Scilab Textbook Companion for Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan[1]

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Book Description

Title: Introduction to Fiber Optics

Author: A. Ghatak and K. Thyagarajan

Publisher: Cambridge, New Delhi

Edition: 1

Year: 1999

ISBN: 81-7596-062-0

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

List of Figures

Chapter 2

Basic Optics

Scilab code Exa 2.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
P=1e-3;//power of laser beam in W
A=3e-6;//cross-sectional area of laser beam in m^2
I=P/A;//power per unit area of laser beam in W/m^2
n=1;//refractive index of air medium
c=3e8;//speed of light in air medium in m/s
meu0=4*(%pi)*1e-7;//permeability of free space in SI
    units
E0=sqrt(2*c*meu0*I/n)//Corresponding electric field
   in V/m
mprintf("Electric field=%.1f V/m",E0);//The answers
   vary due to round off error
```

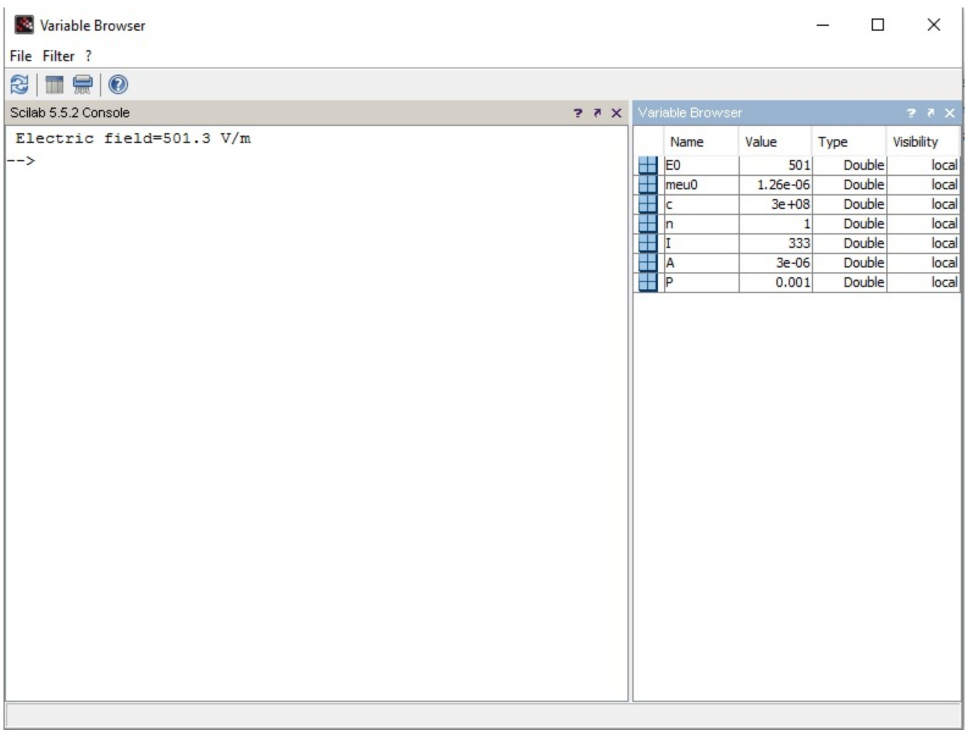
Variable Browser
File Filter ?
Scilab 5.5.2 Console
Electric field=501.3 V/m
-->
Variable Browser
Name Value Type Visibility
E0 501 Double local
meu0 1.26e-06 Double local
c 3e+08 Double local
n 1 Double local
I 333 Double local
A 3e-06 Double local
P 0.001 Double local

Figure 2.1: 1

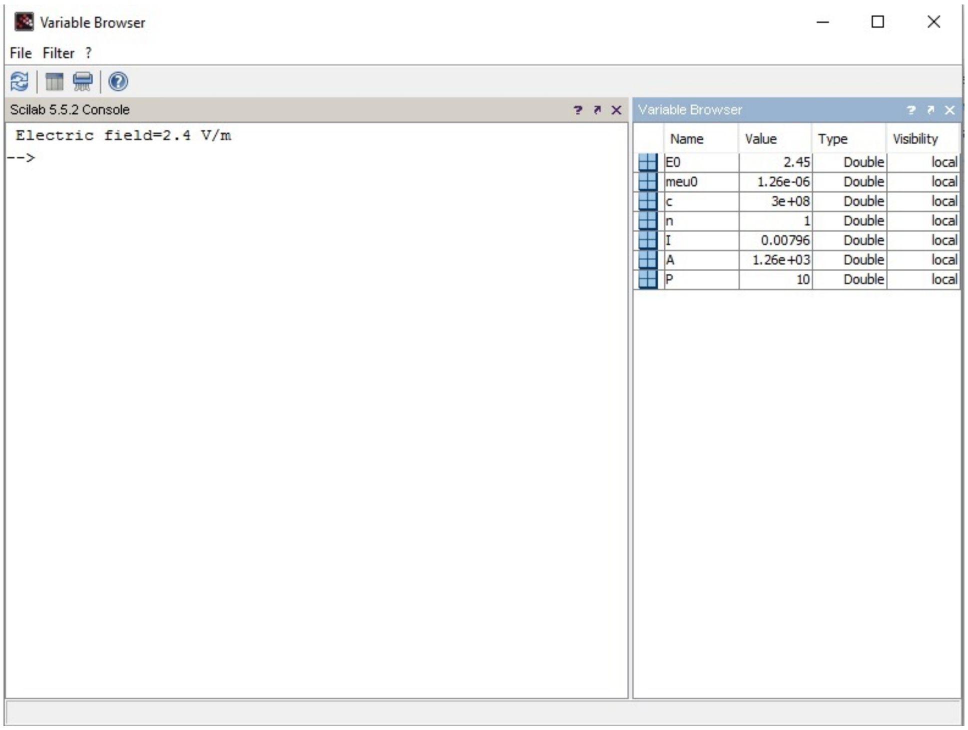

Figure 2.2: 2

Scilab code Exa 2.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
```

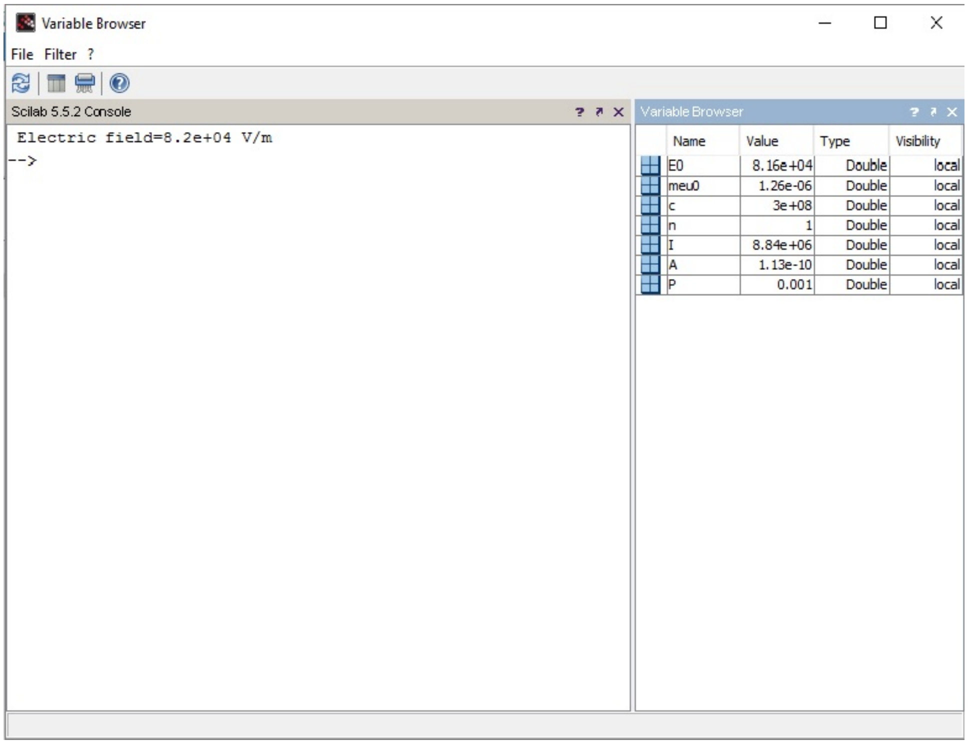

Figure 2.3: 3

```
P=10;//power of bulb in W
A=4*%pi*1e2;//cross-sectional area covered by bulb in m^2
I=P/A;//power per unit area of bulb in W/m^2
n=1;//refractive index of air medium
c=3e8;//speed of light in air medium in m/s
meu0=4*(%pi)*1e-7;//permeability of free space in SI units
E0=sqrt(2*c*meu0*I/n)//Corresponding electric field in V/m
mprintf("Electric field=%.1f V/m",E0);//Final answer
```

Scilab code Exa 2.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
P=1e-3;//power of laser beam in W
A=%pi*(6e-6)^2;//cross-sectional area of spot of
    laser beam in m^2
I=P/A;//power per unit area of laser beam in W/m^2
n=1;//refractive index of air medium
c=3e8;//speed of light in air medium in m/s
meu0=4*(%pi)*1e-7;//permeability of free space in SI
     units
E0=sqrt(2*c*meu0*I/n)//Corresponding electric field
    in V/m
mprintf("Electric field=%.1e V/m",E0);//The answers
    vary due to round off error
```

Scilab code Exa 2.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.4
//OS=Windows XP sp3
//Scilab version 5.5.2
```

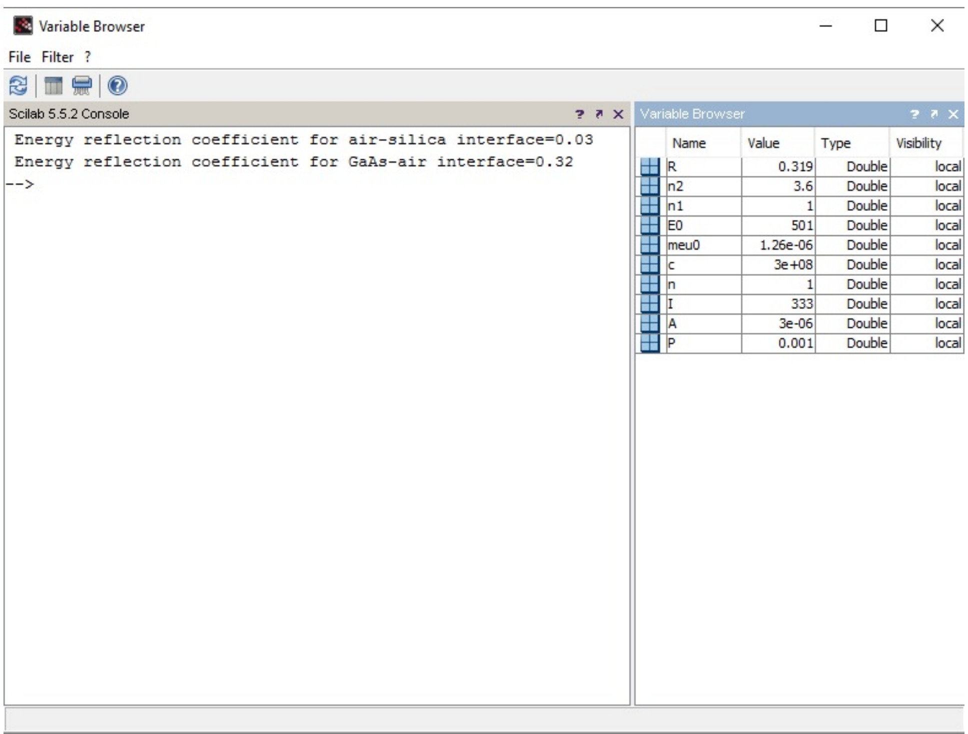
Variable Browser
File Filter ?
Scilab 5.5.2 Console
Energy reflection coefficient for air-silica interface=0.03
Energy reflection coefficient for GaAs-air interface=0.32
-->
Variable Browser
Name Value Type Visibility
R 0.319 Double local
n2 3.6 Double local
n1 1 Double local
E0 501 Double local
meu0 1.26e-06 Double local
c 3e+08 Double local
n 1 Double local
I 333 Double local
A 3e-06 Double local
P 0.001 Double local

Figure 2.4: 4

```
clc;
clear;
//given Case(1)
n1=1;//refractive index of air
n2=1.45;//refractive index of silica
R=[(n1-n2)/(n1+n2)]^2;//corresponding energy reflection coefficient
mprintf("Energy reflection coefficient for air-silica interface=%.2f",R);
//given Case(2)
n1=1;//refractive index of air
n2=3.6;//refractive index of GaAs
R=[(n1-n2)/(n1+n2)]^2;//corresponding energy reflection coefficient
mprintf("\n Energy reflection coefficient for GaAs-air interface=%.2f",R);
```

Scilab code Exa 2.5 5

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.5
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.45;//refractive index of silica
n2=1;//refractive index of air
thetac=asin(n2/n1);//critical angle for the air-silica interface in radians
mprintf("Critical angle for air-silica interface=%.1f degrees",thetac*180/%pi);//multiplying by 180/
```

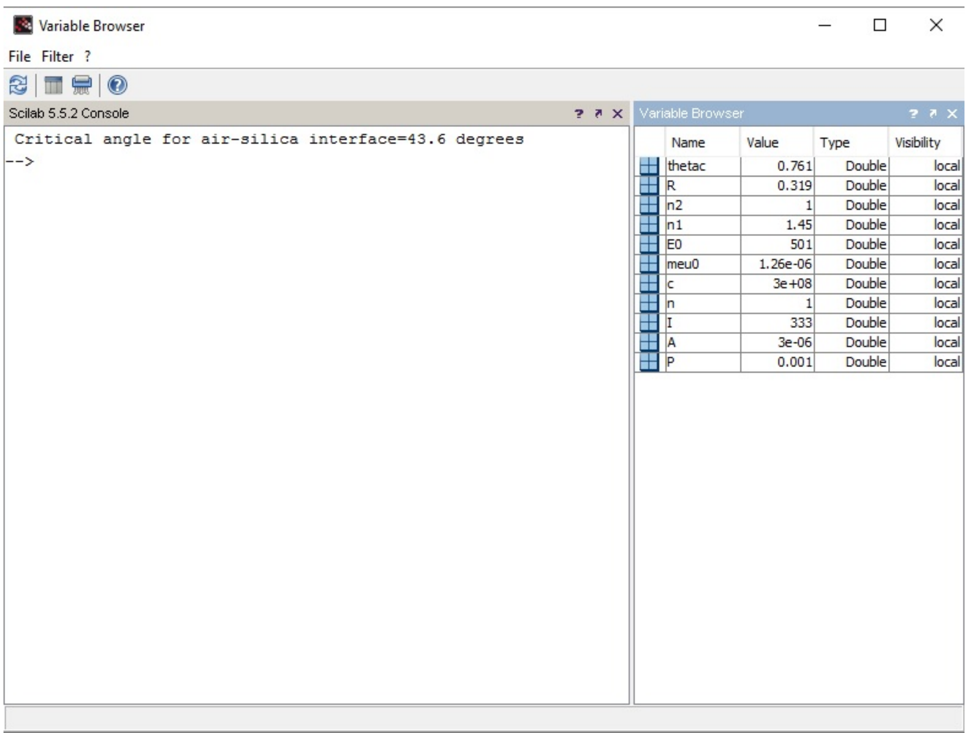
Variable Browser
File Filter ?
Scilab 5.5.2 Console
Critical angle for air-silica interface=43.6 degrees
-->
Variable Browser
Name Value Type Visibility
thetac 0.761 Double local
R 0.319 Double local
n2 1 Double local
n1 1.45 Double local
E0 501 Double local
meu0 1.26e-06 Double local
c 3e+08 Double local
n 1 Double local
I 333 Double local
A 3e-06 Double local
P 0.001 Double local

Figure 2.5: 5

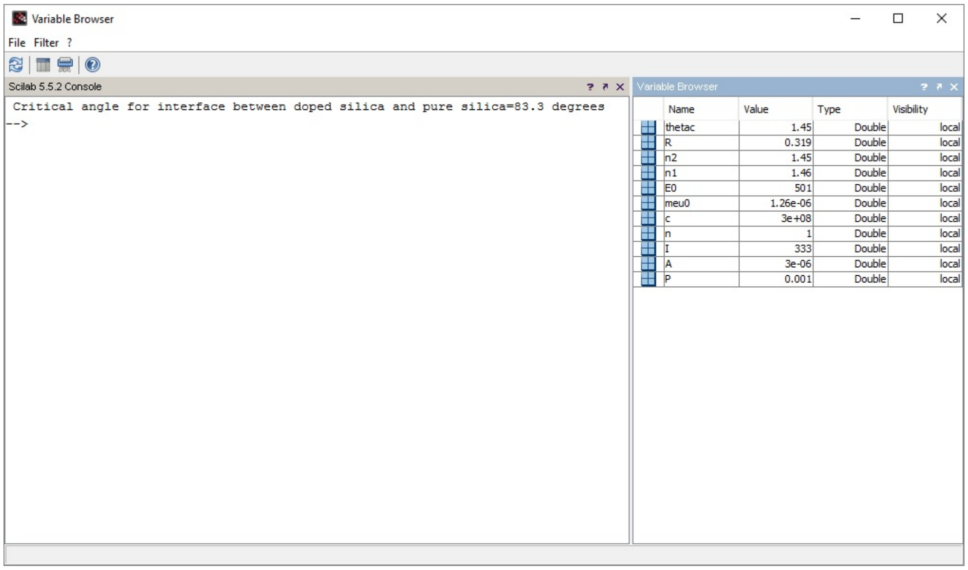

Figure 2.6: 6

```
    pi to convert radians to degrees
```

Scilab code Exa 2.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.46;//refractive index of doped silica
n2=1.45;//refractive index of pure silica
thetac=asin(n2/n1);//critical angle for interface
    between doped silica and pure silica in radians
```

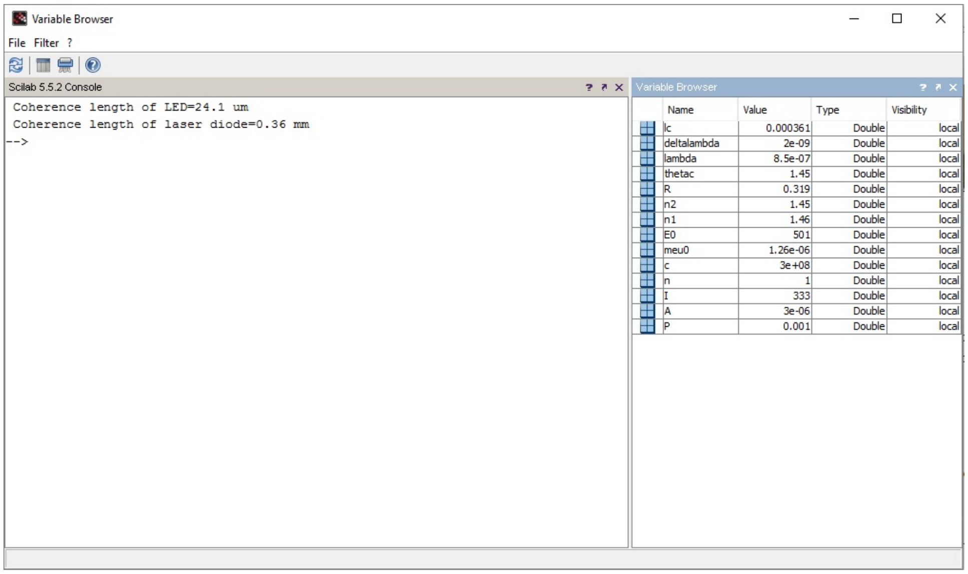

Figure 2.7: 7

```
mprintf("Critical angle for interface between doped
    silica and pure silica=%.1f degrees",thetac*180/
    %pi);//multiplying by 180/pi to convert radians
    to degrees
```

Scilab code Exa 2.7 7

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.7
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given Case(1)
```

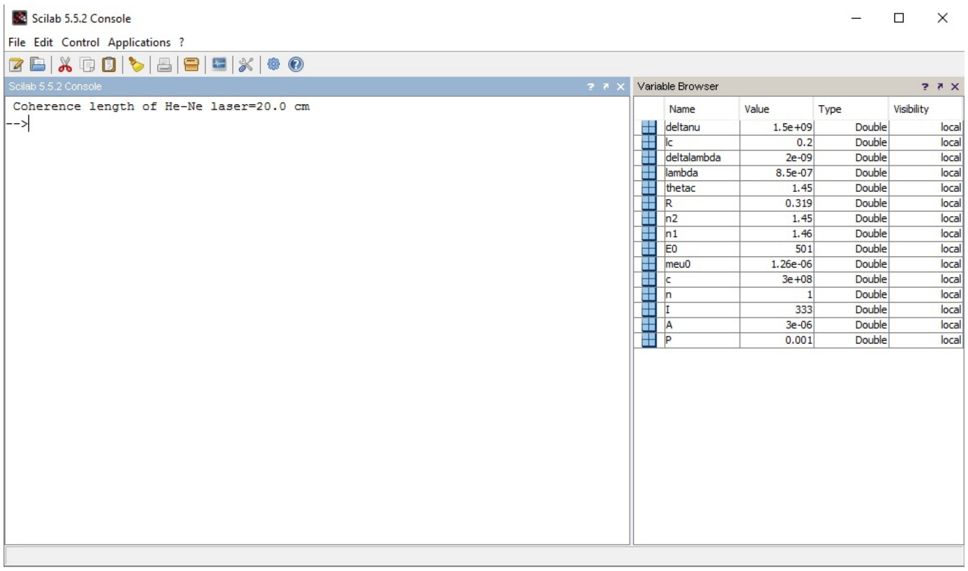

Figure 2.8: 8

```
lambda=850e-9;//wavelength of LED in m
deltalambda=30e-9;//spacing between wavelengths in m
lc=(lambda)^2/deltalambda;//Corresponding coherence length
mprintf("Coherence length of LED=%.1f um",lc/1e-6);//Dividing by 10^(-6) to convert in micrometers
//The answers vary due to round off error
//given Case(2)
lambda=850e-9;//wavelength of laser diode in m
deltalambda=2e-9;//spacing between wavelengths in m
lc=(lambda)^2/deltalambda;//Corresponding coherence length
mprintf("\n Coherence length of laser diode=%.2f mm",lc/1e-3);//Dividing by 10^(-3) to convert in millimeters
```

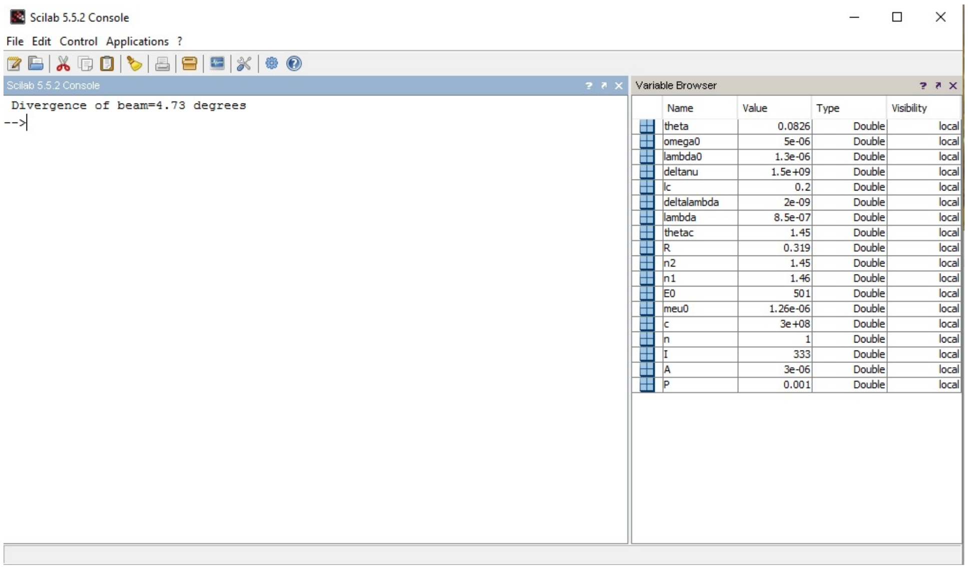

Figure 2.9: 9

Scilab code Exa 2.8 8

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.8
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
deltanu=1.5e9;//change in frequency of He-Ne laser
    in Hz
c=3e8;//speed of light in m/s
lc=c/deltanu;//Corresponding coherence length
mprintf("Coherence length of He-Ne laser=%.1f cm",lc
    /1e-2);//Dividing by 10^(-2) to convert in cm
```

Scilab code Exa 2.9 9

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 2.9
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=1300e-9;//wavelength of single-mode fiber in m
omega0=5e-6;//spot size of beam in m
theta=atan(lambda0/(%pi*omega0));//Corresponding divergence in radians
mprintf("Divergence of beam=%.2f degrees",theta*180/%pi);//multiplying by 180/pi to convert radians to degrees
```

Chapter 7

Modes in Planar Waveguides

Scilab code Exa 7.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 7.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.503;//refractive index of film
n2=1.500;//refractive index of cover
d=4e-6;//thickness of film in m


//Case(1)
lambda0=1e-6;//wavelength  in m
k0=2*(%pi)/lambda0;//free space wave number in rad/m
funcprot(0);//To avoid warning message when function is redefined
mprintf("\n For 1st value of lambda:");
```

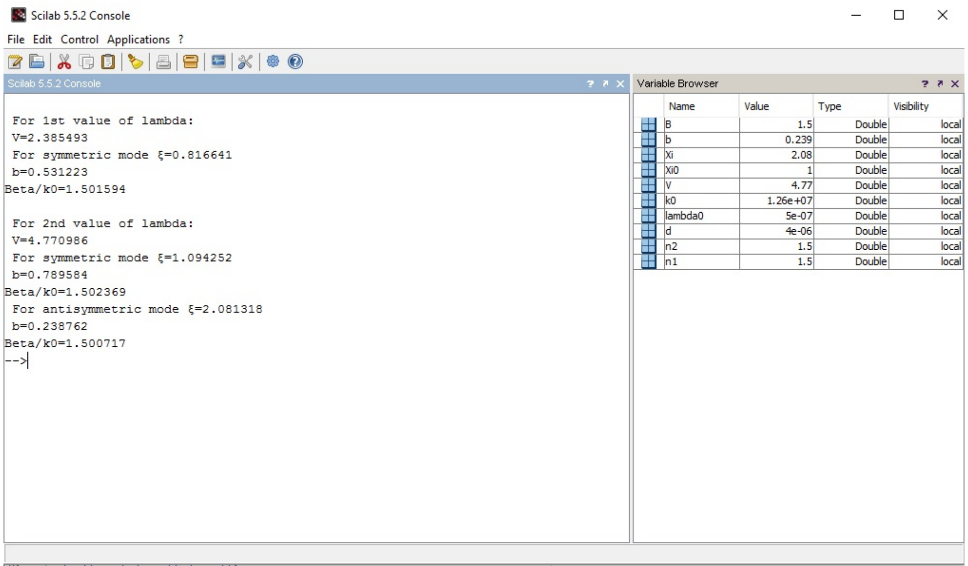

Figure 7.1: 1

```
V=k0*d*sqrt((n1^2)-(n2^2));//dimensionless waveguide
    parameter
mprintf("\n V=%f",V);//The answers vary due to round
    off error

//To find Xi for symmetric TE mode
deff('t=f(Xi)','t=V/2*cos(Xi)-Xi');//Rearranging the
    terms of eqn for symmetric TE modes i.e. '
     tan  =((V/2)^2-  ^2)', we get '  =V/2*cos(  )'
Xi0=0;//Starting value of Xi
Xi=fsolve(Xi0,f);//Root of eqn 't=0'
mprintf("\n For symmetric mode  =%f",Xi);//The
   answers vary due to round off error
b=1-(Xi^2)/(V^2/4);//dimensionless propagation
   constant
mprintf("\n b=%f",b);
B=sqrt(b*((n1^2)-(n2^2))+(n2^2));
mprintf("\nBeta/k0=%f",B);//The answers vary due to
   round off error

```

```
//Case(2)
lambda0=0.5e-6;//wavelength  in m
k0=2*(%pi)/lambda0;//phase constant in rad/m
mprintf("\n\n For 2nd value of lambda:");
V=k0*d*sqrt((n1^2)-(n2^2))//dimensionless waveguide parameter
mprintf("\n V=%f ",V);//The answers vary due to round off error

//To find Xi for symmetric TE mode
deff('t=f(Xi)','t=V/2*cos(Xi)-Xi');//Rearranging the terms of eqn for symmetric TE modes i.e. ' tan =((V/2)^2- ^2)^(1/2)', we get ' =V/2*cos( )'
Xi0=0;//Starting value of Xi
Xi=fsolve(Xi0,f);//Root of eqn 't=0'
mprintf("\n For symmetric mode  =%f",Xi);//The answers vary due to round off error
b=1-(Xi^2)/(V^2/4);//dimensionless propagation constant
mprintf("\n b=%f",b);
B=sqrt(b*((n1^2)-(n2^2))+(n2^2));
mprintf("\nBeta/k0=%f",B);
//To find Xi for antisymmetric TE mode
deff('t=f(Xi)','t=V/2*sin(Xi)-Xi');//Rearranging the terms of eqn for antisymmetric TE modes i.e. '- cot =((V/2)^2- ^2)^(1/2)', we get ' =V/2*sin( )'
Xi0=1;//Starting value of Xi
Xi=fsolve(Xi0,f);//Root of eqn 't=0'
mprintf("\n For antisymmetric mode  =%f",Xi);//The answers vary due to round off error
b=1-(Xi^2)/(V^2/4);//dimensionless propagation constant
mprintf("\n b=%f",b);
B=sqrt(b*((n1^2)-(n2^2))+(n2^2));
mprintf("\nBeta/k0=%f",B);
```

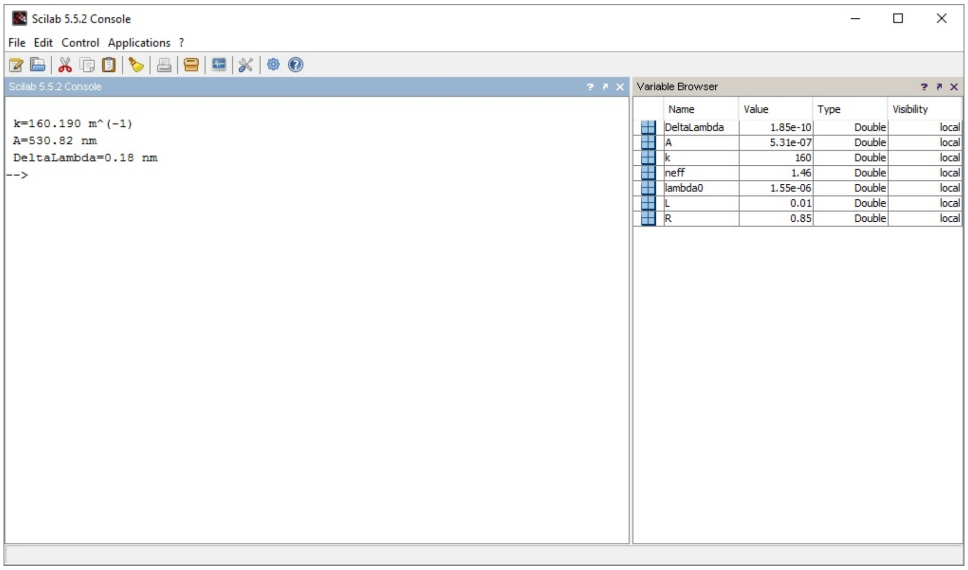

Figure 7.2: 2

Scilab code Exa 7.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 7.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.5;//refractive index of film
n2=1.0;//refractive index of cover
d=.555e-6;//thickness of film in m

```

```
//Case(1)
lambda0=1.3e-6;//wavelength in m
k0=2*(%pi)/lambda0;//free space wave number in rad/m
V=k0*d*sqrt((n1^2)-(n2^2));//dimensionless waveguide parameter
mprintf("V=%f \n",V);//The answers vary due to round off error

//To find Xi for symmetric TE mode
deff('t=f(Xi)','t=V/2*cos(Xi)-Xi');//Rearranging the terms of eqn for symmetric TE modes i.e. '  tan  =((V/2)^2-  ^2)', we get '  =V/2*cos(  )'
Xi0=0;//Starting value of Xi
Xi=fsolve(Xi0,f);//Root of eqn 't=0'
b=1-(Xi^2)/(V^2/4);//dimensionless propagation constant
mprintf("\n b=%f",b);//The answers vary due to round off error
B=sqrt(b*((n1^2)-(n2^2))+(n2^2));
mprintf("\nBeta/k0=%f",B);//The answers vary due to round off error

//To find Xi for symmetric TM mode
deff('t=f(Xi)','t=(1-(n1/n2)^2)*(Xi^2)+(V^2)/4-(Xi*sec(Xi))^2');//Rearranging the terms of eqn for symmetric TE modes i.e. '  tan  =((V/2)^2-  ^2)', we get '  =V/2*cos(  )'
Xi0=0;//Starting value of Xi
Xi=fsolve(Xi0,f);//Root of eqn 't=0'
b=1-(Xi^2)/(V^2/4);//dimensionless propagation constant
mprintf("\n b=%f",b);//The answer provided in the textbook is wrong
B=sqrt(b*((n1^2)-(n2^2))+(n2^2));
mprintf("\nBeta/k0=%f",B);//The answer provided in the textbook is wrong
```

Chapter 8

Propagation Charecteristics of a step index fiber

Scilab code Exa 8.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given Case(1)
n2=1.45;//refractive index of cladding
a=3e-6;//radius of core in m
delta=0.0064//fractional change in refractive index
lambda0=1.546e-6;//wavelength  in m
n1=n2/(1-delta);//refractive index of core
V=2*(%pi)*a*sqrt((n1^2)-(n2^2))/lambda0;//
    corresponding dimensionless V number
mprintf("\n For fiber 1:");
mprintf("\n V=%.1f at lambda0=%.3f um ",V,lambda0/1e
```

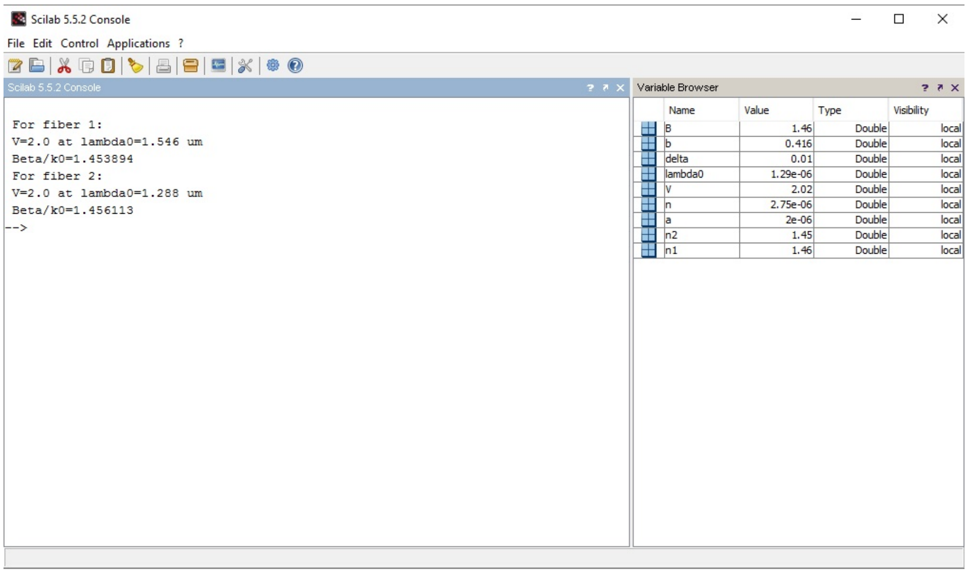

Figure 8.1: 1

```
    -6);//Division by 10^(-6) to convert into um
b=0.41616;//value of dimensionless propagation
    constant corresponding to V=2 as per given table
B=sqrt((n2^2)+b*((n1^2)-(n2^2)));//corresponding
    value of Beta/k0
mprintf("\n Beta/k0=%f",B);//The answers vary due to
     round off error

//given Case(2)
n2=1.45;//refractive index of cladding
a=2e-6;//radius of core in m
delta=0.010//fractional change in refractive index
lambda0=1.288e-6;//wavelength  in m
n1=n2/(1-delta);//refractive index of core
V=2*(%pi)*a*sqrt((n1^2)-(n2^2))/lambda0;//
    corresponding dimensionless V number
mprintf("\n For fiber 2:");
mprintf("\n V=%.1f at lambda0=%.3f um ",V,lambda0/1e
    -6);//Division by 10^(-6) to convert into um
b=0.41616;//value of dimensionless propagation
```

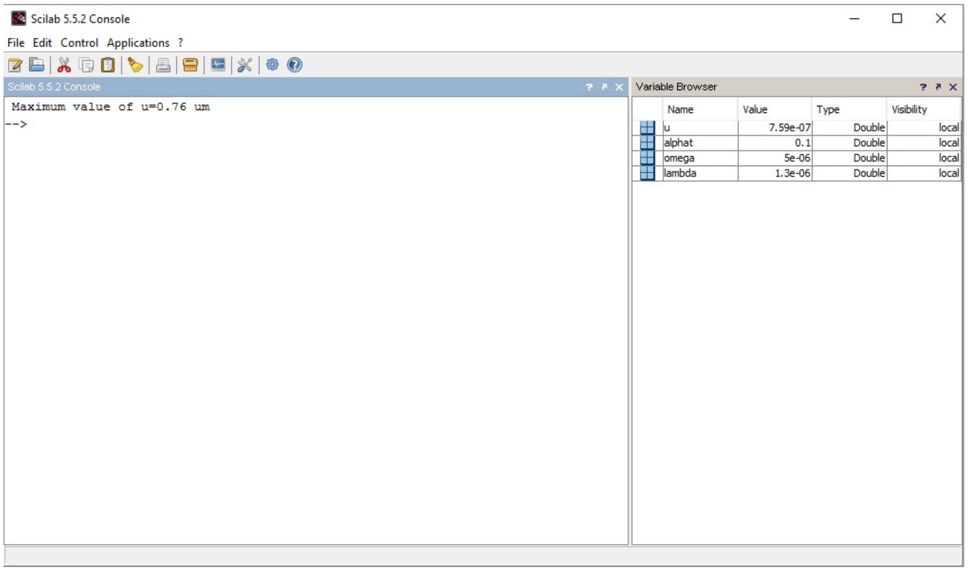

Figure 8.2: 3

```
constant corresponding to V=2 as per given table
B=sqrt((n2^2)+b*((n1^2)-(n2^2)));//corresponding value of Beta/k0
mprintf("\n Beta/k0=%f",B);//The answers vary due to round off error
```

Scilab code Exa 8.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
```

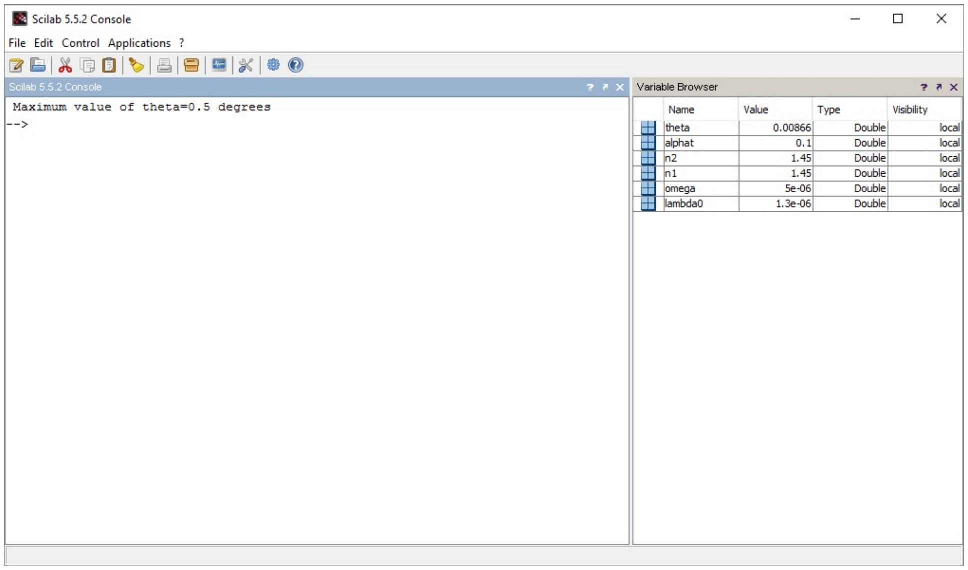

Figure 8.3: 4

```
//given
lambda0=1300e-9;//operating wavelength of single mode fiber in m
omega=5e-6;//spot size of fiber in m
alphat=0.1;//maximum value of loss in dB
u=sqrt(alphat*(omega^2)/4.34);//corresponding maximum value of transverse offset in m
mprintf("Maximum value of u=%.2f um",u/1e-6);//division by 1e-6 to convert in um
```

Scilab code Exa 8.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.4
```

```
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=1300e-9;//operating wavelength of single
    mode fiber in m
omega=5e-6;//spot size of fiber in m
n1=1.45;//refractive index of core
n2=1.45;//refractive index of cladding
alphat=0.1;//maximum value of splice loss due to
    angular misalignment in dB
theta=sqrt(alphat*(lambda0^2)/(4.34*((%pi)*n1*omega)
    ^2));//corresponding maximum value of angular
    misalignment in radians
mprintf("Maximum value of theta=%.1f degrees",theta
    *180/(%pi));//multiplying by 180/pi to convert in
     degrees
```

Scilab code Exa 8.5 5

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.5
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=1300e-9;//operating wavelength of single
    mode fiber in m
omega=5e-6;//spot size of fiber in m
n1=1.45;//refractive index of core
```

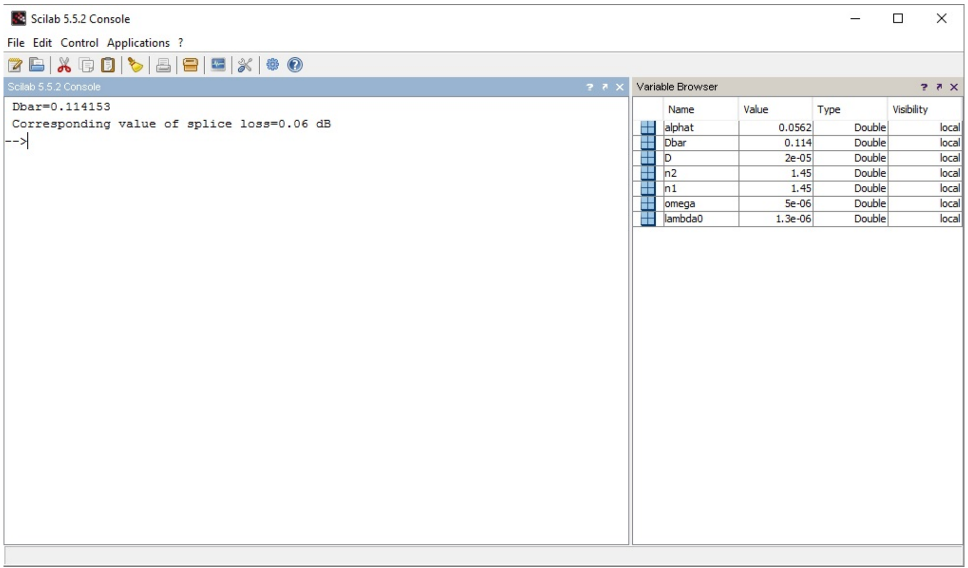

Figure 8.4: 5

```
n2=1.45;//refractive index of cladding
D=20e-6;//longitudinal misalignment in m
Dbar=D*lambda0/(2*(%pi)*n1*(omega^2));//dimensionless normalized separation
mprintf("Dbar=%f",Dbar);//The answers vary due to round off error
alphat=10*log10(1+(Dbar^2));//corresponding value of splice loss due to longitudinal misalignment in dB
mprintf("\n Corresponding value of splice loss=%.2f dB",alphat);
```

Scilab code Exa 8.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K.
```

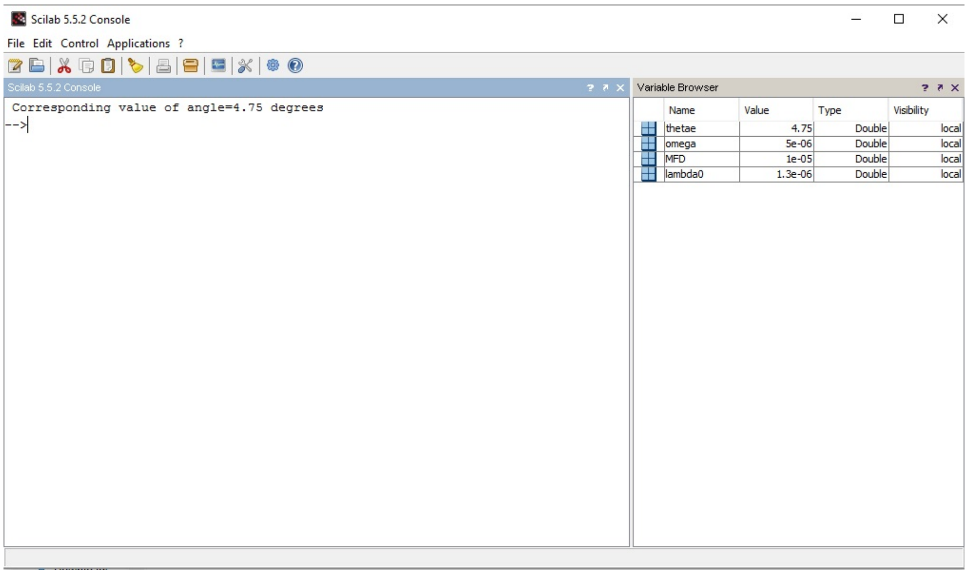

Figure 8.5: 6

```
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=1300e-9;//operating wavelength of single
    mode fiber in m
MFD=10e-6;//mode field diameter of fiber in m
omega=MFD/2;//corresponding spot size of fiber in m
thetae=asind(lambda0/(%pi*omega));//corresponding
    value of angle in degrees where amplitude falls
    to 1/e of maximum value
mprintf("Corresponding value of angle=%.2f degrees",
    thetae);
```

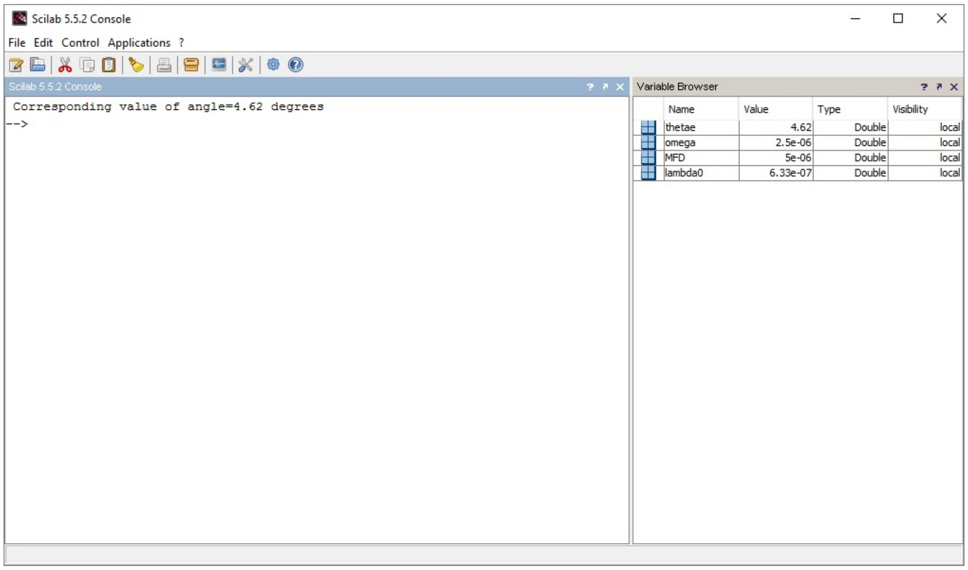

Figure 8.6: 7

Scilab code Exa 8.7 7

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.7
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=633e-9;//operating wavelength of single mode
    fiber in m
MFD=5e-6;//mode field diameter of fiber in m
omega=MFD/2;//corresponding spot size of fiber in m
thetae=asind(lambda0/(%pi*omega));//corresponding
   value of angle in degrees where amplitude falls
   to 1/e of maximum value
```

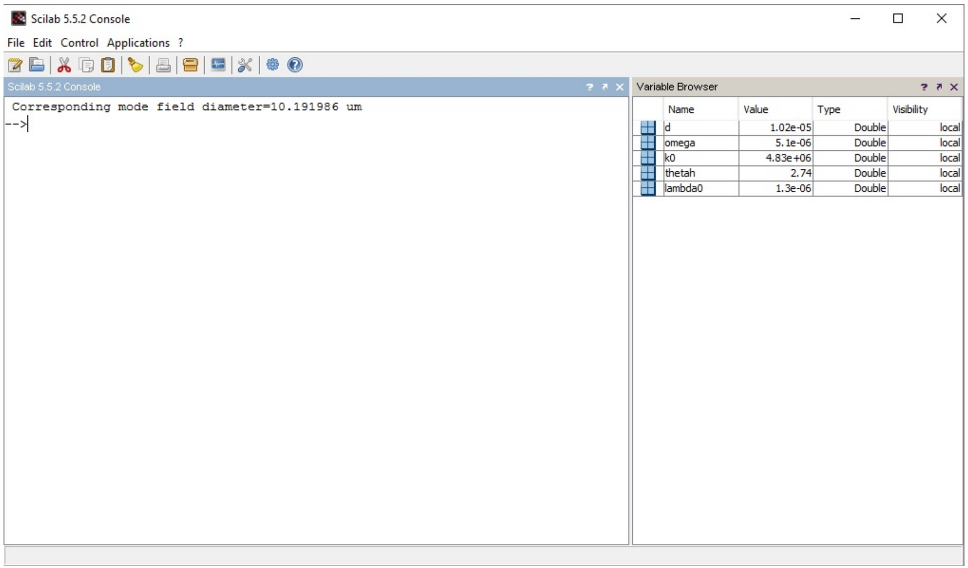

Figure 8.7: 8

```
mprintf("Corresponding value of angle=%.2f degrees",
    thetae);
```

Scilab code Exa 8.8 8

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 8.8
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=1.3e-6;//operating wavelength of single mode
    fiber in m
```

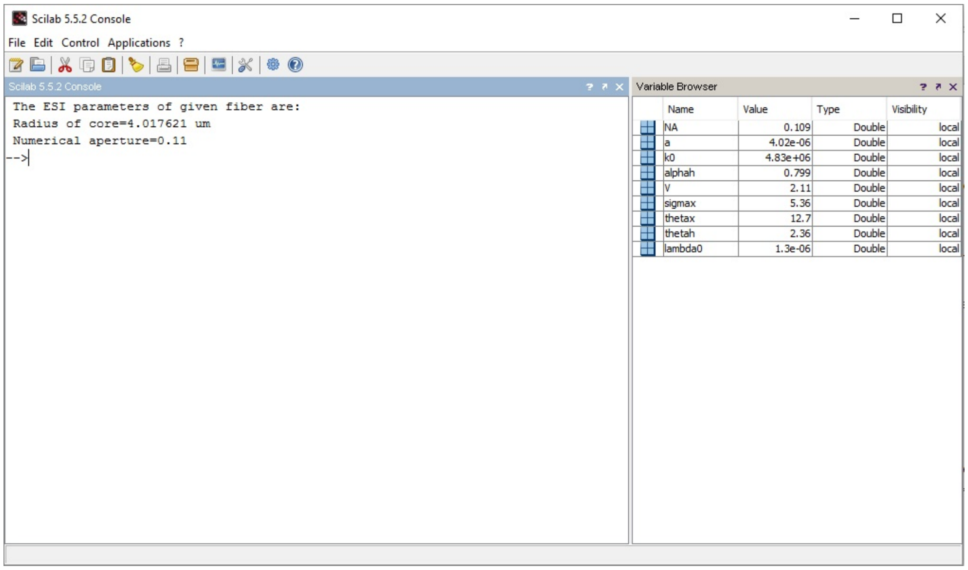

Figure 8.8: 9

```
thetah=2.74;//angle corresponding to 3 dB point in
    degrees
k0=2*%pi/lambda0;//free space wave number in rad/m
omega=sqrt(2*log(2))/(k0*sind(2.74));//corresponding
    spot size of fiber in m
d=2*omega;//corresponding value of Gaussian mode
    field diameter in m
mprintf("Corresponding mode field diameter=%f um",d
    /1e-6)//division by 1e-6 to convert in um
//The answer provided in the textbook is wrong
```

Scilab code Exa 8.9 9

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

```
//Example 8.9
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=1.3e-6;//operating wavelength of single mode fiber in m
thetah=2.357;//angle corresponding to 3 dB point in degrees
thetax=12.73;//angle in degrees at which intensity first becomes zero
sigmax=sind(thetax)/sind(thetah);//ratio of sine of angles
V=8.039-2.347*sigmax+0.3329*sigmax^2-0.0218*sigmax^3+0.00054*sigmax^4;//corresponding dimensionless V number
alphah=-0.7858+0.994*V-0.1155*V^2;
k0=2*%pi/lambda0;//free space wave number in rad/m
a=alphah/(k0*sind(thetah));//radius of core in m
NA=V*lambda0/(2*%pi*a);//corresponding value of numerical aperture
mprintf("The ESI parameters of given fiber are:");
mprintf("\n Radius of core=%f um",a/1e-6);//division by 1e-6 to convert in um
//The answers vary due to round off error
mprintf("\n Numerical aperture=%.2f",NA);
```

Chapter 10

Waveguide Dispersion and design considerations

Scilab code Exa 10.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 10.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.450840;//refractive index of core
n2=1.446918;//refractive imdex of cladding
a=4.1e-6;//radius of core in m
n=2*%pi*a*sqrt((n1^2)-(n2^2))//numerator of the corresponding V number
//corresponding V number expression where lambda0 is in nm
mprintf("V=%.1f/lambda0",n*1e9);//multiplying numerator by 10^9 to convert lambda0 in nm
```

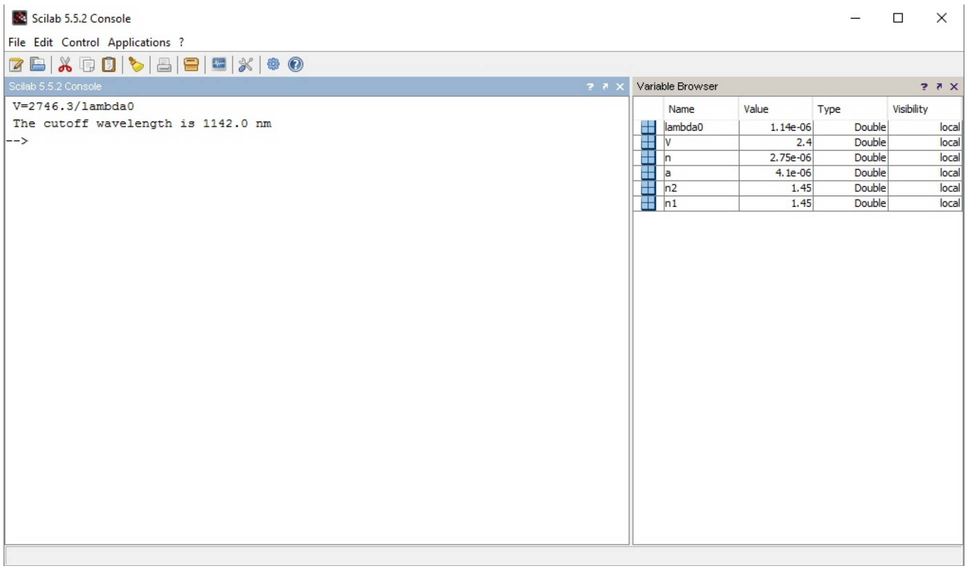

Figure 10.1: 1

```
//For cutoff wavelength:
V=2.4048;
//Since V=n/lambda0
lambda0=n/V;//cutoff wavelength of single mode fiber
    in m
mprintf("\n The cutoff wavelength is %.1f nm",
   lambda0/1e-9);//Division by 10^(-9) to convert
   into nm
```

Scilab code Exa 10.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 10.3
//OS=Windows XP sp3
```

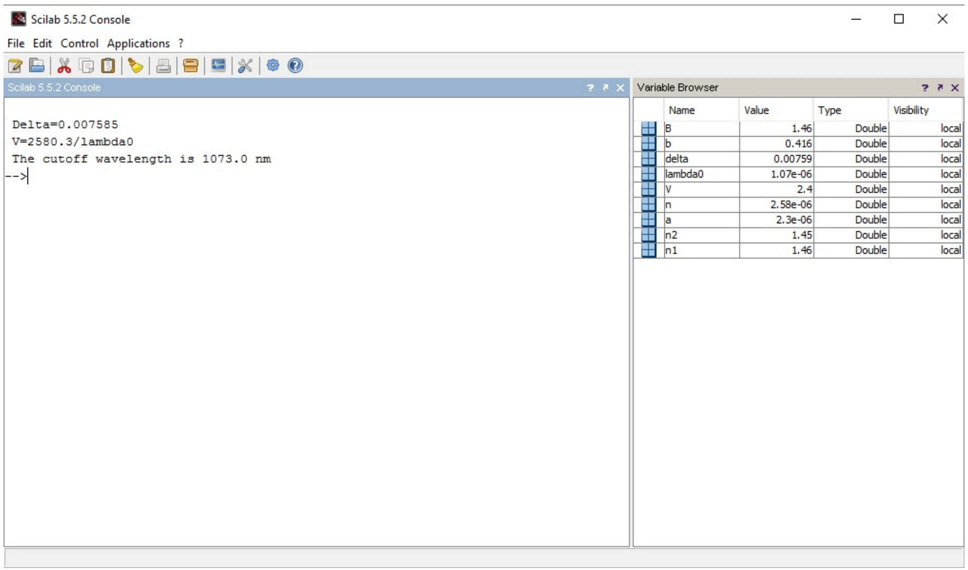

Figure 10.2: 3

```
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.457893;//refractive index of core
n2=1.446918;//refractive imdex of cladding
a=2.3e-6;//radius of core in m
delta=(n1-n2)/n2;//fractional change in refractive
    index
mprintf("\n Delta=%f",delta);//The answers vary due
    to round off error
n=2*%pi*a*sqrt((n1^2)-(n2^2))//numerator of the
    corresponding V number
//corresponding V number expression where lambda0 is
     in nm
mprintf("\n V=%.1f/lambda0",n*1e9);//multiplying
    numerator by 10^9 to convert lambda0 in nm
//For cutoff wavelength:
V=2.4048;
//Since V=n/lambda0
```

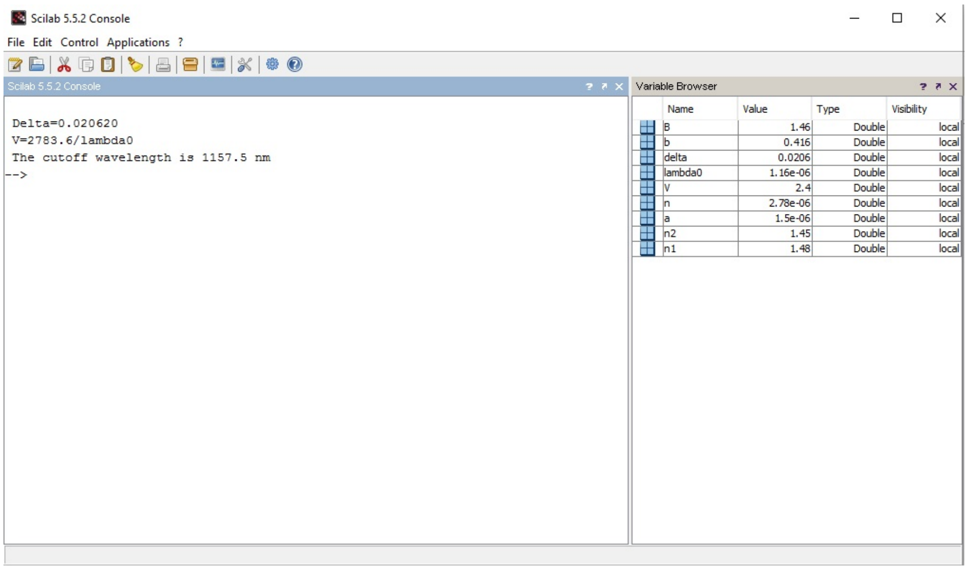

Figure 10.3: 4

```
lambda0=n/V;//cutoff wavelength of single mode fiber
    in m
mprintf("\n The cutoff wavelength is %.1f nm",
    lambda0/1e-9);//Division by 10^(-9) to convert
    into nm
```

Scilab code Exa 10.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 10.4
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
```

```
//given
lambda0=1550e-9;//operating wavelength of single mode fiber in m
n1=1.476754;//refractive index of core
n2=1.446918;//refractive imdex of cladding
a=1.5e-6;//radius of core in m
delta=(n1-n2)/n2;//fractional change in refractive index
mprintf("\n Delta=%f",delta);//The answers vary due to round off error
n=2*%pi*a*sqrt((n1^2)-(n2^2))//numerator of the corresponding V number
//corresponding V number expression where lambda0 is in nm
mprintf("\n V=%.1f/lambda0",n*1e9);//multiplying numerator by 10^9 to convert lambda0 in nm
//For cutoff wavelength:
V=2.4048;
//Since V=n/lambda0
lambda0=n/V;//cutoff wavelength of single mode fiber in m
mprintf("\n The cutoff wavelength is %.1f nm",lambda0/1e-9);//Division by 10^(-9) to convert into nm
//The answers vary due to round off error
```

Chapter 11

Sources for optical communication

Scilab code Exa 11.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 11.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//E1 & E2 are the ground level and first excited
    level of energy respectively
h=6.626e-34;//Planck's constant in SI Units
c=3e8;//speed of electrons in m/s
lambda=694e-9;//wavelength corresponding to the
    energy gap between E1 & E2
//Let E2-E1=DeltaE
DeltaE=h*c/lambda;
mprintf("\n E2-E1=%e",DeltaE);//Energy gap between
```

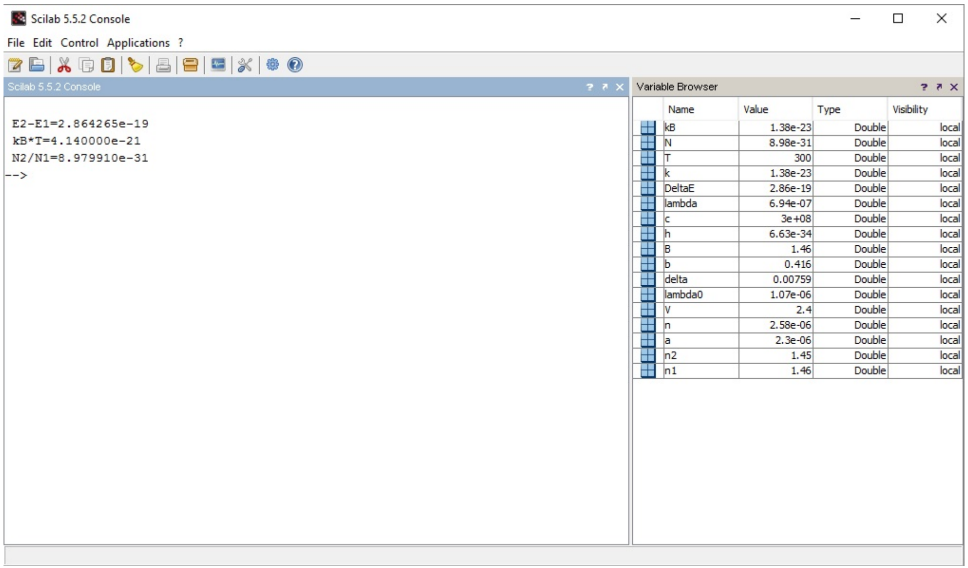

Figure 11.1: 1

```
    E1 & E2 in J
//The answers vary due to round off error
kB=1.38e-23;//Boltzmann constant in SI Units
T=300;//Temperature in K
mprintf("\n kB*T=%e",kB*T);
//Let N2/N1 be N
N=exp(-DeltaE/(kB*T));//Ratio of population density
    at E2 and E1 energy levels
mprintf("\n N2/N1=%e",N);//The answers vary due to
    round off error
```

Scilab code Exa 11.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

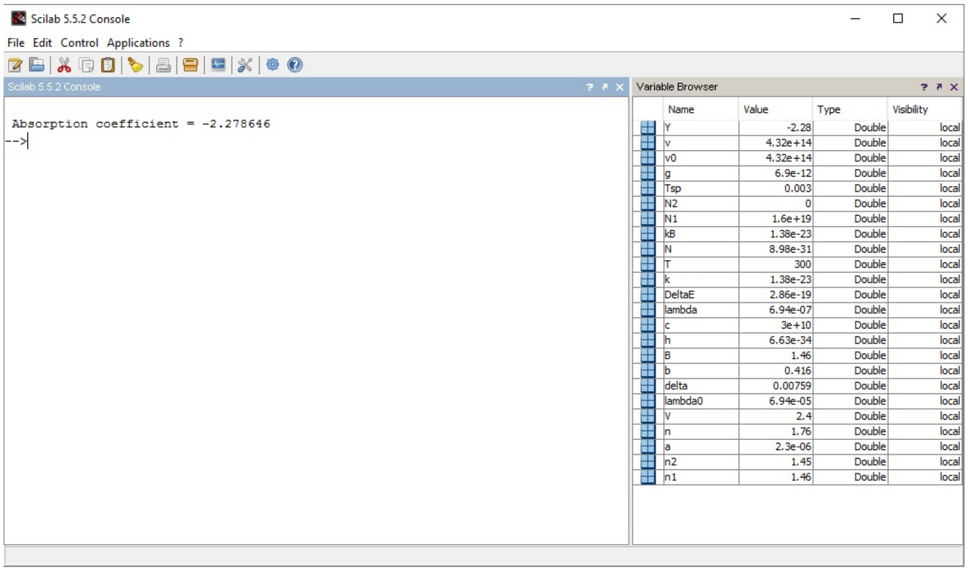

Figure 11.2: 2

```
//Example 11.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//For Cr+3 ions in ruby
N1=1.6e19;//Population density of E1 energy level in cm^(-3)
N2=0;//Population density of E2 energy level in cm^(-3)
n=1.76;//refractive index of medium
Tsp=3e-3;//Spontaneous emission lifetime of atom in sec
//Let g(v0) be g
g=6.9e-12;//normalized lineshape function in s
lambda0=694.3e-7;//wavelength at which absorption takes place in cm
c=3e10;//speed of electrons in cm/s
v=c/lambda0;
```

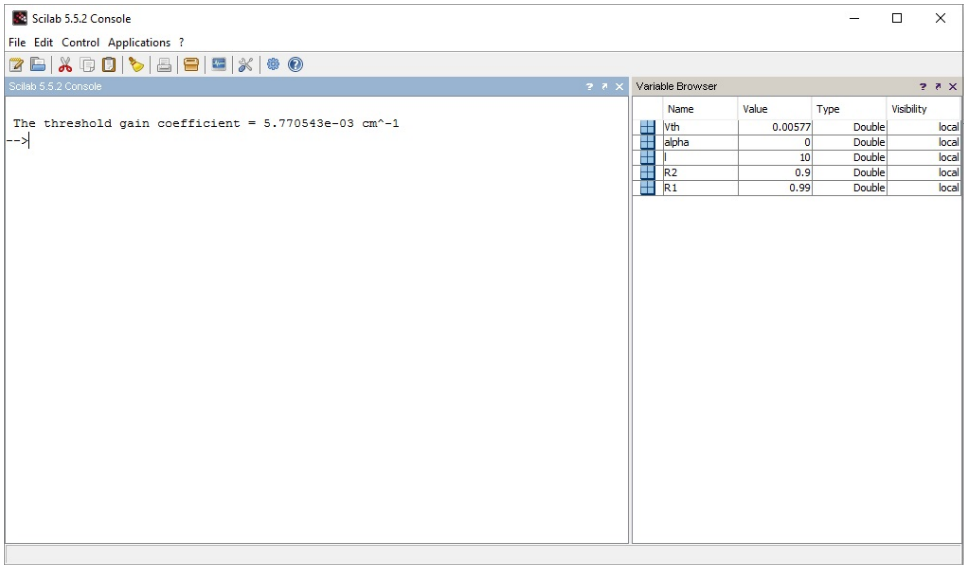

Figure 11.3: 3

```
//Let Y(v0) be Y
Y=((c/n)^2)*g*(N2-N1)/(8*%pi*Tsp*(v^2));//Corresponding gain coefficient of medium
mprintf("\n Absorption coefficient = %f",Y);//The answers vary due to round off error
//negative sign implies absorption
```

Scilab code Exa 11.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 11.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
```

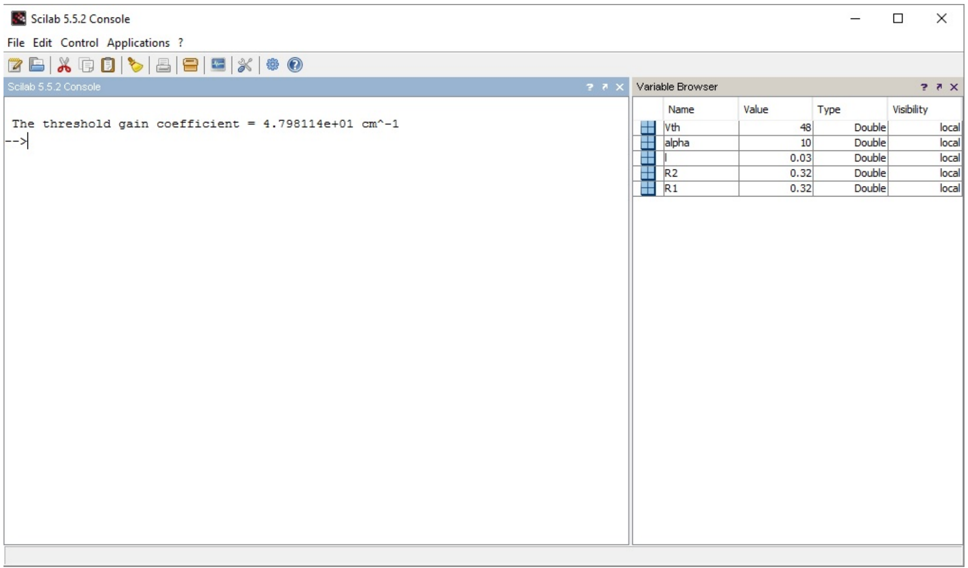

Figure 11.4: 4

```
clear;
//given
R1=0.99;//reflection coefficient of mirror 1
R2=0.9;//reflection coefficient of mirror 2
l=10;//Distance between the two mirrors in cm
alpha=0;//average loss coefficient per unit length
    of resonator in cm^(-1)
Vth=alpha-log(R1*R2)/(2*l);//Corresponding threshold
     gain coefficient in cm^(-1)
mprintf("\n The threshold gain coefficient = %e cm
    ^-1",Vth);//The answers vary due to round off
    error
```

Scilab code Exa 11.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 11.4
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
R1=0.32;//reflection coefficient of mirror 1
R2=0.32;//reflection coefficient of mirror 2
l=300e-4;//Distance between the two mirrors in cm
alpha=10;//average loss coefficient per unit length
   of resonator in cm^(-1)
Vth=alpha-log(R1*R2)/(2*l);//Corresponding threshold
    gain coefficient in cm^(-1)
mprintf("\n The threshold gain coefficient = %e cm
   ^-1",Vth);//The answers vary due to round off
   error
```

Scilab code Exa 11.5 5

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 11.5
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
R1=0.3;//reflection coefficient of mirror 1
R2=0.3;//reflection coefficient of mirror 2
l=500e-4;//Distance between the two mirrors in cm
alpha=5e1;//average loss coefficient per unit length
```

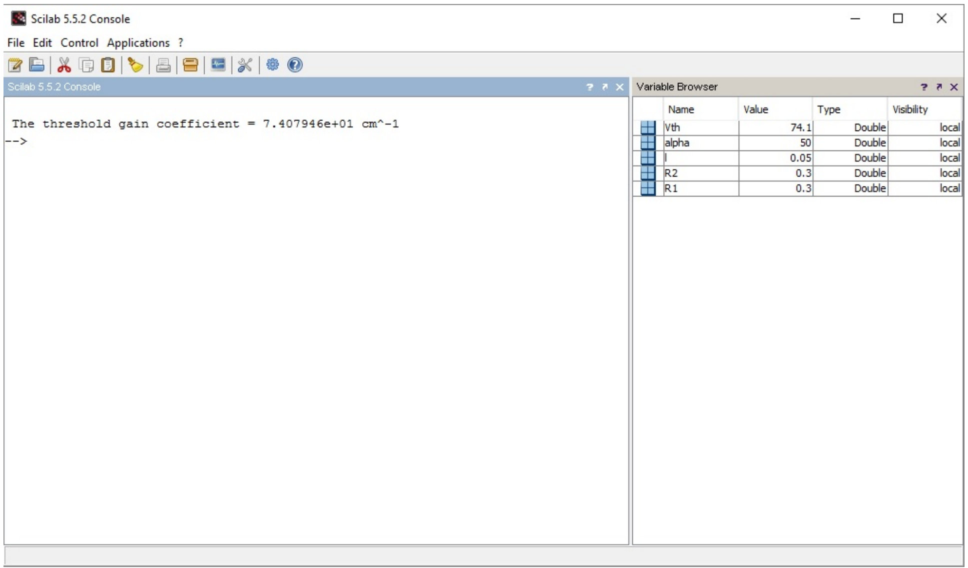

Figure 11.5: 5

```
    of resonator in cm^(-1)
Vth=alpha-log(R1*R2)/(2*l);//Corresponding threshold
    gain coefficient in cm^(-1)
mprintf("\n The threshold gain coefficient = %e cm
   ^-1",Vth);//The answers vary due to round off
   error
```

Scilab code Exa 11.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 11.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
```

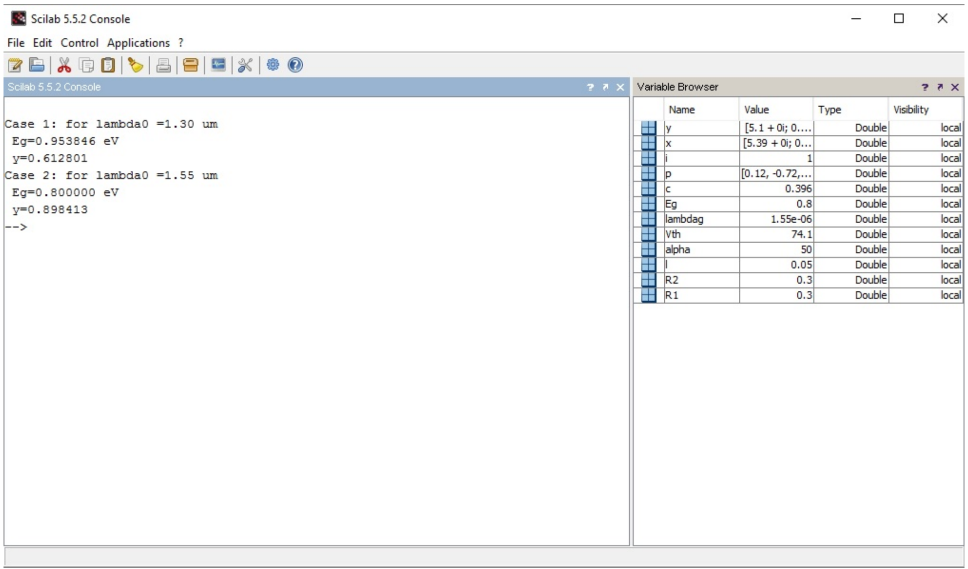

Figure 11.6: 6

```
clear;
//given Case(i)
lambdag=1.30e-6;//emission wavelength in m
//Bandgap energy in eV is given by :
Eg=1.24/(lambdag/1e-6);//Division by 10^(-6) to convert lambdag into um
mprintf("\nCase 1: for lambda0 =1.30 um");
mprintf("\n Eg=%f eV",Eg);//The answers vary due to round off error
p=[0.12 -0.72 1.35-Eg];//Relation between Eg & y is given as 'Eg(y)=1.35-0.72y+0.12y^2 in eV'
y=roots(p);
mprintf("\n y=%f",y(2,1));//Roots are arranged in descending order & y cannot be greater than 1
//The answers vary due to round off error
//given Case(ii)
lambdag=1.55e-6;//emission wavelength in m
//Bandgap energy in eV is given by :
Eg=1.24/(lambdag/1e-6);//Division by 10^(-6) to convert lambdag into um
```

```
mprintf("\nCase 2: for lambda0 =1.55 um");
mprintf("\n Eg=%f eV",Eg);//The answers vary due to
    round off error
p=[0.12 -0.72 1.35-Eg];//Relation between Eg & y is
    given as 'Eg(y)=1.35-0.72y+0.12y^2 in eV'
y=roots(p);
mprintf("\n y=%f",y(2,1));//Roots are arranged in
    descending order & y cannot be greater than 1
//The answers vary due to round off error
```

Chapter 12

Detectors for optical fiber communication

Scilab code Exa 12.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 12.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda=0.8e-6;//wavelength of light in m
n=3.5;//refractive index of Si
e=1.6e-19;//electronic charge in C
h=6.626e-34;//Planck's constant in SI Units
c=3e8;//speed of electrons in m/s
alpha=1e5;//average loss coefficient per unit length
    of resonator in m^(-1)
w=20e-6;//width of depletion layer in m
R=((n-1)/(n+1))^2;//Reflection coefficient of
```

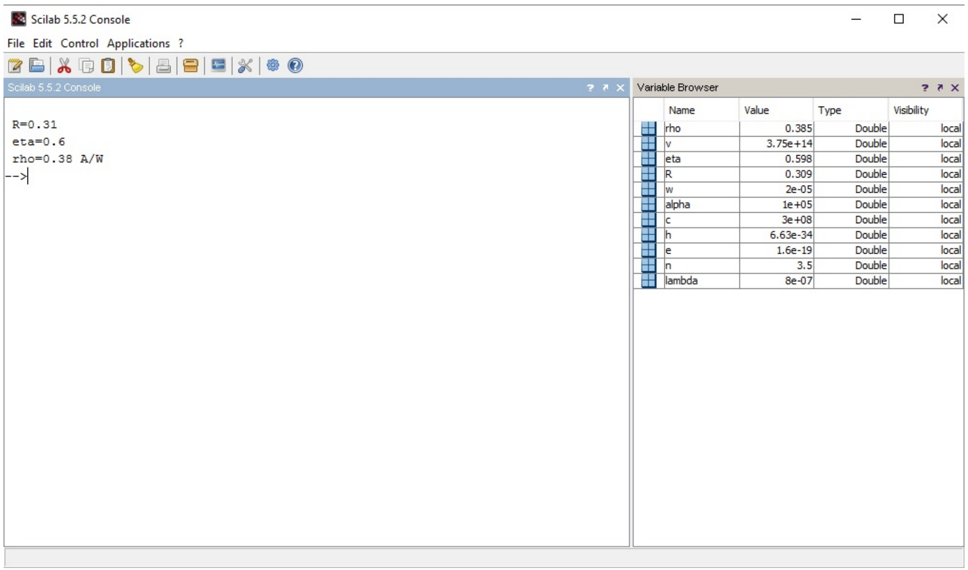

Figure 12.1: 1

```
uncoated Si
mprintf("\n R=%.2f",R);
//Assuming all e-h pairs contribute to photo current i.e. zeta=1
eta=(1-R)*(1-exp(-alpha*w));//Corresponding quantum efficiency
mprintf("\n eta=%.1f",eta);
v=c/lambda;//frequency corresponding to given wavelength in Hz
rho=eta*e/(h*v);//corresponding responsivity in A/W
mprintf("\n rho=%.2f A/W",rho);//The answers vary due to round off error
```

Scilab code Exa 12.2 2

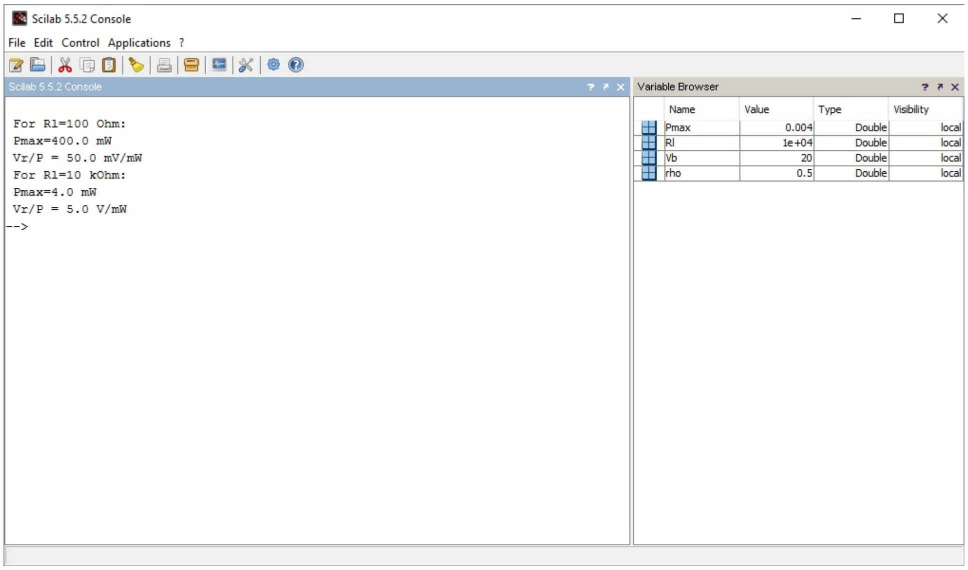

Figure 12.2: 2

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 12.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
rho=0.5;//responsitivity of Si PIN detector in A/W
Vb=20;//reverse bias voltage across the detector in V
//Case (i):
Rl=100;//load resistor in ohms
Pmax=Vb/(rho*Rl);//maximum value of optical power P falling on the photodetector in W
mprintf("\n For Rl=100 Ohm:");
mprintf("\n Pmax=%.1f mW",Pmax/1e-3)//Division by 10^(-3) to convert into mW
mprintf("\n Vr/P = %.1f mV/mW",rho*Rl);//Bias voltage per unit power in mV/mW
```

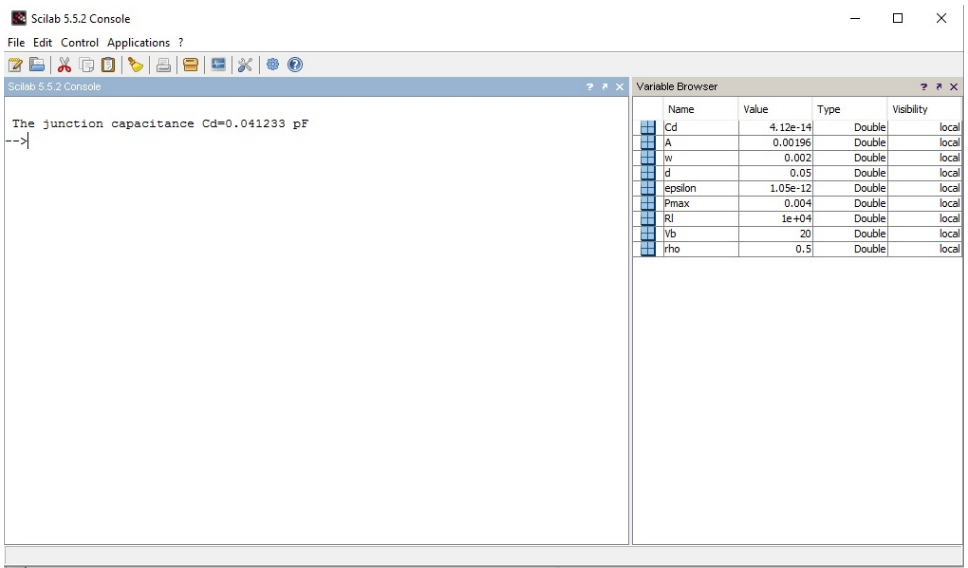

Figure 12.3: 3

```
//Case (ii):
Rl=10e3;//load resistor in ohms
Pmax=Vb/(rho*Rl);//maximum value of optical power P
    falling on the photodetector in W
mprintf("\n For Rl=10 kOhm:");
mprintf("\n Pmax=%.1f mW",Pmax/1e-3)//Division by
    10^(-3) to convert into mW
//Bias voltage per unit power in V/mW :
mprintf("\n Vr/P = %.1f V/mW",rho*Rl/1e3);//Division
    by 10^3 to convert into V/mW
```

Scilab code Exa 12.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

```
//Example 12.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
epsilon=10.5e-13;//permittivity of Si in F/cm
d=500e-4;//diameter of Si detector in cm
w=20e-4;//width of depletion layer in cm
A=%pi*((d/2)^2);//Area of detector in cm^2
Cd=epsilon*A/d;//Junction capacitance in F
mprintf("\n The junction capacitance Cd=%f pF",Cd/1e
    -12);//division by 10^(-12) to convert into pF
//The answer provided in the textbook is wrong
```

Chapter 13

Design Considerations of a fiber optic communication system

Scilab code Exa 13.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//Vc(t)=V0*(1-exp(-t/(R*C))) is the voltage across capacitance in an RC circuit
//Hence, the time t=R*C*(-log(1-Vc/V0))

//The Rise time is the time taken by a system to rise from 10% to 90% of maximum value
//So, it is given as Tr=T90-T10 where T90 is time when Vc is 90% of maximum value and T10 is time when Vc is 10% of maximum value
```

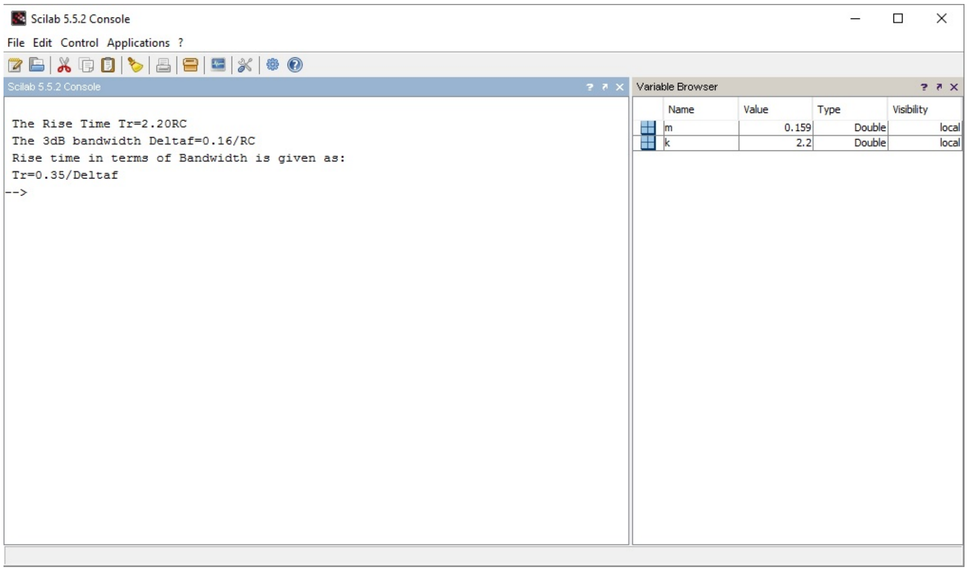

Figure 13.1: 1

```
//i.e. Tr=R*C*(-log(1-0.9))-R*C*(-log(1-0.1))
//Let Tr=R*C*k; where k=log(1-0.1))-log(1-0.9)
k=log(1-0.1)-log(1-0.9);
mprintf("\n The Rise Time Tr=%.2fRC",k);

//Now, The 3dB bandwidth is given as Deltaf=1/(2*%pi*R*C);
//Let Deltaf=m/(R*C); where m=1/(2*%pi)
m=1/(2*%pi);
mprintf("\n The 3dB bandwidth Deltaf=%.2f/RC",m);

//By multiplying expressions of Tr and Deltaf, we eliminate RC from the expressions
//Rearranging te terms, we get Tr in terms of Deltaf
mprintf("\n Rise time in terms of Bandwidth is given as:");
mprintf("\n Tr=%.2f/Deltaf",k*m);
```

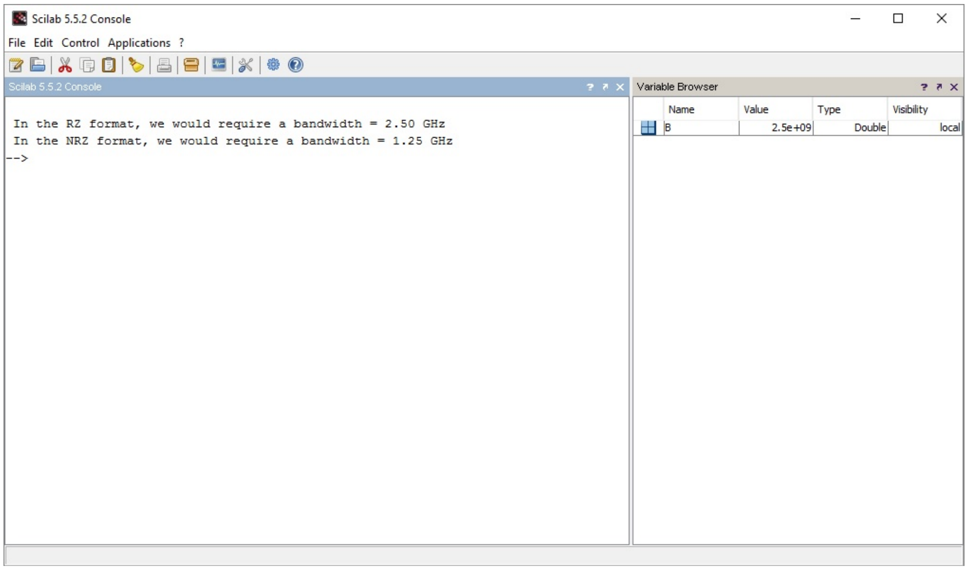

Figure 13.2: 2

Scilab code Exa 13.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
B=2.5e9;//pulse rate of signal in bits/sec

mprintf("\n In the RZ format, we would require a bandwidth = %.2f GHz",B/1e9);//In RZ format, Deltaf=B and Division by 10^9 to convert into GHz
mprintf("\n In the NRZ format, we would require a bandwidth = %.2f GHz",(B/2)/1e9);//In RZ format,
```

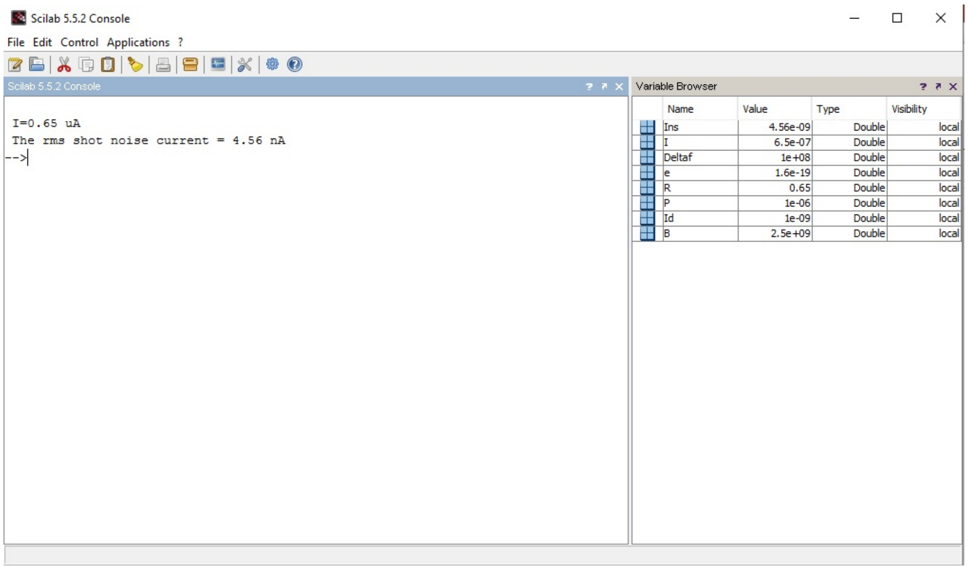

Figure 13.3: 3

```
    Deltaf=B/2 and Division by 10^9 to convert into
    GHz
```

Scilab code Exa 13.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
Id=1e-9;//Dark current of a silicon PIN photodiode
    in A
```

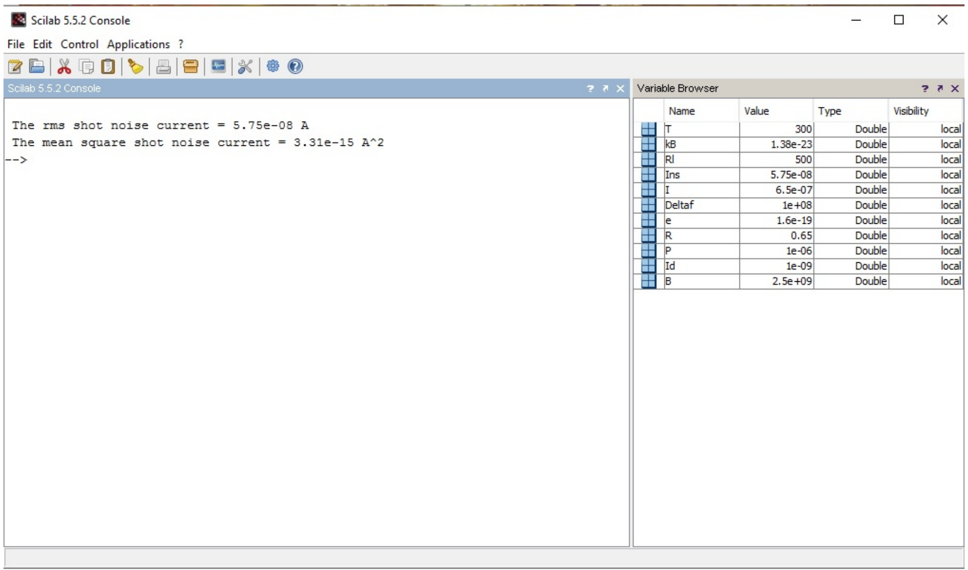

Figure 13.4: 4

```
P=1e-6;//Optical power in W
R=0.65;//Responsivity in A/W
e=1.6e-19//Electronic charge in C
Deltaf=100e6;//Detector bandwidth in Hz

I=R*P;
mprintf("\n I=%.2f uA",I/1e-6)//Division by 10^(-6) to convert into uA
//Let the root mean square shot noise current be Ins
Ins=sqrt(2*e*(I+Id)*Deltaf);//As the root mean square shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot noise current = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA
//The answers vary due to round off error
```

Scilab code Exa 13.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.4
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
Rl=500;//Value of load resistor Rl in Ohms
kB=1.38e-23;//Boltzmann constant in SI Units
Deltaf=100e6;//Bandwidth of detection in Hz
T=300;//Temperature in K

//Let the root mean square shot noise current be Ins
Ins=sqrt(4*kB*T*Deltaf/Rl);//As the root mean square
     shot noise current is the square root of mean
    square shot noise current in A
mprintf("\n The rms shot noise current = %.2e A",Ins
    );
mprintf("\n The mean square shot noise current = %.2
    e A^2",Ins^2)//The answers vary due to round off
    error
```

Scilab code Exa 13.5 5

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.5
```

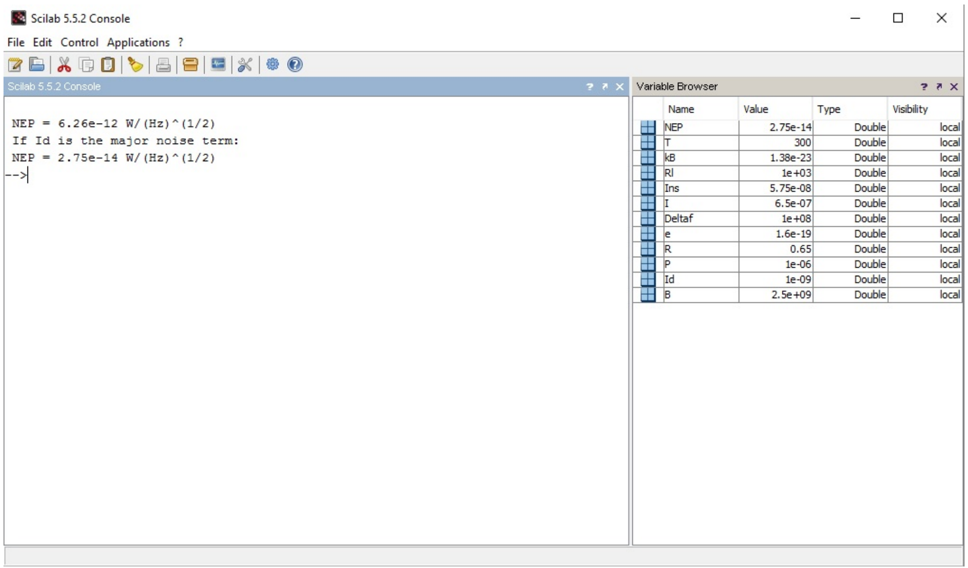

Figure 13.5: 5

```
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
R=0.65;//Responsivity of a Si detector in A/W
Id=1e-9;//Dark current in A
e=1.6e-19;//Electronic charge in C
kB=1.38e-23;//Boltzmann constant in SI Units
Rl=1000;//Assumed value of load resistor Rl in Ohms
T=300;//Assumed value of temperature in K

NEP=1/R*sqrt(2*e*Id+4*kB*T/Rl);//Noise equivalent
    power in W/(Hz)^(1/2)
mprintf("\n NEP = %.2e W/(Hz)^(1/2)",NEP);//The
    answers vary due to round off error
//If Id is the major noise term :
NEP=1/R*sqrt(2*e*Id);//Noise equivalent power in W/(
    Hz)^(1/2)
mprintf("\n If Id is the major noise term:");
```

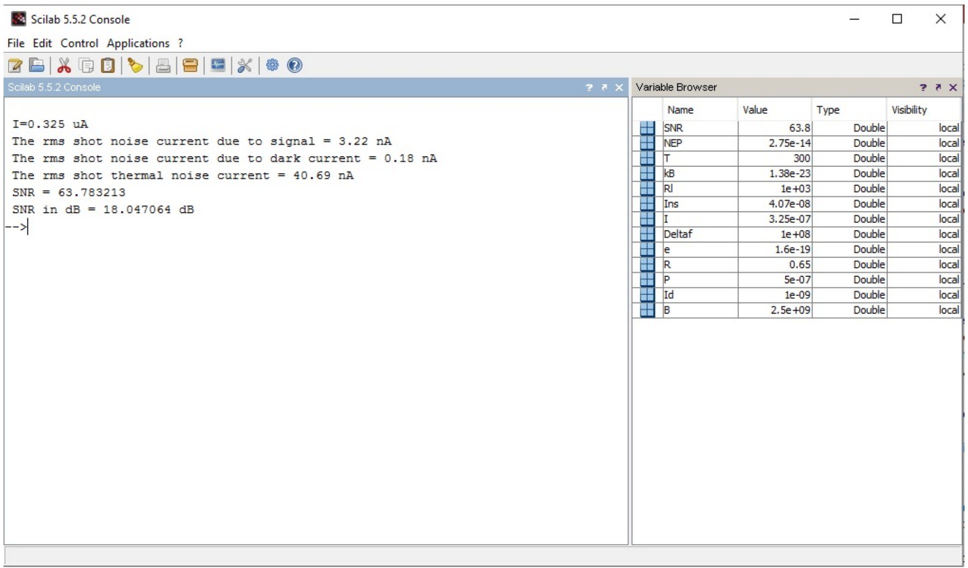

Figure 13.6: 6

```
mprintf("\n NEP = %.2e W/(Hz)^(1/2)",NEP);
```

Scilab code Exa 13.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
Id=1e-9;//Dark current of a silicon PIN photodiode in A
P=500e-9;//Optical power in W
```

```
R=0.65;//Responsivity in A/W
Rl=1000;//Value of load resistor in Ohms
e=1.6e-19//Electronic charge in C
kB=1.38e-23;//Boltzmann constant in SI Units
Deltaf=100e6;//Detector bandwidth in Hz
T=300;//Missing data- Temperature in K

I=R*P;//Signal current in A
mprintf("\n I=%.3f uA",I/1e-6)//Division by 10^(-6) to convert into uA
//Let the root mean square shot noise current be Ins
//The rms shot noise current due to signal is:
Ins=sqrt(2*e*I*Deltaf);//As the root mean square shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot noise current due to signal = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA
//The answers vary due to round off error

//The rms shot noise current due to dark current is:
Ins=sqrt(2*e*Id*Deltaf);//As the root mean square shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot noise current due to dark current = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA

//The rms shot thermal noise current is:
Ins=sqrt(4*kB*T*Deltaf/Rl);//As the root mean square shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot thermal noise current = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA
//The answers vary due to round off error
SNR=((R*P)^2)*Rl/(4*kB*T*Deltaf);//Corresponding Signal-to-noise ratio
```

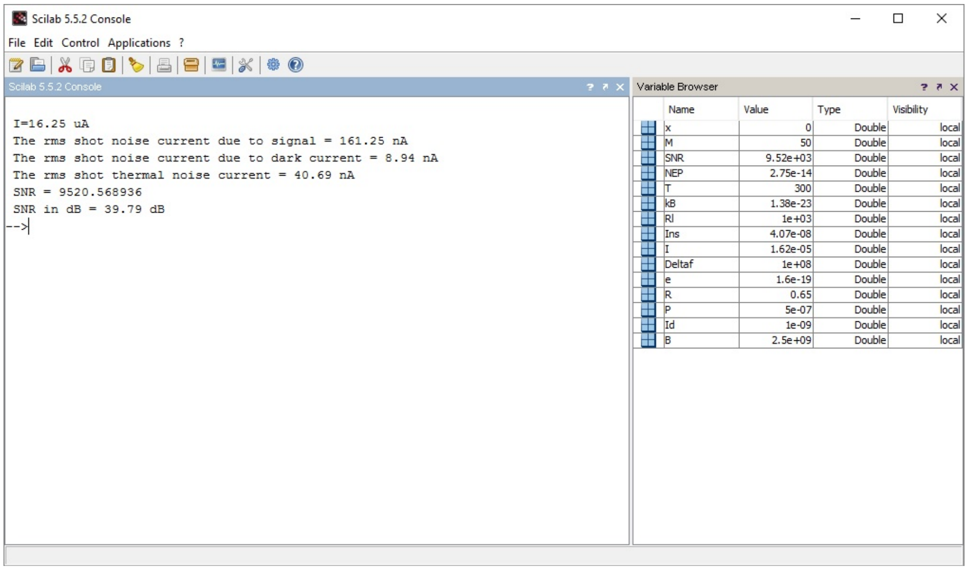

Figure 13.7: 7

```
mprintf("\n SNR = %f",SNR);//The answers vary due to
    round off error
mprintf("\n SNR in dB = %f dB",10*log10(SNR));//For
    conversion to dB
//The answers vary due to round off error
```

Scilab code Exa 13.7 7

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.7
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
```

```
//given
Id=1e-9;//Dark current of a silicon PIN photodiode in A
P=500e-9;//Optical power in W
R=0.65;//Responsivity in A/W
Rl=1000;//Value of load resistor in Ohms
e=1.6e-19//Electronic charge in C
kB=1.38e-23;//Boltzmann constant in SI Units
Deltaf=100e6;//Detector bandwidth in Hz
T=300;//Missing data- Temperature in K
M=50;//Internal gain corresponding to input optical power P
x=0;//No excess noise

I=M*R*P;//Signal current in A
mprintf("\n I=%.2f uA",I/1e-6)//Division by 10^(-6) to convert into uA
//Let the root mean square shot noise current be Ins
//The rms shot noise current due to signal is:
Ins=sqrt(2*e*M*I*Deltaf);//As the root mean square shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot noise current due to signal = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA
//The answers vary due to round off error

//The rms shot noise current due to dark current is:
Ins=sqrt(2*e*(M^2)*Id*Deltaf);//As the root mean square shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot noise current due to dark current = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA
//The answers vary due to round off error

//The rms shot thermal noise current is:
Ins=sqrt(4*kB*T*Deltaf/Rl);//As the root mean square
```

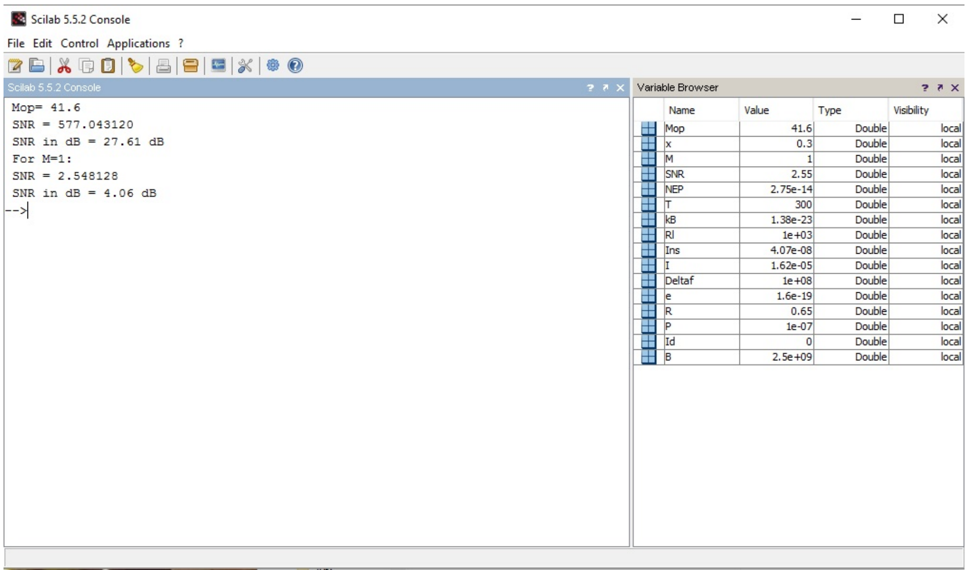

Figure 13.8: 8

```
    shot noise current is the square root of mean square shot noise current in A
mprintf("\n The rms shot thermal noise current = %.2f nA",Ins/1e-9);//Division by 10^(-9) to convert into nA
//The answers vary due to round off error
SNR=((M*R*P)^2)/(2*e*(M^(2+x))*(R*P+Id)*Deltaf+4*kB*T*Deltaf/Rl);//Corresponding Signal-to-noise ratio since x=0
mprintf("\n SNR = %f",SNR);//The answers vary due to round off error
mprintf("\n SNR in dB = %.2f dB",10*log10(SNR));//For conversion to dB
//The answers vary due to round off error
```

Scilab code Exa 13.8 8

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.8
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
P=100e-9;//Optical power in W
R=0.65;//Responsivity in A/W
Rl=1000;//Value of load resistor in Ohms
e=1.6e-19//Electronic charge in C
kB=1.38e-23;//Boltzmann constant in SI Units
Deltaf=100e6;//Detector bandwidth in Hz
T=300;//Missing data- Temperature in K
x=0.3;//Excess noise
Id=0;//Since the dark current is neglected in the example

Mop=(4*kB*T/(x*e*Rl*(R*P+Id)))^(1/(x+2));//Optimum value of internal gain corresponding to input optical power P
mprintf("Mop= %.1f",Mop);//The answers vary due to round off error
SNR=((Mop*R*P)^2)/(2*e*(Mop^(2+x))*(R*P+Id)*Deltaf+4*kB*T*Deltaf/Rl);//Corresponding Signal-to-noise ratio since x=0
mprintf("\n SNR = %f",SNR);//The answers vary due to round off error
mprintf("\n SNR in dB = %.2f dB",10*log10(SNR));//For conversion to dB
//The answers vary due to round off error

//Case (ii):
M=1;//Internal gain corresponding to input optical power P
```

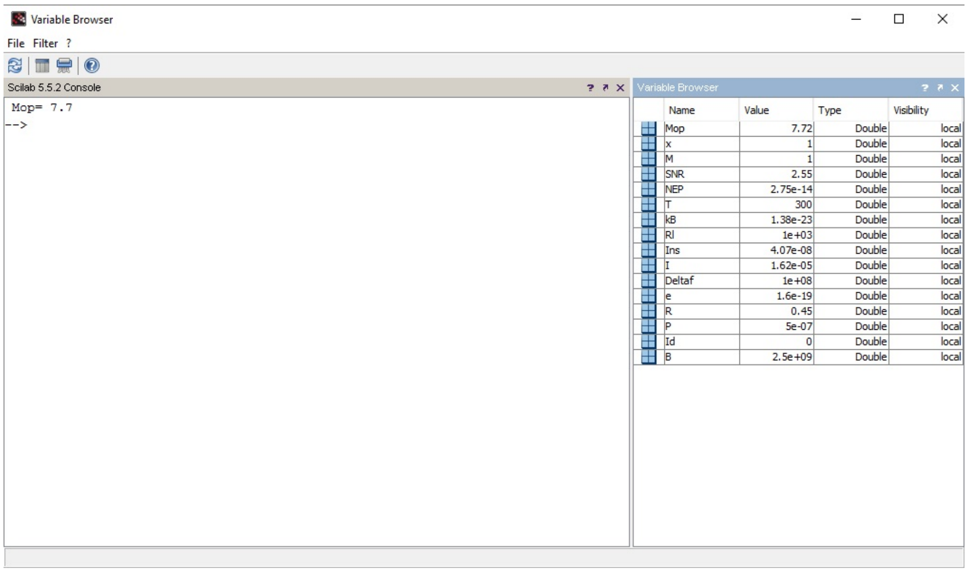

Figure 13.9: 9

```
SNR=((M*R*P)^2)/(2*e*(M^(2+x))*(R*P+Id)*Deltaf+4*kB*T*Deltaf/Rl);//Corresponding Signal-to-noise ratio since x=0
mprintf("\n For M=1:");
mprintf("\n SNR = %f",SNR);//The answers vary due to round off error
mprintf("\n SNR in dB = %.2f dB",10*log10(SNR));//For conversion to dB
//The answers vary due to round off error
```

Scilab code Exa 13.9 9

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.9
```

```
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
P=500e-9;//Optical power in W
R=0.45;//Responsivity in A/W
Rl=1000;//Value of load resistor in Ohms
e=1.6e-19//Electronic charge in C
kB=1.38e-23;//Boltzmann constant in SI Units
T=300;//Missing data- Temperature in K
x=1;//Excess noise
Id=0;//Since the dark current is neglected in the
    example

Mop=(4*kB*T/(x*e*Rl*(R*P+Id)))^(1/(x+2));//Optimum
    value of internal gain corresponding to input
    optical power P
mprintf("Mop= %.1f",Mop);
```

Scilab code Exa 13.10 10

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.10
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
P=100e-9;//Optical power in W
R=0.6;//Responsivity in A/W
Rl=1000;//Value of load resistor in Ohms
```

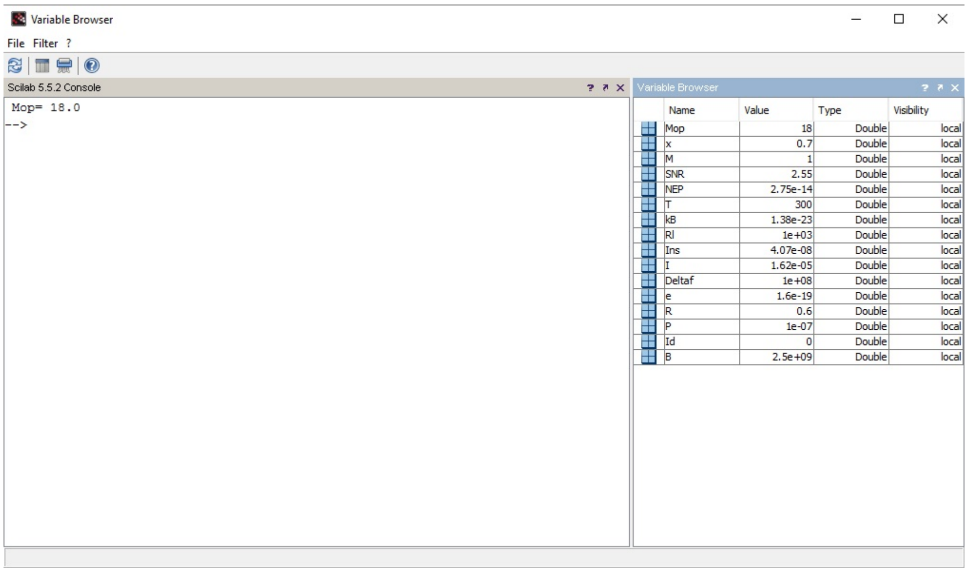

Figure 13.10: 10

```
e=1.6e-19//Electronic charge in C
kB=1.38e-23;//Boltzmann constant in SI Units
T=300;//Missing data- Temperature in K
x=0.7;//Excess noise
Id=0;//Since the dark current is neglected in the
    example

Mop=(4*kB*T/(x*e*Rl*(R*P+Id)))^(1/(x+2));//Optimum
    value of internal gain corresponding to input
    optical power P
mprintf("Mop= %.1f",Mop);
```

Scilab code Exa 13.11 11

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

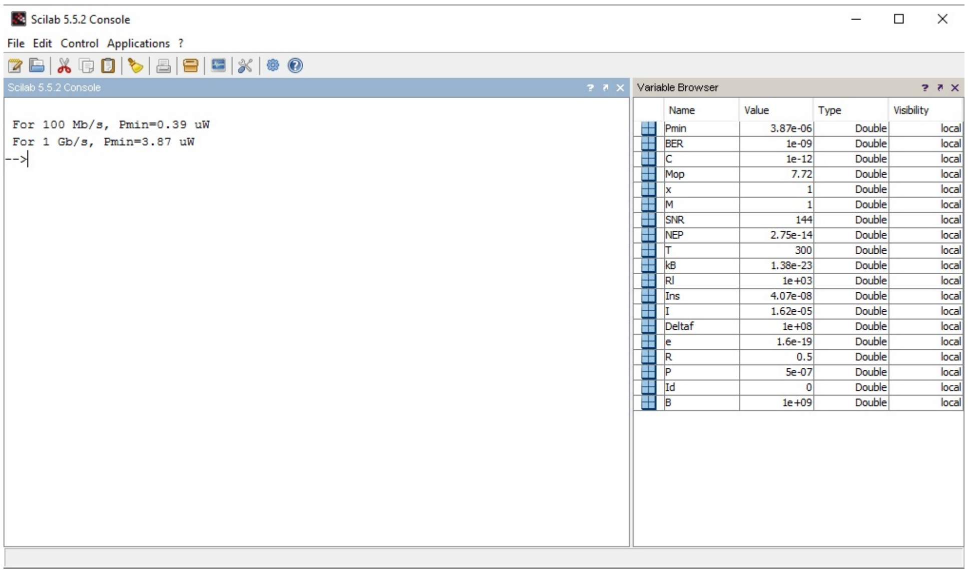

Figure 13.11: 11

```
//Example 13.11
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
R=0.5;//Responsivity in A/W
T=300;//Missing data- Temperature in K
C=1e-12;//Photodiode capacitance in F
BER=1e-9;//Bit error rate
SNR=144;//Signal-to-noise ratio corresponding to BER of (10)^(-9)
kB=1.38e-23;//Boltzmann constant in SI Units

//Case(i):
B=100e6;//Bit rate in b/s
Pmin=B/R*sqrt(2*%pi*kB*T*C*SNR);
mprintf("\n For 100 Mb/s, Pmin=%.2f uW",Pmin/1e-6);//Dividing by 10^(-6) to convert into uW

```

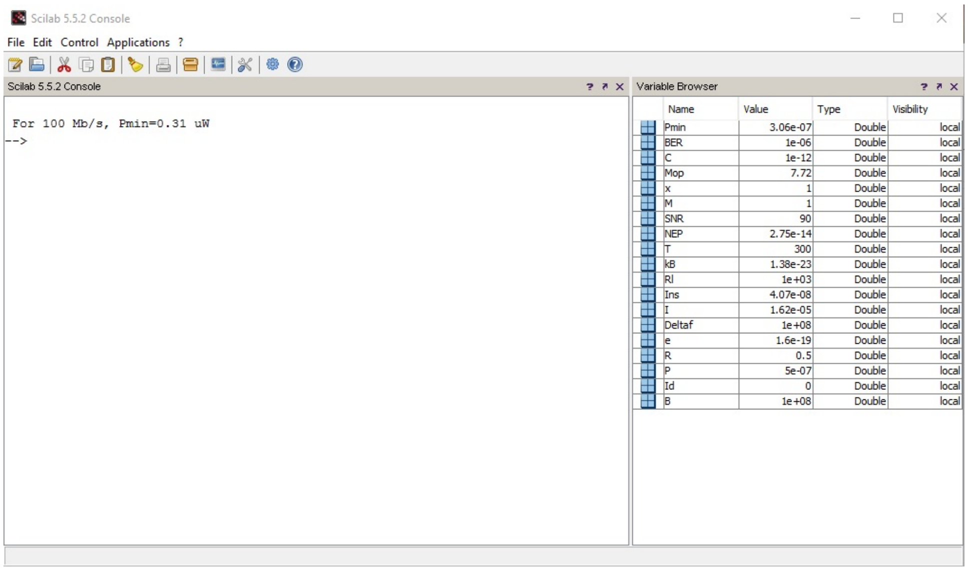

Figure 13.12: 12

```
//Case(ii):
B=1e9;//Bit rate in b/s
Pmin=B/R*sqrt(2*%pi*kB*T*C*SNR);
mprintf("\n For 1 Gb/s, Pmin=%.2f uW",Pmin/1e-6);//
    Dividing by 10^(-6) to convert into uW
```

Scilab code Exa 13.12 12

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.12
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
```

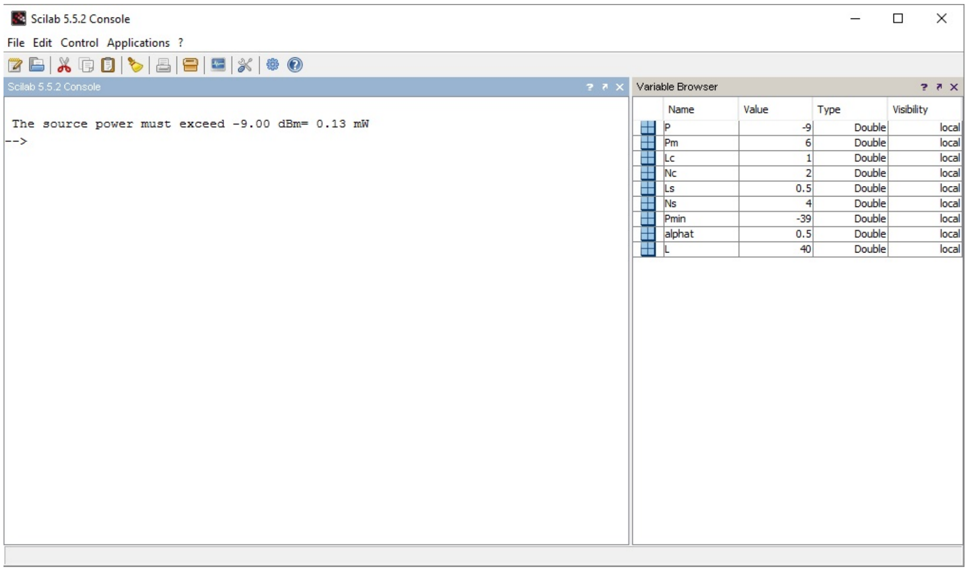

Figure 13.13: 13

```
//given
R=0.5;//Responsivity in A/W
T=300;//Missing data- Temperature in K
C=1e-12;//Photodiode capacitance in F
BER=1e-6;//Bit error rate
SNR=90;//Signal-to-noise ratio corresponding to BER of (10)^(-6)
kB=1.38e-23;//Boltzmann constant in SI Units

B=100e6;//Bit rate in b/s
Pmin=B/R*sqrt(2*%pi*kB*T*C*SNR);
mprintf("\n For 100 Mb/s, Pmin=%.2f uW",Pmin/1e-6); //Dividing by 10^(-6) to convert into uW
//The answers vary due to round off error
```

Scilab code Exa 13.13 13

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.13
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
L=40;//Total fiber length in km
alphat=0.5;//Fiber transmission loss in dB/km
Pmin=-39;//Receiver sensitivity in dBm is the
    minimum power received by receiver
Ns=4;//Number of splices contributing to loss
Ls=0.5;//Loss of each splice in dB
Nc=2;//Number of connectors contributing to loss
Lc=1;//Loss of each connector in dB;
Pm=6;//Power margin in dB
//Let the source power be P
P=Pmin+Pm+Ns*Ls+Nc*Lc+L*alphat;//Minimum value of
    source power in dBm
mprintf("\n The source power must exceed %.2f dBm= %
    .2f mW",P,(10^(P/10)));//Taking 10^(P/10) to
    convert into mW
```

Scilab code Exa 13.14 14

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.14
//OS=Windows XP sp3
//Scilab version 5.5.2
```

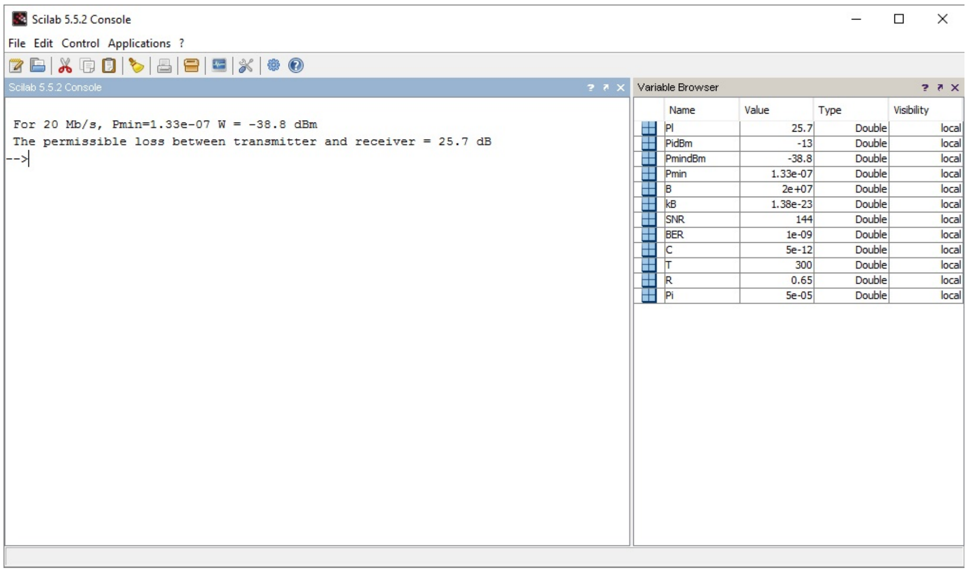

Figure 13.14: 14

```
clc;
clear;
//given
Pi=50e-6;//Source power in W
R=0.65;//Responsivity in A/W
T=300;//Missing data- Temperature in K
C=5e-12;//Photodiode capacitance in F
BER=1e-9;//Bit error rate
SNR=144;//Signal-to-noise ratio corresponding to BER
    of (10)^(-6)
kB=1.38e-23;//Boltzmann constant in SI Units

B=20e6;//Bit rate in b/s
Pmin=(B/R)*sqrt(2*%pi*kB*T*C*SNR);//Receiver
    sensitivity in W
//Let the value of Pmin in dBm be denoted by '
    PmindBm'
PmindBm=10*log10(Pmin/1e-3);//Taking 10*log(Pmin) to
    convert into dBm where Pmin must be in mW
mprintf("\n For 20 Mb/s, Pmin=%.2e W = %.1f dBm",
```

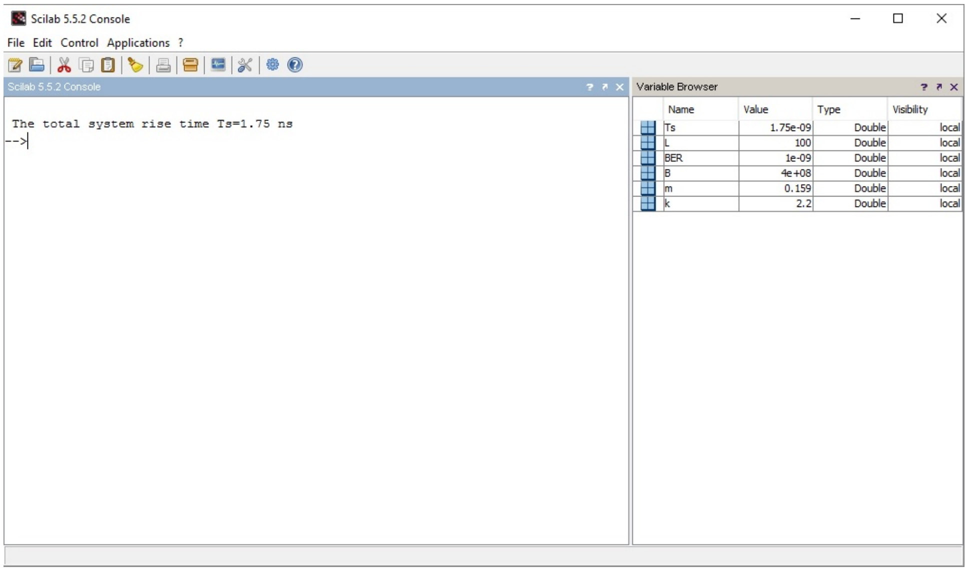

Figure 13.15: 15

```
    Pmin,PmindBm);//The answers vary due to round off
      error
//Let the value of Pi in dBm be denoted by 'PidBm'
PidBm=10*log10(Pi/1e-3);//Taking 10*log(Pi) to
    convert into dBm where Pi must be in mW
Pl=abs(PmindBm-PidBm);//The permissible loss between
      transmitter and receiver in dB
mprintf("\n The permissible loss between transmitter
      and receiver = %.1f dB",Pl);
//The answers vary due to round off error
```

Scilab code Exa 13.15 15

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

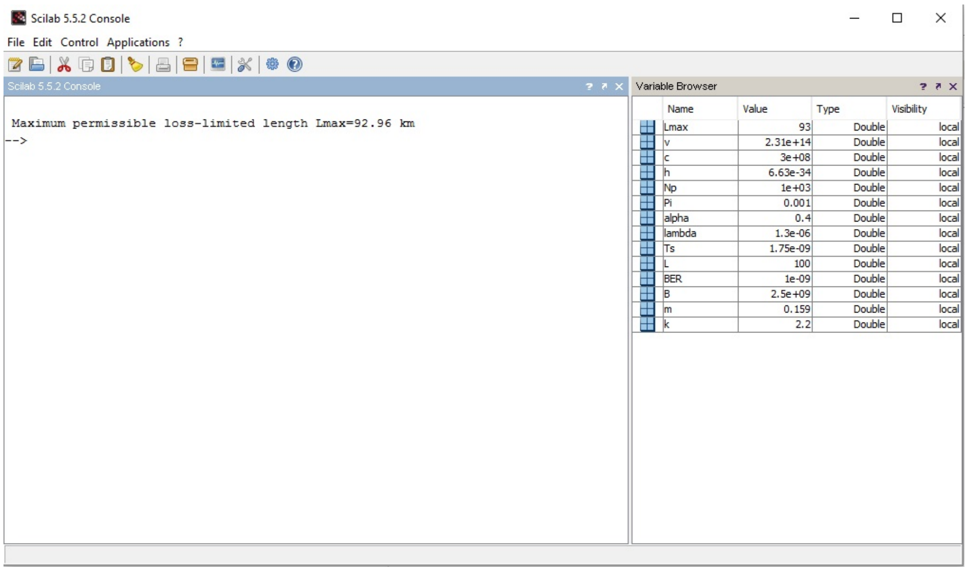

Figure 13.16: 16

```
//Example 13.15
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
B=400e6;//Bit rate in b/s
BER=1e-9;//Bit error rate
L=100;//Total fiber length in km

//The Total system rise time is given as:
Ts=0.7/B;//The expression for total rise time under
    NRZ transmission in s
mprintf("\n The total system rise time Ts=%.2f ns",
    Ts/1e-9);//Dividing by 10^(-9) to convert into ns
```

Scilab code Exa 13.16 16

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.16
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda=1300e-9;//Operating wavekength of the system
   in m
alpha=0.4;//Fiber loss in dB/km
Pi=1e-3;//Input power in W
Np=1000;//Minimum number of photons per bit of
   information
B=2.5e9;//Bit rate in b/s
h=6.63e-34;//Planck's constant in SI Units
c=3e8;//Speed of photons in m/s
v=c/lambda;//Frequency corresponding to the
   operating frequency

Lmax=10/alpha*log10(2*Pi/(Np*B*h*v));//Maximum
   permissible loss-limited length in km
mprintf("\n Maximum permissible loss-limited length
   Lmax=%.2f km",Lmax);//The answers vary due to
   round off error
```

Scilab code Exa 13.17 17

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.17
```

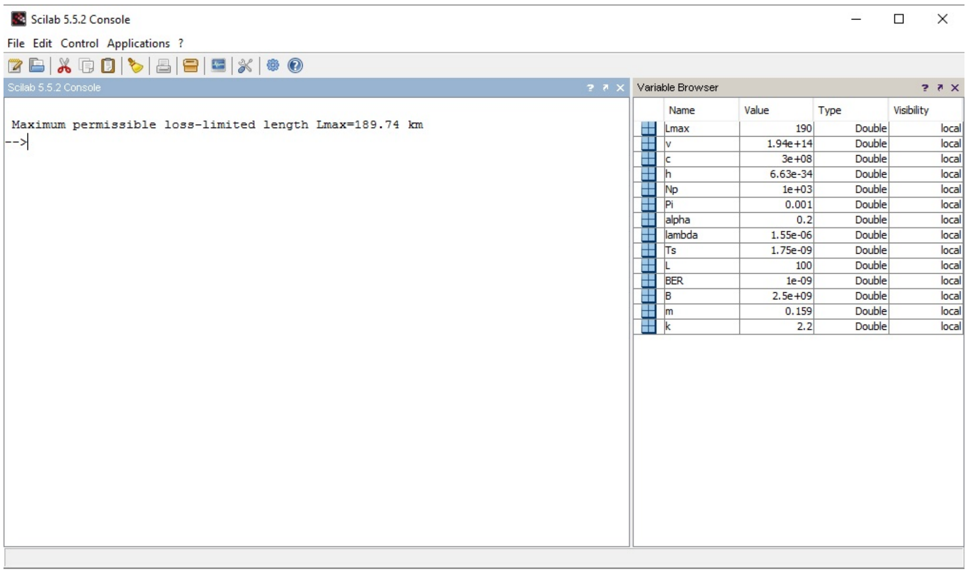

Figure 13.17: 17

```
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda=1550e-9;//Operating wavekength of the system in m
alpha=0.2;//Fiber loss in dB/km
Pi=1e-3;//Input power in W
Np=1000;//Minimum number of photons per bit of information
B=2.5e9;//Bit rate in b/s
h=6.63e-34;//Planck's constant in SI Units
c=3e8;//Speed of photons in m/s
v=c/lambda;//Frequency corresponding to the operating frequency

Lmax=10/alpha*log10(2*Pi/(Np*B*h*v));//Maximum permissible loss-limited length in km
mprintf("\n Maximum permissible loss-limited length
```

```
Lmax=%.2f km",Lmax);//The answers vary due to
    round off error
```

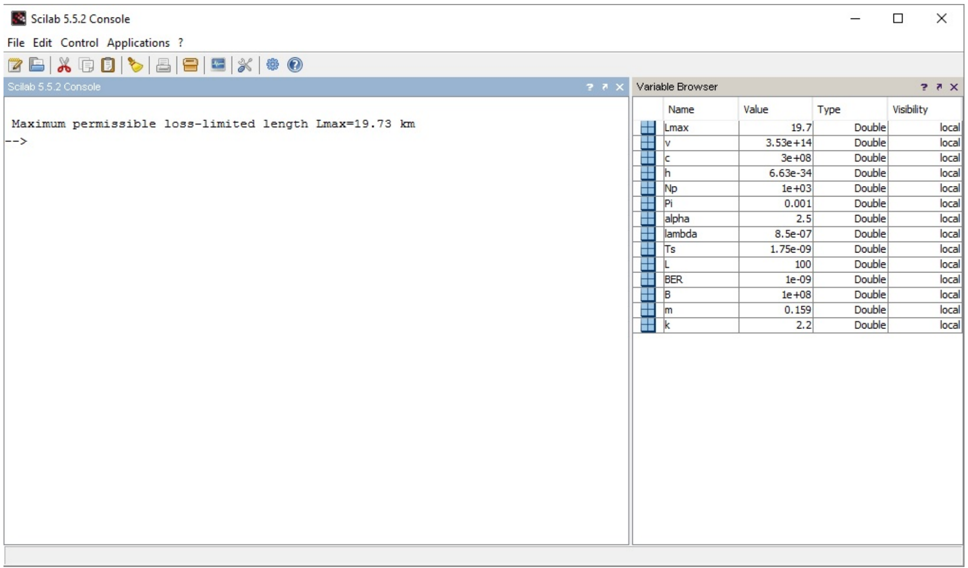

Figure 13.18: 18

Scilab code Exa 13.18 18

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 13.18
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda=850e-9;//Operating wavekength of the system
    in m
```

```
alpha=2.5;//Fiber loss in dB/km
Pi=1e-3;//Input power in W
Np=1000;//Minimum number of photons per bit of
    information
B=100e6;//Bit rate in b/s
h=6.63e-34;//Planck's constant in SI Units
c=3e8;//Speed of photons in m/s
v=c/lambda;//Frequency corresponding to the
    operating frequency

Lmax=10/alpha*log10(2*Pi/(Np*B*h*v));//Maximum
    permissible loss-limited length in km
mprintf("\n Maximum permissible loss-limited length
    Lmax=%.2f km",Lmax);//The answers vary due to
    round off error
```

Chapter 14

Optical fiber Amplifiers

Scilab code Exa 14.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 14.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda=980e-9;//Operating wavelength in m
Sigmapa=3.1e-25;//Absorption cross section at pump
    in m^2
tsp=12e-3;//spontaneous emission lifetime in sec
h=6.626e-34;//Planck's constant in SI Units
c=3e8;//speed of electrons in m/s
v=c/lambda;//frequency corresponding to given
    wavelength in Hz
Ip0=h*v/(Sigmapa*tsp);//Intensity at pump in W/(m^2)
mprintf("\n Ip0=%e W/(m^2)",Ip0)//The answers vary
    due to round off error
```

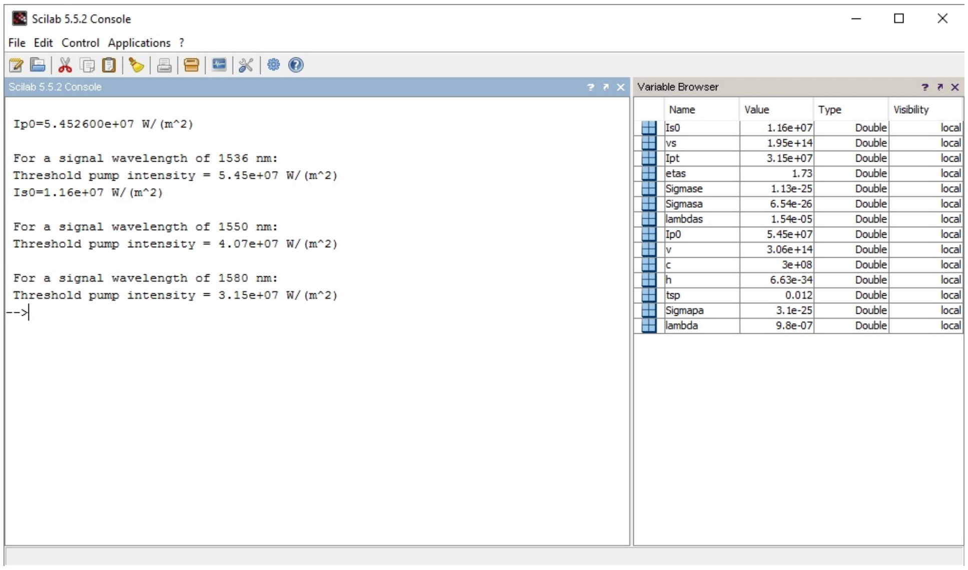

Figure 14.1: 1

```

//Case (i)
lambdas=1536e-9;//Wavelength of signal used
Sigmasa=4.644e-25;//Absorption cross section at
    signal in m^2
Sigmase=4.644e-25;//Emission cross section at signal
    in m^2
etas=Sigmase/Sigmasa;//Ratio of emission to
    absorption cross sections
mprintf("\n\n For a signal wavelength of 1536 nm:");
Ipt=Ip0/etas;//Threshold pump intensity in W/(m^2)
mprintf("\n Threshold pump intensity = %.2e W/(m^2)"
    ,Ipt);//The answers vary due to round off error
vs=c/lambdas;//frequency corresponding to wavelength
    of signal used
Is0=h*vs/((Sigmasa+Sigmase)*tsp);//Corresponding
    intensity at signal in W/(m^2)
mprintf("\n Is0=%.2e W/(m^2)",Is0);//The answers
    vary due to round off error

```

```
//Case (ii)
lambdas=1550e-9;//Wavelength of signal used
Sigmasa=2.545e-25;//Absorption cross section at signal in m^2
Sigmase=3.410e-25;//Emission cross section at signal in m^2
etas=Sigmase/Sigmasa;//Ratio of emission to absorption cross sections
mprintf("\n\n For a signal wavelength of 1550 nm:");
Ipt=Ip0/etas;//Threshold pump intensity in W/(m^2)
mprintf("\n Threshold pump intensity = %.2e W/(m^2)",Ipt);

//Case (iii)
lambdas=15380e-9;//Wavelength of signal used
Sigmasa=0.654e-25;//Absorption cross section at signal in m^2
Sigmase=1.133e-25;//Emission cross section at signal in m^2
etas=Sigmase/Sigmasa;//Ratio of emission to absorption cross sections
mprintf("\n\n For a signal wavelength of 1580 nm:");
Ipt=Ip0/etas;//Threshold pump intensity in W/(m^2)
mprintf("\n Threshold pump intensity = %.2e W/(m^2)",Ipt);
```

Scilab code Exa 14.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 14.4
//OS=Windows XP sp3
//Scilab version 5.5.2
```

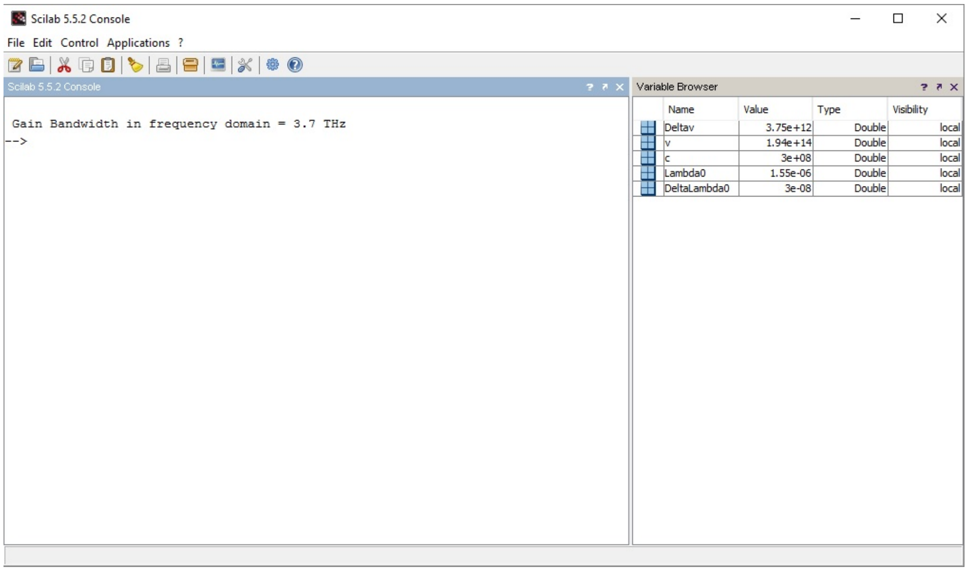

Figure 14.2: 4

```
clc;
clear;
//given
DeltaLambda0=30e-9;//Gain bandwidth in wavelength
    domain in m
Lambda0=1550e-9;//central wavelength in wavelength
    domain in m
c=3e8;//Speed of light in m/s
v=c/Lambda0;
Deltav=DeltaLambda0/Lambda0*v;
mprintf("\n Gain Bandwidth in frequency domain = %.1
    f THz",Deltav/1e12);
```

Chapter 17

Single mode fiber optic components

Scilab code Exa 17.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
n1=1.4532;//refractive index of core
n2=1.45;//refractive index of cladding
a=5e-6;//fiber core radius in m
d=12e-6;//Distance between the fiber axes in m
dbar=d/a;//Ratio of distance between fiber axes to
    the core radius
delta=((n1)^2-(n2)^2)/((n1)^2);//Dimensionless
    quantity

```

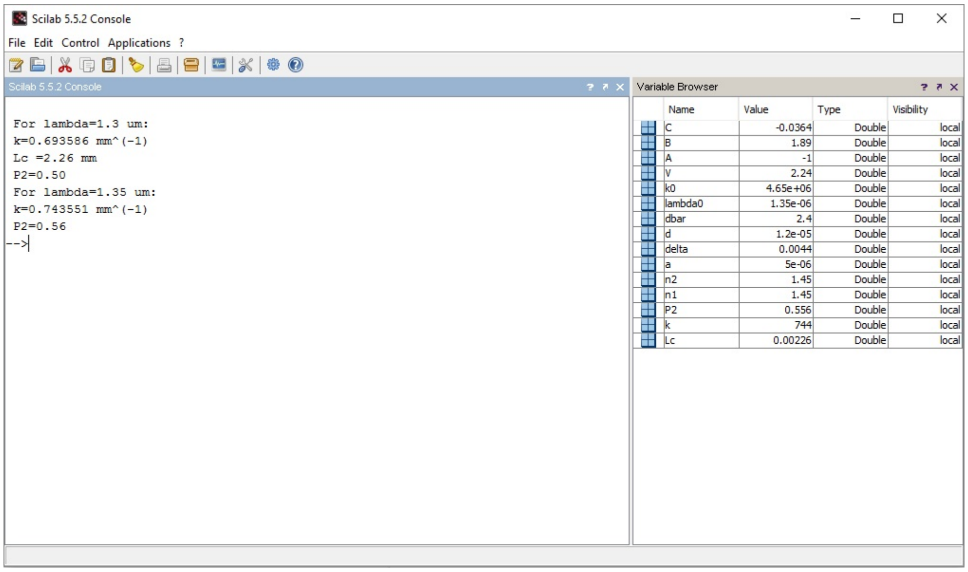

Figure 17.1: 1

```
//Case (i):
lambda0=1.3e-6;//Free space wavelength in m
k0=2*%pi/lambda0;//free space wave number in rad/m
V=k0*a*sqrt((n1^2)-(n2^2));//dimensionless waveguide parameter
//The approximate expression for k consists of constants A, B and C
A=5.2789-3.663*V+0.3841*(V^2);//Expression for constant A in terms of 'V'
B=-0.7769+1.2252*V-0.0152*(V^2);//Expression for constant B in terms of 'V'
C=-0.0175-0.0064*V-0.0009*(V^2);//Expression for constant C in terms of 'V'
k=(%pi/(2*a))*sqrt(delta)*exp(-(A+B*dbar+C*(dbar)^2));//Expression for Coupling Coefficient in m^(-1)
mprintf("\n For lambda=1.3 um:");
mprintf("\n k=%f mm^(-1)",k/1e3);//Dividing by 10^3 to conevert into mm^(-1)
//The answers vary due to round off error
Lc=%pi/(2*k);//Corresponding coupling length in m
```

```
mprintf("\n Lc =%.2f mm",Lc/1e-3);//Dividing by 10^(-3) to convert into mm
P2=(sin(k*Lc/2))^2;//The coupled power at given wavelength
mprintf("\n P2=%.2f",P2);

//Case (ii):
lambda0=1.35e-6;//Free space wavelength in m
k0=2*%pi/lambda0;//free space wave number in rad/m
V=k0*a*sqrt((n1^2)-(n2^2));//dimensionless waveguide parameter
//The approximate expression for k consists of constants A, B and C
A=5.2789-3.663*V+0.3841*(V^2);//Expression for constant A in terms of 'V'
B=-0.7769+1.2252*V-0.0152*(V^2);//Expression for constant B in terms of 'V'
C=-0.0175-0.0064*V-0.0009*(V^2);//Expression for constant C in terms of 'V'
k=(%pi/(2*a))*sqrt(delta)*exp(-(A+B*dbar+C*(dbar)^2));//Expression for Coupling Coefficient in m^(-1)
mprintf("\n For lambda=1.35 um:");
mprintf("\n k=%f mm^(-1)",k/1e3);//Dividing by 10^3 to conevert into mm^(-1)
//The answers vary due to round off error
P2=(sin(k*Lc/2))^2;//The coupled power at given wavelength
mprintf("\n P2=%.2f",P2);//The answers vary due to round off error
```

Scilab code Exa 17.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K.
```

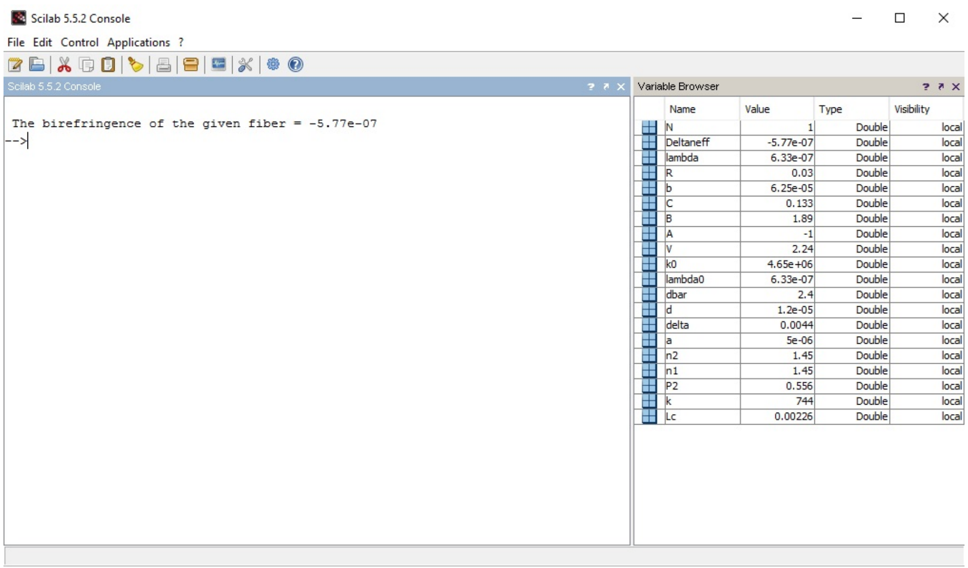

Figure 17.2: 2

```
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
b=62.5e-6;//Outer radius of silica fiber in m
R=30e-3;//Radius of the circular loop formed by the
    fiber in m
lambda=633e-9;//Wavelength in m
C=0.133;//Value of constant C for a silica fiber at
    633 nm
Deltaneff=-C*(b/R)^2;//The Corresponding
    dimensionless birefringence
mprintf("\n The birefringence of the given fiber = %
    .2e",Deltaneff);//The negative sign indicates
    that the polarization of the slow wave is
    perpendicular to the optic axis
```

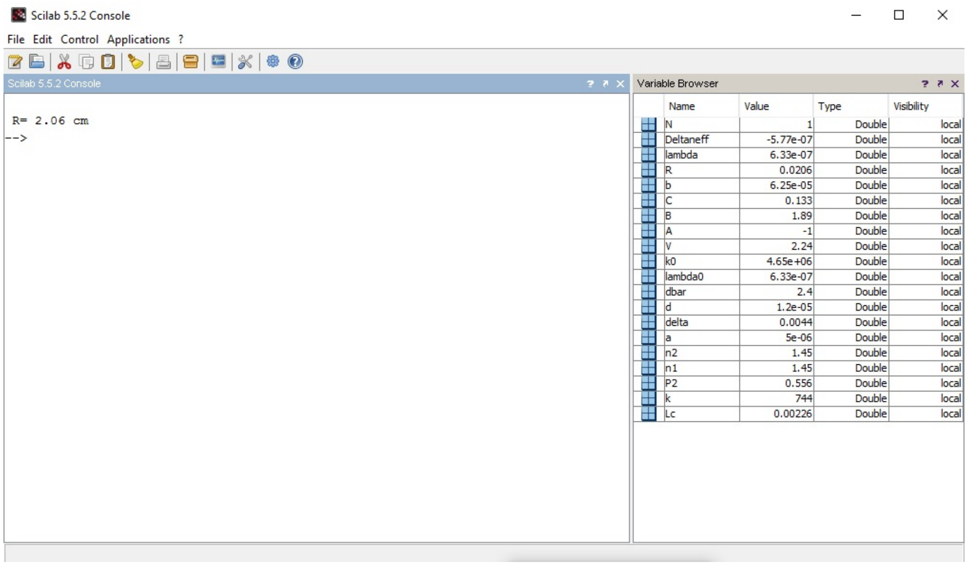

Figure 17.3: 3

Scilab code Exa 17.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=633e-9;//Wavelength in m
b=62.5e-6;//Outer radius of silica fiber in m
N=1;//Number of loops formed by the fiber
C=0.133;//Value of constant C for a silica fiber at
    633 nm
```

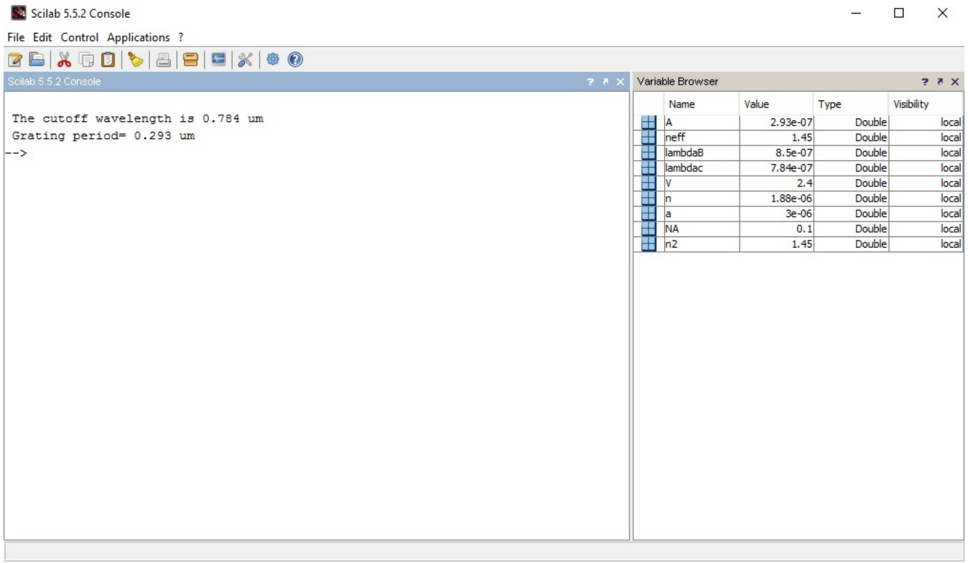

Figure 17.4: 4

```

R=8*%pi*C*(b^2)*N/lambda0;//Radius of the circular
    loop corresponding to a quarter plate formed by
    the fiber in m
mprintf("\n R= %.2f cm",R/1e-2);//Division by
    10^(-2) to convert into cm
//The answers vary due to round off error
```

Scilab code Exa 17.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.4
//OS=Windows XP sp3
//Scilab version 5.5.2
```

```
clc;
clear;
//given
n2=1.45;//refractive imdex of cladding
NA=0.1;//Numerical aperture of the fiber
a=3e-6;//radius of core in m
n=2*%pi*a*NA;//numerator of the corresponding V
    number

//For cutoff wavelength:
V=2.4048;
//Since V=n/lambda0
lambdac=n/V;//cutoff wavelength of single mode fiber
     in m
mprintf("\n The cutoff wavelength is %.3f um",
    lambdac/1e-6);//Division by 10^(-6) to convert
    into um

//Now, For lambdaB=850 nm:
lambdaB=850e-9;//Bragg wavelength in m
neff=1.4517;//Corresponding value of effective index
     in LP01 mode

//Let A be grating period
A=lambdaB/(2*neff);//Grating period in m
mprintf("\n Grating period= %.3f um",A/1e-6);//
    Division by 10^(-6) to convert into um
//The answers vary due to round off error
```

Scilab code Exa 17.5 5

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

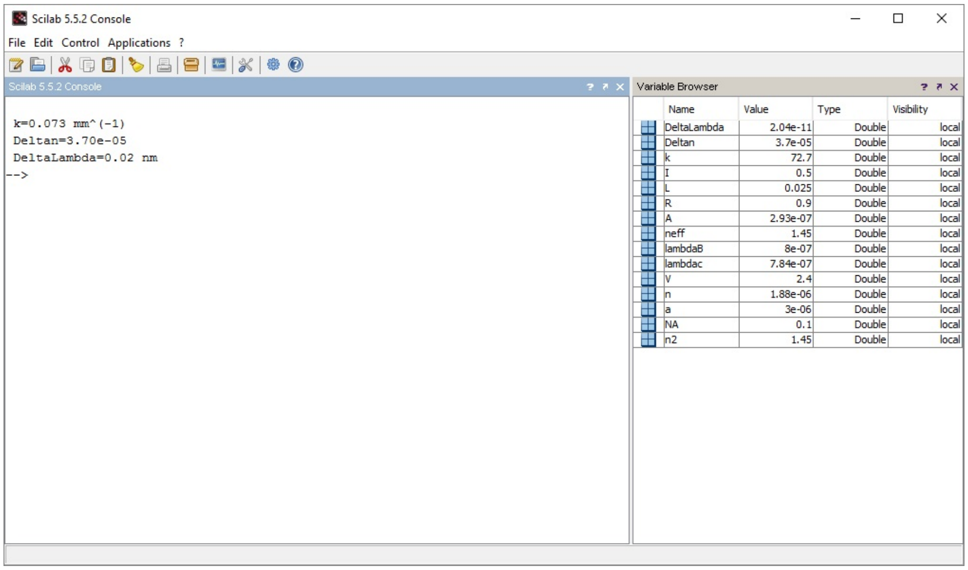

Figure 17.5: 5

```
//Example 17.5
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//Since the reflectivity of fiber is 90%,
R=0.9;//Reflection coefficient of fiber
L=25e-3;//Length of fiber in m
lambdaB=800e-9;//Bragg wavelength in m
neff=1.4517;//Corresponding value of effective index
    in LP01 mode
I=0.5;//Transverse overlap integral of modal
    distribution

//Now, (tanh(k*L))^2=R
//Rearranging terms, we get:
k=atanh(sqrt(R))/L;//Corresponding coupling
    coefficient in m^(-1)
mprintf("\n k=%.3f mm^(-1)",k/1e3);//Dividing by
```

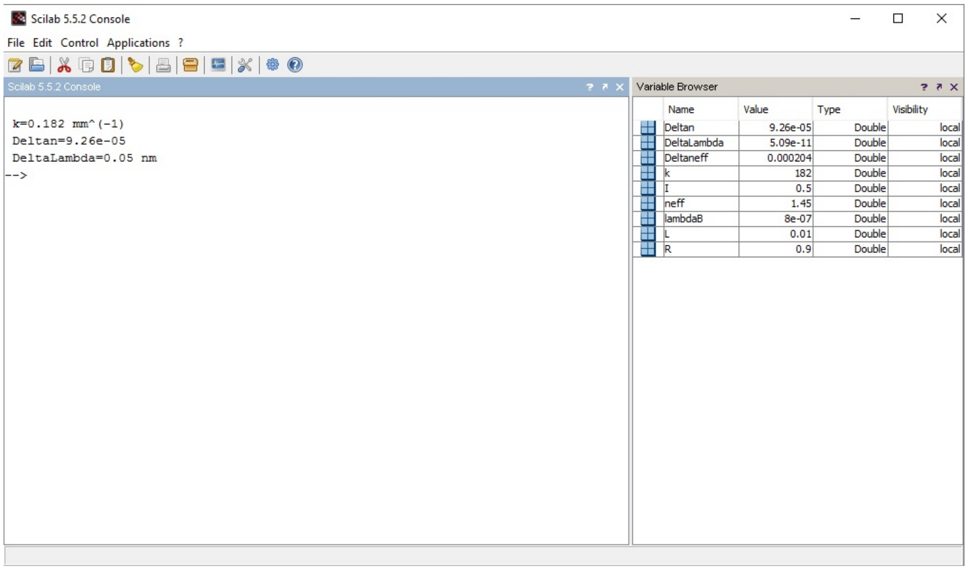

Figure 17.6: 6

```
    10^3 to convert into mm^(-1)

//Rearranging terms of expression k=%pi*Deltan*I/
    lambdaB
Deltan=k*lambdaB/(%pi*I);//Change in refractive
    index
mprintf("\n Deltan=%.2e",Deltan);//Unitless quantity
//The answers vary due to round off error

DeltaLambda=lambdaB^2/(%pi*neff*L)*sqrt((k*L)^2+(%pi
    )^2);//Corresponding bandwidth in m
mprintf("\n DeltaLambda=%.2f nm",DeltaLambda/1e-9);
    //Division by 10^(-9) to convert into nm
```

Scilab code Exa 17.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//Since the reflectivity of fiber is 90%,
R=0.9;//Reflection coefficient of fiber
L=10e-3;//Length of fiber in m
lambdaB=800e-9;//Bragg wavelength in m
neff=1.4517;//Corresponding value of effective index in LP01 mode
I=0.5;//Transverse overlap integral of modal distribution

//Now, (tanh(k*L))^2=R
//Rearranging terms, we get:
k=atanh(sqrt(R))/L;//Corresponding coupling coefficient in m^(-1)
mprintf("\n k=%.3f mm^(-1)",k/1e3);//Dividing by 10^3 to convert into mm^(-1)
//The answers vary due to round off error

//Rearranging terms of expression k=%pi*Deltan*I/lambdaB
Deltan=k*lambdaB/(%pi*I);//Change in refractive index
mprintf("\n Deltan=%.2e",Deltan);//Unitless quantity
//The answers vary due to round off error

DeltaLambda=lambdaB^2/(%pi*neff*L)*sqrt((k*L)^2+(%pi)^2);//Corresponding bandwidth in m
mprintf("\n DeltaLambda=%.2f nm",DeltaLambda/1e-9);//Division by 10^(-9) to convert into nm
```

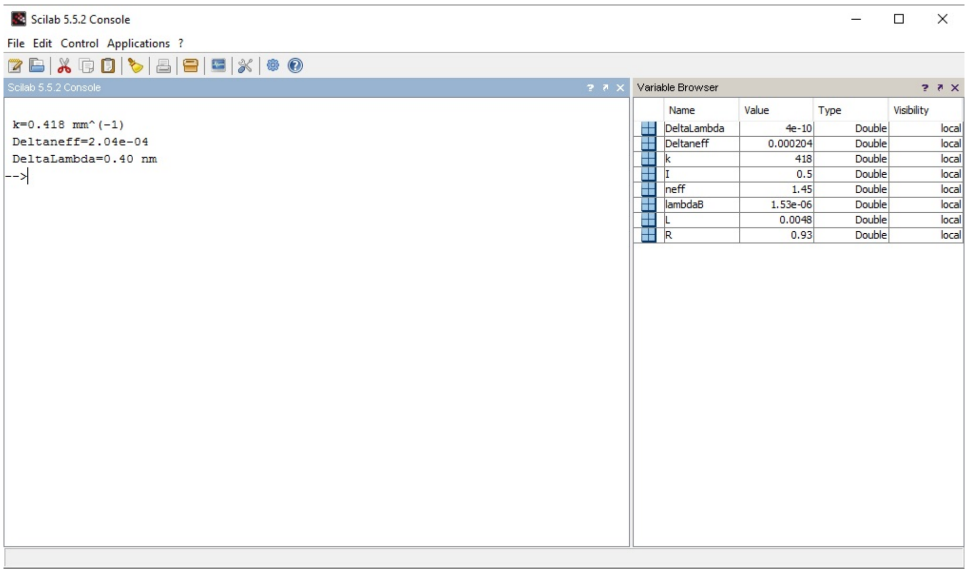

Figure 17.7: 7

Scilab code Exa 17.7 7

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.7
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//Since the peak reflectivity of fiber is 0.93%,
R=0.93;//Reflection coefficient of fiber
L=4.8e-3;//Length of fiber in m
lambdaB=1532.1e-9;//Bragg wavelength in m
neff=1.4517;//Corresponding value of effective index
```

```
in LP01 mode
I=0.5;//Transverse overlap integral of modal distribution

//Now, (tanh(k*L))^2=R
//Rearranging terms, we get:
k=atanh(sqrt(R))/L;//Corresponding coupling coefficient in m^(-1)
mprintf("\n k=%.3f mm^(-1)",k/1e3);//Dividing by 10^3 to convert into mm^(-1)
//The answers vary due to round off error

//Rearranging terms of expression k=%pi*Deltan*I/lambdaB
Deltaneff=k*lambdaB/(%pi);//Change in effective refractive index
mprintf("\n Deltaneff=%.2e",Deltaneff);//Unitless quantity
//The answers vary due to round off error

DeltaLambda=lambdaB^2/(%pi*neff*L)*sqrt((k*L)^2+(%pi)^2);//Corresponding bandwidth in m
mprintf("\n DeltaLambda=%.2f nm",DeltaLambda/1e-9);//Division by 10^(-9) to convert into nm
```

Scilab code Exa 17.8 8

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.8
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
```

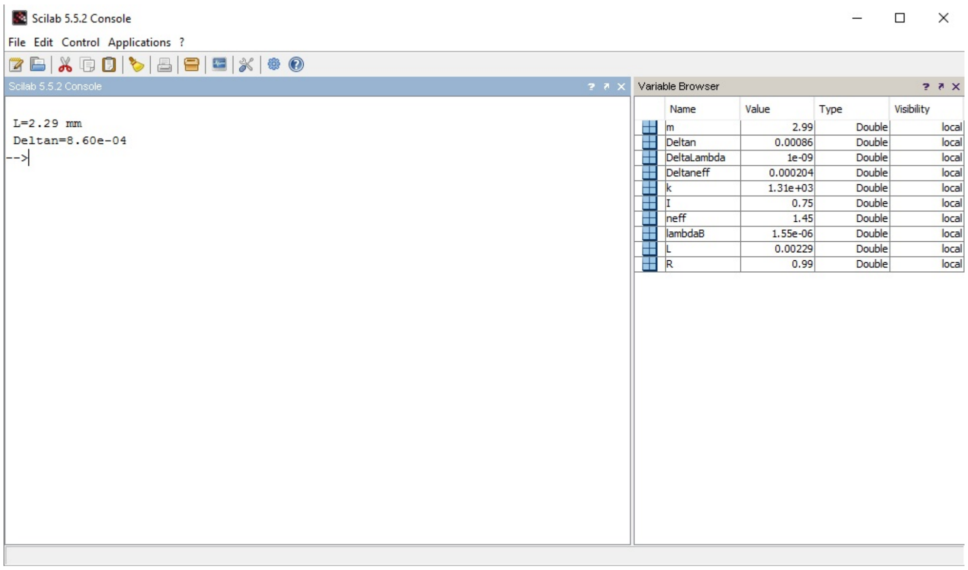

Figure 17.8: 8

```
clear;
//given
//Since the reflectivity of fiber is 99%,
R=0.99;//Reflection coefficient of fiber
lambdaB=1550e-9;//Bragg wavelength in m
neff=1.45;//Corresponding value of effective index in LP01 mode
DeltaLambda=1e-9;//Bandwidth of reflection spectrum in m
I=0.75;//Typical value of transverse overlap integral of modal distribution

//Now, (tanh(k*L))^2=R
//Rearranging terms, we get:  k*L=atanh(sqrt(R))
//Let m=k*L
m=atanh(sqrt(R));

//Rearranging terms of expression DeltaLambda=lambdaB^2/(%pi*neff*L)*sqrt((k*L)^2+(%pi)^2) , we get
```

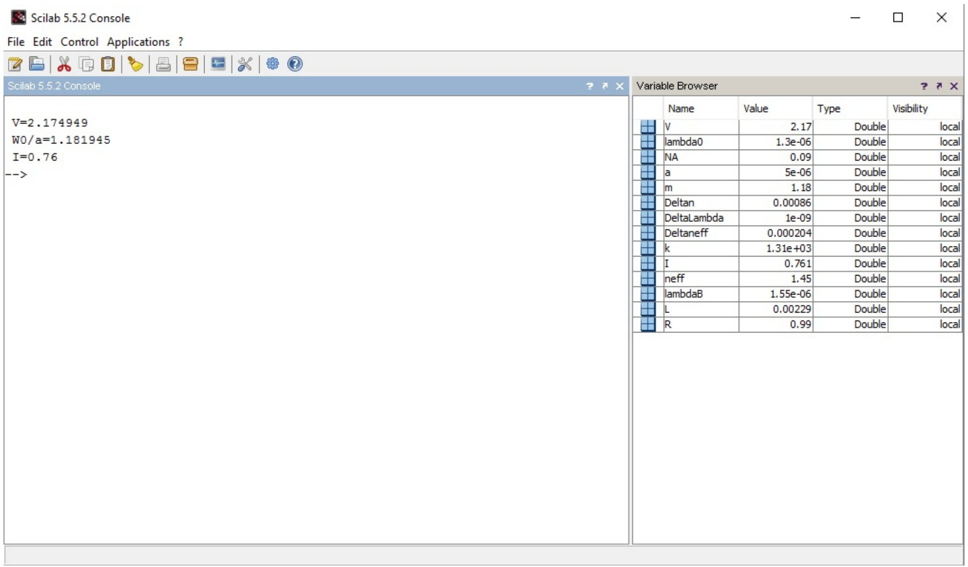

Figure 17.9: 9

```
L=lambdaB^2/(%pi*neff*DeltaLambda)*sqrt(m^2+(%pi)^2) //Since m=k*L
//Length of fiber in m
mprintf("\n L=%.2f mm",L/1e-3);//Division by 10^(-3) to convert into mm

//Rearranging terms of m=k*L, we get:
k=m/L;//Corresponding coupling coefficient in m^(-1)

//Rearranging terms of expression k=%pi*Deltan*I/lambdaB
Deltan=k*lambdaB/(%pi*I);//Change in refractive index
mprintf("\n Deltan=%.2e",Deltan);//Unitless quantity
```

Scilab code Exa 17.9 9

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 17.9
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
a=5e-6;//Fiber core radius in m
NA=0.09;//Numerical aperture of the fiber
lambda0=1.3e-6;//Wavelength of radiation to be reflected from a Bragg grating

V=2*%pi*a*NA/lambda0;//Corrseponding dimensionless V number
mprintf("\n V=%f",V);//The answers vary due to round off error

//Since W0=(0.65+1.619/V^(3/2)+2.879/V^6)*a ,  where W0 is the mode spot size in m
//Let W0=m*a , where m=0.65+1.619/V^(3/2)+2.879/V^6
m=0.65+1.619/V^(3/2)+2.879/V^6;
mprintf("\n W0/a=%f",m);//The answers vary due to round off error

//Given that I=1-exp(-2*(a/W0)^2);
I=1-exp(-2/m^2);//From the assumption that m=W0/a
mprintf("\n I=%.2f",I);
```

Chapter 18

Single mode optical fiber sensors

Scilab code Exa 18.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 18.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambda0=0.633e-6;//Operating wavelength in m
DeltaPhi=1e-6;//Phase change in rad
n=1.45;//refractive index of fiber

DeltaL=DeltaPhi/(2*%pi*n/lambda0);//Corresponding change in fiber length in m
mprintf("\n Corresponding change in fiber length = %.2e m",DeltaL);//The answers vary due to round off error
```

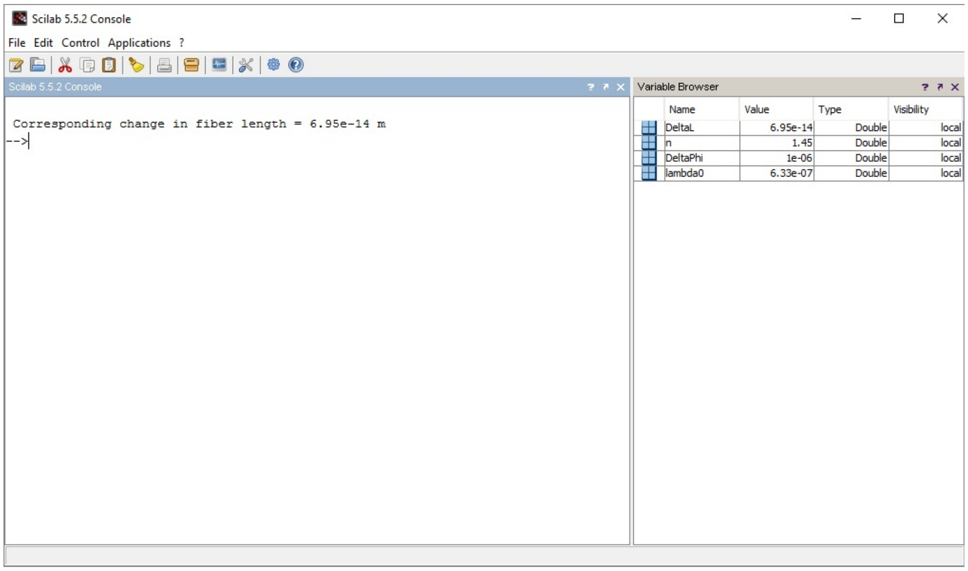

Figure 18.1: 1

Scilab code Exa 18.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 18.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
SPL=20;//Sound Pressure Level of a whisper in dB
Pr=2e-5;//Reference pressure is the threshold of
    hearing in Pa

```

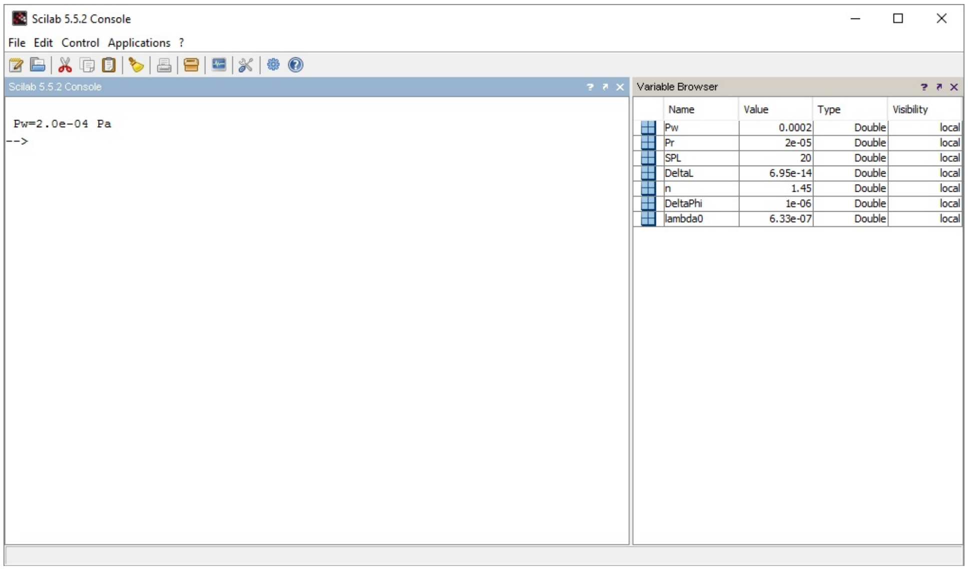

Figure 18.2: 2

```
//Now, SPL=20log10(Pw/Pr)
//Rearranging the terms, we get
Pw=10^(SPL/20)*Pr;
mprintf("\n Pw=%.1e Pa",Pw);
```

Scilab code Exa 18.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 18.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
```

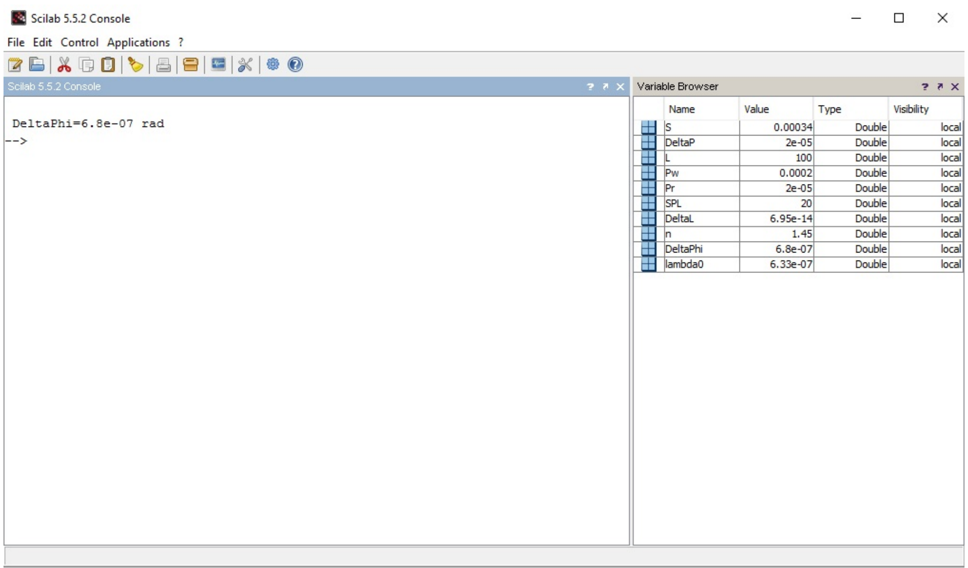

Figure 18.3: 3

```
L=100;//Length of sensing element in m
DeltaP=2e-5;//Threshold of hearing in Pa
S=3.4e-4;//Sensitivity of element in rad/Pa/m

DeltaPhi=S*DeltaP*L;//Corresponding change in phase in rad
mprintf("\n DeltaPhi=%.1e rad",DeltaPhi);
```

Scilab code Exa 18.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 18.4
//OS=Windows XP sp3
//Scilab version 5.5.2
```

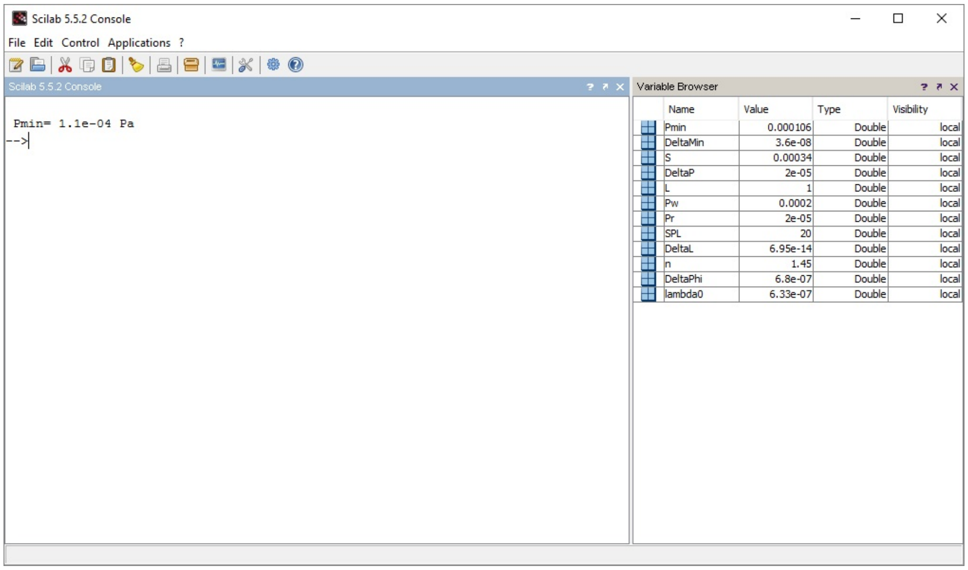

Figure 18.4: 4

```
clc;
clear;
//given
S=3.4e-4;//Sensitivity of the sensing element in rad
    /Pa/m
DeltaMin=3.6e-8;//Minimum detectable phase change in
     rad
L=1;//Length of sensing element in m

Pmin=DeltaMin/(L*S);//Corresponding minimum
    detectable pressure in Pa
mprintf("\n Pmin= %.1e Pa",Pmin);//The answers vary
    due to round off error
```

Scilab code Exa 18.5 5

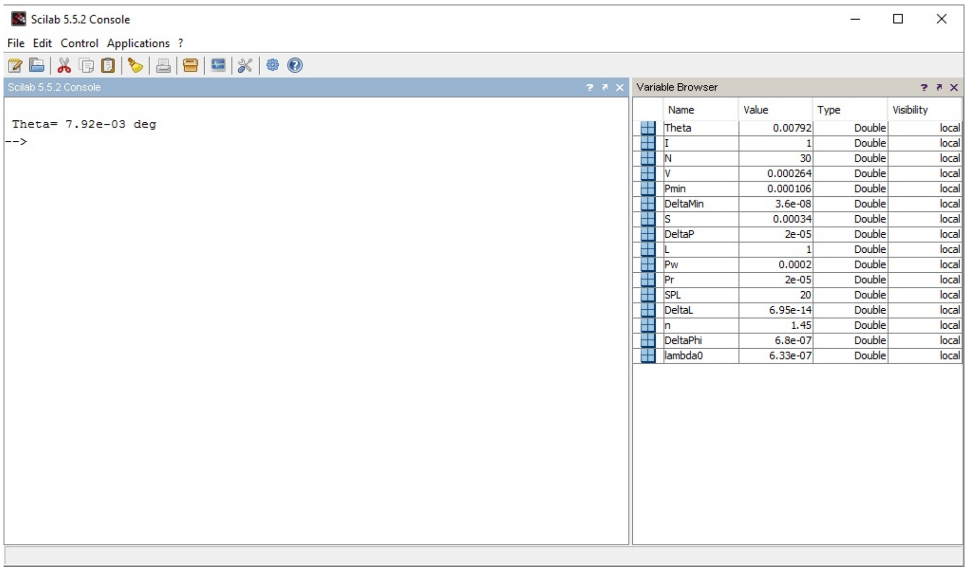

Figure 18.5: 5

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 18.5
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
V=2.64e-4;//Verdet constant for silica in deg/A
N=30;//Number of turns of fiber
I=1;//Current through the fiber in A

Theta=V*N*I;//Corresponding rotation of plane of polarization in deg
mprintf("\n Theta= %.2e deg",Theta);
```

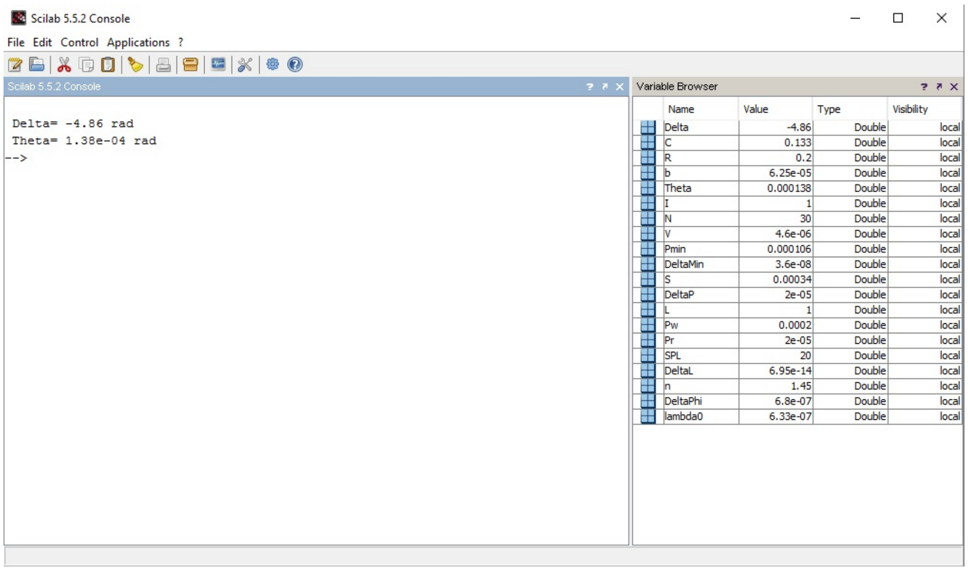

Figure 18.6: 6

Scilab code Exa 18.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 18.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
b=62.5e-6;//Fiber radius in m
R=20e-2;//Loop radius in m
lambda0=633e-9;//Wavelength in m
C=0.133;//Value of constant C for a silica fiber at
    633 nm
V=4.6e-6;//Verdet constant for silica in rad/A
N=30;//Number of turns of fiber
I=1;//Current through the fiber in A

Delta=((2*%pi)^2)*R*N*(-C*(b/R)^2)/lambda0;//The
```

```
Corresponding dimensionless birefringence
mprintf("\n Delta= %.2f rad",Delta);//The negative sign indicates that the polarization of the slow wave is perpendicular to the optic axis

Theta=V*N*I;//Corresponding rotation of plane of polarization in rad
mprintf("\n Theta= %.2e rad",Theta);//The answers vary due to round off error
```

Chapter 21

Periodic Interactions in waveguides

Scilab code Exa 21.1 1

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.1
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
nf=1.51;//refractive index of film
ns=1.50;//refractive index of substrate
nc=1.0;//refractive index of cover
d=4e-6;//thickness of film in m
lambda0=0.6e-6;//Wavelength in m
ne1=1.50862;//Corresponding effective refractive
   index for core
ne2=1.5046;//Corresponding effective refractive
   index for cladding
```

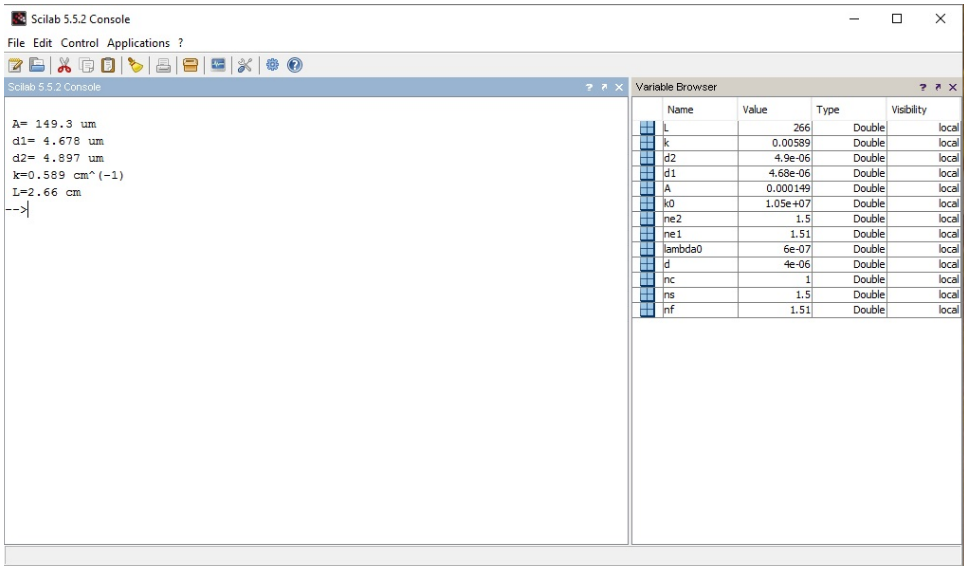

Figure 21.1: 1

```
k0=2*(%pi)/lambda0;//free space wave number in rad/m
//Let A be the period of perturbation in m

A=lambda0/(ne1-ne2);
mprintf("\n A= %.1f um",A/1e-6);//Division by
    10^(-6) to convert into um

d1=d+1/(k0*sqrt(ne1^2-ns^2))+1/(k0*sqrt(ne1^2-nc^2))
    ;//Effective waveguide thickness for mode 1 in m
mprintf("\n d1= %.3f um",d1/1e-6);//Division by
    10^(-6) to convert into um
d2=d+1/(k0*sqrt(ne2^2-ns^2))+1/(k0*sqrt(ne2^2-nc^2))
    ;//Effective waveguide thickness for mode 2 in m
mprintf("\n d2= %.3f um",d2/1e-6);//Division by
    10^(-6) to convert into um
//Assuming h=0.01um in expression for k, we get:
k=%pi/lambda0*0.01e-6*sqrt(((nf^2-ne1^2)*(nf^2-nc^2)
    )/d1*d2*ne1*ne2);//Coupling coefficient in m^-1
mprintf("\n k=%.3f cm^(-1)",k*1e2);//Multiplying by
    10^2 to convert into cm^(-1)
```

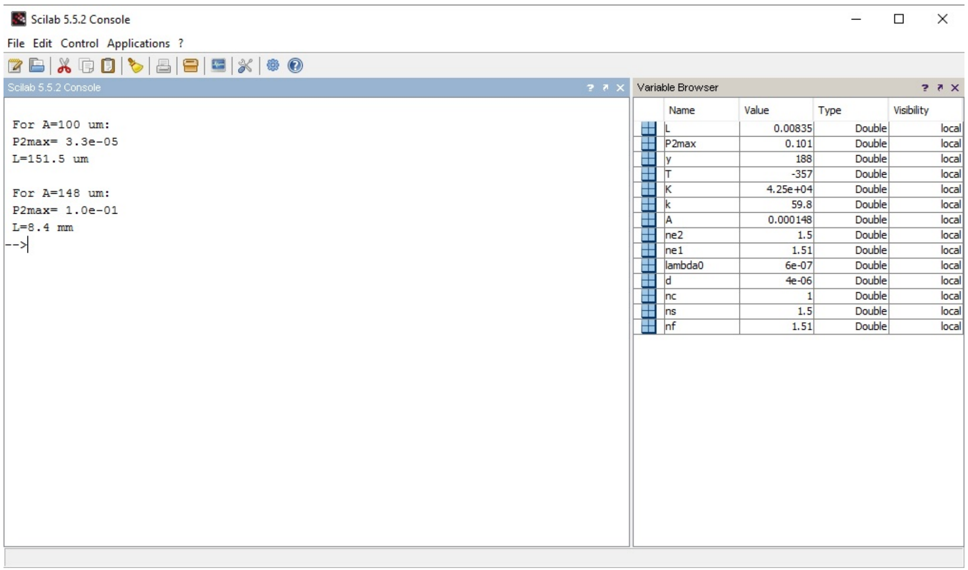

Figure 21.2: 2

```
//The answers vary due to round off error
L=%pi/(2*k);//Length for complete power transfer in
    m
mprintf("\n L=%.2f cm",L/1 e2);//Division by 10ˆ2 to
    convert into cm
//The answers vary due to round off error
```

Scilab code Exa 21.2 2

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.2
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
```

```
clear;
//given
nf=1.51;//refractive index of film
ns=1.50;//refractive index of substrate
nc=1.0;//refractive index of cover
d=4e-6;//thickness of film in m
lambda0=0.6e-6;//Wavelength in m
ne1=1.50862;//Corresponding effective refractive index for core
ne2=1.5046;//Corresponding effective refractive index for cladding
//Let A be the period of perturbation in m


//Case (i):
A=100e-6;
K=2*%pi/A;
k=0.598e2;//coupling coefficient in m^-1 (from previous example)
T=2*%pi/lambda0*(ne1-ne2)-K;//Phase mismatch in m^-1
y=sqrt(k^2+(T/2)^2);//Resultant of k and T in m^-1

mprintf("\n For A=100 um:");
P2max=(k/y)^2;//Maximum power that gets transferred between the modes
mprintf("\n P2max= %.1e",P2max);
L=%pi/(2*y);//Distance for maximum power transfer in m
mprintf("\n L=%.1f um\n",L/1e-6);//Division by 10^(-6) to convert into um
//The answers vary due to round off error


//Case (ii):
A=148e-6;
K=2*%pi/A;
k=0.598e2;//coupling coefficient in m^-1 (from previous example)
```

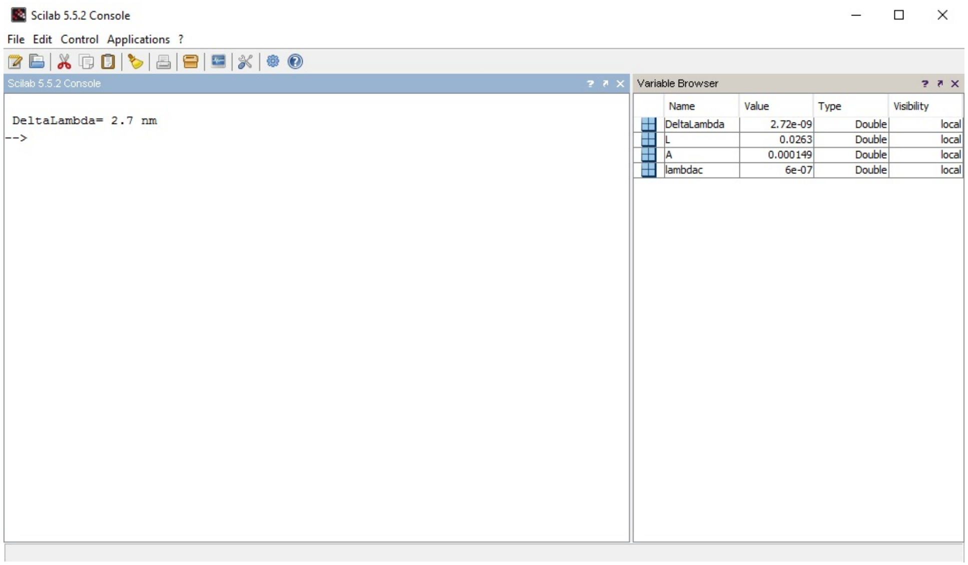

Figure 21.3: 3

```
T=2*%pi/lambda0*(ne1-ne2)-K;//Phase mismatch in m^-1
y=sqrt(k^2+(T/2)^2);//Resultant of k and T in m^-1

mprintf("\n For A=148 um:");
P2max=(k/y)^2;//Maximum power that gets transferred
    between the modes
mprintf("\n P2max= %.1e",P2max);
L=%pi/(2*y);//Distance for maximum power transfer in
    m
mprintf("\n L=%.1f mm",L/1e-3);//Division by 10^(-6)
    to convert into mm
```

Scilab code Exa 21.3 3

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
```

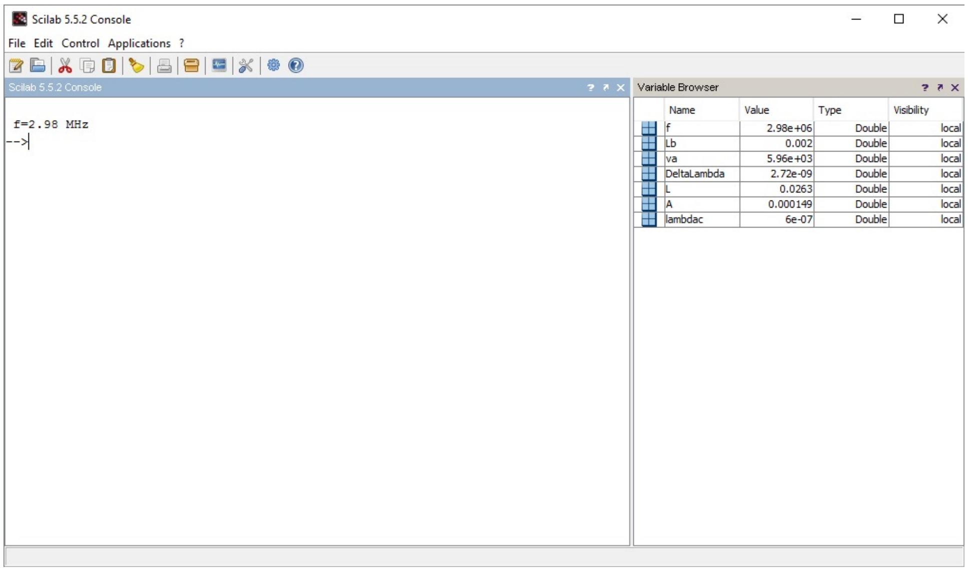

Figure 21.4: 4

```
//Example 21.3
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
lambdac=0.6e-6;//Wavelength in m
//Let A be perturbation of length in m
A=149.3e-6;
L=2.63e-2;//Length of the periodic waveguide in m

DeltaLambda=0.8*A*lambdac/L;//Bandwidth of the
    wavelength filter in m
mprintf("\n DeltaLambda= %.1f nm",DeltaLambda/1e-9);
    //Division by 10^(-9) to convert into nm
```

Scilab code Exa 21.4 4

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.4
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
va=5.96e3;//Velocity of the acoustic wave
Lb=2e-3;//Beat length in m

f=va/Lb;//Acoustic frequency in Hz for Theta=0
    degrees
mprintf("\n f=%.2f MHz",f/1e6);//Division by 10^6 to
     convert into MHz
```

Scilab code Exa 21.5 5

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.5
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
va=5.96e3;//Velocity of the acoustic wave
Lb=1.7e-3;//Beat length in m
Theta=13.5;//Angle between acoustic wave and the
    light waves

```

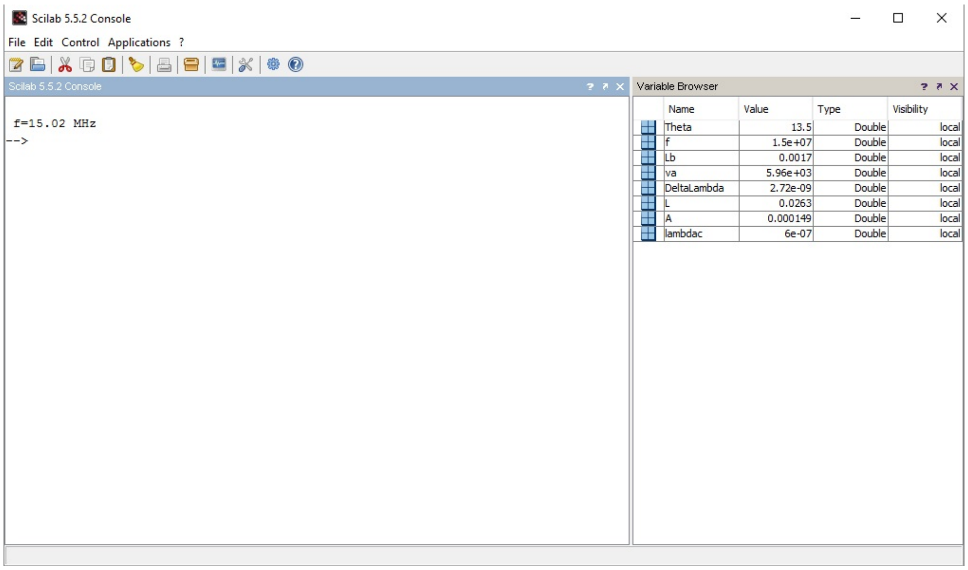

Figure 21.5: 5

```
f=va/(Lb*sind(Theta));//Acoustic frequency in Hz
mprintf("\n f=%.2f MHz",f/1e6);//Division by 10^6 to
    convert into MHz
//The answers vary due to round off error
```

Scilab code Exa 21.6 6

```
//Introduction to Fiber Optics by A. Ghatak and K.
   Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.6
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
```

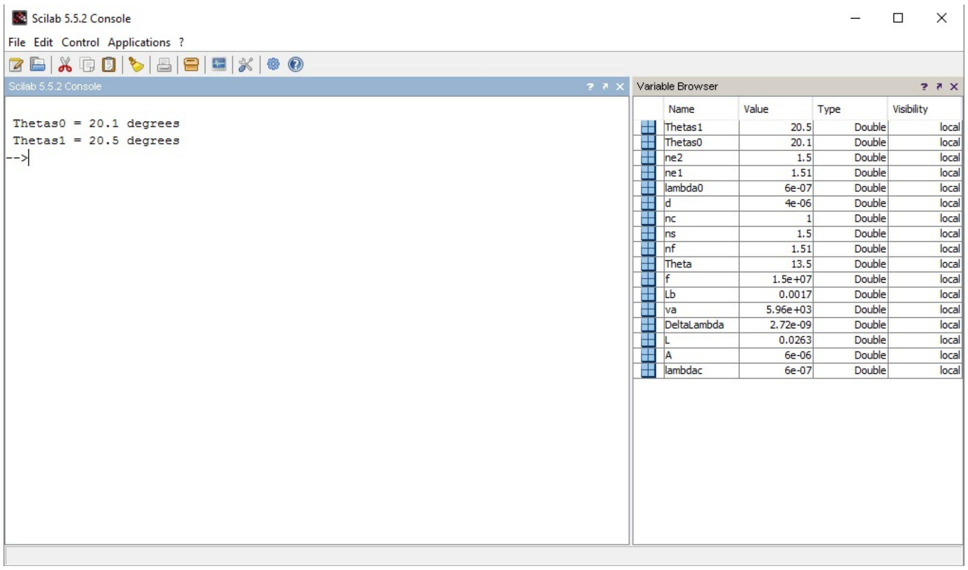

Figure 21.6: 6

```
nf=1.51;//refractive index of film
ns=1.50;//refractive index of substrate
nc=1.0;//refractive index of cover
d=4e-6;//thickness of film in m
lambda0=0.6e-6;//Wavelength in m
ne1=1.50862;//Corresponding effective refractive
    index for core
ne2=1.5046;//Corresponding effective refractive
    index for cladding
//Let A be the perturbation of length in m
A=6e-6;

//Rearranging the terms of the equation 'ne1-lambda0
    /A=ns*cos(Thetas0)', we get:
Thetas0=acosd((ne1-lambda0/A)/ns);
mprintf("\n Thetas0 = %.1f degrees",Thetas0);

//Rearranging the terms of the equation 'ne2-lambda0
    /A=ns*cos(Thetas1)', we get:
Thetas1=acosd((ne2-lambda0/A)/ns);
```

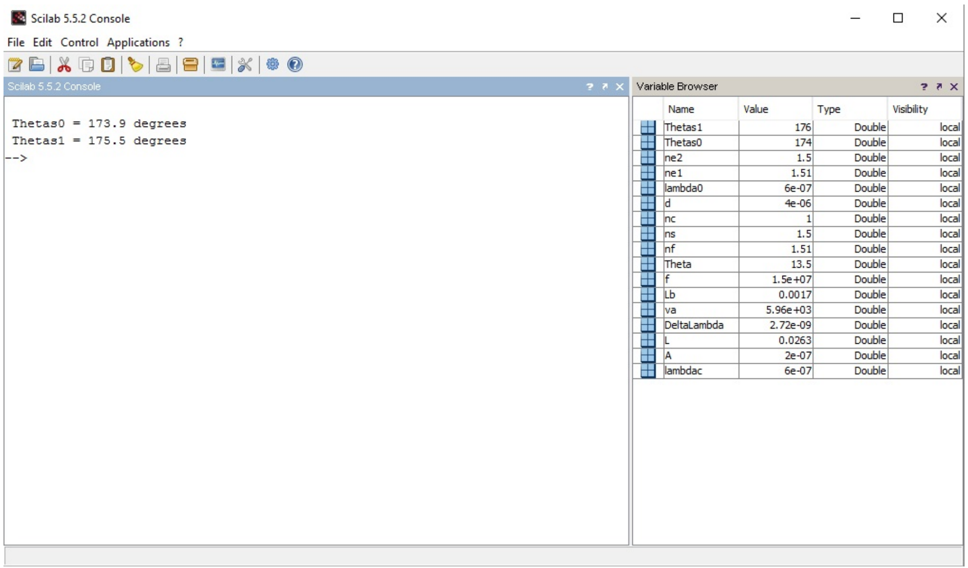

Figure 21.7: 7

```
mprintf("\n Thetas1 = %.1f degrees",Thetas1);
```

Scilab code Exa 21.7 7

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.7
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
nf=1.51;//refractive index of film
ns=1.50;//refractive index of substrate
nc=1.0;//refractive index of cover
```

```
d=4e-6;//thickness of film in m
lambda0=0.6e-6;//Wavelength in m
ne1=1.50862;//Corresponding effective refractive index for core
ne2=1.5046;//Corresponding effective refractive index for cladding
//Let A be the perturbation of length in m
A=0.2e-6;

//Rearranging the terms of the equation 'ne1-lambda0/A=ns*cos(Thetas0)', we get:
Thetas0=acosd((ne1-lambda0/A)/ns);
mprintf("\n Thetas0 = %.1f degrees",Thetas0);

//Rearranging the terms of the equation 'ne2-lambda0/A=ns*cos(Thetas1)', we get:
Thetas1=acosd((ne2-lambda0/A)/ns);
mprintf("\n Thetas1 = %.1f degrees",Thetas1);
```

Scilab code Exa 21.8 8

```
//Introduction to Fiber Optics by A. Ghatak and K. Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.8
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//Since the peak reflectivity of fiber is 0.98,
R=0.98;//Reflection coefficient of fiber
L=1e-3;//Length of interaction in m
lambda0=1092e-9;//Central wavelength in m
```

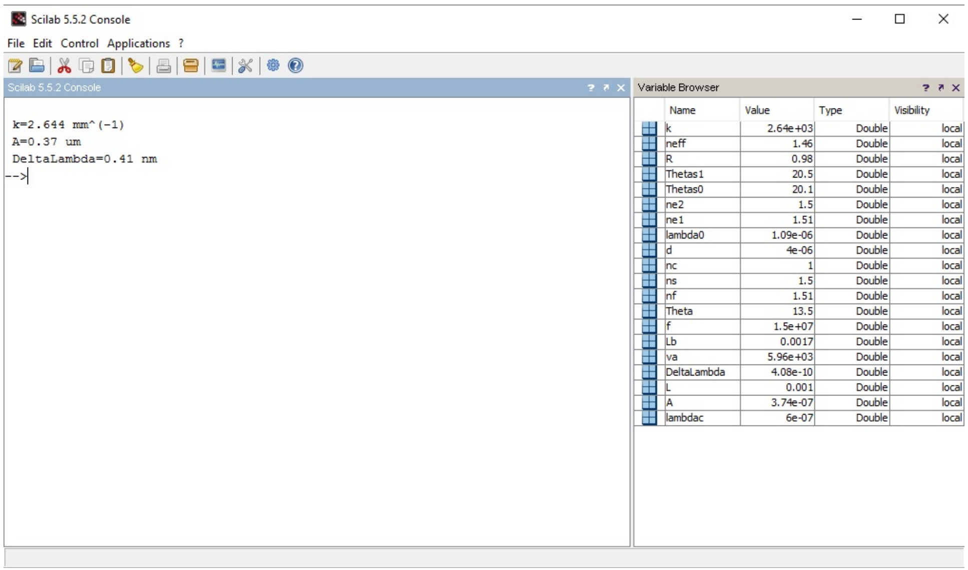

Figure 21.8: 8

```
neff=1.46;//Corresponding value of effective index in LP01 mode

//Now, (tanh(k*L))^2=R
//Rearranging terms, we get:
k=atanh(sqrt(R))/L;//Corresponding coupling coefficient in m^(-1)
mprintf("\n k=%.3f mm^(-1)",k/1e3);//Dividing by 10^3 to convert into mm^(-1)
//The answers vary due to round off error

//Let A be the perturbation of length in m
A=lambda0/(2*neff);
mprintf("\n A=%.2f um",A/1e-6);//Division by 10^(-6) to convert into um

DeltaLambda=lambda0*A/L;//Corresponding bandwidth in m
mprintf("\n DeltaLambda=%.2f nm",DeltaLambda/1e-9);//Division by 10^(-9) to convert into nm
```

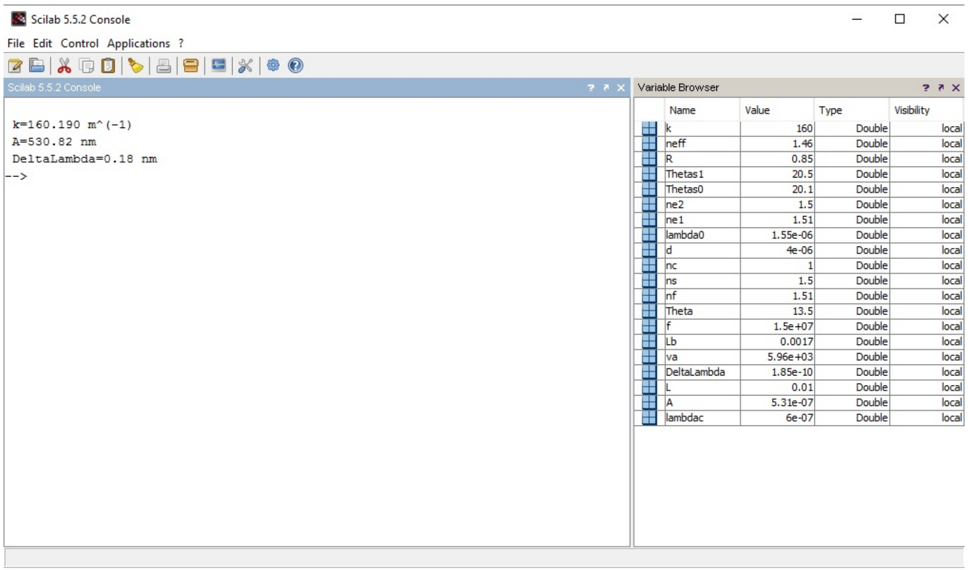

Figure 21.9: 9

```
//The answers vary due to round off error
```

Scilab code Exa 21.9 9

```
//Introduction to Fiber Optics by A. Ghatak and K.
    Thyagarajan, Cambridge, New Delhi, 1999
//Example 21.9
//OS=Windows XP sp3
//Scilab version 5.5.2
clc;
clear;
//given
//Since the peak reflectivity of fiber is 0.85,
R=0.85;//Reflection coefficient of fiber
L=1e-2;//Length of interaction in m
```

```
lambda0=1.55e-6;//Central wavelength in m
neff=1.46;//Corresponding value of effective index in LP01 mode

//Now, (tanh(k*L))^2=R
//Rearranging terms, we get:
k=atanh(sqrt(R))/L;//Corresponding coupling coefficient in m^(-1)
mprintf("\n k=%.3f m^(-1)",k);//The answer provided in the textbook is wrong

//Let A be the perturbation of length in m
A=lambda0/(2*neff);
mprintf("\n A=%.2f nm",A/1e-9);//Division by 10^(-9) to convert into nm
//The answers vary due to round off error

DeltaLambda=lambda0^2/(%pi*neff*L)*sqrt((k*L)^2+(%pi)^2);//Corresponding bandwidth in m
mprintf("\n DeltaLambda=%.2f nm",DeltaLambda/1e-9);//Division by 10^(-9) to convert into nm
//The answer provided in the textbook is wrong
```