Experiments with Operational Amplifiers

3. Resistive feedback circuits

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An operational amplifier is normally used in a negative feedback circuit, and the performance of the circuit is then primarily determined by the magnitude of the external components connected to the amplifier. Examples of the basic operational feedback amplifier configurations using resistive feedback are illustrated in Fig. 3.1.

It is instructive to verify the performance equation for each circuit. Input signal terminals are initially earthed and the offset balance potentiometer adjusted to give zero voltage at the output of the amplifier. An input signal is applied and input and output voltages are measured; resistor values are changed and the measurement is repeated. Both d.c. and a.c. signals may be applied, and an oscilloscope used to monitor and measure a.c. signals. Typical waveforms obtained when the circuit of Fig. 3.1(b) is used to add together a triangular wave and a square wave are shown in Fig. 3.2. Note that if the signal generator has any d.c. offset it may be necessary to apply a.c. signals to the amplifier through a d.c. blocking capacitor.

In the circuit of Fig. 3.1(c) the two inputs should initially be connected together and a sinusoidal signal applied to them. Resistor R_2* should then be trimmed in order to eliminate the common mode signal at the output.

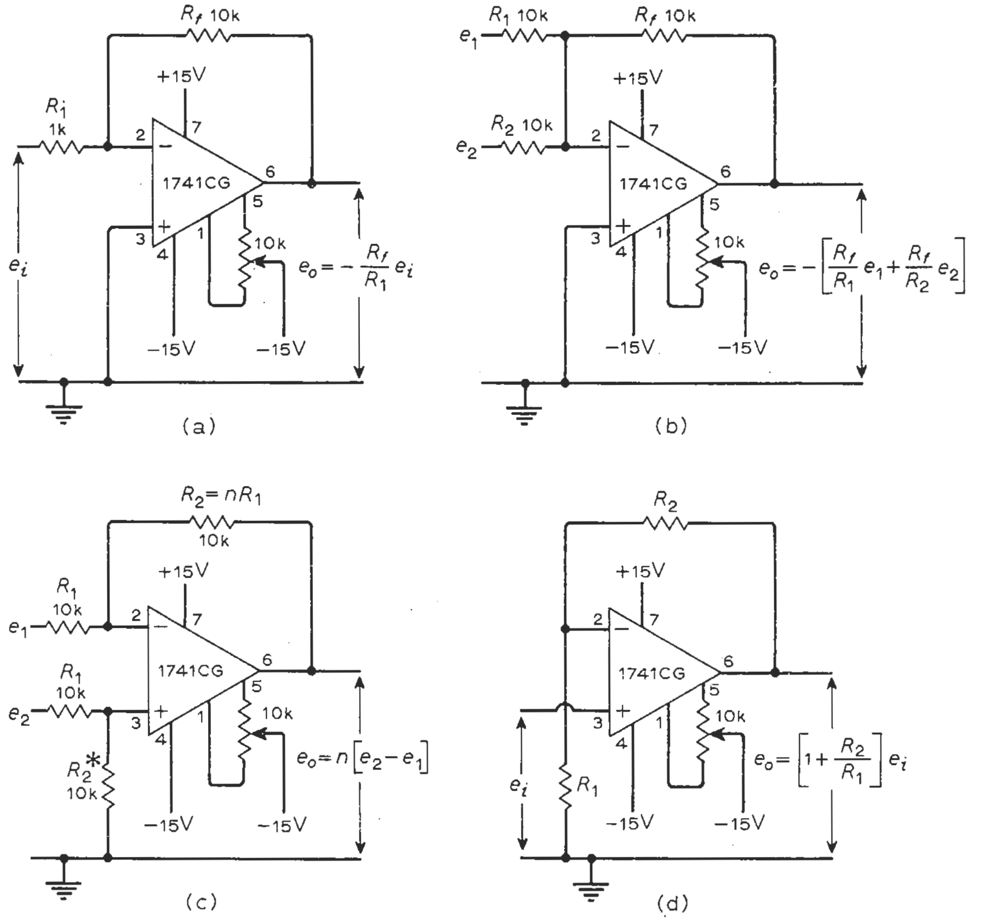

Fig. 3.1. Different arrangements of op-amps with resistive feedback: (a) simple inverter; (b) inverting adder; (c) subtracting amplifier; (d) non-inverting amplifier.

Closed loop gain and bandwidth

The bandwidth of a feedback amplifier is dependent upon the magnitude of the closed loop gain. The effect may be investigated for the follower circuit of Fig. 3.1(d). A typical set of experimental results is shown in the table below.

R_2 (Ω)	R_1 (Ω)	gain (dB)	frequency at which gain falls by 3dB (f_c)	log f_c
10k	10k	6dB	850kHz	5.93
10k	1k	20.8dB	97kHz	4.99
10k	100	40dB	10kHz	4.00
100k	100	60dB	1kHz	3.00

In performing the test the input signal amplitude should be adjusted to give an output signal of amplitude less than one volt, in order to avoid the effects of slew rate limiting at the output. A d.c. path must be provided for the bias current drawn by the non phase-inverting input terminal of the amplifier.

Results are plotted on a log graph in Fig. 3.3. The value obtained previously for the open loop gain of the amplifier is also shown in this graph.

Current to voltage converter

An operational amplifier may be used to measure current in two ways. The current may be converted into a voltage by passing it through a resistor and the voltage amplified by the operational amplifier connected

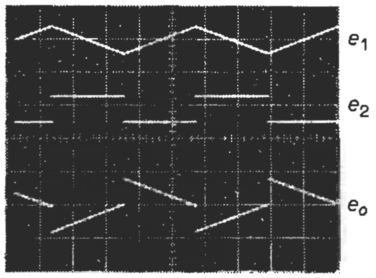

Fig. 3.2. Summation of triangular wave, e_1, and square wave e_2 to give e_0 in circuit of Fig. 3.1(b). Vertical scale 2V/div.; horizontal 1ms/div.

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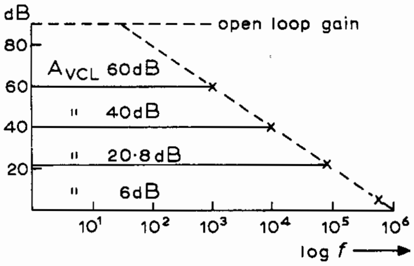

Fig. 3.3. Results of tests showing dependence of bandwidth on closed loop gain.

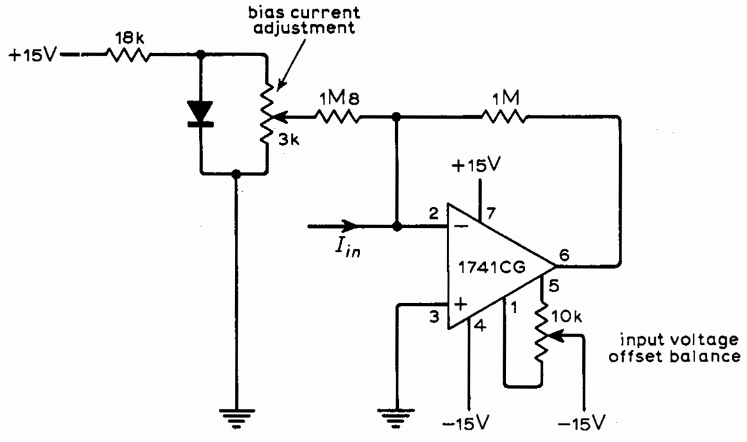

Fig. 3.5. Circuit for adjustment of input voltage offset and input bias current.

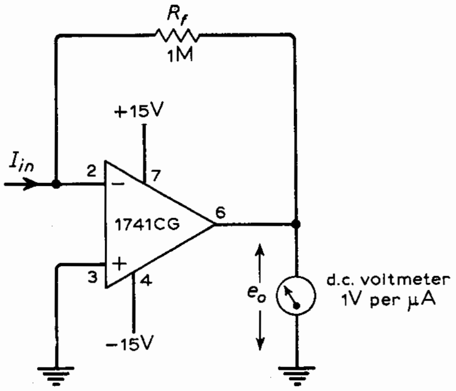

Fig. 3.4. Simple current to voltage converter.

as a non-inverting feedback amplifier. Alternatively the current may be injected directly into the summing point of the amplifier connected in the inverting configuration. Under these circumstances the current is forced to flow through the feedback resistor and the output voltage of the amplifiers is:

$$e_o = -I_{in}R_f$$

The current is converted into a voltage with a scaling factor R_f volts per amp.

A simple circuit for a current to voltage converter is shown in Fig. 3.4. In this circuit the effective input resistance is very small. This means that a current measurement made with the circuit introduces a negligible voltage drop in the measurement circuit. The output voltage offset with zero input current is typically 0.2V.

If the circuit is to be supplied by differing source impedances or if R_f is to be changed (for a change of scale), output offset should be nulled by separate balancing of both input voltage offset and input bias current. A circuit which provides for these adjustments is shown in Fig. 3.5. Input offset voltage is balanced first. Pins 2 and 3 are shorted together and the 10kΩ potentiometer is adjusted for zero amplifier output. The short is now removed and with zero input current the bias current potentiometer is adjusted so that the amplifier again gives zero output.

4. Operational integrators

An operational amplifier, with negative feedback applied to it via a capacitor connected between amplifier output terminal and phase inverting input terminal, may be used to perform the operation of integration. A circuit for a simple operational integrator is shown in Fig. 4.1; if the performance of the amplifier is assumed to be ideal the response of the circuit is described by the equation

$$e_o = -\frac{1}{CR}\int e_i\,dt \qquad (4.1)$$

The time constant $T = CR$ is called the characteristic time of the integrator; it is sometimes convenient to think of $1/T$ as the gain in terms of V/s output per volt input.

Measurement of integrator drift

In the practical circuit shown in Fig. 4.1 amplifier input offset voltage and bias current cause a continuous charging of capacitor C even when e_i is made zero. The output of the single integrator thus drifts with time and the amplifier eventually saturates. With zero applied input signal (resistor R connected to earth), the drift rate is given by the relationship

$$\frac{de_o}{dt} = \pm\frac{V_{io}}{C} + \frac{I_b^-}{C} \qquad (4.2)$$

V_{io} is the amplifier input offset voltage; I_b^- is the bias current drawn by the phase inverting input terminal of the amplifier.

A practical test for the validity of eq. (4.2) can be made by measuring drift rates for various values of capacitor C and resistor R. The following test procedure is suggested. The output of the integrator is applied to the d.c. coupled vertical amplifier of an oscilloscope; the input end of resistor R is earthed. The timebase of the oscilloscope is set to free run at a slow rate (say 1 div/sec). The integrator output is initially set to zero by shorting capacitor C. The short is removed and the drift rate is determined directly by observation and measurement of the slope of the oscilloscope trace. This slope may be positive or negative; it gives the sign of the drift, which is significant, and should therefore be noted. If an oscilloscope with slow sweep speeds is not available the output of the amplifier may be measured with a centre-zero voltmeter. Drift rates may then be found by measuring the change of voltage that takes place in a measured time period. The time period should not be so long that the amplifier drifts into saturation.

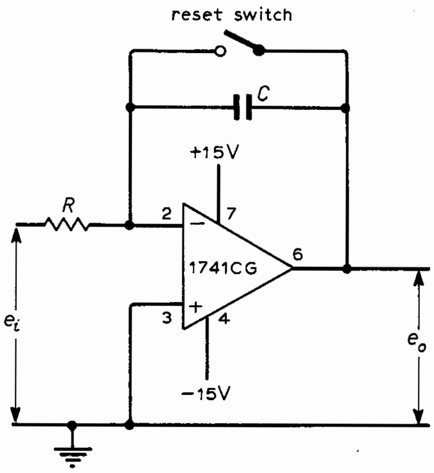

Fig. 4.1. Simple integrator.

A typical set of experimental results is shown in the table below.

	R (Ω)	C (F)	$\frac{1}{C}$	$\frac{de_o}{dt}$
$CR = 2\times10^{-3}$	39k	50n	2×10^7	+1.3V/s
	22k	100n	10^7	+0.35V/s
	3.9k	500n	2×10^6	−0.28V/s
	2.2k	1μ	10^6	−0.4V/s
$CR = 2\times10^{-2}$	390k	50n	2×10^7	+1.76V/s
	220k	100n	10^7	+0.84V/s
	39k	500n	2×10^6	+0.16V/s
	22k	1μ	10^6	+0.1V/s