Scilab Textbook Companion for Microelectronic Circuits by A. S. Sedra And K. C. Smith[1]

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Book Description

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

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

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

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

Contents

List of Scilab Codes

Chapter 1

Introduction to Electronics

Scilab code Exa 1.1 Amplifier gain power and eficiency

```
// Example1.1: Amplifier gain, power and eficiency
// Amplifier operates at +10-V/-10-V power supply.
A_v=9/1; // sinusoidal voltage input of 1V peak and
    sinusoidal output voltage of 9V peak
I_o=9/1000; // 1 kilo ohms load
disp(A_v,"Voltage gain (V/V) =")
disp(20*log10(A_v),"Voltage gain (dB) =")
I_i=0.0001 // sinusoidal current input of 0.1mA peak
A_i=I_o/I_i;
disp(A_i,"Current gain (A/A) =")
disp(20*log10(A_i),"Current gain (dB) =")
V_orms = 9/sqrt(2);
I_orms = 9/sqrt(2);
P_L=V_orms*I_orms; // output power in mW
V_irms=1/sqrt(2);
I_irms=0.1/sqrt(2);
P_I=V_irms*I_irms; // input power in mW
A_p=P_L/P_I;
disp(A_p,"Power gain (W/W) =")
disp(10*log10(A_p),"Power gain (dB) =")
P_dc=10*9.5+10*9.5; // amplifier draws a current of
```

```
    9.5mA from each of its two power supplies
disp(P_dc,"Power drawn from the dc supplies (mW) =")
P_dissipated=P_dc+P_I-P_L;
disp(P_dissipated,"Power dissipated in the amplifier
    (mW)")
n=P_L/P_dc*100;
disp(n,"Amplifier efficiency in percentage")
```

Scilab code Exa 1.2 Gain of transistor amplifier

```
// Example 1.2: Gain of transistor amplifier
// Amplifier has transfer characteristics v_O
   =10-(10^-11)*(exp^40*v_1) applies for v_1 is
   greater than or equal 0V and v_o is greater than
   or equal to 0.3V
L_l = 0.3; // limit L_-
disp(L_l,"The limit L_- (V) =")
v_I=1/40*log((10-0.3)/10^-11); // from the transfer
   characteristics and v_o=0.3V
disp(v_I,"v_I in volts =")
L_u=10-10^-11; // obtained by v_I=0 in transfer
   characteristics
disp(L_u,"the limit L_+ (V) =")
V_I=1/40*log((10-5)/10^-11); // V_O=5V
disp(V_I,"The value of the dc bias voltage that
   results in V_O=5V (V)=")
A_v=-10^-11*exp(40*V_I)*40; // A_v=dv_O/dv_I
disp(A_v,"Gain at the operating point (V/V) =")
disp("NOTE the gain is negative that implies the
   amplifier is an inverting amplifier")
```

Scilab code Exa 1.3 Overall voltage gain of three stage amplifier

```
// Example 1.3 : Overall voltage gain of cthree-stage amplifier
gainloss_in=10^6/(1*10^6+100*10^3); // fraction of input signal is obtained using voltage divider rule , gainloss_in= v_i1/v_s
A_v1=10*100000/(100000+1000); // A_v1 = v_i2/v_i1 is the voltage gain at first stage
A_v2=100*10000/(10000+1000); // A_v2 = v_i3/v_i2 is the voltage gain at second stage
A_v3=100/(100+10); // A_v3 = v_L/v_i3 is the voltage gain at the output stage
A_v=A_v1*A_v2*A_v3; // A_v is the total voltage gain
disp(A_v,"The overall voltage gain (V/V) =")
disp(20*log10(A_v),"The overall voltage gain (dB) =")
gain_src_ld=A_v*gainloss_in;
disp(gain_src_ld,"The voltage gain from source to gain (V/V) =")
disp(20*log10(gain_src_ld),"The voltage gain from source to load (dB) =")
A_i=10^4*A_v; // A_i=i_o/i_i=(v_L/100)/(v_i1/10^6)
disp(A_i,"The current gain (A/A)=")
disp(20*log10(A_i),"The current gain (dB) =")
A_p=818*818*10^4; // A_p=P_L/P_I=v_L*i_o/v_i1*i_i
disp(A_p,"The power gain (W/W) =")
disp(10*log10(A_p),"The power gain (dB) =")
```

Scilab code Exa 1.4 Bipolar junction transistor

```
// Example1.4 : Bipolar junction transistor

// 1,4a
// using voltage divider rule the fraction of input signal v_be=v_s*r_pi/(r_pi+R_s)
// output voltage v_o=-g_mv_be(R_L||r_o)
```

```
r_pi=2.5*10^3; // (ohm)
R_s=5*10^3; // (ohm)
R_L=5*10^3 // (ohm)
g_m=40*10^-3; // (mho)
r_o=100*10^3; // (ohm)
gain=-(r_pi*g_m*(R_L*r_o/(R_L+r_o)))/(r_pi+R_s); // gain=v_o/v_s
disp(gain,"The voltage gain (V/V) =")
gain_negl_r_o=-r_pi*g_m*R_L/(r_pi+R_s);
disp(gain_negl_r_o,"Gain neglecting the effect of r_o (V/V) =")

// 1.4b
// Bi_b=g_m*v_be
// B is short circuit gain
B=g_m*r_pi;
disp(B,"The short circuit gain (A/A) =")
```

Scilab code Exa 1.5 DC gain 3dB frequency and frequency at which gain

```
// Example 1.5 : DC gain, 3dB frequency and frequency at which gain=0 of voltage amplifier

// 1.5b
R_s =20*10^3; // (ohm)
R_i =100*10^3; // (ohm)
C_i =60*10^-12; // (ohm)
u = 144; // (V/V)
R_o = 200; // (ohm)
R_L = 1000; // (ohm)
K=u/((1+R_s/R_i)*(1+R_o/R_L));
disp(K,"The dc gain (V/V)= ")
disp(20*log10(K)," The dc gain (dB) =")
w_o=1/(C_i*R_s*R_i/(R_s+R_i));
disp(w_o,"The 3-dB frequency (rad/s) =")
```

```
f_o= w_o/2/%pi;
disp(f_o,"Frequency (Hz) =")
disp(100*w_o,"unity gain frequency (rad/s)=",100*f_o,"Unity gain frequency (Hz)")
```

Scilab code Exa 1.6 Evaluation of tPHL

```
// Example 1.6: Time for the output to reach (V_OH+V_OL)/2
V_DD=5; // (V)
R=1000; // (ohm)
R_on=100; // (ohm)
V_offset=0.1; // (V)
C=10*10^-12; // (F)
V_OH=5; // (V)
V_OL=V_offset+(V_DD-V_offset)*R_on/(R+R_on);
T=R*C;
v_o_t_PLH=(V_OH+V_OL)/2; //to find t_PLH
t_PLH=0.69*T;// t_PLH is low to high propogtion delay
disp(t_PLH,"time required for he output to reach (V_OH+V_OL)/2 (seconds) =")
```

Chapter 2

Operational Amplifiers

Scilab code Exa 2.1 Closed loop and open loop gain

```
// Example 2.1 : Closed loop and open loop gain
// Consider inverting configuration

// 2.1a
R_1=1000; // (ohm)
R_2=100*10^3; // (ohm)
A=10^3; // (V/V)
disp(A,"A (V/V)")
G=-R_2/R_1/(1+(1+R_2/R_1)/A);
disp(-G,"G")
e=(-G-(R_2/R_1))/(R_2/R_1)*100;
disp(e,"e (%)")
v_1=0.1; // (V)
v_1=G*v_1/A;
disp(v_1,"v_1 (V)")
A=10^4; // (V/V)
disp(A,"A (V/V)")
G=-R_2/R_1/(1+(1+R_2/R_1)/A);
disp(-G,"G")
e=(-G-(R_2/R_1))/(R_2/R_1)*100;
disp(e,"e (%)")
```

```
v_1=0.1; // (V)
v_1=G*v_1/A;
disp(v_1,"v_1 (V)")
A=10^5; // (V/V)
disp(A,"A (V/V)")
G=-R_2/R_1/(1+(1+R_2/R_1)/A);
disp(-G,"G")
e=(-G-(R_2/R_1))/(R_2/R_1)*100;
disp(e,"e (%)")
v_1=0.1; // (V)
v_1=G*v_1/A;
disp(v_1,"v_1 (V)")

// 2.1b
A=50000; // (V/V)
disp(A,"A (V/V)")
G=-R_2/R_1/(1+(1+R_2/R_1)/A);
disp(-G,"G")
disp("Thus a -50% change in the open loop gain
   results in only -0.1% in the closed loop gain")
```

Scilab code Exa 2.3 `Design instrumentation amplifier`

```
// Example 2.3 : Design instrumentation amplifier
R_2=1-50000-1/1000+50;
disp(R_2,"R_2 (ohm)")
R_1=2*R_2/999;
disp(R_1,"R_1 (ohm)")
```

Chapter 3

Diodes

Scilab code Exa 3.1 Peak value of diode current and maximum reverse vo

```
//Example 3.1: Peak value of diode current and
   maximum reverse voltage
//v_s is sinusoidal input voltage with peak 24V
//battery charges to 12V
I_d=(24-12)/100
max_v_rev=24+12;
disp(I_d,"peak value of diode current (A)",
   max_v_rev,"maximum reverse voltage acrossthe
   diode (V)")
```

Scilab code Exa 3.2 Values of Iand V for the circuit given

```
//Example 3.2 : Values of Iand V for the circuit
   given
disp("Consider fig 3.6(a). Assume both diodes are
   conducting")
I_D2=(10-0)/10;
I=(0-(-10))/5-I_D2; // node eqution at B for fig
   3.6(a)
```

```
V_B=0;
V=0;
disp(I,"I (mA)=", V,"V (V)" ,"D_1 is conducting as
    assumed originally")
disp("Consider fig 3.6(a). Assume both diodes are
    conducting")
I_D2=(10-0)/5;
I=(0-(-10))/10-2; // node eqution at B for fig 3.6(b
    )
disp(I,"I (mA)=", V,("V (V)"))
disp("Implies assumption is wrong. lets assume D_1
    is off and D_2 is on")
I_D2=(10-(-10))/15;
V_B=-10+10*I_D2;
I=0;
disp(I,"I (mA)", V_B,"V (V)" ,"D_1 is reverse biased
    ")
```

Scilab code Exa 3.3 Evaluating junction scaling constant

```
//Example 3.3 : Evaluating junction scaling constant
//i-I_S*exp(v/(n*V_T)) implies I_S=i*exp(-v/(n*V_T))
n=1;
i=10^-3; // (A)
v=700; // (V)
V_T=25; // (V)
I_S=i*exp(-v/(n*V_T))
disp(I_S,"I_S (A) for n=1")
n=2;
I_S=i*exp(-v/(n*V_T))
disp(I_S,"I_S (A) for n=2")
disp("These values implies I_S is 1000 times greater
    ")
```

Scilab code Exa 3.4 To determine ID and VD

```
//Example 3.4: To determine I_D and V_D
V_DD=5; // (V)
R=1000; // (ohm)
I_1=1*10^-3; // (A)
V_D=0.7; // (V)
V_1=V_D;
I_D=(V_DD-V_D)/R;
I_2=I_D;
V_2=V_1+0.1*log10(I_2/I_1);
I_D=(V_DD-V_2)/R;
disp(I_D,"The diode current (A)")
V_D=V_2+0.1*log10(I_D/I_2)
disp(V_D,"The diode volage (V)")
```

Scilab code Exa 3.5 Repeating example 4 using piecewise linear model

```
// Example 3.5 : Repeating example 3.4 using
    piecewise linear model
V_D0=0.65; // (V)
r_D=20; // (ohm)
R=1000; // (ohm)
V_DD=5; // (V)
I_D=(V_DD-V_D0)/(R+r_D);
disp(I_D,"I_D (A)")
V_D=V_D0+I_D*r_D;
disp(V_D,"The diod voltage (V)")
```

Scilab code Exa 3.6 Power supply ripple

```
// Example 3.6 : Power supply ripple
V_S=10; // V_S=V_+
V_D=0.7; // (V)
R=10*10^3; // (ohm)
n=2;
V_T=25*10^-3; // (V)
V_s=1; // (V)
I_D=(V_S - V_D)/R;
r_D=n*V_T/I_D;
v_d=V_s*r_D/(R+r_D);
disp(v_d,"v_d(peak (V))")
```

Scilab code Exa 3.7 Percentage change in regulated voltage

```
// Example 3.7 : Percentage change in regulated voltage
V_DD=10; // (V)
V_D=0.7*3; // string of 3 diodes provide this constant voltage
R=1*10^3;
I_D=(V_DD-V_D)/R;
n=2;
V_T= 25*10^-3; // (V)
r_d=n*V_T/I_D; // incremental resistance
r=3*r_d; // total incremental resistance
deltav_O=2*r/(r+R); // deltav is peak to peak change in output voltage
disp(deltav_O,"Percentage change (V) in regulated voltage caused by 10% change in power supply")
I=2.1*10^-3; // The current drawn from the diode string
deltav_O=-I*r; // Decrease in voltage across diode string
```

```
disp(deltav_O,"Decrease in voltage across diode
   string (V)")
```

Scilab code Exa 3.8 line regulation load regulation

```
// Example 3.8 : line regulation load regulation

V_Z=6.8; // (V)
I_Z=0.005; // (A)
r_Z=20; // (ohm)
V=10; // V=V_+
R=0.5*10^3; // (ohm)

// 3.8a
V_ZO=V_Z-r_Z*I_Z;
I_Z=(V-V_ZO)/(R+r_Z)
V_O=V_ZO+I_Z*r_Z;
disp(V_O,"V_O (V)")

// 3.8b
deltaV=1; // change in V is +1 and -1
deltaV_O=deltaV*r_Z/(R+r_Z); // corresponding change
    in output voltage
disp(deltaV_O,"Line regulation (V/V)")

// 3.8c
I_L=1*10^-3; // load current
deltaI_L=1*10^-3;
deltaI_Z=-1*10^-3; // change in zener current
deltaV_O=r_Z*deltaI_Z;
disp(deltaV_O,"Load regulation (V/A)")

// 3.8d
I_L=6.8/2000; // load current with load resistance
   of 2000
```

```
deltaI_Z=-I_L;
deltaV_O=r_Z*deltaI_Z;
disp(deltaV_O,"Corresponding change in zener voltage (V) for zener current change of -3.4mA")

// 3.8e
R_L=0.5*10^3; // (ohm)
V_O=V*R_L/(R+R_L);
disp(V_O,"V_O (V) for R_L=0.5K ohm")

// 3.8f
I_Z=0.2*10^-3; // Zener t be at the edge of breakdown I_Z=I_ZK
V_Z=6.7; // V_Z=V_ZK
I_Lmin=(9-6.7)/0.5; // Lowest current supplied to R
I_L=I_Lmin-I_Z; // load current
R_L=V_Z/I_L;
disp(R_L,"R_L (ohm)")
```

Scilab code Exa 3.9 Value of capacitance C that will result in peak pe

```
// Example 3.9 : Value of capacitance C that will result in peak-peak ripple of 2V
V_P=100; // (V)
V_r=2; // (V)
f=60; // (Hz)
R=10*10^3; // (ohm)
I_L=V_P/R;
C=V_P/(V_r*f*R);
disp(C,"C (V)")
wdeltat=sqrt(2*V_r/V_P);
disp(wdeltat,"Conduction angle (rad)")
i_Dav=I_L*(1+%pi*sqrt(2*V_P/V_r));
disp(i_Dav,"i_Dav (A)")
i_Dmax=I_L*(1+2*%pi*sqrt(2*V_P/V_r));
```

```
disp(i_Dmax,"i_Dmax (A)")
```

Chapter 4

MOS Field Effect Transistors

Scilab code Exa 4.1 To determine operating point parameters

```
// Example 4.1 : To determine operating point
   parameters
L_min=0.4*10^-6; // (m)
t_ox=8*10^-9; // (s)
u_n=450*10^-4; // (A/V^2)
V_t=0.7; // (V)
e_ox=3.45*10^-11;

// 4.1a
C_ox=e_ox/t_ox;
disp(C_ox,"C_ox (F/m^2)")
k_n=u_n*C_ox;
disp(k_n,"k_n (A/V^2)")

// 4.1b
// Operation in saturation region
W=8*10^-6; // (m)
L=0.8*10^-6; // (m)
i_D=100*10^-6; // (A)
V_GS=sqrt(2*L*i_D/(k_n*W)) +V_t;
disp(V_GS,"V_GS (V)")
```

```
V_DSmin=V_GS-V_t;
disp(V_DSmin,"V_DSmin (V)")

// 4.1c
// MOSFET in triode region
r_DS=1000; // (ohm)
V_GS=1/(k_n*(W/L)*r_DS)+V_t;
disp(V_GS,"V_GS (V)")
```

Scilab code Exa 4.2 Design of given circuit

```
// Example 4.2: Design of given circuit to obtain
    I_D=0.4mA and V_D=0.5V
// NMOS transistor is operating in saturation region
I_D=0.4*10^-3; // (A)
V_D=0.5; // (V)
V_t=0.7; // (V)
uC_n=100*10^-6; // (A/V^2)
L=1*10^-6; // (m)
W=32*10^-6; // (m)
V_SS=-2.5; // (V)
V_DD=2.5; // (V)
V_OV=sqrt(I_D*2*L/(uC_n*W));
V_GS=V_t+V_OV;
disp(V_GS,"V_t (V)")
V_S=-1.2; // (V)
R_S=(V_S-V_SS)/I_D;
disp(R_S,"R_S (ohm)")
V_D=0.5; // (V)
R_D=(V_DD-V_D)/I_D;
disp(R_D,"R_D (ohm)")
```

Scilab code Exa 4.3 Design of given circuit

```
// Example 4.3: Design of given circuit to obtain
    I_D=80uA
// FET is operating in saturation region
I_D=80*10^-6; // (A)
V_t=0.6; // (V)
uC_n=200*10^-6; // (A/V^2)
L=0.8*10^-6; // (m)
W=4*10^-6; // (m)
V_DD=3; // (V)
V_OV=sqrt(2*I_D/(uC_n*(W/L)));
V_GS=V_t+V_OV;
V_DS=V_GS;
V_D=V_DS;
disp(V_D,"V_D (V)")
R=(V_DD-V_D)/I_D;
disp(R,"R (ohm)")
```

Scilab code Exa 4.4 Design of given circuit

```
// Example 4.4 : Design of given circuit to obtain
    V_D=0.1V
// MOSFET is operating in triode region
V_D=0.1; // (V)
V_DD=5; // (V)
V_t=1; // (V)
K=1*10^-3; // K=k'_n(W/L)
V_GS=5; // (V)
V_DS=0.1; // (V)
I_D=K*((V_GS-V_t)*V_DS-(V_DS^2)/2);
disp(I_D,"I_D (A)")
R_D=(V_DD-V_D)/I_D;
disp(R_D,"R_D (ohm)")
r_DS=V_DS/I_D;
disp(r_DS,"r_DS (ohm)")
```

Scilab code Exa 4.5 To determine all node voltages and currents throug

```
// Example 4.5: To determine all node voltages and currents through all branches
V_t=1; // (V)
K=1*10^-3; // K=k'_n(W/L)
V_DD=10; // (V)
R_G1=10*10^6; // (ohm)
R_G2=10*10^6; // (ohm)
R_D=6*10^3; // (ohm)
R_S=6*10^3; // (ohm)
p=poly([8 -25 18],'I_D', 'coeff');
I_D=roots(p);
// I_D=0.89mA will result in transistor cut off hence we take the other root of the equation
V_G=V_DD*R_G2/(R_G2+R_G1);
I_D=I_D(1)*10^-3;
disp(I_D,"I_D (A)")
V_S=I_D*R_S;
disp(V_S,"V_S (V)")
V_GS=V_G-V_S;
disp(V_GS,"V_GS (V)")
V_D=V_DD-R_D*I_D;
disp(V_D,"V_D (V)")
// V_D>V_G-V_t the transistor is operating in saturation as initially assumed
```

Scilab code Exa 4.6 Design of given circuit

```
// Example 4.6; Design of given circuit to obtain I_D=0.5mA and V_D=3V
// MOSFET is in saturation
```

```
V_DD=5; // (V)
V_D=3; // (V)
I_D=0.5*10^-3; // (A)
V_t=-1; // (V)
K=1*10^-3; // K=k'_n(W/L)
V_OV=sqrt(2*I_D/K);
V_GS=V_t+(-V_OV)
R_D=V_D/I_D;
V_Dmax=V_D-V_t; // - sign as magnitude of V_t is
    considered
R_D=V_Dmax/I_D;
disp(R_D,"R_D (ohm)")
```

Scilab code Exa 4.7 To determine drain currents and output voltage

```
// Example 4.7: To determine drain currents and
    output voltage
K_n =1*10^-3; // K_n=k_n*W_n/L_n (A/V^2)
K_p = 1*10^-3; // K_p=k_p*W_p/L_p (A/V^2)
V_tn= 1; // (V)
V_tp= -1; // (V)
V_I=-2.5:2.5:2.5; // (V)
V_DD=2.5; // (V)
R=10;// (kilo ohm)
// For V_I=0
I_DP=(K_p*(V_DD-V_tn)^2)/2;
I_DN=I_DP;
disp(I_DP,I_DN,"I_DP (A) and I_DN (A) for V_I=0V")
disp(0,"V_O for V_I =0V")
// For V_I=2.5V
// I_DN=K_N(V_GS-V_tn)V_DS
// I_DN=v_O/R
// Solving the two equations we get
I_DN=0.244*10^-3; // (V)
V_O=-2.44; // (V)
```

```
disp(I_DN,V_O,"V_O and I_DN for V_I=2.5V")
// For V_I=-2.5V Q_N is cut off
I_DP=2.44*10^-3; // (A)
V_O=2.44; // (V)
disp(0,I_DP,V_O,"V_O(V), I_DP (A) and I_DN (A) for
    V_I=-2.5V")
```

Scilab code Exa 4.9 Design of given circuit

```
// Example 4.9 : Design of given circuit to obtain
    I_D=0.5mA
I_d=0.5*10^-3; // (A)
I_S=0.5*10^-3; // (A)
V_t=1:0.5:1.5; // (V)
K_n=1*10^-3; // K_n=k_n*W/L (A/V^2)
V_DD=15; // (V)
V_D=10; // (V)
V_S=5; // (V)
R_D=(V_DD-V_D)/I_d;
R_S=V_S/I_S;
V_OV=sqrt(I_d*2/K_n);
V_GS=V_t+V_OV;
V_G=V_S+V_GS;
// V_t=1.5V
// I_D=K(V_GS-V_t)^2/2
// 7=V_GS+10I_D
// solving above equations
I_D=0.455*10^-3;
deltaI_D=I_D-I_d; // Change in I_D (A)
change=deltaI_D*100/I_d; // Change in %
disp(change,"Change in I_D (%)")
```

Scilab code Exa 4.10 Small signal analysis

```
// Example 4.10 : Small signal analysis
V_t=1.5; // (V)
K=0.00025;//K= k_nW/L (A/V^2)
V_A=50; // (V)
I_D=1.06*10^-3; // (A)
V_D=4.4; // (V)
R_D=10000; // (ohm)
R_L=10000; // (ohm)
V_GS=V_D;
g_m=K*(V_GS-V_t);
r_o=V_A/I_D;
A_v=-g_m*(R_L*R_D*r_o)/(R_D*R_L+R_D*r_o+R_L*r_o);
disp(A_v,"Voltage gain (V/V)")
R_G=10*10^6; //(ohm)
// i_i=v_i*(1-A_v)/R_G
R_in=R_G/(1-(A_v));
disp(R_in,"Input resistance (ohm)")
// v_DSmin=v_GSmin-V_t
v_i=V_t/(1+(-A_v)); // - sign to make A_v positive
disp(v_i," Largest allowable input signal (V)")
```

Scilab code Exa 4.11 To determine all parameters of transistor amplifie

```
// Example 4.11: To determine all parameters of
    transistor amplifier
v_o=90; // (V)
v_i=9; // (V)
R_sig=100*10^3; // (ohm)
R_L=10*10^3; // (ohm)
v_sig=10; // (V)
A_vo=v_o/v_i;
disp(A_vo,"A_vo (V/V)")
G_vo=v_o/A_vo;
disp(G_vo,"G_vo (V/V)")
R_i=G_vo*R_sig/(A_vo-G_vo)
```

```
disp(R_i,"R_i")
disp("assume R_L = 10 kilo ohm is connected")
v_o=70; // (V)
v_i=8; // (V)
A_v=v_o/v_i;
disp(A_v,"A_v (V/V)")
G_v=v_o/A_vo;
disp(G_v,"G_v (V/V)")
R_o=R_L*(A_vo-A_v)/A_v;
disp(R_o,"R_o (ohm)")
R_out=R_L*(G_vo-G_v)/G_v;
disp(R_out,"R_out (ohm)")
R_in=(v_i*100)/(v_sig-v_i);
disp(R_in,"R_in (ohm)")
G_m=A_vo/R_o;
disp(G_m,"G_m (mho)")
A_i=A_v*R_in/R_L;
disp(A_i,"A_i (V/V)")
R_inL0=R_sig/((1+R_sig/R_i)*(R_out/R_o)-1); // R_in|R_L=0 (ohm)
disp(R_inL0,"R_in at R_L=0")
A_is=A_vo*R_inL0/R_o;
disp(A_is,"A_is (A/A)")
```

Scilab code Exa 4.12 Midband gain and upper 3dB frequency

```
// Example 4.12 : Midband gain and upper 3dB frequency
R_sig= 100*10^3; // (ohm)
R_G=4.7*10^6; // (ohm)
R_D=15*10^3; // (ohm)
R_l=15*10^3; // (ohm)
g_m=1*10^-3; // (mho)
r_o=150*10^3; // (ohm)
C_gs=1*10^-12; // (F)
```

```
C_gd=0.4*10^-12; // (F)
R_L= 1/(1/r_o + 1/R_D + 1/R_l)
A_M=R_G/(R_G + R_sig)*g_m*R_L;
disp(A_M,"midband gain A_M (V/V)")
C_eq=(1+g_m*R_L)*C_gd;
C_in=C_gs+C_eq;
f_H=(R_G+R_sig)/(2*%pi*C_in*R_sig*R_G);
disp(f_H,"f_H (Hz)")
```

Scilab code Exa 4.13 Coupling capacitor values

```
// Example 4.13 : Coupling capacitor values
R_G=4.7*10^6; // (ohm)
R_D=15*10^3; // (ohm)
R_L=15*10^3; // (ohm)
R_sig=100*10^3; // (ohm)
g_m=1*10^-3; // (mho)
f_L=100; // (Hz)
C_S=g_m/(2*%pi*f_L)
disp(C_S,"C_S (F)")
f_P2=1/(2*%pi*C_S/g_m);
f_P1=10; // (Hz)
f_P2=10; // (Hz)
C_C1=1/(2*%pi*(R_G+R_sig)*10)
disp(C_C1,"C_C1 (F)")
C_C2=1/(2*%pi*(R_D+R_L)*10)
disp(C_C2,"C_C2 (F)")
```

Chapter 5

Bipolar Junction Transistor

Scilab code Exa 5.1 Design of given circuit with current 2mA

```
// Example 5.1 : Design of given circuit with
   current 2mA
// BJT will be operating in active mode
B=100; // B is beta value
a=B/(B+1); // a is alpha value
v_BE=0.7; // v_BE (V) at i_C=1mA
i_C=1*10^-3:1*10^-3:2*10^-3; // (A)
I_C=2*10^-3; // (A)
V_T=25*10^-3; // (V)
V_C=5; // (V)
V_CC=15; // (V)
V_B=0; // (V)
V_RC=V_CC-V_C;// V_RC is the voltage drop across
   resistor R_C
R_C=V_RC/I_C;
disp(R_C,"Collector Resistance R_C (ohm)")
V_BE=v_BE+V_T*log(i_C(2)/i_C(1));
disp(V_BE,"Base emitter voltage V_BE (V) at i_C=2mA"
   )
V_E=V_B-V_BE;
disp(V_E,"Emitter voltage V_E (V)")
```

```
I_E=I_C/a;
disp(I_E,"Emitter current I_E (A)")
R_E=(V_E-(-V_CC))/I_E;
disp(R_E,"Emitter resistance R_C (ohm)")
```

Scilab code Exa 5.2 Consider a common Emitter circuit

```
// Example 5.2 : Consider a common Emitter circuit
I_S=10^-15; // (A)
R_C=6.8*10^3; // (ohm)
V_CC=10; // (V)
V_CE=3.2; // (V)
V_T=25*10^-3; // (V)

// 5.2a
I_C=(V_CC-V_CE)/R_C;
disp(I_C,"Collector current (A)")
V_BE=V_T*log(I_C/I_S);
disp(V_BE,"V_BE (V)")

// 5.2b
V_in=5*10^-3; // sinuosoidal input 0f peak amplitide
    5mv
A_v=-(V_CC-V_CE)/V_T;
disp(A_v,"Voltage gain")
V_o=-A_v*V_in; // negative sign to make positive
   value of voltage gain
disp(V_o,"Amplitude of output voltage (V)")

// 5.2c
v_CE=0.3// (V)
i_C=(V_CC-v_CE)/R_C;
disp(i_C,"i_C (A)")
v_be=V_T*log(i_C/I_C); // v_BE is positive increment
    in v_BE
```

```
disp(v_be,"required increment (V)")

// 5.2d
v_O=0.99*V_CC;
R_C=6.8*10^3; // (ohm)
i_C=(V_CC-v_O)/R_C;
I_C=1*10^-3; // (A)
disp(i_C,"i_C (A)")
v_be=V_T*log(i_C/I_C);
disp(v_be,"negative increment in v_BE (V)")
```

Scilab code Exa 5.3 Determine RB

```
// Example 5.3 :Determine R_B
// transistor is specified to have B value in the range of 50 to 150
V_C=0.2; // V_C=V_CEsat
V_CC=10; // (V)
R_C=10^3; // (ohm)
V_BB=5; // (V)
V_BE=0.7; // (V)
bmin=50; // range of bete is 50 to 150
I_Csat=(V_CC-V_C)/R_C;
I_BEOS=I_Csat/bmin; // I_B(EOS)=I_BEOS
I_B=10*I_BEOS; // base current for an overdrive factor 10
R_B=(V_BB-V_BE)/I_B;
disp(R_B,"Value of R_B (ohm)")
```

Scilab code Exa 5.4 Analyse the circuit to find node voltages and bran

```
// Example 5.4 : Analyse the circuit to find node voltages and branch currents
```

```
V_BB= 4; // (V)
V_CC=10; // (V)
V_BE=0.7; // (V)
b=100; // beta = 100
R_E=3.3*10^3; // (ohm)
R_C=4.7*10^3; // (ohm)
V_E=V_BB-V_BE;
disp(V_E,"Emitter voltage (V)")
I_E=(V_E-0)/R_E;
disp(I_E,"Emitter current (A)")
a=b/(b+1) // alpha value
I_C=I_E*a;
disp(I_C,"Collector current (A)")
V_C=V_CC-I_C*R_C; // Applying ohm's law
disp(V_C,"Collector voltage (V)")
I_B=I_E/(b+1);
disp(I_B,"Base current (A)")
```

Scilab code Exa 5.5 `Analyse the circuit to find node voltages and bran`

```
// Example 5.5 : Analyse the circuit to find node
   voltages and branch currents
disp("Assuming active mode operation")
V_CC=10; // (V)
R_C=4.7*10^3; // (V)
R_E=3.3*10^3; // (ohm)
V_BE=0.7; // (V)
V_BB=6; // (V)
V_CEsat=0.2; // (V)
V_E=V_BB-V_BE;
disp(V_E,"Emitter voltage (V)")
I_E=V_E/R_E;
disp(I_E,"Emitter current (A)")
V_C=V_CC-I_E*R_C; // I_E=I_C
disp(V_C,"Collector voltage (V)")
```

```
disp("Since V_C < V_B our assumption is wrong\n
    Hence its saturation mode operation")
V_E=V_BB-V_BE;
disp(V_E,"Emitter voltage (V)")
I_E=V_E/R_E;
disp(I_E,"Emitter current (A)")
V_C=V_E+V_CEsat;
disp(V_C,"Collector voltage (V)")
I_C=(V_CC-V_C)/R_C;
disp(I_C,"Collector current (A)")
I_B=I_E-I_C;
disp(I_B,"Base current (A)")
Bforced=I_C/I_B; // transistor is made to operate at
     a forced beta value
disp(Bforced,"forced beta")
```

Scilab code Exa 5.7 Analyse the circuit to find node voltages and bran

```
// Example 5.7: Analyse the circuit to find node
    voltages and branch currents
V_CC=-10; // (V)
R_E=2000; // (ohm)
R_C=1000; // (ohm)
V_EE=10; // (V)
V_E=0.7; // (V) emitter base junction will be
    forward biased with V_E=V_EB=0.7V
disp(V_E,"Emitter base junction is forward biased
    with V_E (V)")
I_E=(V_EE-V_E)/R_E;
disp(I_E,"Emitter current (A)")
B=100; // Assuming beta 100
a=B/(B+1);
I_C=a*I_E; // Assuming the transistor to operate in
    active mode
disp(I_C,"Collector current (A)")
```

```
V_C=V_CC+I_C*R_C;
disp(V_C,"Collector voltage (V)")
I_B=I_E/(B+1);
disp(I_B,"Base current (A)")
```

Scilab code Exa 5.8 Analyse the circuit to find node voltages and bran

```
// Example 5.8 : Analyse the circuit to find node
    voltages and branch currents
V_CC= 10; // (V)
R_C=2000; // (ohm)
V_BB=5; // (V)
V_BE=0.7;
R_B=100*10^3; // (ohm)
B=100; // beta value
I_B=(V_BB-V_BE)/R_B;
disp(I_B,"Base current (A)")
I_C=B*I_B;
disp(I_C,"Collector current (A)")
V_C=V_CC-I_C*R_C;
disp(V_C,"Collector voltage (V)")
V_B=V_BE ; // V_B=V_BE
disp(V_B,"Base voltage (V)")
I_E=(B+1)*I_B;
disp(I_E,"Emitter current (A)")
```

Scilab code Exa 5.9 Analyse the circuit to find node voltages and bran

```
// Example 5.9 :Analyse the circuit to find node
    voltages and branch currents
// assuming that the transistor is saturated
V_CC=-5; // (V)
V_EE=5; // (V)
```

```
R_B=10000; // (ohm)
R_C=10000; // (ohm)
R_E=1000; // (ohm)
V_EB=0.7; // (V)
V_ECsat=0.2; // (V)
// using the relation I_E=I_C+I_B
V_B=3.75/1.2; //(V)
disp(V_B,"Base voltage (V)")
V_E=V_B+V_EB;
disp(V_E,"Emitter voltage (V)")
V_C=V_E-V_ECsat;
disp(V_C,"Collector voltage (V)")
I_E=(V_EE-V_E)/R_E;
disp(I_E,"Emitter current (A)")
I_B=V_B/R_B;
disp(I_B,"Base current (A)")
I_C=(V_C-V_CC)/R_C;
disp(I_C,"Collector current (A)")
Bforced=I_C/I_B; // Value of forced beta
disp(Bforced, "Forced Beta value")
```

Scilab code Exa 5.10 Analyse the circuit to find node voltages and bran

```
// Exampe 5.10 : Analyse the circuit to find node
   voltages and branch currents
V_CC=15; // (V)
R_C=5000; // (ohm)
R_B1=100*10^3; // (ohm)
R_B2=50*10^3; // (ohm)
R_E=3000; // (ohm)
V_BE=0.7; // (V)
B=100; // beta value
V_BB=V_CC*R_B2/(R_B1+R_B2);
disp(V_BB,"V_BB (V)")
R_BB=R_B1*R_B2/(R_B1+R_B2);
```

```
disp(R_BB,"R_BB (ohm)")
I_E=(V_BB-V_BE)/(R_E +(R_BB/(B+1)));
disp(I_E,"Emiter current (A)")
I_B=I_E/(B+1)
disp(I_B,"Base current (A)")
V_B=V_BE+I_E*R_E;
disp(V_B,"Base voltage (V)")
a=B/(B+1); // alpha value
I_C=a*I_E
disp(I_C,"Collector current (A)")
V_C=V_CC-I_C*R_C;
disp(V_C,"Collector voltage (V))")
```

Scilab code Exa 5.11 `Analyse the circuit to find node voltages and bran`

```
// Example 5.11 :Analyse the circuit to find node
   voltages and branch currents
V_CC=15; // (V)
R_C1=5000; // (ohm)
R_B1=100*10^3; // (ohm)
R_B2=50*10^3; // (ohm)
R_E=3000; // (ohm)
V_BE=0.7; // (V)
R_E2=2000; // (ohm)
R_C2=2700; // (ohm)
V_EB=0.7; // (V)
B=100; // beta value
V_BB=V_CC*R_B2/(R_B1+R_B2);
R_BB=R_B1*R_B2/(R_B1+R_B2);
I_E1=(V_BB-V_BE)/(R_E +(R_BB/(B+1)))
disp(I_E1,"I_E1 (A)")
I_B1=I_E1/(B+1)
disp(I_B1,"I_B1 (A)")
V_B1=V_BE+I_E1*R_E;
disp(V_B1,"V_B1 (V)")
```

```
a=B/(B+1); // alpha value
// beta and alpha values are same for the two
    transistors
I_C1=a*I_E1
disp(I_C1,"IC1 (A)")
V_C1=V_CC-I_C1*R_C1;
disp(V_C1,"V_C1 (V))")
V_E2=V_C1+V_EB;
disp(V_E2,"V_E2(V)")
I_E2=(V_CC-V_E2)/R_E2;
disp(I_E2,"I_E2 (A)")
I_C2=a*I_E2;
disp(I_C2,"I_C2 (A)")
V_C2=I_C2*R_C2;
disp(V_C2,"V_C2 (V)")
I_B2=I_E2/(B+1);
disp(I_B2,"I_B2 (A)")
```

Scilab code Exa 5.13 Design of bias network of the amplifier

```
// Example 5.13 : Design of bias network of the
    amplifier
I_E=1*10^-3; // (A)
V_CC=12; // (V)
B=100; // beta value
V_B=4; // (V)
V_BE=0.7; // (V)
R1=80; // (ohm)
R2=40; // (ohm)
V_C=8; // (V)
V_E=V_B-V_BE;
disp(V_E,"Emitter voltage (V)")
R_E=V_E/I_E;
disp(R_E,"Emitter resistance (ohm)")
I_E=(V_B-V_BE)/(R_E+(R1*R2/(R1+R2))/(B+1));
```

```
disp(I_E,"more accurate value for I_E (A) for R1=80
   ohm and R2=40 ohm")
R1=8; // (ohm)
R2=4; // (ohm)
I_E=(V_B-V_BE)/(R_E+(R1*R2/(R1+R2))/(B+1));
disp(I_E,"more accurate value for I_E (A) for R1=8
   ohm and R2=4 ohm")
R_C=(V_CC-V_C)/I_E; // I_E=I_C
disp(R_C,"Collector resistor (ohm)")
```

Scilab code Exa 5.14 Analysis of transistor amplifier

```
// Example 5.14 : Analysis of transistor amplifier
V_CC=10; // (V)
B=100;
R_C=3000; // (ohm)
R_BB=100*10^3; // (ohm)
V_BB=3; // (V)
V_BE=0.7; // (V)
V_T=25*10^-3; // (V)
I_B=(V_BB-V_BE)/R_BB;
disp(I_B,"Base current (A)")
I_C=B*I_B;
disp(I_C,"Collector current (A)")
V_C=V_CC-I_C*R_C;
disp(V_C,"Collecor voltage (V)")
I_E=B*I_C/(B+1);
r_e=V_T/I_E;
disp(r_e,"r_e (ohm)")
g_m=I_C/V_T;
disp(g_m,"g_m (mho)")
r_pi=B/g_m;
disp(r_pi,"r_pi (ohm)")
// v_i is input voltage let us assume it to be 1 V
v_i=1;
```

```
v_be=v_i*r_pi/(r_pi+R_BB)
disp(v_be,"v_be")
v_o=-g_m*R_C*v_be;
disp(v_o,"Output voltage (V)")
A_v=v_o/v_i;
disp(A_v,"Voltage gain")
```

Scilab code Exa 5.17 Amplifier parameters

```
// Example 5.17 : Amplifier parameters
// Transistor amplifier is having a open circuit
   voltage of v_sig of 10mV
v_sig=10*10^-3; // (V)
R_L=10*10^3; // (ohm)
R_sig=100*10^3; // (ohm)
disp("Calculation with R_L infinite")
v_i=9; // (V)
v_o=90; // (V)
A_vo=v_o/v_i;
disp(A_vo,"A_vo (V/V)")
G_vo=v_o/A_vo;
disp(G_vo,"G_vo (V/V)")
R_i=G_vo*R_sig/(A_vo-G_vo)
disp(R_i,"R_i (ohm)")
disp("Calculations with R_L = 10k ohm")
v_o=70*10^-3; // (V)
v_i=8*10^-3; // (V)
A_v=v_o/v_i;
disp(A_v,"Voltage gain A_v (V/V)")
G_v=v_o*10^3/10;
disp(G_v,"G_v (V/V)")
R_o=(A_vo-A_v)*R_L/A_v;
disp(R_o,"R_o (ohm)")
R_out=(G_vo-G_v)*R_L/G_v;
disp(R_out,"R_out (ohm)")
```

```
R_in=v_i*R_sig/(v_sig-v_i);
disp(R_in,"R_in (ohm)")
G_m=A_vo/R_o;
disp(G_m,"G_m (A/V)")
A_i=A_v*R_in/R_L;
disp(A_i,"A_i (A/A)")
R_ino=R_sig/((1+R_sig/R_i)*(R_out/R_o)-1); // R_ino is R_in at R_L=0
disp(R_ino,"R_in at R_L =0")
A_is=A_vo*R_ino/R_o;
disp(A_is,"A_is (A/A)")
```

Scilab code Exa 5.18 Midband gain and 3dB frequency

```
//Example 5.18 : Midband gain and 3dB frequency
// Transistor is biased at I_C=1mA
V_CC=10; // (V)
V_T=25*10^-3;
V_EE=10; // (V)
I=0.001; // (A)
R_B=100000; // (ohm)
R_C=8000; // (ohm)
R_sig=5000; //(ohm)
R_L=5000; // (ohm)
B=100; // beta value
V_A=100; // (V)
C_u=1*10^-12; // (F)
f_T=800*10^6; // (Hz)
I_C=0.001; // (A)
r_x=50; // (ohm)
// Values of hybrid pi model parameters
g_m=I_C/V_T;
r_pi=B/g_m;
r_o=V_A/I_C;
w_T=2*%pi*f_T;
```

```
CpiplusCu=g_m/w_T; // C_u+C_pi
C_pi=CpiplusCu-C_u;
R_l=r_o*R_C*R_L/(r_o*R_C+R_C*R_L+R_L*r_o) // R_l=R_L'
A_M=R_B*r_pi*g_m*R_l/((R_B+R_sig)*(r_pi+r_x+(R_B*R_sig/(R_B+R_sig))));
disp(A_M,"Midband gain (V/V)")
R_seff=(r_pi*(r_x+R_B*R_sig/(R_B+R_sig)))/(r_pi+r_x+R_B*R_sig/(R_B+R_sig)); // Effective source resistance R_seff=R'_sig
C_in=C_pi+C_u*(1+R_l*g_m);
f_H=1/(2*%pi*C_in*R_seff);
disp(f_H,"3dB frequency (Hz)")
```

Scilab code Exa 5.19 To select values of capacitance required

```
// Example 5.19 : To select values of capacitance required
R_B=100000; // (ohm)
r_pi=2500; // (ohm)
R_C=8000; // (ohm)
R_L=5000; // (ohm)
R_sig=5000; // (ohm)
B=100; // beta value
g_m=0.04; // (A/V)
r_pi=2500; //(ohm)
f_L=100; // (Hz)
r_e=25; // (ohm)
R_C1=R_B*r_pi/(R_B+r_pi)+R_sig; // Resistance seen by C_C1
R_E=r_e+R_B*R_sig/((R_B+R_sig)*(B+1)); // Resistance seen by C_E
R_C2=R_C+R_L;// Resistance seen by C_C2
w_L=2*%pi*f_L;
C_E=1/(R_E*0.8*w_L); //C_E is to contribute only 80%
```

```
    of the value of w_L
disp(C_E,"C_E (F)")
C_C1=1/(R_C1*0.1*w_L); //C_C1 is to contribute only
    10% of the value of f_L
disp(C_C1,"C_C1 (F)")
C_C2=1/(R_C2*0.1*w_L); //C_C2 should contribute only
    10% of the value of f_L
disp(C_C2,"C_C2 (F)")
```

Chapter 6

single stage integrated circuit amplifiers

Scilab code Exa 6.1 To find the operating point of NMOS transistor

```
// Example 6.1: To find the operating point of NMOS
   transistor
// Consider NMOS transistor

// 6.1a
I_D=100*10^-6; // (A)
K_n=387*10^-6*10; // K_n=u_n*C_ox(W/L) (A/V^2)
V_th=0.48; // (V)
V_OV=sqrt(2*I_D/K_n);
disp(V_OV,"V_OV (V)")
V_GS=V_th+V_OV;
disp(V_GS,"V_GS (V)")

// 6.1b
I_C=100*10^-6; // (A)
I_S=6*10^-18 // (A)
V_T=0.025; // (V)
V_BE=V_T*log(I_C/I_S);
disp(V_BE,"V_BE (V)")
```

Scilab code Exa 6.2 Comparison between NMOS transistor and npn transis

```
// Example 6.2 : Comparison between NMOS transistor and npn transistor

disp("For NMOS transistor")
I_D=100*10^-6; // (A)
V_a=5; // V'_A=V_a (A)
L=0.4; // (um)
V_T=0.025;
K_n=267*4/0.4*10^-6; // K_n=u_n*C_ox*(W/L) (A/V^2)
V_OV=sqrt(2*I_D/K_n);
g_m=sqrt(2*K_n*I_D)
disp(g_m,"g_m (A/V)")
disp("R_in is infinite")
r_o=V_a*L/I_D;
disp(r_o,"r_o (ohm)")
A_O=g_m*r_o;
disp(A_O,"A_O (V/V)")
disp("For npn transistor")
I_C=0.1*10^-3; // collector current
B_o=100; // beta value
V_A=35; // (V)
g_m=I_C/V_T;
disp(g_m,"g_m (A/V)")
R_in=B_o/g_m;
disp(R_in,"R_in (ohm)")
r_o=V_A/I_C;
disp(r_o,"r_o (ohm)")
A_O=g_m*r_o;
disp(A_O,"A_O (V/V)")
```

Scilab code Exa 6.3 Comparison between NMOS transistor and npn transis

```
// Example 6.3 : Comparison between NMOS transistor
   and npn transistor
// For npn transistor
disp("For npn transistor")
I_C=10*10^-6; // (A)
V_T=0.025; // (V)
V_A=35; // (V)
C_je0=5*10^-15; // (F)
C_u0=5*10^-15; // (F)
C_L=1*10^-12; // (F)
disp("The data calculated for I_C=10uA")
g_m=I_C/V_T;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_C;
disp(r_o,"r_o (ohm)")
A_0=V_A/V_T;
disp(A_0,"A_O (V/V)")
T_F=10*10^-12;
C_de=T_F*g_m;
disp(C_de,"C_de (F)")
C_je=2*C_je0;
disp(C_je,"C_je (F)")
C_pi=C_de+C_je;
disp(C_pi,"C_pi (F)")
C_u=C_u0;
disp(C_u,"C_u (F)")
f_T=g_m/(2*%pi*(C_pi+C_u));
disp(f_T,"f_T (Hz)")
f_t=g_m/(2*%pi*C_L);
disp(f_t,"f_t (Hz)")
disp("The data calculated for I_C=100uA")
I_C=100*10^-6;
g_m=I_C/V_T;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_C;
disp(r_o,"r_o (ohm)")
```

```
A_O=V_A/V_T;
disp(A_O,"A_O (V/V)")
T_F=10*10^-12;
C_de=T_F*g_m;
disp(C_de,"C_de (F)")
C_je=2*C_je0;
disp(C_je,"C_je (F)")
C_pi=C_de+C_je;
disp(C_pi,"C_pi (F)")
C_u=C_u0;
disp(C_u,"C_u (F)")
f_T=g_m/(2*%pi*(C_pi+C_u));
disp(f_T,"f_T (Hz)")
f_t=g_m/(2*%pi*C_L);
disp(f_t,"f_t (Hz)")
disp("The data calculated for I_C=1mA")
I_C=1*10^-3;
g_m=I_C/V_T;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_C;
disp(r_o,"r_o (ohm)")
A_O=V_A/V_T;
disp(A_O,"A_O (V/V)")
T_F=10*10^-12;
C_de=T_F*g_m;
disp(C_de,"C_de (F)")
C_je=2*C_je0;
disp(C_je,"C_je (F)")
C_pi=C_de+C_je;
disp(C_pi,"C_pi (F)")
C_u=C_u0;
disp(C_u,"C_u (F)")
f_T=g_m/(2*%pi*(C_pi+C_u));
disp(f_T,"f_T (Hz)")
f_t=g_m/(2*%pi*C_L);
disp(f_t,"f_t (Hz)")
// For NMOS transistor
L=0.4*10^-6; // (m)
```

```
C_L=1*10^-12; // (F)
disp("The data calculated for I_D = 10uA")
I_D=10*10^-6; // (A)
WbyL=0.12*I_D; // WbyL=(W/L)
disp(WbyL*10^6,"(W/L)")
g_m=8*I_D;
disp(g_m,"g_m (A/V)")
r_o=2/I_D;
disp(r_o,"r_o (ohm)")
A_O=g_m*r_o;
disp(A_O,"A_O (V/V)")
C_gs=(2/3)*WbyL*0.4*0.4*5.8+0.6*WbyL*0.4;
disp(C_gs,"C_gs (fF)")
C_gd=0.6*WbyL*0.4;
disp(C_gd,"C_gd (fF)")
f_T=g_m/(2*%pi*(C_gs*10^-15+C_gd*10^-15));
disp(f_T,"f_T (Hz)")
f_t=g_m/(2*%pi*C_L)
disp(f_t,"f_t (Hz)")
disp("The data calculated for I_D = 100uA")
I_D=100*10^-6; // (A)
WbyL=0.12*I_D; // WbyL=(W/L)
disp(WbyL*10^6,"(W/L)")
g_m=8*I_D;
disp(g_m,"g_m (A/V)")
r_o=2/I_D;
disp(r_o,"r_o (ohm)")
A_O=g_m*r_o;
disp(A_O,"A_O (V/V)")
C_gs=(2/3)*WbyL*0.4*0.4*5.8+0.6*WbyL*0.4;
disp(C_gs,"C_gs (fF)")
C_gd=0.6*WbyL*0.4;
disp(C_gd,"C_gd (fF)")
f_T=g_m/(2*%pi*(C_gs*10^-15+C_gd*10^-15));
disp(f_T,"f_T (Hz)")
f_t=g_m/(2*%pi*C_L)
disp(f_t,"f_t (Hz)")
disp("The data calculated for I_D = 1mA")
```

```
I_D=1*10^-3; // (A)
WbyL=0.12*I_D; // WbyL=(W/L)
disp(WbyL*10^6,"(W/L)")
g_m=8*I_D;
disp(g_m,"g_m (A/V)")
r_o=2/I_D;
disp(r_o,"r_o (ohm)")
A_O=g_m*r_o;
disp(A_O,"A_O (V/V)")
C_gs=(2/3)*WbyL*0.4*0.4*5.8+0.6*WbyL*0.4;
disp(C_gs,"C_gs (fF)")
C_gd=0.6*WbyL*0.4;
disp(C_gd,"C_gd (fF)")
f_T=g_m/(2*%pi*(C_gs*10^-15+C_gd*10^-15));
disp(f_T,"f_T (Hz)")
f_t=g_m/(2*%pi*C_L)
disp(f_t,"f_t (Hz)")
```

Scilab code Exa 6.4 Design of the circuit with output current 100uA

```
// Example 6.4 : Design of the circuit with output
    current =100uA

V_DD=3; // (V)
I_REF=100*10^-6; // (A)
I_D1=100*10^-6; // (A)
L=1*10^-6; // (m)
W=10*10^-6; // (m)
V_t=0.7; // (V)
k_n=200*10^-6; // k_n=k'_n (A/V^2)
V_A=20; // V_A=V'_A (V)
V_OV=sqrt(I_D1*2*L/(k_n*W));
V_GS=V_t+V_OV;
R=(V_DD-V_GS)/I_REF;
V_Omin=V_OV;
```

```
disp(V_Omin,"V_min (V)")
r_o2=V_A/I_REF;
disp(r_o2,"r_o2 (ohm)")
V_O=V_GS;
deltaV_O=1; // Change in V_O (V)
deltaI_O=deltaV_O/r_o2; // Corresponding change in
   I_O (A)
disp(deltaI_O,"The correspondng change in I_O (A)")
```

Scilab code Exa 6.5 Determine 3dB frequency

```
// Example 6.5 : Determine 3dB frequency
// High frequency response of an amplifier can be
   characterized by th transfer function
// F_H(s)=(1-s/10^5)/(1+s/10^4)(1+s/4*10^4)
w_H=1/sqrt(1/10^8+1/(16*10^8)-2/10^10); // w_H=1/
   sqrt(1/w_P1^2+1/w_P2^2-2/w_Z1^2-2w_Z2^2)
disp(w_H,"w_H (rad/s)")
```

Scilab code Exa 6.6 To determine midband gain and upper 3dB frequency

```
// Example 6.6 : To determine midband gain and upper
    3dB frequency
R_in=420*10^3; // (ohm)
R_sig=100*10^3; // (ohm)
g_m=4*10^-3; // (mho)
R_L=3.33*10^3; // R_L=R'_L (ohm)
C_gs=1*10^-12; // F
C_gd=C_gs;
A_M=-R_in*g_m*R_L/(R_in+R_sig)
disp(A_M,"Midband frequency gain A_M (V/V)")
R_gs=R_in*R_sig/(R_in+R_sig);
R=R_gs; //R=R'
```

```
T_gs=C_gs*R_gs; // Oen circuit time constant of C_gs (s)
R_gd=R+R_L+g_m*R_L*R;
T_gd=R_gd*C_gd; // open circuit time constant of C_gd (s)
w_H=1/(T_gs+T_gd); // upper 3dB frequency w_H
f_H=w_H/(2*%pi);
disp(f_H,"Upper 3dB frequency f_H (Hz)")
```

Scilab code Exa 6.7 `Application of miller theorem`

```
// Example 6.7 : Application of miller's theorem

// 6.7a
// By miller's theorem
Z=1000*10^3; // (ohm)
K=-100; // (V/V)
R_sig=10*10^3; // (ohm)
Z_1=Z/(1-K);
disp(Z_1,"Z_1 (ohm)")
Z_2=Z/(1-(1/K));
disp(Z_2,"Z_2 (ohm)")
VobyVsig=-100*Z_1/(Z_1+R_sig); // VobyVsig=(V_o/V_sig)
disp(VobyVsig,"(V_o/V_sig) (V/V)")

//6.7b
// Applying miller's theorem
f_3dB=1/(2*%pi*1.01*10^-6);
disp(f_3dB,"f_3dB (Hz)")
```

Scilab code Exa 6.8 `Analysis of CMOS CS amplifier`

```
// Example 6.8 : Analysis of CMOS CS amplifier
k_n=200*10^-6; // (A/V^2)
W=4*10^-6; // (m)
L=0.4*10^-6; // (m)
I_REF=100*10^-6; // (A)
V_An=20; // (A)
I_D1=0.1*10^-3; // (A)
V_Ap=10; // (V)
V_DD=3; // (V)
I_D2=0.1*10^-3; // (A)
V_tp=0.6; // (V)
V_tn=0.6; // (V)
g_m1=sqrt(2*k_n*(W/L)*I_REF);
disp(g_m1,"g_m1 (A/V)")
r_o1=V_An/I_D1;
disp(r_o1,"r_o1 (ohm)")
r_o2=V_Ap/I_D2;
disp(r_o2,"r_o2 (ohm)")
A_v=-g_m1*r_o1*r_o2/(r_o1+r_o2);
disp(A_v,"A_v (v/V)")
I_D=100*10^-6; // (A)
k_n=65*10^-6; // (A/V^2)
V_OV3=0.53; // (V)
V_SG=V_tp+V_OV3;
disp(V_SG,"V_SG (V)")
V_OA=V_DD-V_OV3;
disp(V_OA,"V_OA (V)")
V_IB=0.93; // (V)
V_IA=0.88; // (V)
disp(V_IA,V_IB,"Coordinates of the extremities of
    the amplifier V_IB and V_IA")
deltavI=V_IB-V_IA; // width of amplifier region
V_OB=0.33; // (V)
deltavO=V_OB-V_OA; // corresponding output range (V)
deltavObydeltavI=-deltavO/deltavI; // Large signal
    voltage gain (V/V)
disp(deltavObydeltavI,"Large signal voltage gain (V/
    V)")
```

Scilab code Exa 6.9 Analysis of CMOS CS amplifier

```
// Example 6.9: Analysis of CMOS CS amplifier
// Consider CMOS open source amplifier
I_D=100*10^-6; // (A)
I_REF=I_D;
uC_n=387*10^-6; // u_n*C_ox=uC_n (A/V^2)
uC_p=86*10^-6; // u_n*C_ox=uC_n (A/V^2)
W=7.2*10^-6; // (m)
L=0.36*10^-6; // (m)
V_An=5*10^-6; // (A)
R_sig=10*10^3; // (ohm)
V_OV=sqrt(2*I_D*L/(W*uC_n));
g_m=I_D/(V_OV/2);
disp(g_m,"g_m (A/V)")
r_o1=5*0.36/(0.1*10^-3);
disp(r_o1,"r_o1 (ohm)")
r_o2=6*0.36/(.1*10^-3);
disp(r_o2,"r_o2 (ohm)")
R_L=r_o1*r_o2/(r_o1+r_o2);
disp(R_L,"R_L (ohm)")
A_m=-g_m*R_L;
disp(A_m,"A_m (V/V)")
C_gs=20*10^-15; // (F)
C_gd=5*10^-15; // (F)
C_in=C_gs+C_gd*(1+g_m*R_L); // using miller
    equivalence
disp(C_in,"C_in (F)")
f_H=1/(2*%pi*C_in*R_sig);
disp(f_H,"f_H (Hz)")
R_gs=10*10^3; // (ohm) using open circuit  time
    constants methods
R_L=9.82*10^3; // (ohm)
R_gd=R_sig*(1+g_m*R_L) + R_L;
```

```
disp(R_gd,"R_gd (ohm)")
R_CL=R_L;
T_gs=C_gs*R_gs;
disp(T_gs,"T_gs (s)")
T_gd=C_gd*R_gd;
disp(T_gd,"T_gd (s)")
C_L=25*10^-15;
T_CL=C_L*R_CL;
disp(T_CL,"T_CL (s)")
T_H=T_gs+T_gd+T_CL;
disp(T_H,"T_H (s)")
f_H=1/(2*%pi*T_H); // 3dB frequency
disp(f_H,"f_H (Hz)")
f_Z=g_m/(2*%pi*C_gd); // frequency of the zero
disp(f_Z,"f_Z (Hz)")
// Denominator polynomial
p=poly([1 1.16*10^-9 0.0712*10^-18],'s','coeff')
disp(p,"Denominator polynomial")
s=roots(p);
f_P2=s(2)/(-2*%pi);
f_P1=s(1)/(-2*%pi)
disp(f_P2,f_P1, "The frequencies f_P1  (Hz) and f_P2
    (Hz) are found as the roots of the denominator
   frequency")
f_H=f_P1;
disp(f_H,"Another estimate for f_H (Hz)")
```

Scilab code Exa 6.10 To determine AM ft fZ f3dB

```
// Example 6.10 : To determine A_M, f_t , f_Z , f_3dB
// Consider the CS amplifier
A_M=-12.3;// (V/V) found from Example 6.9
C_L=25*10^-15; // (F)
C_gd=5*10^-15; // (F)
R_L=9.82*10^3; // (F)
```

```
g_m=1.25*10^-3; // (mho)
f_H=1/(2*%pi*(C_L+C_gd)*R_L); // 3dB frequency
disp(f_H,"f_H (Hz)")
f_t=-A_M*f_H; // Unity-gain frequency - sign to make
    gain positive as only magnitude is considered
disp(f_t,"f_t (Hz)")
f_Z=g_m/(2*%pi*C_gd); // frequency of the zero
disp(f_Z,"f_Z (Hz)")
I_D=400*10^-6; // I_D must be quadrupled by changing
    I_REF to 400uF
V_OV=0.32;
g_m=I_D/(V_OV/2);
disp(g_m,"g_m (A/V)")
r_o1=5*0.36/(0.4*10^-3);
disp(r_o1,"r_o1 (ohm)")
r_o2=6*0.36/(0.4*10^-3);
disp(r_o2,"r_o2 (ohm)")
R_L=(r_o1*r_o2)/(r_o1+r_o2);
disp(R_L,"R_L (ohm)")
A_M=-g_m*R_L;
disp(A_M,"A_M (V/V)")
f_H=1/(2*%pi*(C_L+C_gd)*R_L);
disp(f_H,"f_H (Hz)")
f_t=f_H*-A_M; // Unity gain frequency
disp(f_t,"f_t (Hz)")
```

Scilab code Exa 6.11 Avo Rin Rout Gi Gis Gv fH

```
// Example 6.11 : Avo Rin Rout Gi Gis Gv fH
// Consider the common gate amplifier
g_m=1.25*10^-3; // (A/V)
r_o=18000; // (ohm)
I_D=100*10^-6; // (A)
X=0.2;
R_S=10*10^3; // (ohm)
```

```
R_L=100*10^3; // (ohm)
C_gs=20*10^-15;// (F)
C_gd=5*10^-15;// (F)
C_L=0; // (F)
gmplusgmb=g_m+0.2*g_m; // gmplusgmb=g_m+g_mb
A_vo=1+(gmplusgmb)*r_o;
disp(A_vo,"A_vo (V/V)")
R_in=(r_o+R_L)/A_vo;
disp(R_in,"R_in (ohm)")
R_out=r_o+A_vo*R_S;
disp(R_out,"ohm")
G_v=A_vo*R_L/(R_L+R_out);
disp(G_v,"G_v (V/V)")
G_is=A_vo*R_S/R_out;
disp(G_is,"G_is (A/A)")
G_i=G_is*R_out/(R_out+R_L)
disp(G_i,"G_i (A/A)")
R_gs=R_S*R_in/(R_S+R_in);
R_gd=R_L*R_out/(R_L+R_out);
T_H=C_gs*R_gs+C_gd*R_gd;
f_H=1/(2*%pi*T_H);
disp(f_H,"f_H (Hz)")
```

Scilab code Exa 6.12 Comparison between Cascode amplifier and CS amplif

```
// Example 6.12 : Comparison between Cascode
   amplifier and CS amplifier
// 6.12a
// CS amplifier
g_m=1.25*10^-3;
r_o=20*10^3;
R_L=r_o*r_o/(r_o+r_o);
C_gs=20*10^-15;
R_sig=10000;
C_gd=5*10^-15;
```

```
C_L=5*10^-15;
C_db=5*10^-15;
A_o=g_m*r_o;
disp(A_o,"A_o (V/V)")
A_v=-A_o/2;
disp(A_v,"A_v (V/V)")
T_H=C_gs*R_sig+C_gd*[(1+g_m*R_L)*R_sig+R_L]+(C_L+C_db)*R_L;
disp(T_H,"T_H (s)")
f_H=1/(2*%pi*T_H);
disp(f_H,"f_H (Hz)")
f_t=-A_v*f_H;
disp(f_t,"f_t (Hz)")
// Cascode amplifier
g_m1=1.25*10^-3;
r_o1=20000;
X=0.2;
r_o2=20000;
R_L=20000;
A_o1=g_m1*r_o1;
disp(A_o1,"A_o1 (V/V)")
gm2plusgmb2=g_m1+X*g_m;
A_vo2=1+(gm2plusgmb2)*r_o2;
disp(A_vo2,"A_vo2 (V/V)")
R_out1=r_o1;
R_in2=1/(gm2plusgmb2)+R_L/A_vo2;
disp(R_in2,"R_in2 (ohm)")
R_d1=R_out1*R_in2/(R_out1+R_in2);
disp(R_d1,"R_d1 (ohm)")
R_out=r_o2+A_vo2*r_o1;
disp(R_out,"R_out (ohm)")
vo1byvi=-g_m1*R_d1;
disp(vo1byvi,"(v_o1/v_i) (V/V)")
A_v=-A_o1*A_vo2*R_L/(R_L+R_out);
disp(A_v,"A_v (V/V)")
C_gs1=20*10^-15;
R_sig=10*10^3;
gm1Rd1=1.5;
```

```
C_gd1=5*10^-15;
C_gs2=20*10^-15;
C_db2=5*10^-15;
C_gd2=5*10^-15;
C_db1=5*10^-15;
T_H=R_sig*[C_gs1+C_gd1*(1+gm1Rd1)]+R_d1*(C_gd1+C_db1
    +C_gs2)+((R_L*R_out)/(R_L+R_out))*(C_L+C_db2+
    C_gd2);
f_H=1/(2*%pi*T_H);
disp(T_H,"T_H (s)")
disp(f_H,"f_H (Hz)")
f_t=-A_v*f_H;
disp(f_t,"f_t (Hz)")
// 6.12b
// CS amplifier
A_v=-12.5;
R_L=10*10^3;
disp(A_v,"A_v (V/V)")
T_H=(C_gd+C_L+C_db)*R_L;
disp(T_H,"T_H (s)")
f_H=1/(2*%pi*T_H);
disp(f_H,"F_H (Hz)")
f_t=-A_v*f_H;
disp(f_t,"f_t (Hz)")
// Cascode amplifier
R_L=640*10^3;
R_out=640*10^3;
R_out1=20*10^3;
A_v=-A_o1*A_vo2*R_L/(R_L+R_out);
disp(A_v,"A_v (V/V)")
R_in2=1/gm2plusgmb2+R_L/A_vo2;
disp(R_in2,"R_in2 (ohm)")
R_d1=R_in2*R_out1/(R_in2+R_out1);
disp(R_d1,"R_d1 (ohm)")
T_H=R_d1*(C_gd1+C_db1+C_gs2)+(R_L*R_out/(R_L+R_out))
    *(C_L+C_gd2+C_db2);
disp(T_H,"T_H (s)")
f_H=1/(2*%pi*T_H);
```

```
disp(f_H,"f_H (Hz)")
f_t=-A_v*f_H;
disp(f_t,"f_t (Hz)")
```

Scilab code Exa 6.13 Analysis of CC CE amplifier

```
// Example 6.13: Analysis of CC-CE amplifier
// Consider a CC-CE amplifier
// at an emitter bias current of 1mA for Q_1 and Q_2
g_m=40*10^-3; // (A/V)
r_e=25; // (ohm)
B=100; // beta value
C_u=2*10^-12; // (F)
f_T=400*10^6 // (Hz)
r_pi= B/g_m;
disp(r_pi,"r_pi (ohm)")
C_pi=g_m/(2*%pi*f_T)-C_u;
disp(C_pi,"C_pi (F)")
R_in2=2500; // (ohm)
r_pi2=2500; // (ohm)
r_pi1=2500; // (ohm)
r_e1=0.025; // (ohm)
B_1=100; // beta value
R_in=(B_1+1)*(r_e1+R_in2);
disp(R_in,"R_in (ohm)")
R_sig=4*10^3; // (ohm)
R_L=4000; // (ohm)
Vb1byVsig=R_in/(R_in+R_sig); // (V_b1/V_sig)
disp(Vb1byVsig,"(V_b1/V_sig) (V/V)")
Vb2plusVb1=R_in2/(R_in2+r_e1); // (V_b2/V_b1)
disp(Vb2plusVb1,"(V_b2/V_b1) (V/V)")
VobyVb2=-g_m*R_L; // (V_o/V_b2)
disp(VobyVb2,"(V_o/V_b2) (V/V)")
A_M=VobyVb2*Vb2plusVb1*Vb2plusVb1;
disp(A_M,"A_M (V/V)")
```

```
R_u1=R_sig*R_in/(R_sig+R_in);
disp(R_u1,"R_u1 (ohm)")
R_pi1=(R_sig+R_in2)/(1+(R_sig/r_pi1)+(R_in2/r_e1)); // C_pi1 sees a resistance R_pi1
disp(R_pi1,"R_pi1 (ohm)")
R_out1=25+4000/101;
R_pi2=R_in2*R_out1/(R_in2+R_out1); // C_pi2 sees a resistance R_pi2
disp(R_pi2,"R_pi2 (ohm)")
R_u2=(1+g_m*R_L)*R_pi2+R_L;
disp(R_u2,"R_u2 (ohm)")
C_u1=2*10^-12; // (F)
R_u1=3940; // (ohm)
C_pi1=13.9*10^-12; // (F)
C_u2=2*10^-12; // (F)
C_pi2=13.9*10^-12; // (F)
T_H=C_u1*R_u1+C_pi1*R_pi1+C_u2*R_u2+C_pi2*R_pi2;
disp(T_H,"T_H (s)")
f_H=1/(2*%pi*T_H);
disp(f_H,"f_H (Hz)")
A_M=r_pi*(-g_m*R_L)/(r_pi+R_sig);
disp(A_M,"A_M (V/V)")
R_pi=r_pi*R_sig/(r_pi+R_sig);
disp(R_pi,"R_pi (ohm)")
R_u=(1+g_m*R_L)*R_pi +R_L;
disp(R_u,"R_u (ohm)")
T_H=C_pi*R_pi+C_u*R_u;
disp(T_H,"T_H (s)")
f_H=1/(2*%pi*T_H);
disp(f_H,"f_H (Hz)")
```

Scilab code Exa 6.14 To determine required resistor values

```
// Example 6.14 : To determine required resistor values
```

```
//  The circuits generate a constant current I_D=10
    uA which operate at a supply of 10V
V_BE=0.7; // (V)
V_t=0.025; // (V)
I_REF=10*10^-6; // (A)
V_DD=10; // (V)
I=1*10^-3; // (A)
V_BE1=V_BE+V_t*log(I_REF/I); // Voltage drop across
    Q_1
disp(V_BE1,"V_BE1 (V)")
R_1=(V_DD-V_BE1)/(I_REF); // For the Widlar circuit
    we decide I_REF=1mA and V_BE1=0.7V
disp(R_1,"R_1 (ohm)")
R_2=(V_DD-V_BE)/I;
disp(R_2,"R_2 (ohm)")
R_3=(V_t/I_REF)*log(I/I_REF);
disp(R_3,"R_3 (ohm)")
```

Chapter 7

Differential and multistage amplifier

Scilab code Exa 7.1 `Analysis of differential amplifier`

```
// Example 7.1 Analysis of differential amplifier
// Consider the differential amplifier
B=100; // beta value

// 7.1a
V_T=0.025; // (V)
I_E=0.0005; // (A)
R_E=150; // (ohm)
r_e1=V_T/I_E;  // emitter resistance (ohm)
r_e2=r_e1; // emitter resistance (ohm)
r_e=r_e1;
R_id=2*(B+1)*(r_e+R_E);
disp(R_id,"The input differential resistance R_id (
   ohm)")

// 7.1b
R_id=40000; // (ohm)
R_sig=5000; // (ohm)
R_C=10000; // (ohm)
```

```
R_E=150; // (ohm)
A_v=R_id/(R_id+R_sig); // A_v= v_o/v_sig (V/V)
A_V=2*R_C/(2*(r_e+R_E)); // A_V= v_o/v_id (V/v)
A_d=A_v*A_V; // A_d=v_o/v_sig (V/V)
disp(A_d,"Overall differential voltage gain (V/V)")

// 7.1c
R_EE=200000; // (ohm)
deltaR_C=0.02*R_C; // in the worst case
A_cm=R_C*deltaR_C/(2*R_EE*R_C)
disp(A_cm,"Worst case common mode gain (V/V)")

// 7.1d
CMRR=20*log10(A_d/A_cm)
disp(CMRR,"CMRR in dB")

// 7.1e
r_o=200000; //(ohm)
R_icm=(B+1)*(R_EE*r_o/2)/(R_EE+r_o/2);
disp(R_icm,"Input common mode resistance (ohm)")
```

Scilab code Exa 7.2 Analysis of Active loaded MOS differential amplifi

```
// Example 7.2 : Analysis of Active loaded MOS differential amplifier
W=7.2*10^-6; // (m)
L=0.36*10^-6; // (m)
C_gs=29*10^-15; // (F)
C_gd=5*10^-15; // (F)
C_db=5*10^-15;  // (F)
uC_n=387*10^-6; // uC_n=u_nC_ox (A/V^2)
uC_p=86*10^-6; // uC_p=u_pC_ox (A/V^2)
V_an=5; // V_an=V'_An (V/um) (V)
V_ap=6; // V_ap=V'_Ap (V/um) (V)
I=0.2*10^-3; // (A)
```

```
R_SS=25000; // (ohm)
C_SS=0.2*10^-12; // (F)
C_S=25*10^-15; // (F)
K_n=uC_n*W/L;
I_D=100*10^-6; // bias current (A)
V_OV=sqrt(2*I_D/K_n);
g_m=I/V_OV;
g_m1=g_m;
g_m2=g_m;
r_o1=V_an*0.36/(0.1*10^-3);
r_o2=r_o1;
K_p=uC_p*W/L;
V_OV34=sqrt(2*I_D/K_p); // V_OV3,4
g_m3=2*0.1*10^-3/V_OV34;
g_m4=g_m3;
r_o3=V_ap*0.36/(0.1*10^-3);
r_o4=r_o3;
A_d=g_m*(r_o2*r_o4)/(r_o2+r_o4);
disp(A_d,"A_d (V/V)")
A_cm=-1/(2*g_m3*R_SS);
disp(A_cm,"A_cm (V/V)")
CMRR=20*log10(-A_d/A_cm); // negative sign to make A_cm positive
disp(CMRR,"CMRR in dB")
C_gd1=5*10^-15; // (F)
C_db1=5*10^-15; // (F)
C_db3=5*10^-15; // (F)
C_gs3=20*10^-15; // (F)
C_gs4=20*10^-15; // (F)
C_m=C_gd1+C_db1+C_db3+C_gs3+C_gs4;
C_gd2=5*10^-15; // (F)
C_db2=5*10^-15; // (F)
C_gd4=5*10^-15; // (F)
C_db4=5*10^-15; // (F)
C_x=25*10^-15; // (F)
C_L=C_gd2+C_db2+C_gd4+C_db4+C_x;
disp("poles and zeroes of A_d")
R_o=r_o2*r_o4/(r_o2+r_o4)
```

```
f_p1=1/(2*%pi*C_L*R_o);
disp(f_p1,"f_p1 (Hz)")
f_p2=g_m3/(2*%pi*C_m);
disp(f_p2,"f_p2 (Hz)")
f_Z=2*f_p2;
disp(f_Z,"f_Z (Hz)")
disp("Dominant pole of CMRR is at location of commom
    -mode gain zero")
f_Z=1/(2*%pi*C_SS*R_SS);
disp(f_Z,"f_Z (Hz)")
```

Scilab code Exa 7.3 To determine all parameters for different transist

```
// Example 7.3 : To determine all parameters for
    different transistor
I_REF=90*10^-6; // (A)
V_tn=0.7; // (V)
V_tp=0.8; // Magnitude is cconsidered
uC_n=160*10^-6; // uC_n=u_n*C_ox
uC_p=40*10^-6; // uC_p=u_p*C_ox
V_A=10; // (V)
V_DD=2.5; // (V)
V_SS=2.5; // (V)
L=0.8*10^-6; // (m)
r_o2=222; // (ohm)
r_o4=222; // (ohm)
g_m1=0.3; // (mho)
A_1=-g_m1*r_o2*r_o4/(r_o2+r_o4);
disp(A_1,"A_1 (V/V)")
r_o6=111; // (ohm)
r_o7=111; // (ohm)
g_m6=0.6; // (mho)
A_2=-g_m6*r_o6*r_o7/(r_o6+r_o7);
disp(A_2,"A_2 (V/V)")
disp("For Q_1")
```

```
W=20*10^-6; // (m)
I_D=I_REF/2; // (A)
disp(I_D,"I_D (A)")
K_p=uC_p*W/L;
V_OV=sqrt(2*I_D/K_p);
disp(V_OV,"V_OV (V)")
V_GS=V_tp+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
disp("For Q_2")
W=20*10^-6; // (m)
I_D=I_REF/2; // (A)
disp(I_D,"I_D (A)")
K_p=uC_p*W/L;
V_OV=sqrt(2*I_D/K_p);
disp(V_OV,"V_OV (V)")
V_GS=V_tp+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
disp("For Q_3")
W=5*10^-6; // (m)
I_D=I_REF/2; // (A)
disp(I_D,"I_D (A)")
K_n=uC_n*W/L;
V_OV=sqrt(2*I_D/K_n);
disp(V_OV,"V_OV (V)")
V_GS=V_tn+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
```

```
disp("For Q_4")
W=5*10^-6; // (m)
I_D=I_REF/2; // (A)
disp(I_D,"I_D (A)")
K_n=uC_n*W/L;
V_OV=sqrt(2*I_D/K_n);
disp(V_OV,"V_OV (V)")
V_GS=V_tn+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
disp("For Q_5")
W=40*10^-6; // (m)
I_D=I_REF; // (A)
disp(I_D,"I_D (A)")
K_p=uC_p*W/L;
V_OV=sqrt(2*I_D/K_p);
disp(V_OV,"V_OV (V)")
V_GS=V_tp+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
disp("For Q_6")
W=10*10^-6; // (m)
I_D=I_REF;
disp(I_D,"I_D (A)")
K_n=uC_n*W/L;
V_OV=sqrt(2*I_D/K_n);
disp(V_OV,"V_OV (V)")
V_GS=V_tn+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
```

```
disp(r_o,"r_o (ohm)")
disp("For Q_7")
W=40*10^-6; // (m)
I_D=I_REF;
disp(I_D,"I_D (A)")
K_p=uC_p*W/L;
V_OV=sqrt(2*I_D/K_p);
disp(V_OV,"V_OV (V)")
V_GS=V_tp+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
disp("For Q_8")
W=40*10^-6; // (m)
I_D=I_REF;
disp(I_D,"I_D (A)")
K_p=uC_p*W/L;
V_OV=sqrt(2*I_D/K_p);
disp(V_OV,"V_OV (V)")
V_GS=V_tp+V_OV;
disp(V_GS,"V_GS (V)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
A_0=A_1*A_2;
disp(20*log10(A_0),"The dc open loop gain in dB")
v_ICMmin=-2.5+1;
disp(v_ICMmin,"Lower limit of input common-mode (V)"
    )
v_ICMmax=2.2-1.1;
disp(v_ICMmax,"Upper limit of input common-mode (V)"
    )
v_Omax=V_DD-V_OV;
disp(v_Omax,"Highest allowable output voltage (V)")
v_Omin=-V_SS+V_OV;
```

```
disp(v_Omin,"Lowest allowable output voltage (V)")
```

Scilab code Exa 7.5 Analysis of given circuit

```
// Example 7.5 : Analysis of given circuit
B=100; // beta value
I_E=0.2510^-3; // (A)
R_1=20000; // (ohm)
R_2=20000; // (ohm)
R_3=3000; // (ohm)
R_4=2300; // (ohm)
R_5=15700; // (ohm)
R_6=3000; // (ohm)
r_e1=25/0.25; // (ohm)
r_e2=r_e1; // (ohm)
r_pi1=(B+1)*r_e1;
r_pi2=(B+1)*r_e2;
R_id=r_pi1+r_pi2;
disp(R_id,"Input differential resistance (ohm)")
I_E=1*10^-3;
r_e4=25/1;
r_e5=r_e4;
r_pi4=(B+1)*r_e4;
r_pi5=(B+1)*r_e5;
R_i2=r_pi4+r_pi5;
disp(R_i2,"Input resistance of the second stage R_i2
    (ohm)")
A_1=(R_i2*(R_1+R_2)/((R_i2+R_1+R_2)*(r_e1+r_e2)))
disp(A_1,"Voltage gain of the first stage (V/V)")
r_e7=25/1;
R_i3=(B+1)*(R_4+r_e7);
disp(R_i3,"Input resistance of the third stage R_i3
    (ohm)")
A_2=(-R_3*R_i3)/((R_3+R_i3)*(r_e4+r_e5));
disp(A_2,"Voltage gain of the second stage (V/V)")
```

```
r_e8=25/5;
R_i4=(B+1)*(r_e8+R_6);
disp(R_i4,"Input resistance of the third stage R_i2
    (ohm)")
A_3=(-R_5*R_i4)/((R_5+R_i4)*(r_e7+R_4));
disp(A_3,"Voltage gain of the third stage (V/V)")
A_4=R_6/(R_6+r_e8);
disp(A_4,"Voltage gain of the fourth stage (V/V)")
A=A_1*A_2*A_3*A_4 ; // A=v_o/v_id (V/V)
disp(A,"Overall output gain (V/V)")
disp(20*log10(A),"Overall output gain in dB")
R_o=R_6*(r_e8+R_5/(B+1))/(R_6+r_e8+R_5/(B+1))
disp(R_o,"Output resistance (ohm)")
```

Chapter 8

Feedback

Scilab code Exa 8.1 Analysis of op amp connected in an inverting conf

```
// Example 8.1: Analysis of op amp connected in an
   inverting configuration
// By inspection we can write down the expressions
   for A, B , closed loop gain , the input
   resistance and the output resistance
u=10^4; // (ohm)
R_id=100*10^3; // (ohm)
r_o=1000; // (ohm)
R_L=2000; // (ohm)
R_1=1000; // (ohm)
R_2=10^6; // (ohm)
R_S=10000; // (ohm)
A=u*(R_L*(R_1+R_2)/(R_L+R_1+R_2))*R_id/(((R_L*(R_1+
   R_2))/(R_L+R_1+R_2)+r_o)*(R_id+R_S+(R_1*R_2)/(R_1
   +R_2)))
disp(A,"Voltage gain without feedback (V/V)")
B=R_1/(R_1+R_2); // Beta value
disp(B, "Beta value ")
A_f=A/(1+A*B);
disp(A_f,"Voltage gain with feedback (V/V)")
R_i=R_S+R_id+(R_1*R_2/(R_1+R_2))// Input resistance
```

```
    of the A circuit in fig 8.12a of textbook
R_if=R_i*7;
R_in=R_if-R_S;
disp(R_in,"Input resistance (ohm)")
R_o=1/(1/r_o+1/R_L+1/(R_1+R_2));
R_of=R_o/(1+A*B);
R_out=R_of*R_L/(R_L-R_of);
disp(R_out,"the output resistance (ohm)")
```

Scilab code Exa 8.2 Feedback triple

```
// Example 8.2: Feedback triple
// Consider the given three stage series-series
    feedback
h_fe=100;
g_m2=40*10^-3; // (A/V)
r_e1=41.7; // (ohm)
a_1=0.99; // alpha value
R_C1=9000; // (ohm)
R_E1=100; //(ohm)
R_F=640; // (ohm)
R_E2=100; //(ohm)
r_pi2=h_fe/g_m2;
R_C2=5000; // (ohm)
r_e3=6.25; // (ohm)
R_C3=800; //(ohm)
// First stage gain A_1=V_c1/V_i
A_1=-a_1*R_C1*r_pi2/((R_C1+r_pi2)*(r_e1+((R_E1*(R_F+
    R_E2))/(R_E1+R_F+R_E2))))
disp(A_1,"The voltage gain of the first stage (V/V)"
    )
// Gain of the second stage A_2=Vc2/V_c1
A_2=-g_m2*{(R_C2*(h_fe+1)/(R_C2+h_fe+1))*[r_e3+(R_E2
    *(R_F+R_E1))/(R_E2+R_F+R_E1)]}
disp(A_2,"The second stage gain (V/V)")
```

```
// Third stage gain A_3 I_O/V_i
A_3=1/(r_e3+(R_E2*(R_F+R_E1)/(R_E2+R_F+R_E1)));
disp(A_3,"The third stage gain (V/V)")
A=A_1*A_2*A_3; // combined gain
disp(A,"Combined gain (V/V)")
B=R_E1*R_E2/(R_E2+R_F+R_E1);
disp(B,"Beta value")
A_f=A/(1+A*B);
disp(A_f,"Closed loop gain (A/V)")
A_v=-A_f*R_C3; // Voltage gain
disp(A_v,"Voltage gain (V/V)")
R_i=(h_fe+1)*(r_e1+(R_E1*(R_F+R_E2))/(R_E1+R_F+R_E2)
    );
R_if=R_i*(1+A*B);
disp(R_if,"Input resistance (ohm)")
R_o=(R_E2*(R_F+R_E1)/(R_F+R_E1+R_E2))+r_e3+R_C2/(
    h_fe+1);
R_of=R_o*(1+A*B);
disp(R_of,"Output voltage (ohm)")
r_o=25000; // (ohm)
g_m3=160*10^-3; // (mho)
r_pi3=625; // (ohm)
R_out=r_o+(1+g_m3*r_o)*R_of*r_pi3/(R_of+r_pi3);
disp(R_out,"R_out (ohm)")
```

Scilab code Exa 8.3 Small signal analysis

```
// Example 8.3 : Small signal analysis
B=100; // beta value
I_B=0.015*10^-3; // (A)
I_C=1.5*10^-3; // (A)
V_C=4.7; // (V)
g_m=40*10^-3;
R_f=47000;
R_S=10000;
```

```
R_C=4700;
r_pi=B/g_m;
A=-358.7*10^3; // V_o/I_i= -g_m(R_f||R_C)(R_S||R_F||
    r_pi)
R_i=1400; // R_i=R_S||R_f||r_pi (ohm)
R_o=R_C*R_f/(R_C+R_f);
B=-1/R_f;
A_f=A/(1+A*B); // V_o/I_s
A_v=A_f/R_S; // V_o/V_s
disp(A_v,"The gain (V/V)")
R_if=R_i/(1+A*B);
disp(R_if,"R_if (ohm)")
R_of=R_o/(1+A*B);
disp(R_of,"R_of (ohm)")
```

Scilab code Exa 8.4 Small signal analysis

```
// Example 8.4: Small signal analysis
R_S=10*10^3; // (ohm)
R_B1=100*10^3; // (ohm)
R_B2=15*10^3; // (ohm)
R_C1=10*10^3; // (ohm)
R_E1=870; // (ohm)
R_E2=3400; // (ohm)
R_C2=8000; // (ohm)
R_L=1000; // (ohm)
R_f=10000; // (ohm)
B=100; // beta value
V_A=75; // (V)
A=-201.45 // I_o/I_i (A/A)
R_i=1535; // (ohm)
R_o=2690; // (ohm)
B=-R_E2/(R_E2+R_f);
R_if=R_i/(1+A*B);
disp(R_if)
```

```
R_in=1/((1/R_if)-(1/R_S));
disp(R_in, "R_in (ohm)")
A_f=A/(1+A*B); // I_o/I_S
gain=R_C2*A_f/(R_C2+R_L); // I_o/I_S
disp(gain,"I_o/I_S (A/A)")
R_of=R_o*(1+A*B); // (ohm)
r_o2=75/0.0004; // (ohm)
g_m2=0.016; // (A/V)
r_pi2=6250; // (ohm)
R_out=r_o2*[1+g_m2*(r_pi2*R_of/(r_pi2+R_of))]
disp(R_out,"R_out (ohm)")
```

Chapter 9

Operational amplifier and data converter circuits

Scilab code Exa 9.1 Design of two stage CMOS op amp

```
// Example 9.1 Design of two-stage CMOS op-amp
A_v=4000; // (V/V)
V_A=20; // (V)
k_p=80*10^-6; // k'_n=k_n (A/V^2)
k_n=200*10^-6; // k'_p=k_P (A/V^2)
V_SS=1.65; // (V)
V_DD=1.65; // (V)
V_tn=0.5; // (V)
V_tp=0.5; // (V)
C_1=0.2*10^-12; // (F)
C_2=0.8*10^-12; // (F)
I_D=100*10^-6; // (A)
V_OV=sqrt(V_A^2/A_v);
WbyL_1=I_D*2/(V_OV^2*k_p); // WbyL_1=(W/L)_1
disp(WbyL_1,"Required (W/L) ratio for Q_1")
WbyL_2=WbyL_1; // WbyL_2=(W/L)_2
disp(WbyL_2,"Required (W/L) ratio for Q_2")
WbyL_3=I_D*2/(V_OV^2*k_n); // WbyL_3=(W/L)_3
disp(WbyL_3,"Required (W/L) ratio for Q_3")
```

```
WbyL_4=WbyL_3; // WbyL_4=(W/L)_4
disp(WbyL_4,"Required (W/L) ratio for Q_4")
I_D=200*10^-6;
WbyL_5=I_D*2/(V_OV^2*k_p); // WbyL_5=(W/L)_5
disp(WbyL_5,"Required (W/L) ratio for Q_5")
I_D=500*10^-6;
WbyL_7=2.5*WbyL_5; // WbyL_7=(W/L)_7
disp(WbyL_7,"Required (W/L) ratio for Q_7")
WbyL_6=I_D*2/(V_OV^2*k_n); // WbyL_6=(W/L)_6
disp(WbyL_6,"Required (W/L) ratio for Q_6")
WbyL_8=0.1*WbyL_5; // WbyL_8=(W/L)_8
disp(WbyL_8,"Required (W/L) ratio for Q_8")
V_ICMmin=-V_SS+V_OV+V_tn-V_tp;
disp(V_ICMmin,"The lowest value of input common mode
    voltage")
V_ICMmax=V_DD-V_OV-V_OV-V_tp;
disp(V_ICMmax,"The highest value of input common
   mode voltage")
v_omin=-V_SS+V_OV;
disp(v_omin,"The lowest value of output swing
   allowable")
v_omax=V_DD-V_OV;
disp(v_omax,"The highest value of output swing
   allowable")
R_o=20/(2*0.5);
disp(R_o,"Input resistance is practically infinite
   and output reistance is (ohm)")
G_m2=2*I_D/V_OV;
disp(G_m2,"G_m2 (A/V)")
f_P2=3.2*10^-3/(2*%pi*C_2);
disp(f_P2,"f_P2 (Hz)")
R=1/G_m2;
disp(R,"To move the transmission zero to s=infinite
   , r value selected as (ohm)")
f_t=f_P2*tand(15); // Phase margin of 75 degrees ,
   thus phase shift due to seccond pole must be 15
   degrees
disp(f_t,"f_t (Hz)")
```

```
G_m1=2*100*10^-6/V_OV; // I_D = 100uA
C_C1=G_m1/(2*%pi*f_t);
disp(C_C1,"C_C1 (F)")
SR=2*%pi*f_t*V_OV;
disp(SR,"SR (V/s)")
```

Scilab code Exa 9.2 To determine Av ft fP SR and PD of folded casc

```
// Example 9.2 : To determine A_v,f_t,f_P,SR and P_D
    of folded cascode amplifier
// Consider a design of the folded-cascode op amp
I=200*10^-6; // (A)
I_B=250*10^-6; // (A)
V_OV=0.25; // (V)
k_n=100*10^-6; // k_n=k'_n (A/V^2)
k_p=40*10^-6; // k_p=k'_p (A/V^2)
V_A=20; // V_A=V'_A (V/um)
V_DD=2.5; // (V)
V_SS=2.5; // (V)
V_t=0.75; // (V)
L=1*10^-6; // (m)
C_L=5*10^-12; // (F)
disp("Data calculated for Q1")
I_D=I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q2")
I_D=I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
```

```
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q3")
I_D=I_B-I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_p*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q4")
I_D=I_B-I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_p*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q5")
I_D=I_B-I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q6")
I_D=I_B-I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
```

```
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q7")
I_D=I_B-I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q8")
I_D=I_B-I/2;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q9")
I_D=I_B;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_p*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
disp("Data calculated for Q10")
I_D=I_B;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_p*V_OV^2); // WbyL =W/L
```

```
disp(WbyL,"W/L")
disp("Data calculated for Q11")
I_D=I;
disp(I_D,"I_D (A)")
g_m=2*I_D/V_OV;
disp(g_m,"g_m (A/V)")
r_o=V_A/I_D;
disp(r_o,"r_o (ohm)")
WbyL=2*I_D/(k_n*V_OV^2); // WbyL =W/L
disp(WbyL,"W/L")
gmro=160; // gmro=g_m*r_o
disp(gmro,"g_m*r_o for all transistors is (V/V)")
V_GS=1;
disp(V_GS,"V_GS for all transistors is (V)")
V_ICMmin=-V_SS+V_OV+V_OV+V_t;
disp(V_ICMmin,"The lowest value of input common mode
    voltage (V)")
V_ICMmax=V_DD-V_OV+V_t;
disp(V_ICMmax,"The highest value of input common
    mode voltage (V)")
v_omin=-V_SS+V_OV+V_OV+V_t;
disp(v_omin,"The lowest value of output swing
    allowable (V)")
v_omax=V_DD-V_OV-V_OV;
disp(v_omax,"The highest value of output swing
    allowable (V)")
r_o2=200*10^3; // r_o calculated for Q2
r_o10=80*10^3; // r_o calculated for Q10
R_o4=gmro*(r_o2*r_o10)/(r_o2+r_o10);
r_o8=133333; // r_o calculated for Q8
R_o6=gmro*r_o8;
R_o=R_o4*R_o6/(R_o4+R_o6);
disp(R_o,"Output resistance (ohm)")
G_M=0.0008;
A_v=G_M*R_o;
disp(A_v,"Voltage gain (V/V)")
f_t=G_M/(2*%pi*C_L);
disp(f_t,"Unity gain bandwidth (Hz)")
```

```
f_P=f_t/A_v;
disp(f_P,"Dominant pole frequency (Hz)")
SR=I/C_L;
disp(SR,"Slew Rate (V/s)")
I_t=0.5*10^-3; // total current
V_S=5; // Supply voltage
P_D=I_t*V_S;
disp(P_D,"Power dissipated (W)")
```

Scilab code Exa 9.3 To determine input offset voltage

```
// Example 9.3 : To determine input offset voltage
r_e=2.63*10^3; // (ohm)
R=1000; // (ohm)
I=9.5*10^-6; // (A)
deltaRbyR=0.02; // 2% mismatch between R_1 and R_2
G_m1=10^-3/5.26; // (A/V)
deltaI=deltaRbyR/(1+deltaRbyR + r_e/R); // Change of
    deltaI in I_E (A)
V_OS=deltaI/G_m1;
disp(V_OS,"Offset voltage (V)")
```

Chapter 10

Digital CMOS logic circuits

Scilab code Exa 10.1 To determine tPHL tPLH and tP

```
// Example 10.1 : To determine t_PHL, t_PLH and t_P
// Consider CMOS inverter
C_ox=6*10^-15; // (F/um^2)
uC_n=115*10^-6; //uC_n=u_n*C_ox (A/V^2)
uC_p=30*10^-6; //uC_p=u_p*C_ox (A/V^2)
V_tn=0.4; // (V)
V_tp=-0.4; // (V)
V_DD=2.5; // (V)
W_n=0.375*10^-6; // W for Q_N
L_n=0.25*10^-6; // L for Q_N
W_p=1.125*10^-6; // W for Q_P
L_p=0.25*10^-6; // L for Q_P
C_gd1=0.3*W_n*10^-9; // (F)
C_gd2=0.3*W_p*10^-9; // (F)
C_db1=10^-15; // (F)
C_db2=10^-15; // (F)
C_g3= 0.375*0.25*6*10^-15+2*0.3*0.375*10^-15; // (F)
C_g4=1.125*0.25*6*10^-15+2*0.3*1.125*10^-15; // (F)
C_w=0.2*10^-15; // (F)
C=2*C_gd1+2*C_gd2+C_db1+C_db2+C_g3+C_g4+C_w; // (F)
i_DN0=uC_n*W_n*(V_DD-V_tn)^2/(2*L_n); // i_DN0 =
```

```
i_DN(0) (A)
i_DNtPHL=uC_n*W_n*((V_DD-V_tn)*V_DD/2-((V_DD/2)^2)/2)/L_n; // i_DNtPHL = i_DN(t_PHL) (A)
i_DNav=(i_DN0+i_DNtPHL)/2; // i_DN|av (A)
t_PHL=C*(V_DD/2)/i_DNav;
disp(t_PHL,"t_PHL (s)")
t_PLH=1.3*t_PHL; // Since W_p/W_n=3 and u_n/u_p=3.83 thus t_PLH is greater than t_PHL by 3.83/3
disp(t_PLH,"t_PLH (s)")
t_P=(t_PHL+t_PLH)/2;
disp(t_P,"t_P (s)")
```

Scilab code Exa 10.2 WbyL ratios for the logic circuit

```
// Example 10.2 : W/L ratios for the logic circuit
//For basic inverter
n=1.5;
p=5;
L=0.25*10^-6; // (m)
WbyL=2*n; // W/L for Q_NB , Q_NC , Q_ND
disp(WbyL,"W/L ratio for Q_NB")
disp(WbyL,"W/L ratio for Q_NC")
disp(WbyL,"W/L ratio for Q_ND")
WbyL=n; // W/L ratio for Q_NA
disp(WbyL,"W/L ratio for Q_NA")
WbyL=3*p; // W/L for Q_PA, Q_PC , Q_PD
disp(WbyL,"W/L ratio for Q_PA")
disp(WbyL,"W/L ratio for Q_PC")
disp(WbyL,"W/L ratio for Q_PD")
```

Scilab code Exa 10.3 To determine the parameters of pseudo NMOS inverte

```
// Example 10.3 : To determine the parameters of pseudo NMOS inverter
// Consider a pseudo NMOS inverter
uC_n=115*10^-6; //uC_n=u_n*C_ox (A/V^2)
uC_p=30*10^-6; //uC_p=u_p*C_ox (A/V^2)
V_tn=0.4; // (V)
V_tp=-0.4; // (V)
V_DD=2.5; // (V)
W_n=0.375*10^-6; // W for Q_N (m)
L_n=0.25*10^-6; // L for Q_N (m)
r=9;

// 10.3a
V_OH=V_DD;
disp(V_OH,"V_OH (V)")
V_OL=(V_DD-V_tn)*(1-sqrt(1-1/r));
disp(V_OL,"V_OL (V)")
V_IL=V_tn+(V_DD-V_tn)/sqrt(r*(r+1));
disp(V_IL,"V_IL (V)")
V_IH=V_tn+2*(V_DD-V_tn)/(sqrt(3*r));
disp(V_IH,"V_IH (V)")
V_M=V_tn+(V_DD-V_tn)/sqrt(r+1);
disp(V_M,"V_M (V)")
NM_H=V_OH-V_IH;
NM_L=V_IL-V_OL;
disp(NM_L,NM_H,"The highest and the lowest values of allowable noise margin (V)")

// 10.3b
WbyL_p=uC_n*(W_n/L_n)/(uC_p*r); // WbyL_p=(W/L)_p
disp(WbyL_p,"(W/L)_p")

//10.3c
I_stat=(uC_p*WbyL_p*(V_DD-V_tn)^2)/2;
disp(I_stat,"I_stat (A)")
P_D=I_stat*V_DD;
disp(P_D,"Static power dissipation P_D (W)")

```

```
//10.3d
C=7*10^-15;
t_PLH=1.7*C/(uC_p*WbyL_p*V_DD);
disp(t_PLH,"t_PLH (s)")
t_PHL=1.7*C/(uC_n*(W_n/L_n)*sqrt(1-0.46/r)*V_DD);
disp(t_PHL,("t_PHL (s)"))
t_p=(t_PHL+t_PLH)/2;
disp(t_p,"t_p (s)")
```

Scilab code Exa 10.4 To determine parameters for NMOS transistor

```
// Example 10.4 : To determine parameters for NMOS
    transistor
// Consider NMOS transistor switch
uC_n=50*10^-6; //uC_n=u_n*C_ox (A/V^2)
uC_p=20*10^-6; //uC_px    '=u_p*C_ox (A/V^2)
V_t0=1; // (V)
y=0.5; // (V^1/2)
fie_f=0.6/2; // (V)
V_DD=5; // (V)
W_n=4*10^-6; // (m)
L_n=2*10^-6; // (m)
C=50*10^-15; // (F)

// 10.4a
V_t=1.6; // (V)
V_OH=V_DD-V_t; // V_OH is the value of v_O at which
   Q stops conducting (V)
disp(V_OH,"V_OH (V)")

// 10.4b
W_p=10*10^-6; // (m)
L_p=2*10^-6; // (m)
i_DP=uC_p*W_p*((V_DD-V_OH-V_t0)^2)/(2*L_p);
disp(i_DP,"Static current of the inverter (A)")
```

```
P_D=V_DD*i_DP;
disp(P_D,"Power dissipated (W)")
V_O=0.08; // Output voltage (V) found by equating
    the current of Q_N=18uA
disp(V_O," The output voltage of the inverter (V) ")

// 10.4c
i_D0=uC_n*W_n*((V_DD-V_t0)^2)/(2*2*10^-6); // i_D0=
    i_D(0) (A) current i_D at t=0
v_O=2.5; // (V)
V_t=V_t0+0.5*(sqrt(v_O+2*fie_f)-sqrt(2*fie_f)); //
    at v_O=2.5V
i_DtPLH=(uC_n*W_n*(V_DD-v_O-V_t)^2)/(2*L_n); //
    i_DtPLH=i_D(t_PLH) (A) current i_D at t=t_PLH
i_Dav=(i_D0+i_DtPLH)/2; // i_Dav=i_D|av (A) average
    discharge current
t_PLH=C*(V_DD/2)/i_Dav;
disp(t_PLH,"t_PHL (s)")

// 10.4d
// Case with v_t going low
i_D0=uC_n*W_n*((V_DD-V_t0)^2)/(2*2*10^-6); // i_D0=
    i_D(0) (A) current i_D at t=0
i_DtPHL=uC_n*W_n*((V_DD-V_t0)*v_O-(v_O^2)/2)/(L_n);
    // i_DtPHL=i_D(t_PHL) (A) current i_D at t=T_PHL
i_Dav=(i_D0+i_DtPHL)/2; // i_Dav=i_D|av (A) average
    discarge current
t_PHL=C*(V_DD/2)/i_Dav;
disp(t_PHL,"t_PHL (s)")

// 10.4e
t_P=(t_PHL+t_PLH)/2;
disp(t_P,"t_P (s)")
```

Chapter 11

Memory and advanced digital circuits

Scilab code Exa 11.1 Min WbyL ratio to ensure flip flop will switch

```
// Example 10.1 : To determine t_PHL, t_PLH and t_P
// Consider CMOS inverter
C_ox=6*10^-15; // (F/um^2)
uC_n=115*10^-6; //uC_n=u_n*C_ox (A/V^2)
uC_p=30*10^-6; //uC_p=u_p*C_ox (A/V^2)
V_tn=0.4; // (V)
V_tp=-0.4; // (V)
V_DD=2.5; // (V)
W_n=0.375*10^-6; // W for Q_N
L_n=0.25*10^-6; // L for Q_N
W_p=1.125*10^-6; // W for Q_P
L_p=0.25*10^-6; // L for Q_P
C_gd1=0.3*W_n*10^-9; // (F)
C_gd2=0.3*W_p*10^-9; // (F)
C_db1=10^-15; // (F)
C_db2=10^-15; // (F)
C_g3= 0.375*0.25*6*10^-15+2*0.3*0.375*10^-15; // (F)
C_g4=1.125*0.25*6*10^-15+2*0.3*1.125*10^-15; // (F)
C_w=0.2*10^-15; // (F)
```

```
C=2*C_gd1+2*C_gd2+C_db1+C_db2+C_g3+C_g4+C_w; // (F)
i_DN0=uC_n*W_n*(V_DD-V_tn)^2/(2*L_n); // i_DN0 =
    i_DN(0) (A)
i_DNtPHL=uC_n*W_n*((V_DD-V_tn)*V_DD/2-((V_DD/2)^2)
    /2)/L_n; // i_DNtPHL = i_DN(t_PHL) (A)
i_DNav=(i_DN0+i_DNtPHL)/2; // i_DN|av (A)
t_PHL=C*(V_DD/2)/i_DNav;
disp(t_PHL,"t_PHL (s)")
t_PLH=1.3*t_PHL; // Since W_p/W_n=3 and u_n/u_p=3.83
     thus t_PLH is greater than t_PHL by 3.83/3
disp(t_PLH,"t_PLH (s)")
t_P=(t_PHL+t_PLH)/2;
disp(t_P,"t_P (s)")
```

Scilab code Exa 11.2 Design of two stage CMOS op amp

```
// Example 11.2 Design of two-stage CMOS op-amp

uC_n=50*10^-6; // u_n*C_ox (A/V^2)
uC_p=20*10^-6; // u_p*C_ox (A/V^2)
V_tn0=1; // (V)
V_tp0=-1; // (V)
fie_f=0.6/2; // (V)
y=0.5; // (V^1/2)
V_DD=5; // (V)
W_n=4*10^-6; // (m)
L_n=2*10^-6; // (m)
W_p=10*10^-6; // (m)
L_p=2*10^-6; // (m)
W=10*10^-6; // (m)
L=10*10^-6; // (m)
C_B=1*10^-12; // bit line capacitance (F)
deltaV=0.2; // 0.2 V decrement
WbyL_eq=1/(L_p/W_p+L_n/W_n); // WbyL_eq=(W/L)_eq
// Equivalent transistor will operate in saturation
```

```
I=(uC_n*WbyL_eq*(V_DD-V_tn0)^2)/2
r_DS=1/(uC_n*(W_n/L_n)*(V_DD-V_tn0));
v_Q=r_DS*I; // v_Q=r_DS*I
I_5=0.5*10^-3; // (A)
deltat=C_B*deltaV/I_5;
disp(deltat, "The time (s) required to develop an
    output voltage of 0.2V")
```

Scilab code Exa 11.3 Time required

```
// Example 11.3 : Time required for v_B to reach 4.5
    V
// Consider sense-amplifier circuit
uC_n=50*10^-6; //uC_n=u_n*C_ox (A/V^2)
uC_p=20*10^-6; //uC_p=u_p*C_ox (A/V^2)
W_n=12*10^-6; // (m)
L_n=4*10^-6; // (m)
W_p=30*10^-6; // (m)
L_p=4*10^-6; // (m)
v_B=4.5; // (V)
C_B=1*10^-12; // (F)
V_GS=2.5; // (V)
V_t=1; // (V)
deltaV=0.1; // (V)
g_mn=uC_n*(W_n/L_n)*(V_GS-V_t); // (A/V)
g_mp=uC_p*(W_p/L_p)*(V_GS-V_t); // (A/V)
G_m=g_mn+g_mp; // (A/V)
T=C_B/G_m; // (s)
deltat=T*(log(v_B/V_GS)-log(deltaV));
disp(deltat,"The time for v_B to reach 4.5V (s)")
```

Chapter 12

Filters and tuned amplifiers

Scilab code Exa 12.4 To design tuned amplifier

```
// Example 12.4 To design tuned amplifier

cfg=-10; // Center frequency gain (V/V)
g_m=0.005; // (A/V)
r_o=10000; // (ohm)
f_o=1*10^6; // (Hz)
B=2*%pi*10^4; // Bandwidth
R=-cfg/g_m;
R_L=R*r_o/(r_o-R);
disp(R_L,"R_L (ohm)")
C=1/(R*B)
disp(C,"C (F)")
w_o=2*%pi*f_o;
L=1/(w_o^2*C);
disp(L,"L (H)")
```

Chapter 14

Output Stages and amplifier

Scilab code Exa 14.1 `To design a Class B Output Amplifier`

```
// Example 14.1 To design a Class B Output Amplifier

P_L=20; // Average power (W)
R_L=8; // Load resistance (ohm)
V_o=sqrt(2*P_L*R_L);
disp(V_o,"Supply voltage required (V)")
V_CC=23; // We select this voltage (V)
I_o=V_o/R_L;
disp(I_o,"Peak current drawn from each supply (A)")
P_Sav=V_CC*I_o/%pi; // P_S+ = P_S- = P_Sav
P_S=P_Sav+P_Sav; // Total supply power
disp(P_S,"The total power supply (W)")
n=P_L/P_S; // n is power conversion efficiency
disp(n*100,"Power conversion efficiency %")
P_DPmax=V_CC^2/(%pi^2*R_L);
P_DNmax=P_DPmax;
disp(P_DPmax,"Maximun power dissipated in each
   transistor (W)")
```

Scilab code Exa 14.2 To determine quiescent current and power

```
// Example 14.2 To determine quiescent current and power
// Consider Class AB Amplifier
V_CC=15; // (V)
R_L=100; // (ohm)
v_O=-10:10:10; // Amplitude of sinusoidal output voltage (V)
I_S=10^-13; // (A)
V_T=25*10^-3; // (V)
B=50; // Beta value
i_Lmax=10/(0.1*10^3); // Maximum current through Q_N (A)
// Implies max base curent  in Q_N is approximately 2mA
I_BIAS=3*10^-3; // We select I_BIAS=3mA in order to maintain a minimum of 1mA through the diodes
I_Q=9*10^-3; // The area ratio of 3 yeilds quiescent current of 9mA
P_DQ=2*V_CC*I_Q;
disp(P_DQ,"Quiescent power dissipation (W)")
//For v_O=0V base current of Q_N is 9/51=0.18 mA
// Leaves a current of 3-0.18=2.83mA to flow through the diodes
I_S= (10^-13)/3; // Diodes have I_S = (1*10^-13)/3
V_BB=2*V_T*log((2.83*10^-3)/I_S);
disp(V_BB,"V_BB (V) for v_O = 0V")
// For v_O=+10V, current through the diodes will decrease to 1mA
V_BB=2*V_T*log((1*10^-3)/I_S);
disp(V_BB,"V_BB (V) for v_O = +10V")
// For v_O=-10V , Q_N will conduct very small current thus base current is negligible
// All of the I_BIAS(3mA) flows through the diodes
V_BB=2*V_T*log((3*10^-3)/I_S);
disp(V_BB,"V_BB (V) for v_O = -10V")
```

Scilab code Exa 14.3 Redesign the output stage of Example 2

```
// Example 14.3 Redesign the output stage of Example
   14.2
V_T=25*10^-3; // (V)
I_S=10^-14; // (A)
I_Q=2*10^-3; // Required quiescent current (A)
// We select I_BIAS=3mA which is divided between I_R
   and I_C1
// Thus we select I_R=0.5mA and I_C1=2.5mA
V_BB=2*V_T*log(I_Q/10^-13);
disp(V_BB,"V_BB (V)")
I_R=0.5*10^-3;
R1plusR2=V_BB/I_R; // R1plusR2 = R_1+R_2
I_C1=2.5*10^-3;
V_BE1=V_T*log(I_C1/I_S);
disp(V_BE1,"V_BE1 (V)")
R_1=V_BE1/I_R;
disp(R_1,"R_1 (ohm)")
R_2=R1plusR2-R_1;
disp(R_2,"R_2 (ohm)")
```

Scilab code Exa 14.4 To determine thermal resistance junction temperat

```
// Example 14.4 To determine thermal resistance,
   junction temperature
// Consider BJT with following specifications
P_D0=2; // Maximum power dissipation (W)
T_A0=25; // Ambient temperature (degree celcius)
T_Jmax=150; // maximum junction temperature (degree
   celcius)

```

```
// 14.4a
theta_JA=(T_Jmax-T_A0)/P_D0; // Thermal resistance
disp(theta_JA,"The thermal resistance (degree
   celsius/W)")

// 14.4b
T_A=50; // (degree celcius)
P_Dmax=(T_Jmax-T_A)/theta_JA;
disp(P_Dmax,"Maximum power that can be dissipated at
    an ambient temperature of 50 degree celsius (W)"
   )

// 14.4c
T_A=25; // (degree celcius)
P_D=1; // (W)
T_J=T_A+theta_JA*P_D;
disp(T_J,"Junction temperature (degree celcius) if
   the device is operating at T_A=25 degree celsius
   and is dissipating 1W")
```

Scilab code Exa 14.5 `To determine the maximum power dissipated`

```
// Example 14.5 To determine the maximum power
   dissipated
// Consider a BJT with following specifications
T_Jmax=150; // (degree celcius)
T_A=50; // (degree celcius)

// 14.5a
theta_JA=62.5; // (degree celcius/W)
P_Dmax=(T_Jmax-T_A)/theta_JA;
disp(P_Dmax,"The maximum power (W) that can be
   dissipated safely by the transistor when operated
    in free air")

```

```
//14.5b
theta_CS=0.5; // (degree celcius/W)
theta_SA=4; // (degree celcius/W)
theta_JC=3.12; // (degree celcius/W)
theta_JA=theta_JC+theta_CS+theta_SA;
P_Dmax=(T_Jmax-T_A)/theta_JA
disp(P_Dmax,"The maximum power (W) that can be
    dissipated safely by the transistor when operated
     at an ambient temperature of 50 degree celcius
    but with a heat sink for which theta_CS= 0.5 (
    degree celcius/W) and theta_SA = 4 (degree
    celcius/W) (W)")

// 14.5c
theta_CA=0 // since infinite heat sink
P_Dmax=(T_Jmax-T_A)/theta_JC;
disp(P_Dmax,"The maximum power (W) that can be
    dissipated safely if an infinite heat sink is
    used and T_A=50 (degree celcius)")
```