Digital Logic Families

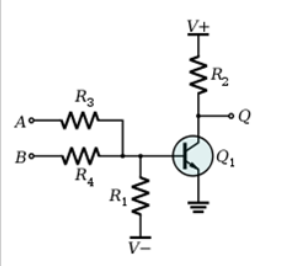
In Digital Designs, our primary aim is to create an Integrated Circuit (IC). A Circuit configuration or arrangement of the circuit elements in a special manner will result in a particular Logic Family. Electrical Characteristics of the IC will be identical. In other words, the different parameters like Noise Margin, Fan In, Fan Out etc will be identical.  
Different ICs belonging to the same logic families will be compatible with each other.

The basic Classification of the Logic Families are as follows:  
A) Bipolar Families  
B) MOS Families  
C) Hybrid Devices

A) Bipolar Families:  
1. Diode Logic (DL)  
2. Resistor Transistor Logic (RTL)  
3. Diode Transistor Logic (DTL)  
4. Transistor- Transistor Logic (TTL)  
5. Emitter Coupled Logic (ECL) or Current Mode Logic (CML)  
6. Integrated Injection Logic (IIL)  
B) MOS Families:  
1. P-MOS Family  
2. N-MOS Family  
3. Complementary-MOS Family  
â€¢ Standard C-MOS  
â€¢ Clocked C-MOS  
â€¢ Bi-CMOS  
â€¢ Pseudo N-MOS  
â€¢ C-MOS Domino Logic  
â€¢ Pass Transistor Logic  
C) Hybrid Family:  
Bi-CMOS Family  
Diode Logic  
In DL (diode logic), only Diode and Resistors are used for implementing a particular Logic. Remember that the Diode conducts only when it is Forward Biased.

Disadvantages of Diode Logic  
â€¢ Diode Logic suffers from voltage degradation from one stage to the next.  
â€¢ Diode Logic only permits OR and AND functions.

Resistor Transistor Logic  
In RTL (resistor transistor logic), all the logic are implemented using resistors and transistors. One basic thing about the transistor (NPN), is that HIGH at input causes output to be LOW (i.e. like a inverter). In the case of PNP transistor, the LOW at input causes output to be HIGH.



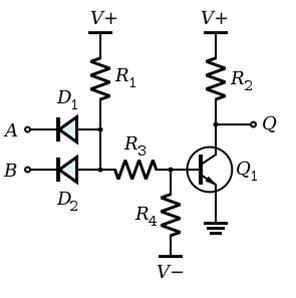
Advantage:

* Less number of Transistors

Disadvantage:

* High Power Dissipation
* Low Fan In

Diode Transistor Logic  
In DTL (Diode transistor logic), all the logic is implemented using diodes and transistors.

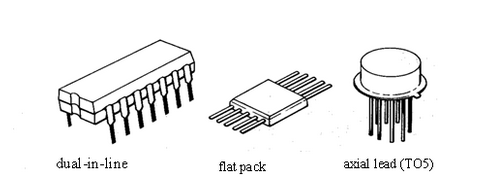


Disadvantage:  
â€¢ Propagation Delay is Larger  
**Transistor Transistor Logic**

In Transistor Transistor logic or just TTL, logic gates are built only around transistors.  
TTL Logic has the following sub-families:  
â€¢ Standard TTL.  
â€¢ High Speed TTL  
â€¢ Low Power TTL.  
â€¢ Schhottky TTL.  
â€¢ Low Power Schottky TTL  
â€¢ Advanced Schottky TTL  
â€¢ Advanced Low Power Schottky TTL  
â€¢ Fast Schottky  
**Emitter Coupled Logic**  
The main specialty of ECL is that it is operating in Active Region than the Saturation Region. That is the reason for its high speed operation. As you can see in the figure, the Emitters of the Transistors Q1 and Q2 are coupled together.

Disadvantage:  
â€¢ Large Silicon Area  
â€¢ Large Power Consumption

Some Characteristics we consider for the selection of a particular Logic Family are:  
â€¢ Supply voltage range  
â€¢ Speed of response  
â€¢ Power dissipation  
â€¢ Input and output logic levels  
â€¢ Current sourcing and sinking capability  
â€¢ Fan in  
â€¢ Fan-out  
â€¢ Noise margin  
Introduction of Digital logic families  
Miniature, low-cost electronics circuits whose components are fabricated on a single, continuous piece of semiconductor material to perform a high-level function. This IC is usually referred to as a monolithic IC first introduced in 1958. The digital ICs are categorized as,  
1. Small scale integration SSI <12 no of gates  
2. Medium scale integration MSI 12 to 99 no of gates  
3. Large scale integration LSI 100 to 9999 no of gates  
4. Very large scale integration VLSI 10,000 or more  
In this section, we will be concern only with the digital IC. Digital IC can be further categorized into bipolar or unipolar IC.  
Bipolar ICs are devices whose active components are current controlled while unipolar ICs are devices whose active components are voltage controlled.  
IC Packaging  
1. IC packaging Protect the chip from mechanical damage and chemical contamination.  
2. Provides a completed unit large enough to handle.  
3. So that it is large enough for electrical connections to be made.  
4. Material is molded plastic, epoxy, resin, or silicone. Ceramic used if higher thermal dissipation capabilities required. Metal/glass used in special cases.  
Three most common packages for ICs are  
a) dual-in-line (DIPS) (most common)  
b) flat pack  
c) axial lead (TO5)



Characteristics of Digital ICs  
Input /Output voltage level:  
The following currents and voltages are specified which are very useful in the design of digital systems.  
High-level input voltage, VIH : This is the minimum input voltage which is recognized by the gate as logic 1.  
Low-level input voltage, VIL: This is the maximum input voltage which is recognized by the gate as logic 0.  
High-level output voltage, VOH: This is the minimum voltage available at the output corresponding to logic 1.  
Low-level output voltage, VOL: This is the maximum voltage available at the output corresponding to logic 0.

High-level input current, IIH : This is the minimum current which must be supplied by a driving source corresponding to 1 level voltage.

Low-level input current, IIL: This is the minimum current which must be supplied by a driving source corresponding to 0 level voltage.

High-level output current, IOH: This is the maximum current which the gate can sink in 1 level.

Low-level output current, IOL: This is the maximum current which the gate can sink in 0 level.

High-level supply current, ICC (1): This is the supply current when the output of the gate is at logic 1.

Low-level supply current, ICC (0): This is the supply current when the output of the gate is at logic (0).

Propagation Delay:

Definition: The time required for the output of a digital circuit to change states after a change at one or more of its inputs. The speed of a digital circuit is specified in terms of the propagation delay time. The delay times are measured between the 50 percent voltage levels of input and output waveforms. There are two delay times, *tp*HL: when the output goes from the HIGH state to the LOW state and *tp*LH, corresponding to the output making a transition from the LOW state to the HIGH state. The propagation delay time of the logic gate is taken as the average of these two delay times.

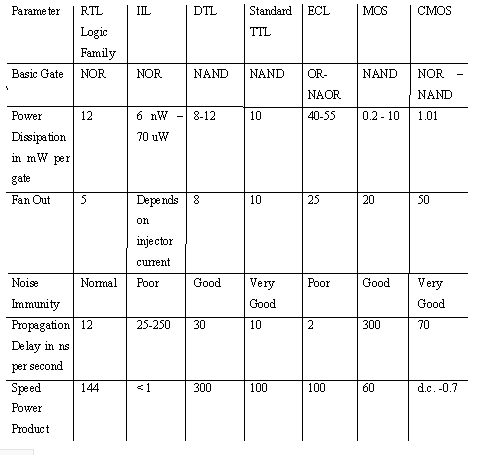
Fan-in

*Defination: Fan-in (input load factor* is the number of input signals that can be connected to a gate without causing it to operate outside its intended operating range. expressed in terms of standard inputs or units loads (ULs).

Fan-out

*Defination:Fan-out (output load factor)* is the maximum number of inputs that can be driven by a logic gate. A fanout of 10 means that 10 unit loads can be driven by the gate while still maintaining the output voltage within specifications for logic levels 0 and 1.

Digital IC gates are classified not only by their logic operation, but also by the specific logic circuit family to which it belongs. Each logic family has its own basic electronic circuit upon which more complex digital circuits and functions are developed.  
Different types of logic gate families :  
RTL : Resistor Transistor Logic gate family  
DCTL : Direct Coupled Transistor Logic gate family  
RCTL : Resistor Capacitor Transistor Logic gate family  
DTL : Diode Transistor Logic gate family  
TTL : Transistor Transistor logic gate family  
IIL : Integraeted Injection gate family



## History of Integrated Circuits

Origin of Integrated Circuits can be traced back to 1947 when the first transistor was invented by William B Shockley and his co-workers at Bell Laboratories. This paved way for the need of a small platform where all the electronic components could be fabricated using small wirings.

In 1949, German engineer Werner Jacobi filed a patent for a circuit he developed using 5 transistors in a 3-stage arrangement. This circuit operated similarly to the present Integrated Circuit. Though his invention could not garner much interest, yet it managed to result in cheaper and portable devices such as hearing aids.

The full-fledged idea of an integrated circuit was developed by Geoffrey Dummer, an employee of Royal Radar Establishment, Ministry of Defence, Britain, in 1952. However, it was a failure practically as he was never able to build an IC.

Later, in 1957, Jack Kilby, an employee of the US Army proposed an idea of small ceramic wafers, each consisting of one component. As his idea gained traction, he started working on improving his designs. He demonstrated the first working IC on September 12, 1958, while being an employee of Texas Instruments. In fact, the term Integrated Circuit was coined after his invention.

However, Kilby’s IC was made up of Germanium and has lots of limitations. Around August 1959, Robert Noyce, at Fairchild Semiconductors, developed an IC chip using Silicon.

Jay Last, a team leader at the same company, also produced the first planar IC, which used transistors in two pairs. However, though his prototype was a success, his idea was not accepted by the company.

The transition of IC application from military applications to commercial market was possible with the development of IC chips for use in Apollo spacecraft, by Fairchild.

Later, Robert Noyce created the PN-Junction isolation IC using an idea from kurtLehovec, which later paved a way for the development of CMOS Integrated Circuits.

Era of the 50s and 60s saw a tough competition between different companies in claiming their monopoly over integrated circuits. It was the integrated circuits which made it possible to shrink computers size while gaining the memory size.

## Classification of ICs on basis of chip sizes

Integrated Circuits can be classified based on its integration scale. An integration scale denotes the number of components fitted into a standard Integrated Circuit.

### Small Scale Integration

* The early developed ICs were the small-scale integrated circuits which contained only a few transistors.
* A number of transistors ranged from 2 to 10.
* Nowadays, a single small-scale integrated circuit chip contains about 3 to 30 gates.

### Medium Scale Integration

* The next in line to the IC family were the medium scale integrated circuits which contained hundreds of transistors.
* A Medium Scale Integrated Circuit contains about 30 to 300 gates per chip.

### Large Scale Integration

* Large Scale Integrated circuits were the next to MSI chips.
* Each LSI chip contained tens of thousands of transistors.
* A Large-Scale Integrated Circuit contains about 300 to 3000 gates per chip.

### Very Large-Scale Integration

* Development of VLSI chip paved a way to the creation of the first microprocessor, by fabrication of a CPU on a single microchip.
* A VLSI chip contained about 1 to 4 million transistors.
* A single chip contains about more than 3000 gates.

### Ultra-Large-Scale Integration

* When millions and billions of transistors are embedded on a single silicon chip, the integration technology is known as Ultra Large-Scale Integration.
* This technique was first used during the late 1980s, specifically for the development of Intel 8086 series.
* Another example of chips built on ULSI technology is Intel 486 and Pentium series of processors.

## Classification on basis of applications

### Linear Integrated Circuits

Linear Integrated Circuits have operations over a continuous range of signals. The relationship between input and output for a linear AC is always linear. In other words, the output of a Linear IC is proportional to its input. Applications include amplification, oscillation, mixing, modulation, etc. A linear or an Analog IC works on a continuous Analog signal.

The first developed linear ICs were the Operational Amplifiers. Recent Linear ICs include Differential Amplifiers, Voltage Regulators, Phase Locked Loops, Analog Multiplier, etc. An OpAmp is the fundamental building block in Analog Circuits.

### Digital Integrated Circuits

Integrated Circuits which perform logical functions, i.e. using binary inputs, are termed as Digital Integrated Circuits. Most of the Digital ICs are manufactured using Monolithic technology. However, for specific applications, Thick and Thin film technologies are used. Digital ICs have been instrumental in the realization of electronic systems. Logic Gates are the basic building blocks of a digital IC. Typical examples include Flip-Flops, Counters, Shift registers, etc.

### Mixed Signal Integrated Circuits

Another class of Integrated Circuits which works on both Analog and Digital signals are the Mixed-Signal Integrated Circuits. Both the Analog and Digital circuits are present on the same chip. Applications include FM Tuners in media players, Digital to Analog/Analog to Digital Converters, and Ethernet applications.

Challenges in developing a mixed signal IC arises due to different power needs and consumption for Digital and Analog components.

## Classification on basis of Fabrication

### Monolithic Integrated Circuits

As the word implies, Monolithic Integrated Circuits are manufactured or fabricated on a single chip of Silicon. All the active and passive circuit components are formed at the same time, using diffusion steps.

Monolithic ICs are mostly used in applications where identical characteristics of components are required and hence they are cheap and highly reliable.

#### Example of Monolithic IC

A classic example of a Monolithic IC is the operational amplifier IC741. It is an 8-pin IC, first developed by Fairchild Semiconductors, and later by companies like Motorola, National Semiconductors, etc.

This IC is available in the dual in-line package, with pins 2 and 3 as Inverting and Non-Inverting inputs respectively and 6 as output. It requires a dual power supply, with positive supply to pin 7 and negative supply to pin 4.

#### Advantages of Monolithic ICs

1. Smaller in size and less weight.
2. Low cost and less production time.
3. Highly reliable, due to no soldered joints and fewer interconnections.
4. Complex circuits can be fabricated easily, thus achieving improved functional performance.
5. As components are fabricated very close to each other, small signal operation is possible as it eliminates any chance of stray signal pickup.
6. No external projections required as all components are fabricated inside the chip.

#### Disadvantages of Monolithic ICs

1. Fabrication of components very nearer to each other also results in poor isolation between them.
2. Inductors cannot be fabricated on a Monolithic IC.
3. Small size causes low power rating and the IC can only be used for low power applications.

### CMOS Integrated Circuit

Due to their low power consumption and lower threshold voltage capabilities, CMOS Integrated Circuits are preferred over conventional FET Integrated Circuits. A Complementary Metal Oxide Semiconductor (CMOS) IC consists of an N-MOS and P-MOS devices fabricated together on the same chip. It consists of a Polysilicon gate structure which helps to reduce the threshold voltage of the device, thus enabling operation at low voltage levels.

#### Fabrication of CMOS IC consists of 4 basic steps as given below

a. **N-well Process**: It involves fabrication of a PMOS transistor in an N-type well or tub, which is diffused in the P-type substrate. A layer of Silicon Dioxide under a Polysilicon gate provides the required isolation between transistors.

b. **P-well Process**: Difference between N-well and P-well process is that the latter is used to fabricate PMOS transistors.

c. **Twin Hub Process**: Involves fabrication of both NMOS and PMOS transistors.

d. **Silicon on Insulator Technology:** A trending technology in the fabrication of CMOS ICs is the SOI technology which involves the epitaxial growing of Silicon over an insulator layer. The transistors are then grown over the top of this layer.

### Hybrid Integrated Circuit

A Hybrid Integrated Circuit contains separate individual components attached on a Ceramic substrate. These components are interconnected using either metallization pattern or bonding wires. The active and passive components are diffused on the chip. Since the passive components can be trimmed to precision at higher values, the Hybrid ICs improve the circuit performance. This technology is used mostly for small quantity customized circuits.

#### Classification of Hybrid Integrated Circuits

Based upon the method used to form the passive components and the related interconnections on the substrate, Hybrid Integrated Circuits (ICs) can be categorized into two types – Thick Film and Thin Film ICs.

Thin Film ICs have film thickness varying from 50 to 20000 Armstrong units. The thin films are deposited using any of the technologies like vacuum evaporation, plating technique, sputtering and screening.

These ICs have high-frequency packaging density and high component packaging density. Using this technology, resistors can be trimmed to precision values. This feature makes the Thin film ICs suitable for ladder type Digital to Analog Converters.

Thick Film ICs have film thickness varying between 125000 to 625000 Armstrong units. This technology produces high-density circuits containing passive components at low cost. Techniques like screen printing and substrate firing are used for thick film deposition. These ICs are used in applications like automobile electronic circuits, digital watches, electronic toys, etc, where high frequency and size are important.

#### Advantages

a. They are smaller in size and hence portable.

b. They are less vulnerable to variations in physical parameters.

c. Due to the absence of parasitic capacitance, operating speed is high.

d. Low power consumption and hence they can be operated using batteries.

e. The absence of soldered joints makes the ICs more reliable.

f. Simpler design and standard packaging.

#### Disadvantages

The small size of the ICs results in poor dissipation of power. This, in turn, would destroy the IC due to the production of a large amount of heat owing to an increase in current.

## Widely Used Integrated Circuits

### Logic Gate IC

Logic Gates are combinational circuits which provide a logical output based on different input signals. It can have 2 to 3 inputs, but only 1 output.

Common examples are the Transistor-Transistor Logic (TTL) 7400 series ICs and the 4000 series CMOS ICs. IC 7408, a quad 2 input AND gate, available in Plastic Dual in Line Package, is a TTL Integrated Circuit.

### Timer ICs

A Timer IC is a monolithic IC, which produces accurate timing cycles with 100 percent or 50 percent duty cycle. The first Timer IC was developed by Signetic Corporation in 1970. Widely used Timer IC is the 555 Timer IC, which can be used in an 8-pin or 14 pin configurations. It can be used as a pulse generator or an Oscillator.

### Operational Amplifiers

An OpAmp or an Operational Amplifier is a high gain voltage amplifier with a differential input and a single ended output. It consists of an inverting and a non-inverting input.

### Voltage Regulator ICs

A voltage regulator IC provides a constant DC output irrespective of the changes in DC input. Commonly used regulators are uA723, LM309, LM105, and 78XX series Integrated Circuits.