Experiment

Study of digital logic families

1 Objectives

To understand basic gate operation of following logic families:

1. Diode-Resistor Logic (DRL)
2. Diode-Transistor Logic (DTL)
3. Transistor-Transistor Logic (TTL)

2 Theory

Digital logic gates

All digital electronic circuits and microprocessor-based systems contain hardware elements called Digital Logic Gates that perform the logical operations of AND, OR and NOT on binary numbers. In digital logic only two voltage levels or states are allowed, and these states are generally referred to as Logic "1" or Logic "0", High or Low, True or False and which are represented in *Boolean Algebra* and *Truth Tables* by the numbers "1" and "0" respectively. A good example of a digital logic level is a simple light as it is "ON" or "OFF".

Logic operations can be performed using any non-linear device that has at least two distinct regions of operation. Obvious choices are the semiconductor diode and the bipolar junction transistor. Voltage levels are assigned to logic levels 0 and 1.

While many voltage level assignments are possible, one common assignment is:

$$\text{logic 1 (HIGH)} \sim 5\ \text{V}$$

$$\text{logic 0 (LOW)} \sim 0\ \text{V}$$

This is known as "Positive logic" system. There is also a complementary "Negative Logic" system in which the values and the rules of a logic "0" and a logic "1" are reversed. But, unless stated otherwise, we shall only refer to the Positive Logic convention for all the experiments. It is important to note that noise, power source fluctuations, loading by other circuits, and other factors will cause the logic level voltages to vary over some range.

Simple digital logic gates

Simple digital logic gates can be made by combining transistors, diodes and resistors as discrete components. Let us investigate some of such circuits using Diode-resistor logic (DRL), Diode-transistor Logic (DTL) and Transistor-transistor logic (TTL) as described below.

2.1 Diode-resistor logic (DRL)

Diode logic gates use diodes to perform OR and AND logic functions as shown in the circuit diagram. Connection of the LED at the output is optional which simply displays the logical state of the output, i.e. the logic state of output is 0 or 1, if LED is **OFF** or **ON**, respectively. Diodes have the property of easily passing an electrical current in one direction, but not the other. Thus, diodes can act as a logical switch. Diode logic gates are very simple and inexpensive and can be used effectively in limited space. However, they cannot be used extensively due to the obvious logic level shift when gates are connected in series. In addition, they cannot perform a NOT function, so their usefulness is quite limited. This type of logic circuit is rarely found in integrated form.

2.1.1 Circuit components/equipment

1. Resistors: 1 kΩ (3 Nos.), 10 kΩ (1 No.)
2. 1N914 diodes or equivalent (2 Nos.)
3. DC Power supply (5V)
4. A Red/Green LED
5. Connecting wires
6. Breadboard

2.1.2 Circuit diagram

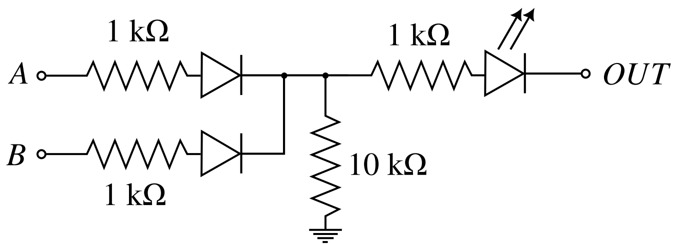

Figure 1: DRL OR gate.

2.1.3 Procedure

1. Assemble the circuit on your breadboard for OR/AND operation as shown in Figure 1 and Figure 2.

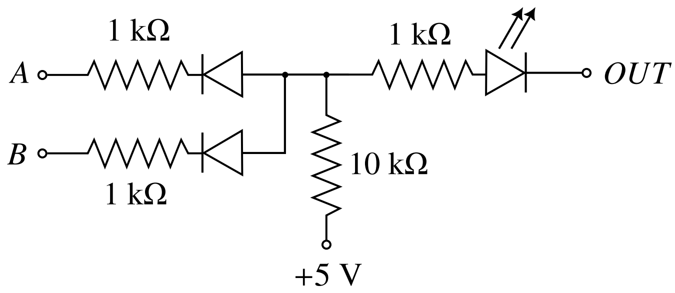

Figure 2: DRL AND gate.

2. Turn on power to your experimental circuit.
3. Apply all four possible combinations of inputs at A and B from the power supply using dip switch.
4. For each input combination, note the logic state of the output, Q, as indicated by the LED (ON = 1; OFF = 0), and record that result in the table.
5. Compare your results with the truth table of a logic "OR"/ "AND" operation.
6. When you have completed your observations, turn off the power to your experimental circuit

2.1.4 Truth tables

A	B	$Q = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

(a)

A	B	$Q = A \cdot B$
0	0	0
0	1	0
1	0	0
1	1	1

(b)

Table 1: (a) Logic "OR" operation. (b) Logic "AND" operation.

2.1.5 Observations

1. DRL "OR" gate

Input		**Output**
A	B	$Q = A + B$
0	0	
0	1	
1	0	
1	1	

2. DRL "AND" gate

Input		Output
A	B	$Q = A \cdot B$
0	0	
0	1	
1	0	
1	1	

2.2 Diode-transistor logic (DTL)

The simple 2-input Diode-Resistor gate can be converted into a NAND/NOR universal gate by the addition of a single transistor inverting (NOT) stage employing DTL. **Diode-Transistor Logic**, or **DTL**, refers to the technology for designing and fabricating digital circuits wherein logic gates employ diodes in the input stage and bipolar junction transistors at the output stage. The output BJT switches between its cut-off and saturation regions to create logic 1 and 0, respectively. The logic level shift problem of DRL gates is not present in DTL and TTL gates so that gates may be connected in series indefinitely. If a gate drives several similar gates in parallel problems may occur: the maximum number of gates that can be driven in parallel is identified as the "fanout" of a gate. DTL offers better noise margins and greater fan-outs than RTL (**Resistor-Transistor Logic**), but suffers from low speed, especially in comparison to TTL. Diodes take up far less room than resistors, and can be constructed easily. In addition, the internal resistance of a diode is small when the diode is forward biased, thus allowing for faster switching action. As a result, gates built with diodes in place of most resistors can operate at higher frequencies. Because of this diode-transistor logic (DTL) rapidly replaced RTL in most digital applications.

DTL inverter circuit

The DTL inverter uses a transistor and a collector load resistor as shown in the circuit diagram. The input is connected through a pair of diodes in series with the base of the transistor. The diode connected directly to the transistor base serves to raise the input voltage required to turn the transistor on to about 1.3 to 1.4 V. Any input voltage below this threshold will hold the transistor off. The base resistor is also connected which should be sufficient to turn the transistor on and off quickly thus enabling higher switching speeds.

Circuit components

1. Resistors: 1 kΩ (2 Nos.), 4.7 kΩ (1 No.)
2. 1N914/1N4148 silicon diodes or equivalent (2 Nos.)
3. 2N4124 NPN silicon transistor (1 No.)
4. A Surface mount dip switch

5. DC Power supply (5 V)
6. A Red/Green LED
7. Connecting wires
8. Breadboard

Circuit diagram

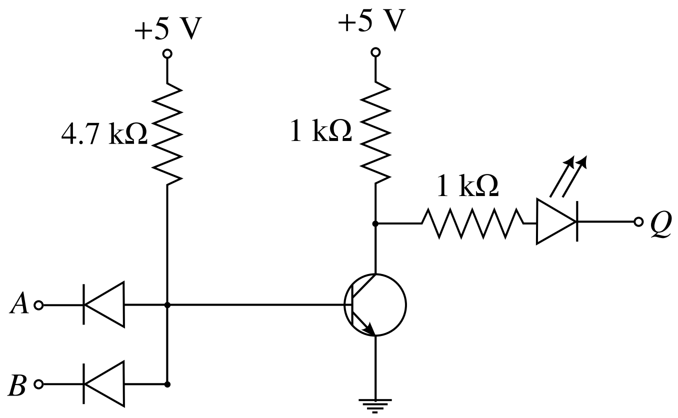

Figure 3: DTL NAND gate.

Similar to DTL NAND circuit one can construct the NOR gate by using a DRL OR gate followed by a transistor inverter, as shown in circuit diagram Figure 4. One can also construct a DTL NOR more elegantly by combining multiple DTL inverters with a common output as shown in the schematic diagram Figure 5. Any number of inverters may be combined in this fashion to allow the required number of inputs to the NOR gate. (You should try both the circuits!)

Circuit components

1. All the components from the DTL Inverter circuit, except power supply and 4.7 kΩ resistor

2. 1N914/1N4148 silicon diodes or equivalent (1 No., in addition to the previous two)

OR

1. All the components from the DTL Inverter circuit

2. 1N914/1N4148 silicon diodes or Equivalent (2 Nos., in addition to the previous two)

3. 2N4124 NPN silicon transistor or Equivalent (1 No., in addition to the previous one)

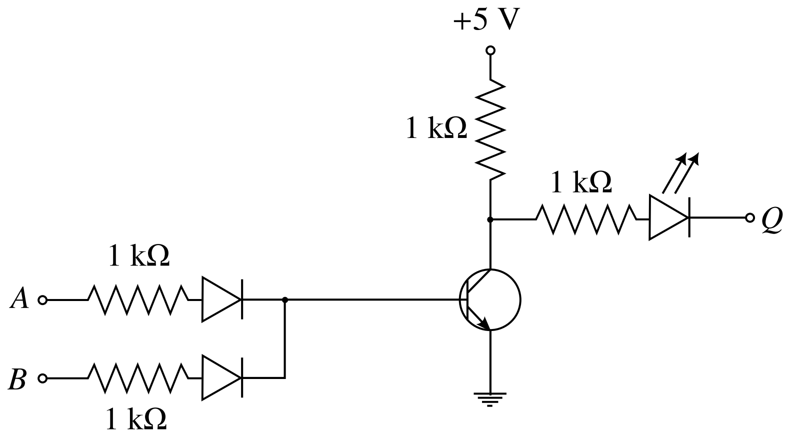

Figure 4: DTL NOR gate (variant 1).

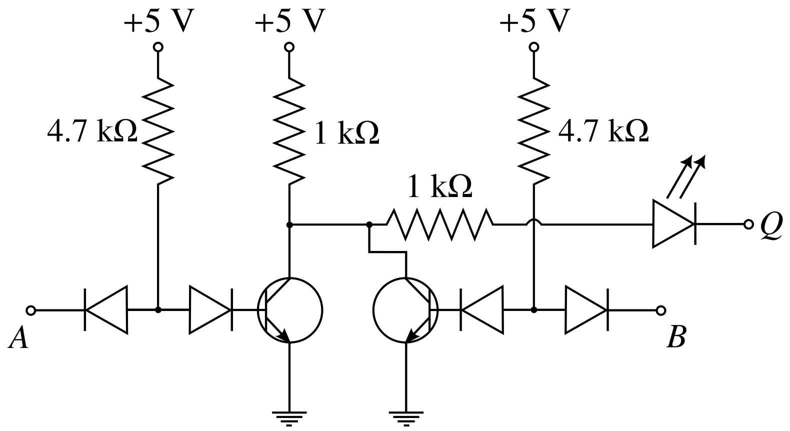

Figure 5: DTL NOR gate (variant 2).

2.2.1 Procedure

1. Assemble the circuit on your breadboard for NOT/NAND/NOR operation. First, start with the inverter circuit. Keep this circuit intact after finishing the inverter experiment. The rest two circuits can be constructed by just adding extra components to the inverter circuit.

2. Turn on power to your experimental circuit.

3. Apply all four possible combinations of inputs at *A* and *B* from the power supply using dip switch.

4. For each input combination, note the logic state of the output, *Q*, as indicated by the LED (ON = 1; OFF = 0), and record that result in the table.

5. Compare your results with the truth table of a logic NOT/NAND/NOR operation.

6. When you have completed your observations, turn off the power supply.

2.2.2 Truth tables

A	$Q = \overline{A}$
0	0
0	1

(a)

A	B	$Q = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0

(b)

A	B	$Q = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

(c)

Table 2: (a) Logic "NOT" operation. (b) Logic "NOR" operation. (c) Logic "NAND" operation.

2.2.3 Observations

1. DRL "NOT" gate

Input	**Output**
A	$Q = \overline{A}$
0	
1	

2. DRL "NOR" gate

Input		**Output**
A	B	$Q = \overline{A + B}$
0	0	
0	1	
1	0	
1	1	

3. DRL "NAND" gate

Input		**Output**
A	B	$Q = \overline{A \cdot B}$
0	0	
0	1	
1	0	
1	1	

2.3 Transistor-transistor logic (TTL)

Transistor-transistor logic uses bipolar transistors in the input and output stages. TTL is commonly found in relatively low speed applications. Thus, before using commercial ICs that uses TTL, let's first understand the circuit in discrete form.

TTL inverter circuit

Looking at the DTL inverter circuit, one can note that the two diodes are opposed to each other in direction. That is, their P-type anodes are connected together and to the pull-up resistor, while one cathode is the signal input and the other is connected to the transistor's base. Thus, one can replace these two diodes with a single NPN transistor as shown in the circuit diagram. This makes lot of sense owing to the fact that the amount of space required by a transistor in an IC is essentially the same as the space required by a diode and by eliminating the space required by one diode at the same time.

Circuit components

1. 2N4124 NPN silicon transistors (2 Nos.)
2. Resistors: 1 kΩ (2 Nos.), 4.7 kΩ (1 No.)
3. A Surface mount dip switch
4. D.C. Power supply (5 V)
5. A Red/Green LED
6. Connecting wires
7. Breadboard

Circuit diagram

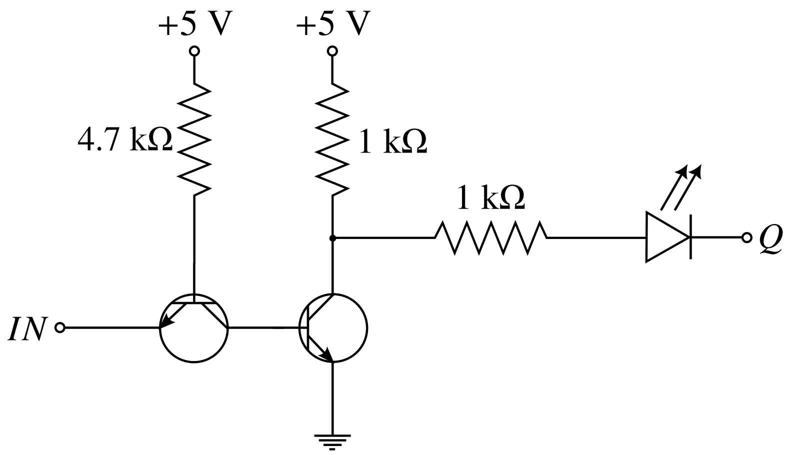

Figure 6: TTL inverter circuit.

TTL NOR circuit

TTL integrated circuits provide multiple inputs to NAND gates by designing transistors with multiple emitters on the chip. Unfortunately, we can't very well simulate that on a breadboard socket. However, a NOR gate can be designed using an extra inverter transistor just as in the case of DTL NOR gate.

Circuit components

1. All the components of the TTL inverter circuit
2. 2N4124 NPN silicon transistors or equivalent (2 Nos.)
3. 4.7 kΩ resistor (1 No.)

Circuit diagram

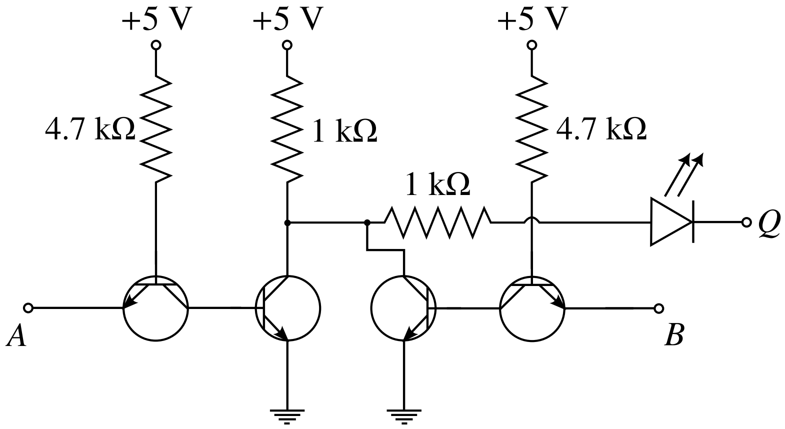

Figure 7: TTL NOR circuit.

2.3.1 Procedure

1. Assemble the circuit on your breadboard for TTL NOT/NOR operation. First, start with the inverter circuit. Keep this circuit intact to use it further in NOR circuit.

2. Turn on power to your experimental circuit. Apply all four possible combinations of inputs at *A* and *B* from the power supply using dip switch.

3. For each input combination, note the logic state of the output, *Q*, as indicated by the LED (ON = 1; OFF = 0), and record that result in the table.

4. Compare your results with the truth table of a logic NOT/NOR operation.

5. When you have completed your observations, turn off the power supply.

2.3.2 Truth tables

A	$Q = \overline{A}$
0	0
0	1

(a)

A	B	$Q = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0

(b)

Table 3: (a) Logic "NOT" operation. (b) Logic "NOR" operation.

2.3.3 Observations

1. DRL "NOT" gate

Input	**Output**
A	$Q = \overline{A}$
0	
1	

2. DRL "NOR" gate

Input		**Output**
A	B	$Q = \overline{A + B}$
0	0	
0	1	
1	0	
1	1	

2.3.4 Precautions