XMUT204 Electronic Design

Tutorial 4: BJT Characteristics and Biasing

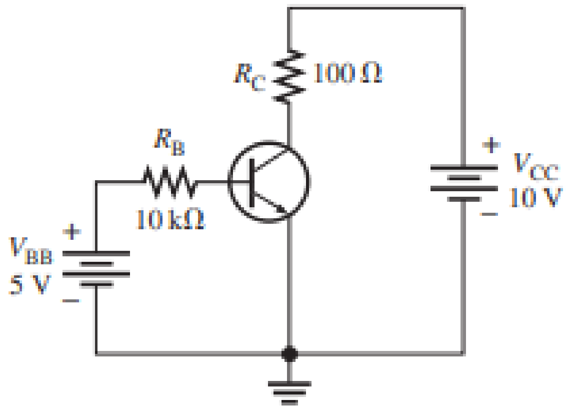
A. BJT Characteristics

1. Determine the region of operations of BJT transistor. [4 marks]

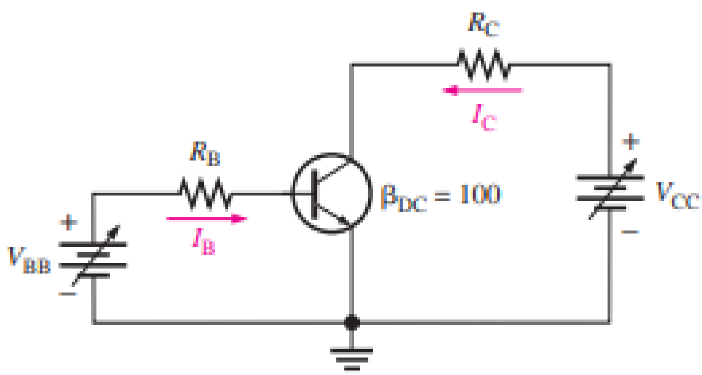
2. Why it is a bad idea to do the design of a transistor circuit based on a specific (supplied) value of β_{DC}. [4 marks]

3. Determine the DC current gain β_{DC} and the emitter current I_E for a transistor where I_B = 50 µA and I_C = 3.65 mA. [4 marks]

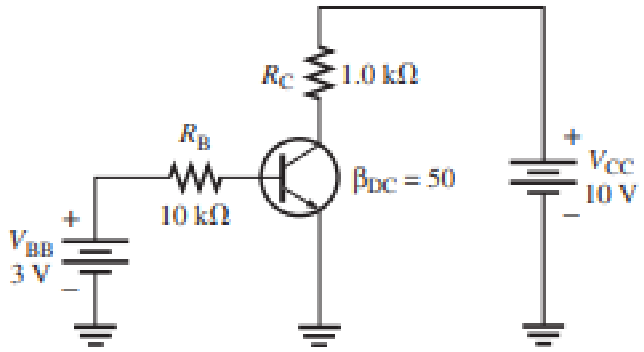
4. Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of given below. The transistor has a β_{DC} = 150. [12 marks]



5. Sketch an ideal family of collector curves for the circuit in the figure below for I_B from 5 µA to 25 µA in 5 µA increments. Assume β_{DC} = 100 and that V_{CE} does not exceed breakdown. [10 marks]

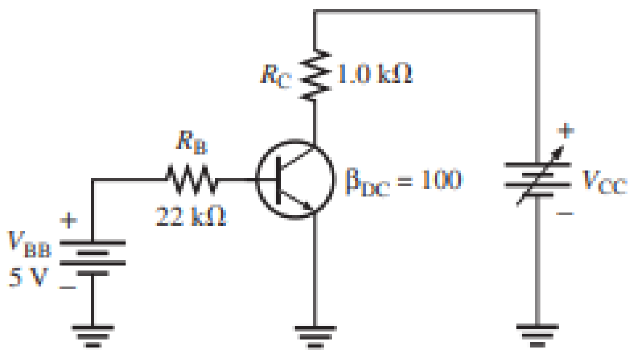


6. Determine whether or not the transistor in the figure below is in saturation. Assume V_{CE}(sat) = 0.2 V. [8 marks]



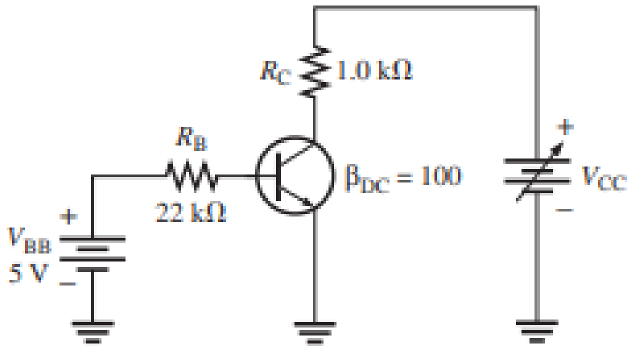
7. A certain transistor is to be operated with V_{CE} = 6 V. If its maximum power rating is 250 mW, what is the most collector current that it can handle? [4 marks]

8. The transistor in the figure below has the following maximum ratings: $P_{D(\max)}$ = 800 mW, $V_{CE(\max)}$ = 15 V, and $I_{C(\max)}$ = 100 mA. Determine the maximum value to which V_{CC} can be adjusted without exceeding a rating. Which rating would be exceeded first? [14 marks]

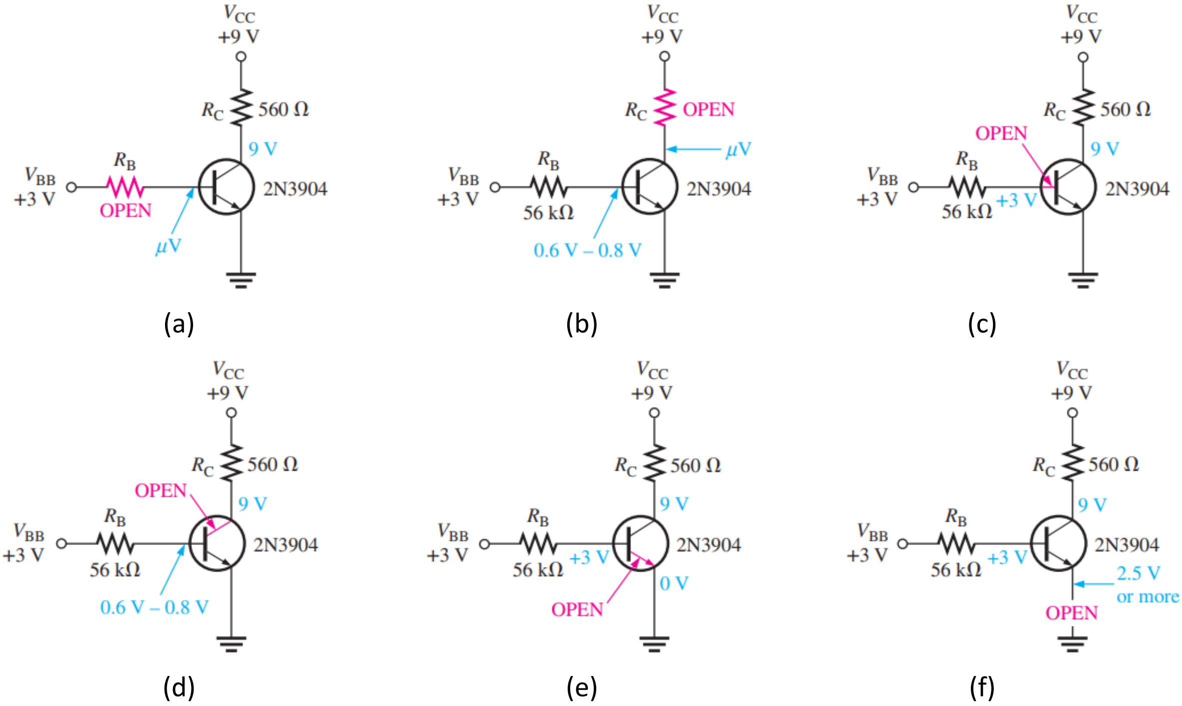


9. A certain transistor has a $P_{D(\max)}$ of 1 W at 25°C. The derating factor is 5 mW/°C. What is the $P_{D(\max)}$ at a temperature of 70°C? [4 marks]

10. A 2N3904 transistor is used in the circuit as shown below (i.e. the same BJT circuit as in Question 6). Determine the maximum value to which V_{CC} can be adjusted without exceeding a rating. Which rating would be exceeded first? Refer to the datasheet of this transistor. [10 marks]



11. Observe the following operational conditions and measured electrical parameters of the 2N3904 NPN BJT transistor-based circuits.



a. Symptoms: Readings from V to a few mV at base due to floating point and 9 V at collector because transistor is in cutoff. [2 marks]

b. Symptoms: A very small voltage may be observed at the collector when a meter is connected due to the current path through the BC junction and the meter resistance. [2 marks]

c. Symptoms: It is observed that 3 V at base lead and 9 V at collector because transistor is in cutoff. [2 marks]

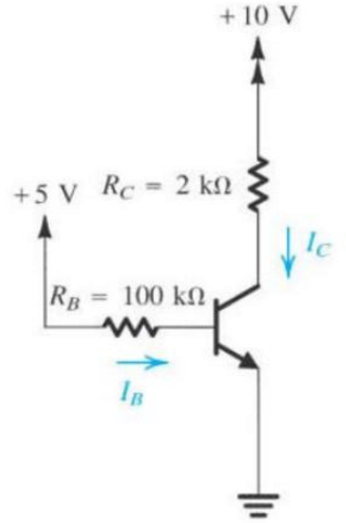
d. Symptoms: It is observed that 0.6 V – 0.8 V at base lead due to forward voltage drop across base-emitter junction and 9 V at collector because the open prevents collector current. [2 marks]

e. Symptoms: It is observed that 3 V at base lead and 9 V at collector because there is no collector current. Then, we have 0 V at the emitter as normal. [2 marks]

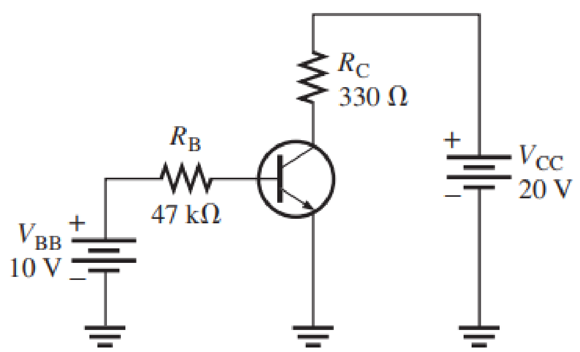
f. Symptoms: It is observed that 3 V at base lead and 9 V at collector because there is no collector current. Then, we have 2.5 V or more at the emitter due to the forward voltage drop across the base-emitter junction. The measuring voltmeter provides a forward current path through its internal resistance. [2 marks]

B. BJT Biasing Circuits

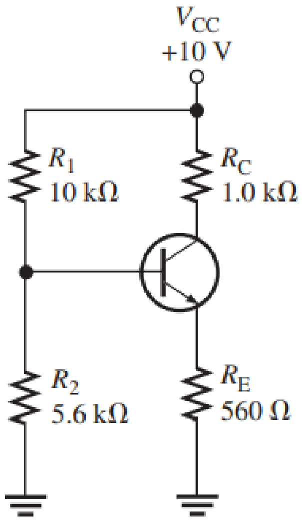
1. Analyse the DC biased NPN BJT transistor circuit below to determine the voltages at all nodes and the currents in all branches. Assume β = 100. [10 marks]



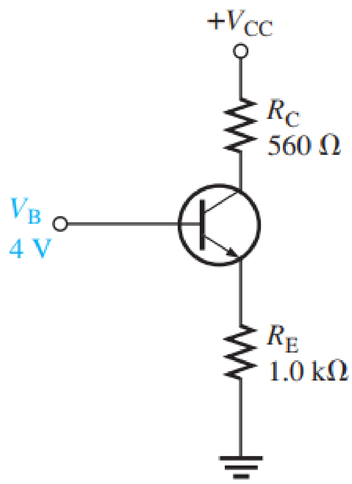
2. Determine the Q-point for the DC biased NPN BJT transistor circuit in figure given below and draw the DC load line. Find the maximum peak value of base current for linear operation. Assume β_{DC} = 200. [20 marks]



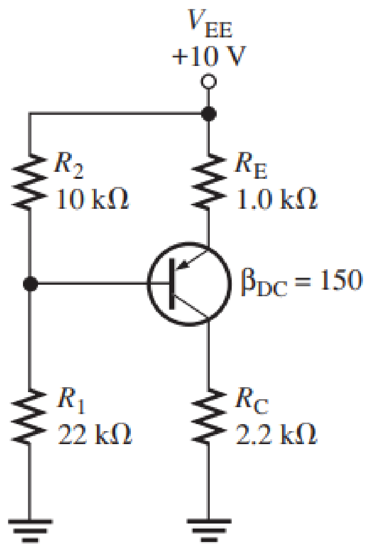
3. Determine V_{CE} and I_C in the voltage-divider biased NPN BJT transistor circuit of figure given below if β_{DC} = 100. [12 marks]



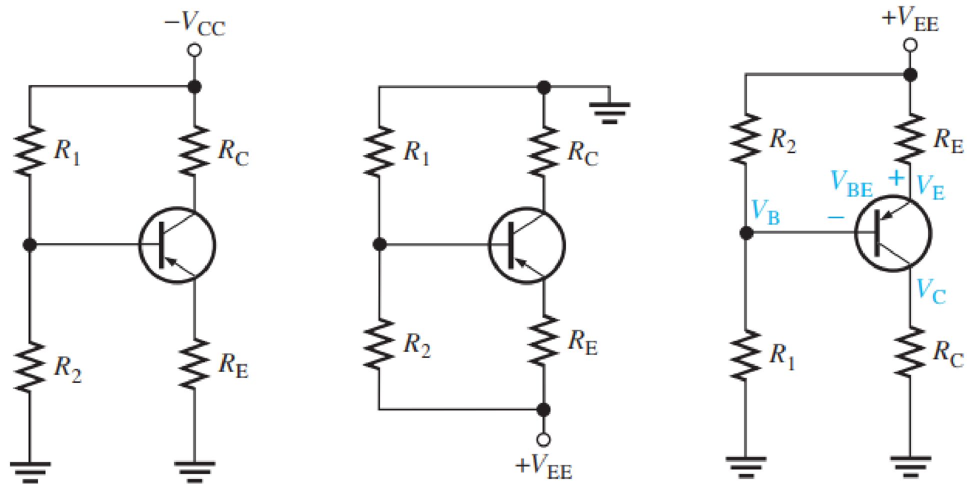
4. Determine the DC input resistance looking in at the base of the transistor in the figure below. Knowing that β_{DC} = 125 and V_B = 4 V. [4 marks]



5. Find I_C and V_{EC} for the voltage-divider biased PNP BJT transistor circuit in the figure given below. [14 marks]



6. Find I_C and V_{CE} for a voltage-divider biased PNP BJT transistor circuit with these values: R_1 = 68 kΩ, R_2 = 47 kΩ, R_C = 1.8 kΩ, R_E = 2.2 kΩ, V_{CC} = -6 V, and β_{DC} = 75. Refer to the figure (a) below, which shows the schematic with a negative supply voltage. [14 marks]

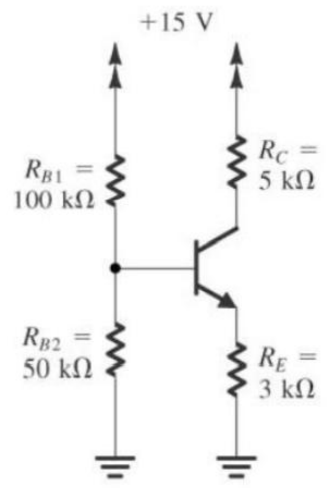


(a) Negative collector supply voltage, V_{CC}

(b) Positive emitter supply voltage, V_{EE}

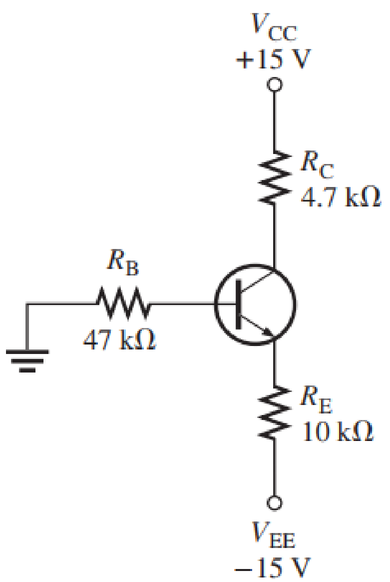
(c) The circuit in (b) redrawn

7. Analyse the voltage-divider biased NPN BJT transistor circuit below to determine the voltages at all nodes and the currents in all branches. Assume β = 100. [20 marks]

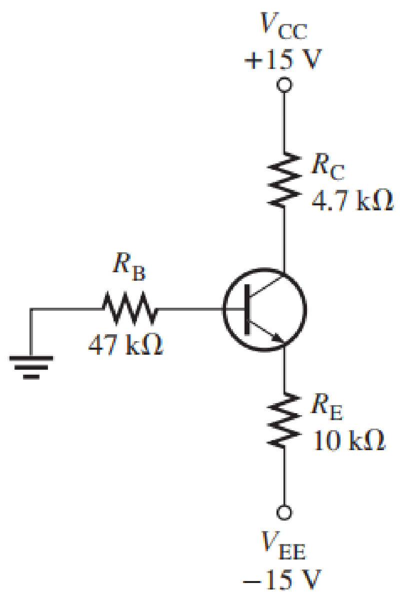


C. Other BJT Biasing Methods

1. Calculate I_E and V_{CE} for the emitter biased NPN BJT transistor circuit in the figure given below using the approximations $V_E \cong -1$ V and $I_C \cong I_E$. [8 marks]

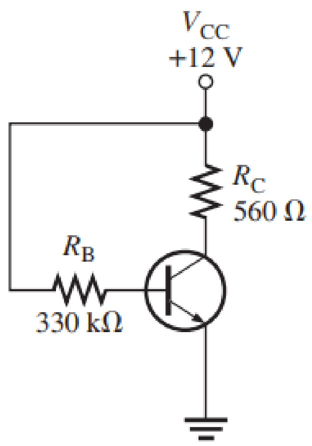


2. Determine how much the Q-point (I_C, V_{CE}) for the emitter biased NPN BJT transistor circuit in the figure given below will change if β_{DC} increases from 100 to 200 when the given transistor is replaced by another type of BJT transistor. [20 marks]



3. Determine how much the Q-point (I_C, V_{CE}) for the base biased NPN BJT transistor circuit in the figure below will change over a temperature range where β_{DC} increases from 100 to 200.

[14 marks]

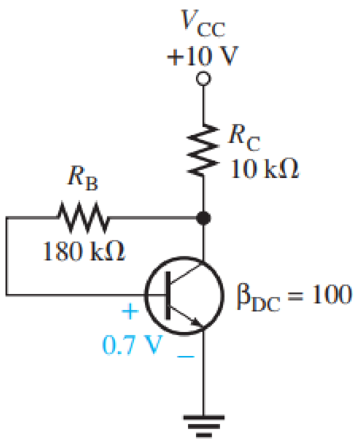


4. The base-biased NPN BJT transistor circuit from previous question is converted to emitter-feedback biased by the addition of a 1 kΩ emitter resistor. All other values are the same and a transistor with a β_{DC} = 100 is used.

   Determine how much the Q-point will change if the first transistor is replaced with one having a β_{DC} = 200. Compare the results to those of the base-bias circuit. [14 marks]

5. Calculate the Q-point values (I_C and V_{CE}) for the collector-feedback biased NPN BJT transistor circuit in the figure given below. Compare the performance of the circuit with the one in the previous question (e.g. with modified base biased scheme) when β_{DC} is varied from 100 to 200.

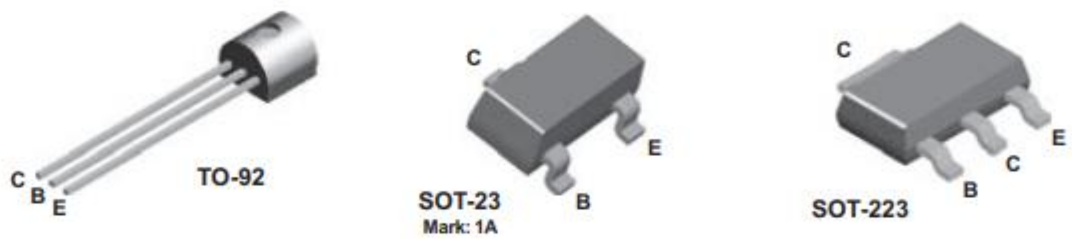
[14 marks]


V_{CC}
+10 V
R_C
10 kΩ
R_B
180 kΩ
$\beta_{DC} = 100$
+
0.7 V
−

Appendix 1 – Datasheet of BJT Transistor 2N3904

FAIRCHILD SEMICONDUCTOR™

2N3904 MMBT3904 PZT3904



NPN General Purpose Amplifier

This device is designed as a general purpose amplifier and switch. The useful dynamic range extends to 100 mA as a switch and to 100 MHz as an amplifier.

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Absolute Maximum Ratings* $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Characteristic	Max			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

**Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

Electrical Characteristics

T_A = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Max	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0 mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10 μA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10 μA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1 mA, V_{CE} = 1.0 V I_C = 1.0 mA, V_{CE} = 1.0 V I_C = 10 mA, V_{CE} = 1.0 V I_C = 50 mA, V_{CE} = 1.0 V I_C = 100 mA, V_{CE} = 1.0 V	40 70 100 60 30	 300	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10 mA, V_{CE} = 20 V, f = 100 MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0 V, I_E = 0, f = 1.0 MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5 V, I_C = 0, f = 1.0 MHz		8.0	pF
NF	Noise Figure	I_C = 100μA, V_{CE} = 5.0 V, R_S =1.0kΩ,f=10 Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0 V, V_{BE} = 0.5 V,		35	ns
t_r	Rise Time	I_C = 10 mA, I_{B1} = 1.0 mA		35	ns
t_s	Storage Time	V_{CC} = 3.0 V, I_C = 10mA		200	ns
t_f	Fall Time	I_{B1} = I_{B2} = 1.0 mA		50	ns

*Pulse Test: Pulse Width ≤ 300μs, Duty Cycle ≤ 2.0%