CHAPTER 4

DIGITAL LOGIC FAMILIES

4.1 INTRODUCTION

The switching characteristics of semiconductor devices have been discussed in Chapter 3. Basically, there are two types of semiconductor devices: bipolar and unipolar. Based on these devices, digital integrated circuits have been made which are commercially available. Various digital functions are being fabricated in a variety of forms using bipolar and unipolar technologies. A group of compatible ICs with the same logic levels and supply voltages for performing various logic functions have been fabricated using a specific circuit configuration which is referred to as a *logic family*.

4.1.1 Bipolar Logic Families

The main elements of a bipolar IC are resistors, diodes (which are also capacitors) and transistors. Basically, there are two types of operations in bipolar ICs:

1. Saturated, and
2. Non-saturated.

In saturated logic, the transistors in the IC are driven to saturation, whereas in the case of non-saturated logic, the transistors are not driven into saturation.

The saturated bipolar logic families are:

1. Resistor–transistor logic (RTL),
2. Direct–coupled transistor logic (DCTL),
3. Integrated–injection logic (I^2L),
4. Diode–transistor logic (DTL),
5. High–threshold logic (HTL), and
6. Transistor–transistor logic (TTL).

The non-saturated bipolar logic families are:

1. Schottky TTL, and
2. Emitter-coupled logic (ECL).

4.1.2 Unipolar Logic Families

MOS devices are unipolar devices and only MOSFETs are employed in MOS logic circuits.

The MOS logic families are:

1. PMOS
2. NMOS, and
3. CMOS (5-V and low-voltage CMOS)

While in PMOS only *p*-channel MOSFETs are used and in NMOS only *n*-channel MOSFETs are used in complementary MOS (CMOS), both *p*- and *n*-channel MOSFETs are employed and are fabricated on the same silicon chip.

4.1.3 BiCMOS Logic Family

BiCMOS logic circuits use CMOS devices for input and logic operations and bipolar devices for output.

4.2 CHARACTERISTICS OF DIGITAL ICs

With the widespread use of ICs in digital systems and with the development of various technologies for the fabrication of ICs, it has become necessary to be familiar with the characteristics of IC logic families and their relative advantages and disadvantages. Digital ICs are classified either according to the complexity of the circuit, as the relative number of individual basic gates (2-input NAND gates) it would require to build the circuit to accomplish the same logic function or the number of components fabricated on the chip. The classification of digital ICs is given in Table 4.1.

Table 4.1 *Classification of Digital ICs*

IC Classification	Equivalent individual basic gates	Number of components
Small-scale integration (SSI)	Less than 12	Up to 99
Medium-scale integration (MSI)	12–99	100–999
Large-scale integration (LSI)	100–999	1,000–9,999
Very large-scale integration (VLSI)	Above 1,000	Above 10,000

The various characteristics of digital ICs used to compare their performances are:

1. Speed of operation,
2. Power dissipation,
3. Figure of merit,
4. Fan-out,
5. Current and voltage parameters,
6. Noise immunity,
7. Operating temperature range,
8. Power supply requirements, and
9. Flexibilities available.

4.2.1 Speed of Operation

The speed of a digital circuit is specified in terms of the propagation delay time. The input and output waveforms of a logic gate are shown in Fig. 4.1. The delay times are measured between the 50 per cent voltage levels of input and output waveforms. There are two delay times: t_{pHL}, when the output goes from the HIGH state to the LOW state and t_{pLH}, 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.

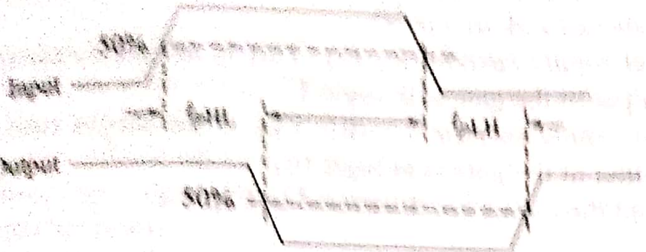

Fig. 4.1 *Input and Output Voltage Waveforms to Define Propagation Delay Times*

4.2.2 Power Dissipation

This is the amount of power dissipated in an IC. It is determined by the current, I_{CC}, that it draws from the V_{CC} supply, and is given by $V_{CC} \times I_{CC}$. I_{CC} is the average value of $I_{CC}(0)$ and $I_{CC}(1)$. This power is specified in milliwatts It is known as static power dissipation, i.e., the power consumed by the circuit when input signals are not changing.

4.2.3 Figure of Merit

The figure of merit of a digital IC is defined as the product of speed and power. The speed is specified in terms of propagation delay time expressed in nanoseconds.

$$\text{Figure of merit} = \text{propagation delay time } (ns) \times \text{power (mW)}$$

It is specified in pico joules ($ns \times mW = pJ$)

A low value of speed-power product is desirable. In a digital circuit, if it is desired to have high speed, i.e. low propagation delay, then there is a corresponding increase in the power dissipation and vice-versa.

4.2.4 Fan-Out

This is the number of similar gates which can be driven by a gate. High fan-out is advantageous because it reduces the need for additional drivers to drive more gates.

4.2.5 Current and Voltage Parameters

The following currents and voltages are specified which are very useful in the design of digital systems.

High-level input voltage, V_{IH}: This is the minimum input voltage which is recognised by the gate as logic 1.

Low-level input voltage, V_{IL}: This is the maximum input voltage which is recognised by the gate as logic 0.

High-level output voltage, V_{OH}: This is the minimum voltage available at the output corresponding to logic 1.

Low-level output voltage, V_{OL}: This is the maximum voltage available at the output corresponding to logic 0.

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

Low-level input current, I_{IL}: This is the minimum current which must be supplied by a driving stage corresponding to 0 level voltage.

High level output current, I_{OH}: This is the maximum current which the gate can sink in 1 level.

Low level output current, I_{OL}: This is the maximum current which the gate can sink in 0 level.

High level supply current, I_{CC} (1): This is the supply current when the output of the gate is at logic 1.

Low level supply current, I_{CC} (0): This is the supply current when the output of the gate is at logic (0).

The current directions are illustrated in Fig. 4.2.

Fig. 4.2 A Gate With Current Directions Marked

4.2.6 Noise Immunity

The input and output voltage levels defined above are shown in Fig. 4.3. Stray electric and magnetic fields may induce unwanted voltages, known as *noise*, on the connecting wires between logic circuits. This may cause the voltage at the input to a logic circuit to drop below V_{IH} or rise above V_{IL} and may produce undesired operation. The circuit's ability to tolerate noise signals is referred to as the *noise immunity*, a quantitative measure of which is called *noise margin*. Noise margins are illustrated in Fig. 4.3.

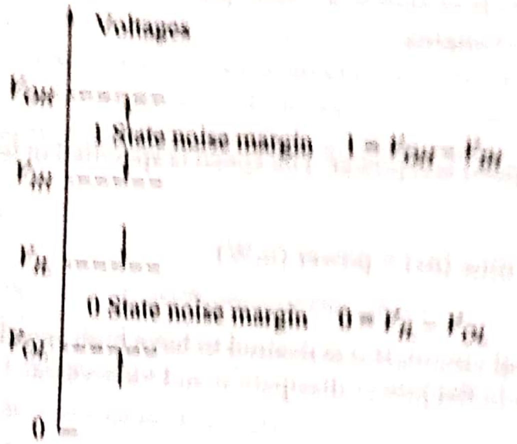

Fig. 4.3 *Voltage Levels and Noise Margins of IC's*

The noise margins defined above are referred to as *dc noise margins*. Strictly speaking, the noise is generally thought of as an a.c. signal with amplitude and pulse width. For high speed IC's, a pulse width of a few microseconds is extremely long in comparison to the propagation delay time of the circuit and therefore, may be treated as d.c. as far as the response of the logic circuit is concerned. As the noise pulse width decreases and approaches the propagation delay time of the circuit, the pulse duration is too short for the circuit to respond. Under this condition, a large pulse amplitude would be required to produce a change in the circuit output. This means that a logic circuit can effectively tolerate a large noise amplitude if the noise is of a very short duration. This is referred to as *ac noise margin* and is substantially greater than the dc noise margin. It is generally supplied by the manufacturers in the form of a curve between noise margin and noise pulse width.

4.2.7 Operating Temperature

The temperature range in which an IC functions properly must be known. The accepted temperature ranges are: 0 to + 70 °C for consumer and industrial applications and −55 °C to +125 °C for military purposes.

4.2.8 Power Supply Requirements

The supply voltage(s) and the amount of power required by an IC are important characteristics [to] choose the proper power supply.