UNIT 9 LINEAR ICs—AMPLIFIERS AND VOLTAGE REGULATORS

Structure

9.1 INTRODUCTION

In the Units 7 and 8, linear IC op amps wore described in detail basically because they find large scale applications in the electronic circuitry. There are several other widely used special purpose linear ICs. The description of all such ICs available in the market is beyond the scope of this unit. However, a few but most popular have been selected for coverage in this unit.

Small signal amplifiers amplify voltages giving at the load larger and amplified voltages. However, the power amplifiers or large signal amplifiers supply to their current operated loads a large signal current. Such loads are like speakers and motors. The operational amplifier is essentially a small signal amplifier which amplifies voltage, The current capability of op amps is also limited. The maximum current that can be obtained in case of general purpose op amp 741C with $R_L = 0$ is 25 mA. This current will obviously decrease with increase in R_L. In several applications, like audio systems, much higher current is required which cannot be supplied by general purpose op amps. Thus the loads like speakers and motors cannot be driven directly by the output of op amps. To boost the current one has to use power amplifiers based on either transistors or spccialised ICs which are now commonly available in the market. In this unit, a special purpose power amplifer IC LM380, which is quite commonly used in audio systems, will be described.

Another linear IC which is quite popular now a days for its use in almost all kinds of power supplies is the voltage regulator. A voltage regulator is one that gives a constant voltage regardless of changes in the load current. An excellent performance voltage regulator can be designed using an op amp, zener diode, two resistors, and one or more transistors. All. these components and some others were integratod first by Fairchild Semiconductor Division in 1968 to give a voltage regulator. Further advancement in the IC technology greatly improved voltage regulators. Currently a variety of three-terminal fixed voltage regulators for scvornl positive and negative voltages and adjustable voltage regulators for a range of positive and negative voltages are available in the market. In this unit, 7800 and 7900 series of fixed positive and negative voltage regulator ICs, and LM317 and LM337 series of adjustable positive and negative voltage regulator ICs will be described.

Objectives

After studying this unit, you should be able to:

- draw the pin-out and block diagrams of IC LM380,
- use IC LM380 as an audio power amplifier with fixed, enhanced and variable gains,
- draw the pin-out diagrams of voltage regulators ICs of 7800, 7900, LM317 and LM337 series,

  choose an appropriate voltage regulator for your application,
- design a voltage regulation circuit for a fixed positive or negative, and adjustable positive or negative output voltages,

  using ICs of 7800, 7900 and LM317 and LM337 series,
- use a voltage regulator as a current source of desired value.

9.2 POWER AMPLIFIER IC EM380

The IC LM380 is a power audio amplifier manufactured by National semiconductor. It is an integration on a single chip of a pnp emitter follower, differential amplifier, common emitter and quasi-complementary emitter follower. The minimum power delivered by it to a load of 8 Ω is 2.5 W (rms). This makes it highly suitable for consumer electronics and other applications.

9.2.1 Characteristics of LM380

1) It has internally fixed gain of 50.
2) Output of LM380 is automatically selfcentred to one-half of the supply voltage.
3) Output is also short circuit proof,
4) It has an internal thermal limiting arrangement and therefore there is no need to use a separate heat sink.
5) Its input stage allows input signals to be ac coupled or direct coupled to either of the inputs with reference to the ground.
6) It can work on a wide range of supply voltage from 5 to 22 V.
7) It has a bandwidth of 100 kHz when used with 2 W power output and 8 Ω load.
8) It has a sufficiently large peak current capability with a maximum of 1.3 A.
9) Total harmonic distortion is as low as 0.2%.
10) It is available in standard dip package.

9.2.2 Pin-out and Block Diagram

LM380 is a 14-pin IC with standard DIP package. Its pin-out diagram is shown in Fig.9.1. The central three pins on both sides of the package (pins 3, 4, and 5 on the left, and pins 10, 11 and 12 on the right sides) are connected to a copper lead frame so as to work as a heat sink. Note also that pin 2 is a non-inverting input and pin 6 is inverting input and the output is taken from pin 8. A capacitor of a few microfarads should be connected between the bypass pin 1 and the ground pin 7 to decouple the input stage from the supply voltage. Internally fixed voltage gain of 50 can be changed by external circuitry as explained later. Fig.9.2 shows the block diagram of LM380. The asterisk indicates ground heat sink pins.

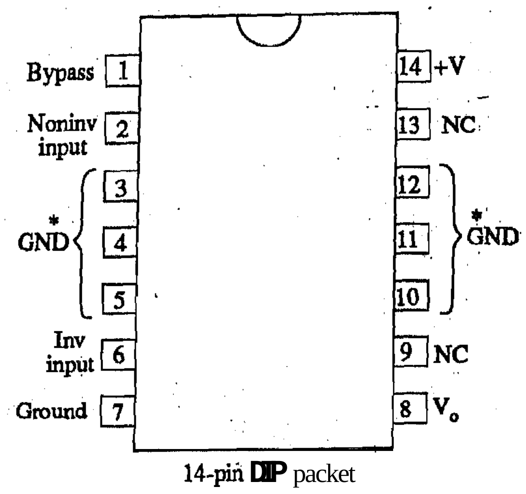

Fig.9.1: Pin-out diagram of the IC LM380 power audio amplifier.

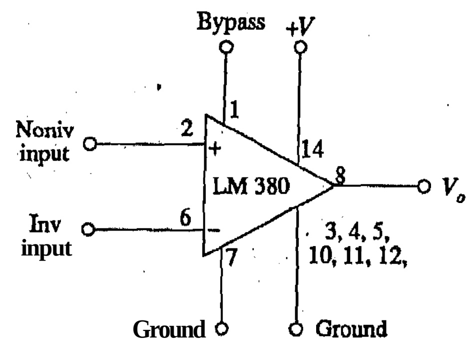

Fig.9.2: Block diagram of the IC LM380.

9.2.3 Fixed Gain Audio Amplifier

Simplest circuit using **LM380** is that of an **audio power** amplifier shown in **Fig.9.3**. Because of the characteristics of **LM380** outlined in section **(9.2.1)** and as is clear from the circuit, only a few components are externally required for use with this IC. Either of the inverting and non-inverting inputs of **LM380** can be used. If the **non-inverting** input pin 2 is used, then the inverting input pin 6 may be either left open or connected to the ground directly or through a resistor or capacitor. If the inverting pin 6 is used, **then** the non-inverting input pin 2 is connected to **ground** directly or through a resistor or capacitor. The bias supply should be **decoupled,** in either **case,** by connecting a capacitor of 0.1 **μF** between supply pin 14 and the ground. If working in rf sensitive area, then an RC combination is also used between output pin 8 and ground, as **shown** in **Fig.9.3,** to avoid unwanted oscillations in the range of 5 to 10 MHz.

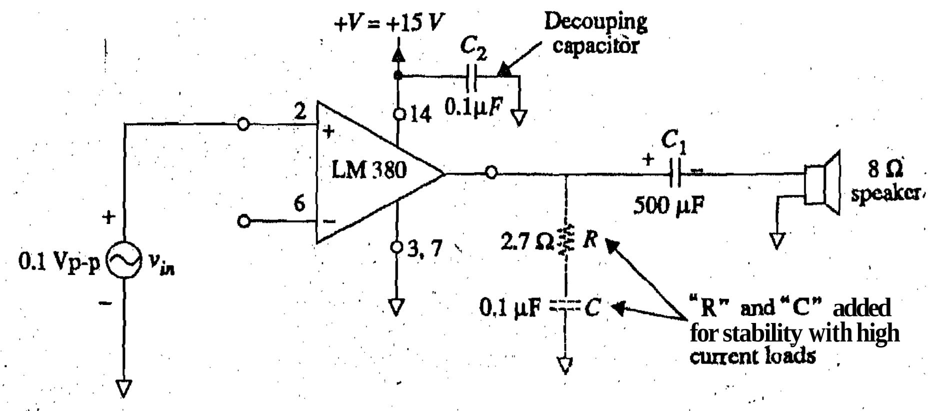

Fig.9.3: Audio power amplifier circuit using the IC LM380.

9.2.4 Higher and Variable Gain Amplifier

As stated earlier, the gain of LM380 is internally fixed at 50. However, it can be changed and made variable by using some external components. By making use of positive feedback the gain of LM380 can be increased to a gain as high as 300. Fig.9.4 shows a circuit using LM380 in its inverting configuration and designed for a gain of 200. Fig.9.5 shows a circuit designed for a variable gain upto 50 using a potentiometer between two inputs of the IC.

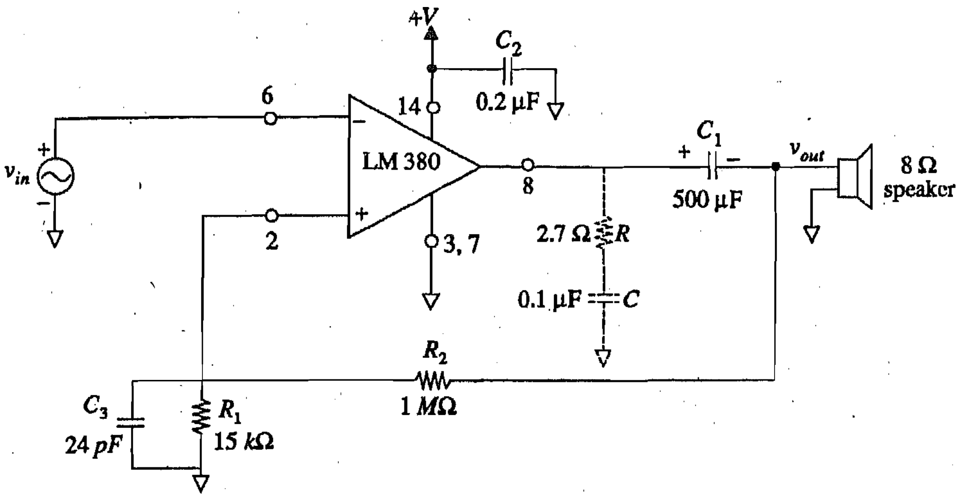

Fig.9.4: The IC LM380 power audio amplifier with a gain of 200 using positive feedback

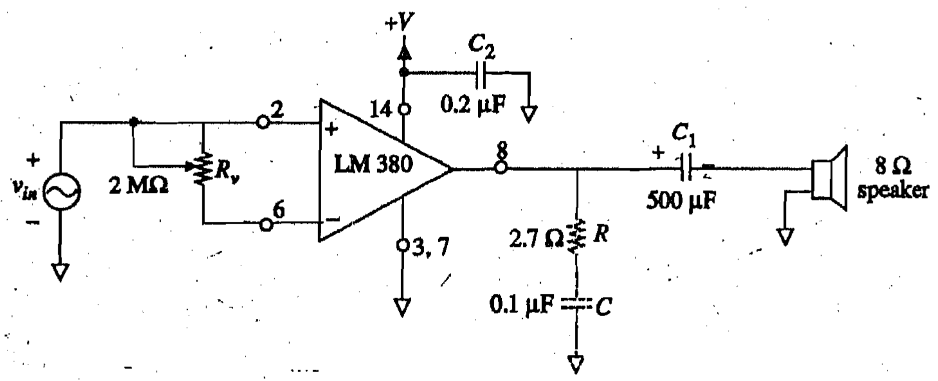

Fig.9.5: The IC LM380 p e r audio amplifier with a variable gain upto 50.

SAQ 1

What is the main difference between small signal amplifier and large signal or power amplifier?

9.3 VOLTAGE REGULATOR ICs

There are several types of voltage regulator ICs. Fixed output voltage regulators with positive or negative output are available for several fixed standard voltages between ±5 V and ±24 V. The voltage of the adjustable output voltage regulators with positive or negative output can be adjusted between ±1.2 V to ±37 V. The voltage regulator ICs with output currents of 0.1 A to 10 A are also available. Most regulators are three-pin devices while some special regulators are multi-pin devices.

9.3.1 Dropout Voltage

The instantaneous voltage at the input of an IC regulator must always be greater than the dc output voltage of the regulator by a value typically equal to 0.5 V to 3 V even during the low point on the input ripple voltage. In case of 7800 series of the IC voltage regulators this value is 2V. This voltage is known as dropout voltage or headroom.

The μA7815 is a voltage regulator with a fixed positive voltage output of 15V. Suppose a power supply, unregulated output of which is connected to the input of the μA7815, has a capacitor filter and a ripple voltage of 2V. As shown in Fig.9.6, the minimum load voltage from the power supply which is minimum input voltage to the regulator is given by

$$V_{I\,min} = V_O + \text{dropout voltage} \quad (9.1)$$

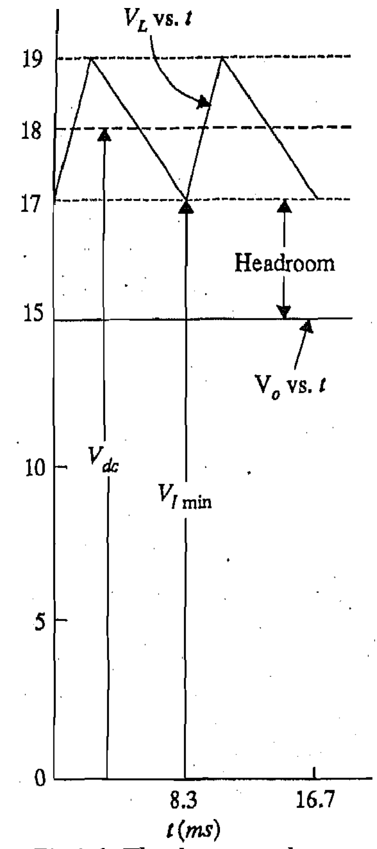

Fig.9.6: The dropout voltage.

where $V_{I\,min}$ is the minimum input voltage to the regulator, V_O is regulated voltage output from the regulator. Thus

$$V_{I\,min} = 15V + 2V = 17V.$$

Therefore, the dc voltage output of the power supply feeding the rcgulator should be at least 18V (17V + half the ripple voltage, i.e. 1V in this example). The dropout voltage or headroom should not be too large either. A higher dc voltage fed by the power supply to the regulator wastes more heat in the regulator.

SAQ 2

Will you use a fixed voltage regulator IC giving it too much headroom?

9.3.2 Self Protection Circuits

There is internal circuitry to protect these devices from load currents exceeding the limiting values. If the load current exceeds the limiting value specified by the manufacturer, then the load current is autoinatically limited until the overload current is removed. And also, these regulators sense whether heat sinking is proper or not. If the internal temperature of the regulator exceeds 150 to 175°C, it shuts down its operation. Once the fault in heat sinking is removed, the regulator starts functioning again.

9.3.3 Performance Parameters

There are four performance parameters associated with voltage regulators. These are line or input regulation, load regulation, temperature stability and ripple rejection. The input regulation is the change in the output voltage for a change in the input voltage and is measured as a percentage of output voltage. The load regulation is the change in the output voltage for a change in the input voltage. It is also measured as a percentage of the output voltage. Temperature stability is the change in the output voltage per unit change in the temperature and is measured in mV/°C. Ripple rejection is the ratio of peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage and is expressed in decibels (dB). For better regulations, the values of input regulation, load regulation and temperature stability should be smaller, and the value of ripple rejection should be higher.

SAQ 3

For a voltage regulator IC, define ripple rejection.

9.3.4 Fixed Voltage Regulators

The IC 7800 series of voltage regulators is for fixed positive voltage output with several voltage options from 5 to 24V. They have three pins—input, output and common ground. With proper heat sinking, they can deliver currents greater than 1 A. The package type and pin connections are shown in Fig.9.7. Standard application circuit for the voltage regulators is shown in Fig.9.8. The Capacitor C_I is needed if the regulator is located much away from the power supply filter, while C_O, though not required, improves the transient response of the regulator.

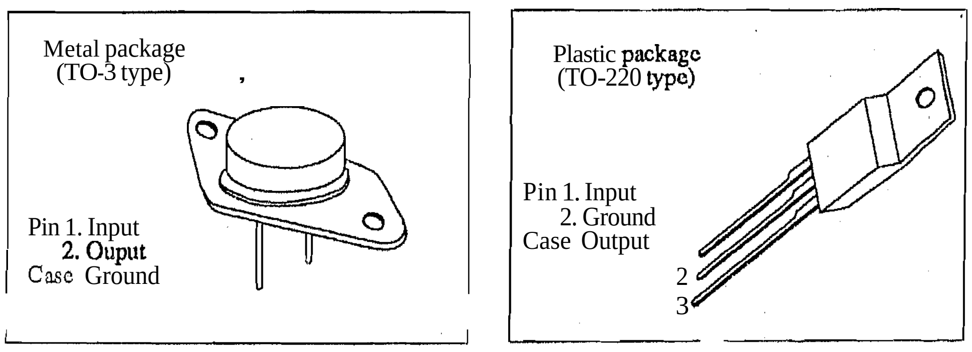

Fig.9.7: Package types and pin connections for the 7800 series ICs.

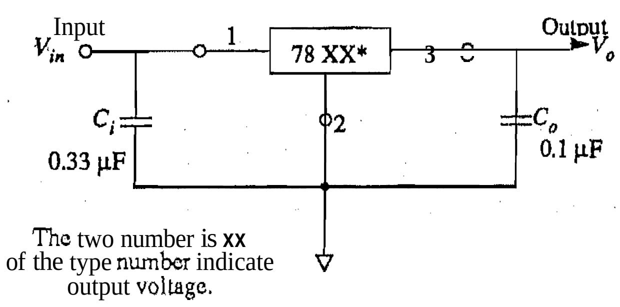

Fig.9.8: Standard application circuit for 7800 series ICs.

The IC 7800 series regulators can also be used as current sources. Consider the circuit of Fig.9.9 in which the 7805 is being used as a current source of 0.25 mA. The current supplied to the load resistor R_L is given by

$$I_L = \frac{V_R}{R} + I_Q \tag{9.2}$$

where I_Q is the quiscent current and its typical valuc is equal to 4.3 mA for the IC 7805. From Fig.9.9, V_R is the voltage drop across R which is the output voltage of the regulator. Therefore, $V_R = V_{23} = 5$ V. With $R = 20\ \Omega$, $V_R/R = 0.25$ A. Thus

$$I_L = 0.25\,\text{A} + 4.3\,\text{mA} \approx 0.25\,\text{A}$$

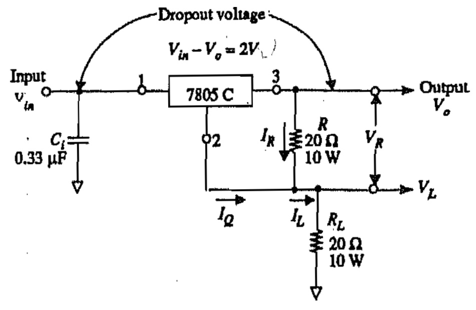

Fig.9.9: The IC 7805 as a current source.

The current $I_L = 0.25$ A is flowing through the load resistor R_L of 20Q producing a voltage drop across R_L equal to $V_L = I_L R_L = 5$V. The output voltage with reference to the ground is

$$V_O = V_R + V_L \tag{9.3}$$

$$= 5\text{V} + 5\text{V} = 10\text{V}.$$

With 2V dropout voltage in case of the IC 7805, the minimum input voltage required is 12V. Thus, we have a current source of 0.25 A. The amount of load current can be controlled by the choice of the value of R. However, the amount of a minimum input voltage required depends upon the valuc of R_L and the dropout voltage.

The IC 7900 series is of fixed negative voltage regulators. These arc complements to the IC 7800 series fixed voltage regulators. They arc also available in the same range in which the 7800 ICs are available and have two extra option of –2 and –5.2 V. The package types and the pin-out diagram for the IC 7900 scrics are shown in Fig.9.10.

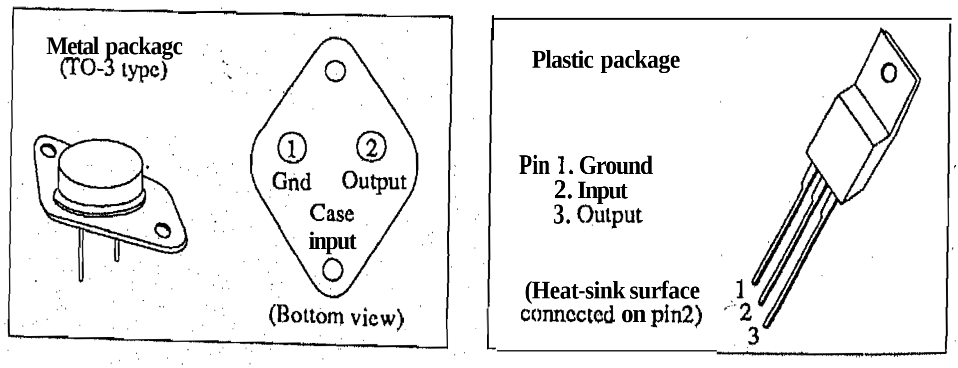

Fig.9.10: Package types and pin connrctionr for the 7900 series ICs.

9.3.5 Adjustable Voltage Regulator

The pin connections of four standard package regulators are shown in Fig.9.11.

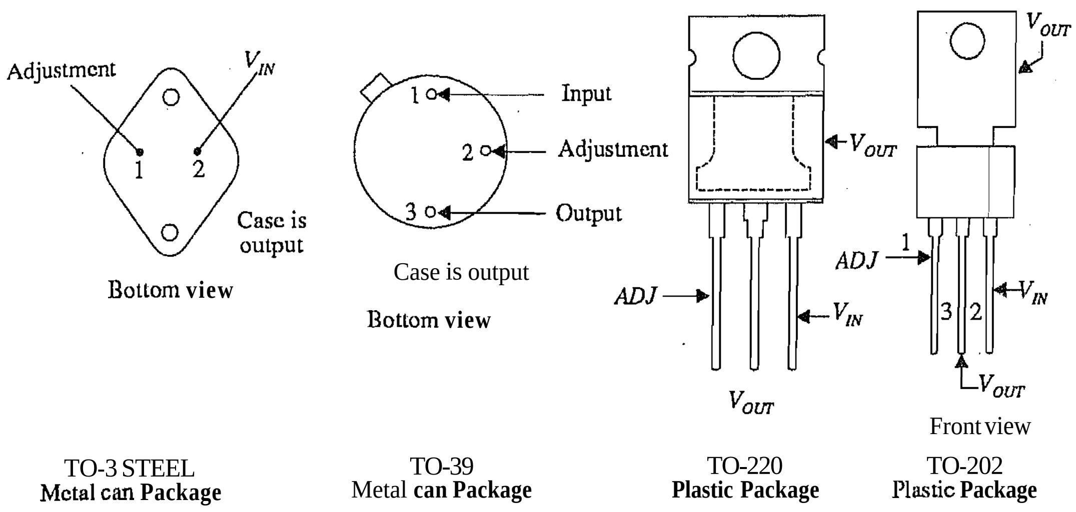

Fig.9.11: Standard package types and pin connections for the LM317 series ICs.

A typical connection diagram for using these ICs is shown in Fig.9.12. A 240Ω resistor R_1 is connected between the output and adjustment pins to conduct a current of $I_1 = V_{REF}/R$ through R_1. Since the reference voltage is constant, therefore I_1 is also constant for the value of R_1. This resistor is known as current set or programme resistor as it sets the current I_1. A small but fixed value of current also flows out of the adjustment pin through the output set resistor R_2. The maximum value of the current I_{ADJ} is 100 μA. Thus the output voltage is

$$V_O = R_1 I_1 + (I_1 + I_{ADJ})\, R_2$$

$$= I_1\, (R_1 + R_2) + I_{ADJ}\, R_2$$

$$= \frac{V_{REF}}{R_1}\,(R_1 + R_2) + I_{ADJ}\, R_2$$

$$= V_{REF}\left(1 + \frac{R_2}{R_1}\right) + (100\ \mu\text{A})\, R_2 \qquad (9.4)$$

$$= V_{REF}\left(1 + \frac{R_2}{R_1}\right) \qquad (9.5)$$

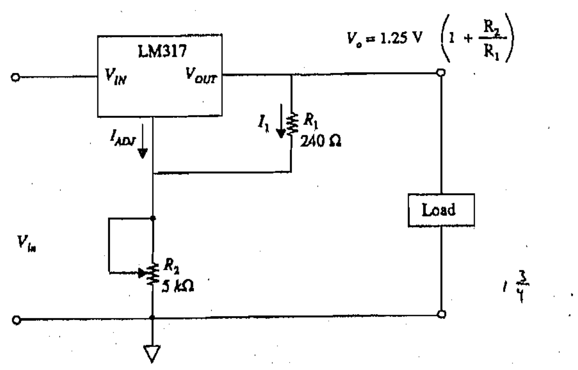

Fig.9.12: A connection diagram for the IC LM317.

The second term is ignored as it is very small (Maximum I_{ADJ} = 100 μA). Thus any desired value of the regulated output voltage can be obtained by changing R_2. The current set resistor R_1 which is normally 240Ω is connected directly to the regulator output pins rather than near the load for good load regulation, The dropout voltage for the LM317 is 3V. So the lower point on the input voltage should be at least 3V above the regulated output voltage.

The bypass capacitors C_1 (0.1 μF) and C_2 (1 μF tantalum) are connected as shown in Fig.9.12. While C_1 minimises the problems caused by long leads between the rectifier and the regulator, C_2 improves transient response. Any ripple voltage from the rectifier will be reduced by a factor of 1000 if R_2 is bypassed by a 10 μF electrolytic capacitor. While using external capacitor, it becomes quite often necessary to provide additional protection by connecting diodes D_1 and D_2 as shown in Fig.9.13 to prevent the capacitors from discharging through low current points into the regulator. However, the diodes are not needed if the output is less than 25 V and the bypass capacitors are of values less than 25 μF.

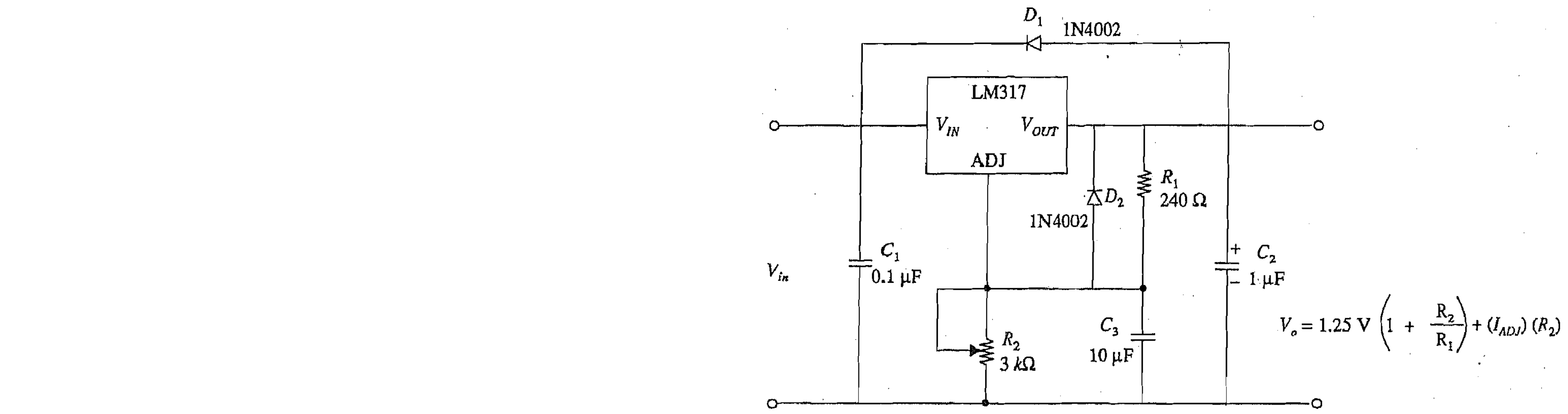

Fig.9.13: Use of capacitors and protective circuit for the IC LM317.

The IC LM337 series of adjustable voltage regulators is the complement of the IC LM317 series devices. They are also available in tlie same range of voltages and currents as shown in Table 9.2. The package types and pin connections are shown in Fig.9.14, The adjustable regulators operate in the same way as the positive adjustable regulators with the difference that R_1 is 120 Ω.

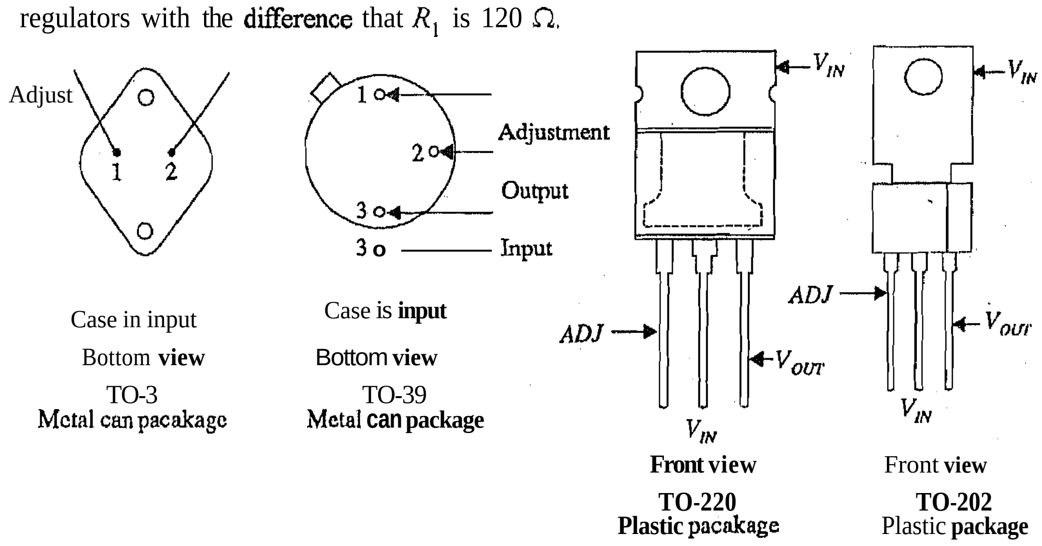

Fig.9.14: Standard package types and pin connections for the LM337 series of ICs.

Example 9.2

Using an IC LM317, design an adjustable voltage regulator for an output voltage of 5 to 20V.

Solution:

Using equation (9.4) and $R_1 = 240\,\Omega$, we get

$$5\text{V} = 1.25\left(1+\frac{R_2}{240\,\Omega}\right) + (100\,\mu\text{A})\,R_2$$

$$= 1.25 + R_2\left(\frac{1.25}{240} + 10^{-4}\right)$$

$$= 1.25 + R_2\,(5.3 \times 10^{-3})$$

$$R_2 = \frac{3.75}{(5.3)\,(10^{-3})}$$

$$= 708\,\Omega$$

Similarly, for 20V, the value of R_2 is

$$20 = 1.25\left(1+\frac{R_2}{240}\right) + (10^{-4})\,R_2$$

$$R_2 = \frac{18.75}{(5.3)\,(10^{-3})}$$

$$= 3538\,\Omega.$$

Thus to obtain an adjustable voltage regulator for the voltage range from 5 to 20V, we need to vary the value of R_2 from $708\,\Omega$ to $3538\,\Omega$. Therefore, connect a carbon potentiometer of $5\,\text{k}\Omega$ as variable R_2. As stated earlier, connect C_1 of $0.1\,\mu\text{F}$, C_2 of $1\Omega\mu\text{F}$ and C_3 of $10\,\mu\text{F}$ for improved ripple rejection.

SAQ 5

What is reference voltage for the ICs LM317 and LM337?

SAQ *6*

What is dropout voltage in case of the ICs LM317 and LM337?

9.4 SUMMARY

- Though general purpose op amps can be used satisfactorily in certain applications, yet it is easier and cheaper to use some special purpose linear ICs commercially available in the market.
- Power amplifiers supply large signal current to current operated loads like speakers and motors. The IC LM380 manufactured by National Semiconductor is a very popular linear IC used in audio amplifiers. It can deliver a minimum of 2.5W (rms) power to a load of $8\,\Omega$. The gain of the IC LM380 is internally fixed at 50. However, it can be increased upto 300 and varied upto 50 by using positive feedback through external circuitry.
- The 7800 series of the voltage regulator IC is used for getting fixed positive regulated voltages in the range of 5 to 24V. These ICs require a dropout voltage of 2V, that is the input voltage to the regulator should be at least 2V more than the regulated voltage required even at the lowest point at the input ripple. Two capacitors C_I and C_O are used if the regulator is away from the power supply and to'improve transient response respectively.
- The 7900 series of ICs is the complement of the IC 7800 series and is for fixed negative regulated voltages. These ICs work in the same way as the 7800 series ICs works.

- The IC 7800 series voltage regulators can also be used as current source of desired values as stated in the text. Apart from the regulator IC, only two resistors are required for this application.
- The LM317 series of ICs is for adjustable positive regulated voltages. The voltage range available from the series is from 1.2V to 57V. The dropout voltage for these ICs is 3V. Apart from the IC, a 240Ω resistor is used between the output and adjustment pins to set the current and another resistor used is a carbon potentiometer which sets the adjustable output voltage. As stated in the text, three capacitors are also used with the IC for improved performance and ripple rejection.
- The IC LM337 series is the coinplement of the IC LM317 and is for adjustable negative regulated voltages. These ICs function in the same way as the ICs of the LM317 series function The only difference here is that the current set resistor is of 120Ω rather than 240 as in the case of LM317

9.5 TERMINAL QUESTIONS

1) What are the important characteristics of the IC LM380?
2) The output of a power supply with a capacitor filter is having a ripple voltage of 3V. What should be the dc voltage output of this power supply if the regulated output desired is of 10V? What is the number code of the regulator chosen by you for' this purpose?
3) A voltage regulator IC has a ripple rejection of 60 dB. If the ripple voltage at the input of the regulator is 5V, then what is value of the ripple at the regulator output?
4) Design an adjustable vollage regulator using IC LM317 for a voltage range of 8 to 16V.

9.6 SOLUTIONS AND ANSWERS

SAQs

1. Small signal amplifiers are basically voltage amplifiers which give at the load larger amplified voltages, while the large signal or power amplifiers supply large-signal currents to current-operated loads like speakers and motors. This is the main difference between the small-signal and large signal or power amplifiers.
2. No, because it will waste more heat in the regulator.
3. Definition given in section (9.3.3).
4. In case of ICs of 7800 serics, pin 1 is input, pin 2 is ground and pin 3 is output. Whereas, in case of ICs of 7900 series, pin 1 is ground, pin 2 is input and pin 3 is output.
5. It is the fixed voltage developed between the output and adjustment pins and is 1.25V.
6. 3V.

TQs

1) Characteristics are listed in section (9.2.1).
2) Choose the regulator IC 7810. This IC has a dropout voltage of 2V. Therefore, $V_{i\,min}$ = 10V + 2V = 12V. But the given power supply has a ripple of 3V. Hence the dc output of the power supply should be $V_{i\,min}$ +half the ripple voltage, that is 12 + 1.5 = 13.5V.

3) Ripple rejection $= 20 \log \frac{\text{ripple at input}}{\text{ripple at output}} = 60\,\text{dB}$ (given)

It means that log term should be equal to 3. It would be so when numerator in the log term is 1000 and denominator is 1. Hence, the input and output ripples are in the ratio of 1000:1. Since the input ripple is of 5V, the output ripple would be 5mV.

[Another way is to **put** the value of input ripple, and solve the equation for the output ripple].

4) Follow the steps given in the example 9.2 in the text. The value of R_2 for 8V is 1273Ω, and that for 16V is 2783Ω. Therefore, a carbon potentiometer of 3kΩ should be used.