Experiments with operational amplifiers

9. Multivibrators: free-running, monostable and bistable circuits

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Operational amplifiers are normally used in negative feedback circuits but when appropriate positive feedback connections are made to them they can be used to generate both sinusoidal and non-sinusoidal waveforms of defined frequency. In this section we investigate the way in which positive feedback may be applied to an operational amplifier in order to give a multivibrator type of circuit.

A circuit suitable for investigating the behaviour of a simple free-running multivibrator is illustrated in Fig. 9.1. Positive feedback is applied to the amplifier by the connection between the output terminal and non-phase-inverting input terminal via the divider R_2, R_1. The divider gives a positive feedback fraction

$$\beta = \frac{R_1}{R_1 + R_2}$$

The amplifier switches regeneratively and repetitively between saturated states, remaining in alternate states for time periods governed by capacitor charging. The amplifier remains in positive saturation for a time period.

$$t_1 = CR \log_e \frac{V^+_{o\,sat} - \beta V^-_{o\,sat}}{V^+_{o\,sat} - \beta V^+_{o\,sat}} \qquad (9.1)$$

and in negative saturation for a period

$$t_2 = CR \log_e \frac{V^-_{o\,sat} - \beta V^+_{o\,sat}}{V^-_{o\,sat} - \beta V^-_{o\,sat}} \qquad (9.2)$$

If the positive and negative output saturation limits have the same magnitude the two timing periods are equal and the waveforms produced are symmetrical.

It is suggested that the action of the circuit and the validity of eqns. 9.1 and 9.2 be investigated by observing and recording the waveforms at terminals 6, 3, and 2. Quantitative measurements should be made with the positive and negative swings and time periods of all waveforms recorded.

Typical waveforms for the circuit are illustrated in Fig. 9.2. The upper trace shows the amplifier output voltage as it switches between positive and negative saturation limits. The middle trace shows the signal at the non-phase-inverting input terminal switching between the limits $\beta V^+_{o\,sat}$ and $\beta V^-_{o\,sat}$, and the lower trace shows the exponential charging at the phase-inverting

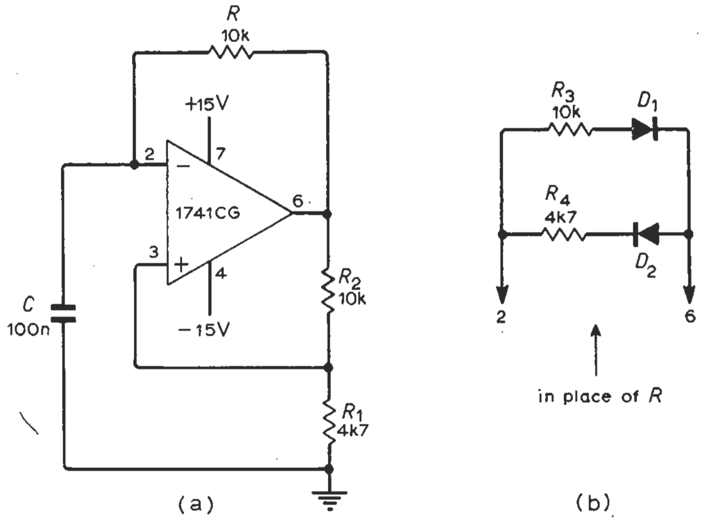

Fig. 9.1(a). Free-running multivibrator; (b) alternative timing resistors.

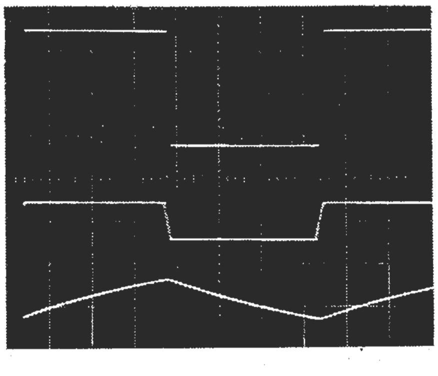

Fig. 9.2. Free-running multivibrator waveforms: upper trace, pin 6; middle trace, pin 3; lower trace, pin 2. Vertical scale, 10V/div.; horizontal scale, 0.2ms/div.

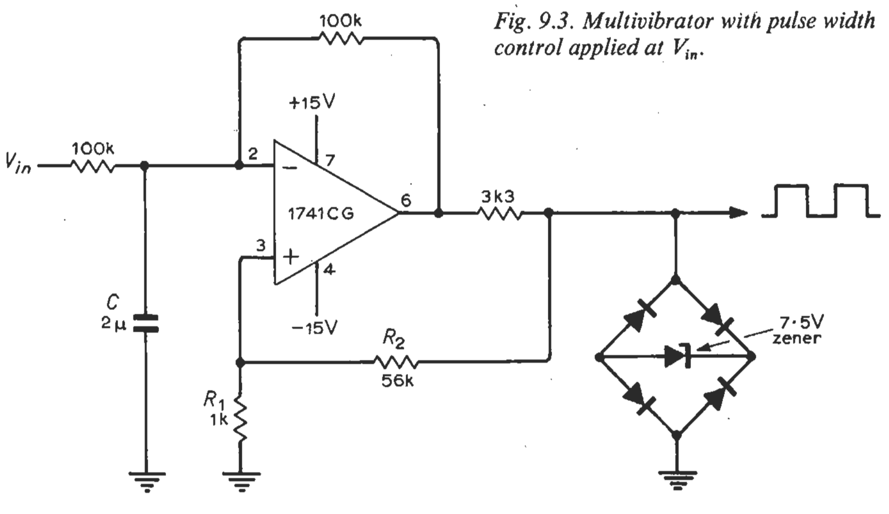

Fig. 9.3. Multivibrator with pulse width control applied at V_{in}.

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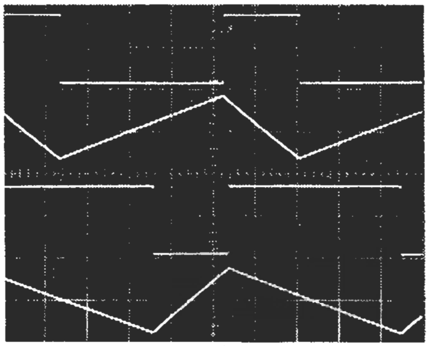

Fig. 9.4. Waveforms for free-running multivibrator (Fig. 9.3) with pulse width control. Traces show output voltage (10V/div.) and voltage at pin 2 (0.2V/div.) for V_{in} of +5V and −5V respectively. Horizontal scale, 2ms/div.

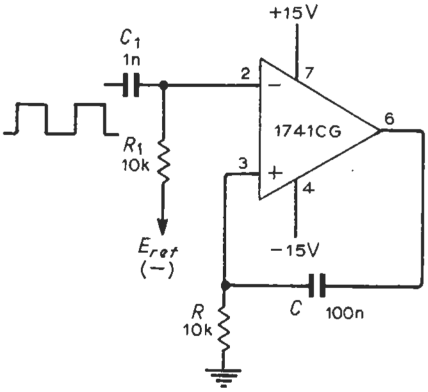

Fig. 9.5. Monostable multivibrator with timing period controlled by a reference voltage.

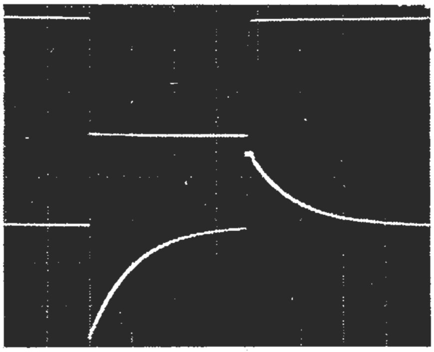

Fig. 9.6. Monostable waveforms for reference voltage −0.5V. Upper trace, pin 6; lower trace, pin 3. Vertical scale, 10V/div.; horizontal scale, 1ms/div.

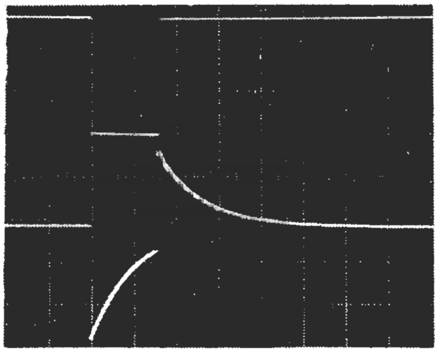

Fig. 9.7. Monostable waveforms for reference voltage −5V. Upper trace, pin 6; lower trace, pin 3. Vertical scale 10V/div.; horizontal scale, 1ms/div.

input terminal. The exponential goes up and down between the limits $\beta V^+_{o\,sat}$ and $\beta V^-_{o\,sat}$.

Components values should be substituted in eqns. 9.1 and 9.2 in order to compare predicted timing periods with those obtained experimentally. Further understanding of circuit action may be gained by changing component values and by making separate changes in the values of the positive and negative power supplies. The effect on the waveforms of each change should be noted and recorded, and the reader should then attempt to explain for himself these effects in terms of the action of the circuit.

A markedly non-symmetrical waveform can be obtained by using alternative timing resistors (R_3 and R_4) switched into the circuit by means of the diodes D_1 and D_2 as shown in Fig. 9.1(b). Resistor R in (a) should be replaced by this network and the observed waveforms recorded and explained. Note that the upper frequency limit for the action of the multivibrator circuit is set by amplifier slewing rate. This point should be verified.

Control of the pulse width produced by a free running multivibrator can be obtained by injecting an additional current into the phase inverting input terminal of the amplifier. The effect of this current is to increase one timing period and decrease the other. The action may be investigated using the circuit illustrated in Fig. 9.3.

The circuit includes a method for symmetrically clamping the output voltage limits of the amplifier by means of a diode bridge and zener diode. The clamp is not essential to the action of the circuit but is included to illustrate a method of output limiting. Output limiting may be applied to any of the switching circuits described in this section if the application requires it.

Waveforms obtained with the circuit of Fig. 9.3 are shown in Fig. 9.4. The traces show output voltage and voltage at pin 2 for V_{in} of +5V and −5V respectively. Pulse width is not linearly related to the input voltage because capacitor C charges exponentially. Linearity can be improved by reducing the amplitude of the waveform at pin 2 (by reducing R_1).

The circuit for a monostable multivibrator with timing period controlled by the magnitude of a reference voltage is given in Fig. 9.5. The permanently stable state for this circuit is with the amplifier output at its positive saturation limit, this condition being maintained by the negative reference voltage applied to the phase inverting input terminal of the amplifier. A positive triggering voltage applied to the phase inverting input terminal, of sufficient magnitude to bring the amplifier out of saturation, causes the circuit to switch regeneratively to its temporarily stable state. The circuit returns to its permanently stable state when the voltage at the non-phase-inverting terminal, which switches below earth by an amount ($V^+_{o\,sat} - V^-_{o\,sat}$), exponentially rises to the reference voltage level. The timing period for the circuit is given by the equation

$$T = CR \log_e \frac{V^+_{o\,sat} - V^-_{o\,sat}}{E_{ref}} \qquad (9.3)$$

The action of the circuit may be investigated by applying a square wave of level, say,

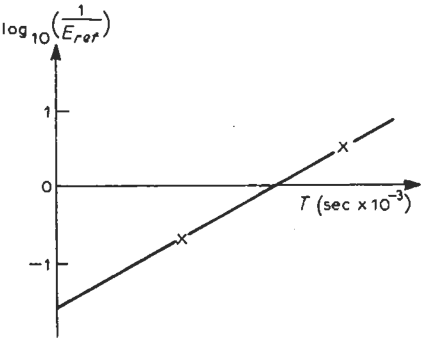

Fig. 9.8. Plot of $\log_{10}(1/E_{ref})$ against T.

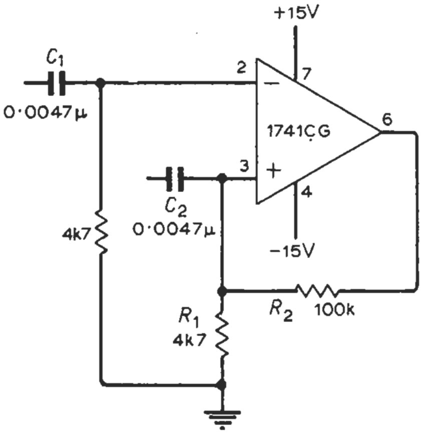

Fig. 9.9. Bistable multivibrator. Triggering may be applied at C_1 or C_2.

6V and frequency approximately 200Hz t the phase inverting input terminal via capacitor C_1. The square wave is differentiate by C_1R_1 and the positive pulses cause th monostable to make transitions. The waveforms appearing at pins 6 and 3 should b observed and recorded for different value of the reference voltage in the range −0.5V to −5V. Typical waveforms for referenc voltages −0.5V and −5V are shown i Figs. 9.6 and 9.7 respectively.

The validity of eqn. 9.3 is most conveniently checked by presenting the result graphically as shown in Fig. 9.8. By expressing logarithms to the base 10 and rearranging eqn. 9.3, the equation may be written

$$\log_{10}\frac{1}{E_{ref}} = \frac{T}{2.3CR} - \log(V^+_{o\,sat} - V^-_{o\,sat})$$

The graph in Fig. 9.8 should thus have slope of value $1/(2.3CR)$ and make an intercept on the vertical axis at a value equal t $-\log_{10}(V^+_{o\,sat} - V^-_{o\,sat})$.

A circuit which uses an operational amplifier as a bistable multivibrator is show in Fig. 9.9. Positive feedback applied vi resistors R_2, R_1 causes the amplifier outpu to remain at either its positive or negativ saturation limit.

Triggering pulses may be applied to th circuit at either input terminal via the capacitors C_1, C_2. The pulse polarity require to produce a transition depends upon th state of the circuit; this point should b verified experimentally.