Logic gate circuits (Various logic families)

Objective: To understand basic gate operation of following logic families:

(i) Diode-Resistor Logic (DRL)
(ii) Diode-Transistor Logic (DTL)
(iii) Transistor-Transistor Logic (TTL)

Overview:

Digital Logic States

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 for the electrical engineer are the semiconductor diode and the bipolar junction transistor. Particular voltage levels are assigned to logic levels 0 and 1.

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

***logic 1* (*HIGH*)---- ~ 5 V**
***logic 0* (*LOW*) ---- ~ 0 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 Basic 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.

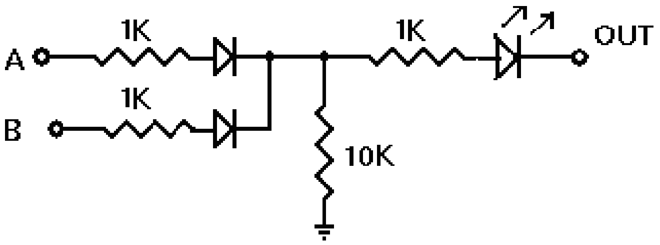
(i) Diode-Resistor Logic (DRL)

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.

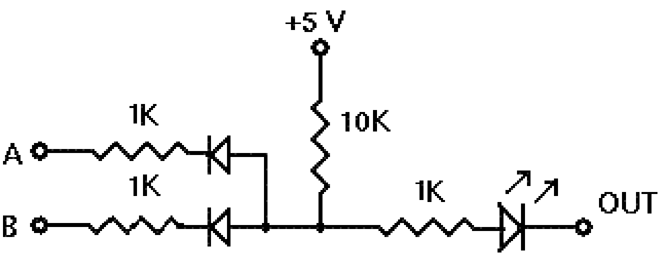
Circuit Components/Equipments:

1. Resistors (1KΩ, 3 Nos; 10KΩ, 1 No.)
2. 1N914 diodes or equivalent (2 Nos.)
3. A Surface mount dip switch
4. D.C. Power supply (5V)
5. A Red/Green LED
6. Connecting wires
7. Breadboard

Circuit Diagram:



DRL OR gate



DRL AND Gate

Procedure:

1. Assemble the circuit on your breadboard for OR/AND operation.
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

Truth Tables:

Logic "OR" operation

A	**B**	**Q = A+B**
0	0	0
0	1	1
1	0	1
1	1	1

Logic "AND" operation

A	**B**	**Q = A.B**
0	0	0
0	1	0
1	0	0
1	1	1

Observations:

(I) DRL **OR** gate:

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

(II) DRL **AND** gate:

Input		**Output**
A	**B**	**Q = A.B**
0	0	
0	1	
1	0	
1	1	

Discussions:

Precautions:

(ii) 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.

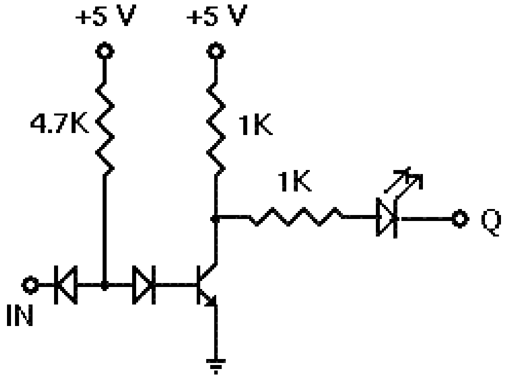
DTL Inverter Circuit

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 volts. 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/Equipments:

1. Resistors (1K 2 Nos., 4.7K; 1 No.)
2. 1N914/1N4148 silicon diodes (2 Nos.)
3. 2N4124 NPN silicon transistor (1 No.)
4. A Surface mount dip switch
5. D.C. Power supply (5V)
6. A Red/Green LED
7. Connecting wires
8. Breadboard

Circuit Diagram:



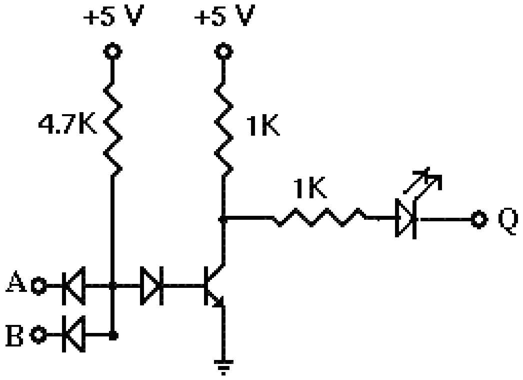
DTL NAND Circuit

The DTL NAND gate combines the DTL inverter with a simple Diode-Resistor Logic (DRL) AND gate as shown in its circuit diagram. Thus, any number of inputs can be added simply by adding input diodes to the circuit. The problem of signal degradation caused by Diode Logic is overcome by the transistor, which amplifies the signal while inverting it. This means DTL gates can be cascaded to any required extent, without losing the digital signal.

Circuit Components:

1. All the components from the DTL Inverter circuit
2. 1N914/1N4148 silicon diodes (1No.,in addition to the previous two)

Circuit Diagram:



DTL NOR Circuit

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 (i). One can also construct a

DTL NOR more elegantly by combining multiple DTL inverters with a common output as shown in the schematic diagram (ii). 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!)

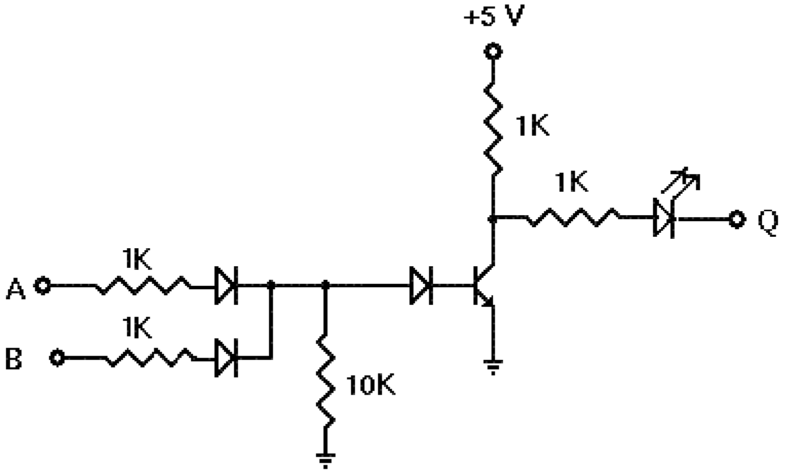
Circuit Components:

1. All the components from the DTL Inverter circuit, except power supply and 4.7 K resistor
2. 1N914/1N4148 silicon diodes (1No.,in addition to the previous two)

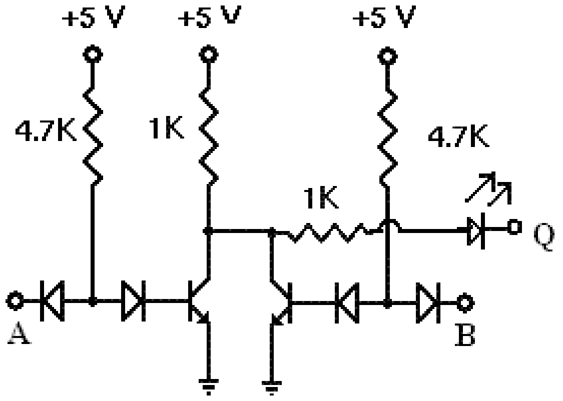
Or

1. All the components from the DTL Inverter circuit
2. 1N914/1N4148 silicon diodes (2Nos.,in addition to the previous two)
3. 2N4124 NPN silicon transistor (1No.,in addition to the previous one)

Circuit Diagram:



(i)



(ii)

Procedure:

1. Assemble the circuit on your breadboard for NOT/NAND/NOR operation. First, start with the inverter circuit. Keep this circuit in tact 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.

Truth Tables:

Logic "NOT" operation

A	**Q = A'**
0	1
1	0

Logic "NOR" operation

A	**B**	**Q = (A+B)'**
0	0	1
0	1	0
1	0	0
1	1	0

Logic "NAND" operation

A	**B**	**Q = (A.B)'**
0	0	1
0	1	1
1	0	1
1	1	0

Observations:

(I) DTL **NOT** gate:

Input **A**	**Output** **Q = A'**
0	
1	

(II) DTL **NOR** gate:

Input		**Output**
A	**B**	**Q = (A+B)'**
0	0	
0	1	
1	0	
1	1	

(III) DTL **NAND** gate:

Input		**Output**
A	**B**	**Q = (A.B)’**
0	0	
0	1	
1	0	
1	1	

Discussions:

Precautions:

(iii) 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.

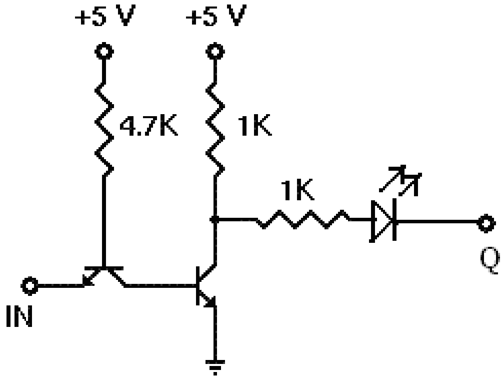
TTL Inverter Circuit

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/Equipments:

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

Circuit Diagram:



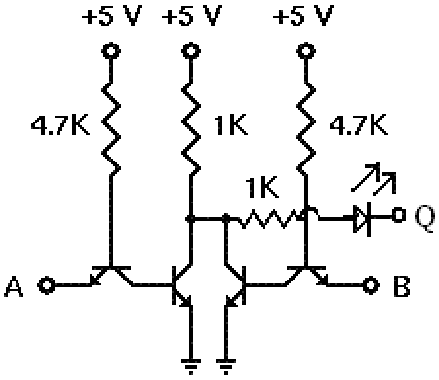
TTL NOR Circuit

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 transistors just as in the case of DTL NOR gate.

Circuit Components/Equipments:

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

Circuit Diagram:



Procedure:

1. Assemble the circuit on your breadboard for TTL NOT/NOR operation. First, start with the inverter circuit. Keep this circuit in tact 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.

Truth Tables:

Logic "NOT" operation

A	**Q = A'**
0	1
1	0

Logic "NOR" operation

A	**B**	**Q = (A+B)'**
0	0	1
0	1	0
1	0	0
1	1	0

Observations:

(I) TTL **NOT** gate:

Input **A**	**Output** **Q = A'**
0	
1	

(II) TTL **NOR** gate:

Input		**Output**
A	**B**	**Q = (A+B)'**
0	0	
0	1	
1	0	
1	1	

Discussions:

Precautions:

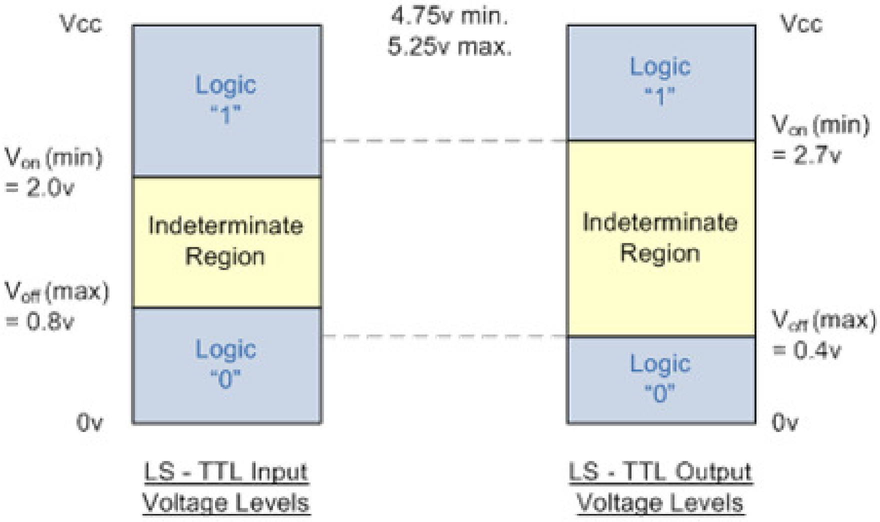
Boolean Logic Operations using Digital ICs

Objective: To study and verify various Boolean logic operations and the De Morgan's laws using digital ICs.

Overview:

Standard commercially available **Digital Logic Gates** are available in two basic forms, **TTL** which stands for *Transistor-Transistor Logic* such as the 7400 series, and **CMOS** which stands for *Complementary Metal-Oxide-Silicon* which is the 4000 series of Integrated Circuits, (IC) or "chips" as it is commonly called. Generally speaking, **TTL** IC's use NPN type *Bipolar Junction Transistors* while **CMOS** IC's use *Field Effect Transistors* or FET's for both their input and output circuitry.

There are a large variety of logic gate types in both the Bipolar and CMOS families of digital logic gates such as 74L, 74LS, 74ALS, 74HC, 74HCT, 74ACT etc, with each one having its own distinct advantages and disadvantages and the exact voltages required to produce a logic "0" or logic "1" depends upon the specific logic group or family. However, when using a standard +5 volt supply any TTL voltage input between 2.0V and 5V is considered to be a logic "1" or "HIGH" while any voltage input below 0.8v is recognized as a logic "0" or "LOW". TTL outputs are typically restricted to narrower limits of between 0 V and 0.4 V for a "low" and between 2.7 V and 5 V. The voltage region between the maximum voltage of logic "0" and minimum voltage of logic "1" of either input or output is called the *Indeterminate Region*. CMOS logic uses a different level of voltages with a logic "1" level operating between 3 and 15 volts.



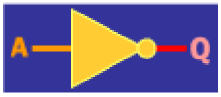
TTL Input & Output Voltage Levels

There are several simple gates that you need to learn about. With these simple gates you can build combinations that will implement any digital component you can imagine.

- The simplest possible gate is called an "inverter," or a **NOT gate**. It takes one bit as input and produces output as its opposite. The logic table for NOT gate and its symbol are shown below.

NOT Gate

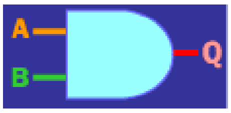
A	Q
0	1
1	0



- The **AND gate** performs a logical "and" operation on two inputs, A and B:

AND Gate

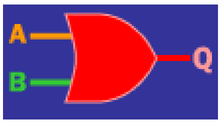
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1



- The **OR gate** performs a logical "or" operation on two inputs, A and B:

OR Gate

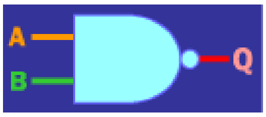
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1



- It is quite common to recognize two others as well: the **NAND** and the **NOR** gate. These two gates are simply combinations of an AND or an OR gate with a NOT gate.

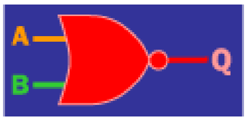
NAND Gate

A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0



NOR Gate

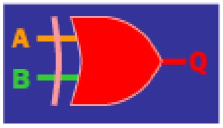
A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0



- The final two gates that are sometimes added to the list are the **XOR** and **XNOR** gates, also known as "exclusive or" and "exclusive nor" gates, respectively. Here are their tables:

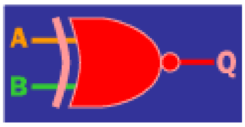
XOR Gate

A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0



XNOR Gate

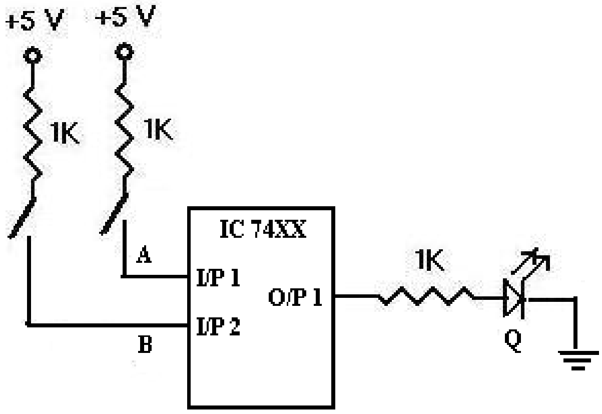
A	B	Q
0	0	1
0	1	0
1	0	0
1	1	1



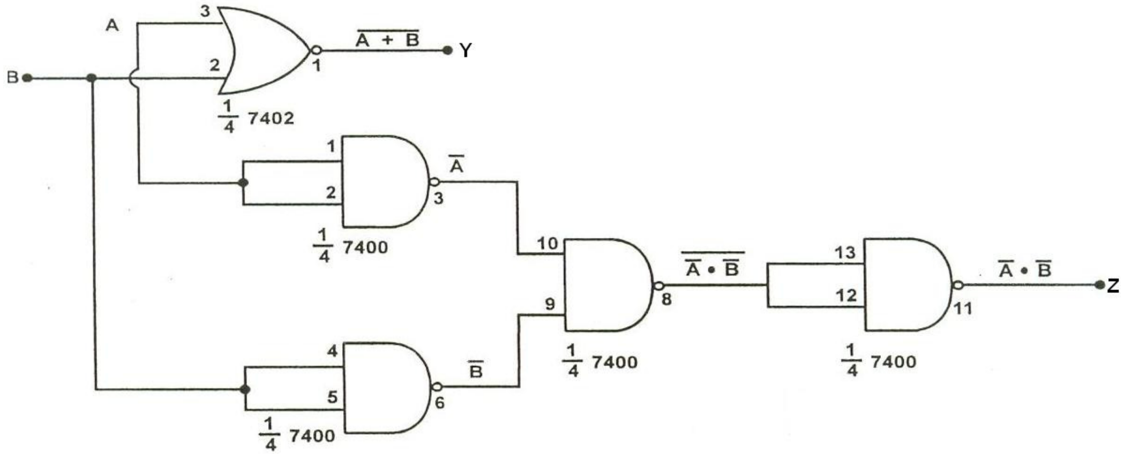
Circuit Components/Equipments:

(i) Digital ICs, (ii) Resistors, (iii) DIP switch, (iv) D.C. Power supply (5V), (v) LEDs, (vi) Breadboard, (vii) Connecting wires.

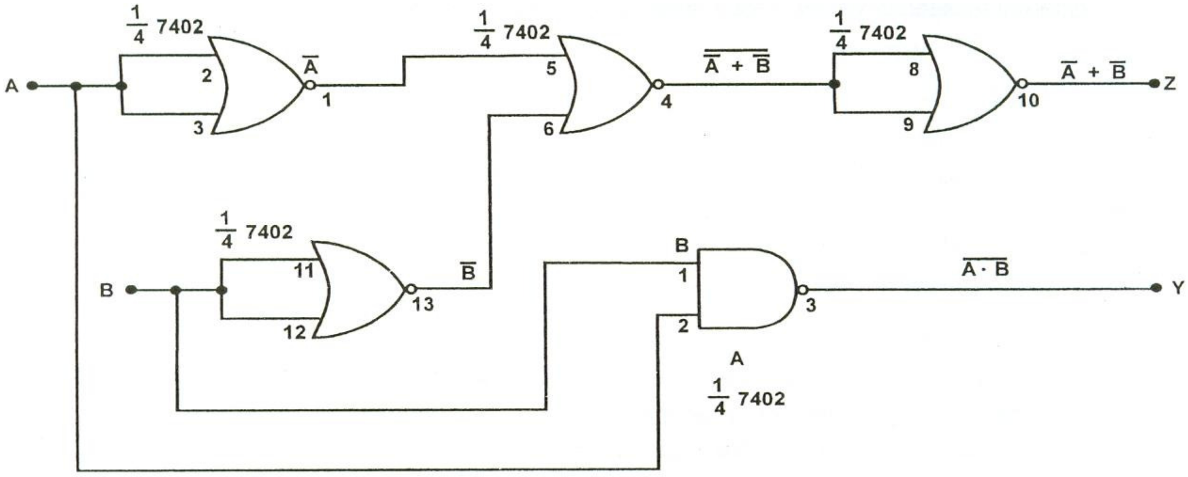
Circuit Diagrams: (in general, for all ICs)



De Morgan's law: $\overline{(A + B)} = \bar{A} \cdot \bar{B}$



De Morgan's law: $(\overline{A \cdot B}) = \bar{A} + \bar{B}$



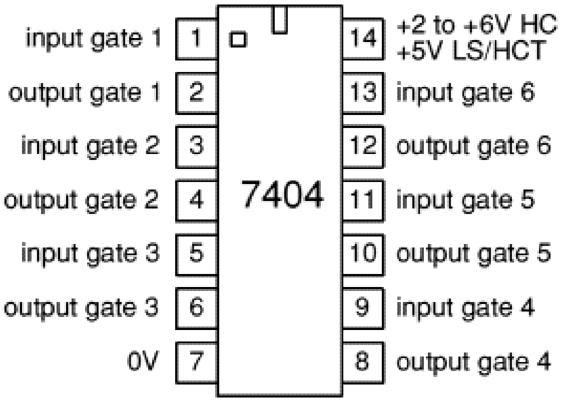
Procedure:

1. Place the IC on the breadboard.
2. Connect pin 14 (V_{CC}) to 5V and pin 7 (ground) to 0V terminal of the power supply.
3. Following the general circuit diagram facilitate all possible combinations of inputs from the power supply, using dip switch and resistors. Connect the output pin to ground through a resistor and LED.
4. Turn on power to your experimental circuit.
5. For each input combination, note the logic state of the outputs as indicated by the LEDs (ON = 1; OFF = 0), and record the result in the table.
6. Compare your results with the truth table for operation.

7. For verification of De Morgan’s laws, follow the respective circuit diagrams using appropriate ICs. Follow the general circuit diagram for connections for input and output using dip switch and LEDs.
8. Monitor the outputs Y and Z using LEDs and confirm that Y and Z are the same for any states of A and B.
9. When you are done, turn off the power to your experimental circuit.

Observations: Verification of Boolean Logic Operations

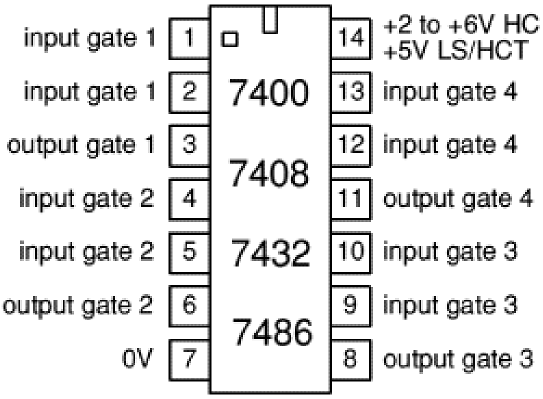
(I) Inverter gate (NOT): IC 7404LS



Gate # 1/2/../6

I/P (A)	O/P (Q)
0	
0	
1	
1	

(II) 2-input AND gate: IC 7408LS



Gate # 1/2/../4

I/P (A)	I/P (B)	O/P (Q)
0	0	
0	1	
1	0	
1	1	

(III) 2-input OR gate: IC 7432LS

Gate # 1/2/../4

I/P (A)	I/P (B)	O/P (Q)
0	0	
0	1	
1	0	
1	1	

(IV) 2-input EX-OR gate: IC 7486LS

Gate # 1/2/../4

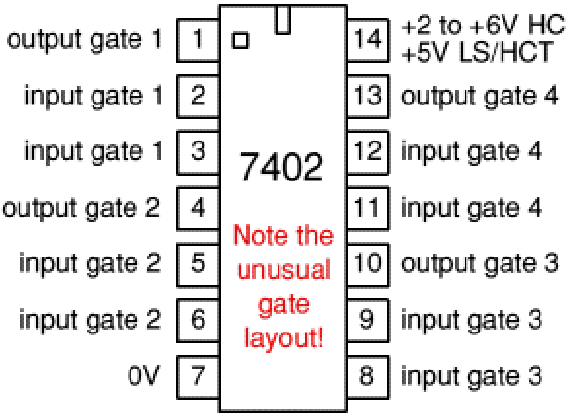
I/P (A)	I/P (B)	O/P (Q)
0	0	
0	1	
1	0	
1	1	

(V) 2-input NAND gate: IC 7400LS

Gate # 1/2/../4

I/P (A)	I/P (B)	O/P (Q)
0	0	
0	1	
1	0	
1	1	

(VI) 2-input NOR gate: IC 7402LS



Gate # 1/2/../4

I/P (A)	I/P (B)	O/P (Q)
0	0	
0	1	
1	0	
1	1	

Verification of De Morgan's laws:

$$\overline{(A+B)} = \bar{A} \cdot \bar{B}$$

I/P (A)	I/P (B)	$\overline{(A+B)}$	Y(Observed)	$\bar{A}$	$\bar{B}$	$\bar{A} \cdot \bar{B}$	Z(Observed)
0	0						
0	1						
1	0						
1	1						

$$(\overline{\boldsymbol{A}\cdot\boldsymbol{B}}) = \overline{\boldsymbol{A}} \;+ \overline{\boldsymbol{B}}$$

I/P (A)	**I/P (B)**	$(\overline{\boldsymbol{A}\cdot\boldsymbol{B}})$	**Y(Observed)**	$\overline{\boldsymbol{A}}$	$\overline{\boldsymbol{B}}$	$\overline{\boldsymbol{A}} \;+ \overline{\boldsymbol{B}}$	**Z(Observed)**
0	0						
0	1						
1	0						
1	1						

Discussions:

Precautions:

Multiplexor and Demultiplexor circuits

Objectives:

(i) To design and study a 4 – 1 multiplexer circuit.

(ii) To design and study a 1 – 4 demultiplexer circuit.

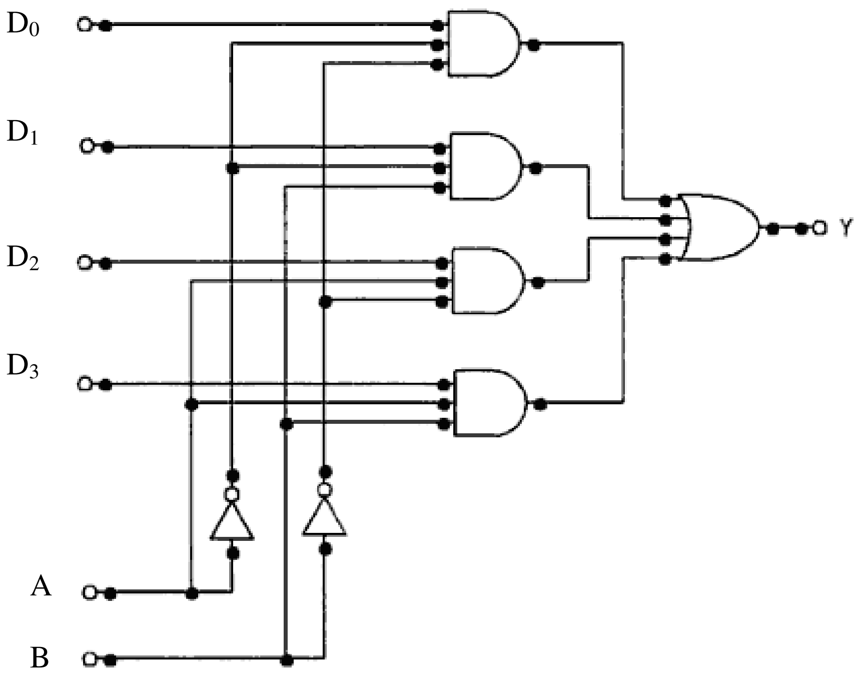
Overview:

Multiplexers:

A multiplexer (or MUX) is a circuit with many inputs but only one output and acts like a very fast acting rotary switch. It selects one of many analog or digital input signals (2, 4, 8, 16 and so on) and forwards the selected input into a single line output. The selection of a particular input channel is controlled by a set of select inputs. A digital multiplexer of 2^n input channels can be controlled by n number of select lines.

A 4-to-1 line multiplexer, for example, consists of 4 input channels and 2 selection inputs. Its circuit diagram and truth table are shown below. The data input channels D_0 to D_3 are selected by combinations of select inputs A and B. To understand its operation, let us consider that the select input combination AB is 01. The AND gate associated with D_1 will have two inputs of logic 1 and the third input is D_1. Thus the output of this AND gate will follow D_1. The other three AND gates have at least one of their inputs at logic 0 to make their output 0, irrespective of the rest of the data inputs X (0 or 1). Hence the OR output will follow D_1 only.

Circuit Diagram:



Characteristic Table:

X = 0 or 1

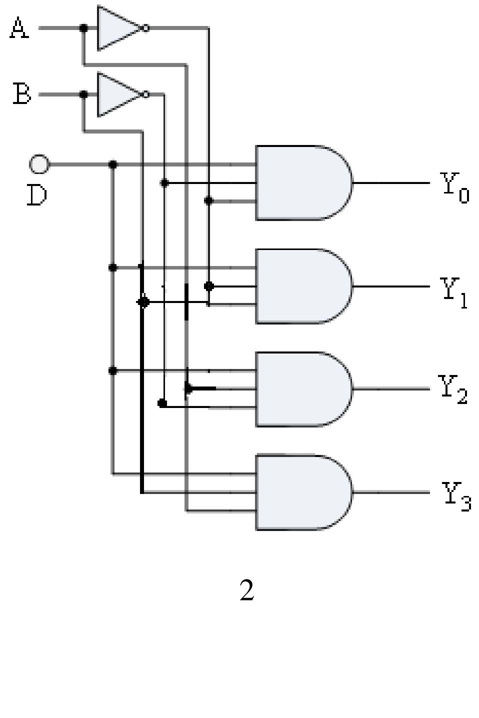
Selection Inputs		**Input Channels**				**Output**
A	**B**	**D_0**	**D_1**	**D_2**	**D_3**	**Y**
0	0	0	X	X	X	0
0	0	1	X	X	X	1
0	1	X	0	X	X	0
0	1	X	1	X	X	1
1	0	X	X	0	X	0
1	0	X	X	1	X	1
1	1	X	X	X	0	0
1	1	X	X	X	1	1

The multiplexer is a very useful combinational device that has uses in many different applications such as signal routing, data communications and data bus control.

Demultiplexers:

A demultiplexer circuit is the reverse of a multiplexer circuit. Demultiplexing is the process that receives information from one channel, i.e. single input and distributes the data over several output channels. Selection of a specific output line is controlled by the selection input lines. A 1-to-4 demultiplexer circuit is shown in the circuit diagram along with its characteristic table. The selection input lines A and B activate an AND gate according to its bit combination. The input line D (0 or 1) is common to one of the inputs of all AND gates. So the input D is passed to that particular output line which is activated by the particular AND gate. As an example, for the selection input combination 00, input D is transmitted to Y_0. The truth table for a 1-to-4 demultiplexer is given below.

Circuit Diagram:



Characteristic Table:

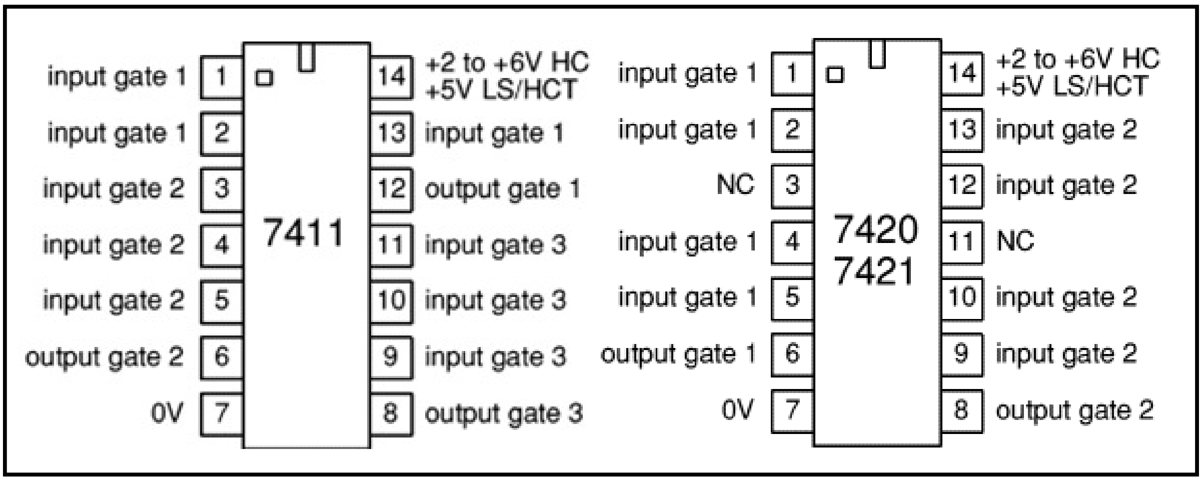
D = 0 or 1

Selection inputs		**Output Channels**			
A	**B**	**Y_0**	**Y_1**	**Y_2**	**Y_3**
0	0	D	0	0	0
0	1	0	D	0	0
1	0	0	0	D	0
1	1	0	0	0	D

Circuit components/Equipments:

1. Resistors (1KΩ, 7 Nos)
2. ICs (3 input AND-7411, 2 Nos; 4 input NAND-7420, 1 No; NOT-7404, 1 No.)
3. A Surface mount dip switch
4. D.C. Power supply (5V)
5. Red/Green LEDs (4 Nos)
6. Connecting wires
7. Breadboard

Circuit Diagrams: Already provided with text. Use logic $\overline{\overline{A}.\overline{B}} = A + B$ to make an OR gate using the 4 input NAND gate.



Pin configurations for IC 7411 and 7420

Procedure:

1. Assemble the circuits one after another on your breadboard as per the circuit diagrams.
2. Connect the ICs properly to power supply and ground following the pin configurations for different ICs.
3. Using dip switch and resistors, facilitate all possible combinations of data and select inputs from the power supply.
4. Turn on power to your experimental circuit.
5. For each select and data input combination, note the logic state of the outputs as indicated by the LEDs (ON = 1; OFF = 0), and record the result in the table.
6. Compare your results with the truth table for operation.
7. When you are done, turn off the power to your experimental circuit.

Observations:

Table for Multiplexer (4-to-1):
Table for Demultiplexer (1-to-4):

Discussions:

Precautions: