SEC1302 - ANALOG INTEGRATED CIRCUITS

UNIT 5 SPECIAL FUNCTION ICS

Integrated circuit Tuned amplifier, Instrumentation Amplifier, Series and shunt voltage regulator, Optocoupler, CMOS Operational Amplifier- Dc analysis- small signal analysis- specifications of IC MC 14573.

5.1 Integrated circuit Tuned amplifier

The IC MC 1550 is the differential amplifier stage in monolithic integrated form. It is very versatile and flexible device. It is an excellent basic building block for the design of various communication applications such as,

i) Tuned amplifier with automatic gain control

ii) Amplitude modulator

iii) Video amplifier.

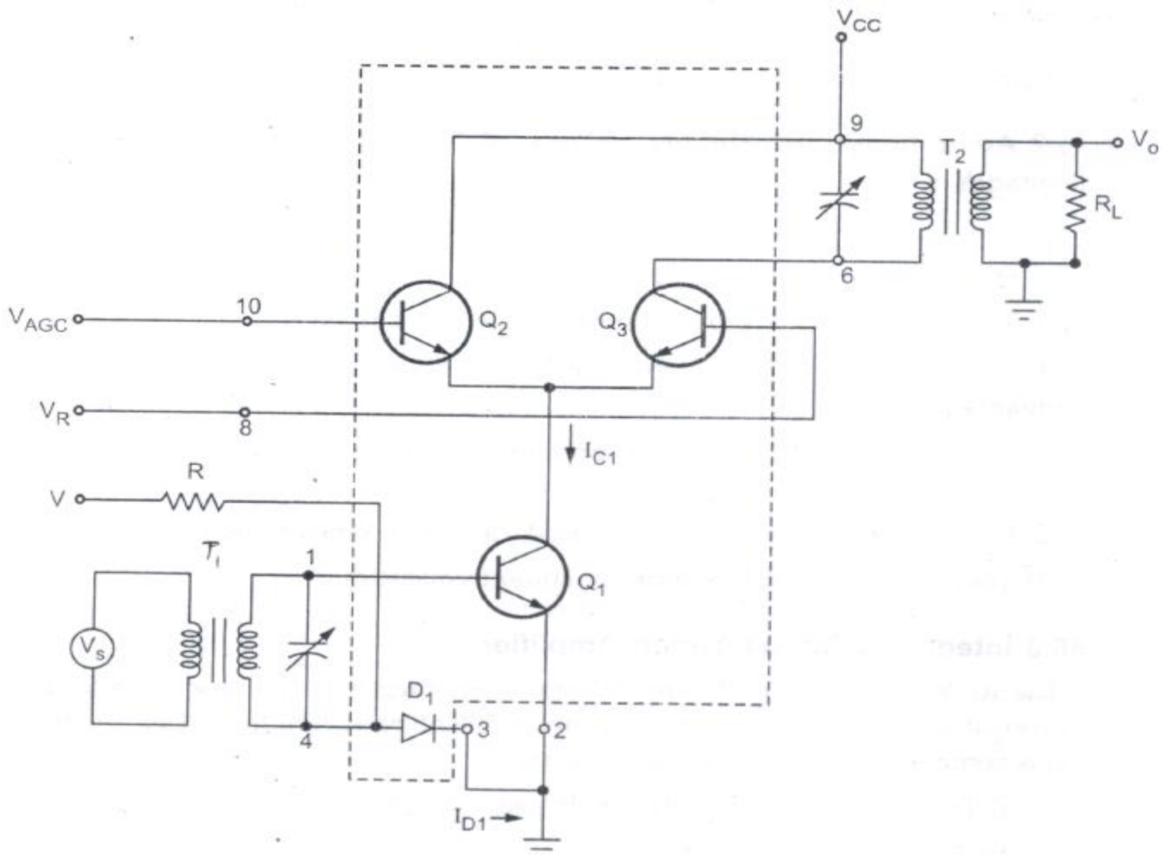

Fig. 7.136 Tuned amplifier using MC 1550

The basic circuit of MC 1550 is shown in the Fig. 7.136. This circuit with certain external component can be used to design a tuned amplifier which amplify a signal over a narrow band of frequencies centered at f_r. The simplified schematic diagram for tuned amplifier using MC 1550 is shown in the Fig. 7.136. Here, input signal is applied through the tuned transformer T_1 to the base of Q_1. The load R_L is connected across the tuned transformer T_2 in the collector circuit of Q_3. The transistor Q_1 and Q_3 provides the amplification whereas Q_2 provides the control of magnitude of the gain. The combination of Q_1 and Q_3 acts as a common-emitter and common-base cascode (CE-CB) pair. Recall that the input resistance and the current gain of a cascode pair are essentially the same as those of a CE stage, the output resistance is the same as that of a CB stage, and the reverse-open-circuit voltage amplification is given as $h_r = h_{re}\ h_{rb} \approx 10^{-7}$. This extremely small value of h_r provided by cascode pair makes this circuit especially useful in tuned amplifier design. The reduced reverse internal feedback due to cascode connection simplifies tuning, reduces the possibility of oscillation, and results in improved stability of the tuned amplifier.

The voltage V_{AGC} applied to the base of transistor Q_2 is used to provide atutomatic gain control. The variation in V_{AGC} cause changes in the division of the current between transistors Q_2 and Q_3. When V_{AGC} is greater than V_R, Q_2 conducts more than Q_3, reducing voltage gain. On the other hand when V_R is greater than V_{AGC} Q_3 conducts more than Q_2 which increases voltage gain. At V_R greater than V_{AGC} by 120 mV, Q_2 is cut-off and the collector current of Q_1 flows through Q_3, providing maximum voltage gain A_V. The change in V_{AGC} causes the change in the division of current and not the collector current of Q_1. Thus the input impedance of Q_1 remains constant and the input circuit is not tuned.

The voltage V and resistance R establish the dc current I_{D1} through the diode D_1. The voltage V_{BE1} is nearly equal to V_{D1} and the collector current I_{C1} is within the ± 5% of I_{D1}.

$$= \frac{2\,\Delta R\,V_{dc}}{2\,R} = \frac{\Delta R\,V_{dc}}{R} \quad \text{... (4)}$$

Hence the net output voltage is,

$$\boxed{V_o = \frac{A\,\Delta R\,V_{dc}}{R}} \quad \text{... (5)}$$

The output voltage is proportional to the change in the resistance, which inturn depends upon the applied weight. The meter connected at the output can be calibrated in kilograms.

5.2 Instrumentation Amplifier

The instrumentation amplifier is very commonly required in various practical applications, as seen earlier. Many manufacturers have manufactured instrumentation amplifier ICs which allow higher optimization of parameters required for the particular application like CMRR, gain control, gain linearity, stability etc. The examples of such dedicated instrumentation amplifier ICs are AD 521/524/624/625 (Analog devices), LM 363 (National Semiconductors) and Amp-01 and Amp-05 (Precision monolithic). In such monolithic ICs the first stage differential amplification is achieved by matched transistor pair rather than op-amps. This is because transistor pair is faster than op-amps and less sensitive to common mode signals. Hence the restriction to get matched resistances gets relaxed. Let us study the internal circuit details of instrumentation amplifier IC, Amp-01.

Circuit Diagram of AMP-01

The Fig. 3.101 shows the simplified internal circuit diagram of instrumentation amplifier IC AMP-01.

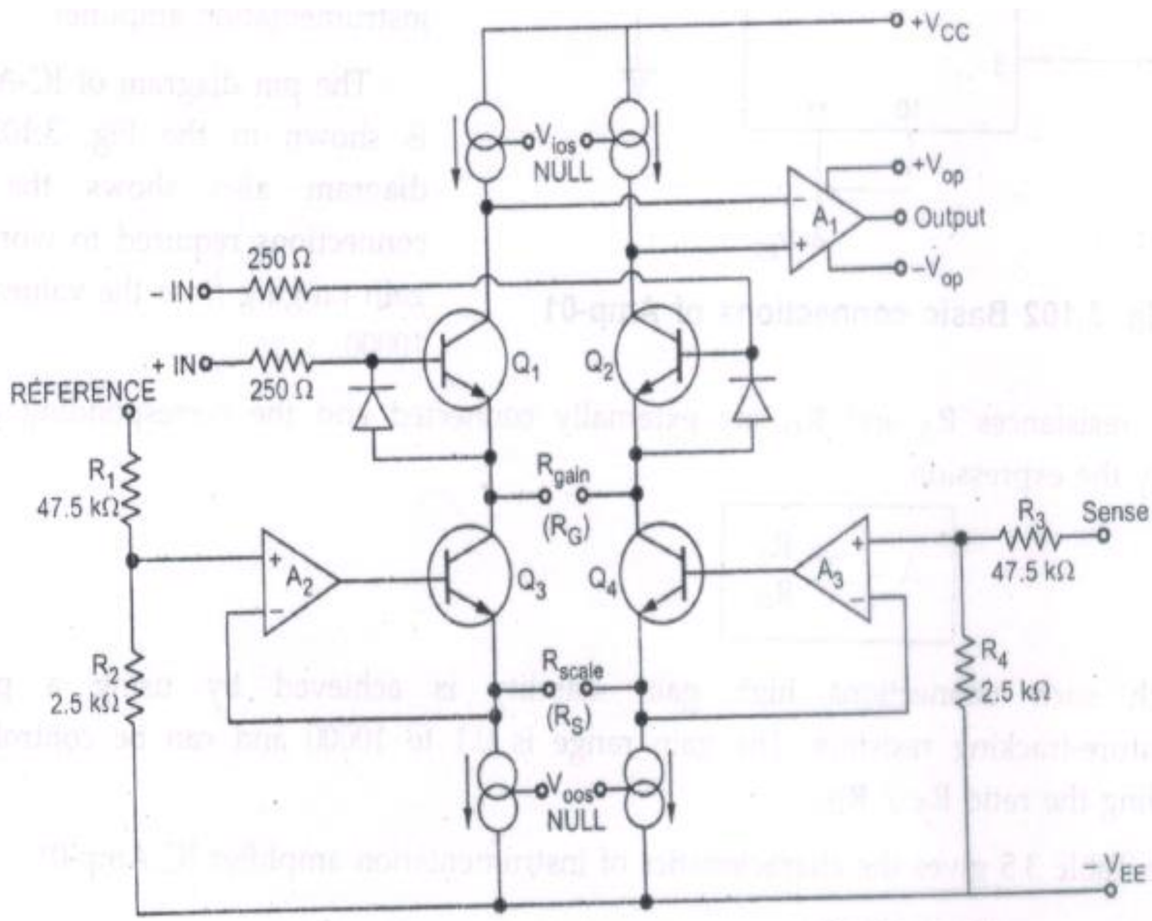

Fig. 3.101 Internal circuit diagram of IC Amp-01

The circuit shows that the resistance R_G and R_S are to be connected externally which in turn control the gain of the instrumentation amplifier. The V_{ios} i.e., input offset voltage and V_{oos} i.e. output offset voltage, NULL provisions are also available. The pair of transistors Q_1 and Q_2 forms a differential amplifier and plays an important role in differential input amplification, required at the first stage. + IN and –IN are the input terminals where differential input is to be applied.

When a differential signal is applied between the input terminals available from bases of the transistors Q_1 and Q_2, the currents through Q_1 and Q_2 get unbalanced. Due to this, there exists a potential difference between the inverting and non-inverting terminals of op-amp A_1. For op-amp the voltage of noninverting terminals V_p and inverting terminal V_n must be same and potential difference between them must be zero. So for unbalanced currents in Q_1 and Q_2, the op-amp A_1 responds in the opposite direction in order to restore the balanced condition at its input which is $V_n = V_p$.

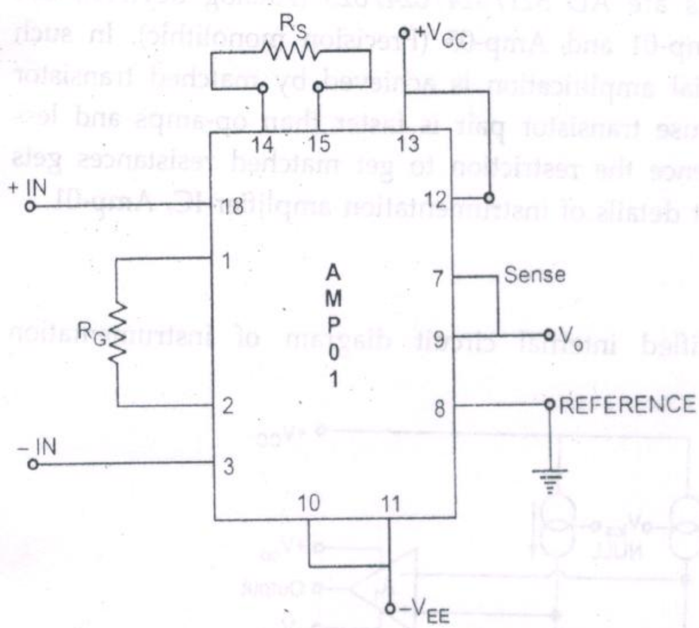

Fig. 3.102 Basic connections of Amp-01

To achieve this, A_1 applies a suitable drive to the bottom transistor pair Q_3 and Q_4 through the op-amp A_3. The amount of drive needed depends on two things, one the ratio of the externally connected resistances R_S and R_G and the second is the magnitude of the differential input. This drive forms the output of the instrumentation amplifier.

The pin diagram of IC-Amp-01 is shown in the Fig. 3.102. The diagram also shows the basic connections required to work with gain ranging from the values 0.1 to 10000.

The resistances R_S and R_G are externally connected and the corresponding gain is given by the expression.

$$A = 20 \frac{R_S}{R_G} \quad \text{... (1)}$$

With such connections high gain stability is achieved by using a pair of temperature-tracking resistors. The gain range is 0.1 to 10000 and can be controlled by controlling the ratio R_S / R_G.

The Table 3.5 gives the characteristics of instrumentation amplifier IC Amp-01.

Characteristics of AMP-01	
Parameter	**Value**
Offset voltage	15 μV
Offset voltage drift	0.1 μV/°C
Noise	0.2 μV p-p (0.1 Hz to 10Hz)
Output drive	± 10 V at ± 50 mA
Capacitive load stability	to 1μF
Gain range	0.1 to 10000
Linearity	16 bit at gain 1000
CMRR	140 dB at gain 1000
Bias current	1 nA
Provides output stage thermal shutdown	

Table 3.5

7.12.1 Shunt Voltage Regulator

The heart of any voltage regulator circuit is a control element. If such a control element is connected in shunt with the load, the regulator circuit is called shunt voltage regulator. The Fig. 7.41 shows the block diagram of shunt voltage regulator circuit.

The unregulated input voltage V_{in}, tries to provide the load current. But part of the current is drawn by the control element, to maintain the constant voltage across the load. If there is any change in the load voltage, the sampling circuit provides a feedback signal

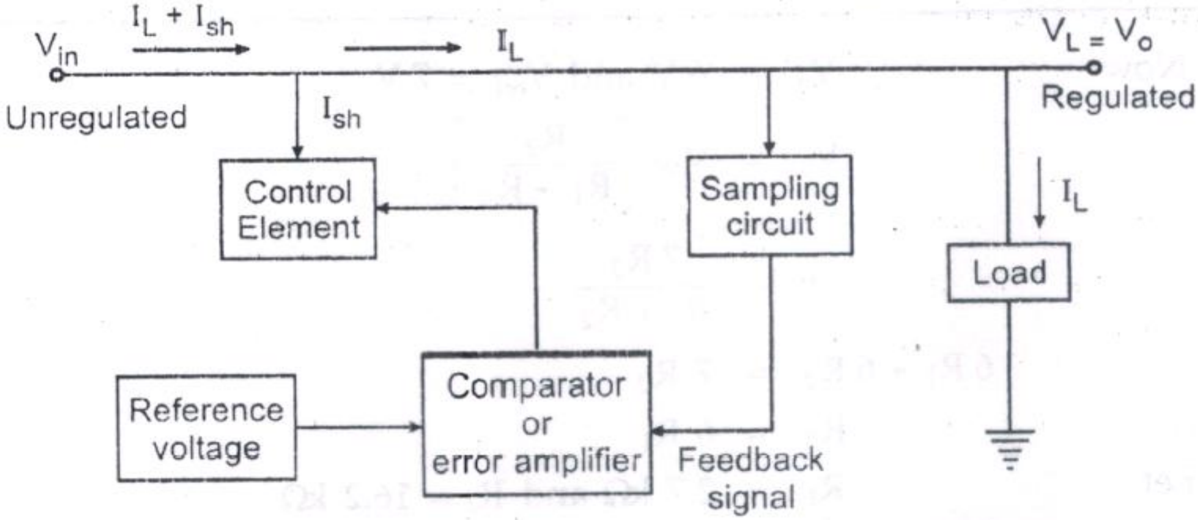

Fig. 7.41 Block diagram of shunt voltage regulator

to the comparator circuit. The comparator circuit compares the feedback signal with the reference voltage and generates a control signal which decides the amount of current required to be shunted to keep the load voltage constant. For example if the load voltage increases then the comparator circuit decides the control signal based on the feedback information, which draws the increased shunt current I_{sh}. Due to this the load current I_L decreases, hence the load voltage decreases to its normal value.

Key Point : *Thus the control element maintains the constant output voltage by shunting the current, hence the circuit is called shunt voltage regulator.*

7.12.2 Series Voltage Regulator

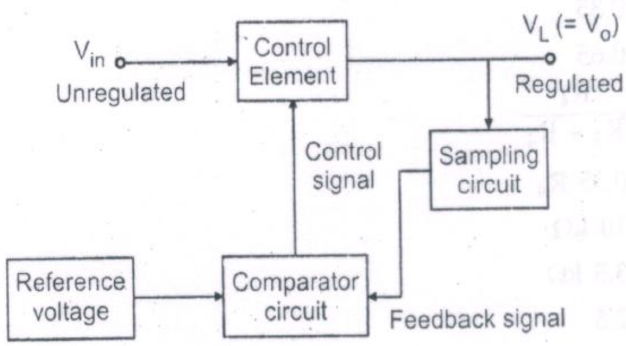

Fig. 7.42 Block diagram of series voltage regulator

If in a voltage regulator circuit, the control element is connected in series with the load, the circuit is called series voltage regulator circuit. The Fig. 7.42 shows the block diagram of series voltage regulator circuit.

The unregulated d.c. voltage is the input to the circuit. The control element, controls the amount of the input voltage, that gets to the output. The sampling circuit provides the necessary feedback signal. The comparator circuit compares the feedback with the reference voltage to generate the appropriate control signal.

For example, if the load voltage tries to increase, the comparator generates a control signal based on the feedback information. This control signal causes the control element to decrease the amount of the output voltage. Thus the output voltage is maintained constant.

Key Point: *Thus, control element which regulates the load voltage based on the control signal is in series with the load and hence the circuit is called series voltage regulator circuit.*

7.16 Three Terminal Fixed Voltage Regulators

As the name suggests, three terminal voltage regulators have three terminals namely input which is unregulated (V_{in}), regulated output (V_o) and common or a ground terminal. These regulators do not require any feedback connections. The Fig. 7.58 shows the basic three terminal voltage regulator.

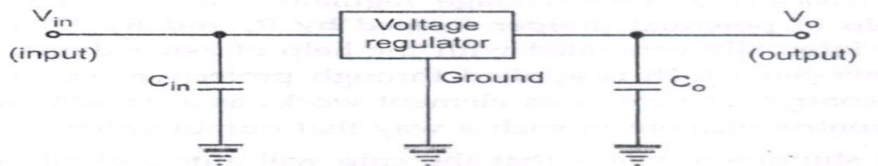

Fig. 7.58 Basic three terminal voltage regulator

The capacitor C_{in} is required if regulator is located at appreciable distance, more than 5cm from a power supply filter. The output capacitor C_o may not be needed but if used it improves the transient response of the regulator i.e. regulator response to the transient changes in the load. This capacitor also reduces the noise present at the output. The difference between V_{in} and V_o ($V_{in} - V_o$) is called as dropout voltage and it must be typically 2.0 V even during the low point on the input ripple voltage, for the proper functioning of the regulator.

7.16.1 Block Diagram of Basic Three Terminal IC Regulator

The Fig. 7.59 shows the functioal block diagram of basic three terminal IC regulator.

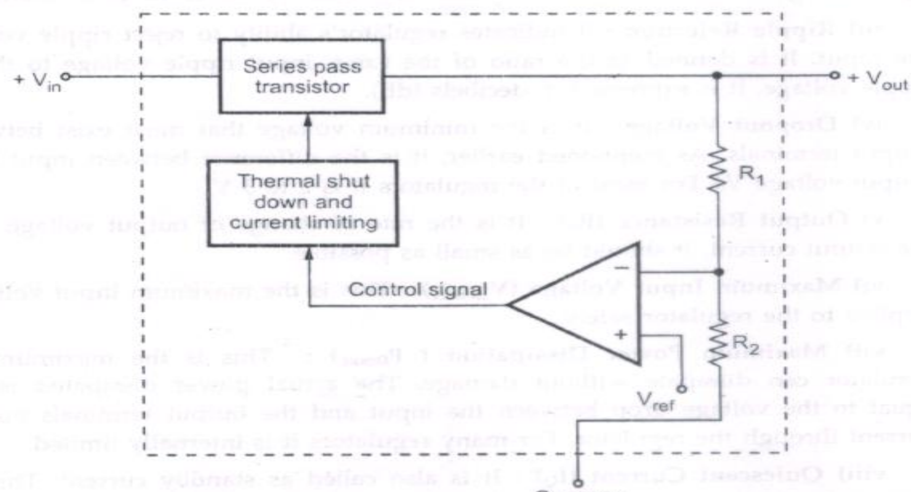

Fig. 7.59 Functional block diagram of a typical three terminal IC voltage regulator

This is basically a series voltage regulator circuit. A part of output voltage is taken *with the help of potential divider formed by R_1 and R_2. This is compared with reference* voltage, V_{ref} internally generated with the help of zener diode. After comparison, a control signal is generated which is applied through protective circuit to the series pass transistor working as control element. This element works as a variable resistance. The control signal adjusts the control element in such a way that output voltage remains constant.

Thermal shutdown means that the chip will automatically turn itself off if the internal temperature exceeds, typically, 175° C. The current limiting circuit will protect the chip from excessive load current. Because of the thermal shutdown and current limiting, the IC voltage regulator chip is almost indestructible.

7.16.3 IC Series of Three Terminal Fixed Voltage Regulators

The popular IC series of three terminal regulators is μA78XX and μA79XX. The series μA 78XX is the series of three terminal **positive** voltage regulators while μA79XX is the series of three terminal **negative** voltage regulators. The last two digits denoted as XX, indicate the output voltage rating of the IC.

Such series is available with seven voltage options as indicated in Table 7.4.

Device type	Output Voltage	Device type	Output Voltage
7805	5.0 V	7905	–5.0 V
7806	6.0 V	7906	–6.0 V
7808	8.0 V	7908	–8.0 V
7812	12.0 V	7912	–12.0 V
7815	15.0 V	7915	–15.0 V
7818	18.0 V	7918	–18.0 V
7824	24.0 V	7924	–24.0 V

Table 7.4

The 79XX series voltage regulators are available with same seven options as 78XX series, as indicated in Table 7.4. In addition, two extra voltages –2 V and –5.2 V are also available with ICs 7902 and 7905.2 respectively.

These ICs are provided with adequate heat sinking and can deliver output currents more than 1A. These ICs do not require external components. These are provided with internal thermal protection, overload and short circuit protection.

The two series are available in various versions like low power and high power versions. The low power versions are available in plastic or metal packages, like small signal transistors. The higher power versions are packaged in TO-3 type metal cans or in To-220 type moulded plastic packages like power transistors.

7.39.3 IC Optocoupler

Optocouplers are available in a variety of packages, the most common being six pin mini dual-in-line package. The examples of such IC optocouplers are MCT2E and MCT2.

The MCT2E is optically coupled isolator consisting of a Gallium Arsenide infrared emitting diode and an NPN silicon phototransistor, mounted in a standard 6 pin dual-in-line package. The circuit is shown in the Fig. 7.147.

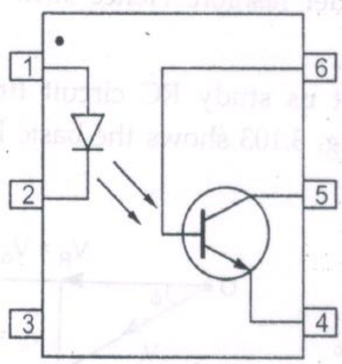

Fig. 7.147 Circuit of MCT2E optocoupler

7.39.3.1 Features of IC Optocoupler

The various features of MCT2E are,

1) The isolation voltage of ± 2500 V.
2) High d.c. current transfer ratio.
3) Total power dissipation is 250 mW.
4) Input to output isolation resistance of 1×10^{11} Ω.
5) Low cost dual in line package.

In the six pin dual-in-line package, optocoupler with photodarlington is also available. It is shown in the Fig. 7.148.

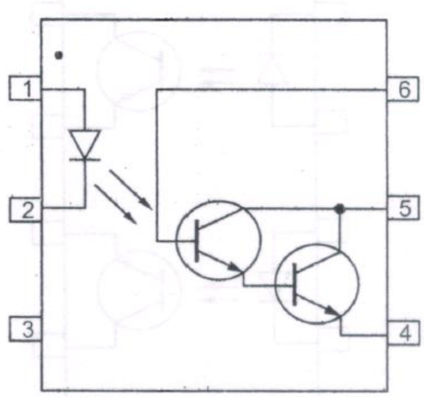

Fig. 7.148 IC optocoupler with photodarlington

7.39.3.2 Various Packages of IC Optocoupler

Other than six pin dual-in-line package, 8 pin dual isolating optocoupler is also available. The circuit of 8 pin dual isolating optocoupler is shown in the Fig. 7.149.

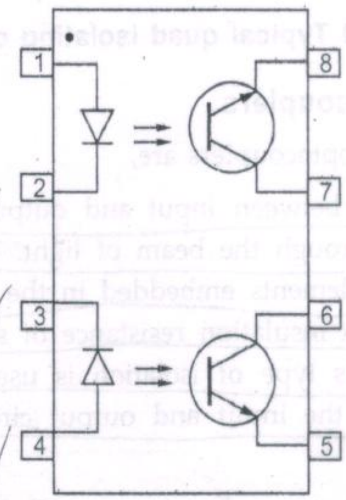

Fig. 7.149 Typical dual isolating optocoupler

7.39.4 Advantages of Optocouplers

The various advantages of optocouplers are,

1. The electrical isolation between input and output circuit. The coupling between input and output is through the beam of light. There is a transparent insulating cap between the two elements embedded in the design to permit the passage of light. So there exists an insulation resistance of several megaohms between input and output circuit. This type of isolation is useful in high voltage applications where the voltages of the input and output circuits differ by several thousand volts.
2. The response times of optocouplers is so small that they can be used to transmit data in the megahertz range.
3. Capablc of wideband signal transmission.
4. Unidirectional signal transfer means that output does not loop back to the input circuit.
5. Easy interfacing with logic devices.
6. Compact and light weight.
7. Much faster than the isolation transformers and relays.
8. As signal transfer is unilateral, changing load do not affect input.
9. The problems such as noise, transients, contact bounce etc. are completely eliminated.

13.2 CMOS OPERATIONAL AMPLIFIER

The bipolar op-amp IC 741 is capable of sourcing and sinking large load currents. This is facilitated by the emitter-follower output stage which achieves very low output resistance, and this characteristic was used in IC 741 for minimizing the loading effects.

On the other hand, the CMOS op-amps are normally designed for particular applications, wherein only a few picofarads of capacitive loads are required to be driven. Therefore, most of the CMOS op-amps do not require a low resistance output stage. When the op-amp input terminals are not connected directly to the IC external terminals, they do not need electrostatic input protection devices also. The folded cascode op-amp involving a current mirror CMOS design is presented in this section.

13.2.1 Description of the Circuit

Figure 13.1 shows a simplified circuit diagram of an all-CMOS op-amp MC14573. The PMOS transistors M_1 and M_2 form the input differential pair, and the NMOS transistors M_3 and M_4 form the active load of the differential pair. The differential amplifier input stage is biased by the transistors M_5 and M_6 which form the current mirror. The reference current for the current mirror is determined by an external resistor R_{set}.

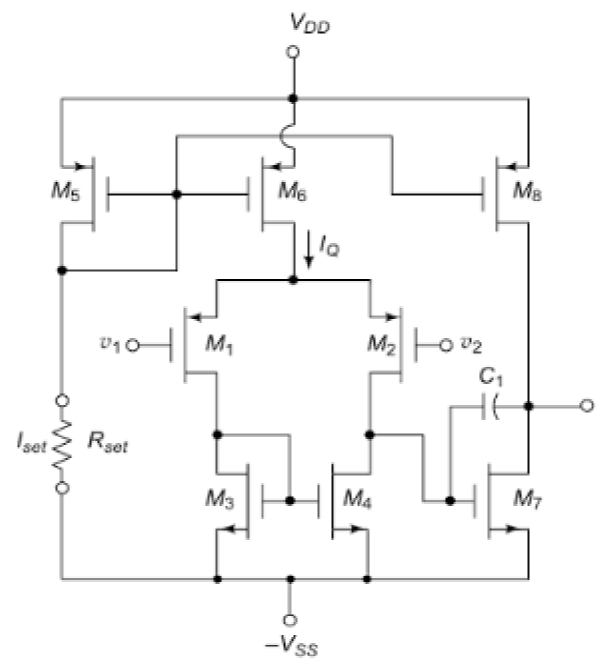

Fig. 13.1 *Simplified circuit of CMOS op-amp MC14573*

The second stage acting as the output stage consists of the common-source connected transistor M_7. The transistor M_8 provides the bias current acting as the active load for the transistor M_7. An internal compensation capacitor C_1 is connected between the drain and gate of transistor M_7 to provide stability.

13.2.2 DC Analysis of MC14573

Considering that the transistors M_5 and M_6 are matched, the reference current and the bias current of the input-stage are given by

$$I_{set} = I_Q = \frac{V_{DD} - V_{SS} - V_{SG5}}{R_{set}} \tag{13.1}$$

From the basic MOS transistor theory and its square law equation, the reference current and source-to-gate voltage are given by

$$I_{set} = K_{p5}\left(V_{SG5} + V_{Thp}\right)^2 \tag{13.2}$$

where V_{Thp} is the threshold voltage for the PMOS transistor M_5, and K_{p5} is its conductance parameter.

13.2.3 Small-Signal Analysis

The small-signal differential voltage gain of the input stage is given by

$$A_d = \sqrt{2K_{p1}I_Q}\left(r_{o2} \| r_{o4}\right) \tag{13.3}$$

where r_{o2} and r_{o4} are the output resistances of transistors M_2 and M_4 respectively. The input impedance of the second stage is infinite due to the gate-channel oxide insulator. Therefore, it results in zero loading effect by the second stage. Assuming the channel length parameter coefficient λ to be the same for all transistors, we have

$$r_{o2} = r_{o4} = \frac{1}{\lambda I_D} \tag{13.4}$$

where I_D, the quiescent drain current in M_2 and M_4, is given by $I_D = \frac{I_Q}{2}$.

The gain of the second stage is

$$A_{v2} = g_{m7}\left(r_{o7} \| r_{o8}\right) \tag{13.5}$$

where

$$g_{m7} = 2\sqrt{K_{n7}I_{D7}} \tag{13.6}$$

and the resistances $r_{o7} = r_{o8} = \frac{1}{\lambda I_{D7}}$.

Equation 13.5 indicates that there is no loading effect due to an external load connected at the output.

13.2.4 Specifications of the IC MC14573

The pin diagram of the quad low-power op-amp is shown in Fig. 13.2.

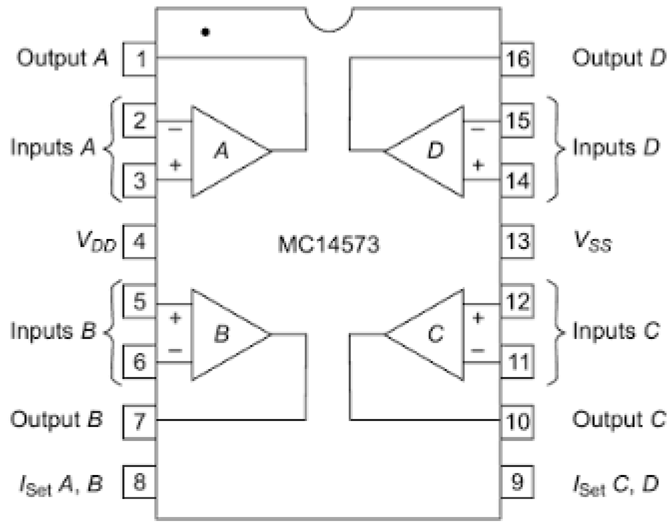

Fig. 13.2 *Pin diagram of quad op-amp MC14573*

It consists of four op-amps configured using CMOS devices in a monolithic structure. The operating current is programmable using the resistor connected at pin 9 and it is set by the resistor R_{set} connected between V_{SS} and any one or both of the I_{set} pins 8 and 9. This makes the IC versatile for making a trade-off between the power dissipation and slew rate characteristics. The op-amps are internally compensated. The set current for each op-amp pair of the comparator is given by $I_{set} = \frac{V_{DD} - V_{SS} - 1.5V}{R_S}$ where R_S represents the single programming resistor.When two programming resistors are employed, the set currents are given by $I_{set} = \frac{V_{DD} - V_{SS} - 1.5V}{2R_S}$. The total device current is typically thirteen times that of I_{set} per pair when the outputs are in *low* state, whereas it is five times I_{set} per pair when the outputs are in *high* state. When the op-amps are employed in the linear region, the device current is set between the values of five and thirteen times I_{set}.

While using a single op-amp, the I_{set} terminal for the pair is normally tied to V_{DD} for achieving minimum power consumption. For minimizing the power consumption of the unused pair of comparators, it is preferable to use a high value set resistor R_S with the inputs connected to a voltage that will force the output to V_{DD}. It is to be noted that increasing the value of I_{set} for comparators will decrease the propagation delay. The normally obtainable maximum output voltage V_{OH} for a given value of load resistor R_L with respect to V_{SS} is given by

$$V_{OH} = 4 \times I_{Set} \times R_L - 0.05V.$$

The typical op-amp slew rate (SR) value achievable for MC14573 is given by $SR \approx 0.041 I_{set}$.

The MC14574 and MC14575 also fall in the family of quad op-amps and comparators. These ICs are excellent building blocks for consumer, industrial, automotive and instrumentation applications. Some applications of these ICs are in active filters, voltage reference circuits, waveform generator circuits, ADCs and comparator circuits. These ICs are usable in both line and battery operated applications.