# Lecture (07) Bipolar Junction Transistor (2)

## By:

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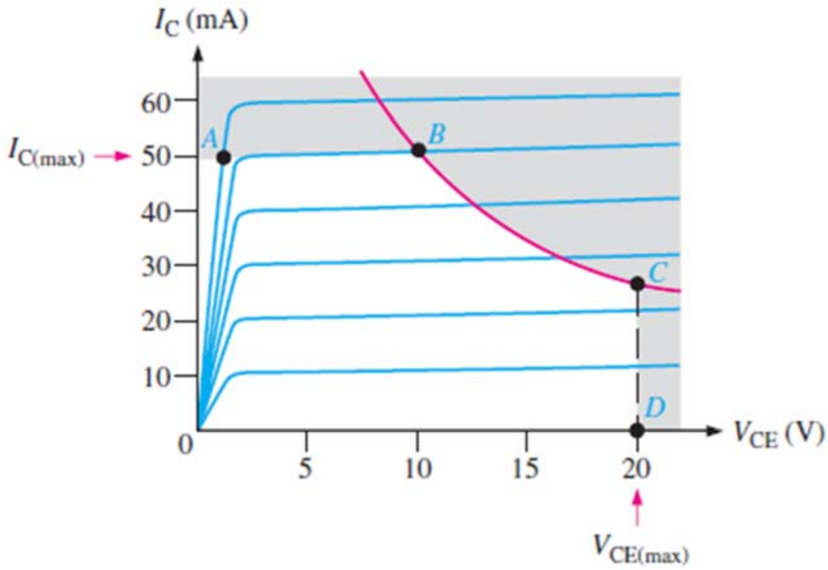
**Maximum Transistor Ratings**

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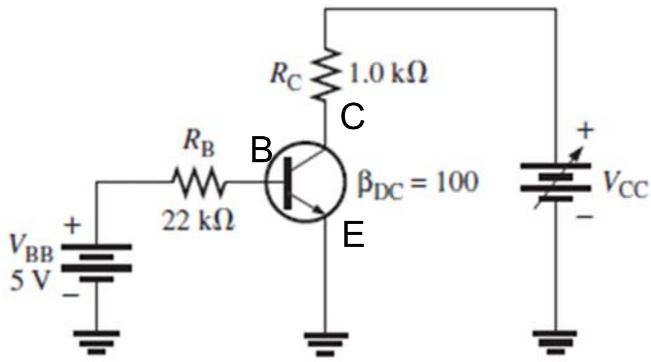
$$I_C = \frac{P_{D(max)}}{V_{CE}} = \frac{250 \text{ mW}}{6 \text{ V}} = \mathbf{41.7\ mA}$$



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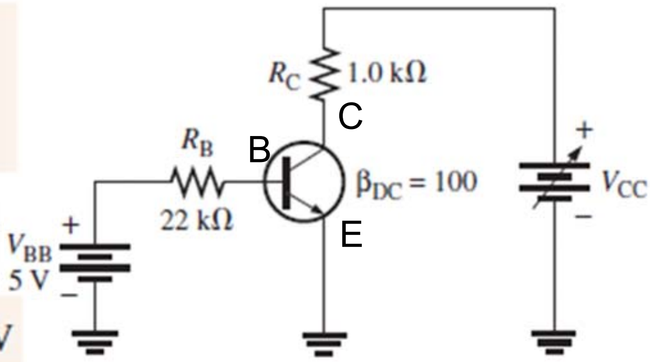
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{22\text{ k}\Omega} = 195\ \mu\text{A}$$

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

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

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




- Vcc max occures when Vce max, calculated using KVL

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

# Example 02

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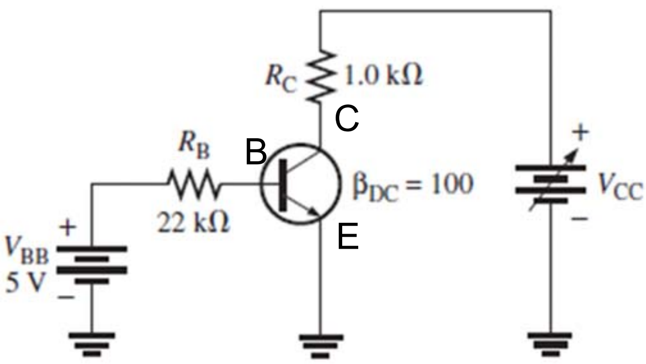
- Now calculating PD @ $V_{CEmax}$

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




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 *P*D(max)**

- *P*D(max) is usually specified at 25°C. For higher temperatures, *P*D(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

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

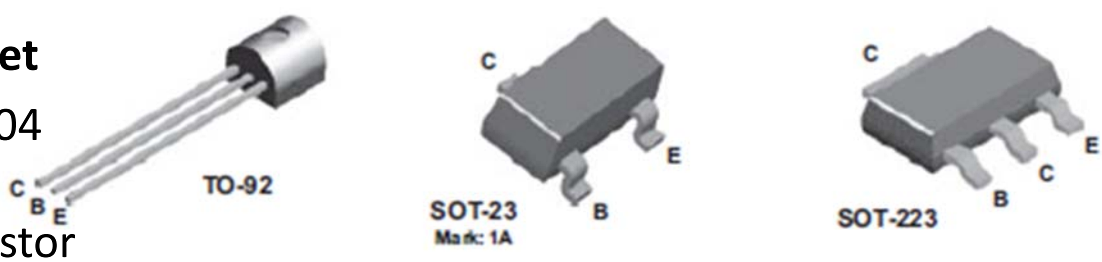


## BJT Datasheet

- 2N3904 *npn* transistor

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.

**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<br>Derate above 25°C | 625<br>5.0 | 350<br>2.8 | 1,000<br>8.0 | mW<br>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 cm².



## 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<br>$I_C = 1.0$ mA, $V_{CE} = 1.0$ V<br>$I_C = 10$ mA, $V_{CE} = 1.0$ V<br>$I_C = 50$ mA, $V_{CE} = 1.0$ V<br>$I_C = 100$ mA, $V_{CE} = 1.0$ V | 40<br>70<br>100<br>60<br>30 | <br><br>300<br><br> | |
| $V_{CE(sat)}$ | Collector-Emitter Saturation Voltage | $I_C = 10$ mA, $I_B = 1.0$ mA<br>$I_C = 50$ mA, $I_B = 5.0$ mA | | 0.2<br>0.3 | V<br>V |
| $V_{BE(sat)}$ | Base-Emitter Saturation Voltage | $I_C = 10$ mA, $I_B = 1.0$ mA<br>$I_C = 50$ mA, $I_B = 5.0$ mA | 0.65<br> | 0.85<br>0.95 | V<br>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, $R_S = 1.0k\Omega$, f=10 Hz to 15.7kHz | | 5.0 | dB |

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SWITCHING CHARACTERISTICS

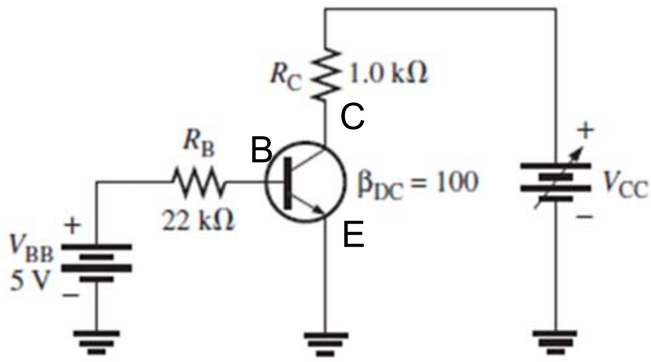
| | | | | | |
|---|---|---|---|---|---|
| $t_d$ | Delay Time | $V_{CC} = 3.0 V, V_{BE} = 0.5 V,$ | | 35 | ns |
| $t_r$ | Rise Time | $I_C = 10 mA, I_{B1} = 1.0 mA$ | | 35 | ns |
| $t_s$ | Storage Time | $V_{CC} = 3.0 V, I_C = 10mA$ | | 200 | ns |
| $t_f$ | Fall Time | $I_{B1} = I_{B2} = 1.0 mA$ | | 50 | ns |

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



# Example 04

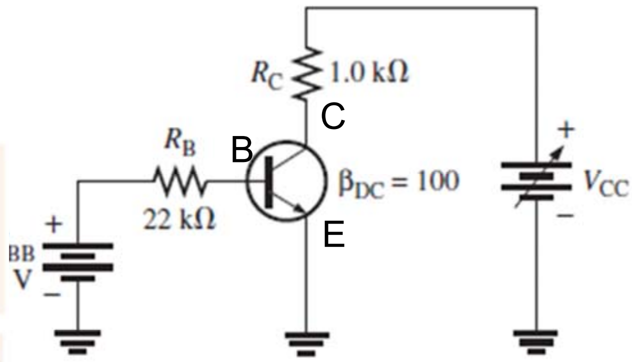
A 2N3904 transistor is used in the circuit of Figure 4–19 (Example 4–6). Determine the maximum value to which $V_{CC}$ can be adjusted without exceeding a rating. Which rating would be exceeded first? Refer to the datasheet in Figure 4–20.



# 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.

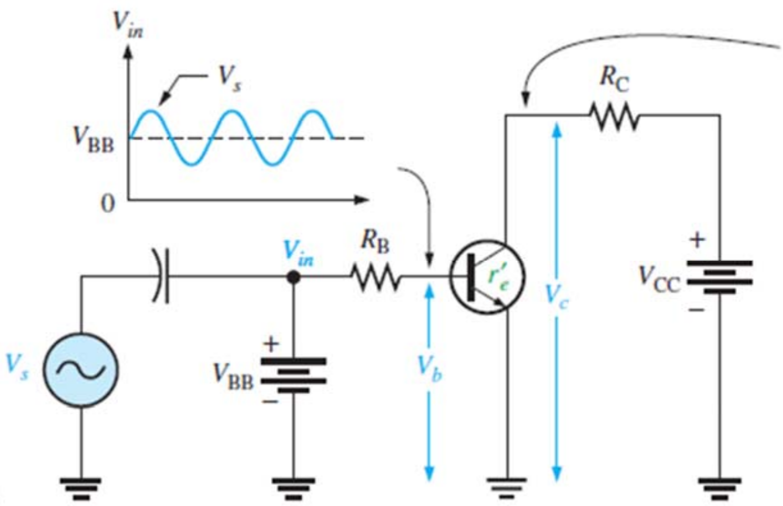
# THE BJT AS AN AMPLIFIER

- **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

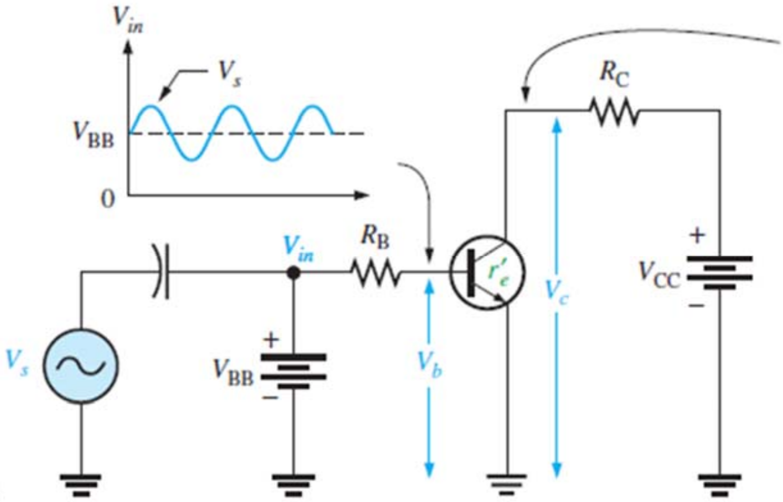
$$V_b = I_e r'_e$$

- 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

$$V_c \cong I_e R_C$$





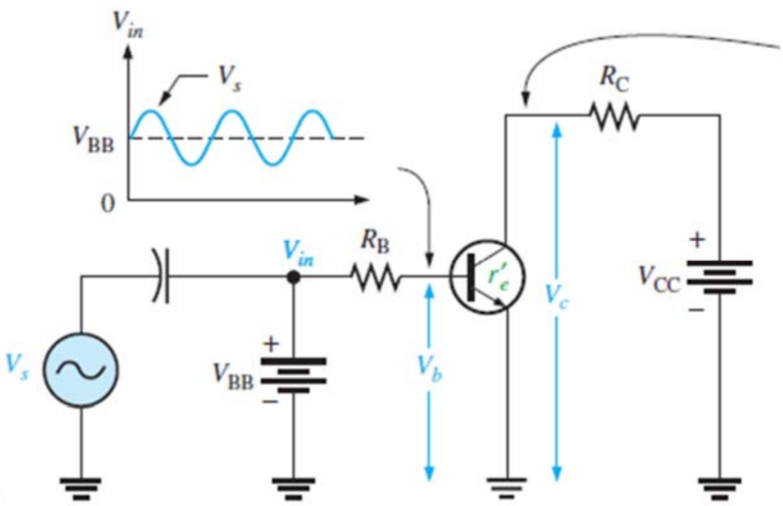

- But remember that Vb

$$V_b = V_s - I_b R_B.$$

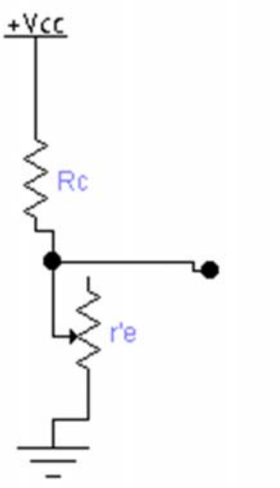
- the ac voltage gain, *Av*, of the transistor

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

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



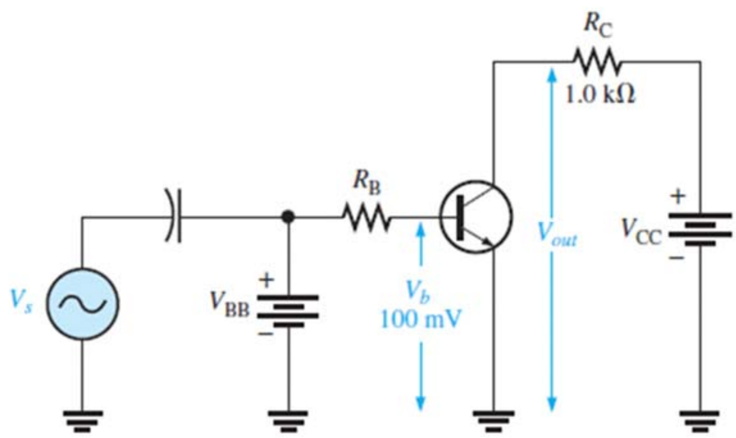
$$\frac{VRc}{Vr'e} = \frac{Ic \times RC}{Ie \times r'e} = \frac{\text{Rc}}{\text{r}'\text{e}}$$






# 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

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