

Early Effect in Bipolar Transistors: A 101

view

Early Effect occurs in bipolar [transistors](#) and is the variation in the effective width of the base arising from changes in the base-to-collector voltage.

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Early Effect, also known as base width modulation, is a phenomenon observed in bipolar junction transistors that significantly influences their behaviour, particularly at higher collector-emitter voltages.

It is not widely known, but can significantly affect the performance of bipolar transistors in a number of applications and circuit design. [Circuit design software](#)



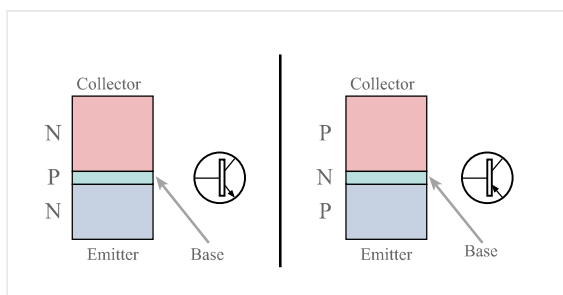
Bipolar Junction Transistor Fundamentals

Exploring the Early effect, it's crucial to understand the basic operation of a BJT. A BJT is a three-terminal semiconductor device consisting of three doped regions:

Emitter: Heavily doped with majority carriers (electrons for an NPN transistor).

Base: Lightly doped with minority carriers.

Collector: Moderately doped with majority carriers.



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Fact of the day: It was in this month in 1916 that W Schottky in Germany described the principle of the superhet radio as a powerful and selective amplifier. He never made the receiver to prove his idea and was beaten to this goal by Edwin Armstrong. Also on this day in 1923, Charles Jenkins, an inventor from Dayton, Ohio, who invented a mechanical television system called radiovision and claimed to have transmitted the earliest moving silhouette images.

Quote: *Science can purify religion from error and superstition. Religion can purify science from idolatry and false absolutes.* Pope John Paul II (Karol Wojtyła)

Point to ponder: A photon that takes eight minutes to travel from the Sun to Earth took 100,000 years to get from the centre to the surface of the Sun.

Basic structure and circuit symbols for NPN & PNP transistors

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ward-active region, the emitter-base junction is forward-biased, while the collector-base junction is reverse-biased. This creates a narrow depletion region at the collector-base junction, effectively isolating the collector from the emitter.

Physics of the Early Effect

The Early effect arises from the widening of the collector-base depletion region as the collector-emitter voltage (V_{CE}) increases. This widening reduces the effective base width, leading to an increase in collector current.

The Early effect occurs due to the following:

Reverse Bias: The reverse bias across the collector-base junction creates an electric field that repels majority carriers in the collector.

Region Expansion: As V_{CE} increases, the reverse bias across the collector-base junction also increases. This stronger electric field extends the depletion region deeper into the base region.

Effective Base Width Reduction: The widening of the depletion region effectively reduces the width of the active base region. This reduction in base width has a significant impact on transistor characteristics.

Impact of the Early Effect on Transistor Characteristics

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The Early effect has several key consequences on the behavior of a BJT:

Collector Current Increase: As the base width decreases, the probability of minority carriers (electrons for NPN) injected from the emitter reaching the collector increases. This leads to an increase in the collector current (I_C) for a given base current (I_B).

Output Resistance Reduction: The Early effect results in a decrease in the output resistance of the BJT. Output resistance (r_o) is defined as the change in collector-emitter voltage (V_{CE}) divided by the change in collector current (I_C) at constant base current (I_B). A lower output resistance implies that the collector current is more sensitive to changes in collector-emitter voltage.

Early Voltage (V_A): The Early voltage (V_A) is a parameter that characterizes the magnitude of the Early effect. It is defined as the extrapolated voltage at which the collector current theoretically becomes infinite.

A larger Early voltage indicates a weaker Early effect.

Output conductance (g_o) is the reciprocal of the output resistance. It represents the change in collector current with respect to change in collector-emitter voltage. The Early effect increases the output conductance of the BJT.

Implications for Circuit Design

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The Early effect has significant implications for the design of BJT-based circuits:

Current Gain Variation: The increase in collector current due to the Early effect can lead to variations in the DC current gain (β) of the transistor. This can affect the performance of circuits that rely on a constant current gain.

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QUIZZLY

Take a quick quiz about this page:

Why is it important to understand the Early Effect in circuit design?

- ☐ It helps in choosing the right resistor values
- ☐ It influences the performance and stability of BJT-based circuits
- ☐ It determines the physical size of the transistor
- ☐ It has no significance in modern electronics

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is amplifiers.

Output Impedance: The reduction in output resistance due to the early effect can impact the overall output impedance of circuits. This is particularly important in circuits that drive low-impedance loads.

Stability: The early effect can contribute to feedback effects in circuits, potentially leading to instability. Proper circuit design is necessary to mitigate these effects.

Techniques to Mitigate the Early Effect

Several techniques can be employed to minimize the impact of the early effect:

Cascode Configuration: The cascode configuration is a common technique that uses two transistors in series. The first transistor operates as a common-emitter amplifier, while the second transistor operates as a common-base amplifier. The common-base stage provides a high output impedance, which helps to reduce the impact of the early effect.

Current Mirrors: Current mirrors are circuits that generate a replica of a given current. By using transistors with early voltages, current mirrors can be designed to be less sensitive to variations in collector-emitter voltage.

Feedback Techniques: Feedback techniques can be used to stabilize circuit performance and reduce the impact of variations caused by the early effect.

The early effect is an inherent characteristic of bipolar junction transistors that influences their behavior significantly. Understanding the underlying physics and its impact on transistor characteristics is crucial for the successful design of analog circuits. By employing appropriate techniques, such as cascode configurations and feedback, the impact of base width modulation can be mitigated, leading to improved circuit performance and stability.

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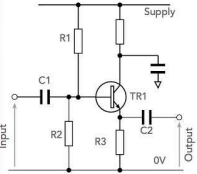
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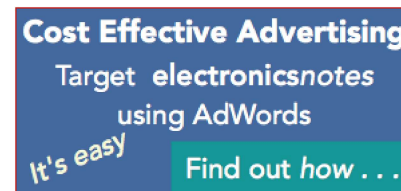
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