Analogue function generator

A straight-line approximation design

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This article describes a versatile function approximator, whose analogue input and output signals are related by a segmented characteristic. The function characteristics are made up of a number of straight lines (segments), each one joining the next, at "break points," to form a continuous line. A variable characteristic is obtained by adjusting the position of intersection of any two segments.

The generation of an analogue function from an input variable has many applications, especially in the fields of measurement and process control. An example would be the linearization of a signal from a non-linear transducer in a control system.

The circuit described can be used to generate many functional relationships between its input and output signals, using a straight-line "fit" technique to produce the required characteristic.

Straight line approximators are not new. The diode function generator[1], which is a typical example of past designs, consists of the type of circuit shown in Fig. 1(a). As more of the feedback diodes are brought into conduction, so the effective amplifier gain alters. A typical characteristic for the circuit is shown in Fig. 1(b).

This scheme has two major drawbacks. Firstly, diode action affects its temperature stability, and secondly, altering one of the feedback resistors means the resetting of all of the resistors that follow it. A different approach is needed in order to obtain versatility.

Mark-to-space-ratio averaging

If we were to apply a zero-to-five-volt square wave to a simple single-time-constant CR smoothing network, any variation of the mark-to-space ratio (m.t.s.r.) would cause a change in the output of the CR smoothing network. This output change has two extreme limits, namely zero and five volts, which correspond to a total absence of a pulse (zero percent m.t.s.r.), and a pure d.c. level of five volts (100% m.t.s.r.), being applied to the input of the CR network. Indeed, the output of the network varies linearly with respect to the m.t.s.r.

Now consider three d.c. levels: zero, five, and seven volts, for example. Switching between the first two and filtering, as above, will produce a zero-to-five-volt signal depending on the m.t.s.r. However, if we now consider switching in the same way between the last two (five and seven volts), the output of the filter will be somewhere between five and seven volts, depending on the m.t.s.r. This process may be expanded still further.

The circuit described in this text has ten adjacent d.c. levels. Each level can be switched on and off, and there is a criterion that only adjacent pairs of levels can be switched, as in the simplified three-level case above. Interpolation between each level, by the m.t.s.r. process, is the basis of the function generator design.

Signal-to-time averaged b.c.d. circuit

The input to the signal-to-time averaged binary-coded-decimal (b.c.d.) circuit lies between set limits. If we choose this input to vary over zero to nine volts, relative to the circuit common, and consider the 0 to 100% variation of the input, we may divide it into nine equal intervals defined by ten input voltages (i.e. 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9V). Call these ten voltages, break voltages.

The ten break voltages correspond to the ten break points of the straight-line function generator, which composes its required function out of a nine-segment line ("fit"). As will be seen later, each break point of the function can be individually adjusted (without affecting any other), so that many different functions may be generated in a highly versatile manner.

The input to the circuit is scaled and fed into the non-inverting inputs of a string of nine comparators (see Fig. 2). Each comparator is set to "trip" (change state) at successively increased voltage levels.

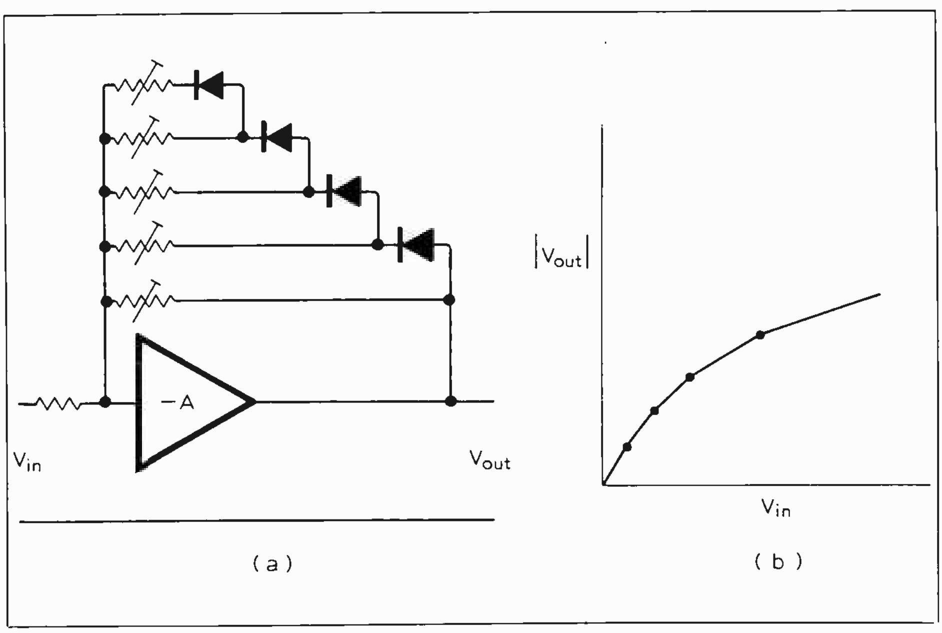


Fig. 1. (a) A typical diode function generator in which the amplifier gain alters as more of the feedback diodes are brought into conduction. (b) shows a typical characteristic for this circuit.

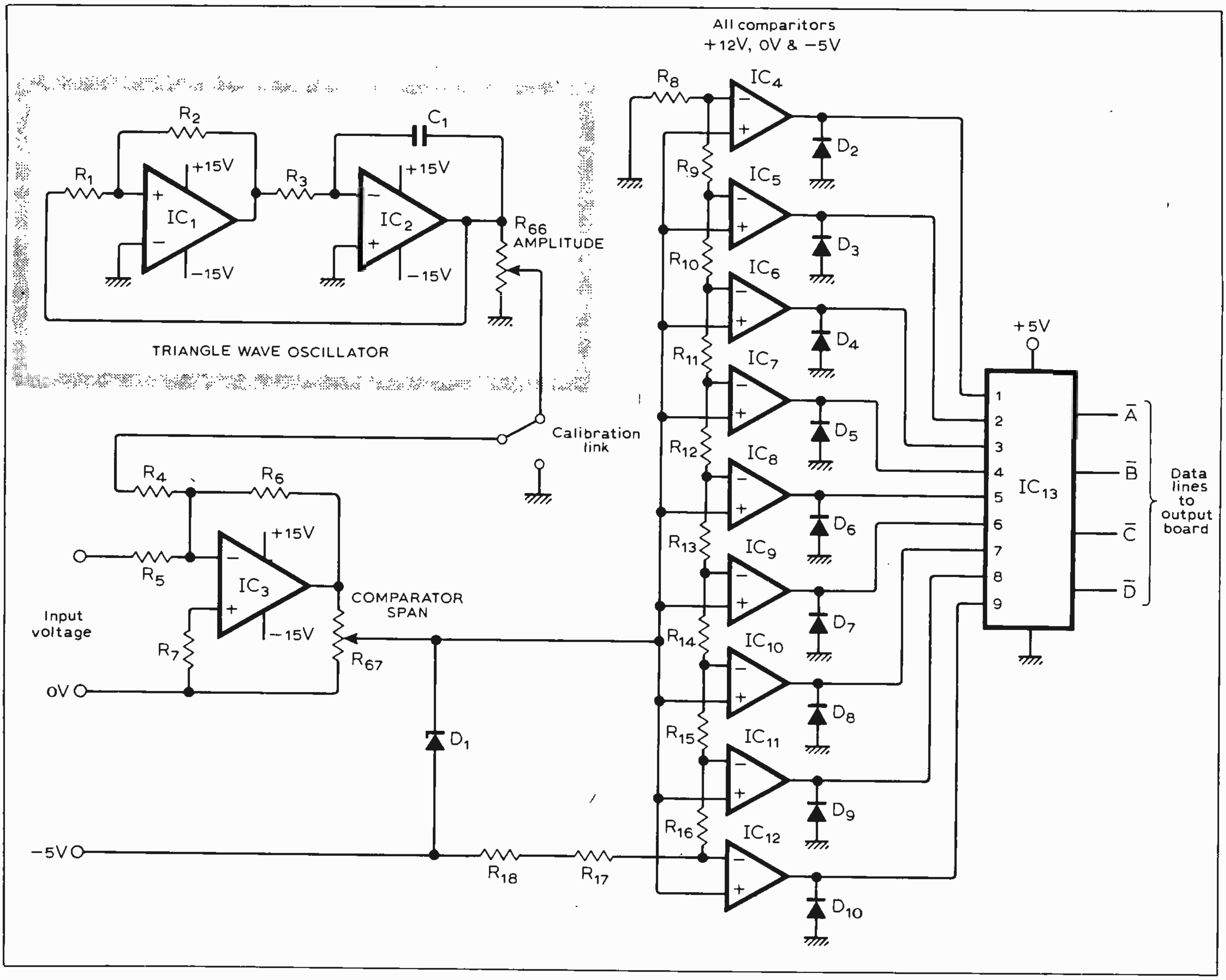


Fig. 2. Signal-to-time-averaged b.c.d. circuit consisting of nine comparators, each set to change state successively as the input voltage-level increases. The output from the encoder i.c. is in inverted-b.c.d. (see text).

The scaling is set such that, as the input voltage passes the break voltages of 1, 2, 3, 4, 5, 6, 7, 8 and 9 volts, comparators 1 to 9 trip in turn.

The output of each comparator passes into an encoder i.c. (SN74147) and the resulting inverted-b.c.d. output from this section of the circuit contains information about the input signal and the input break voltages. The exact value of the input signal relative to the ten input break-voltages is obtained by using a time averaging technique. A triangular wave, of peak-to-peak amplitude equal to the intervals (in this case 1V) between the ten break voltages, is added to the input signal. This resulting signal, which is applied to the input of the comparators, will lie between two break voltages (assuming that the input signal is not mid-way between two break voltages), see Fig. 4.

Consider now one period of the triangle waveform, and observe the time within the period that the combined signal spends between break voltages. It can be seen that this time, relative to the period of the triangular wave, is a direct function of the magnitude of the input signal. Each time the combined input voltage crosses a break voltage, the comparator for that break voltage will trip and change the b.c.d. output of this section of the circuit. It can therefore be seen that the average state of the b.c.d. output, in terms of time, will yield the exact position of the input signal relative to the ten input break voltages.

Note that for a static input signal, the typical b.c.d. output will consist of two adjacent b.c.d. states; the m.t.s.r. of each state being determined by the input magnitude relative to the ten break voltages.

Output and function generation section

The output circuit converts the time averaged b.c.d. signal of the previous state into a meaningful output. Basically, each b.c.d. state fed into the output section switches on one of ten voltage levels, all of which are pre-set by potentiometers to the functional characteristic required by the user. The voltage levels are then summed up by a summing amplifier (see Fig. 3). After passing through a second-order RC filter, the resulting signal appears at the output of a buffer amplifier (IC_{17}). Finally, the signal is scaled by the output amplifier.

The actual function generation of the circuit is achieved by mark-to-space ratio averaging, as mentioned earlier. However, here the magnitude of the input signal determines which voltages are switched on and off and what m.t.s.r. is applied to the switching voltages. The user, however, dictates the magnitude of each of the voltages switched, and therefore the way the average of the voltages changes as the m.t.s.r. of each voltage varies. Therefore, the final output of the circuit (after scaling) consists of a nine segment characteristic having ten break points, see Fig. 5. Note that each segment joins smoothly with its adjacent segments. Note also, that the break points are all independently adjustable. This means that virtually any (but not every) characteristic/function may be approximated by a nine segment fit using this circuit.

It would not be difficult to expand on

Fig. 3. Output circuit board. Bc.d. outputs of the circuit shown in Fig. 2, feed ten voltage levels, all of which are set by potentiometers to represent the characteristic of the required function (see text).

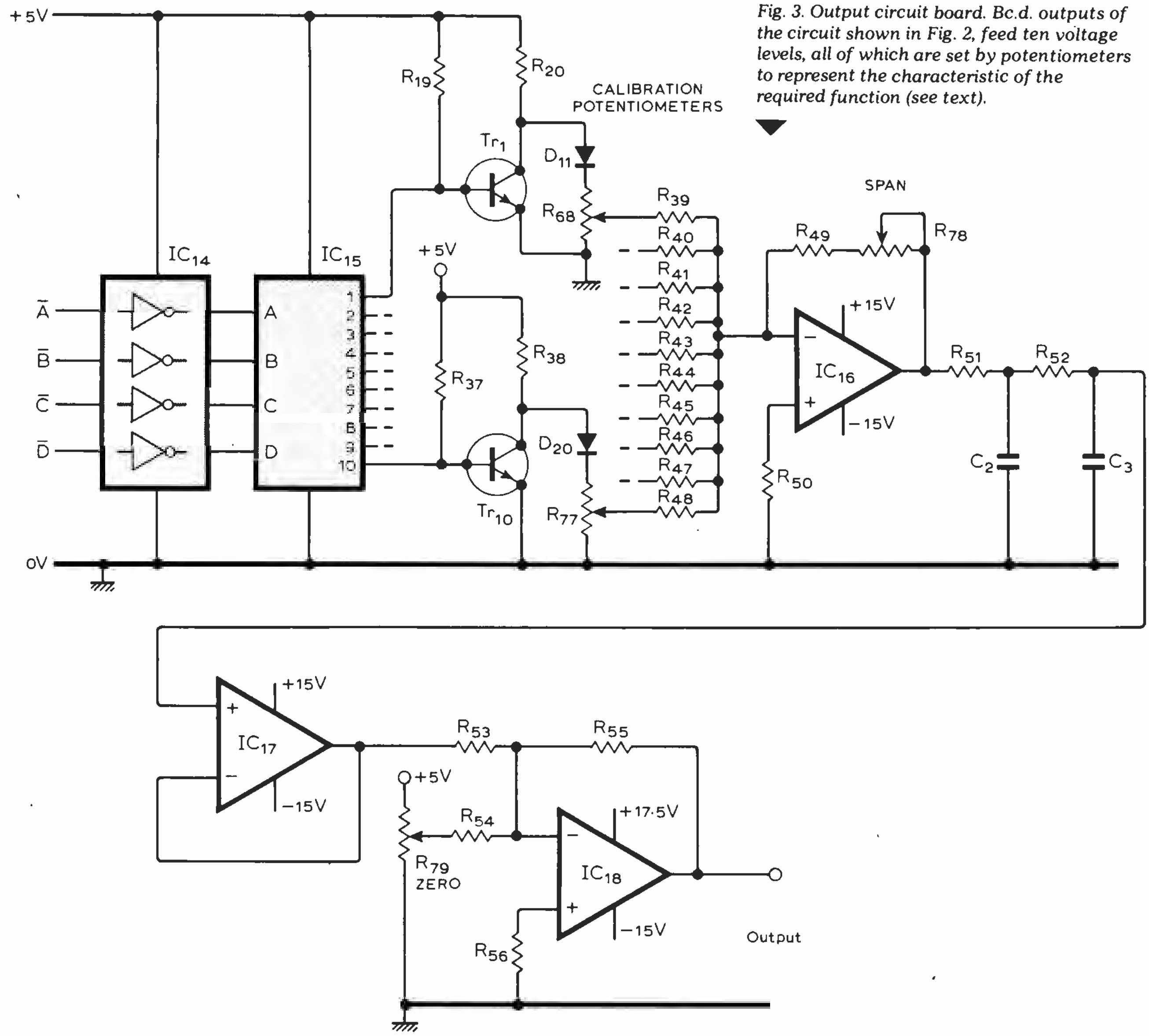


Fig. 4 shows how the time (t_x) – the time which the input signal plus the triangular wave (see text) spends between break voltages – is directly proportional to the magnitude of the input signal. That is, $V_x/V_y = t_x/t_y$.

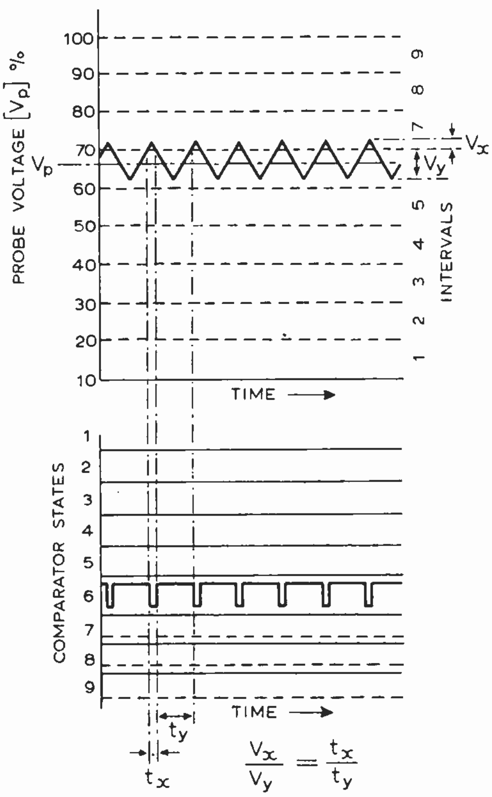
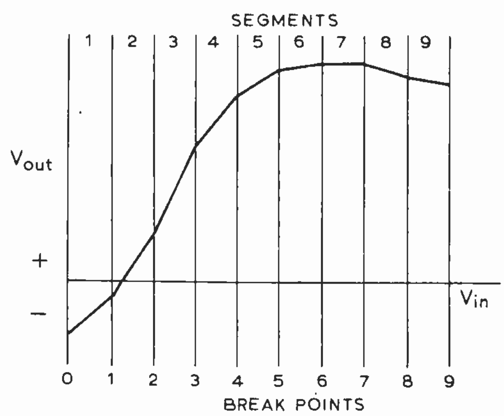


Fig. 5. An example characteristic for the analogue function generator described in the text.



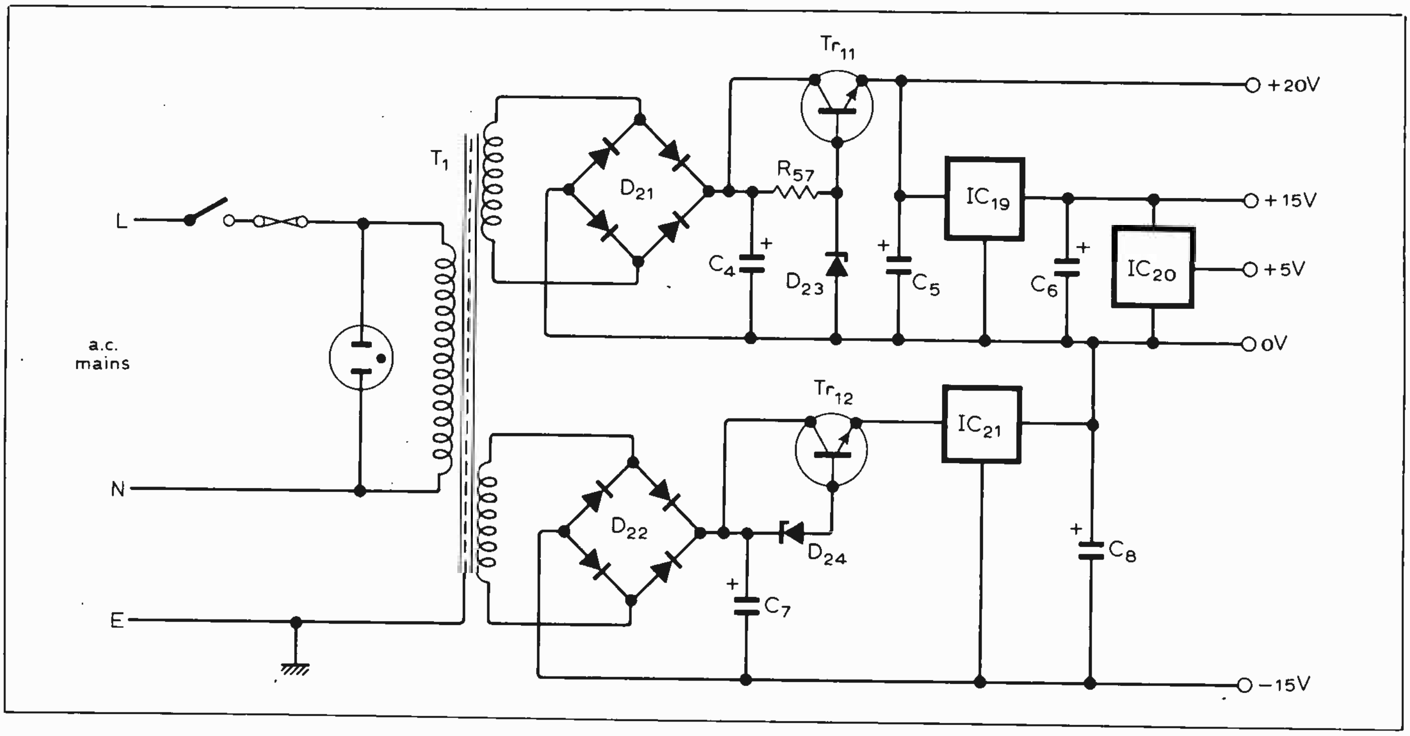


Fig. 6. Main power supply circuit.

the above idea, and produce a fit composed of more than nine segments.

Design considerations

For the circuit to be able to resolve small changes in the input, and convey the information to the b.c.d. signal, the hysteresis effect at the input (differential) of the comparators at small differential signals (specifically at the break points) must be considered. The design should also allow for the slew rate of the comparators so that the relatively fast t.t.l. can respond to the fast-changing differential input signals to the comparators.

In this case a resolution of 0.1% was desired and, with a maximum considered input hysteresis voltage of 5mV, this set the maximum signal to the comparators, for 100% input to the complete circuit, at five volts. The slew rate of the comparators was effectively speeded up by lowering the frequency of the triangular wave to about 200Hz. This gives ample time for the comparators to respond to a 5mV input differential.

The non-inverting input to the comparators is protected by using a zener diode tied to the −5V rail (see circuit). The choice of comparators and b.c.d. encoder i.c. also necessitates the incorporation of diodes D_2 to D_{10} inclusive. This arises due to the lack of input protection diodes on the l.s.i. chip, and the possible 'harmful' voltage surges at the comparator outputs. The final output of the circuit is provided with full zero and span adjustments so that the output can be calibrated.

The function generator is considerably accurate, because the conversion is largely digital. The prototype, which used metal film resistors and cermet potentiometers, showed a negligible change due to ambient temperature fluctuations.

There are many applications for this circuit. They include linearity correction of non-linear signals, generation of mathematical functions, and the generation of voltage programming functions.

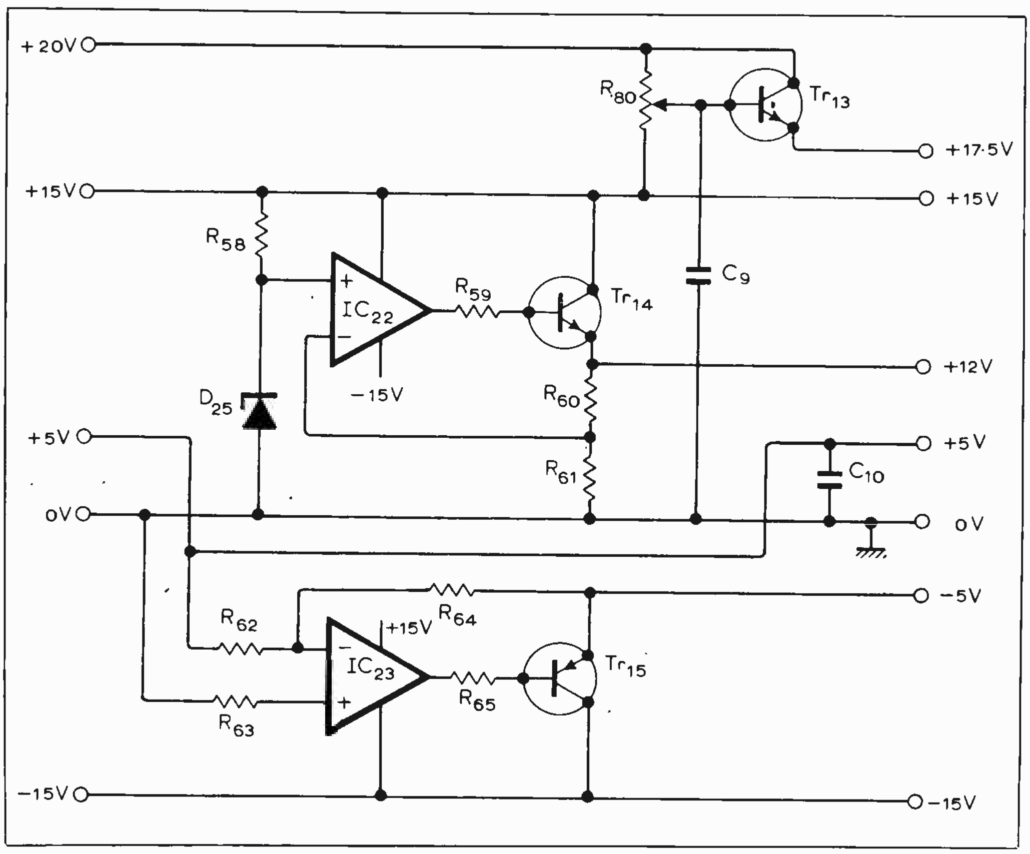
Generation of periodic waveforms

The following is as an application example of the analogue function generator being used to produce continuous functions, of variable period and complex shape. This may sound difficult, but it is really very easy.

Consider the arranged input/output characteristic (or transfer function) of the analogue function generator to be a single period of the first waveform in Fig. 8. Remember, that this complex function has been pre-programmed into the analogue function generator by use of the adjustable trimpots R_{68} to R_{77}.

Now, by using a ramp generator attached to the input of the analogue function generator, the output of the last-mentioned generator will follow

Fig. 7. Power supplies for the mother board.



the programmed characteristic as the ramp rises, returning back to the start of the characteristic as the sharp edge of the ramp falls. Therefore the output of the analogue function generator will be a continuous complex function, of programmable shape and period equal to that of the ramp input. Fig. 8 shows examples of repetitive waveforms generated in this manner.

Component list

Resistors (all 2% metal oxide unless otherwise stated)

1	39k
2	100k
3	22k
4, 5	3k
6	6.8k
7	1.2k
8-17	825, 1% or better
18	1.5k
19-37 (odd)	39k, 10% carbon
20-38 (even)	4.7k
39-48	2k
49	220k
50	1.2k
51, 52	220k, 10% carbon
53, 54	1k
55	2k
56	200
57	120, 10% carbon
58	1.2k
59	130, 10% carbon
60, 61	1.2k
62	1k
63	470, 10% carbon
64	1k
65	1.5k

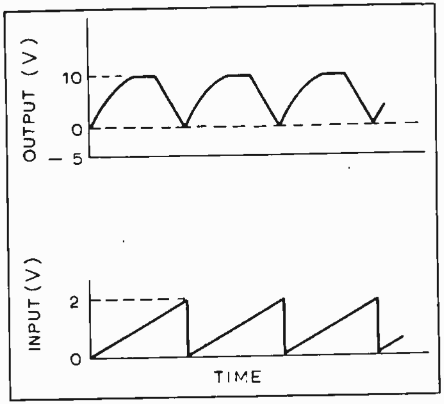


Fig. 8. Examples of periodic waveforms which can be produced by the analogue function generator

Variable resistors (Cermet trimmers)

66, 67	10k
68-77, 79	1k
78	50k

Diodes

1	6.8V 5% 400mW zener
2-20	1N914
21, 22	100V 2A bridge rectifier
23	20V } 5% 400mW zeners
24	5.6V } 5% 400mW zeners
25	6.2V } 5% 400mW zeners

Integrated circuits

1-3	μA741C
4-12	μA710
13	SN74147
14	SN7404
15	SN7442
16-18	μA741C
19, 21	μA7815 regulator (1A)
20	μA7805 regulator
22, 23	μA741C

All available from Bi-Pak Electronics, Ware, except IC_{13} which can be obtained from Aries Electronics, Maidenhead

Transistors

1-10	2N3709
11	2N3055
12-14	2N3053
15	2N2904

Transformer

Primary: 240V r.m.s.
Secondary: 2 × 20V r.m.s. at 300mA
Barrie Electronics, London

Capacitors (μF unless otherwise stated)

1	220n
2, 3	2.2
4, 7	680E
5	10E
6	22E
8	6.3E
9, 10	10n

Reference

1 Crump, A. E. Diode function generators, *Wireless World*, Dec. 1967, pp. 594-598.

A set of two p.c.bs for the function generator and power supply is available for £7 inclusive from M. R. Sagin at 23 Keyes Road, London NW2.