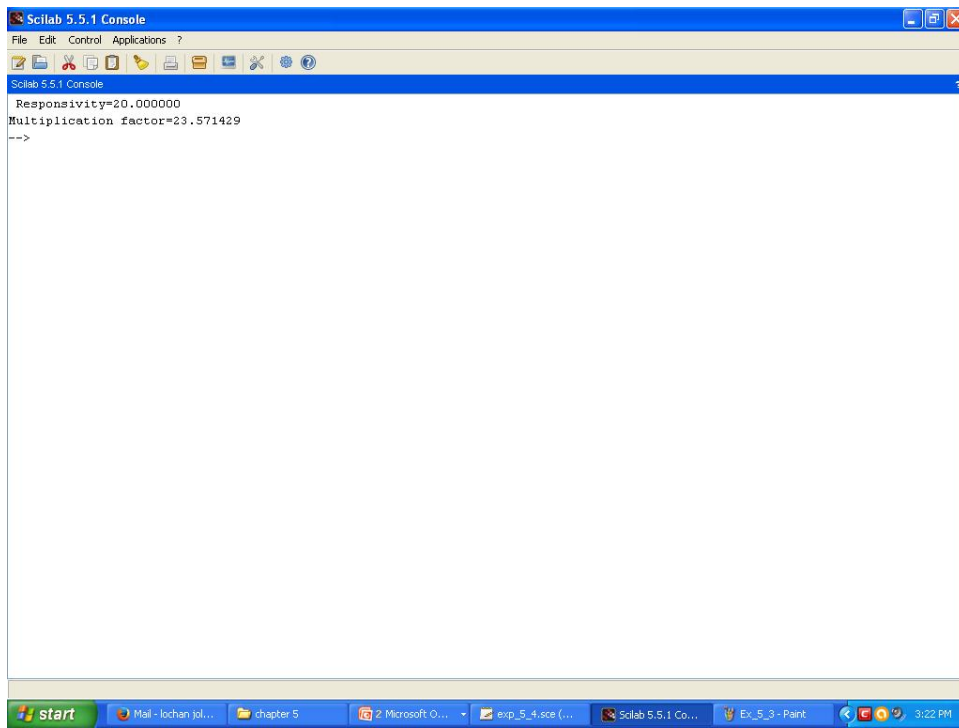


Figure 5.4: 4

```
9 R1=50//load resistance in ohm
10 Cd=3*1e-12//Junction capacitance in farad
11 tau=2*R1*Cd//Circuit time constant in sec
12 f3dB=(0.35/tau_tr)//3dB bandwidth in Hz
13 mprintf("Circuit time constant =%f ns",tau*1e9)//
    multiplication by 1e9 to convert unit from s to
    ns
14 mprintf("\n3dB bandwidth=%fMHz",f3dB*1e-6)//
    multiplication by 1e-6 to convert unit from Hz to
    MHz
```

Scilab code Exa 5.4 4

```
1 //Optical Fiber communication by A selvarajan
2 //example 5.4
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 I=100*1e-9//current in A
9 P=5*1e-9//Incident power in W
10 h=6.6*10^-34//planck's constant
11 c=3*10^8//velocity of light in m/s
12 q=1.6*10^-19//charge of an elctron in columb
13 eta=0.7//quantum efficiency
14 lambda=1.5*10^-6//wavelength in m
15 R=I/P;//APD responsivity in A/W
16 M= (R*h*c)/(q*eta*lambda);//Multiplication factor
17 mprintf(" Responsivity=%f" ,R)
18 mprintf(" \nMultiplication factor=%f" ,M)
```

Scilab code Exa 5.5 5

```
1 //Optical Fiber communication by A selvarajan
2 //example 5.5
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 h=6.6*10^-34//planck's constant
9 c=3*10^8//velocity of light in m/s
10 q=1.6*10^-19//charge of an elctron in columb
```

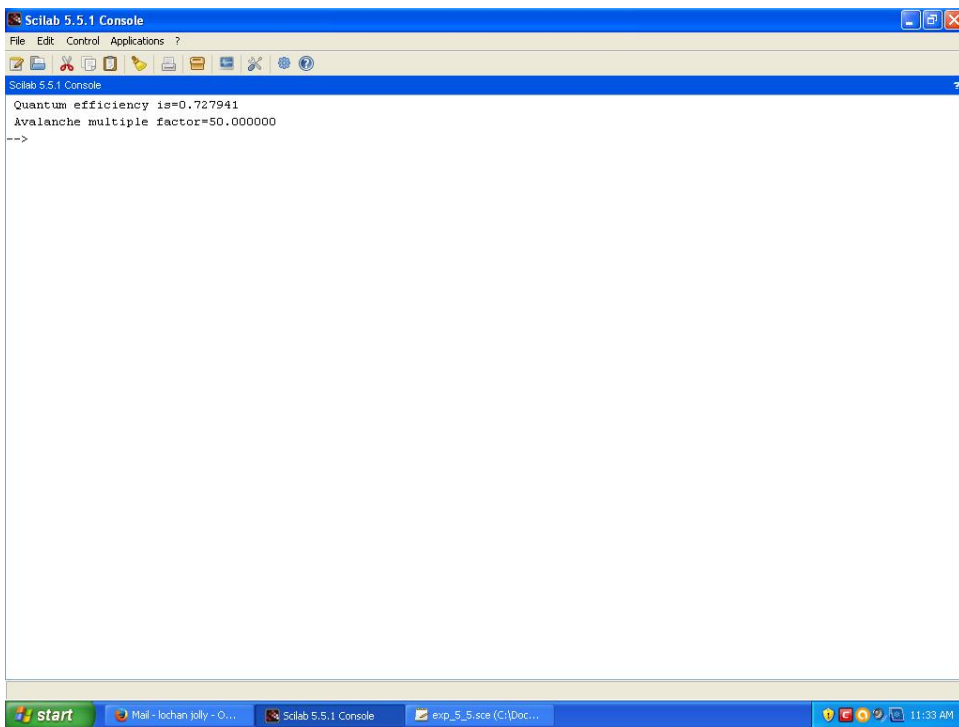


Figure 5.5: 5

```

11 lambda=0.85*10^-6//wavelength in m
12 I=0.1//incident light intensity in mW/mm2
13 Iph1=10*1e-6//photocurrent in pin in A
14 Iph2=500*1e-6//photocurrent in APD in A
15 A=0.2//detector area in mm2
16 P=I*A//Power seen by detector in mW
17 photons_generated=P*1e-3/(h*c/lambda)//photons
   Generated
18 Rate=Iph1/q//rate of carrier generation for pin
19 eta=Rate/photons_generated;//Quantum efficiency for
   pin
20 M=Iph2/Iph1//Multiplication factor
21 mprintf('Quantum efficiency is=%f',eta);//The
   answers vary due to round off error
22 mprintf('\n Avalanche multiple factor=%f',M);

```

Chapter 6

Integrated Optics and Photonic Circuits

Scilab code Exa 6.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 6.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 lamda=1.55;//wavelength in um
9 n1=1.51;//Film refractive index
10 n2=1.5;//substrate refractive index
11 t=(lamda)/(2*%pi*sqrt(n1*n1-n2*n2));//Thickness of
    film in um
12 mprintf('Film thickness=%fum',t);
```

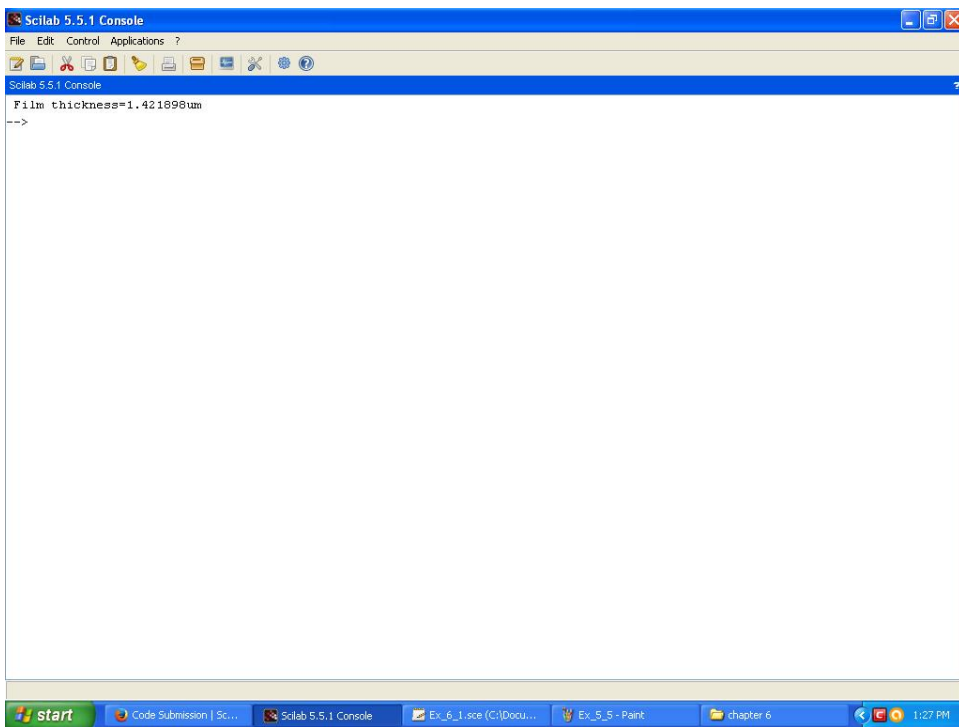


Figure 6.1: 1

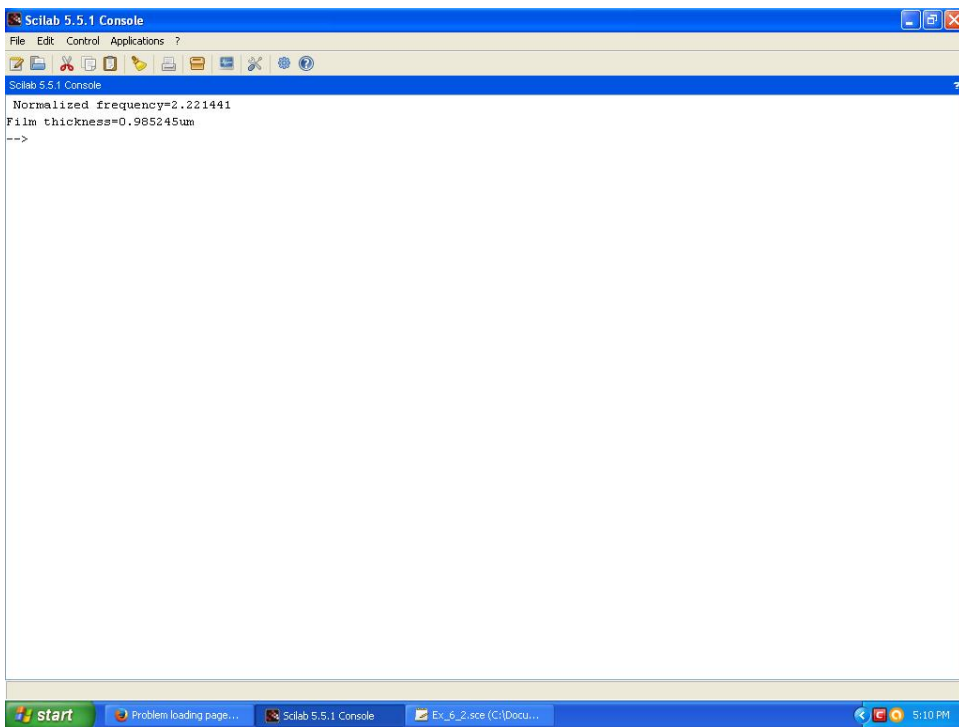


Figure 6.2: 2

Scilab code Exa 6.2 2

```
1 //Optical Fiber communication by A selvarajan
2 //example 6.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 b=0.5//normalized propoagation constant
9 V=(2*atan(b/(1-b))/(sqrt(1-b)))//normalized
    frequency
10 mprintf('Normalized frequency=%f',V)
11 lamda=1.3;//wavelength in um
12 n1=2.21;//Film refractive index
13 n2=2.2;//substrate refractive index
14 t=(lamda)/(2*%pi*sqrt(n1*n1-n2*n2));//Thickness of
    film in um
15 mprintf('\\nFilm thickness=%fum',t);
```

Scilab code Exa 6.3 3

```
1 //Optical Fiber communication by A selvarajan
2 //example 6.3
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 lamda=1.3;//wavelength in um
```

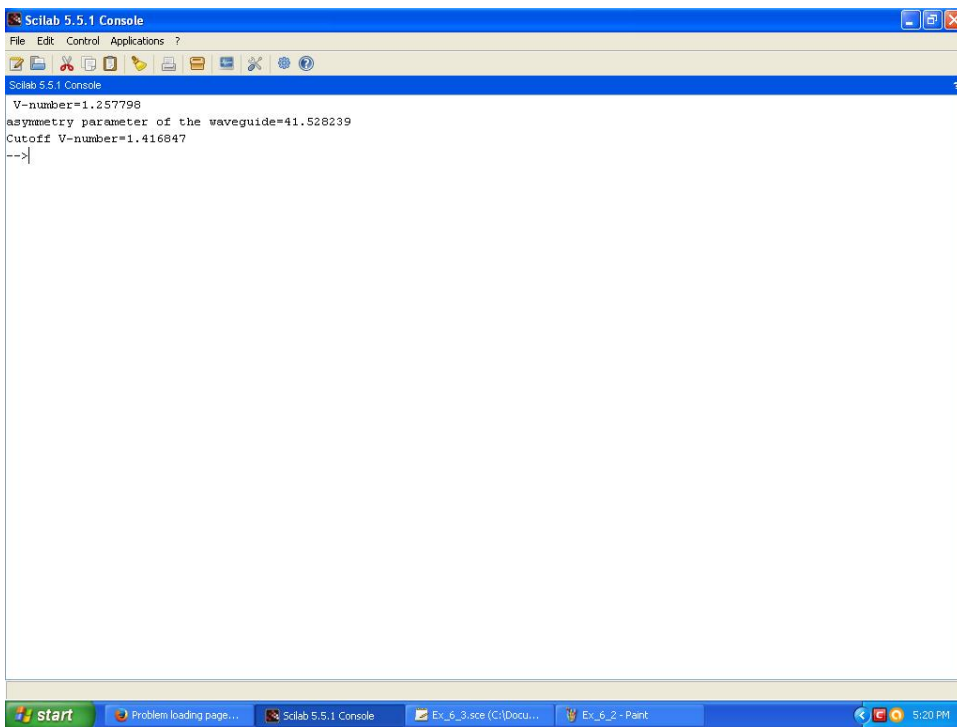


Figure 6.3: 3

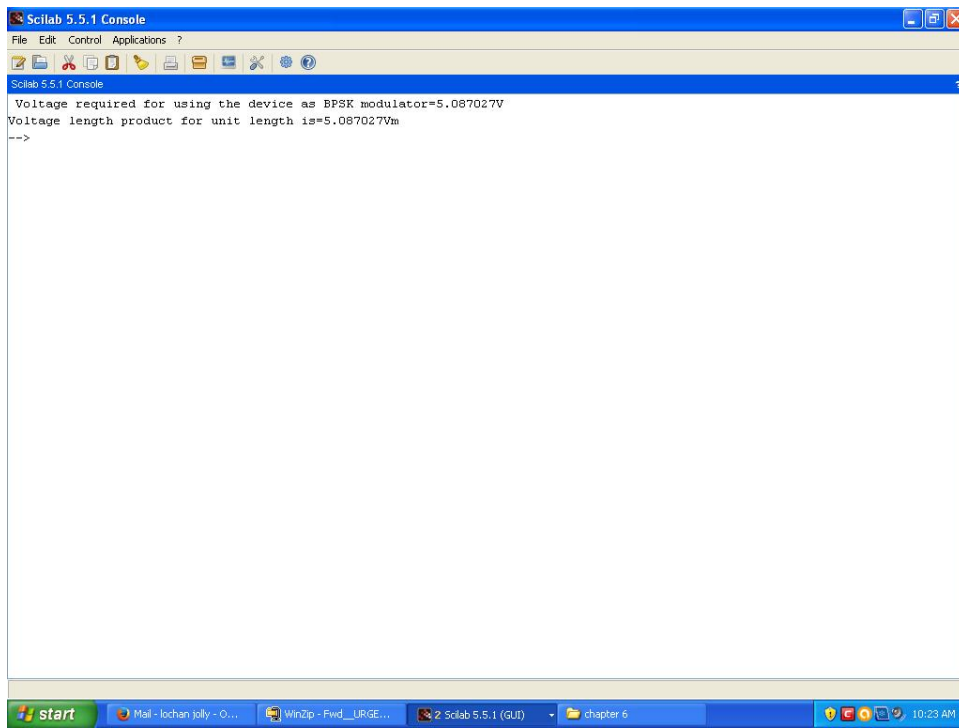


Figure 6.4: 4

```

9  nf=1.51; //Film refractive index
10 t=1.5; //Film thickness in um
11 ns=1.5 //Waveguide refractive index
12 na=1 //refractive index of air
13 V=(2*%pi*t/lamda)*sqrt(nf^2-ns^2) //V-number
14 a=(ns^2-na^2)/(nf^2-ns^2) //asymmetry parameter of
    the waveguide
15 Vc=atan(a^0.5) //cutoff V-number
16 mprintf("V-number=%f",V)
17 mprintf("\nasymmetry parameter of the waveguide=%f",
    a)
18 mprintf("\nCutoff V-number=%f",Vc)

```

Scilab code Exa 6.4 4

```
1 //Optical Fiber communication by A selvarajan
2 //example 6.4
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 delta_phi=%pi
9 d=4*10^-6//seperation between electrodes
10 n=2.2// approximate index in absence of voltage
11 r13=30*10^-12//poper electro optic coefficient
12 row=0.4//overlap factor
13 lambda=1300*1e-9//wavelength in m
14 L=8*10^-3//length of electrode in m
15 delta_n=delta_phi*lambda/(2*%pi*L)//change in
    refractive index
16 V_pi=2*d*delta_n/(n^3*row*r13)//Voltage required for
    using the device as BPSK modulator
17 mprintf("Voltage required for using the device as
    BPSK modulator=%fV",V_pi)
18 mprintf("\\nVoltage length product for unit length is
    =%fVm",V_pi)
```

Scilab code Exa 6.5 5

```
1 //Optical Fiber communication by A selvarajan
2 //example 6.5
3 //OS=Windows XP sp3
```

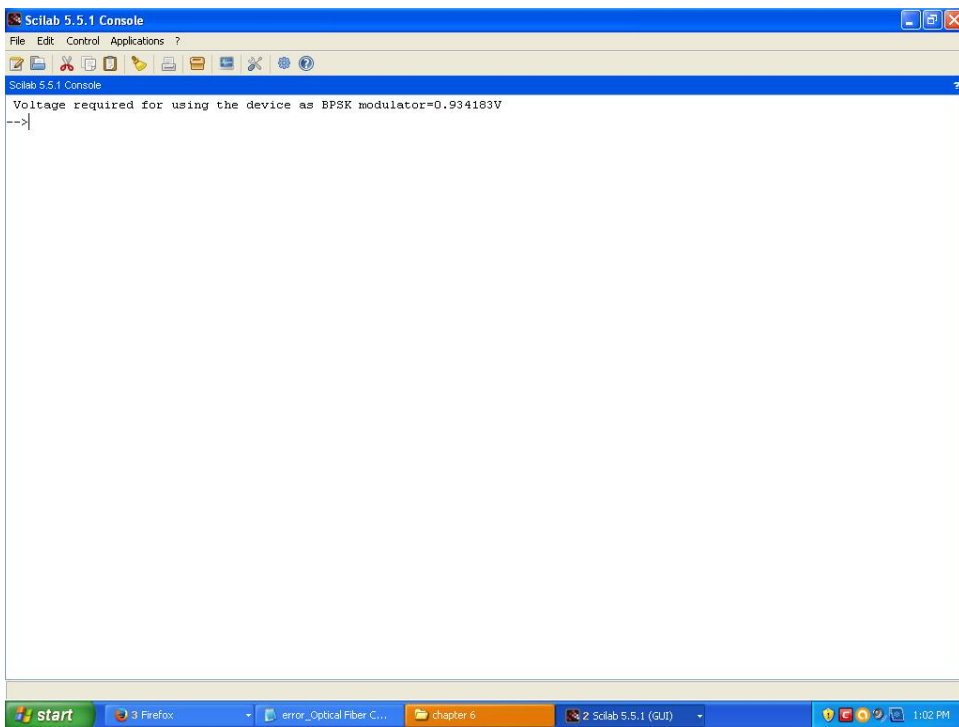


Figure 6.5: 5

```

4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 d=10*10^-6//seperation between electrodes
9 ne=2.2// approximate index in absence of voltage
10 r33=32*10^-12//proper electro optic coefficient
11 lambda=1*1e-6//wavelength in m
12 L=5*10^-3//length of electrode in m
13 V=d*lambda/(2*pi*ne^3*r33*L)//Voltage required for
    using the device as BPSK modulator
14 mprintf("Voltage required for using the device as
    BPSK modulator=%fV",V)//the answer is different
    because of rounding off error

```

Scilab code Exa 6.6 6

```

1 //Optical Fiber communication by A selvarajan
2 //example 6.6
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 delta_L=1/100//error in effective interaction length
9 P=(%pi/2*delta_L)^2//cross talk power output in W
10 mprintf("cross talk power output=%fx10^-4W",P*10^4);
    //multiplication by 10^4 to convert unit from W
    to 10^-4 W
11 PdB=10*log10(P)//power in dB
12 mprintf("\ncross talk power output=%fdB",PdB)

```

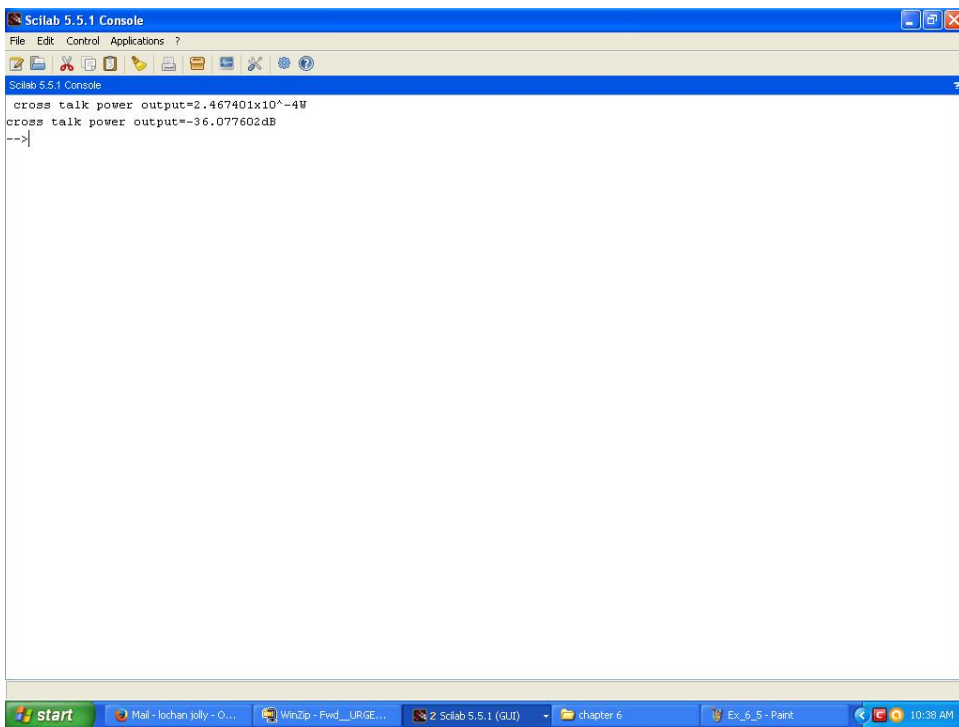


Figure 6.6: 6

Chapter 7

Wavelength Division Multiplexing

Scilab code Exa 7.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 7.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 //given
8 delta_lambda=60e-9;//delta lambda in m
9 lambda=1550e-9;//wavelength in m
10 c=3e8//velocity of light in m/s
11 CS=75*1e9//Channel spacing in Hz
12 Power_margin=30//power margin in dB
13 Fiber_loss=0.25//fiber loss in dB/Km
14 channel_capacity=2.5*1e9//channel capacity STM-16 in
    bps
15 delta_f=(c*delta_lambda)/lambda^2;//frequency
    bandwidth in Hz
```

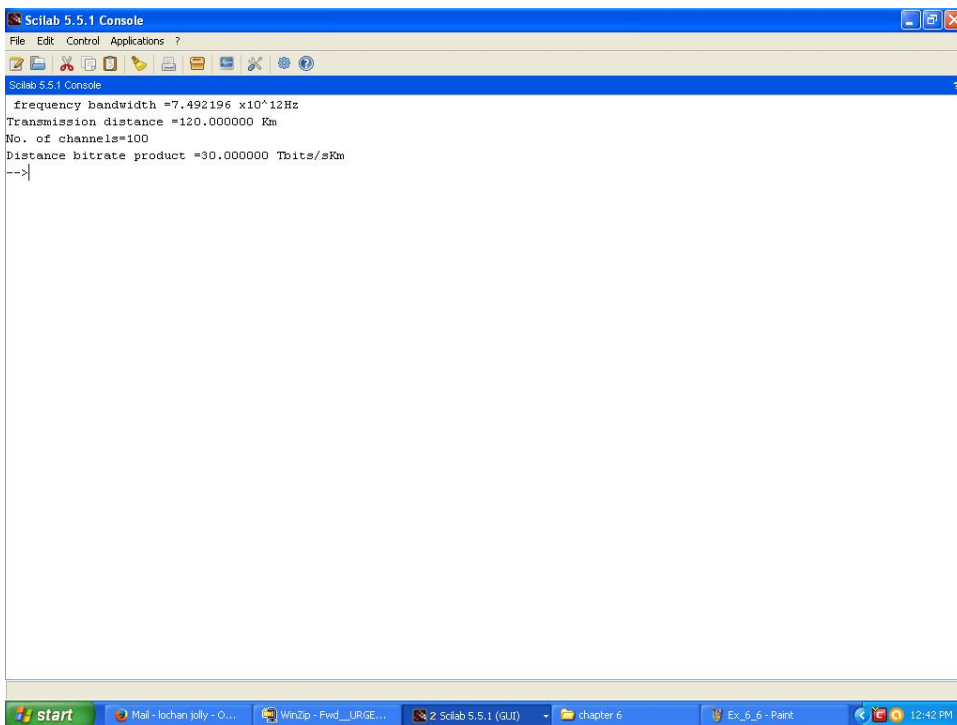


Figure 7.1: 1

```

16 transmission_distance=Power_margin/Fiber_loss//
    Transmission distance in Km
17 No_channels=round(delta_f/CS);//No. of channels
18 distance_bitrate_product=No_channels*
    channel_capacity*transmission_distance//distance
    bitrate product in bpsKm
19 mprintf("frequency bandwidth =%f x10^12Hz",delta_f/1
    e12)////division by 1e12 to convert unit from Hz
    to 10^12 Hz
20 mprintf("\nTransmission distance =%f Km",
    transmission_distance)
21 mprintf("\nNo. of channels=%i",No_channels)
22 mprintf("\nDistance bitrate product =%f Tbits/sKm",
    distance_bitrate_product/1e12)////division by 1
    e12 to convert unit from bits/sKm to Tbits/sKm

```

Chapter 8

Coherent Optical Communication

Scilab code Exa 8.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 8.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 eta=0.8;//quantum efficiency of detection
8 Ps=2e-9;//received optical power in W
9 h=6.62*1e-34;//plancks constant
10 lambda=1500*1e-9//wavelength in m
11 c=3*1e8//velocity of light in m/s
12 new=c/lambda;//frequency in Hz
13 B=1e6;//Signal Bandwidth in Hz
14 SNR=(eta*Ps)/(2*h*new*B);//signal to noise ratio
15 SNRdB=10*log10(SNR)//signal to noise ratio in dB)
16 mprintf("signal to noise ratio=%f",SNR)//the answer
    in textbook is wrong
```

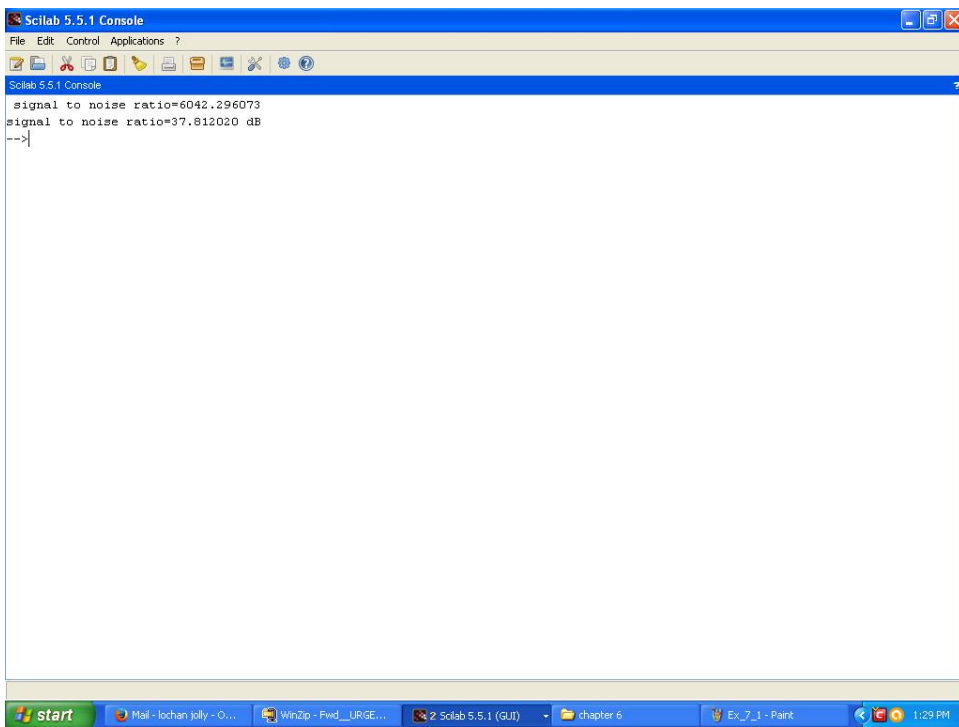


Figure 8.1: 1

```
17 mprintf("\\nsignal to noise ratio=%f dB",SNRdB)//the  
    answer in textbook is wrong
```

Chapter 9

Optical Amplifiers

Scilab code Exa 9.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 9.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 lambda=1.3*1e-6//wavelength in m
8 c=3*1e8//velocity of light in m/s
9 SNRoutdB=30//signal to noise ratio at output in dB
10 SNRout=10^(SNRoutdB/10);//signal to noise ratio at
    output normal scale
11 new=c/lambda;//frequency in Hz
12 h=6.6e-34;//plancks constant
13 P=0.5e-3;//Input power in W
14 NFdB=4//noise figure in dB
15 NF=10^(NFdB/10);//noise figure in normal scale
16 SNRin=NF*SNRout//signal to noise ratio at input
    normal scale
17 delta_Be=P/(2*h*new*SNRin);//receiver bandwidth in
```

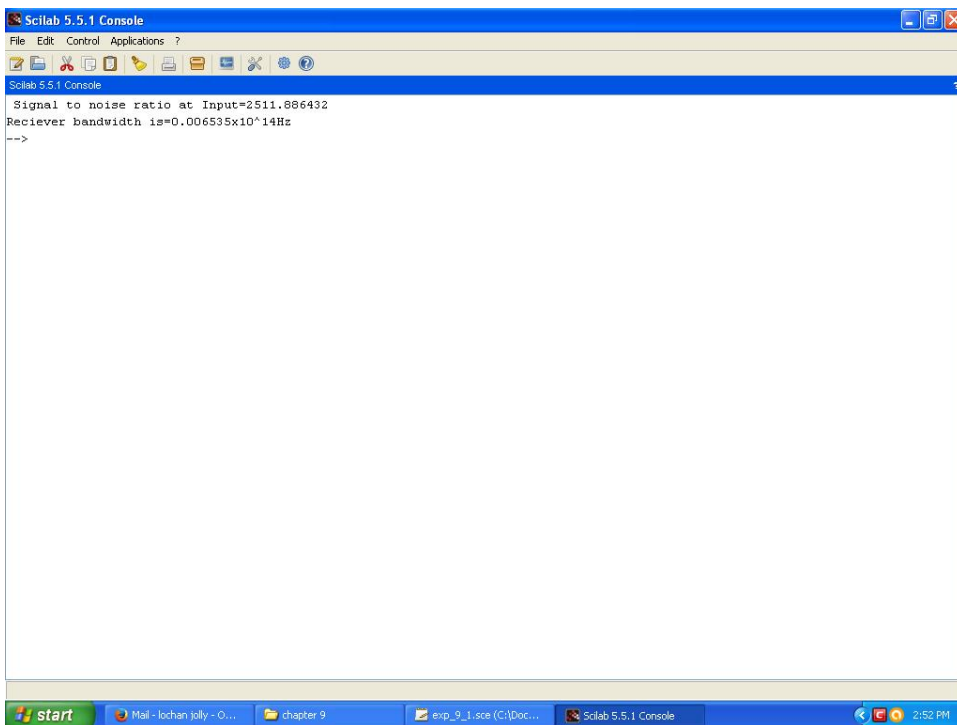



Figure 9.1: 1

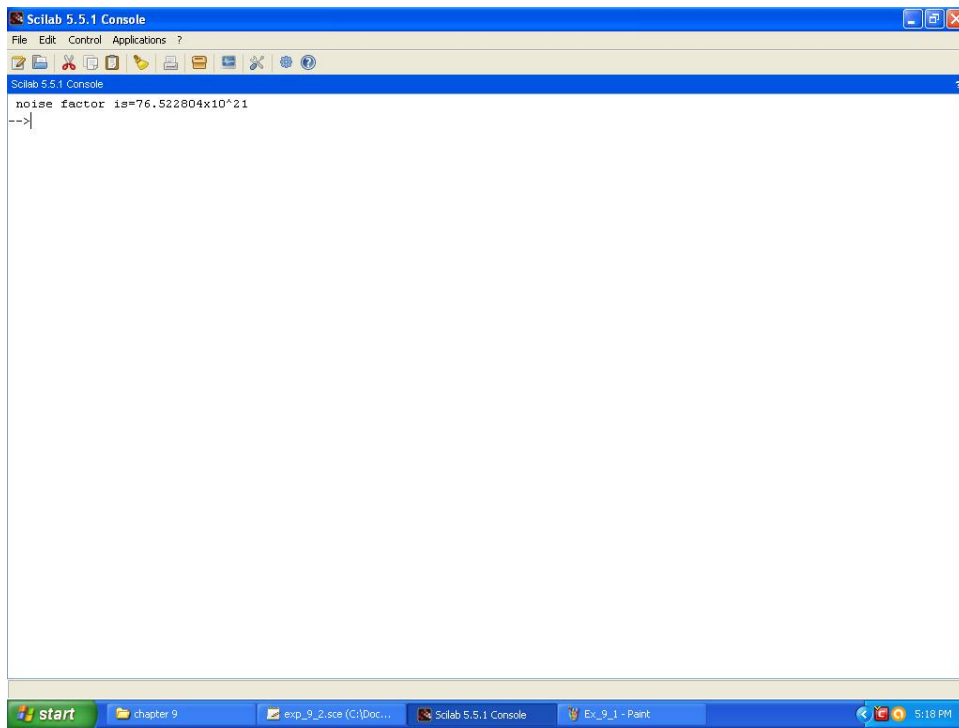


Figure 9.2: 2

```
Hz
18 mprintf('Signal to noise ratio at Input=%f',SNRin)
19 mprintf('\nReciever bandwidth is=%fx10^14Hz',
    delta_Be/1e14); // division by 1e14 to convert the
    unit from Hz to 10^14 Hz
20 // The answer given in textbook is wrong
```

Scilab code Exa 9.2 2

```
1 //Optical Fiber communication by A selvarajan
2 //example 9.2
```

```

3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 PASE=1e-3; //amplified spontaneous emission power in
      W
8 Gdb=20; //optical amplifier gain in dB
9 G=10^(Gdb/10); //optical amplifier gain in normal
      scale
10 delta_newbynew=5e-6; //fractional bandwidth
11 h=6.6e-34; //planck's constant
12 ns=PASE/((G-1)*h/delta_newbynew); //noise factor
13 mprintf('noise factor is=%fx10^21 ',ns/1e21); //
      division by 1e21 to convert the unit from Hz to
      10^21 Hz
14 // The answer given in textbook is wrong

```

Scilab code Exa 9.3 3

```

1 //Optical Fiber communication by A selvarajan
2 //example 9.3
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 L=50 //link length in Km
8 Fiber_loss=0.2 //fiber loss in dB/Km
9 Req_Gain=Fiber_loss*L //required Gain
10 Fn1db=5 //Noise figure in dB
11 Fn2db=5 //Noise figure in dB
12 Fn3db=5 //Noise figure in dB
13 Fn1=10^(Fn1db/10); //Noise figure in normal scale for
      all amplifiers

```

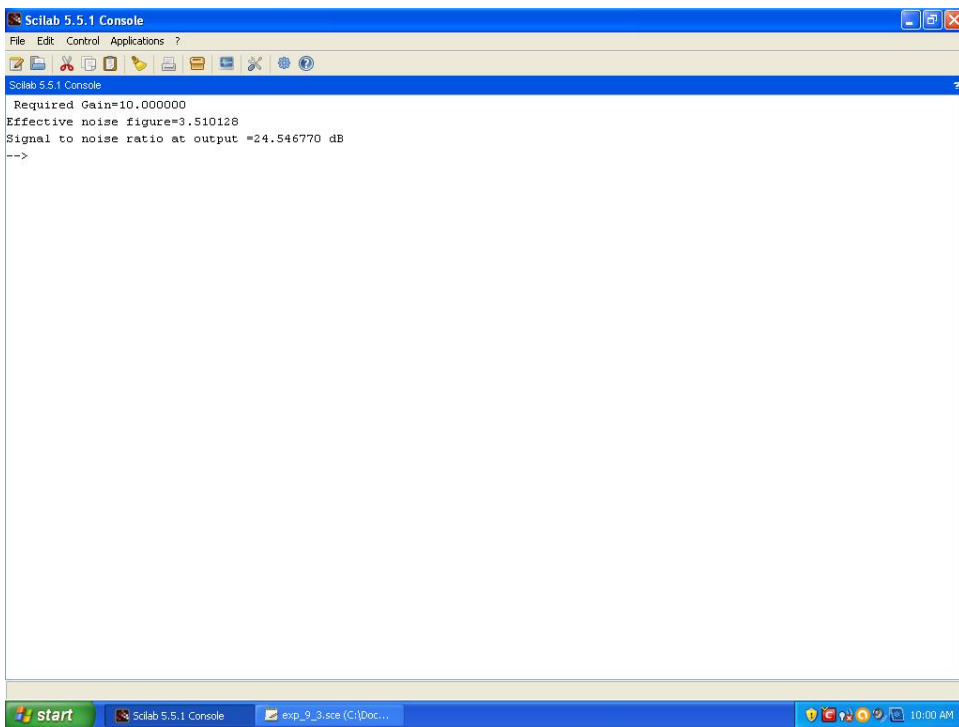


Figure 9.3: 3

```

14 Fn2=10^(Fn2db/10); //Noise figure in normal scale for
    all amplifiers
15 Fn3=10^(Fn3db/10); //Noise figure in normal scale for
    all amplifiers
16 G1=10^(Req_Gain/10) //gain in normal scale
17 G2=10^(Req_Gain/10) //gain in normal scale
18 Fneff=Fn1+(Fn2/G1)+(Fn3/(G1*G2)); //Effective noise
    figure
19 SNRindb=30; //Signal to noise ratio at input in dB
20 SNRout=10^(SNRindb/10)/Fneff; //Signal to noise ratio
    at output in dB
21 SNRoutdb=10*log10(SNRout);
22 mprintf(" Required Gain=%f", Req_Gain)
23 mprintf("\nEffective noise figure=%f", Fneff)
24 mprintf("\nSignal to noise ratio at output =%f dB",
    SNRoutdb)

```

Chapter 10

Photonic Switching

Scilab code Exa 10.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 10.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 Xx=-30//crosstalk in dB
8 L=0.3//typical value
9 N=5//no. of switches Nb+Nc
10 SXR=Xx-L*(N)-10*log10(5*(10^(-L*N/10))/N)//Signal
    power to noise power in dB
11 mprintf('Minimum and maximum SXR values=%fdB',SXR)
```

Scilab code Exa 10.2 2

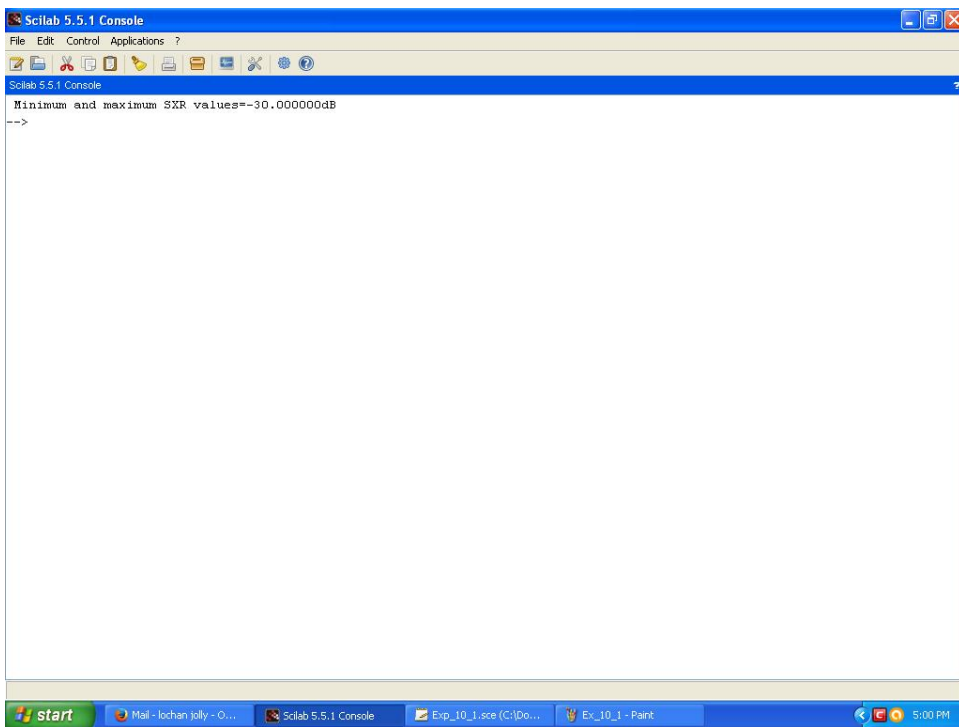


Figure 10.1: 1

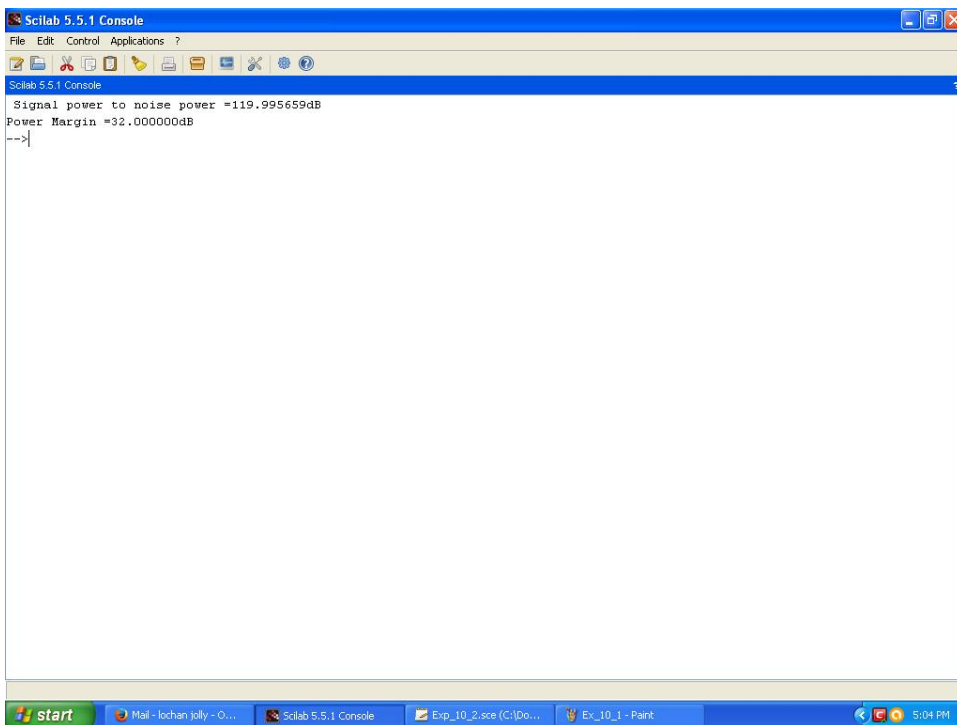


Figure 10.2: 2


```

1 //Optical Fiber communication by A selvarajan
2 //example 10.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 PB=40//power budget in dB
8 x=-30//crosstalk in dB assumed
9 N=4//no. of switches
10 Lin=1//insertion loss of in dB
11 Linw=Lin*N//worst case insertion loss of in dB
12 Lc=2//worst case connector loss in dB
13 L=Linw+2*Lc//total power lost in the worst case
    signal path in dB
14 Power_margin=PB-L//power margin in dB
15 K=0;
16 for i=1:N
17 K=K+((( -1)^(i+1))*(10^(-x/10))^i);
18 end
19 SbyN=10*log10(K)//Signal power to noise power in dB
20 mprintf('Signal power to noise power =%fdB',SbyN)
21 mprintf('\\nPower Margin =%fdB',Power_margin)//The
    Textbook answer is wrong

```

Chapter 11

Fiber Optic Communication System Design

Scilab code Exa 11.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 11.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 BW=7//bandwidth in MHz
8 SNR=60//signal to noise ratio in dB
9 Pin=0//Launched power in dBm
10 Trise_source=20//risetime at source LED in ns
11 delta_lambda=20//spectra width in nm
12 lambda=850;//operating wavelength in nm
13 c=2.998*10^5;//velocity of light in Km/sec
14 R=0.3//Detector PIN FET responsivity in A/W
15 Cdiode=3//diode capacitance in pf
16 trise_detector=1//risetime at detector in ns
17 S=-30//sensitivity in dbm
```

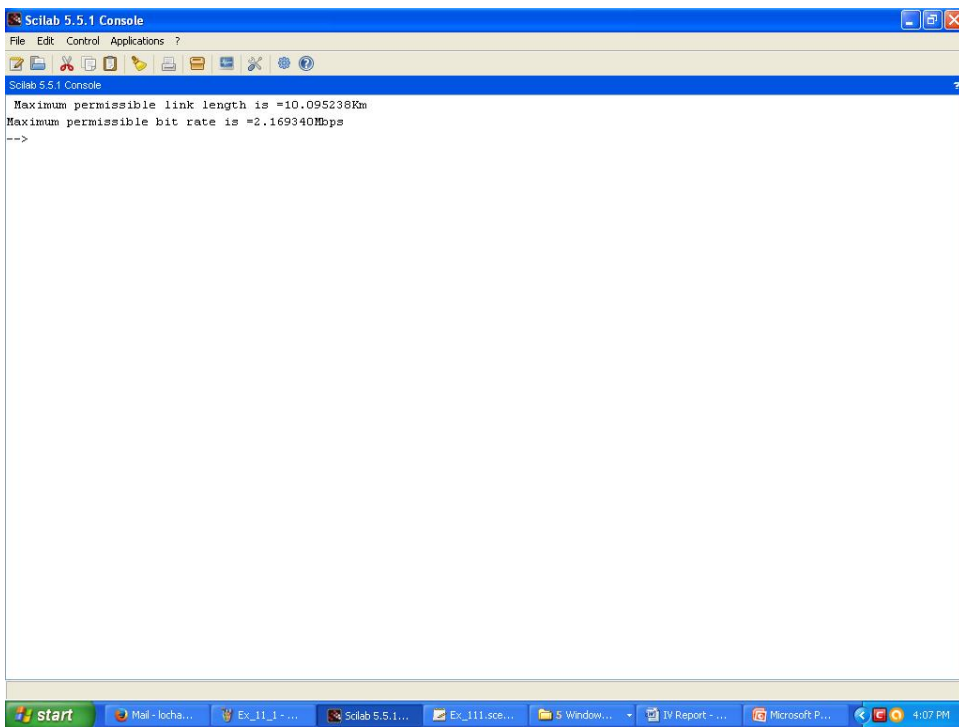


Figure 11.1: 1

```

18 Lsplice=0.2//splice loss in dB/connector
19 NA=0.2//numerical aperture for GI/MM
20 n1=1.46//refractive index of core
21 A=2//attenuation in dB/Km
22 Ls=3//loss due to source in dB
23 Ld=1//loss due to detector in dB
24 Psm=5//system margin in dB
25 c=3*10^8//velocity of light in m/s
26
27 //solution
28
29 Available_power=Pin-S;//available power in dB
30 Total_loss=Ls+Ld+Psm;
31 Power_left=Available_power-Total_loss;//power left
    in dB
32 L=(Power_left+Lsplice)/(Lsplice/2+2);
33 tmod=L*10^3*(NA^2)/(2*c*n1);//modal dispersion in s
34 Bit_rate=1/tmod;//bit rate in bps
35 mprintf('Maximum permissible link length is =%fKm',L
    );
36
37 mprintf('\nMaximum permissible bit rate is =%fMbps',
    Bit_rate/10^6);//division by 10^6 to convert the
    unit from bps to Mbps//the answer is different
    because of rounding off

```

Scilab code Exa 11.2 2

```

1 //Optical Fiber communication by A selvarajan
2 //example 11.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;

```

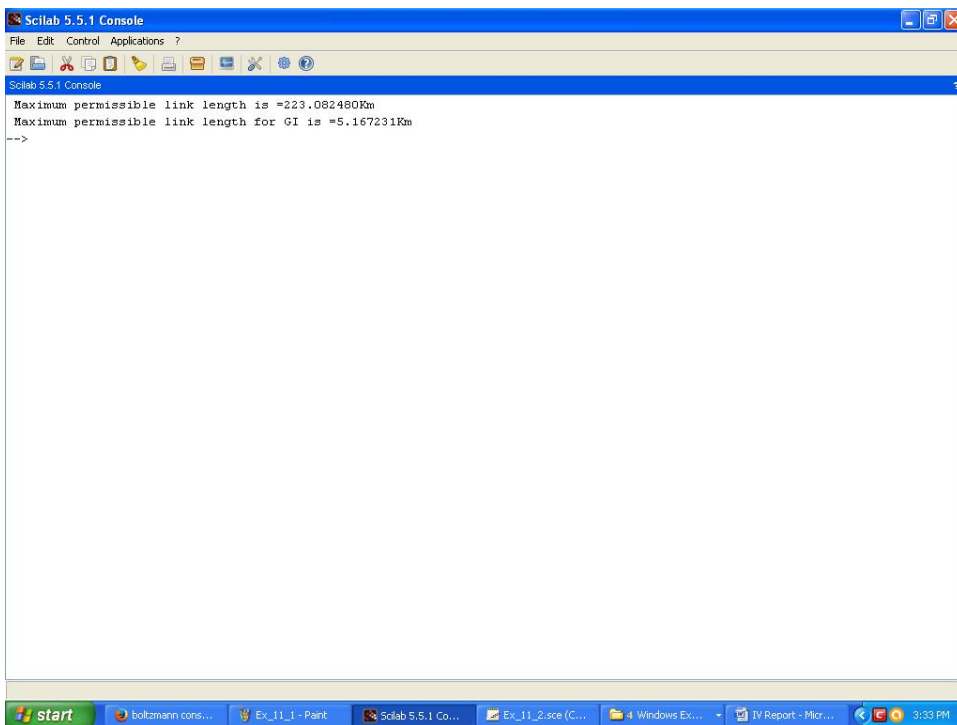


Figure 11.2: 2

```

6 clear all;
7 BW=7//bandwidth in MHz
8 SNR=60//signal to noise ratio in dB
9 Pin=0//Launched power in dBm
10 Trise_source=4//risetime at source LED in ns
11 delta_lambda=1//spectra width in nm
12 lambda=1300;//operating wavelength in nm
13 c=2.998*10^5;//velocity of light in Km/sec
14 R=0.3//Detector PIN FET responsivity in A/W
15 Cdiode=3//diode capacitance in pf
16 trise_detector=5//risetime at detector in ns
17 F=2.1//amplifier noise figure in dB
18 Camp=2//amplifier capacitance in pf
19 L=2//minimum link length in Km
20 Lsplice=0.5//splice loss in dB/connector
21 NA=0.22//numerical aperture for GI/MM
22 BWGI=600//GI/MM fiber bandwidth in MHz F3dB_optical
23 Te=630//temperate in Kelvin
24 K=1.38064852 *10^-23//boltzman constant in m2 kg s^-2
    K-1
25 //solution
26 Rload=1/(2*%pi*(Cdiode+Camp)*BW)*10^6//maximum load
    resistance in ohm Actual value
27 Rload=4300//approximated value in ohm
28 BWRx=1/(2*%pi*(Cdiode+Camp)*Rload)//receiver BW in
    Hz
29 SbyN=10^(SNR/10)//SNR in normal scale
30 Pmin=10*log10(sqrt(SbyN*4*K*Te*BW/(0.5*Rload*R^2)))
    //input power in W
31 L1=Pmin/0.2//power budget limited link length in Km
32 mprintf('Maximum permissible link length is =%fKm',
    L1);
33
34 Trise_required=(0.35/BW)*10^3//Bandwith budgetting
    rise time required is rise time required in ns//
    multiplication by 10^3 to convert msec to ns
35 Trise_receiver=2.19*Rload*(Cdiode+Camp)*10^-3//rise
    time of receiver in ns//multiplication by 10^3 to

```

```

    convert msec to ns
36 Trise_fiber=sqrt(Trise_required^2-Trise_receiver^2-
    Trise_source^2)//fiber dispersion in ns
37 //for GI
38 f3dB_electrical=0.71*BWGI;//3dB elctrical BW in
    MHzKm
39 t_intra_modal=1//intra modal dispersion in ns/Km
40 t_inter_modal=3//intermodal dispersion in ns/Km
41 t_fiber_GI=sqrt(t_intra_modal^2+t_inter_modal^2);//
    rise time of fiber in ns/Km
42 L2=Trise_fiber/t_fiber_GI//link length in Km
43 mprintf('\n Maximum permissible link length for GI
    is =%fKm',L2);

```

Chapter 13

Video Transmission

Scilab code Exa 13.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 13.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 Sigma_s=0.1//source dispersion inns
8 Sigma_D=0.1//detector dispersion in ns
9 Sigma_F=0.05//fiber dispersion in ns
10 bitrate=622//bitrate in Mbps
11 STM_rate=250//4 channel VSB PCM
12 Power_margin=30//power margin in dB
13 system_margin=6//system margin in dB
14 Average_loss=0.6//average loss in dB/Km
15
16 //solution
17 Sigma_max=STM_rate/bitrate//max dispersion allowed
18 L2=sqrt((Sigma_max-Sigma_s^2-Sigma_D^2)/(Sigma_F^2))
    //dispersion limited maximum length in Km
```

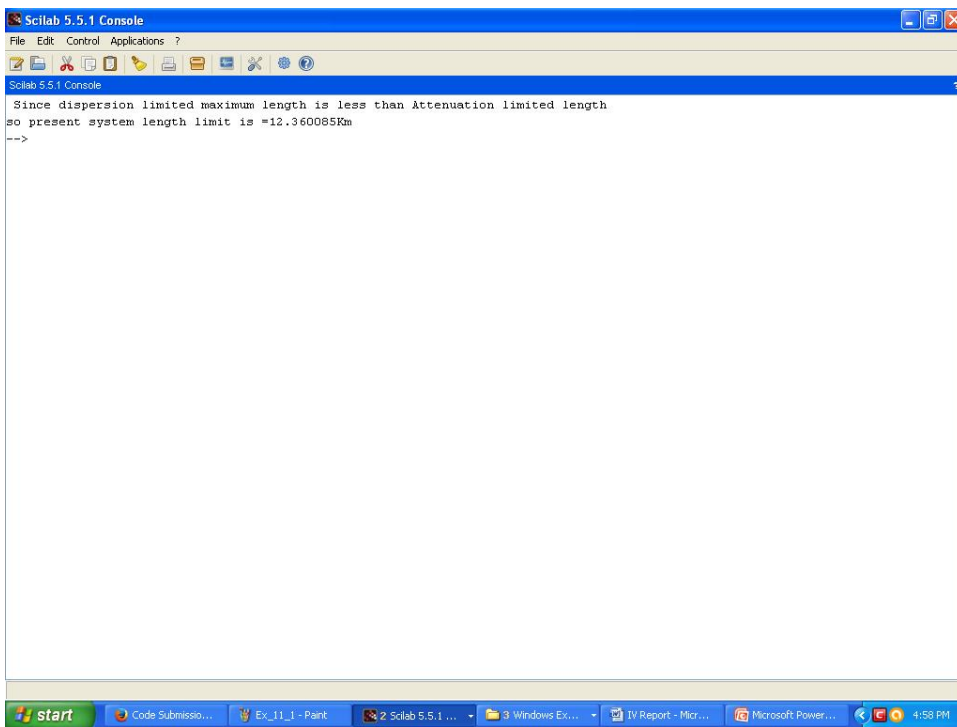



Figure 13.1: 1

```
19 L1=(Power_margin-system_margin)/Average_loss//  
    Attenuation limited length in km  
20 mprintf("Since dispersion limited maximum length is  
    less than Attenuation limited length \nso present  
    system length limit is =%fKm ",L2)
```

Chapter 14

Data Communication and LAN

Scilab code Exa 14.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 14.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 N=256//no. of nodes
8 Lc=0.25//loss per coup;er in dB
9 Power_margin=30//power margin in dB
10 system_margin=6//system margin in dB
11 Average_loss=0.6//average loss in dB/Km
12 TxRX_powergain=32//transmitter to receiver power
   gain in dB
13 Avg_Tr_loss=0.5//average transmitter loss in dB/Km
14
15 //solution
16 Nc=log2(N)//since 2x2 couplers are used
17 Ns=N/2//each stage coupler
18 T_Nc=Nc*Ns//total no. of couplers
```

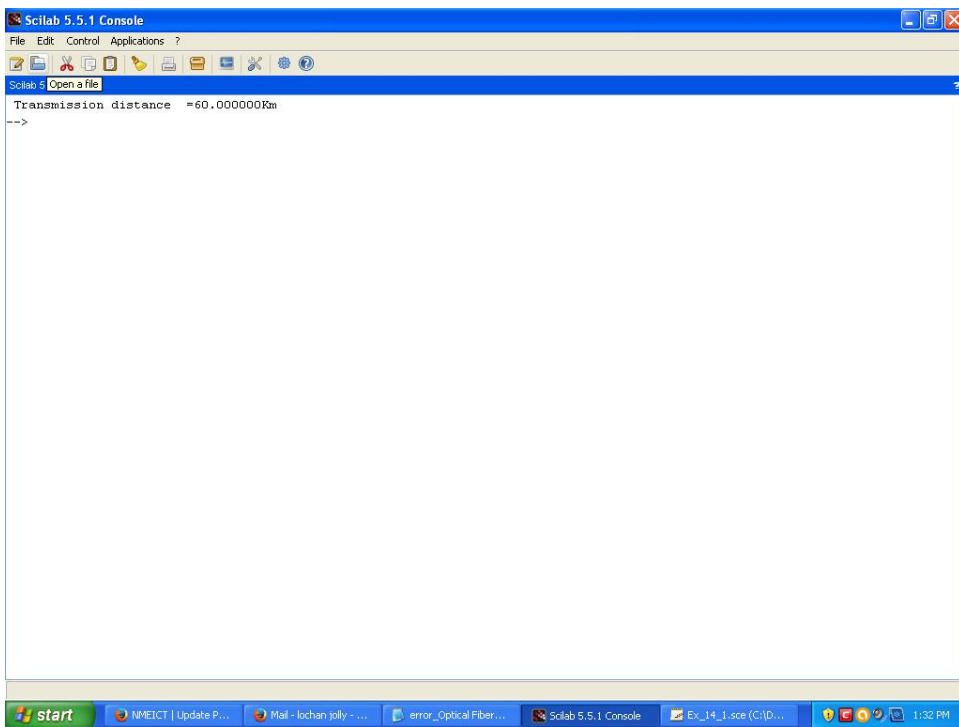


Figure 14.1: 1

```
19 Total_Lc=Nc*Lc//total coupler loss in dB
20 Permissible_loss=TxRX_powergain-Total_Lc//
    permissible cable loss in dB
21 L=Permissible_loss/Avg_Tr_loss//Transmission
    distance in Km
22 mprintf(" Transmission distance   =%fKm ",L)
```

Chapter 16

Soliton Communication Systems

Scilab code Exa 16.1 1

```
1 //Optical Fiber communication by A selvarajan
2 //example 16.1
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 lambda=850;//operating wavelength in nm
8 Beta2=-1//dispersion regime ps2/Km
9 Gama=2//nonlinearity in /W-Km
10 TFWHM=10//fundamental soliton width in ps
11 To=TFWHM/1.763//pulse width in ps
12 Ppeak=1/(Gama*(To2))//peak power in W
13 mprintf("Peak power required to maintain fundamental
    soliton=%fmW",Ppeak*103)//multiplication by
    103 is to convert the unit from w to mW
```

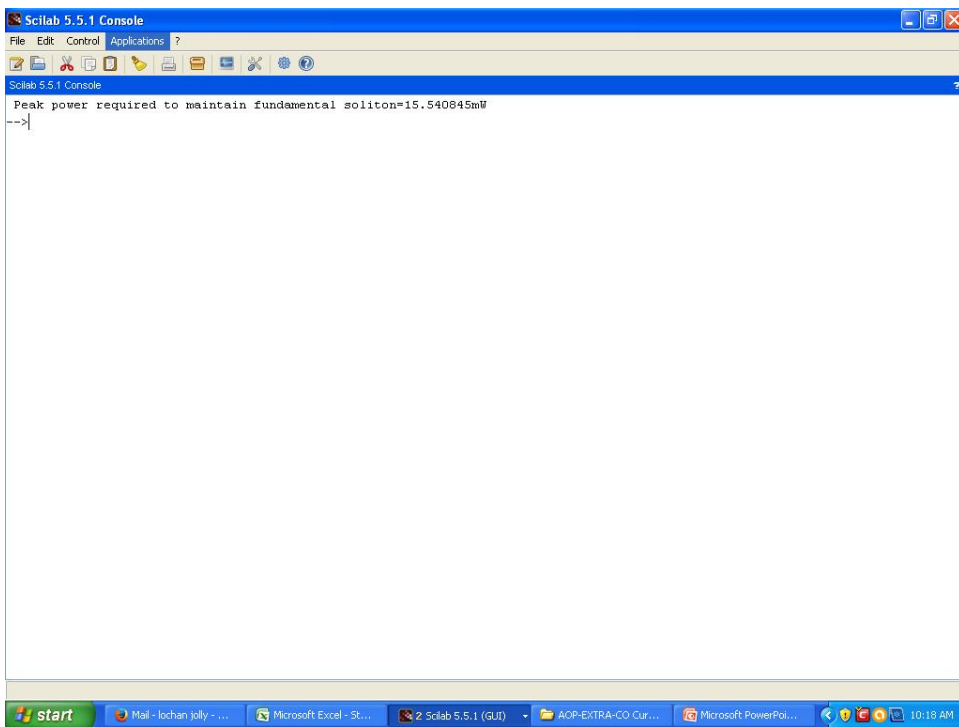


Figure 16.1: 1

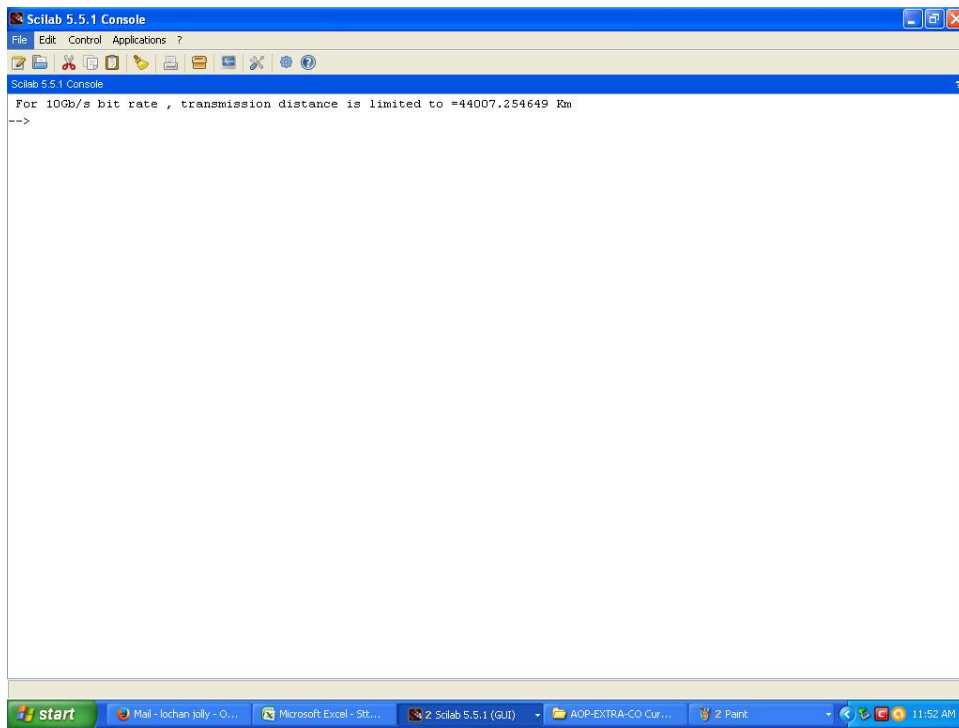


Figure 16.2: 2

Scilab code Exa 16.2 2

```
1 //Optical Fiber communication by A selvarajan
2 //example 16.2
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 lambda=1.55;//operating wavelength in um
8 Beta2=-1//dispersion regime ps2/Km
```

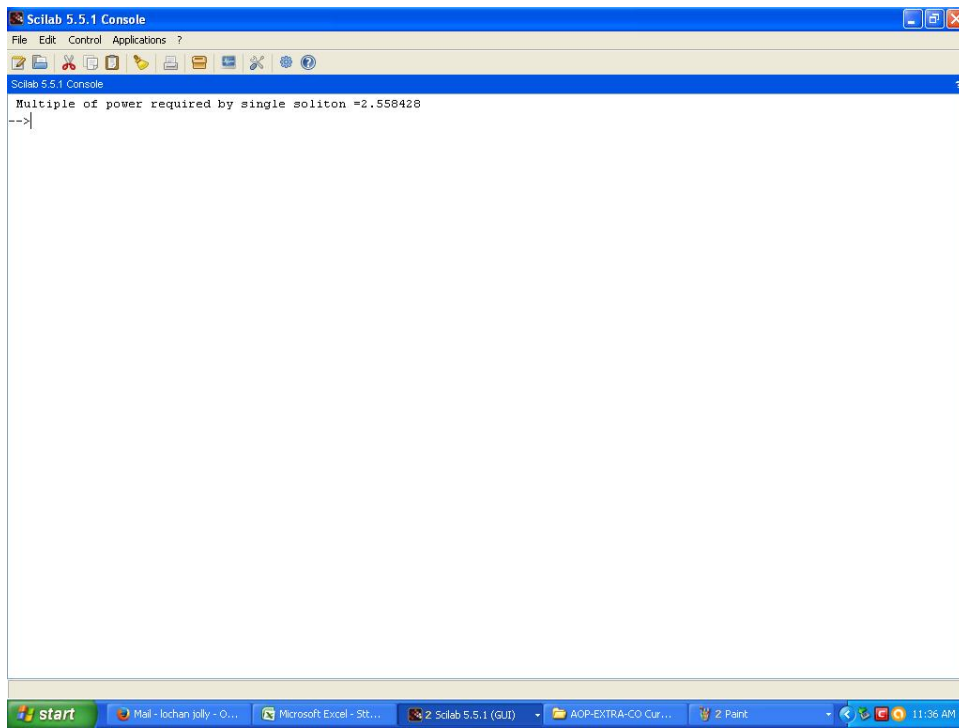



Figure 16.3: 3

```
9 B=10//bitrate in Gb/s
10 two_qo=12//separation between two neighbouring
    solitons in normalized units
11 LT=%pi*exp(two_qo/2)/(8*(two_qo/2)^2*abs(Beta2)
    *10^-24)/(B^2*(10^18))//distance transmission
    limit in Km
12 mprintf('For 10Gb/s bit rate , transmission distance
    is limited to =%f Km',LT)//the answer is
    different because of rounding off
```

Scilab code Exa 16.3 3

```

1 //Optical Fiber communication by A selvarajan
2 //example 16.3
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 alpha=0.2//fiber loss in dB/Km
8 LA=50//Amplifier spacing in Km
9 G=(alpha*LA)//gain in fiber
10 PbyPo=G*log(G)/(G-1)//Multiple of power required by
    single soliton
11 mprintf('Multiple of power required by single
    soliton =%f ',PbyPo)// the answer is slightly
    varing due to rounding error

```

Scilab code Exa 16.4 4

```

1 //Optical Fiber communication by A selvarajan
2 //example 16.4
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 lambda=1.55;//operating wavelength in um
8 LA=50//Amplifier spacing in Km
9 qo=6//Half of separation between two neighbouring
    solitons in normalized units
10 Beta2=-1//dispersion regime ps2/Km
11 B=1/(4*(qo)2*abs(Beta2))//bandwidth in THz
12 mprintf('Communication Link bitrate is limited to =
    %f GHz',B*103)// Multiplication by 103 to
    convert unit from THz to GHz
13 //the answer is wrong

```

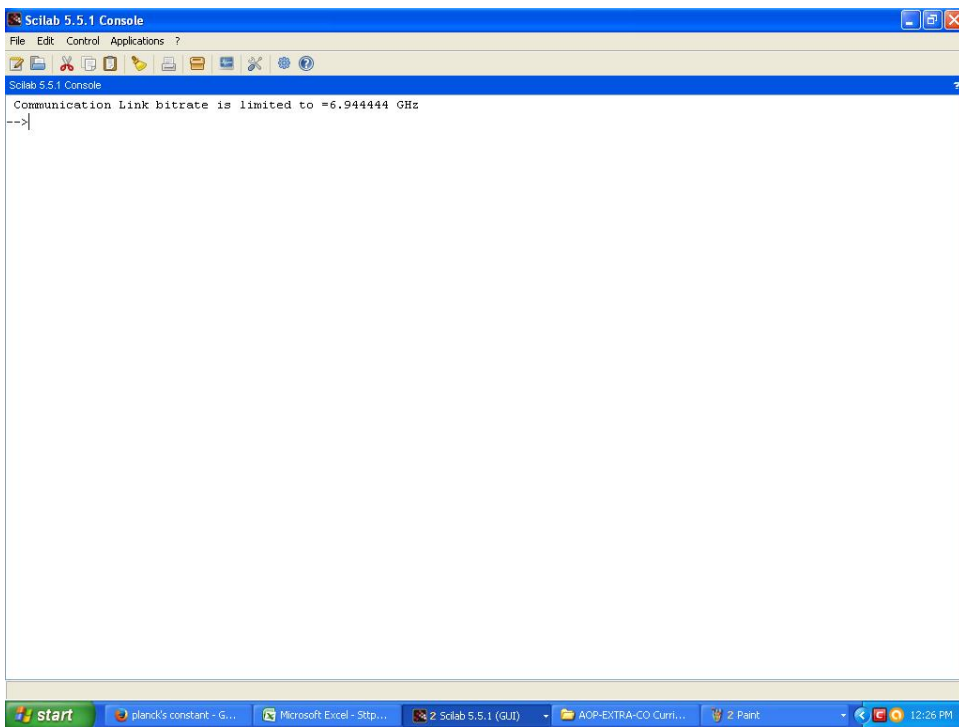


Figure 16.4: 4

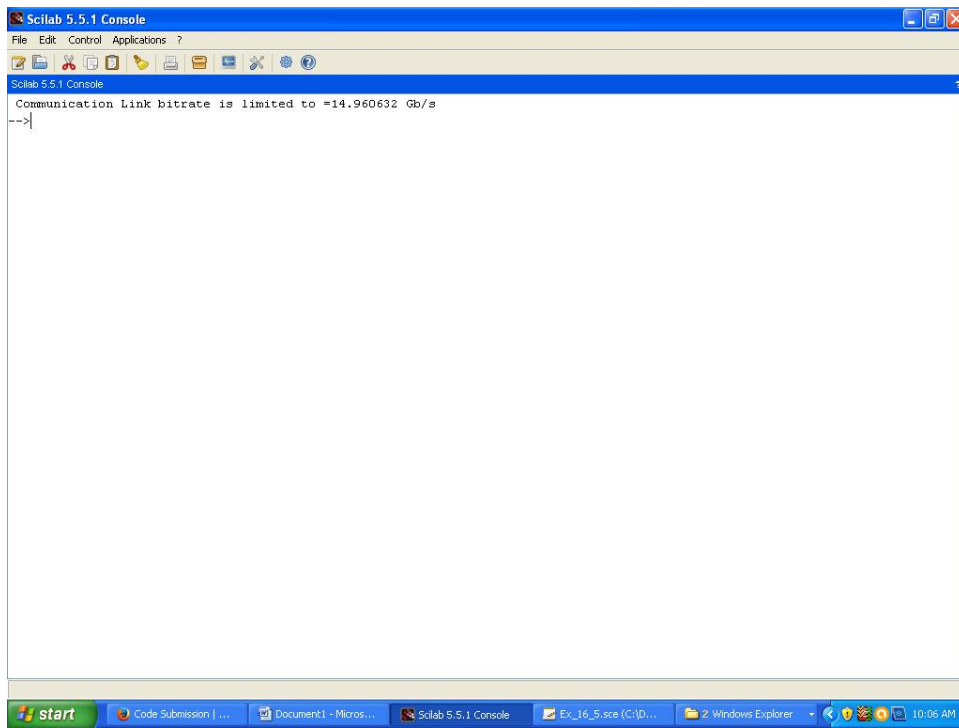


Figure 16.5: 5

Scilab code Exa 16.5 5

```
1 //Optical Fiber communication by A selvarajan
2 //example 16.5
3 //OS=Windows XP sp3
4 //Scilab version 5.5.1
5 clc;
6 clear all;
7 LT=10000//Transmission distance in Km
8 alpha=0.2//fiber loss in dB/Km
```

```

9 lambda=1.55*10^-6; //operating wavelength in m
10 Gama=2 //nonlinearity in /W-Km
11 LA=50 //Amplifier spacing in Km
12 D=1 //dispersion parameter ps/(Km-nm)
13 FG=3.518 //Fiber gain factor
14 fj=0.1 //timing jitter factor
15 h=6.62607004 * 10^-34 //planck's constant in m2 kg /
    s
16 nsp=2 //spontaneous emission factor
17 qo=6 //Half of separation between two neighbouring
    solitons in normalized units
18 B1=((9*pi*fj^2*LA)/(nsp*FG*qo*lambda*h*Gama*D
    *10^-3)) //variable converting la
19 B2=B1^(1/3) //variable
20 B=B2/LT //bandwidth in THz
21 mprintf('Communication Link bitrate is limited to =
    %f Gb/s ',B*10^3) // Multiplication by 10^3 to
    convert unit from THz to GHz
22 //the answer is wrong

```
