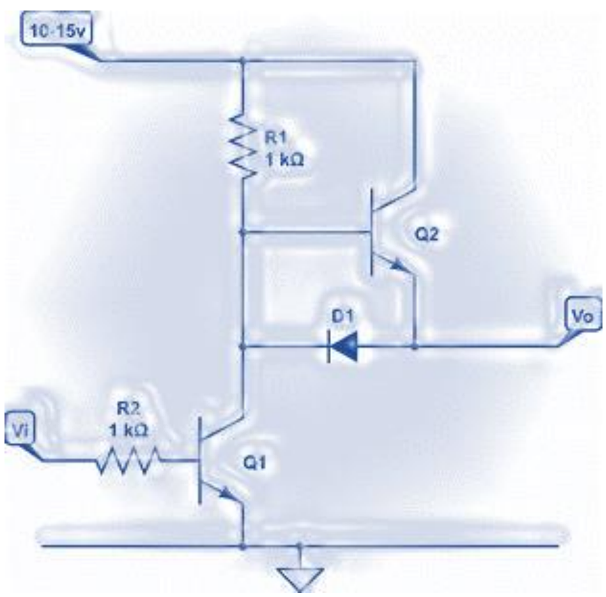
Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class 2^{nd}
Subject: Electronic Circuits
Lecturer: Dr. Rami Qays Malik, MSC. Huda Asaad
1st term – Lect. Multiple BJT Networks

Electronic Circuit

Lecture 6 (9^{th} Week)

Multiple BJT Networks



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Lecture Description	
Target Audience	The second stage for undergraduate students / Department of Medical Instrumentation Techniques Engineering
General Objective	studying **Multiple BJT Networks** is to understand how to design and analyze circuits that use more than one Bipolar Junction Transistor (BJT) in various configurations.
Central Idea	Multiple BJT Networks is to use Bipolar Junction Transistors (BJTs) in various interconnected configurations to create complex electronic circuits that provide specific characteristics, such as amplification, current control, and signal integration.
Behavioral Objectives	Upon completing this lecture, students will be able to: • The different types of bipolar junction transistor (BJT) networks used in advanced circuits. • States the fundamental laws that govern the operation of these networks, such as Ohm's Law and Kirchhoff's laws of current and voltage. • Explains how transistors work in multi-layer networks, and how the characteristics of each layer affect the others. • Is able to analyze a circuit containing multiple BJT networks using analysis techniques.
Time	2 hr.
Academic Year	2024-2025

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وصف المحاضرة	
الفئة المستهدفة	طلبة الدراسة الاولية من المرحلة الثانية /قسم هندسة تقنيات الأجهزة الطبية
الهدف العام	دراسة **شبكات الترانزستورات الثنائية القطب المتعددة هو** فهم كيفية تصميم وتحليل الدوائر التي تستخدم أكثر من ترانزستور واحد من نوع BJT في تكوينات متنوعة
الفكرة الرئيسية	استخدام ترانزستورات الوصلة الثنائية (BJT) في تكوينات متعددة ومتداخلة لإنشاء دوائر إلكترونية معقدة توفر خصائص معينة، مثل التضخيم، والتحكم في التيار، وتكامل الإشارة
الأهداف السلوكية	عند الانتهاء من هذه المحاضرة، سيتمكن الطالب من: • أن الأنواع المختلفة من شبكات الترانزستور الثنائية القطب (BJT) المستخدمة في الدوائر المتقدمة. • يذكر القوانين الأساسية التي تحكم عمل هذه الشبكات، مثل قانون أوم وقانون كيرشوف للتيار والجهد • يشرح كيفية عمل الترانزستورات في شبكات متعددة الطبقات، وكيف تؤثر خصائص كل طبقة على الأخرى • يتمكن من تحليل دائرة تحتوي على شبكات متعددة من الترانزستورات الثنائية القطب باستخدام التحليل.
الوقت	2 ساعة
السنة الدراسية	2024-2025

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4.5. Voltage Divider Bias Configuration

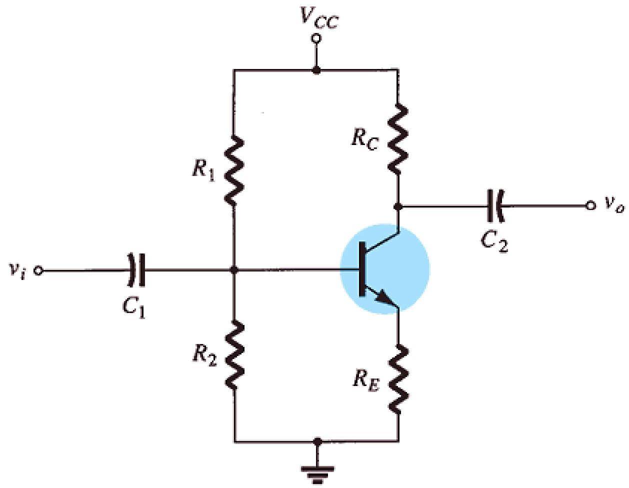


Fig. (1). Voltage-divider bias configuration.

When analyzed precisely, the sensitivity of the circuit to variations in beta is relatively low. If the circuit parameters are chosen appropriately, the resulting levels of I_{CQ} and V_{CEQ} can be nearly independent of beta. Recall from earlier discussions that the Q-point is defined by specific levels of I_{CQ} and V_{CEQ}, as illustrated in Fig. (2). While the level of I_{BQ} will change with variations in beta, the operating point determined by I_{CQ} and V_{CQ} can remain stable if the circuit parameters are correctly selected.

Methods for Analyzing the Voltage-Divider Configuration:

- There are two methods for analyzing the voltage-divider configuration:
  - **Exact Method**: This method can be applied to any voltage-divider configuration and provides precise results.
  - **Approximate Method**: This method can only be applied under specific conditions and allows for a quicker and simpler analysis.

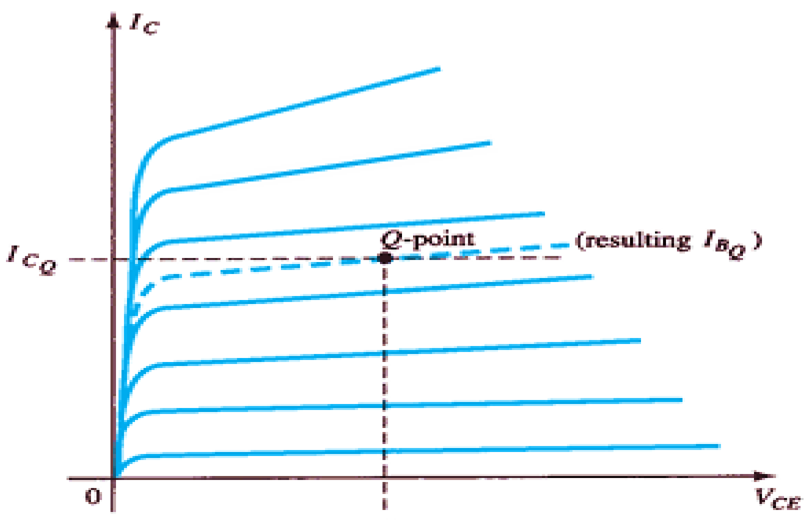


Fig. (2). Defining the Q-point for the voltage-divider bias configuration.

Exact Method

For the DC analysis, the network an be modified as depicted in Fig. (3). Subsequently, the input side of the network can be simplified further for DC analysis. Using this configuration, the Thevenin equivalent network for the portion of the circuit left of the base terminal can be determined as follows:

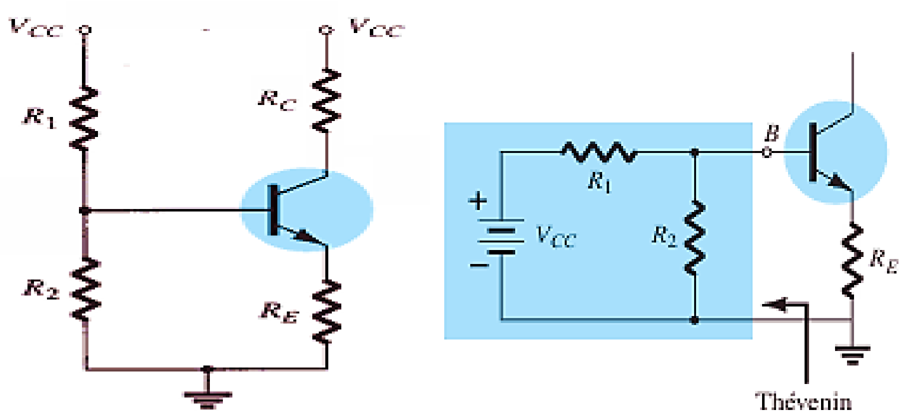
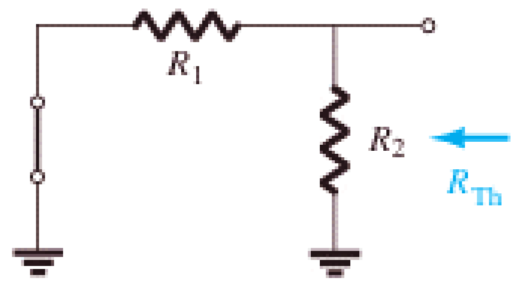


Fig. (3). DC components of the voltage divider configuration and redrawing the input side of the network.

R_{th} The voltage source is substituted with a short-circuit equivalent,

$$\boldsymbol{R_{th} = R_1 \| R_2}$$



$\boldsymbol{E_{th}}$ The voltage source V_{CC} is reintroduced to the network, and the open-circuit Thevenin voltage of Fig. 4. is determined as follows: using the voltage-divider rule, we get:

$$\boldsymbol{E_{th} = V_{R2} = \frac{R_2 V_{CC}}{R_1 + R_2}}$$

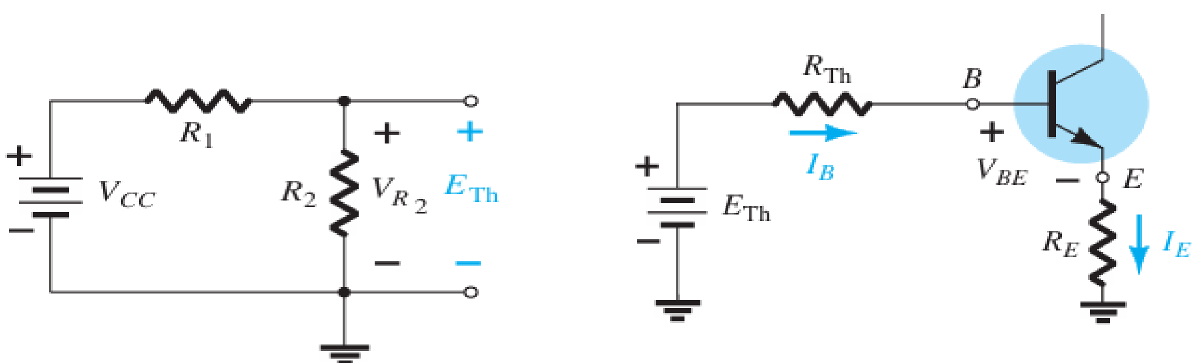


Fig. (4). Inserting the Thevenin equivalent circuit

The Thevenin network is then redrawn. by first applying Kirchhoff's voltage law in the clockwise direction for the loop indicated:

$$E_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$$

Substituting $I_E = (\beta + 1) I_B$ and solving for I_B yields:

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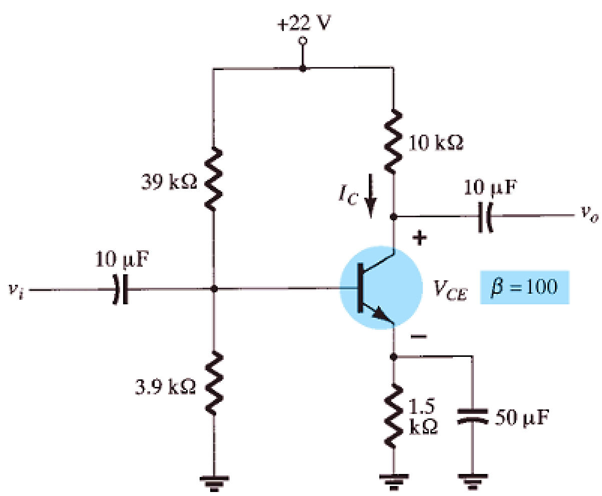
$$I_B = \frac{E_{th} - V_{BE}}{R_{th} + (\beta + 1)R_E}$$

the remaining quantities of the network can be found in the same manner as developed for the emitter-bias configuration. That is:

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

Example 1: Determine the dc bias voltage V CE and the current I C for the voltage divider configuration of Fig. (5).



$$R_{th} = R_1 \| R_2$$

$$R_{th} = \frac{39\ k\Omega \times 3.9\ k\Omega}{39\ k\Omega + 3.9\ k\Omega} = 3.55\ k\Omega$$

$$E_{th} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{3.9\ k\Omega\ \times 22\ V}{39\ k\Omega + 3.9\ k\Omega} = 2\ V$$

$$I_B = \frac{E_{th} - V_{BE}}{R_{th} + (\beta + 1)R_E} = \frac{2\,V - 0.7\,V}{3.55 + (100 + 1)} = 8.38\,\mu A$$

$$I_C = \beta\, I_B = 100 \times 8.38\,\mu A = 0.84\,mA$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E) = 22\,V - (0.84)(10 + 1.5) = 22 - 9.66 = 12.34\,V$$

Approximate Method

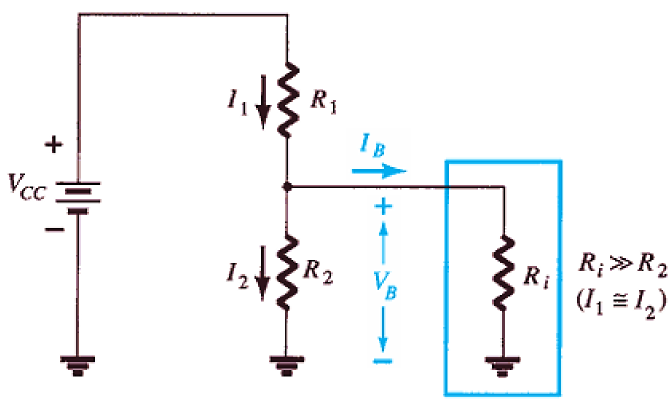


Fig. (5). Partial-bias circuit for calculating the approximate base voltage V_B

the key points for the input section of the voltage-divider configuration:

- The input section of the voltage-divider configuration can be modeled by a network similar to Fig. (5).
- R_i Represents the equivalent resistance between the base and ground for the transistor, with an emitter resistor R_E.
- The reflected resistance between the base and emitter is given by:

$$R_i = (\beta + 1)R_E$$

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- When R_I is significantly larger than the resistance R_2:
    - The base current I_B will be much smaller than I_2.
    - Current I_2 will be approximately equal to I_1 because current follows the path of least resistance.
- Assuming I_B is nearly 0 A compared to I_1 and I_2:
    - $I_1 = I_2$
    - Resistors R_1 and R_2 can be treated as series elements.
- The voltage across R_2 (also the base voltage) can be calculated using this series relationship.

It is determined using the voltage-divider rule, which is where the configuration gets its name.

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2}$$

Since $R_I = (\beta + 1)R_E$, the condition that determines whether the approximate approach can be applied is: βR_E.

$$\beta R_E \geq 10\ R_2$$

Once V_B is determined, the value of V_E can then be calculated:

$$V_E = V_B - V_{BE}$$

and the emitter current can be determined from

$$I_E = \frac{V_E}{R_E}$$

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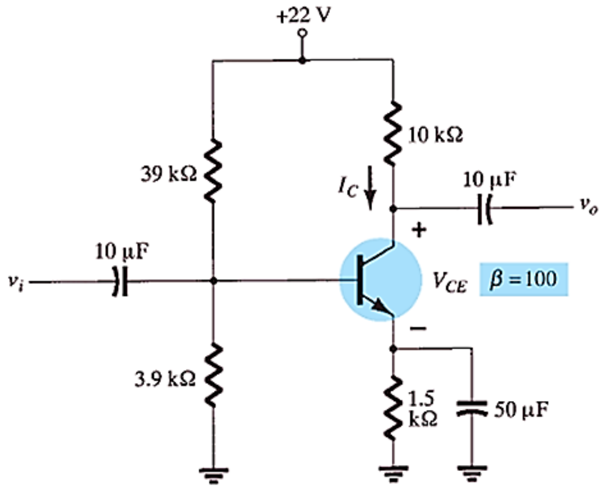
And, $$I_E \cong I_{CQ}$$

The collector-to-emitter voltage is determined by:

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

Example 2: Repeat the analysis of Fig. below using the approximate technique, and compare solutions for I_{CQ} and V_{CEQ}.



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$$\beta R_E \geq 10\, R_2$$

$$(100\times 1.5\, k\Omega) \geq 10 \times 3.9\, k\Omega$$

$$150\ \text{k}\boldsymbol{\Omega} \geq 39\, k\Omega$$

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{(3.9\, k\Omega\ \times 22\, V)}{39\, k\Omega + 3.9\, k\Omega} = 2\, V$$

The main difference between the exact and approximate techniques lies in the effect of R_{th} in the exact analysis, which separates E_{th} and V_B.

$$V_E = V_B - V_{BE}$$

$$V_E = 2\,V - 0.7\,V$$

$$V_E = 1.3\,V$$

$$I_{CQ} \cong I_E = \frac{V_E}{R_E} = \frac{1.3\,V}{1.5\,K\Omega} = 0.867\,mA$$

Compared to 0.84 mA with the exact analysis. Finally,

$$V_{CEQ} = V_{CC} - I_C(R_C + R_E)$$

$$V_{CEQ} = 22\,V - 0.867(10 + 1.5)$$

$$V_{CEQ} = 12.03\,V$$

4.6. Multiple BJT Networks

So far, only single-stage BJT configurations have been introduced. This section will cover some popular networks using multiple transistors, demonstrating how the methods introduced in this chapter can be applied to networks with any number of components. The R-C coupling in Fig. (6). is one of the most common, where the collector output of one stage is directly connected to the base of the next stage using a coupling capacitor C_C. The capacitor is selected to block DC between stages while acting as a short circuit for any AC signal. This network has two voltage-divider stages, but the same coupling can be applied between any configurations, such as fixed-bias or emitter-follower setups. Replacing C_C and other capacitors with open-circuit equivalents yields the two bias arrangements shown in Fig. (7), allowing each stage to be analyzed separately without interference from the other. Of course, the 20 V DC supply must be applied to each isolated component.

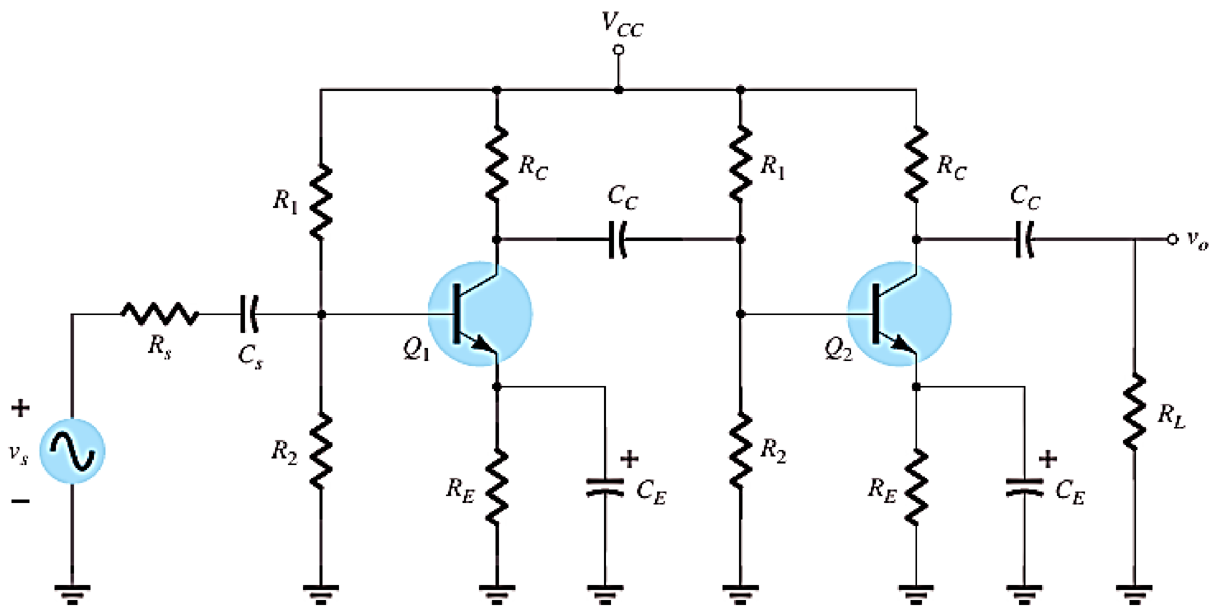

Fig. (6). R–C coupled BJT amplifiers

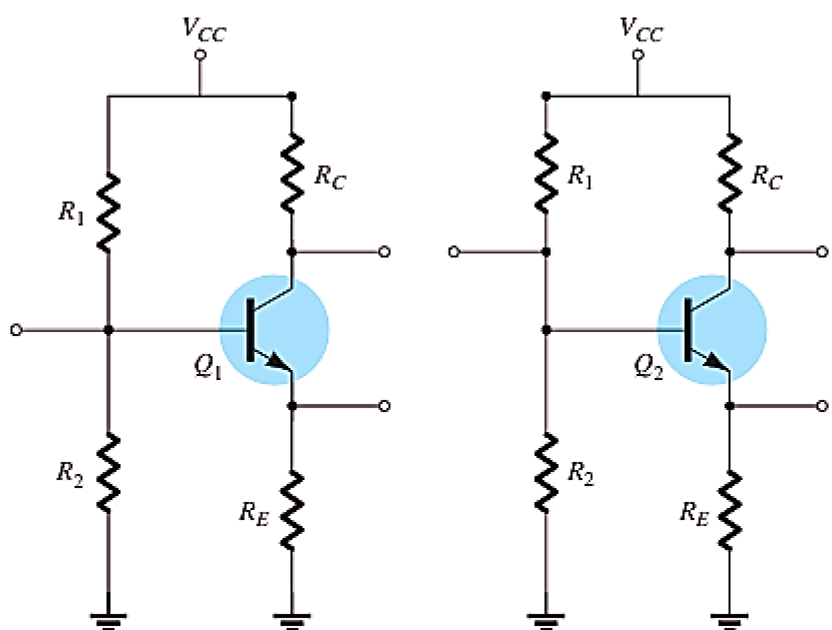

Fig. (7). DC equivalent of Fig. (6).

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For the dc analysis of Fig. (8). assuming a beta β_1 for the first transistor and β_2 for the second: Assuming $\beta >> 1$ for each transistor, we find the net beta for the configuration is:

$$\beta_D = \beta_1 \beta_2$$

$$V_{BED} = V_{BE1} + V_{BE2}$$

$$I_{B1} = \frac{V_{CC} - V_{BED}}{R_B + (\beta_D + 1)R_E}$$

$$I_{C2} \cong I_{E2} = \beta_D I_{B1}$$

$$V_{E2} = I_{E1} R_E$$

$$V_{C2} = V_{CC}$$

$$V_{CE2} = V_{CC} - V_{E2}$$

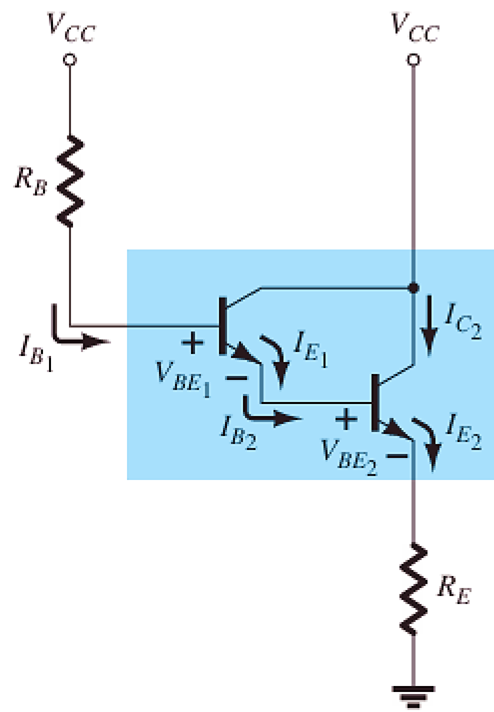

Fig.(8). DC equivalent Circuit

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Example 3: Determine the dc levels for the currents and voltages of the direct-coupled amplifier of Fig. (9).

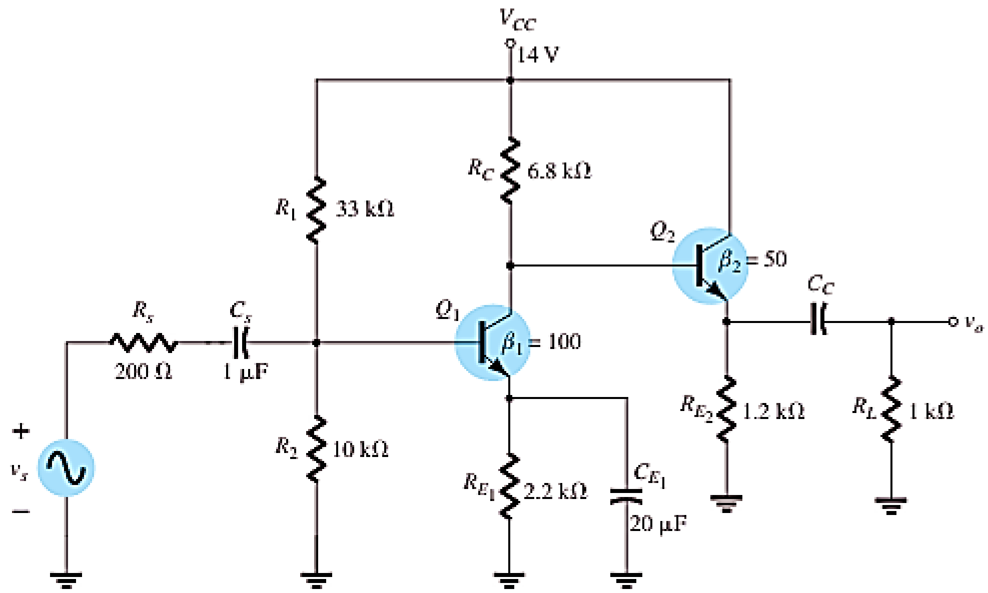

Fig. (9). Direct- coupled amplifier.

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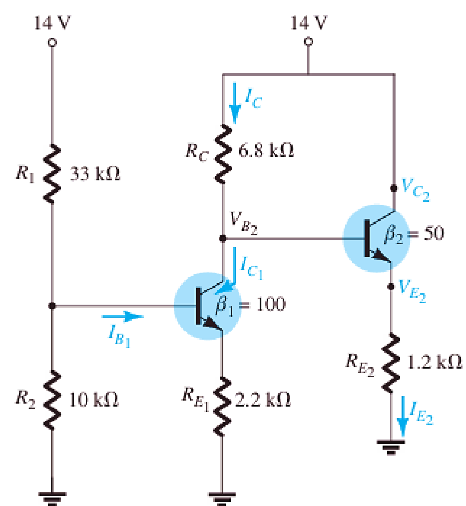

$$I_{B1} = \frac{E_{th} - V_{BE}}{R_{th} + (\beta + 1)R_E}$$

$$R_{th} = R_1 \| R_2 = 33 \,\|10 = 7.67 \,k\Omega$$

$$E_{th} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{10 \,k\Omega \,\times 14 \,V}{10 \,k\Omega + 33 \,k\Omega} = 3.26 \,V$$

$$I_{B1} = \frac{E_{th} - V_{BE}}{R_{th} + (\beta + 1)R_E} = \frac{3.26 \,V - 0.7 \,V}{7.67 \,k\Omega + (100 + 1)2.2 \,k\Omega}$$

$$I_{B1} = 11.17 \mu A$$

$$I_{C1} = \beta \, I_{B1} = 100 \times 11.17 \,\mu A = 1.12 \,mA$$

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$$V_{B2} = V_{CC} - I_C R_C = 14\ V - (1.12mA \times 6.8k\Omega) = 6.38\ V$$

$$V_{E2} = V_{B2} - V_{BE2} = 6.38\ V - 0.7\ V = 5.68\ V$$

$$I_{E2} = \frac{V_{E2}}{R_{E2}} = \frac{5.68\ V}{1.2\ k\Omega} = 4.73\ mA$$

$$V_{C2} = V_{CC} = 12\ V$$

$$V_{CE2} = V_{C2} - V_{E2} = 14 - 5.68 = 8.32\ V$$

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Summary:

- Relies on dividing voltage using resistors.
- Resistors are connected in series to divide voltage between components.
- Used to set and adjust the appropriate voltage in electronic circuits.
- Commonly used in signal control and amplification circuits.
- Involves circuits with more than one BJT transistor working together.
- Used to enhance functional performance such as amplification or signal control.
- Can be in series, parallel, or multi-phase configurations.
- Improves frequency response and signal amplification efficiency.
- Increases control over current flow and isolates inputs from outputs.