Lecture (07) Bipolar Junction Transistor (2)

By:

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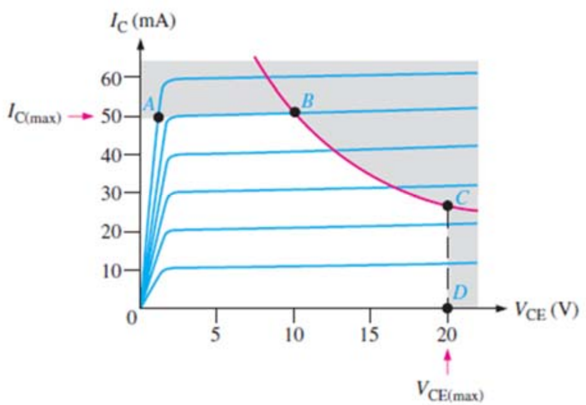
Maximum Transistor Ratings

- The product of *V*CE and *I*C must not exceed the maximum power dissipation
- Both *V*CE and *I*C cannot be maximum at the same time.
- If *V*CE is maximum, *I*C can be calculated as $I_C = \frac{P_{D(max)}}{V_{CE}}$
- If *I*C is maximum, *V*CE can be calculated by $V_{CE} = \frac{P_{D(max)}}{I_C}$
- Assume *P*D(max) is 500 mW, *V*CE(max) is 20 V, and *I*C(max) is 50 mA

- transistor cannot be operated in the shaded portion of the graph.
- *I*C(max) is the limiting rating between points *A* and *B*, *P*D(max) is the limiting rating between points *B* and *C*, and *V*CE(max) is the limiting rating between points *C* and *D*.



$P_{D(max)}$	V_{CE}	I_C
500 mW	5 V	100 mA
500 mW	10 V	50 mA
500 mW	15 V	33 mA
500 mW	20 V	25 mA

Example 01

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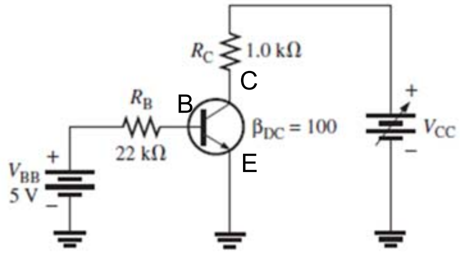
$$I_C = \frac{P_{D(max)}}{V_{CE}} = \frac{250\text{ mW}}{6\text{ V}} = \mathbf{41.7\text{ mA}}$$

Example 02

The transistor in Figure 4–19 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?



Example 02

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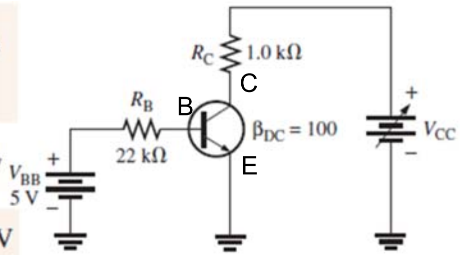
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{22\text{ k}\Omega} = 195\ \mu\text{A}$$

$$I_C = \beta_{DC} I_B = (100)(195\ \mu\text{A}) = 19.5\text{ mA}$$

I_C is much less than $I_{C(max)}$ and ideally will not change with V_{CC}. It is determined only by I_B and β_{DC}.



$$V_{R_C} = I_C R_C = (19.5\text{ mA})(1.0\text{ k}\Omega) = 19.5\text{ V}$$

- Vcc max occures when Vce max, calculated using KVL

$$V_{CC(max)} = V_{CE(max)} + (V_{R_C} = 15\text{ V} + 19.5\text{ V} = \mathbf{34.5\text{ V}}$$

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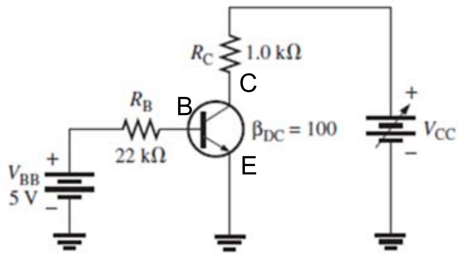
- Now calculating PD @ V_{CEmax}

$$P_D = V_{CE(max)} I_C = (15\text{ V})(19.5\text{ mA}) = 293\text{ mW}$$



Since $P_{D(max)}$ is 800 mW, it is *not* exceeded when $V_{CC} = 34.5$ V. So, $V_{CE(max)} = 15$ V is the limiting rating in this case.

Derating *PD*(max)

- *PD*(max) is usually specified at 25°C. For higher temperatures, *PD*(max) is less.
- example, a derating factor of 2 mW/°C indicates that the maximum power dissipation is reduced 2 mW for each degree Celsius increase in temperature.

Example 03

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?

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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?

The change (reduction) in $P_{D(max)}$ is

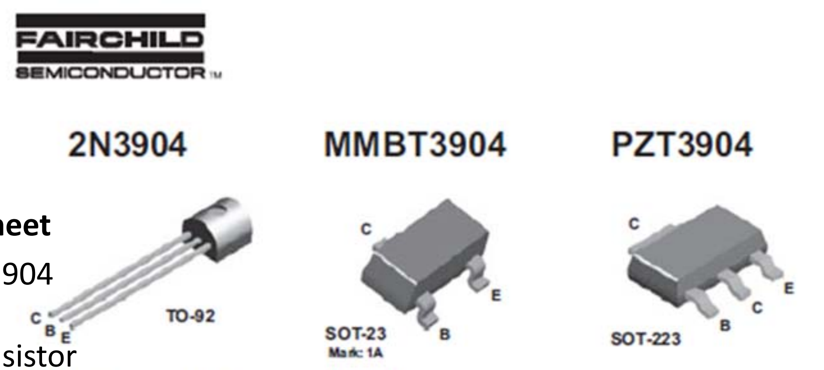
$$\Delta P_{D(max)} = (5\ \text{mW/°C})(70°\text{C} - 25°\text{C}) = (5\ \text{mW/°C})(45°\text{C}) = 225\ \text{mW}$$

Therefore, the $P_{D(max)}$ at 70°C is

$$1\ \text{W} - 225\ \text{mW} = \mathbf{775\ mW}$$

BJT Datasheet

- 2N3904 *npn* transistor



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.

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

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
$R_{θJC}$	Thermal Resistance, Junction to Case	[illegible]			°C/W
$R_{θJA}$	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	$I_C = 10\ \mu A$, $I_E = 0$	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	$I_E = 10\ \mu A$, $I_C = 0$	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 [illegible] 100 [illegible] 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 [illegible]	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	$I_C = 100\ \mu A$, $V_{CE} = 5.0$ V, $R_S = 1.0 k\Omega$, f = 10 Hz to 15.7 kHz		5.0	dB

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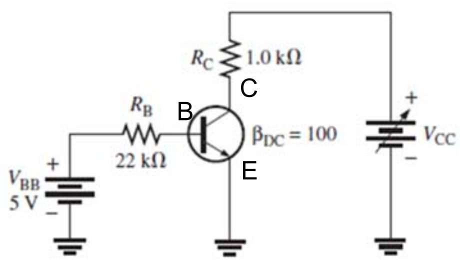
SWITCHING CHARACTERISTICS

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, $I_C = 10$mA		200	ns
t_f	Fall Time	$I_{B1} = I_{B2} = 1.0$ mA		50	ns

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

Example 04

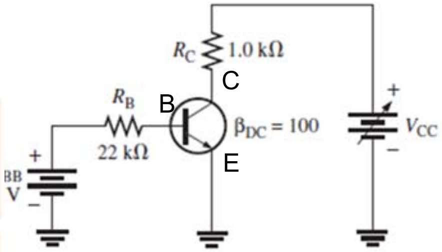
A 2N3904 transistor is used in the circuit of Figure 4–19 (Example 4–6). Determine the maximum value to which V_{CC} can be adjusted without exceeding a rating. Which rating would be exceeded first? Refer to the datasheet in Figure 4–20.



Example 04

A 2N3904 transistor is used in the circuit of Figure 4–19 (Example 4–6). 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 in Figure 4–20.

$$P_{D(max)} = P_D = 625\text{ mW}$$
$$V_{CE(max)} = V_{CEO} = 40\text{ V}$$
$$I_{C(max)} = I_C = 200\text{ mA}$$



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{22\text{ k}\Omega} = 195\ \mu\text{A}$$
$$I_C = \beta_{DC} I_B = (100)(195\ \mu\text{A}) = 19.5\text{ mA}$$

$$V_{R_C} = I_C R_C = (19.5\text{ mA})(1.0\text{ k}\Omega) = 19.5\text{ V}$$

$$V_{CC(max)} = V_{CE(max)} + V_{R_C} = 40\text{ V} + 19.5\text{ V} = 59.5\text{ V}$$

$$P_D = V_{CE(max)} I_C = (40\text{ V})(19.5\text{ mA}) = 780\text{ mW}$$

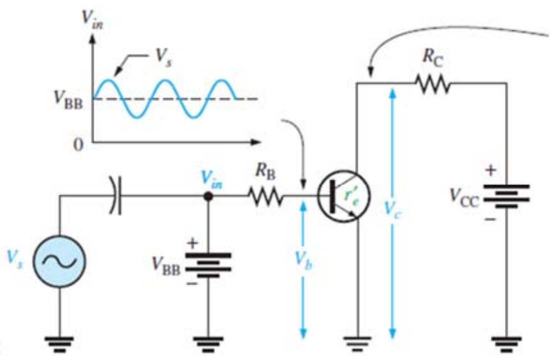
Power dissipation exceeds the maximum of 625 mW specified on the datasheet.

THE BJT AS AN AMPLIFIER

- **Amplification** is the process of linearly increasing the amplitude of an electrical signal and is one of the major properties of a transistor.
- a BJT exhibits current gain (β) When a BJT is biased in the active (or linear) region,

DC quantities	AC quantities
VBE	Vbe
VCE	Vce
IC	Vb
IB	Vc
IE	r'e
VB	
VC	

- An ac voltage, *Vs*, is superimposed
- on the dc bias voltage *V*BB by capacitive coupling as shown. The dc bias voltage *V*CC
- is connected to the collector through the collector resistor, *R*C.



- The ac input voltage produces an ac base current, which results in a much larger ac collector current.
- The ac collector current produces an ac voltage across *R*C, thus producing an amplified, but inverted,
- internal ac emitter resistance r'e is designated in and appears in series with *R*B.
- The ac base voltage is

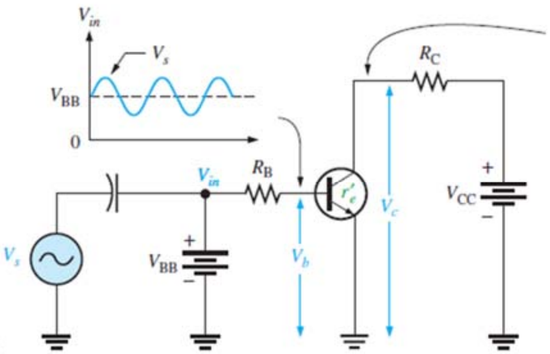
$$V_b = I_e r'_e$$

- The ac collector voltage, *Vc*, equals the ac voltage drop across *R*C

$$V_c = I_c R_C$$

- Since the $I_c \cong I_e$, ac collector voltage is

$$V_c \cong I_e R_C$$



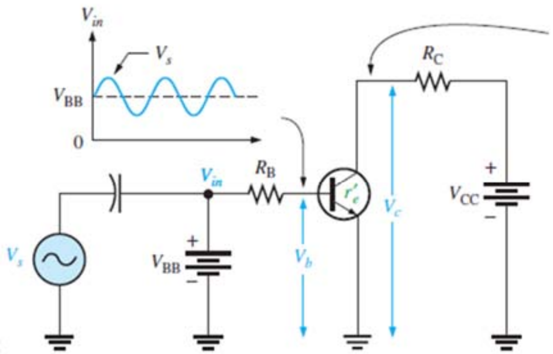
- But remember that Vb

$$V_b = V_s - I_b R_B.$$

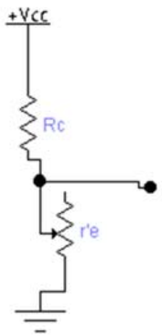
- the ac voltage gain, *Av*, of the transistor

$$A_v = \frac{V_c}{V_b} \cong \frac{I_e R_C}{I_e r'_e}$$

$$A_v \cong \frac{R_C}{r'_e}$$

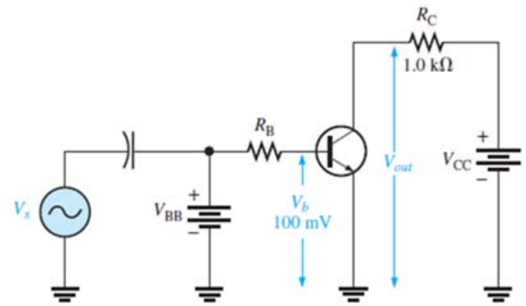


$$\frac{VRc}{Vr'e} = \frac{Ic \times RC}{Ie \times r'e} = \frac{\text{Rc}}{\text{r'e}}$$



Example 05

Determine the voltage gain and the ac output voltage in Figure 4–22 if $r'_e = 50\ \Omega$.



Example 05

Determine the voltage gain and the ac output voltage in Figure 4–22 if $r'_e = 50\ \Omega$.

The voltage gain is

$$A_v \cong \frac{R_C}{r'_e} = \frac{1.0\ \text{k}\Omega}{50\ \Omega} = \mathbf{20}$$

Therefore, the ac output voltage is

$$V_{out} = A_v V_b = (20)(100\ \text{mV}) = \mathbf{2\ V\ rms}$$