# Scilab Textbook Companion for Microwave and Radar Engineering by M. Kulkarni[1]

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# Book Description

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

**Exa** Example (Solved example)

**Eqn** Equation (Particular equation of the above book)

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

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

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# List of Scilab Codes

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# Chapter 3

# Transmission Lines

**Scilab code Exa 3.1** Terminating Impedance

```
1  //chapter-3 page 47 example 3.1
2  //
    ════════════════════════════════════════════════════════════════

3  clc;
4  clear;
5
6  Z0=100;//Characteristic Impedance in ohms
7  S=5;//Voltage Standing Wave Ratio(VSWR)
8
9  //CALCULATION
10 Zm=Z0*S;//Termainating impedance at a max of the
      voltage standing wave
11 Zl=Zm;//Loading Impedance
12
13 //OUTPUT
14 mprintf('Terminating impedance at a maximum of the
      voltage standing wave is Zl= %3.0f ohms',Zl);
15
16 //═══════════════════════END OF PROGRAM
      ════════════════════════════════
```

**Scilab code Exa 3.2** power

```
1  //chapter-3 page 48 example 3.3
2  //
   =================================================
3  clc;
4  clear;
5
6  R=8;//Resistance of a transmission line in ohm/km
7  L=0.002;//Inductance of a transmission line in henry
       /km
8  C=0.002*(10^(-6));//Capacitance of a transmission
       line in Farads
9  G=0.07*(10^(-6));//Conductance of a transmission
       line in siemens/km
10 f=2000;//Frequency in Hz
11 w=2*(%pi)*f;//Angular Frequency in rad/sec
12 Vs=2;//Input Voltage in volts
13 l=500;//Length of Transmission line in km
14
15 //CALCULATIONS
16 Z0=sqrt((R+(w*L*(%i)))/(G+(w*C*(%i))));//
       Characteristic Impedance
17 x=real(Z0);
18 y=imag(Z0);
19 disp('Characteristic Impedance in ohms is ');
20 disp(Z0);
21 g=sqrt((R+(w*L*(%i)))*(G+(w*C*(%i))));//Propagation
       Constant
22 a=real(g);//Attenuation Constant in NP/km
23 b=imag(g);//Phase Constant in rad/km
24 Is=Vs/Z0;
25 I0=Is*exp(-(g*l));//Load current
```

8

```
26  m=sqrt((real(I0))^2+(imag(I0)^2));
27  P=(m^2)*x;//Power delivered to the load in watts
28
29  //OUTPUT
30  mprintf('\nAttenuation Constant is a=%1.6f NP/km \
        nPhase Constant is b=%1.6f rad/km \nPower
        delivered to the load is P=%1.6f watts',a,b,P);
31
32  //================END OF PROGRAM
        ================================
```

**Scilab code Exa 3.3** phase velocity

```
1  //chapter-3 page 48 example 3.3
2  //
        ==============================================
3  clc;
4  clear;
5
6  w=4*(%pi);//Angular Frequency in rad/sec
7  b=0.02543;//Phase Constant in rad/km
8
9  //CALCULATION
10 Vp=w/b;//Phase Velocity in km/sec
11
12 //OUTPUT
13 mprintf('Phase Velocity is Vp=%3.2f km/sec',Vp);
14
15 //=========END OF PROGRAM===========================
16
17 //NOTE:CHECK THE CALCULATION PART GIVEN IN THE
        TEXTBOOK
18      //GIVEN ANSWER 494.22 KM/SEC
19      //GETTING ANSWER 494.16 KM/SEC
```

**Scilab code Exa 3.4** power

```scilab
1  //chapter-3 page 48 example 3.4
2  //_____

3  clc;
4  clear;
5
6  f=37.5*10^6;//Frequency in Hz
7  c=3*10^8;//Velocity of Light in m/sec
8  l1=10;//Length of line in met
9  Vg=200;//Generator Voltage in volts(rms)
10 Zint=200;//Internal Resistance of Generator in ohms
11 Z0=200;//Characteristic Impedance in ohms
12 Zl=100;//Load impedance in ohms
13
14 //CALCULATIONS
15 w=c/f;//Wave Length in met
16 b=2*(%pi)/w;
17 l1=(5/4)*w;//For Lossless Line
18 Zi=Z0*((Zl+(Z0*(%i)*tan(b*l1)))/(Z0+(Zl*(%i)*tan(b*
       l1))));//Input Impedance at Generator end
19 Vs=Vg*(Zi/(Zi+Z0));//Voltage in line in volts
20 Is=Vg/(Zi+Z0);//Current in Line drawn from Generator
        in amps
21 Ps=Vs*Is;//Power drawn in line
22 Pl=Ps;//For Lossless Lines Power delivered to load
       is equal to the Power drawn in line
23 Il=sqrt((Pl/Zl));//Current flowing in the load
24 m=real(Il);//Magnitude of Current flowing in the
       load
25 p=imag(Il);//Phase of Current flowing in the load
26
```

```
27  //CALCULATIONS
28  mprintf('\nCurrent drawn from Generator is Is=%1.3f
        amps \nMagnitude of Current flowing in the load
        is m=%1.3f \nPhase of Current flowing in the load
         is p=%2.2f deg \nPower delivered to load is Pl=
        %2.2f watts ',Is,m,p,Pl);
29
30  //==============================END OF PROGRAM
    ================================================
```

**Scilab code Exa 3.5** VSWR and Reflection coefficient

```
1  //chapter −3 page 50 example 3.5
2  //
    ================================================
3  clc;
4  clear;
5
6  Z0=50;//Characteristic Impedance in ohms
7  f=300*10^6;//Frequency in Hz
8  Zl=50+(50*(%i));//Terminating load impedance in ohms
9  w=((3*10^8)/f);//Wave Length
10
11  //CALCULATIONS
12  p=((Zl-Z0)/(Zl+Z0));//Reflection Coefficient(Complex
        Form)
13  y=real(p);
14  z=imag(p);
15  x=sqrt(y^2+z^2);//Reflection Coefficient Value
16  s=((1+x)/(1-x));//Voltage Standing Wave Ratio(VSWR)
17
18  //OUTPUT
19  mprintf('\nReflection Coefficient is x=%1.4f \
```

```
      nVoltage  Standing  Wave  Ratio(VSWR)  is  s=%1.2f',x,
      s);
20
21  //==================END  OF  PROGRAM
      ===================================
```

**Scilab code Exa 3.6** point of attachment

```
1  //chapter-3  page  50  example  3.6
2  //
     ===============================================================
3  clc;
4  clear;
5
6  Zl=100;//Pure  Load  resistance  of  a  dipole  antenna  in
         ohms
7  Z0=600;//Characteristic  Impedance  of  a  wire  feeder
       in  ohms
8  f=100*10^6;//Frequency  in  Hz
9  c=3*10^8;//Velocity  of  Light  in  m/sec
10
11  //CALCULATIONS
12  w=c/f;//Wave  Length  in  met
13  l=((w/(2*(%pi)))*atan(sqrt(Zl/Z0)));//The  position
       of  the  Stub  in  met
14  x=atand(sqrt((Zl*Z0))/(Zl-Z0));
15  y=180+x;//In  Degrees
16  l1=((w/(2*(%pi)))*y);//Length  of  Short  Circuited
       Stub  in  met
17  l0=l1*((%pi)/180);
18
19  //OUTPUTS
20  mprintf('\nThe  Point  of  Attachment  is  l=%1.3f  met  \
       nLength  of  SC  Stub  is  l1=%1.2f  met',l,l0);
```

```
21
22 //════════════════════════════END OF PROGRAM
       ════════════════════════════════════════════
```

────────────────────────────────────────────

**Scilab code Exa 3.7** Terminating Impedance

```
 1 //chapter−3 page 50 example 3.7
 2 //
       ════════════════════════════════════════════

 3 clc;
 4 clear;
 5
 6 Z0=50;//Characteristic Impedance in ohms
 7 S=3.2;//Voltage Standing Wave Ratio(VSWR)
 8
 9 //It is possible to measure the load impedance if
       the line is assumed lossless,by measuring the
       VSWR,wavelength and the distance from the load to
        the nearest voltage minimum
10 //CALCULATIONS
11 w=1;//Assume Wavelength in met
12 Xmin=0.23*w;//Distance from the load to the nearest
       voltage minimum in met
13 b=(2*(%pi))/w;
14 Zl=Z0*((1-(S*(%i)*tan(b*Xmin)))/(S-((%i)*tan(b*Xmin)
       )));//Load impedance in ohms
15 disp('Load impedance in ohms is ');
16 disp(Zl);
17
18
19 //════════════════════════════END OF PROGRAM
       ════════════════════════════════════════════
```

```
20
21 //Note: Check the answer given in Text book once. I
        think it is wrong in text book..
```
---

**Scilab code Exa 3.8** VSWR and Impedance

```
1 // chapter -3 page 51 example 3.8
2 //
        =====================================================================

3 clc;
4 clear;
5
6 Z0=50;//Characteristic Impedance in ohms
7 Zl=100;//Load impedance in ohms
8 f=300*10^3;//Frequency in Hz
9 Pl=0.05;//Load Power in watts
10 c=3*10^8;//Velocity of Light in m/sec
11
12 //CALCULATIONS
13 w=c/f;//Wave Length in met
14 p=((Zl-Z0)/(Zl+Z0));//Reflection Coefficient
15 S=((1+p)/(1-p));//Voltage Standing Wave Ratio(VSWR)
16
17 //Since Zl>Z0, first Vmax is located at the load and
        first Vmin is located at Wavelength/4
18 x1max=0;//Position of first Vmax (located at the
     load) from load in met
19 x1min=w/4;//Position of first Vmin from load in met
20 Vmax=sqrt(Pl*Zl);//Value of maximum voltage in volts
21 Vmin=Vmax/S;//Value of minimum voltage in volts
22 Zmax=Z0*S;//Impedance at Vmax in ohms
23 Zmin=Z0/S;//Impedance at Vmin in ohms
24
25 //OUTPUTS
```

```
26  mprintf('\nVoltage Standing Wave Ratio(VSWR) is S=%1
        .0f \nPosition of first Vmax from load is x1max=
        %d met (located at the load) \nPosition of first
        Vmin from load is x1min=%3.0f met \nValue of
        maximum voltage is Vmax=%1.2f volts \nValue of
        minimum voltage is Vmin=%1.2f volts \nImpedance
        at Vmax is Zmax=%3.0f ohms \nImpedance at Vmin is
        Zmin=%2.0f ohms',S,x1max,x1min,Vmax,Vmin,Zmax,
        Zmin);
27
28  //================================END OF PROGRAM
    ================================================
```

**Scilab code Exa 3.9** Reflection loss

```
1  //chapter-3 page 52 example 3.9
2  //
    ==================================================

3  clc;
4  clear;
5
6  Z0=600;//Characteristic Impedance in ohms
7  Zs=50;//Generator impedance in ohms
8  l=200;//Length of transmission line in met
9  Zl=500;//Load impedance in ohms
10
11 //CALCULATIONS
12 p=((Zl-Z0)/(Zl+Z0));//Reflection Coefficient
13 x=abs(p);
14 Lr=10*log10(1/(1-x^2));//Reflection loss in dB
15 La=0;//Since the line is lossless,attenuation loss
       is zero dB
16 Lt=La+Lr;//Transmission loss in dB
```

```
17  Lrt=10*log10(x);//Return loss in dB
18
19  //OUTPUT
20  mprintf('\nReflection loss is Lr=%1.3f dB \
        nTransmission loss is Lt=%1.3f dB \nReturn loss
        is Lrt=%2.3f dB',Lr,Lt,Lrt);
21
22  //===========================END OF PROGRAM
        ==================================================
```

**Scilab code Exa 3.10** Characteristic Impedance

```
1  //chapter-3 page 52 example 3.10
2  //
       ==================================================
3  clc;
4  clear;
5
6  f=1000;//Frequency in Hz
7  l=10000;//Length of open wire transmission line in
        met
8  z1=2930;//Magnitude of a short circuit impedance in
        ohms
9  p1=26;//Phase of a short circuit impedance in deg
10 z2=260;//Magnitude of a open circuit impedance in
        ohms
11 p2=-32;//Phase of a open circuit impedance in deg
12 //CALCULATIONS
13 Zsc=((z1*cosd(p1))+((%i)*(z1*sind(p1))));
14 Zoc=((z2*cosd(p2))+((%i)*(z2*sind(p2))));
15 Z0=sqrt(Zsc*Zoc);//Characteristic Impedance in ohms
16 disp('Characteristic Impedance in ohms is');
17 [ro,theta]=polar(Z0)
```

```
18  disp(ro);
19  disp(theta*180/%pi);
20  g=((1/l)*(atanh(sqrt(Zsc/Zoc))));//Propagation
        Constant
21  disp(g)
22  b=imag(g);//Phase Constant
23  w=2*f*(%pi);//Angular Frequency in rad/sec
24  Vp=w/b;//Phase Velocity in m/sec
25  disp(Vp)
26  //OUTPUT
27  mprintf('\nPhase Velocity is Vp=%5.2f m/sec',Vp);
28
29  //==========================END OF PROGRAM
    ===================================================

30
31
32  //Note: Check the calculation once
```

# Chapter 4

# Microwave Transmission Lines

**Scilab code Exa 4.1** Characteristic Impedance

```
1  //chapter-4 page 141 example 4.1
2  //
   _____

3  clc;
4  clear;
5
6  d=0.0049;//Diameter of inner conductor in met
7  D=0.0110;//Inner Diameter of outer conductor in met
8  er=2.3;//Polyethylene dielectric
9  c=3*10^8;//Velocity of Light in m/sec
10
11 //CALCULATIONS
12 x=log(D/d);
13 L=(2*10^(-1)*x);//Inductance per unit lengths in
      microH/m
14 C=(55.56*(er/x));//The Capacitance per unit lengths
      in picoF/m
15 R0=(x*(60/sqrt(er)));//The Characteristic Impedance
      in ohms
16 V=(c/sqrt(er))/(10^3);//The Velocity of propagation
```

```
        in Km/ s
17
18  //OUTPUT
19  mprintf('\nInductance per unit lengths is L=%1.5 f
        microH/m \nThe Capacitance per unit lengths is C=
        %2.2 f picoF/m \nThe Characteristic Impedance is
        R0=%2.2 f ohms \nThe Velocity of propagation is V=
        %6.2 f Km/ s ',L,C,R0,V);
20
21    //=============================END OF PROGRAM
        ==========================================
```

___

**Scilab code Exa 4.2** attenuation and phase constants

```
1  //chapter−4 page 142 example 4.2
2  //
        ====================================================

3  clc;
4  clear;
5
6  R=0.05;//Resistance in ohm/m
7  L=0.16173*10^(-6);//Inductance per unit lengths in H
        /m
8  C=0.15802*10^(-6);//The Capacitance per unit lengths
        in F/m
9  V=197814.14;//The Velocity of propagation in Km/s
10  l=50;//Length of Coaxial Line in met
11  Pin=480;//Input Power to the System in watts
12  f=3*10^9;//Frequency in Hz
13  c=3*10^5;//Velocity of Light in Km/sec
14  e0=8.854*10^(-12);//Permittivity in free space in F/
        m
15
```

```
16  //CALCULATIONS
17  Z0=sqrt(L/C);
18  A=(R/(2*Z0));//Attenuation Constant in NP/m
19  w=(2*(%pi)*f);//Angular Frequency in rad/sec
20  B=(w*sqrt(L*C));//Phase Constant in rad/m
21  Vp=(1/sqrt(L*C))/(10^3);//Phase Velocity in Km/s
22  er=(((c/V)^2)/e0);//Relative Permittivity
23  Pl=(2*Pin*l);//Power Loss in watts
24
25  //OUTPUT
26  mprintf('\nAttenuation Constant is A=%1.4f NP/m \
        nPhase Constant is B=%4.3f rad/m \nPhase Velocity
         is Vp=%4.3f Km/s \nRelative Permittivity is er=
        %12.2f \nPower Loss is Pl=%5.0f watts',A,B,Vp,er,
        Pl);
27
28  //==========================END OF PROGRAM
        ===================================
```

**Scilab code Exa 4.3** breakdown power

```
1  //chapter−4 page 142 example 4.3
2  //
        ================================================
3  clc;
4  clear;
5
6  //For an air filled coaxial cable
7  f=9.375*10^9;//operating frequency in Hz
8  c=3*10^10;//Velocity of Light in cm/sec
9  disp('Assuming a ratio of (b/a)=2.3 and (b+a)<(w/pi)
         to exclude higher order modes and a dominant
        mode propagating');
10  a=0.36432;//length of coaxial cable in cm
```

```
11  x=2.3; //ratio  of  b/a
12
13  //CALCULATION
14  w0=(c/f); //free  space  wavelength  in  cm
15  Pbd=(3600*(a^2)*log(x)); //Breakdown  power  of  a
       coaxial  cable  in  kW
16
17  //OUTPUT
18  mprintf('\nBreakdown  power  of  a  coaxial  cable  is  Pbd
       =%3.0f  kW',Pbd);
19
20  //==============================END  OF  PROGRAM
       ===============================
```

**Scilab code Exa 4.4** Characteristic Impedance

```
1  //chapter−4  page  142  example  4.4
2  //
       =================================================

3  clc;
4  clear;
5
6  b=0.3175; //Distance  between  ground  planes  of  strip
       line  in  cm
7  d=0.0539; //Diameter  of  circular  conductor  in  cm
8  er=2.32; //Dielectric  Constant
9  c=3*10^8; //Velocity  of  Light  in  m/sec
10
11  //CALCULATION
12  Z0=((60/sqrt(er))*log((4*b)/(d*(%pi)))); //
       Characteristic  Impedance  in  ohms
13  V=(c/sqrt(er))/(10^3); //The  Velocity  of  propagation
       in  Km/s
14
```

```
15  //OUTPUT
16  mprintf('\nCharacteristic  Impedance  is  Z0=%2.2f  ohms
        \nThe  Velocity  of  propagation  is   V=%5.2f  Km/s',
        Z0,V);
17
18  //===============================END  OF  PROGRAM
        ==================================================
```

_____

**Scilab code Exa 4.5** Characteristic Impedance

```
1   //chapter-4  page  143  example  4.5
2   //
        ==================================================

3   clc;
4   clear;
5
6   //For  a  microstrip  transmission  line
7   er=9.7;//relative  dielectric  constant  of  an  alumina
        substrate
8   x1=0.5;//w/h  ratio  in  first  transmission  line
9   x2=5;//w/h  ratio  in  second  transmission  line
10  c=3*10^8;//Velocity  of  Light  in  m/sec
11
12  //CALCULATION
13  disp('For  case1:  w/h=0.5');
14  disp('Since  x1=0.5<1,  for  this  we  use  high  impedance
        analysis');
15  Eeff1=(((er+1)/2)+((er-1)/2)*(1/((sqrt(1+(12/x1)))
        +(0.04*(1-x1)^2))));//Effective  dielectric
        constant
16  Zo1=((60/sqrt(Eeff1))*log((8/x1)+(x1/4)));//
        Characteristic  impedance  in  ohms
17  V1=(c/sqrt(Eeff1))/10^8;//Velocity  of  propagation  in
```

```
        10^8 m/ sec
18  mprintf ('\nEffective dielectric constant is Eeff1=%1
       .2 f \nCharacteristic impedance is Zo1=%2.2 f ohms
       \nVelocity of propagation is V1=%1.1 f *10^8 m/ sec
       ',Eeff1,Zo1,V1);
19
20  disp ('For case2: w/h=5');
21  disp ('here x2>1');
22  Eeff2 =(((er+1)/2)+((er-1)/2)*(1/(sqrt(1+(12/x2))))) ;
       // Effective dielectric constant
23  Zo2 =((120*(%pi)/sqrt(Eeff2))*(1/(x2+1.393+(0.667*log
       (1.444+x2)))));// Characteristic impedance in ohms
24  V2 =(c/sqrt(Eeff2))/10^8;// Velocity of propagation in
       10^8 m/ sec
25  mprintf ('\nEffective dielectric constant is Eeff2=%1
       .2 f \nCharacteristic impedance is Zo2=%2.2 f ohms
       \nVelocity of propagation is V2=%1.2 f *10^8 m/ sec
       ',Eeff2,Zo2,V2);
26
27  //==========================END OF PROGRAM
       ======================
```

**Scilab code Exa 4.6** ratio of areas

```
1  // chapter -4 page 144 example 4.6
2  //
       ================================================================

3  clc ;
4  clear ;
5
6  //To calculate the ratio of circular waveguide cross
       -sectional area to the rectangular waveguide
       cross section
7  disp ('Assuming that both these waveguides have
```

23

```
        similar  or  equal  cutoff  frequencies/wavelengths');
 8
 9  disp('Case1:  When TE wave is  propagated');
10  disp('For  standard  rectangular  waveguides  a=2b  and
        For  TE11  dominant  mode  in  circular  waveguide  wc1
        =(2(pi)r)/1.841 ');
11  disp('where  r  is  the  radius  of  the  circular
        waveguide  and  wc1  is  the  cutoff  wavelength  for
        circular  waveguide ');
12  disp('It  is  given  wc1=wc2  where  wc2  is  the  cutoff
        wavelength  for  rectangular  waveguide ');
13  disp('For  TE10(dominant  mode)  of  propagation  in
        rectangular  waveguide  wc2=2a ');
14  disp('Since  wc2=(2ab)/(sqrt((mb)^2+(nb)^2))  as  m=1;n
        =0  for  TE10  wc2=2ab/b=2a ');
15  disp('By  equating  wc1=wc2 ,  we  get  a=1.70645 r ');
16  disp('For  a  standard  waveguide  a=2b  therefore ,  b=a/2
        ');
17  disp('Now  the  area  of  rectangular  waveguide=a*b=a*a
        /2=1.70645 r *1.70645 r /2=1.456 r^2 ');
18  disp('Area  of  rectangular  waveguide=1.456 r^2  ,Area
        of  circular  waveguide=(pi)*r^2 ');
19  disp('Ratio  of  area  of  circular  to  area  of
        rectangular  waveguide=(Area  of  circular  waveguide
        /Area  of  rectangular  waveguide)=(pi*r^2)/(1.456 r
        ^2)=2.1576873=2.2 ');
20  disp('This  clearly  shows  that  the  space  occupied  by
        a  rectangular  waveguide  system  is  less  compared
        to  that  for  a  circular  waveguide  system.Hence
        circular  waveguides  are  not  preferred  in  some
        applications ');
21
22  disp('Case2:  When TM wave is  propagated');
23  disp('For  TM01  mode  wc1=(2*pi*r)/(Pnm)min=(2*pi*r)/
        Pnm=(2*pi*r)/2.405  where  r  is  the  radius  of
        circular  waveguide  wc1=2.6155 r ');
24  disp('Now  if  wc2  is  the  wavelength  for  TM11  wave
```

```
          propagating  in  a  standard  rectangular  waveguide
          wc2=wc1  but  wc2=(2ab)/sqrt(a^2+b^2)');
25  disp('For  standard  waveguides,we  know  a=2b,  wc2=(2*2
          b*b)/sqrt(4b^2+b^2)=(4b^2)/sqrt(5b^2)=4b/sqrt(5)'
          );
26  disp('By  equating  wc1=wc2,  we  get  2.6155r=4b/sqrt(5)
          =>b=1.4621r');
27  disp('Area  of  rectangular  waveguide=b*b=b^2  but  b
          =1.4621r,  so  Area  of  rectangular  waveguide
          =(1.4621r)^2=2.132r^2  and  Area  of  circular
          waveguide=  pi*r^2');
28  disp('Ratio  of  area  of  circular  to  area  of
          rectangular  waveguide=(Area  of  circular  waveguide
          /Area  of  rectangular  waveguide)=(pi*r^2)/(2.132r
          ^2)=1.5');
29
30  //===============================END  OF  PROGRAM
          =================================
```

_____

**Scilab code Exa 4.7** breadth of the guide

```
1  //chapter−4  page  146  example  4.7
2  //
       ===========================================================
3  clc;
4  clear;
5
6  //For  a  rectangular  waveguide
7  disp('For  a  rectangular  waveguide  the  dominant  mode
          is  the  TE10  mode.TE10  mode  can  propagate  at  a
          lower  frequency');
8  f=9*10^9;//frequency  in  Hz
9  wg=4;//guide  wavelength  in  cm
10  c=3*10^10;//Velocity  of  Light  in  cm/sec
```

```
11  disp('For TE10 mode wc=2a');
12
13  //CALCULATION
14  w0=(c/f);//free space wavelength in cm
15  wc=(w0/sqrt(1-(w0/wg)^2));//Cutoff wavelength for
        TE10 mode in cm
16  disp('Free space wavelength w0 in cm is');
17  disp(w0);
18  disp('Cutoff wavelength wc in cm is');
19  disp(wc);
20  disp('Since wc>w0, the wave propagates');
21  a=(wc/2);//length of the guide in cm
22  b=(wc/4);//breadth of the guide in cm
23
24  //OUTPUT
25  mprintf('\nlength of the guide is a=%1.0f cm \
        nbreadth of the guide is b=%1.1f cm',a,b);
26
27  //==============================END OF PROGRAM
        ===============================
```

**Scilab code Exa 4.8** guide wavelength

```
1  //chapter-4 page 147 example 4.8
2  //
        ===================================================

3  clc;
4  clear;
5
6  a=10;//breadth of a rectangular waveguide in cm
7  f=2.5*10^9;//Frequency in Hz in TE10 mode
8  c=3*10^10;//Velocity of Light in cm/sec
9
10 //CALCULATION
```

```
11  wc=2*a;//Cutoff  wavelength  for  TE10  mode  in  cm
12  w0=(c/f);//Free  space  wavelength  in  cm
13  x=sqrt(1-(w0/wc)^2);
14  wg=(w0/x);//Guide  wavelength  in  cm
15  Vp=(c/x)/10^5;//Phase  Velocity  in  Km/sec
16  Vg=((c^2)/Vp)/10^10;//Group  Velocity  in  Km/sec
17
18  //OUTPUT
19  mprintf('\nCutoff  wavelength  for  TE10  mode  is  wc=%2
        .0f  cm  \nGuide  wavelength  is  wg=%2.0f  cm  \nPhase
        Velocity  is  Vp=%7.2f  Km/sec  \nGroup  Velocity  is
        Vg=%6.2f  Km/sec ',wc,wg,Vp,Vg);
20
21  //==========================END  OF  PROGRAM
        ================================
```

**Scilab code Exa 4.9** guide wavelength

```
1  //chapter-4  page  147  example  4.9
2  //
        ===============================================================
3  clc;
4  clear;
5
6  f=8.6*10^9;//frequency  in  Hz
7  c=3*10^10;//Velocity  of  Light  in  cm/sec
8  a=2.5;//Length  of  a  Waveguide  in  cm
9  b=1;//Width  of  a  Waveguide  in  cm
10
11  //CALCULATION
12  disp('The  condition  for  the  wave  to  propagate  along
        a  guide  is  that  wc>w0.');
13  w0=c/f;//free  space  wavelength  in  cm
14  disp('Free  space  wavelength  w0  in  cm  is ');
```

```
15  disp(w0);
16  disp('For TE waves, wc=(2ab/sqrt((mb)^2+(na)^2))');
17  disp('For TE01 waves');
18  m1=0;
19  n1=1;
20  wc1=((2*a*b)/(sqrt((m1*b)^2+(n1*a)^2)));//Cutoff
        wavelength for TE01 mode in cm
21  disp('Cutoff wavelength for TE01 mode in cm is');
22  disp(wc1);
23  disp('Since wc for TE01=2cm is not greater than w0
        TE01,will not propagate for TE01 mode.');
24  disp('For TE10 waves');
25  m2=1;
26  n2=0;
27  wc2=((2*a*b)/(sqrt((m2*b)^2+(n2*a)^2)));//Cutoff
        wavelength for TE10 mode in cm
28  disp('Cutoff wavelength for TE10 mode in cm is');
29  disp(wc2);
30  disp('Since wc TE10 > w0 TE10 is a possible mode.');
31  fc=(c/wc2)/10^9;//Cutoff frequency in GHz
32  disp('For TE11 and TM11 waves');
33  m3=1;
34  n3=1;
35  wc3=((2*a*b)/(sqrt((m3*b)^2+(n3*a)^2)));//Cutoff
        wavelength for TE11 mode in cm
36  disp('Cutoff wavelength for TE11 and TM11 modes in
        cm is');
37  disp(wc3);
38  disp('As wc for TE11 and TM11 is < w0 both TE11 and
        TM11 do not propagate as higher modes.');
39  wg=(w0/sqrt(1-(w0/wc2)^2));//Guide wavelength in cm
40  disp('From the above analysis we conclude that only
        TE10 mode is possible');
41
42  //OUTPUT
43  mprintf('\nCutoff frequency is fc=%1.0f GHz \nGuide
        wavelength is wg=%1.3f cm',fc,wg);
44
```

`//`═══════════════════════════════════END OF PROGRAM
═══════════════════════════

_____

**Scilab code Exa 4.10** area

```
1  //chapter -4 page 148 example 4.10
2  //
═══════════════════════════════════════════════

3  clc;
4  clear;
5
6  //For an air filled circular Waveguide in the
       dominant mode
7  c=3*10^10;//Velocity of Light in cm/sec
8  disp('For an air filled circular Waveguide TE11 is
       the dominant mode ie propagated');
9  wc=10;//cutoff wave length in cm
10
11  //CALCULATION
12  r=((1.841*wc)/(2*(%pi)));//radius of circular
       Waveguide in cm
13  A=(%pi)*r^2;//Cross sectional area of the guide in
       sq.cms
14  fc=(c/wc)/10^9;//Cutoff frequency for TE11 mode in
       GHz
15  disp('Cutoff frequency for TE11 mode in GHz is');
16  disp(fc);
17  disp('Frequncy above 3GHz can be propagated through
       the waveguide');
18
19  //OUTPUT
20  mprintf('\nCross sectional area of the guide is A=%2
       .2f sq.cms',A);
21
```

_____

**Scilab code Exa 4.11** possible modes

```
1  //chapter-4 page 149 example 4.11
2  //
     ═══════════════════════════════════════════════════════════════

3  clc;
4  clear;
5
6  //For a rectangular waveguide
7  f=5*10^9;//frequency in Hz
8  c=3*10^10;//Velocity of Light in cm/sec
9  a=4;//Length of Rectangular Waveguide in cm
10 b=3;//Width of Rectangular Waveguide in cm
11
12 //CALCULATION
13 disp('The condition for the wave to propagate along
      a guide is that wc>w0.');
14 w0=c/f;//free space wavelength in cm
15 disp('Free space wavelength w0 in cm is');
16 disp(w0);
17 disp('For TE waves, wc=(2ab/sqrt((mb)^2+(na)^2))');
18 disp('For TE01 waves');
19 m1=0;
20 n1=1;
21 wc1=((2*a*b)/(sqrt((m1*b)^2+(n1*a)^2)));//Cutoff
      wavelength for TE01 mode in cm
22 disp('Cutoff wavelength for TE01 mode in cm is');
23 disp(wc1);
24 disp('Since wc for TE01=6cm is not greater than w0
      TE01,will not propagate for TE01 mode.');
25 disp('For TE10 waves');
```

```
26  m2=1;
27  n2=0;
28  wc2=((2*a*b)/(sqrt((m2*b)^2+(n2*a)^2)));//Cutoff
        wavelength for TE10 mode in cm
29  disp('Cutoff wavelength for TE10 mode in cm is');
30  disp(wc2);
31  disp('Since wc TE10 > w0 TE10 is a possible mode.');
32  disp('For TE11 waves');
33  m3=1;
34  n3=1;
35  wc3=((2*a*b)/(sqrt((m3*b)^2+(n3*a)^2)));//Cutoff
        wavelength for TE11 mode in cm
36  disp('Cutoff wavelength for TE11 mode in cm is');
37  disp(wc3);
38  disp('As wc TE11 < w0 TE11 does not propagate.');
39
40  //==============================END OF PROGRAM
        ==============================
```

**Scilab code Exa 4.12** guide wavelength

```
1  //chapter-4 page 149 example 4.12
2  //
        =====================================================================

3  clc;
4  clear;
5
6  //For an air filled circular Waveguide in the
        dominant mode
7  D=4;//Inner diameter of an air filled circular
        Waveguide in cm
8  c=3*10^10;//Velocity of Light in cm/sec
9
10  //CALCULATION
```

```
11  disp('The dominant mode in the circular waveguide
        would be like TE11,wc is maximum');
12  r=D/2;//radius in cm
13  wc=((2*(%pi)*r)/1.841);//Cutoff wavelength in cms
14  fc=(c/wc)/10^9;//Cutoff frequency in GHz
15  mprintf('\nCutoff wavelength is wc=%1.4f cms \
        nCutoff frequency is fc=%1.3f GHz',wc,fc);
16  disp('Since cut−off frequency is 4.395 GHz,
        frequencies higher than fc will be propagated.
        Assume a signal of frequency of 5 GHz is being
        propagated');
17  f=5*10^9;//frequency of signal in Hz
18  w0=(c/f);//free space wavelength in cm
19  wg=(w0/sqrt(1-(w0/wc)^2));//Guide wavelength in cm
20  mprintf('\nWave length in the guide is wg=%2.2f cm',
        wg);
21
22  //═══════════════════════════END OF PROGRAM
        ════════════════════════════
```

**Scilab code Exa 4.13** frequency

```
1  //chapter−4 page 150 example 4.13
2  //
        ══════════════════════════════════════════════════════

3  clc;
4  clear;
5
6  //For a rectangular waveguide in TE10 mode
7  a=6;//Length of Rectangular Waveguide in cm
8  b=4;//Width of Rectangular Waveguide in cm
9  c=3*10^10;//Velocity of Light in cm/sec
10 x=4.55;//distance between maximum and minimum in cm
11
```

```
12  //CALCULATIONS
13  wc=2*a;//Cutoff wavelength for a TE10 mode in cms
14  wg=4*x;//Guide Wavelength in cm
15  w0=(wg/sqrt(1+(wg/wc)^2));////Free space wavelength
        in cm
16  f=(c/w0)/10^9;//Frequency of the wave in GHz
17
18  //OUTPUT
19  mprintf('\nFrequency of the wave is f=%1.3f GHz',f);
20
21  //================================END OF PROGRAM
        ================================
```

**Scilab code Exa 4.14** guide wavelength

```
 1  //chapter-4 page 151 example 4.14
 2  //
        ===============================================================
 3  clc;
 4  clear;
 5
 6  //For a rectangular waveguide
 7  b=2.5;//Length of Rectangular Waveguide in cm
 8  a=5;//breadth of Rectangular Waveguide in cm
 9  c=3*10^10;//Velocity of Light in cm/sec
10  w0=4.5;//Free space wavelength in cm
11
12  //CALCULATION
13  disp('For a TE10 mode which is the dominant mode');
14  wc=2*a;//Cutoff wavelength in cm
15  wg=(w0/sqrt(1-(w0/wc)^2));//Guide wavelength in cm
16  Vp=(c/sqrt(1-(w0/wc)^2))/10^10;//Phase Velocity in
        10^10 cm/sec
17  B=((2*(%pi)*sqrt(wc^2-w0^2))/(w0*wc));//Phase
```

```
        constant  in  radians
18
19  //OUTPUT
20  mprintf('\nGuide  wavelength  is  wg=%1.5f  cm  \nPhase
        constant  is  B=%1.3f  radians  \nPhase  Velocity  is
        Vp=%1.2f  *10^10  cm/sec ',wg,B,Vp);
21
22  //════════════════════════════END  OF  PROGRAM
        ════════════════════════════════════
23
24  //Note:  Check  the  answers  once
25  //Correct  answers  are
26  //Guide  wavelength  is  wg=5.03903  cm
27  //Phase  constant  is  B=1.247  radians
28  //Phase  Velocity  is  Vp=3.36  *10^10  cm/sec
```

**Scilab code Exa 4.15** possible modes

```
1  //chapter−4  page  152  example  4.15
2  //
        ══════════════════════════════════════════════════════════
3  clc;
4  clear;
5
6  wcTE10=16;//Critical  wavelength  of  TE10  mode  in  cm
7  wcTM11=7.16;//Critical  wavelength  of  TM11  mode  in  cm
8  wcTM21=5.6;//Critical  wavelength  of  TM21  mode  in  cm
9  disp('For  any  wave  to  be  propagated ,  the  condition
        to  be  met  is  wc>wo');
10  wo1=10;//Free  space  wavelength  in  cm
11  wo2=5;//Free  space  wavelength  in  cm
12  disp('Critical  wavelength  of  TE10  mode  in  cm  is ');
13  disp(wcTE10);
14  disp('Critical  wavelength  of  TM11  mode  in  cm  is ');
```

```
15  disp(wcTM11);
16  disp('Critical wavelength of TM21 mode in cm is');
17  disp(wcTM21);
18  disp('For wo1=10cm,The mode that propagates only
        TE10.Because wcTE10>wo1 and all other modes that
        is TM11 TM21 donot propagate');
19  disp('For wo2=5cm');
20  disp('wcTE10>wo2, so TE10 mode propagates');
21  disp('wcTM11>wo2, so TE11 mode propagates');
22  disp('wcTE21>wo2, so TE21 mode propagates');
```

**Scilab code Exa 4.16** Characteristic Impedance

```
1  //chapter-4 page 152 example 4.16
2  //

3  clc;
4  clear;
5
6  n=120*(%pi);//Intrinsic Impedance
7  a=3;//Length of Rectangular Waveguide in cm
8  b=2;//Width of Rectangular Waveguide in cm
9  f=10^10;//Frequency in Hz
10 c=3*10^10;//Velocity of Light in cm/sec
11
12 //CALCULATION
13 wc=((2*a*b)/sqrt(a^2+b^2));//Cutoff wavelength in
       TM11 mode in cms
14 w0=(c/f);//Free space wavelength in cms
15 ZTM=(n*sqrt(1-(w0/wc)^2));//Characteristic Wave
       Impedance in ohms
16
17 //OUTPUT
18 mprintf('\nCharacteristic Wave Impedance is ZTM=%2.3
```

```
      f  ohms ' ,ZTM) ;
19
20
21  //════════════════════════END  OF  PROGRAM
      ═══════════════════════════════════
22
23  //Note :  Check  the  given  answer  once  it  is  wrong
24   // currect  answer  is  163.242  ohms
```

**Scilab code Exa 4.17** guide wavelength

```
1  //chapter −4  page  152  example  4.17
2  //
      ═════════════════════════════════════════════════════════════════

3  clc ;
4  clear ;
5
6  c =3∗10^10;// Velocity  of  Light  in  cm/ sec
7  f =6∗10^9;// Frequency  in  Hz
8
9  //CALCULATION
10  fc =(0.8∗ f ) ;// Given  Cutoff  frequency  for  TE11  mode  in
      Hz
11  wc =( c / fc ) ;// Cutoff  wavelength  in  cms
12  D=((1.841∗ wc ) /(% pi ) ) ;// Diameter  of  waveguide  in  cm
13  w0 =( c / f ) ;// Free  space  wavelength  in  cm
14  wg =( w0/ sqrt (1 −( w0/ wc )^2) ) ;// Guide  wavelength  in  cm
15
16  //OUTPUT
17  mprintf ( ' \ nDiameter  of  the  waveguide  is  D=%1.4 f  cm  \
      nGuide  wavelength  is  wg=%1.3 f  cm ' ,D, wg ) ;
18
19  //════════════════════════END  OF  PROGRAM
      ═══════════════════════════════════
```

**Scilab code Exa 4.18** proof

```
1  //chapter-4 page 153 example 4.18
2  //
   _____

3  clc;
4  clear;
5
6  //For a TE10 mode
7  a=1.5;//Length of an air filled square Waveguide in
       m
8  b=1;//breadth of an air filled square Waveguide in
       cm
9  c=3*10^10;//Velocity of Light in cm/sec
10 f=6*10^9;//Impressed Frequency in Hz
11 er=4;//dielectric constant
12
13 //CALCULATION
14 wc=2*a;//Cutoff wavelength in cm
15 fc=(c/wc)/10^9;//Cutoff frequency in GHz
16 disp('Cutoff frequency in GHz is');
17 disp(fc);
18 disp('The impressed frequency of 6 GHz is less than
       the Cutoff frequency and hence the signal will
       not pass through the guide');
19 w=(c/f);//Wavelength in cm
20 disp('Alternatively, the wavelength of the impressed
        signal in cm is');
21 disp(w);
22 wair=w;
23 disp('which is longer than the cutoff wavelength (3
       cm) and hence no propagation of the wave');
24 w1=wair/sqrt(er);//Wavelength in cm
```

```
25  disp('If the waveguide is loaded with dielectric of
        er=4, then the wavelength in cm is');
26  disp(w1);
27  disp('which is lessthan wair');
28  disp('Now the signal with 6 GHz frequency will pass
        through the dielectric loaded waveguide');
29
30  //=============================END OF PROGRAM
        =================================
```

**Scilab code Exa 4.19** amount of attenuation

```
1  //chapter −4 page 153 example 4.19
2  //
      ================================================================

3  clc;
4  clear;
5
6  a=0.015;//Length of hollow Rectangular Waveguide in
        m
7  b=1;//breadth of hollow Rectangular Waveguide in cm
8  f=6*10^9;//Frequency in Hz in TE10 mode
9  c=3*10^8;//Velocity of Light in m/sec
10 m=1;//Value of m in TE10 mode
11 n=0;//Value of n in TE10 mode
12 u=4*(%pi)*10^(-7);//Permeability in free space in
        Henry
13 e=8.854*10^(-12);//Permittivity in free space in F/m
14
15 //CALCULATION
16 wc=2*a;//Cutoff wavelength for TE10 mode in m
17 fc=c/wc;//Cutoff frequency in Hz
18 w=2*(%pi)*f;//Angular frequency in rad/sec
19
```

```
20  //So 6GHz signal will not pass through waveguide but
        will get attenuated
21  A=(sqrt((m*(%pi)/a)^2+(n*(%pi)/b)^2-(w^2*u*e)));//
        Attenuation in NP/m
22  AdB=A*(20/log(10));//Attenuation in dB/m
23
24  //OUTPUT
25  mprintf('\Amount of Attenuation is A=%3.1f NP/m \
        nAttenuation is AdB=%4.2f dB/m',A,AdB);
26
27  //==============================END OF PROGRAM
        ==============================
```

Scilab code Exa 4.20 max power handling capacity

```
1  //chapter-4 page 154 example 4.20
2  //
    =============================================================
3  clc;
4  clear;
5
6  a=3;//Length of Rectangular Waveguide in cm
7  b=1;//Width of Rectangular Waveguide in cm
8  f=9*10^9;//Frequency in Hz in TE10 mode
9  c=3*10^10;//Velocity of Light in cm/sec
10 Emax=3000;//Max potential gradient in V/cm
11
12 //CALCULATION
13 w0=(c/f);//Free space wavelength in cms
14 disp('Free space Wavelength in cm is');
15 disp(w0);
16 wc=2*a;//Cutoff wavelength in TE10 mode in cms
17 wg=(w0/sqrt(1-(w0/wc)^2));//Guide wavelength in cms
18 disp('Guide Wavelength in cm is');
```

```
19  disp(wg);
20  P=((6.63*10^(-4))*(Emax^2)*a*b*(w0/wg))/1000;//Power
        handling  capability  of  the  waveguide  in  kW
21
22  //OUTPUT
23  mprintf('\nPower  handling  capability  of  the
        waveguide  is  P=%2.3f kW',P);
24
25
26  //═══════════════════════════════END  OF  PROGRAM
        ═══════════════════════════════
```

Scilab code Exa 4.21 maximum power

```
1   //chapter−4  page  154  example  4.21
2   //
        ════════════════════════════════════════════════════════

3   clc;
4   clear;
5
6   d=5;//Internal  Diameter  of  circular  waveguide  in  cm
7   f=9*10^9;//Frequency  in  Hz  in  TE11  mode
8   c=3*10^10;//Velocity  of  Light  in  cm/sec
9   Emax=300;//Max  field  strength  in  V/cm
10
11  //CALCULATION
12  w0=(c/f);//Free  space  wavelength  in  cms
13  wc=((d*(%pi))/1.841);//Cutoff  wavelength  in  TE11
        mode  in  cms
14  wg=(w0/sqrt(1-(w0/wc)^2));//Guide  wavelength  in  cms
15  Pmax=(0.498*(Emax^2)*(d^2)*(w0/wg))/1000;//Maximum
        power  in  kWatts
16
17  //OUTPUT
```

```
18  mprintf('\nMaximum power is Pmax=%4.2f kWatts',Pmax)
       ;
19
20
21  //================================END OF PROGRAM
        =================================
```

_____

**Scilab code Exa 4.22** peak value of electric field

```
 1  //chapter −4 page 155 example 4.22
 2  //
        ==============================================================
 3  clc;
 4  clear;
 5
 6  //For an air filled square waveguide
 7  a=0.01;//Length of an air filled square Waveguide in
         m
 8  b=0.01;//breadth of an air filled square Waveguide
       in m
 9  c=3*10^8;//Velocity of Light in m/sec
10  f=30*10^9;//Frequency in Hz in TE11 mode
11  Pmax=746;//Max power =1 horsepower  in W
12  n=120*(%pi);//Impedance of freespace in ohms
13
14  //CALCULATION
15  w0=(c/f);//Free space wavelength in m
16  wc=2*a;//Cutoff wavelength in m
17  ZTE=(n/sqrt(1-(w0/wc)^2));//Impedance in ohms
18  Emax=(sqrt((Pmax*4*ZTE)/(a*b)))/1000;//The Peak
        value of Electric field occuring in the guide in
        kV/m
19  //From P=(1/2)*Integration(Re(E*H))da
20  //and Pmax=(1/(4*ZTE))*Emax^2*a*b
```

```
21
22  //OUTPUT
23  mprintf('\nThe Peak value of Electric field occuring
        in the guide is Emax=%3.2f kV/m',Emax);
24
25  //========================END OF PROGRAM
        =============================
```

**Scilab code Exa 4.23** breakdown power

```
 1  //chapter-4 page 156 example 4.23
 2  //
        =================================================
 3  clc;
 4  clear;
 5
 6  //For an air filled rectangular waveguide
 7  a=0.023;//Length of an air filled  Rectangular
        Waveguide in m
 8  b=0.01;//breadth of an air filled Rectangular
        Waveguide in m
 9  c=3*10^8;//Velocity of Light in m/sec
10  f=9.375*10^9;//Frequency in Hz in TE11 mode
11  w0=0.01;//Free space wavelength in m
12  wc=0.02;//Cutoff wavelength in m
13  Pmax=746;//Max power =1 horsepower   in W
14
15  //CALCULATION
16  wo=(c/f);//Free space wavelength in cm
17  Pbd=(597*a*b*sqrt(1-(wo/(2*a))^2));//The breakdown
        power for the dominant mode ie TE11 in W
18  wg=(w0/sqrt(1-(w0/wc)^2));//Guide wavelength in m
19  Emax=(sqrt((Pmax*wg)/(6.63*10^(-4)*w0)))/1000;//Max
        electric field in kV/m
```

```
20
21  //OUTPUT
22  mprintf('\nThe breakdown power for the dominant mode
        ie TE11 is Pbd=%1.5f W \nMax electric field is
        Emax=%1.4f kV/m',Pbd,Emax);

23
24  //===========================END OF PROGRAM
        ===================================

25
26
27  //Note: Check the answers once
28  //Correct answers are
29  //The breakdown power for the dominant mode ie TE11
        is Pbd=0.09864 W
30  //Max electric field is Emax=1.1398 kV/m
```

**Scilab code Exa 4.24** breakdown power

```
1  //chapter-4 page 156 example 4.24
2  //
        =======================================================

3  clc;
4  clear;
5
6  a=2.5;//Radius of circular waveguide in cm
7  d=5;//Internal Diameter of circular waveguide in cm
8  f=9*10^9;//Frequency in Hz in TE11 mode
9  c=3*10^10;//Velocity of Light in cm/sec
10
11  //CALCULATION
12  w0=(c/f);//Free space wavelength in cms
13  wc=((d*(%pi))/1.841);//Cutoff wavelength in TE11
        mode in cms
14  fc=(c/wc);//Cutoff frequency in Hz
```

```scilab
15  Pbd=(1790*(a^2)*sqrt(1-(fc/f)^2))/1000; //Breakdown
        Power in TE11 mode in kW
16
17  //OUTPUT
18  mprintf('\nBreakdown Power in TE11 mode is Pbd=%5.3f
        kW',Pbd);
19
20  //===========================END OF PROGRAM
        ==================================
```

# Chapter 5

# Cavity Resonators

**Scilab code Exa 5.1** minimum distance

```
1  //chapter-5 page 174 example 5.1
2  //
   ================================================================
3  clc;
4  clear;
5
6  //For a circular waveguide
7  a=3;//radius in cm
8  f0=10*10^9;//resonant frequency of a circular
      resonator in Hz
9  disp('Given the mode of operator is TM011 so here n
      =0,m=1,p=1');
10 c=3*10^10;//Velocity of light in cm/sec
11 m=1;
12 n=0;
13 p=1;
14 Pnm=2.405;//dominant mode value[TM01]
15
16 //CALCULATION
17 d=((p*(%pi))/(sqrt((2*(%pi)*f0/c)^2-(Pnm/a)^2)));//
```

```
      The minimum distance between the two end plates
      in cms
18
19 //OUTPUT
20 mprintf('\nThe minimum distance between the two end
      plates of a circular waveguide is d=%1.2f cms',d)
      ;
21
22 //================================END OF PROGRAM
      ==============================
```

---

**Scilab code Exa 5.2** lowest resonant frequency

```
1 //chapter−5 page 174 example 5.2
2 //
      ================================================================

3 clc;
4 clear;
5
6 //For a rectangular cavity resonator
7 a=2;//breadth in cm
8 b=1;//height in cm
9 l=3;//length of rectangular waveguide in cm
10 disp('Lowest resonant frequency is obtained for the
      dominant mode TE10[f=c/w where w increases as f
      decreases. In dominant mode wc is maximum]');
11 disp('So the dominant mode is TE101 so here m=1,n=0,
      p=1');
12 c=3*10^10;//Velocity of light in cm/sec
13 m=1;
14 n=0;
15 p=1;
16
17 //CALCULATION
```

```
18  f0=((c/2)*sqrt((m/a)^2+(n/b)^2+(p/l)^2))/10^9;//The
        resonant  frequency  of  a  rectangular  cavity
        resonator  in  GHz
19
20  //OUTPUT
21  mprintf('\nThe  resonant  frequency  of  a  rectangular
        cavity  resonator  is  f0=%1.0f  GHz',f0);
22
23  //=============================END  OF  PROGRAM
        ==============================
```

---

**Scilab code Exa 5.3** resonant frequency

```
1  //chapter−5  page  175  example  5.3
2  //
       ================================================
3  clc;
4  clear;
5
6  //For  a  circular  resonator
7  D=12.5;//diameter  in  cm
8  l=5;//length  of  circular  waveguide  in  cm
9  disp('Given  the  mode  of  operator  is  TM012  so  here  n
        =0,m=1,p=2');
10  c=3*10^10;//Velocity  of  light  in  cm/sec
11  m=1;
12  n=0;
13  p=2;
14  Pnm=2.405;//dominant  mode  value [TM01]
15
16  //CALCULATION
17  a=D/2;//radius  in  cm
18  f0=((c/(2*(%pi)))*sqrt((Pnm/a)^2+((p*(%pi))/l)^2))
        /10^9;//The  resonant  frequency  of  a  circular
```

```
        resonator in GHz
19
20 //OUTPUT
21 mprintf('\nThe resonant frequency of a circular
       resonator is f0=%1.2f GHz',f0);
22
23 //=========================END OF PROGRAM
       ==============================
```

---

**Scilab code Exa 5.4** resonant frequency

```
 1 //chapter−5 page 175 example 5.4
 2 //
       ================================================================
 3 clc ;
 4 clear ;
 5
 6 //For a circular resonator
 7 a=3;//radius in cm
 8 b=2;//dimension in cm
 9 l=4;//length of circular waveguide in cm
10 disp('Given the mode of operator is TE101 so here m
       =1,n=0,p=1');
11 c=3*10^10;//Velocity of light in cm/sec
12 m=1;
13 n=0;
14 p=1;
15
16 //CALCULATION
17 f0=((c/2)*sqrt((m/a)^2+(n/b)^2+(p/l)^2))/10^9;//The
       resonant frequency of a circular resonator in GHz
18
19 //OUTPUT
20 mprintf('\nThe resonant frequency of a circular
```

```
        resonator is f0=%1.2f GHz',f0);
21
22 //================================END OF PROGRAM
    ==================================
```

_____

# Chapter 6

# Microwave Components

**Scilab code Exa 6.2** distance to be shifted

```
1  //Chapter −6, Example  6.2 , Page  234
2  //
      _____
3  //Input parameters
4  //[ s ]=[0 ,(0.3+(%i)*(0.4));(0.3+(%i)*(0.4)) ,0];//
      scattering  matrix  of  a  two  port
5  //Calculations
6  //to  find  l  such  that  S12  and  S21  will  be  real  when
      port1  is  shifted  lm  to  the  left
7  //let  port  1  be  shifted  by  phi1  degree  to  the  left
      and  port2  position  be  remained  unchanged  i.e.,
      phi2=delta
8  //Then  [ phi]=[e^−(j*phi1) ,0;0 ,1]
9  //[S']=[ phi]*[ s ]*[ phi]
10  //for  S12  and  S21  to  be  real
11  phi1=53.13;//in  degrees
12  phi1=phi1*(%pi/180);//phi  in  radians
13  b=34.3;//measured  in  rad/m
14  l=(phi1)/b;//distance  of  shift  in  m
15  //Output
```

```
16  mprintf (" distance that the position of part1 should
       be shifted to the left so that S21 and S12 will
       be real numbers is %1.4 f m",l)
17  //===================================END OF PROGRAM
       ==============================
```

**Scilab code Exa 6.3** Scattering parameters

```
1   //Chapter −6, Example  6.3 , Page  236
2   //
       ================================================

3   clc ;
4   //Input  parameters
5   D=30;// directivity  in  dB
6   VSWR =1; //VSWR at  each  port  under  matched  conditions
7   C=10;// coupling  factor
8   // Calculations
9   S41= sqrt (0.1) ;
10  S14=S41 ;// under  matched  and  lossless  conditions
11  S31= sqrt ((( S41 )^2) /(10) ^(D/10) ) ;
12  S13=S31 ;
13  S11 =( VSWR -1) /( VSWR +1) ;
14  S22=S11 ;
15  S33=S22 ;
16  S44=S33 ;
17  // let  input  power  is  given  at  port1
18  //p1=p2+P3+p4
19  S21= sqrt (1 -( S41 )^2 -( S31 )^2) ;
20  S12=S21 ;
21  S34= sqrt ((0.5) *(1+( S12 )^2 -0.1 -0.0001) ) ;
22  S43=S34
23  S23= sqrt (1 -10^ -4 -( S34 )^2)
24  S32=S23 ;
25  S24= sqrt (1 -0.1 -( S34 )^2)
```

```
26  S42=S24;
27  [S]=[S11,S12,S13,S14;S21,S22,S23,S24;S31,S32,S33,S34
        ;S41,S42,S43,S44];
28  //Output
29  mprintf("The scattering matrix is");
30  disp([S])
31  //==================================END OF PROGRAM
        =============================
```

**Scilab code Exa 6.4** powers in the remaining ports

```
1  //Chapter-6, Example 6.4, Page 238
2  //
        ==========================================================
3  clc;
4  //Input parameters
5  a1=32*10^-3;//power in watts
6  a2=0;
7  a3=0;
8  //Calculations
9  [S]=[0.5,-0.5,0.707;-0.5,0.5,0.707;0.707,0.707,0];//
        S-matrix for H-plane tee
10  //[B]=[b1,b2,b3]
11  [B]=[S].*[a1,0,0;0,0,0;0,0,0];
12  b1=(0.5)^2*a1;//power at port 1
13  b2=(-0.5)^2*a1;//power at port 2
14  b3=(0.707)^2*a1;//power at port 3
15  //Output
16  mprintf("Thus b1,b2,b3 are %g W,%g W,%g W
        respectively",b1,b2,b3);
17  //==================================END OF PROGRAM
        =============================
```

**Scilab code Exa 6.5** power

```
1  //Chapter -6, Example 6.5, Page 239
2  //
    _____

3  clc;
4  //Input parameters
5  [S]=[0.5,-0.5,0.707;-0.5,0.5,0.707;0.707,0.707,0];
6  R1=60;//load at port1 in ohms
7  R2=75;//load at port2 in ohms
8  R3=50;//characteristic impedance in ohms
9  P3=20*10^-3;//power at port 3 in Watts
10 //calculations
11 p1=(R1-R3)/(R1+R3);
12 p2=(R2-R3)/(R2+R3);
13 P1=0.5*P3*(1-(p1)^2);//power delivered to the port1
       in Watts
14 P2=0.5*P3*(1-(p2)^2);//power delivered to the port2
       in Watts
15 //Output
16 mprintf("Thus power delivered to the port1 and port2
        are %g W,%g W respectively",P1,P2);
17 //======================================END OF PROGRAM
    ================================
```

**Scilab code Exa 6.6** Reflected power

```
1  //Chapter -6, Example 6.6, Page 239
2  //
    _____
```

```
3  clc;
4  //Input parameters
5  p1=0.5;//reflection coefficient at port 1
6  p2=0.6;//reflection coefficient at port 2
7  p3=1;//reflection coefficient at port 3
8  p4=0.8;//reflection coefficient at port 4
9  //[S
       ]=[0,0,0.707,0.707;0,0,0.5,-0.707;0.707,0.707,0,0;-0.707,0.707,0,
       S matrix of magic Tee
10 //solving for b1,b2,b3,b4 we get it as
11 //calculations
12 b1=0.6566;
13 b2=0.7576;
14 b3=0.6536;
15 b4=0.0893;
16 P1=(b1)^2;//power at port1 in watts
17 disp(P1);
18 P2=(b2)^2;//power at port2 in watts
19 disp(P2);
20 P3=(b3)^2;//power at port3 in watts
21 disp(P3);
22 P4=(b4)^2;//power at port4 in watts
23 disp(P4);
24 //==========================================END OF PROGRAM
       ==================================
```

**Scilab code Exa 6.7** Scattering matrix

```
1  //Chapter-6, Example 6.7, Page 240
2  //
       ================================================
3  clc;
4  //Input parameters
5  ins=0.5;//insertion loss in db
```

```
6  iso=30;//isolation loss in db
7  //Calculations
8  S21=10^-(ins/20);//insertion loss=0.5=-20*log[S21]
9  S12=10^-(iso/20);//isolation loss=30=-20*log[s12]
10 S11=0;
11 S22=0;
12 [S]=[S11,S12;S21,S22];
13 disp(S);
14 //================================END OF PROGRAM
   ==========================
```

**Scilab code Exa 6.9** Scattering matrix

```
1  //Chapter-6, Example 6.9, Page 241
2  //
   ======================================================

3  clc;
4  //Input parameters
5  ins=0.5;//insertion loss in db
6  iso=20;//isolation loss in db
7  S=2;//VSWR
8  //Calculations
9  S21=10^-(ins/20);//insertion loss=0.5=-20*log[S21]
10 S13=S21;
11 S32=S13;
12 S12=10^-(iso/20);//isolation loss=30=-20*log[s12]
13 S23=S12;
14 S31=S23;
15 p=(S-1)/(S+1);
16 S11=p;
17 S22=p;
18 S33=p;
19 [S]=[S11,S12,S13;S21,S22,S23;S31,S32,S33];
20 disp(S);
```

```
21 // for  a  perfectly  matched , non−reciprocal , lossless  3−
       port  circulator , [ S ]  is  given  by
22 // [ S]=[ 0 , 0 , S13 ; S21 , 0 , 0 ; , 0 , S32 , 0 ]
23 // i . e . , S13=S21=S32=1
24 // [ S]=[ 0 , 0 , 1 ; 1 , 0 , 0 ; 0 , 1 , 0 ]
25 //================================END  OF  PROGRAM
       =============================
```

---

**Scilab code Exa 6.10** output powers

```
1 // Chapter −6 ,  Example  6.10 ,  Page  242
2 //
       ======================================================

3
4 clc  ;
5 clear ;
6 close ;
7 In_loss =0.5;  // i n s e r t i o n  l o s s  ( i n dB)
8 C =20;  // coupling  coefficient  i n  dB
9 D =35;  // directivity  i n  dB
10 Pi_Pf =10^( C /10)  ;
11 Pi =90;  // i n  Watts
12 Pf=Pi/ Pi_Pf  ;
13 Pf_Pb =10^( D /10)  ;
14 Pb=Pf/ Pf_Pb  ;
15 P_rec =(Pi -Pf -Pb);  // Power  r e c e i v e d  ( i n
     Watts  )
16 P_rec_dB =10* log (Pi/ P_rec )/ log (10)  ;
17 P_rec_eff = P_rec_dB - In_loss  ;  // E f f e c t i v
     e  power  r e c e i v e d  ( i n dB)
18 disp ( Pf  , 'Output  power  through  coupled  port  ( i n
       Watts )=' ) ;
19 disp ( Pb  , 'Output  power  through  isolated  port  ( i
     n  Watts )=' ) ;
```

```
20  disp ( P_rec_dB , ' Power  r e c e i v e d  ( i n  dB)=
        ' ) ;
21  disp ( P_rec_eff , ' E f f e c t i v e  power  r e c e
        i v e d  ( i n  dB)=' ) ;
22
23
24  //                                                    END  OF PROGRAM
```

**Scilab code Exa 6.11** coupling isolation directivity

```
1  // Chapter −6,  Example  6.11 ,  Page  242
2  //

3  clc ;
4  // Calculations
5  S13 =0.1*( cos (90*%pi/180)+(%i)*sin (90*%pi/180)) ; //
        conversion  from  polar  to  rectangular
6  S13 = abs ( S13 ) ;
7  C = -20*log10 ( S13 ) ; // coupling  coefficient  in  dB
8  S14 =0.05*( cos (90*%pi/180)+(%i)*sin (90*%pi/180)) ; //
        conversion  from  polar  to  rectangular
9  S14 = abs ( S14 ) ;
10 D =20* log10 ( S13 / S14 ) ; // directivity  in  dB
11 I = -20*log10 ( S14 ) ; // isolation  in  dB
12 mprintf ( " Thus  coupling , directivity  and  isolation  are
         %1.0 f  dB,%1.2 f  dB  and  %2.2 f  dB  respetively  " ,C ,D
        , I ) ;
13 //                                                    END  OF PROGRAM
```

**Scilab code Exa 6.12** VSWR

```
1  //chapter-6 page 244 example 6.12
2  //
   _____

3  clc;
4  clear;
5
6  x=3.5;//distance between two minimas in cm
7  y=0.25;//distance between twice minimum power points
       in cm
8
9  //CALCULATION
10 wg=2*x;//guided wavelength in cm
11 S=(wg/(y*(%pi)));//Voltage Standing Wave Ratio(VSWR)
12
13 //OUTPUT
14 mprintf('\nVoltage Standing Wave Ratio(VSWR) is S=%1
       .4f',S);
15
16 //==========================END OF PROGRAM
       ==============================
```

**Scilab code Exa 6.13** phase shift

```
1  //chapter-6 page 244 example 6.13
2  //
   _____

3  clc;
4  clear;
5
6  wg=7.2;//guide wavelength in cm
7  x=10.5;//Position of reference null without the
       waveguide component in cm
8  y=9.3;//Position of reference null with the
```

```
        waveguide  component  in  cm
 9
10  //CALCULATION
11  z=x-y;//Path  difference  introduced  due  to  the
        component  in  cm
12  p=(2*(%pi)*(z/wg));//Phase  difference  introduced  in
        rad
13  Pd=(p*180)/(%pi);//Phase  shift  introduced  in  deg
14
15  //OUTPUT
16  mprintf('\nPhase  shift  introduced  is  Pd=%2.0f  deg',
        Pd);
17
18  //================================END  OF  PROGRAM
        ================================
```

# Chapter 7

# Microwave Measurements

**Scilab code Exa 7.1** measured distance

```
1 //chapter-7 page 278 example 7.1
2 //
   _____

3 clc;
4 clear;
5
6 a=4;//Length of Waveguide in cm
7 b=2.5;//breadth Waveguide in cm
8 f=10^10;//Frequency in Hz
9 x=0.1;//distance between twice minimum power points
     in cm
10 c=3*10^10;//Velocity of Light in cm/sec
11
12 //CALCULATION
13 wc=2*a;//Cutoff wavelength in TE10 mode in cms
14 w0=(c/f);//Free space wavelength in cms
15 wg=(w0/sqrt(1-(w0/wc)^2));//Guide wavelength in cms
16 S=(wg/(x*(%pi)));//Voltage Standing Wave Ratio(VSWR)
       for double minimum method
17
```

```
18  //OUTPUT
19  mprintf('\nFor double minimum method, Voltage
        Standing Wave Ratio(VSWR) is S=%2.1f',S);
20
21  //============================END OF PROGRAM
        ==============================
```

Scilab code Exa 7.2 VSWR and Reflected power

```
1  //chapter-7 page 279 example 7.2
2  //
    ===================================================================
3  clc;
4  clear;
5
6  x=3;//O/P incident power from first directional
        coupler in mW
7  y=0.1;//O/P reflected power from second directional
        coupler in mW
8
9  //CALCULATION
10 Pi=x*100;//Incident Power in mW
11 Pr=y*100;//Reflected Power in mW
12 p=sqrt(Pr/Pi);//Reflection Coefficient
13 S=((1+p)/(1-p));//Voltage Standing Wave Ratio(VSWR)
14
15 //OUTPUT
16 mprintf('\nVoltage Standing Wave Ratio(VSWR)in the
        main waveguide is S=%1.2f \nReflected Power is Pr
        =%2.0f mW',S,Pr);
17
18 //============================END OF PROGRAM
        ==============================
```

**Scilab code Exa 7.3** VSWR

```
1 //chapter−7 page 279 example 7.3
2 //
       ============================================================
3 clc;
4 clear;
5
6 Pi=2.5;//Incident Power from one directional coupler
        in mW
7 Pr=0.15;//Reflected Power from other directional
      coupler in mW
8
9 //CALCULATION
10 p=sqrt(Pr/Pi);//Reflection Coefficient
11 S=((1+p)/(1-p));//Voltage Standing Wave Ratio(VSWR)
12
13 //OUTPUT
14 mprintf('\nVoltage Standing Wave Ratio(VSWR)in the
      waveguide is S=%1.2f',S);
15
16 //=========================END OF PROGRAM
       =============================
```

**Scilab code Exa 7.4** Reflected power

```
1 //chapter−7 page 279 example 7.4
2 //
       ============================================================
3 clc;
```

```
4 clear;
5
6 S=2;//Voltage Standing Wave Ratio(VSWR)
7 C=30;//Coupling Power of a Directional Coupler in dB
8 Pf=4.5;//Coupler Incident Sampling Power in mW
9
10 //CALCULATION
11 p=((S-1)/(S+1));//Reflection Coefficient
12 Pi=Pf*10^(C/10);//Incident Power in mW [From C=10log
      (Pi/Pf)]
13 Pr=(Pi*(p^2))/10^3;//Reflected Power in W [From p=
      sqrt(Pr/Pi)]
14
15 //OUTPUT
16 mprintf('\nValue of Reflected Power is Pr=%1.2f W',
      Pr);
17
18 //==========================END OF PROGRAM
      ================================
```

# Chapter 8

# Microwave Tubes and Circuits

**Scilab code Exa 8.1** electron velocity and etc

```
1  //chapter-8 page 336 example 8.1
2  //_____

3  clc;
4  clear;
5
6  //For a four cavity Klystron
7  V0=14500;//Beam voltage in V
8  I=1.4;//Beam current in A
9  f=10^10;//Operation frequency in Hz
10 p0=10^(-6);//dc electron charge density in C/m^3
11 p=10^(-8);//RF charge density in C/m^3
12 V=10^5;//Velocity perturbations in m/sec
13 e0=8.854*10^(-12);//Permittivity of free space in F/
      m
14 R=0.4;
15
16 //CALCULATION
17 v0=(0.593*10^6*sqrt(V0))/10^8;//The dc electron
      velocity in 10^8 m/sec
```

```
18  w=2*(%pi)*f;//angular frequency in rad/sec
19  v=v0*10^8;
20  c=(w/v);//The dc Phase Constant
21  wp=(sqrt(1.759*10^11*(p0/e0)))/10^8;//The Plasma
       Frequency in 10^8 rad/sec
22  wp1=wp*10^8;
23  wq=(R*wp1)/10^8;//The Reduced Plasma Frequency in
       10^8 rad/sec
24  J0=p0*v;//The dc beam current density in A/sqm
25  J=(p*v)+(p0*V);//The instantaneous beam current
       density in A/sqm
26
27  //OUTPUT
28  mprintf('\nThe dc electron velocity is v0=%2.3f
       *10^8 m/sec \nThe dc Phase Constant is c=%1.2f
       rad/sec\nThe Plasma Frequency is wp=%1.2f *10^8
       rad/sec \nThe Reduced Plasma Frequency is wq=%1.3
       f *10^8 rad/sec \nThe dc beam current density is
       J0=%2.1f A/sqm \nThe instantaneous beam current
       density is J=%1.3f A/sqm',v0,c,wp,wq,J0,J);
29
30  //===========================END OF PROGRAM
       ===============================
```

Scilab code Exa 8.2 power and etc

```
1  //chapter-8 page 337 example 8.2
2  //
       =============================================================

3  clc;
4  clear;
5
6  //For a 2 cavity klystron amplifier
7  Av=15;//Voltage gain in dB
```

```
8  Pin =0.005; //I/P power in W
9  Rin =30000; //Rsh of i/p cavity in ohms
10 R0=40000; //Rsh of o/p cavity in ohms
11 Rl=40000; //load impedance in ohms
12 R=20000; //Parallel resistance of R0 and Rl (R0//Rl)
      in ohms
13
14 //CALCULATION
15 Vin=sqrt(Pin*Rin); //The input rms voltage in V [
      From Pin=Vin^2/Rin]
16 V0=Vin*10^(Av/20); //The output rms voltage in V [
      From Av=20log(V0/Vin)]
17 P0=(V0^2)/R; //The Power delivered to the load in W
18
19 //OUTPUT
20 mprintf('\nThe input rms voltage is Vin=%2.2f V \
      nThe output rms voltage is V0=%2.2f V \nThe Power
       delivered to the load is P0=%1.4f W',Vin,V0,P0);
21
22 //==============================END OF PROGRAM
      ==============================
```

**Scilab code Exa 8.3** efficiency and etc

```
1  //chapter -8 page 338 example 8.3
2  //
      ================================================
3  clc;
4  clear;
5
6  //For a reflex klystron
7  n=2; //peak mode value
8  V0=300; //beam voltage in V
9  I0=0.02; //beam current in A
```

```
10  Vs =40; // signal  voltage  in  V
11  J1 =1.25; // bessel  coefficient  for  n=2
12
13  //CALCULATION
14  Pdc=V0*I0; //The  input  power  in  watts
15  Pac=((2*Pdc*J1)/((2*n*(%pi))-((%pi)/2))); //The
        output  power  in  watts
16  n=(Pac/Pdc)*100; // Efficiency  in  percentage
17
18  //OUTPUT
19  mprintf('\nThe  input  power  is  Pdc=%1.0f  watts  \nThe
        output  power  is  Pac=%1.2f  watts  \nEfficiency  is  n
        =%2.1f  percentage ',Pdc ,Pac ,n);
20
21  //=========================END  OF  PROGRAM
        ==============================
```

---

**Scilab code Exa 8.4** electron velocity and etc

```
1  //chapter -8  page  338  example  8.4
2  //
        ================================================
3  clc;
4  clear;
5
6  //For  a  2  cavity  klystron  amplifier
7  V0 =900; //Beam  voltage  in  V
8  I0 =0.03; //Beam  current  in  A
9  f=8*10^9; // frequency  in  Hz
10  d=0.001; // gap  spacing  in  either  cavity  in  m
11  L=0.04; // spacing  between  centers  of  cavities  in  m
12  Rsh =49000; // Effective  shunt  impedance  in  ohms
13  J1 =0.582; // value  of  J1(X)
14  X=1.841; // bunching  parameter
```

```
15
16  //CALCULATION
17  v0=(0.593*10^6*sqrt(V0))/10^6;//velocity of electron
        in 10^6 m/sec
18  w=2*(%pi)*f;//angular frequency in rad
19  v=v0*10^6;
20  T0=(L/v)/10^(-8);//dc transit time of electrons in
        10^(-8) sec
21  a=w*T0*10^(-8);//transit angle in rad
22  tg=w*d/v;//average gap transit angle in rad
23  Tg=tg*(180/(%pi));
24  Bi=(sind(Tg/2))/(tg/2);//beam coupling coefficient
25  Bo=Bi;//output cavity coupling coefficient
26  V1max=((3.68*V0)/(Bi*a));//Input voltage for Maximum
        output voltage in V
27  R0=V0/I0;//impedance in ohms
28  Av=(Bo^2*a*Rsh*J1)/(R0*X);//Voltage gain
29  AvdB=20*log10(Av);//Voltage gain in dB
30
31  //OUTPUT
32  mprintf('\nVelocity of electron is v0=%2.2f *10^6 m/
        sec \nThe dc transit time of electrons is T0=%1.3
        f *10^(-8) sec \nInput voltage for Maximum output
         voltage is V1max=%2.3f V \nVoltage gain is Av=%2
        .2f \nThe Voltage gain in dB is AvdB=%2.2f dB',v0
        ,T0,V1max,Av,AvdB);
33
34  //===========================END OF PROGRAM
        ==============================
35
36  //Note: Check the calculation given in text book for
        voltage gain Rsh=49 kohms
37  //but, taken as 40 kohms
38  //correct answers areVoltage gain is Av=28.52
39  //The Voltage gain in dB is AvdB=29.10 dB
```

**Scilab code Exa 8.5** efficiency and etc

```
1  //chapter-8 page 339 example 8.5
2  //_____

3  clc;
4  clear;
5
6  //For a 2 cavity klystron amplifier
7  V0=1200;//Beam voltage in V
8  I0=0.028;//Beam current in A
9  f=8*10^9;//frequency in Hz
10 d=0.001;//gap spacing in either cavity in m
11 L=0.04;//spacing between centers of cavities in m
12 Rsh=40000;//Effective shunt impedance in ohms
13 J1=0.582;//value of J1(X)
14 X=1.841;//bunching parameter
15
16 //CALCULATION
17 w=2*(%pi)*f;//angular frequency in rad
18 v0=0.593*10^6*sqrt(V0);//velocity of electron in m/
       sec
19 Vomax=((3.68*V0*v0)/(w*L));//max output power in V
20 tg=(w*d)/v0;//avg gap transit angle in rad
21 Tg=tg*(180/(%pi));
22 Bi=(sind(Tg/2))/(tg/2);//beam coupling coefficient
23 Bo=Bi;//output cavity coupling coefficient
24 Vimax=Vomax/Bi;//The input microwave voltage in
       order to generate maximum output voltage in V
25 t0=w*L/v0;//transit angle in rad
26 R0=V0/I0;//impedance in ohms
27 Av=((Bo^2*J1*t0*Rsh)/(R0*X));//Voltage gain
28 I2=2*I0*J1;
```

```
29  V2=Bo*I2*Rsh;
30  disp('neglecting beam loading');
31  Eff=0.58*(V2/V0)*100;//Efficiency in %
32  G0=1/R0;
33  GB=(G0/2)*(Bo*(Bo-cos(Tg/2)));//Beam loading
        conductance in mhos
34  RB=(1/GB)/1000;//Beam loading resistance in Kohms
35  disp('Beam loading resistance in Kohms is');
36  disp(RB);
37  disp('The value 73 kohms is very much comparable to
        Rsh and cannot be neglected because Tg is quite
        high');
38
39  //OUTPUT
40  mprintf('\nThe input microwave voltage in order to
        generate maximum output voltage is Vimax=%2.2f V
        \nThe voltage gain is Av=%2.2f percentage \nBeam
        loading conductance is GB=%1.10f mhos',Vimax,Av,
        GB);
41
42  //==============================END OF PROGRAM
        ================================
```

**Scilab code Exa 8.6** electronic efficiency and etc

```
1  //chapter-8 page 338 example 8.4
2  //
        ==================================================
3  clc;
4  clear;
5
6  //For a reflex klystron
7  n=2;//peak mode value
8  V0=500;//beam voltage in V
```

```
 9  Rsh =20000;//Shunt resistance in ohms
10  L=0.001;//distance in m
11  f=8*10^(9);////Operation frequency in Hz
12  V1=200;//microwave gap voltage in V
13  x=1.759*10^11;//e/m value in C/kg
14  J1=0.582;
15
16  //CALCULATION
17  disp('Assume the gap transit time and beam loading
        are neglected ');
18  w=2*(%pi)*f;//angular frequency in rad
19  VR=(V0+(( sqrt (8*V0/x)*w*L)/((2*(%pi)*n)-((%pi)/2))))
        ;//Repeller voltage in V
20  disp('Assuming output coupling coefficient Bo=1');
21  I0=(V1/(2*J1*Rsh))/10^(-3);//Beam current necessary
        to obtain an microwave gap voltafe of 200V in mA
22  v0=0.593*10^6* sqrt (V0);//velocity of electron in m/
        sec
23  t0=((w*2*L*v0)/(x*(VR+V0)));//transit angle in rad
24  Bi=1;//beam coupling coefficient [assume]
25  X=((Bi*V1*t0)/(2*V0));
26  disp('Since X=1.51, from graph,J1(X)=0.84');
27  XJ1=0.84;
28  Eff=((2*(XJ1))/((2*n*(%pi))-((%pi)/2)))*100//
        Efficiency in %
29
30  //OUTPUT
31  mprintf('\nRepeller voltage is VR=%3.2f V \nThe dc
        necessary to give an microwave gap voltafe of 200
        V is I0=%1.2f mA \nElectronic Efficiency is Eff=
        %2.2f percentage ',VR,I0,Eff);
32
33  //=============================END OF PROGRAM
        ==============================
34
35  //Note: Check the answer for VR once
36  //Correct answer is Repeller voltage is VR=1189.36 V
```

**Scilab code Exa 8.7** efficiency and etc

```
1  //chapter-8 page 342 example 8.7
2  //
    ============================================================
3  clc;
4  clear;
5
6  //For a reflex klystron
7  n=1;//mode value
8  Pi=0.04;//the dc input power in W
9  x=0.278;//ratio of V1 over V0
10
11 //CALCULATION
12 X=x*3*(%pi)/4;
13 J1=0.3205;//bessel coefficient value [JI(X')]
14 ef=((2*X*J1)/((2*(%pi)*n)-((%pi)/2)))*100;//
       Efficiency of the reflex klystron in %
15 Pout=((ef/100)*Pi)/10^(-3);//Total power output in
        mW
16 p=20;//percentage of the power delivered by the
       electron beam dissipated in the cavity walls
17 Pd=Pout*(100-p)/100;//Power delivered to load in mW
18
19 //OUTPUT
20 mprintf('\nEfficiency of the reflex klystron is ef=
       %1.2f percentage\nTotal power output is Pout=%1.3
       f mW \nIf the 20 percentage of the power
       delivered by the electron beam is dissipated in
       the cavity walls then the Power delivered to load
        is Pd=%1.2f mW',ef,Pout,Pd);
21
22 //===========================END OF PROGRAM
```

**Scilab code Exa 8.8** cyclotron frequency and etc

```
1  //chapter−8 page 342 example 8.8
2  //
                  ==========================================================================

3  clc;
4  clear;
5
6  //For a circular magnetron
7  a=0.15;//inner radius in m
8  b=0.45;//outer radius in m
9  B=1.2*10^(-3);//magnetic flux density in Wb/sqm
10 x=1.759*10^11;//Value of e/m in C/kg
11 V=6000;//beam voltage in V
12
13 //CALCULATION
14 V0=((x/8)*(B^2)*(b^2)*(1-(a/b)^2)^2)/1000;//Hull cut
       −off voltage in kV
15 Bc=((sqrt(8*(V/x)))/(b*(1-(a/b)^2)))*1000;//Cut−off
        magnetic flux density in mWb/sqm
16 fc=((x*B)/(2*(%pi)))/10^9;//Cyclotron frequency in
       GHz
17
18 //OUTPUT
19 mprintf('\nHull cut−off voltage is V0=%2.3f kV\nCut−
       off magnetic flux density is Bc=%1.6f mWb/sqm \
       nCyclotron frequency is fc=%1.4f GHz',V0,Bc,fc);
20
21 //===========================END OF PROGRAM
                  ====================================
22
23
```

```
24  //Check the answers once
25  //Correct answers are
26  //Hull cut−off voltage is V0=5.066 kV
27  //Cut−off magnetic flux density is Bc=1.305953 mWb/
       sqm
28  //Cyclotron frequency is fc=0.0336 GHz
```

**Scilab code Exa 8.9** phase velocity and anode voltage

```
1  //chapter−8 page 343 example 8.9
2  //
       ==================================================================

3  clc;
4  clear;
5
6  //For a helical TWT
7  c=3*10^8;//Velocity of light in m/sec
8  d=0.002;//diameter in m
9  x=5000;//no.of turns per m
10 m=9.1*10^(-31);//mass of an electron in kg
11 e=1.6*10^(-19);//charge of an electron in C
12
13 //CALCULATION
14 y=(%pi)*d;//circumference in m
15 p=1/x;//pitch in m
16 Vp=(c*p)/y;//Axial phase velocity in m/sec
17 V0=((m*Vp^2)/(2*e));//The Anode voltage at which the
       TWT can be operated for useful gain in V
18
19 //OUTPUT
20 mprintf('\nAxial phase velocity is Vp=%6.2f m/sec \
       nThe Anode voltage at which the TWT can be
       operated for useful gain is V0=%2.2f V',Vp,V0);
21
```

_____

**Scilab code Exa 8.10** electron velocity and etc

```scilab
1  //chapter−8 page 344 example 8.10
2  //
      ========================================================
3  clc;
4  clear;
5
6  //For a 2 cavity klystron amplifier
7  V0=900;//Beam voltage in V
8  I0=0.03;//Beam current in A
9  f=8*10^9;//frequency in Hz
10 d=0.001;//gap spacing in either cavity in m
11 L=0.04;//spacing between centers of cavities in m
12 Rsh=40000;//Effective shunt impedance in ohms
13 y=0.582;//value of J1(X)
14 X=1.841;
15
16 //CALCULATION
17 v0=(0.593*sqrt(V0)*10^6)/10^7;//The electron
      velocity in 10^7 m/sec
18 v=v0*10^7;
19 t0=(d/v)/10^(-10);//Transit time in 10^(−10) sec
20 t=t0*10^(-10);
21 a=2*(%pi)*f*t;//Gap transit angle in rad
22 Bi=(sin(a/2))/(a/2);//Beam coupling coefficient
23 Bo=Bi;
24 to=(2*(%pi)*f*L)/v;//dc transit angle in rad
25 disp('For maximum outout voltage,V2  J1(X)=0.582,X
      =1.841');
26 V1=((2*V0*X)/(Bo*to))//The input voltage for maximum
```

```
          output voltage in V
27 Ro=(V0/I0);
28 Av=((Bo^2*to*y*Rsh)/(Ro*X));//Voltage gain
29 AvdB=10*log10(Av);//Voltage gain in dB
30
31 //OUTPUT
32 mprintf('\nThe electron velocity is v0=%1.1f *10^7 m
      /sec \nThe dc electron Transit time is t0=%1.2f
      *10^(-10) sec \nThe input voltage for maximum
      output voltage is V1=%2.2f V \nVoltage gain is Av
      =%2.2f \nVoltage gain in dB is AvdB=%2.2f dB',v0,
      t0,V1,Av,AvdB);
33
34 //==============================END OF PROGRAM
      ==============================
```

**Scilab code Exa 8.11** dc electron velocity and etc

```
1 //chapter-8 page 345 example 8.11
2 //
      ==============================================
3 clc;
4 clear;
5
6 //For a four cavity Klystron
7 V0=20000;//Beam voltage in V
8 I=2;//Beam current in A
9 f=9*10^9;//Operation frequency in Hz
10 p0=10^(-6);//dc electron charge density in C/m^3
11 p=10^(-8);//RF charge density in C/m^3
12 V=10^5;//Velocity perturbations in m/sec
13 e0=8.854*10^(-12);//Permittivity of free space in F/
      m
14 R=0.5;
```

```
15
16  //CALCULATION
17  v0=(0.593*10^6*sqrt(V0))/1000;//The dc electron
       velocity in Km/sec
18  w=2*(%pi)*f;//angular frequency in rad/sec
19  v=v0*1000;
20  c=(w/v);//The dc Phase Constant
21  wp=(sqrt(1.759*10^11*(p0/e0)))/10^8;//The Plasma
       Frequency in 10^8 rad/sec
22  wp1=wp*10^8;
23  wq=(R*wp1)/10^8;//The Reduced Plasma Frequency in
       10^8 rad/sec
24  J0=p0*v;//The dc beam current density in A/sqm
25  J=(p*v)-(p0*V);//The instantaneous beam current
       density in A/sqm
26
27  //OUTPUT
28  mprintf('\nThe dc electron velocity is v0=%4.2f Km/
       sec \nThe dc Phase Constant is c=%3.2f rad/sec\
       nThe Plasma Frequency is wp=%1.2f *10^8 rad/sec \
       nThe Reduced Plasma Frequency is wq=%1.3f *10^8
       rad/sec \nThe dc beam current density is J0=%2.2f
        A/sqm \nThe instantaneous beam current density
       is J=%1.4f A/sqm',v0,c,wp,wq,J0,J);
29
30  //═══════════════════════════END OF PROGRAM
       ═══════════════════════════
```

**Scilab code Exa 8.12** gap transit angle

```
1  //chapter-8 page 345 example 8.12
2  //
       ═══════════════════════════════════════════════

3  clc;
```

```
4 clear;
5
6 //For a reflex klystron
7 f=5*10^9;//Frequency of operation in hz
8 V0=1000;//anode voltage in V
9 d=0.002;//cavity gap in m
10 Vr=-500;//repeller voltage in V
11
12 //CALCULATION
13 N=7/4;//mode value
14 VR=abs(Vr);
15 L=(((VR+V0)*N)/(6.74*10^(-6)*f*sqrt(V0)))/10^(-3);//
      Optimum length of the drift region in mm
16 u=5.93*10^5*sqrt(V0);// in m/sec
17 w=2*(%pi)*f;//angular frequency in rad
18 Tg=(w*d)/u;//Gap transit angle in rad
19
20 //OUTPUT
21 mprintf('\nOptimum length of the drift region is L=
      %1.3f mm \nGap transit angle is Tg=%1.3f rad',L,
      Tg);
22
23 //================================END OF PROGRAM
      ================================
```

**Scilab code Exa 8.13** efficiency and etc

```
1 //chapter-8 page 346 example 8.13
2 //
      ================================================
3 clc;
4 clear;
5
6 //For a 2 cavity klystron amplifier
```

```
7  V0=1200;//Beam  voltage  in  V
8  I0=0.03;//Beam  current  in  A
9  f=10*10^9;//frequency  in  Hz
10 d=0.001;//gap  spacing  in  either  cavity  in  m
11 L=0.04;//spacing  between  centers  of  cavities  in  m
12 Rsh=40000;//Effective  shunt  impedance  in  ohms
13 J1=0.582;//value  of  J1(X)
14 X=1.841;//bunching  parameter
15
16 //CALCULATION
17 v0=0.593*10^6*sqrt(V0);//velocity  of  reference
       electron  in  m/sec
18 w=2*(%pi)*f;//angular  frequency  in  rad
19 a=w*L/v0;//transit  angle  without  RF  voltage  in  rad
20 tg=a*d/L;//average  gap  transit  angle  in  rad
21 Bi=(sin(tg/2))/(tg/2);//beam  coupling  coefficient
22 V1max=((2*X*V0)/(Bi*a));//Input  RF  voltage  for
       Maximum  output  voltage  in  V
23 B0=Bi;//output  cavity  coupling  coefficient
24 V2=2*B0*I0*J1*Rsh;//in  V
25 Av=V2/V1max;//Voltage  gain
26 AvdB=20*log10(Av);//Voltage  gain  in  dB
27 n=0.58*(V2/V0)*100;//Maximum  efficiency  in  %
28
29 //OUTPUT
30 mprintf('\nInput  RF  voltage  for  Maximum  output
       voltage  is  V1max=%2.2f  V  \nThe  Voltage  gain  is
       AvdB=%2.2f  dB  \nMaximum  efficiency  is  I0=%2.2f
       percentage',V1max,AvdB,n);
31
32 //================================END  OF  PROGRAM
       ==============================
33
34 //Note:  Check  the  answers  once
35 //There  are  slight  changes  in  values
36 //Input  RF  voltage  for  Maximum  output  voltage  is
       V1max=55.28  V
37 //The  Voltage  gain  is  AvdB=24.35  dB
```

```
38  //Maximum  efficiency  is  I0=44.11  percentage
```

**Scilab code Exa 8.14** cyclotron angular frequency and etc

```
1  //chapter−8 page 347 example 8.14
2  //
                                    =============================================================
3  clc;
4  clear;
5
6  //For aa X−band cylindrical magnetron
7  a=0.04;//inner radius in m
8  b=0.08;//outer radius in m
9  B=0.01;//magnetic flux density in Wb/sqm
10  x=1.759*10^11;//Value of e/m in C/kg
11  V=30000;//beam voltage in V
12
13  //CALCULATION
14  w=(x*B)/10^9;//Cyclotron angular frequency in 10^9
        rad/sec
15  VHC=((x/8)*(B^2)*(b^2)*(1-(a/b)^2)^2)/1000;//Hull
        cut−off voltage in kV
16  Bc=((sqrt(8*(V/x)))/(b*(1-(a/b)^2)))*1000;//Cut−off
        magnetic flux density in mWb/sqm
17
18  //OUTPUT
19  mprintf('\nCyclotron angular frequency is w=%1.3 f
        *10^9 rad/sec \nHull cut−off voltage is VHC=%1.4 f
         kV \nCut−off magnetic flux density is Bc=%2.3 f
        mWb/sqm ',w,VHC,Bc);
20
21  //==========================END OF PROGRAM
        =============================
```

**Scilab code Exa 8.15** efficiency and etc

```
1  //chapter−8 page 348 example 8.15
2  //
   _____

3  clc;
4  clear;
5
6  //For a reflex klystron
7  n=2;//peak mode value
8  V0=280;//beam voltage in V
9  I0=0.022;//beam current in A
10 Vs=30;//signal voltage in V
11 J1=1.25;//bessel coefficient for n=2
12
13 //CALCULATION
14 Pdc=V0*I0;//The input power in watts
15 Pac=((2*Pdc*J1)/((2*n*(%pi))-((%pi)/2)));//The
       output power in watts
16 n=(Pac/Pdc)*100;//Efficiency in percentage
17
18 //OUTPUT
19 mprintf('\nThe input power is Pdc=%1.2f watts \nThe
       output power is Pac=%1.1f watts \nEfficiency is n
       =%2.2f percentage ',Pdc,Pac,n);
20
21 //==============================END OF PROGRAM
   ================================
```

**Scilab code Exa 8.16** repeller voltage and etc

```
1  //chapter -8  page  348  example  8.16
2  //
      ===============================================================

3  clc;
4  clear;
5
6  //For  a  reflex  klystron
7  n=2;//peak  mode  value
8  V0=300;//beam  voltage  in  V
9  Rsh=20000;//Shunt  resistance  in  ohms
10 L=0.001;//distance  in  m
11 J1=0.582;//bessel  coefficient  value  [JI(X')]
12 f=8*10^(9);////Operation  frequency  in  Hz
13 V1=200;//RF  gap  voltage  in  V
14 x=1.759*10^11;//e/m  value  in  C/kg
15
16 //CALCULATION
17 disp('Assume  the  gap  transit  time  and  beam  loading
      are  neglected ');
18 w=2*(%pi)*f;//angular  frequency  in  rad
19 VR=(V0+((sqrt(8*V0/x)*w*L)/((2*(%pi)*n)-((%pi)/2))))
      ;//Repeller  voltage  in  V
20 disp('Assuming  output  coupling  coefficient  Bo=1');
21 I0=(V1/(2*J1*Rsh))/10^(-3);//Beam  current  necessary
      to  obtain  an  RF  gap  voltafe  of  200V  in  mA
22
23 //OUTPUT
24 mprintf('\nThe  Repeller  voltage  is  VR=%3.2f  V  \nBeam
      current  necessary  to  obtain  an  RF  gap  voltafe  of
      200V  is  I0=%1.2f  mA',VR,I0);
25
26 //=========================END  OF  PROGRAM
      ==============================
```

# Chapter 9

# Solid State Microwave Devices

**Scilab code Exa 9.1** frequency

```
1  // chapter −9  page  411  example  9 . 1
2  //
   ================================================================

3  clc ;
4  clear ;
5
6  L =2*10^( -6) ;// Drift  Length  of  a  IMPATT  diode  in  m
7  Vd =(10^7) *(10^( -2) ) ;// Drift  Velocity  for  Siin  m/ sec
8
9  //CALCULATION
10 f =( Vd /(2* L) ) /10^9 ;// Operating  Frequency  in  GHz
11
12 //OUTPUT
13 mprintf ( '\ nOperating  Frequency  of  the  IMPATT  diode
      is  f=%2.0 f  GHz ' ,f) ;
14
15 //===========================END  OF  PROGRAM
   ===============================
```

**Scilab code Exa 9.2** threshold electric field

```
1  //chapter-9 page 411 example 9.2
2  //
       ============================================
3  clc;
4  clear;
5
6  L=75*10^(-6);//Device Length in m
7  V=25;//Voltage Pulse Amplified in V
8  f=10*10^9;//Operating Frequency in Hz
9
10 //CALCULATION
11 Eth=(V/L)/10^5;//Threshold Electric Field in kV/cm
12
13 //OUTPUT
14 mprintf('\nThreshold Electric Field is Eth=%1.2f kV/
       cm',Eth);
15
16 //===========================END OF PROGRAM
       ===============================
```

**Scilab code Exa 9.3** power gain

```
1  //chapter-9 page 411 example 9.3
2  //
       ============================================
3  clc;
4  clear;
5
```

```
6  fs =2*10^9;//Signal  Frequency  in  Hz
7  fp =12*10^9//Pump  Frequency  in  Hz
8  Ri =16;//O/P  resistance  of  signal  generator  in  ohms
9  Rs =1000;//On  types  resistance  of  signal  generator  in
       ohms
10
11 //CALCULATION
12 P=10*log10((fp-fs)/fs);//Power  gain  in  dB
13 Pusb =10*log10((fp+fs)/fs);//Power  gain  as  USB
       converter  in  dB
14
15 //OUTPUT
16 mprintf('\nPower  gain  is  P=%1.2f  dB  \nPower  gain  as
       USB  converter  is  Pusb=%1.2f  dB',P,Pusb);
17
18 //═══════════════════════════END  OF  PROGRAM
       ═══════════════════════════
19
20
21 //Note:  Answer  given  in  textbook  is  wrong  Check  it
       once ..
22 //Correct  answers  are  Power  gain  is  P=6.99  dB
23 //                       Power  gain  as  USB  converter  is
       Pusb=8.45  dB
```

**Scilab code Exa 9.4** breakdown voltage and etc

```
1  //chapter −9  page  411  example  9.4
2  //
       ═══════════════════════════════════════════════════

3  clc ;
4  clear ;
5
6  es =12.5;//Relative  Dielectric  constant
```

```
7  e0 =8.854*10^( -12) ;//Permittivity in Free Space in F/
        m
8  N=3.2*10^22;//Donor Concentration per m^3
9  L=8*10^( -6) ;//Length of Si BARITT diode in m
10 q=1.6*10^( -19) ;//Charge of an Electron in C
11
12 //CALCULATION
13 Vc=((q*N*L^2)/(2*es*e0))/10^3;//Critical Voltage in
        kV
14 Vbd=2*Vc ;//Breakdown Voltage in kV
15 Ebd=(Vbd/L)/100;//Breakdown Electric Field in kV/cm
16
17 //OUTPUT
18 mprintf('\nCritical Voltage is Vc=%1.2f kV \
        nBreakdown Voltage is Vbd=%1.2f kV \nBreakdown
        Electric Field is Ebd=%6.2f kV/cm',Vc,Vbd,Ebd);
19
20 //==========================END OF PROGRAM
        =========================
```

**Scilab code Exa 9.5** Avalanche zone velocity

```
1  //chapter -9 page 412 example 9.5
2  //
        ==================================================================================

3  clc ;
4  clear ;
5
6  J=33000;//Current density in A/sqcm
7  Na=2.5*10^16;//Doping Concentation in TRAPATT diode
        per cubic cm
8  q=1.6*10^( -19) ;//Charge of an Electron in C
9
10 //CALCULATION
```

```
11  Vz=(J/(q*Na))/10^5;//Avalanche Zone Velocity in Km/
        sec
12
13  //OUTPUT
14  mprintf('\nAvalanche Zone Velocity is Vz=%2.1f Km/
        sec',Vz);
15
16  //================================END OF PROGRAM
        ==================================
```

**Scilab code Exa 9.6** power gain

```
1  //chapter-9 page 412 example 9.6
2  //
        ===========================================================
3  clc;
4  clear;
5
6  //For an IMPATT diode power amplifier
7  Rd=25;//Negative Resistance in ohms
8  Rl=50;//Load Resistance in ohms
9
10  //CALCULATION
11  x=abs(Rd);
12  G=((-x-Rl)/(-x+Rl))^2;//Power gain of an IMPATT
        diode
13
14  //OUTPUT
15  mprintf('\nPower gain of an IMPATT diode is G=%1.0f'
        ,G);
16
17  //================================END OF PROGRAM
        ==================================
```

**Scilab code Exa 9.7** minimum voltage

```
1  //chapter−9 page 412 example 9.7
2  //
      _____

3  clc;
4  clear;
5
6  //For a Gunn Diode
7  L=5*10^(-4);//Drift Length in cm
8  Vg=3300;//Voltage gradient in V/cm [Vg>3.3 kV/cm]
9
10 //CALCULATION
11 Vmin=Vg*L;//Minimum Voltage needed to initiate Gunn
       effect in volts
12
13 //OUTPUT
14 mprintf('\nMinimum Voltage needed to initiate Gunn
       effect is Vmin=%1.2f volts',Vmin);
15
16 //==========================END OF PROGRAM
      ============================
```

**Scilab code Exa 9.8** rational frequency

```
1  //chapter−9 page 412 example 9.8
2  //
      _____

3  clc;
4  clear;
```

```
 5
 6  //For a Gunn Diode
 7  L=20*10^(-4);//Active Length in cm
 8  Vd=2*10^7;//Drift Velocity of Electrons in cm/sec
 9  Ec=3.3*10^3;//Criticl Field for GaAs in V/cm
10
11  //CALCULATION
12  fn=(Vd/L)/10^9;//Natural(Rational) Frequency in GHz
13  Vc=L*Ec;//Critical Voltage of the diode in volts
14
15  //OUTPUT
16  mprintf('\nNatural(Rational) Frequency is fn=%2.0f
       GHz \nCritical Voltage of the diode is Vc=%1.1f
       volts',fn,Vc);
17
18  //=============================END OF PROGRAM
       ===================================
```

**Scilab code Exa 9.9** efficiency and etc

```
 1  //chapter-9 page 412 example 9.9
 2  //
       ===================================================================
 3  clc;
 4  clear;
 5
 6  //For an IMPATT diode
 7  Lp=0.5*10^(-9);//Inductance in Henry
 8  Cj=0.5*10^(-12);//Capacitance in Farad
 9  Ip=0.8;//RF peak current in A
10  Rl=2;//Load Resistance in ohms
11  Vbd=100;//Breakdown Voltage in V
12  Ib=0.1;//dc Bias current in A
13
```

```
14  //CALCULATION
15  f=(1/(2*(%pi)*sqrt(Lp*Cj)))/10^9;//Resonant
        Frequency in GHz
16  n=((Rl*Ip^2)/(2*Vbd*Ib))*100;//Efficiency in
        Percentage
17
18  //OUTPUT
19  mprintf('\nResonant Frequency is f=%2.0f GHz \
        nEfficiency is n=%1.1f percentage',f,n);
20
21  //===========================END OF PROGRAM
        ==============================
```

---

**Scilab code Exa 9.10** drift time

```
1  //chapter-9 page 413 example 9.10
2  //
        =======================================================

3  clc;
4  clear;
5
6  //For an IMPATT diode
7  L=2*10^(-6);//Drift Length in m
8  Vd=10^5;//Carrier Drift Velocity (Assume/Consider)
        in m/sec
9
10  //CALCULATION
11  t=(L/Vd)/10^(-9);//Drift Time of the Carrier in nano
        sec [From f=(1/2t)=(Vd/2L)]
12  t1=t*10^(-9);
13  f=(1/(2*t1))/10^9;//Operating Frequency of the diode
        in GHz
14
15  //OUTPUT
```

```
16  mprintf('\nDrift Time of the Carrier is t=%1.2 f nano
        sec \nOperating Frequency of the diode is f=%2.0
        f GHz',t,f);
17
18  //═════════════════════════════END OF PROGRAM
        ══════════════════════════════
```

___

Scilab code Exa 9.11 breakdown voltage and etc

```
1  //chapter−9 page 413 example 9.11
2  //
        ═══════════════════════════════════════════════════════════
3  clc;
4  clear;
5
6  //For an M−Si−M Basitt diode
7  er=11.8;//Relative dielectric constant of Si
8  e0=8.854*10^(-12);//Permittivity of freespace in F/m
9  N=3*10^(21);//Donor Concentration per m^3
10 L=6.2*10^(-6);//Si Length in m
11 q=1.6*10^(-19);//Charge of an Electron in C
12
13 //CALCULATION
14 Vbd=((q*N*L^2)/(er*e0));//Breakdown Voltage in V
15 Ebd=(Vbd/L)/10^3;//Breakdown Electric Field in kV/m
16
17 //OUTPUT
18 mprintf('\nBreakdown Voltage is Vbd=%3.1 f V \
        nBreakdown Electric Field is Ebd=%5.0 f kV/m',Vbd,
        Ebd);
19
20 //═════════════════════════════END OF PROGRAM
        ══════════════════════════════
```

___

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**Scilab code Exa 9.12** max power gain and etc

```
1  //chapter-9 page 413 example 9.12
2  //
        _____

3  clc;
4  clear;
5
6  //For an upconverter parametric amplifier
7  rQ=8;//figure of merit for a diode nonlinear
        capacitor
8  r=0.2;
9  y=8;//ratio of output frequency over signal
        frequency (f0/fs)
10 Td=300;//Diode Temperature in K
11 T0=300;//Ambient Temperature in K
12
13 //CALCULATION
14 X=((rQ)^2)/y;
15 G=((y*X)/(1+sqrt(1+X))^2);//Max power gain
16 GdB=10*log10(G);//Maximum Power Gain in dB
17 F=(1+((2*Td/T0)*((1/rQ)+(1/rQ)^2)));//Noise Figure
18 FdB=10*log10(F);//Noise Figure in dB
19 BW=2*r*sqrt(y);//Bandwidth
20
21 //OUTPUT
22 mprintf('\nMaximum Power Gain is GdB=%1.2f dB\nNoise
        Figure is FdB=%1.2f dB \nBandWidth is BW=%1.2f',
        GdB,FdB,BW);
23
24 //=============================END OF PROGRAM
        ==================================
```

**Scilab code Exa 9.13** gain and etc

```scilab
1  //chapter-9 page 414 example 9.13
2  //
     _____
3  clc;
4  clear;
5
6  //For a negative resistance parametric amplifier
7  fs=2*10^9;//Signal Frequency in Hz
8  fp=12*10^9;//pump Frequency in Hz
9  fi=10*10^9;//idler Frequency in Hz
10 fd=5*10^9;//Frequency in Hz
11 Ri=1000;//o/p resistance of idler generator in ohms
12 Rg=1000;//o/p resistance of signal generator in ohms
13 RTs=1000;//total series resistance at fs in ohms
14 RTi=1000;//total series resistance at fi in ohms
15 r=0.35;
16 rQ=10;//figure of merit
17 Td=300;//Avg Diode Temperature in K
18 T0=300;//Ambient Temperature in K
19 C=0.01*10^(-12);//Capacitance in F
20
21 //CALCULATION
22 ws=2*(%pi)*fs;
23 wi=2*(%pi)*fi;
24 R=((r^2)/(ws*wi*RTi*C^2));//Equivalent noise
     resistance in ohms
25 a=(R/RTs);
26 G=((4*fi*a*Rg*Ri)/(fs*RTs*RTi*(1-a)^2));//Gain
27 GdB=10*log10(G);//Gain in dB
28 F=(1+((2*Td/T0)*((1/rQ)+(1/rQ)^2)));//Noise Figure
29 FdB=10*log10(F);//Noise Figure in dB
```

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```
30  BW=((r/2)*(sqrt(fd/(fs*G)))) ;
31
32  //OUTPUT
33  mprintf('\nEquivalent noise resistance is R=%4.1f
        ohms\nGain is GdB=%2.1f dB\nNoise Figure is FdB=
        %1.2f dB \nBandWidth is BW=%1.3f',R,GdB,FdB,BW);
34
35  //============================END OF PROGRAM
        ==============================
36
37  //Note: Check the Bandwidth answer is once It should
        be 0.027
```

# Chapter 10

# Microwave Communication Systems

**Scilab code Exa 10.1** radio horizon

```
1  //chapter-10  page  486  example  10.1
2  //
   ========================================================
3  clc;
4  clear;
5
6  ht=144;//TV transmitter antenna height in m
7  hr=25;//TV receiver antenna height in m
8  //Radio horizon is about 4/3 as far as the optical
       horizon
9
10 //CALCULATION
11 dr=4*sqrt(hr);//distance in km
12 dt=4*sqrt(ht);//Radio Horizon in km
13 d=dt+dr;//The Maximum distance of Propagation of the
       TV signal in km
14
15 //OUTPUT
```

```
16  mprintf('\nThe Maximum distance of Propagation of
        the TV signal is d=%2.0f km \nRadio Horizon is dt
        =%2.0f km',d,dt);
17
18  //═══════════════════════════END OF PROGRAM
        ═════════════════════════════
```
_____



**Scilab code Exa 10.2** value of factor

```
1  //chapter-10 page 486 example 10.2
2  //
        ══════════════════════════════════════════════════════════

3  clc;
4  clear;
5
6  r=6370*10^3;//radius of the earth in m
7  x=-0.05*10^(-6);//the gradient of refractive index
        of air near the ground per m [du/dh]
8
9  //CALCULATION
10 k=1/(1+(r*x));//The value of the factor by which the
        horizon distance of a transmitter will be
        modified
11
12 //OUTPUT
13 mprintf('\nThe value of the factor by which the
        horizon distance of a transmitter will be
        modified is k=%1.4f',k);
14
15 //═══════════════════════════END OF PROGRAM
        ═════════════════════════════
```
_____

**Scilab code Exa 10.3** power

```
1  //chapter-10 page 487 example 10.3
2  //=================================================================
3  clc;
4  clear;
5
6  //For a microwave LOS link
7  f=2*10^9;//frequency of operation in Hz
8  c=3*10^8;//Velocity of light in m/sec
9  r=50000;//repeater spacing in m
10 PrdBm=-20;//required carrier power at the receiver i
       /p to avoid deterioration due to fading and noise
        in dBm
11 GtdB=34;//antenna gain of transmitter in dB
12 GrdB=34;//antenna gain of receiver in dB
13 LdB=10;//coupling and waveguide loss in transmitter
       in dB
14
15 //CALULATION
16 w=c/f;//wavelength in m
17 x=(w^2)/(4*(%pi));
18 y=(4*(%pi)*r^2);
19 PtdBm=PrdBm+(10*log10(y))-GtdB-(10*log10(x))+LdB-
       GrdB;//The required Carrier Transmitter power in
       dBm
20
21 //OUTPUT
22 mprintf('\nThe required Carrier Transmitter power is
        PtdBm=%2.1f dBm',PtdBm);
23
24 //========================END OF PROGRAM
       ========================================
```

**Scilab code Exa 10.4** power

```
1  //chapter-10 page 487 example 10.4
2  //
     _____
3  clc;
4  clear;
5
6  //For a geostationary communication satellite
7  f=6*10^(9);//uplink frequency in Hz
8  Pt=1000;//Transmitter power in W
9  x=36000*10^3;//vertical distance between surface of
       earth and satellite in m
10 a=5;//antenna elevation angle in deg
11 GtdB=60;//antenna gain of transmitter in dB
12 GrdB=0;//antenna gain of receiver in dB
13 c=3*10^8;//Velocity of light in m/sec
14
15 //CALCULATION
16 Gt=10^(GtdB/10);//antenna gain of transmitter
17 Gr=10^(GrdB/10);//antenna gain of receiver
18 w=c/f;//wavelength in m
19 Ar=(w^2)*(Gr/(4*(%pi)));//area in sqm
20 r=x/(sind(a));//distance between transmitter and
       receiver in m [From Sine formula and diagram]
21 Pr=((Pt*Gt*Ar)/(4*(%pi)*r^2))/10^(-12);//The
       received power at the input of the satellite
       receiver in pico watts
22
23 //OUTPUT
24 mprintf('\nThe received power at the input of the
       satellite receiver is Pr=%1.2f pico watts(pW)',Pr
       );
```

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```
25
26 //═════════════════════════════════END  OF  PROGRAM
      ═════════════════════════════
```

**Scilab code Exa 10.5** antenna beam angle

```
1  // chapter −10  page  487  example  10.5
2  //
      ══════════════════════════════════════════════
3  clc ;
4  clear ;
5
6  x1 =35855;// Distance  between  geostationary  orbit  to
      surface  of  earth  in  km
7  x2 =6371;// Distance  between  center  of  earth  to
      surface  of  earth  in  km
8
9  //CALCULATION
10 x=x1+x2;// distance  of  satellite  from  center  of  earth
       in  km
11 y=x2*(%pi);// Circumference  of  half  circle  arc  in  km
12 b=y/x;//Beam  angle  in  rad
13 Bdeg =(b*180)/(%pi);//Beam  angle  in  deg
14
15 //OUTPUT
16 mprintf ('\nAntenna  Beam  angle  required  by  a
      satellite  antenna  to  provide  full  global  coverage
       from  a  geostationary  orbit  is  Bdeg=%2.2f  deg ',
      Bdeg);
17
18 //═════════════════════════════════END  OF  PROGRAM
      ═════════════════════════════
```

**Scilab code Exa 10.6** round trip time

```
1  //chapter-10 page 488 example 10.6
2  //
   _____

3  clc;
4  clear;
5
6  //For a satellite communication system
7  h=35855;//Distance between geostationary orbit to
       surface of earth in km
8  r=6371;//Distance between center of earth to surface
        of earth in km
9  a=5;//earth station elevation angle wrt the
       geostationary satellite in deg
10 b=5;//angle in deg
11 c=3*10^5;//Velocity of light in km/sec
12 b1=90;//angle for vertical transmission in deg
13 a1=0;
14
15 //CALCULATION
16 d=(sqrt((r+h)^2-(r*cosd(a))^2))-sind(b);//distance
       in km
17 T=2*(d/c);//The round trip time between the earth
       station and the satellite in sec
18 d1=(sqrt((r+h)^2-(r*cosd(a))^2))-sind(b);//distance
       in km
19 Tv=(2/c)*(d1-r);//The round trip time for vertical
       transmission between the earth station and the
       satellite in sec
20
21 //OUTPUT
22 mprintf('\nThe round trip time between the earth
```

```
        station  and  the  satellite  is  T=%1.3f  sec  \nThe
        round  trip  time  for  vertical  transmission  between
         the  earth  station  and  the  satellite  is  Tv=%1.3f
        sec ',T,Tv);
23
24 //=========================END OF PROGRAM
      =========================
```

**Scilab code Exa 10.7** figure of merit

```
1 //chapter-10 page 488 example 10.7
2 //
      ================================================================
3 clc;
4 clear;
5
6 Tant=25;//effective noise temperature in K
7 Tr=75;//receiver noise temperature in K
8 GdB=45;//Isotropic power gain of the antenna in dB
9
10 //CALCULATION
11 T=Tant+Tr;//The total noise in K
12 TdB=10*log10(T);//The total noise in dB
13 MdB=GdB-TdB;//Figure of merit of earth station in dB
14
15 //OUTPUT
16 mprintf('\nFigure of merit of earth station is MdB=
      %2.0f dB',MdB);
17
18 //=========================END OF PROGRAM
      =========================
```

**Scilab code Exa 10.8** CNR

```
1  //chapter -10  page  488  example  10.8
2  //
      ================================================================
3  clc ;
4  clear ;
5
6  //For  a  Satellite  communication  link
7  EIRPdB =55.5;// Satellite  ESM  in  dBW
8  MdB =35;//G/T  ratio  of  earth  station  in  dB
9  LfsdB =245.3// Freespace  loss  in  dB
10
11  //CALCULATION
12  CNRdB = EIRPdB + MdB - LfsdB +228.6;// Carrier  to  Noise
      Ratio  at  the  earth  station  receiver  in  dB
13
14  //OUTPUT
15  mprintf ( '\nCarrier  to  Noise  Ratio  at  the  earth
      station  receiver  is  CNRdB=%2.1 f  dB ',CNRdB);
16
17  //====================END  OF  PROGRAM
      ==============================
```

**Scilab code Exa 10.9** system noise temperature

```
1  //chapter -10  page  489  example  10.9
2  //
      ================================================================
3  clc ;
4  clear ;
5
6  D =30;// Diameter  of  a  dish  antenna  with  circular
```

```
          aperture  in  m
7  f =4*10^9; //down  link  frequency  in  Hz
8  MdB =20; //G/T  ratio  of  earth  station  in  dB
9  c =3*10^8; // Velocity  of  light  in  m/sec
10
11  //CALCULATION
12  A =((%pi)/4)*D^2; // area  in  sqm
13  w=c/f; // wavelength  in  m
14  G =(4*(%pi)*A)/w^2; // Gain
15  GdB =10* log10 (G) ; // Gain  in  dB
16  TsdB=GdB-MdB; //The  System  Noise  Temperature  in  dB
17
18  //OUTPUT
19  mprintf ( '\nThe  System  Noise  Temperature  is  TsdB=%2.2
      f  dB ' ,TsdB );
20
21  //===============================END  OF  PROGRAM
      =============================
```

_____

**Scilab code Exa 10.10** HPBW

```
1  //chapter -10  page  489  example  10.10
2  //
      ===============================================
3  clc ;
4  clear ;
5
6  //For  a  parabolic  antenna
7  Gp =1500; //Power  gain
8  w =0.1; // wavelength  in  m
9
10  //CALCULATION
11  D= sqrt (Gp)*(w/(%pi)); //Diameter  of  the  circular
      mouth  of  a  parabolic  antenna  in  m
```

```
12  HPBW=58*(w/D);//Half Power BeamWidth of the antenna
       in deg
13
14  //OUTPUT
15  mprintf('\nDiameter of the circular mouth of a
       parabolic antenna is D=%1.4f m \nHalf Power
       BeamWidth of the antenna is HPBW=%1.3f deg',D,
       HPBW);
16
17  //=============================END OF PROGRAM
       ===========================
```

**Scilab code Exa 10.11** gain

```
1  //chapter−10 page 490 example 10.11
2  //
       =====================================================

3  clc;
4  clear;
5
6  D=1;//Assume diameter of the parabolic reflectors in
       the original system in m
7  w=1;//Assume wavelength in m
8
9  //CALCULATION
10  D1=2*D;//diameter of the parabolic reflectors in the
       modified system in m
11  G=6*(D/w)^2;//gain in original system
12  G1=6*(D1/w)^2;//gain in modified system
13  GdB=10*log10(G1/G);//Overall gain that can be
       expected in dB
14  GdBo=2*GdB;//Overall gain of the system(combining
       the two antennas one at the Tx and other at the
       Rx) in dB
```

```
15
16  //OUTPUT
17  mprintf('\nOverall gain that can be expected is GdB=
        %1.0f dB \nOverall gain of the system(combining
        the two antennas one at the Tx and other at the
        Rx) is GdBo=%1.0f dB',GdB,GdBo);
18
19  //==============================END OF PROGRAM
        ===================================
20
21  //Note: Check the answer once ..it should be GdB=10
        log(4)=6 dB and GdBo=12dB
```

**Scilab code Exa 10.12** gain

```
1  //chapter-10 page 490 example 10.12
2  //
        ===================================================

3  clc;
4  clear;
5
6  D=3;//dimension of a paraboloid in m
7  f=3*10^9;//frequency (S band) in Hz
8  c=3*10^8;//Velocity of light in m/sec
9
10  //CALCULATION
11  w=c/f;//wave length in m
12  BWFN=140*(w/D);//BeamWidth between First Nulls in
        deg
13  BWHP=70*(w/D);//BeamWidth between HalfPower points
        in deg
14  G=6*(D/w)^2;//Gain of the antenna
15
16  //OUTPUT
```

```
17  mprintf ('\nBeamWidth between First Nulls is BWFN=%1
        .2 f deg \nBeamWidth between HalfPower points is
        BWHP=%1.2 f deg \nGain of the Antenna is G=%4.0 f '
        ,BWFN ,BWHP ,G ) ;
18
19  //===========================END OF PROGRAM
        ================================
```

**Scilab code Exa 10.13** power gain

```
1  // chapter −10  page  490  example  10.13
2  //
        =========================================================
3  clc ;
4  clear ;
5
6  l =1; //( Assume )−dimension ( wavelength )  in  cm
7
8  //CALCULATION
9  x =5* l ; // given  square  aperture  of  an  optimum  horn
        antenna  as  a  side  dimension  in  cm
10  A=x*x ; // Area  in  sq . cm
11  Gp =4.5*(A/l ^2) ; // Power  gain  of  an  optimum  horn
        antenna
12
13  //OUTPUT
14  mprintf ('\nPower  gain  of  an  optimum  horn  antenna  is
        Gp=%3.1 f  ',Gp) ;
15
16  //===========================END OF PROGRAM
        ================================
```

# Chapter 11

# Radars

**Scilab code Exa 11.1** max range

```
1  //chapter -11 page 504 example 11.1
2  //
       _____

3  clc;
4  clear;
5
6  //For a radar system
7  Pt=600000;//peak pulse power in W
8  Smin=10^(-13);//minimum detectable signal in W
9  Ae=5;//cross sectional area of the radar antenna in
       sq m
10 w=0.03;//wavelength in m
11 s=20;//radar cross sectional area in sq m
12
13 //CALCULATION
14 Rmax=(((Pt*s*Ae^2)/(4*(%pi)*Smin*w^2))^(1/4))/1000;
       //Maximum range of a radar system in km
15 RMax=Rmax/1.853;//In nautical miles; 1 nm=1.853 km
16
17 //OUTPUT
```

```
18  mprintf('\nMaximum range of a radar system is Rmax=
        %3.3f km',Rmax);
19  disp('In nautical miles; 1 nm=1.853 km');
20  mprintf('\nMaximum range of a radar system in
        nautical miles is RMax=%3.0f nm',RMax);
21
22  //══════════════════════════END OF PROGRAM
        ══════════════════════════════
```

_____

**Scilab code Exa 11.2** max range

```
1  //chapter −11 page 504 example 11.2
2  //
        ═════════════════════════════════════════════════════════

3  clc;
4  clear;
5
6  //For a radar system
7  Pt=250000;//peak transmitted power in W
8  G=2500;//power gain of the antenna
9  Smin=10^(-14);//minimum detectable signal in W
10 Ae=10;//cross sectional area of the radar antenna in
        sq m
11 f=10*10^9;//frequency of radar in Hz
12 s=2;//radar cross sectional area in sq m
13 c=3*10^8;//Velocity of light in m/sec
14
15 //CALCULATION
16 w=c/f;//wavelength in m
17 Rmax=(((Pt*G*Ae*s)/(Smin*(4*(%pi))^2))^(1/4))/1000;
        //Maximum range of a radar system in km
18
19 //OUTPUT
20 mprintf('\nMaximum range of a radar system is Rmax=
```

```
      %3.2f  km',Rmax);
21
22  //==========================END  OF  PROGRAM
       ========================
```

_____

**Scilab code Exa 11.3** RCS

```
 1  //chapter-11  page  504  example  11.3
 2  //
       ==================================================

 3  clc;
 4  clear;
 5
 6  //For  a  marine  radar  system
 7  Pt=250000;//peak  transmitted  power  in  W
 8  G=4000;//power  gain  of  the  antenna
 9  R=50000;//maximum  range  of  radar  in  m
10  Pr=10^(-11);//minimum  detectable  signal  in  W
11  f=10*10^9;//frequency  of  radar  in  H
12  c=3*10^8;//Velocity  of  light  in  m/sec
13
14  //CALCULATION
15  w=c/f;//wavelength  in  m
16  Ae=((G*w^2)/(4*(%pi)));//cross  sectional  area  of  the
        radar  antenna  in  sq  m
17  s=((Pr*(4*(%pi)*R^2)^2)/(Pt*G*Ae));//The  cross
       section  of  the  target  the  radar  can  sight  in  sq  m
18
19  //OUTPUT
20  mprintf('\nThe  cross  section  of  the  target  the  radar
        can  sight  is  s=%2.2f  sq  m',s);
21
22  //==========================END  OF  PROGRAM
       ========================
```

**Scilab code Exa 11.4** Duty cycle and etc

```
1  //chapter-11 page 505 example 11.4
2  //
   _____

3  clc;
4  clear;
5
6  //For a guided missile tracking radar
7  Pt=400000;//transmitted power in W
8  prf=1500;//pulse repitition frequency in pps(pulse
      per sec)
9  tw=0.8*10^(-6);//pulse width in sec
10 c=3*10^8;//Velocity of light in m/sec
11
12 //CALCULATION
13 Runamb=(c/(2*prf))/1000;//Unambiguous range in km
14 dc=tw/(1/prf);//Duty cycle
15 Pav=Pt*dc;//Average power in W
16 n1=1;
17 BW1=(n1/tw)/10^6;//Suitable BW in MHz for n=1
18 n2=1.4;
19 BW2=(n2/tw)/10^6;//Suitable BW in MHz for n=1.4
20
21 //OUTPUT
22 mprintf('\nUnambiguous range is Runamb=%3.0f km \
      nDuty cycle is dc=%1.4f \nAverage power is Pav=%3
      .0f W',Runamb,dc,Pav);
23 disp('For efficiency n=1,suitable bandwidth in MHz
      is ');
24 disp(BW1);
25 disp('For efficiency n=1.4,suitable bandwidth in MHz
       is ');
```

```
26  disp(BW2);
27
28  //===========================END  OF  PROGRAM
        ==============================
```

_____

**Scilab code Exa 11.5** max range

```
1  //chapter−11 page 505 example 11.5
2  //
        ===========================================================

3  clc;
4  clear;
5
6  //For a military radar
7  Pt=2500000;//power output in W
8  f=5*10^9;//frequency of radar in H
9  c=3*10^8;//Velocity of light in m/sec
10 D=5;//antenna diameter in m
11 B=1.6*10^6;//receiver bandwidth in Hz
12 s=1;//radar cross sectional area in sq m
13 NF=12;//noise figure in dB
14
15 //CALCULATION
16 w=c/f;//wavelength in m
17 F=10^(NF/10);//noise figure
18 Rmax=(48*((Pt*s*D^4)/(B*(F-1)*w^2))^(1/4));//Maximum
        detection range in km
19
20 //OUTPUT
21 mprintf('\nMaximum detection range of a radar is
        Rmax=%3.0f km',Rmax);
22
23 //===========================END  OF  PROGRAM
        ==============================
```

**Scilab code Exa 11.6** factor

```
1  //chapter-11 page 506 example 11.6
2  //=========================================================
3  clc;
4  clear;
5
6  //For a civilian radar
7  Rmax=30;//maximum range in kms
8  x=50;
9  y=2;
10 disp('Maximum range with an equivalent echoing area
       of 50 times in kms is');
11 R=Rmax*x^(1/4);
12 disp(R);
13 disp('Range would be increased if Tx power is
       doubled by a factor of');
14 f=y^(1/4);
15 disp(f);
16
17 //==========================END OF PROGRAM
       ==========================
```