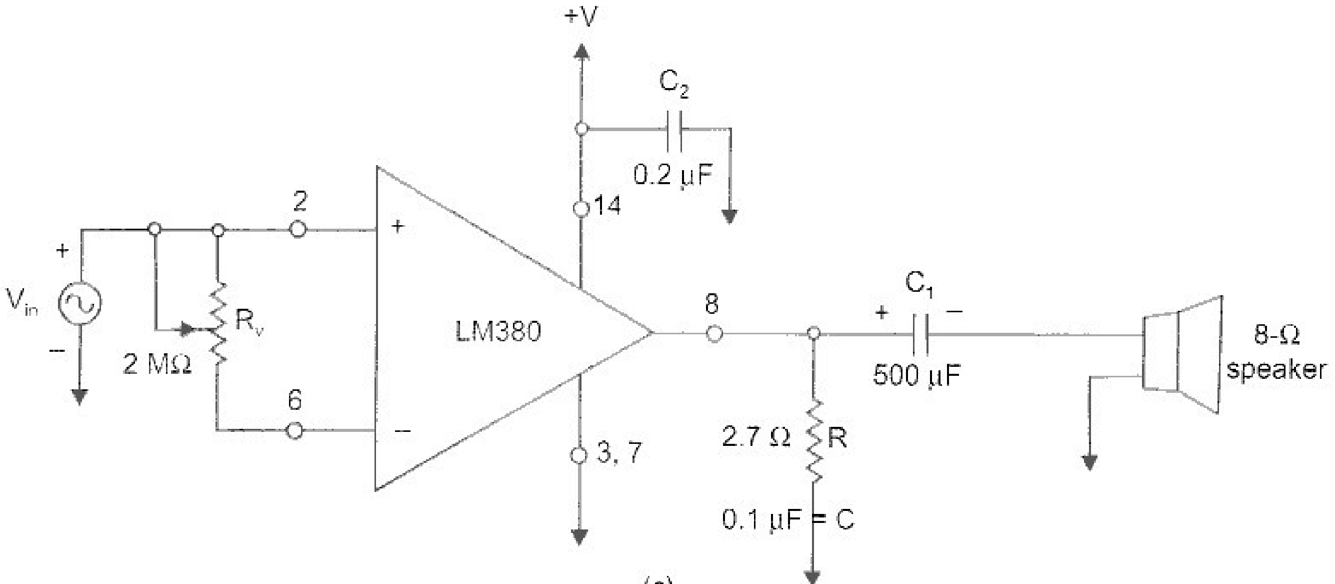


(c)

**Fig. 4.48** Audio power amplifier with variable gain

It is also possible to obtain variable gains up to 50 by using a potentiometer across the two input terminals as shown in Fig. 4.48.

## Bridge Power Audio Amplifier

If more power is required, than two LM380s can be used in the bridge configuration as shown in Fig. 4.49. The maximum output voltage swing will be twice that of a single LM380 and therefore the power delivered to the load will be four times. For better performance, a potentiometer $R_4$ should be used to balance the output offset voltages of the LM380s.

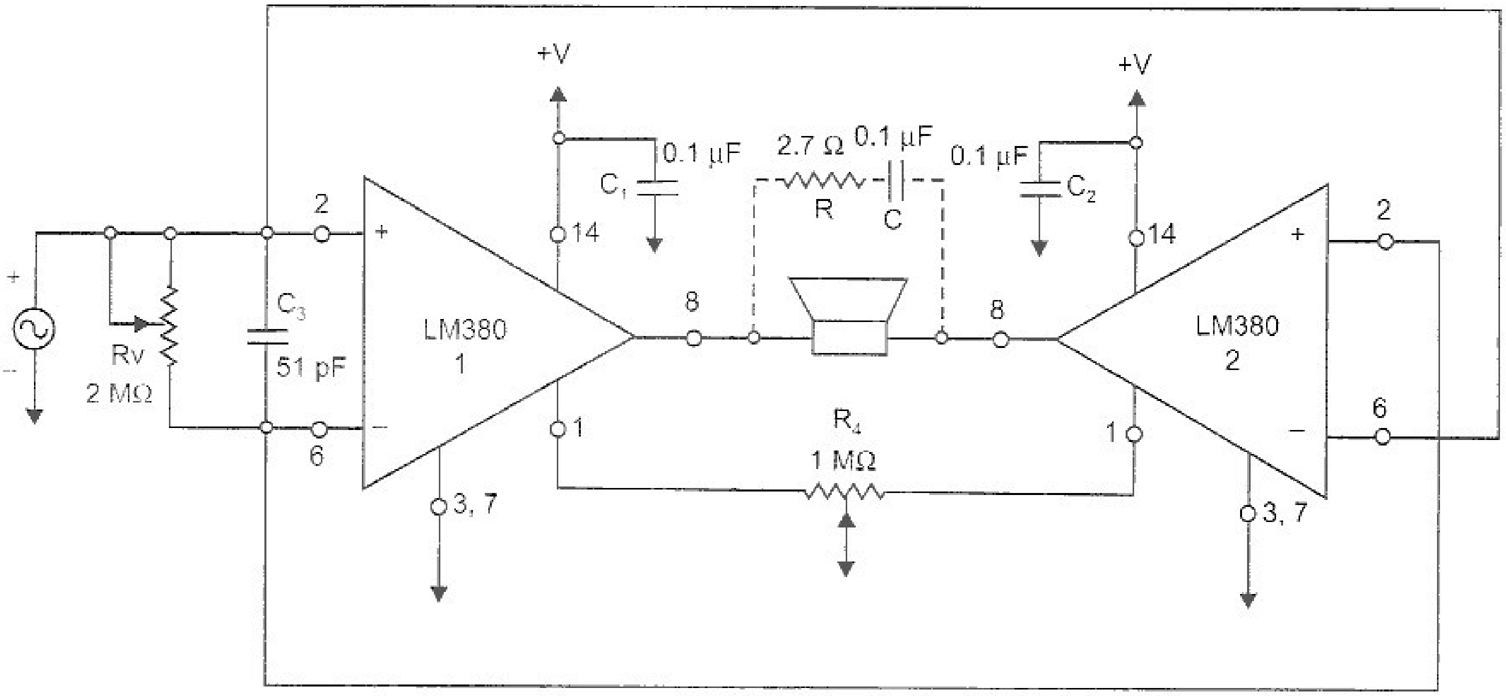


**Fig. 4.49** LM380s used in bridge configuration to provide more power (*R* and *C* for stability with high-current loads.)

## LM380 as Intercom System

A simple and inexpensive intercom system can be made by using the LM380 as shown in Fig. 4.50. The speakers used in this figure are permanent-magnet types and hence act as microphones as well. The talk and listen modes are defined with reference to a master station. When the switch is in the talk position, the master speaker acts as the microphone [see Figure 4.50 (a)]. On the other hand, when the switch is in the listen mode, the remote speaker acts as the microphone [Figure 4.50 (b)]. In either position the overall gain of the circuit is the same and depends on the turns ratio of the transformer $T$ as well as the internal gain of the LM380. For example, if the turns ratio $N_1/N_2 = 20$, the overall gain of the circuit will be 50 × 20 = 1000. However, the internal gain of the LM380 can be controlled with the use of potentiometer $R_v$.

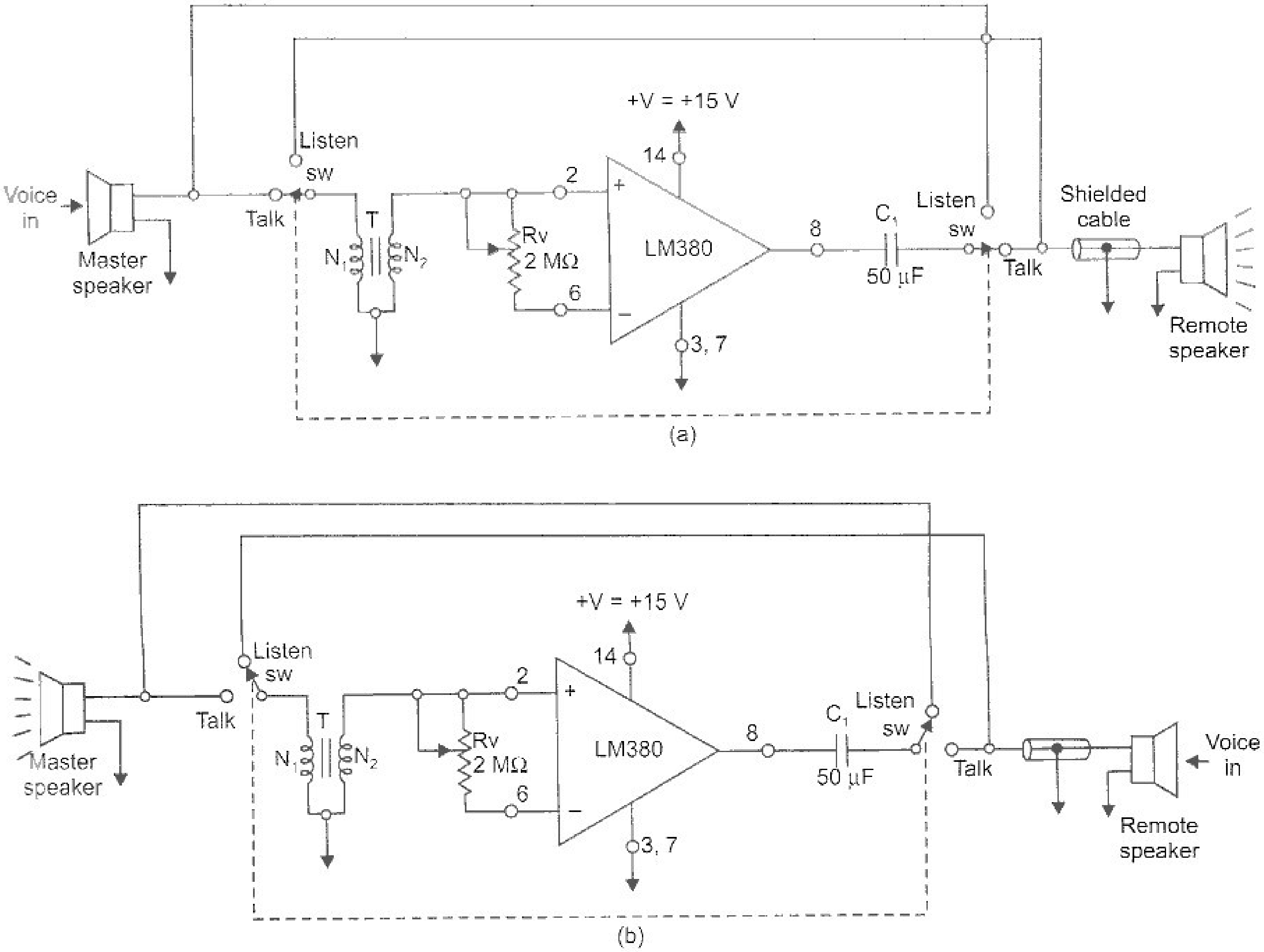


**Fig. 4.50** Intercom systems using the LM380: (a) Talk mode, (b) Listen mode

## Siren/Alarm using LM380 Power Amplifier

A siren/alarm system can be designed using LM380 power amplifier, as shown in Fig. 4.51. The MC1458 is a dual op-amp consisting of op-amps $A_1$ and $A_2$. The output of $A_1$ is square wave while the output of $A_2$ is a triangular or sawtooth waveform. The switch SW1 connects

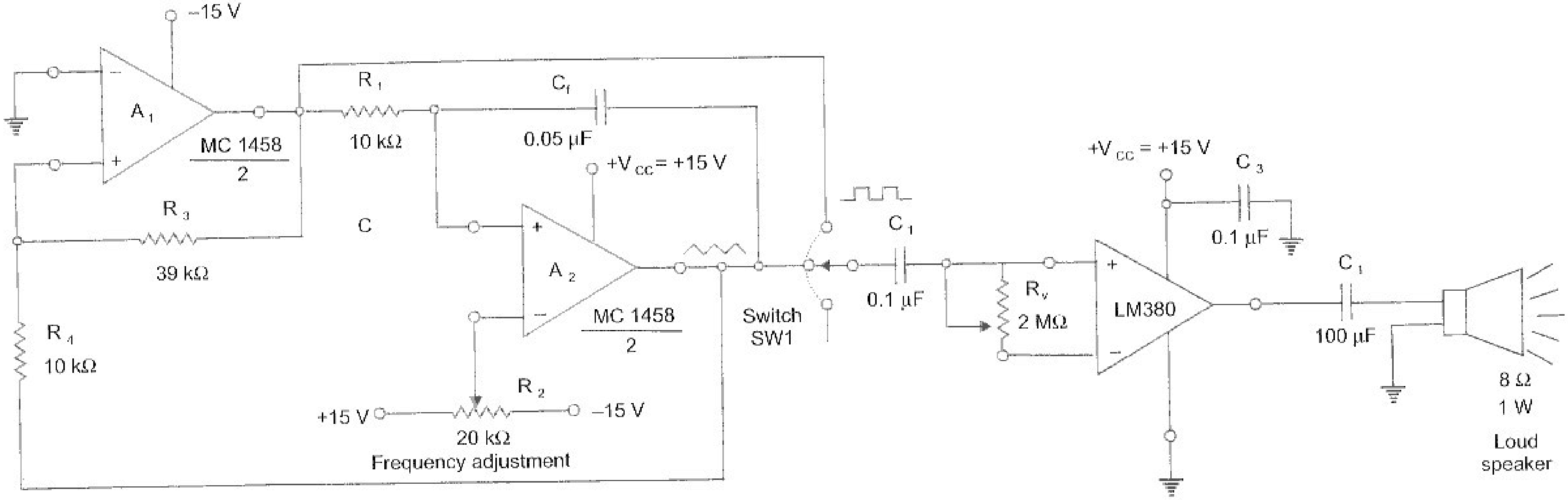


Fig. 4.51 Siren/alarm system using LM 380

the outputs of $A_1$ and $A_2$ to the LM380 audio amplifier. Only one output at a time, either of $A_1$ or $A_2$ gets connected to LM380 with the help of switch SW1. The LM380 drives the 8 Ω, 1 W speaker. The potentiometer $R_v$ connected at the input terminals of LM380 controls the sound level. The sound level depends upon the switch position, $R_2$ and capacitor $C_f$. Thus varying sound intensities can be obtained.

## SUMMARY

1. An op-amp can be used to perform mathematical operations such as scale changer, addition and subtraction.
2. An instrumentation amplifier is useful for amplifying low level signals which are obtained by sensing with a transducer in the measurement of physical quantities like temperature, water flow etc.
3. Op-amps can be used for amplifying both ac and dc inputs. A capacitively coupled amplifier is used for amplifying ac signals only.
4. The *V*-to-*I* converters are useful in low voltage dc and ac voltmeters, LED and zener diode testers.
5. The *I*-to-*V* converters are used for testing photo devices.
6. A diode in the feedback loop of an op-amp behaves as a precision diode as its cut-in voltage gets divided by the open-loop gain of op-amp.
7. A precision diode may be used for half-wave rectification, full wave rectification, peak-value detector, clipper and clamper.
8. A sample and hold circuit samples an input signal and holds on to its last sampled value until the input is sampled again. This circuit is used in analog to digital interfacing and pulse modulating systems.
9. Op-amp may be used to perform functions such as ln, log, antilog, multiply or divide signals.
10. The op-amp integrator and differentiator are useful for signal wave shaping.
11. Integrators are preferred over differentiators for analog computers as the gain of integrator decreases with increasing frequency and hence signal to noise ratio of integrator is higher than that of differentiator.
12. Monolithic audio power amplifiers with built in heat sink are available.
13. The operational transconductance amplifier (OTA) outputs a current proportional to its input voltage. OTAs are used to build programmable gain voltage amplifiers, voltage controlled resistances, neural networks etc.

## REVIEW QUESTIONS

4.1. Show with the help of circuit diagram an op-amp used as (i) scale changer, (ii) phase shifter, (iii) inverting adder and (iv) non-inverting adder. Draw an op-amp circuit whose output is $V_1 + V_2 - V_3 - V_4$.

4.2. What is an instrumentation amplifier? Draw a system whose gain is controlled by an adjustable resistance.

4.3. Explain the difference between the dc and ac amplifiers.

4.4. Draw and explain the operation of an ac voltage follower having very high input resistance.

4.5. Draw the circuit of a voltage to current converter if the load is (i) floating and (ii) grounded. Is there any limitation on the size of the load when grounded?

4.6. Draw and explain the operation of a current to voltage converter. If 741C is used, what is the lowest value of current that may be measured?

4.7. What is a precision diode?

4.8. Draw the circuit of a full-wave rectifier and explain how it gives the average value.

4.9. Name the circuit that is used to detect the peak value of the non-sinusoidal waveforms. Explain the operation.

4.10. Draw a sample and hold circuit. Explain its operation and indicate its uses.

4.11. Draw the circuit of a clipper which will clip the input signal below a reference voltage.

4.12. Draw the circuit of a log amplifier using two op-amps and explain its operation.

4.13. Indicate how two analog voltages are multiplied using log-antilog amplifiers.

4.14. Explain how to get the square and square root of the given analog signal.

4.15. What are the limitations of an ordinary op-amp differentiator? Draw the circuit of a practical differentiator that will eliminate these limitations.

4.16. Draw the circuit of a lossy integrator showing initial conditions.

4.17. Explain the difference between the integrator and differentiator and give one application of each.

4.18. Show the symbolic representation of the building blocks used in analog computer.

4.19. Explain why integrators are preferred over differentiators in analog computer.

4.20. Show the feedback arrangement to increase the gain of an audio power amplifier.

4.21. Discuss few applications of LM380 audio power amplifier.

4.22. What is the difference in OTA and conventional op-amp?

4.23. Discuss the application of OTA as programmable voltage amplifier and voltage controlled resistor.

## PROBLEMS

4.1. (i) Find $V_o$ in the circuit shown in Fig. P.4.1 if $R_f = 10$ kΩ, $R_1 = 2$ kΩ and $R_2 = 5$ kΩ.

(ii) Find $R_1$ and $R_2$ in Fig. P.4.1 if $V_o$ is the average of $V_1$ and $V_2$ and $R_f = 10$ kΩ.

4.2. Calculate $V_o$ for the circuit of Fig. P. 4.2. for $V_1 = 5$ V, $V_2 = 2$ V.

4.3. (i) In Fig. 4.2 (a), $V_1 = 0.1$ V, $V_2 = 0.2$ V, $V_3 = -0.3$ V, $R_1 = 4$ kΩ, $R_2 = 3$ kΩ, $R_3 = 1$ kΩ, $R_f = 4.7$ kΩ. Find output voltage $V_o$.

(ii) The circuit of Fig. 4.2 (b) is to be used as an averaging amplifier with the following specifications: $V_1 = V_2 = 1.5$ V, $V_3 = 3$ V, $R_1 = R_2 = R_3 = R = 1.5$ kΩ, and $V_o = 5$ V. Determine the value of $R_f$.

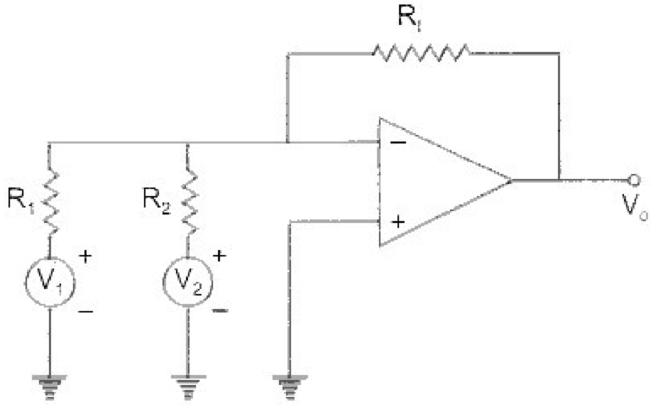


Fig. P. 4.1

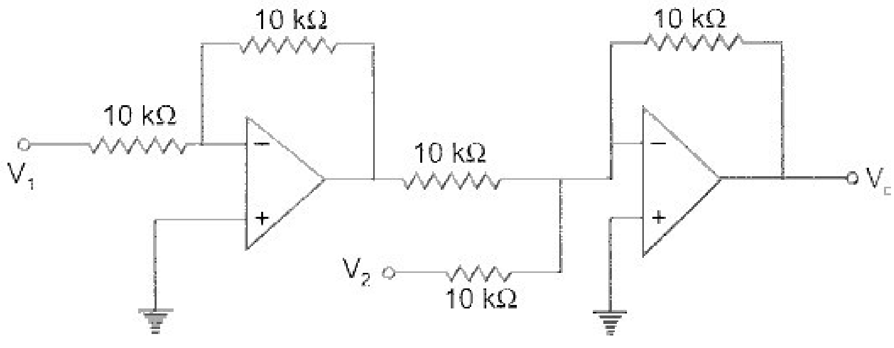


Fig. P. 4.2

4.4. In the circuit of Fig. P. 4.4, it can be shown that

$$V_o = a_1 V_1 + a_2 V_2 + a_3 V_3$$

Find the values of $a_1$, $a_2$ and $a_3$. Also find the value of $V_o$ if (i) $R_4$ is short circuited (ii) $R_4$ removed (iii) $R_1$ is short circuited.

4.5. Figure P. 4.5 shows a diff-amp with double ended output. Show that $V_o = \frac{R_2}{R_1}(V_1 - V_2)$ where $V_o = V_4 - V_3$.

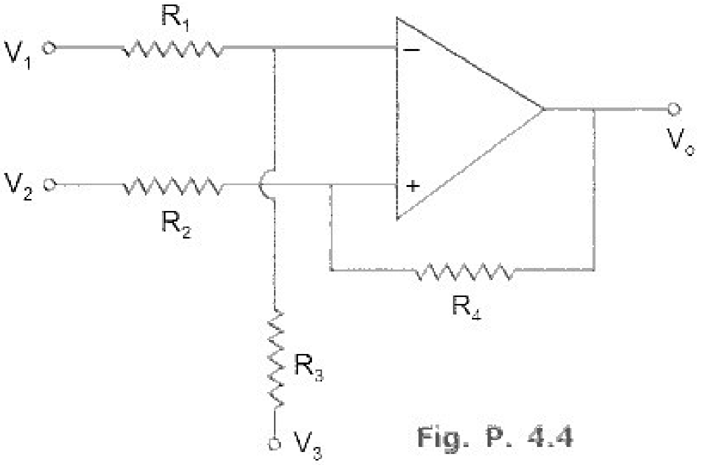


Fig. P. 4.4

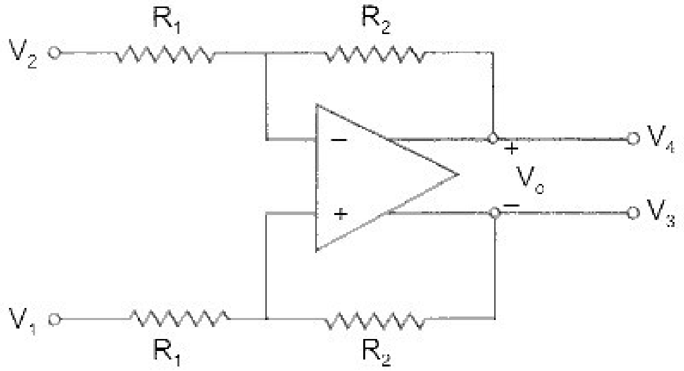


Fig. P. 4.5

4.6. For the instrumentation amplifier shown in Fig. P. 4.6 verify that,

$$V_o = \left(1 + \frac{R_2}{R_1} + \frac{2R_2}{R}\right)(V_2 - V_1).$$

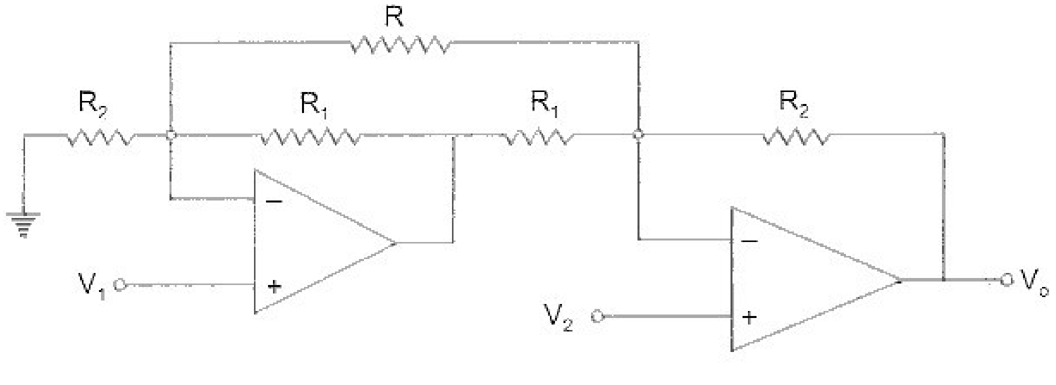


Fig. P. 4.6

4.7. In a peak detector of the type shown in Fig. 4.13 (a), $C$ = 0.01 μF, $v_i$ = 2 V pp square wave at 1 kHz. Draw the approximate output voltage waveform. Assume $R_f$ for the diode = 100 Ω.

4.8. In the circuit shown in Fig. P. 4.8. input is a sweep voltage $v_i = \alpha t$. Show that the output

$$v_o = -\alpha R'C - \alpha \frac{R'}{R} t.$$

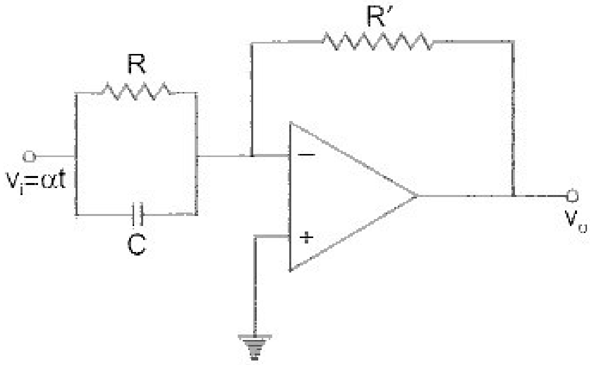


Fig. P. 4.8

4.9. The input $v_i$ to a differentiator of Fig. 4.21 (a) is shown in Fig. P. 4.9. Find the output $v_o$ if $R_f = 2$ kΩ and $C_1 = 0.1$ μF.

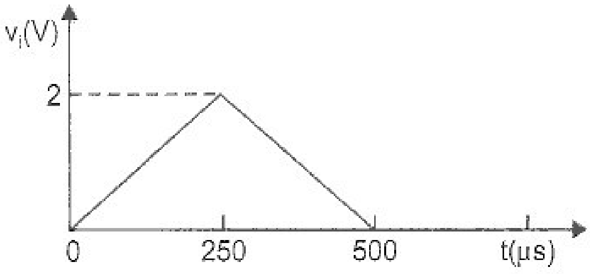


**Fig. P. 4.9**

4.10. In the integrator of Fig. 4.23, find the output $v_o$, if $R_1 = 10$ kΩ, $C_f = 0.02$ μF, $v_o(0) = 0$, and the input voltage is,

$$v_i = 4 \cos 10^4 t + 1.$$

4.11. Find the gain in dB of the lossy integrator of Fig. 4.25 (a) if $R_f = 10$ kΩ, $R_1 = 1$ kΩ, $C_f = 0.01$ μF, for (a) ω = 0, (b) ω = 10,000 rad/s.

4.12. Find $R_f$ and $R_1$ in Fig. 4.25 (a) so that the peak gain is 20 dB and the gain is 3 dB down from its peak when $f$ = 10,000 Hz. Use a capacitor of 1 nF.

4.13. Prove that the circuit shown in Fig. P. 4.13 is a non-inverting integrator with $v_o = \frac{2}{RC}\int v_i \, dt$.

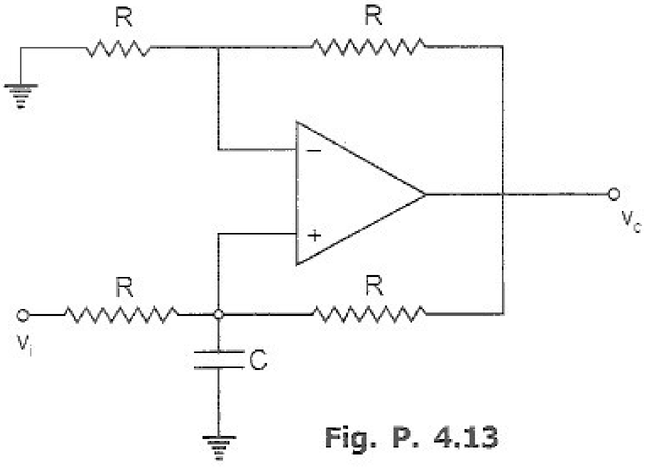


**Fig. P. 4.13**

4.14. An op-amp is used as an adder-integrator for two inputs $V_1$ and $V_2$. Two supply voltages + 10V and −10 V are available to allow for an initial output voltage which may be anywhere between −5 V and +5 V. Indicate the system using ganged switches so that in position 1, the initial condition is set and in position 2, the integration takes place.

4.15. Find the transfer function $v_o/v_i$ of the circuit shown in Fig. P. 4.15.

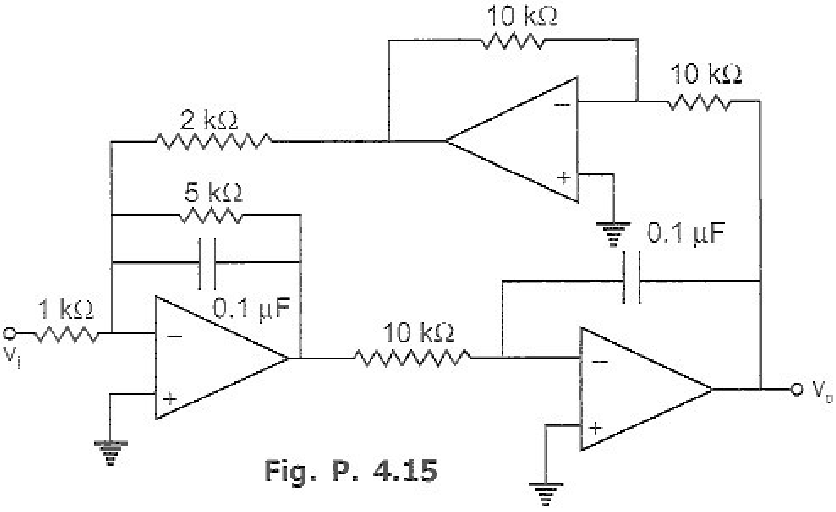
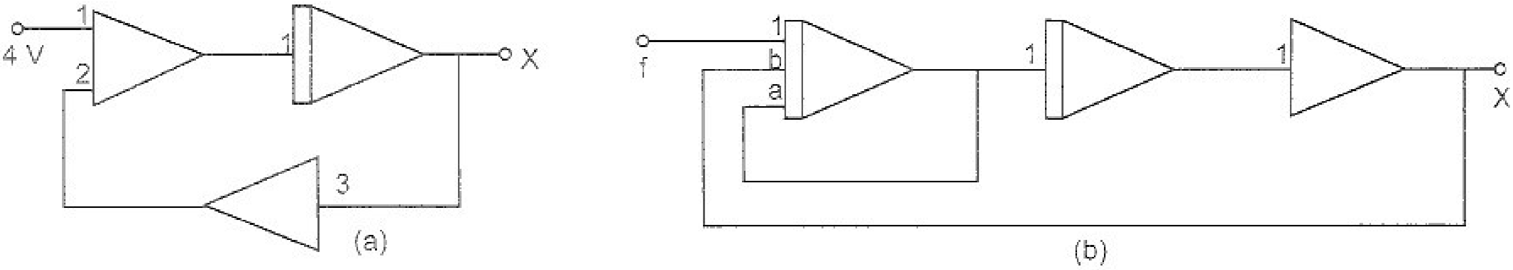


**Fig. P. 4.15**

4.16. Find the differential equation satisfied by the output $X$ in the circuit of Fig. P. 4.16 (a, b).



(a)

(b)

**Fig. P. 4.16**

4.17. Set up a computer simulation to solve the differential equation,

$$\frac{d^2 v}{dt^2} + 2v - 5 \sin \omega t = 0$$

where, $v(0) = -1$ and $\dot{v}(0) = 0$

Simulate also the input sinewave.

**Experiment 4.1**

To demonstrate the operation of an inverting summing amplifier using 741 op-amp.

## PROCEDURE

1. Connect the circuit as shown in Fig. E. 4.1 (a).
2. Since it is usually not possible to have two signal generators for one experiment, op-amp 1 is used as a voltage follower to give two signals $v_2$ and $v_1$ shown in Fig. E. 4.1. (a). In this case, the two input signals $v_1$ and $v_2$ will be equal. Set the signal generator to give peak-to-peak voltage of 1 V at 100 Hz.
3. Measure the output voltage $v_o$ using a CRO. The output should be

$$v_o = -\frac{R_f}{R_2} v_2 - \frac{R_f}{R_1} v_1$$

4. Observe the waveforms $v_1$, $v_2$ and $v_o$.
5. Note the phase of the output voltage $v_o$ with respect to input voltage.
6. If it is desired to add unequal voltages, use op-amp 1 as a non-inverting amplifier as shown in Fig. E. 4.1 (b). For the values chosen, the gain of the non-inverting amplifier will be 2.

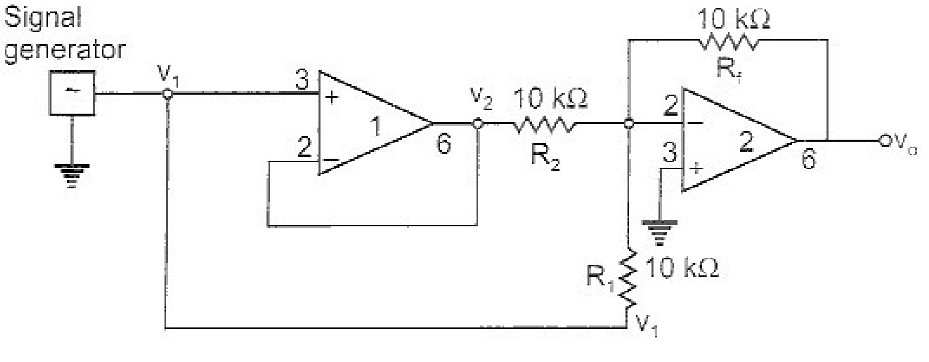


**Fig. E. 4.1** (a) An inverting summing amplifier

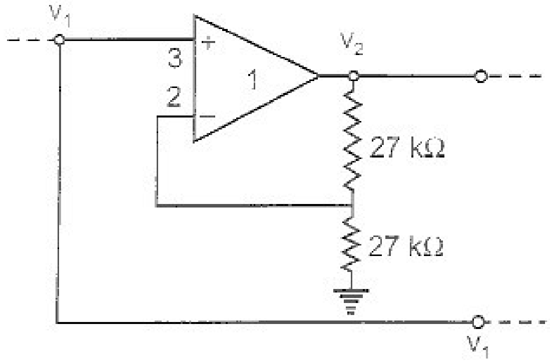


**Fig. E. 4.1** (b) Op-amp '1' connected as non-inverting amplifier

7. Set the signal generator to give 1 V pp sinewave at 100 Hz.
8. Repeat step 3, 4 and 5.

### Experiment 4.2

To demonstrate the operation of a Practical Differentiator.

## Design Aspects

### Practical Differentiator

In Fig. E. 4.2 the resistor $R_1$ reduces the high frequency noise and capacitor $C_f$ helps in suppressing oscillations. The circuit will provide reasonably accurate differentiation upto a frequency $f_a$, where,

$$f_a = \frac{1}{2\pi R_f C_1} \text{ Hz} \qquad \text{[see Eq. (4.71)]}$$

The values of $R_1$ and $C_f$ should be chosen so that $f_b = 10 f_a$ where,

$$f_b = \frac{1}{2\pi R_1 C_1} \qquad \text{[see Eq. (4.74)]}$$

and $\quad R_1C_1 = R_fC_f$

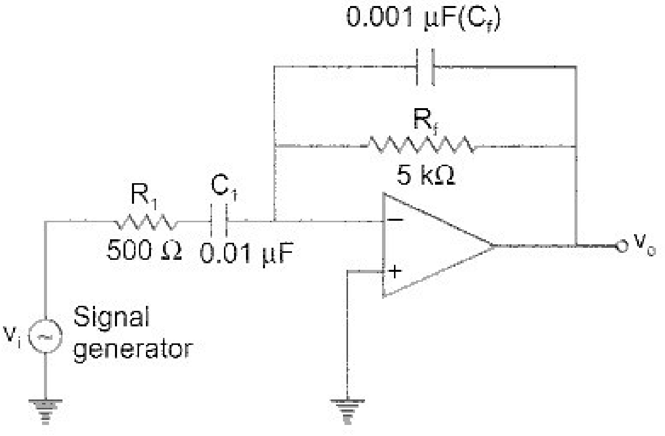


Fig. E. 4.2 A practical differentiator

For the given component values the highest frequency $f_a$ or $f_{max}$ up to which circuit will provide accurate differentiation is,

$$f_a = \frac{1}{2\pi R_f C_1} = \frac{1}{2\pi \times 5 \times 10^3 \times .01 \times 10^{-6}} = 3.18 \text{ kHz}$$

Thus, if we give an input signal of frequency 3 kHz, i.e.

If $\quad v_i(t) = 1 \sin 2\pi\ 3000t$

$$\text{Then, } v_o = -R_f C_1 \frac{dV_i}{dt}$$

$$= -5 \times 10^3 \times .01 \times 10^{-6} \frac{d(1 \sin 2\pi 3000\, t)}{dt} = -0.94 \cos 2\pi\ 3000t$$

The output waveform is also sinusoidal but it lags input by 90°. Note that the input frequency has not changed, but the amplitude has. The output amplitude of a differentiator is directly proportional to the input frequency, thus, if input frequency is changed to 1.5 kHz, the output amplitude will be half the present value.

## PROCEDURE

(i) Connect the differentiator circuit shown in Fig. E. 4.2. Adjust the signal generator to produce a 5 volt peak sine wave at 100 Hz.

(ii) Observe input $v_i$ and output $v_o$ simultaneously on the oscilloscope. Measure and record the peak value of $v_o$ and the phase angle of $v_o$ with respect to $v_i$.

(iii) Repeat step (ii) while increasing the frequency of the input signal. Find the maximum frequency at which the circuit performs differentiation. Compare it with the calculated value of $f_a$.

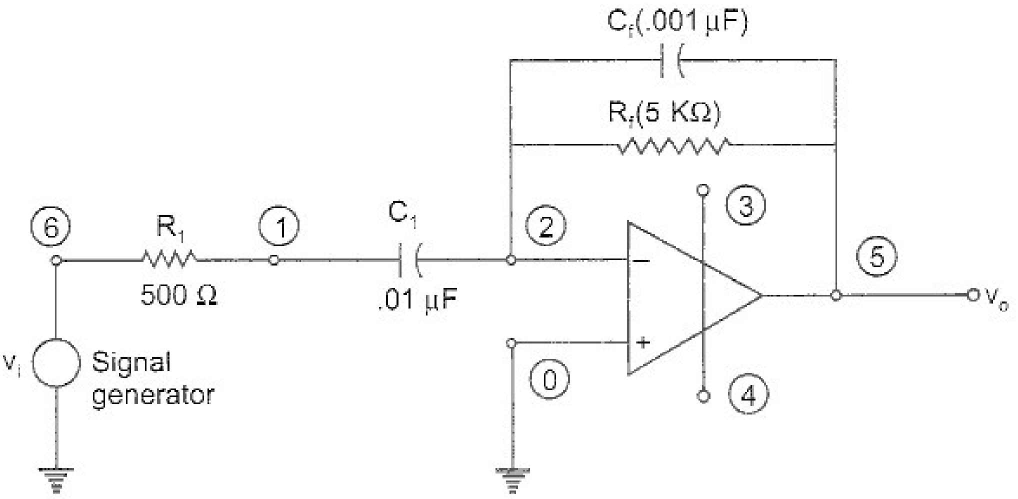


Fig. C. 4.2 (a) Practical differentiator redrawn for PSPICE program

### Computer Program 4.2

The circuit of a practical differentiator shown in Fig. E. 4.2 has been redrawn in Fig. C. 4.2 (a) where various terminals have been numbered for writing the PSPICE program. The program listing is shown in Fig. C. 4.2 (b) and the output waveforms for a sinusoidal input of 3 kHz is shown in Fig. C. 4.2 (c). It may be noted that the output is plotted after several cycles of the input has passed through to achieve steady state results.

### Fig. C. 4.2 (b) Program Listing

```
*Practical Differentiator-sine wave input
* * * * Circuit Description
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * *
```

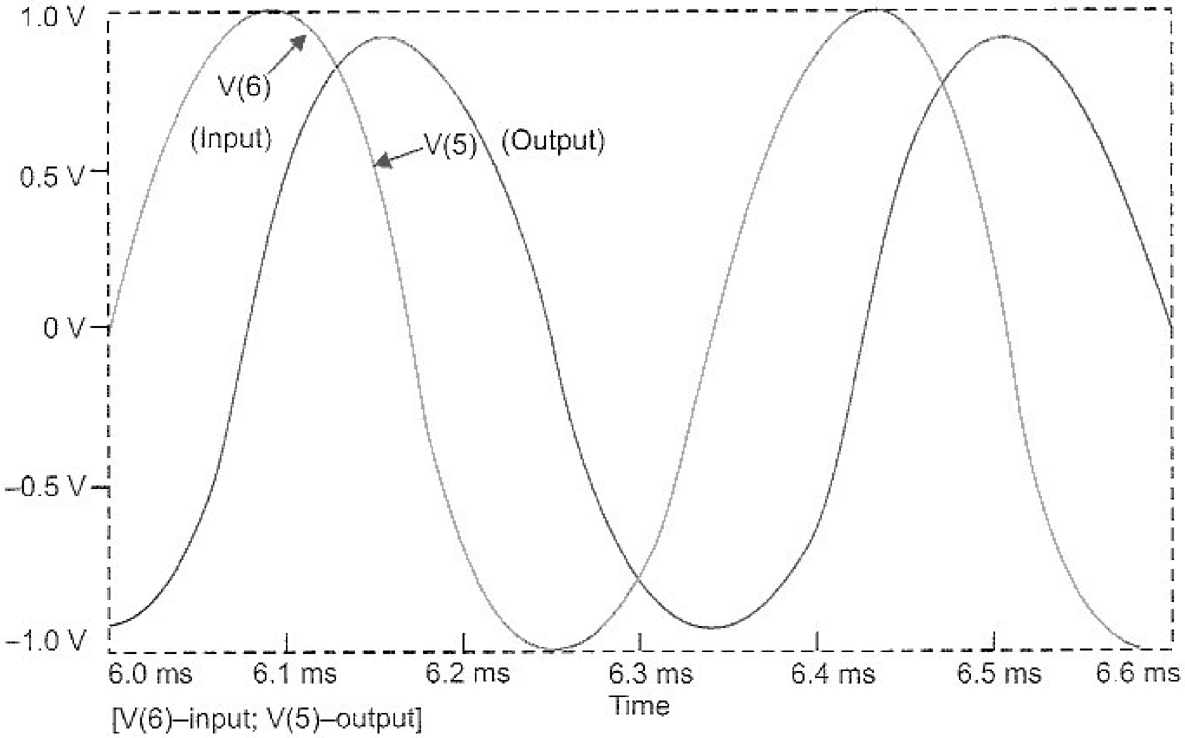


Fig. C 4.2 (c) Input and output waveforms of a practical differentiator

```
    R1  6  1  .5K
    C1  1  2  .01µF
    RF  2  5  5K
    CF  2  5  .001µF
*   Op-amp analysis
    X1  0  2  3  4  5  µA741
    . LIB  EVAL.LIB
*   Power supplies
    VCC  3  0  DC  15V
    VEE  0  4  DC  15V
*   Input signal source
    Vi  6  0  sin  (0  1V 3 kHz)
*   Output
    .TRAN  6µs  6600µs  6000µs  .001ms
    .PROBE
    .END
```

### Experiment 4.3

To demonstrate the operation of a Lossy Integrator.

### Design Aspects

Figure E. 4.3 (a) shows a lossy integrator designed in Example 4.4.

The resistor $R_f$ (100 kΩ) is connected across the 0.01 μF capacitor to prevent the amplifier from saturation due to the presence of any dc offset in the input.

Choose $R_f C_f$ = period of the signal to be integrated = $1/f_a$ and $R_f = 10\ R_1$.

For $f < f_a$, the circuit behaves as an inverting amplifier and output is given by

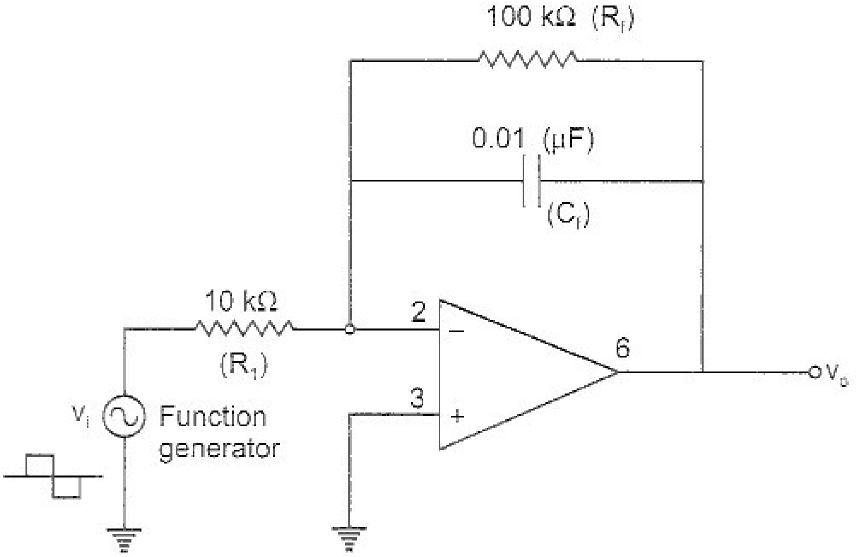


**Fig. E. 4.3** (a) A Lossy integrator

$$v_o = -\frac{R_f}{R_1} v_i$$

For $f > f_a$ the circuit is an integrator and output is

$$v_o = \frac{1}{R_1 C_f} \int v_i \, dt$$

### PROCEDURE

(i) Connect the integrator circuit shown in Fig. E. 4.3 (a). Set the function generator to produce a square wave of 1 V peak-to-peak amplitude at 500 Hz. View simultaneously output $v_o$ and input $v_i$.

(ii) Slowly adjust the input frequency until the output is a good triangular waveform. Measure the amplitude and frequency of the input and output waveforms.

(iii) Verify the following relationship between $R_1C_f$ and input frequency $f$ for good integration

$$f > f_a = \frac{1}{R_1C_f}$$

(iv) Now set the function generator to a sine wave of 1 V peak-to-peak and frequency 500 Hz. Adjust the frequency of the input until the output is a negative going cosine wave. Measure the frequency and amplitude of the input and output waveforms.

### Computer Program 4.3

The circuit diagram of the Lossy Integrator designed in Example 4.4 has been redrawn in Fig. C. 4.3 (a) with various nodes numbered for writing the PSPICE program. The program listing is shown in Fig. C. 4.3 (b). The response of the circuit for sine wave, step input and square wave input have been shown in Fig. C. 4.3 (c).

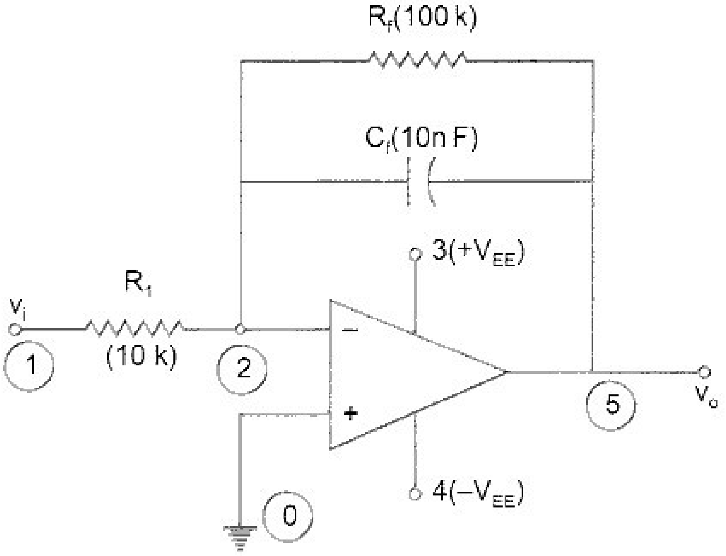


**Fig. C. 4.3** (a) Circuit for Program 4.3

**Fig. C. 4.3 (b): Program Listing**

```
**************************
*  A Lossy Integrator
   R1  1  2  10K
   RF  2  5  100K
   CF  2  5  10nF
*  Op-amp analysis
   X1  0  2  3  4  5  µA741
   .LIB EVAL.LIB
*  Power supplies
   VCC  3  0  DC  15V
   VEE  0  4  DC  15V
*  Sine wave input
   Vi  1  0  sin  (0  1V 5Khz)
*  Output for sinewave input
   .TRAN  .5ms  2.5ms  2ms  .001ms
*  Square Wave Input
*  Vi  1  0  PULSE (−1V 1V 0ms 0ms 0ms .1ms .2ms)
*  Output for square wave input
*  .TRAN  .2µs  5ms  4ms  .001ms
*  Step Input
   * Vi 1 0 PULSE (0V 1V  0ms 0ms 0ms 1ms 1ms)
   * Output for step input
   * .TRAN  .2µs  .3ms  0ms  .001ms
   .PROBE
   .END
```

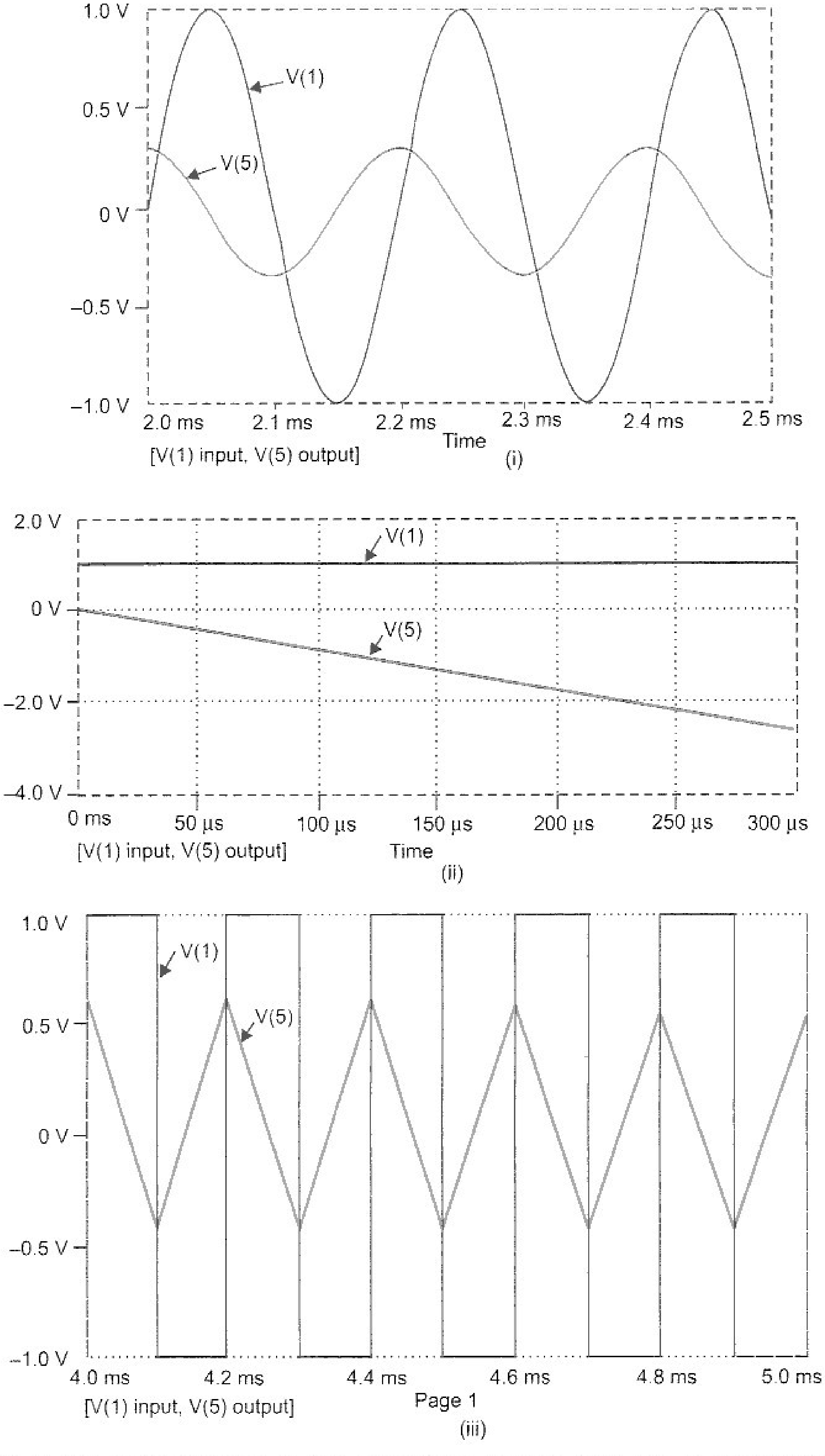


**Fig. C. 4.3** (c) Response to (i) Sine wave input, (ii) Step input, (iii) Square wave input