CHAPTER 12

12.1

(a) Under the quasistatic assumption the carriers and hence the device under analysis are assumed to respond to a time-vaying signal as if it were a d.c. bias. In the derivation of the generalized two-port model, one specifically equates the total time-varying terminal currents (i_B, i_C) to the d.c. currents that would exist under equivalent biasing conditions.

(b) Two separate definitions are necessary because, contrary to the polarities assumed in the development of the generalized small-signal model, the I_B and I_C currents were previously taken to be positive flowing *out* of the base and the collector terminals in a *pnp* BJT. (As noted in Section 10.1, the direction of positive current was so chosen to avoid unnecessary complications, serious sign-related difficulties, in the physical description of current flow inside the BJT when operated in the standard amplifying mode.)

(c) The Hybrid-Pi model gets its name from the π-like arrangement of circuit elements with "hybrid" (a combination of conductance and resistance) units.

(d) Names (see the first paragraph in Subsection 12.1.2):

g_m...transconductance
r_c...output resistance
r_π...input resistance
r_μ...feedthrough resistance

(e) The capacitors model the collector-base and emitter-base *pn* junction capacitances which cannot be neglected at higher frequencies.

(f) The minority carrier concentration in the base continues to increase as pictured in plot (iii) of Fig. 12.4(d) until a maximum build-up consistent with the applied biases is attained. The base current varies as Q_B/τ_B and therefore also continues to increase toward a saturating maximum value. (In the quantitative analysis, i_B increases from $I_{CC}\tau_t$ at the start of saturation to a saturating value of $I_{BB}\tau_B$.) Once saturation biased, i_C remains essentially constant at $i_C \cong I_{CC} = V_{CC}/R_L$.

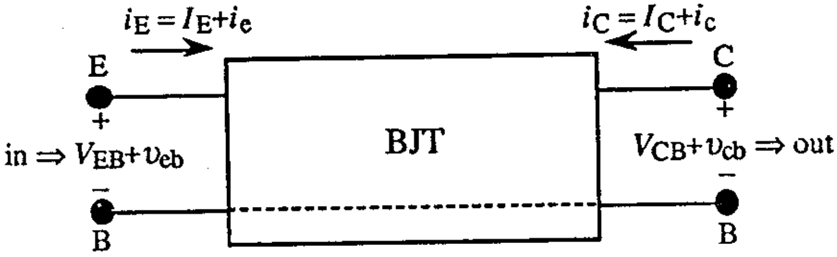
(g) In words, the *base transit time* is the average time taken by minority carriers to diffuse across the quasineutral base. Mathematically (see Eq. 12.22), $\tau_t = W^2/2D_B$.

(h) $\beta_{dc} = I_C/I_B = \tau_B/\tau_t$

(i) An $i_B < 0$ aids the widthdrawal of stored charge from the quasineutral base, which in turn reduces both the storage delay time and the fall time.

(j) A Schottky diode clamp is a circuit arrangement where a Schottky diode is connected between the collector and base of a BJT as pictured in Fig. 12.7(a). The Schottky diode conducts at a lower forward bias than a *pn* junction and therefore minimizes the forward (saturation-mode) bias that is applied to the BJT under turn-on conditions. This reduces the stored charge and speeds up the turn-off transient. (Also see Subsection 12.2.4.)

12.2
The BJT viewed as a two-port network and connected in the common-base configuration is pictured below.



Invoking the quasistatic assumption we can write

$$i_E(V_{EB}+v_{eb}, V_{CB}+v_{cb}) \cong I_E(V_{EB}+v_{eb}, V_{CB}+v_{cb}) = I_E(V_{EB}, V_{CB}) + i_e$$

$$i_C(V_{EB}+v_{eb}, V_{CB}+v_{cb}) \cong I_C(V_{EB}+v_{eb}, V_{CB}+v_{cb}) = I_C(V_{EB}, V_{CB}) + i_c$$

or

$$i_e = I_E(V_{EB}+v_{eb}, V_{CB}+v_{cb}) - I_E(V_{EB}, V_{CB})$$

$$i_c = I_C(V_{EB}+v_{eb}, V_{CB}+v_{cb}) - I_C(V_{EB}, V_{CB})$$

Next performing a Taylor series expansion of the first term on the right-hand side of the above equations, and keeping only first order terms, we obtain

$$I_E(V_{EB}+v_{eb}, V_{CB}+v_{cb}) = I_E(V_{EB}, V_{CB}) + \left.\frac{\partial I_E}{\partial V_{EB}}\right|_{V_{CB}} v_{eb} + \left.\frac{\partial I_E}{\partial V_{CB}}\right|_{V_{EB}} v_{cb}$$

$$I_C(V_{EB}+v_{eb}, V_{CB}+v_{cb}) = I_C(V_{EB}, V_{CB}) + \left.\frac{\partial I_C}{\partial V_{EB}}\right|_{V_{CB}} v_{eb} + \left.\frac{\partial I_C}{\partial V_{CB}}\right|_{V_{EB}} v_{cb}$$

which when substituted into the preceding equations gives

$$i_e = \left.\frac{\partial I_E}{\partial V_{EB}}\right|_{V_{CB}} v_{eb} + \left.\frac{\partial I_E}{\partial V_{CB}}\right|_{V_{EB}} v_{cb}$$

$$i_c = \left.\frac{\partial I_C}{\partial V_{EB}}\right|_{V_{CB}} v_{eb} + \left.\frac{\partial I_C}{\partial V_{CB}}\right|_{V_{EB}} v_{cb}$$

If the direction of positive current flow is as defined in Fig. 10.2 ($+I_E$ out and $+I_C$ in for an *npn* BJT, $+I_E$ in and $+I_C$ out for a *pnp* BJT), then introducing

$$g_{11} \equiv \underset{\substack{\Uparrow \\ npn \\ +I_E \text{ out}}}{\left.\frac{\partial I_E}{\partial V_{BE}}\right|_{V_{BC}}} = \underset{\substack{\Uparrow \\ pnp \\ +I_E \text{ in}}}{\left.\frac{\partial I_E}{\partial V_{EB}}\right|_{V_{CB}}} \; ; \qquad g_{12} \equiv \underset{\substack{\Uparrow \\ npn \\ +I_E \text{ out}}}{\left.\frac{\partial I_E}{\partial V_{BC}}\right|_{V_{BE}}} = \underset{\substack{\Uparrow \\ pnp \\ +I_E \text{ in}}}{\left.\frac{\partial I_E}{\partial V_{CB}}\right|_{V_{EB}}}$$

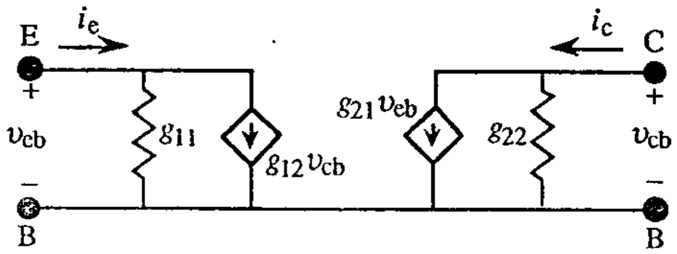
$$g_{21} \equiv \underset{\substack{\Uparrow \\ npn \\ +I_C \text{ in}}}{\left.\frac{\partial I_C}{\partial V_{EB}}\right|_{V_{CB}}} = \underset{\substack{\Uparrow \\ pnp \\ +I_C \text{ out}}}{\left.\frac{\partial I_C}{\partial V_{BE}}\right|_{V_{BC}}} \; ; \qquad g_{22} \equiv \underset{\substack{\Uparrow \\ npn \\ +I_C \text{ in}}}{\left.\frac{\partial I_C}{\partial V_{CB}}\right|_{V_{EB}}} = \underset{\substack{\Uparrow \\ pnp \\ +I_C \text{ out}}}{\left.\frac{\partial I_C}{\partial V_{BC}}\right|_{V_{BE}}}$$

yield the emitter and collector a.c. current node equations

$$i_e = g_{11} v_{eb} + g_{12} v_{cb}$$

$$i_c = g_{21} v_{eb} + g_{22} v_{cb}$$

The low-frequency small-signal equivalent circuit characterizing the a.c. response of the BJT connected in the common base configuration is therefore concluded to be



12.3

From an inspection of Fig. 11.5(d), one concludes $I_C \cong 1.1$ mA at the specified operating point. Given the BJT is to be modeled using the simplified equivalent circuit of Fig. 12.2(a), and assuming $T = 300$ K, one computes (referring to Eqs. 12.9),

$$g_m = \frac{qI_C}{kT} = \frac{1.1\times10^{-3}}{0.0259} = \mathbf{4.25 \times 10^{-2}\ S}$$

$$r_\pi = \frac{kT/q}{I_B} = \frac{0.0259}{5\times10^{-6}} = \mathbf{5.18 \times 10^{3}\ \Omega}$$

12.4

The node equations appropriate for the B and C terminals in the Hybrid-Pi model (Fig. 12.2b) assume the form

$$i_b = v_{be}/r_\pi + v_{bc}/r_\mu$$

$$i_c = g_m v_{be} + v_{cb}/r_\mu + v_{ce}/r_o$$

But $v_{bc} = -v_{cb} = v_{be} - v_{ce}$. Thus

$$i_b = v_{be}\left(\frac{1}{r_\pi} + \frac{1}{r_\mu}\right) - v_{ce}\left(\frac{1}{r_\mu}\right)$$

$$i_c = v_{be}\left(g_m - \frac{1}{r_\mu}\right) + v_{ce}\left(\frac{1}{r_\mu} + \frac{1}{r_o}\right)$$

A comparison of the preceding equations with text Eqs. (12.6) leads to the conclusion

$$g_{11} = \frac{1}{r_\pi} + \frac{1}{r_\mu} \qquad g_{12} = -\frac{1}{r_\mu}$$

$$g_{21} = g_m - \frac{1}{r_\mu} \qquad g_{22} = \frac{1}{r_\mu} + \frac{1}{r_o}$$

Clearly $r_\mu = -1/g_{12}$. Moreover, substituting $1/r_\mu = -g_{12}$ into the other three expressions allows us to solve for the remaining Hybrid-Pi parameters in terms of the generalized model parameters. Specifically,

$$r_\pi = 1/(g_{11} + g_{12}) \qquad r_\mu = -1/g_{12}$$

$$g_m = g_{21} - g_{12} \qquad r_o = 1/(g_{22} + g_{12})$$

Although in a somewhat different order, the preceding are Eqs. (12.10).

12.5

Computations were first performed to determine the V_{EB} values required to obtain an $I_C = 1$ mA with and without accounting for base width modulation. These V_{EB} voltages were then incorporated directly into the final program (P_12_05.m on the Instructor's disk). In the MATLAB program, the user is asked whether he/she wishes to input V_{EB} and V_{EC} or to use the preset values. The small incremental voltage deviations from the d.c. voltage values used in approximating the partial derivatives appearing in Eqs. (12.5) were varied until a factor of two change in the incremental values led to no change to five significant places in the computed g_{ij} parameters. The g_{ij} parameters were in turn used to compute the Hybrid-Pi parameters employing Eqs. (12.10).

Sample results with and without accounting for base width modulation are tabulated below. In both cases there is at most a third-place difference between the g_m and r_π computed from first principles and the g_m and r_π computed using Eqs. (12.9). As expected, g_{12} and g_{22} are approximately zero when base width modulation is assumed to be negligible, and therefore r_o and r_μ become infinite. Finite values are obtained for r_o and r_μ when base width modulation is included. Note that base width modulation has little effect on g_m but leads to a significant increase in r_π. An increase in $\beta_{dc} \cong g_m r_\pi$ is of course expected when base width modulation is included.

No base-width modulation

$g_m = 3.8685\times10^{-2}$ S
$r_o = \infty$
$r_\pi = 4.5960\times10^{3}\ \Omega$
$r_\mu = \infty$

$g_m = 3.8612\times10^{-2}$ S ...using Eq. (12.9)
$r_\pi = 4.6047\times10^{3}\ \Omega$

$V_{EB} = 0.67416$ V
$V_{EC} = 10$ V
$I_C = 1.0000$ mA

With base-width modulation included

$g_m = 3.8510\times10^{-2}$ S
$r_o = 1.4932\times10^{5}\ \Omega$
$r_\pi = 5.9530\times10^{3}\ \Omega$
$r_\mu = 7.5141\times10^{7}\ \Omega$

$g_m = 3.8611\times10^{-2}$ S ...using Eq. (12.9)
$r_\pi = 5.9761\times10^{3}\ \Omega$

$V_{EB} = 0.66961$ V
$V_{EC} = 10$ V
$I_C = 1.0000$ mA

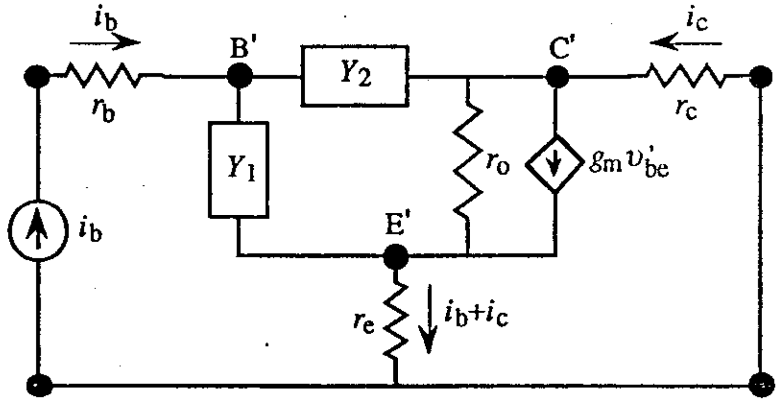
MATLAB program script...

```
%Computation of the Hybrid Pi Parameters (Problem 12.5)

%Initialization
clear;  close
format compact;  format short e
bw=input('Include base-width modulation?  1-Yes, 2-No...');
s=input('Manually input VEB and VEC?  1-Yes, 2-No...');

%Input Eber-Moll Parameters
BJT0

%Voltages used in Calculation
VbiE=kT*log(NE*NB/ni^2);
VbiC=kT*log(NC*NB/ni^2);
if s==1,
VEB0=input('Input VEB in volts, VEB = ');
VEC0=input('Input VEC in volts, VEC = ');
else
VEC0=10
if bw==1,  VEB0=0.669606
else       VEB0=0.674162
end;  end

%iB and iC Calculations
VEB=VEB0;
VEC=VEC0;
iB=[];
iC=[];
for i=1:5,
  if bw==1,
  VCB=VEB-VEC;
  BJTmod
  else
  end
IB0=(1-aF).*IF0+(1-aR).*IR0;
IB1=(1-aF).*IF0+(1-aR).*IR0.*exp(-VEC/kT);
IB=(IB1.*exp(VEB/kT)-IB0);
IC=((aF.*IF0-IR0.*exp(-VEC/kT)).*(IB+IB0)./IB1+IR0-aF.*IR0);
%Reset Voltages
if i==1, VEB=VEB0-0.0001;  else;  end
if i==2, VEB=VEB0+0.0001;  else;  end
if i==3, VEB=VEB0;  VEC= VEC0-0.01;  else;  end
if i==4, VEC=VEC0+0.01;  else;  end
iB=[iB,IB];
iC=[iC,IC];
end
```

```
%Compute Generalized Two-Port Model Parameters
g11=(iB(3)-iB(2))/0.0002;
g12=(iB(5)-iB(4))/0.02;
g21=(iC(3)-iC(2))/0.0002;
g22=(iC(5)-iC(4))/0.02;
fprintf('\nHybrid-Pi Model Parameters\n')
gm=g21-g12
if g22+g12==0    ro=inf
else             ro=1/(g22+g12)
end
rpi=1/(g11+g12)
if g12==0, rmu=inf
else,      rmu=-1/g12
end
fprintf('\ngm and rpi computed using Eqs.(12.9)\n')
gm=iC(1)/0.0259
rpi=0.0259/iB(1)
```

12.6

(a) The high-frequency equivalent circuit of Fig. 12.2(c) with $v_{ce} = 0$ can be manipulated into the form



where

$$Y_1 = \frac{1}{r_\pi} + j\omega C_{eb}$$

$$Y_2 = \frac{1}{r_\mu} + j\omega C_{cb}$$

Combining node and loop analysis we note

$$i_b = Y_1 v_{be}' - Y_2 v_{cb}' \qquad (1)$$

$$i_c = g_m v_{be}' + Y_2 v_{cb}' + v_{ce}'/r_o \qquad (2)$$

$$i_c r_c + v_{ce}' + (i_b + i_c) r_e = 0 \qquad (3)$$

$$v_{be}' - v_{ce}' + v_{cb}' = 0 \qquad (4)$$

Eq. (4) is used to eliminate v_{cb}' in Eqs. (1) and (2). Eqs. (1) and (2) are then combined to eliminate v_{be}'. Next Eqs. (3) is used to eliminate v_{ce}'. Finally, the i_c/i_b ration is formed giving

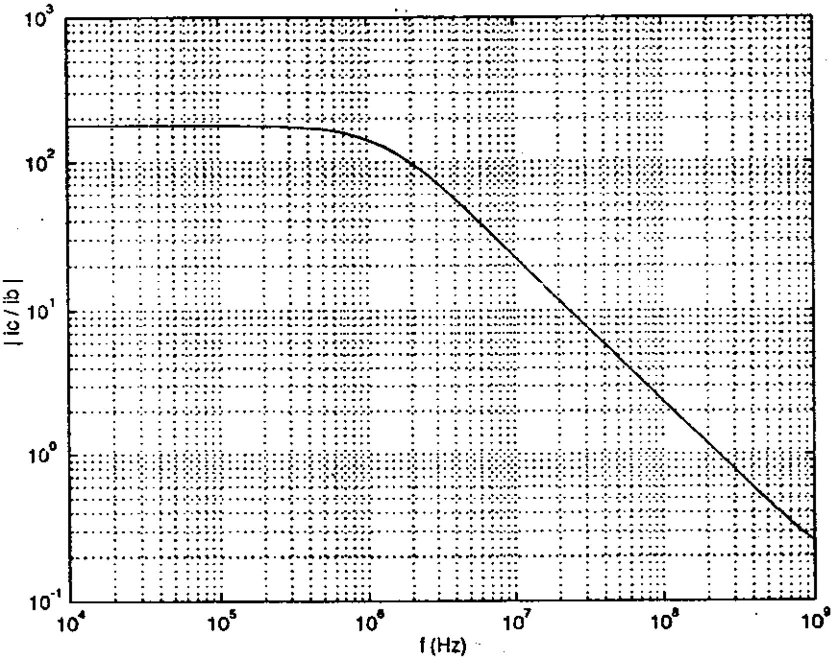
$$\boxed{\frac{i_c}{i_b} = \frac{\left(Y_2 + \frac{1}{r_o}\right)r_e + \left(\frac{g_m - Y_2}{Y_1 + Y_2}\right)(Y_2 r_e - 1)}{\left(\frac{Y_2 - g_m}{Y_1 + Y_2}\right)(r_e + r_c)Y_2 - \left(Y_2 + \frac{1}{r_o}\right)(r_e + r_c) - 1}}$$

(b) With $r_e = 0$ as given in the list of parameters, the i_c/i_b ratio simplifies to

$$\frac{i_c}{i_b} = \frac{\left(\frac{Y_2 - g_m}{Y_1 + Y_2}\right)}{\left(\frac{Y_2 - g_m}{Y_1 + Y_2}\right)r_c Y_2 - \left(Y_2 + \frac{1}{r_o}\right)r_c - 1}$$

Using the MATLAB program to compute $|i_c/i_b|$ versus frequency, one determines an $\boxed{f_T = 235\ \text{MHz}}$. Data sheets list the f_T of the 2N3906 *pnp* BJT to be approximately 200 MHz. (It should be noted that the Electronics Workbench software program was used to determine the d.c. operating point that produced an $I_C = 1$ mA. The series resistances listed in the problem statement were those quoted by the EW program. Zero-bias capacitance values employed in computing the Hybrid-Pi parameters were also extracted from the Electronics Workbench program.)

A plot of $|i_c/i_b|$ versus frequency, and the MATLAB m-file constructed to generate the plot and determine f_T, are reproduced on the next page.



MATLAB program script...

```
%Problem 12.6...fT determination

%Initialization
clear;  close

%Parameters
gm=3.86e-2;
rpi=4.65e3;
ro=2.00e4;
rmu=3.59e6;
Ceb=23.6e-12;
Ccb=2.32e-12;
rb=10;
rc=2.8;
re=0;
```

```
%|ic/ib| vs. frequency
f=logspace(4,9,200);
w=2.*pi.*f;
Y1=1/rpi+j.*w.*Ceb;
Y2=1/rmu+j.*w.*Ccb;
R=(Y2-gm)./(Y1+Y2);
Den=R.*rc.*Y2 - (Y2+1/ro).*rc - 1;
beta=abs(R./Den);    %beta=|ic/ib|
%Plot
loglog(f,beta);  grid
xlabel('f (Hz)');  ylabel('| ic / ib |')
```

12.7

The Eqs. (6.68)/(6.69) solution for the I_{DIFF} flowing in a narrow base diode is

$$I_{DIFF} = qA \frac{D_P}{L_P} \frac{n_i^2}{N_D} \frac{\cosh(x_c'/L_P)}{\sinh(x_c'/L_P)} \left(e^{qV_A/kT} - 1\right)$$

For application to a BJT we make the symbol replacements...$D_P \to D_B$, $L_P \to L_B$, $N_D \to N_B$, $x_c' \to W$, and $V_A \to V_{EB}$. Then

$$I_{DIFF} = qA \frac{D_B}{L_B} \frac{n_i^2}{N_B} \frac{\cosh(W/L_B)}{\sinh(W/L_B)} \left(e^{qV_{EB}/kT} - 1\right)$$

Since $W/L_B << 1$ in a standard transistor, the cosh/sinh factor can be expanded as noted in the problem statement to obtain

$$\frac{\cosh(W/L_B)}{\sinh(W/L_B)} \cong \frac{L_B}{W}\left[1 + \frac{1}{3}\left(\frac{W}{L_B}\right)^2\right] \qquad \text{... } W/L_B << 1$$

and

$$I_{DIFF} \cong \left(qA \frac{D_B}{W} \frac{n_i^2}{N_B}\right)\left[1 + \frac{1}{3}\left(\frac{W}{L_B}\right)^2\right]\left(e^{qV_{EB}/kT} - 1\right)$$

Introducing the substitutions cited in Subsection 7.3.2, that is,

$$\left(\frac{W}{L_B}\right)^2 = \frac{W^2}{D_B \tau_B} \Rightarrow \frac{W^2}{D_B \tau_B}(1 + j\omega\tau_B)$$

and

$$\left(e^{qV_{EB}/kT} - 1\right) \Rightarrow (qv_{eb}/kT)e^{qV_{EB}/kT}$$

yields the corresponding a.c. relationship

$$i_{diff} \cong \left(qA \frac{D_B}{W} \frac{n_i^2}{N_B}\right)\left(1 + \frac{1}{3}\frac{W^2}{D_B \tau_B} + j\omega \frac{W^2}{3D_B}\right)\left(\frac{qv_{eb}}{kT}\right) e^{qV_{EB}/kT}$$

Finally, by definition,

$$Y_D = G_D + j\omega C_D = i_{diff}/v_{eb}$$

and therefore

$$\boxed{C_D = \left(\frac{W^2/3D_B}{kT/q}\right)\left(qA \frac{D_B}{W} \frac{n_i^2}{N_B}\right) e^{qV_{EB}/kT} = \frac{2}{3}\left(\frac{\tau_t}{kT/q}\right)\left(qA \frac{D_B}{W} \frac{n_i^2}{N_B}\right) e^{qV_{EB}/kT}}$$

12.8

The pictured "on" point in Fig. 12.3(b) lies right on the $I_B = V_S/R_S$ line. Therefore $I_{BB} \equiv V_S/R_S = 30\mu A$.

Inspecting the plot we find $I_{CC} \equiv V_{CC}/R_L = 5.0$ mA.

We know $\beta_{dc} = I_C/I_B = \tau_B/\tau_t$. Although base width modulation clearly causes β_{dc} to vary somewhat depending on the d.c. operating point, it is reasonable to employ a median value in obtaining the desired estimate. Specifically, using the point where the load line crosses the $I_B = 15\ \mu A$ characteristic, we obtain

$$\frac{\tau_B}{\tau_t} = \frac{I_C}{I_B} \cong \frac{(0.624)(V_{CC}/R_L)}{I_B} = \frac{(0.624)(5\times 10^{-3})}{15\times 10^{-6}} = 208$$

Thus

$$\frac{I_{CC}\tau_t}{I_{BB}\tau_B} \cong \frac{(5\times 10^{-3})}{(30\times 10^{-6})(208)} = \mathbf{0.80}$$

12.9

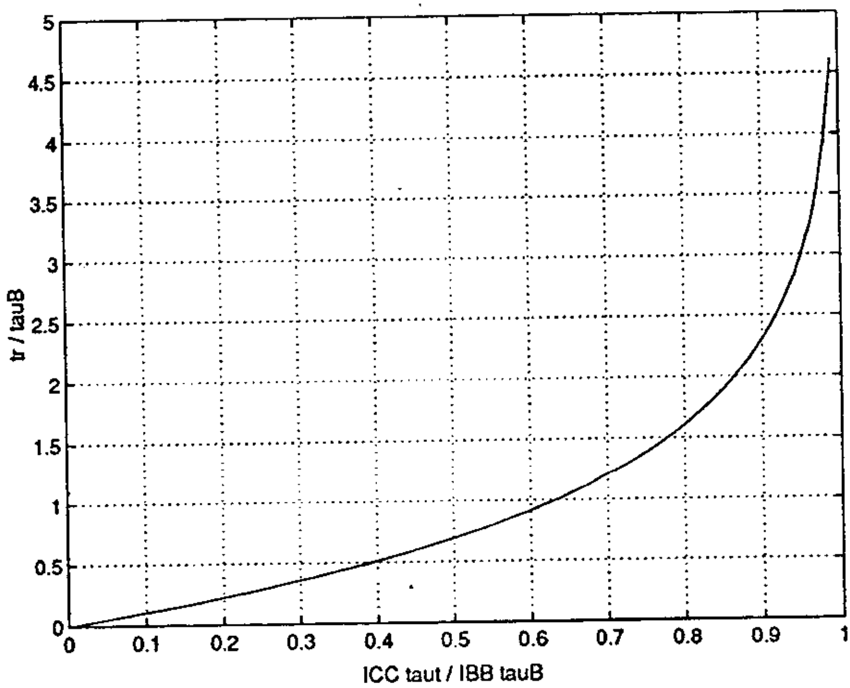
(a)/(b) The required plots and the generating MATLAB m-file are reproduced below. The computational relationships used in producing the plots were

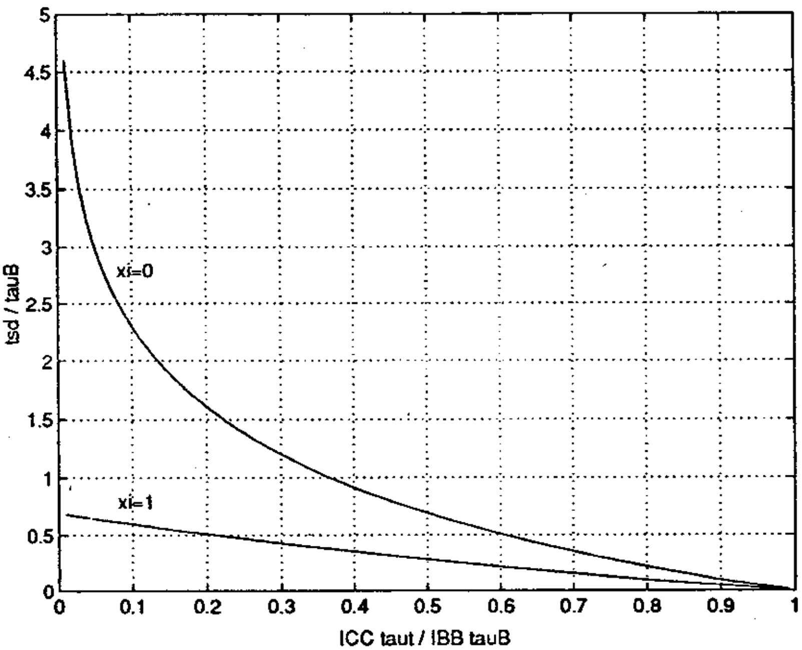
$$\frac{t_r}{\tau_B} = \ln\left(\frac{1}{1-x}\right)$$

$$\frac{t_{sd}}{\tau_B} = \begin{cases} \ln\left(\frac{1}{x}\right) & \text{... if } \xi = 0 \\ \ln\left(\frac{2}{1+x}\right) & \text{... if } \xi = 1 \end{cases}$$

where

$$x = I_{CC}\tau_t / I_{BB}\tau_B$$





MATLAB program script...

```
%Rise and Storage-Delay Time plots (Prob. 12.9)
%Initialization
clear;  close
%Rise time computation
x=linspace(0.01,0.99);
rise=log(1./(1-x));  %rise=tr/tauB
plot(x,rise);  grid
xlabel('ICC taut / IBB tauB');  ylabel('tr / tauB')
pause
%Storage-Delay Time computation
delay0=log(1./x);        %delay0=tsd/tauB, xi=0
delay1=log(2./(1+x));  %delay1=tsd/tauB, xi=1
plot(x,delay0,x,delay1);  grid
xlabel('ICC taut / IBB tauB');  ylabel('tsd / tauB')
text(0.08,2.8,'xi=0');  text(0.08,0.8,'xi=1')
```

12.10

(a) Let t_1 be the time when $i_C = 0.9I_{CC}$ and t_2 the time when $i_C = 0.1I_{CC}$. Making use of Eq. (12.31b), we can then write

$$i_C(t_1) = 0.9I_{CC} = I_{BB}\frac{\tau_B}{\tau_t}\left[(1+\xi)e^{-t_1/\tau_B} - \xi\right]$$

$$i_C(t_2) = 0.1I_{CC} = I_{BB}\frac{\tau_B}{\tau_t}\left[(1+\xi)e^{-t_2/\tau_B} - \xi\right]$$

Solving for the t's yields

$$t_1 = \tau_B \ln\left(\frac{1+\xi}{0.9I_{CC}\tau_t/I_{BB}\tau_B + \xi}\right)$$

$$t_2 = \tau_B \ln\left(\frac{1+\xi}{0.1I_{CC}\tau_t/I_{BB}\tau_B + \xi}\right)$$

and per the measurements-based definition

$$\boxed{t_f = t_2 - t_1 = \tau_B \ln\left(\frac{0.9I_{CC}\tau_t/I_{BB}\tau_B + \xi}{0.1I_{CC}\tau_t/I_{BB}\tau_B + \xi}\right) = \tau_B \ln\left(\frac{0.9x+\xi}{0.1x+\xi}\right)}$$

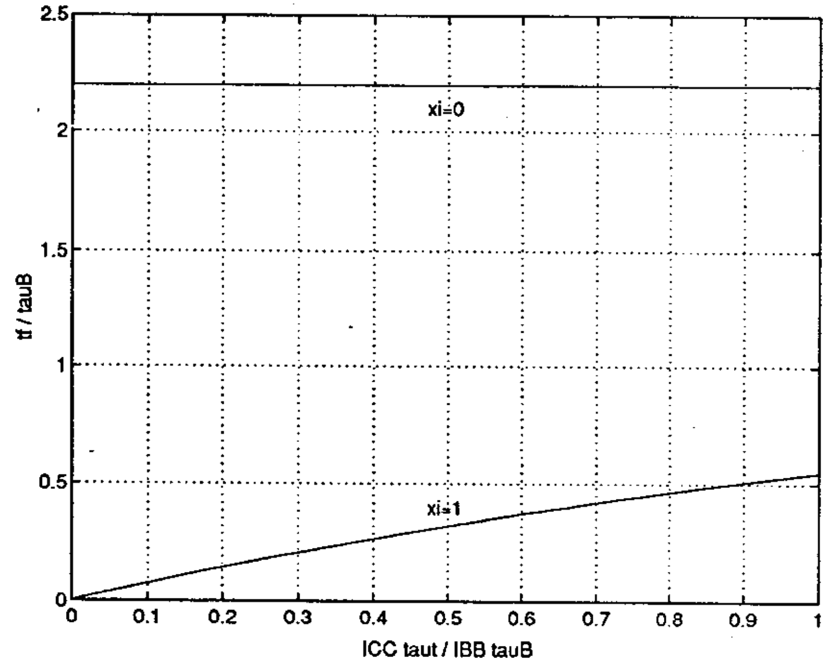
where $x = I_{CC}\tau_t/I_{BB}\tau_B$

(b) With $\xi = 0$ and $\xi = 1$, the part (a) relationship simplifies to

$$\frac{t_f}{\tau_B} = \begin{cases} \ln 9 & \text{... if } \xi = 0 \\ \ln\left(\dfrac{0.9x+1}{0.1x+1}\right) & \text{... if } \xi = 1 \end{cases}$$

The requested t_f/τ_B versus x plot is displayed on the next page along with the script of the MATLAB m-file used to generate the plot.

Consistent with the analysis in Subsection 12.2.3, the plotted fall times decrease when $\xi > 0$. This occurs because an $i_B < 0$ aids the withdrawal of charge from the quasineutral base. If the x-ratio increases either due to an increase in I_{CC} or a decrease in I_{BB}, the charge storage is enhanced relative to the charge removal capability of the base current. Thus, the t_f/τ_B ratio for the $\xi = 1$ curve increases with increasing x. When $\xi = 0$, the charge removal from the base occurs only by recombination and the fall-time collector current assumes the simple form, $i_C = A\exp(-t/\tau_B)$. Since t_f is always evaluated employing the same relative i_C values, $i_C(t_1)/i_C(t_2)$ = constant = $\exp(t_f/\tau_B)$, and t_f/τ_B is seen to be a constant independent of x.



MATLAB program script...

```
%Fall Time (Problem 12.10)

%Initialization
clear;  close

%Fall Time computations
x0=[0,1];
y0=[log(9),log(9)];                    %tf/tauB when xi=0
x1=linspace(0,1);
y1=log((0.9.*x1+1)./(0.1.*x1+1));  %tf/tauB when xi=1
plot(x0,y0,x1,y1);  grid
xlabel('ICC taut / IBB tauB');  ylabel('tf / tauB')
text(0.47,2.1,'xi=0');  text(0.47,0.4,'xi=1')
```