LOGIC GATES

Transistor as a device:

The functionality of a transistor as a device relies on various factors, encompassing its configuration (Common Base, Common Collector, or Common Emitter), the applied biasing conditions to the emitter-base (E-B) and base-collector (B-C) junctions, and the specific operational region—namely, cut-off, active, or saturation. When a transistor operates in the cut-off or saturation state, it serves as a switch. In these states, it can be either fully turned-off (cut-off) or fully turned-on (saturation), effectively functioning as an electronic switch. Conversely, to employ the transistor as an amplifier, it must function within the active region. In this region, characterized by appropriate biasing conditions, the transistor amplifies input signals. The selection of configuration, biasing, and operational region thus dictates the transistor's role, whether as a switch or an amplifier, providing versatility in its applications within electronic circuits.

Transistor as a switch:

Our goal is to understand how a transistor operates as a switch. To achieve this, we'll examine the behavior of a base-biased transistor in the Common Emitter (CE) configuration, depicted in figure (a). By utilizing Kirchhoff's voltage rule to analyze both the input and output sides of this circuit, we can establish the following relationships:

1. Input Side Equation:

$$V_{BB} = I_B \cdot R_B + V_{BE}$$

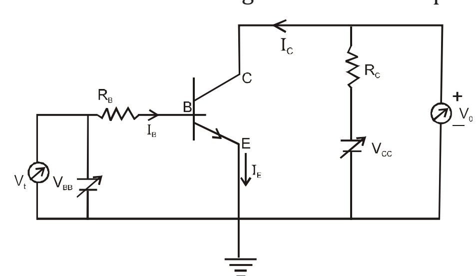
The equation provided pertains to the application of Kirchhoff's voltage rule to the input side of the circuit. In this context, V_{BB} represents the DC input voltage (V_i), I_B signifies the base current, R_B denotes the base resistance, and V_{BE} is the base-emitter voltage.

2. Output Side Equation:

$$V_{CE} = V_{CC} - I_C \cdot R_C$$

The equation described corresponds to the application of Kirchhoff's voltage rule to the output side of the circuit. Here, V_{CE} is regarded as the DC output voltage (V_o), V_{CC} represents the collector supply voltage, I_C denotes the collector current, and R_C signifies the collector resistance.

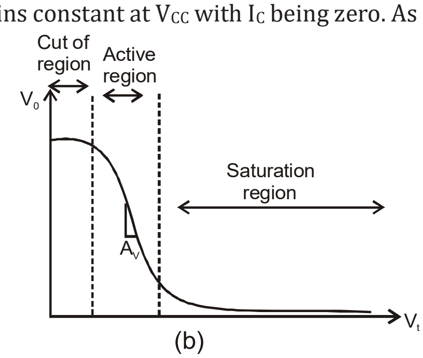
By considering V_{BB} as the DC input voltage (V_i) and V_{CE} as the DC output voltage (V_o), we can represent the relationships as $V_i = I_B \cdot R_B + V_{BE}$ and $V_o = V_{CC} - I_C \cdot R_C$. Examining how V_o changes with increasing V_i reveals intriguing behavior.



(a)

When V_i is below 0.6 V, indicating the cut-off state, V_o remains constant at V_{CC} with I_C being zero. As V_i exceeds 0.6 V, the transistor transitions into the active state, resulting in a linear decrease in V_o due to the rise in I_C. However, beyond a certain threshold, the change becomes nonlinear, marking the transition to the saturation state. The transitional regions exhibit nonlinearity, indicating that the shift from cut-off to active and from active to saturation is not sharply defined.

Regarding the Si transistor, when V_i is at a low level, insufficient to forward-bias the transistor, V_o remains high (at V_{CC}). Conversely, when V_i reaches a level adequate to drive the transistor into saturation, V_o decreases nearly to zero. The transistor is deemed switched off when it's not conducting and switched on when driven into saturation. Therefore, establishing low and high states according to specific voltage levels corresponding to cut-off and saturation enables us to assert that a low input deactivates the transistor, while a high input activates it.



(b)

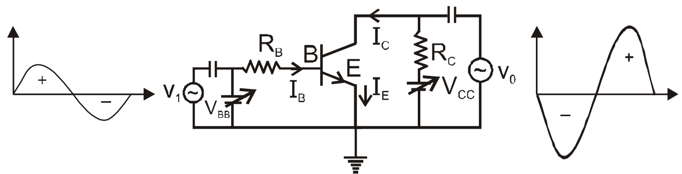
Transistor as an amplifier

To effectively employ the transistor as an amplifier, it's pivotal to position its operating point within the middle of the active region. Achieving this involves setting V_{BB} at a point within the linear section of the transfer curve, ensuring that both the DC base current (I_B) and the corresponding collector current (I_C) remain constant. Consequently, the DC voltage $V_{CE} = V_{CC} - I_C R_C$ also remains constant. The collective values of V_{CE} and I_B determine the amplifier's operating point.

Introducing a small sinusoidal voltage with amplitude v_s atop the DC base bias, accomplished by serially connecting the signal source with the V_{BB} supply, leads to sinusoidal variations in the base current superimposed on the DC value of I_B. This, in turn, causes the collector current to exhibit sinusoidal variations superimposed on the value of I_C, resulting in corresponding changes in V_o. The AC variations across the input and output terminals can be measured by blocking the DC voltages using larger capacitors.

In the aforementioned amplifier scenario, AC signal consideration was absent. Typically, amplifiers are designed to amplify alternating signals. By introducing an AC input signal (v_i) to be amplified atop the DC bias V_{BB}, the output is extracted between the collector and ground. Understanding the amplifier's operation is facilitated by assuming $v_i = 0$ initially. Applying Kirchhoff's law to the output loop yields $V_{CC} = V_{CE} + I_C R_L$, while the input loop gives $V_{BB} = V_{BE} + I_B R_B$.

When v_i is not zero, the expression becomes $V_{BE} + v_i = V_{BE} + I_B R_B + \triangle I_B (R_B + r_i)$. The change in V_{BE} is related to the input resistance r_i and the change in I_B, yielding $v_i = \triangle I_B (R_B + r_i) = r\triangle I_B$. The change in I_B causes a corresponding change in I_C. We introduce a parameter β_{ac}, similar to β_{dc} defined in the equation, as $\beta_{ac} = \frac{\triangle I_C}{\triangle I_B} = \frac{\triangle i_c}{\triangle i_b}$.



This parameter, denoted as β_{ac}, is also recognized as the AC current gain (A_i), and in the linear region of the output characteristics, β_{ac} typically closely approximates β_{dc}.

The alteration in I_C resulting from a change in I_B induces variations in V_{CE} and the voltage drop across resistor R_L, considering V_{CC} is constant.

These variations can be expressed using the equation:

$$\triangle V_{CC} = \triangle V_{CE} + R_L \cdot \triangle I_C = 0 \text{ Or } \triangle V_{CE} = -R_L \cdot \triangle I_C$$

The change in V_{CE} corresponds to the output voltage v_o, and from the equation, we obtain:

$$v_o = \triangle V_{CE} = -\beta_{ac} R_L \triangle I_B$$

The voltage gain (A_v) of the amplifier is calculated as:

$$A_v = \frac{\triangle V_{CE}}{\triangle V_i} = -\beta_{ac} R_L \frac{\triangle I_B}{\triangle V_i}$$

The negative sign indicates that the output voltage is phase-opposite to the input voltage. Considering the transistor characteristics discussed earlier, which involve a current gain β_{ac} in the Common Emitter (CE) configuration, and the introduction of the voltage gain (A_v), the power gain (A_p) can be expressed as the product of the current gain and voltage gain.

Mathematically, $A_p = \beta_{ac} \times A_v$. As both β_{ac} and A_v are greater than 1, this yields an AC power gain. It is crucial to recognize, however, that the transistor does not function as a power-generating device; the energy for the increased AC power at the output is supplied by the battery.

Note:

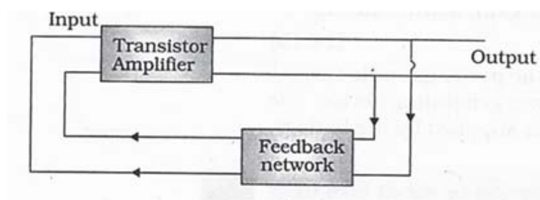
Operating as a Common Emitter (CE) amplifier, the transistor displays several characteristics:

- AC Current Gain (β_{ac}): The AC current gain, denoted as β_{ac}, is expressed as the ratio of the collector current (i_c) to the base current (i_b) at constant V_{CE}.
- DC Current Gain (β_{dc}): The DC current gain, β_{dc}, is defined as the ratio of i_c to i_b.
- Voltage Gain (A_v): The voltage gain, A_v, is calculated as the ratio of the output voltage (V_o) to the input voltage (V_i), which is equal to β_{ac} multiplied by the resistance gain.

- Power Gain (A_p): The power gain, A_p, is given by the ratio of the output power (P_o) to the input power (P_i), which is equal to β_{ac} squared multiplied by the resistance.
- Transconductance (g_m): This parameter, represented as g_m, is the ratio of the change in collector current to the change in emitter-base voltage, expressed as $\frac{i_c}{V_{EB}}$. Additionally, g_m equals A_v divided by the load resistance (R_L).
- Phase Difference (Between Output and Input): The phase difference between the output and input signals is opposite due to the amplifier's characteristics.
- Application: Common Emitter amplifiers are typically utilized for audible frequency amplification.

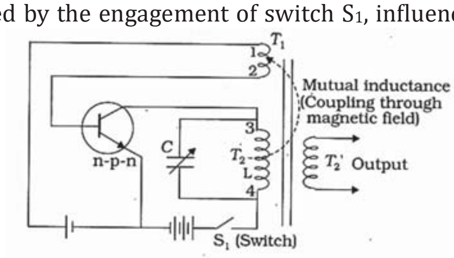
Oscillatory circuit

Oscillators are circuits within electronics that produce a consistent, recurring waveform at a specific frequency. In an oscillator, an AC output is generated autonomously, even in the absence of external input signals. This unique function stems from a process where a portion of the output power is looped back to the input, aligning with the original power in phase. This process, known as positive feedback, is depicted in figure (a). Feedback can be established through various methods such as inductive coupling, which involves mutual inductance, or by utilizing LC (inductance-capacitance) or RC (resistance-capacitance) networks. These feedback mechanisms contribute to the self-sustaining nature of the oscillator, allowing it to continuously produce AC output without requiring external stimuli.



(a)

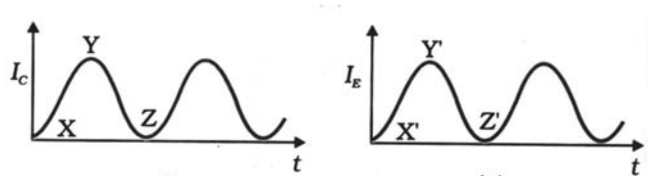
Let's examine the situation where switch S_1 is activated to provide the required bias for the initial activation. Naturally, this action leads to a surge in collector current within the transistor. Subsequently, this current path is directed through the coil designated as T_2, featuring terminals labeled as 3 and 4 in Figure b. The current flow through this coil is an integral aspect of the activation process initiated by the engagement of switch S_1, influencing the dynamic behavior of the system.



(b)

The rise in collector current triggered by the activation of switch S1 does not immediately reach its peak amplitude. Instead, it gradually increases from point X to point Y, as shown in Figure (C).

During this progression, the inductive coupling between coil T_2 and coil T_1 becomes active, resulting in the generation of current within the emitter circuit. It's important to emphasize that this emerging current within the emitter circuit constitutes the 'feedback' mechanism, establishing a connection from the input to the output. As a consequence of this positive feedback mechanism, the current in the emitter circuit (referred to as T_1 emitter current) also experiences a gradual increase from point X' to point Y', as depicted in Figure (C) (ii).



(c)

The complex interaction between currents and feedback mechanisms drives the dynamic evolution of the system, demonstrating the inherent complexity in the circuit's operation.

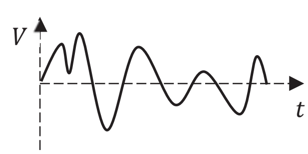
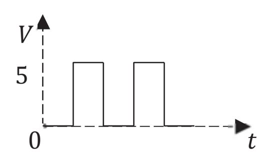
Once transistor T_2 reaches saturation, the current in its collector circuit reaches the value Y, indicating that the maximum collector current has been attained and cannot increase further. Consequently, the magnetic field around T_2 stops expanding as the collector current remains steady. As a result, the feedback loop from T_2 to T_1 is interrupted because the static magnetic field no longer induces additional feedback.

As the feedback diminishes, the emitter current starts to decrease. This reduction in emitter current leads to a drop in collector current, causing the magnetic field around coil T_2 to weaken. Consequently, T_1 detects a diminishing field in T_2, opposite to the initial operation when the field was growing. This results in a simultaneous decrease in both emitter current (IE) and collector current (IC), causing the transistor to return to its original state as it was when the power was initially switched on.

This entire sequence of events repeats cyclically. The transistor undergoes a process of being driven to saturation, transitioning to cut-off, and then returning to saturation. The duration of the transition from saturation to cut-off and back is determined by the time constant of the tank circuit or tuned circuit, represented by the inductance (L) of Coil T_2 and the capacitance (C) connected in parallel to it. The resonance frequency (v) of this tuned circuit governs the frequency at which the oscillator oscillates and can be expressed as $\nu = \frac{1}{2\pi\sqrt{LC}}$

Digital electronics

Digital electronics is a branch of electronics that deals with circuits and systems that operate using discrete, quantized signals, typically represented as binary numbers. Unlike analog electronics, which deals with continuous signals, digital electronics processes information in the form of digital data, where each bit can represent one of two states: 0 or 1. This binary representation allows digital systems to perform logical operations, arithmetic computations, data storage, and signal processing with high precision and reliability.

Analog signal	Digital signal
Voltage/current values that are constant and unchanging.	Only distinct voltage values are considered. ($0 \rightarrow 0$ V, $1 \rightarrow 5$ V)
	
In amplifiers, oscillators, and similar devices.	Digital watches, computers, robots, and other devices.

Digital electronics finds applications in various fields, including telecommunications, computing, control systems, and consumer electronics.

It encompasses the design, analysis, and implementation of digital circuits and systems, such as logic gates, flip-flops, counters, registers, and microprocessors.

One of the fundamental concepts in digital electronics is Boolean algebra, which provides a mathematical framework for describing and analyzing the behavior of digital circuits. Using Boolean algebra, designers can express logic functions and design digital circuits to perform specific tasks efficiently.

Digital electronics has revolutionized the modern world, enabling the development of advanced computing devices, communication systems, digital media, and automation technologies. It continues to evolve rapidly, driving innovations in areas such as artificial intelligence, internet of things (IoT), and digital signal processing.

Binary System

A binary system typically refers to a system consisting of two objects or components that are closely related or interact with each other in some way. In astronomy, a binary system often refers to a pair of stars that are bound together by gravity and orbit around a common center of mass. Binary stars are quite common in the universe, and they can vary in terms of their size, mass, and distance between them.

Binary systems can also exist in other contexts, such as in computing where binary code is used to represent data and perform calculations using only two possible states, usually represented as 0 and 1. In this case, the binary system is fundamental to how computers operate, with binary digits (bits) forming the basis of digital information storage and processing.

Additionally, in mathematics, a binary system can refer to any system that involves two distinct elements or choices, such as binary arithmetic, where numbers are represented using only the digits 0 and 1.

Boolean algebra

Boolean algebra is a branch of mathematics and a fundamental concept in computer science and logic. It deals with variables that can have only two possible values: true (often represented as 1) and false (often represented as 0). It was introduced by the mathematician George Boole in the 19th century and has since become a cornerstone of digital logic and computer science.

In Boolean algebra, variables, constants, and operators are used to represent logical statements and operations. The basic operators in Boolean algebra are AND, OR, and NOT. These operators are used to manipulate and combine logical statements to produce new statements.

Here's a brief overview of the basic Boolean operators:

AND Operator (&& or ·): Represents the logical conjunction. It returns true only if both operands are true, otherwise, it returns false.

OR Operator (|| or +): Represents the logical disjunction. It returns true if at least one of the operands is true, otherwise, it returns false.

NOT Operator (! or ¯): Represents logical negation. It returns the opposite value of the operand. If the operand is true, NOT returns false; if the operand is false, NOT returns true.

Boolean algebra is widely used in digital circuit design, computer programming, and logical reasoning. It provides a formalism for expressing and analyzing logical relationships, making it a fundamental tool in many areas of science and engineering.

Logic Gates - AND, OR, NOT, NOR, NAND

Logic Gates:

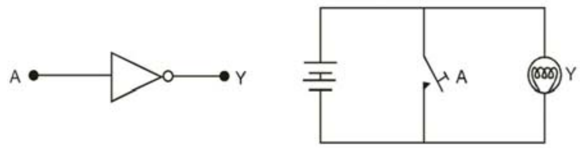
A logic gate represents a fundamental component within digital circuits, designed to operate based on specific logical conditions between input and output voltages. Its primary function is to either permit the passage of a signal or block it altogether. Operating on predetermined logical relationships between input and output voltages, a gate serves as a crucial mechanism for controlling the flow of information within a digital system. Among the commonly utilized logic gates are NOT, AND, OR, NAND, and NOR gates. Each of these gates is denoted by a distinctive symbol and is characterized by a specific function delineated through a truth table. This truth table systematically presents all feasible input logic level permutations along with their corresponding output logic levels, facilitating a comprehensive understanding of the gate's operational behavior. These logic gates are typically implemented using semiconductor devices, forming essential building blocks in digital circuitry.

(a) The NOT Gate:

The NOT gate stands as a foundational element in logical circuitry, featuring a singular input (A) and a lone output (Y). Its operation adheres to the Boolean expression "NOT A equals Y," signifying that the output Y represents the inversion or negation of the input A.

In practical application, when the input A assumes the value of 1, the output Y corresponds to 0, and conversely, when A equals 0, Y becomes 1. This binary interplay emerges due to the inherent binary system's restriction to solely two digits, 0 and 1.

Fundamentally, the NOT gate serves to complement the input signal. In the event of the input being true (1), the NOT gate converts it into a false state (0), and reciprocally, transforms a false input (0) into a true output (1). This functionality holds significant importance in digital logic operations, where logical states undergo manipulation to execute diverse computational functions. The logic symbol representing the NOT gate is illustrated in the accompanying diagram.



Truth table

A	$Y = \bar{A}$
0	1
1	0

(a) (b) (c)

The operational principles of the NOT gate, showcasing the relationship between input A and resulting output Y, are elucidated through the practical implementation of an electric circuit, depicted in the provided diagram. This circuit comprises a switch (representing input A) linked in parallel to both a battery and a bulb (symbolizing output Y). The circuit's functionality unfolds as follows:

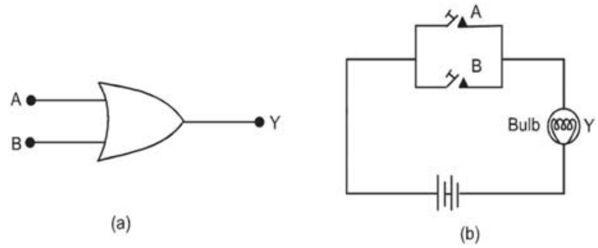
1. In the scenario where the switch A remains open (A = 0), electric current courses through the circuit, consequently causing the bulb to emit light (Y = 1).
2. Conversely, when the switch A is closed (A = 1), the circuit's continuity is broken, impeding the flow of electric current and thereby resulting in the bulb failing to emit light (Y = 0).

These distinct operational states of input A and their corresponding outcomes for output Y are meticulously organized and tabulated, as demonstrated in the accompanying diagram. This tabulation serves as a concise representation of the NOT gate's truth table, effectively outlining the logical correlations between input and output states in a coherent and accessible manner.

(b) **The OR Gate:**

The OR gate constitutes a pivotal logical element characterized by two input variables, designated as A and B, and a solitary output variable denoted as Y. Its operational logic adheres to the Boolean expression A + B = Y, signifying 'A OR B equals Y'. This expression indicates that the output Y results from the logical OR operation applied to inputs A and B.

In practical application, the output Y of the OR gate adopts a true (1) state if either input A or input B, or both, are true. Conversely, if both inputs A and B are false (0), the output Y remains false. The logic symbol representing the OR gate is visually presented in the accompanying diagram. This symbol serves as a succinct depiction of the gate's logical function, facilitating its integration into digital circuit diagrams and logical operations.



Truth Table

A	B	Y(= A+ B)
0	0	0
0	1	1
1	0	1
1	1	1

(a) (b) (c)

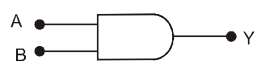
The myriad possible input combinations of A and B, alongside the resulting output Y of the OR gate, can be elucidated through the practical implementation of an electrical circuit, depicted in the accompanying diagram. This circuit comprises two switches, designated as A and B (representing the inputs), arranged in parallel to both a battery and a bulb Y (symbolizing the output).

The operational dynamics of the circuit unfold as follows:

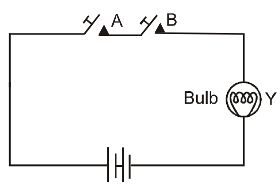
In the event that either switch A or switch B, or both, are closed, thus completing the circuit (A = 1 or B = 1), electric current flows, thereby causing the bulb to illuminate (Y = 1).
Conversely, when both switches A and B are in the open position, consequently breaking the circuit (A = 0 and B = 0), the flow of electric current is disrupted, resulting in the bulb failing to emit light (Y = 0).

(c) The AND Gate:

Similar to the OR gate, the AND gate serves as a vital logical element featuring two inputs, A and B, and a solitary output designated as Y. Its operational logic abides by the Boolean expression A.B = Y, interpreted as 'A AND B equals Y.' This expression underscores that the output Y stems from the logical AND operation applied to inputs A and B.
In practical application, the output Y of the AND gate assumes a true (1) state solely when both inputs A and B are true. If either input A or input B, or both, are false (0), the output Y remains false. The logic symbol representing the AND gate visually encapsulates its logical function and constitutes an essential component of digital circuit diagrams.
This gate assumes a pivotal role in logical operations, where the amalgamation of true and false states in the inputs yields specific outcomes predicated on the logical AND relationship between the inputs.



(a)



(b)

Truth table

A	B	Y(= A. B)
0	0	0
0	1	0
1	0	0
1	1	1

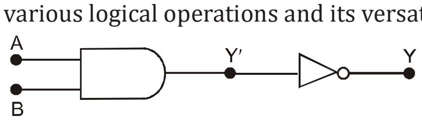
(c)

Combinations of gates:

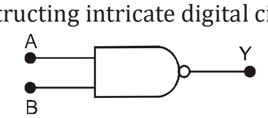
Various configurations of the three fundamental logic gates—OR, AND, and NOT—give rise to complex digital circuits commonly referred to as 'gates.' Combinations of these elementary gates are frequently employed in crafting more intricate logic circuits. Particularly noteworthy are the NAND gate and the NOR gate, recognized as universal gates due to their widespread usage.
The NAND gate is created by combining an AND gate followed by a NOT gate. This arrangement yields an output that represents the inversion of the logical AND operation between its inputs. Conversely, the NOR gate is formed by combining an OR gate followed by a NOT gate, resulting in an output that signifies the negation of the logical OR operation between its inputs.
The versatility of these NAND and NOR gates lies in their capability to implement any logical function independently. As a result, they serve as a flexible foundation for constructing a diverse range of digital circuits, underscoring their importance in the realm of digital logic design.

(i) The NAND gate:

The NAND gate is a composite structure formed by combining an AND gate with a NOT gate. In the configuration of a NAND gate, the output Y' (the complement of Y) originating from the AND gate is directly connected to the input of a NOT gate, as depicted in the accompanying diagram. This arrangement gives rise to a logical operation where the output of the NAND gate represents the negation of the logical AND operation conducted on its inputs.
Visually, the logic symbol representing the NAND gate is portrayed in the diagram, serving as a concise depiction of its logical function. This symbol plays a crucial role in the representation and interpretation of digital circuit diagrams, where the NAND gate is widely utilized due to its capacity to execute various logical operations and its versatility in constructing intricate digital circuits.



(a)



(b)

The defining Boolean expression of the NAND gate is articulated as 'A AND B negated equals Y.' This expression signifies that the output Y of the NAND gate stems from the negation of the logical AND operation applied to its input variables A and B.

To formulate the truth table for the NAND gate, one can methodically amalgamate the truth tables of its constituent AND and NOT gates. In the provided illustration, the output Y' from the AND gate's truth table undergoes a negation operation (NOT), yielding the corresponding outputs Y for the NAND gate. Consequently, the resulting table delineates the correlation between input combinations (A and B) and the resultant output Y for the NAND gate.

This truth table provides a thorough reference, elucidating the logical results linked with diverse input scenarios for the NAND gate. It encapsulates the fundamental characteristics of the NAND gate's operation and facilitates comprehension of its function within digital circuits.

A	B	$Y' (= A.B)$	$Y (= \overline{A.B}) = \overline{Y'}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

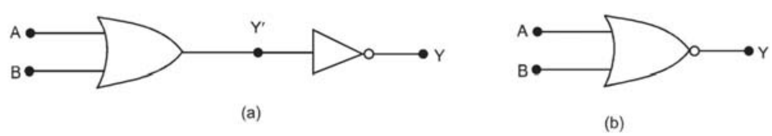
$\Rightarrow$

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(ii) **The NOR Gate:**

The NOR gate is a compound logical structure created by combining an OR gate with a NOT gate. In the configuration of a NOR gate, the output Y' (the complement of Y) from the OR gate is directly connected to the input of a NOT gate, as depicted in the provided diagram. This setup results in a logical operation where the output of the NOR gate represents the negation of the logical OR operation applied to its input variables.

Visually, the logic symbol representing the NOR gate is depicted in the diagram, serving as a succinct portrayal of its logical function. This symbol plays a pivotal role in the representation and interpretation of digital circuit diagrams, where the NOR gate is widely utilized due to its capability to execute various logical operations and its flexibility in constructing complex digital circuits.



The Boolean expression that characterizes the NOR gate is articulated as 'A OR B negated equals Y.' This expression conveys that the output Y of the NOR gate derives from the negation of the logical OR operation applied to its input variables A and B. In simpler terms, the NOR gate yields a true output (1) only when both input variables A and B are false (0), while it generates a false output (0) when at least one of the inputs is true. This Boolean expression succinctly encapsulates the core logic governing the NOR gate's behavior, highlighting its significance in digital circuitry, where it fulfills specific logical operations.

A	B	$Y' (= A+B)$	$Y (= \overline{A+B}) = \overline{Y'}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

The truth table of the NOR gate is obtained by combining the truth tables associated with the OR and NOT gates. In Figure (a), the outputs Y' from the OR gate's truth table undergo a negation operation (NOT) to produce the corresponding outputs Y for the NOR gate.

To clarify, the truth table of the OR gate illustrates the logical outcomes for various combinations of input variables A and B.

The application of the negation operation to the OR gate's outputs generates the complementary values for these outcomes, thereby establishing the truth table for the NOR gate.

This resultant truth table offers a comprehensive depiction of the NOR gate's behavior, delineating the correlation between input combinations and the resulting output states. It serves as a valuable tool for comprehending the logical operations executed by the NOR gate within digital circuits.

(iii) The XOR Gate:

The expression governing the XOR gate in Boolean form is:

$$y = A \cdot \bar{B} + \bar{A} \cdot B$$

Interpreted as "Y equals A XOR B," where ⊕ represents the exclusive OR (XOR) operation. The XOR gate produces an output of true (1) when the count of true inputs (1) is odd, and it yields false (0) when the count of true inputs is even. Put differently, the XOR gate outputs true when inputs A and B differ in logical states, and it outputs false when they share the same logical state. This concise Boolean expression encapsulates the foundational logic driving the behavior of the XOR gate, rendering it a pivotal component in digital circuitry design.