《线性电路实验》预习报告

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1 Electrical Characteristics pf NPN Transistor SS8050 (宏嘉诚)

Maximum Ratings (Ta=25°C Unless otherwise specified)

PARAMETER	SYMBOL	UNIT	VALUE
Collector-Base Voltage	V_{CBO}	V	40
Collector-Emitter Voltage	V_{CEO}		25
Emitter-Base Voltage	V_{EBO}		5.0
Collector Current	I_C	A	1.5
Collector Power Dissipation	P_C	mW	300
Storage temperature	T_{stg}	°C	-55 ~+150
Junction temperature	T_j	°C	-55 ~+150
Typical Thermal Resistance	$R_{\theta J\text{-}A}$	°C /W	417

Electrical Characteristics (Ta=25°C Unless otherwise noted)

PARAMETER	SYMBOL	UNIT	Condition	Min	Max
Collector-Base Breakdown Voltage	$V_{(BR)CBO}$	V	I_C=100μA, I_E=0	40	—
Collector-Emitter Breakdown Voltage	$V_{(BR)CEO}$		I_C=100μA, I_B=0	25	—
Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$		I_E=100μA, I_C=0	5.0	—
Collector-Base cut-off current	I_{CBO}	μA	V_{CB}=40V, I_E=0	—	0.1
Collector-Emitter cut-off current	I_{CEO}		V_{CE}=20V, I_B=0	—	0.1
Emitter-Base cut-off current	I_{EBO}		V_{EB}=5.0V, I_C=0	—	0.1
DC Current Gain	$h_{FE(1)}$	—	I_C=100mA, V_{CE}=1.0V	120	350
	$h_{FE(2)}$		I_C=800mA, V_{CE}=1.0V	40	—
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	V	I_C=800mA, I_B=80mA	—	0.5
Base-Emitter Saturation Voltage	$V_{BE(sat)}$	V	I_C=800mA, I_B=80mA	—	1.2

Small-signal Characteristics

ITEM	SYMBOL	Condition	UNIT	Min	Max
Transition frequency	f_T	I_C=50mA, V_{CE}=10V,f=30MHz	MHz	100	—

Ratings And Characteristics Curves (Ta=25°C Unless otherwise specified)

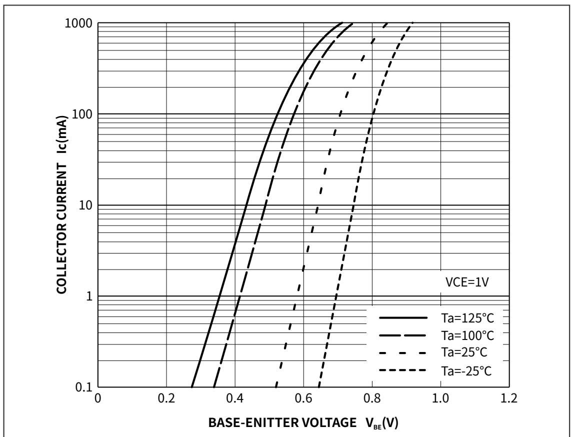


Fig.5 Base-Emitter On Voltage

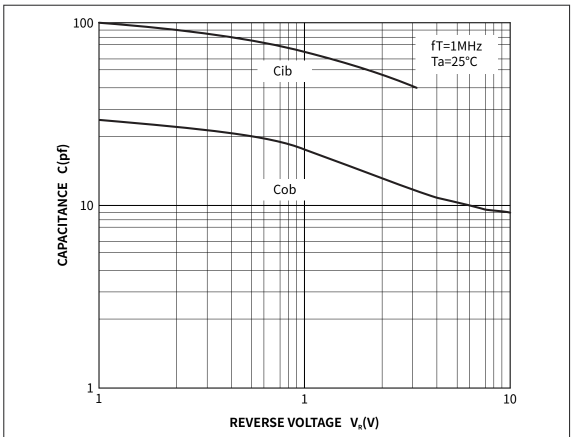


Fig.6 Cob/Cib-$V_{CB}V_{EB}$

Ratings And Characteristics Curves (Ta=25°C Unless otherwise specified)

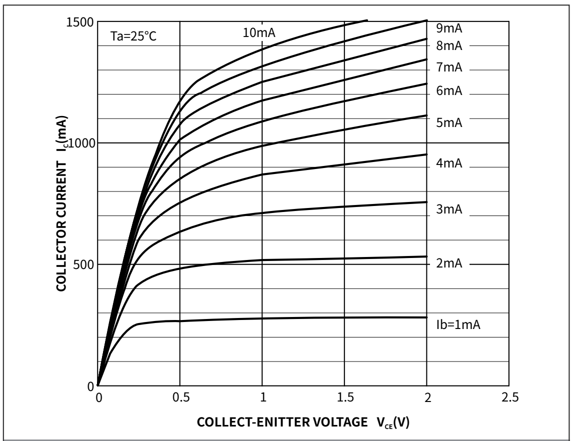


Fig.1 Static Characteristic

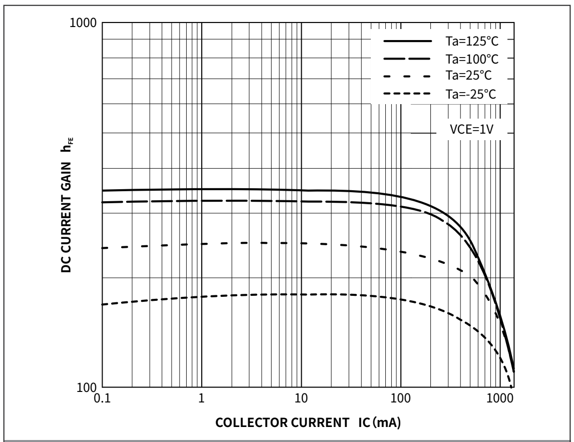


Fig.2 DC Current Gain

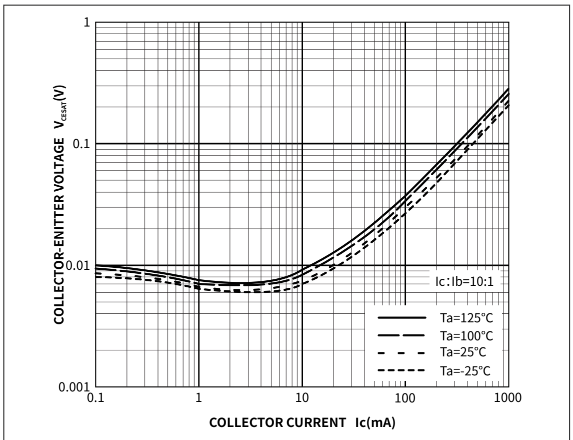


Fig.3 Collector-Emitter Saturation Voltage

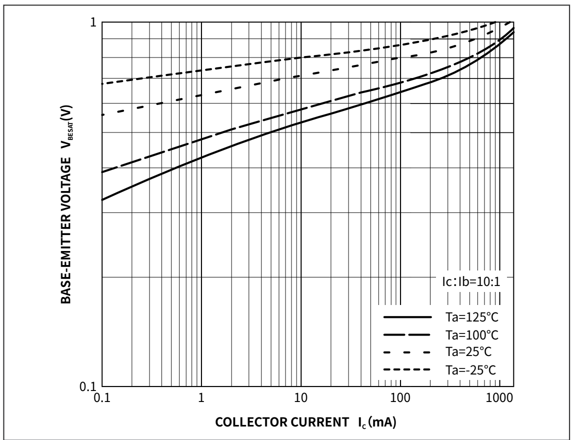


Fig.4 Base-Emitter Saturation Voltage

2 Technical Parameters of The Oscilloscope and The Multimeter

我们的示波器测量范围和精度均高于万用表，因此采用示波器进行测量。示波器 (Rigol 200MSO2202A) 的主要参数如下：

(1) 带宽：200 MHz

(2) 输入阻抗：:（1 MΩ±1%）||（16 pF±3 pF）或 50 Ω±1.5%

(3) 时基档位：1.000 ns/div 至 1.000 ks/div

(4) 时基精度: ≤±25 ppm

(5) 垂直档位：输入阻抗为 50 Ω 时：500 µV/div 至 1 V/div

(6) 输入阻抗为 1 MΩ 时：500 µV/div 至 10 V/div

(7) 偏移范围：输入阻抗为 50 Ω 时：500 µV/div 至 50 mV/div：±2 V ；51 mV/div 至 200 mV/div：±10 V ；205 mV/div 至 1 V/div：±12 V

(8) 输入阻抗为 1 MΩ 时：500 µV/div 至 50 mV/div：±2 V ；51 mV/div 至 200 mV/div：±10 V ；205 mV/div 至 2 V/div：±50 V ；2.05 V/div 至 10 V/div：±100 V

(9) 直流增益精度：±2% 满刻度

(10) 直流偏移精度：±0.1 div±2 mV±1% 偏移值

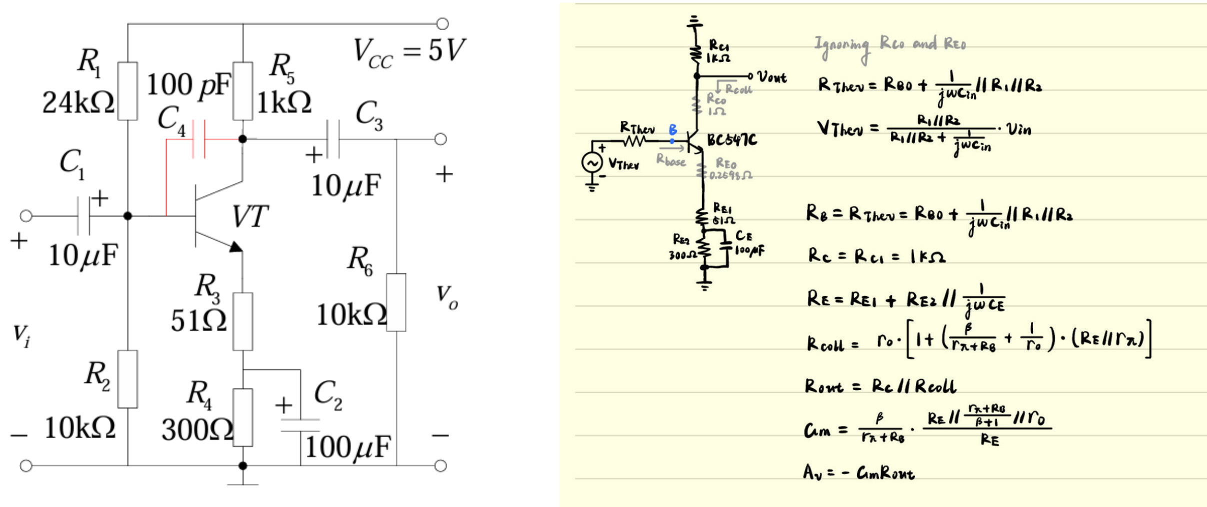
万用表 (Unit UT61E) 的主要参数如下：

(1) 精度：AC 电压测量范围：220mV/2.2V/22V/220V/750V

(2) AC 电压测量精度：±(0.8% + 10 digit)

(3) AC 电压测量带宽：45Hz-10kHz
(4) AC 电流量程：220µA/2.2mA/22mA/220mA/10A
(5) AC 电流测量准确度：±(0.8% + 10 digit)
(6) AC 电流测量带宽：45Hz-10kHz

3 Common-Emitter Amplifier Design



(a) Circuit Schematic

(b) Small-Signal (Mid-band) Gain Calculation

图 1: Design of Common-Emitter Amplifier

4 Input and Output Impedance Calculation

If considering the coupling capacitors, we have:

$$R_{in} = \frac{1}{j\omega C_1} + R_1 \parallel R_2 \parallel R_{base}, \quad R_{base} = r_\pi + R_E \cdot \frac{\beta r_O + r_O + R_C}{R_E + r_O + R_C} \tag{1}$$

$$R_{out} = \frac{1}{j\omega C_3} + R_5 \parallel R_{coll}, \quad R_{coll} = r_O \cdot \left[1 + \left(\frac{\beta}{r_\pi + R_B} + \frac{1}{r_O}\right)(R_E \parallel (r_\pi + R_B))\right] \tag{2}$$

$$\text{where } \ R_B = R_{Thev} = r_{bb'} + \frac{1}{j\omega C_1} \parallel R_1 \parallel R_2 \tag{3}$$

From another perspective, ignoring the coupling capacitors, we have:

$$R_{in} = R_1 \parallel R_2 \parallel R_{base}, \quad R_{base} = r_\pi + R_E \cdot \frac{\beta r_O + r_O + R_C}{R_E + r_O + R_C} \tag{4}$$

$$R_{out} = R_5 \parallel R_{coll}, \quad R_{coll} = r_O \cdot \left[1 + \left(\frac{\beta}{r_\pi + R_B} + \frac{1}{r_O}\right)(R_E \parallel (r_\pi + R_B))\right] \tag{5}$$

$$\text{where } \ R_B = R_{Thev} = R_{B0} + R_1 \parallel R_2 = r_{bb'} + R_1 \parallel R_2 \tag{6}$$

Note that the impedances denote small-signal quantities despite we use the uppercase. For instance, **ignoring** C_1 **and** C_3 **but considering** C_2, and assuming the parameters of the transistor is given by:

$$I_S = 4.679 \times 10^{-14}\ \text{A} \tag{7}$$

$$n_f = 1.01,\ \beta = 250,\ V_A = 52.64\ \text{V}, \tag{8}$$

$$R_{B0} = r_{bb'} = 1\ \Omega,\ R_{E0} = 0.2598\ \Omega,\ R_{C0} = 1\ \Omega \tag{9}$$

it can be derived that the quiescent operation point is:

$$I_C = 2.178\ \text{mA},\ I_B = 8.712\ \text{uA},\quad V_{BE} = 0.644\ \text{V},\ V_{CE} = 2.0547\ \text{V} \tag{10}$$

$$V_E = 0.7651\ \text{V},\quad V_B = 1.4091\ \text{V},\quad V_C = 2.8198\ \text{V} \tag{11}$$

Therefore, the small-signal gain and other parameters is given by (calculated at 1kHz):

$$A_v = -15.6618 - 0.4088j \overset{\text{abs}}{=} -15.6671,\quad |R_{in}| = 4.8297\ \text{k}\Omega,\quad |R_{out}| = 992.0509\ \Omega \tag{12}$$

5 Input/Output Impedance Measurement

Assuming the open-circuit voltage gain is A_0, the input source resistance is R_S, we have:

$$A_v = \frac{R_{in}}{R_{in} + R_S} A_0 \Longrightarrow R_{in} = \frac{R_S}{\frac{A_0}{A_v} - 1} \quad (R_L = \infty) \tag{13}$$

$$A_v = \frac{R_L}{R_L + R_{out}} A_0 \Longrightarrow R_{out} = \left(\frac{A_0}{A_v} - 1\right) R_L \quad (R_S = 0) \tag{14}$$

Appendix: Matlab Codes of OP, Gain and Impedance Calculation

```matlab
% dc point calculation
clc, clear, close all

% 电路参数
R_1 = 24e3;
R_2 = 10e3;
R_C1 = 1e3;
R_E1 = 51;
R_E2 = 300;

% SPICE 参数
Vcc = 5;
I_S = 4.679e-14;
R_B0 = 1;
R_C0 = 1;
R_E0 = 0.2598;
beta = 250;
n_f = 1.01;
V_A = 52.64;

% 其它参数
R_E_all = R_E0 + R_E1 + R_E2
R_all = R_C0 + R_C1 + R_E0 + R_E1 + R_E2
V_T = 26e-3;


tv_Ic = Vcc/R_all*1000
tv_Ib = tv_Ic/beta*1000

func_I_C = @(V_BE, V_CE) I_S*exp(V_BE/(n_f*V_T)).*(1 + V_CE/V_A)
array_V_BE = linspace(600, 670, 8)*10^(-3);
array_V_CE = linspace(1, 5, 100);
matrix_I_C = func_I_C(array_V_BE, array_V_CE');

MyPlot(array_V_CE, matrix_I_C');

V_B = @(I_C) (Vcc - I_C*R_1/beta) / (1 + R_1/R_2)
```

```
eq = @(I_C) I_C - I_S .* exp(  (V_B(I_C) - I_C.*R_E_all) / (n_f*V_T)  ) .* (1 + (Vcc - I_C.*R_all)/V_A)
range_I_C = linspace(0, 5e-3, 200);
stc = MyPlot_2window(range_I_C, eq(range_I_C), range_I_C, abs(eq(range_I_C)));
stc.ax1.YLim = [-1 1];
stc.ax1.XLim = [0 range_I_C(end)];
stc.ax2.YLim = [-1 1];
stc.ax2.XLim = [0 range_I_C(end)];
stc.ax2.YScale = 'log';

% dc point calculation
I_C = fzero(eq, [0 4e-3]);
disp(['I_C = ', num2str(I_C*1000, '%.8f') ' mA'])
I_B = I_C/beta
V_B_ = V_B(I_C)
V_C = Vcc - I_C*(R_C0 + R_C1)
V_E = I_C*R_E_all
V_BE = V_B(I_C) - V_E
V_CE = V_C - V_E


% dc point simulation
V_C = 2.74563
V_B = 1.43601
V_E = 0.793003
V_CE = V_C - V_E
V_BE = V_B - V_E

% ac gain calculation
f = 1e3;
omega = 2*pi*f;
C_in = 10e-6;
C_out = 10e-6;
C_E = 100e-6;

R_B = R_B0 + MyParallel_n([1/(1j*omega*C_in), R_1, R_2])
R_C = R_C1
R_E = R_E1 + MyParallel(R_E2, 1/(1j*omega*C_E))


r_O = V_A/I_C
g_m = I_C/(n_f*V_T)
r_pi = beta/g_m

R_base = r_pi + R_E * (beta*r_O + r_O + R_C)/(R_E + r_O + R_C)
R_in = MyParallel_n([R_1, R_2, R_base])
R_in_abs = abs(R_in)

R_coll = r_O * (  1 + (beta/(r_pi + R_B) + 1/r_O)*MyParallel(R_E, r_pi) )
R_out = MyParallel(R_C, R_coll)
R_out_abs = abs(R_out)
G_m = beta/(r_pi + R_B) / R_E * MyParallel_n([R_E, (r_pi + R_B)/(beta + 1), r_O])
A_v = -G_m*R_out
A_v_abs = -abs(A_v)
```