17

Integrated Circuits

TOPICS DISCUSSED

- Concept of integrated circuits
- Process of manufacturing of ICs
- Advantages of ICs
- Operational amplifiers
- Applications of op-amps
- Timer IC
- Applications of IC 555
- Voltage regulator ICs
- Digital ICs

17.1 INTRODUCTION

Electronic components and circuits have undergone tremendous changes in terms of reduction of their size i.e., miniaturization, reduction of cost, improvement of reliability, reduction in power consumption, ease of replacement, etc. Going by history, the initial effort was to reduce the size of discrete components. This was followed by the development of printed circuit boards (PCBs) which troduction of integrated circuits called ICs. An integrated circuit is a combination of components like resistors, capacitors, diodes, transistors, etc. and their interconnections, fabricated into an extremely tiny single chip of silicon. A chip is an extremely small part of silicon wafer on which an IC is fabricated or grown. Fig. 17.1 shows a silicon wafer of thickness less than 1mm. The wafer contains a large number of square areas usually less than 1cm^2. A large number of circuit components along with their interconnections are accommodated in a single chip.

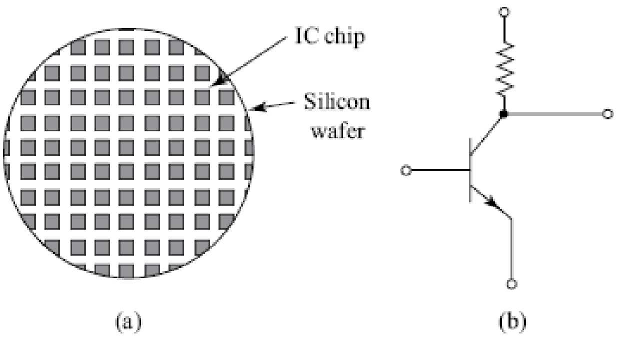


Figure 17.1 (a) A silicon wafer having a large number of square-shaped chips made on it;
(b) a sample of circuits to be constructed on a single chip

A silicon wafer will contain a large number of square-shaped chips and each chip will accommodate a large number of circuits. For example, one chip of size 4 mm^2 may contain 40 transistors, 35 resistors, a number of capacitors, and other such components along with their interconnections.

An IC is, therefore, a complete electronic circuit in miniature form grown into a single chip of silicon. An electronic circuit generally contains a number of active and passive components. Active components are those which are capable of producing gains like transistors, FETs, MOSFETs, etc. Passive components are resistors, inductors, capacitors, etc.

ICs have by and large replaced discrete circuit design using individual components. ICs can be used to perform specific functions and they can be replaced as a whole in case any defect occurs in the functioning of the IC.

From the fabrication point of view ICs are classified into monolithic circuits or hybrid circuits, which uses a combination of different processes.

A monolithic circuit is a complete circuit having active and passive circuit components and their interconnections made on a single chip (the word monolithic is derived from a Greek word mono = single, lithic = stone or piece). Integrated circuit technology has developed small scale integration to very large scale integration. Small

The fabrication of ICs involves a very special and sophisticated technology. Here we will briefly mention only the steps involved. The steps are as follows:

1. *Wafer preparation:* Wafer is a very thin surface of p-type silicon which provides the base or substrate on which the circuit elements are grown or developed. Wafers are made by slicing a p-type round silicon material of certain diameter. These wafers are polished to a mirror finish surface.
2. *Epitaxial growth:* On the p-type substrate an n-type layer is grown by placing the wafer in a furnace in an atmosphere of phosphorous gas at 1200°C. Thus, an epitaxial layer of n-type material is formed on the p-type wafer.
3. *Diffused isolation:* A thin layer of silicon dioxide is formed on the n-type layer by oxidation method, i.e., by oxidizing the wafer in dry oxygen. Next, a thin coating of a chemical, called photoresist is made on the SiO_2 layer.

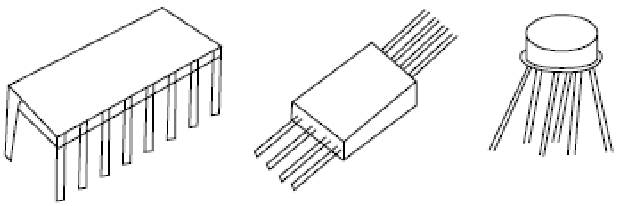


Figure 17.2 IC packages of various types

Following these, use is made of a mask, ultraviolet exposure, etching, scrubbing and diffusion. Thus, the monolithic process of IC fabrication involves wafer preparation, epitaxial growth, diffused isolation, base and emitter diffusion, etching, metallization (making of contacts and interconnections), checking of circuitry, separating the wafer into individual chips, mounting, packaging, sealing, and testing. Fig. 17.2 shows some of the IC packages available. Integrated circuit components like resistors, capacitors, diodes, transistors, etc. are made from the monolithic structure. For example, resistors are made using the resistivity of the diffused areas, diodes are made utilizing the p–n junctions available in the diffused structure, both n–p–n and p–n–p transistors are produced on the substrate by the diffusion process.

17.3 HYBRID INTEGRATED CIRCUITS

Hybrid or multichip integrated circuits are made by interconnecting a number of monolithic ICs. Hybrid ICs are also made by using a combination of monolithic technique and their filming technique. Here, the active components of the desired circuit is first made using the monolithic technique which has a layer of SiO_2 as its cover. Thin film technique is then employed to form the passive components on the SiO_2 surface. Connections are then made from the film to the monolithic structure.

modulators, voltage regulators, etc. In linear ICs the electrical signals are analogous to the physical quantities, and hence they are often referred to as analog circuits.

The major application of ICs is in the field of computers and logic circuits. Digital circuits are concerned with two levels of voltage, i.e., high or low which in turn can make a switch closed or open. The two states are referred to as 1 and 0. A closed switch is referred to as a binary 1, and an open switch or the absence of a signal is referred to as a binary 0.

Most commonly used linear IC is found in operational amplifiers (op-amps). With some suitable external components like resistors and capacitors, op-amps are used in amplifiers as integrators and differentiators, in filters and other such applications. A general purpose op-amp is numbered IC 741.

Digital ICs find applications in switching circuits, flip-flops, counters, registers, microprocessors, clock chips, calculator chips, memory chips, multivibrators, etc.

Advantages of IC technology over discrete circuits

Integrated circuit technology has brought in a number of advantages over the fabrication of electronic circuits using individual circuit components, i.e., discrete circuits. The advantages are highlighted as follows:

1. Miniaturization of circuits, batch production, i.e., a large number of identical circuits can be produced together.
2. Reduction of cost of production.
3. Smaller size and less weight, suitable for space applications like in aircraft, space vehicles, etc.
4. Maintenance is easy, the whole of the IC is replaced in case of any fault. There is no need for repair of components.
5. Less likely to be faulty. Since ICs are manufactured in monolithic structure, there is very little scope for the circuit to go faulty except for misuse.
6. Performance of ICs are better than discrete circuits in high-frequency applications.

Digital ICs are also classified according to the number of components or gates placed on one chip.

Large-scale integration (LSI) will have more than 100 components and very large scale integration (VLSI) will have more than 1000 components in a single chip.

Integrated circuits are manufactured by various manufactures like Fairchild, Motorola, Texas instruments, National semiconductor, Signetics, etc. They put their brand name along with a particular number on each type of ICs they produce. For example, operational amplifier, manufactured by various manufacturers name them as

Motorola	MCI 741
National Semiconductor	LM 741

The last three digits in each case is 741. Irrespective of who manufactures an op-amp, the specification for an IC 741 is the same. We shall discuss in brief IC 741 which is an op-amp, IC555 which is a timer, and IC78XX series which are voltage regulators.

17.5 OPERATIONAL AMPLIFIERS

An operational amplifier is abbreviated as op-amp. An op-amp is the best-known linear integrated circuit. Originally op-amps were meant for performing operations like integration, subtraction, differentiation, etc., and hence the name was given.

Such operations are useful in analog computers. However, op-amps can also be used in signal amplification, filters, oscillators, voltage regulators, analog to digital (A to D) and digital to analog (D to A) converters, etc. Manufacturers provide a number of informations of the IC they supply including their pin diagrams. The informations provided include intended applications, maximum ratings, electrical characteristics, performance limitations, equivalent circuit, etc. Maximum ratings may include supply voltage, internal power dissipation, temperature range, etc. The pin diagrams of an IC 741 in eight-pin metal can package and eight-pin mini dip package are shown in Fig. 17.3.

An op-amp is a high-gain directly coupled linear differential amplifier. The performance of an op-amp is controlled by negative feedback from the output to the input. It is called a differential amplifier since it amplifies the difference between the two input signals. An op-amp amplifies both ac and dc input signals.

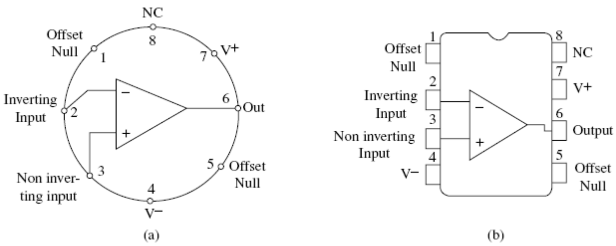


Figure 17.3 Pin diagrams of IC op-amp 741. (a) 8-pin mini dip packaging;
(b) 8-pin metal can packaging

The circuit symbol of an op-amp has been shown in Fig. 17.4. The input terminals are marked a and b. Terminal a is marked negative while terminal b is marked positive. Terminal a is the inverting terminal. The input provided at this terminal appears inverted at the output with amplification. Terminal b is non-inverting. The output for input at b appears non-inverted but amplified. When signals are provided at both a and b terminals, the output at terminal c is proportional to the difference of the two signals.

The internal circuit is quite elaborate. But the user of an op-amp

The power supply voltages which are usually balanced with respect to the ground are applied to terminals 7 and 4, i.e., to terminal d and e as in Fig. 17.4 Terminals d and e are often not shown in the circuit diagrams using op-amps.

An ideal op-amp has the following characteristics:

1. Infinite input impedance
2. Zero output impedance
3. Infinite voltage gain
4. Infinite bandwidth
5. Perfect balance (i.e., output is zero when both the inputs are equal)

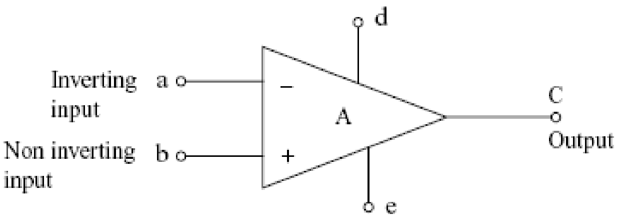


Figure 17.4 Symbolic representation of a basic op-amp

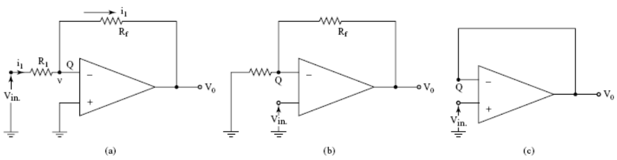


Figure 17.5 Op-amp with negative feedback working as (a) inverting amplifier; (b) non-inverting amplifier; (c) voltage follower

A practical op-amp will have finite but very high input impedance, very high voltage gain, finite bandwidth and low output impedance. A practical op-amp may not have perfect balance. The output is fed back to the inverting input terminal to provide negative feedback for the op-amp. Fig. 17.5 shows an op-amp with negative feedback. i.e., the output is connected back to the –ve input terminal. Input is connected to the inverting or non-inverting terminals and the output obtained in each case has been shown. For simplicity, analysis of the circuit and derivation of formula have been avoided. Some op-amp applications are explained as follows.

17.6 OP-AMP APPLICATIONS

In all the cases shown in Fig. 17.5, the output has been fed back to the inverting input terminal so as to provide a negative feedback. As shown in Fig. 17.5 (a), the output terminal is connected to the inverting input terminal through a feedback resistance R_f. The non-inverting terminal has been connected to the ground. The input voltage is

$$i_1 = \frac{V_{in} - \upsilon}{R_1}$$

As the input impedance of the op-amp is infinite, the whole of i_1 will pass through R_f. The op-amp having infinite input impedance will not allow any current to flow through it.

Therefore,

$$i_1 = \frac{V_{in} - \upsilon}{R_1} = \frac{\upsilon - V_0}{R_f} \qquad \text{(i)}$$

As the open-loop gain, A of the amplifier is infinite, and the output voltage, V_0 is finite, we have

$V_0 = A\upsilon$ or, $A\upsilon = V_0/A$

If A tends to infinity,

v will tend to zero.

Thus, the potential of point Q can be considered equal to zero. This is also referred to as a virtual ground potential. With v = 0, from equation (i),

$$\frac{V_{in}}{R_1} = \frac{-V_0}{R_f}$$

or,

$$V_0 = -\left(\frac{R_f}{R_1}\right)V_{in} \qquad \text{(ii)}$$

The negative sign indicates that the output voltage is inverted. The closed loop voltage gain is $\frac{R_f}{R_1}$. Thus, the input voltage appears at the output terminal multiplied by a $\frac{R_f}{R_1}$. and gets inverted.

Fig. 17.5 (b) shows a non-inverting amplifier. The output voltage, V_0 can be calculated as

$$V_0 = \left(1 + \frac{R_f}{R_1}\right)V_{in} \qquad \text{(iii)}$$

The output is positive, i.e., non-inverted and is multiplied by a factor, $\left(1+\frac{R_f}{R_1}\right)$.

In Fig. 17.5 (c), R_f has been made zero, i.e., output terminal is directly connected to point Q so that using equation (iii), we can write

$V_0 = (1+0)V_{in} = V_{in}$

This circuit is called a unity gain voltage follower. Such a circuit is used for impedance matching in electronic devices and circuits.

17.6.1 Op-amp As a Summing Amplifier

Op-amps can be used for adding and subtracting two input signals. They can also be used as differentiators and integrators. Analog computers use extensive op-amp circuits for these functions. These are discussed in brief as follows.

Fig. 17.6 shows an adder, i.e., a summing amplifier and a subtractor, i.e., a differential amplifier circuit.

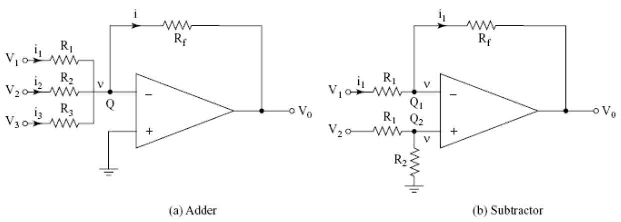


Figure 17.6 (a) Op-amp used as an adder or summer; (b) op-amp used as a differential amplifier

Assuming point Q at potential υ, and assuming no current flowing through the amplifier

$i_1 + i_2 + i_3 = i$

$$\frac{V_1-\upsilon}{R_1}+\frac{V_2-\upsilon}{R_2}+\frac{V_3-\upsilon}{R_3}=\frac{\upsilon-V_0}{R_f}$$

and $$V_0 = A\upsilon$$

or, $$\upsilon = \frac{V_0}{A}$$

If A → a, v → 0 (virtual ground)

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = -\frac{V_0}{R_f}$$

If

$R_1 = R_2 = R_3$,

$$V_0 = -\frac{R_f}{R}(V_1 + V_2 + V_3)$$

Now if we make

$R_f = R$,

Then,

$V_0 = -(V_1 + V_2 + V_3)$

The output voltage, V_0 is equal to the algebraic sum of the input voltages. By choosing a suitable ratio of R_f/R, the output voltage can be made equal to the sum of the desired ratio of the input voltages. The circuit is called a summing amplifier circuit.

17.6.2 Op-amp As a Differential Amplifier (Subtractor)

Fig. 17.6 (b) shows a differential amplifier, or a difference amplifier, or simply a subtractor. Here, the difference between two voltages, viz V_2 and V_1 can be amplified using this circuit. Again, assume that the amplifier has infinite gain and infinite input impedance, point Q_1 and Q_2 at virtual ground, i.e., zero potential. Amplifier allows no current flow through it. Looking at the inverting input terminal and feedback path

$$i_1 = \frac{V_1 - \upsilon}{R_1} = \frac{\upsilon - V_0}{R_2} \qquad \text{(iv)}$$

From the non-inverting input terminal

$$\frac{V_2 - \upsilon}{R_1} = \frac{\upsilon}{R_2} \qquad \text{(v)}$$

$$\frac{(V_2 - V_1)}{R_1} = \frac{V_0}{R_2}$$

or,
$$V_0 = \frac{R_2}{R_1}(V_2 - V_1)$$

Thus, the output voltage, V_0 is the difference of the two input voltages and is multiplied by a factor R_2/R_1.

Now we will consider the use of an op-amp as a differentiator and as an integrator.

17.6.3 Op-amp As a Derivative Amplifier

In a differentiator, the output voltage is proportioned to the derivative of the input voltage with respect to time. As in previous cases, the point Q is assumed to be at zero potential. Virtually no current flows through the amplifier as it has infinite input impedance and infinite gain. The charge on the capacitor, q is equal to

$q = CV_1$

$$\int i\,dt = CV_1$$

or,
$$i = C\frac{dV_1}{dt} \quad \text{(vi)}$$

Again

$$\frac{\upsilon - V_0}{R} = i$$

Assuming v = 0,

$$i = -\frac{V_0}{R} \quad \text{(vii)}$$

using equations (vi) and (vii),

$$-\frac{V_0}{R} = C\frac{dV_1}{dt}$$

or,
$$V_0 = (-CR)\frac{dV_1}{dt}$$

Thus, the output voltage, V_0 is the derivative of the input voltage V_1 and the multiplying factor is (– CR).

17.6.4 Op-amp As an Integrator

In an integrator, the output voltage is proportional to the integration of the input voltage with respect to time and $$\upsilon - V_0 = \frac{Q}{C}$$

Again $V_0 = A\upsilon$

or, $$\upsilon = \frac{V_0}{A}$$

If $A \to \alpha$, $v \to 0$.

The point Q of which potential is v tends to zero.

Assuming $\upsilon = 0$

$$\frac{V_1}{R} = i$$

and $$-V_0 = \frac{q}{C} = \frac{\int idt}{C}$$

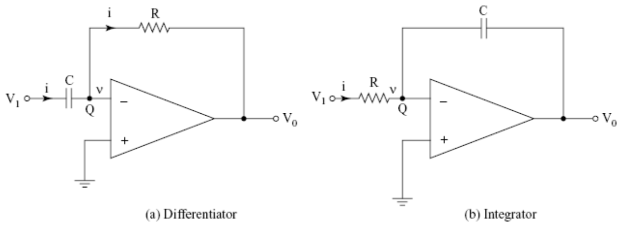


Figure 17.7 (a) Op-amp used as a differentiator; (b) op-amp used as an integrator

or, $$V_0 = -\frac{\int idt}{C} = \int \frac{V_1\, dt}{CR}$$

or, $$V_0 = \left(-\frac{1}{CR}\right) \int V_1\, dt$$

The output voltage V_0 is an integral of input voltage V_1 multiplied by proportionality constant $\left(-\frac{1}{CR}\right)$. This circuit is therefore called an integrator.

17.6.5 Other Applications of Op-amps

There are many applications of op-amps in the field of electronics. Some of them are mentioned below.

3. Analog computer which is constructed by using op-amp integrators and adders to solve differential equations.
4. Waveform generators or function generators. Function generators are also incorporated in analog computers to solve non linear differential equations.
5. Oscillators and filters. The oscillators are used to generate repetitive alternating current and voltage waveforms of fixed amplitude and frequency. Filters pass a specified band of frequencies and block signals of frequencies outside this band. Active filters use transistors and op-amps while passive filters use resistors, inductors and capacitors.

17.7 THE 555 TIMER INTEGRATED CIRCUIT

The 555 timer is a very popular timer IC widely used in the field of electronics and control engineering. Signetics Corporation of USA first developed this chip in the 1970s. Nowadays this IC is being manufactured by many semiconductor companies. However, regardless of the manufacturer, all the IC 555 chips provide the same basic functions and are packaged the same way.

The 555 timer contains 23 transistors, 2 diodes, and 16 resistors on a single silicon chip.

17.7.1 Three Operating Modes of IC 555

This timer has three operating modes:

1. *Monostable mode:* in this mode the timer functions as a 'one shot' multivibrator. A multivibrator generates nonsinusoidal waveforms. It is an oscillator operating in two modes or states. At stable state the output is low. When a trigger pulse is applied, the output becomes high but automatically returns to stable state (i.e., low output) after a time interval determined by externally connected RC network. In a monostable multivibrator a trigger input will cause the timer to get switched on for a time determined by the external components, R and C connected to it. A monostable circuit has only one stable state and one quasi-stable state. A triggering signal is required to induce a transition from stable to quasi-stable state The circuit will remain in quasi-stable state for some time. However, eventually it will return to its stable state with no external signal required to change that state. Since, the circuit is *stable in one state* it is called monostable. The stable state will mean low or no output voltage and quasi-stable state will mean high output voltage (also called cut-off state and saturation state).
2. *Astable mode:* the astable mode of operation has two states, both of which are quasi-stable. The astable mode of operation will, therefore, make successive transitions from one quasi-stable state to other without the aid of an external triggering signal. An astable multivibrator will alternate automatically and continuously between two states at a rate determined by the circuit components.
3. *Bistable mode:* this is also referred to as Schmitt trigger. The 555 IC can operate as a flip-flop. A flip-flop multivibrator operates in two states but requires an external trigger pulse to change from one state of operation to the other.

Monostable multivibrator generates a single cycle, and hence can be

17.7.2 Pin Configuration of IC 555

The 555 timer is an extensively used IC. The 8-pin diagram of a mini dual-in-line package (DIP-8) has been shown in Fig. 17.8. The IC 556 is a 14-pin DIP that combines two 555s in a single chip.

The functions of each pin of IC 555 are mentioned below:

Pin 1 ground: this is the ground pin connected to 0 V rail. This is also called negative, or 0 V or earth rail. All the voltages are measured with respect to this terminal.

Pin 2 trigger: This pin connects to a comparator and is used to set the control flip-flop. When it is taken low, it causes the output to go high. Triggering is accomplished by taking the pin below a certain voltage, called low.

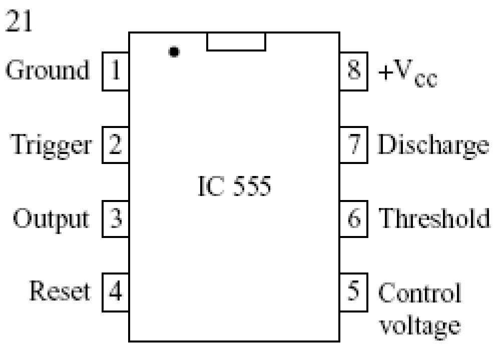


Figure 17.8 Pin diagram of an IC 555 timer

Pin 3 output: Output is taken from pin 3. The load can be connected between pin 3 and pin 1 or between pin 3 and pin 8. To make the output high, the trigger pin is momentarily taken from high to low. The output can be turned to a low by making the threshold pin (pin 6) go from a low to a high. The output can also be made to go low by taking the reset pin (pin 4) to a low state.

Pin 4 reset: The reset pin has an over riding function. It will force the output pin to go low regardless of the state of the trigger pin (pin 2). It can be used to terminate an output pulse prematurely when not in use. It is recommended that the reset pin be tied to the positive rail, i.e., to $+V_{CC}$ to avoid the possibility of false resetting.

Pin 5 control voltage: By applying a voltage to this pin, it is possible to vary the timing of the timer chip independent of the RC network. The control voltage may be varied from 45 to 90 per cent of the V_{CC} in the monostable mode to control the width of the output pulse. When in astable mode, the control voltage can be varied from 1.7 V to the full V_{CC}. Frequency-modulated output is produced by varying the control voltage. When not in use the control voltage pin should be connected to ground with a 10 nano farad capacitor so as to avoid a reference voltage of $+2/3V_{CC}$. To make the output to go low, the threshold pin is taken from a low to a level above $2/3V_{CC}$.

Pin 7 discharge: This pin is connected to the open collector of an n–p–n transistor inside the chip. A capacitor is connected between pin 7 and ground which gets discharged when the transistor is turned on. That is to say, when the transistor is turned on, pin 7 is effectively shorted.

Pin 8 supply terminal: This pin is the positive supply terminal for the 555, also referred to as $+V_{CC}$. The supply voltage operating range is from +5V to +18V.

17.7.3 Functional Block Diagram of IC 555

Fig. 17.9 shows the functional block diagram of 555 timer IC. The timer consists of two comparators (these are op-amps), an R–S flip-flop, two transistors and three equal-value (5 kΩ) resistors in series forming a voltage divider. Because of the use of three 5 kΩ resistors, the timer was given the name 555.

The three resistors of equal value i.e., R divides the V_{CC} into $\frac{1}{3}V_{cc}$.

The voltage across the inverting terminal of the comparator 1 is $+\frac{2}{3}V_{CC}$. Voltage across the non-inverting terminal of the comparator 2 is $+\frac{1}{3}V_{CC}$. The comparator 1 compares the threshold voltage with reference voltage $+\frac{2}{3}V_{CC}$. Comparator 2 compares the trigger voltage with reference voltage $+\frac{1}{3}V_{CC}$.

Thus, the reference voltage of the comparators are one-third and two-third of the supply voltage which may be between + 5 V and + 18 V. The output of both the comparators are supplied to the RS flip-flop. The flip-flop changes its state in accordance with the output of the comparators. The flip-flop changes states when the trigger input at pin 2 is brought down below $+\frac{1}{3}V_{CC}$. When this occurs the output (at pin 3) changes state to $+V_{CC}$. However, if the threshold input (at pin 6) is now raised above $+\frac{2}{3}V_{CC}$, the output will return to ground. The n–p–n transistor, T_1 is the discharge transistor. Pin 7, i.e., the discharge pin is connected to the collector of this transistor. The emitter is connected to the ground. When this tranduce a single pulse when triggered or can produce a continuous pulse train as long as it remains powered.

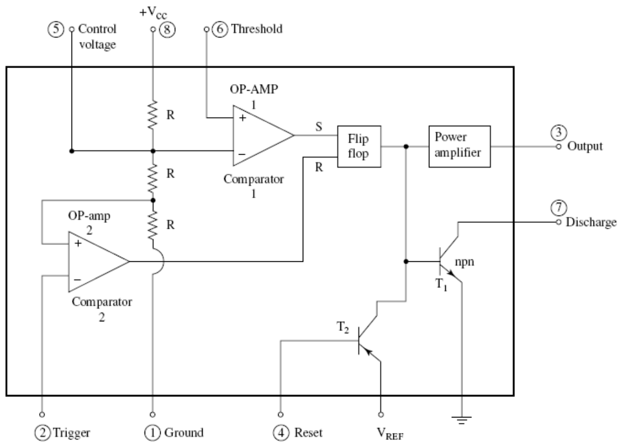


Figure 17.9 Block diagram representation of an IC 555 timer

Fig. 17.10 shows the functional block diagram of the 555 timer again. Comp A and Comp B are the two voltage comparators. In the voltage comparator a reference voltage is connected to the V_{in}-(inverting input). When the signal voltage at V_{in+} rises above the reference, or goes below the reference voltage, the output voltage goes high or low. Three 5 kΩ resistors provide the reference voltages for the voltage comparators at $\frac{2}{3}V_{CC}$ for comparator A and $\frac{1}{3}V_{CC}$ for comparator B. When the threshold input at terminal 6 is above $\frac{1}{3}V_{CC}$, the flip-flop is reset, and when the trigger input is $\frac{2}{3}V_{CC}$, the flip-flop is set. The output is taken from an interface circuit driven by the flip-flop.

17.7.4 Monostable Application of IC 555

In monostable application the external connection of the IC 555 has been shown in Fig. 17.11.

The timer circuit will operate as a mono-shot or single-shot multivibrator. When the trigger gets a negative pulse, the flip-flop is set, making high turning off the discharge transistor (see Fig. 17.10), which would then allow the discharge capacitor C (as in 15.12) to be charged up towards V_{CC}.

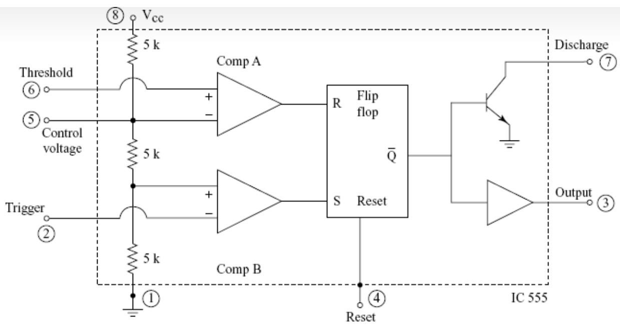


Figure 17.10 Functional block diagram of IC 555 timer (same diagram as in Fig. 17.9 redrawn)

When the capacitor voltage reaches ⅔V_{CC}, the threshold signal causes the flip-flop to be reset, discharging the capacitor again. The voltage waveforms of monostable operation have been shown in Fig. 17.11 (b).

It can be seen from the waveforms that the output remains low until the trigger signal is applied. With the application of negative trigger voltage, the output goes high while the capacitor gets charged and then goes back to low, and it remains low until another trigger pulse is received. The name single shot is appropriately given because multiple trigger shots during charging of the capacitor has no effect on the output. However, the trigger voltage must return to the high level again before the flip-flop can be reset by the threshold voltage signal. The time t of the output wave depends on the time taken by the capacitor to get charged up from a discharged state from near zero voltage to ⅔V_{CC}. The capacitor has been shown getting discharged instantaneously; however, the rate of discharge will depend upon the discharge transistor.

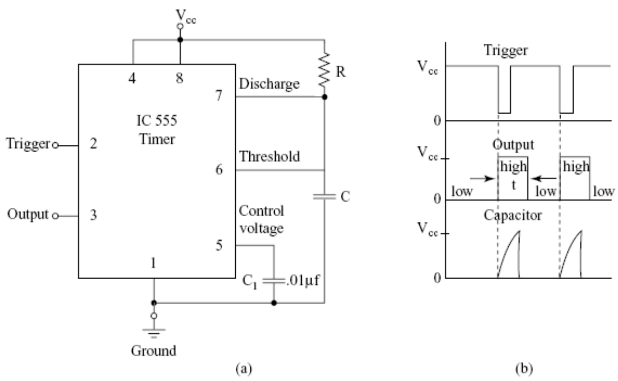


Figure 17.11 (a) IC 555 timer in monostable operating mode; (b) waveforms of voltages in monostable operation

17.7.5 Astable Application of IC 555

Here, both the trigger input and the threshold input are connected to the capacitor. An additional resistance R_1 has been connected between the capacitor and the discharge transistor to slow down the discharge of the capacitor. When the capacitor discharges to ⅓V_{CC}, the comparator B (i.e., the trigger comparator as shown in Fig. 17.10) sets the flip-flop which in turn switches the discharge transistor off, allowing the capacitor getting charged through the resistors R and R_1. When the capacitor voltage reaches ⅔V_{CC} the threshold input voltage resets the flip-flop, the discharge transistor is turned on and the capacitor starts discharging again. Between the voltage ⅔V_{CC} and ⅔V_{CC} the capacitor charges and discharges and we get an output voltage waveform as has been shown in Fig. 17.12 (b). It is to be noted that the charging time of the capacitor can be made more than the discharge time, and consequently the timer output will be high for a longer duration than its low value. The 0.01μF capacitor connected between terminal 5 and ground, acts to reduce the transient noise on the power supply. Thus, as we have seen, the operation of 555 timer IC is dependent upon the charging and discharging behaviour of the capacitor.

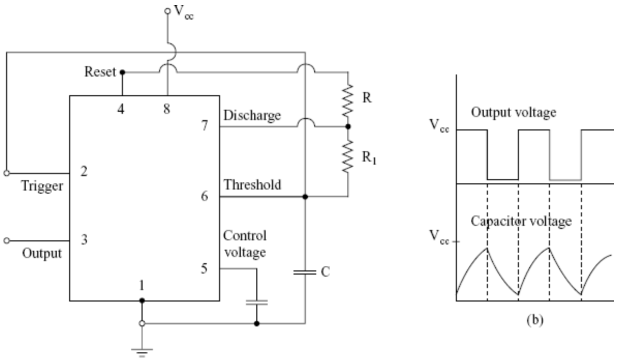


Figure 17.12 (a) IC 555 timer in astable operating mode; (b) voltage waveforms

17.7.6 An IC 555 Timer Astable Oscillator Circuit

A practical circuit of an IC 555 timer astable oscillator circuit has been shown in Fig. 17.13 drawn in a slightly different way. The students may try out this circuit for its working. We may choose R = R_1 = 10 kΩ, C = 10 μF, C_1 = 0.01μF, supply voltage to the IC, i.e., V_{CC} = +9 V, a red LED, a series resistance of 470 Ω. The LED red light has been used to indicate clearly that the circuit is working. A LED will require about 5 mA to 20 mA of current to emit light.

The current flowing through the LED circuit will be equal to the output voltage divided by the LED series resistance of 470 Ω. Assuming a voltage drop across the LED of 1.7 V, the current flowing through t

will be $\frac{9-1.7}{470} = 15\,\text{mA},$ which is sufficient for the LED to light up. The timer will drive a 'high' or

'low' output depending on the charging cycle of the series resistor

The trigger pin 2 and the threshold pin 6 are attached to the two comparators (op-amps) and are connected together to the external capacitor. When power is first supplied, i.e., V_{CC} is switched on, the capacitor is uncharged and the lower comparator sets the output voltage to high. This allows the capacitor to charge through R and R_1. When the charge of the capacitor reaches ⅔V_{CC}, the upper comparator is triggered, causing the output to go low. When the voltage across the capacitor is ⅔V_{CC}, the lower comparator is triggered, setting the output to high.

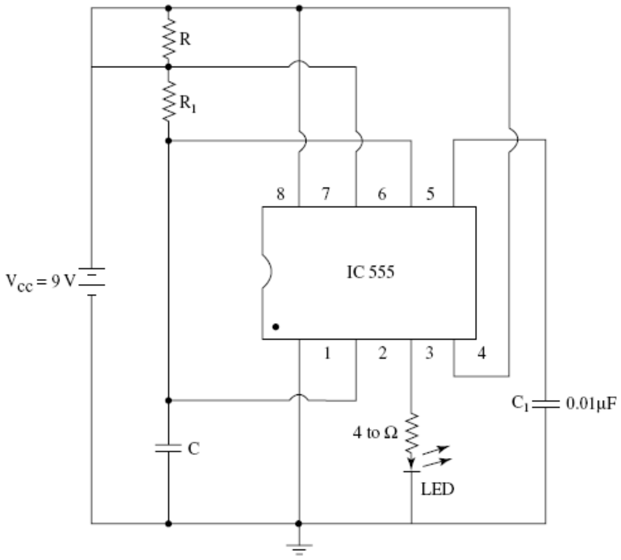


Figure 17.13 IC 555 timer is used as an astable oscillator

This type of oscillators find many applications like in quartz watch to keep track of time in AM radio to create a carrier wave for the station, in computers where a specialized oscillator called a clock serves as a sort of pacemaker for the microprocessor, in wireless receivers and transmitters, in cell phones, pagers, in music synthesizers etc.

17.8 IC VOLTAGE REGULATORS OR REGULATOR ICS

A voltage regulator converts a varying input voltage into a constant 'regulated' output voltage. Thus, a voltage regulator supplies a constant voltage at the output regardless of the magnitude of load current supplied. IC voltage regulators are relatively cheap as compared to regulators designed using op-amps. IC voltage regulators are available in a variety of output voltages. The LM 78 xx series of voltage regulators are designed for positive voltage input. Table 17.1 shows all the LM 78 xx regulators with their input and output voltage ranges. There are negative voltage regulators that are marked LM 79 xx.

These are fixed output voltage regulators. The other types of voltage regulators are adjustable output voltage regulators, switching

The fixed voltage regulators of LM 78 xx series which are also positive voltage regulators, are described in brief as follows. With proper heat sink, the LM 78 xx ICs can handle output current even somewhat more than 1000 mA. Linear voltage regulators are manufactured by companies like *Fair Child* and *ST Microelectronics.*

As mentioned, LM 78 xx series of voltage regulators are designed for positive voltage input. For negative voltage input LM 79 xx series is used. The last two digits in these numbers indicate the output voltage. For example, the LM 7805 regulator gives a regulated output voltage of +5 V and LM 7905 gives an output voltage of –5 V. These ICs, although internally complex are inexpensive and easy to use. In Fig. 17.14 (a) has been shown a three terminal voltage regulator IC.

Two capacitors $C_1$and C_2 are connected on the input and output sides. The output capacitor, C_2 helps in isolating the effect of transients that may appear on the regulated supply line. C_2 is a high-quality tantalum capacitor with capacitance of around 1.0 μF connected close to the regulator using short connecting leads in order to improve the stability of output. The capacitor C_1 is required when the regulator is located more than 5 cm away from the power supply filter. A 5 V regulated power supply using IC 7805 has been shown in Fig. 17.15.

Table 17.1 IC 78 xx Voltage Regulators

Device type	Output voltage	Input voltage range
LM 7805	5 V	7-25 V
LM 7806	6 V	8-25 V
LM 7808	8 V	10.5-25 V
LM 7809	9 V	11.5-25 V
LM7812	12 V	14.5-25 V
LM7815	15 V	17.5-25 V
LM7818	18 V	21-33 V
LM7824	24 V	27-38 V

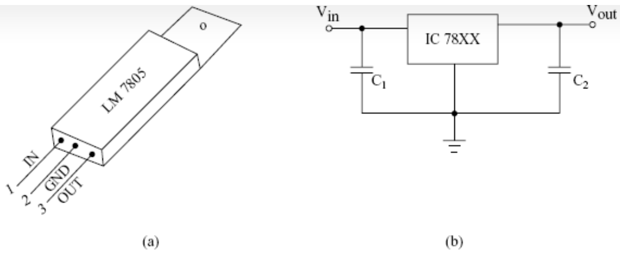


Figure 17.14 (a) The physical configuration of a regulator IC; (b) typical circuit connection

In Fig. 17.15 has been shown a 5 V dc voltage regulator using a step-down transformer, full-wave bridge rectifier, filter, and an IC 7805 regulator. A circuit for an adjustable regulator using 78 xx series of ICs will be as shown in Fig. 17.16.

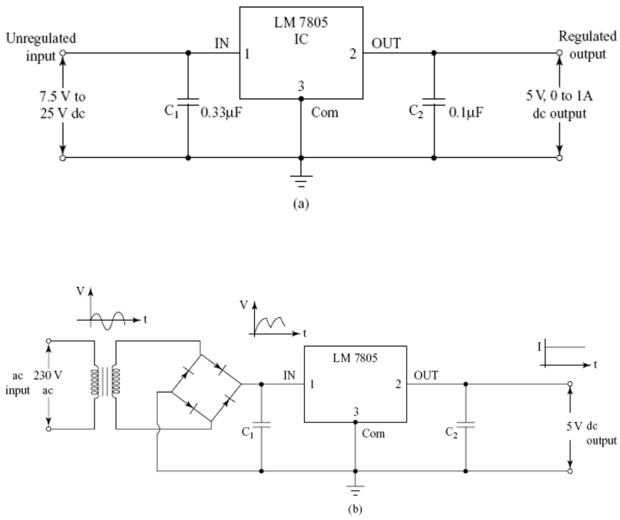
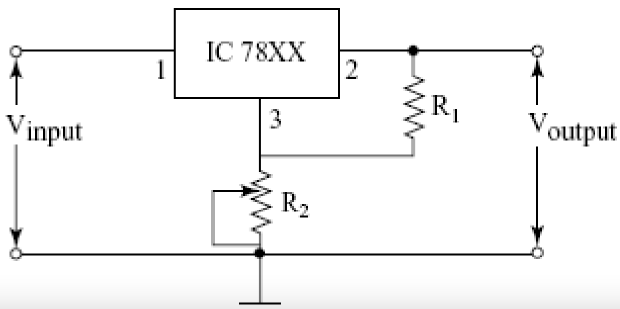


Figure 17.15 (a) Regulated power supply with dc input and dc output; (b) regulated 5 V dc. Power supply with 230 V, 50 Hz ac supply as input.



Adjustable output voltage can be obtained by using two resistances in the circuit as has been shown. We may use the input and output side capacitors in the circuit. Voltage regulators are available either in plastic package or in metal can package.

17.9 DIGITAL INTEGRATED CIRCUITS

Digital ICs are a collection of resistors, diodes, and transistors fabricated on a single piece of semiconductor material, usually silicon, and is referred to as chip. The fabricated resistors, diodes, and transistors reside in the chip and are called logic gates. Digital circuits are often made from large assemblies of logic gates. Each logic gate represents a function of Boolean algebra or Boolean logic (truth table).

The output of the logic gate is an electrical voltage that can control more logic gates. Integrated circuits are the least expensive way to make logic gates in large volumes. Integrated circuits are designed by engineers using *electronic design automation software*. The integrated chip is enclosed in a protective plastic package with connecting pins extended out for connecting the IC to other devices.

Digital circuit, digital system, digital logic are the terms often used interchangeably.

IC 74 xx series

The IC 74 xx is a transistor–transistor logic (TTL) integrated circuit. These were used in 1960s and 1970s to build mini computers and mainframe computers. In IC 74 xx, the xx varies from 00 to 99 and beyond. The 74xx series contains hundreds of devices that provide basic logic gates, flip-flops, counters, arithmetic logic units (ALU), etc. The 74 xx series originated with TTL-integrated circuits and were made by Texas Instruments of USA. Later, several semiconductor manufacturing companies like Sylvania, Motorola, National Semiconductor, Fairchild, Signetics, etc., brought out compatible (equivalent) in function and logic level newer sub-series of ICs. Digital integrated circuits are constructed using bipolar transistors. Nowadays the sub-series of 74 xx ICs are made using CMOS (complementary metal oxide semiconductor) technology. Digital ICs produced for various logic functions are shown in Table 17.1. Fig. 17.17 shows an IC 7400 which is one of the 74 xx digital logic devices. This IC chip contains four numbers of two input NAND gates. We have known that NOT gates can be built using transistors and AND gates can be built using diodes or transistors. The logic circuit in which a NOT gate follows an AND gate is called a NOT AND or NAND gate. NAND gates can be made with diode–transistors logic (DTL) or transistor–transistor logic (TTL).

The IC 7400 chip shown in the figure has 14 pins marked 1 to 14 in the anticlockwise direction with the notch placed vertically up. The pin 14 is marked for power supply, V_{CC} which is +5 V and pin 7 is the ground pin. All the other pins are the input and output terminals of the four NAND gates. Each gate uses two pins for input and one pin for its output. The truth table for the two input NAND gate has been shown in Fig. 17.17 (d).

From the list of 7400 series of integrated circuits it is seen that IC

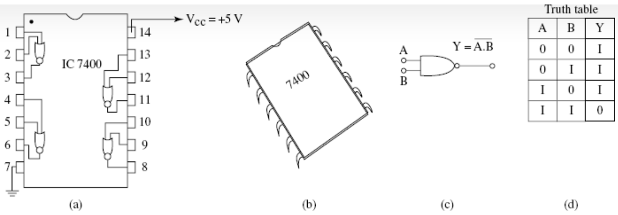


Figure 17.17 (a) IC 7400 with four 2-input NAND gates; (b) sketch of the IC chip; (c) symbolic representation of the NAND gate; (d) the truth table for the gate

Digital IC chips are commonly available in dual-in-line pakage (DIP). We had seen a 14-pin IC 7400. ICs with 16-, 20-, 24-, 28-, 40-, and 64-pin packages are also available.

Digital ICs are often categorized according to their circuit complexity. The complexity is measured by the number of equivalent logic gates in an IC. There are at present five standard levels of complexity of integrated circuits as indicated in Table 17.2.

With ICs, electronic circuits and components are becoming smaller and less expensive. Modern electronics using ICs find applications in mobile communication, satellite and aerospace communication, high-speed computers, home appliances and in automatic control systems. Electronics using ICs are becoming the brains and nerves of our complex society.

TTL 74 series is the most widely used family of digital ICs in the SSI and MSI categories. Fig. 17.18 shows a standard TTL inverter circuit. It contains several bipolar transistors, and hence the name TTL (transistor–transistor logic) is given.

Table 17.2 Integrated Circuits with Their Level of Complexity

Complexity	Approximate number of gates per chip	Typical products
Small-scale integration (SSI)	Less than 12	Logic gates, flip-flops
Medium-scale integration (MSI)	12 to 99	Counters, multiplexers, adders
Large-scale integration (LSI)	100 to 9999	8 bit microprocessors, ROM, RAM
Very Large-scale integration (VLSI)	10,000 to 99,999	16 bit and 32 bit microprocessors, sophisticated computer peripherals
Ultra large-scale integration (ULSI)	100,000 or more	64 bit microprocessors, real-time image processing

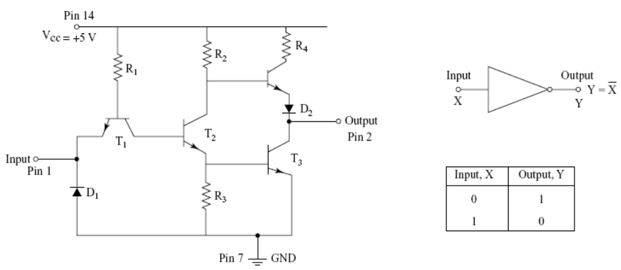


Figure 17.18 A TTL inverter circuit

As shown in Fig. 17.18, dc power supply voltage of +5 V has been connected to pin 14, and pin 7 has been connected to ground. Pin 1 is for the input. The inverted output is obtained at pin 2. A number of inverter circuits are made available through IC 7405. This has been indicated in Table 17.3.

also know about all the ICs that are available and the functions they would perform.

Table 17.3 List of 7400 Series Integrated Circuits

The following is the incomplete list of 7400 series digital logic integrated circuits.

- 7400 : Quad 2-input NAND gate
- 7401 : Quad 2-input NAND gate with open collector outputs
- 7402 : Quad 2-input NOR gate
- 7404 : Hex Inverter
- 7405 : Hex Inverter with open collector outputs
- 7408 : Quad 2-input AND gate
- 7410 : Triple 3-input NAND gate
- 7411 : Triple 3-input AND gate
- 7412 : Triple 3-input
- 7413 : Dual Schmitt trigger 4-input NAND gate
- 7420 : Dual 4-input NAND gate
- 7421 : Dual 4-input AND gate
- 7425 : Dual 4-input NOR gate with strobe
- 7427 : Triple 3-input NOR gate
- 7430 : 8-input NAND gate
- 7431 : Hex delay elements
- 7432 : Quad 2-input OR gate
- 7433 : Quad 2-input NOR buffer with open collector outputs
- 7436 : Quad 2-input NOR gate (different pinout than 7402)
- 7437 : Quad 2-input NAND buffer
- 7438 : Quad 2-input NAND buffer with open collector outputs
- 7439 : Quad 2-input NAND buffer
- 7440 : Dual 4-input NAND buffer
- 7441 : BCD to decimal decoder/NIXIE tube driver
- 7442 : BCD to decimal decoder
- 7443 : Excess-3 to decimal decoder
- 7444 : Excess-3-Gray to decimal decoder
- 7445 : BCD to decimal decoder/driver
- 7446 : BCD to 7-segment decoder/driver with 30 V

pullups

- 7449 : BCD to 7-segment decoder/driver with open collector outputs
- 7450 : Dual 2-Wide 2-input AND-OR-INVERT gate (one gate expandable)
- 7451 : Dual 2-Wide 2-Input AND-OR-INVERT gate
- 7452 : Expandable 4-Wide 2-input AND-OR gate
- 7453 : Expandable 4-Wide 2-input AND-OR-INVERT gate
- 7454 : 4-Wide 2-Input AND-OR-INVERT gate
- 7455 : 2-Wide 4-Input AND-OR-INVERT gate (74H version is expandable)
- 7456 : 50:1 Frequency divider
- 7457 : 60:1 Frequency divider
- 7458 : Dual 4-bit decade counter
- 7459 : Dual 4-bit binary counter
- 7460 : Dual 4-input expander
- 7461 : Triple 3-input expander
- 7462 : 3-2-2-3-input expander
- 7463 : Hex current sensing interface gates
- 7464 : 4-2-3-2-input AND-OR-INVERT gate
- 7465 : 4-2-3-2 input AND-OR-INVERT gate with open collector output
- 7470 : AND-gated positive edge triggered J-K flip-flop with preset and clear
- 74H71 : AND-OR-gated J-K master–slave flip-flop with preset
- 74L71 : AND-gated R-S master–slave flip-flop with preset and clear
- 7472 : AND-gated J-K master–slave flip-flop with preset and clear
- 7473 : Dual J-K flip-flop with clear
- 7474 : Dual D positive edge triggered flip-flop with preset and clear
- 7475 : 4-bit bistable latch
- 7476 : Dual J-K flip-flop with preset and clear
- 7477 : 4-bit bistable latch
- 74H78, 74L78 : Dual J-K flip-flop with preset, common clear, and common clock
- 74LS78A: Dual negative edge triggered J-K flip-flop with preset, common clear, and common clock
- 7479: Dual D flip-flop
- 7480: Gated full adder
- 7481: 16-bit random access memory
- 7482: 2-bit binary full adder

- 7486: Quad 2-input XOR gate
- 7487: 4-bit true/complement/zero/one element
- 7488: 256-bit read-only memory
- 7489: 64-bit random access memory
- 7490: Decade counter (separate divide-by-2 and divide-by-5 sections)
- 7491: 8-bit shift register, serial in, serial out, gated input
- 7492: Divide-by-12 counter (separate divide-by-2 and divide-by-6 sections)
- 7493: 4-bit binary counter (separate divide-by-2 and divide-by-8 sections)
- 7494: 4-bit shift register, dual asynchronous presets
- 7495: 4-bit shift register, parallel In, parallel out, serial input, bidirectional
- 7496: 5-bit parallel-in/parallel-out shift register, asynchronous preset
- 7497: Synchronous 6-bit binary rate multiplier
- 7498: 4-bit data selector/storage register
- 7499: 4-bit bidirectional universal shift register
- 74100: Dual 4-bit bistable latch
- 74101: AND-OR-gated J-K negative-edge-triggered flip-flop with preset
- 74102: AND-gated J-K negative-edge-triggered flip-flop with preset and clear
- 74103: Dual J-K negative-edge-triggered flip-flop with clear
- 74104: J-K master–slave flip-flop
- 74105: J-K master–slave flip-flop
- 74106: Dual J-K negative-edge-triggered flip-flop with preset and clear
- 74107: Dual J-K flip-flop with clear
- 74107A: Dual J-K negative-edge-triggered flip-flop with clear
- 74108: Dual J-K negative-edge-triggered flip-flop with preset, common clear, and common clock
- 74109: Dual J-Not-K positive-edge-triggered flip-flop with clear and preset
- 74110: AND-gated J-K master-slave flip-flop with data lockout
- 74111: Dual J-K master-slave flip-flop with data lockout
- 74112: Dual J-K negative-edge-triggered flip-flop with clear and preset
- 74113: Dual J-K negative-edge-triggered flip-flop with preset

- 74118: Hex set/reset latch
- 74119: Hex set/reset latch
- 74120: Dual pulse synchronizer/drivers
- 74121: Monostable multivibrator
- 74122: Retriggerable monostable multivibrator with clear
- 74123: Dual retriggerable monostable multivibrator with clear
- 74124: Dual voltage-controlled oscillator
- 74125: Quad Bus buffer with three-state outputs, negative enable
- 74126: Quad Bus buffer with three-state outputs, positive enable
- 74128: Quad 2-input NOR line driver
- 74130: Quad 2-input AND gate Buffer with 30 V open collector outputs
- 74131: Quad 2-input AND gate Buffer with 15 V open collector outputs
- 74132: Quad 2-input NAND Schmitt trigger
- 74133: 13-Input NAND gate
- 74134: 12-Input NAND gate with three-state output
- 74135: Quad exclusive-OR/NOR gate
- 74136: Quad 2-input XOR gate with open collector outputs
- 74137: 3 to 8-line decoder/demultiplexer with address latch
- 74138: 3 to 8-line decoder/demultiplexer
- 74139: Dual 2 to 4-line decoder/demultiplexer
- 74140: Dual 4-input NAND line driver
- 74141: BCD to decimal decoder/nixie tube driver
- 74142: Decade counter/latch/decoder/nixie tube driver
- 74143: Decade counter/latch/decoder/7-segment driver, 15 m A constant current
- 74144: Decade counter/latch/decoder/7-segment driver, 15 V open collector outputs
- 74145: BCD to decimal decoder/driver
- 74147: 10-line to 4-line priority encoder
- 74148: 8-line to 3-line priority encoder
- 74150: 16-line to 1-line data selector/multiplexer
- 74151: 8-line to 1-line data selector/multiplexer
- 74152: 8-line to 1-line data selector/multiplexer
- 74153: Dual 4-line to 1-line data selector/multiplexer
- 74154: 4-line to 16-line decoder/demultiplexer

noninverting

- 74158: Quad 2-line to 1-line data selector/multiplexer, inverting
- 74159: 4-line to 16-line decoder/demultiplexer with open collector outputs
- 74160: Synchronous 4-bit decade counter with asynchronous clear
- 74161: Synchronous 4-bit binary counter with asynchronous clear
- 74162: Synchronous 4-bit decade counter with synchronous clear
- 74163: Synchronous 4-bit binary counter with synchronous clear
- 74164: 8-bit parallel-out serial shift register with asynchronous clear
- 74165: 8-bit serial shift register, parallel load, complementary outputs
- 74166: Parallel-load 8-bit shift register
- 74167: Synchronous decade rate multiplier
- 74168: Synchronous 4-bit up/down decade counter
- 74169: Synchronous 4-bit up/down binary counter
- 74170: 4 by 4 register file with open collector outputs
- 74172: 16-bit multiple port register file with three-state outputs
- 74173: Quad D flip-flop with three-state outputs
- 74174: Hex D flip-flop with common clear
- 74175: Quad D edge-triggered flip-flop with complementary outputs and asynchronous clear
- 74176: Presettable decade (bi-quinary) counter/latch
- 74177: Presettable binary counter/latch
- 74178: 4-bit parallel-access shift register
- 74179: 4-bit parallel-access shift register with asynchronous clear and complementary Q_D outputs
- 74180: 9-bit odd/even parity generator and checker
- 74181: 4-bit arithmetic logic unit and function generator
- 74182: Lookahead carry generator
- 74183: Dual carry-save full adder
- 74184: BCD to binary converter
- 74185: Binary to bcd converter
- 74186: 512-bit (64 × 8) read only memory with open collector outputs
- 74187: 1024-bit (256 × 4) read only memory with open collector outputs
- 74188: 256-bit (32 × 8) programmable read-only

- 74191: Synchronous up/down binary counter
- 74192: Synchronous up/down decade counter with clear
- 74193: Synchronous up/down binary counter with clear
- 74194: 4-bit bidirectional universal shift register
- 74195: 4-bit parallel-access shift register
- 74196: Presettable decade counter/latch
- 74197: Presettable binary counter/latch
- 74198: 8-bit Bidirectional universal shift register
- 74199: 8-bit Bidirectional universal shift with j-not-k serial inputs
- 74200: 256-bit RAM with three-state outputs
- 74201: 256-bit (256 × 1) RAM with three-state outputs
- 74206: 256-bit RAM with open collector outputs
- 74209: 1024-bit (1024 × 1) RAM with three-state output
- 74210: Octal Buffer
- 74219: 64-bit (16 × 4) RAM with noninverting three-state outputs
- 74221: Dual monostable multivibrator with Schmitt trigger input
- 74222: 16 by 4 synchronous FIFO memory with three-state outputs
- 74224: 16 by 4 synchronous FIFO memory with three-state outputs
- 74225: Asynchronous 16 × 5 FIFO memory
- 74226: 4-bit parallel latched bus transceiver with three-state outputs
- 74230: Octal buffer/driver with three-state outputs
- 74232: Quad NOR Schmitt trigger
- 74237: 1-of-8 decoder/demultiplexer with Address Latch, active high outputs

17.10 REVIEW QUESTIONS

1. State the different levels of integration in integration circuits.
2. Briefly describe the manufacturing processes of monolithic integrated circuits.
3. Mention the advantages of ICs over discrete components.
4. Describe various types of IC packages.
5. Distinguish between linear and digital ICs.
6. What is an operational amplifier? Mention few applications of op-amps.
7. Show Application of an op-amp as an interting amplifier.

10. Show the use of an op-amp as a differentiator and as an integrator.
11. Mention any five applications of operational Amplifiers.
12. Draw the PIN diagram of an IC 555 timer, Explain the function of each pin.
13. Draw and explain the functional block diagram of an IC 555.
14. Explain the working of an IC 555 timer in monostable operating mode. Draw the voltage waveforms.
15. Explain the working of an IC 555 timer in astable operating mode. Draw the voltage waveforms.
16. Explain the working of an IC 555 timer as an astable multivibrator.
17. Show the use of a voltage regulator IC for converting 230 V ac into a low-voltage regulated dc.
18. What are the different types of IC voltage regulators?
19. What are digital ICs? Name any two digital IC, and the function they perform.
20. Draw the PIN diagram of an IC 7400 with four two-input NAND gates. Draw the truth table for the gate.
21. Show the classification of integrated circuits with their leave of complexity or miniaturization.
22. Draw and explain or TTL inverter circuit.

Multiple Choice Questions

1. Which of the following statements is not true for an integrated circuit?
    1. Integrated circuits are basically microelectronic circuits
    2. Integrated circuit is basically a complete circuit
    3. Integrated circuits are very small in size
    4. Integrated circuits consists only of active circuit components.
2. Microprocessors are
    1. small-scale integrated circuits (SSI)
    2. medium-scale integrated circuits (MSI)
    3. large-scale integrated circuits (LSI)
    4. very-large scale integrated circuits (VLSI).
3. Logic gate is an example of
    1. SSI
    2. MSI
    3. LSI
    4. VLSI.
4. Which of the following is a timer?
    1. IC 741
    2. IC 555
    3. IC 78XX
    4. IC 79XX.
5. For which of the following functions op-amps are not used
    1. integrator
    2. differentiator

1. IC 555
2. IC 741
3. MC 1741
4. IC 78XX.

7. A IC 555 will have

    1. 2 comparators, 1 RS flip-flop, 1 discharge transistor
    2. 2 comparators, 2 RS flip-flop, 1 discharge transistor
    3. 1 comparator, 2 RS flip-flop, 1 discharge transistor
    4. 1 comparator, 1 RS flip-flop, 1 discharge transistor.

8. Which of the following is not a voltage regulator IC?

    1. IC 7805
    2. IC 7808
    3. IC 7812
    4. IC 741.

9. An operational amplifier (op-amp) is basically

    1. a negative feedback amplifier
    2. positive feedback amplifier
    3. ow-gain amplifier
    4. none of these.

10. Which of the following statements is not true?

    1. Logic gates, flip-flops, counters, shift registers, etc. form a digital integrated circuit
    2. The NAND or NOR gates are the universal building block of digital systems
    3. TTL stands for transistor–transistor logic
    4. In an integrated circuit only active components incorporated in a single chip.

Answers to Multiple Choice Questions

1. d)
2. (a)
3. (b)
4. (d)
5. (a)
6. (a)
7. (a)
8. (d)
9. (a)
10. (d)