LAB 8: Diode and Transistor Logic Gates

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## OBJECTIVES:

* To investigate and verify the operation of diode AND gate.
* To investigate and verify the operation of the diode OR gate.
* To understand the operation of transistor NOT gate (transistor as a switch/inverter).
* To investigate and verify the operation of the transistor NAND gate.
* To investigate and verify the operation of the transistor NOR gate.

## EQUIPMENT AND COMPONENTS:

* Basic Circuits Training Board
* 2N3904 Transistor
* Jumper Wires
* Palm Scope / DMM
* Resistors
* DC Power Supply

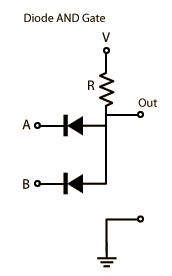
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## The simple diode logic gates

One important area in which diodes can be used is logic gates. These gates work on the principle of **on** and **off**. Since diodes inherently exhibit this behavior, so these are ideally suited to form simple diode gates. Several kinds of logic gates are possible, namely, OR, AND, NAND, NOR, exclusive-OR, and exclusive-NOR. However, only two logic gates are possible using diodes. These are **OR** and **AND** gates. Before performing the lab, consider the following points for better understanding.

* The dc power supply used for diode gate circuits will be 10 volts.
* The two voltage levels will be used to represent logic 0 (zero) and logic 1 (one).
* The logic 0 or simply 0 is ideally equal to zero volts. Practically any voltage less than 0.8 volts is considered as logic 0.
* The logic 1 or simply 1 is ideally 10 volts. From a practical point of view, any voltage above 2 volts and up to 10 volts is taken as logic 1.

## Diode AND-logic gate

A simple diode logic and-gate employing two diodes and a resistor are depicted in the figure given below. Two dc inputs can be applied to this gate circuit. We can also add more diodes to form a three input or even a four input and-gate. For simplicity, we will consider here only two input and gate. Since only two inputs are applied to the and-gate so likely input combinations exist. Let us assume, that the two diodes used are identical.

The four input combinations for the diode logic gate of the above figure and the associated outputs are represented in the table given below.

*Fig. A diode AND-gate*

|  |  |  |
| --- | --- | --- |
| **A** | **B** | **Output** |
| 0 | 0 |  |
| 0 | 1 |  |
| 1 | 0 |  |
| 1 | 1 |  |

Consider the first input combination i.e. and . Both the inputs are at logic 0. Both diodes will be on, so the output will be 0.7 V (logic 0). Suppose the dc power supply is of 10 V and resistance is of . The current flowing through the resistance of will be

The current flowing through the diodes D1 & D2 will be

Now consider the second input combination i.e. and . The diode D1 will be on but D2 will be off. Again, the output will be at 0.7 V (logic 0). The current flowing through the diode D1 will be .

Consider the third input combination i.e. and . Now the diode D2 will be on but D1 will be off. Again, the output will be at 0.7 V (logic 0). The current flowing through the diode D2 will be .

Now consider the fourth input combination i.e. and . Both the diodes D1 and D2 will be off and the output will be 10 V (logic 1). There will be no current flowing through the diodes i.e. as both the diodes will be off.

Such a logic gate whose output is logic 1 when it's one input AND the second input are (all) logic 1is called an AND-logic gate. Its output is the ordinary multiplication of the two inputs.

## Diode OR-logic gate

A simple diode logic or-gate employing two diodes and a resistor is depicted in the figure given below. Two dc inputs can be applied to this gate circuit. We can also add more diodes to form a three input or even a four input and-gate. For simplicity, we will consider here only two input or-gate. Since only two inputs are applied to the and-gate so likely input combinations exist. Let us assume, that the two diodes used are identical.

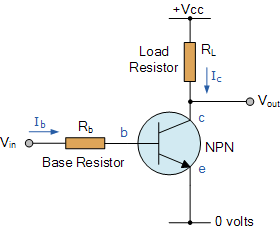
*Fig. A diode OR-gate*

The four input combinations for the OR-diode logic gate of the above figure and the associated outputs are represented in the table given below.

|  |  |  |
| --- | --- | --- |
| **A** | **B** | **Output** |
| 0 | 0 |  |
| 0 | 1 |  |
| 1 | 0 |  |
| 1 | 1 |  |

Consider the first input combination i.e. and . Both the diodes will be off, so the output will be 0 V (logic 0). The current through the resistance will be 0 mA. Now consider the second input combination i.e. and , the diode D2 connected to the second input B will be on but the diode D1 connected to the first input A will remain off, so the output will be (logic 1). If the value of the resistance is then the current flowing through the resistance will be 9.3 mA. For the 3rd input combination i.e. and , the diode D2 connected to the second input B will be off but the diode D1 connected to the first input A will be on, so again the output will be (logic 1). Also, the current flowing through the resistance will be 9.3 mA.

Now for the fourth input combination i.e. and , both the diodes D1 and D2 will be on. The output will be 9.3 V and the current through the resistance will be The current through each diode will be the half of the total current flowing through the resistance.

Such a logic gate whose output is logic 1 when at least it is one input [or second input (or both) is (are)] logic 1 is called an OR logic gate.

## Transistor NOT-logic gate

Transistors are widely used in digital logic circuits and switching applications. Recall that the waveforms encountered in those applications periodically alternate between a low and a high voltage. The fundamental transistor circuit used in switching applications is called an inverter, the NPN version of which is shown in the figure below.

Note in the figure that the transistor is in a common emitter configuration. A resistor is connected in series with the base. The supply voltage Vcc is set to be 15 V. The output is the voltage between the collector and emitter as usual.

*Fig. Transistor NOT-gate*

When the input to the inverter is high (12 V), the base-emitter junction is forward biased and current flows through into the base. The values of and are chosen so that the amount of base current is enough to saturate the transistor, that is, to drive it into the saturation region of its output characteristics.

The input current (base current) can be calculated by the following equation.

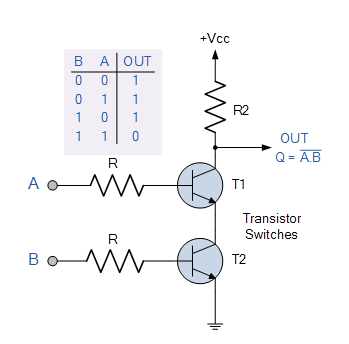
The collector current can be calculated by multiplying the base current with the current amplification factor β. The output current at the saturation point is called saturation current and is very nearly equal to the intercept of the load line of the Ic-axis. When the transistor is saturated, it is said to be ON. The output voltage is given by the equation . Note that the value of the output voltage is very nearly zero (typically about 0.1 V).

This analysis has shown that a high input to the inverter (12 V) results in a low output (logic 0).

When the input to the transistor is low, that is 0 V, the base-emitter junction has no forward bias applied to it, so no base current, and hence no collector current, flows. There is, therefore, no voltage drop across , and it follows that the output voltage is the same as the supply voltage (15 V). This fact is made evident by substituting in the equation for .

The transistor is said to be in the cut-off region. The output voltage is equal to the supply voltage (logic 1) when the input voltage is 0 V (logic 0).

|  |  |
| --- | --- |
| **Input** | **Output** |
| 0 | 1 (cut-off) |
| 1 | 0 (saturation) |

A transistor inverter is often called a transistor switch. This terminology is appropriate because the ON and OFF states of the transistor correspond closely to the closing and opening of a switch connected between the collector and the emitter. When the transistor is ON or saturated, the voltage between collector and emitter is nearly zero, as it would be across a closed switch, and the current is maximum possible, . When the transistor is OFF, no current flows from collector to emitter and the voltage is maximum, as it would be across an open switch. The switch is opened or closed by the input voltage. A high input closes it and a low input opens it.

## Transistor NAND-logic gate

A simple 2-input logic NAND gate can be constructed using RTL Resistor-transistor switches connected as shown below with the inputs connected directly to the transistor bases. Either transistor must be cut-off “OFF” for output at Q.

*Fig. NAND logic-gate*

Logic NAND Gates are available using digital circuits to produce the desired logical function and is given a symbol whose shape is that of a standard AND gate with a circle, sometimes called an “inversion bubble” at its output to represent the NOT gate symbol.

The four input combinations for the NAND logic gate of the above figure and the associated outputs are represented in the table given below.

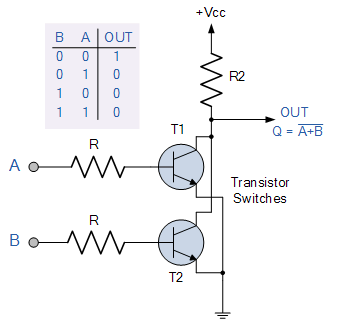
|  |  |  |
| --- | --- | --- |
| **A** | **B** | **Output** |
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

A two-input NAND gate produces a LOW output if both of its inputs are HIGH. It is easy enough to create a NAND gate by using just two transistors.

If both of the inputs are HIGH, both of the transistors will conduct through their collector-emitter paths, which creates a short circuit to ground. This causes the current to bypass the output altogether, which in turn causes the output to go LOW.

If either transistor turns off, however, the supply current cannot flow through the transistors to the ground, so the supply voltages will appear at the output of the NAND gate (logic 1). Thus, the output is HIGH if either one of the inputs is LOW. If both inputs are HIGH, the output is LOW.

## Transistor NOR-logic gate

A simple 2-input logic NOR gate can be constructed using RTL Resistor-transistor switches connected as shown below with the inputs connected directly to the transistor bases. Both transistors must be cut-off “OFF” for output at Q.

**Logic NOR Gates** are available using digital circuits to produce the desired logical function and is given a symbol whose shape is that of a standard OR gate with a circle, sometimes called an “inversion bubble” at its output to represent the NOT gate symbol.

*Fig. NOR logic-gate*

The four input combinations for the NOR-transistor logic gate of the above figure and the associated outputs are represented in the table given below. The inclusive NOR (Not-OR) gate has an output that is normally at logic level “1” and only goes “LOW” to a logic level “0” when **ANY** of its inputs are at logic level “1”. The **Logic NOR Gate** is the reverse or “*Complementary*” form of the inclusive OR gate.

|  |  |  |
| --- | --- | --- |
| **A** | **B** | **Output** |
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

This circuit is similar to an OR gate circuit, except that the output is connected to the collector of both transistors and the emitter of each transistor is connected to the ground. If either one of the transistors is on, current from Vcc will be short-circuited to the ground, bypassing the output. As a result, the output will be HIGH only when both inputs are LOW. If either input is HIGH or both inputs are HIGH, the output will be LOW.

## Procedure

* Connect the circuits as shown in the figures and set the supply voltage Vcc.
* Verify the outputs for the diode AND logic and OR logic gates.
* Verify the outputs for the transistor NAND logic and NOR logic gates.
* For the transistor as an inverter, verify the truth table for a NOT gate.
* Measure the input current (base current) and the output current (collector current) with the help of an ammeter. Also, calculate both the currents. Record the readings in the table given below.
* Measure the output voltage VCE with a voltmeter. Also, calculate the output voltage.

## Observations

Vcc = \_\_\_\_\_\_\_\_, = \_\_\_\_\_\_\_\_\_\_, = \_\_\_\_\_\_\_\_\_, Voltages applied at the base = \_\_\_\_\_\_\_\_

|  |  |  |
| --- | --- | --- |
|  | Calculated | Measured |
| Current Amplification factor |  |  |
| Base Current |  |  |
| Collector Current |  |  |
| Output Voltage (VCE) |  |  |

## Task

* For the transistor NOT gate, perform the calculations for the base current, collector current, and the output voltage on a separate page.

# REVIEW QUESTIONS:

Q: What is the purpose of studying the diodes and transistors as logic gates? What are their applications?

**COMMENTS:**

Comments that you learned during your practice.